



HSPA EVOLUTION

HSPA EVOLUTION – BEYOND 3GPP RELEASE 10

Many mobile operators around the world have HSPA technology to thank for their mobile broadband success. But as subscription rates continue to rise dramatically, fed by huge smartphone sales and the demand for bandwidth-hungry data, mobile operators face increasing challenges to keep their customer bases satisfied. HSPA evolution provides a cost-efficient answer.

HSPA DRIVES MOBILE BROADBAND

The rapid growth of mobile broadband traffic in recent years has been driven and facilitated by the twin landmark appearances of, and developments in, new devices and HSPA technology. HSPA has a large footprint across many markets, providing wide-area coverage for a variety of terminals, including popular smartphones.

Several commercial LTE networks have also been deployed recently, aimed at meeting the longer-term needs of mobile broadband consumers. HSPA networks have a larger ecosystem, and consequently the majority of growth in mobile broadband traffic in coming years is likely to occur in these networks. One thing is certain – there will be no slowdown in the pace of mobile broadband traffic growth. Ericsson estimates that mobile broadband subscriptions will top 5 billion by 2016 – and by that time, it is expected that more than 75 percent of these subscriptions will use HSPA networks.

As such, HSPA technology must continually evolve so that it can handle this extensive growth and the corresponding consumer demand for higher data rates and better coverage. Additionally, operators facing a lack of spectrum, or experiencing faster-than-expected traffic growth, must improve spectral efficiency. The large increase in smartphone-generated traffic in networks places even more requirements on HSPA networks – and these requirements must be accommodated.

The beauty of HSPA evolution is that previous investments in infrastructure are protected while the network is being upgraded. While today's data demands had not been foreseen when operators invested in HSPA technology, even just a few years ago, the capability of the technology is such that upgrades, rather than new network rollouts, will provide a response to the data challenges that operators will experience in coming years. Accordingly, HSPA evolution is highly appealing to operators simply on the basis of its cost-effectiveness.

The natural progression of HSPA is to evolve the technology to meet the IMT-A requirements established ITU [1]. These requirements apply to systems with capabilities beyond those of IMT2000 systems. When the improvements become part of the standard, the evolved HSPA technology will perform on a par with other 4G technologies. This evolved HSPA technology is clearly capable of meeting operator demands for increased capacity and end-user demands for higher data rates.

Although carefully selected, the IMT-A scenarios have been simplified to some extent so that the results can be more easily evaluated and compared. Therefore, it is necessary to expand the analysis beyond the IMT-A requirements by considering the actual user experience in real-world scenarios.

The new traffic patterns originating from smartphones are among the developments that are not fully covered in the IMT-A evaluation scenarios. The number of smartphones using mobile networks has grown at a massive pace in recent years. Such growth presents obvious challenges for HSPA networks rolled out in the recent past, so it is vital that the continued evolution of HSPA takes smartphone traffic into account.

This paper outlines the route towards IMT-A compliance. It refers to some of the major advances made possible by earlier 3GPP HSPA releases and how the continuous development of those achievements, and new functionality, are influencing the development of the next release – 3GPP Release 11 (R11). An analysis of HSPA Release 10 (R10) indicates that many of the IMT-A requirements have already been fulfilled. This paper also outlines the changes that have been made to the standard to improve handling in response to growth in smartphone use. It highlights how HSPA should be developed to meet the needs of smartphone users, while preserving network resources and terminal battery life. The significance of the smartphone challenge is specifically addressed in section 3 of this paper.

HSPA ON A PAR WITH 4G

ITU has developed a process for determining whether or not mobile systems are IMT-A capable [1][2][3]. To qualify as IMT-A capable, a system must fulfill a specific set of requirements. For some of these requirements, a simple assessment against the standard is sufficient to determine whether a system is IMT-A capable. In this paper, such requirements are referred to as capabilities. Other performance requirements must be evaluated through the use of simulation scenarios that have been carefully specified by ITU. If a technology has these capabilities and fulfills these performance requirements, ITU can classify the technology as IMT-A capable. Two wireless technologies are currently classified as IMT-A capable: LTE R10 and IEEE 802.16m.

