The Mobile Broadband Evolution:

3GPP Release 8 and Beyond

HSPA+, SAE/LTE and LTE-Advanced

3G Americas℠

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PREFACE

The growing commercialization of Universal Mobile Telecommunications System (UMTS), also known as Wideband Code Division Multiple Access (WCDMA), has been the topic of an annual white paper by 3G Americas since 2003, when the focus was Third Generation Partnership Project (3GPP) Release '99 (Rel-99). With the rapid progress of the evolutionary 3GPP roadmap from UMTS to High Speed Packet Access (HSPA), four additional "annual" papers were published by 3G Americas to provide the most current information on Rel-5 (2004 white paper), to Rel-6 (2005 white paper), to Rel-7 (2006 white paper), and then *UMTS Evolution from Release 7 to Release 8 – HSPA and SAE/LTE* was published in 2007 and updated in June 2008. This most recent paper provided a detailed discussion of the new Evolved EUTRA (E-UTRA) or Long Term Evolution (LTE) air-interface and Evolved Packet Core (EPC, formerly termed the SAE) as well as progress on HSPA+. Since it was published, 3GPP has been focused on completion of the EPC and LTE or E-UTRAN (E-UTRA refers to the air interface and E-EUTRAN refers to the radio access network, or more specifically, eNodeB) specifications in Rel-8, which is targeted for the first quarter of 2009. However, it should be noted that the Layer 1 specifications work by RAN1, which has the largest impact on long lead development items such as ASICs, has been mostly complete and stable since September 2008. Further, development efforts have been ongoing in parallel with the standards specification work, so the March 2009 completion date for Rel-8 is not delaying development work. The Rel-8 specifications include enhancements to the Evolved HSPA (i.e. HSPA+) technology, as well as the introduction of the EPS which consists of a flat-IP based all-packet core (SAE/EPC) coupled with a new OFDMA-based RAN (EUTRAN/LTE).

This new 2009 paper, ***The Mobile Broadband Evolution: 3GPP Release 8 and Beyond*** provides detailed discussions on the HSPA+ enhancements in Rel-8 as well as the EPS, EPC and LTE architecture, features/capabilities and performance estimates. The paper also addresses 3GPP planning for Rel-9 and Rel-10 content which has already begun. In addition to further enhancements to Evolved HSPA or HSPA+, Rel-9 will be focused on features that enhance upon the Rel-8 EPC/LTE capabilities in areas such as location, emergency and broadcast services, support of CS over LTE, Home NodeB/eNodeB architecture considerations (i.e. support for femtocell type applications) and IMS evolution. Further, a new study item in 3GPP will define evolution of the LTE technology to meet IMT-Advanced requirements (called LTE-Advanced), at the same time as work is commencing on the above Rel-9 enhancements. 3GPP recognizes the need to develop a solution and specification to be submitted to the International Telecommunication Union (ITU) for meeting the IMT-Advanced requirements, and therefore, in parallel with Rel-9 work, 3GPP is working on the LTE-Advanced study item which is likely to define the bulk of the content for Rel-10. The white paper ***The Mobile Broadband Evolution: 3GPP Release 8 and Beyond*** includes discussion of Rel-10 and what requirements will officially define "4G" technologies with the significant new technology enhancements to EPC/LTE for meeting the very aggressive IMT-Advanced requirements.

In December 2005, Cingular Wireless (now AT&T) launched UMTS enhanced with High Speed Downlink Packet Access (HSDPA) in 16 major markets throughout the U.S., becoming the first operator in the world to launch HSDPA on a wide-scale basis. At the writing of this paper, AT&T has deployed HSPA – capable of peak theroretical downloads speeds of 3.6 Mbps -- across the company's 3G footprint, available in more than 350 U.S. cities (with populations greater than 100,000), including the top 100 major markets (MSAs). Additionally, T-Mobile USA launched UMTS/HSDPA in New York City in the 1700/2100 MHz bands in May 2008 beginning its nationwide rollout with 130 cities in 27 major markets and over 100 million pops covered at the end of 2008. HSPA is the fastest nationwide wireless network in the United States.

3G Americas' first UMTS white paper, *UMTS to Mobilize the Data World*, reported on the progress of UMTS: from its inception in 1995, to standardization by the European Telecommunications Standards Institute (ETSI) in January 1998, to the commercial launch by Japan's NTT DoCoMo and other operator trial launches. The paper provided documentation on the installation, testing and preparation of UMTS networks on several continents and the prediction that UMTS and EDGE (Enhanced Data for GSM Evolution) would serve as complementary technologies for GSM operators throughout the world.

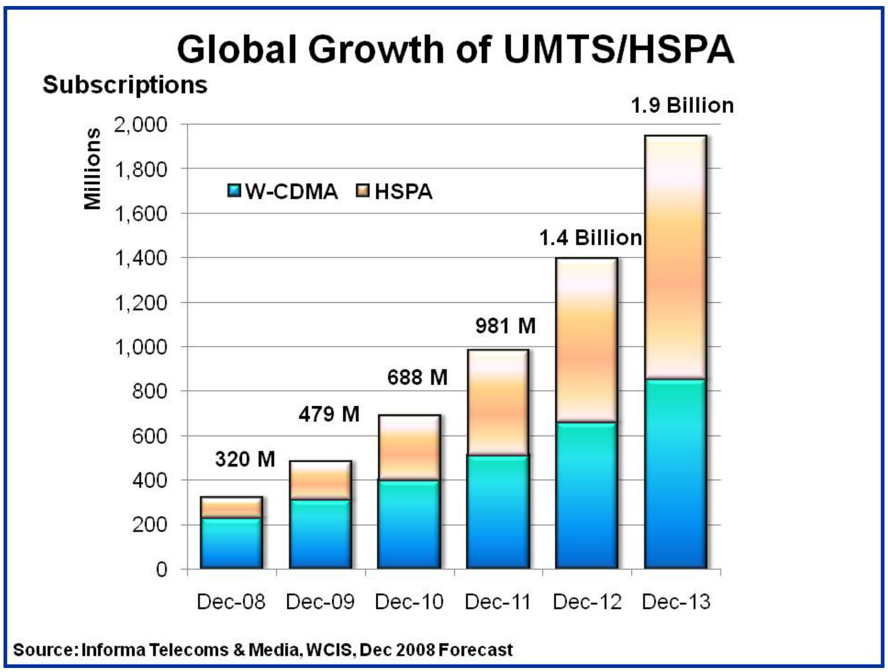

Figure1. Global UMTS Subscriber Growth Forecast[1]

The rapid growth of UMTS led to a focus on its next significant evolutionary phase, namely Release 5 (Rel-5). 3GPP Rel-5 – first deployed in 2005 – has many important enhancements that are easy upgrades to the initially deployed Release 1999 (Rel-99) UMTS networks. Rel-5 provides wireless operators with the improvements they need to offer customers higher-speed

[1] *World Cellular Information Service Forecast*. Informa Telecoms and Media. December 2008.

wireless data services with vastly improved spectral efficiencies through the HSDPA feature. In addition to HSDPA, Rel-5 introduces the IP Multimedia Subsystem (IMS) architecture that promises to greatly enhance the end-user experience for integrated multimedia applications and offer mobile operators a more efficient means for offering such services. There are many operators who have already deployed IMS architecture. UMTS Rel-5 also introduced the IP UTRAN concept to recognize transport network efficiencies and reduce transport network costs.

The 3G Americas' white paper titled, *The Evolution of UMTS – 3GPP Release 5 and Beyond*, was published in June 2004, updated in November 2004, and provided an overview and status update of the key 3GPP Rel-5 specifications and features discussed above. The December 2005 white paper, *The Global Evolution of UMTS/HSDPA – 3GPP Release 6 and Beyond*, provided information on the commercialization and industry progress towards the evolution of UMTS to Release 6 (Rel-6) with discussion of future evolutions of the technology.

The next white paper, *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond,* focused on Rel-7 and looked at what lies beyond with the Long Term Evolution (LTE) and System Architecture Evolution (SAE) initiatives and was published in July 2006 and updated in December 2006.

A further review of Rel-7, and an introduction to the improved features of Rel-8, was provided in *UMTS Evolution from Release 7 to Release 8 – HSPA and SAE/LTE*, first published in July 2007, first updated in December 2007, and further updated in June 2008.

Now, ***The Mobile Broadband Evolution: 3GPP Release 8 and Beyond*** explores the growing demands for wireless data as well as the development of technologies as previously described to support these growing demands. The appendices include lists of both commitments and deployments for UMTS and HSDPA/HSUPA and EDGE/UMTS, as well as the progress of leading UMTS and LTE vendors. Additionally, there is also a brief introduction to Evolved EDGE. In this white paper, the roadmap for the 3GPP evolution is clearly defined.

This paper has been prepared by a working group of 3G Americas' member companies and the material represents the combined efforts of many experts from 3G Americas' membership.

1 INTRODUCTION

Demand for wireless data services is growing faster than ever before. While demand for applications such as text messaging (SMS), Web and WAP access, Multimedia Messaging (MMS) and content downloads has kick-started the wireless data market, the demand for higher bandwidth video applications such as video sharing, mobile video and IPTV is quickly growing. Most UMTS/HSPA operators today are offering some type of mobile broadband service and many PC vendors offer notebooks with built-in HSDPA capabilities that will boost data usage even further. Clearly, data revenues are playing an increasingly important role for operators, driving the need for higher bit rates, lower latency and more spectrally efficient support of data services.

There was significant growth in HSDPA and HSUPA deployments in 2008. The combination of HSDPA and HSUPA, called HSPA, provides a very spectrally efficient wireless solution which many operators have now commercially deployed, leading the operators to begin focusing on enhancements to HSPA through 3GPP Rel-7. The evolution to 3GPP Rel-7 will bring improved support and performance for real-time conversational and interactive services such as Push-to-talk Over Cellular (PoC), picture and video sharing, and Voice and Video over IP through the introduction of features like MIMO (Multiple Input Multiple Output antennaes), Continuous Packet Connectivity (CPC) and Higher Order Modulations (HOMs). These Rel-7 enhancements are often called Evolved HSPA or HSPA+. Since the Evolved HSPA enhancements are fully backwards compatible with Rel-99/Rel-5/Rel-6, the evolution to Evolved HSPA has been made smooth and simple for operators.

3GPP is now nearing completion of the Rel-8 specification (targeted for March 2009) which, in addition to further enhancements of the HSPA technology, defines a new OFDMA-based technology through the Long Term Evolution (LTE) work item. This new OFDMA-based air-interface is also often referred to as the Evolved UMTS Terrestrial Radio Access (EUTRA). Rel-8 also defines a new flatter-IP core network to support the EUTRAN through the System Architecture Evolution (SAE) work item, which has recently been renamed the Evolved Packet Core (EPC) Architecture (Note: the complete packet system consisting of the EUTRAN and the EPC is called the Evolved Packet System (EPS)). In this paper, the terms LTE and EUTRAN will both be used to refer to the evolved air-interface and radio access network based on OFDMA, while the terms SAE and EPC will both be used to refer to the evolved flatter-IP core network. Additionally, at times EPS will be used when referring to the overall system architecture. The combination of LTE and SAE provides the long-term vision for 3GPP to an all-IP, packet-only wideband OFDMA system expected to further improve performance by providing higher data rates, improved spectral efficiency and reduced latency. The ability of LTE to support bandwidths wider than 5 MHz is of particular importance as the demand for higher wireless data speeds and spectral efficiencies continues to grow. Note that although the completion of Rel-8 is targeted for March 2009, the Layer 1 specifications for Rel-8 have been mostly complete since September 2008, so many of the long lead items for development have been stable for awhile at this point.

With the completion of Rel-8 nearing, planning has already begun with 3GPP for Rel-9 and Rel-10. There is an aggressive target schedule for Rel-9 (to complete in one year by March 2010), which will add feature functionality and performance enhancements to both HSPA and LTE. For HSPA, additional multi-carrier and MIMO options are being explored. For LTE, additional features and enhancements to support emergency services, location services and broadcast services are the focus. Enhancements to support Home NodeB/eNodeB (i.e. femtocells) and the evolution of the IMS architecture will also be a focus of Rel-9.

While planning and work for Rel-9 is well under way, 3GPP has recognized that there is a need to begin planning and work for Rel-10 (in parallel with Rel-9 work) in order to be prepared for participating in the IMT-Advanced evaluation and certification process led by the ITU. The ITU has defined requirements that will officially define and certify technologies as "4G," and will be looking for technology submissions from standards organizations in the 2009 timeframe which will be evaluated and potentially certified in the 2010 timeframe and targets the certified technology specifications to be published by early 2011. There is currently a study item in 3GPP, called LTE-Advanced, which is evaluating technology enhancements to LTE in order to meet the requirements of IMT-Advanced. Some of the key technology enhancements under consideration for LTE-Advanced include carrier aggregation, collaborative/network MIMO, advanced interference coordination techniques and relays. The LTE-Advanced work has already submitted an early proposal to the ITU indicating 3GPP's intention to submit an LTE-based technology proposal to the IMT-Advanced process in 2009. Assuming LTE-Advanced is certified to be IMT-Advanced compliant, 3GPP targets to have the Rel-10 specification complete by March 2010 to meet the ITU publication timeline.

This paper will first discuss the progress on the deployment status of the UMTS and HSPA technologies, followed by the progress and plans toward Rel-7/Rel-8 Evolved EDGE, HSPA+ and LTE deployments. The growing demands for wireless Voice over IP (VoIP) and packet data will then be demonstrated, which provides the basis for the drive towards even wider bandwidth wireless solutions defined by LTE. A detailed discussion of the LTE/SAE technology will then follow including a summary of the LTE performance studies conducted in 3GPP. Finally, details on Rel-9 planning and LTE-Advanced studies for Rel-10 will be discussed.

2 PROGRESS OF REL-99/REL-5/REL-6 UMTS

Rel-99 UMTS specifications, initially standardized in early- to mid-1999 and published by 3GPP in March 2000, provided the evolutionary path for GSM, GPRS and EDGE technologies, enabling more spectrally efficient and better performing voice and data services through the introduction of a 5 MHz UMTS carrier. Rel-4 was completed in March 2001, Rel-5 was published in March 2002 and Rel-6 was completed in March 2005.

The first commercial deployment of UMTS networks began with the launch of FOMA by NTT DoCoMo in 2001, with 2003 as the year when Rel-99 UMTS networks were more widely commercialized. The number of commercially deployed UMTS systems has grown rapidly since then, as substantiated in the 270 commercial UMTS networks as of year end 2008 and listed on the global deployment status list in *Appendix B* of this paper. Rel-4 introduced call and bearer separation in the Core Network, and Rel-5 introduced some significant enhancements to UMTS including HSDPA, IMS and IP UTRAN.[2] Rel-6 introduced further enhancements to UMTS including HSUPA (or E-DCH), MBMS and Advanced Receivers.[3]

Leading manufacturers worldwide support UMTS/HSPA and to illustrate the rapid progress and growth of UMTS, detailed descriptions of recent accomplishments from each of the 3G Americas' participating vendors on Rel-99, Rel-5, Rel-6, Rel-7 and Rel-8 UMTS are included in *Appendix A* of this white paper. A few of these technology milestones are also summarized in this section.

2.1 PROGRESS TIMELINE

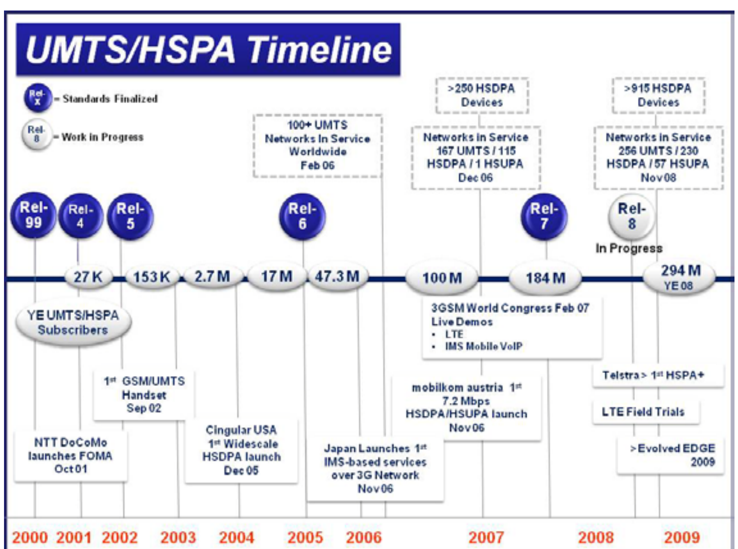

Figure 2. 3GPP UMTS/HSPA Timeline[4]

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[2] *3GPP Rel-5 and Beyond - The Evolution of UMTS*. 3G Americas. November 2004.
[3] *The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond*. 3G Americas. December 2005.
[4] 3G Americas. December 2008.

In November 2003, HSDPA was first demonstrated on a commercially available UMTS base station in Swindon, U.K. and was first commercially launched on a wide-scale by Cingular Wireless (now AT&T) in December 2005 with notebook modem cards, followed closely thereafter by Manx Telecom and Telekom Austria. In June 2006, "Bitė Lietuva" of Lithuania became the first operator to launch HSDPA at 3.6 Mbps, a record speed at that time. As of December 31, 2008, there were more than 252 commercial HSDPA networks in 112 countries with 57 additional operators with networks planned, in deployment or in trial with HSDPA (see *Appendix B*). It is expected that almost all UMTS operators will deploy HSDPA and, likewise, all HSDPA operators will upgrade to HSUPA. AT&T was the first U.S. carrier to deploy enhanced upload speeds through HSUPA in its HSPA networks with upload speeds between 500 Kbps and 1.2 Mbps and download speeds ranging up to 1.7 Mbps.

Currently, the UMTS standard is available worldwide for use in the 850, 900, 1700, 1800, 1900, 2100, 1700/2100 and 2600 MHz bands. Additionally, the standard will be expanded for use in the 700 MHz bands which were auctioned in the U.S. in April 2008 with AT&T and Verizon as two of the primary auction winners already announcing their future deployment of LTE in this band. There will be further opportunities for introducing UMTS in frequency bandwidths smaller than 5 MHz (e.g. the 450 MHz) spectrum band. Such a wide selection of bands benefits operators because it provides more flexibility.

Infrastructure and devices are currently supported by a variety of vendors in the 850, 900, 1700, 1800, 1900, 2000, 2100 and 1700/2100 MHz bands and will also be supported for all future frequency bands, including 700, 2500 and 2600 MHz as well as the 1500 MHz band in Japan and 2300 MHz in the U.S. One vendor cites the mobile-data throughput capability of the most cost-effective base station as more than 400 GB per day, resulting in a broadband radio network at a cost close to $1 per GB. With reportedly up to 70% lower base station site expenditure, the GSM/UMTS infrastructure costs have encouraged operators to deploy 3G UMTS technology.

Already a reality in the market, HSPA mobile broadband equipment today supports peak rates of 14 Mbps downlink and 5.8 Mbps uplink, capabilities that are typically added to existing networks using a simple software-only upgrade, which can be downloaded remotely to the UMTS RNC and Node B. Operators such as Telstra in Australia were reporting mobile broadband downlink speeds of 2.3 Mbps at a range of up to 120 miles (200 km) from cell site. Vendors are enhancing network quality with advances such as flat-IP femtocells, enabling operators to provide comprehensive in-building or in-home coverage.

Initial network deployments of HSDPA were launched with PC data cards in 2005. On December 31, 2008, there were a reported 1,053 HSPA mobile broadband devices commercially offered, including 336 handsets, 76 data cards, 272 notebooks, 55 wireless routers, 99 USB modems and 46 embedded modules. HSDPA data cards support all UMTS frequency bands to allow for international roaming, typically fall back to UMTS, EDGE and GPRS, and are offered by a 126 device manufacturers as of December 2008.[5] At the end of 2008, many notebooks were supporting HSPA at 7.2 Mbps downlink, and 2 Mbps uplink in addition to EDGE.

[5] http://hspa.gsmworld.com/devices/default.asp

HSDPA handsets were commercially available by 2Q 2006 with HSDPA handhelds first launched in South Korea in May 2006 and in North America by Cingular (now AT&T) in July 2006. In addition to allowing data to be downloaded at up to 1.8 Mbps, the initial handsets offered such applications as satellite-transmitted Digital Multimedia Broadcasting (DMB) TV programs, with two- to three-megapixel cameras, Bluetooth, radios and stereo speakers for a variety of multimedia and messaging capabilities. As of December 2008, there were more than 294 HSPA handsets available supporting speeds of 7.2 Mbps downlink, 2 Mbps uplink in addition to EDGE.[6]

Handset manufacturers are developing some strong collaborative relationships and initiating promising technologies. For instance, UMA (Unlicensed Mobile Access) devices have been delivered to the market and will greatly improve indoor coverage and make calls more affordable. T-Mobile USA launched UMA devices for customers on their T-Mobile@Home offering. Also, device manufacturers are working with financial services companies like Visa and MasterCard to develop contactless payment services, or, in other words, using cell phones as credit cards or e-wallets. The first Near Field Communication (NFC) mobile payment trials in the U.S. began in mid 2007 following the introduction of NFC-enabled mobile phones at CES in January 2007.

Mobilkom Austria completed the first live HSUPA demonstration in Europe in November 2006. One month later, the first HSUPA mobile data connection on a commercial network (of 3 Italia) was established. In 2007, Mobilkom Austria launched the world's first commercial HSUPA and 7.2 Mbps HSDPA network in February, followed by commercial 7.2 USB modems in April and 7.2 data cards in May. There were numerous announcements of commercial network upgrades to Rel-6 HSUPA throughout 2H 2007 and as of December 2008, there are 60 commercial networks and 101 operators who have already announced plans to deploy HSUPA (see *Appendix B*).

Beyond HSPA, leading vendors are actively developing and testing IMS device implementation. The GSMA's IMS (Videoshare) Interoperability Test Sessions yielded important early successes in demonstrating IMS functionality in 2006 as well as ensuring interoperable solutions that will increase the take-up of this next step in the GSM/UMTS evolution. This was further supported by vendors at the 2007 World Congress with demonstrations of IMS VideoShare on all types of devices.

In November 2006, Softbank Mobile Corp. in Japan launched the world's first IMS-based services over a 3G network with new exciting 3G services initially including push-to-talk, presence and group list management. IMS Mobile VoIP over HSPA was demonstrated for the first time on a mobile terminal at the World Congress 2007.

IMS serves as the cornerstone for next-generation blended lifestyle services and vendors are also supporting IMS development across multiple frequency bands to deliver valuable applications and services. More than 100 operators had commercial or contracted IMS networks throughout the world in 2008, and trials of various IMS network elements were being conducted. IMS developer programs are available in Germany, the U.S., China and Singapore to encourage the creation of advanced IMS applications and services. IMS solutions like the "service enhancement layer" allow for integration of a set of software technologies that enable wireless, wireline and converged network operators to create and deliver simple, seamless, secure,

[6] *Ibid.*

portable and personal multimedia services to their customers. IMS networks are intuitive – device, application and end-user aware – resulting in the creation of an ecosystem of real-time multimedia applications and services. Mobile softswitches – compliant with 3GPP Release 4, 5, 6 and 7 architecture – that are in the market today, support a smooth evolution to VoIP and IMS. By providing IMS, CS core interworking with SIP call control and end-to-end VoIP support, with or without IMS, can deliver mobile voice service with up to 70% savings in operating expenditures. Some vendors' IMS solutions optimize core network topology by moving from vertically implemented services towards common session control, QoS policy management and charging control. IMS "intuitive networks" are device-, application- and end-user aware, resulting in the creation of an ecosystem of best-in-breed real-time multimedia applications and services.

Technology milestones and advances in the evolution of UMTS and HSPA continue to develop as the number of 3G customers grows at a rapidly increasing rate. With the structure for services and applications beginning to grow more secure, the demand for wireless data services and other advanced voice applications is also demonstrating tremendous growth. Refer to *Appendix A* for more detailed information on the progress of UMTS Rel-99 to Rel-8.

3 PROGRESS AND PLANS FOR REL-7/REL-8: EVOLVED EDGE, HSPA EVOLVED/HSPA+ AND EPC/LTE

There was significant progress on Rel-7 standards over the course of 2006-2007 and the standards were finalized in mid 2007. After the specifications were approved in January 2008 for Rel-8 standards, work continued throughout the year, and the complete final standards will be published in March 2009.

Vendors are proceeding well in developing the commercial introduction of Rel-7/HSPA+. As an example, MIMO techniques were developed by vendors as well as flat-IP base stations, an innovation that integrates key components of 3G mobile networks into a single network element optimized to support UMTS/HSPA data services, and "flattens" what is typically a more complex architecture. At the 3GSM World Congress in 2007, live demonstrations of One GTP Tunnel with a flat-IP base station showed a flat architecture by extending the one tunnel approach of the Packet Switched Network to the Radio Access Network – consisting of a base station and single core network node on the user plane. One leading vendor already cited 30 Direct Tunnel deployments as of November 2008, eight of which were already commercial, and this is a key component of the flat architecture used in LTE.

Rel-7 features are being commercially introduced as HSPA+, at times with MIMO, as well as with key components of 3G mobile networks to "flatten" what is typically a more complex architecture. Trials began as early as 3Q 2007 and several planned commercial announcements were made in 2007 and 2008, including AT&T, TerreStar Networks and Stelera Wireless in the U.S. and T2 Slovenia in Europe. HSPA Evolution eases the path to LTE as the two technologies use the same flat network architecture. Telstra in Australia launched the first commercial HSPA+ in December 2008. HSPA+ terminals have been announced and demonstrated with commercial availability expected in the first part of 2009.

Speeds of up to 42 Mbps are supported by HSPA+ or HSPA Evolution. These speeds are achieved by combining new higher order modulation technology (64QAM), together with 2x2 Multiple Input Multiple Output (MIMO) antenna technology. HSPA evolution at 42 Mbps was first demonstrated at CTIA Wireless 2008 using a form-factor handheld device. The improved speed will assist operators in leveraging existing network infrastructure to meet growing consumer appetite for advanced multimedia services. Some operators may choose to deploy HSPA+ with higher order modulation and forestall MIMO. They will achieve excellent advances and benefits, with speeds up to 21 Mbps without deploying MIMO. AT&T has announced its intentions to deploy HSPA+ in 2009 and has indicated it will not deploy MIMO. Vodaphone has also announced that it will upgrade HSPA with software but will not install new hardware (MIMO).

Advantages of HSPA+ include its cost-efficient scaling of the network for rapidly growing data traffic volumes, the ability to work with all HSPA devices and improved end-user experience by reducing latency.

EDGE offers an important software upgrade of existing infrastructure, now in its third iteration, called Downlink Dual Carrier EDGE. Based on Rel-7, Downlink Dual Carrier EDGE doubles data speeds to 592 Kbps compared to current EDGE network data speeds. One leading infrastructure vendor has already made the first live mobile end-to-end call and will have this product available early in 2009. A further update, called EGPRS 2B, will provide downlink speeds of up to 1.2 Mbps and uplink up to 473 Kbps, quadrupling the current capabilities of EDGE. This work is also in development by vendors.

Evolved EDGE or EDGE Evolution, also part of Rel-7, is a software upgrade of existing infrastructure expected for availability in 2009. EDGE Evolution will boost data speeds by up to 300% and will significantly improve latency, coverage and spectrum efficiency of existing GSM/EDGE equipment. This improved data performance in GSM will be as important as high-speed HSPA is today and LTE will be in tomorrow's networks.

Demonstrated live at the Mobile World Congress and CTIA Wireless in 2007 were some of the future-proof solutions that formed an integral building block for the System Architecture Evolution (SAE). This included support for an integrated Voice Call Continuity (VCC) solution for GSM–WLAN handover.

LTE lab trials between vendors and operators began in 2007. In November 2007, LTE test calls were completed between infrastructure vendors and device vendors using mobile prototypes representing the first multi-vendor over-the-air LTE interoperability testing initiatives. Live 2X2 LTE solutions in 20 MHz were demonstrated at both the Mobile World Congress 2008 and CTIA Wireless 2008. Among the new exciting applications demonstrated on LTE networks at various bands including the new 1.7/2.1 GHz AWS band were HD video blogging, HD video-on-demand and video streaming, multi-user video collaboration, video surveillance, online gaming and even CDMA to LTE handover showing the migration possible from CDMA and EV-DO to LTE.

Some vendors offer equipment that is "software definable" for the ideal upgrade path to LTE. Beginning in 3Q 2008, UMTS/HSPA base stations that can be upgraded to LTE via software in the same frequency became available; operators can deploy the base stations with UMTS/HSPA technology and then upgrade to LTE in the second half of 2009. Many bands are supported by these base stations including the 1.7/2.1 GHz AWS band and the recently auctioned 700 MHz bands in the U.S. One leading vendor delivered the new LTE-ready hardware to more than ten major operators in Europe, Asia and North America by the end of 2008.

New base stations developed in 2008 are compact energy-efficient site solutions that support GSM/EDGE, UMTS/HSPA and LTE in a single package. Many vendors are offering LTE-capable base stations, providing a clear evolutionary path for operators into the future. These multi-standard base stations offer many options that make choices simpler while providing greater freedom of choice. Cost-effective deployment and development of new high-speed mobile broadband services, mobile TV and web applications are all supported by many of today's base stations. Infrastructure and other product development for LTE is in progress by many vendors and the first LTE equipment systems will go to market by the end of 2009 by vendors, including Alcatel-Lucent, Ericsson, Motorola, and Nokia Siemens Networks.

Many field trials for LTE were conducted in 2008. Field trials in realistic urban deployment scenarios were created for LTE as early as December 2007, and with a 2X2 MIMO antenna system, the trials reached peak data rates of up to 173 Mbps and still more than 100 Mbps over distances of several hundred meters. The trial demonstrated that future LTE networks can run on existing base station sites.

LTE operating in both FDD and TDD modes on the same base station was first demonstrated in January 2008. By using the same platform for both paired and unpaired spectrum, LTE provides large economies of scale for operators.

In order to make LTE licensing as fair and reasonable as possible, in April 2008, a joint initiative was announced by leading vendors Alcatel-Lucent, Ericsson, NEC, NextWave Wireless, Nokia, Nokia Siemens Networks and Sony Ericsson to enhance the predictability and transparency of IPR licensing costs in future 3GPP LTE/SAE technology. This initiative includes a commitment to an IPR licensing framework that provides more predictable maximum aggregate IPR costs for LTE technology and enables early adoption of this technology into products.

In April 2008, the first public announcements of LTE being demonstrated at high vehicular speeds were announced with download speeds of 50 Mbps in a moving vehicle at 110 km/h. By August, demonstrations of the first LTE mobility handover at high vehicular speeds were completed and announced jointly by LTE infrastructure and device manufacturers.

T-Mobile announced successful live-air testing of an LTE trial network, in real-world operating conditions with a leading vendor during September 2008. Data download rates of 170 Mbps and upload rates of 50 Mbps were repeatedly demonstrated with terminals and devices, on a test drive loop that included handoffs between multiple cells and sectors.

In 2008, the first commercially available LTE-capable platform was announced for mobile devices that offered peak data downlink rates of up to 100 Mbps and uplink rates of up to 50 Mbps. The first products based on the LTE platforms will be data devices such as laptop modems, USB modems for notebooks and other small-form modems suitable for integration with other handset platforms to create multi-mode devices. Since LTE supports handover and roaming to existing mobile networks, all of these devices can have ubiquitous mobile broadband coverage from day one.

The key elements of success for new technologies include the networks, the devices and the applications. Infrastructure vendors are partnering with many leading application vendors to make sure operators can fully exploit an LTE network's potential to increase operator revenues.

As operators evolve their networks toward LTE and EPS architecture and consider software solutions, they can build upon the capabilities of their proven HLR to incorporate carrier grade RADIUS AAA for packet switched traffic, Diameter-based AAA and HSS support for the IMS core. Inclusive functional suites take full advantage of the communications and media software solutions to insure data-level coherence and behavioural consistency of the overall mobility management solution across all access domains and technology generations. Linked with pan-generational mobility and data management products, able to service multiple fixed and mobile access domains, operators can leverage the CMS Policy Controller to ensure quality of service and provide a fine degree of control for service offerings consistent with the Open Mobile Alliance (OMA) and 3GPP Rel-8 specifications.

With a strategy to consolidate, converge and innovate, the architecture of SAE/EPS simplifies the network and improves performance, communications and media software solutions; it supplies the service provider with the means to create and deploy the innovative services that will ultimately justify the expense of re-architecting and re-implementing both the access and core software network structures.

By third quarter 2008, the Next Generation Mobile Networks Alliance (NGMN) selected LTE as the sole technology that matched their requirements successfully. Other technologies such as mobile WiMAX and Ultra Mobile Broadband were not selected at that time. NGMN is an organization comprised of the world's major mobile network operators as well as leading manufacturers.

A strong ecosystem is needed to support the launch of a new technology and offer the benefits of scope and scale. The LTE SAE Trial Initiative (LSTI) has provided support to ensure timely development of the LTE ecosystem and all leading vendors for LTE are actively participating in LSTI. Early co-development and testing with chipset, device and infrastructure vendors will help accelerate comprehensive interworking and interoperability activities and the availability of the complete ecosystem. Some manufacturers will support a complete in-house ecosystem providing LTE chipsets, handsets and CPE, backhaul solutions and experience in deploying OFDM/LTE mobile broadband networks. The future for LTE and its already impressive ecosystem is evidence of a well defined standard.

Vendors are already progressing beyond LTE with the next generation of technologies for IMT-Advanced, called LTE-Advanced. New ground has already been demonstrated for mobile broadband communications beyond LTE that the technological development path for the next stage of LTE is secure and future-proof. For more information on the progress of LTE-Advanced, see section 7.8 of this paper.

Detailed information on the progress of Rel-7 and Rel-8 features by members of 3G Americas is presented in *Appendix A* ofthis white paper.

4 THE GROWING DEMANDS FOR WIRELESS DATA APPLICATIONS

Ever since the rollout of HSDPA networks and flat-rate pricing plans, the wireless industry has seen unprecedented growth in mobile broadband average revenue per user (ARPU). Consumer adoption curves are showing the “hockey stick” effect on charts and, as wireless voice ARPU hits the flat rate ceiling, data ARPU is proving to be the next big growth engine for mobile operators. The main driver for this growth in data revenues is simple: Internet-savvy users are now being armed with Internet-friendly handheld devices, which give them the means to satisfy their need for content and “connectedness.” Additionally, the networks are evolved for high-speed connectivity and wide-scale deployments and are offering tremendous coverage for true mobility. In fact, on a worldwide basis, users are able to roam and continue to maintain their applications and services. Therefore, with great mobile devices in hand and network coverage in place, the applications have definitely evolved.

Social communication patterns have also evolved, largely due to increasing frequency of electronic contact (e.g. MySpace, Facebook, Twitter) and there is an ever-growing demand for new and innovative applications that capitalize on the simultaneous voice and data sessions available with HSPA today and in the future with LTE.

Flat-rate pricing plans provide one stimulus for increased data usage such as the $99 “all-you-can-eat” packages that many operators have introduced in Europe and North America over the past five years. By eliminating the need for customers to track or limit their daily data megabyte consumption, applications and downloadable content have been growing in size and volume. The operator bonus of the flat-rate plans is the acceleration of the mobile broadband adoption curve – but the potential downside for operators is the need to quickly drive down cost/bit in order to meet growing demand while also contributing to profits.

Users and operators will benefit greatly from Rel-7 features, and the growing demands for wireless data are driving the need for even higher data rates and higher spectral efficiency. As HSPA networks continue their expansive worldwide rollout, the question remains how far mobile operators can leverage these technological advances to boost ARPU with data services. Manufacturers are enabling a slew of applications that are driving innovations in mobile handsets and crossing barriers into a wide variety of vertical enterprise markets. Likewise, consumers are driving the demand for mobile content such as entertainment, advertising and Multimedia Messaging Services (MMS).

When considering that there were more than 3.5 billion GSM/HSPA subscriptions worldwide by December 2008, including more than 290 million 3G UMTS/HSPA subscriptions, the tremendous opportunity for the uptake of wireless data services and applications is clear.[7]

In this section, the growing demands for wireless data are demonstrated by examples of increased operator ARPU from data services, a variety of 3G applications for consumers and the

[7] *World Cellular Information Service*. Informa Telecoms & Media. December 2008.

enterprise and analysts' predictions for their growth, and the introduction of a greater variety of wireless data devices such as smartphones and embedded modules for PC notebooks.

4.1 WIRELESS DATA TRENDS AND FORECASTS

"Wireless technology is the printing press of the 21st century," said Steve Largent, President and CEO of CTIA- The Wireless Association®. "What started as a simple call has transformed into a cultural phenomena of instant communication and broader and equal access to the world at our fingertips. From the 'brick' phone of the 80's, to today's 3G broadband world, wireless has evolved from mere voice communication to a new era of data transmission and democratizing communications that are transforming our commerce and culture along the way."

Wireless technology has become one of the fastest global dispersions of any technology in history. The first commercial cell phone call was placed on October 13, 1983 to the grandson of Alexander Graham Bell in Germany from the president of Ameritech Mobile Communications at a ceremony held outside of Soldier Field in Chicago, Illinois. The wireless industry has come a long way in 25 years.[8] As of end of 2008, there were more than 271 million wireless subscribers in the U.S. – 87.5% of the total U.S. population – and 3.5 billion active cell phones worldwide.

Several trends are contributing factors to the overall growth of wireless technology and driving the demand for wireless applications, including the replacement of wireline with wireless telecommunications and the increased uptake of mobile broadband services versus fixed broadband service. According to research published by the Telecommunications Industry Association, wireless technology will be growing much faster than communications in terms of revenue over the next few years. With bandwidth consumption driving communications revenue growth by 10% per year through to 2011, wireless data will see up to 34% annual growth in the same time period. At the same time, landline revenue in the U.S. will continue to decline from 2007's $174.7 billion (U.S.) to $153 billion by the end of 2011.[9]

J.D. Power and Associates reported that more than one-fourth of wireless phone customers have replaced their traditional home landlines and are now using wireless service exclusively to communicate on a daily basis.[10] Kirk Parson, senior director of wireless services at J.D. Power and Associates explains that with the improved user experience for wireless customers, coupled with the increase in the number of features and applications available for cell phones, it is no surprise to find that many wireless subscribers are choosing to replace their landline with entirely wireless service. "Wireless service has truly improved to the point where quality and performance are no longer barriers in the decision-making process around switching to exclusive wireless service usage," he noted.[11]

The rapid and widespread success of mobile broadband services is sparking a data traffic boom. Vodafone reported that data traffic increased by more than tenfold in the year ended March 31,

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[8] *CTIA-The Wireless Association Celebrates 25 Years of Mobile Communication*. CTIA. 10 October 2008.
[9] Talbot, Chris. *Wireless Data and WiMAX Growing Significantly.* ConnectIT. 30 September 2008.
[10] *J.D. Power and Associates Reports: One in Four Wireless Customers in the U.S. Report Replacing Their Landline Home Phone with Wireless Service.* J.D. Power and Associates. 2 October 2008.
[11] *Ibid.*

2008 compared to March 2007.[12] Wireless broadband services will create significant opportunities for revenue growth and cellular technologies will take the largest share, reports telecoms adviser firm Analysys Mason.[13]

The increased uptake of mobile broadband services data traffic – with more than 100 million subscriptions worldwide using more than 300 live networks[14] – is partly due to the trend of flat-rate mobile broadband tariffs. The flat-rate pricing movement that was started by Willcom in Japan, and moved to Europe, now is taking firm roots in the U.S. market with industry wide flat-rate pricing plans that include data services. All the major carriers offer flat-fee access plans for most of the new smartphones being introduced in the market.[15]

Data penetration had reached 56% and 3G penetration had reached 37% in 3Q 2008 in the U.S., up from 30% 3G penetration in 2Q 2008. Smartphone penetration has been inching up as well.[16] Analyst Chetan Sharma notes these trends are expected and the diffusion of mobile broadband will continue to create new opportunities and revenues for the ecosystem.[17]

The number of data subscribers has likewise been on the rise in the U.S. with messaging volumes averaging over 105 billion messages per month or at the average of one message per subscription every two hours.[18] In comparison, users in the Philippines routinely send one message every hour.[19] Text messaging in the U.S. continues to be enormously popular and is doubling every year, with more than 384 billion text messages reported by carriers in 2008 between January 1 and June 30 – an average of more than 2 billion per day[20] – more than 22 billion more text messages than for all of 2007.

Early 2007 was a milestone year when worldwide mobile handset shipments exceeded one billion for the first time, and in 2008, the world crossed another highly significant milestone by reaching 50% mobile penetration point worldwide. Another milestone in 2008, gross industry revenues were estimated to reach one trillion dollars.[21] Portio Research projects 75% global penetration by 2011.[22] This is an exciting time for the wireless cellular industry.

[12] *Mobile Traffic Growth Sparking Data Traffic Boom.* Max Digital Media Newswire. 4 August 2008.
[13] *Wireless Broadband to Exceed 2 Billion Customers by 2015*. FierceWireless. 30 July 2008.
[14] *Mobile Traffic Growth Sparking Data Traffic Boom.* Max Digital Media Newswire. 4 August 2008.
[15] *U.S. Wireless Data Market Update – Q3 2008*. Chetan Sharma. 16 November 2008.
[16] *Ibid.*
[17] *US Wireless Data Market Update – Q2 2008.* Chetan Sharma. August 2008.
[18] *Ibid.*
[19] *Ibid.*
[20] *CTIA-The Wireless Association Celebrates 25 Years of Mobile Communication*. CTIA. 10 October 2008.
[21] *Global Wireless Data Market Update – 1H 2008.* Chetan Sharma. 2008.
[22] *Worldwide Mobile Penetration will Reach 75% by 2011.* Press Release. 25 October 2007.

4.2 WIRELESS DATA REVENUE

Although 3G capabilities have been available to a critical mass for only a few years, the worldwide percentage of total revenue from data services increased on average to account for almost 20% of the global service revenues by the first half of 2008 according to Chetan Sharma.[23] According to Lehman Global Equity Research, among 3G subscribers that use mobile data applications, it is estimated that monthly data ARPU is nearly twice the average data ARPU for 2G subscribers.[24] In the U.S., the average industry percentage contribution of data-to-service revenues exceeded 23%.[25] In 2007, this figure stood at approximately 17.7% and this figure was predicted to rise to 25% by the end of 2008 according to Chetan Sharma. Most carriers around the world have double-digit percentage contributions to their overall ARPU from data services. Many leading operators consistently exceed 30% data revenues with DoCoMo and Softbank exceeding 40%.[26]

NTT DoCoMo continues to dominate the wireless data revenues rankings with almost $4.98 billion in data services revenues in 3Q 2008, thus exceeding the $10 billion mark in just nine months.[27] AT&T is among the select group of five global operators who are now generating $2 billion or more in data revenues per quarter, including NTT DoCoMo, China Mobile, KDDI and Verizon.[28]

According to a report by Pyramid Research entitled, *Mobile Data Best Practices,* mobile data will account for 29% of the global mobile services revenue in 2012, up from 19% in 2007. Pyramid says clearly the mobile data opportunity is soaring: 2007 mobile data revenue was more than double what it was in 2004 and is expected to double again to $300 billion by 2012.[29]

The U.S. remains a very strong market for operator revenues, and continued its rapid growth in wireless data service revenues in the first half of 2008 to $14.8 billion, up 40% from the first half of 2007, when data revenues were reported at $10.5 billion.[30] From SMS messaging to newer services such as mobile advertising, social networking and others, different services have helped to add billions to the revenues generated for 1H 2008. While Japan continues to remain the leader in the global markets with regards to new applications and services, the U.S. market

[23] *1H 2008 Report*. Chetan Sharma. 2008.
[24] *Ibid.*
[25] *U.S. Wireless Data Market Update – Q3 2008.* Chetan Sharma. 1 November 2008.
[26] *Ibid.*
[27] *Ibid.*
[28] *Ibid.*
[29] *Mobile Data Best Practices: Positioning and Revenue Opportunities in Emerging and Developed Markets*. Pyramid Research, report referenced in *Mobile Data Revenue to Double by 2012.* Cellular-News. 15 April 2008.
[30] *CTIA- The Wireless Association Releases Latest Wireless Industry Survey Results.* CTIA. 10 September 2008.

expanded its lead over Japan in mobile data service revenues for the year in the first half of 2008 and is unlikely to cede ground in the months to come, according to Chetan Sharma.[31]

Based on 3Q 2008 earnings reports from mobile operators in the region, Informa Telecoms & Media and Merrill Lynch cited the average data contribution to ARPU in Latin America was 14%. Countries with the highest data contribution to ARPU were: Argentina (27%), Venezuela (31%), Mexico (17%), Ecuador (16%), Chile (11%), Brazil (10%), Peru (8%) and Colombia (5%).

Messaging and mobile email continues to be the largest source of mobile data use and SNL Kagan predicts that 62% of wireless subscribers will utilize these services by 2017. Additionally, SNL Kagan expects mobile data revenue to increase by a compound annual growth rate of 16% from $24 billion in 2007 to exceed $100 billion in 2017 and wireless subscribers will reach 90% per capita penetration.[32]

4.3 3G DEVICES

The number of 3G enabled terminals has increased significantly since their introduction in 2004. Also, the size, features and weight of these units have fallen to a point where these handsets are more competitive vis-à-vis 2G handsets. In May 2008, Lehman estimated the average selling price of 3G handsets (not differentiating between 3G technologies) to have declined to around US$250, with the lowest priced unit at around US$125 (from Chinese vendors such as Huawei and ZTE).[33] Lehman speculates that more network operators are willing to subsidize the cost of 3G handsets for their high-end customers as an encouragement to switch to 3G and thereby open up capacity on their 2G networks and reducing overall CAPEX requirements. Lehman perceives improved 3G terminal devices with more attractive pricing as a contributing factor in driving 3G subscriber growth going forward.[34]

The sheer volume and variety of HSPA devices continues to explode. As of year-end 2008, there were more than 1,053 commercial HSPA devices worldwide from 126 suppliers including including 336 handsets, 76 data cards, 272 notebooks, 55 wireless routers, 99 USB modems and 46 embedded modules plus other devices such as surveillance cameras.[35] For example, a wireless dome camera system by CCTV with HSUPA connectivity that can be rapidly installed for remote monitoring applications onto lighting columns, buildings or any fixed structure will fall back to HSDPA, UMTS and GPRS technologies for coverage in almost any environment. In addition, the new devices are not solely enterprise-oriented, for example, T-Mobile USA launched a cellular picture frame just in time for the holiday shopping season in 2008. The T-Mobile Cameo is a picture frame with its own cellular modem so it can receive photos directly from mobile phones and sells for $100 plus a $10 monthly service fee. This is a unique way for operators to increase their subscribership without actually adding new human subscribers.

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[31] *1H 2008 Report*. Chetan Sharma. 2008.
[32] *SNL Kagan Expects Wireless Data Revenue to Increase at a 16% Annual Rate Over the Next Decade.* FierceWireless. 1 August 2008.
[33] Wuh, Paul. *Global 3G Developments: 3G subs accelerate, more data revenue in '09*. Lehman Global Equity Research. 23 May 2008.
[34] *Ibid.*
[35] http://hspa.gsmworld.com

One of the most rapidly growing device segments is smartphones. In fact, despite the gloomy economic picture and the problems experienced by some leading mobile handset vendors, global shipments of smartphones hit a new peak of just under 40 million units in Q3 2008, according to analyst firm Canalys.[36] Smartphones globally represented around 13% of the total mobile phone market up from 11% in the second quarter of 2008.[37] It is expected that the market for smartphones will grow from around 10% of the total global handset market in 2007 to 31% of the market in 2012, according to ABI Research.[38]

The Kelsey Group and ConStat conducted a consumer study of U.S. mobile phone users and reported that 18.9% of mobile consumers now use a smartphone.[39] Among those surveyed, 49.2% plan to purchase an advanced mobile device within the next two years. "We are seeing a qualitative difference in consumer usage of mobile phones, particularly with the energetic uptake of smartphones," stated Steve Marshall, director of research and consulting, The Kelsey Group. "The aggressive projections about mobile are approaching reality, as smartphones are now becoming mainstream platforms for commercial usage."[40]

Smartphones contain high-end operating systems, such as RIM's Blackberry (proprietary Java-based S), Nokia E61 and 6650 (Symbian Series 60 OS), HTC's G1 (Google's Android OS), Sony Ericsson's Xperia X1, LG's Incite and HTC's FUZE (Windows Mobile 6.1 Professional), Apple's iPhone (proprietary OS X) or Palm Treo (Windows Mobile OS or Palm OS). Other vendors are joining this successful handset market venture as the competition heats up, such as Huawei, with outlined plans for Android and Symbian smartphones in the first half of 2009. Huawei already has a Windows Mobile smartphone and will target operator-branded devices.

Kevin Fitchard, editor for Telephony Wireless Review, interprets carrier data revenues to be just as dependent – if not more dependent – on the devices they offer than the availability or even the speeds of the data services themselves. As an example, the iPhone helped drive AT&T data revenues in Q1 2008 even on the EDGE network. In the April 29, 2008 article, Telephony editor Rich Karpinski anticipated the July 2008 debut of the iPhone 3G as the ultimate test to take advantage of AT&T's 3G (HSPA) service and identified the device as a potential driver for market share, sales and revenue further noting that the combination of the next-gen iPhone and 3G services represent the perfect alchemy, potentially driving iPhone sales and AT&T data revenues to altogether new heights.[41] The launch returned favorable results and AT&T's data revenues continue to escalate, up 51.2% year-over-year in the fourth quarter of 2008 with more than 1.9 million iPhone 3G devices sold, 40% of which were sold to customers new to AT&T with net customer adds at 2.1 million, building its subscriber base to 77 million.[42]

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[36] *Global Smart Phone Shipments Rise 28% - Apple Takes #2 Position*. Cellular-News. 7 November 2008.
[37] *Ibid.*
[38] *By 2013 One in Every Three Phones Sold Will Be a Smartphone*. ABI Research. 20 March 2008.
[39] *Rapid Adoption of Smartphones Driving Mobile Search Activity*. Cellular-News. 3 November 2008.
[40] *Ibid.*
[41] Karpinski, Rich. *Devices drive data usage, operators find.* Telephony Wireless Review. 29 April 2008.
[42] *AT&T Reports Fourth Quarter and Full-Year Results Highlighted by Robuts Wireless Data Growth, Accelerated Uverse TV Ramp, Continued Double-Digit Growtin in IP Data Services*. AT&T. Fourth Quarter Press Release and Investor Briefing. 28 January 2009.

If there is a moral to the *Telephony* story, it is that offering data services in and of themselves may not draw customers as strongly as offering highly appealing devices that are based around those services. It is the same story as in the wireless voice market: consumers like – and buy – cool devices.

iPhone users have turned out to be prodigious consumers of wireless data. For example, the iPhone customers of T-Mobile in Germany consume 30 times more data than its other wireless customers, according to analyst Chetan Sharma. Sharma estimates that iPhone users in the U.S. consume two-and-a-half to three-times more data than users of other cell phones. Faster [3G] networks could widen that gap and further extend the iPhone's influence in the telecommunications world. "iPhone is not only having an impact on data revenues, but also on device design, mobile advertising road maps and applications and services that are being contemplated for the future," Chetan Sharma stated.[43]

Spurred by the popularity of Apple's iPhone and its elegant user interface, global shipment of touch-screen display modules are expected to more than double from 2008 to 2012 according to iSuppli.[44] iSuppli expects the market to grow from 341 million units in 2008 to 833 million units by 2013 with a CAGR of 19.5% from 2008. The touch-screen market is characterized by more than 100 suppliers, in excess of 300 OEM/integrators and a wealth of technological alternatives.[45]

Matt Booth, senior vice president and program director, The Kelsey Group stated, "We believe the introduction of more user-friendly smartphones is ushering in a new mobile paradigm where devices now offer an Internet experience that is as easy as traditional voice connectivity. The implication is that users will increasingly turn to their smartphones for local commercial and social search experiences, and the data certainly suggest this is already happening."[46]

Handset transition will drive the emergence of mobile TV services, according to a market study by ARC Chart. The report forecasts that 295 million specialist handset devices – that can receive one or another format of mobile TV – will be sold by 2012. Furthermore, 61 million non-handset devices will be added, making total shipments of 356 million devices which can view mobile TV.[47]

GPS is one of the features that will become more prevalent in 3G handsets and enable increased data applications. According to Berg Insight, there were 175 million handsets that support GPS technology as of April 2008, and this number will grow to more than a half a billion worldwide in five years.[48] Analyst firm Canalys reported on European smartphone sales noting 38% of devices now come with GPS and 58% can connect using WiFi.[49]

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[43] Markoff, John. *The Guessing Game Has Begun on the Next iPhone*. The New York Times. 28 May 2008.
[44] *Touch-Screen Shipments Expected to Reach 833 Million by 2013*. iSuppli. 20 May 2008.
[45] *Ibid.*
[46] *Rapid Adoption of Smartphones Driving Mobile Search Activity*. Cellular-News. 3 November 2008.
[47] *Mobile TV Business Models, Technologies and Markets 2008-12.* ARC Chart. May 2008.
[48] *Berg Insight says GPS-enabled handset shipments will reach 560 million units in 2012*. Berg Insight. 15 January 2008.
[49] Marek, Sue. *Report: Smartphone Capabilities are Causing Battery Drain.* FierceWireless. 18 August 2008.

While the mobile phone is by far the most common device to connect to mobile networks, the number of non-handset devices is set to grow dramatically reported ARChart.[50] Termed “mobile Internet peripherals and devices” by ARChart, this category encompasses products such as data cards, laptops, ultra-mobile PCs, game consoles, eBooks, digital signs, ATMs and a host of other M2M applications. Sitting within all these devices is a wireless data module providing a connection to a wide-area network. ARChart forecasts that unit shipments of these mobile data modules will grow from a base of 10 million in 2007 to 370 million units by 2013, representing a market value of $11 billion; and service revenue generated by operators from these products will hit US$93 billion worldwide by 2013.[51]

An initial group of 16 equipment manufacturers and mobile companies jumped on board for the “Mobile Broadband” laptop branding program with the GSMA featuring a special service mark that will appear on a range of notebook PCs featuring embedded HSPA 3G connectivity.[52] According to Pyramid Research, addressing a potential mass market valued at 70 million units worldwide and an untapped $50 billion fills a gap not already taken by dongles and data cards and positioning cellular networks as an alternative to WiFi and DSL. Integrating Mobile Broadband into notebook PCs is the only the first step in a wider strategy for this initiative to deliver wireless Internet access and management to a whole range of previously unconnected devices – from cameras and MP3 players to refrigerators, cars and set-top boxes. However, only devices that offer a truly untethered Mobile Broadband experience will qualify to carry the new service mark right out of the box in 91 countries across the world. Launch participants included 3 Group, Asus, Dell, ECS, Ericsson, Gemalto, Lenovo, Microsoft, Orange, Qualcomm, Telefónica Europe, Telecom Italia, TeliaSonera, T-Mobile, Toshiba and Vodafone – some of the world’s largest technology brands and operators serving more than 760 million connections (Wireless Intelligence).[53]

4.4 3G APPLICATIONS

The mobile phone continues to be the main device of choice for communication between users whether via voice, SMS, IM, or MMS/video, thereby creating communities of like-minded users who readily create, distribute and consume content. It is also rapidly becoming the single most important source of consumption of entertainment, news and ad content. Finally, it is becoming the device of choice for content generation whether via video recordings, photographs or audio recordings.

While the global economy is showing more and more signs of slowing down, mobile messaging growth is continuing at a healthy pace. Some fascinating mobile messaging trends emerged in the third quarter of 2008. These trends included the use of messaging for social and political change and marketing, as evidenced by U.S. President-elect Barack Obama’s successful mobile campaign, the use of mobile messaging for charitable donations and a significant uptick in the use of mobile messaging by enterprises and financial institutions.

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[50] *Non-Handset Devices to Account for $90 Billion in Operator Revenues by 2013*. Cellular-News. 29 September 2008.
[51] *Ibid.*
[52] *Industry Giants Unite to Deliver Mobile Broadband Future.* GSMA. 30 September 2008.
[53] *Ibid.*

In a recent report from ABI Research, it was cited that mobile messaging services revenues will grow from $151 billion in 2008 to greater than $212 billion globally by 2013.[54] Analyst Dan Shey commented, "Mobile messaging ARPUs are 85%+ of all handset data services revenues regardless of region."[55] There are five common platforms that comprise mobile messaging: SMS, MMS, voicemail, IM and email/unified messaging.

