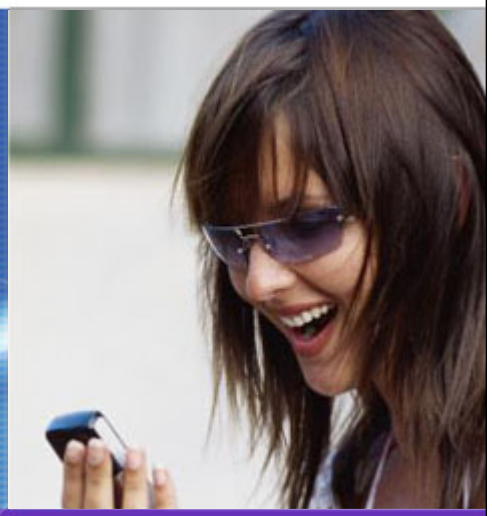
Long Term Evolution and Enhanced Packet Core (LTE and EPC) – A Prelude to 4G Wireless Systems



Amit Mukhopadhyay, Ph. D

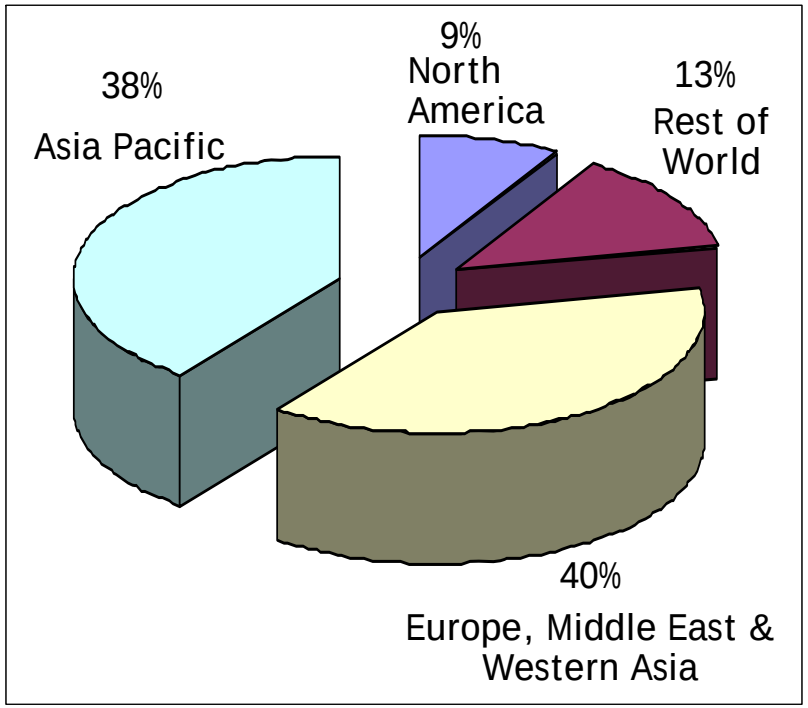
Network Planning, Performance & Economic Analysis, Bell Laboratories

Chief Technologies Office

Alcatel-Lucent

Global Subscriber View

Total Worldwide Subscribers – 3,530M



Largest Service Providers

(Subscribers as of 1Q08)

1	China Mobile	392M
2	Vodafone[1]	148M
3	China Unicom	167M
4	América Móvil	149M
5	Orange	112M
6	Telefonica LATM	103M
7	T-Mobile (NA & EU)	92M
8	Mobile Telesystems	85M
9	AT&T	71M
10	Verizon Wireless	67M
11	NTT DoCoMo	53M
12	Sprint	53M

The Top 12 Carriers Worldwide Account for 43% of the Total Wireless Subscribers

Source: Dell'Oro Quarterly Mobility Report (1Q08)

1. Does Not Include Verizon Wireless Subscribers

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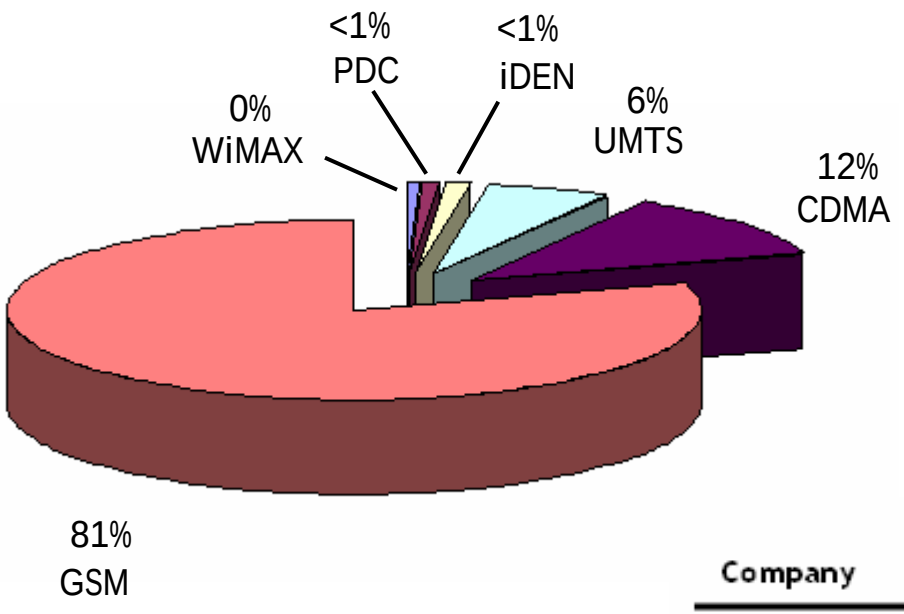
Technology Summary (2G-3G)



Global Subscribers By Technology (1Q08)

- GSM Technology Dominates Globally with 81% Market Share
- CDMA is the Most Commonly Deployed Technology in North America with About 50% Market Share

North America Technology by Company (1Q08)