CAPABILITIES OF IMT-A SYSTEMS

Support for higher bandwidths: One of the IMT-A capability requirements is that a system must support downlink transmission bandwidths of up to 40MHz.

Following 3GPP Release 8 (R8), HSPA has facilitated multi-carrier operation, which enables Node-B to schedule data simultaneously on multiple carriers. This functionality obviously results in an increase in peak rates. But more interestingly, it also results in an increase in spectral efficiency. Recent evolutions have continued to capitalize on that breakthrough. As of R10, HSPA supports multi-carrier operation on up to four carriers in the downlink (which can be spread across one or two frequency bands) and up to two carriers in the uplink. 3GPP is currently specifying an 8-carrier HSDPA operation as part of the R11 requirements.

The performance of an 8-carrier HSDPA system is depicted in Figure 1. While the 8-carrier solution, of course, outperforms the 4-carrier solution, a single 8-carrier system also provides higher capacity than a pair of 4-carrier solutions.

Peak spectral efficiency: ITU has also established a set of uplink and downlink requirements for peak spectral efficiency – defined as the peak rate divided by the bandwidth used. The IMT-A requirements are listed in Table 1, along with proven values for HSPA R10 and estimated values for HSPA R11.

The IMT-A requirements were met in LTE R10 with features such as DL 4x4 MIMO, UL 2x2 MIMO and UL 64QAM. Table 1 also shows how the inclusion of similar features in HSPA R11 would clearly exceed the IMT-A peak spectral efficiency requirements through the resulting predicted values.

Features introduced to increase peak spectral efficiency will also improve performance in certain scenarios. Such benefits are

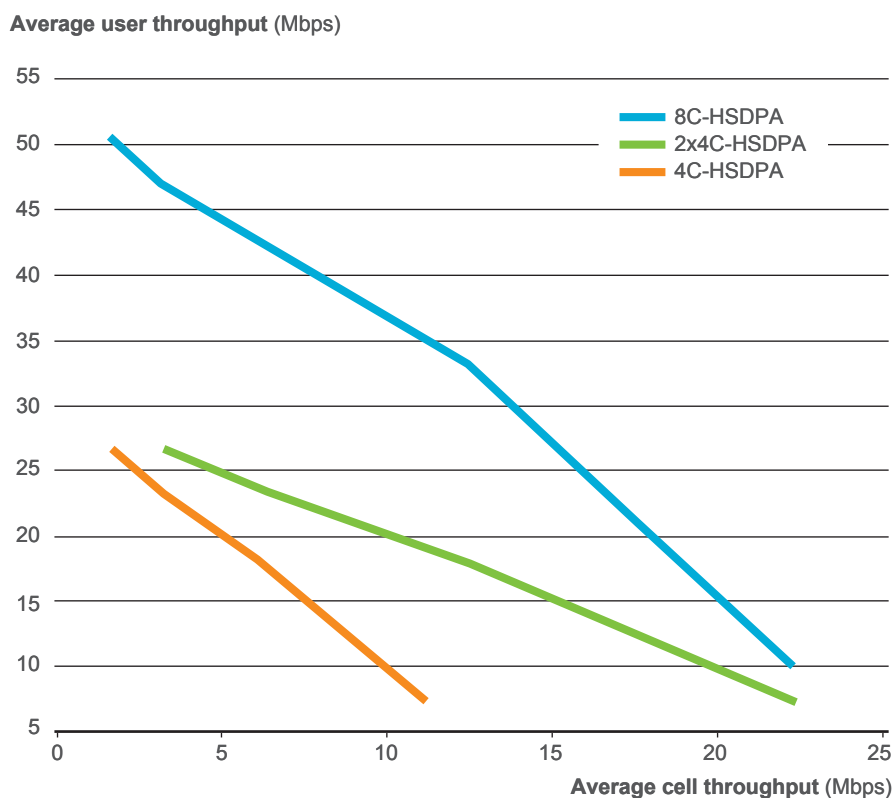


Figure 1: Performance of an 8-carrier HSDPA system compared with the performance of two R10 HSDPA systems.