Smartphone and cell phone users have traditionally relied on their devices strictly for voice calls, text messaging and email access. However, recent studies are finding that more individuals are turning to their phones for recreation and leisure. Consumer demand for high end mobile handsets, coupled with increasing interest in mobile social networking and entertainment, is skyrocketing due to innovations in technology and phones' abilities to serve multiple purposes.[56]

In a Nielsen survey of iPhone users and their data usage, 70% listened to audio tracks on their phones (39% downloaded music directly to the device), 66% downloaded software and applications, and 35% watched video on their phones (making them seven-times as likely as the typical mobile subscriber to do so).[57] Nielsen also reported that 98% of iPhone users use at least one data service and 43% have a monthly bill of more than $100 (compared to 20% of all subscribers).[58]

According to a consumer study conducted by mobile technology and applications developer Artificial Life, 46% of U.S. mobile subscribers now turn to their phones for entertainment purposes.[59] Additionally, Strategy Analytics reports that total spending on mobile media services by U.S. consumers and advertisers, including Web access, video and music products, will more than double – from almost $47 billion in 2007 to over $102 billion by 2012.[60]

Mobile Internet is benefiting from the popularity of social networking websites (SNS), according to M:Metrics. The media authority reported that social networking and Internet commerce is compelling smartphone users to spend an average of four hours and thirty-eight minutes per month browsing the mobile Web in the U.S. and two and a half hours per month in Britain. M:Metrics noted that Craigslist was the most popular mobile Internet destination while MySpace and Facebook and were third and fourth most popular, respectively. Facebook was named the number one most popular search term in the UK.[61]

In an online study conducted by ABI Research, 46% of those who use social networks have also visited a social network using a mobile phone, of which nearly 70% had visited MySpace and 67% had visited Facebook. No other social networking sites were reported to have reached 15%

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[54] *No Slowing of Mobile Messaging Services Growth in Tough Economic Times*. FierceWireless. 10 November 2008.
[55] *Ibid.*
[56] Ankeny, Jason. *Not Just Busienss as Usual – Artificial Life Discovers Almost Half of U.S. Mobile Phone Users Turn to Their Devices for Entertainment*. FierceWireless. 1 October 2008.
[57] *Nielsen: 3.6 million iPhone users 13+ (and other iPhone insights).* Fierce Wireless. 13 November 2008.
[58] *Ibid.*
[59] Ankeny, Jason. *Study: Half of U.S. Users Embracing Mobile Entertainment.* FierceMobileContent. 1 October 2008.
[60] *Ibid.*
[61] *Americans Spend More Than 4.5 Hours per Month Browsing on Smartphones, Nearly Double the Rate of the British.* Press Release (Market Wire) M:Metrics. 21 May 2008.

mobile adoption.[62] Michael Wolf, ABI Research director, explains, "The social network is increasingly becoming a central hub for communication across online and mobile domains for many consumers. To a degree, it allows them to centralize messaging, communication and even digital media consumption through a centralized property on various screens. We believe this centralization of a consumer's digital lifestyle through social networks will only increase adoption of mobile social networking in coming years."[63]

Online social networking is growing strongly as mobile versions of favorite social networks are becoming more available. The ability of members to access a social networking site from anywhere will enhance the utility of the SNS and thus boost the amount of advertising revenue that it can generate. ABI Research forecasts that in 2013, more than 140 million subscribers will utilize the "anytime, anywhere" services, generating more than $410 million in subscription revenues.[64] In addition to an increase in subscription revenues, SNSs could present operators with considerable opportunities in mobile advertising and mobile content sales. Social networking accounts for almost 40% of worldwide mobile web traffic, topping the 60% mark in some countries including the U.S., South Africa and Indonesia as of May 2008 and reported by browser development firm Opera Software.[65]

Pyramid forecasts 300 million mobile social networking users by 2010, representing 7% of worldwide mobile subscribers. By 2012, an expected 18% of mobile users, 950 million users worldwide, will be accessing at least one social networking site via their mobile device.[66]

Social networking has experienced an explosion in popularity online. By the end of 2007 there were an expected 230 million active memberships in such online websites.[67] Social networking giants such as MySpace and Facebook have seen dramatic year-on-year growth in the U.S. From September 2007 to 2008, MySpace had a total of 59 million users and Facebook reported 39 million users.[68] MySpace, Facebook, YouTube and Flickr are just some of the many social networks online, and there are many different variants. Now, both the social networking industry and telecoms and media industries are bringing such services and user-generated content (UGC) to mobile devices.

In 2007, MySpace introduced an ad-supported mobile version of its site and in early 2008, launched its mobile platform. Like the PC version of MySpace, the service allows users to send and receive messages, add friends, blog, post pictures or search. In recent months, MySpace has launched mobile applications for Android as well as for Blackberry phones.

[62] *MySpace and Facebook Fast Becoming The Leading Mobile Social Networks.* FierceWireless. 6 October 2008.
[63] *Ibid.*
[64] *Online Social Networking Goes Mobile: 140 Million Users by 2013.* ABI Research. 2 September 2008.
[65] *State of the Mobile Web.* Reported by Opera Software referenced in *Opera: Social Networking 40% of Mobile Web Traffic.* FierceWireless. 20 May 2008.
[66] *Ibid.*
[67] Winterbottom, Daniel. *Social networking has potential to drive mobile revenues, but also to add to network woes.* Informa. 19 November 2007.
[68] Chartier, David. *Studies: Social Networks Exploding, May Appear in Government.* Ars Technica. 26 October 2008.

For those who have Android phones, mobile applications include features such as instant photo upload from Android to a MySpace profile and the ability to access information on user profiles. The application is also integrated with Shazam, which allows users to identify music to connect to music artists' MySpace pages.[69] The MySpace mobile application for Blackberry allows users to use their mobile devices to send and receive MySpace mail, update their status, view and send bulletins, add comments and post photos. MySpace now has developed applications for Android, Sidekick, iPhone and BlackBerry.[70]

Facebook also has expanded into mobile, allowing users to update their profiles from mobile devices and to be alerted when they receive messages from their friends. Facebook SMS allows users to receive notifications or update their status with text messages. According to mobile team engineer Wayne Chang, Facebook's mobile user base expanded from 5 million to 15 million since the beginning of 2008. On the Facebook Blog, Facebook mobile team engineer Wayne Chang wrote that in the 24 hours after the site began allowing subscribers to comment on their friends' status updates to the Facebook mobile site, users posted close to a million status comments.[71] "People are hungry for interactive mobile features worldwide, and Facebook users are no exception," he wrote.

Facebook users can access its mobile site, m.facebook.com, which works on nearly any mobile browser worldwide, or if they have a smartphone they can access the extended site, x.facebook.com. Facebook's mobile platform extends applications to phones with additional applications for specific devices, such as Palm, Blackberry and iPhone.[72] People can tag and upload photos and send Facebook invitations from their BlackBerry's address book. Facebook's mobile user base is growing faster than the website.[73]

Globally, the total value of the user-generated content (UGC) market, which includes social networking, online dating and personal content delivery (PCD) services, will increase from nearly $1.1 billion in 2008 to more than $7.3 billion in 2013, with social networking surpassing dating to become the largest revenue generating segment by 2009, according to a report by Juniper Research [74] The report also addresses the increasing significance played by advertising, which will account for nearly one-third of total revenues in the UGC space by the end of the forecast period, and more than half of mobile social networking revenues.[75] The number of active users of mobile social networking is expected to rise from 54 million in 2008 to nearly 730 million in 2013 according to Juniper. Juniper also predicts that by 2013, there will be more than 9 billion downloads from PCD sites, of which 32% will be ad-supported.[76]

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[69] Zeman, Eric. *Android Market Gouged of Apps, But Mobile MySpace Gets Added*. Over the Air: InformationWeek's Mobile Weblog. 20 October 2008.
[70] *Ibid.*
[71] Chang, Wayne. *A Rush for Change.* The Facebook Blog. 10 November 2008.
[72] *Ibid.*
[73] Winterbottom, Daniel. *Social networking has potential to drive mobile revenues, but also to add to network woes*. Informa. 19 November 2007
[74] *Press Release: Advertising to Fuel Mobile Social Networking Growth as UGC Revenues Reach $7.3bn by 2013, Juniper Report Reveals.* Juniper Research. 16 September 2008.
[75] *Ibid.*
[76] *Ibid.*

Mobile location-based social networking is predicted to become a key driver for the uptake of location-based services as it provides a unifying framework for a large set of applications such as friend finders, local search and geo-tagging.[77] According to ABI Research, the emergence of location-based social mobile networking services offered by providers such as GyPSii, Pelago and Loopt is revolutionizing social networking by allowing users to share real-life experiences through geo-tagged user-generated multimedia content, exchange recommendations about places, identify nearby friends and set up last-minute face to face meetings. Location-based mobile social networking revenues are predicted to generate $3.3 billion by 2013.[78]

While many location-based service (LBS) applications will include features that allow users to share experiences in real-time via fixed social networking sites such as Facebook and MySpace, fully-equipped mobile location-based social networking sites will also gain momentum with more than 82 million subscriptions expected by 2013. ABI Research director Dominique Bonte commented that, "while growth will be mainly driven by the availability of multimedia-centric GPS handsets, other mobile form factors will also become important." [79] One key factor that will be critical for location-enabled social sites to achieve significant market share is licensing agreements with carriers and handsets manufacturers. While initially a wide range of business models will coexist, ultimately advertising-based models are expected prevail due to the perfect fit with the local search- and content-driven social context.[80]

Today, the idea that mobile phones could become an extension of a person's wallet or purse has become a reality. The industry has settled on NFC technology as the most suitable way of transforming mobile devices into a payment method. This allows the development of proximity payment solutions, whereby mobile devices can be used in a fashion similar to other contactless payment methods. Examples of these include PayPass and PayWaves, contactless cards from, respectively, Visa and MasterCard. Transit operators, for example, can use handset-based proximity payments (NFC) to achieve savings through a reduction in their operating costs.[81] The processing cost of an electronic transaction is around 40% cheaper than that of a paper ticket.[82] ARC Chart predicts that based on the strength of trials and pilots conducted in 2007, that in 2008, device manufacturers would begin to ship NFC-enabled handsets in earnest, forecasting shipments to increase at a CAGR of 338% for the period 2008-2012, culminating in shipment of 504 million devices in 2012.[83]

While the mobile market today is dominated by digital goods and purchases such as ringtones, music, games and infotainment, Juniper Research reports that there are three high potential markets which offer new opportunities for the future: contactless NFC, mobile money transfer and

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[77] *82 Million Location-Based Mobile Social Networking Subscriptions by 2013.* Cellular-News. 6 November 2008.
[78] *Location-based Mobile Social Networking Will Generate Global Revenues of $3.3 Billion by 2013.* ABI Research. 1 August 2008.
[79] *82 Million Location-Based Mobile Social Networking Subscriptions by 2013.* Cellular-News. 6 November 2008.
[80] *Ibid.*
[81] *Driving Mobile Payments and Ticketing with NFC Handsets*. ARC Chart. May 2008.
[82] *Ibid.*
[83] *Ibid.*

physical goods purchases via mobile devices. These markets will together generate transactions worth over $600 billion globally by 2013, according to Juniper Research.[84]

GSMA recently called for full NFC functionality, including the standardized "Single Wire Protocol" to be built into commercially available mobile handsets from mid-2009, in order to insure that consumers can reap the benefits of mobile payments services as soon as possible.[85] A series of operator trials have demonstrated that consumers can use UICC-based NFC handsets to quickly, easily and securely pay for goods and services in shops, restaurants and train stations. Kris Rinne, Senior Vice President, Architecture and Planning, AT&T, commented that "as one of the first operators to trial mobile payments, we've seen firsthand, the willingness of consumers to adapt to this new payment channel which is very much dependent upon the availability of NFC handsets and the associated ecosystem." The GSMA issued a consolidated set of minimum requirements in what is coined the "Pay-Buy-Mobile" ecosystem.[86] The GSMA also is working closely with leading financial intermediaries and banks to promote globally interoperable transaction solutions. Both MasterCard and Visa are supporting trials with their PayPass and Visa payWave features respectively, that enable NFC-equipped phones to affect payment transactions at secure contactless point of sale terminals. Motorola, Nokia, Sagem, Samsung and LG are among the handset makers developing phones for NFC-enabled mobile payment services. Gemalto, G&D and KEBT are among the UICC card suppliers supporting NFC-enabled mobile payment service.[87]

Juniper Research expects that over 400 million subscribers worldwide will use their mobile phones for ticketing by 2013 with total gross mobile ticketing transactions value reaching $92 billion.[88] A number of cinemas, football and baseball teams are now beginning to offer options for ticket purchase and delivery. Benefits for the ticketing issuers include reduced cost, better security to help fight against fraud and improved environmental footprint by reducing paper usage. Early use of mobile barcode technology will be further improved by the emergence of NFC, particularly for the transportation ticketing sector. These services are already in play in the Far East and China with important trials in North America and Western Europe. Juniper's report predicts that together these top three regions will account for over 80% of mobile ticketing on a gross transaction basis by 2013.[89]

Vendors are working to extend the reach of mobile TV. One example is the May 2008 announcement by Alcatel-Lucent and Quantum SpA of their cooperation to develop terrestrial or hybrid (terrestrial and satellite) mobile broadcast solutions adhering to the new DVB-SH mobile broadcast standard.[90] Seamless multimedia mobility for mass market Mobile TV is their goal, through Pay TV digital set-top boxes for the automotive industry, Pocket TV Portable Media Players and the software that brings together unique applications through the convergence of

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[84] *Juniper Research Forecasts Total Mobile Payments to Grow Nearly Ten Fold by 2013.* Juniper Research. 3 September 2008.
[85] *GSMA Calls for Pay-Buy-Mobile Handsets*. GSMA. 18 November 2008.
[86] *Ibid.*
[87] *Ibid.*
[88] Ankeny, Jason. *Forecast: 400 Million Mobile Ticketing Users by 2013*. FierceWireless. 21 October 2008.
[89] *Ibid.*
[90] *Alcatel-Lucent and Quantum SpA Cooperate to Extend the Reach of DVB-SH Mobile TV*. Alcatel-Lucent. 6 May 2008.

Mobile TV, the Internet and location based services into a single personal device. Key drivers include in-car multimedia entertainment, portable devices with larger screens and navigation services to accelerate the advent of mass market mobile TV, by providing end users with an experience that complements their traditional TV experience.

ARC Chart forecasts that 295 million specialist handset devices – that can receive mobile TV in one form or another – will be sold by 2012. Furthermore, 61 million non-handset devices will be added, totaling shipments of 356 million devices that are enabled to view mobile TV.[91]

New research indicates that entertainment and gaming applications have become the two most popular mobile tools for smartphone users, according to Gartner, Inc.[92] A November 2008 report conducted by The NPD Group found that although smartphone usage is still highest for the primary purpose of communication, including features such as making and receiving phone calls and sending and receiving text and/or email messages, more smartphone owners are playing games than using business-related applications on their devices.[93]

Although mobile gaming has not been around for long, the mobile gaming industry has already reached the billion dollar benchmark.[94] The U.S. market for mobile games is projected to grow from $344 million in 2007 to $1.15 billion in 2012, while spending on mobile music will surpass $4 billion in 2012, from just under $1 billion last year according to eMarketer.[95] Additionally, Gartner, Inc. projects the mobile gaming industry will be worth $4.5 million in 2008, a 16.1% increase over 2007 revenues.[96]

A study conducted by In-Stat found that about one-third of respondents said they have played a game on their handset and about one-fifth of respondents said they have downloaded games from Internet sites other than their mobile carrier's site. In-Stat noted that it believes significant momentum for the gaming industry worldwide will continue to make the sector a key contributor to wireless data usage and revenues and the industry is expected to exceed $6.8 billion by 2013.[97]

The worldwide market for location-based communications services on mobile devices was expected to have exceeded $1.6 billion in 2008 as an increasing number of cellular and wireless carriers provide customized services based upon a location-awareness of their end-users.[98] According to a market research study from The Insight Research Corporation, consumers of mobile telecommunications services are adopting location-based services along with other IP-enabled services such as presence based services, telephony, fixed-mobile convergence, file sharing and streaming services.[99] Robert Rosenberg, Insight Research, says, "In the early 1990s

[91] *Mobile TV Business Models, Technologies and Markets 2008-12*. ARC Chart. May 2008.
[92] Ankeny, Jason. *Not Just Business As Usual – Artificial Life Discovers Almost Half of U.S. Mobile Phone Users Turn to Their Devices for Entertainment*. FierceWireless. 1 October 2008.
[93] *Smartphone Owners Play Games More Often Than Use the Business Tools.* Cellular-News. 11 November 2008.
[94] *Mobile Gaming: $1B and Counting*. RCR Wireless. 29 October 2008.
[95] *Mobile Content Still Gathering Steam.* eMarketer. 27 October 2008.
[96] Ankeny, Jason. *Not Just Business As Usual – Artificial Life Discovers Almost Half of U.S. Mobile Phone Users Turn to Their Devices for Entertainment*. FierceWireless. 1 October 2008.
[97] *Mobile Gaming: $1B and Counting*. RCR Wireless. 29 October 2008.
[98] *Location Based Services Spending in 2008 Tops $1.6 Billion.* Cellular-News. 11 November 2008.
[99] *Ibid.*

the use of global positioning systems with wireless telecommunications was restricted to military applications. Now the application is commonplace, with applications that range from automobile navigation systems to mothers using the technology to keep track of their children based on cell phone location." Additionally, worldwide subscribers to location-based communications services on mobile devices were expected to increase by nearly 168% in 2008 and to rise from 16 million in 2007 to 43.2 million in 2008, according to a Gartner report. [100]

In correspondence with the rapid consumer adoption of smartphones is a significant increase in the level of mobile search activity. Findings from a recent study conducted by Mobile Market View, which measured the activities consumers performed using their mobile devices, indicate a growth rate of mobile Internet users that is in line with The Kelsey Group's U.S. Mobile Advertising Forecast: 2007-2012 (September 2007), which projected mobile Internet users would grow at a compound annual growth rate of 19% through 2012. [101] According to the latest Mobile Market View findings, the percentage of mobile users who access the Internet from their mobile devices increased from 32.4% in 2007 to 38.9% in 2008, an annual growth rate of 20%. [102] Matt Booth, senior vice president and program director of Interactive Local Media for The Kelsey Group noted that, "We believe the introduction of more user-friendly smartphones is ushering in a new mobile paradigm where devices now offer an Internet experience that is as easy as traditional voice connectivity. The implication is that users will increasingly turn to their smartphones for local commercial and social search experiences and the data certainly suggest that this is already happening." [103]

The ubiquity of mobile services and increasing adoption of various mobile data services have provided mobile operators with new channels of communication and always-on connectivity to their target audience, according to Frost & Sullivan. Its report, *U.S. Mobile Advertising and Search Markets*, finds that the market revenues are expected to reach $1,893.5 million in 2012. [104] Frost & Sullivan Industry Analyst Vikrant Gandhi notes, "Adoption of mobile advertising by the nation's largest mobile operators and innovative mobile virtual network operators (MVNOs) is a testament to the perceived potential of the market. Mobile advertising efficiently serves the expectations of advertisers, mobile operators, and even subscribers when offered in a highly targeted, non-intrusive manner." Mobile advertisements are mainly in the form of messaging, wireless application protocol (WAP), mobile video, in-application, and performance-based advertising within search, WAP and other environments. [105]

Juniper Research notes that mobile advertising is becoming increasingly important in the user-UGC space, and by 2013, ad-funded social networks will provide the bulk of UGC revenues. [106] By the end of the forecast period, advertising is expected to account for nearly one-third of total

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[100] *Dataquest Insight: Location-Based Services Subscriber and Revenue Forecast 2006-2011*. Gartner. 12 February 2008.
[101] *Rapid Adoption of Smartphones Driving Mobile Search Activity.* Cellular-News. 3 November 2008.
[102] *Ibid.*
[103] *Ibid.*
[104] *Mobile Advertising Turns the Corner with Tier-1 Mobile Operators Adopting the Service.* Press Release. Frost and Sullivan. 15 September 2008.
[105] *Ibid.*
[106] *Press Release: Advertising to Fuel Mobile Social Networking Growth as UGC Revenues Reach $7.3bn by 2013, Juniper Report Reveals.* Juniper Research. 16 September 2008.

revenues in the UGC market and more than half of mobile social networking revenues.[107] Dr. Windsor Holden of Juniper Research states, "Whereas initially there was a perception that users would pay a small mobility premium to access social networks on their handsets, it rapidly became clear that to achieve truly mass adoption, it would be necessary to offer free membership and then to augment that with advertising and the sale of premium content."[108]

Coupons delivered and redeemed via mobile phone are forecast to be used by some 200 million mobile subscribers worldwide by 2013, according to a study by Juniper Research. The report concluded that the mobile coupons market is most advanced in Japan and Korea, but that growing numbers of mobile coupon services are being offered in the U.S. and Europe across all main retail sectors, including entertainment, restaurants, shopping and grocery. Juniper projects that developed nations of the Far East, North America and Western Europe will account for the major part of the market by 2013.[109] Nearly all mobile coupon usage is currently in the Far East, but by 2013, North America and Western Europe will together account for nearly 20% of coupon redemption values. The report notes that technology is also a factor, with most mobile coupons today delivered by a code – often a bar code – and SMS. Juniper predicts that in the future, NFC will become popular in this application.[110]

Another tremendous area of growth for wireless data will be in machine-to-machine (M2M) wireless mobile connections. According to ABI Research senior analyst Sam Lucero, "traditional mobile network operators are raising the visibility of machine-to-machine (M2M) efforts that are already pretty robust. Our informational calculation is that mobile network operators now own 85-90% of the M2M market, and we expect that share to grow, in the context of an overall expanding pie." Lucero further explains that the reason MNOs would make an aggressive push into the M2M market is that, "the core voice/data market is becoming saturated and the operators are looking for new areas that show high growth and, if accessed correctly, can return fairly high margins."[111]

According to a research report by Berg Insight, the number of machines connected to mobile networks in Europe is expected to grow by 34.2% in 2008 and reach 14.1 million at year-end. By 2013 this number is projected to reach 58.6 million.[112] The number of connected machines in Europe is increasing, and is predicted to reach almost 60 million in a five year period.[113]

Business cases suggest that in terms of earned revenue per KB, or per message, margins can be better with M2M than in consumer services. The devices use low levels of data, so where a consumer could buy 1Gb of data for under $50 month, an M2M "user" might pay something like $4Mb – but then only use 350KB to 1Mb monthly.[114] As a result, profitability per subscriber

[107] *Ibid.*
[108] *Ibid.*
[109] *Press Release: Promotional Coupons sent via Mobile Phones to Exceed 200m Users by 2013 finds Juniper Research.* Juniper Research. 12 November 2008.
[110] *Ibid.*
[111] *Mobile Operators Reclaiming the Machine-to-Machine Connectivity Market.* Cellular-News. 23 October 2008.
[112] *Berg Insight Says 14.1 Million Machines Will Be Connected to Mobile Networks in Europe At the End of 2008.* Press Release. Berg Insight. 27 October 2008.
[113] *Ibid.*
[114] *M2M*. Mobile Communications International. November 2008.

becomes more relevant. Rami Avidan of Wyless projects next generation technologies will help drive the business in new and innovative ways, however, this is a view for the next two to four years. Avidan estimates that 95% of the customers are happy with GPRS/EDGE/3G today.[115] However, as capacity requirements increase, specialized devices for M2M applications are developed, and companies partner to address vertical market application opportunities, the M2M market will require the benefits of LTE.

4.5 IP MULTIMEDIA SUBSYSTEM (IMS)

IMS is an important component of 3GPP evolution, and this architecture is rapidly maturing. IMS is expected to provide mobile telephone operators with a forecasted $300 billion in extra revenue over the next five years (through 2013) according to ABI Research due to new services delivered with IMS. “Until recently IMS was mainly the province of fixed-line operators,” said senior analyst Nadine Manjaro. “But now it is essential to the success of mobile and fixed operators who are losing revenue from traditional sources. IMS enables rapid development and deployment of new services.”[116]

Perhaps a remaining challenge is the integration of IMS without operators disrupting existing services. Introducing IMS into a wireless network is not a a trival task, and requires support and coordination between a complex ecosystem, including IMS core, IMS Application Servers, devices/terminals, IT/billing/customer care/OSS/etc., and in many cases enhancements and modifications to existing 2G and 3G infrastructure to provide seamless service delivery across the old and new networks. This need is being met by a wide variety of vendors, including all the infrastructure members of 3G Americas, who have products and services which support, in various ways, operators’ ambitions to migrate towards IMS.

Work was conducted by organizations such as the GSM Association in 2008 to test carrier ENUM services and make it easier to send IMs, MMS, emails, videos and any other IP content between mobiles and fixed line phones, as well as mobile-to-mobile transmissions. Bharti, mobilkom Austria, SMART, Telekom Austria, Telecom Italia and Telenor were involved in the “Pathfinder” service pilot that successfully provided fixed and mobile operators with a single routing mechanism, to simplify and reduce the cost of delivery of a wide range of IP-based services to end-users. “Pathfinder” achieved full commercial service by the end of 2008 and automatically translates a phone number into an IP-based address making it transparent for users to initiate a wide range of IP-based communications via their existing phone numbers and handset address books.

“As we move to the end of the decade, mobile networks will emerge with a flat all-IP architecture using 3GPP standards to deliver multimedia services and VoIP,” said Ian Cox, principal analyst at ABI Research. “In the meantime operators want to offer attractive calling plans to consumer and enterprise users. This will enable a single device to use both mobile and fixed broadband network, improving business efficiency and enabling users to access directory information easily

[115] *Ibid.*
[116] *IP Multimedia Subsystems’ $300 Billion Opportunity*. ABI Research. 13 March 2008.

from their favorite device." [117] According to a March 2008 study by ABI Research, fixed mobile convergence market could grow to 250 million users by 2012. Converged services on fixed and mobile networks were available and new femtocell trials and announcements were forthcoming in 2008.

Based on research by Strategy Analytics, the market for enterprise Fixed-Mobile Convergence (FMC) solutions are expected to grow to over $50 billion by 2012. New factors are pushing the enterprise market towards a tipping point at which companies can see the business process benefits of FMC, resulting in unreserved implementation. Analysis indicates that UMA services will initially generate the more significant revenues due to its early market entry, but this position will be eroded over time by SIP-based services. "SIP-based services will initially be implemented by large multi-nationals with the capacity to carry voice traffic on their private MPLS network," stated David Kerr of Strategy Analytics. "Consequently, SIP-based revenues will overtake UMA revenues toward the end of the forecast period [2012]." [118]

The 3GPP evolution path to IMS has been well thought out over multiple years, developed and matured in standards for a similar period of time, and is now reaching maturity in terms of commercialization.

4.6 IN-BUILDING WIRELESS SYSTEMS

With the GSM operator able to offer fully-converged connectivity using the existing core network, subscribers may seamlessly roam from the cellular network to a WLAN, maintaining the call as they move from one network to the other. As cellular operators increase the variety of services and applications they offer to their customers the issue of in-building coverage increases in significance. A range of solutions make in-building wireless systems economically viable. System configurations may include passive and active distributed antenna systems, multi-band repeaters and antennas, picocells, femtocells, coax, fiber and CAT-5 cabling. In-building wireless systems will create the network conditions for public safety band coverage, alternative broadband and voice network access and managed services.

As VoIP and SIP are deployed, there will be a natural progression to FMC infrastructure for mobile networks. UMA service, the most well known, is represented by dual mode cellular or Wi-Fi handsets. Other services have entered the market, including femtocells.

ABI Research reports that deployment growth of in-building wireless systems (passive distributed antenna systems, active distributed antenna systems, distributed repeater solutions and distributed radio solutions) has accelerated to nearly 26% and by 2013, more than 500,000 buildings will utilize an in-building wireless system. [119] ABI Research forecasts worldwide

[117] *FMC Market to Count 250M Users by 2012*. ABI Research. 21 March 2008.
[118] *Enterprise FMC Market to Reach $50 Billion by 2012*. Strategy Analytics. 21 May 2008.
[119] *In-Building Wireless Systems Will Reach 500,000+ Buildings Through 2013, According to ABI Research.* Press Release. Business Wire. 19 May 2008.

deployment revenues from in-building wireless systems to grow from $3.8 billion in 2007 to more than $15 billion in 2013. [120]

However, operators and building owners hold a major influence on the in-building wireless market as result of their tendency to deploy in-building wireless networks. [121] According to Dan Shey, principle analyst with ABI Research, in-building wireless networks will also change the marketplace for serving business customers as well. “In-building wireless systems establish a footprint for the delivery of information and services. And successful mobile telecommunication providers will leverage these networks to fundamentally change the way data and communications are delivered to mobile customers.” [122]

Both dual-mode handsets and home base stations or femtocells will be used by operators to enable them to fulfill their strategies. Main players using UMA include BT, Orange, TeliaSonera and T-Mobile USA. Others who have deployed FMC but have not used UMA include Telecom Italia, O2 Germany and AT&T. Numerous operators are trialing femtocells as part of their convergence strategies and announcements have been made by several operators including AT&T (2H 2009) and Verizon (early 2010).

4.7 VOIP OVER CELLULAR

Industry interest in “VoIP over Cellular” is increasing. Reasons include the prospects of higher ARPU through richer communication (evolution currently driven by Internet players); lower OPEX through the offering of all mobile services from a common PS platform; and fixed/mobile convergence. The movement is to standardize an ‘IMS Multimedia Telephony’ service in 3GPP for many reasons: standardized services have benefits over proprietary solutions in terms of mass market potential; IMS is the standardized IP service engine for 3GPP access; and the service should make use of IP’s multimedia capability and flexibility, while retaining key telephony characteristics. 3GPP is the entity with major mobile telephony expertise to accomplish this standardization process.

The HSUPA networks initially deployed in 2H 2007, which now total 60, achieved the bidirectional capability needed to run real VoIP over Cellular.

The evolution of mobile VoIP will rapidly eclipse voice over Wi-Fi and become a mainstream form of communication according to a study from Disruptive Analysis. The analyst firm predicts that the number of VoIP over 3G users could grow from virtually zero in 2007 to over 250 million by the end of 2012. This is comfortably in excess of the expected number of FMC users with dual-mode VoWLAN/cellular phones. [123] The report demonstrates that “it will be operators themselves which will be mainly responsible for the push towards VoIP because it will enable them to fit more phone calls into their scarce spectrum allocations, reduce operating expenses by combining fixed and mobile core networks and launch new services like push-to-talk and voice integrated

[120] *In-Building Wireless System to Exceed Revenue of $15 Billion by 2013*. ABI Research. 24 March 2008.
[121] *In-Building Wireless Systems Will Reach 500,000+ Buildings Through 2013, According to ABI Research.* Press Release. Business Wire. 19 May 2008.
[122] *Ibid.*
[123] *Over 250m VoIP Users Over 3G Mobile Networks by 2012*. Disruptive Analysis. 13 November 2007.

'mashups' VoIP over 3G also fits well with the move towards femtocells. Future generations of wireless technology – such as LTE – are 'all-IP', so unless mobile operators continue to run separate voice networks in parallel, they will inevitably transition to VoIP at some point." [124]

There is a tremendous amount of information available on the growth of wireless data. Additional information has been included in Appendix B of this paper.

4.8 SUMMARY

Networks, devices and applications remain three key elements in the success of the maturing wireless market for wireless data services. Advancements and enhancements in these areas have catered to wireless users' demands for anytime, anywhere connections. This increase in consumer demand and adoption largely contributes to the push for development and growth in the wireless industry in addition to providing operators with opportunities to increase revenue growth.

The demands for wireless data are the drivers for continued development of the UMTS standards. In the following section, developments in 3GPP for UMTS Rel-8 and beyond are reviewed.

[124] *Ibid.*

5 OVERVIEW OF 3GPP REL-8, EVOLVED HSPA/HSPA+ ENHANCEMENTS AND EVOLVED PACKET SYSTEM (EPS): SAE/EPC AND LTE/EUTRAN

The 3GPP Rel-8 specifications are nearing completion with publication plans by March 2009. The Rel-8 specifications include enhancements to the Evolved HSPA (i.e. HSPA+) technology, as well as the introduction of the EPS which consists of a flat-IP based all-packet core (SAE/EPC) coupled with a new OFDMA-based RAN (EUTRAN/LTE). This section provides detailed discussions on the HSPA+ enhancements in Rel-8 followed by detailed discussions of the EPS, EPC and LTE architecture, features/capabilities and performance estimates.

5.1 EVOLVED HSPA/HSPA+ ENHANCEMENTS

3GPP Rel-8 contains improvements to the downlink to support data rates up to 42Mbps, using either a combination of MIMO and 64QAM or dual-carrier HSDPA for operation on two 5MHz carriers with 64QAM. In the uplink, Enhanced CELL_FACH supports Enhanced Uplink functionality and, in addition, improved Layer 2 has been introduced in the uplink direction.

5.1.1 MIMO WITH 64QAM MODULATION IN DOWNLINK

Rel-8 combines MIMO and 64QAM modulation (two features in Rel-7) to boost the peak downlink rate over a single 5MHz carrier to 42Mbps.

The term MIMO refers to the use of more than one transmit antenna in the base station and more than one receive antenna in UEs. The transmitter chain for the standardized MIMO scheme applies separate coding, modulation and spreading for up to two transport blocks transmitted over two parallel streams, thereby doubling the achievable peak rate in the downlink. The UE radio propagation conditions determine how many streams (one or two) will be transmitted.

In Rel-7, 16QAM is the highest-order modulation used in combination with MIMO. Therefore, four bits can be transmitted per modulation symbol, resulting in a peak rate of 28Mbps. The upgrade to 64QAM in Rel-8 allows six bits to be transmitted per symbol, which increases the peak rate by 50% to 42Mbps. To the greatest possible extent, the introduction of MIMO with 64QAM modulation reuses the protocol changes introduced in Rel-7 for MIMO and 64QAM respectively.

5.1.2 DUAL-CARRIER OPERATION IN DOWNLINK

In deployments where multiple downlink carriers are available, the new multicarrier operation offers an attractive way of increasing coverage for high bit rates. Rel-8 introduces dual-carrier operation in the downlink on adjacent carriers. This technique doubles the peak rate from 21Mbps to 42Mbps without the use of MIMO – it doubles the rate for users with typical bursty traffic; therefore, it also doubles the average user throughput, which translates into a substantial increase in cell capacity.

A dual-carrier user can be scheduled in the primary serving cell as well as in a secondary serving cell over two parallel HS-DSCH transport channels. All non-HSDPA-related channels reside in the primary serving cell, and all physical layer procedures are essentially based on the primary serving cell. Either carrier can be configured to function as the primary serving cell for a particular user. As a consequence, the dual-carrier feature also facilitates an efficient load balancing between carriers in one sector. As with MIMO, the two transport channels perform hybrid automatic repeat request (HARQ) retransmissions, coding and modulation independently. A difference compared to MIMO is that the two transport blocks can be transmitted on their respective carriers using a different number of channelization codes.

In terms of complexity, adding a dual-carrier receiver to UEs is roughly comparable to adding a MIMO receiver. Because the two 5MHz carriers are adjacent, they can be received using a single 10MHz radio receiver, which is already be available if the UE is LTE-capable.

5.1.3 ENHANCEMENTS TO COMMON STATES

Users should always be kept in the state that gives the best trade-off between data rate availability, latency, battery consumption and usage of network resources. As a complement to the data rate enhancements made to the dedicated state (CELL_DCH), 3GPP has also made significant enhancements to the common states (URA_PCH, CELL_PCH and CELL_FACH).

Rel-7 introduces HSDPA mechanisms in the common states in order to improve their data rates, latency and code usage. Rel-8 introduces corresponding enhancements in the uplink, allowing base stations to configure and dynamically manage up to 32 common E-DCH resources in each cell. This enhancement improves latency and data rates for keep-alive messages (for example, from VPN or messenger applications) as well as web-browsing events, providing a seamless transition from E-DCH in common state to E-DCH in dedicated state.

As a further improvement of the CELL_FACH state, Rel-8 introduces discontinuous reception (DRX), which significantly reduces battery consumption. Therefore, UEs can remain in CELL_FACH for long periods of time. DRX is now supported in all common and dedicated states.

5.2 EVOLVED PACKET SYSTEM (EPS): SAE/EPC AND EUTRAN/LTE

Sections 5.2.1 and 5.2.2 provide details on the EPS/SAE/EPC architecture and EUTRAN/LTE air-interface respectively.

5.2.1 EVOLVED PACKET SYSTEM (EPS) ARCHITECTURE

In its most basic form, the EPS architecture consists of only two nodes in the user plane: a base station and a core network Gateway (GW). The node that performs control-plane functionality (MME) is separated from the node that performs bearer-plane functionality (GW), with a well-defined open interface between them (S11), and by using the optional interface S5 the Gateway (GW) can be split into two separate nodes (Serving Gateway and the PDN Gateway). This allows for independent scaling and growth of throughput traffic and control signal processing and operators can also choose optimized topological locations of nodes within the network in order to optimize the network in different aspects. The basic EPS architecture is shown in Figure 3, where support nodes such as AAA and policy control nodes have been excluded for clarity.

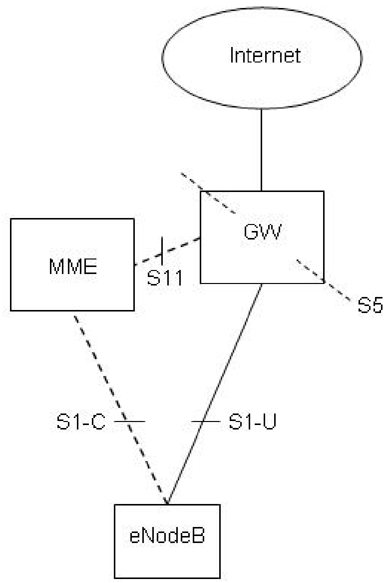

Figure 3. Basic EPS architecture [125]

The EPS architecture has a similar functional distribution as the HSPA -Direct Tunnel PS core network architecture. This allows for a very easy integration of HSPA networks to the EPS, as shown in Figure 4. Reference point S12 between UTRAN and Serving GW is for user plane tunneling when Direct Tunnel is established. It is based on the Iu-u/Gn-u reference point using the GTP-U protocol as defined between SGSN and UTRAN or respectively between SGSN and GGSN. Reference point S4 provides related control and mobility support between GPRS Core and the 3GPP Anchor function of Serving GW. In addition, if Direct Tunnel is not established, it also provides the user plane tunneling.

[125] Ericsson. Q2 2007.

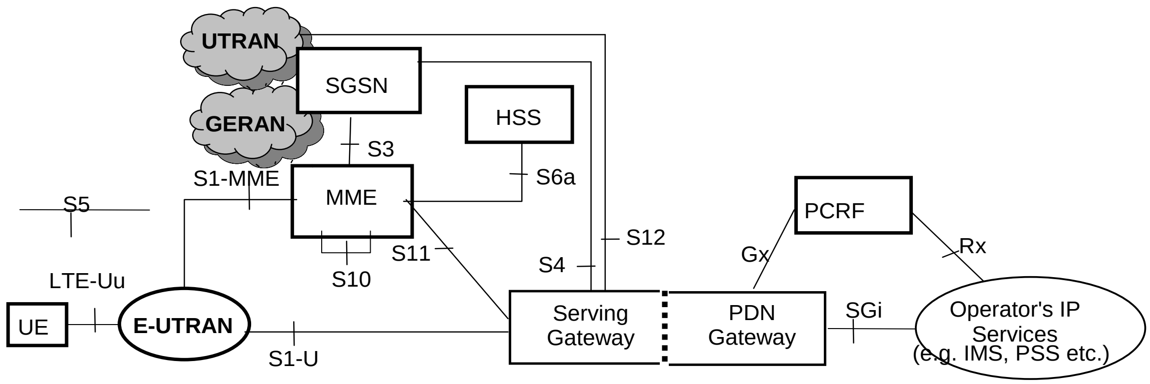

Figure 4. Example configuration for EPS support of 3GPP Accesses including UMTS/HSPA

The example in Figure 4 requires the SGSN to implement the new reference point S3 and S4 as defined in 3GPP Rel-8. In this particular implementation, S5 is an internal interface between Service Gateway and PDN Gateway. In some operator deployment scenarios, it may be preferred that not all SGSN needs to be upgraded to Rel-8 SGSN that supports S3 and S4. Hence, 3GPP also specifies interworking between the EPS and 3GPP 2G and/or 3G SGSNs, which provides only Gn and Gp interfaces but no S3 or S4 reference points. Figure 5 shows an example of architecture for interoperation with Gn/Gp SGSNs.

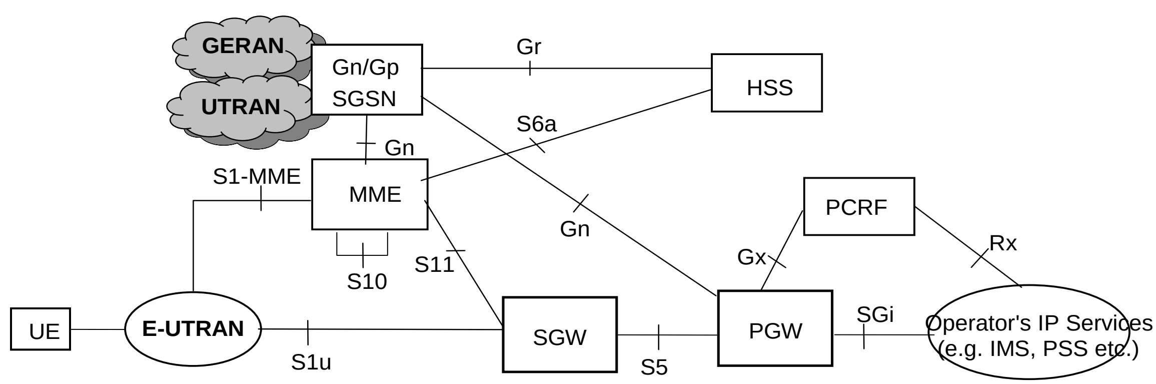

Figure 5. Example architecture for interoperation with Gn/Gp SGSNs

NOTE: If the Rel-7 SGSN applies Direct Tunnel there is a user plane connection between PGW and UTRAN.

The EPS is also capable of integrating non-3GPP Access networks. Figure 6 shows more details of the basic architecture of the EPS in a roaming scenario with support of non-3GPP access networks. In this view, some of the network elements which may be physically co-located or distributed, according to product development and deployment scenarios, are all shown as separate entities. For instance, the Serving Gateway may or may not be co-located with the MME and the Serving Gateway and the PDN Gateway may or may not be co-located in the same physical node.

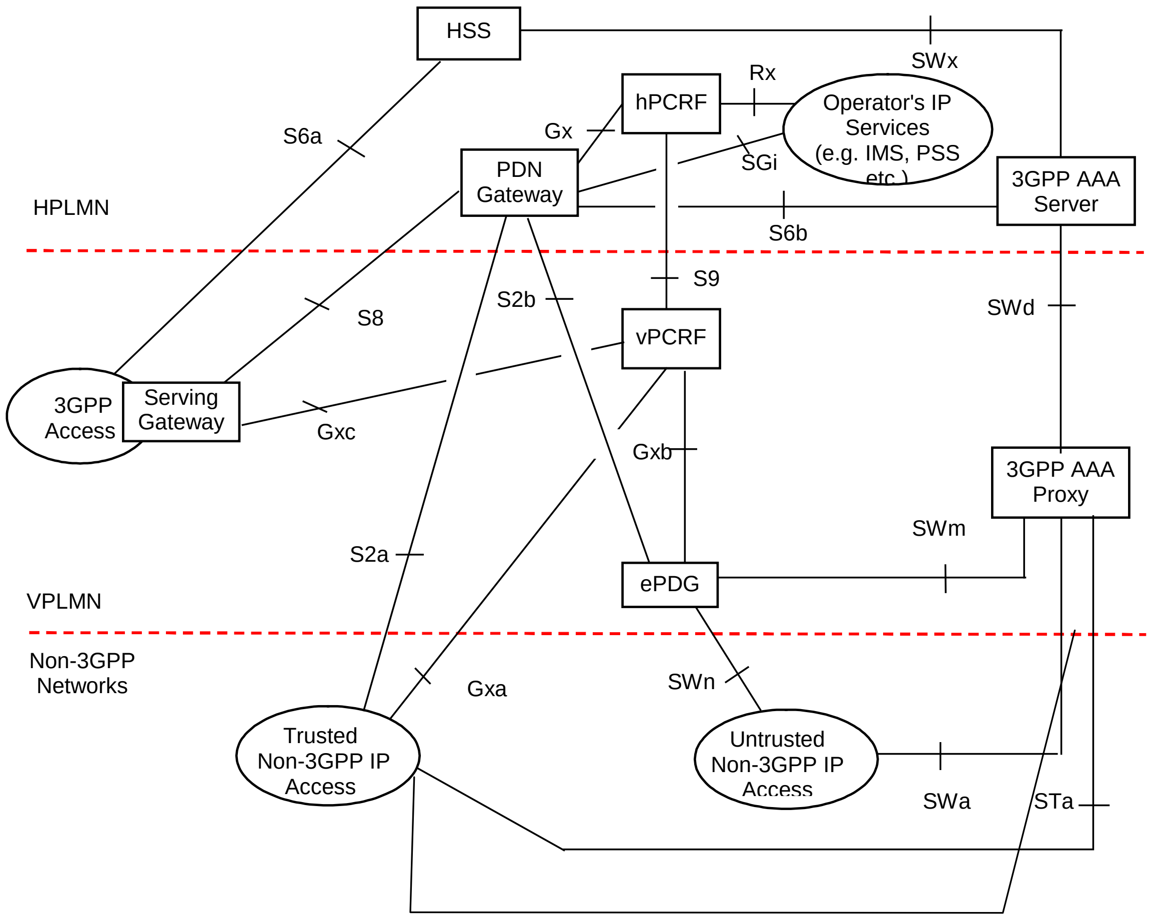

Figure 6. Detailed EPS architecture view [126]

5.2.1.1 FUNCTIONAL NODES

The basic architecture of the EPS contains the following network elements:

- **eNodeB**
    - Functions for Radio Resource Management
    - IP header compression and encryption of user data stream
    - Selection of an MME at UE attachment when no routing to an MME can be determined from the information provided by the UE

[126] *Ibid.*

    - Routing of User Plane data towards Serving Gateway
    - Scheduling and transmission of paging messages (originated from the MME)
    - Scheduling and transmission of broadcast information (originated from the MME or O&M)
    - Measurement and measurement reporting configuration for mobility and scheduling

- **Mobility Management Entity (MME):** The MME manages mobility, UE identities and security parameters. MME functions include:
    - NAS signaling and related security
    - Inter CN node signaling for mobility between 3GPP access networks (terminating S3)
    - Idle mode UE Tracking and Reachability (including control and execution of paging retransmission)
    - Tracking Area list management
    - Roaming (terminating S6a towards home HSS)
    - GW selections (Serving GW and PDN GW selection)
    - MME selection for handovers with MME change
    - SGSN selection for handovers to 2G or 3G 3GPP access networks
    - HRPD access node (terminating S101 reference point) selection for handovers to/from HRPD
    - Authentication
    - Bearer management functions including dedicated bearer establishment
    - Lawful Interception of signaling traffic
    - Support for Single Radio VCC and CS Fallback for 2G/3G and 1xRTT CDMA

- **Serving Gateway:** The Serving Gateway is the node that terminates the interface towards EUTRAN. For each UE associated with the EPS, at a given point of time, there is a single Serving Gateway. Serving GW functions include:
    - The local Mobility Anchor point for inter-eNodeB handover
    - Mobility anchoring for inter-3GPP mobility (terminating S4 and relaying the traffic between 2G/3G system and PDN Gateway)
    - EUTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure
    - Transport level packet marking in the uplink and the downlink, e.g. setting the DiffServ Code Point, based on the QCI of the associated EPS bearer
    - Accounting on user and QCI granularity for inter-operator charging

- Lawful Interception
- Packet routing and forwarding
- Some charging support

- **PDN Gateway:** The PDN Gateway is the node that terminates the SGi interface towards the PDN. If a UE is accessing multiple PDNs, there may be more than one PDN GW for that UE. PDN GW functions include:
  - Policy enforcement
  - Per-user based packet filtering (by e.g. deep packet inspection)
  - Charging support
  - Transport level packet marking in the uplink and downlink, e.g. setting the DiffServ Code Point, based on the QCI of the associated EPS bearer
  - Lawful Interception
  - UE IP address allocation
  - Packet screening
  - DHCP functions

- **Evolved UTRAN (eNodeB):** The eNodeB supports the LTE air interface and includes functions for radio resource control, user plane ciphering and Packet Data Convergence Protocol (PDCP).

5.2.1.2 SUPPORT FOR NON-3GPP ACCESSES

For a non-roaming and roaming architecture for EPS, there are three possible types of interfaces in EPS to support non-3GPP access: S2a, S2b, and S2c:

1. S2a provides the user plane with related control and mobility support between Trusted non-3GPP IP access and the Gateway;
2. S2b provides the user plane with related control and mobility support between ePDG and the Gateway;
3. S2c provides the user plane with related control and mobility support between UE and the Gateway. This reference point is implemented over Trusted and/or Untrusted non-3GPP Access and/or 3GPP access.

In non-roaming scenario it is the HPLMN's operator decision if a non-3GPP IP access network is used as Trusted or Untrusted non-3GPP Access Network.

In roaming scenario, the HSS/3GPP AAA Server in HPLMN makes the final decision of whether a non-3GPP IP access network is used as Trusted or Untrusted non-3GPP Access Network. The HSS/3GPP AAA Server may take the VPLMN's policy and capability returned from the 3GPP AAA Proxy or roaming agreement into account.

For supporting multiple PDNs, the same trust relationship shall apply to all of the PDNs that the UE connects to from a certain non-3GPP Access Network, i.e. it shall not be possible to access one PDN using the non-3GPP access network as Trusted, while access to another PDN using the same non-3GPP access network as Untrusted.

For Untrusted non-3GPP accesses the EPS, an external Packet Data Gateway (ePDG) is used.

The functionality of ePDG includes the following:

- Functionality defined for the PDG in TS 23.234 [7] for the allocation of a remote IP address as an IP address local to the ePDG which is used as CoA when S2c is used;
- Functionality for transportation of a remote IP address as an IP address specific to a PDN when S2b is used;
- Routing of packets from/to PDN GW (and from/to Serving GW if it is used as local anchor in VPLMN) to/from UE;
- De-capsulation/Encapsulation of packets for IPSec and PMIP tunnels (the latter only if network based mobility (S2b) is used);
- Mobile Access Gateway (MAG) according to draft-ietf-netlmm-proxymip6 [8] if network based mobility (S2b) is used;
- Tunnel authentication and authorization (termination of IKEv2 signaling and relay via AAA messages);
- Local mobility anchor within Untrusted non-3GPP access networks using MOBIKE (if needed);
- Transport level packet marking in the uplink;
- Enforcement of QoS policies based on information received via AAA infrastructure;
- Lawful Interception;
- Allocation of GRE key, which is used to encapsulate downlink traffic to the ePDG on the PMIP-based S2b interface.

A UE connected to one or multiple PDN GWs uses a single ePDG. In case of handover between ePDGs, the UE may be temporarily connected to two ePDGs.

5.2.1.3 SUPPORT OF POLICY CONTROL AND CHARGING

The Policy Control and Charging (PCC) functionality is supported via the functionality of the PCRF which is described in TS 23.203 with additional functionality listed in TS 23.401 and 23.402. Additionally, the PCRF terminates the Gxa, Gxb and Gxc reference points with the appropriate IP-CANs to support non-3GPP accesses PCC.

5.2.1.3.1 HOME PCRF

In addition to the h-PCRF functionality listed in TS 23.401, in this document the Home PCRF:

- Terminates the Gx reference point for roaming with home routed traffic;
- Terminates the Gxa, Gxb or Gxc/S9 reference points as appropriate for the IP-CAN type.

5.2.1.3.2 VISITED PCRF

In addition to the v-PCRF functionality listed in TS 23.401, in this document the Visited PCRF:

- Terminates the Gxa, Gxb or Gxc reference points as appropriate for the IP-CAN type;
- Terminates the S9 reference point.

5.2.1.4 INTERFACES & PROTOCOLS

To support the new LTE air interface as well as roaming and mobility between LTE and UTRAN/GERAN the EPS architecture contains the following interfaces:

- **X2:** The X2 interface connects neighboring eNodeBs to each other and is used for forwarding contexts and user data packets at inter-eNodeB handover.
- **S1-MME:** Reference point for the control plane protocol between E-UTRAN and MME
- **S1-U:** Serves as a reference point between E-UTRAN and Serving GW for the per bearer user plane tunneling and inter eNodeB path switching during handover
- **S3:** Enables user and bearer information exchange for inter 3GPP access network mobility in idle and/or active state. It is based on Gn reference point as defined between SGSNs.
- **S4:** Provides related control and mobility support between GPRS Core and the 3GPP Anchor function of Serving GW and is based on Gn reference point as defined between SGSN and GGSN. In addition, if Direct Tunnel is not established, it provides the user plane tunneling.
- **S5:** Provides user plane tunneling and tunnel management between Serving GW and PDN GW. It is used for Serving GW relocation due to UE mobility and if the Serving GW needs to connect to a non-collocated PDN GW for the required PDN connectivity.
- **S6a:** Enables transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between MME and HSS
- **S6d:** Enables transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between S4-SGSN and HSS
- **Gx:** Provides transfer of (QoS) policy and charging rules from PCRF to Policy and Charging Enforcement Function (PCEF) in the PDN GW
- **S8:** Inter-PLMN reference point providing user and control plane between the Serving GW in the VPLMN and the PDN GW in the HPLMN. It is based on Gp reference point as defined between SGSN and GGSN. S8 is the inter PLMN variant of S5.
- **S9:** Provides transfer of (QoS) policy and charging control information between the Home PCRF and the Visited PCRF in order to support local breakout function

- **S10:** Serves as a reference point between MMEs for MME relocation and MME to MME information transfer
- **S11:** Serves as a reference point between MME and Serving GW
- **S12:** Serves as a reference point between UTRAN and Serving GW for user plane tunneling when Direct Tunnel is established. It is based on the Iu-u/Gn-u reference point using the GTP-U protocol as defined between SGSN and UTRAN or respectively between SGSN and GGSN. Usage of S12 is an operator configuration option.
- **S13:** Enables UE identity check procedure between MME and EIR
- **SGi:** Reference point between the PDN GW and the packet data network. Packet data network may be an operator external public or private packet data network or an intra operator packet data network (e.g. for provision of IMS services). This reference point corresponds to Gi for 3GPP accesses.

5.2.1.5 INTERFACES & PROTOCOLS FOR NON-3GPP ACCESSES

To support non-3GPP accesses the EPS also included the following interfaces:

- **S2a:** The S2a interface provides the user plane with related control and mobility support between Trusted non-3GPP IP access and the PDN Gateway. S2a is based on Proxy Mobile IPv6 (PMIP) and to support accesses that do not support PMIP also Mobile IPv4.
- **S2b:** The S2b interface provides the user plane with related control and mobility support between ePDG and the PDN Gateway. S2b is based on the Proxy Mobile IPv6 (PMIP).
- **S2c:** The S2c interface provides the user plane with related control and mobility support between UE and the PDN Gateway. It is implemented over Trusted and/or Untrusted non-3GPP Access and/or 3GPP access and it is based on the DS-MIPv6 protocol.
- **S6b:** The S6b interface is is the reference point between PDN Gateway and 3GPP AAA server/proxy for mobility related authentication if needed
- **Gxa:** The Gxa interface provides transfer of (QoS) policy information from PCRF to the Trusted non-3GPP accesses
- **Gxc:** The Gxc interface provides transfer of (QoS) policy information from PCRF to the Serving Gateway
- **PMIP-based S8:** S8 is the roaming interface in case of roaming with home routed traffic. It provides the user plane with related control between Gateways in the VPLMN and HPLMN.
- **SWa:** The SWa interface connects the Untrusted non-3GPP IP Access with the 3GPP AAA Server/Proxy for transport of access authentication, authorization and charging-related information
- **STa:** The STa interface is the equivalent of SWa for Trusted non-3GPP IP Accesses
- **SWd:** The SWa interface connects the 3GPP AAA Proxy to the 3GPP AAA Server
- **SWm:** The SWm interface is used for AAA signaling (transport of mobility parameters, tunnel authentication and authorization data)

- **SWn:** The SWn interface is the reference point between the Untrusted non-3GPP IP Access and the ePDG, is has the same functionality as Wn which is defined in TS 23.234 for interworking between 3GPP systems and WLAN.
- **SWu:** The SWu interface handles the support for IPSec tunnels between the UE and the ePDG
- **SWx:** The SWx interface is used for transport of authentication data between 3GPP AAA Server and HSS
- **S101**: The S101 interface enables interactions between MME of EPS and eAN/PCF of CDMA access to allow for pre-registration and handover execution signaling between EPS and CDMA for an optimized handover
- **S102:** S102 is a special interface used for voice call handover between EPS and 1xRTT network. The S102 reference point is used to convey 3GPP2 1x CS signaling messages between the MME and 3GPP2 1x CS IWS. These 1x CS signaling messages are actually exchanged between the UE and the 3GPP2 1x CS IWS, and S102 is only one link in the overall UE-1x CS IWS tunneling path. On the remaining portion of the tunneling path, the 3GPP2 1x CS signaling messages are encapsulated in E-UTRAN/EPS tunneling messages (UE-MME).
- **S103**: S103 is the User Plane interface between SGW of EPS and HSGW of CDMA is used to bearer data connections to minimize packet losses in mobility from EPS to HRPD in an optimized handover

5.2.1.6 SYSTEM ASPECTS

This section will discuss QoS/Bearer, Identities and Security Aspects of the EPS architecture.