	Company	Market Share	Key Spectrum	Base Technology
1	AT&T	26.9% ↑	Cellular/PCS/AWS/700	GSM/UMTS
2	Verizon Wireless	26.1% ↑	Cellular/PCS/AWS/700	CDMA
3	Sprint/Clearwire	18.8% ↓	PCS/2500	CDMA/iDEN
4	T-Mobile USA	11.4% ↑	PCS/AWS	GSM
5	Alltel	5.1% ↑	Cellular/PCS	CDMA
6	U.S. Cellular	2.5% ↓	Cellular/PCS/AWS/700	CDMA
7	MetroPCS	1.5% ↑	PCS/AWS	CDMA
8	All Others	7.7% ↓	PCS/Cellular/AWS/700	All

Source: Del'Oro Group Mobility Report Five Year Forecast (January 2008)

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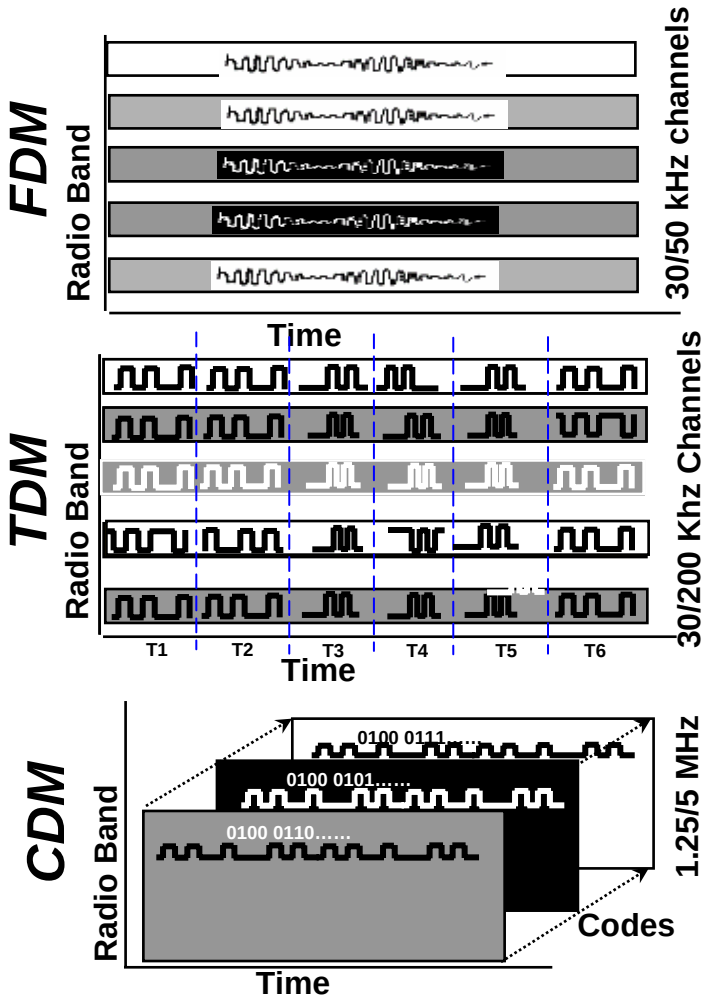
Mobile Technologies

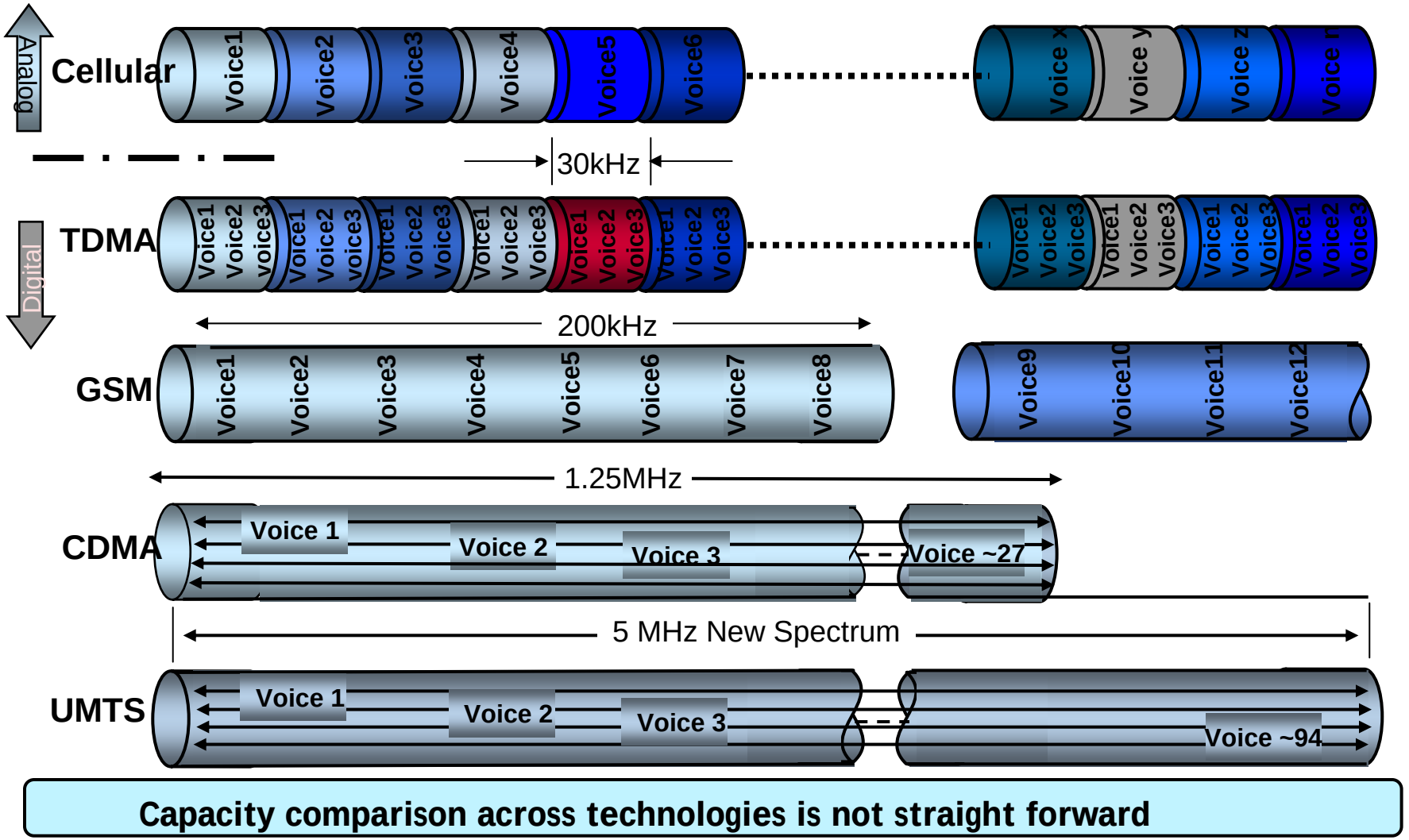
• GSM uses "Time Division Multiplexing" and CDMA & UMTS use "Code Division Multiplexing"
• US and European Standards Differ