Table 1: IMT-A requirements for peak spectral efficiency. The peak spectral efficiency for HSPA R10 and potential values for HSPA R11 are also provided.

	IMT-A	HSPA R10	HSPA R11 (potential)
Downlink (bps/Hz)	≥15.0	8.6	17.2
Uplink (bps/Hz)	≥6.75	2.3	6.9

clearly shown in the comparison of the performance of DL 4x4 MIMO with that of HSDPA R10, outlined in Figure 2.

Latency: Latency is a huge influencing factor for mobile broadband subscribers when it comes to customer loyalty, so it is not surprising that the IMT-A system requirements are tough in terms of low-latency provision, both for the control plane and user plane. These requirements are listed in Table 2.

Latency evaluation is conducted under the conditions specified in [1]. Control-plane latency is measured as the time it takes to establish a user-plane connection from an idle state. User-plane latency is the one-way transit time between a packet being available in the terminal and the same packet being available in the base station.

HSPA R10 fulfills the IMT-A latency requirements. From an idle state such as CELL_PCH, a user-plane connection can be set up in less than 100ms, thereby fulfilling the requirement for control-plane latency. Also, assuming that the terminal is in an active state, the transit time for a packet is significantly less than 10ms, thereby fulfilling the requirement for user-plane latency, as shown in Table 2.

Handover interruption time: Another important characteristic of a cellular system is the interrupt that occurs during a handover. ITU requirements relating to handover interruption are outlined in Table 3. Because HSPA R10 implements soft handover in the uplink and synchronized handovers in the downlink, there are essentially no interruptions during a handover. HSPA R10 therefore fulfills the IMT-A requirements for handover interruption.

PERFORMANCE REQUIREMENTS

In addition to bandwidth and peak spectral efficiency requirements, ITU has formulated performance criteria that must be met by all IMT-A capable systems. The systems must perform at a high level in terms of:

- Average and cell-edge spectral efficiency in the uplink and downlink
- Voice over IP (VoIP) capacity
- Mobility traffic channel rate

Cell-edge spectral efficiency is defined as the fifth percentile of the user bit rates, divided by the bandwidth. An assessment of the performance requirements was conducted in four test-case scenarios, which differed in terms of deployment and mobility:

- Indoor hotspot
- Urban micro
- Urban macro
- Rural macro.

Further specific conditions relating to performance evaluation are defined in [3]. HSPA R10 performance for average and cell-edge spectral efficiency was evaluated for each of the four scenarios. The results for average spectral efficiency are outlined in Figure 3, while Figure 4 displays the results for cell-edge spectral efficiency. In both cases, HSPA R10 performance is compared with the IMT-A requirements.

Average user throughput (Mbps)