5.2.1.6.1 QOS AND BEARER CONCEPT

Within EPS, a logical concept of a bearer has been defined to be an aggregate of one or more IP flows related to one or more services. The bearer concept is valid for both GTP-based S5/S8 and PMIP-based S5/S8. For E-UTRAN access to the EPC the PDN connectivity service is provided by an EPS bearer in case of GTP-based S5/S8, and by an EPS bearer concatenated with IP connectivity between Serving GW and PDN GW in case of PMIP-based S5/S8.

One EPS bearer is established when the UE connects to a PDN, and that remains established throughout the lifetime of the PDN connection to provide the UE with always-on IP connectivity to the PDN. That bearer is referred to as the default bearer. Any additional EPS bearer that is established to the same PDN is referred to as a dedicated bearer. The distinction between default and dedicated bearers is transparent to the access network (e.g. E-UTRAN).

The EPS bearer exists between the UE and the PDN gateway and is used to provide the same level of packet forwarding treatment to the aggregated IP flows constituting the bearer. Services with IP flows requiring a different packet forwarding treatment would therefore require more than one EPS bearer. The UE performs the binding of the uplink IP flows to the bearer while the PDN Gateway performs this function for the downlink packets.

In order to provide low latency for always on connectivity, a default bearer will be provided at the time of startup. This default bearer will be allowed to carry all traffic which is not associated with a dedicated bearer. Dedicated bearers shall be used to carry traffic for IP flows that have been identified to require a specific packet forwarding treatment. They may be established at the time of startup; for example, in the case of services that require always-on connectivity and better QoS than that provided by the default bearer. The default bearer is always non-GBR, with the resources for the IP flows not guaranteed at eNodeB, and with no admission control. However, the dedicated bearer can be either GBR or non-GBR. A GBR bearer has a Guaranteed Bit Rate (GBR) and Maximum Bit Rate (MBR) while more than one non-GBR bearer belonging to the same UE shares an Aggregate Maximum Bit Rate (AMBR). Non-GBR bearers can suffer packet loss under congestion while GBR bearers are immune to such losses.

Currently, based on the protocol being used on S5 and S8 interfaces, EPS allows for two flavors of bearers. Figure 7 shows the GTP-U based bearer. In this case, the GTP tunnel IDs over S5/S8a interfaces have a one-to-one mapping to S1 interface Tunnel IDs as well as to Radio Bearer IDs over the Radio Bearer. The mappings are stored in the respective nodes performing the mapping for the duration of the session. The IP flows are identified by the UE and the PDN GW by uplink and downlink packet filters respectively. So the aggregated IP flows constituting a bearer are carried from the UE over the radio interface to eNodeB, from eNodeB to the Serving

Gateway, and then onwards to the PDN Gateway as on a single logical bearer with the same level of QoS (or packet forwarding characteristic).

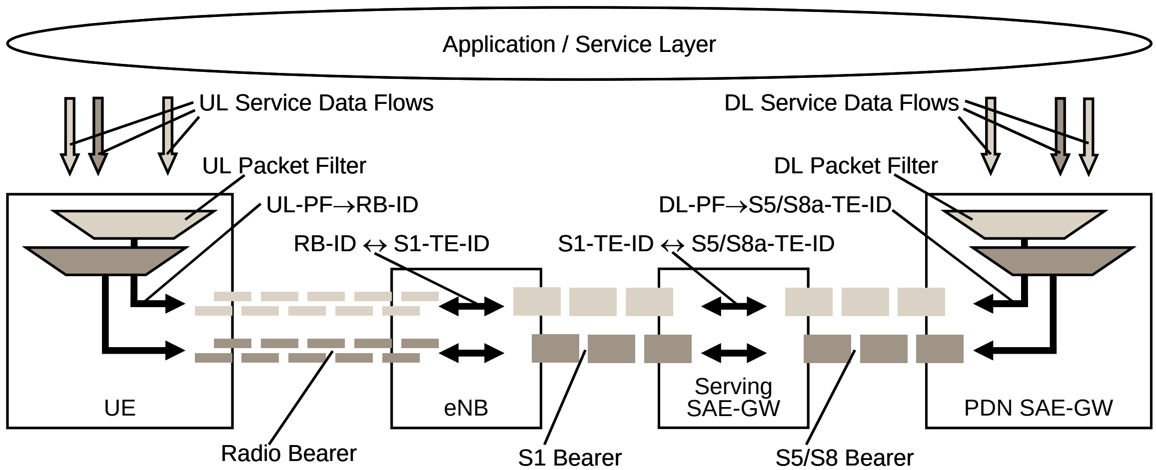

Figure 7. Two Unicast bearers (GTP-u Based S5/S8) [127]

For a bearer, QoS is defined by two parameters: 1) Label and 2) Allocation and Retention Priority (ARP). QoS of a GBR bearer is defined also by the bitrates GBR and MBR. A Label provides a simple mapping from an integer value to eNodeB specific QoS parameters that control bearer level packet forwarding treatment. High level packet forwarding characteristics mapping to label include: GBR/non-GBR nature of the bearer, packet loss rate and packet delay budget. The operator may decide to have mapping of these characteristics to specific Labels pre-configured to allow for a well-defined set of QoS compliant services. The meaning of the Label can also be standardized across roaming partners to allow for consistent service experience. ARP does not have any impact on packet forwarding behavior but is used to decide if a bearer request (including during handoffs) can be accepted based on resource availability.

The initial bearer level QoS parameter values of the default bearer are assigned by the network, based on subscription data (in case of E-UTRAN the MME sets those initial values based on subscription data retrieved from HSS). The PCEF may change those values based in interaction with the PCRF or based on local configuration. For E-UTRAN, the decision to establish or modify a dedicated bearer can only be taken by the EPC, and the bearer level QoS parameter values are always assigned by the EPC.

5.2.1.6.2 IDENTITIES

The terminal and the network entities in an EPS network need identities for addressing, mobility, connectivity, confidentiality and other purposes. These include both permanent and temporary identities. Where possible, effort has been made that the EUTRAN reuses currently used

[127] *Two Unicast Bearers*. 3GPP TS 23.401

identities from GSM and UMTS as this is beneficial, for example, in UE mobility and identification. In addition, because of new functionalities and features introduced in EPS, new identities are needed. For example, an EPS bearer identity uniquely identifies an EPS bearer for one UE accessing via E-UTRAN. The EPS Bearer Identity is allocated by the Mobility Management Entity (MME). MME also allocates a Globally Unique Temporary Identity (GUTI) to the UE. With non-3GPP access types being part of the EPS, 3GPP users will be identified in a non-3GPP access by a Network Access Identifier (NAI) defined in IETF RFC 4282. The home network realm and a root NAI will be derived from an IMSI. Decorated NAI will be used for proper routing of the messages using NAI. Use of non-3GPP identities within an EPS system for authentication, authorization and accounting purposes is currently not allowed.

5.2.1.6.3 SECURITY ASPECTS

This section will discuss certain security aspects of the EPS, namely Subscriber Authentication and Traffic Protection.

SUBSCRIBER AUTHENTICATION

In EPS, the subscriber authentication occurs between the UE and the MME using an enhanced version of the 3G AKA protocol. It has been agreed to allow the use of Rel-99 USIM, but use of SIM is not allowed. In EPS architecture for authentication, a new functional entity called Access Security Management Entity (ASME) has been introduced which will be collocated with the MME for NAS signaling protection (encryption and integrity verification). In this new architecture the CK/IK keys are confined to the home network with the ASME receiving derived keys from them (K_ASME) for authentication with the UE. ASME provides keys derived from K_ASME to the collocated MME. Similarly eNodeB also receives keys from ASME which are derived from K_ASME. The key hierarchy and derivation process is shown in Figure 8. While the MME keeps the keys, the eNodeB deletes all the keys when the UE goes into idle mode. ASME keeps the K_ASME for future reuse. At inter eNodeB handovers, new eNodeB-specific keys maybe derived by the source and/or destination eNodeB. Keys are bound to specific algorithms, so when changing MME or eNodeB, a change of algorithm can occur. This should be reported to the UE which would require new derivation of keys both at the destination MME or eNodeB and the UE. Since the user plane is encrypted in the eNodeB for over-the-air downlink transmission, changing the Serving GW does not imply any update of security keying material unless accompanied by inter eNodeB handover.

For handovers between EUTRAN and 3G/2G systems, the key exchange occurs between the MME and the SGSN. For UTRAN/GERAN to EUTRAN handovers SGSN sends CK/IK to MME in the relocation request message. MME and UE will derive K_ASME from it and re-authenticates the UE as soon as possible to derive fresh keying material. For EUTRAN to UTRAN/GERAN, the MME puts the K_ASME through a one way function to derive CK/IK from it which is then sent to the SGSN. The details of the key derivation for UTRAN/GERAN to EUTRAN handovers are defined in 3GPP TS 33.401.

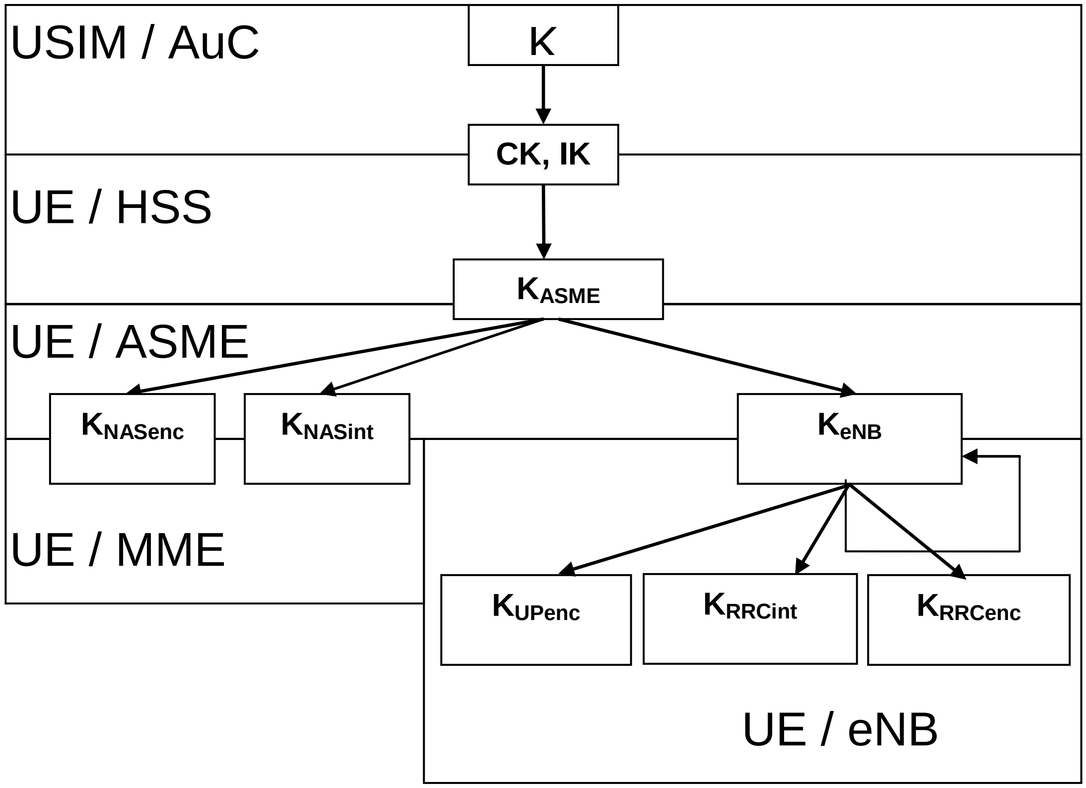

Figure 8. Key Hierarchy in EPS [128]

TRAFFIC PROTECTION

Security termination points for various traffic types terminating at the terminal is shown in Figure 9. With the user plane encryption in EPS being placed in eNodeB, system security has to be handled more carefully compared to UMTS. Different deployment environments may call for different implementation – specific security solutions to provide the appropriate level of security. As an example of an eNodeB implementation, the radio interface encryption and S1 interface encryption could be integrated on the same Integrated Circuit. While there are several potential implementations, 3GPP has decided at this stage not to focus on a specific implementation technology in order to allow for future evolution in security technology. The aim is to have a single set of high level security requirements for all types of eNodeBs.

[128] Ericsson. Q2 2007.

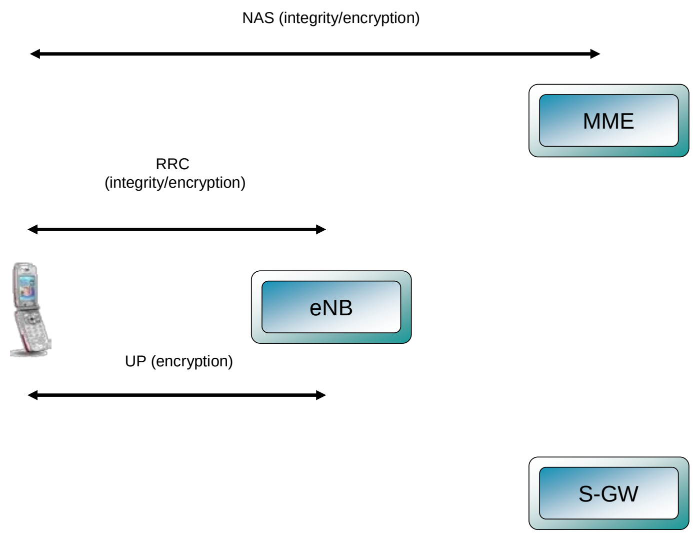

Figure 9. Security termination points for traffic to/from the UE [129]

The security termination points for traffic that is internal to EPS are shown in Figure 10. There is ongoing work in 3GPP to provide integrity protection and encryption on these interfaces and one proposal is NDS/IP. In addition, applicability of these solutions to other types of base stations (e.g. eHSPA) is under consideration. Since ciphering is now located in eNodeB, as described above, additional security requirements are also being considered.

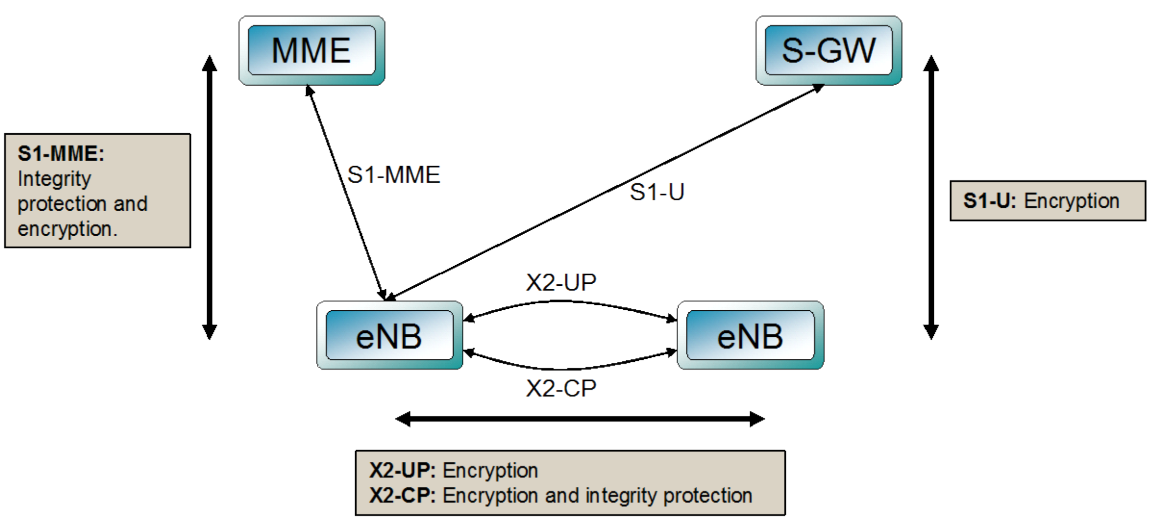

Figure 10. Security termination points for traffic internal to EPS [130]

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[129] *Ibid.*
[130] *Ibid.*

5.2.1.6.5 ROAMING AND NON-ROAMING SCENARIOS

One of the important aspects of the EPS is the support of roaming. Within the EPS specification, there are two documents focused on roaming aspects: TS 23.401 focuses on 3GPP access roaming (and specifically GTP based roaming, over the GTP based S8 interface), while TS 23.402 focuses on mobility and roaming with non-3GPP access using Proxy MIP (over the PMIP-based S8 interface).

Figure 11 exemplifies the roaming architecture for 3GPP access only. The roaming architecture for 3GPP access for Home routed traffic consists of a Serving Gateway (SGW) in the visited network which links/connects GTP based S1 interface tunnels with a GTP interface (GTP-based S8) towards a PDN GW in the home network.

Figure 12 exemplifies the roaming architecture for non-3GPP access (via S2) via S8 based on PMIP. Non-3GPP access connects via the S2 interfaces to either a SGW in the visited network or a PDN GW in the home network. The connectivity via a SGW in the visited network may apply in cases where the home network operator relies on a visited network 3GPP operator to manage the agreements with non-3GPP access operators in the visited network. The connectivity with the Home network PDN GW is used when there is a direct roaming agreement between visited non-3GPP networks and the Home 3GPP network. As of SA2#68, this chaining of S8 and S2 is supported in Rel-8 only with PMIP based S8. If GTP based S8 is used, the chaining of S8 and S2 is not allowed in Rel-8 and this is an item to be discussed for Rel-9 of the EPS specifications.

The signaling of QoS to the visited network for the EPS bearer requires the deployment of an inter-carrier PCC infrastructure based on the S9 interface, when PMIP based S8 is used.

A distinction is also made between Trusted non-3GPP networks and Untrusted 3GPP networks. Untrusted 3GPP networks access needs to be mediated by an E-PDG (Evolved Packet Data Gateway), which terminates IPsec tunnels from the UE. See sections 5.1.3 and 5.1.4 for discussion of the various interfaces shown in Figures 11 and 12.

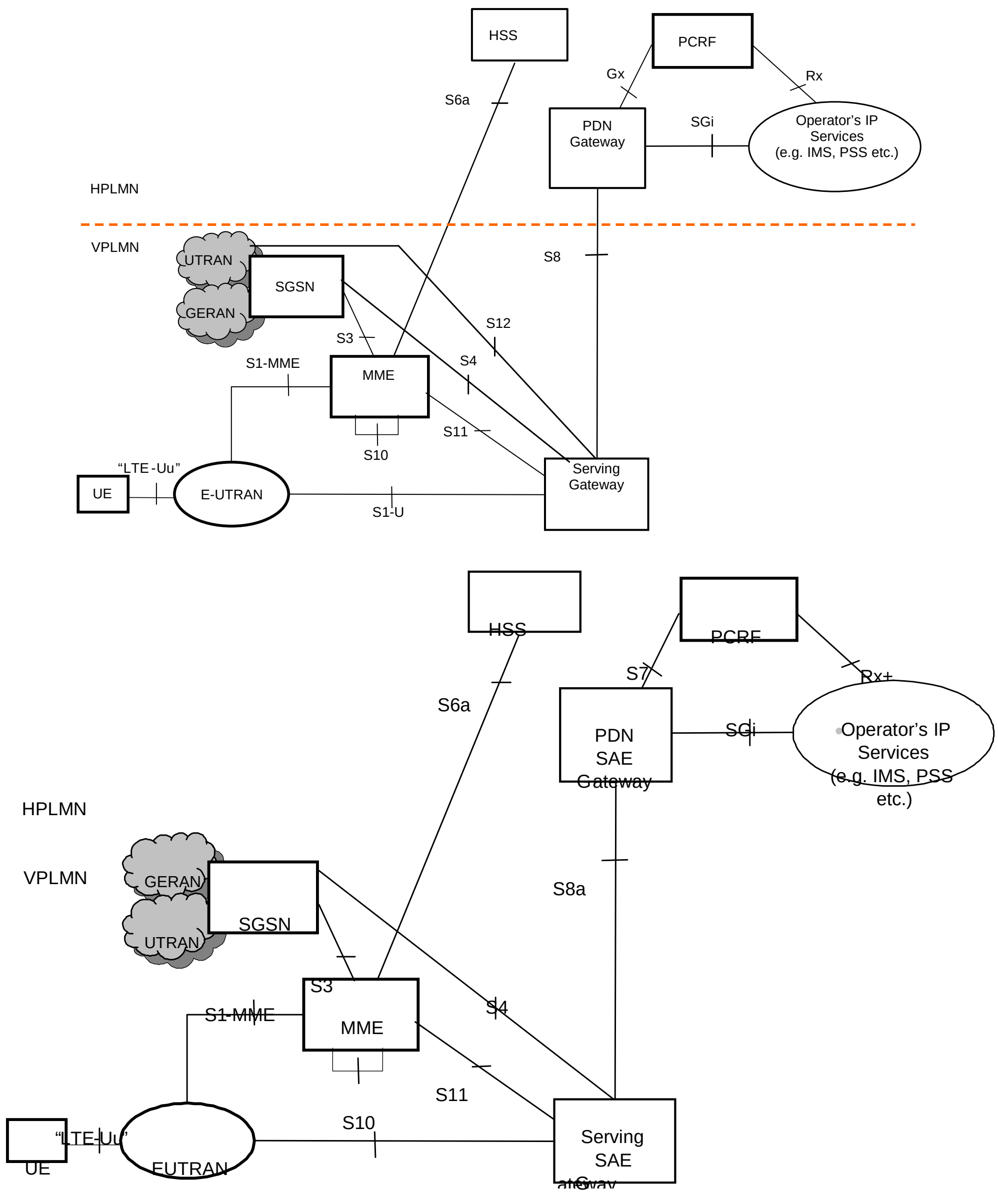

Figure 11. Roaming architecture (home routed case, 3GPP only networks) [131]

[131] *GPRS Enhancements for EUTRAN*. 3GPP TS 23.401.

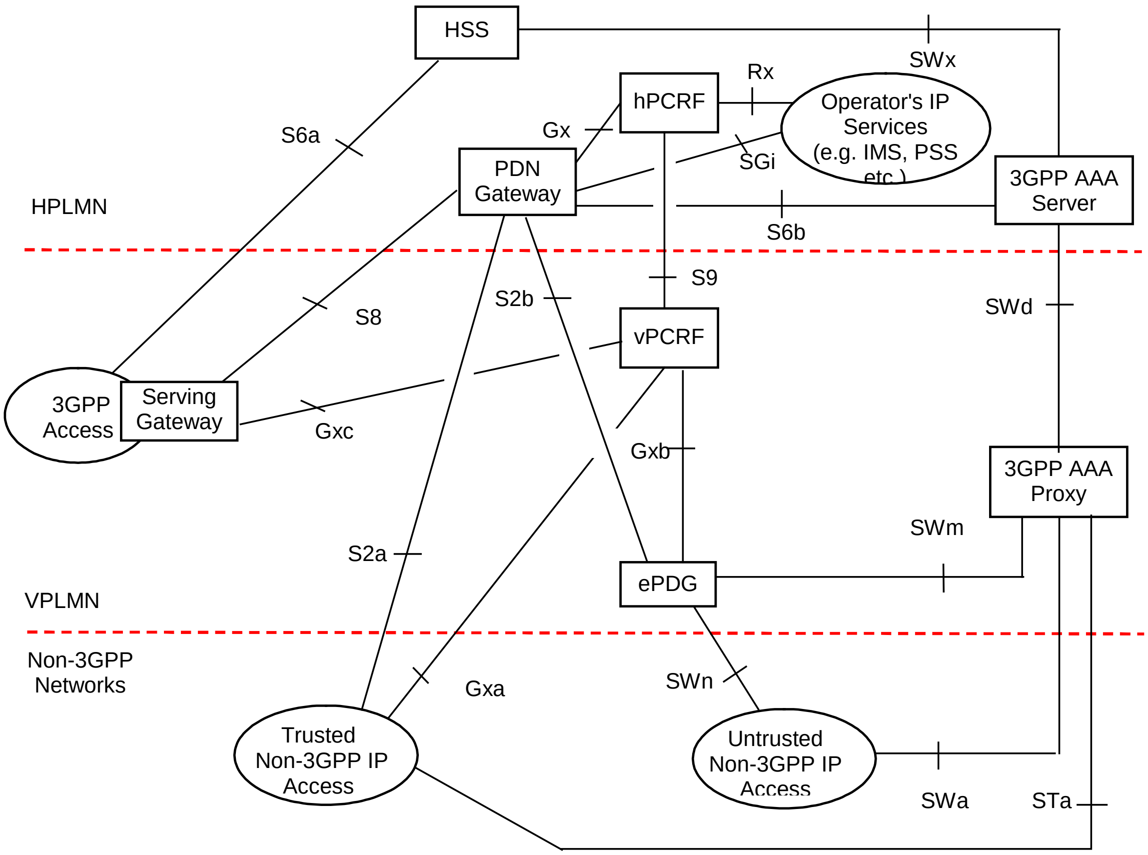

Figure 12. Roaming architecture (home routed case, including non-3GPP networks) [132]

5.2.2 EUTRAN AIR-INTERFACE

This section presents UTRAN Long Term Evolution (LTE) Air-interface. 3GPP has defined a new packet-only wideband radio with flat architecture as part of the 3GPP radio technology family in addition to GSM/GPRS/EDGE and WCDMA/HSDPA/HSUPA. This section covers the LTE physical layers, radio interface protocols and architecture. 3GPP has defined both FDD and TDD options for LTE, but this section mainly focuses on the specifics of the FDD system. For information about TDD systems please refer to section 5.3 of this white paper.

3GPP began investigating LTE in 2004. The feasibility study began in March 2005 and the key issues were to agree on the multiple access method and the network architecture in terms of the functional split between the radio access and the core network. The feasibility study on the EUTRAN technology alternatives was concluded by September 2006 when 3GPP finalized selection of the multiple access and basic radio access network architecture. 3GPP's conclusion was that Orthogonal Frequency Division Multiple Access (OFDMA) is to be used in downlink

[132] *Architecture Enhancements for Non-3GPP Accesses*. 3GPP TS 23.402.

direction and Single Carrier Frequency Division Multiple Access (SC-FDMA) is to be used in the uplink direction. These techniques are discussed in detail in the following downlink and uplink sections.

The Multiple antenna systems section discusses current considerations of multi-antenna technologies for the LTE standard. In all next generation cellular standards, including LTE, the target is to increase capacity and/or to provide spatial diversity. The technologies being considered in this section are Multiple Input Multiple Output (MIMO), Spatial Multiplexing, Space-Time Coding and Beamforming. Finally, Interference Mitigation aspects are considered as identified in the LTE study item. Presented techniques for inter-cell interference mitigation are interference randomization, interference cancellation and interference co-ordination/avoidance.

The 3GPP LTE Rel-8 specification was functionally frozen in December 2008, with the RAN1 specifications stable since September 2008. The RAN1 specifications have the biggest impact on long term lead development items. The current working view of the official completion date for Rel-8 is March 2009, fulfilling needs for data rates and performance beyond HSDPA and HSUPA evolution. The LTE is designed to facilitate the integration with existing GSM and WCDMA deployments for seamless coverage offering. The chosen uplink technology ensures a power efficient transmitter for the device transmission and maximizes the uplink coverage. The LTE performance, together with flat architecture, ensures low cost per bit for a competitive service offering for end users.

5.2.2.1 DOWNLINK

This section provides some details about the downlink LTE structure defined in 3GPP and a brief introduction on mapping between the transport and physical channel is provided. An overview of LTE downlink structure and numerology is also provided, followed by a discussion on downlink reference signal (RS) structure. Details of DL control channels are then discussed, along with DL and UL scheduling grants design and Ack/Nack channel. An overview of the synchronization channel and a description of the Primary broadcast control and MCH channels are discussed. Finally, the DSCH performance for the Single Input Multiple Output (SIMO) case and for MBMS transmission is discussed.

In the downlink, Orthogonal Frequency Division Multiplexing (OFDM) is selected as the air-interface for LTE. OFDM is a particular form of multi-carrier modulation (MCM). Generally, MCM is a parallel transmission method which divides an RF channel into several narrower bandwidth subcarriers and transmits data simultaneously on each subcarrier. OFDM is well suited for high data rate systems which operate in multi-path environments because of its robustness to delay spread. The cyclic extension enables an OFDM system to operate in multi-path channels without the need for a complex Decision Feedback Equalizer (DFE) or MLSE equalizer. As such, it is straightforward to exploit frequency selectivity of the multi-path channel with low-complexity receivers. This allows frequency-selective scheduling in addition to frequency-diverse scheduling and frequency reuse one-deployments. Furthermore, due to its frequency domain nature, OFDM enables flexible bandwidth operation with low complexity. Smart antenna technologies are also easier to support with OFDM, since each subcarrier becomes flat faded and the antenna weights can be optimized on a per-subcarrier or block of subcarriers basis. In addition, OFDM enables broadcast services on a synchronized single frequency network (SFN) with appropriate cyclic prefix design. This allows broadcast signals from different cells to combine over-the-air, thus significantly increasing the received signal power and supportable data rates for broadcast services.

5.2.2.1.1 MAPPING BETWEEN TRANSPORT AND PHYSICAL CHANNELS

The LTE downlink (DL) comprises the following physical channels:

a) Physical downlink shared channel (PDSCH)

b) Physical downlink control channel (PDCCH)

c) Physical broadcast channel (PBCH)

d) Physical multicast channel (PMCH)

e) Physical control format indicator channel (PCFICH)

f) Physical Hybrid ARQ indicator channel (PHICH)

The mapping between transport and physical channels are shown in Figure 13. Currently, four transport channels are defined for LTE – Broadcast Channel (BCH), Paging Channel (PCH), Downlink Shared Channel (DL-SCH), and Multicast Channel (MCH).

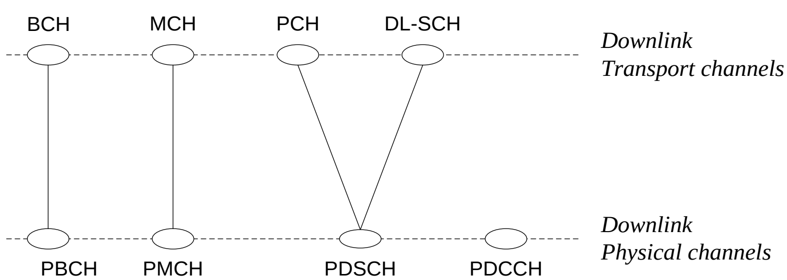

Figure 13. Mapping between downlink transport channels and downlink physical channels [133]

5.2.2.1.2 LTE DOWNLINK FRAME STRUCTURE AND NUMEROLOGY

Table 1 provides an example of downlink sub-frame numerology for different spectrum allocations. LTE supports a wide range of bandwidths (e.g. 1.4/3/5/10/15/20 MHz etc.). It may be noted that the 15 kHz subcarrier spacing is large enough to avoid degradation from phase noise and Doppler (250km/h at 2.6 GHz) with 64QAM modulation.

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[133] *EUTRAN Overall Description*. 3GPP TS 36.300. V8.4.0.

Table 1. Typical parameters for downlink transmission scheme [134]

Transmission BW (MHz)		1.4	3	5	10	15	20
Subframe duration		1.0 ms					
Subcarrier spacing		15 kHz					
Sampling frequency (MHz)		1.92	3.84	7.68	15.36	23.04	30.72
Number of occupied subcarriers		73	181	301	601	901	1201
Number of OFDM symbols per sub frame		14/12 (Normal/Extended CP)					
CP length (μs)	Normal	4.69 × 6, 5.21x1					
	Extended	16.67					

The downlink sub-frame structure with normal cyclic prefix length is shown in Figure 14. Each sub-frame is comprised of two slots of length 0.5ms (either 6 or 7 OFDM symbols depending on the cyclic prefix length). For normal cyclic prefix, within each slot, reference symbols for antenna ports 0 and 1 are located in the 1^{st} and 5^{th} OFDM symbols, while reference symbols for antenna ports 2 and 3 are located in the 2^{nd} OFDM symbol. The reference symbol structure shown in Fig. 14 is for a two transmit antenna system, whereas the R0 reference symbols would be transmitted on the first Tx antenna while the R1 reference symbols would be transmitted on the second Tx antenna. See 3GPP TS 36.211, "Physical Channels and Modulation" for further details on the reference symbol structure for 1 Tx, 2 Tx and 4 Tx antenna configurations. The structure shown in Fig. 14 allows a simple channel estimator to be used as well as other excellent, low-complexity channel estimation techniques such as MMSE-FIR and IFFT-based channel estimators.

[134] i) *EUTRAN Overall Description*. 3GPP TS 36.300. RP-070136. RAN#35.
ii) *Physical Channels and Modulation*. 3GPP TS 36.211.

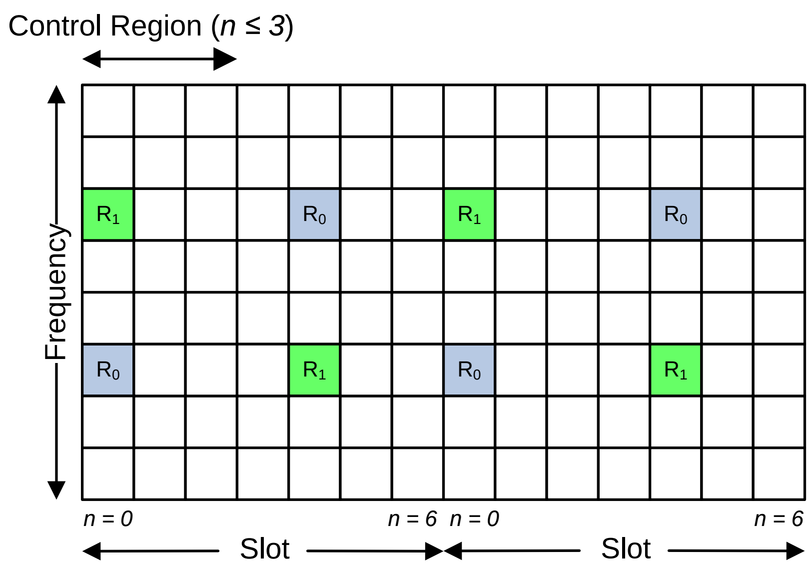

Figure 14. E-UTRA downlink sub-frame structure [135]

In addition to common DL RS signal, a UE specific reference signal is defined to support DL Beamforming techniques. A single dedicated reference signal pattern is defined where the eNB can semi-statically configure a UE to use the UE-specific reference signal as the phase reference for data demodulation of a single codeword. The UE-specific RS are transmitted for a maximum of 1 stream. When UE-specific RS are configured for a UE it uses a maximum of 2 common RS, corresponding to the two first antenna ports.

The transmitted signal in each slot is described by a resource grid of subcarriers and OFDM symbols. The resource grid and structure for a downlink slot is illustrated in Figure 15. The basic element in the resource grid is called a resource element which corresponds to a single subcarrier associated with an antenna port. One, two or four transmit antenna ports are supported. A resource block is defined as $N_{\mathrm{symb}}^{\mathrm{DL}}$ consecutive OFDM symbols in the time domain and $N_{\mathrm{sc}}^{\mathrm{RB}}$ consecutive subcarriers in the frequency domain. Thus, a resource block consists of $N_{\mathrm{symb}}^{\mathrm{DL}} \times N_{\mathrm{sc}}^{\mathrm{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain as shown in Table 2 (see section 5.2.1.6 for explanation on the 7.5 kHz tone spacing option used for Enhanced Multi Broadcast Multicast Service or E-MBMS).

[135] *Physical Channels and Modulation*. 3GPP TS 36.211.

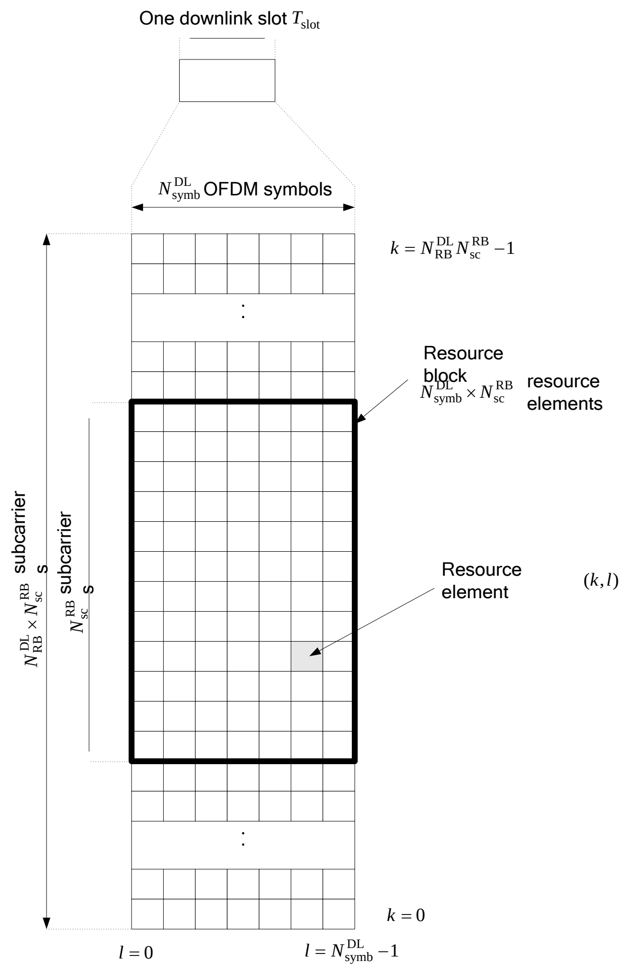

Figure 15. Downlink Resource Grid [136]

[136] *Ibid.*

Table 2. Resource block parameters. [137]

Configuration		N_{sc}^{RB}	N_{symb}^{DL}
Normal cyclic prefix	$\Delta f = 15\,\text{kHz}$	12	7
Extended cyclic prefix	$\Delta f = 15\,\text{kHz}$		6
	$\Delta f = 7.5\,\text{kHz}$	24	3

The downlink shared channel (DL-SCH) uses the above structure and numerology and supports QPSK, 16QAM and 64QAM modulation using an R=1/3 mother Turbo code. The Turbo code used is the same as Rel-6 UMTS Turbo code except the Turbo code internal interleaver is based on Quadratic Polynomial Permutation (QPP) structure. DL-SCH supports HARQ using soft combining, adaptive modulation and coding, MIMO/Beamforming with scheduling done at NodeB.

5.2.2.1.3 LTE DOWNLINK CONTROL CHANNEL STRUCTURE

Downlink (DL) control signaling is carried by three physical channels: (1) Physical Control Format Indicator Channel (PCFICH) to indicate the number of OFDM symbols used (*n*) for control in this subframe; (2) Physical HARQ Indicator Channel (PHICH) which carries downlink ACK/NACK associated with uplink data transmission; and (3) Physical Downlink Control Channel (PDCCH) which carries the downlink scheduling assignments, uplink scheduling grants, and power control commands. An example of how downlink control signaling is mapped in a subframe is shown in Figure 16.

[137] *Ibid.*

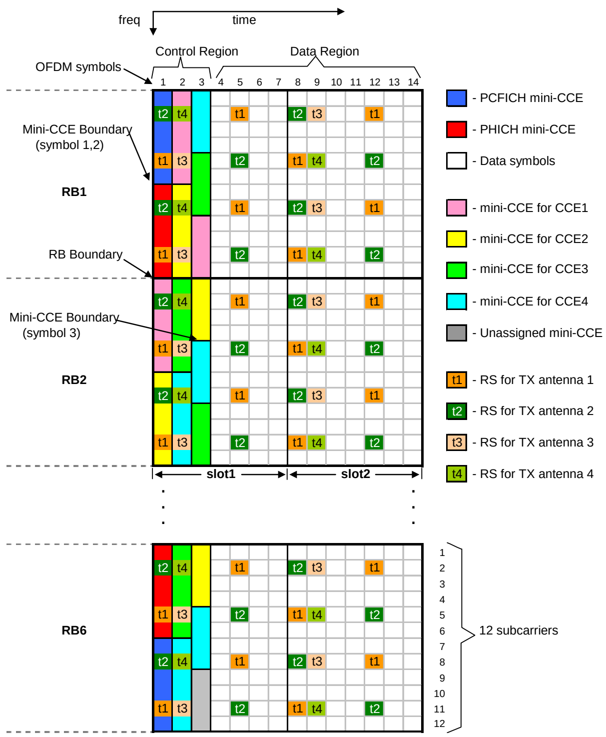

Figure 16. Example of n=3 DL control signaling mapping

Information fields in the downlink scheduling grant are used to convey the information needed to demodulate the downlink shared channel. They include resource indication such as resource block and duration of assignment, transport format such as multi-antenna information, modulation scheme, and payload size, and HARQ support such as process number, redundancy version and new data indicator. Similar information is also included in the uplink scheduling grants. Eleven Downlink Control Information (DCI) formats are supported, namely:

i) Format 0 – uplink scheduling assignment;

ii) Format 1 – downlink scheduling assignment for one PDSCH codeword;

iii) Format 1A – compact downlink scheduling assignment for one PDSCH codeword;

iv) Format 1B – compact downlink scheduling assignment for one PDSCH codeword with precoding information;

v) Format 1C – very compact downlink scheduling assignment for one PDSCH codeword (BCH, RACH, PCH);

vi) Format 1D – compact downlink scheduling assignment for one PDSCH codeword with precoding and power offset information (DL MU-MIMO);

vii) Format 2 – downlink scheduling assignment for UEs configured in closed-loop spatial multiplexing mode;

viii) Format 2A – downlink scheduling assignment for UEs configured in open-loop spatial multiplexing mode;

ix) Format 3 – transmission of TPC commands for PUCCH and PUSCH with 2-bit power adjustments;

x) Format 3A – transmission of TPC commands for PUCCH and PUSCH with 1-bit power adjustments; and xi) Random Access Response Grant.

Downlink control signaling is located in the first *n* OFDM symbols as shown in Fig. 16. This enables support for micro-sleep (i.e., the receiver can wake up within one symbol and seeing no assignment, go back to sleep within one symbol for a battery life savings of 64% to 71%), reducing buffering and latency. A Control Channel Format Indicator field comprising a maximum of 2 bits, signals the number of OFDM symbols (*n*) used for downlink control signaling every sub-frame. This field is transmitted in the first OFDM symbol.

Multiple control channels are used in the LTE downlink and a user monitors a number of control channels in two kinds of search spaces i) common search space and ii) UE specific search space. Each channel carries information associated with an RNTI. Only one mother code rate using R=1/3 K=7 convolutional code with tail biting with QPSK modulation is used for the control channel. Higher and lower code rates are generated through rate matching. There is no mixing of control signaling and data in an OFDM symbol.

Each scheduling grant is defined based on fixed size control channel elements (CCE) which are combined in a predetermined manner to achieve different coding rates. Each CCE is comprised of multiple mini-CEs also called resource element groups (REGs) that are distributed throughout time and frequency control resource. Interleaving of the REGs is done using a sub-block interleaver that is configured on a cell-specific basis. Note that the number of control channel elements or the number of control channel symbols in the sub-frame is transmitted by the NodeB in every sub-frame. Because multiple control channel elements can be combined to reduce the effective coding rate, a terminal's control channel assignment would then be based on channel quality information reported. A user/terminal then monitors a set of candidate control channels in the common and/or UE specific search space (defined in Table 3) which may be configured by higher layer signaling. The size of the control channel elements varies with different bandwidth allocation and is a multiple of 6. It may be noted that 1, 2, 4 and 8 control channel elements can be aggregated to yield approximate code rates of 2/3, 1/3, 1/6 and 1/12.

Table 3. UE Search Space Summary

Search Space			Number of PDCCH candidates	DCI formats
Type	Aggregation Level	Size [in CCEs]		
UE-specific	1	6	6	0, 1, 1A,1B, 2
	2	12	6	
	4	8	2	
	8	16	2	
Common	4	16	4	0, 1A, 1C, 3/3A
	8	16	2	

An example of predefined coding rates is shown in Table 3 for a 5MHz system with a control element of size 36 subcarriers. See 3GPP TS 36.211, "Physical Channels and Modulation", TS36.212 "Multiplexing and Channel Coding" and TS36.213 "Physical Layer Procedures" on the 3GPP website (http://www.3gpp.org) for more details on the LTE DL control channel structure.

Table 4. Example predefined coding rates [138]

#CE Aggregated (36 RE each)	Effective Encoding Rate (R)for CCHs	
	UL Non-Persistent ($N_{payload}$ =38 bits)	DL Non-Persistent ($N_{payload}$ = 46 bits)

[138] *E-UTRA DL L1/L2 Control Channel Design*. 3GPP R1-070787. Motorola RAN1#48. St. Louis. USA. February 2007.

1	0.528 (UL MCS, R~1/2)	0.639 (DL MCS, R~2/3)
2	0.264	0.319
3	0.176	0.213
4	0.132	0.160
5	0.106	0.128
6	0.088	0.106
7	Not Used	0.091

CEs combined to achieve lower Effective R

DL PHYSICAL HARQ INDICATOR CHANNEL (PHICH)

The downlink acknowledgment comprises of one-bit control information sent in association with uplink data transmission. The resources used for the acknowledgment channel are configured on a semi-static basis and are defined independently of the grant channel (i.e. a set of resource elements (REs) are semi-statically allocated for this purpose). Because only one information bit is to be transmitted, a hybrid of CDM/FDM multiplexing among acknowledgments is used. Hybrid CDM/FDM allows for power control between acknowledgments for different users and provides good interference averaging. In addition, it can provide frequency diversity for different users. ACK/NACK resource assignment is based on an implicit relationship based on the resource block assignment. With BPSK modulation and I/Q multiplexing, each PHICH channel can carry 8 acknowledgments for normal cyclic prefix.

DL PHYSICAL CONTROL FORMAT INDICATOR CHANNEL (PCFICH)

The PCFICH is used to dynamically indicate the number of OFDM symbols used (*n*) for control in a subframe. It is transmitted in the first OFDM symbol of the subframe and the three values are indicated by three sequences of length 16 QPSK symbols. Predefined codewords based on (3,2) simplex coding with repetition and systematic bits with dmin=21 is used. To provide maximum frequency diversity, the PCFICH is transmitted over the system bandwidth. Transmit diversity is also supported using the same diversity scheme as the PDCCH. In addition, cell specific scrambling, tied to the cell ID, is used.

5.2.2.1.4 LTE DOWNLINK SYNCHRONIZATION CHANNEL STRUCTURE

The DL Synchronization Channel is sent so that the terminals can obtain the correct timing for the DL frame structure, acquire the correct cell, find the number of antennas in BCH and also assist to make handover decisions. Two types of synchronization signals, namely Primary synchronization signal (P-SCH) and Secondary synchronization signals (S-SCH), are defined and used by the terminals for cell search. The P-SCH and S-SCH are transmitted on subframe 0 and 5 and occupy two symbols in a subframe as shown in Fig. 17. Both the P-SCH and S-SCH are transmitted on 64 active subcarriers, centered on the DC subcarrier.

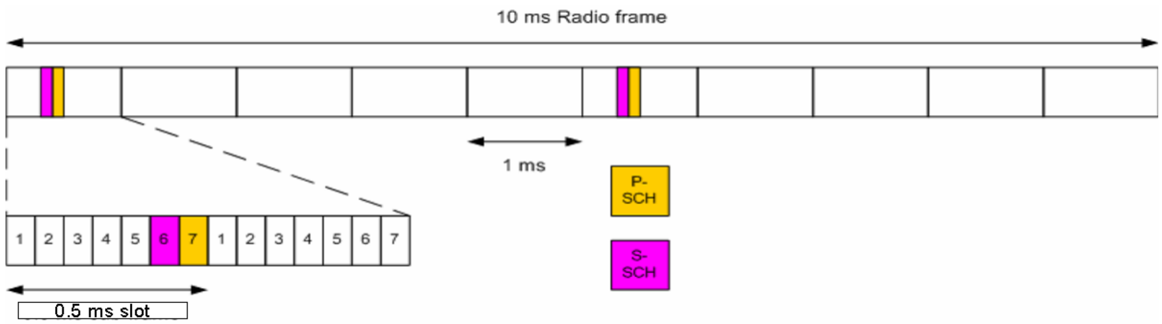

Figure 17. SCH Frame Structure [139]

The P-SCH identifies the symbol timing and the cell ID within a cell ID group while the S-SCH is used for detecting cell ID group, BCH antenna configuration and CP length. The cell search flow diagram is shown in Figure 18. The neighbor-cell search is based on the same downlink signals as initial cell search. See 3GPP TS 36.211 "Physical Channels and Modulation" on the 3GPP website (http://www.3gpp.org) for further details on the P-SCH and S-SCH structure.

[139] *Outcome of Cell Search Drafting Session*. 3GPP R1-062990. Nokia et.al. RAN1#46-bis. Seoul, S. Korea. October 2006.

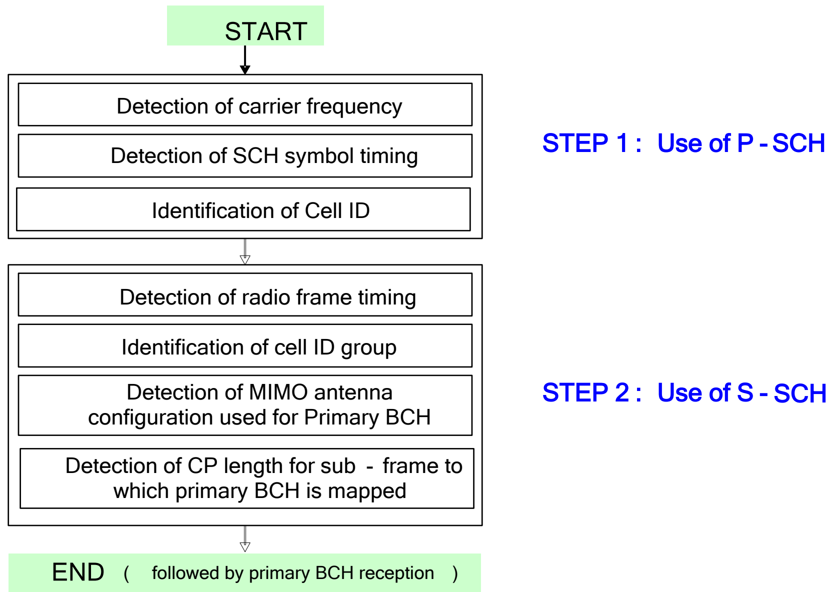

Figure 18. Cell Search Flow Diagram [140]

5.2.2.1.5 LTE BROADCAST CONTROL CHANNEL (BCH) STRUCTURE

The BCH has a fixed pre-defined transport format and is broadcasted over the entire coverage area of the cell. In LTE, the broadcast channel is used to transmit the System Information field necessary for system access. Due to the large size of the System Information field, it is divided into two portions – Master Information Block (MIB) transmitted on the P-BCH and System Information Blocks (MIB) transmitted on the PDSCH. The P-BCH contains basic L1/L2 system parameters necessary to demodulate the PDSCH which contains the remaining System Information Blocks. The P-BCH is characterized by the following:

a. Single fixed size transport block per TTI

b. Modulation scheme is QPSK

c. P-BCH is transmitted on 72 active subcarriers, centered around the DC subcarrier

d. No HARQ

Master Information Block (MIB) is transmitted on the P-BCH over 40 ms as shown in Figure 19. CRC masking is used to implicitly tell the UE the number of TX antennas at the eNB (1, 2 or 4). Convolutional coding R=1/3 is used, coded bits are rate-matched to 1920 bits for normal CP. The details of scrambling, modulation, layer mapping and precoding and mapping to resource elements are outlined in Section 6.6 of TS 36.211 vsn. 8.4.0.

[140] *Three Step Cell Search Method for E-UTRA R1-062722*. NTT DoCoMo et.al. RAN1#46-bis. Seoul, S. Korea. October 2006.

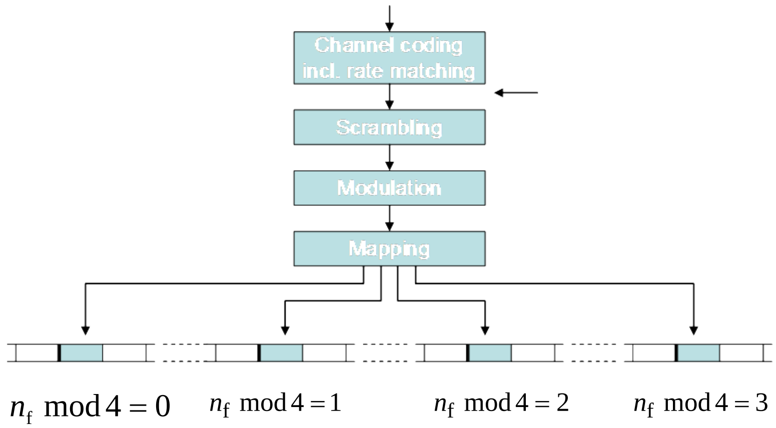

Figure 19. MIB transmission over P-BCH

5.2.2.1.6 LTE E-MBMS STRUCTURE

Due to the narrowband nature of the tones used to transmit information in an OFDM system, over-the-air combining of broadcast transmissions from multiple BTS is inherent for OFDM. This does require that the exact same information be broadcast on the same tone resources from all the BTS at very nearly the exact same time. Such broadcast systems are often called Multicast Broadcast Single Frequency Networks (MBSFNs). This implies that only semi-static configuration of the broadcast resource assignments is possible. A fundamental requirement for multi-cell MBSFN deployment is inter-site synchronization for which the cells should be synchronized within a few micro-seconds. For MBSFN transmission, the same signal is transmitted from a cluster of neighboring cells so that the energy in each subcarrier from different cells participating in the MBSFN operation is naturally combined over-the-air. Further for SFN operation, the CP duration should be long enough compared to the time difference between the signals received from multiple cells. As such, the MBSFN sub-frames use extended cyclic prefix shown in Table 2. The 7.5 KHz subcarrier spacing using 33 µs CP duration is only applicable for standalone E-MBMS operation using a dedicated carrier.

The MBSFN and unicast traffic (DL-SCH) can also be multiplexed in a TDM fashion on a sub-frame basis with the MBSFN sub-frames preferably using an extended CP duration of 16.5 µs. The reference signal structure for MBSFN sub-frame is shown in Figure 20. In this structure, only the first reference signal is present for unicast transmission.

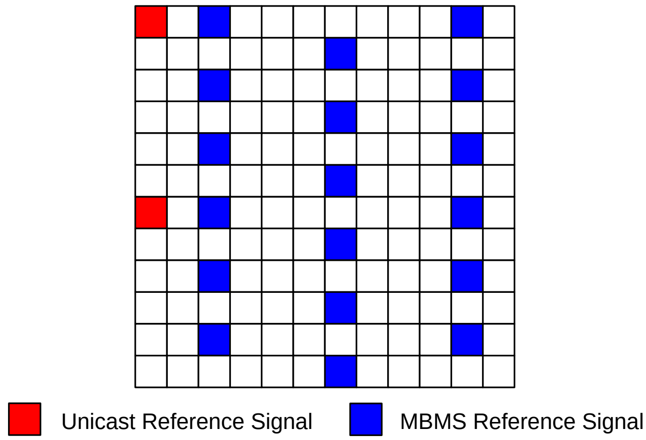

Figure 20. Reference signal structure for mixed carrier MBSFN [141]

5.2.2.1.7 LTE DL PERFORMANCE WITH SINGLE INPUT MULTIPLE OUTPUT (SIMO)

3GPP evaluated LTE downlink performance and results were finalized in May 2007. DL peak data rates for 20 MHz of spectrum allocation, assuming that 2 long blocks in every sub-frame are reserved for reference signals and control signaling with a code rate of 1, provide the following results:

- 115.2 Mbps with 16QAM and 2 layer transmission
- 172.8 Mbps with 64QAM and 2 layer transmission

Downlink user throughput results are presented in Figure 21 and Spectrum efficiency results in Figure 22. These results assume one TX antenna at the BTS and two receive antennas at the UE. The results shown are defined by 3GPP as case 3, which assumes a 2 GHz carrier center frequency, 1732 m inter-site distance, 10 MHz BW, 3 km/hr fading and a full queue traffic model. Non-ideal channel estimation is assumed, and the average CQI per RB is reported every 5ms with a 2ms delay. Localized allocation (using frequency selective scheduling) is simulated. Cell edge user throughput corresponds to the lowest five percentile user throughput.