What's the difference between GSM, CDMA and UMTS?



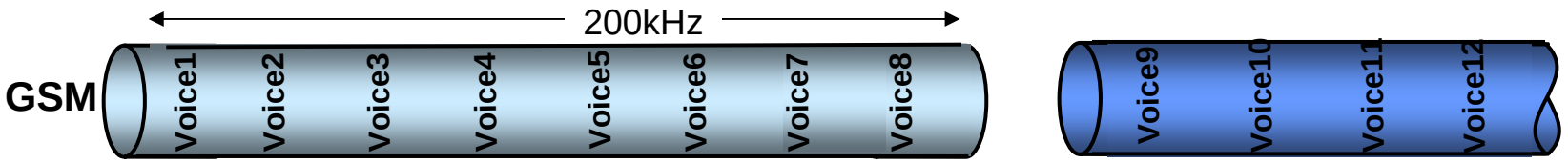
- **Analog - Advanced Mobile Phone System (AMPS) Frequency Division Modulation (FDM)**
  - Non Digital Transmission
  - Each User Assigned a Channel for Voice or Tones
    - 30 KHz (US)
    - 50 Khz (EU)
- **Digital – Time Division Multiple Access (TDMA)/ Global System for Mobile Communications (GSM)**
  - Time Division Multiplexing (TDM)
  - TDMA uses 30 kHz Channels (US)
  - TDMA Channels carry 3 conversations each
  - GSM uses 200 kHz Channels (EU)
  - GSM Channels carry 8 conversations each
- **Digital – Code Division Multiple Access (CDMA)/ Universal Mobile Telecommunications System (UMTS)/ Wideband CDMA (WCDMA)**
  - Spread Spectrum Technology
  - Code Division Multiplexing (CDM)
  - Users Are Assigned a Spreading Code and Use the Same Carrier to Carry Digitized Voice or Data Streams
  - CDMA uses 1.25 MHz Channels (US)
  - UMTS/WCDMA uses 5 MHz Channels (EU)

Comparing Air Interfaces (2G-3G)



Packet Data Options for GSM (2G)

What are GPRS and EDGE?



General Packet Radio Service (GPRS)

- Each Time Slot (TS) Can Carry Voice or ~14 Kbps Packet Data
- All 8 TS Can Be Combined for a Peak of 114 Kbps
- In the "Real World" 20-40 Kbps is typically assigned to Data

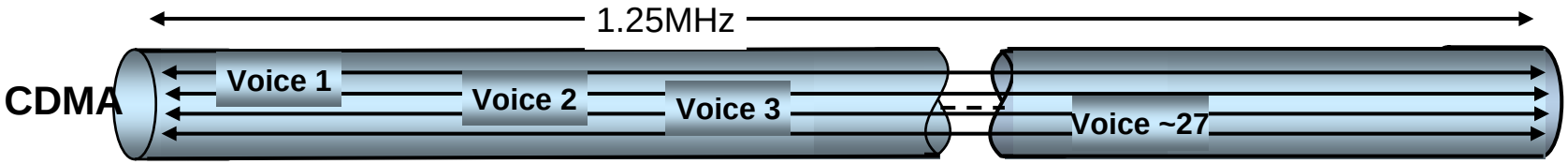
Enhanced Data rate for GSM Evolution (EDGE)

- Uses Newer More Sophisticated Coding Schemes on Each TS
- Each TS Can Now Support up to 59 Kbps
- All 8 TS Can Be Combined for a Peak 384 Kbps (472 K in Theory)

- **GPRS and EDGE are Wireless Data Technologies Associated with GSM**
- **Capacity is Increased by Combining Time Slots and Enhancing Coding Schemes**

Packet Data Options for CDMA (3G)

What are “1X”, EVDO and DORA/Rev A?



CDMA2000 1X

- **Each Spreading Code Can Carry Voice or 9.6 Kbps Packet Data**
- **Up to 16 Codes Can Be Combined for a Peak of 153 Kbps**
- **Real World Performance Is 60-80 Kbps (e.g. bandwidth sharing)**

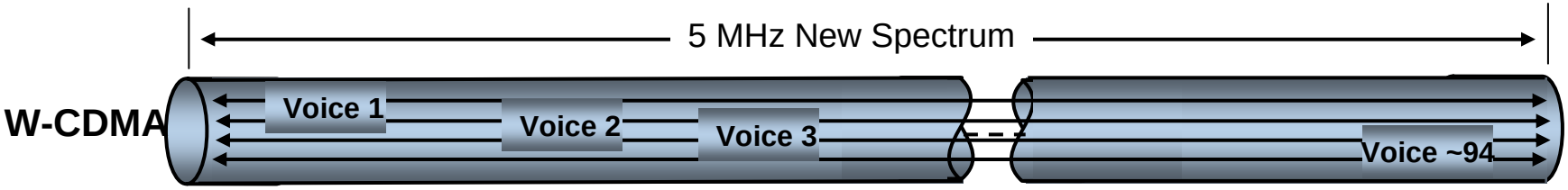
CDMA2000 1xEV-DO

- **One CDMA Carrier Is Dedicated to Data**
- **New Spreading Codes and Time Division Techniques Combine for a Peak Data Rate of 2.4 Mbps**
- **Real World Performance Is 600k-1.2 Mbps on the Forward Link and 100 Kbps on the Reverse Link**
- **Revision A Peak Data rate of 3.1Mbps on Forward and 1.8 on Reverse links (Rev A or DORA)**
- **Revision B aggregates up to 15 Rev A carriers for even faster Forward and Reverse links (Rev B)**