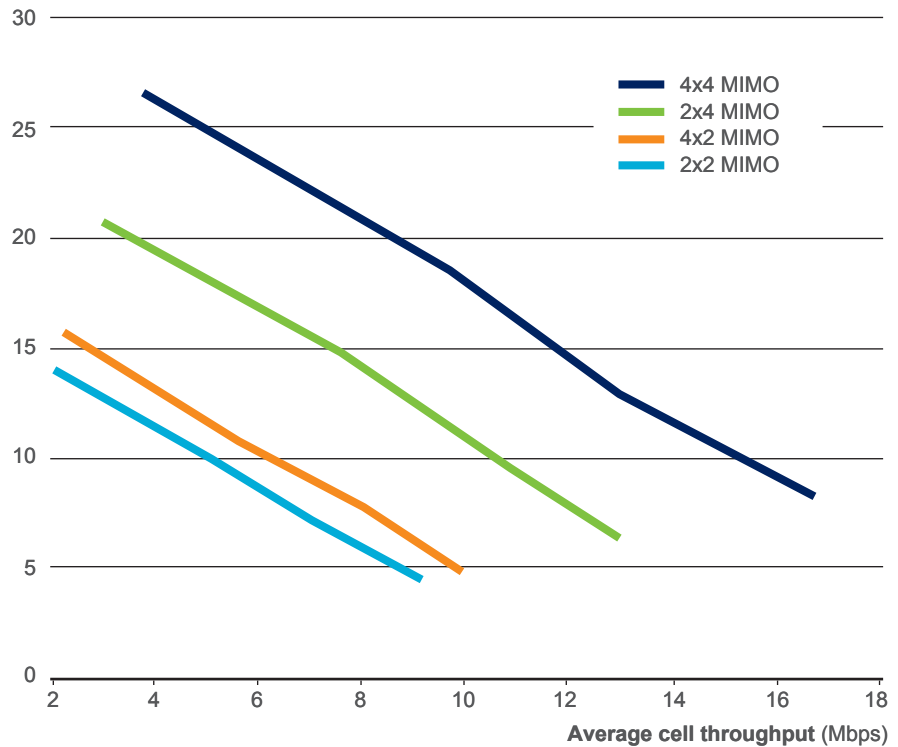


Figure 2: The performance of DL 4x4 MIMO compared with the performance of HSDPA R10.

Table 2: IMT-A requirements for latency.

	IMT-A requirement	HSPA R10
Control plane	<100ms	76ms
User plane	<10ms	8.67ms

Table 3: IMT-A requirements for handover interruption.

	IMT-A requirement	HSPA R10
Intra-frequency	≤27.5ms	0ms
Inter-frequency within a band	≤40ms	0ms
Inter-band	≤60ms	0ms

The results clearly show that HSPA R10 fulfills the IMT-A requirements.

Powerful linear receivers and the incorporation of eight receive antennas per cell were key factors enabling the uplink performance to exceed the IMT-A requirements. The requirements would have been more difficult to fulfill with fewer receive antennas. State-of-the-art radio resource management functionality, including link and rank adaptation, was used to boost downlink performance.

Thanks to the strength and adaptability of HSPA technology, these kinds of evolutionary measures made it possible to deliver performance results beyond the IMT-A requirements.

VoIP capacity and mobility traffic channel rate are also significant considerations in the continued evolution of HSPA technology. In terms of IMT-A requirements for VoIP capacity and traffic channel rate, performance evaluation has yet to be conducted.

Fulfilling the IMT-A requirements is important. ITU has put significant time and effort into quantifying and defining the requirements that future wireless systems should meet. Systems that fulfill the capabilities and achieve the target performance are therefore well-placed to handle increasing demands on user bit rates and system capacity.

However, current mobile systems face additional challenges not foreseen by ITU when it stipulated the requirements. In particular, the large increase in data traffic from smartphones has placed new demands on wireless systems, due to new traffic patterns and user behavior. The ability to meet such demands will be essential in the evolution of wireless systems, particularly HSPA technology.

Average spectral efficiency
[bps/Hz/cell]