[141] *Physical Channels and Modulation*. 3GPP TS 36.211.

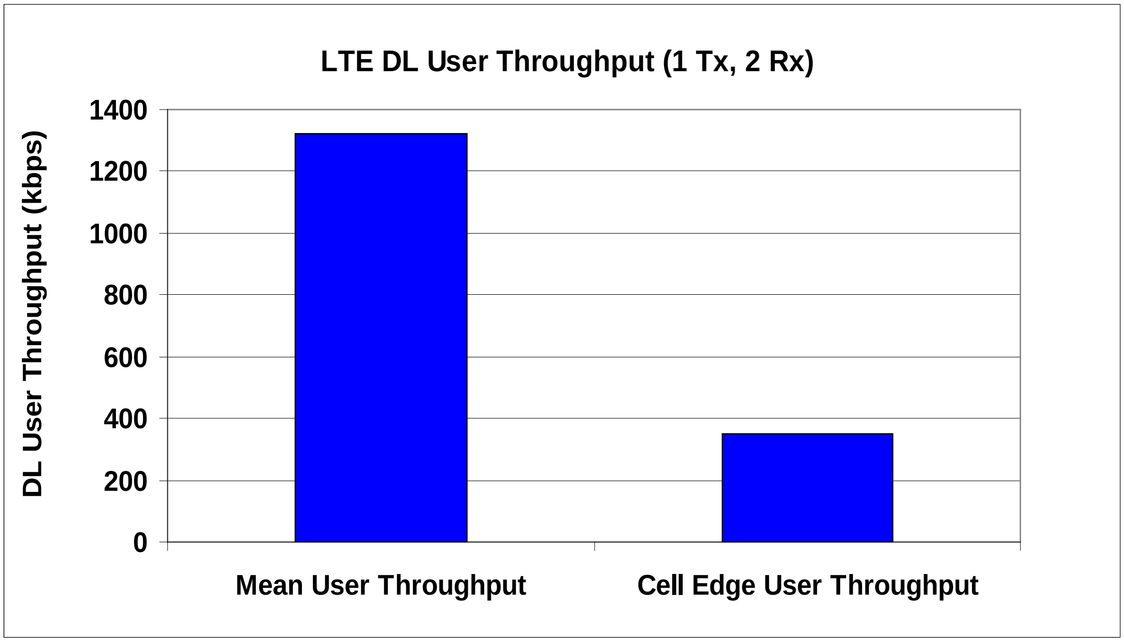

Figure 21. LTE DL User throughput [142]

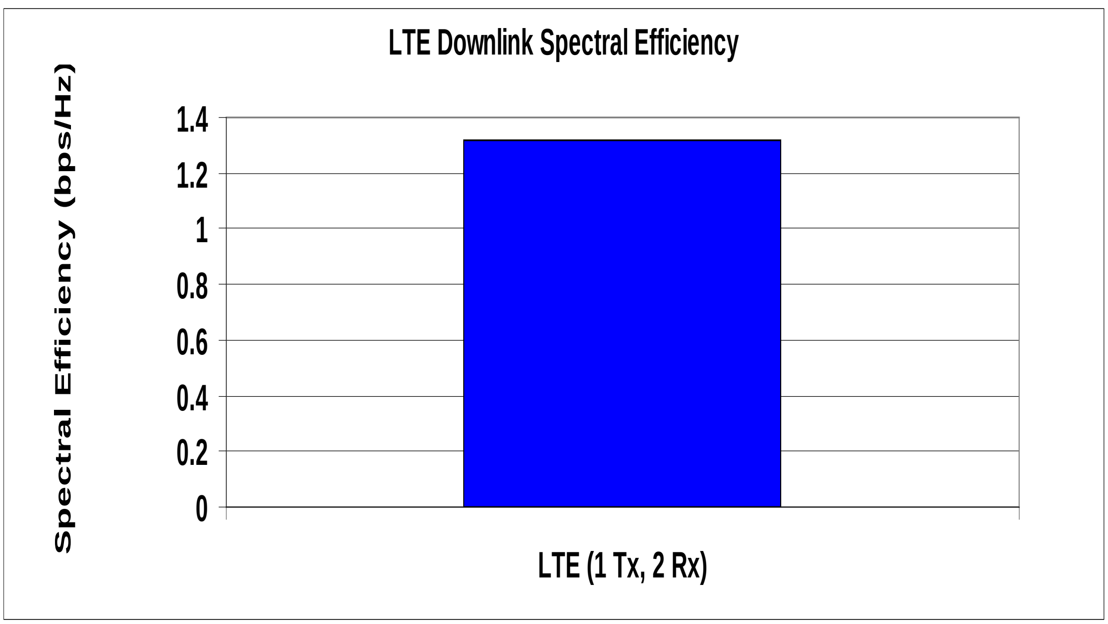

Figure 22. LTE DL Spectrum efficiency [104]

[142] *LS on LTE Performance Evaluation Work*. 3GPP TSG R1-072580 RAN WG1#49.

5.2.2.1.8 LTE E-MBMS PERFORMANCE

In this section, performance of LTE MBMS is demonstrated. A two-ring hexagonal grid layout was simulated with a dual port UE receiver operation assumed in spatially uncorrelated channels and 10MHz of offered bandwidth. UE's were randomly dropped with uniform spatial probability density in all cells comprising the center site and the first ring of cell sites. The performance metric used was coverage (%) versus spectral efficiency (bps/Hz) where a UE was defined to be in outage if the simulated packet or frame erasure rate (FER) at a specific location was greater than 1%.

Results were generated for both the 15 kHz extended cyclic prefix (CP) mode (12 OFDM symbols per subframe, applicable to both unicast/MBMS-mixed scenarios) and 7.5kHz long CP mode (6 OFDM symbols per subframe, applicable for MBMS-dedicated cells only). Single Frequency Network (SFN) operation was assumed, in an MBMS-dedicated carrier mode.

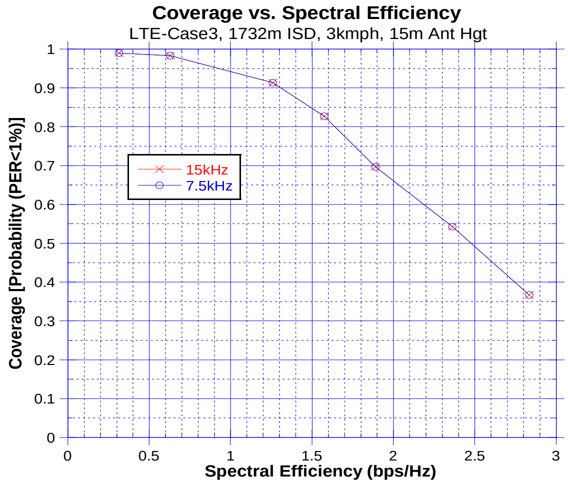

Figure 23. Coverage vs. spectral efficiency at 3km/hr [143]

Figure 23 and Figure 24 show coverage versus the spectral efficiency at 3 km/hr and 350 km/hr speeds respectively. As shown, both numerologies have similar performance at low speeds but the 7.5 kHz numerology performance degrades compared to 15 kHz numerology at high speed. In these deployment scenarios, impairments due to high Doppler frequency are accentuated by the 2GHz carrier frequency and limit the performance of the 7.5 kHz numerology.

[143] *E-MBMS Performance Evaluation*. 3GPP R1-071975. Motorola. RAN1 Conference Call. April 2007.

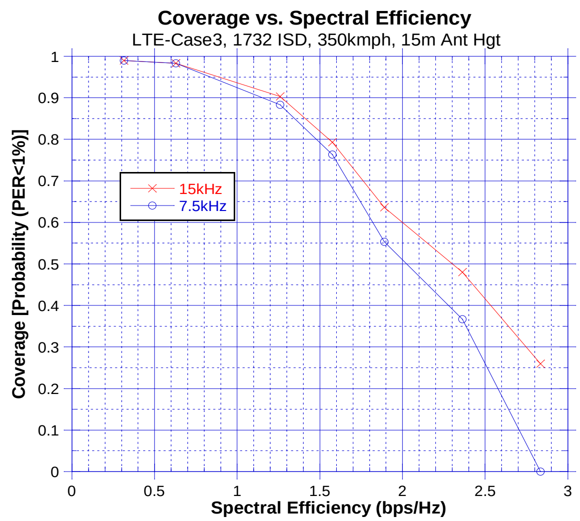

Figure 24. Coverage vs. spectral efficiency at 350kmph [144]

DL SCHEDULING AND RESOURCE ALLOCATION

In the LTE downlink, frequency selective scheduling (FSS) can significantly (e.g. 20-30%) improve system capacity over time domain scheduling (TDS). With FSS, the scheduler assigns transmission resources to a user using the resource blocks (or frequency bands) that will offer the best performance. This requires knowledge of the channel associated with each frequency band, which is normally obtained through feedback from the UE. In contrast, frequency diverse scheduling (FDS) assigns transmission resources that are distributed across the transmission bandwidth. This reduces the feedback overhead significantly since only channel quality information for the entire bandwidth (rather than per resource block) is required. In LTE, both frequency selective and frequency diverse scheduling are supported. The frequency diverse mode may be used at higher speeds, for edge-of-cell operation, low-overhead services and for some control channels. The proportional fair scheduler is the preferred scheduling algorithm. This scheduler falls in the class of normalized C/I scheduler with a delay component for handling both delay non-sensitive and delay-sensitive traffic and is used to compute the priority level of each UE at each scheduling instance.

[144] *Ibid.*

5.2.2.2 UPLINK

This section provides some details about the uplink LTE structure defined in 3GPP. The Single Carrier FDMA was chosen in order to reduce Peak to Average Ratio (PAR), which has been identified as a critical issue for use of OFDMA in the uplink where power efficient amplifiers are required. Another important requirement was to maximize the coverage. For each time interval, the base station scheduler assigns a unique time-frequency resource to a terminal for the transmission of user data, thereby ensuring intra-cell orthogonality. Slow power control, for compensating path loss and shadow fading, is sufficient as no near-far problem is present due to the orthogonal uplink transmissions. Transmission parameters, coding and modulation are similar to the downlink transmission.

The chosen SC-FDMA solution is based on the use of cyclic prefix to allow high performance and low complexity receiver implementation in the eNodeB. As such the receiver requirements are more complex than in the case of OFDMA for similar link performance but this is not considered to be a problem in the base station. The terminal is only assigned with contiguous spectrum blocks in the frequency domain to maintain the single-carrier properties and thereby ensure power-efficient transmission. This approach is often referred to as blocked or localized SC-FDMA. The general SC-FDMA transmitter and receiver concept with frequency domain signal generation and equalization is illustrated in Figure 25.

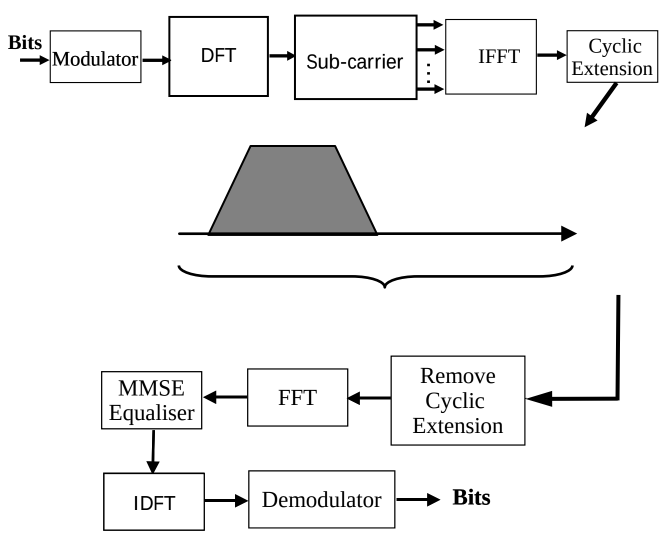

Figure 25. SC-FDMA transmitter and receiver chains with frequency domain equalization [145]

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[145] Lindholm, Jari and Timo Lunttila, Kari Pajukoski, Antti Toskala, Esa Tiirola. *EUTRAN Uplink Performance*. International Symposium on Wireless Pervasive Computing 2007 (ISWPC 2007). San Juan, Puerto Rico, USA. 5-7 February 2007.

5.2.2.2.1 MAPPING BETWEEN TRANSPORT AND PHYSICAL CHANNEL

The LTE uplink (UL) comprises of the following physical channels:

- Physical random access channel (PRACH)
- Physical uplink control channel (PUCCH)
- Physical uplink shared channel (PUSCH)

The mapping between transport and physical channels are shown in Figure 26. Currently, two transport channels are defined for LTE – Random Access Channel (RACH) and Uplink Shared Channel (UL-SCH).

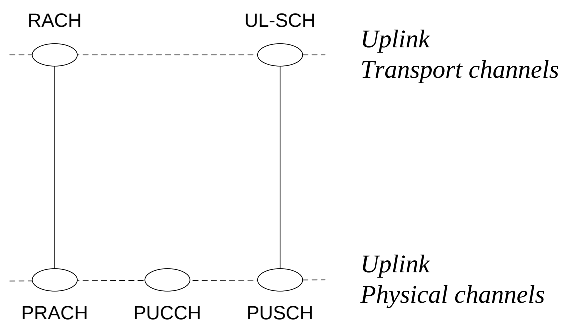

Figure 26. Mapping between uplink transport channels and uplink physical channels [146]

5.2.2.2.2 FRAME STRUCTURE AND NUMEROLOGY

All bandwidth options have the same transmission time interval (TTI), which has been agreed to be 1.0 millisecond. This was chosen to enable very short latency with L1 Hybrid ARQ combined with good cell edge performance. The channel coding in EUTRAN is based on turbo codes. Uplink transmission is organized into radio frames with the duration of 10 milliseconds. Two radio frame structures are supported. Type 1 is applicable to both FDD and TDD and Type 2 only for TDD. Frame structure type 1 consists of 20 slots of length 0.5 ms numbered from 0 to 19. A subframe is defined as two consecutive slots. For FDD, 10 subframes are available for downlink transmission and 10 subframes are available for uplink transmissions in each 10 millisecond interval. Uplink and downlink transmissions are separated in the frequency domain. Frame structure of Type 1 is shown in Figure 27.

[146] *E-UTRA and EUTRAN*. Overall Description. Stage 2. 3GPP TS 36.300 V8.0.0 (2007-03).

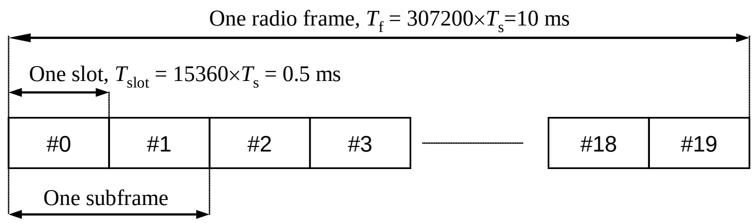

Figure 27. Frame structure type 1 [147]

Other key parameters have relationships with the multiple access method, such as the 15 kHz subcarrier spacing of OFDM. This selection is a compromise between support of high Doppler frequency, overhead from cyclic prefix, implementation imperfections, etc. To optimize for different delay spread environments, two cyclic prefix values, 4.7 µs and 16.7 µs, are supported.

Doppler will also impact the parameterization, as the physical layer parameterization needs to maintain the connection at 350 km/h. However, it has been recognized that scenarios above 250 km/h are specific cases, such as the high-speed train environment. The optimization target is clearly the lower mobile terminal speeds, below 15 km/h, and performance degradation is allowed for higher speeds. The parameterization was chosen in such a way that common sampling rates with GSM/EDGE and UMTS can be utilized to reduce complexity and cost and enable easy dual mode/multimode implementation.

5.2.2.2.3 SHARED CHANNEL STRUCTURE

Shared channel in the uplink is called Physical Uplink Shared Channel (PUSCH). The same set of modulations is supported as in PDSCH in downlink but use of 64QAM is optional for devices up to Class 5, in which it is mandatory. Also multi-antenna uplink transmission is not specified in the first phase of LTE specifications. In the uplink direction up to 20 MHz bandwidth may also be used, with the actual transmission bandwidth being multiples of 180 kHz resource blocks, identical to downlink resource block bandwidth. The channel coding is the same as on the PDSCH. PUSCH may reach up to a 50-60 Mbps user data rate with single antenna transmission using 16QAM modulation.

5.2.2.2.4 REFERENCE SIGNAL

Two types of uplink reference signals are supported:

- demodulation reference signal, associated with transmission of uplink data and/or control signaling;
- sounding reference signal, not associated with uplink data transmission

[147] *Physical Channels and Modulation*. 3GPP TS 36.211 V1.1.0 (2007-05).

For the generic frame structure, the demodulation reference signal is mapped to SC-FDMA symbol $l = 3$. The same value of k_0 as for the PUSCH transmitted in the long SC-FDMA symbols in the subframe shall be used. The sounding reference signal is mapped to the last SC-FDMA symbol in a subframe in every second subcarrier.

5.2.2.2.5 CONTROL CHANNEL STRUCTURE

Physical Uplink Control Channel (PUCCH) carries uplink control information. The PUCCH is never transmitted simultaneously with the PUSCH. The block of bits to be transmitted on the physical uplink control channel are further coded with a UE-specific code sequence prior to modulation enabling multiple UEs' PUCCHs to be code multiplexed on the same time-frequency resource.

The PUCCH shall be mapped to a control channel resource in the uplink. A control channel resource is defined by a code and two resource blocks, consecutive in time, with hopping at the slot boundary. Mapping of modulation symbols for the physical uplink control channel is illustrated in Figure 28.

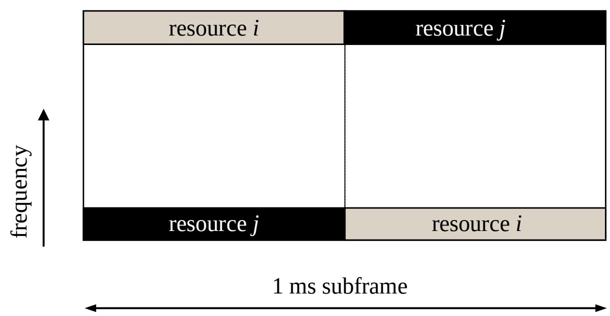

Figure 28. Physical uplink control channel [148]

Depending on the presence or absence of uplink timing synchronization, the uplink physical control signaling can differ. In the case of time synchronization being present, the outband control signaling on PUCCH consists of:

- CQI/PMI
- ACK/NAK
- Scheduling request

The CQI informs the scheduler about the current channel conditions as seen by the UE. If MIMO transmission is used, the CQI includes necessary MIMO-related Precoding Matrix Information

[148] *Ibid.*

(PMI). The HARQ feedback in response to downlink data transmission consists of a single ACK/NAK bit per HARQ process.

5.2.2.2.6 RANDOM ACCESS

The physical layer random access burst, illustrated in Figure 29, consists of a cyclic prefix of length T_{CP} and a preamble sequence of length T_{SEQ}. The parameter values are listed in Table 4 and depend on the frame structure and the random access configuration. Higher layers control the preamble format.

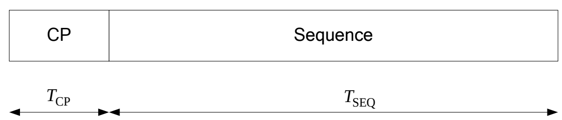

Figure 29. Random access preamble format (generic frame structure) [149]

Table 4. Random access burst parameters. [150]

Preamble format	T_{CP}	T_{SEQ}
0	$3168 \cdot T_s$ (~100 μs)	$24576 \cdot T_s$ (~800 μs)
1	$21024 \cdot T_s$ (~680 μs)	$24576 \cdot T_s$ (~800 μs)
2	$6240 \cdot T_s$ (~200 μs)	$2 \cdot 24576 \cdot T_s$ (~1600 μs)
3	$21024 \cdot T_s$ (~680 μs)	$2 \cdot 24576 \cdot T_s$ (~1600 μs)
4 (frame structure type 2 only)	$448 \cdot T_s$ (~15 μs)	$4096 \cdot T_s$ (~130 μs)

The different preamble formats can be used depending on the cell type and base station implementation. For example, a large cell with difficult propagation environment would benefit

[149] *Ibid.*
[150] *Ibid.*

from a longer cyclic prefix and a long sequence would mean that a lower transmit power is sufficient for the detection of the PRACH. The cell configuration dictates in which sub-frames the random access transmission is allowed defining the capacity allocated for PRACH.

In the frequency domain, the random access burst occupies a bandwidth corresponding to six resource blocks (72 subcarriers, 1.08 MHz) in a subframe or a set of consecutive subframes configured to be used for random access preamble transmissions by higher layers for both frame structures. Higher layers configure the location in frequency of the random access burst.

From the physical layer perspective, the L1 random access procedure encompasses the transmission of random access preamble and random access response. The remaining messages are scheduled for transmission by the higher layer on the shared data channel as any uplink data transmission and are not considered part of the L1 random access procedure.

5.2.2.2.7 POWER CONTROL

Power control determines the energy per resource element (EPRE). The term resource element energy denotes the energy prior to CP insertion. The term resource element energy also denotes the average energy taken over all constellation points for the modulation scheme applied.

Uplink power control consists of open and closed loop components and controls energy per resource element applied for a UE transmission. For intra-cell uplink power control the closed loop component adjusts a set point determined by the open loop power control component.

Upon reception of an a-periodic transmit power command in an uplink scheduling grant, the UE shall adjust its transmit EPRE accordingly. EPRE is set in the UE.

5.2.2.2.8 PERFORMANCE ESTIMATES

3GPP evaluated LTE uplink performance and results were finalized in May 2007. UL peak data rates for 20 MHz spectrum allocation, assuming that 2 long blocks in every sub-frame are reserved for reference signals and a code rate of 1, provide the following results:

- 57.6 Mbps with 16QAM
- 86.4 Mbps with 64QAM

Uplink user throughput results are presented in Figure 30 and Spectrum efficiency results in Figure 31. In simulations E-UTRA baseline is assuming one TX antenna in the UE and two receive antennas at the eNodeB. Case 1 is a scenario with the Inter site distance of 500 m. Case 3 is a larger cell scenario with the Inter site distance of 1732 m.

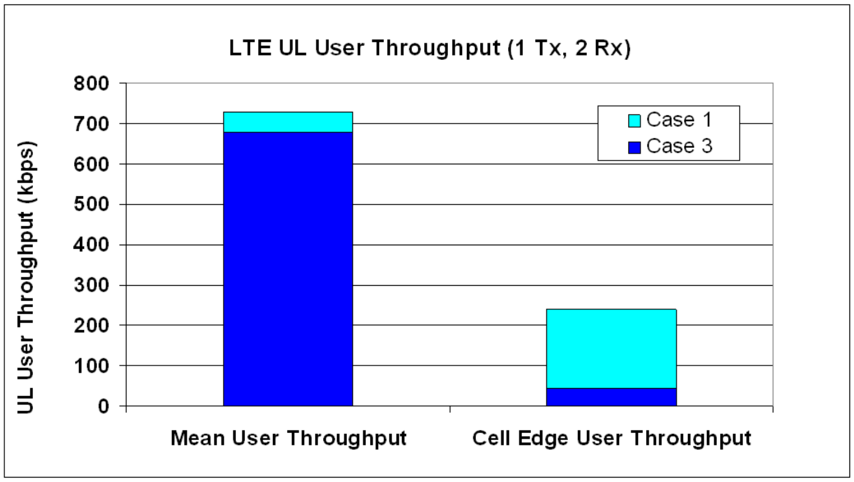

Figure 30. LTE UL User throughput [151]

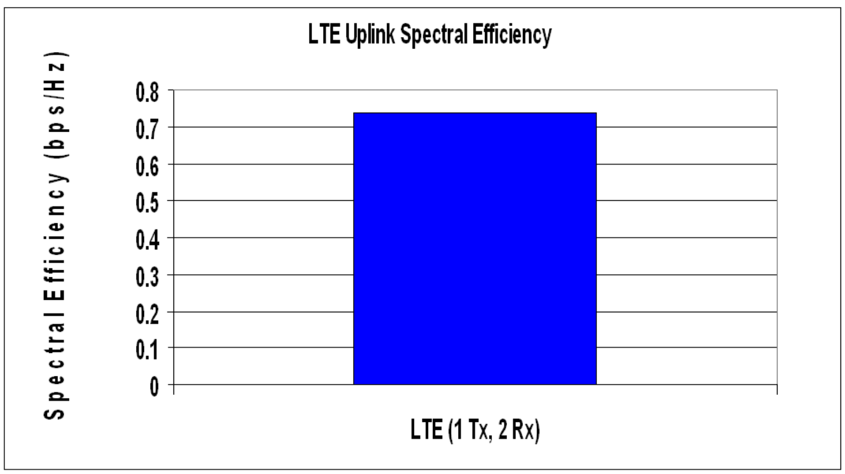

Figure 31. LTE UL Spectrum efficiency [152]

Uplink VoIP capacity results are presented in Figure 32 for 10 MHz spectrum allocation showing 634 users/sector in DL and 482 users in UL. The VoIP capacity on the UL can be further enhanced (especially Case-3) using semi-persistent scheduling (SPS) and TTI bundling.

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[151] *LS on LTE Performance Evaluation Work*. 3GPP TSG R1-072580 RAN WG1#49.
[152] *Ibid.*

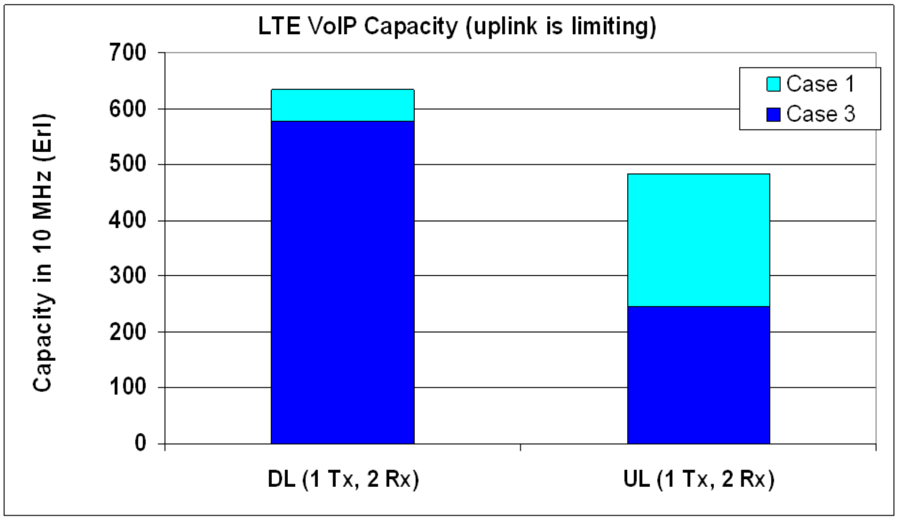

Figure 32. LTE VoIP capacity [153]

5.2.2.2.9 CHANNEL DEPENDENT FREQUENCY DOMAIN SCHEDULING

One of the most attractive features in SC-FDMA is the chance to flexibly schedule user data traffic in the frequency domain. The principle of frequency domain scheduling in EUTRAN is presented in Figure 33. The available spectrum is divided into resource blocks (RB) consisting 12 adjacent subcarriers. The duration of a single RB is 0.5 millisecond. One or more neighboring RBs can be assigned to a single user by the base station and multiple users can be multiplexed within the same frequency band on different resource blocks.

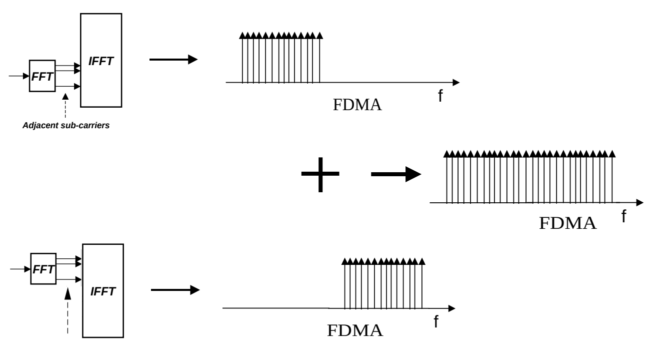

Figure 33. The principle of frequency domain scheduling in EUTRAN [154]

[153] *Ibid.*
[154] Lindholm, Jari et al. *EUTRAN Uplink Performance*. International Symposium on Wireless Pervasive Computing 2007 (ISWPC 2007). San Juan, Puerto Rico, USA. 5-7 February 2007.

In order to optimize the use of frequency spectrum, the base station utilizes the so-called sounding reference signals sent by the UEs. Based on the channel state information estimated from the sounding pilots, the base station is able to divide the available frequency band between UEs. The spectrum allocation can be changed dynamically as the propagation conditions fluctuate. The base station can be configured to use the channel state information for example maximizing cell throughput or favoring cell-edge users with coverage limitations.

5.2.2.3 RADIO ACCESS PROTOCOL ARCHITECTURE

3GPP has defined a functional split for the EPS between radio access and core networkas shown in Figure 34. All radio-related signaling and all layers of retransmission are located in eNodeB, which is the only remaining element of the radio access network. It is natural that MAC layer functionality similar to HSDPA/HSUPA operation will remain in the eNodeB. The new functionalities in base stations compared to HSDPA/HSUPA are the Radio Link Control Layer (RLC) and Radio Resource Control (RRC). Also ciphering and header compression as functions of Packet Data Convergence Protocol (PDCP) were decided to be located in eNodeB.

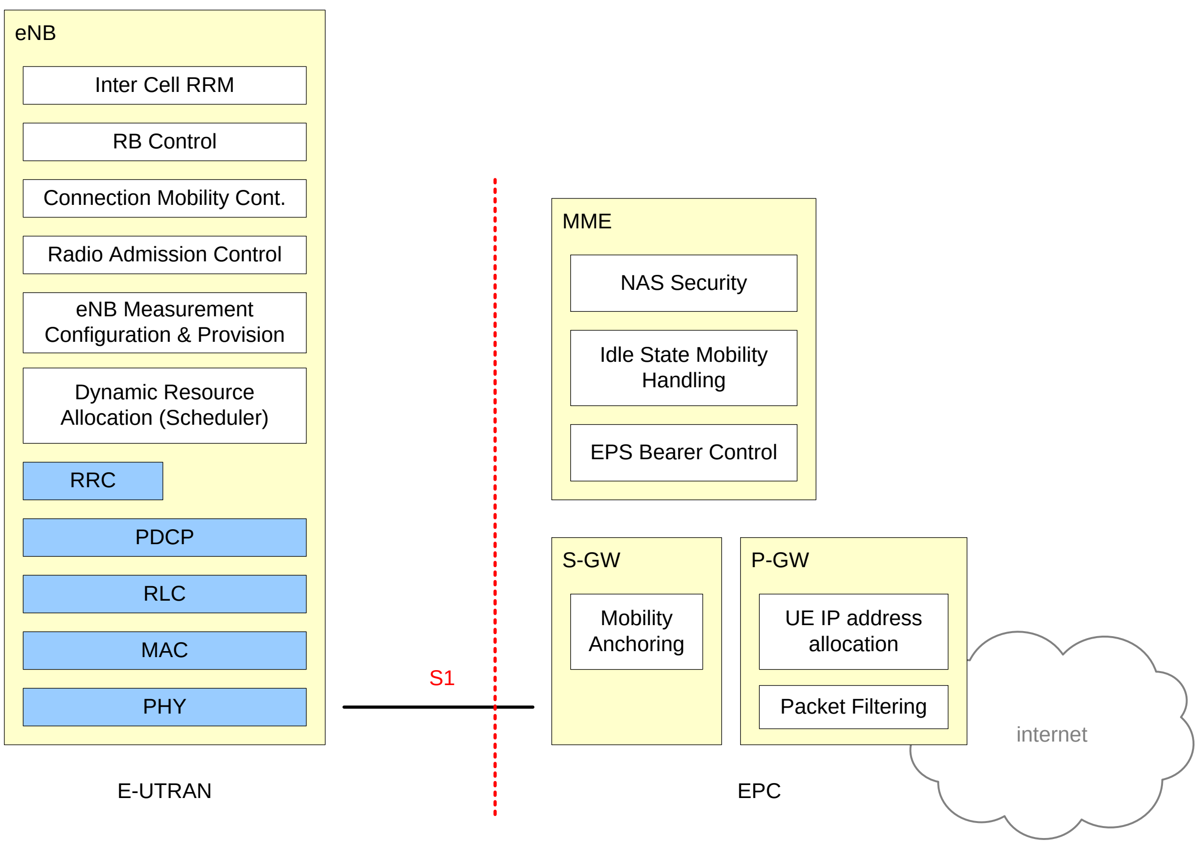

Figure 34. Functional Split between radio access and core network [155]

[155] 3GPP TS 36.300 v8.6.0 (2008-09) E-UTRA and E-UTRAN Overall description; Stage 2 (Release 8).

The radio access protocol in the eNodeB involves the following layers and the protocols in those layers (the blue boxes in eNodeB in Figure 34):

- **Layer 1**

  The Layer 1 is the Physical layer that supports the E-UTRAN air interface. Refer to the section 5.2.1 and 5.2.2 for details of the E-UTRAN uplink and downlink.

- **Layer 2**

  The Layer 2 is split in to the following sub layers:

  - **MAC**

    The main functions of the MAC sub layer includes mapping between logical channels and transport channels, multiplexing/demultiplexing of RLC PDUs belonging to one or different radio bearers into/from transport blocks (TB) delivered to/from the physical layer on transport channels, traffic volume measurement reporting, error correction through HARQ, priority handling between logical channels of one UE, priority handling between UEs by means of dynamic scheduling and transport format selection and padding.

  - **RLC**

    The main functions of RLC sub layer includes transfer of upper layer PDUs supporting acknowledged mode (AM) or unacknowledged mode (UM), transparent mode (TM) data transfer, error correction through automatic repeat request (ARQ), segmentation according to the size of the TB, re-segmentation of PDUs that need to be retransmitted, concatenation of SDUs for the same radio bearer, in-sequence delivery of upper layer PDUs except at handover, duplicate detection, protocol error detection and recovery and SDU discard and reset.

  - **PDCP**

    The PDCP sub layer performs both user plane and control plane functions. The PDCP sub layer functions in the user plane includes header compression and decompression(ROHC only), transfer of user data, in-sequence delivery of upper layer PDUs at handover for RLC AM, duplicate detection of lower layer SDUs at handover for RLC AM, retransmission of PDCP SDUs at handover for RLC AM, ciphering and timer-based SDU discard in uplink. The PDCP sub layer functions in the control plane include ciphering and integrity protection and transfer of control plane data.

  - **RRC**

    The RRC sub layer performs the following control plane functions: broadcast of system information related to access stratum (AS) and non-access stratum (NAS), paging, establishment, maintenance and release of an RRC connection between the UE and E-UTRAN, signaling radio bearer management, security handling, mobility management, including UE measurement reporting and configuration, active mode handover, idle mode mobility control, MBMS notification services and radio bearer management for MBMS, QoS management and NAS direct message transfer to/from NAS from/to UE.

From the radio access point-of-view, the important characteristic is that LTE specifications do not need to support soft handover (i.e. the simultaneous reception/transmission from multiple radio cells).

5.2.2.4 MULTI-ANTENNA SOLUTIONS

This section will give an overview of the various multi-antenna techniques to define/clarify terminology and the specific multi-antenna techniques being adopted for LTE.

5.2.2.4.1 OVERVIEW OF MULTI-ANTENNA TECHNIQUES

Multiple antenna systems are being considered in all next generation cellular standards, including LTE, to increase capacity or to provide spatial diversity. The technologies being considered are MIMO, Spatial Multiplexing, Space-Frequency Coding, and Beamforming.

The use of multiple antennas to improve performance is not new to the cellular industry. Current generation cellular systems use multiple antennas to provide receive diversity at the base station in order to overcome multi-path fading on the UL and transmit diversity in the DL, and to increase coverage and capacity. The diversity is created by utilizing either two vertically polarized antennas spatially separated by a distance of typically 10λ, or by utilizing a single dual-polarized antenna, typically with a slant-45º polarization.

An early application of antenna arrays was for beamforming. In beamforming, multi-column arrays of antenna elements with a spacing of lambda/2 are used to create an antenna with a desired directional beam pattern. One example of an SDMA Beamformer is a Switched Fixed Beam Array where a series of discrete beams are generated from the array, each of the beams having its own input port and unique azimuth pointing direction. For use in the military, and then in communications, more advanced smart antennas have been developed that allow adaptive beam shaping, and steering, through a combination of gain/phase adjustments that are controlled using digital signal processing. Smart antenna or Adaptive Array (AA) technology forms dynamic beams that are a function of the propagation channel and interference environment (see Figure 35). AA technology works best in low-scattering environments by improving received signal power and reducing co-channel interference. The performance of pure beamforming systems is degraded in the cases of channels with significant angular spread such as indoors or in urban cellular deployments. Beamforming technology has had some success in cellular systems (e.g., the current deployment of TD-SCDMA in China).

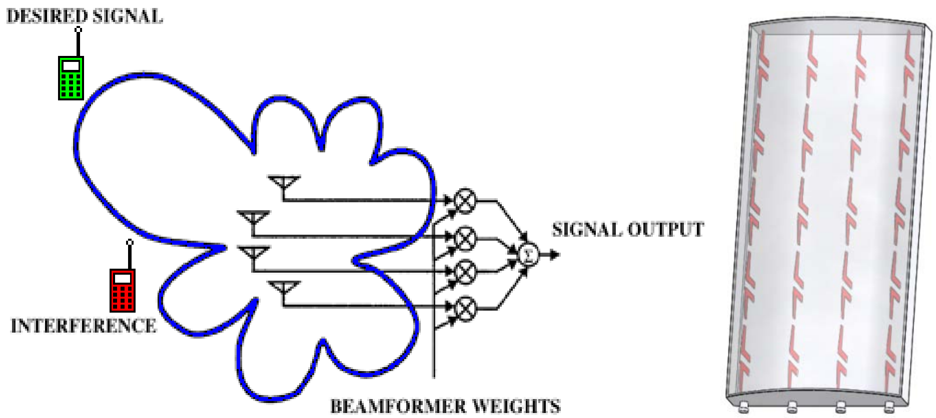

Figure 35. Conceptual depiction of an AA system implemented with 4-column, vertically polarized planar array

In the last few years Multiple-Input Multiple Output (MIMO) technology has emerged as one of the most promising approaches to achieve higher data rates in cellular systems. While MMO systems increase complexity with the use of multiple antennas and associated DSP systems at both the transmitter and the receiver, they provide significant benefit by increasing the theoretical capacity (Shannon capacity) linearly with the number of transmit and receive antenna pairs. This dramatic increase in spectral efficiency can only be achieved if the channel is in a sufficiently rich scattering environment. A typical MIMO system with two transmit and two receive antennas, 2x2 MIMO, is shown in Fig. 36.

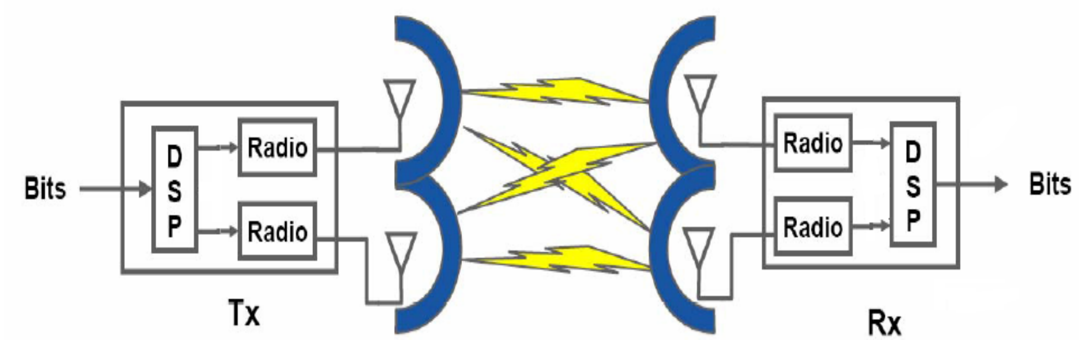

Figure 36. 2x2 MIMO system [156]

[156] Bhagavatula, Ramya and Dr. Robert Heath, Jr. *Analysis of MIMO Antenna Designs for 3GPP – LTE Cellular Systems.* Wireless Networking and Communications Group. The University of Texas at Austin. 8 June 2007.

The signals that are propagated through the antennas in a MIMO system must remain decorrelated, so the RF coupling between arrays must be minimized. This can be achieved by spatial separation of the antennas or, in the case of a dual-polarized antenna, by the orthogonality of the two cross-polarized arrays (see Figure 37).

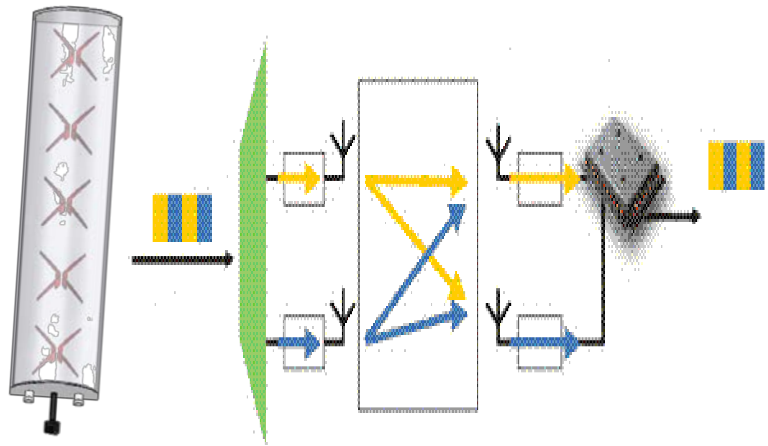

Figure 37. Conceptual depiction of a 2x2 MIMO system implemented with dual-pole, slant-45 base station antenna and two antennas in the UE [157]

MIMO: Space-Time coding

Space-time coded MIMO systems provide diversity gain to combat multi-path fading in the link. In this system, copies of the same signal, coded differently, are each sent over a different transmit antenna. The use of multiple antennas, on both sides of the link, creates additional independently faded signal paths thereby increasing the maximum diversity gain that can be achieved (see Figure 38).

[157] *Ibid.*

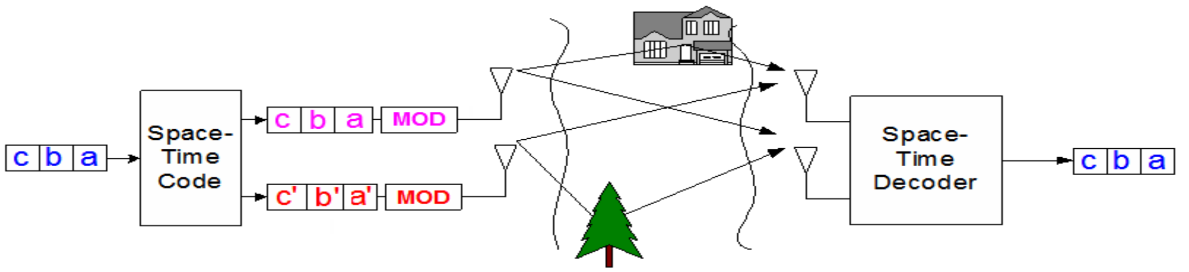

Figure 38. Illustration of Space Time Coding in a 2x2 MIMO system [158]

In LTE another technique, Space Frequency Block Coded (SFBC) MIMO systems is used. It provides diversity gain to combat multi-path fading in the link just like in space-time coding, but in principle only one receive antenna is sufficient. In this system, copies of the same signal, coded differently, are each sent over a different transmit antenna and frequency tone.

MIMO: Spatial Multiplexing

Spatial Multiplexed MIMO systems increase spectral efficiency by utilizing powerful signal processing algorithms to exploit multi-path propagation in the MIMO communications link. Independent data streams, using the same time-frequency resource, are each sent over a transmit antennas, providing multiplexing gain, resulting in increased system capacity (see figure 39). In case of open loop per antenna rate control (PARC), two independent streams are transmitted over two antennas. On the other hand, in case of closed loop per stream rate control (PSRC), the streams are not independent, because precoding is used.

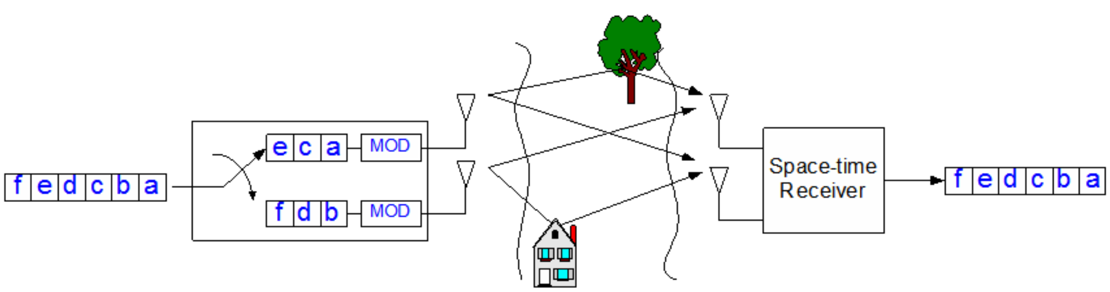

Figure 39. Illustration of Spatial Multiplexing in a 2x2 MIMO system [159]

[158] *Ibid.*

MIMO: MU-MIMO vs. SU-MIMO

MIMO transmission can be divided into multi-user and single-user MIMO (MU-MIMO and SU-MIMO, respectively). The difference between the two is that in SU-MIMO all the streams carry data for/from the same user while in the case of MU-MIMO the data of different users is multiplexed onto a single time-frequency resource.

The basic principle of uplink MU-MIMO with 2x2 antenna configuration is depicted in Figure 40. Each of the two UEs transmits a single data stream simultaneously using the same frequency band. The eNodeB receives the transmitted signals with two antennas. The reference signals of the UEs are based on CAZAC sequences which are code multiplexed using cyclic shifts. This enables accurate channel estimation, which is crucial in MIMO systems. Using the channel state information, the eNodeB can separate and decode the both streams.

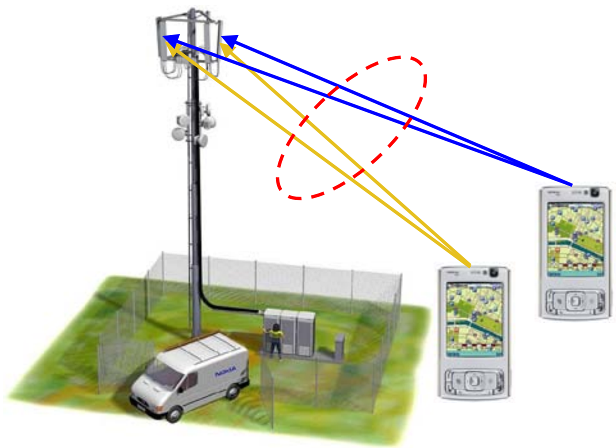

Figure 40. The basic principle of uplink MU-MIMO with 2x2 antenna configuration [160]

Uplink MU-MIMO also sets requirements for the power control. In the case of Single-Input Single Output (SISO) or Single-Input Multiple Output (SIMO), due to the nature of FDMA, rather slow power control is sufficient. When several users are multiplexed on the same frequencies, the near-far problem well known from CDMA-based systems arises.

LTE has all of these modes of multiple antenna systems.[161] SU-MIMO as well as MU-MIMO techniques are available in UL and DL. Diversity techniques and beamforming algorithms are also included. The status of MIMO in 3GPP LTE standardization will be discussed further in the next section.

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[159] Bhagavatula, Ramya and Dr. Robert Heath, Jr. *Analysis of MIMO Antenna Designs for 3GPP – LTE Cellular Systems*. Wireless Networking and Communications Group. The University of Texas at Austin. 8 June 2007.

[160] Lindholm, Jari et al. *EUTRAN Uplink Performance*. International Symposium on Wireless Pervasive Computing 2007 (ISWPC 2007). San Juan, Puerto Rico, USA. 5-7 February 2007.

[161] *LTE MIMO Ad Hoc Summary, R1-071818.* 3GPP TSG RAN WG1 Meeting #48bis. St. Julians, Malta. 26-30 March 2007.

5.2.2.4.2 MIMO STATUS IN 3GPP LTE STANDARDIZATION

This section discusses the 3GPP standards status of MIMO options for LTE.

Downlink

In the downlink, MU-MIMO as well as SU-MIMO schemes is considered. For MU-MIMO, a unitary codebook-based precoding approach has been selected for the feedback. The NodeB remains free with regard to the actual technique applied based on the feedback. The number of bits provided for identifying a specific codebook matrix has been limited to 3, thereby limiting the number of codebook elements to 8. Although configurations of up to 4 different layers are envisaged, a limitation to 2 parallel codewords has been agreed upon. The feedback overhead is a critical issue. To limit the amount of feedback, the following agreements have been reached regarding feedback granularities:

- Precoding vector: In the frequency selective case, the precoding matrix index (PMI) refers to a different number of PRBs, depending on the bandwidth (e.g. 4 adjacent PRBs in case of 10 MHz)
- Rank information: Whole band

The SU-MIMO schemes incorporate a codebook based precoding scheme with feedback for both 2-Tx and 4-Tx case.

The MIMO concept is supported by appropriate reference symbol schemes. To allow for per antenna channel estimation, the time-frequency positions of a reference symbol pertaining to a specific antenna are left unused on the other antennas.

With regard to Tx diversity in the DL, a space frequency block code (SFBC) scheme has been agreed for the 2 Tx and a combination of SFBC and frequency selective transmit diversity for the 4 Tx case.

Uplink

In the uplink, there have been discussions at 3GPP on the standardization of SU-MIMO vs. MU-MIMO concepts. SU-MIMO concepts require not only two antennas but also two parallel RF Tx chains in the UE. This implies an increase in complexity compared to MU-MIMO, which doesn't require any additional measures at the UE. Therefore, it has been agreed to incorporate only MU-MIMO in the first LTE release and to incorporate SU-MIMO in the later LTE releases. To this end, all necessary provisions for SU-MIMO (e.g. in terms of reference signals) are already included in the first release.

In addition, a switched Tx diversity scheme is provided in the first release allowing the switching between two Tx antennas while only needing one RF chain in transmitting direction. The reference symbols in UL are derived from CAZAC sequences. Between several antennas of the same UE, cyclic shifts of the sequences are used for separation. This way, the later planned introduction of SU-MIMO is already taken into consideration.

5.2.2.4.3 LTE PERFORMANCE WITH MULTI-ANTENNAS

This section discusses the performance of various multi-antenna options studied in the 3GPP RAN1 group.

DOWNLINK PERFORMANCE

An aggregate performance summary of several MIMO configurations, as evaluated by various 3GPP members, has been compiled by the 3GPP.[162] Figures 41-43 show the spectral efficiency, mean user throughput and cell edge throughput performance of SU-MIMO for 2x2, 4x2 and 4x4 DL antenna configurations from the 3GPP study.

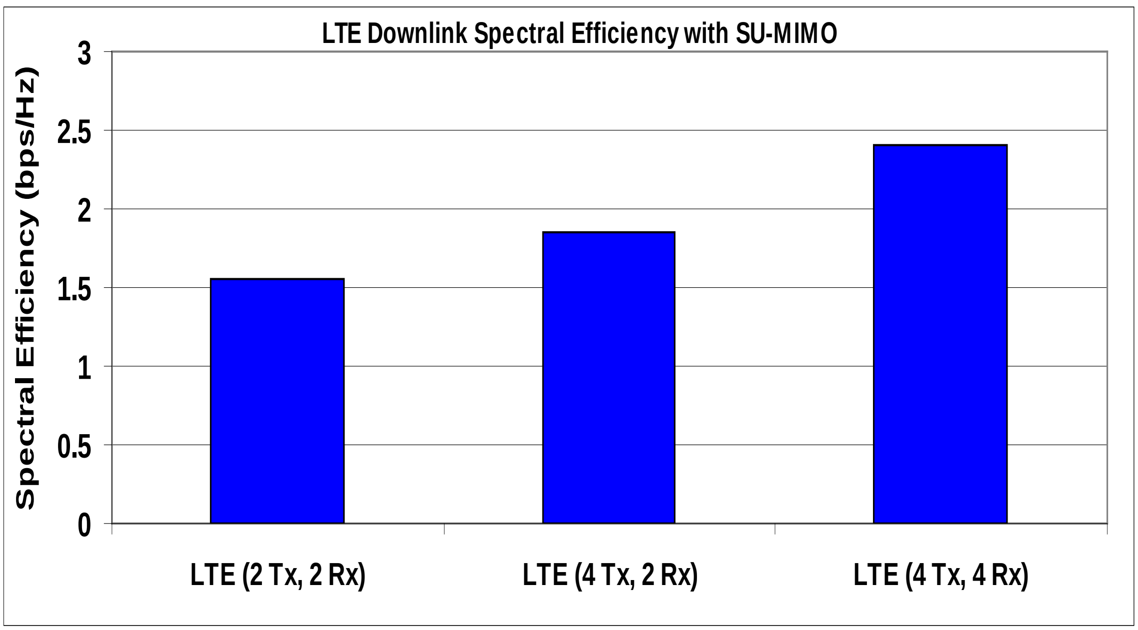

Figure 41. LTE Downlink Spectral Efficiency Performance with multi-antennas[163]

[162] *LS on LTE Performance Verification Work, R1-072580*. 3GPP TSG-RAN WG1 #49. Kobe, Japan. 7-11 May 2007.
[163] *Ibid.*

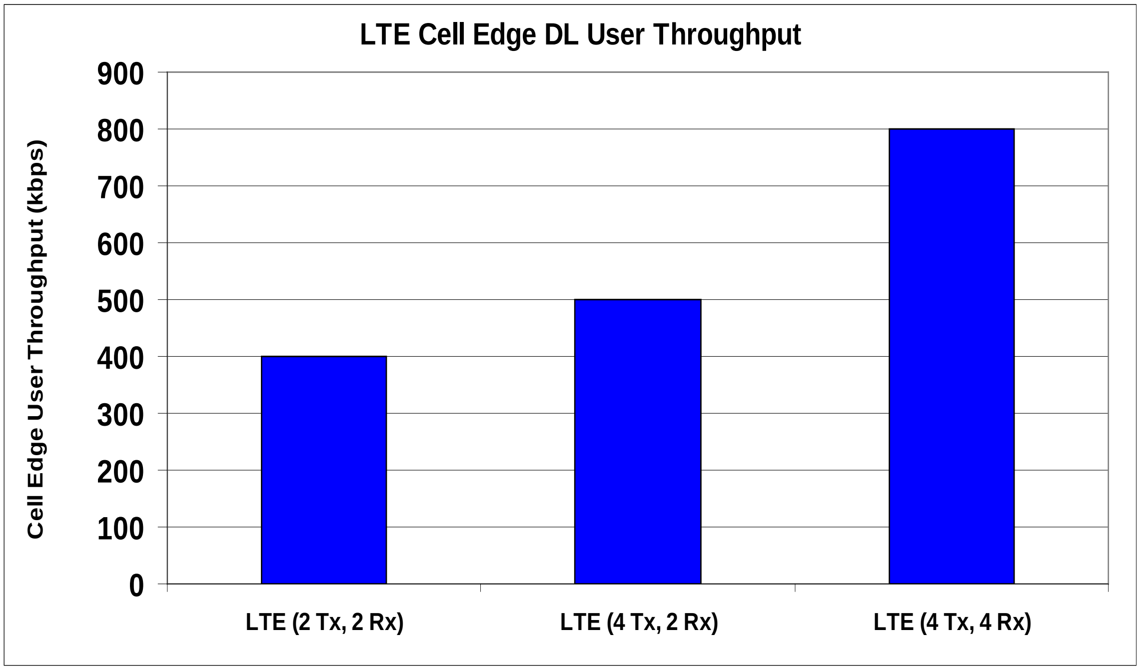

Figure 42. LTE Downlink Mean User throughput Performance with multi-antennas [164]

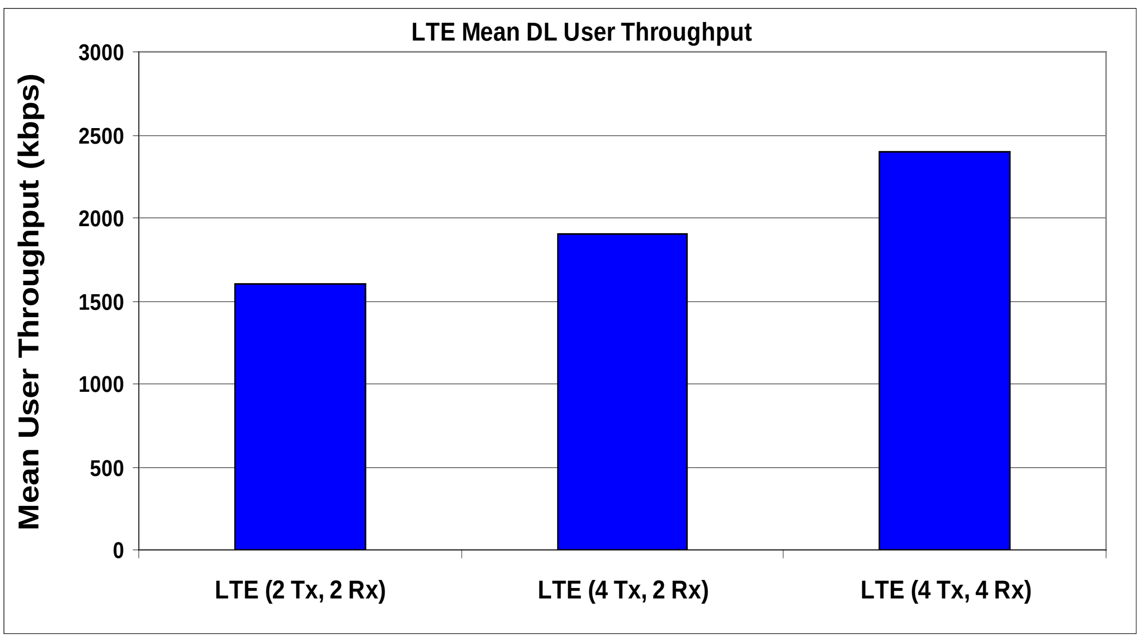

Figure 43. LTE Downlink Cell EDGE Performance with multi-antennas [165]

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[164] *Ibid.*
[165] *Ibid.*

An aggregate performance summary of several MIMO configurations, as evaluated by various 3GPP members, has been compiled by the 3GPP. [166] Figures 44-46 show the spectral efficiency, mean user throughput and cell edge throughput performance of MU-MIMO for the 1x2 UL antenna configuration compared to SIMO 1x2 and 1x4 UL from the 3GPP study.