- **3G1X and EVDO are Wireless Data Technologies Associated with CDMA**
- **Rev A and Rev B Increase Capacity by Enhancing Algorithms**

Packet Data Options for UMTS (3G)

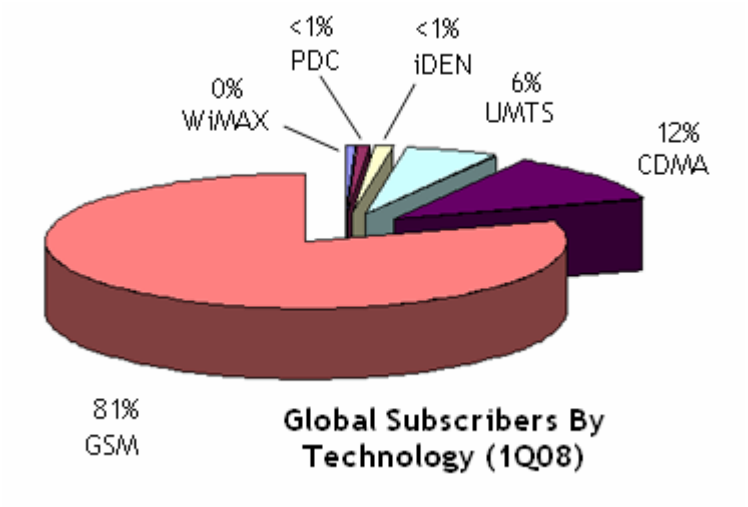
What are HSDPA and HSUPA?



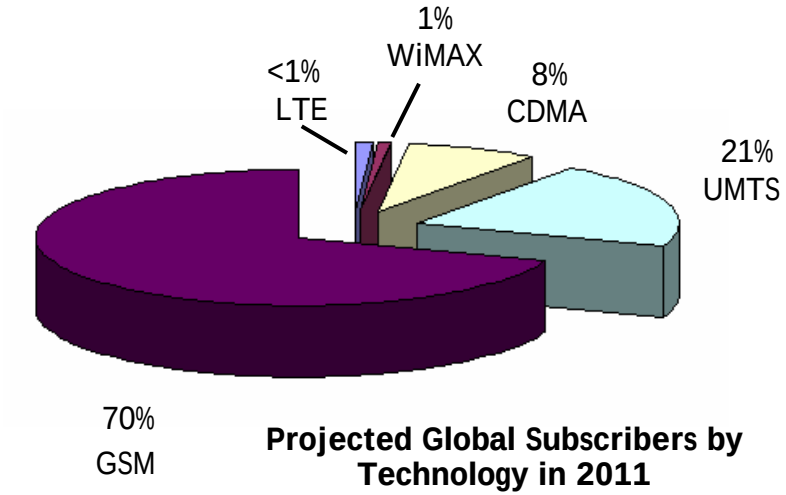
- Each Spreading Code Can Carry Voice or Packet Data
- New Spreading Codes Combine for a Peak Data Rate of 2 Mbps
- High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) Provide Increased Performance by Using Improved Modulation Schemes and by Refining the Protocols by Which Handsets and Base Stations Communicate (Next Evolution is HSPA+)
- Addition of HSDPA Provides Peaks of 14.4 Mbps With Per Sector Aggregate Throughputs of 2+ Mbps

- **Spreading Codes are Combined to increase Capacity**
- **HSDPA and HSUPA are Wireless Data Technologies Associated with UMTS**

Global Technology Directions



Global Subscribers By Technology (1Q08)



Projected Global Subscribers by Technology in 2011

- GSM Technology Base Migrates to UMTS and LTE Creating Global Economies of Scale
- CDMA Maintains a Large Base in North America, but Begins to Decline as 4G Technologies are Deployed
- WiMAX Emerges as a Potential Alternative to LTE
- Core Network Convergence Facilitates Evolution

4G Provides an Opportunity for a Unified Global Technology Standard

Source: Del'Oro Group Mobility Report Five Year Forecast (January 2008)