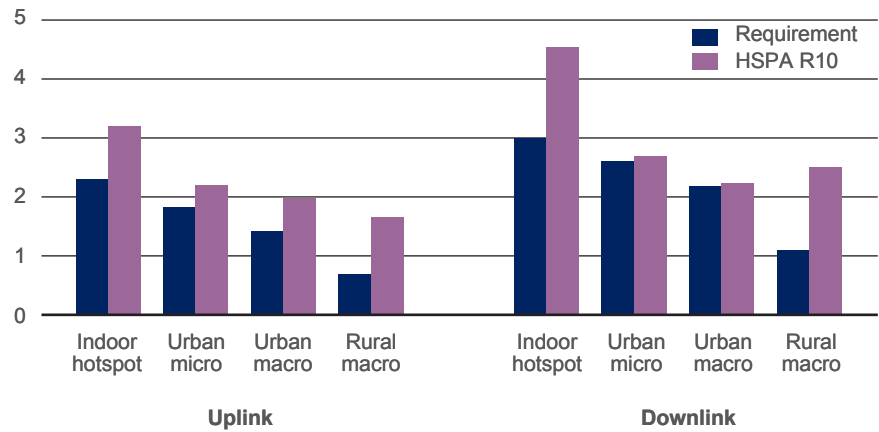


Figure 3: Average spectral efficiency, IMT-A requirements versus HSPA performance.

Cell-edge spectral efficiency
[bps/Hz/cell]

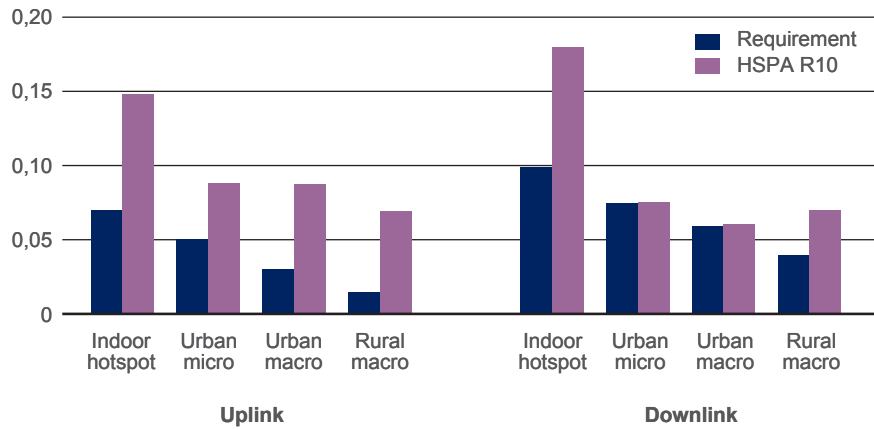


Figure 4: Cell-edge spectral efficiency, IMT-A requirements versus HSPA performance.

SMARTPHONES AND PERFORMANCE

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HSPA RADIO RESOURCE CONTROL (RRC) STATES

One factor that currently limits end-user experience in an HSPA system is the RRC state machine. This state machine was included in the original release of the WCDMA standard (R99), and remained unchanged until HSPA Release 7 (R7). It was designed to boost performance while simultaneously limiting resource consumption in both the network and the terminal. Figure 5 outlines the RRC states that can be assigned to HSPA user equipment (UE).

Due to the limited bit rates and spectral efficiency of other states, data transmission takes place almost exclusively in the CELL_DCH state. When the data transmission has ended, the terminal remains in the same state for an average time of about half a second before it is moved to a more resource-efficient state.

3GPP R7 was a landmark in terms of the speed at which terminals could be moved between states. Prior to 3GPP R7, transition to CELL_DCH could take 2s from the idle state and about 500ms from other states. The consequence was a delay in down-switches to avoid associated delays in up-switches, which led to high consumption of network resources and a high rate of battery usage. 3GPP R7 and R8 features specifically addressed this situation.

Signaling channel transmission rates were increased to speed up the state changes. As a result, the transition to CELL_DCH takes less than 1s from the idle state and about 200ms from the other states. The new features significantly increased user data rates in CELL_FACH as well as making it possible, for the first time, to transmit user data during state change.

Another improvement was the fast dormancy feature introduced in 3GPP R8, which enables the UE to indicate that it has finalized its transmission. This extra information enables the network to determine the appropriate state into which the UE should be moved.

A further improvement meant that terminal power consumption in CELL_FACH could be reduced by introducing discontinuous reception (DRX).

CELL_FACH: THE SMARTPHONE STATE

While the improvements in releases 7 and 8 were significant, the major growth and impact of smartphone traffic presents major challenges for the RRC state machine.