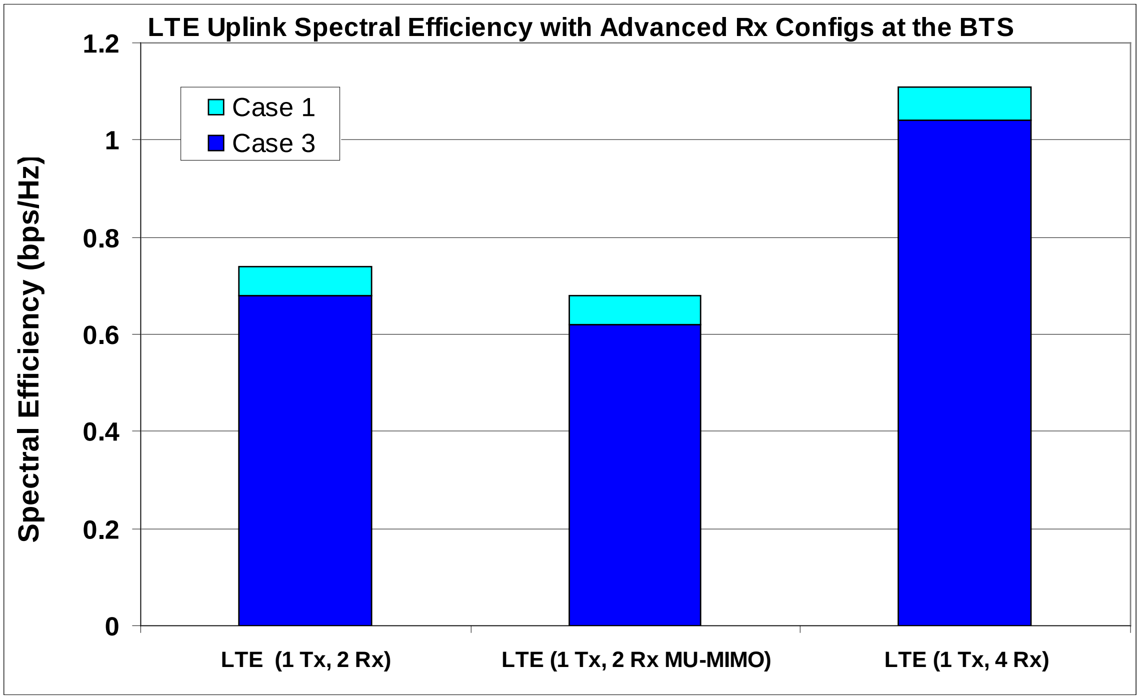


Figure 44. LTE Uplink Spectral Efficiency Performance with multi-antennas [167]

[166] *Ibid.*
[167] *Ibid.*

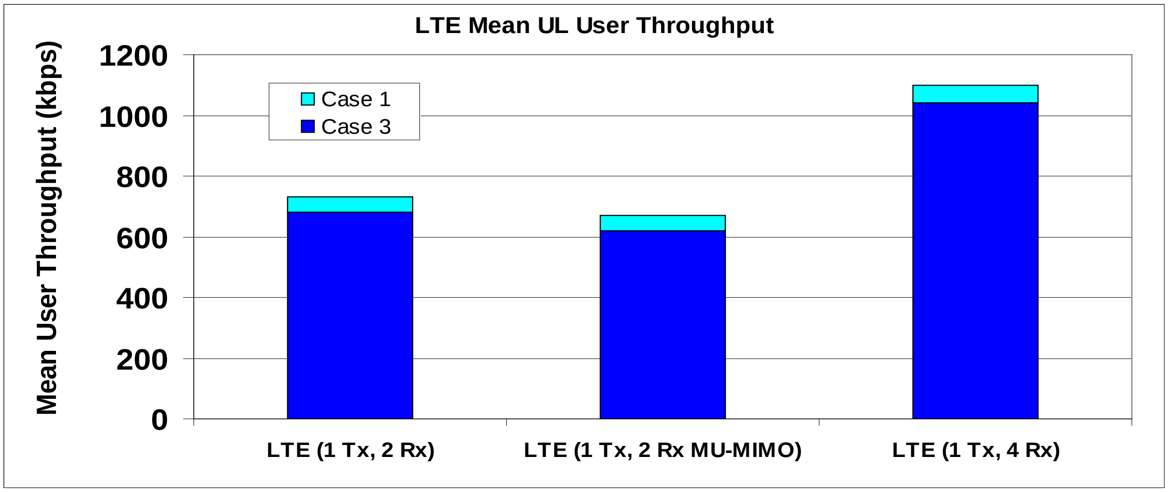


Figure 45. LTE Uplink Mean Throughput Performance with multi-antennas [168]

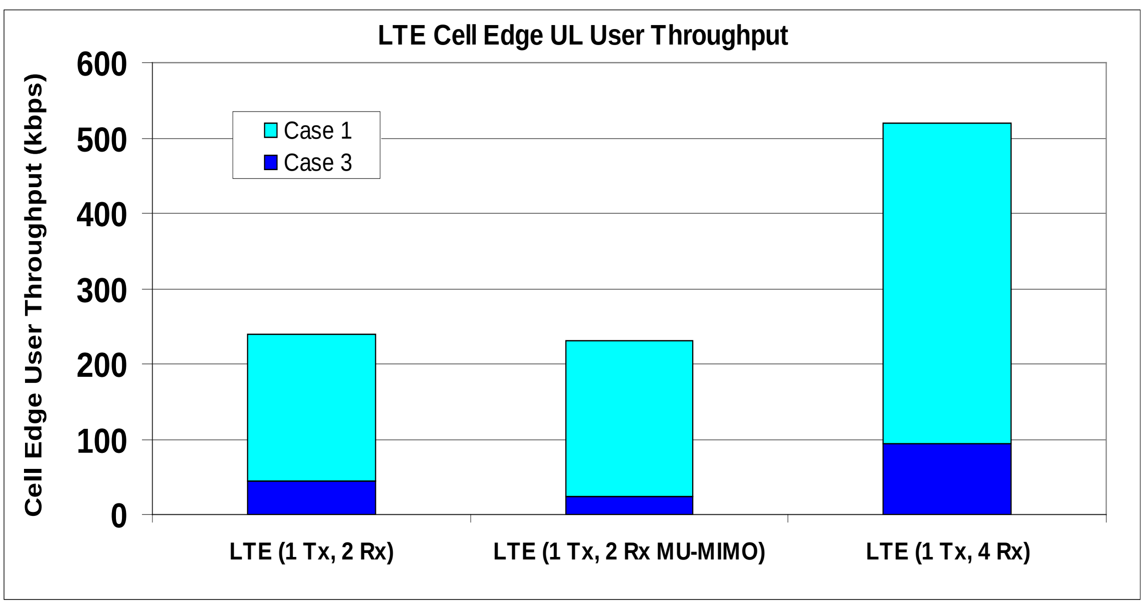


Figure 46. LTE Uplink cell edge performance with multi-antennas [169]

[168] *Ibid.*
[169] *Ibid.*

5.2.2.5 INTERFERENCE MITIGATION TECHNIQUES

This section discusses interference mitigation techniques for improving spectral efficiency and/or cell edge user experience. It should be noted that the techniques discussed in this section are not mandatory for LTE, but randomization and co-ordination/avoidance are supported by specification in the standard. The techniques can be viewed as enhancements or optimizations that can be used for LTE to improve performance. However, the interference mitigation techniques discussed in this section are particularly beneficial for managing interference in LTE deployments using frequency reuse 1 (i.e. deployments that are typically interference limited).

As identified in the LTE work there are basically three approaches to inter-cell interference mitigation:

- Inter-cell-interference randomization
- Inter-cell-interference cancellation
- Inter-cell-interference co-ordination/avoidance

In addition, the use of beamforming antenna solutions is a general method that can also be seen as a means for downlink inter-cell-interference mitigation. These approaches can be combined and they are not necessarily mutually exclusive.

5.2.2.5.1 INTERFERENCE RANDOMIZATION

Inter-cell-interference randomization aims at randomizing the interfering signal(s), which can be done by scrambling, applying (pseudo) random scrambling after channel coding/interleaving or by frequency hopping. The randomization in general makes the interference more uniform so that a single strong interfering signal (e.g. generated from a cell edge user) will tend to have a small/tolerable impact on a large number of users in adjacent cells, rather than a large/destructive impact on a few users in adjacent cells (thus increasing outage).

5.2.2.5.2 INTERFERENCE CANCELLATION

Interference at the receiver can be considered irrespective of the interference mitigation scheme adopted at the transmitter.

Two methods can be considered:

- Interference cancellation based on detection/subtraction of the inter-cell interference by explicitly modeling the interfering symbols. In order to make inter-cell-interference cancellation complexity feasible at the receiver, it is helpful that the cells are time-synchronized.
- Spatial suppression by means of multiple antennas at the UE: It should be noted that the availability of multiple UE antennas is an assumption for E-UTRA. This can be done without a synchronization of the cells and the corresponding receiver is usually called Interference rejection combining (IRC)-Receiver.

Whether the performance improvements by this type of receiver can be assumed is implementation specific.

5.2.2.5.3 INTERFERENCE CO-ORDINATION / AVOIDANCE

This section discusses the concept of interference co-ordination and avoidance.

DOWNLINK PRINCIPLE

In contrast to previous WCDMA modulation, OFDM and SC-FDMA have the property that they are frequency division multiplexing access methods. (The complex exponentials used on modulation are the eigen-functions of the quasi LTI channel).

Thus, almost independent of the channel transmission, interference created on certain frequencies such as in a physical resource block (PRB) only affects those frequencies such as the same PRB in a neighbor cell. Interference in these schemes is predictable and avoidable. This property can be used for specific interference avoidance methods in UL and in DL.

In Downlink, the common theme of inter-cell-interference co-ordination/avoidance is to apply restrictions to the downlink resource management in a coordinated way between cells. These restrictions can be in the form of restrictions as to what time/frequency resources are available to the resource manager or restrictions on the transmit power that can be applied to certain time/frequency resources. Such restrictions in a cell will provide improved SIR and cell-edge data-rates/coverage on the corresponding time/frequency resources in a neighbor cell.

DOWNLINK STATIC SCHEMES

In static schemes these restrictions are distributed to the different cells and are constant on a time scale corresponding to days. Different kinds of restriction distributions can be used which involve frequency or cell planning in an area (e.g. an inverted re-use 7 scheme (FFR=6/7) as shown in Figure 47).

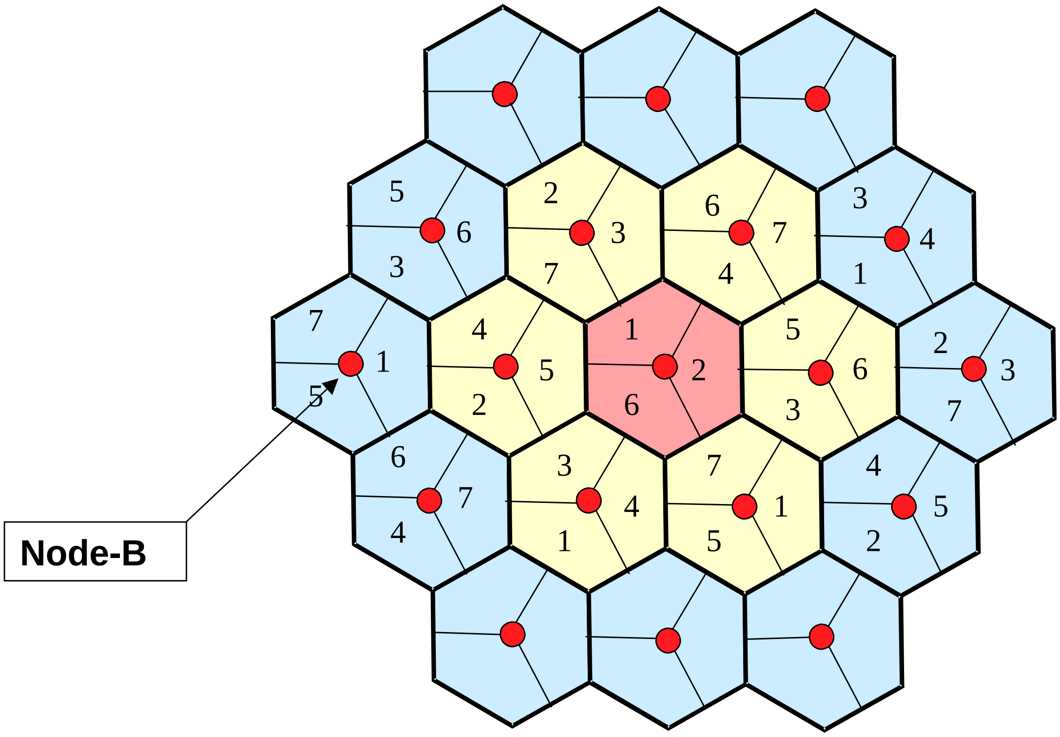


Figure 47. Cell planning for inverted re-use 7 scheme (FFR=6/7) [170]

DOWNLINK FREQUENCY DOMAIN SCHEDULING

Frequency domain scheduling that is an allocation of parts of a spectrum with better quality to a UE is also a part of the interference avoidance. It can by itself exploit the SIR improvements if interference measurements would be part of the CQI reporting and if these SIR improvements of certain resource blocks are stable enough and the channel quality reports are frequent enough so that the scheduler can take advantage of them. Its value depends on whether interference measurements are included when calculating the CQI reports.

By using static Interference co-ordination with a cell planning, the SIR improvement are made more stable than the frequency selective fading and the scheduling can rely on just path-loss and shadowing measurements.

UPLINK PRINCIPLE

In uplink, the theme is to apply preferences and restrictions to the frequencies available for UL scheduling or for the transmit power to be available on certain frequencies. For example, by introducing a preference for a certain frequency subset depending on the nearest neighbor of a

[170] Alcatel-Lucent. Q2 2007.

UE, a decrease in interference on the remaining non-preferred subsets in the neighbor cell can be obtained and that improves the sector throughput in total.

UPLINK SEMI-STATIC SCHEMES

The restrictions can also be distributed between cells on a demand basis depending on the load in a certain cell border area. This is a feature that only an FDMA system can provide. For example depending on the load (e.g. a geometrical concentration of terminals at the border between two cells), the restrictions are distributed between the two involved and possibly some other neighbor cells. This allows a spectrum efficiency increase. In this way, with different loads, one low-loaded cell can specifically help a higher loaded neighbor cell.

Semi-static and static schemes can also be combined and built on top of each other. The reconfiguration of the restrictions is done on a time scale of the order of seconds or longer. Inter-node communication corresponds to information needed to decide on reconfiguration of the scheduler restrictions (examples of communicated information include traffic-distribution within the different cells, downlink interference contribution from cell A to cell B, etc.) as well as the actual reconfiguration decisions. The signaling rate is in the order of tens of seconds to minutes.

5.3 LTE TDD

In LTE, TDD mode is viewed solely as a physical layer manifestation and therefore invisible to higher layers. As a result, there is no operational difference between the two modes at higher layers or in the system architecture. At the physical layer, the fundamental design goal is to achieve as much commonality between the two modes as possible. As a result, the main design differences between the two modes stem from the need to support various TDD UL/DL allocations and provide co-existence with other TDD systems. In this regard, several additional features not available for FDD were introduced. Table 5 provides a brief overview of the physical layer features available only in TDD.

Table 5. Features only available in TDD

Feature	TDD Implementation
Frame structure	Introduction of a special subframe for switching from DL to UL and to provide coexistence with other TDD systems
Random access	Additional short random access format available in special subframe, multiple random access channels in a subframe
Scheduling	Multi-subframe scheduling for uplink
ACK/NACK	Bundling of acknowledgements or multiple acknowledgements on uplink control channel
HARQ process number	Variable number of HARQ processes depending on the UL/DL allocation

In addition to the features outlined in Table 5, FDD and TDD modes also differs in the time placement of the synchronization signals. Unlike in FDD, where the primary and secondary synchronization signals are contiguously placed within one subframe, for TDD the two signals are placed in different subframes and separated by two OFDM symbols.

The TDD frame structure is shown in Figure 48. Each radio frame spans 10ms and consists of ten 1ms subframes. Subframes 0 and 5 are always downlink subframes as they contain synchronization signal and broadcast information necessary for the User Equipment (UE) to perform synchronization and obtain relevant system information. Subframe 1 is a special subframe that serves as a switching point between downlink to uplink transmission. It contains three fields: Downlink Pilot Time Slot (DwPTS) Guard Period (GP), and Uplink Pilot Time Slot (UpPTS) that will subsequently be explained in details. No special subframe is provisioned for switching from uplink to downlink transmission. Instead, appropriate timing advance at the UE will be employed to create the necessary guard period.

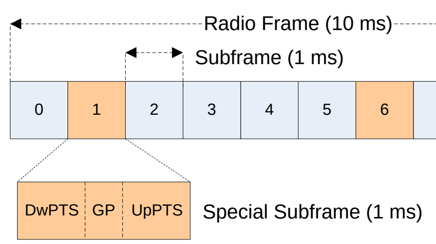


Figure 48. TDD Frame Structure

Two switching point periodicities are supported: 5ms and 10ms. For the 5ms switching point periodicity, subframe 6 is likewise a special subframe identical to subframe 1. For the 10ms switching point periodicity, subframe 6 is a regular downlink subframe. Table 6 illustrates the possible UL/DL allocations.

Table 6. Uplink-downlink allocations

UL/DL Configuration	Period (ms)	Subframe									
		0	1	2	3	4	5	6	7	8	9
0	5	D	S	U	U	U	D	S	U	U	U
1		D	S	U	U	D	D	S	U	U	D
2		D	S	U	D	D	D	S	U	D	D
3	10	D	S	U	U	U	D	D	D	D	D
4		D	S	U	U	D	D	D	D	D	D
5		D	S	U	D	D	D	D	D	D	D
6	5	D	S	U	U	U	D	S	U	U	D

As shown in Figure 49, the total length of DwPTS, GP, and UpPTS fields is 1ms. However, within the special subframe the length of each field may vary depending on co-existence requirement with legacy TDD systems and supported cell size. The supported configurations can be found in

TS36.211 “Physical Channels and Modulation” on the 3GPP website (http://www.3gpp.org). Note that this assumes that the Node-B (base station in UMTS terminology) and UE switching time to be less than the duration of an OFDM symbol with extended cyclic prefix (CP).

An example of coexistence with legacy UMTS Low Chip-Rate (LCR) TDD system is shown in Figure 49 where switching point alignment between the two systems is illustrated.

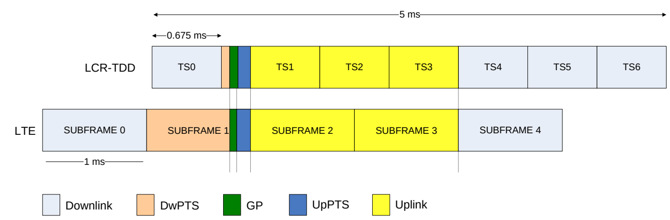


Figure 49. Coexistence with LCR-TDD UMTS system.

Obviously, to minimize the number of special subframe patterns to be supported, not all legacy TDD configurations can be supported. For LCR-TDD configurations, Table 7 was designed to provide co-existence with the 5DL:2UL and 4DL:3UL LCR-TDD splits which are generally viewed as the most common deployment configurations.

Table 7. DwPTS/GP/UpPTS length (OFDM symbols).

<table>
<tr><th rowspan="2">Format</th><th colspan="3">Normal CP</th><th colspan="3">Extended CP</th></tr>
<tr><th>DwPTS</th><th>GP</th><th>UpPTS</th><th>DwPTS</th><th>GP</th><th>UpPTS</th></tr>
<tr><td>0</td><td>3</td><td>10</td><td rowspan="5">1</td><td>3</td><td>8</td><td rowspan="4">1</td></tr>
<tr><td>1</td><td>9</td><td>4</td><td>8</td><td>3</td></tr>
<tr><td>2</td><td>10</td><td>3</td><td>9</td><td>2</td></tr>
<tr><td>3</td><td>11</td><td>2</td><td>10</td><td>1</td></tr>
<tr><td>4</td><td>12</td><td>1</td><td>3</td><td>7</td><td rowspan="3">2</td></tr>
<tr><td>5</td><td>3</td><td>9</td><td rowspan="4">2</td><td>8</td><td>2</td></tr>
<tr><td>6</td><td>9</td><td>3</td><td>9</td><td>1</td></tr>
<tr><td>7</td><td>10</td><td>2</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>8</td><td>11</td><td>1</td><td>-</td><td>-</td><td>-</td></tr>
</table>

5.4 OTHER REL-8 ENHANCEMENTS

This section in addition to the other topics mentioned below scopes out the enhancements in the area of UICC/USIM in Rel-8/Rel-9 perspectives.

5.4.1 COMMON IMS

Since Rel-7, 3GPP's definition of IMS has been open to access by non-cellular technologies. This has generated cooperation with groups specifying IMS for wireline applications (e.g ETSI TISPAN and Cablelabs). In Rel-8, 3GPP's Organizational Partners (OPs) have decided that 3GPP should be the focus for all IMS specification under their responsibility.

The "common IMS" work is an agreement between the 3GPP OPs to migrate work on the IMS and some associated aspects to 3GPP for all access technologies. This will simplify the deployment of Fixed Mobile Convergence (FMC) solutions, minimize the risk of divergent standardization and make the standardization process more efficient.

Rel-8 will be the first release directly impacted by Common IMS. 3GPP is working with groups in the OPs to manage the transfer of work. SDOs outside the 3GPP OPs are, of course, not bound by the Common IMS agreement. 3GPP will continue to work with bodies like ITU-T, 3GPP2 and Cablelabs on the use of IMS specifications in their areas.

5.4.2 MULTIMEDIA PRIORITY SERVICE

Mobile networks have proved to be a valuable asset to individuals and emergency services at times of crisis. However major disasters can provoke network overload situations. Without prioritization of traffic, communications required by providers of essential services can be disrupted.

The multimedia priority service enhances IMS to provide special support for disaster recovery and national emergency situations. The Multimedia Priority Service allows suitable authorized persons to obtain preferential treatment under network overload situation. This means that essential services will be able to continue even following major indicants. It is intended that users provided with Multimedia Priority Service will be members of the government or emergency services.

Multimedia Priority Service provides IMS functions similar to those already available in the CS network. When this feature is deployed, disaster recovery will be assisted by the multimedia capabilities of IMS. This feature is also an enabler to the eventual replacement of CS networks by IMS.

5.4.3 IMS ENHANCEMENTS FOR SUPPORT OF PACKET CABLE ACCESS

IMS is suitable for many types of access technology. 3GPP has encouraged cooperation outside the cellular area to maximize the applicability and commonality of IMS specifications. This work item introduces in 3GPP, specific enhancements to IMS that are primarily of interest to the Packet Cable community. However it is anticipated that some of the aspects will also be of interest to other IMS users. The areas of functionality standardized in Release 8 were the following:

- Security: the cable environment requires a specific security approach driven by its particular architecture for home networking. This work item enhances IMS security to fit in the packet cable architecture
- Regulatory: cable networks are often used for residential “primary line” support. This means that they must comply with regulatory features covering this aspect. This work item provides the necessary regulatory features for cable deployment in North America and other regions. This includes support for equal access circuit carrier, local number portability for IMS, and handling of local numbering. Interworking to ISUP for equal access and local number portability are also included in the work item.

5.4.4 IMS SERVICE BROKERING

Current IMS specifications provide a framework that allows operators to customize IMS services and to build new services based on IMS capabilities. This framework aims to provide richer and simpler service development capabilities than previous technologies such as Intelligent Networking (IN).

IMS Service Brokering aims to enhance the existing service deployment technology in IMS to further simplify the deployment of services and to make the system more efficient. In particular, IMS Service Brokering considers the possible interactions between several developed services and how these will impact the network.

In 3GPP Rel-8, as a result of a study into service interaction service brokering, the IMS architecture has been enhanced to:

- allow errors from Application Servers to be discarded at the S-CSCF, so supplemental services do not result in the termination of the primary session establishment;
- allow an explicit sequence of services to be invoked in the Application Server to be signaled;
- use the capabilities of the UE in the service-triggering decision process;
- retain the identity of the original called party through multiple service activations to prevent operator policy violation.

3GPP may also consider adding more service-brokering capabilities in later releases as more requirements are identified.

5.4.5 VCC ENHANCEMENTS

There are three main areas of work related to VCC for Rel-8: IMS Centralized Services (ICS), Service Continuity (SC) and VCC for Single Radio Systems (i.e. between LTE/HSPA access and CS domain). These are discussed below.

5.4.5.1 IMS CENTRALIZED SERVICES (ICS)

IMS Centralized Service (ICS) is an approach that provides communication services wherein all services and service control are based on IMS mechanisms and enablers.

ICS users are IMS subscribers with supplementary services subscription in IMS. ICS user services are controlled in IMS based on IMS mechanisms with the CS core network basic voice service used to establish voice bearers for IMS sessions when using non VoIP capable PS or CS access. In particular, ICS solves a Rel-7 VCC limitation by allowing mid-call services to be invoked within IMS when using CS access for the media bearer.

IMS services are delivered over 3GPP CS, VoIP capable and non VoIP capable 3GPP PS, and non-3GPP PS access networks. ICS provides the necessary signaling mechanisms to enable user transparent service continuity between these access networks.

Centralization of service control in IMS provides consistent user service experience across disparate access networks by providing service consistency as well as service continuity when transitioning across access networks.

5.4.5.2 SERVICE CONTINUITY (SC)

Service Continuity (SC) reuses the Rel-7 VCC principles by providing an IMS controlled model for session anchoring and session transfer, but allows for a richer set of multimedia session continuity scenarios when the user is moving between 3GPP, non-3GPP and between 3GPP and non-3GPP access systems. The scope of the feature includes the following:

- PS-PS Service Continuity
- PS-CS Service Continuity
- PS-PS in conjunction with PS-CS Service Continuity
- Adding or Deleting Media flows to an existing multimedia session

Service Continuity assumes an IMS centralized service model for execution of services and describes procedures for multimedia session continuity for UEs that do and do not have ICS capabilities. Service Continuity of mid-call services between PS and CS access systems can only be provided when using a UE which has ICS capabilities.

5.4.5.3 VOICE CALL CONTINUITY BETWEEN LTE/HSPA ACCESS AND CS DOMAIN (SINGLE RADIO VCC)

Rel-7 VCC requires simultaneous activation of CS and PS radio channels for enablement of service continuity between CS and PS systems. This is not possible when transitioning between SAE/LTE access and CS access and with transitions involving some other combinations of 3GPP radio systems such as 2G CS and 3G PS. The solution requires some assistance from the core network (below IMS).

Single Radio VCC uses the IMS controlled procedures described in Service Continuity (SC) for execution of session transfer and provides voice call continuity for the following:

- LTE/HSPA to 3GPP 2G-CS/3G-CS
- LTE to 3GPP2 1x CS

The capability is restricted to the transfer of a single voice session and there is no support for hand-back of the session to LTE/HSPA. Additionally, there is no support for voice call continuity when the session is originated in the CS domain.

5.4.6 UICC: INTERNET SERVICES AND APPLICATIONS

UICC (3GPP TS 31.101) is treated as the Trusted operator anchor in the user domain for LTE/SAE, leading to evolved applications and security on the UICC. With the completion of Rel-8 features, the UICC is termed to be playing significant roles in many part of the network.

Some of the Rel-8 achievements from standards (ETSI, 3GPP) are in the following areas:

USIM (TS 31.102):

USIM has gained considerable traction in the features enhancement for LTE. USIM has its placeholder in authentication and secure access to EPC while also for non-3GPP access systems USIM is mandated. 3GPP has approved some of the important features in the USIM that enables efficient network selection mechanisms. With the addition of CDMA2000, HRPD access technologies into the PLMN, PLMN's can be used to for selection among CDMA and UMTS and LTE technologies. While major work is ongoing in deploying USIM for provisioning in EPS (also known as LTE/SAE) and Home (e)NodeB.

In addition, the storage of the ICE (In Case of Emergency) user information has been standardized.

Toolkit Features Improvement (TS 31.111):

Work has been completed with regards to the proactivity of UICC to trigger contactless interfaces adding UICC to be proactive in contactless interfaces. This feature finalizes the integration of the contactless interface into the UICC and provides a complete eco-system for deployment of contactless services.

Updates to the current toolkit features are ongoing for terminals having limited capabilities (e.g. Datacard or M2M modules). This is very beneficial in the M2M market where the terminal lacks a screen or a keyboard, requesting appropriate testing specifications.

Other enhancements will enable UICC applications to trigger Device management or device synchronization operation and interact in DVB networks.

Contact Manager:

R8 has been the opportunity to define a Multimedia phone book (TS 31.220) based on OMA DS technology and its corresponding JavaCard API (TS 31.221).

Remote Management Evolution (TS 31.115 and TS 31.116):

With the IP sessions becoming prominent, an additional capability to multiplex the remote application and file management over a single CAT TP link in a BIP session has been completed. Additional tasks being worked out to develop and capitalize the IP layer for remote application management (RAM) over HTTP. With the latest addition of AES algorithm and suppression of a simple DES algorithm support to the remote management provides additional flexibility and security for remote sessions with the UICC.

Confidential Application Management in UICC for third parties:

While the work is ongoing, an improvement to the security model in the UICC is targeted to host confidential (e.g. third party) applications. This is with regards to the new business models arising with MNOs, such as MVNO, M-Payment and Mobile TV. Some of the key features are but not limited to memory rental on UICC, secure management of this memory and its content by the third party vendor. This is expected to be useful to support (e.g. contactless payment applications).

Secure Channel between the UICC and terminal:

The implementation of the secure channel solution has been finalized enabling a Trusted and secure communication between the UICC and the terminal. This feature also provides the functionality between two applications residing respectively on the UICC and on the Terminal. Now with USB interface receiving attention, the secure channel is applicable to both the ISO and USB interface.

6 PLANNING FOR REL-9 AND REL-10: EPC/LTE ENHANCEMENTS AND LTE-ADVANCED

Section 5 has demonstrated significant progress towards completion of the 3GPP Rel-8 specifications, which are targeted to be published in the first quarter of 2009. While the work towards completion and publication of Rel-8 continues, planning for Rel-9 and Rel-10 content has begun. In addition to further enhancements to Evolved HSPA or HSPA+, Rel-9 will be focused on EPC/LTE enhancements. Due to the aggressive schedule for Rel-8, it was necessary to limit the EPC/LTE content of Rel-8 to essential features (namely the functions and procedures to support EPC/LTE access and interoperation with legacy 3GPP and 3GPP2 radio accesses) plus a handful of high priority non-essential features (such as Single Radio Voice Call Continuity, generic support for non-3GPP accesses, local breakout and CS fallback). The aggressive schedule for Rel-8 was driven by the desire for fast time-to-market LTE solutions without compromising the most critical feature content.

To minimize the impact of the lower priority EPC/LTE features that were not included in Rel-8, 3GPP is targeting a Rel-9 specification that will quickly follow Rel-8 to enhance the initial Rel-8 EPC/LTE specification. The current working view for Rel-9 in 3GPP targets the freezing of the service description (i.e. stage 1) by December 2008, the freezing of the logical analysis (i.e. stage 2) by June 2009 in order to complete the Rel-9 specification (stage 3 freezing) by December 2009. It is recognized that this is an aggressive timeline for Rel-9 and therefore prioritization of content will be required. A full list of features being discussed for Rel-9 is available at http://www.3gpp.org/ftp/Specs/html-info/FeatureList--Rel-9.htm, and some of the features getting the most consideration include:

6.1 HSPA ENHANCEMENTS

Possible enhancements could include further multi-carrier scenarios, control plane optimizations, latency reductions, Home NodeB improvements and enhancements to improve coverage (e.g. Beamforming/MIMO enhancements and/or interference cancellation). In particular, 3GPP is currently studying ways to further improve user data rates for HSPA in the downlink and uplink direction.

6.1.1 DOWNLINK

MIMO is considered to be combined with Dual-Cell HSDPA, providing data rate enhancements up to 84Mbps within 10MHz of spectrum.

Further evolution of multi carrier HSDPA considers the usage of three to four 5MHz downlink carriers for HSDPA transmission to a UE. These carriers can reside either in one frequency band or in two frequency bands, e.g. two adjacent 5MHz carriers in one frequency band can be combined with a third 5MHz carrier in a second frequency band. If the two adjacent 5MHz carriers use MIMO, the total achievable data rate for such a combination reaches 105Mbps in the downlink. Simulations show that for typical bursty traffic, not only the peak data rate, but also the average user throughput scales linearly with the number of downlink carriers used.

The support for UE reception on two frequency bands is an enabler to DC-HSDPA for operators who do not have adjacent 5MHz carriers available in one band, and is therefore of key importance for the further evolution of multi carrier HSPA.

6.1.2 UPLINK

As a consequence of increased data rates in downlink, the uplink data rates need to be improved too. From the aggregation of multiple FDD downlink carriers, the paired FDD uplink carriers can be utilized for improved uplink transmissions. 3GPP studies the usage of two adjacent 5MHz carriers for dual carrier uplink transmissions (DC-HSUPA) supporting data rates of up to 23Mbps. A further benefit of utilizing two uplink carriers is the possibility to support more efficient load balancing in the uplink direction.

6.2 LTE ENHANCEMENTS

MBMS for LTE – definition of the architecture and procedures for support of broadcast/multicast services over LTE. Note that the OFDM-based LTE air-interface provides the potential for significant performance benefits for broadcast/multicast services (compared to MBMS over W-CDMA) due to the ability to support MBSFN (Multi-media Broadcast over Single Frequency Network) operation.

IMS Emergency over GPRS and EPS – support for meeting regional regulatory requirements for PS based emergency calls over GPRS and the EPS.

LCS Control Plane for EPS – support for fulfilling location service requirements through use of the control plane. This is important since the use of user plane location only may not be adequate to meet emergency, lawful intercept, security, etc. requirements.

CS Domain Services over EPS – define an architecture that is capable of extending the "traditional" MSC-Server based set of CS voice, supplementary and value-adding services and business principles (e.g. for roaming and interconnect) to the evolved PS access.

6.3 OTHER ENHANCEMENTS

Architecture Aspects of Home NodeB/eNodeB – continued work to build on the foundation from Rel-8 (which provides the basic functionalities for support of Home NodeB/eNodeBs) and to add further functionalities that will enable the mobile operators to provide more advanced services as well as improving the user experience. This work will focus on security, quality of service, charging and access restrictions for Home NodeB/eNodeBs.

IMS Evolution – study the feasibility of enhancing the IMS network architecture by investigating architectural improvements, means to improve system-level load balancing and reliability, system enhancements for local breakout and optimal routing of media and possibilities for reducing configuration workload to save OPEX.

At the same time as the work on these Rel-9 enhancements, 3GPP recognizes the need to develop a solution and specification to be submitted to the ITU for meeting the IMT-Advanced requirements (which are discussed in Section 7). Therefore, in parallel with Rel-9 work, 3GPP is working on a study item called LTE-advanced (which is likely to define the bulk of the content for Rel-10) to include significant new technology enhancements to EPC/LTE for meeting the very aggressive IMT-Advanced requirements for what will officially define "4G" technologies. Section 7 provides details of the IMT-Advanced requirements, timeline and process for technology evaluation, consensus and specification, the 3GPP work plans and timeline for developing an EPC/LTE submission (call LTE-Advanced) to the ITU for meeting the IMT-Advanced requirements and discusses some of the likely technologies being studied for LTE-Advanced to meet the aggressive IMT-Advanced requirements.

7 OVERVIEW AND STATUS OF IMT-ADVANCED AND LTE-ADVANCED

This section provides a view into:

1) the on-going work on the global development of the next generation technologies (4G) being defined in the context of IMT-Advanced; and
2) the developments by 3GPP to add its technology expertise into the to-be-defined family of IMT-Advanced.

The material is structured into an overview of the ITU-R requirements for IMT-Advanced, the 3GPP target requirements for its solution, LTE-Advanced, and a discussion of the timelines, process, and workplans of both the ITU-R and 3GPP as they collaboratively work towards defining the technology of the next (4^{th}) generation future.

7.1 SPECIFYING IMT-ADVANCED – THE ITU-R ROLE [171]

The International Telecommunication Union (ITU) [172] is the internationally recognized entity chartered to produce an official definition of the next generation of wireless technologies. Its Radiocommunication Sector (ITU-R) is establishing an agreed and globally accepted definition of 4G wireless systems that is inclusive of the current multi-dimensioned and diverse stakeholder universe.

The ITU [173] is close to releasing a full set of documentation for this definition. It has held ongoing consultations with the global community over many years on this topic in Working Party 8F [174]

[171] Information in this section is adapted from 3G Americas white paper *Defining 4G Understanding the ITU Process for the Next Generation of Wireless Technology.*
[172] http://www.itu.int.
[173] ITU materials used by permission.

under the scope of a work item known as *Question ITU-R 229-1/8 "Future development of IMT-2000 and systems beyond IMT-2000."* Following a year-end 2007 restructure in ITU-R, this work is being addressed under the new Study Group 5 umbrella (replacing the former Study Group 8) by Working Party 5D which is the new name for the former WP 8F.

This work has addressed the future beyond 3G that is comprised of a balance among a Spectrum view, a Marketplace View, a Regulatory View and a Technology View. These are the key elements for business success in wireless and must each be considered for successful next generation technology development.

Significant work has been completed in ITU-R, establishing the nucleus of what should be encompassed in a 4G system. In particular, ITU-R, working under a mandate to address systems beyond 3G, has progressed from delivering a vision of 4G in 2002 to establishing a name for 4G in 2005 (*IMT-Advanced*). In 2006, ITU-R set out the principles for the process for the development of *IMT-Advanced*. These early deliverables have stimulated research and development activities worldwide, spawned ideas for potential technologies and promoted views on spectrum required to address a rapidly growing wireless world.

By the end of 2008, ITU-R advanced beyond the vision and framework and had concluded work on a set of requirements which along with evaluation guidelines by which technologies and systems can, in the near future, be determined as being part of *IMT- Advanced* and in so doing, earn the right to be considered 4G.

Starting in 2008 and throughout 2009, ITU-R will hold an open call for the "first invitation" of 4G (*IMT-Advanced*) candidates. Subsequent to the close of the submission period for the "first invitation" an assessment of those candidates' technologies and systems will be conducted under the established ITU-R process, guidelines, and timeframes for this IMT-Advanced "first invitation." The culmination of this open process will be a 4G, or *IMT-Advanced* family. Such a 4G family, in adherence to the principles defined for acceptance into this process, is globally recognized to be one which can grow to include all aspects of a marketplace that will arrive beyond 2010, thus complementing and building upon an expanding and maturing 3G business.

[174] Working Party 8F held responsibility for the IMT-2000 and "Beyond IMT-2000" from its inception in the year 2000 through its disbanding in 2007 when it was superseded by WP 5D. The archive records of this work on IMT may be found at http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rwp8f&lang=en.

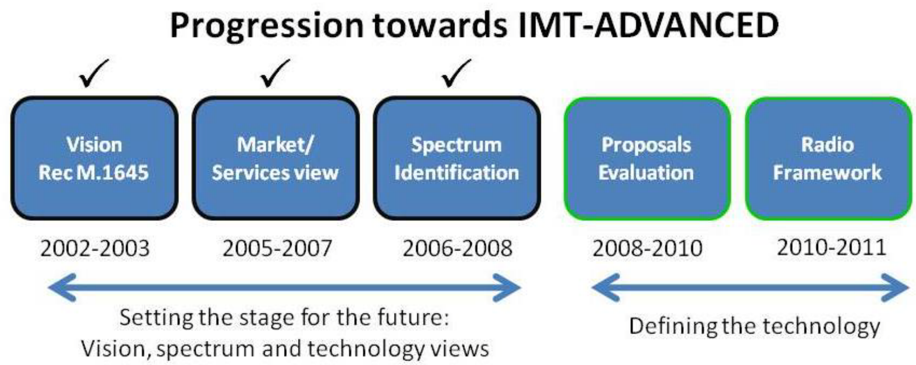


Figure 50. Progression towards IMT-Advanced [175]

7.2 THE 3GPP ROLE

3GPP technologies have been an essential and widely deployed part of the 3G technology family under the ITU-R IMT-2000 family since the on-set of these recommendations [176] released by the ITU-R. 3GPP has continued its role of enhancing its members of the IMT-2000 family through all released revisions of Recommendation ITU-R M.1457 and has continued this evolution of 3G through the incorporation of LTE technology in the ITU-R work.

3GPP plays an important role in IMT-Advanced. 3GPP has had a program underway for developing technology solutions for IMT-Advanced beginning with 3GPP workshops on the "Systems beyond IMT-2000."

The purpose of these workshops was to contribute to the international understanding of IMT-Advanced, and to further the development of LTE-Advanced. The first workshop was held on November, 26th 2007, as an informational and educational session to inform 3GPP of relevant information related to IMT-Advanced in the ITU-R. A more detailed second workshop on IMT-Advanced and LTE-Advanced on was held on 7-8 April, 2008, attended by over 160 international participants and addressed 58 documents. During this workshop, operators' and manufacturers' views on possible requirements for LTE-Advanced as well as ideas/proposals for LTE-Advanced were exchanged and discussed. On May 27, 2008, 3GPP held a third workshop to focus specifically on the 3GPP requirements for LTE-Advanced.

[175] Source: 3G Americas, 2008.
[176] Recommendation ITU-R M.1457 *Detailed specifications of the radio interfaces of International Mobile Telecommunications-2000 (IMT-2000).*

3GPP continues with its working assumption that the 3GPP proposal for IMT-Advanced shall be based on E-UTRAN capabilities and the requirements for IMT-Advanced in ITU-R shall initially be not less than those contained in 3GPP TR 25.913 [177].

Furthermore, 3GPP has set an objective to establish (in Study & Work Items) requirements and capabilities higher than those contained in TR 25.913 towards meeting ITU-R requirements for IMT-Advanced.

In this regard, 3GPP has initiated, under the LTE-Advanced Study Item work, document TR 36.913, *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Further Advancements for E-UTRA (LTE-Advanced)*.

7.3 REFERENCES

Throughout this section, references are made to 3GPP and ITU-R Working Party 5D and to the ITU-R webpage for the IMT-Advanced submission and evaluation process. The following are the relevant entry point links:

- The 3GPP homepage: http://www.3gpp.org.
- The ITU-R Working Party 5D homepage: http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rwp5d&lang=en
- The ITU-R homepage for IMT-Advanced submission and evaluation process: http://www.itu.int/ITU-R/index.asp?category=study-groups&rlink=rsg5-imt-advanced&lang=en
- ITU-R publications are available at:
  - ITU-R "M" series Recommendations: http://www.itu.int/rec/R-REC-M/e
  - ITU-R "M" series Reports: http://www.itu.int/publ/R-REP-M/en

7.4 TARGET REQUIREMENTS FOR IMT-ADVANCED

As defined in Report ITU-R M.2134 *Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s)*:

> "International Mobile Telecommunications-Advanced (IMT-Advanced) systems are mobile systems that include the new capabilities of IMT that go beyond those of IMT-2000. Such systems provide access to a wide range of telecommunication services including advanced mobile services, supported by mobile and fixed networks, which are increasingly packet-based."

[177] 3GPP Technical Report 25.913. *Requirements for Evolved UTRA (E-UTRA) and Evolved UTRAN (E-UTRAN) (Release 7).*

The goal of the IMT-Advanced requirements is to provide the baseline requirements for consistent definition, specification, and evaluation of the candidate Radio Interface Technologies (RITs) or Set of RITs (SRITs) for IMT-Advanced. These requirements will work in conjunction with the development of Recommendations and Reports, such as the evaluation criteria [178], and the circular letter [179] framework. The requirements ensure that IMT-Advanced technologies are able to fulfill the objectives of IMT-Advanced, and to set a specific level of minimum performance that each proposed technology needs to achieve in order to be considered by ITU-R WP 5D for IMT-Advanced.

The requirements are not intended to restrict the full range of capabilities or performance that candidate technologies for IMT-Advanced might achieve, nor are they designed to describe how the IMT-Advanced technologies might perform in actual deployments under operating conditions that could be different from those presented in ITU-R Recommendations and Reports on IMT-Advanced.

The requirements in this section are directly out of Report ITU-R M.2134.

[178] Report ITU-R M.2135 – *Guidelines for evaluation of radio interface technologies for IMT-Advanced.*
[179] ITU-R Circular Letter 5/LCCE/2 (and Addendum 1) *Further information on the invitation for submission of proposals for candidate radio interface technologies for the terrestrial components of the radio interface(s) for IMT Advanced and invitation to participate in their subsequent evaluation.*

7.4.1 CELL SPECTRAL EFFICIENCY

Cell[180] spectral efficiency (η) is defined as the aggregate throughput of all users (the number of correctly received bits (i.e. the number of bits contained in the SDUs delivered to Layer 3, over a certain period of time) divided by the channel bandwidth divided by the number of cells. The channel bandwidth for this purpose is defined as the effective bandwidth times the frequency reuse factor, where the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

The cell spectral efficiency is measured in bit/s/Hz/cell.

Denoted by χi the number of correctly received bits by user i (downlink) or from user i (uplink) in a system comprising a user population of N users and M cells. Furthermore, let ω denote the channel bandwidth size and T the time over which the data bits are received. The cell spectral efficiency is then defined according the Eq. 1.

$$\eta = \frac{\sum_{i=1}^{N} \chi i}{T \cdot \omega \cdot M} \quad \text{(Equation 1)}$$

Table 7.11-1 Cell Spectral Efficiency

Test environment **	Downlink (b/s/Hz/cell)	Uplink (b/s/Hz/cell)
Indoor	3	2.25
Microcellular	2.6	1.80
Base coverage urban	2.2	1.4
High speed	1.1	0.7

These values were defined assuming an antenna configuration of downlink 4x2, uplink 2x4. However this does not form part of the requirement and the conditions for evaluation are described in Report ITU-R M.2135.

[180] For the purposes of the IMT-Advanced requirements, a cell is equivalent to a sector, e.g. a 3-sector site has 3 cells.

7.4.2 PEAK SPECTRAL EFFICIENCY

The peak spectral efficiency is the highest theoretical data rate (normalized by bandwidth), which is the received data bits assuming error-free conditions assignable to a single mobile station, when all available radio resources for the corresponding link direction are utilized (that is excluding radio resources that are used for physical layer synchronization, reference signals or pilots, guard bands and guard times).

The minimum requirements for peak spectral efficiencies are as follows:

- Downlink peak spectral efficiency is 15 bits/s/Hz
- Uplink peak spectral efficiency is 6.75 bits/s/Hz

These values were defined assuming an antenna configuration of downlink 4x4, uplink 2x4. However this does not form part of the requirement and the conditions for evaluation are described in Report ITU-R M.2135.

For information, theoretical peak data rates can then be determined as in the following examples, which are calculated by multiplying the peak spectral efficiency and the bandwidth:

- Example Downlink peak data rate in 40 MHz is 600 Mb/s.
- Example Downlink peak data rate in 100 MHz is 1500 Mb/s.
- Example Uplink peak data rate in 40 MHz is 270 Mb/s.
- Example Uplink peak data rate in 100 MHz is 675 Mb/s.

7.4.3 BANDWIDTH

Scalable bandwidth is the ability of the candidate RIT to operate with different bandwidth allocations. This bandwidth may be supported by single or multiple RF carriers. The RIT shall support a scalable bandwidth up to and including 40 MHz, however, proponents are encouraged to consider extensions to support operation in wider bandwidths (e.g. up to 100 MHz) and the research targets expressed in Recommendation ITU-R M.1645 [181]

7.4.4 CELL EDGE USER SPECTRAL EFFICIENCY

The (normalized) user throughput is defined as the average user throughput (i.e., the number of correctly received bits by users (i.e. the number of bits contained in the SDU delivered to Layer 3) over a certain period of time, divided by the channel bandwidth and is measured in b/s/Hz. The cell edge user spectral efficiency is defined as 5% point of CDF of the normalized user throughput. The table below lists the cell edge user spectral efficiency requirements for various test environments.

[181] ITU-R Recommendation M.1645. *Framework and overall objectives of the future development of IMT-2000 and systems beyond IMT-2000.*

With χi denoting the number of correctly received bits of user i, Ti the active session time for user i and ω the channel bandwidth, the (normalized) user throughput of user i γi is defined according to Eq. 2.

$$\gamma i = \frac{\chi i}{T_i \cdot \omega}$$

(Equation 2)

Table 7.14-1 Cell Edge User Spectral Efficiency

Test environment* *	Downlink (b/s/Hz)	Uplink (b/s/Hz)
Indoor	0.1	0.07
Microcellular	0.075	0.05
Base coverage urban	0.06	0.03
High speed	0.04	0.015

** The test environments are described in ITU-R M.2135.

These values were defined assuming an antenna configuration of *downlink 4x2, uplink 2x4*. However this does not form part of the requirement and the conditions for evaluation are described in Report ITU-R M.2135.

7.4.5 LATENCY

7.4.5.1 CONTROL PLANE LATENCY

Control plane (C-Plane) latency is typically measured as transition time from different connection modes, e.g. from idle to active state. A transition time (excluding downlink paging delay and wireline network signaling delay) **of less than 100 ms** shall be achievable from idle state to an active state in such a way that the user plane is established.

7.4.5.2 USER PLANE LATENCY

The User Plane latency (also known as Transport delay) is defined as the one-way transit time between an SDU packet being available at the IP layer in the user terminal/base station and the availability of this packet (PDU) at IP layer in the base station/user terminal. User plane packet delay includes delay introduced by associated protocols and control signaling assuming the user terminal is in the active state. IMT-Advanced systems shall be able to achieve a User Plane Latency **of less than 10 ms** in unloaded conditions (i.e. single user with single data stream) for small IP packets (e.g. 0 byte payload + IP header) for both downlink and uplink.

7.4.6 MOBILITY

The following classes of mobility are defined:

- Stationary: 0 km/h
- Pedestrian: > 0 km/h to 10 km/h
- Vehicular: 10 to 120 km/h
- High speed vehicular: 120 to 350 km/h

The mobility classes that shall be supported in the respective test environment are defined in the table below.

A mobility class is supported if the traffic channel link data rate, normalized by bandwidth, on the uplink, is as shown in the table below, when the user is moving at the maximum speed in that mobility class in each of the test environments.

Table 7.15-1 Traffic Channel Link Data Rates

	Bits/s/Hz	Speed (km/h)
Indoor	1.0	10
Microcellular	0.75	30
Base Coverage Urban	0.55	120
High Speed	0.25	350

These values were defined assuming an antenna configuration of downlink 4x2, uplink 2x4. However this does not form part of the requirements and the conditions for evaluation are described in Report ITU-R M.2135.

Table 7.15-2 Mobility Classes

	Test environments*			
	Indoor	**Microcellular**	**Base coverage urban**	**High speed**
Mobility classes supported	Stationary, pedestrian	Stationary, pedestrian, Vehicular (up to 30 km/h)	Stationary, pedestrian, vehicular	High speed vehicular, vehicular

* The test environments are described in Report ITU-R M.2135.

7.4.7 HANDOVER

The handover interruption time is defined as the time duration during which a user terminal cannot exchange user plane packets with any base station. The handover interruption time includes the time required to execute any radio access network procedure, radio resource control signaling protocol, or other message exchanges between the user equipment and the radio access network, as applicable to the candidate RIT or SRIT. For the purposes of determining handover interruption time, interactions with the core network (i.e. network entities beyond the radio access network) are assumed to occur in zero time. It is also assumed that all necessary attributes of the target channel (that is, downlink synchronization is achieved and uplink access procedures, if applicable, are successfully completed) are known at initiation of the handover from the serving channel to the target channel.

The IMT-Advanced proposal shall be able to support handover interruption times specified in the table below.

Table 7.17-1 Handover Interruption Times

Handover Type	Interruption Time (ms)
Intra-Frequency	27.5
Inter-Frequency - within a spectrum band - between spectrum bands	 40 60

In addition inter-system handovers between the candidate IMT-Advanced system and at least one IMT system shall be supported, but are not subject to the limits in the above table.

7.4.8 VOIP CAPACITY

VoIP capacity was derived assuming a 12.2 kbps codec with a 50% activity factor such that the percentage of users in outage is less than 2% where a user is defined to have experienced a voice outage if less than 98% of the VoIP packets have been delivered successfully to the user within a one way radio access delay bound of 50 ms.

However, this codec does not form a part of the requirements and the conditions for evaluation are described in Report ITU-R M.2135.

The VoIP capacity is the minimum of the calculated capacity for either link direction divided by the effective bandwidth in the respective link direction.

In other words, the effective bandwidth is the operating bandwidth normalized appropriately considering the uplink/downlink ratio.

These values were defined assuming an antenna configuration of 4x2 in the downlink and 2x4 in the uplink. However the antenna configuration is not a minimum requirement and the conditions for evaluation are described in Report ITU-R M.2135.

Table 7.18.1 VoIP Capacity

Test environment**	Min VoIP capacity (Active users/sector/MHz)
Indoor	50
Microcellular	40
Base coverage urban	40
High speed	30

7.5 TARGET REQUIREMENTS FOR 3GPP LTE-ADVANCED TO MEET/EXCEED ITU-R IMT-ADVANCED REQUIREMENTS

7.5.1 ESTABLISHING THE 3GPP WORK ON SATISFYING IMT-ADVANCED – THE CREATION OF LTE-ADVANCED

3GPP has responded to the global developments of IMT-Advanced by taking on board the ITU-R requirements and timeframes for IMT-advanced and has agreed a Study Item [182] for its candidate technology development. 3GPP has given the nomenclature of **LTE-Advanced** to its candidate technology in order to reflect the basis of LTE as its starting point for any needed enhancements required to exceed the ITU-R performance benchmarks and to be a forward pointer into the "Advanced" realm.