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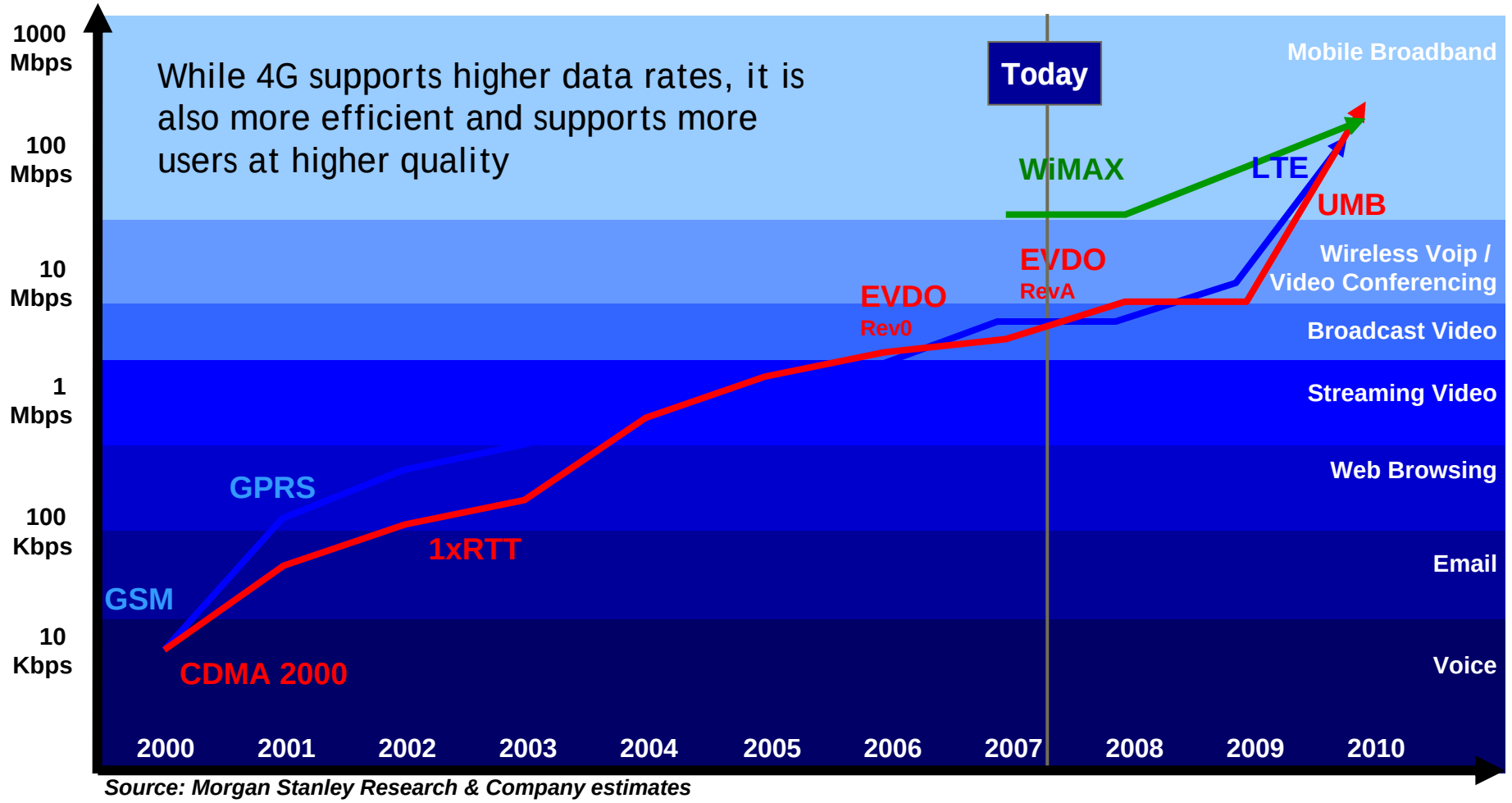
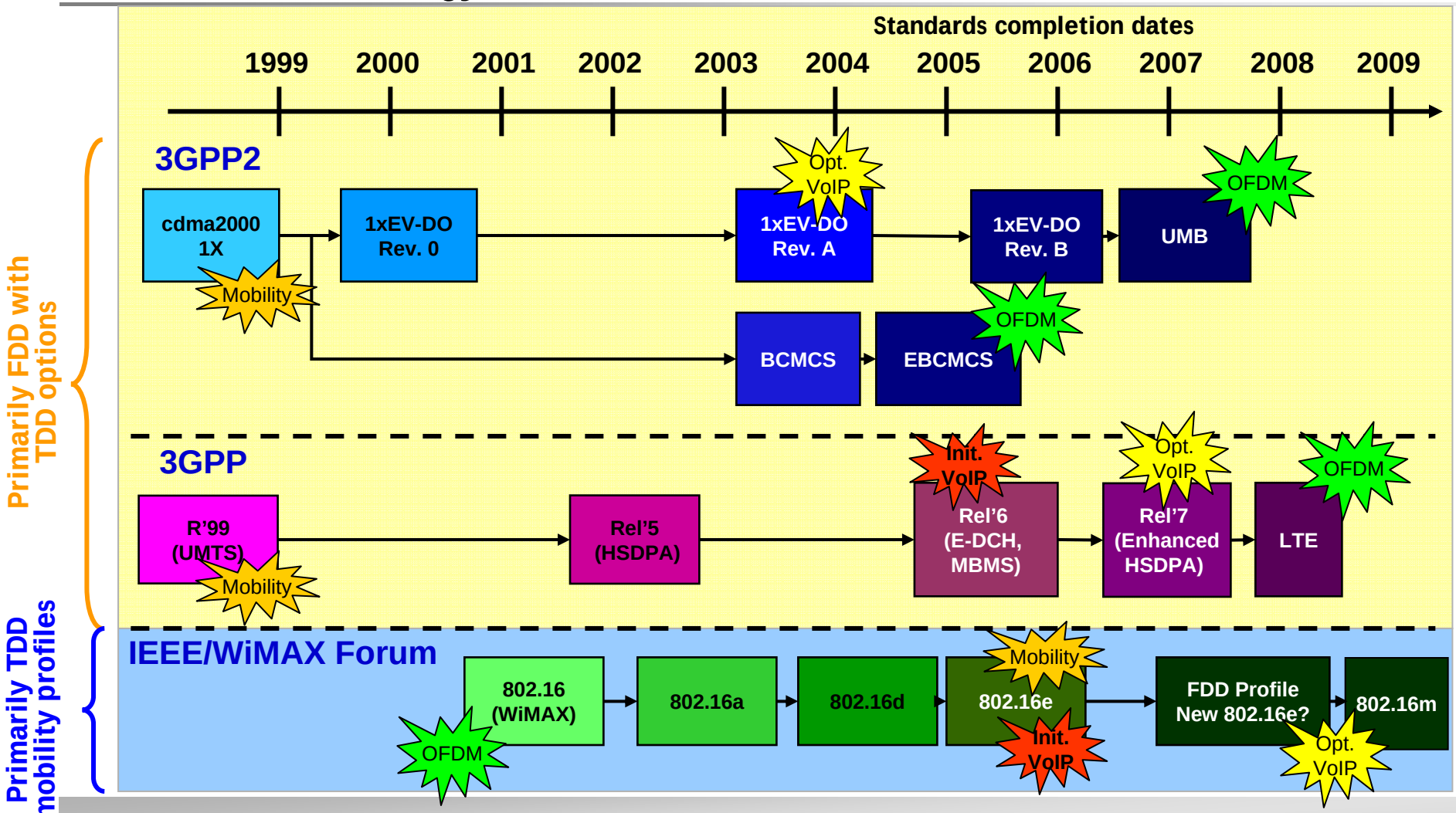
Mobile Broadband: Expect Significant Leaps Forward…