Smartphone traffic patterns are difficult to predict, are intermittent in nature and are irregularly spread over relatively long time intervals compared with classic interactive traffic. This has a strong impact on UE

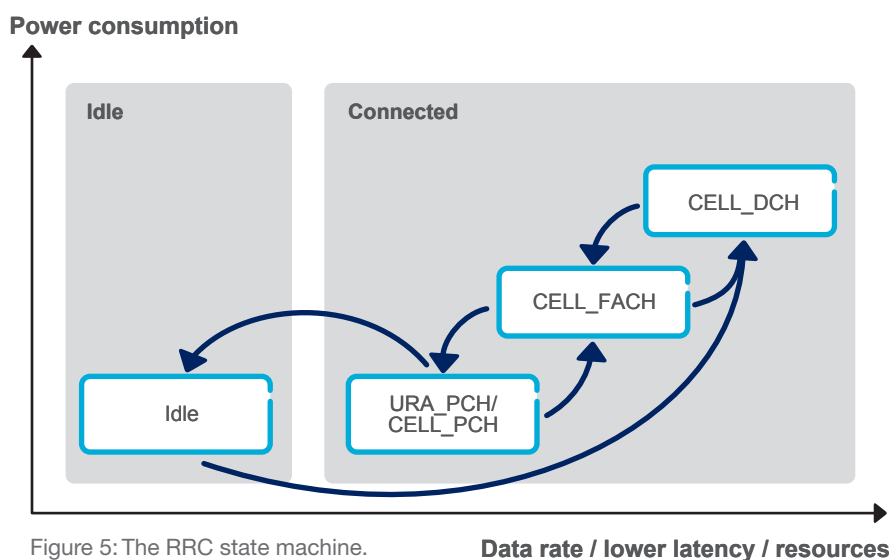


Figure 5: The RRC state machine.

Data rate / lower latency / resources

state switching, as it represents a challenge to established models of resource allocation dimensioning, user-handling and quality-of-service provisioning. The ideal answer would enable smartphones to be kept in the same state for the longest possible period of time. It should be possible for this state to efficiently serve non-critical traffic by maintaining a low consumption of network and battery resources. A switch to other states should only occur when the highest data rates are required or when total inactivity is detected. This would also reduce the amount of signaling traffic.

No current RRC state has all of the properties required to achieve this. With the exception of CELL_FACH and CELL_DCH, all RRC states are limited or disabled in terms of transmission and reception of data. Introducing behavioral changes in this respect would effectively mean a change in the very definition of these states and would require massive efforts and new agreements for standardization.

The high resource and power consumption experienced by the terminal and the network while in CELL_DCH state rules out its deployment to handle smartphone traffic, even with the introduction of Continuous Packet Connectivity (CPC). In fact, terminals that are kept in the CELL_DCH state are a major source of uplink interference, even after their transmissions have ended. In terms of the CELL_FACH state, the 3GPP R7 and R8 evolutions improved latency and provided smoother and faster transition between states for mobile broadband-capable terminals. The fundamental capabilities of this state make it highly attractive for handling smartphone traffic. With further improvements to facilitate better control of network resources, increase downlink spectrum efficiency, improve uplink coverage, decrease the terminal power consumption and further reduce transmission latency in the state, it becomes possible to substantially extend the period of time that smartphones can be kept in the CELL_FACH state. Frequent packet traffic can be transmitted efficiently without having to transit to CELL_DCH. Because terminals in the CELL_FACH state generate substantially less uplink interference, the overall uplink interference is also significantly reduced.

In terms of improvements, the introduction of fast channel-state information feedback in the CELL_FACH state would increase downlink spectrum efficiency. It would also contribute to optimal network resource allocation and boost downlink transmission performance in the CELL_FACH state to similar levels as those achieved in the CELL_DCH state. However, the highest user bit rates will still only be supported in the CELL_DCH state, using features such as MIMO.