In particular the LTE-Advanced Study Item states, in part, the following (section numbers of the original document retained):

Work Item Description

Title - Further advancements for E-UTRA (LTE-Advanced)

Is this Work Item a "Study Item"? (Yes / No): Yes

1 **3GPP Work Area**

X	Radio Access(E-UTRA)
	Core Network
	Services

2 Linked work items *(list of linked WIs)*

3 Justification

IMT-Advanced is entering the phase of the process in ITU-R addressing the development of the terrestrial radio interface recommendations. To announce this stage of the process for IMT-Advanced, ITU-R has issued a Circular Letter (CL) to invite submission of candidate Radio Interface Technologies (RITs) or a set of RITs (SRITs) for IMT-Advanced. The key features of IMT-Advanced delineated in the CL are:

- a high degree of commonality of functionality worldwide while retaining the flexibility to support a wide range of services and applications in a cost efficient manner;

[182] RP080137 Work Item Description for further advancements for E-UTRA (LTE-Advanced) 3GPP TSG RAN#39. March 2008.

- compatibility of services within IMT and with fixed networks;
- capability of interworking with other radio access systems;
- high quality mobile services;
- user equipment suitable for worldwide use;
- user-friendly applications, services and equipment;
- worldwide roaming capability; and
- enhanced peak data rates to support advanced services and applications (100 Mbit/s for high and 1 Gbit/s for low mobility were established as targets for research).

The base line requirements for IMT-Advanced will be concluded in ITU-R WP 5D #2 (June 2008) and communicated in an Addendum to the Circular Letter in the July 2008 timeframe.

In the WRC-07, the following spectrum bands were proposed as additions to the prior identified bands, and the parts of the existing and new bands are globally or regionally identified for IMT, which is the new root term to encompass both IMT-2000 and IMT-Advanced.

- 450 MHz band
- UHF band (698-960 MHz)
- 2.3 GHz band
- C-band (3 400-4 200 MHz).

In 3GPP, E-UTRA should be further evolved for the future releases in accordance with:

- 3GPP operator requirements for the evolution of E-UTRA
- The need to meet/exceed the IMT-Advanced capabilities

Considering the above, 3GPP TSG-RAN should study further advancements for E-UTRA (LTE-Advanced) toward meeting:

- Requirements for IMT-Advanced and provide ITU-R with proposals of RITs or SRITs according to the defined ITU-R time schedule provided in the Circular Letter and its Addendums.
- 3GPP operators requirements for the evolution of E-UTRA.

4 Objective

a) Define a framework for further advancements of LTE (to be referred to as LTE-Advanced) considering:

- The time schedule of ITU-R
- That the work on LTE-Advanced must not introduce any delay to the completion of the Release 8 specification of LTE

- That the general enhancements of LTE specifications are maintained and progressed in a focused and efficient manner

b) Define requirements for of LTE-Advanced based on the ITU-R requirements for IMT-Advanced as well as 3GPP operators own requirements for advancing LTE considering:

- LTE radio technology and architecture improvements
- Support for all radio modes of operation
- Interworking with legacy RATs (scenarios and performance requirements)
- Backward compatibility of LTE-Advanced E-UTRA/E-UTRAN with E-UTRA/E-UTRAN i.e.
    - an LTE terminal can work in an LTE-Advanced E-UTRAN;
    - an LTE-Advanced terminal can work in an E-UTRAN; and
    - non-backward compatible elements could be considered based on RAN decision.
- Newly identified frequency bands and existing frequency bands, and their advantages and limitations, in particular, the consideration of the WRC-07 conclusions, to ensure that LTE-Advanced can accommodate radio channel bandwidths commensurate with the availability in parts of the world of wideband channels in the spectrum allocations (above 20 MHz) and at the same time being mindful on the need to accommodate those parts of the world where the spectrum allocations will not have availability of wideband channels.

c) Identify potential solutions, technologies for the enhancements of E-UTRA (LTE-Advanced). The study areas include:

- Physical layer
- Radio interface layer 2 and RRC
- E-UTRAN architecture
- RF, including Aspects of wider channel bandwidth than 20 MHz
- Advanced system concepts

d) To develop documents that will serve as a basis for the documentation to be submitted to ITU-R to provide the 3GPP proposals for IMT-Advanced:

- An “Early Proposal” submission that would be sent to ITU-R, to be agreed at RAN #41 (9-12 September 2008), for submission to WP 5D #3 (8-15 October 2008).
- A “Complete Technology” submission that would be sent to ITU-R, to be agreed at RAN #44 (26-29 May 2009), for submission to WP 5D #5 (planned for 10-17 June 2009).
- A “Final” submission to incorporate updates, additional specific details or feature additions, *and* the required self-evaluation that would be sent to ITU-R, to be agreed

at RAN #45 (22-25 September 2009), for submission to WP 5D #6 (planned for 13-20 Oct 2009).

- 3GPP should take note, that by ITU-R convention, the formal submission deadline for ITU-R meetings has been established as 16:00 hours UTC, seven calendar days prior to the start of the meeting.

e) Make recommendations for future WIs

f) For reference, the Circular Letter as received from the ITU-R (and future Addendums to the same) are annexed to this Work Item and should become an integral part of the WI.

7.5.2 DEFINING THE LTE-ADVANCED CAPABILITY SET AND TECHNOLOGY VIEWS

In the normal method of work in 3GPP, the results of the efforts addressing the Study Item are captured in one or more documents under the nomenclature of Technical Reports. TR 36.913 [183] is the document currently in progress for the LTE-Advanced. As the technology work in 3GPP unfolds additional details will be provided in TR36.913.

7.6 3GPP LTE-ADVANCED TIMELINE AND SUBMISSION PLANS TO ITU-R FOR IMT-ADVANCED

7.6.1 THE ITU-R IMT-ADVANCED PROCESS AND TIMELINES AS RELATES TO IMT-ADVANCED CANDIDATE TECHNOLOGY SUBMISSIONS [184]

One of the concluding aspects of defining 4G (*IMT-Advanced*) could be considered the actual publication of criteria for 4G, and the call for technology submissions the subsequent evaluations, assessments and decision-making. This will launch the quantification of these developing technologies and ultimately establish the family of 4G systems.

It is acknowledged that the Partnership Projects (3GPP [185] and 3GPP2 [186]) and industry Standard Development Organizations (SDOs) are and will continue to be an integral part of this global process. Other technology proponent entities will also be important contributors and an integral part of this process.

In keeping with the normal method of work, ITU-R has announced to its members and externally to relevant organizations the details of this process, the established timeline and the criteria for the first invitation of IMT-Advanced.

---

[183] TR 36.913 *3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Requirements for Further Advancements for E-UTRA (LTE-Advanced) (Release 8).*
[184] Information in this section is adapted from 3G Americas white paper *Defining 4G Understanding the ITU Process for the Next Generation of Wireless Technology.*
[185] Third Generation Partnership Project. http://www.3gpp.org.
[186] Third Generation Partnership Project 2. http://www.3gpp2.org.

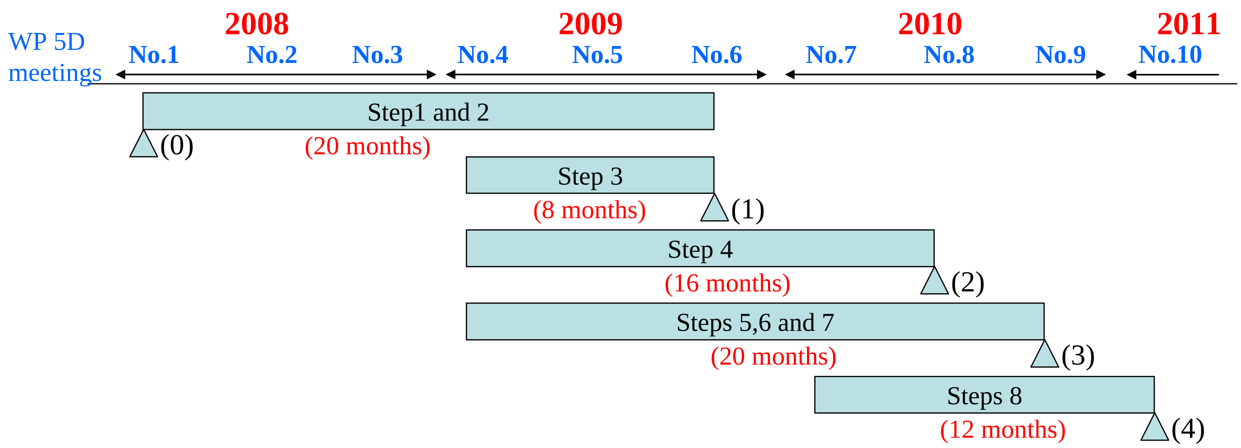
This announcement was provided in Circular Letter 5/LCCE/2 and its Addenda, *Invitation for submission of proposals for candidate radio interface technologies for the terrestrial components of the radio interface(s) for IMT-Advanced and invitation to participate in their subsequent evaluation.*

The purpose of the Circular Letter (initially released in March 2008) is to invite the submission of proposals for candidate radio interface technologies (RITs) or a set of RITs (SRITs) for the terrestrial components of IMT-Advanced.

The Circular Letter also initiates an ongoing process to evaluate the candidate RITs or SRITs for IMT-Advanced, and invites the formation of independent evaluation groups and the subsequent submission of evaluation reports on these candidate RITs or SRITs.

Two key figures directly extracted from Document ITU-R IMT-ADV/2-1 as revised in July 2008 [187] (which forms the basis for this same information contained in the official ITU-R IMT-Advanced webpage operating under the guidance of Circular Letter 5/LCCE/2) provides a time schedule for the first invitation for candidate RITs or SRITs and a flow diagram for the detailed procedure.

[187] The ITU-R IMT-ADV document series may be found at: http://www.itu.int/md/R07-IMT.ADV-C.



Steps in radio interface development process:

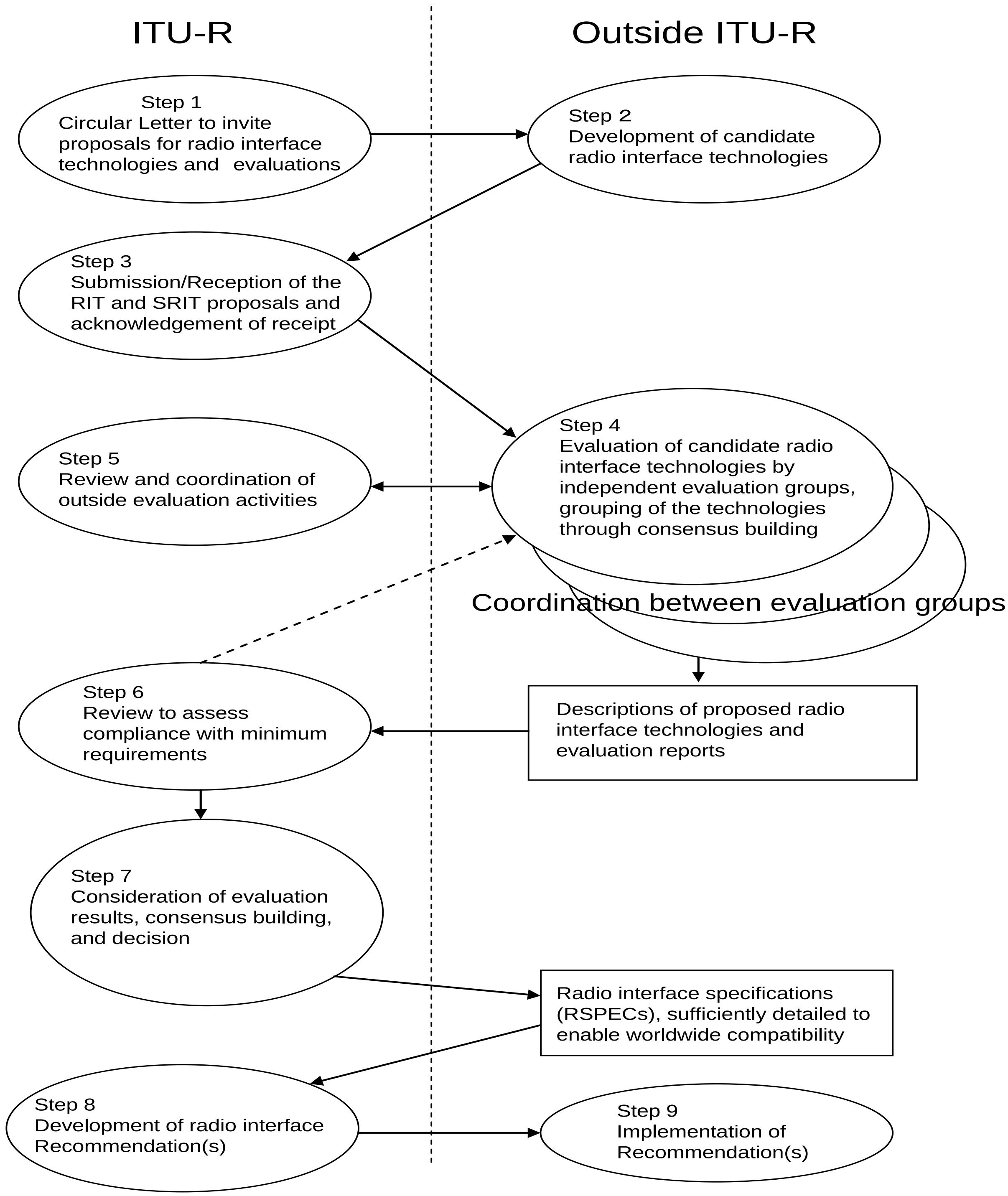
Step 1: Issuance of the circular letter
Step 2: Development of candidate RITs and SRITs
Step 3: Submission/Reception of the RIT and SRIT proposals and acknowledgement of receipt
Step 4: Evaluation of candidate RITs and SRITs by evaluation groups
Step 5: Review and coordination of outside evaluation activities
Step 6: Review to assess compliance with minimum requirements
Step 7: Consideration of evaluation results, consensus building and decision
Step 8: Development of radio interface Recommendation(s)

Critical milestones in radio interface development process:

(0): Issue an invitation to propose RITs	March 2008
(1): ITU proposed cut off for submission of candidate RIT and SRIT proposals	October 2009
(2): Cut off for evaluation report to ITU	June 2010
(3): WP 5D decides framework and key characteristics of IMT-Advanced RITs and SRITs	October 2010
(4): WP 5D completes development of radio interface specification Recommendations	February 2011

IMT-Advanced A2-01

Figure 51. Schedule for the Development of IMT-Advanced Radio Interface Recommendations



[IMT-Advanced A2-02]

Figure 52. IMT-Advanced Terrestrial Component Radio Interface Development Process

In August 2008, the ITU-R released an Addendum to Circular Letter 5/LCCE/2 which announced the availability of "the further relevant information associated with the IMT-Advanced requirements, evaluation criteria and submission templates for the development of IMT-Advanced."

The Circular Letter Addendum draws attention to the IMT-Advanced web page. Of note is Document Report ITU-R M.2133, *Requirements, evaluation criteria, and submission templates for the development of IMT-Advanced.*

Report ITU-R M.2133 supports the process for IMT-Advanced initiated by Circular Letter 5/LCCE/2 and its Addendums. It addresses the requirements, evaluation criteria, as well as submission templates required for a *complete submission* of candidate radio interface technologies (RITs) and candidate sets of radio interface technologies (SRITs) for IMT-Advanced. In essence it can be considered as an umbrella document providing the context and relationships among these critical portions of the IMT-Advanced.

In particular, document Report ITU-R M.2133 establishes very specific information formats for the submission of candidate radio interface technologies for consideration for IMT-Advanced through the use of templates. These templates cover not only the description of the candidate radio interface technology but also cover the compliance of the technology with the established requirements for IMT-Advanced in the areas of spectrum, services and technical performance.

Report ITU-R M.2133 also establishes through reference to Report ITU.R M.2135 *Guidelines for evaluation of radio interface technologies for IMT-Advanced.*

Quoting from Report ITU.R M.2135, Section 2 SCOPE is instructive on the evaluation:

> "This Report provides guidelines for both the procedure and the criteria (technical, spectrum and service) to be used in evaluating the proposed IMT-Advanced radio interface technologies (RITs) or Sets of RITs (SRITs) for a number of test environments and deployment scenarios for evaluation.
>
> These test environments are chosen to simulate closely the more stringent radio operating environments. The evaluation procedure is designed in such a way that the overall performance of the candidate RIT/SRITs may be fairly and equally assessed on a technical basis. It ensures that the overall IMT-Advanced objectives are met.
>
> This Report provides, for proponents, developers of candidate RIT/SRITs and evaluation groups, the common methodology and evaluation configurations to evaluate the proposed candidate RIT/SRITs and system aspects impacting the radio performance, to be applied to the evaluation of IMT-Advanced candidate technologies.
>
> This Report allows a degree of freedom so as to encompass new technologies. The actual selection of the candidate RIT/SRITs for IMT-Advanced is outside the scope of this Report.

The candidate RIT/SRITs will be assessed based on those evaluation guidelines. If necessary, additional evaluation methodologies may be developed by each independent evaluation group to complement the evaluation guidelines. Any such additional methodology should be shared between evaluation groups and sent to the Radiocommunication Bureau as information in the consideration of the evaluation results by ITU-R and for posting under additional information relevant to the evaluation group section of the ITU-R IMT-Advanced web page (http://www.itu.int/ITU-R/go/rsg5-imt-advanced)."

It must also be noted that the same set of evaluation guideline and criteria are to be utilized by the technology proponents in performing a *self-evaluation* of their technology submission which is mandated as part of the *complete submission.*

7.6.2 THE 3GPP WORKPLAN IN RESPONSE TO ITU-R IMT-ADVANCED TIMELINES AND PROCESS

3GPP in developing LTE-Advanced has acknowledged the timelines established by the ITU-R for IMT-Advanced candidate technology submissions. The 3GPP LTE-Advanced Study Item has established three tranches for submissions to the ITU-R Working Party 5D in response to the 3GPP work plan for LTE-Advanced [188]. These deliverables will serve as a basis for the documentation to be submitted to ITU-R to provide the 3GPP proposals for IMT-Advanced:

- **An "Early Proposal" submission** that would be sent to ITU-R, to be agreed at RAN #41 (9-12 September 2008), for submission to WP 5D #3 (8-15 October 2008). This submission was finalized in 3GPP TSG RAN #41 based on current views of the work and anticipated technology aspects as document RP080763 and became input document 5D/291 to the WP 5D #3 meeting.
- **A "Complete Technology" submission** that would be sent to ITU-R, to be agreed at RAN #44 (26-29 May 2009), for submission to WP 5D #5 (planned for 10-17 June 2009).
- **A "Final" submission** to incorporate updates, additional specific details or feature additions, ***and* the required self-evaluation** that would be sent to ITU-R, to be agreed at RAN #45 (22-25 September 2009), for submission to WP 5D #6 (planned for 13-20 Oct 2009).

In order to further understand the timing relationship a diagram (3GPP Detailed Timelines for ITU-R) is provided below to show, in a common picture, the timelines of ITU-R and 3GPP and the respective critical dates for deliverable development and the formal submission deadlines.

[188] RP080138 Workplan for SI LTE-Advanced 3GPP TSG RAN#39. March 2008.

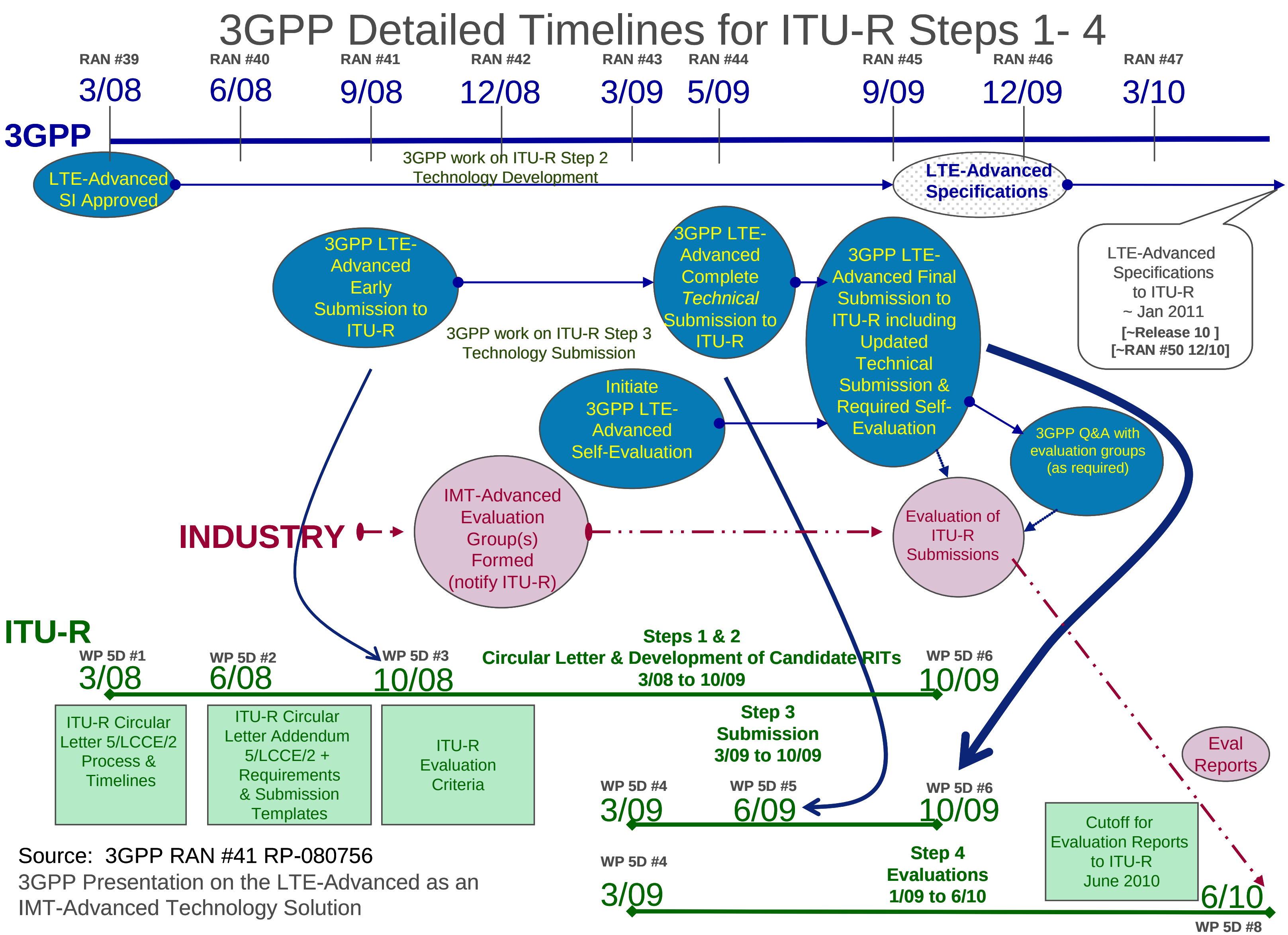


Figure 53. 3GPP Timelines for ITU-R Steps 1-4

7.7 POTENTIAL FEATURES/TECHNOLOGIES BEING INVESTIGATED FOR 3GPP LTE-ADVANCED

LTE-Advanced is intended to meet the diverse requirements of advance applications that will become common in the wireless market place in the foreseeable future. It will also dramatically lower the CAPEX and OPEX of future broadband wireless networks. Moreover, LTE-Advanced will be an evolution of LTE which will provides for backward compatibility with LTE and will meet or exceed all IMT-Advanced requirements.

This section will discuss the technologies currently under study in 3GPP for LTE-Advanced. The organization of the discussion is as follows: The technologies that are needed to enhance the LTE system so that it will meet the IMT-Advanced requirements are discussed. These technologies include Single User uplink-MIMO (SU-UL-MIMO) and Carrier aggregation (CA). Other technologies which will further enhance the performance of the LTE-Advanced system and lower the OPEX and CAPEX network cost will then be discussed. These technologies includes downlink single user MIMO, multi-user MIMO, collaborative and network MIMO, inter-cell interference coordination and relay.

7.7.1 SINGLE USER UPLINK MIMO AND MULTIPLE ACCESS

Before discussing the technologies for SU-UL-MIMO it is useful to recall the technologies that are currently defined in the LTE system for downlink MIMO. The enhancement of the LTE system from traditional single input single output (SISO) transmission (as is used in UMTS), to MIMO transmission can be classified into roughly two categories: channel reciprocity techniques and channel non-reciprocity techniques. Among the techniques that take advantage of channel reciprocity are Beamforming (BF) and Multi-user MIMO (MU-MIMO). With these techniques, the enhanced Node-B (eNB) uses a sounding reference from the UE to determine the channel state and assumes that the channel as seen by the eNB is the same as that seen by the UE (channel reciprocity) and forms transmission beams accordingly. It should be noted that since the transmitter has information about the channel, the transmitter may use this information for beamforming including generation of weights for antenna weighting/precoding. These techniques are well suited to time division duplex (TDD) systems.

The channel non-reciprocity techniques can be further separated into open loop MIMO (OL-MIMO), closed loop MIMO (CL-MIMO) and multi-user MIMO (MU-MIMO). OL-MIMO is used in the case where the transmitter has no knowledge of the channel state information (CSI). Since the Node–B has no knowledge of the CSI from the UE, these techniques cannot be optimized for the specific channel condition seen by the UE but they are robust to channel variation. Consequently, these techniques are well suited to high speed mobile communication. OL-MIMO can be classified into transmit diversity (TXD) and spatial multiplexing (SM) techniques. The TXD techniques will increase diversity order which may result in reduced channel variation and better performance. These techniques include transmit antenna switching (TAS), space-frequency block coding (SFBC), cyclic delay diversity (CDD) and frequency selective transmit diversity (FSTD), etc. The SM techniques allow multiple spatial streams that are transmitted sharing the same time-frequency resource.

In the case where the UE sends CSI to the eNB, CL-MIMO can be used to significantly increase the spectral efficiency. CL-MIMO, utilizes the CSI feedback from the UE to optimize the transmission for specific UE's channel condition. As a result of this feedback, it is vulnerable to channel variations. In general, it can be said that CL-MIMO has higher spectral efficiency then OL-MIMO in low speed environment but has poorer spectral efficiency than OL-MIMO in high speed environments. SM techniques can also be used to significantly increase the spectral efficiency of CL-MIMO. The multiple spatial streams are separated by an appropriate receiver (e.g. using successive interference cancellation). This will increase peak rate and potentially the capacity, benefiting from high SINR and uncorrelated channels. The spatial multiplexing techniques can be classified into single code word (SCW) and multiple code words (MCW). In the former, the multiple streams come from one turbo encoder, which could achieve remarkable diversity gain. In the latter, the multiple streams are encoded separately, which can use the SIC receiver to reduce the co-channel interference between the streams significantly.

In the case where there are a large number of UEs in a cell, the cell spectral efficiency can be further increased through the use of MU-MIMO. It should be noted that MU-MIMO and space division multiple access (SDMA) are sometimes used interchangeably in the literature. With MU-MIMO, unlike single user MIMO (SU-MIMO) where a radio resource is used by one user, multiple users share the same radio resource. LTE currently allows for multiple users to be assigned to the same resource and thus can support simple MU-MIMO techniques with a codebook that is optimized for SU-MIMO. Using the SU-MIMO codebook allows for simplification of the LTE system implementation but it limits significantly the gains possible with MU-MIMO. Moreover, advanced MU-MIMO techniques such as, for example, zero forcing beamforming are not very well supported in LTE. A discussion of MU-MIMO techniques for LTE-Advance can be found in 7.7.4.

The current IMT-Advanced requirements imply that uplink of LTE-Advanced must be enhanced with the support of MIMO transmission because the requirements are unachievable without it. Consequently SU-UL-MIMO has become a very important study item in 3GPP LTE-A. The techniques currently under study are parallel to those in the downlink. In particular, it is likely that the open loop and closed loop MIMO techniques discussed above for the downlink will be supported for the uplink. Spatial multiplexing of up to four layers will be considered. It should be noted, however, that SU-UL-MIMO support for LTE-Advanced is complicated by the fact that DFT spread OFDM (DFT-S-OFDM) was used for the LTE uplink. This allowed the uplink of LTE to have low peak-to-average-power ratio (PAPR) but it may limit the gains possible with SM. Therefore, 3GPP is currently studying the possibility to use OFDMA for supporting SM techniques. For the case of non SM transmission with contiguous carriers, DFT-S-OFDM is the baseline. If carrier aggregation is supported 3GPP is currently studying whether DFT-S-OFDM or OFDM should be used with non contiguous carriers. Also under intense study are MIMO techniques that are compatible with low PAPR such as STBC-II scheme, joint MCW spatial multiplex with TAS, cell edge enhancement techniques via single rank beamforming, etc.

7.7.2 CARRIER AGGREGATION

Beside SU-UL-MIMO, the other technology that will be crucial for LTE-Advanced to meet the IMT-Advanced requirements is CA. This need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than that in LTE while at the same time ensuring backward compatibility with LTE. Consequently in order to support bandwidths larger than 20 MHz, two or more component carriers are aggregated together in LTE-Advanced. An LTE-Advanced terminal with reception capability beyond 20 MHz can simultaneously receive transmissions on multiple component carriers. An LTE Rel-8 terminal, on the other hand, can receive transmissions on a single component carrier only, provided that the structure of the component carrier follows the Rel-8 specifications.

The spectrum aggregation scenarios can be broadly classified into three categories: 1) Intra-band adjacent; 2) Intra-band non-adjacent; and 3) Inter-band. Examples of various scenarios are provided in Figure 7.4.2-1.

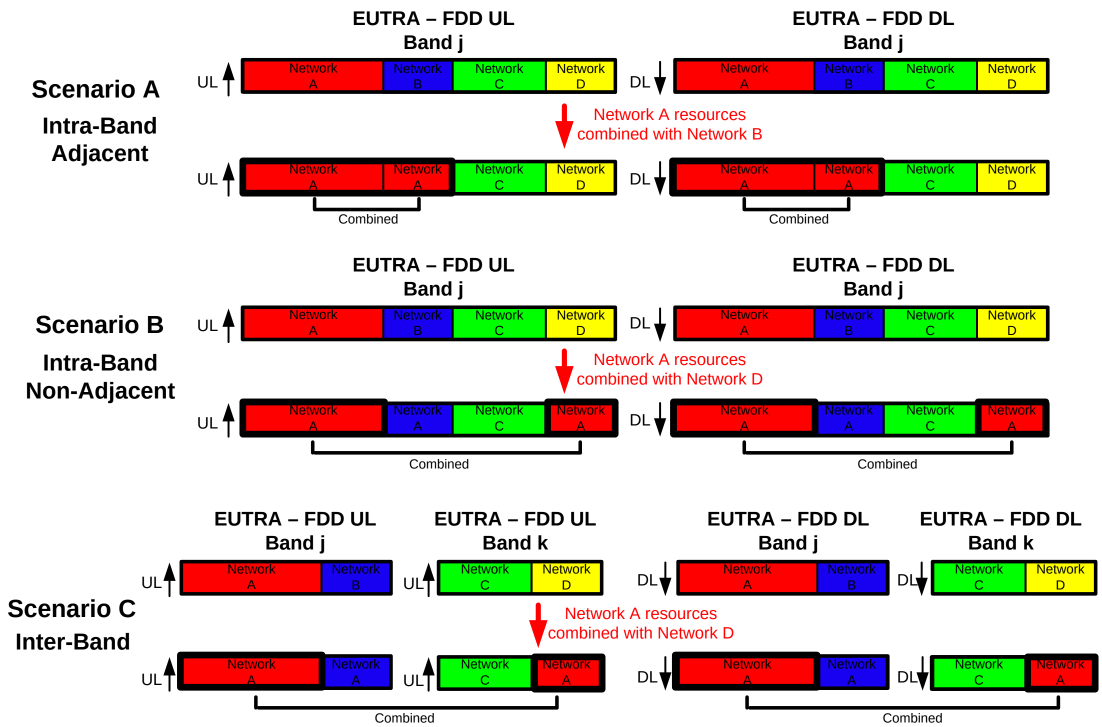


Figure 54. Spectrum Aggregation Scenarios for FDD

The current baseline in 3GPP for CA is that the component carriers will use the LTE Release 8 numerology and occupy a maximum of 110 resource blocks. Both contiguous component carriers and non contiguous component carriers will be supported with the needed frequency spacing between the component carriers being defined later if needed. Although the component carriers may be non-backward compatible to LTE, the system will be able to configure all component carriers to be LTE Release 8 compatible. It will also be possible for an LTE-Advanced UE to aggregate a different number of component carriers of possibly different bandwidths in the UL and the DL. However, in TDD deployments, the number of component carriers in UL and DL is typically the same.

For the MAC to PHY mapping strategy, the current baseline is that one transport block, HARQ entity, and HARQ feedback per component carrier. This option can provide maximum reuse of Release 8 functionalities and better HARQ performance due to carrier component based link adaptation but with the drawback of multiple HARQ feedback in each TTI. This baseline also implies that the uplink transmission format will be a multi-carrier transmission consisting of an aggregation of single carrier DFT-S-OFDM (NxDFT-S-OFDM) (Figure 7.4.2-2). An analysis of the frequency diversity gains are currently underway to determine if the baseline should be generalized to support multiple TBs and HARQ entities where each TB can be mapped to multiple component carriers.

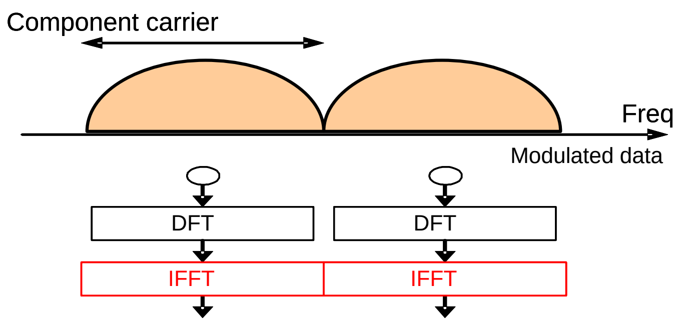


Figure 55. An illustration of NxDFT-S-OFDM

7.7.3 SINGLE USER DOWNLINK MIMO

Previous discussions have focused on technology enhancements to be applied to LTE for LTE-Advanced to meet the IMT-Advanced requirements. In the next part of the discussion, the focus will be on technological enhancements to LTE that will significantly enhance its performance and lower its CAPEX and OPEX.

In order to improve the spatial efficiency of the downlink, extension of LTE downlink spatial multiplexing to up to eight layers is considered for LTE advanced.

7.7.4 MULTI-USER MIMO

Although MU-MIMO is currently supported in Release 8, the current design suffers from several key deficits. Key among these is the lack of interference signaling in the downlink without which the UE cannot estimate the CQI which leads to CQI reporting errors. Due to this lack of interference information, interference suppressing receivers cannot be used in LTE. This will become more important because it is anticipated that an LTE-Advanced UE will most likely have multiple receive antennas. Consequently, for LTE-Advanced, MU-MIMO is a technology with strong potential to increase the system throughput by supporting multiple user transmissions over the same radio resource for both OL and CL MIMO. It provides higher system throughput by exploiting multi-user diversity gain and joint signal processing to reduce the inter-stream interference among different users in the spatial domain with attractive performance-complexity trade-off.

For downlink MU-MIMO, the techniques that are currently under study in 3GPP can be roughly classified into two categories; fixed beam and user specific beams. For fixed beam MU-MIMO, the base station will be configured to transmit multiple beams steadily while the scheduler allocates an individual user to a suitable beam to achieve best performance. This scheme is suitable for high mobility UEs and can operate without dedicated pilots. With more closely spaced antenna elements, it could provide improved performance via sharper pointed beams.

In the case of user specific beams, the beams are generated for each user adaptively based on individual user's CSI. The user specific beams can provide better performance than static fixed-beams because of improved SINR (better beam pointing and interference suppression) but it requires that the UE feeds back the CSI to the eNB and that the channel changes insignificantly between the CSI measurement and the transmission. Consequently, this scheme is suitable for low to moderate mobility scenarios. User specific

MU-MIMO currently under study can be classified into unitary codebook based and non-unitary codebook based techniques. The unitary code book based MU-MIMO forms the beam from an optimal unitary codebook. The performance of unitary codebook MU-MIMO is generally worse than that of the non-unitary codebook based MU-MIMO because the channel seen by the UE does not exactly match the unitary codeword. This will cause inter-user interference and degrade performance. For non-unitary codebook based MU-MIMO, the beams can be formed exactly in the direction of the UE and in the case of zero forcing beamforming, the set of beams that are used for the transmission can be made exactly orthogonal. However, since user specific non-unitary codebook based beams are used, a user specific reference signal is needed for channel estimation. Although the MU-MIMO schemes discussed so far are codebook based, it should be noted that MU-MIMO schemes based upon non-codebook type feedback are also possible.

For the UL, joint processing could be done on base station for MU-MIMO. The MMSE-SIC is the optimal scheme to reach the MU-MIMO capacity region. Furthermore, the optimization, with each user's transmit power constrained, belongs to a convex programming problems for which efficient numerical optimization is now possible.

7.7.5 COLLABORATIVE AND NETWORK MIMO

Coordinated multi-point transmission/reception (CoMP) is considered for LTE-Advanced as a candidate to improve the coverage of high data rates, the cell-edge throughput, and/or system efficiency as well as lower CAPEX and OPEX. Two categories of techniques have been proposed on LTE-Advanced DL CoMP: Coordinated scheduling and/or beamforming, and joint processing/transmission. In the first category, the transmission to a single UE is instantaneously transmitted from one of the transmission points. The transmissions will be decided based on the central scheduler's decision according to best link and/or interference suppression. The best serving set of users will be selected so that the transmitter beamformings are constructed to reduce the interference to other neighboring user, while increasing the served users' signal strength. For joint process/transmission, the transmission to a single UE is simultaneously transmitted from multiple transmission points. The multi-point transmissions will be coordinated as a single transmitter with antennas that are geographically separated. This scheme has higher performance with the stringent requirement on backhaul communication overhead for data and/or signaling exchange among multiple points and synchronization.

Depending on the geographical separation of multi-antenna, and the coordinated multi-point processing method (e.g. coherent or noncoherent), the coordinated zone definition (e.g. cell-centric or user-centric), network MIMO and collaborative MIMO have been proposed for LTE-Advanced. Depending on if the same data to a UE is shared at different eNBs, collaborative MIMO includes single-cell antenna processing with multi-cell coordination, or multi-cell antenna processing. The first technique can be implemented via precoding with interference nulling by exploiting the additional degrees of spatial freedom at an eNB. The latter technique includes collaborative precoding and CL macro diversity. In collaborative precoding, each eNB performs multi-user precoding towards multiple UEs, and each UE receives multiple streams from multiple eNBs. In CL macro diversity, each eNB performs precoding independently, and multiple eNBs jointly serve the same UE.

Uplink coordinated multi-point reception implies reception of the transmitted signal at multiple geographically separated points. Scheduling decisions can be coordinated among cells to control interference.

7.7.6 INTER-CELL INTERFERENCE COORDINATION

The resource management cooperation among eNBs for controlling inter-cell interference is an efficient way to improve the cell edge spectral efficiency. The inter-cell interference coordination (ICIC) enhancement currently being studied for LTE-Advanced can be classified into dynamic interference coordination (D-ICIC) and static interference coordination (S-ICIC). In D-ICIC the utilization of frequency resource, spatial resource (beam pattern) or power resource is exchanged dynamically among eNBs. This scheme is flexible and adaptive to implement the resource balancing in unequal load situations. For S-ICIC, both static and semi-static spatial resource coordination among eNBs are being considered.

7.7.7 RELAYS

Recently, there has been an upsurge of interest on multi-hop relay in LTE-Advanced. The concept of Relay Node (RN), has been introduced to enable traffic/signaling forwarding between eNB and UE to improve the coverage of high data rates, group mobility, cell edge coverage, and to extend coverage to heavily shadowed areas in the cell or areas beyond the cell range. It provides throughput enhancement especially for the cell edge users and offers the potential to lower the CAPEX and OPEX by keeping the cell sizes relatively large.

The relay nodes are wirelessly connected to the radio access network via a donor cell. The connections that are currently under study can be either in-band or out-band. In in-band connection, the eNB to relay link shares the same band with the direct eNB to UE link within the donor cell. In this case, Rel-8 UEs should be able to connect to the donor cell. For out-band connection, on the other hand, the eNB to relay connection is at a different band from that of the direct eNB to UE link.

The types of relays currently under study in 3GPP can be roughly separated by the layers within the protocol stack architecture that are involved in the relay transmission. Layer 1 (L1) relay, also called amplify-and-forward relay is simple and easy to implement through RF amplification with relatively low latency. However, the noise and interference are also amplified along with the desired signal. Besides, strict isolation between radio reception and transmission at RN is necessary to avoid self-oscillation, which limits its practical applications. Layer 2 (L2) relay performs the decode-and-forward operation and has more freedom to achieve performance optimization. Data packets are extracted from RF signals, processed and regenerated, and then delivered to the next-hop. This kind of relay can eliminate propagating the interference and noise to the next hop, so it can reinforce signal quality and achieve much better system performance. Layer 3 (L3) relay also called self-backhauling, has less impact to eNB design and it may introduce more overhead compared with L2 relay.

From the point of view of UE knowledge, the relays under study in 3GPP can be classified into two types; transparent and non-transparent. In transparent relay, the UE is not aware that it is communicating with the eNB via a relay. Transparent relay was proposed for the scenarios where it is intended to achieve throughput enhancement of UEs located within the coverage of the eNB with less latency and complexity but it may also be used for filling in coverage holes. The transparent relay operation supports the separation of the control signal and the data transmission. Since the UE is located within the coverage of the eNB, the DL control signal from the eNB can directly reach the UE without going through the RN. Therefore, the UE may synchronize to the eNB and receives some control signals, e.g. through SCH, PDCCH, directly from eNB, while the data traffic is still forwarded by the RN. The direct DL control connection between eNB and UE would reduce the scheduling latency and the signaling overhead for multi-hop relay networks. In non transparent relay the UE is aware that it is communicating with the eNB via a RN. All the data traffic and control signal transmission between eNB and UE are forwarded along the same relay path. Although non transparent relaying is applicable for almost all cases, wherever the

UE is, within the coverage of eNB or coverage holes, it may not be an efficient way for all scenarios, because both the data and control signaling are conveyed multiple times over the relay links and the access link of a relay path.

Depending on the relaying strategy, a relay may be part of the donor cell or control cells of its own. In the case the relay is part of the donor cell, the relay does not have a cell identity of its own (but may still have a relay ID). At least part of the RRM is controlled by the eNodeB to which the donor cell belongs, while parts of the RRM may be located in the relay. In this case, a relay should preferably support also LTE Rel-8 UEs. Smart repeaters, decode-and-forward relays and different types of L2 relays are examples of this type of relaying.

In the case the relay is in control of cells of its own, the relay controls one or several cells and a unique physical-layer cell identity is provided in each of the cells controlled by the relay. The same RRM mechanisms are available and from a UE perspective there is no difference in accessing cells controlled by a relay and cells controlled by a “normal” eNodeB. The cells controlled by the relay should support also LTE Rel-8 UEs. Self-backhauling (L3 relay) uses this type of relaying.

Cooperative relaying is principally a distributed MIMO system in multi-hop relay environments. The same time-frequency resource block is shared by multiple RNs and these distributed deployed RNs operate collaboratively to form virtual MIMO transmissions. Additionally, cooperative relaying potentially simplifies the implementation of inter-RN handover due to the concept of the “virtual cell”, i.e., every UE is always served by one or more RNs which provide the best performance. Therefore, smooth handover is expected in multi-hop relay-based networks. The collaborative transmission and reception of multiple RNs can improve signal quality due to spatial diversity or increase the spectrum efficiency as a result of spatial multiplexing.

7.8 PROGRESS OF LTE-ADVANCED

Researchers conducted the world’s first demonstration of LTE-Advanced technology in December 2008, breaking new ground with mobile broadband communications beyond LTE. A leading infrastructure company’s researchers successfully demonstrated Relaying technology proposed for LTE-Advanced, enabling an exceptional end-user experience delivered consistently across the network. The demonstration illustrated how advances to Relaying technology can further improve the quality and coverage consistency of a network at the cell edge – where users are furthest from the mobile broadband base station.

Relaying technology, which can also be integrated in normal base station platforms, is cost efficient and easy to deploy as it does not require additional backhaul. The demonstration of LTE-Advanced means operators can plan their LTE network investments knowing that the already best-in-class LTE radio performance, including cell edge data rates, can be further improved and that the technological development path for the next stage of LTE is secure and future-proof.

In the demonstration, performance enhancements were achieved by combining an LTE system supporting a 2x2 MIMO antenna system and a Relay station. The Relaying operated in-band, which meant that the relay stations inserted in the network did not need an external data backhaul. They were connected to the nearest base stations by using radio resources within the operating frequency band of the base station itself. The improved cell coverage and system fairness, meaning offering higher user data rates for and fair treatment of users distant from the base station, will allow operators to utilize existing LTE network infrastructure and still meet growing bandwidth demands.

The LTE-Advanced demonstration used an intelligent demo relay node embedded in a test network forming a FDD in-band self-backhauling solution for coverage enhancements. With this demonstration the performance at the cell edge could be increased up to 50% of the peak throughput.

8 CONCLUSIONS

The amazing uptake in commercial HSPA deployments, the growing number of subscriptions, the increasing number and success of data services and applications, increasing operator ARPU from data services, as well as the abundance of HSPA devices are the result of a fruitful marriage between a globally accepted standard and an easy evolutionary upgrade of existing UMTS systems. It is evident that the HSPA technology as defined in 3GPP Rel-5 and Rel-6 has in a very short time period created a self-supporting ecosystem. In this ecosystem, the technology's global presence, abundance of devices and services and excellent and cost effective performance will attract more end-users, services, operators and vendors which will in turn drive expansion of coverage, more services and devices to the market, increased performance and cost effectiveness.

In this good-natured circle it becomes more and more important to provide an ever improving performance with higher peak rates, lower latency, etc. and above all it is important to deploy more spectrally and cost efficient systems that can handle the increasing demands with a relatively low marginal cost. This paper has described how the evolutionary 3GPP roadmap introduces new features in Rel-7 and Rel-8 to accommodate this continuous need for improvements, and has demonstrated that this evolution will continue beyond Rel-8 with further HSPA and LTE enhancements and features in Rel-9 and the introductions of LTE-Advanced in Rel-10. The evolutionary approach relies on backwards compatibility and seamless mobility so that in existing networks, improvements can be deployed only in parts of the network where the demand is high enough, thus ensuring the lowest possible cost.

For Rel-8, the main bulk of the work in 3GPP is focused on providing a new radio interface (LTE) and system architecture (EPC) to cater to the rapid growth in IP data traffic, provide peak theoretical rates to above 100 Mbps for downlink and 50 Mbps for uplink, and reduce latency to levels comparable with fixed broadband Internet. In addition, Rel-8 defines improvements in HSPA to achieve higher rates through dual carrier or combined 64QAM+MIMO operation. With the Rel-8 specification nearing completion (targeted for March 2009), planning is already under way in 3GPP for Rel-9 and Rel-10. Further multi-carrier and MIMO options are being explored for HSPA in Rel-9, while additional feature content to support things like emergency services, location services and multicast/broadcast services are the focus of Rel-9 for LTE. In addition, support of Home NodeB/eNodeB (i.e. femtocells) and IMS enhancements will also be a focus of Rel-9 for both HSPA and LTE.

In parallel to Rel-9 work, it is recognized that work on Rel-10 is required to define significant enhancements to Rel-8/Rel-9 LTE in order to meet IMT-Advanced requirements. A study item in 3GPP called LTE-Advanced is therefore underway to look at carrier aggregation schemes, enhanced single and multi-user MIMO techniques, collaborative/network MIMO, interference coordination schemes and relay enhancements. 3GPP is targeting this LTE-Advanced work to be submitted to the ITU for evaluation in 2009-2010, and targets the Rel-10 specification defining LTE-Advanced to be complete in time for the ITU publication of the technologies meeting the IMT-Advanced requirements and thus officially being certified as "4G."

APPENDIX A: DETAILED VENDOR PROGRESS **ON REL-99, REL-5, REL-6, REL-7, HSPA EVOLVED/HSPA+ & SAE/LTE**

The following sections were contributed by companies represented in the working group for this 3G Americas white paper. This is not a comprehensive document of all the progress made to date by the vendor community, but is representative of some of the activities at leading members of the UMTS/HSPA eco-system.

Alcatel-Lucent first demonstrated HSDPA in March 2003 and has since played a significant role in the commercialization of the technology, powering the first two commercial HSDPA network launches in the world – Cingular in the United States (now AT&T) and Manx Telecom (a wholly owned subsidiary of O2) on the Isle of Man, respectively.

In another commercial milestone, the first HSDPA commercial services launched by Orange (March 2006) were based on Alcatel-Lucent equipment. Additionally, Alcatel-Lucent, in conjunction with China Netcom, completed a successful UMTS trial in Shanghai, which included the industry's first successful field trial of HSDPA technology in China.

Alcatel-Lucent has been a pioneer in the introduction of HSUPA technology as well, having completed live demonstrations of the technology at several major wireless trade shows including 3GSM World Congress 2006 – including the industry's first simultaneous HSUPA and HSDPA calls – and CTIA Wireless 2006. Alcatel-Lucent also completed the first commercial HSUPA launch in Europe with Mobilkom Austria, and has since supported commercial HSUPA launches for other operators worldwide.

Alcatel-Lucent is also in an ideal position to support the future introduction of Rel-7 features commonly referred to as HSPA+, through its early leadership in development of MIMO (aka Bell Labs Layered Space and Time, or "BLAST") and its Base Station Router (BSR), an innovation that integrates key components of 3G mobile networks into a single network element optimized to support UMTS/HSPA data services, and "flattens" what is typically a more complex architecture.

The BSR was selected as the winner of a CTIA WIRELESS 2006 Wireless Emerging Technologies (E-tech) Award in the category of *"Most Innovative In-Building Solution."* The UMTS BSR solution is now focused on the femto-cellular space, aimed primarily at the domestic market for in-home high-speed multimedia services. Good traction is being achieved in the market, with a number of wins and several trials beginning in Q3 of 2007, although none are yet publicly disclosed.

These developments, as well as expertise gained through the development of the OFDM radio technology also used in other standards (WiMAX, UMB, DVB-H), give Alcatel-Lucent invaluable experience in the development of efficient LTE radio solutions. Alcatel-Lucent started its LTE program in early 2006 and has been demonstrating early LTE capabilities while the standardization and development of LTE progresses. Alcatel-Lucent's Bell Labs research teams have been leading research into OFDM-based technologies, ensuring that the Alcatel-Lucent solution provides operators with the most innovative, efficient and highest performing solution possible.

On November 15, 2007 Alcatel-Lucent and LG Electronics announced that the two companies have completed LTE test calls using Alcatel-Lucent's LTE solution and mobile device prototypes from LG. This accomplishment — one of the industry's first multi-vendor, over-the-air LTE interoperability testing initiatives — highlights the strength of the two companies' LTE development efforts and represents a key milestone in the commercialization of this next-generation wireless technology. Alcatel-Lucent was awarded the first LTE trial with Verizon/Vodafone on November 29, 2007, and continues to demonstrate LTE innovation leadership. LTE demonstrations are available today and the first field trials are planned in 2008 with commercial availability in 2009.

Alcatel-Lucent is an industry leader in the introduction of commercial IMS networks announcing commercial agreements with AT&T and its predecessors (Cingular, SBC, BellSouth), Netia, Sprint, Manx Telecom, PAETEC and an initial deployment in China. Alcatel-Lucent's IMS-based solution serves as the cornerstone for next-generation blended lifestyle services, and Alcatel-Lucent is continuously evolving its IMS solution with new features and capabilities.

On December 30, 2006, Alcatel-Lucent completed the acquisition of Nortel's UMTS Terrestrial Radio Access Network (UTRAN) portfolio and business. As a result, Alcatel-Lucent has one of the industry's most comprehensive WCDMA portfolios, and can support deployments covering all markets and frequency bands (including AWS and 900 MHz spectrum bands).

Alcatel-Lucent currently has more than 50 W-CDMA customer contracts with strong worldwide presence in the most dynamic data markets including Korea (with SKT, KTF), the US with AT&T, in Europe with Orange Group, Vodafone Group, and the Mobilkom (Austria) Group. Leveraging Alcatel-Lucent's strong presence in high-growth markets like in Africa, or in Asia, Alcatel-Lucent is continuing to gain market growth in the W-CDMA business. Recent wins include Globacom in Nigeria, mCell in Mozambique, Vodacom in South Africa and BSNL in India.

Ericsson: Today's mobile broadband services enabled by Ericsson WCDMA/HSPA systems support up to 21 Mbps on the downlink and 5.8 Mbps on the uplink. In December 2008, Ericsson was the first vendor to provide the first step of HSPA Evolution in commercial networks in both Australia and Europe when 21 Mbps downlink speeds where enabled by Telstra and 3 Sweden. Key characteristics in Ericsson's WCDMA/HSPA offering for mobile broadband are superior radio performance with a comprehensive RBS portfolio for optimized coverage and capacity, excellent in-service-performance built on scalable, and future proof 3G platforms with an easy path to HSPA Evolution that will increase current HSPA speeds to 42 – 84 Mbps on the downlink and more than 12 Mbps on the uplink within the coming years. Furthermore, Ericsson HSPA equipment is the superior support for mixing Rel-99 voice and data traffic with HSPA traffic on the same carrier. The flexible solution allows for simultaneously high Rel-99 load and significant HSPA data rates which defers the need for the operator to add an additional carrier.

HSPA technology has a strong momentum right now. According to 3G Americas, Oct 2008, HSPA networks have been rolled out in 93 countries, spread on all continents. As of October 2008, Ericsson has supplied 109 out of 221 launched HSPA networks worldwide and of these, 38 supporting 7.2 Mbps or more and 37 are using HSPA on the Uplink. Ericsson is the primary supplier to operator Telstra who became the first in the world to trial peak downlink speeds of 21Mbps based on HSPA Evolution in December of 2008. This is a further demonstration that Ericsson is the market leader in introducing the latest HSPA network solutions in operator networks that give customers the best possible mobile broadband experience.

Moving on to the next step in mobile broadband, Ericsson was the first company to demonstrate LTE operating in both FDD and TDD modes on the same base station platform, in January 2008. By using the same platform for both paired and unpaired spectrum, LTE provides large economies of scale for operators. In order to make LTE licensing as fair and reasonable as possible, in April 2008 Ericsson announced its role in a joint initiative with Alcatel-Lucent, NEC, NextWave Wireless, Nokia, Nokia Siemens Networks and Sony Ericsson to enhance the predictability and transparency of IPR licensing costs in future 3GPP LTE/SAE technology. This initiative includes a commitment to an IPR licensing framework that provides more predictable maximum aggregate IPR costs for LTE technology and enables early adoption of this technology into products. In 2008, Ericsson unveiled the world's first commercially available LTE-capable platform for mobile devices, the M700, which offers peak data downlink rates of up to 100 Mbps and uplink rates of up to 50 Mbps. The first products based on M700 will be data devices such as laptop modems, USB modems for notebooks and other small-form modems suitable for integration with other handset platforms to create multi-mode devices. Since LTE supports hand-over and roaming to existing mobile networks, all these devices can have ubiquitous mobile broadband coverage from day one. Product development for LTE is in progress and the first LTE systems will go to market at the end of 2009.

Ericsson's RBS3000 radio base station family allows for 30% fewer sites, increases capacity by 50-150% and is optimized for cost efficiency at every site. It also enhances power efficiency, with power consumption cut by a further 35-55%. It includes distributed, carry-to-site, multi-access GSM/UMTS and mega capacity products for both indoor and outdoor use. The RBS3000 portfolio currently supports 850, 900, 1700/2100, 1700, 1900 and 2100MHz frequency bands and will fully support all forthcoming frequency bands, including 1800 and 2500MHz.