Source: Morgan Stanley Research & Company estimates

Wireless technologies evolving to become more broadband
WiMAX as a disruptive technology benefiting from the first-mover effect

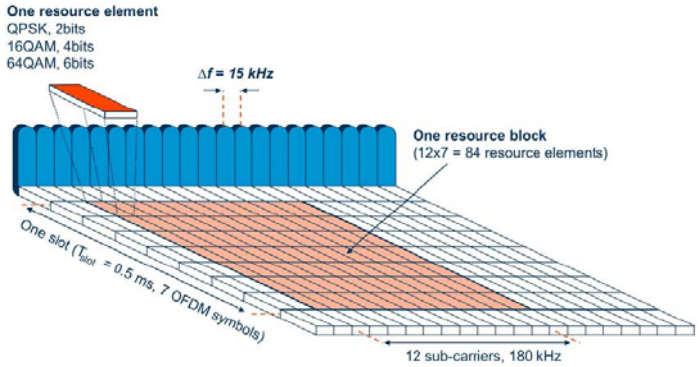
Standards Technology Evolutions



LTE is the 3GPP successor to UMTS/HSPA

4G Mobile Technology

What is “4G Mobile Technology”? What are LTE and WiMAX & how are they different?



OFDM – Orthogonal Frequency Division Multiple Access

- Each User is Allocated a Group of Resource Blocks, Depending Upon the User Needs, Resource Availability and Scheduling Mechanism
- A Resource Block is a Grid of Sub-Carriers and a Time Slot
- The Higher the Number of Resource Blocks Allocated and the Higher the Modulation Scheme, The Greater the User Throughput

Telecom Industry (EU)

- **Long Term Evolution (LTE)**
  - Orthogonal Frequency Division Multiplexing[1]
  - Flexible Spectrum Allocation (1.40-20 MHz)
  - Well Suited for Real-Time App. (e.g. VoIP)
  - Evolved Packet Core (EPC)[2]

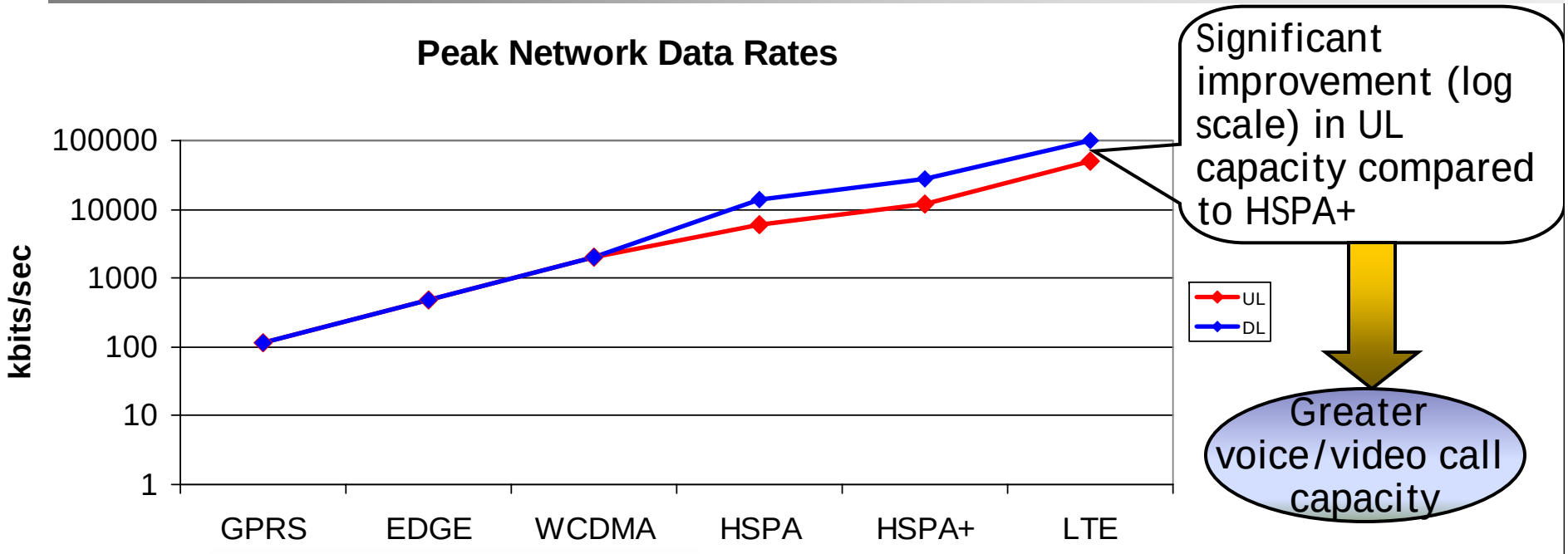
Computer Industry (US)

- **Worldwide Interoperability for Microwave Access – WiMAX (IEEE 802.16)**
  - Orthogonal Frequency Division Multiplexing
  - Multiple Spectrum Allocations (3.5-10 MHz)
  - Significantly Different from “WiFi”
    - → Broad Area (vs. Local)
    - → Dedicated Spectrum (vs. Shared)

- **4G Introduces OFDM, which Provides Improved Spectral Efficiency and Capacity**
- **LTE & WiMAX are Competing 4G Standards, Both Based on OFDM Technologies**