One limitation of Enhanced Dedicated Channel (E-DCH) in the standardized R8 CELL_FACH state is the lack of support for concurrent use of 2ms and 10ms transmission time intervals (TTIs). In reality, this means that in most cells, for coverage reasons, the application of E-DCH in the CELL_FACH state requires the use of 10ms TTI. This means that subscribers using the shorter-latency cell will be denied the benefits of the 2ms TTI. Therefore, it is logical that concurrent support for both TTIs is a natural evolution of the standard and introduced for E-DCH in the CELL_FACH state. This would mean that the only subscribers needing to use the 10ms TTI would be those in locations with poor coverage, while the remaining subscribers could benefit from the advantages of the 2ms TTI.

E-DCH in the CELL_DCH state provides the valuable option of using per-hybrid automatic repeat request (HARQ) grants for users of 2ms enhanced uplink (EUL). A grant then becomes valid only in a subset of the HARQ processes, making it possible to introduce uplink TDM. This capability should also be introduced in the CELL_FACH state to improve radio interface control and the handling of small packets. Furthermore, although E-DCH should be the preferred option to carry uplink traffic in the CELL_FACH state, the handling of extremely small packets is conducted more efficiently by the R99 PRACH. Accordingly, such a fallback option should also be introduced in the standard.

As already outlined, UE battery consumption in the CELL_FACH state is still too high. More aggressive DRX schemes must therefore be introduced to make it possible for the UE to remain in the CELL_FACH state for longer time periods. Since downlink transmissions can only be initiated when the UE receiver is switched on, the introduction of longer DRX cycles comes at the price of increasing latency for network-originating transmissions. Further latency enhancements may also be required to counteract the impact of longer DRX cycles.

The above-mentioned improvements to the CELL_FACH state are all part of ongoing R11 work.

CONCLUSION

The HSPA ecosystem is undoubtedly the main facilitator of the massive growth in mobile broadband traffic. A large number of well-functioning HSPA networks now provide wide-area coverage in many markets, while a great variety of HSPA devices are also available, including many popular smartphones.

There is no doubt that mobile broadband traffic growth will continue to accelerate and, accordingly, that operators must upgrade their HSPA networks and provide the service capabilities demanded by their customers.

Such upgrades will only be possible through the evolution of HSPA technology. The latest stage in HSPA evolution relates to the need to improve the standard so that it meets the IMT-A requirements that were not fulfilled by R10. This primarily concerns support for higher bandwidths and higher peak spectral efficiency.

Additional improvements relate to developing the RRC state machine. Such improvements will allow networks to handle smartphone traffic more efficiently and improve the subscriber experience by reducing network resource consumption and terminal battery consumption.

Significantly, the proposed evolution of the standard enables existing networks to be upgraded in a cost-efficient manner. With continued evolution of the standard, HSPA technology will be well placed to handle future capacity-related requirements and subscriber demand. Ericsson is committed to driving this evolution to the benefit of the industry.

GLOSSARY

3GPP	3rd Generation Partnership Project
4G	4th-generation mobile wireless standards
CPC	Continuous Packet Connectivity
DL	downlink
DRX	discontinuous reception
E-DCH	Enhanced Dedicated Channel
EUL	enhanced uplink
HARQ	hybrid automatic repeat request
HSDPA	High-Speed Downlink Packet Access
HSPA	High-Speed Packet Access
IEEE	Institute of Electrical and Electronics Engineers
IMT2000	International Mobile Telecommunications-2000, better known as 3G
IMT-A	IMT-Advanced
ITU	International Telecommunication Union
LTE	Long Term Evolution
MIMO	multiple-input, multiple-output
PRACH	Physical Random Access Channel
QAM	quadrature amplitude modulation
RRC	Radio Resource Control
TDM	time-division multiplexing
TTI	transmission time interval
UE	user equipment
UL	uplink
VoIP	Voice over IP
WCDMA	Wideband Code Division Multiple Access

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