In 2008, Ericsson announced the new RBS 6000 base station family. The RBS 6000 is a no-compromise, energy efficient compact site solution that supports GSM/EDGE, WCDMA/HSPA and LTE in a single package. The RBS 6000 is build with cutting-edge technology and at the same time provides backwards compatibility with the highly successful RBS 2000 and RBS 3000 product lines. Base stations delivered since 2001 are LTE-capable, supporting operators with a clear and stable evolutionary path into the future. As a multi-standard base station, the RBS 6000 offers many options that make choices simpler while providing greater freedom of choice. Cost-effective deployment and development of new, high-speed mobile broadband services, mobile TV and web applications requires a smart solution that provides a real performance leap. The RBS 6000 family not only ensures a smooth transition to new technology and functionality minimizing OPEX, but also reduces environmental impact.

Ericsson has signed 58 IMS system contracts for commercial launch. All based on the IMS (IP Multimedia Subsystem) standard. 31 of these contracts have been deployed and are running live commercial traffic. All Ericsson IMS contracts include a CSCF and HSS and may include one or more of the following applications: IP Telephony, IP Centrex, Messaging, Push to Talk, weShare, and Presence.

They are distributed over the Americas, Europe, Asia-Pacific and Africa and include fixed network implementations, GSM/GPRS, WCDMA/HSPA and WiMAX.

The Mobile TV business is booming and many operators around the world have already introduced Mobile TV services. The two-way unicast capabilities of existing cellular networks are, by far, the most used technology to date of mobile TV. Out of just over 200 launched mobile TV services in the world, more than 180 are distributed over these existing cellular telecommunication networks. Ericsson supports over 80 of them and has a market leader position as vendor of Mobile TV & Video Solutions. Already back in April 2006, Ericsson showcased its enhanced program guide for mobile TV that integrates TV and on-demand mobile TV services in one location in one device. It also allows users to easily access stored content for playback, making the mobile TV service even more attractive and personal.

Gemalto, a 1.6b euros leader in digital security, is the largest provider of smart cards and remote management servers. In 2007, Gemalto provided close to one billion SIM and UICC to over 500 operators worldwide. Gemalto is also well positioned in providing over-the-air platforms and operated services to conduct remote updates of data as well as application download and maintenance.

Additionally, Gemalto provides Trusted products and personalization services to Governments, Corporations, and Financial Institutions.

Gemalto demonstrated the following use cases taking advantage of Release 7 and Release 8 features:

- **DVD quality video streaming at 4 Mbps over TCP-IP** from the UICC **with parallel gaming** via a browser session: In this demonstration presented in October 2007, a consumer launches the phone's browser and views a video streamed directly from the UICC while simultaneously playing a game of Othello.

- **Offline operator services portal based on Smart Card Web Server technology:** In this demonstration, the consumer views xHTML pages with top ten music and videos that can be trialed and purchased. These xHTML pages, stored in the UICC, can be browsed using the wap browser of the handset and provide shortcuts to launch premium SMS services, set up calls, or manage local UICC NFC applications. Gemalto demonstrated two implementations of the interface: one with the BIP TCP Server over classic ISO and another with TCP-IP over USB-IC.

- **Contactless transit, payment, and smart poster applications processed in the UICC for NFC trials**. Overall, Gemalto demonstrated that the UICC can run the MasterCard Paypass, Visa Paywave, JCB, and PBOChina contactless payment applications in separate security domains, with multiple instantiations (i.e. multiple credit cards using the same application), and remote personalization (i.e. credit card remote issuance in the UICC). For richer brand presentation during transactions, Gemalto relied on the Single Wire Protocol (Release 7), HCI and the Smart Card Web Server. The Single Wire Protocol was demonstrated with LG, Motorola, Nokia, Sagem, and Samsung devices.

Gemalto participates in all the publicly announced GSM Association Pay-Buy-Mobile trials (Korea, Taiwan, France), including the industry first "Payez Mobile" with 4 MNOs, 6 banks, Visa and Mastercard where it provides the UICC and the TSM remote personalization services.

Hewlett-Packard: The HP Communications & Media Solutions (CMS) organization is part of HP Software, the fourth-largest software company in the world. Relied upon by hundreds of communication service providers around the globe, including the majority of the world's largest telecom companies, HP CMS can attribute both its market and technology leadership to a unique fusion of expertise and intellectual property. Offering a broad portfolio of integrated solutions, platforms, and services as well as a unique combination of telecommunications and IT expertise, HP CMS empowers service providers to position their business for success.

Today, the HP CMS Personalized Communication solution family supports over 200 million subscribers across 5 continents. Through this family of solutions HP is providing comprehensive support for mobility and data management that encompasses requirements ranging from 2G through 4G. As operators evolve their networks toward LTE technologies and the EPS architecture they can build upon the capabilities of the proven CMS HLR to incorporate carrier grade RADIUS AAA for packet switched data traffic, Diameter based AAA, and HSS support for the IMS core. This inclusive functional suite takes full advantage of the CMS Profile Manager to insure data-level coherence and behavioral consistency of the overall mobility management solution across all access domains and technology generations. The CMS Profile Manager, which comprises the data layer, anticipates need of the Common Profile Storage (CPS) Framework and the ideas behind User Data Convergence that will mature in Release 9 and 10 of the 3GPP specifications.

Support for comprehensive policy management is also provided as part of the HP CMS Personalized Communication solution family. Linked with the pan-generational mobility and data management products, able to service multiple fixed and mobile access domains, operators can leverage the CMS Policy Controller to insure quality of service and provide a fine degree of control for service offerings consistent with the OMA and 3GPP Release 8 specifications. These same technologies also link the network application environment to back office and operational systems and can be utilized to grow the revenue potential of a business while helping to control capital and operational expenses.

Through the Rich Communication solution family HP CMS offers a complete portfolio of multimedia technologies and solutions designed to help operators satisfy the demands of today's increasingly sophisticated end user. Consistent with the theme of all CMS solution families, the Rich Communication portfolio is designed to contain operator costs as well as open up new revenue streams. Based on the CMS Media Platform (configured as an IVR, IP media server, MRF or MRFP), it is possible to use the same platform in circuit-switched, pre-IMS and IMS networks. A suite of call completion, messaging, mobile video and network IVR solutions are available. CMS is a leader in interactive voice services with over 4,000 deployed platforms, and is the largest Voice XML media platform provider with over 600,000 voice and video ports deployed worldwide.

Working cooperatively with the well known HP Labs centers around the world, CMS has made substantial innovations in the methods and techniques of transcoding and transframing to allow for the development of innovative services where, with the evolution to a common IMS core network, users may employ a variety of devices and access networks with different capabilities while communicating.

For deploying rich communication solutions over a standard IMS network HP, based on its extensive deployment experience, has led in the standardization of control for the MRF in both 3GPP Release 8 and the IETF media control group, which had remained undefined since Release 5. To compliment this and to stimulate the innovation and rapid creation of new rich communication services and extend the pool of application developers and knowledge HP has also co-lead a team of experts in the definition and development of JSR 309, which is intended to be the standard, protocol independent API for writing multimedia services and applications for both IMS and non-IMS networks.

Operators and service providers can deploy services more efficiently and cost effectively with the CMS Service Delivery Platform (SDP). Complementary to the Rich and Personalized Communication portfolios, the CMS SDP Release 2.0 sets the Service Oriented Architecture (SOA) standard for the enterprise incorporating service Governance, Content Enablement, and Data Management capabilities. They are complemented by the HP Next Generation OSS (NGOSS) solutions based on the Telemanagement Forum (TMF) NGOSS model. As a leader in MTF NGOSS program steering, HP has implemented and extended critical NGOSS concepts to realize a solution vision that is deployed at a number of telecom operators.

All of the solutions mentioned above, and more, support the HP CMS strategy of "consolidate, converge and innovate". This strategy aligns closely with the ideas behind EPS, which is to simplify the network and improve performance, then takes them further by supplying the service provider with the means to create and deploy the innovative services that will ultimately justify the expense of re-architecting and re-implementing both the access and core software network structures.

Huawei Technologies is a global organization and a leader in innovative telecommunications products and technology, providing next generation networks for 70% of the world's top 50 operators and enabling telecommunications services for well over 1 billion subscribers. Huawei's R&D strengths and innovative products have resulted in their being ranked as one of the top tier mobile network providers. In 2007, Huawei established a No.1 position with 45% share of new-added UMTS commercial contracts. As of Q308, Huawei has won more than 121 UMTS/HSPA contracts within an overall total of 231 3G commercial contracts. Huawei's 3G-oriented EnerG GSM solution continues to advance and, also as of Q308, shipments of GSM BTS exceeded 2.6 million TRXs. Shipments from Q1 to Q3 in 2008 alone reached 1.1 million.

Huawei has demonstrated a strong commitment in supporting operators on the evolution of GSM to UMTS/HSPA and LTE with market-leading products. Huawei was first to commercially deploy a Distributed NodeB solution (DNBS) in the first quarter of 2005 and commands a first place in DNBS market share. Based on these solid foundations, Huawei has built a new 4th generation NodeB as a truly flexible platform. It is a multi-carrier, multi-technology platform that can support GSM / UMTS / HSPA / LTE on the same platform. GSM / UMTS / HSPA / LTE operation can be supported simultaneously in the same Baseband Unit. The characteristics of RRUs are software definable within the same frequency band. Additionally, RRU reliability is enhanced by use of industry-leading passive convection heat dissipation design.

In October of 2008, TELUS announced they had entered into a multi-year, multi-million dollar agreement whereby Huawei will provide Radio Access Network technology for TELUS' new next generation wireless network. Reinforcing TELUS' leadership in the mobile broadband market and the ability to provide clients with the best service and networks in Canada, TELUS announced on October 10, 2008 its plans to build in association with Bell Canada a next generation wireless network beginning immediately with equipment from Huawei. Initially based on the latest version of High Speed Packet Access (HSPA) technology, the network will complement TELUS' existing 3G network solutions and future-proofs TELUS for a smoother transition to fourth generation technology based on the emerging, global long-term evolution (LTE) standard. A full national launch is expected by early 2010.

Huawei has emerged as a leading supplier of UMTS/HSPA solutions as evidenced by the following list of "firsts":

- January 2006: Huawei launched the first HSDPA commercial network in Europe in Portugal for Optimus, supporting downlink speeds of 14.4Mbps following the success of a pilot trial begun in May 2005

- April 2006: Huawei demonstrated the first UMTS base station solution for the AWS band at CTIA Wireless

- June 2006: PCCW launched its first 3G MobileTV service using Huawei's innovative Cell Multimedia Broadcast (CMB) technology over a Huawei deployed HSDPA network

- January 2007: A new international high speed benchmark was established after a successful test on Shanghai's Maglev Railway, demonstrating strong HSDPA performance at a speed of 430 km/h. Huawei-patented Doppler Frequency Shift Cancellation technology along with robust handover algorithms were instrumental in demonstrating average HSDPA throughputs of 1.8 Mbps (Category 6 UE) and 1.3 Mbps (Category 3 UE).

- February 2007: Huawei, partnering with Qualcomm, showcased the first demonstration of MBMS at the 3GSM World Congress. The solution was based on the MSM7200 chipset and demonstrated reception of TV programs at 256 Kbps over a UMTS/HSPA network. In the same timeframe, Huawei released the world's first HSUPA USB modem with ability to support 7.2 Mbps downlink and 2 Mbps uplink data rates. These achievements were followed by the deployment of the first commercial HSUPA-network in Asia-Pacific for StarHub in Singapore.

Huawei's strong R&D capabilities and inventive solutions have been recognized by Vodafone in deploying its DNBS UMTS solution in Spain, and in May 2007 Vodafone Global awarded the "2007 Global Supplier Award for Outstanding Performance" to Huawei at the second annual Global Supplier Conference.

Huawei is a trailblazer in an All-IP product portfolio. Huawei led the industry in the development of an IP-based RAN portfolio with Native IP RAN as well as Clock over IP synchronization and All-IP Element Fabric. Huawei was first to commercialize Iub over IP transmission and in July 2006, Huawei deployed the first IP-based HSDPA Radio Access Network in Japan for eMobile. Following that achievement, in October 2007, Huawei deployed the first IP BSS commercial network in the world for China Mobile helping the operator reduce CAPEX and OPEX by transforming the network to an all-IP infrastructure. In Dec. 2007, Telefonica O2 signed a 10K NodeB UMTS/GSM contract with Huawei to build and expand their network in Germany and T-Mobile awarded a UMTS Packet Core Network across its five key Western European markets with a capacity of 20 Million subscribers.

Huawei is an industry leader in the FMC IMS arena. In December 2006, Huawei was first in the industry to release a FMC IMS solution based on IMS 3.0. In October 2007, Huawei received the prestigious Global Telecoms Business (GTB) Innovation awards for its outstanding performance in:

- KPN's All-IP project (end-to-end network transformation award)
- BT's 21CN pilot project (core network transformation award)
- PCCW's Mobile TV launch (mobile TV award)

Huawei commercial success has a foundation of innovative technology derived from extensive research. By the end of December 2007, Huawei had applied more than 3000 patents for UMTS, including 133 basic patents. Its share has reached 7% of the gross of all the basic patents and ranks in the Top 5 globally.

Motorola: Motorola's UMTS/HSPA solutions address the very specific needs of mobile operators worldwide and make the most of today's challenging market environment. Support for full 15 code HSDPA, HSUPA, HSPA+, IP backhaul options and a host of global operating frequencies are just a few of the many features that Motorola's solutions deliver. Specifically, these features not only provide time to market advantages and improved user experience, but also target mobile operators' network CAPEX and OPEX, providing opportunities to minimize Total Cost of Ownership. For example, Motorola's solutions employ the latest developments such as multi-carrier power amplifiers that feature digital pre-distortion and A-Doherty techniques to maximize efficiency, minimize running costs and ultimately reduce the network's impact on the environment.

Motorola's *"Zero Foot Prrint"* solution offers cost-effective deployment options to deliver UMTS/HSPA capability. In addition to providing increased opportunities in areas that are likely to see high return on investment, this solution also increases opportunities in areas where previously deployment costs meant that the business case was unfavorable. Using a distributed architecture, the *"Zero Foot Print"* solution comprises units that are physically small and thus relatively easy to site, a major consideration in dense urban areas where space is invariably a premium. When combined with features such as RAN site sharing, remote antenna adjustment and the various backhaul techniques offered, Motorola's UMTS/HSPA solutions open up a host of exciting deployment opportunities and capabilities.

Early in 2007, Motorola announced it was extending its mobile broadband reach with Long Term Evolution (LTE), drawing upon expertise, research, and deployment of OFDM-based networks to develop solutions to meet the needs of mobile operators pursuing migration of their 2G or 3G cellular networks.

LTE promises to provide an unrivalled user experience with ultra fast mobile broadband, very low latency services while delivering a very compelling business proposition for mobile operators with flexible spectrum bandwidth, smooth migration and the ability to deliver low cost per bit voice and data services. LTE's ability to interconnect with other access technologies will also enable mobile operators to converge their LTE and fixed-line broadband networks giving them the ability to provide their subscribers with a media mobility experience.

In 2004, Motorola first demonstrated OFDM and MIMO at speeds of up to 300Mbps and established itself as a market leader in IEEE 802.16e WiMAX. Motorola's expertise in collapsed IP architecture led directly to leadership in LTE RAN standards, where Motorola was a leading technical contributor and editor of core, performance and test specifications. This experience and expertise is fully integrated into Motorola's LTE RAN and EPC solution. In addition to LTE infrastructure, Motorola's leadership in home and video solutions, LTE chipsets, handsets, CPE, backhaul solutions and OFDM mobile broadband network deployment experience translate to a world class Motorola LTE solution for mobile operators. A robust ecosystem partnered with Motorola's unique experience and expertise enables 3GPP and 3GPP2 mobile operators to migrate to LTE with confidence, whilst mitigating risk.

Motorola continues to demonstrate its commitment to LTE by both achieving "Industry First" milestones and making LTE and innovative applications accessible to mobile operators.

Motorola brings LTE to life on the streets of Barcelona! During Mobile World Congress 2009, Motorola demonstrates the maturity of its LTE Solution by deploying a Long Term Evolution (LTE) network in a real-world environment for operators to experience live LTE moving through the streets of Barcelona. During that drive tour mobile operators will experience the performance of LTE, including site to site hand-over and a chance to try a number of demanding applications, including High Definition (HD) streaming video and a collection of high bandwidth and low latency Internet-based applications. In addition, the LTE drive tour van will connect over LTE to Motorola's booth to demonstrate HD video blogging between the two locations. Visitors can also see Motorola's prototype LTE chipset/device powering further live demonstrations on the Motorola booth including:

- LTE video streaming experience using Motorola's end-to-end video solutions
- LTE QoS impact on user experience and LTE MIMO capabilities
- UMTS to LTE handoff - to demonstrate how LTE successfully integrates with existing cellular networks using Motorola's own LTE UE prototype

In February 2009, Motorola launched a LTE trial network and testing lab in Swindon, United Kingdom. The occasion was marked with a live, over the air, standards compliant LTE call during which high-speed data services were streamed using Motorola's LTE infrastructure operating in the 2.6GHz spectrum and a prototype LTE device. The Swindon facility offers mobile operators the ability to engage in LTE technology field trials and detailed real-world equipment testing.

In November 2008, Motorola demonstrated the Industry's First Over-the-Air LTE data sessions in 700MHz spectrum.

As part of Mobile World Congress 2008 and CTIA 2008 presence, Motorola demonstrated how its LTE solution can accelerate the delivery of personal media experience. Using Motorola LTE RAN standards compliant LTE eNode-B and LTE chipset with elements from Motorola LTE end-to-end ecosystem (video solutions, VoD servers, MPEG4 encoders, backhaul, UE …) Motorola showed a number of exciting new applications and solutions that illustrate how mobile operators can gain a competitive advantage with Motorola LTE. LTE demonstrations included:

- HD video blogging
- HD video on demand & Media mobility
- Online gaming
- Industry 1st CDMA to LTE hand over; showing the smooth migration from CDMA and EV-DO to LTE

Motorola started service provider lab trials in 2007 and is currently involved in a number of service provider field trials and working with LSTI on additional trial and interworking activities. Here, Motorola's terminal chipset and base station architectures, field trial program, test and certification activities and deployment roadmaps envisage complete, integrated support for LTE-TDD (TD-LTE) operation as well as LTE-FDD mode. Further, inter-RAT (Radio Access Technology) support to enable rapid technology migration to 3GPP-LTE technology remains an integral part of Motorola's LTE capability and technology roadmap. In March 2008, Motorola introduced its new OFDM common broadband solution (for LTE FDD and TDD); this 3rd generation OFDM platform leverages Motorola extensive OFDM mobile broadband expertise and will be commercially available for LTE networks by end of 2009, giving Motorola the advantage of deploying LTE technology on a field proven platform.

Nokia is the world leader in mobility, driving the transformation and growth of the converging Internet and communications industries. The company makes a wide range of mobile devices with services and software that enable people to experience music, navigation, video, television, imaging, games, business mobility and more.

With the 5th most valuable brand in the world, (according to Interbrand) and approximately one billion users of Nokia devices today, the company is also able to bring unrivalled consumer insight into the development of behavior and new services among subscribers in different countries, growth areas for new technologies, and new innovations, such as services under the Ovi umbrella being continuously rolled out. No other consumer durables company has such a wide customer base.

The convergence of the Internet, mobility and context-awareness is changing the way people communicate, share, search and consume content over mobile, and with its services and software strategy, Nokia is positioning itself to take advantage of the changing landscape of our industry. This has been underlined in 2008 with demonstrations, launches and speeches from Nokia executives at recognized industry events such as CES, Las Vegas, Mobile World Congress, Barcelona, Games Developer Conference, San Francisco, CTIA, Las Vegas, Web 2.0 Expo, San Francisco, and CTIA Wireless IT & Entertainment, San Francisco.

With the largest product portfolio in the industry, Nokia is leading the development of multi-radio and mobile broadband devices to offer the best choice of connection for consumers. We believe that the market is being shaped by an increased emphasis on data traffic as wireless communications converges with computing, digital imaging and the Internet, making it possible for consumers to use handheld devices for multiple purposes. Nokia is at the forefront of this converging industry, pushing it forward with cutting-edge products and the development of open standards. We see it is consumers who ultimately benefit from open standards, economies of scale and a high number of suppliers, as we have seen with GSM and its evolution, expanding its footprint around the globe.

There are many industry firsts which Nokia has pioneered and are entrenched in the wireless industry. These include the first Wi-Fi mobile device, the first commercial mobile TV device and the first dual-mode GSM/EDGE and WCDMA handset, among others. As well as being the #1 GSM and WCDMA device manufacturer, Nokia has also introduced (as of 1 November, 2008), 43 HSDPA enabled devices, for much faster connectivity speeds and improved downloading capabilities. In the first quarter of 2009, Nokia is expected to introduce their first HSUPA device.

Nokia devotes substantial time and resources to creating standards and specifications for the communications industry. We promote open standards that match our customers' needs. Nokia maintains strong global contacts to monitor and influence technological developments. We actively participate in standardization and R&D projects in cooperation with universities, research institutes, and other companies.

A great example is the *Mobile Millennium* project where researchers from Nokia and UC Berkeley, with support from the U.S. Department of Transportation, have constructed an unprecedented traffic monitoring system capable of fusing GPS data from cell phones with data from existing traffic sensors. The system gathers data in a privacy preserving environment, relying on the “Virtual Trip Lines” technology, a data sampling paradigm that anonymizes the GPS-based position information and aggregates it into a single data stream. The aggregated data is then encrypted and sent to a computer system, which blends it with other sources of traffic data and broadcasts this real-time, data rich information back to the phones and to the internet through a user friendly interface.

Forum Nokia provides technical know how to over 3.7 million third party developers for all Nokia supported technologies, many of which are open source. The maemo platform on our Internet tablets, the web browser in S60 and Open C are all examples of our commitment to working in the open source community. Forum Nokia continues to be the leading community dedicated to mobile developers.

Nokia’s commitment to openness and open standards is also evidenced by its support for the Symbian Foundation. The Foundation members share the vision that the Foundation will unify the software platform, supercharge innovation and accelerate the availability of new services and compelling experiences for consumers and business users around the world. The combined platform is already one of the most advanced and widely used open mobile software platforms, with more than 200 million phones, across 235 models, already shipped by multiple vendors and tens of thousands of third-party applications already available for Symbian OS-based devices.

In the summer of 2008, Nokia’s acquisition of Trolltech was completed. The Qt framework is widely used and endorsed for application development both in desktop and mobile environments with strong open source community support. Nokia plans to continue to license Trolltech technology under both commercial and open source licenses.

In a longer term view of broadband wireless connectivity, Nokia continues to support the GSM family of technologies and its evolution through GSM-WCDMA to HSPA and further towards LTE. From a technological point of view, LTE benefits for consumers include an enriched user experience with real time, interactive services and seamless connectivity; broadband mobility at a decreasing cost; economies of scale, bringing rapid availability for the mass market. Nokia believes it is important for the world's leading manufacturer to support multiple technologies within its portfolio in order to provide a choice of solutions for its global customer base. Nokia will introduce LTE devices to coincide with wide commercial availability of networks.

In the U.S., Nokia has developed some strong collaborative relationships, and has initiated promising technologies. Our R&D site in San Diego is focused on this goal, and is Nokia’s only R&D facility dedicated to the development of products specifically for a single market. Nokia is committed to working hand-in-hand with its North American operator customers to deliver a full range of compelling new devices tailored for their specific needs.

Nokia Siemens Networks is a leader in the global communications infrastructure market with nearly 600 customers in 150 countries providing a full range of solutions, products and applications for fixed, mobile and converged networks across its four business units – Radio Access, Converged Core, IP Transport, and Operations and Business Software. Additionally, Nokia Siemens Networks offers a broad range of professional services from consultancy to outsourced operations; systems integration to hosting; and from network design to care, including a full range of network implementation and turnkey solutions. The Services portfolio is delivered through a global organization with 20,000+ experts across seven regions.

At the forefront of WCDMA/HSPA development, Nokia Siemens Networks is the global industry leader with over 130 WCDMA and over 100 HSPA radio network references worldwide. Nokia Siemens Networks has led the industry in flat network architectures, underscored by its innovative 3GPP-standardized Internet-HSPA (I-HSPA) technology, that deliver superior value for high volume traffic.

At the heart of Nokia Siemens Networks radio evolution is the Flexi Base Station platform that supports GSM/EDGE, WCDMA/HSPA, WIMAX and LTE. It is the smallest, most energy efficient, full capacity multi-technology base station platform whose size and unique modular, waterproof design can be deployed virtually anywhere, making site acquisition easier and more affordable. The newest member of the market-leading Flexi Base station family, the Flexi Multiradio Base Station combines GSM/EDGE, WCDMA/HSPA and LTE in one module and allows operators to evolve via software upgrades as well as save on additional energy efficiency. It joins the Flexi Multimode Base Station that has a fully software definable upgrade to LTE, which means operators can deploy the base station with WCDMA/HSPA technology and then upgrade to LTE via software in the same frequency band beginning in the second half of 2009. Both the Flexi Multiradio and the Flexi Multimode Base Stations supports most IMT frequency bands including the 1.7/2.1GHz AWS band and the 700 MHz band in the United States.

As part of its radio solutions, Nokia Siemens Networks provides a comprehensive network and service management system, NetAct, which helps the service providers to monitor, manage and optimize their networks and services, thus improving the service quality for their customers.

Nokia Siemens Networks is a pioneer in LTE research and technology development, a frontrunner in 3GPP standardization, and is actively driving the early tests of LTE technology within the LTE/SAE trial initiative (LSTI). Nokia Siemens Networks also is a pioneer in the Direct Tunnel core network technology that is a key component of the flat network architecture used in LTE.

In December 2008, Nokia Siemens Networks announced that its researchers conducted the world's first demonstration of LTE-Advanced technology, illustrating how advances to Relaying technology can further improve the quality and coverage consistency of a network at the cell edge -- where users are farthest from the mobile broadband base station.

In 2007, Nokia Siemens Networks and Panasonic Mobile Communications were also selected by NTT DoCoMo to be their Super 3G / Long Term Evolution vendor. Verizon Wireless, the first CDMA operator selecting LTE as their next generation mobile broadband technology, selected Nokia Siemens Networks as a vendor in their LTE trials. By the end of 2008, Nokia Siemens Networks will be delivering the new LTE-ready hardware to more than 10 major mobile operators in Europe, Asia and North America, reinforcing its position as the frontrunner in LTE with a scalable, flat architecture.

Additionally, the company continues to innovate in EDGE. In December 2008, Nokia Siemens Networks made the world's first Downlink Dual Carrier EDGE end-to-end call with mobile devices, bringing the promise of doubling today's EDGE network data speeds to a level that will provide support to a host of applications such as posting video clips to blogs or steaming news on mobile TV.

The core network solutions that Nokia Siemens Networks has developed and deployed connect over 1.3 billion subscribers in over 250 countries. Serving over 800 million subscribers worldwide, the Nokia Siemens Networks' Mobile Softswitch is the most mature platform available in the market today and has been chosen by over 200 mobile operators to date, with over 140 commercial networks in live use, making it number one in the market. The Nokia Siemens Networks Mobile Softswitch supports an architecture that is compliant with 3GPP Release 4, 5, 6 and 7 with adaptive support for 2G and 3G voice, IP transport, and all key voice compression algorithms. It supports a smooth evolution to VoIP and IP Multimedia Subsystem (IMS) by providing IMS – CS core inter-working with SIP call control, and end-to-end VoIP support, with or without IMS, and can deliver mobile voice service with up to 70% savings in operating expenditures.

Nokia Siemens Networks also offers the hiQ VoIP platform with deployments across all types of networks. The platform supports Web Services SDKs which enable operators to combine communication services with the IT world.

Nokia Siemens Networks has a long track record in providing packet core solutions that support market evolution with market leading reliability: the first vendor to introduce service aware packet core (2003); a combined 2G/3G SGSN on the market since 2006; an industry leader in providing Direct Tunnel functionality in SGSN since 2007. Nokia Siemens Networks will introduce Mobility Management Entity (MME) and Service Architecture Evolution Gateway (SAE GW) for LTE networks in 2009. Most recently, Nokia Siemens Networks announced its Evolved Pack Core network solution for LTE allowing operators to modernize their core data network to support a wide variety of access types using a common core network.

Nokia Siemens Networks Packet Core has over 270 customer references, including over 170 references for the combined 2G/3G SGSN and 140 for the Flexi ISN. With over 30 Direct Tunnel deployments to date, including 8 live deployments, Nokia Siemens Networks is a leader in the technological evolution to LTE.

Nokia Siemens Networks is also a leader in IMS with over 30 references for IMS Core in wireline and wireless networks worldwide, supporting user-centric multimedia and fixed-mobile convergence solutions. The Nokia Siemens Networks' IMS optimizes Core Network topology by moving from vertically implemented services towards common session control, QoS policy management and charging control.

Following its acquisition of Apertio, Nokia Siemens Networks is the clear number 1 in subscriber data management with a complete solution for real-time data consolidation, including common repository, centralized provisioning, suite of applications, and network and service management. There are over 1 billion subscribers in NSN Network databases worldwide, and its common database solution is used by over 690 million customers of 60 operators in 36 countries.

Nortel has developed Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) as the fundamental building blocks for future advanced wireless technologies. Practical Spatial Division Multiple Access (SDMA) technologies from Nortel, such as fixed beam forming using light weight antenna solutions further increase the performance advantages of OFDM and MIMO. Nortel began investing in OFDM and MIMO in 1998 in anticipation of their adoption in mobility networks. Since then, the company has demonstrated OFDM/MIMO commercial benefits and feasibility to more than 100 customers worldwide.

Long Term Evolution (LTE) - Nortel is accelerating the evolution of current 2G/3G networks to LTE with a comprehensive solution that offers significant value to service providers. Nortel places an emphasis on technology leadership and simplicity in its LTE solution to achieve the lowest total cost of ownership for operators, with improved user experience versus legacy technologies. The company's time-to-market leadership strategy includes early co-development and testing with LTE chipset and device vendors that will help accelerate comprehensive IOT activities and the availability of a complete LTE ecosystem. Nortel is leading several key projects as the activity manager within the LTE SAE Trial Initiative (LSTI), to ensure timely development of the LTE ecosystem. Nortel is also partnering with many leading application vendors to make sure operators can fully exploit an LTE network's potential to increase operator revenues.

In 2005, Nortel was the chief proponent of the advantages of OFDM/MIMO for 3GPP, and helped to drive the introduction of OFDM/MIMO into the 3GPP standards. In 2006, Nortel delivered a prototype solution utilizing Uplink Multi-user MIMO (also known as Collaborative MIMO) technology and achieved a connection speed in the uplink that was up to 15 times faster than the fastest mobile connectivity at the time. At 3GSM World Congress in February 2007, Nortel publicly demonstrated the world's first pre-standards LTE uplink and downlink air interface supporting video streaming and file transfers to multiple devices.

At Mobile World Congress 2008 in Barcelona and CTIA 2008 in Las Vegas, Nortel demonstrated LIVE AIR LTE at various spectrum bands, including the new North American AWS band (1700/2100 MHz), running a variety of applications, including high definition video streaming, Live TV, multi user video collaboration and video surveillance, as well as Nortel-Microsoft Unified Communications and examples of social networking tools. These live-air demonstrations included advanced RF and MAC features showing the implementation of the 3GPP Rel-8 standard. In April, 2008, Nortel made the first public announcement of LTE being demonstrated at high vehicular speeds, as customers visiting Nortel's LTE Center of Excellence in Ottawa witnessed download speeds over 50 Mbps in a moving vehicle at 110 kmph. In August 2008, Nortel and LGE completed and announced the first demonstration of LTE mobility handover at high vehicular speeds.

In September 2008, Nortel jointly with T-Mobile completed and announced successful live-air testing of an LTE trial network, in real-world operating conditions. Data download rates of 170 Mbps and upload rates of 50 Mbps were repeatedly demonstrated with LGE terminals and devices, on a four kilometer drive test loop, that included handoffs between multiple cells and sectors.

Nortel also delivers fully compliant 3GPP solutions for core network deployments. In December 2005, Nortel was selected to deploy North America's largest 2G/3G 3GPP R4 compliant network including MSC (Mobile Switching Center) Server and Media Gateway products. The Nortel 3GPP voice core solution is based on Nortel's industry leading ATCA platform. This platform, already deployed with operators world-wide, has been adapted to serve as Nortel's new Access Gateway which supports multiple wireless packet core functions including GGSN, SGSN, MME, S-GW, PDN-GW and Home Agent for use with GPRS, UMTS, LTE/SAE and WiMAX. Nortel's ATCA product leadership is widely recognized within the industry and resulted in two "Best of Show" awards at the 2008 Advanced TCA Summit. Nortel and all of its customers can benefit from the high density and capacity of these 3GPP core solutions.

http://www.advancedtcasummit.com/English/Conference/BOS.html

Operational costs are critical elements of operators' total cost of ownership. To substantially reduce the operations cost for LTE networks, Nortel has developed and currently offers a comprehensive Self Optimizing Networks (SON) solution spanning as an end to end capability across the entire LTE portfolio and its associated network management tools. Nortel views SON as one of several enablers to reduce OPEX and increase reliability and robustness of deployed LTE networks, as early-adopters of next generation wireless technologies move aggressively to relatively lower cost LTE operating models.

Nortel has been the worldwide leader in Carrier VoIP for six consecutive years according to Dell'Oro Group and Nortel is the recognized leader in design and deployment of Next Generation VoIP and SIP Multimedia networks. The company is building on this expertise, which includes extensive portfolio of SIP patents, to bring an open IMS solution to market. Nortel IMS is the "Intuitive Network" that is device-, application-, and end-user-aware, resulting in the creation of an eco-system of best-in-breed real-time multimedia applications and services that operate as part of its standards-compliant IMS portfolio. Operators acknowledge Nortel's many contributions to 3GPP, 3GPP2 (aligning CDMA evolution towards LTE), MMD, TISPAN and PCMM standards.

www.nortel.com/lte

APPENDIX B: FURTHER INFORMATION ON WIRELESS DATA REVENUE

The information contained in this Appendix is supplemental to section 4: The Growing Demands for Wireless Data Applications.

Further Information on Wireless Data Revenue

AT&T, the largest GSM carrier in the U.S., added 2.1 million net subscribers in 4Q 2008, reaching a total of 77 million. Wireless data revenues increased 51.2% to $3.1 billion versus results in the year-earlier quarter, driven by increases in mobile web access, messaging, email and related services. According to AT&T, nearly 80 billion wireless text messages crossed the AT&T network in the fourth quarter, more than double the total for the year-earlier fourth quarter. Internet access revenues and multimedia message volumes also continued their robust growth. The fourth quarter of 2008 marked the 12th consecutive quarter with wireless data revenue growth above 50 percent. Data represented 26.6 percent of AT&T's fourth-quarter wireless service revenues, up from 19.9 percent in the year-earlier quarter. Wireless data growth has also begun to reflect wider usage of the advanced capabilities and high speeds available with AT&T's 3G UMTS/HSPA network which was available in about 350 cities in the fourth quarter. To spur continued strong growth in wireless data services, AT&T has expanded its 3G network coverage to nearly 350 cities. AT&T's 3G network is the nation's fastest, according to data compiled by leading independent wireless research firms, and allows typical download speeds of up to 1.7 megabits per second. AT&T also offers the broadest global coverage of any U.S. provider, with voice roaming available in more than 200 countries; access to e-mail, the Web and other data applications in more than 160 countries; and access to mobile broadband 3G networks in more than 65 countries. [189] AT&T also plans to begin upgrades to its 3G HSPA network in 2009 by deploying HSPA+.

T-Mobile USA reported that it had 32.1 million customers, adding 670,000 net new customers in during the third quarter of 2008. This was a favorable number of additions for the fourth largest carrier in the U.S. Data service revenues continued to rise to $850 million in the third quarter of 2008, representing 17.3% of blended ARPU, or $8.90 per customer, compared to 16.6% of blended ARPU, or $8.60 per customer in the second quarter of 2008. Data service revenues in 3Q 2008 have increased 28% year-over-year. Robust growth in messaging revenue at T-Mobile USA continues to be the most significant driver of data ARPU as customers continued to shift toward purchasing plans that included messaging. The total number of SMS and MMS messages increased to 49 billion in the 3Q 2008, compared to 41 billion in the second quarter of 2008. Strong GPRS / EDGE access and usage revenues were another significant driver of the increase in data services revenues. T-Mobile took giant steps to meet the demands of its customers by driving new innovations such as the introduction of the T-Mobile@Home landline replacement service, and the unveiling of the T-Mobile G1 with Google – the world's first device built on the fully open Android operating platform. [190] T-Mobile has established its nationwide rollout of high-speed 3G HSDPA services, which at the end of 2008 covered 127 major markets and over 100 million POPs with speeds greater than 1 Mbps. T-Mobile continues to work with the U.S. government to clear spectrum in the 1700/2100 AWS bands for its HSDPA expansion. With the introduction of its sophisticated 3G

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[189] *AT&T Reports Fourth Quarter and Full-Year Results Highlighted by Robuts Wireless Data Growth, Accelerated Uverse TV Ramp, Continued Double-Digit Growtin in IP Data Services*. AT&T. Fourth Quarter Press Release and Investor Briefing. 28 January 2009.
[190] *T-Mobile USA Reports Third Quarter 2008 Results.* T-Mobile. 6 November 2008.

devices, and the continued rollout of its 3G network, T-Mobile is poised to continue growth of data services.

Rogers Wireless in Canada reported an addition of 239,000 net subscribers [191] in the nine months ended September 30, 2008. Year-over-year, wireless data revenue increased by approximately 38%, reaching $253 million and representing 16.5% of network revenue compared to 13.5% in the corresponding period of 2007. This increase in data revenue reflects the continued growth of text and multimedia messaging services, wireless Internet access, smartphone devices, downloadable ring tones, music and games and other wireless data services.

Telcel, the América Móvil operation that is market leader in Mexico, closed 2007 with data revenues reaching approximately 18% of total company revenues; up from 13% at the end of 2006 (Note: América Móvil does not report data ARPU on quarterly reports). Telcel launched UMTS/HSDPA in February 2008, starting with four major cities in a first phase of 13 markets; at the end of September HSDPA covered 60% of the Mexican population. In addition to the launch by Telcel, its parent company, América Móvil, completed 14 commercial UMTS/HSDPA 3G networks during 2007 and 3Q 2008 in Latin America, operated as Claro in Argentina, Brazil, Chile, Dominican Republic, El Salvador, Guatemala, Honduras, Nicaragua, Paraguay, Peru and Uruguay and operated as Comcel in Colombia and Porto in Ecuador. Their enhanced UMTS/HSDPA wireless networks enable clients to have access to value added services at high-speed data transmission rates, including wireless broadband accesses. [192] As of the end of 2007, America Movil reported that in Argentina, Paraguay and Uruguay (Mercosur region) the data revenues rose by 56% annually, representing 29% of the service revenues in the region. [193] By YE 2008, America Movil will cover the main cities of Latin America with 3G UMTS/HSDPA mobile broadband.

Telefonica has launched 3G HSDPA commercially in five countries, operated as VIVO in Brazil and Movistar in Argentina, Chile, Mexico and Uruguay. Most of their remaining properties in eight countries of Latin America will have 3G HSDPA commercial launches throughout 2009. [194]

Although 3G (UMTS/HSPA and EV-DO) accounted for only around 9% of all mobile devices as of May 2008, non-voice applications have continued to become an important source of revenue for wireless carriers (mainly in the form of SMS, ring tones and other downloads), according to Paul Wuh in the Lehman Global Equity Research Report. [195] In the developed markets in Asia, Europe and North America, non-voice revenue accounts for 20-35% of the total ARPU. In Japan, the most developed 3G market in the world according to Wuh, 76% of all mobile subscribers use 3G devices, and non-voice revenue represents more than 30% of total ARPU. In order to encourage greater data usage, NTT DoCoMo first introduced unlimited data packages for its UMTS subscribers in June 2004. With more than 45% of Japans' 3G subscribers on unlimited data packages, average data usage has increased to 19 MB/month in 2007 from 0.96 MB/month in 2003. DoCoMo reported that 75% of its subscribers had data ARPU of about US $38/month and the remaining 25% had data ARPU around US $12/month in 4Q 2007.

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[191] *Rogers Reports Third Quarter 2008Financial and Operating Results.* Rogers Communications, Inc. 28 October 2008.

[192] *3Q 2008 Financial and Operating Report*. America Movil.

[193] *4Q 2007 Financial and Operating Report*. America Movil.

[194] Source: 3G Americas.

[195] Wuh, Paul. *Global 3G Developments: 3G subs accelerate, more data revenue in '09*. Lehman Global Equity Research. 23 May 2008.

Wuh notes that many of the factors that contributed to the data growth in Japan will also help accelerate 3G adoption in other developed markets throughout the world. [196]

Further Information on 3G Devices

An interesting study by comScore noted the fastest growth for iPhone sales, particularly since the July 2008 appearance of iPhone 3G which offers high-speed internet access, came from households that earn less than the median income. [197] "We see that lower-income consumers are increasingly turning to mobile devices to access the internet, to listen to music and for email," said Mark Donovan, senior analyst at comScore. "A 'Swiss-Army knife of a device' like the iPhone offers a phone, a music player, a camera and a way to connect to the internet, which may appeal to consumers cutting back their spending on gadgets."

In fact, the NPD Group statistics indicate that iPhone 3G lead U.S. consumer mobile phone purchases in the third quarter of 2008. [198] The iPhone replaced the top-selling RAZR by Motorola, which NPD believes "represents a watershed shift in handset design from fashion to fashionable functionality." Ross Rubin, NPD noted that "four of the five best-selling handsets in the third quarter were optimized for messaging and other advanced Internet features." [199] The NPD report found the features that motivated U.S. consumers were 43% wanted a camera and 36% wanted SMS. The greatest year-over-year rise in sales was phones with a full QWERTY keyboard with Bluetooth-enabled and music-enabled phones also key growth features.

Many smartphones today are incorporating browsers that support the latest capabilities such as AJAX and RSS, as well as websites optimized for viewing on a mobile device. ABI Research sees this segment of the mobile browser market accounting for the vast majority of growth over the next five years, as the open-Internet browser (OIB) segment for mobile grows from 76 million in 2007 to nearly 700 million browsers delivered in 2013. [200] Michael Wolf, research director at ABI Research stated, "The focus today for mobile browser developers is to take advantage of the latest web standards while developing solutions tailored towards the unique experience of using a browser on a mobile phone." Recent commercial solutions from companies such as Openwave as well as those using open-source solutions target towards allowing customers to access content on the web without limitations due to browser constraints. [201]

Further Information on 3G Applications

Using the example of the 2008 presidential election, mobile messaging played a key role in campaign strategy by assisting in getting out the vote and transforming group messaging and will go down in history as one of the most mobile-friendly elections of all time. [202] Mobile campaigning is credited with being a more cost-effective alternative to traditional campaigning methods, such as door-to-door canvassing which costs around \$20 to \$30 per voter, compared to \$1.26 per SMS. [203] Research found that text message reminders to new voters increased an individual's likelihood of voting by close to five

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[196] *Ibid.*
[197] Silver, Sara. *Some Shed Their Gadgets by Turning to One: iPhone*. Wall Street Journal. 30 October 2008.
[198] *The NPD Group: iPhone 3G Leads U.S. Consumer Mobile Phone Purchases in the Third Quarter of 2008.* The NPD Group. 10 November 2008.
[199] *Ibid.*
[200] *Mobile Browser Market is Transforming and Will Grow to 1.5 Billion Units in 2013*. ABI Research. 11 April 2008.
[201] *Ibid.*
[202] Makki, Leila. *Obama's Victory Aided by Mobiles?* TelecomTV. 5 November 2008.
[203] *Ibid.*

percentage points, according to a study by Princeton and Michigan Universities, together with the U.S. Student Public Interest Research Group (PIRG) New Voter Project Mobile Voter and Working Assets. Another large feature of the elections was real time information via mobile phones.[204]

Text messaging (SMS) has become the cash cow for mobile operators and soon that may be changed by instant messaging (IM). In the U.S., text messaging activity increased significantly in the first half of 2008, according to CTIA, with 75 billion messages reported in the month of June 2008 alone – about 2.5 billion messages a day – representing a 160% increase over the 28.8 billion messages reported in June 2007.[205] Text messaging is doubling every year. Carriers reported 384 billion text messages between January 1 and June 30, 2008, which calculates to 22 billion more text messages than for all of 2007.[206] Text messaging has also increased in the U.K., as British mobile phone users are sending a reported 217 million messages a day, averaging 1.5 billion per week or 6.5 billion text messages per month. A report by the Mobile Data Association showed an average of 60 million more messages a day than in the same period in 2007.[207]

Although U.S. consumers have been slower to embrace text messaging than some other regions of the world, they may not be so slow to move to instant messaging which has an installed base of 1.2 billion online IM users – low hanging fruit for Mobile Instant Messaging (MIM) vendors – and is expected to grow to 1.9 billion in the next four years.[208]

Mobile Instant Messaging (MIM) is used by 8% of mobile customers worldwide according to a study by TNS Global Telecoms.[209] M:Metrics figures that MIM has grown 19% in the same timeframe with 7.9% of U.S. mobile customers sending instant messages from their handsets. That figure mirrors European uptake of MIM which, according to Forrester Research, will triple in the next three years.[210]

Analysys Research defines mobile media and entertainment services as excluding messaging, mobile browsing and data charges, and reports $3.1 billion in revenue in 2007 with a forecast of growth to $6.6 billion by 2012, a compound annual growth rate of 16.3%.[211] Analysys forcasts 2010 as the point when the technical and market environment will improve and growth will accelerate. Analysys anticipates mobile media and entertainment services will account for 12.3% of non-voice revenue by 2012, with mobile TV and video-on-demand enjoying the most significant consumer uptake. Mobile Internet services are accounting for a 13% increase in visitors to leading websites over home PC traffic alone, according to research by Nielsen. The study found that weather- and entertainment-related websites were the biggest beneficiaries of mobile Internet usage, both reporting a 22% increase in traffic. Gaming and music both reported a 15% increase while email-related websites showed an increase of 11%. The study also noted that of the 87 million U.S. mobile users that have access to mobile Internet services, around 13.7% actively use the mobile Internet each month.[212] Strategy Analytics also projects that the population of cellular users engaging in mobile content and applications delivered over cellular networks will ramp from 406 million to over 870 million in the same period.[213] Nitesh Patel, Senior Analyst, Global Wireless

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[204] *Ibid.*
[205] *CTIA- The Wireless Association Releases Latest Wireless Industry Survey Results*. CTIA. 10 September 2008.
[206] *CTIA-The Wireless Association Celebrated 25 Years of Mobile Communication.* CTIA. 10 October 2008.
[207] Makki, Leila. *Brits are SMS Mad*. Telecom TV. 29 October 2008.
[208] Gibbs, Colin. *SMS vs. MIM.* RCR. 3 May 2008.
[209] *Ibid.*
[210] *Ibid.*
[211] *Forecast: Mobile Media Revs to Double by 201*2. FierceMobileContent. 22 April 2008.
[212] *Mobile Internet Extends the Reach of Leading Internet Sites by 13%.* Nielsen. 1 May 2008.
[213] *Mobile Media and Services Spending to Reach $102 Billion in 2012. Strategy Analytics*. 17 April 2008.

Practice noted, "Over the next five years, we project continued growth in consumer acceptance and spending across a range of media applications distributed over cellular networks, particularly web access, video, music and mobile TV." [214]

Mobile financial services (MFS) are showing signs of a promising future. From about 10 million people at the end of 2007, it is envisioned that more than 1.4 billion people worldwide will benefit from mobile financial services in 2015 by using mobile wallets – software than enables consumer to manage their money, including making and receiving payments, using their mobile phone – according to research by Edgar Dunn, a specialist mobile banking and payments consultancy firm in partnership with the GSMA. [215]

Handsets can now be used to buy online, via 'swipe' points in retail outlets using Near Field Communication (NFC), and mobile-to-mobile purchase. However, the phone can be used as more than a banking tool – it can serve as the location for the account, hold all the financial information, and be used as the primary security measure. User adoption of mobile banking, in the form of remittance, money transfers, bill payments, commerce and financial transactions is on the rise with the help of driving forces from financial and credit communities, software providers, e-commerce companies, device manufacturers and mobile network operators. Research conducted by MQA Research and commissioned by Fiserv shows that 75% of consumers surveyed in April were willing to conduct mobile banking, a 26% increase from two years prior. [216]

Additionally, the results of a web-based survey by Compass Intelligence showed an estimated 7.2% of mobile phone users who are employed, and 18 years of age and older, use mobile banking. Stephanie Atkinson, Managing Partner of Compass Intelligence noted that, "the growth in smartphone adoption is expected to be a leading factor in the future adoption of mobile banking. With the rapid growth of smartphone adoption, mobile-banking becomes easier and more user-friendly because devices, especially newer models, have a resemblance to the look and feel of computers. [217]

One example of HSPA delivery of mobile banking is Telstra and the National Australia Bank (NAB) which joined to offer 3G HSPA technology based mobile ATMs (cash machines) at temporary venues. The ATMs will be deployed at major sports and cultural events across Australia to provide convenient access to cash for the public.

Although mobile payment is still a nascent service, it is expected grow to 103.9 million in 2011, according to a study by Gartner. [218] Gartner defines mobile payment as paying for a product or service using mobile technologies, such as Short Message Service (SMS), Wireless Application Protocol (WAP), Unstructured Supplementary Service Data (USSD) and Near Field Communications (NFC). The payment is made via the phone, although not necessarily over a wireless network, as in the case of NFC. SMS is the dominant mobile payment technology today, driven by mobile money transfers, and it will remain the dominant technology through 2011 according to Gartner. Gartner excluded telebanking or using a mobile phone to call the service center, as well as mobile ticketing where the ticket value has been prepaid and is stored on the phone. [219] The Asia Pacific region leads the market with 28 million projected users in 2008 – 85%

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[214] *Ibid.*
[215] *Mobile Financial Services to Thrive with the Right Regulation*. GSMA. 6 February 2008.
[216] McElligott, Tim. *The Banking Anti-Crisis*. www.billingworld.com. 30 September 2008.
[217] *An Estimated 7.2 Percent of Mobile Phone Users Use Mobile Banking.* Cellular-News. 3 November 2008.
[218] *Gartner Says Worldwide Mobile Payment Users to Total 33 Million in 2008.* Gartner. 21 April 2008.
[219] *Ibid.*

of the world's total. North America is expected to have one million users and Western Europe half that amount in 2008. [220]

Juniper Research expects over 612 million mobile phone users will generate more than $587 billion worth of financial transactions by 2011 [221] and that more than 100 million mobile users worldwide will be making international money transfers by 2013. [222]

The mobile banking end game will be about much more than checking balances and paying bills. It will evolve into a mobile wallet, allowing banks to generate greater electronic payment volume through the combination of electronic loyalty programs, mobile marketing, and contactless payments. Juniper Research reports that financial institutions are delivering an increasing variety of products in the mobile environment, from fund transfers, bill payment and presentation to account management and customer service. As a result, the annual number of global mobile banking transactions is forecast to rise from 2.7 billion in 2007 to 37 billion by 2011, as a greater number of services are deployed worldwide. Juniper expects the number of consumers accessing banking services on their mobile phones to increase tenfold over the next four years, reaching 816 million by 2011. [223]

Ovum forecasts that the mobile payment market (m-payment) will grow from $12 billion in 2007 to around $150 billion in 2012. Most of the current market originates in Japan, where mobile contactless payment and online shopping services are already well advanced. Three segments of mobile payment are also forecast by Ovum: 1) Mobile contactless payments are expected to grow from $3 billion in 2007 to $52 billion in 2012. This market mainly lies in Japan, North America, Western Europe as well as a few developed Asia-Pacific countries; 2) Online shopping is expected to grow from $8 billion in 2007 to $41 billion in 2012. It is anticipated that as the Internet becomes mobile with a new generation of mobile devices and Internet access tariffs, a growing share of the business-to-consumer e-commerce market will take place on mobiles; 3) The money transfers sector is expected to grow from $1 billion in 2007 to $58 billion in 2012. This market opportunity lies mainly in developing countries. [224]

The mobile entertainment market — including ringtones, mobile games, mobile music, mobile TV and video services, full-track music downloads, ringback tones, and graphics/themes — is expected to account for 5.1% of the estimated $800 billion in total global wireless service revenue by 2011, and 23% of all mobile data revenue according to IDC forecasts. [225] IDC sees the vast majority of mobile entertainment revenue derived from ringtones, ringback tones and mobile TV and video services.

According to comScore, mobile video penetration was at 3% in the U.S. In the month of August 2008, comScore numbers showed that 6.5 million Americans watched mobile video. AT&T, exclusive carrier of the iPhone, ranked highest among providers, with 4.4% of subscribers accessing programmed or on-demand mobile video. On-demand video was the most popular, with 3.6 million viewers and of that,

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[220] *Ibid.*
[221] *Financial Transactions Conducted Via Mobile Phone to Generate Over $587 billion by 2011*. Juniper Research. 30 January 2008.
[222] McElligott, Tim. *The Banking Anti-Crisis*. www.billingworld.com. 30 September 2008.
[223] *Source: Juniper Research, Mobile Financial Services Banking & Payment Markets 2007-2011*. Juniper Research. February 2008. Referenced in *Mobile Banking Users to Increase Tenfold by 2011*. Telecoms.com. 17 April 2008.
[224] *Mobile Payment Market Forecasts*. Ovum. 23 April 2008.
[225] *IDC Predicts Ringback Tones Will Be the Single Largest Source for Mobile Entertainment Revenue by 2010*. IDC. 4 March 2008.

amateur content (read: YouTube) was most popular with 1.3 million viewers, followed by music videos and comedy. [226]

Mobile video messaging services are at the center of the technology convergence that is allowing mobile customers to achieve greater levels of self-expression and online community participation. ABI Research expects the opportunity for mobile video services to produce a compound annual growth rate of nearly 60%, amounting to $10 billion in 2012. [227]

With the growth of sophisticated devices like the iPhone, video sites such as YouTube, and Wi-Fi and 3G networks, consumers are downloading more videos on their phones. Analyst firm ARC estimated that the mobile online video market would generate worldwide revenue of $5 billion in 2008. [228] Mobile video is being facilitated by advances in solutions that automate real-time adaptation and delivery of video content over multiple networks to any device.

Music delivered to mobile phones via operators' networks (mobile music) is on the rise, currently representing around 13% of global recorded music retail value. A report from Understanding & Solutions forecasts an increase to almost 30% by 2011, amounting to $11 billion. [229] Since most new handsets now come with built-in music functionality, and recent developments from manufacturers and operators have helped improve the user experience when searching for, purchasing and using mobile music, many barriers have been removed for this mobile entertainment segment. [230]

More users are playing games on their handsets. According to Juniper Research, on-portal mobile gambling is expected grow to more than $27.5 billion by 2013 as the result of a dramatic shift in operator attitudes towards mobile wagering, handset UI improvements and legislative changes that allow for more markets to introduce remote betting. While EU intervention is influencing liberalization of European gambling markets, there remains minimal if any progress in the U.S. market, where remote gambling services are still prohibited. Juniper predicts that U.S. commercial wagering deployments will not arrive until 2010 at the very earliest. [231]

Sports-betting, in particular, is expected to excel, comprising the majority of annual mobile wagers over the next five years, but mobile lottery services – which are increasingly popular in key Latin American and Asian markets – will achieve the highest adoption level, attracting close to 400 million worldwide users by the end of 2013. [232] Juniper forecasts that global gross win from mobile gambling services will increase from just under $192 million in 2008 to $3.4 billion by 2013 and that, moving forward, Western Europe will remain the largest regional market. [233]

Mobile search ads will create their own sector of business in the advertising space. According to ABI Research, the market for mobile search ads is projected to jump from $813 million in 2008 to $5 billion in 2013. Over the same period, SMS searches will increase nearly six-fold, from 13 billion to in excess of 76 billion. [234]

[226] Albrecht, Chris. *ComScore: 6.5Mj Mobile Vid Watchers in August*. New TeeVee. 31 October 2008.
[227] *A $10 billion Mobile Video Messaging Opportunity for 2012*. ABI Research. 9 April 2008.
[228] *Dilithium Unveils Content Adaptor for Real-Time Mobile Video.* Dilithium. 13 May 2008.
[229] *Mobile to Account for 30% of Music Retail Value by 2011*. Understanding and Solutions. December 2007.
[230] *Ibid.*
[231] Ankeny, Jason. *Forecast: Mobile Gambling Growth to $27.5B by 2013*. FierceWireless. 5 November 2008.
[232] *Ibid.*
[233] *Ibid.*
[234] *Mobile Search Critical as Search Advertising Races Towards $5 Billion in 2013*. ABI Research. 16 April 2008.