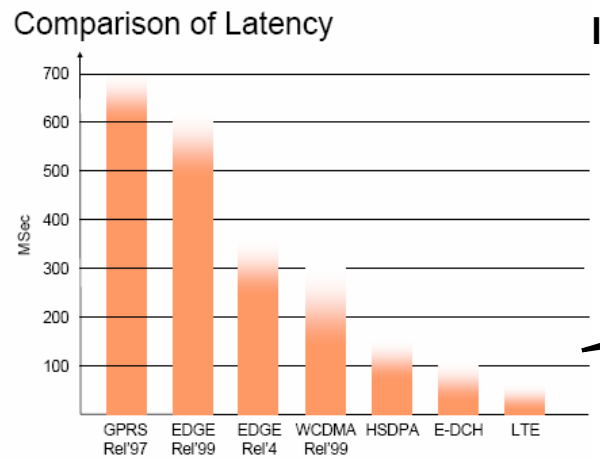
1. Uplink is SC-FDMA, Similar to OFDM but Better Suited for Handheld Devices (Battery Conservation) 2. Formerly Called System Architecture Evolution (SAE)

Evolution of 3GPP Radio Rates



Significant improvement (log scale) in UL capacity compared to HSPA+

Greater voice/video call capacity



Improved push-to-talk, interacative gaming, experience

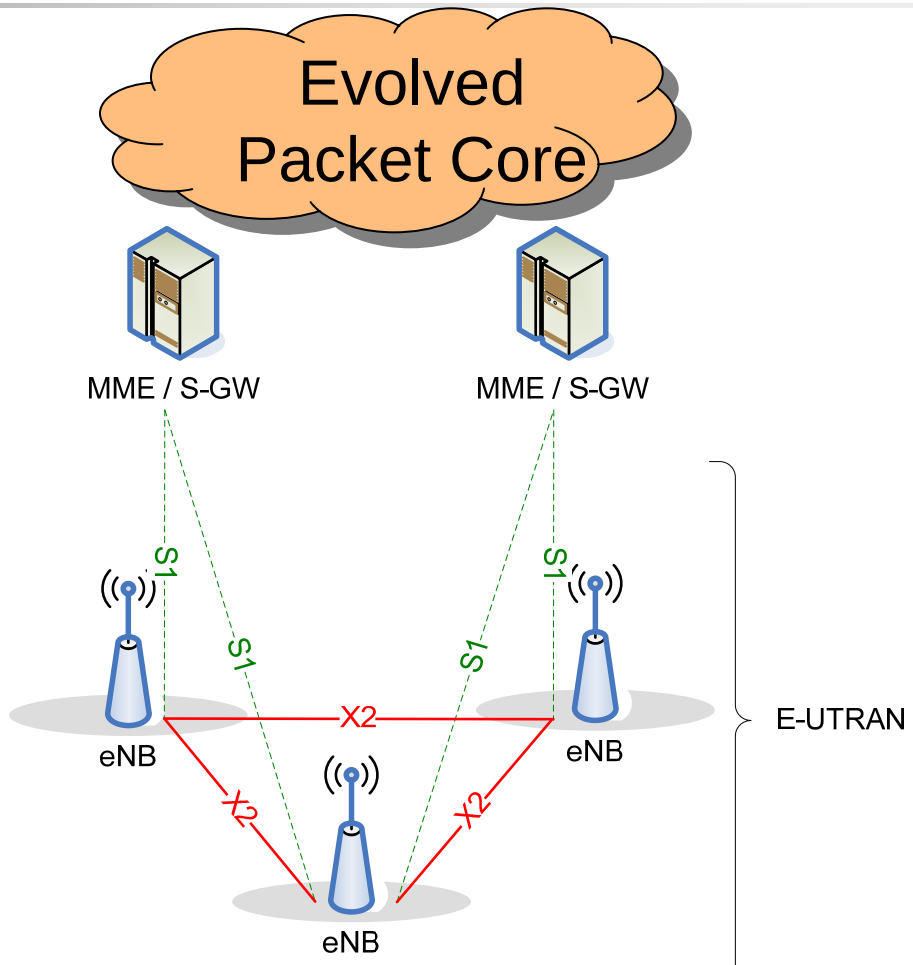
3GPP LTE & EPC

LTE Key Features:

- Improvements in spectral efficiency (5 bps/Hz DL, 2.5bps/Hz UL), user throughput (up to 100 Mbps), latency (10 ms UE-eNodeB), cell edge bit rate
- Simplification of the radio network – flexible spectrum allocation (1.4 – 20 MHz), no soft handoffs, variable duplex operation, no RNC
- Efficient support of packet-based services: MBMS, IMS, etc. (no circuit-based service)

EPC (formerly SAE) Key Features:

- Improvement in latency (50 ms UE-Packet GW), capacity, throughput
- Optimization for IP traffic and services
- Handover to/from non-3GPP access technologies (e.g., CDMA 1X EV-DO, WiMAX etc.)



MME/S-GW = Mobility Management Entity/ Serving Gateway

eNB = eNodeB

LTE Air Interface Characteristics

- Downlink based on OFDMA (Orthogonal Frequency Division Multiple Access)
  - OFDMA offers improved spectral efficiency, capacity etc (WiMAX, WiFi, DVB-SH,… are all using OFDMA technology)
- Uplink based on SC-FDMA (Single Carrier FDMA)
  - SC-FDMA is similar to OFDMA but is better suited for uplink from hand-held devices (battery power conservation)
- Both FDD and TDD modes
  - Provides deployment flexibility in spectrum allocation
  - With FDD, DL and UL transmissions are carried out simultaneously in two different frequency bands
  - With TDD, DL and UL transmissions are carried out at different time intervals within the same frequency band
- Significant reduction in delay over air interface, idle to active mode transition
  - Well suited for real time applications (e.g., VoIP, PoC, gaming,…)
- Large improvement in uplink spectral efficiency (compared to UMTS/HSPA)
  - Efficient for peer-to-peer applications (e.g., file sharing, P2P video,…)
- Support of advanced adaptive MIMO
  - Balance average/peak throughput, coverage/cell-edge bit rate