Juniper Research expects nearly 1.3 billion users – 30% of the mobile subscriber base – to use local mobile search services by 2013.[235] Juniper believes that advertising supported local search will be the key to driving this sector, with the caveat that the effectiveness of advertising in this sector will vary widely according to local conditions. The best equipped regions are thought to be Western Europe and North America, as countries within these regions typically have good local digital information suppliers such as Yellow and White Pages, as well as good mapping data. Total mobile search revenues are expected to reach $4.8 billion by 2013 with the caution from Juniper that “advertising overload” might act as a disincentive to consumers.[236]

Every six months, The Mobile Marketing Association updates its global Mobile Advertising Guidelines providing advertising guidelines and best practices necessary to implement mobile advertising initiatives, including mobile web banner, MMS messaging, downloadable applications and mobile TV and video.[237] With guidelines in place, consumers can expect to see more ads on mobile phones. Informa Telecoms & Media projected the mobile advertising industry would be worth $1.72 billion in 2008 and will rise to $12.09 billion in 2013.[238] According to eMarketer, worldwide spending on mobile advertising reached nearly $2.7 billion in 2007 and was expectedo each $4.6 billion in 2008, rising to $19.1 billion by 2012.[239] Most ad dollars will go to text messaging; SMS, MMS text-messaging and mobile instant messaging. Mobile email will account for more than $14 billion of the $19 billion total expected in 2012; up from $2.5 billion in 2007. The expansion of display and search advertising on mobile phones worldwide is expected to reach $1.2 billion and $3.7 billion respectively by 2012.[240]

Arthur D. Little predicts that in the coming years, mobile advertising is poised to be the next major digital media platform for brands to reach customers, and the key telecoms players have a great deal to gain from bringing their services to the market early.[241] Roughly 60% annual growth in mobile advertising spending over the next four years is predicted in its 2008 report. Future mobile advertising formats will be more interactive and dynamic than online advertising or mobile advertising today, including call waiting, idle-screen advertisements, mobile TV ads, games and voicemail ads. Push ads via SMS/MMS are another traditional option. The Arthur D. Little report cites the Blyk case study: Blyk, a UK-based Mobile Virtual Network Operator, successfully launched large-scale mobile advertising to early adopters with a 29% response rate by using highly defined target groups and user data to achieve such a positive rate compared to .05% response rate for typical online marketing campaigns.[242]

A report from GfK and social network website, Limbo revealed that mobile advertising awareness grew 33% in nine months, suggesting an increased allocation of advertising dollars to mobile formats through the first nine months of 2008. Nearly four out of ten, or 104 million, Americans with a mobile phone recall seeing advertising on their devices between the months of July and September 2008, marking the first time the number of Americans aware of mobile advertising has exceeded 100 million in a three month period.[243] The most commonly viewed mobile ads were in the form of SMS messages, reaching 60 million consumers – a 42% increase in nine months. The report also noted that although Mobile Web

[235] *Local Mobile Search Finds Favor*. Juniper Research. 29 April 2008.
[236] *Ibid.*
[237] *Mobile Marketing Association Publishes Updated Global Mobile Advertising Guidelines.* Mobile Marketing Association. 28 October 2008.
[238] *Mobile Advertising: Cutting Through the Hype, 2nd Edition.* Informa Telecoms & Media. 10 July 2008.
[239] *eMarketer: Worldwide mobile ad spending to hit $19.1 billion by 2012.* eMarketer. 27 March 2008.
[240] *Ibid.*
[241] Little, Arthur D. *Report Forecasts 60% Annual Growth in Mobile Advertising over the Next 4 Years*. 20 May 2008.
[242] *Ibid.*
[243] *More Than 100 Million Americans Viewed Mobile Ads in Q3 2008.* Cellular-News. 3 November 2008.

advertising had about half the reach of SMS ads, it also saw strong growth, with 31 million people recalling ads in this format. [244]

A report by Media Analyst Screen Digest examined the emerging market for rich media advertising delivered to consumers via their mobile phone in the form of TV, video, games, user-generated content (UGC) and music. Screen Digest projects the market for rich media advertising on mobile will reach $2.79 billion by 2012, with global mobile TV advertising accounting for the lion's share at $2.44 billion. By 2012, advertising will account for 20% of mobile TV revenues. The reason for success? More ubiquitous than the PC, the mobile method offers the opportunity to send personalized messages to people in all markets. Advertising sent via mobile phones reaches the recipient directly, wherever they are, at any time and location, offering effective targeting as well as interactivity and consumer engagement. "The potential is huge, and some of the world's largest companies are vying for control of what they see as the next major advertising medium," stated David MacQueen, co-author of the report. [245]

Key findings of survey conducted by Transverse and iGR consultancy provided insight to mobile customers' phone use and their willingness to view advertisements in exchange for discounts to their monthly service bill. "Mobile advertising has taken on many forms, and is generally considered to be obtrusive. But when consumers are given the choice to receive ads and share their usage patterns in exchange for discounts, mobile advertising has the potential to be highly targeted and highly effective," stated Iain Gillott, President of iGR. [246] Among those surveyed, 46% said that a 25 to 50% discount on their monthly bill was enough of an incentive to provide access to their usage patterns, including browsing, email and texting habits, as well as location – but not personal information such as the content of texts and emails.

Another area of tremendous growth will be in machine-to-machine (M2M) wireless mobile connections. Berg Insight estimates the number of cellular connections used for M2M communication will grow from 37.5 million connections in 2007 at a CAGR of 37.9% to 186 million connections in 2012. [247] At of the end of 2007, the GSM family of technologies dominated the market and accounted for 71% of the total number of active connections. UMTS/WCDMA has primarily been adopted for M2M applications in Japan. Berg Insight found that, in general, the number of M2M applications corresponded to between 1-3% of the reported number of mobile subscribers in developed markets. [248]

ABI Research sees continued strong growth in machine-to-machine communications markets with about 95 million cellular M2M modules shipping in 2013. Of shipments to the three main market segments – telematics, telemetry and wireless local loop – about 34 million devices are expected to be for telematics and 39 million for telemetry. [249] Until about 2011, the major growth will be found in the telemetry segment, since it encompasses a wide range of applications including smart metering, POS terminals, and remote monitoring and control applications. After 2011, ABI expects to see a spike in telematics applications, which exist now, but from 2011 will be driven by mandates such as Europe's eCall initiative (cellular connections in every vehicle) and in North America by a much stronger competitive reaction to OnStar. [250] ABII Research also predicts that in 2012, there will be a strong overall growth in North American

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[244] *Ibid.*
[245] *Mobile Advertising Using Rich Media Formats*. Screen Digest. 29 April 2008.
[246] *Survey Finds 61 Percent of Mobile Users Would Agree to View Advertising for Discount on Monthly Bill.* FierceWireless. 18 November 2008.
[247] *Berg Insight Says 186 Million Machines will be Connected to Mobile Networks in 2012*. Berg Insight. 6 May 2008.
[248] *Ibid.*
[249] *95 Million Cellular M2M Modules to Ship in 2013*. Analyst Insider from ABI Research. 19 November 2008.
[250] *Ibid.*

telematics revenue – which includes commercial, OEM and aftermarket – reaching almost $1.5 billion. On the other hand, Telemetry – which includes AMI, security, RMAC and vending – will accrue revenue not quite $1.2 billion. [251]

Berg Insight forecasts that vehicle telematics applications will dominate the machine-to-machine cellular market in most parts of the world and account for more than half of all network connections in 2012. "In North America OnStar already gives peace of mind to millions of drivers. Europe is well on the way to introducing the eCall automatic emergency call system and several Latin Americas countries are considering mandatory tracking devices on all new cars to combat epidemic vehicle crime," stated Tobias Ryberg, senior analyst. [252]

[251] *Telematics Outshines Telemetry in North America, According to ABI Research.* Business Wire. ABI Research. 22 February 2008.

[252] *Berg Insight Says 186 Million Machines will be Connected to Mobile Networks in 2012*. Berg Insight. 6 May 2008.

Further Information on IP Multimedia Subsystem (IMS)

The growth of IMS was confirmed by Mind Commerce stating that IMS components and User Equipments (UEs) are poised for an explosive growth in the duration 2008-2012. The IMS Component market will grow from and expected $1.6 billion in 2008 to nearly $8 billion in 2012 at a CAGR of 49% and the UE market will grow from 3.9 billion in 2008 to 34.9 billion in 2012 at a CAGR of 73%. [253]

[253] *Multimedia Subsystem (IMS): The Market for Components and User Equipment*. Reportthinker.com. January 2008.

GLOBAL UMTS AND HSPA OPERATOR STATUS		UMTS Summary			HSPA Summary		
31-Dec-08	Red = commercially available	UMTS OPERATORS IN SERVICE	270		HSDPA OPERATORS IN SERVICE		252
Source: Informa Telecoms & Media, WCIS		COUNTRIES IN SERVICE	117		HSDPA COUNTRIES IN SERVICE		112
		PLANNED + IN DEPLOYMENT	53		HSDPA PLANNED + IN DEPLOYMENT		57
Information accurate to the best of our knowledge as of date published		POTENTIAL & LIC. AWARDED	28		HSUPA OPERATORS IN SERVICE		60
Please send updates to info@3gamericas.org		EDGE + UMTS COMMERCIAL	189		HSUPA PLANNED		101
Country	**Operator**	**UMTS Status**	**Start Date**	**EDGE**	**HSDPA Status**	**Start Date**	**HSUPA**
Latin America							
Argentina	Claro (America Movil)	In Service	Nov-07	EDGE	In Service	Nov-07	Dec-09
Argentina	Telecom Personal	In Service	May-07	EDGE	In Service	May-07	
Argentina	Telefonica Moviles (Movistar)	In Service	Jul-07	EDGE	In Service	Jul-07	
Aruba	SETAR	In Service	Dec-07		In Service	Dec-07	
Bolivia	Millicom (Tigo)	In Service	Aug-08	EDGE	In Service	Aug-08	
Brazil	Brasil Telecom	In Service	May-08	EDGE	In Service	May-08	
Brazil	CTBC	In Service	Apr-08	EDGE	In Service	Apr-08	
Brazil	Sercomtel	In Service	Dec-08	EDGE	In Service	Dec-08	
Brazil	Claro (America Movil)	In Service	Nov-07	EDGE	In Service	Nov-07	
Brazil	Oi	In Service	May-08	EDGE	In Service	Dec-08	
Brazil	TIM	In Service	Apr-08	EDGE	In Service	Apr-08	
Brazil	VIVO	In Service	Sept-08	EDGE	In Service	Sep-08	**Sep-08**
Chile	Entel PCS	In Service	Dec-06	EDGE	In Service	Dec-06	
Chile	Claro (America Movil)	In Service	Jan-08		In Service	Jan-08	
Chile	Telefonica Moviles / Movistar	In Service	Dec-07	EDGE	In Service	Dec-07	
Colombia	Milicom (Tigo)	In Service	Dec-08	EDGE	In Service	Dec-08	
Colombia	Comcel (America Movil)	In Service	Jan-08	EDGE	In Service	Jan-08	
Colombia	Movistar (Telefonica Moviles)	In Service	Dec-08	EDGE	In Service	Dec-08	
Costa Rica	ICE Telefonia Celular	In Deployment	Q4 2010		Planned	Q4 2010	
Dominican Rep.	Claro (America Movil)	In Service	Sep-08	EDGE	In Service	Sep-08	
Ecuador	Porta (America Movil)	In Service	Sep-08	EDGE	In Service	Sep-08	

Ecuador	Movistar (Telefonica Moviles)	Planned	Q1 2009	EDGE	Planned	Q1 2009	
El Salvador	Claro (America Movil)	In Service	Jan-08		In Service	Jan 08	2009
El Salvador	Millicom (Tigo)	In Service	Aug-08	EDGE	In Service	Aug-08	
French West Indies	Outremer Telecom	In Deployment	Mar-09		In Deployment	Mar-09	Jan-13
Guatemala	Claro (America Movil)	In Service	Apr-08	EDGE	In Service	Apr-08	
Guatemala	Millicom (Tigo)	In Service	Aug-08	EDGE	In Service	Aug-08	
Honduras	Millicom (Tigo)	In Service	Aug-08	EDGE	In Service	Aug-08	
Honduras	Claro (America Movil)	In Service	Feb-08		In Service	Aug-08	Jun-09
Jamiaca	Claro (America Movil)	In Service	Sep-08	EDGE	In Service	Sept-08	
Mexico	Telcel (America Movil)	In Service	Feb-08	EDGE	In Service	Feb-08	Jun-09
Mexico	Telefonica Moviles/Movistar	In Service	Nov-08	EDGE	In Service	Nov-08	
Nicaragua	Claro (America Movil)	In Service	Apr-08		In Service	Apr-08	
Panama	Movistar (Telefonica Moviles)	In Service	Dec-08	EDGE	In Service	Dec-08	
Paraguay	Claro (America Movil)	In Service	Nov-07	EDGE	In Service	Nov-07	
Paraguay	Millicom (Tigo)	In Service	Aug-08	EDGE	In Service	Aug-08	
Paraguay	Personal	In Service	Mar-08	EDGE	In Service	Mar-08	
Peru	Claro (America Movil)	In Service	Apr-08	EDGE	In Service	Apr-08	
Puerto Rico	AT&T	In Service	Nov-08	EDGE	In Service	Nov-06	Dec-08
Puerto Rico	Claro (America Movil)	In Service	Sep-08	EDGE	In Service	Sep-08	
Uruguay	Ancel	In Service	Jul-07	EDGE	In Service	Jul-07	Dec-08
Uruguay	Claro (America Movil)	In Service	Nov-07		In Service	Nov-07	
Uruguay	Telefonica Moviles /Movistar	In Service	Jul-07	EDGE	In Service	Jul-07	
Venezuela	Movistar (Telefonica Moviles)	In Service	Dec 08	EDGE	In Service	Dec 08	
Venezuela	Digitel	Planned	2009	EDGE	Planned	2009	
Venezuela	Movilnet	Planned	Dec-09		Planned	Dec-09	
North America							
Canada	BCE	Planned	N/A		Planned		
Canada	Rogers Wireless	In Service	Nov-06	EDGE	In Service	Nov-06	**Jul-08**
Canada	Telus	Planned	N/A		Planned		
USA	AT&T	In Service	Jul-04	EDGE	In Service	Dec-05	**Nov-07**
USA	Cincinnati Bell Wireless	In Deployment	2009	EDGE			
USA	Edge Wireless	In Deployment	Dec-08	EDGE	In Deployment	Dec-08	Mar-09
USA	Stelera Wireless / Data Only	In Service	Dec-07		In Service	Dec-07	**Dec-07**
USA	T-Mobile USA	In Service	May-08	EDGE	In Service	May-08	Planned
USA	Terrestar	In Deployment	2008		In Deployment	2008	
Western Europe							
Israel	Cellcom Israel	In Service	Jun-04	EDGE	In Service	Jun-06	**Sep-07**

Israel	Pelephone (CDMA to HSDPA)	In Deployment	Dec-08		In Deployment	Dec-08	
Israel	Partner Comm. (Orange)	In Service	Nov-04		In Service	Mar-06	**Dec-07**
Andorra	STA	In Service	Dec-06		Planned	Dec-08	Dec-08
Austria	ONE (Orange Plc)	In Service	Dec-03		In Service	Jun-06	Dec-08
Austria	Hutchison 3G (3)	In Service	May-03		In Service	Sep-06	**Jan-08**
Austria	Mobilkom Austria	In Service	Apr-03	EDGE	In Service	Jan-06	**Aug-07**
Austria	T-Mobile Austria	In Service	Dec-03	EDGE	In Service	Mar-06	**Jun-08**
Belgium	KPN BASE (Orange)	In Deployment	Mar-09	EDGE	Planned	Mar-09	Mar-09
Belgium	Belgacom Mobile (Proximus)	In Service	Sep-05	EDGE	In Service	Jun-06	**Jul-08**
Belgium	Mobistar	In Service	Dec-06	EDGE	In Service	Jun-07	**Jan-08**
Cyprus	MTN (Areeba)	In Service	Oct-05	EDGE	In Service	Mar-08	Jun-09
Cyprus	Kibris Telsim	Planned	Jun-09		Planned	Jun-09	
Cyprus (Northern)	KKT Cell (Turkcell)	Planned	N/A		Planned	N/A	
Cyprus	CYTA Mobile	In Service	Mar-06		In Service	Jun-08	Jun-09
Denmark	3	In Service	Oct-03		In Service	Nov-06	Mar-09
Denmark	Sonofon	In Service	Sep-06	EDGE	In Service	Sep-07	Mar-09
Denmark	TDC Mobil	In Service	Nov-05		In Service	Jan-08	Mar-09
Denmark	TeliaSonera	In Service	Dec-07	EDGE	In Service	Dec-07	**Mar-08**
Finland	Alands Mobiltelefon	In Service	Jun-06	EDGE			
Finland	Finnet / DNA Finland	In Service	Dec-05	EDGE	In Service	Feb-07	**Dec-08**
Finland	Elisa	In Service	Nov-04	EDGE	In Service	Apr-06	**Dec-08**
Finland	Sonera	In Service	Oct-04	EDGE	In Service	May-07	Jun-09
France	Bouygues Telecom	In Service	Apr-07	EDGE	In Service	Apr-07	**Nov-07**
France	Orange France	In Service	Dec-04	EDGE	In Service	Oct-06	**Jan-08**
France	SFR	In Service	Nov-04	EDGE	In Service	Jun-06	**May-08**
Germany	E-Plus	In Service	Aug-04		In Deployment	Dec-08	Mar-09
Germany	O2	In Service	Jul-04		In Service	Dec-06	Mar-09
Germany	T-Mobile Deutschland	In Service	May-04	EDGE	In Service	Mar-06	**Nov-07**
Germany	Vodafone D2	In Service	May-04	EDGE	In Service	Mar-06	**Jul-07**
Greece	Cosmote	In Service	May-04	EDGE	In Service	Jun-06	**Apr-08**
Greece	Panafon (Vodafone)	In Service	Aug-04		In Service	Nov -06	Mar-09
Greece	WIND Hellas (TIM)	In Service	Jan-04	EDGE	In Service	Sep-08	Mar-09
Guernsey	Wave Telecom	In Service	Jul-04	EDGE	In Service	Nov-06	Mar-09
Guernsey	C&W Guernsey /Sure.mobile	In Service	Sep-07	EDGE	In Service	Sep-07	Mar-09
Guernsey	Airtel-Vodafone	In Service	Mar-08		In Service	Mar-08	
Iceland	NOVA	In Service	Sep-07		In Service	Dec-07	Mar-09
Iceland	Iceland Telecom / Siminn	In Service	Sep-07	EDGE	In Service	Sep-07	**Sep-07**
Ireland	Hutchison (3)	In Service	Jul-05		In Service	Dec 06	Mar-09
Ireland	O2	In Service	Mar-05	EDGE	In Service	Jul-07	**Jul-08**
Ireland	Vodafone Ireland	In Service	Nov-04		In Service	Dec-06	Mar-09
Ireland	Meteor Communications	In Service	Sept-08	EDGE	In Service	Sept-08	

Isle of Man	Manx Telecom	In Service	Nov-05		In Service	Nov-05	Mar-09
Italy	H3G (3)	In Service	Mar-03		In Service	Feb-06	**Jul-07**
Italy	TIM	In Service	May-04	EDGE	In Service	May-06	**Oct-07**
Italy	Vodafone Italia	In Service	May-04		In Service	Jun-06	**Sep-07**
Italy	Wind	In Service	Oct-04	EDGE	In Service	Jun-07	Mar-09
Jersey	Cable & Wireless /sure.Mobile	In Service	Sep-06	EDGE	In Service	Dec-07	Mar-09
Jersey	Jersey Telecoms	In Service	Jun-06		In Service	Sep-07	Mar-09
Jersey	Airtel-Vodafone	In Service	Jun-07	EDGE	In Service	Jun-07	
Liechtenstein	Orange	In Service	Feb-07		In Service	June-07	Dec-08
Liechtenstein	mobilkom	In Service	Mar-07		In Service	Mar-07	Dec-08
Liechtenstein	Telecom FL (Swisscom)	In Service	Feb-07	EDGE	In Service	Jun-07	Dec-08
Liechtenstein	Tele2 (Tango)	In Service	Jun-08		In Service	Jun-08	Dec-08
Luxembourg	LUX Communications (VOX)	In Service	May-05	EDGE	In Service	Jun-07	Mar-09
Luxembourg	P&T Luxembourg (LUXGSM)	In Service	Jun-03	EDGE	In Service	May-07	Mar-09
Luxembourg	Tele2 (Tango)	In Service	Jul-04		In Service	Dec-07	Mar-09
Madeira	Optimus	In Service	Feb-06		In Service	Feb-06	
Malta	MobIsle Comm. (go mobile)	In Service	Apr-07	EDGE	In Service	Apr-07	Mar-09
Malta	Vodafone	In Service	Aug-06		In Service	Dec-06	Mar-09
Monaco	Monaco Telecom / Monacell	In Service	Jun-06		Planned	Mar-09	
Netherlands	KPN Mobile (Telfort)	In Service	Oct-04	EDGE	In Service	Dec-06	**Feb-08**
Netherlands	T-Mobile Netherlands	In Service	Jan-06	EDGE	In Service	Apr-06	Dec-08
Netherlands	Vodafone Libertel	In Service	Jun-04		In Service	Jul-06	Dec-08
Norway	Hi3G Access	Planned	Mar-09		Planned	Mar-09	Mar-09
Norway	Netcom (TeliaSonera)	In Service	Jun-05	EDGE	In Service	Apr-07	Mar-09
Norway	Telenor Mobil	In Service	Dec-04	EDGE	In Service	Nov-07	Mar-09
Portugal	Optimus	In Service	Jun-04		In Service	Dec-06	Mar-09
Portugal	TMN (Telemovel)	In Service	Apr-04		In Service	Apr-06	Mar-09
Portugal	Vodafone Telecel	In Service	May-04		In Service	Mar-06	**Sep-07**
Spain	Amena / Orange	In Service	Oct-04		In Service	Jun-06	**Apr-08**
Spain	Telefónica Móviles (Movistar)	In Service	May-04		In Service	Oct-06	**Aug-07**
Spain	Vodafone España	In Service	May-04		In Service	Jun-06	**Sep-07**
Spain	Xfera (Yoigo)	In Service	Dec-06		In Service	Dec-07	**Dec-08**
Sweden	HI3G	In Service	May-03		In Service	Nov-06	**Sep-07**
Sweden	TeliaSonera	In Service	Mar-04	EDGE	In Service	June-07	
Sweden	Svenska UMTS-Nät (Tele2)	In Service	Mar-04		In Service	April-07	Mar-09
Sweden	Telenor Sverige AB (Vodafone)	In Service	Jul-04		In Service	Jun-07	Mar-09
Switzerland	Orange	In Service	Sep-05	EDGE	In Service	Apr-07	Dec-08
Switzerland	Swisscom Mobile	In Service	Dec-04	EDGE	In Service	Mar-06	**Feb-08**

Switzerland	TDC Switzerland (sunrise)	In Service	Dec-05	EDGE	In Service	Feb-07	**Mar-08**
Switzerland	Team 3G	License Awarded					
UK	Hutchison 3G (3)	In Service	Mar-03		In Service	Aug-06	Dec-08
UK	O2	In Service	Mar-05		In Service	Feb-07	**Sep-08**
UK	Orange	In Service	Dec-04	EDGE	In Service	Feb-07	**Apr-08**
UK	T-Mobile UK	In Service	Oct-05		In Service	Aug-06	**Jul-08**
UK	Vodafone	In Service	Nov-04		In Service	Jun-06	**Sep-07**
Eastern Europe							
Albania	Eagle Mobile	In Service	Mar-08	EDGE	Planned	Dec-08	Dec-08
Armenia	K-Telecom/Vivacell/MTS	Planned	Q1 2009				
Armenia	Armentel	Planned	Q1 2009				
Belarus	MTS Belarus	Planned	Q4 2009	EDGE	Planned	Q4 2009	
Bosnia-Herzegovina	BH Telecom	In Deployment	Mar-09		In Deployment	Mar-09	
Bosnia-Herzegovina	HT Mostar	In Deployment	Mar-09		In Deployment	Mar-09	
Bosnia-Herzegovina	Telkom Srpske	In Deployment	Mar-09		In Deployment	Mar-09	
Bulgaria	BTC (Vivatel)	In Service	Apr-07	EDGE	In Service	Apr-07	Mar-09
Bulgaria	Cosmo Bulgaria Mobile/Globul	In Service	Jun-06		In Service	Sep-06	Mar-09
Bulgaria	MobilTel (M-TEL/Vodafone)	In Service	Mar-06	EDGE	In Service	Mar-06	**Aug-07**
Croatia	T-Mobile	In Service	Jan-06	EDGE	In Service	Nov-06	
Croatia	Tele2	Planned	Mar-09		Planned	Dec-08	
Croatia	VIPNet	In Service	Oct-05	EDGE	In Service	Apr-06	**Apr-07**
Czech Republic	Telefonica O2 (Eurotel)	In Service	Dec-05	EDGE	In Service	Apr-06	Jan-09
Czech Republic	T-Mobile	In Service	Dec-06	EDGE	In Deployment	Sep-09	
Czech Republic	Vodafone	In Deployment	Mar-09	EDGE	In Deployment	Mar-09	
Estonia	Elisa / Radiolindja	In Service	Jun-06	EDGE	In Service	Jan-08	Mar-09
Estonia	Bravocom	In Service	July 06	EDGE	In Service	Jul-06	
Estonia	EMT	In Service	Oct-05	EDGE	In Service	Apr-06	**Dec-07**
Estonia	Tele2 Eesti	In Service	Nov-06		In Service	Nov-06	Jun-09
Estonia	ProGroup Holding	In Deployment	Jun-09		In Deployment	Jun-09	Jun-09
Georgia	Geocell	In Service	Dec-06		In Service	Jun-08	
Georgia	Telecom Invest Georgia	License Awarded	Q1 2009				
Georgia	Magticom	In Service	Jul-06	EDGE			
Hungary	Pannon GSM	In Service	Oct-05	EDGE	In Service	Aug-07	Dec-08
Hungary	T-Mobile	In Service	Aug-05	EDGE	In Service	Sep-06	**Sep-07**
Hungary	Vodafone	In Service	Jun-06		In Service	Jun-07	Dec-08
Latvia	Bité	In Service	Jun-06	EDGE	In Service	Jul-07	**Feb-08**

Latvia	LMT	In Service	Dec-04	EDGE	In Service	Aug-06	Dec-08
Latvia	Tele2	In Service	Dec-05		In Service	Mar-07	Dec-08
Lithuania	Bité	In Service	Apr-06	EDGE	In Service	Jun-06	**Feb-08**
Lithuania	Omnitel	In Service	Feb-06	EDGE	In Service	Jun-06	Dec-08
Lithuania	Tele2 (Tango)	In Service	Mar-07		Planned	Jun-09	Mar-09
Macedonia	Cosmofon	In Service	Aug-08	EDGE	In Service	Aug-08	
Moldava	Moldcell	In Service	Oct-08		In Service	Oct-08	
Montenegro	T-Mobile	In Service	Jun-07	EDGE	In Service	Jun-07	Mar-09
Montenegro	ProMonte	In Service	Jun-07	EDGE	In Service	Jun-07	Mar-09
Montenegro	M:Tel (Telekom Srbija)	In Service	Jul-07	EDGE	In Service	Jul-07	
Poland	Centertel (Orange)	In Service	Jun-06	EDGE	In Service	Dec-06	**Dec-07**
Poland	P4 (Play)	In Service	Mar-07		In Service	Mar-07	Dec-08
Poland	Polkomtel / Plus GSM	In Service	Sep-04	EDGE	In Service	Oct-06	**Dec-07**
Poland	Polska Telefonia Cyfrowa (Era)	In Service	Apr-06	EDGE	In Service	Oct-06	**Sep-08**
Romania	MobiFon / Vodafone	In Service	Apr-05		In Service	May-06	**Mar-08**
Romania	Orange Romania	In Service	Jun-06	EDGE	In Service	Jun-07	**Oct-07**
Romania	ZAPP Mobile (ex-CDMA)	In Service	May-08		In Service	May-08	
Romania	DigiMobile (RCS&RDS)	In Service	Feb-07		In Deployment	Dec-08	Dec-08
Russia	VimpelCom	In Service	Sep-08		In Service	Sep-08	
Russia	MegaFon	In Service	Oct-07	EDGE	In Service	Oct-07	Mar-09
Russia	Mobile TeleSystems (MTS)	In Service	May-08		In Service	May-08	
Serbia	Telenor (Ex-Mobtel)	In Service	Mar-07	EDGE	In Service	Mar-07	
Serbia	Telecom Srbija	In Service	Dec-06	EDGE	In Service	Dec-06	
Serbia	VIP Mobile (TopNet)	In Service	Jul-07				
Slovak Republic	Orange Slovensko	In Service	Mar-06	EDGE	In Service	Sep-06	**Nov-07**
Slovak Republic	T-Mobile Slovakia	In Service	Jan-06	EDGE	In Service	Aug-06	Dec-09
Slovak Republic	Telefonica O2 Slovak Republic	Planned	Mar-09	EDGE			
Slovenia	Mobitel	In Service	Dec-03	EDGE	In Service	Sep-06	**Dec-07**
Slovenia	Si.Mobile (Vodafone)	In Service	Sep-07	EDGE	In Service	Sep-07	Mar-09
Slovenia	T-2	In Deployment	Mar-09		Planned	Mar-09	
Slovenia	Tus Mobile	In Service	Jul-07		In Service	Jul-08	Mar-09
Tajikistan	Josa Babilon Mobile	In Service	Jun-05		Planned	Dec-08	
Tajikistan	Indigo Tajikistan	In Service	Sep-06		In Deployment	Mar-09	
Tajikistan	Tacom	In Service	Sep-06		In Service	Sep-08	
Tajikistan	TT Mobile	In Service	Jun-05		Planned	Jun-09	
Turkey	AVEA	Potential License	Q4 2009	EDGE			
Turkey	Telsim	Potential License	Q4 2009				
Turkey	Turkcell	Potential Licence	Q4 2009	EDGE			
Ukraine	life:)	In Trial	n/a		In Trial	n/a	
Ukraine	Ukrtelecom	In Service	Nov-07		In Service	Nov-07	
Uzbekistan	Unitel (Beeline)	Planned	Q1 2009				

Uzbekistan	Coscom	Planned	Q1 2009		In Trial	n/a	
Uzbekistan	MTS-Uzbekistan	In Service	Dec-08		In Service	Dec-08	
Uzbekistan	Uzdunrobita	Planned	Q1 2009		Planned	n/a	
Middle East							
Bahrain	Batelco	In Service	Dec-07	EDGE	In Service	Dec-07	
Bahrain	Zain (ex-MTC Vodafone)	In Service	Dec-03	EDGE	In Service	May-06	
Kuwait	Zain	In Service	Mar-06	EDGE	In Service	Jan-07	Mar-09
Kuwait	Wataniya Telecom	In Service	Mar-06	EDGE	In Service	Mar-06	
Oman	Nawras Telecom (TDC)	In Service	Dec-07	EDGE	In Service	Dec-07	
Oman	Oman Mobile / Omantel	In Service	Dec-08		In Service	Dec-08	Dec-08
Qatar	Q-TEL	In Service	Jul-06		In Service	Jul-07	
Saudi Arabia	Etisalat / Mobily	In Service	Jun-06	EDGE	In Service	Jul-06	
Saudi Arabia	STC/ Al Jawwal	In Service	Jun-06	EDGE	In Service	Jun-06	
Saudi Arabia	Zain	In Service	Aug-08	EDGE	In Service	Aug-08	Dec-08
Syria	MTN	In Deployment	Jan-09	EDGE	Planned	Jan-09	
Syria	SyriaTel	In Service	Aug-08	EDGE	In Service	Aug-08	
UAE	Etisalat	In Service	Jan-04	EDGE	In Service	Apr-06	
UAE	Du	In Service	Feb-07	EDGE	In Service	May-07	
Africa							
Cote D'Ivoire	Orange Cote d'Ivoire	Potential License	Q1 2009				
Egypt	Etisalat Misr	In Service	May-07	EDGE	In Service	May-07	
Egypt	MobiNil (ECMS)	In Service	Sep-08	EDGE	In Service	Sep--08	
Egypt	Vodafone Egypt	In Service	May-07		In Service	May-07	
Ghana	Scancom - MTN	In Deployment	Mar-09		In Deployment	Mar-09	
Ghana	Zain (Western Telesystems)	In Service	Dec-08		In Service	Dec-08	
Kenya	Safaricom	In Service	Dec-07	EDGE	In Service	Mar-08	
Libya	El Madar Tel. Company (Orbit)	In Deployment	Jan-09	EDGE	In Deployment	Jan-09	
Libya	Libyana	In Service	Sep-06		In Service	Sep-08	
Mauritius	Cellplus Mobile Communications	In Service	Mar-06		In Service	Dec-07	
Mauritius	Millicom Mauritius (Emtel)	In Service	Nov-04		In Service	Sep-07	
Morocco	Ittissalat Al-Magreb / Maroc Telecom	In Service	Jan-08		In Service	Jan-08	
Morocco	Medi Telecom (Meditel) Mobile ADSL	In Service	Apr-07		In Service	Apr-07	
Mozambique	mCel	In Service	Dec-08		In Service	Dec-08	
Namibia	MTC	In Service	Dec-06	EDGE	In Service	Dec-06	Jun-09
Namibia	Powercom -Cell One	In Service	Mar-07		In Service	Jun-07	Sep-09
Nigeria	Globacom - GloMobile	In Service	Dec-07		In Service	Dec-07	
Nigeria	MTN Nigeria	In Service	Dec-07		In Service	Dec 07	
Nigeria	Zain (formerly Celtel)	In Service	Feb-08		Trial Launch	Nov-06	
Rwanda	RwandaTel	Planned	Jan-09		Planned	Jan-09	

Senegal	Orange Senegal	In Service	Sept-08		In Service	Sep-08	
Seychelles	Telecom Seyshelles (AIRTEL)	In Service	Dec-06	EDGE	In Service	Dec-06	Dec-08
South Africa	3C Telecom. Cell C	In Service	Jun-06	EDGE	In Service	Nov-08	
South Africa	MTN	In Service	Jun-05	EDGE	In Service	Mar-06	**Sep-07**
South Africa	Vodacom	In Service	Dec-04	EDGE	In Service	Apr-06	**Dec-08**
Sudan	Bashair Telecom / Areeba	In Service	Q1 2006	EDGE			
Sudan	Zain	In Service	Apr-08	EDGE	In Service	Apr-08	
Tanzania	Vodacom	In Service	Feb-07		In Service	Feb 07	Jun-09
Tunisia	Tunisie Telecom	Potential License	Q4 2008	EDGE			
Uganda	Uganda Telecom Ltd	In Service	Nov-07	EDGE	In Service	Mar-08	
Zimbabwe	Econet Wireless	Planned	Q4 2008				
Asia Pacific							
Australia	3 / Hutchison Australia	In Service	May-03		In Service	Mar-07	Dec-08
Australia	SingTel/Optus	In Service	Nov-05		In Service	May-07	Jun-09
Australia	Telstra	In Service	Sep-05	EDGE	In Service	Oct-06	**Sep-07**
Australia	Vodafone	In Service	Oct-05		In Service	Oct-06	Dec-08
Australia	Virgin Mobile	In Service	Jul-07		In Service	July-07	
Bangladesh	GrameenPhone	Potential License	Mar-10	EDGE	Planned	Dec 2010	
Bangladesh	PBTL	Potential License	Jun-10				
Bangladesh	Sheba Telecom	Potential License	Jun-10				
Bangladesh	TM International	Potential License	Jun-10	EDGE			
Bangladesh	Warid Telecom	Potential License	Dec-10	EDGE			
Bhutan	Bhutan Telecom - B-Mobile	In Service	May-08	EDGE	In Service	May-08	Jun-09
Bhutan	Tashi Infocomm	Planned	Mar-09				
Brunei/Borneo	B-Mobile	In Service	Sep-05				
Brunei/Borneo	DST Com	In Service	May-08	EDGE	In Service	May-08	Mar-09
Cambodia	Cambodia Shinawatra	In Service	Oct-07	EDGE	In Service	Oct-07	
Cambodia	CadComm (QB)	In Service	Jan-08		In Service	Mar-08	
Cambodia	Cambodia GSM (MobiTel)	In Service	Oct-06	EDGE	In Service	Mar-08	
China	China Mobile	Planned	Dec-09	EDGE	Planned	Dec-09	
Fiji	Vodafone Fiji	In Service	Nov-08		In Deployment	Mar-09	Dec-09
French Polynesia	Mara Telecom	In Deployment	Mar-09		In Deployment	Mar-09	
French Polynesia	Tikiphone (VINI)	In Service	Dec-08	EDGE	In Deployment	Mar-09	Mar-09
Guam	DoCoMo Pacific	In Service	Oct-08		In Service	Oct-08	
Hong Kong	Hong Kong CSL (New World)	In Service	Dec-04	EDGE	In Service	Sep-06	Mar-09
Hong Kong	3HK - Hutchison	In Service	Jan-04		In Service	Nov-06	Dec-10
Hong Kong	SmarTone Vodafone	In Service	Dec-04		In Service	Jun-06	**Dec-07**
Hong Kong	PCCW Mobile (ex-Sunday)	In Service	Jul-06	EDGE	In Service	Aug-07	Mar-09
India	Aircel	Potential License	Dec-09	EDGE			

India	Bharti Televentures	Planned	Mar-08	EDGE	Planned	Dec-08	
India	BPL Cellular	Planned/In Deployment	Dec-09	EDGE			
India	BSNL	Planned	Sep-09	EDGE	Planned	Sep-09	Sep-09
India	Dishnet Wireless	Potential License	Dec-09	EDGE			
India	Essar Spacetel	Potential License	Dec-09				
India	Idea Cellular	Potential License	Dec-09	EDGE			
India	MTNL	In Service	Dec-08		In Service	Dec-08	Mar-09
India	Reliance	Planned	Mar-08				
India	Spice Telecom	Planned	Jun-08		Planned	Dec-08	
India	Tata Teleservices	Planned	Mar-08				
Indonesia	Excelcomindo Pratama ProXL	In Service	Oct-06		In Service	Jan-07	Mar-09
Indonesia	Hutchison CP Telecommunications	In Service	Dec-06		In Service	Jun-07	Mar-09
Indonesia	Indosat IM2 /Matrix/Mentari/IM3	In Service	Nov-06		In Service	Oct-07	Mar-09
Indonesia	Satelindo (Indosat)	In Service	Dec-06	EDGE	In Service	Mar-07	Mar-09
Indonesia	Telkomsel	In Service	Aug-06	EDGE	In Service	Apr-07	Mar-09
Japan	eAccess / eMobile	In Service	Mar-07		In Service	Mar-07	Mar-10
Japan	Softbank (ex-Vodafone)	In Service	Dec-02		In Service	Oct-06	
Japan	NTT DoCoMo (FOMA)	In Service	Oct-01		In Service	Aug-06	Dec-08
Macau	CTM	In Service	Jun-07		In Service	Jun-07	Jun-09
Macau	Hutchison (3)	In Service	Oct-07		In Service	Oct-07	
Malaysia	Maxis	In Service	Jul-05	EDGE	In Service	Sep-06	Mar-09
Malaysia	Telekom Malaysia/Celcom 3G	In Service	May-05	EDGE	In Service	Sep-06	Mar-09
Malaysia	Umobile	In Service	Mar-08		In Service	Mar-08	
Malaysia	DiGi	In Deployment	Mar-09	EDGE	In Deployment	Mar-09	
Maldives	Dhiraagu	Potential License	2010				
Maldives	Wataniya	In Service	Apr-08	EDGE	In Service	May-08	Dec-08
Mongolia	Mobicom	Potential License	Dec 2009				
Mongolia	Skytel	Potential License	Dec 2009				
Nepal	Nepal Telecom Corp	In Service	May-07		In Service	Sep-07	
Nepal	Spice Nepal	Potential License	Sep 2012	EDGE			
New Zealand	Econet Wireless / NZ Comm.	Planned	Sep-08		Planned	Sep-08	Mar-09
New Zealand	Vodafone 2100	In Service	Aug-05		In Service	Oct-06	Mar-09
New Zealand	Vodafone 900	In Service	Jul-08		In Service	Jul-08	
New Zealand	Telecom New Zealand	In Deployment	Jun-09	EDGE	In Deployment	Jun-09	Jun-09
Pakistan	PMCL - Mobilink	Potential License	Sep-09	EDGE			
Pakistan	PTML - Ufone	Potential License	Sep-09	EDGE			
Pakistan	Telenor	Potential License	Sep-09	EDGE			
Philippines	Globe Telecom	In Service	May-06	EDGE	In Service	May-06	Mar-09
Philippines	SMART / Piltel	In Service	May-06	EDGE	In Service	Jan-07	Mar-09
Philippines	Digitel	In Service	Jul-06	EDGE	In Service	Aug-08	

Singapore	MobileOne	In Service	Feb-05		In Service	Dec-06	**Dec-08**
Singapore	SingTel Mobile	In Service	Feb-05		In Service	May-07	**Dec-08**
Singapore	StarHub	In Service	Apr-05		In Service	Aug-07	**Aug-07**
South Korea	KTF SHOW	In Service	Dec-03		In Service	Jun-06	**Jun-07**
South Korea	SK Telecom 3G+	In Service	Dec-03		In Service	May-06	**Oct-07**
Sri Lanka	Bharti Airtel	In Deployment	Jun-09	EDGE	In Deployment	Jun-09	Jun-09
Sri Lanka	Dialog GSM	In Service	Aug-06	EDGE	In Service	Aug-06	Mar-09
Sri Lanka	Hutchison	Planned	Dec-08	EDGE			
Sri Lanka	Mobitel	In Service	Dec-07	EDGE	In Service	Dec-07	**Dec-07**
Taiwan	Chunghwa Telecom	In Service	Jul-05		In Service	Sep 06	Mar-09
Taiwan	FarEasTone	In Service	Jul-05		In Service	Sep 06	Mar-09
Taiwan	Taiwan Mobile Co. (TWM)	In Service	Oct-05		In Service	Jan-07	Mar-09
Taiwan	VIBO	In Service	Dec-05		In Service	Sep-08	Mar-09
Thailand	AIS - UMTS 900	In Service	May-08	EDGE	In Service	May-08	
Thailand	DTAC	In Deployment	1Q 2009	EDGE	In Deployment	1Q 2009	
Thailand	TOT	Potential License	Q4 2008				
Vietnam	Mobifone Vietnam	Planned	n/a		Planned	n/a	

In Service: Operator has commercially launched its network to both consumer and enterprise markets, with handsets and/or data cards available in retail outlets.

In Deployment: Operator is building the network or has launched limited non-commercial trials, including those with "friendly" users.

Planned: Licensee is in planning stages of deploying network.

License Awarded: License has been awarded, but licensee has not announced date to deploy network or roll-out.

Potential License: Some level of speculation. Government policy or privatization process indicates that licensing opportunities may become available. Operator may have announced that if they receive spectrum, they may deploy the technology.

APPENDIX D: ACRONYM LIST

1x	Short for 1xRTT
1xEV-DO	CDMA20001xEV-DO or 1 times Evolution-Data Optimized or Evolution-Data Only
1xEV-DV	CDMA20001xEV-DV or 1 times Evolution-Data Voice
1xRTT	1 times Radio Transmission Technology (CDMA20001xRTT technology)
3GPP	Third Generation Partnership Project
AA	Adaptive Array
AAA	Authentication, Authorization and Accounting
ACK/NAK	Acknowledgement/Negative Acknowledgement
AES	Advanced Encryption Standard
AKA	Authentication and Key Agreement
AM	Acknowledged Mode
AMBR	Aggregate Maximum Bit Rate
ARP	Allocation and Retention Priority
ARPU	Average Revenue Per User
AS	Access Stratum
ASIC	Application-Specific Integrated Circuit
ASME	Access Security Management Entity
ARQ	Automatic Repeat Request
ATCA	Advanced Telecommunication Computing Architecture
ATM	Automated Teller Machine
AuC	Authentication Center
AWS	Advanced Wireless Spectrum
BCH	Broadcast Channel
BIP	Bearer Independent Protocol
Bits/s/Hz	Spectral efficiency is measured in bit/s/Hz, the net bitrate or throughput divided by the bandwidth in Hertz
Bps/Hz	Bits per second per Hertz
BSK	Binary Shift Keying
BSR	Base Station Router
BTS	Base Transceiver Station
BW	Bandwidth
CA	Carrier Aggregation
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenses
CAZAC	Constant Amplitude Zero Autocorrelation Waveform
CCE	Control Channel Elements
CDD	Cyclic Delay Diversity
CDF	Cumulative Distribution Function
CDM	Code Division Multiplexing
CELL_DCH	UTRAN RRC state where UE has dedicated resources
CELL_FACH	UTRAN RRC transition state between Cell_PCH and Cell_DCH
CELL_PCH	UTRAN RRC state where UE has no dedicated resources are allocated
C/I	Carrier to Interference Ratio (CIR)
CK/IK	Ciphering Key/Integrity Key
CMS	Communication and Media Solutions
CN	Control Network
CoA	Care of Address
CP	Cyclic Prefix
C-Plane	Cell Plane
CPC	Continuous Packet Connectivity
CPE	Customer premise Equipment
CQI	Channel Quality Indications

CRC	Cyclic Redundancy Check
CS	Circuit Switched
CSI	Channel State Information
CTIA	Cellular Telecommunication Industry Association
DRX	Discontinuous Reception
DC	Direct Current
DCH	Dedicated Channel
DC-HSUPA	Dual Carrier- High Speed Uplink Packet Access
DCI	Downlink Control Information
DES	Data Encryption Standard
DFE	Decision Feedback Equalizer
DFT	Discrete Fourier Transformation
DFT-S-OFDM	Discrete Fourier Transformation-Spread- Orthogonal Frequency Division Multiplexing
DHCP	Dynamic Host Configuration Protocol
D-ICIC	Dynamic Interference Coordination
DIP	Dominant Interferer Proportion
DL	Downlink
DL-SCH	Downlink Shared Channel
DMB	Digital Multimedia Broadcasting
DNBS	Distributed Node B Solution
DS	Dual Stack
DS-MIPv6	Dual Stack – Mobile Internet Protocol version 6
DSP	Dual Slant Pole
E-DCH	Enhanced Dedicated Channel (also known as HSUPA)
EDGE	Enhanced Data for GSM Evolution
EGPRS	Enhanced GPRS
EIR	Equipment Identity Register
eNB	Enhanced Node B
ENUM	Telephone Number Mapping from E.164 NUmber Mapping
EPC	Evolved Packet Core; also known as SAE (refers to flatter-IP core network)
ePDG	external Packet Data Gateway
EPS	Evolved Packet System is the combination of the EPC/SAE (refers to flatter-IP core network) and the LTE/EUTRAN
EPDG	Evolved Packet Data Gateway
EPRE	Energy Per Resource Element
E-MBMS	Enhanced Multi Broadcast Multicast Service
ETSI	European Telecommunication Standards Institute
EUTRA	Evolved Universal Terrestrial Radio Access
EUTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
EV-DO	Evolution Data Optimized or Data Only
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDMA	Frequency Division Multiple Access
FDS	Frequency Diverse Scheduling
FER	Frame Erasure Rate
FFR	Fractional Frequency Re-use
FIR	Finite Impulse Response
FMC	Fixed Mobile Convergence
FOMA	Freedom of Mobile Multimedia Access: brand name for the 3G services offered by Japanese mobile phone operator NTT DoCoMo.
FSS	Frequency Selected Scheduling
FSTD	Frequency Selctive Transmit Diversity
GB	Gigabyte
GBR	Guaranteed Bit Rate
GERAN	GSM EDGE Radio Access Network
GGSN	Gateway GPRS Support Node

Gi	Interface between GPRS and external data network
Gn	IP Based interface between SGSN and other SGSNs and (internal) GGSNs. DNS also shares this interface. Uses the GTP Protocol
Gp	Guard Period
GPRS	General Packet Radio System
GRE	Generic Routing Encapsulation
GSM	Global System for Mobile communications
GSMA	GSM Association
GTP	GPRS Tunneling Protocol
GTP-U	The part of GTP used for transfer of user data
GUTI	Globally Unique Temporary Identity
GW	Gateway
Gxa, Gxb, Gxc	IMS reference points
HARQ	Hybrid Automatic Repeat Request
HCI	Host Controller Interface
HD	High Definition
HLR	Home Location Register
HOM	Higher Order Modulation
HPLMN	Home PLMN
HPCRF	Home PCRF
HRPD	High Rate Packet Data (commonly known as 1xEV-DO)
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSPA +	High Speed Packet Access Plus (also known as HSPA Evolution or Evolved HSPA)
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTML	Hyper-Text Markup Language
HTTP	Hyper Text Transfer Protocol
ICE	In Case of Emergency
ICS	IMS Centralized Services
IDs	identifies
IDFT	Inverse Discreet Fourier Transform
I-HSPA	Internet -High Speed Packet Access
IM	Instant Messaging
IMS	IP Multimedia Subsystem
IN	Intelligent Networking
IP	Internet Protocol
IP-CAN	Internet Protocol Connectivity Access Network
IPSec	Internet Protocol Security
ISP	Internet Service Provider
ITU	International Telecommunication Union
ITU-R	International Telecommunication Union – Radiotelecommunications Sector
Iur	Interface between two RNCs
IWS	Interworking Signaling
K-ASME	ASME Key
kHz	Kilohertz
LBS	Location Based Services
LCR	Low Chip-Rate
LCS	LoCation Service
LMMSE	Linear Minimum Mean Square Error
LSTI	LTE Standard Trial Initiative
LTE	Long Term Evolution (Evolved Air Interface based on OFDMA)
LTI	Linear Time Invariant
M2M	Machine-to-Machine
MAC	Media Access Control
Mbps	Megabitz per Second

MBMS	Multimedia Broadcast/Multicast Service
MBR	Maximum Bit Rate
MBSFN	Multicast Broadcast Single Frequency Networks
MCH	Multicast Channel
MCM	Multimedia Carrier Modulation
MCS	Modulation and Coding Scheme
MCW	Multiple Codewords
MFS	Mobile Financial Services
MHz	Megahertz
MIM	Mobile Instant Messaging
MIMO	Multiple Input Multiple Output
MIB	Master Information Block
MIP	Mobile IP
MITE	IMS Multimedia Telephony Communication Enabler
MLSE	Maximum Likelihood Sequence Estimation
MOBIKE	Mobility and Multi-homing Protocol for Internet Key Exchange
MRFP	Multimedia Resource Function Processor
MMD	Multi-Media Domain
MME	Mobility Management Entity
MMS	Multimedia Messaging Service
MMSE	Multimedia Messaging Service Environment
MNO	Mobile Network Operator
ms	Milliseconds
MSA	Metropolitan Statistical Area
MU-MIMO	Multi-User Multiple Input Multiple Output
MVNO	Mobile Virtual Network Operator
NAI	Network Access Identifier
NAS	Non Access Stratum
NDS/IP	Network Domain Security/Internet Protocol
NFC	Near Field Communications
NGN	Next Generation Network
OFDMA	Orthogonal Frequency Division Multiplexing Access (air interface)
OL-MIMO	Open Loop Multiple Input Multiple Output
O&M	Operations and Maintenance
OMA	Open Mobile Architecture
OP	Organizational Partner
OPEX	Operating Expenses
OS	Operating System
PAPR	Peak to Average Power Ratio
PAR	Peak to Average Ratio
PARC	Per-Antenna Rate Control
PBCH	Primary BCH
PCC	Policy and Charging Convergence
PCD	Personal Content Delivery
PCEF	Policy and Charging Enforcement Function
PCFICH	Physical Control Format Indicator Channel
PCH	Paging Channel
PCMM	Packaged Core Memory Model
PCRF	Policy and Changing Rules Function
PDA	Personal Desktop Assistant
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDG	Packet Data Gateway
PDN	Public Data Network
PDU	Packet Data Unit
PDSCH	Physical Downlink Shared Channel

P-GW	PDN Gateway
PHICH	Physical Hybrid ARQ Indicator Channel
PHY/MAC	Physical layer/Medium Access Control
PLMN	Public Land Mobile Network
PMCH	Physical Multicast Channel
PMI	Precoding Matrix Index
PMIP	Proxy Mobile IPv6
PoC	Push-to-talk over Cellular
PRACH	Physical Random Access Channel
PRB	Physical Resource Block
PS	Packet Switched
P-SCH	Primary Synchronization Signal
PSRC	Per Stream Rate Control
PUUCH	Physical Uplink Access Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QCI	QoS Class Index
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
Qt	"cutie" is a cross application development framework
R&D	Research and Development
RAB	Radio Access Bearer
RACH	Random Access Channel
RAM	Remote Application Management
RAN1	Working group within 3GPP focused on physical layer specifications
RAT	Radio Access Technology
RB	Radio Bearer
REL-X	Release '99, Release 4, Release 5, etc. from 3GPP standardization
RF	Radio Frequency
RIT	Radio Interface Technology
RLC	Radio Link Control Layer
RN	Relay Node
RNC	Radio Network Controller
RNTI	Radio Network Temporary Identifier
RRC	Radio Resource Control
RRM	Radio Resource Management
RRU	Remote Radio Unit
RS	Reference Signal
SAE	System Architecture Evolution also known as Evolved Packet System (EPS) Architecture (refers to flatter-IP core network)
SBLB	Service Based Local Policy
SC	Service Continuity
SC-FDMA	Synchronization Channel – Frequency Division Multiple Access
S-CSCF	Serving- Call Session Control Function
SCW	Single Codeword
SDK	Software Development Kit
SDP	Service Delivery Platform
SDU	Service Data Unit
SFBA	Switch Fixed Beam Array
SFBC	Space Frequency Block Code
SFN	Single Frequency Network
SGi	Reference point between the PDN-GW and the packet data network
SGSN	Serving GPRS Support Node
S-GW	Serving Gateway
SIC	Successive Interference Cancellation
S-ICIC	Static Interference Coordination

SIM	Subscriber Identity Module
SIMO	Single Input Multiple Output
SIP	Session Initiated Protocol
SIR	Signal-to-Interference Ratio
SISO	Single Input Single Output
SM	Spatial Multiplexing
SMS	Short Message Service
SNS	Social Networking Site
SOA	Service-Oriented Architecture
SRIT	Set of Radio Interface Technologies
S-SCH	Secondary Synchronization Code
SU-MIMO	Single-User Multiple Input Multiple Output
SU-UL-MIMO	Single-User Uplink Multiple Input Multiple Output
TAS	Transmit Antenna Switching
TB	Transport Blocks
TCP-IP	Transmission Control Protocol/Internet Protocol
TDD	Time Division Duplex
TDM	Time Division Multiplexing
TDS	Time Domain Scheduling
TD-SCDMA	Time Division- Spatial Code Division Multiple Access
TE-ID	Tunnel Endpoint Identifier
TF	Transport Format
TISPAN	Telecoms & Internet converged Services & Protocols for Advanced Networks, a standardization body of ETSI
TP	Transport Protocol
TRX	Tranceiver
TS	Technical Specification
TSM	Transport Synchronous Module
TTI	Transmission Time Interval
TxD or TXD	Transmit Diversity
UE	User Equipment
UGC	User Generated Content
UICC	User Interface Control Channel
UL	Uplink
UL-SCH	Uplink Shared Channel
UM	Unacknowledged Mode
UMA	Unlicensed Mobile Access
UMB	Ultra Mobile Broadband
UMTS	Universal Mobile Telecommunication System, also known as WCDMA
UpPTS	Uplink Pilot Time Slot
USB	Universal Serial Bus
USB-IC	Universal Serial Bus – Integrated Circuit
USIM	UMTS SIM
USSD	Unstructured Supplementary Service Data
UTRA	Universal Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VCC	Voice Call Continuity
VoIP	Voice over Internet Protocol
VPCRF	Visiting PCRF
VPLMN	Visiting PLMN
VPN	Virtual Private Network
WAP	Wireless Application Protocol
WCDMA	Wideband Code Division Multiple Access
WI	Work Item
Wi-Fi	Wireless Internet or IEEE 802.11 standards
WiMAX	Worldwide Interoperability for Microwave Access based on IEEE 802.16 standard

WIM	Wireless Internet Module
WLAN	Wireless Local Area Network
WRC	World Radio Conference

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