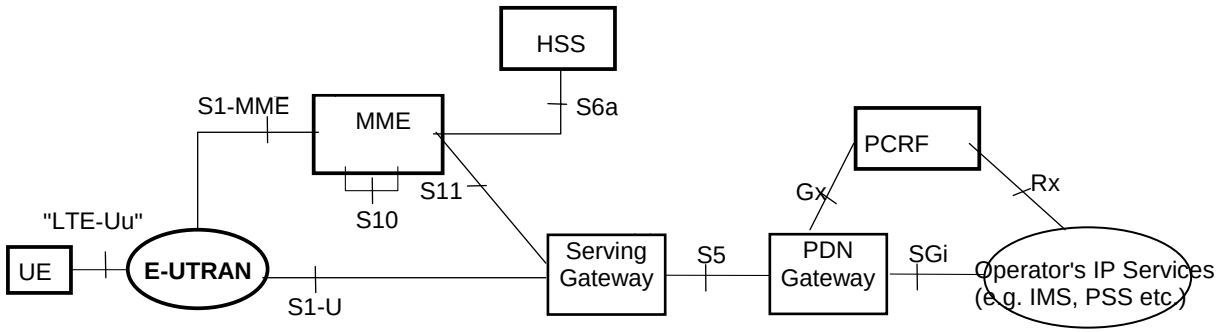
3GPP SAE (aka EPC)

SAE focus is on:

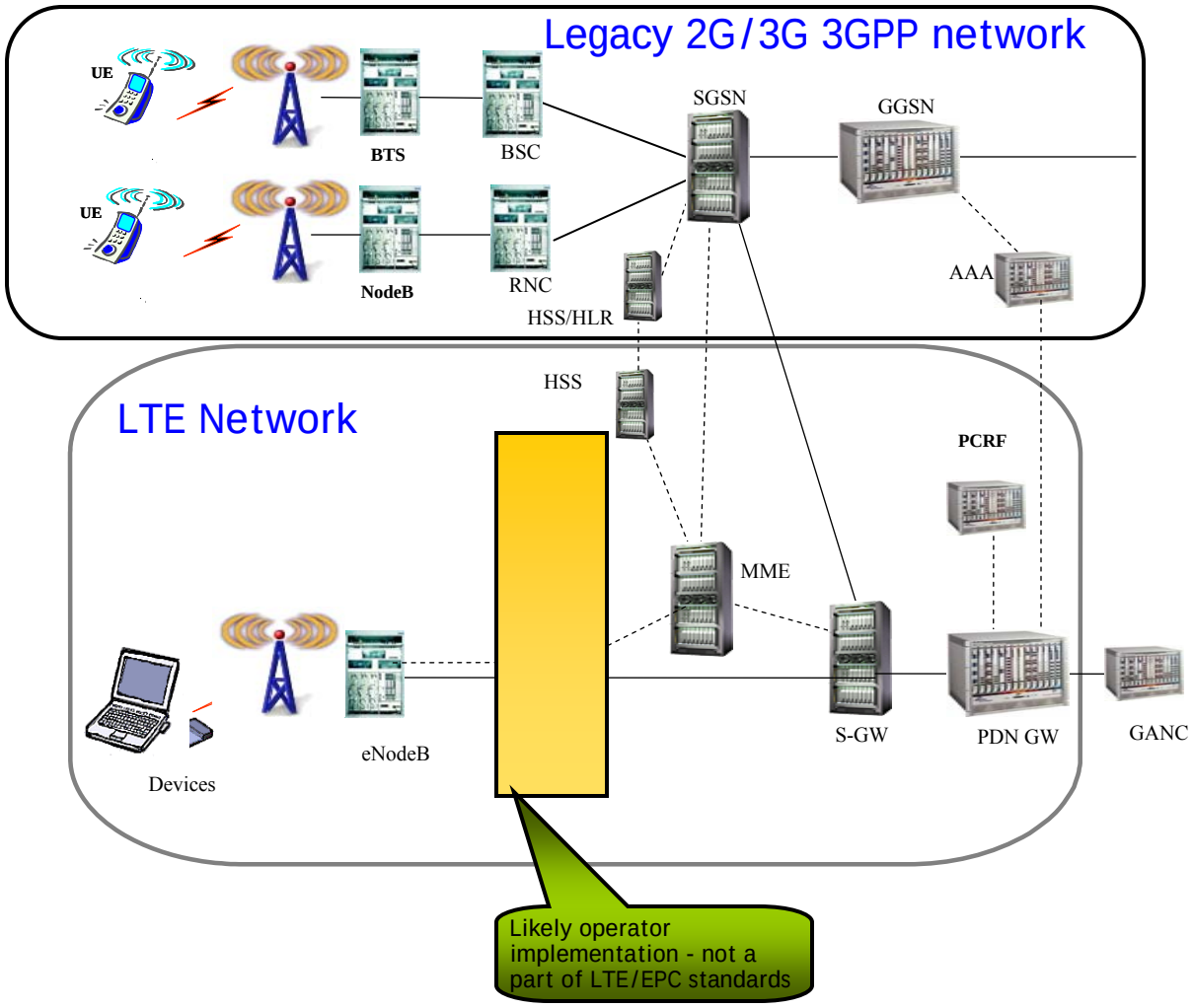
- enhancement of Packet Switched technology to cope with rapid growth in IP traffic
  - higher data rates
  - lower latency
  - packet optimised system

Key Goals:

- Improvement in latency, capacity, throughput
- Simplification of the core network
- Optimization for IP traffic and services
- Simplified support and handover to/from non-3GPP access technologies
- Load sharing arrangements, no single point of failure



Coexistence of 2G/3G Packet Data Networks and LTE/EPC



BTS: Base Tansceiver Station

BSC: Base Station Controller

RNC: Radio Network Controller

SGSN: Serving GPRS Support Node

GGSN: Gateway GPRS Support Node

HLR: Home Location Register

HSS: Home Subscriber Server

AAA: Accounting, Authentication and Authorization

eNodeB: evolved NodeB

MME: Mobility Management Entity

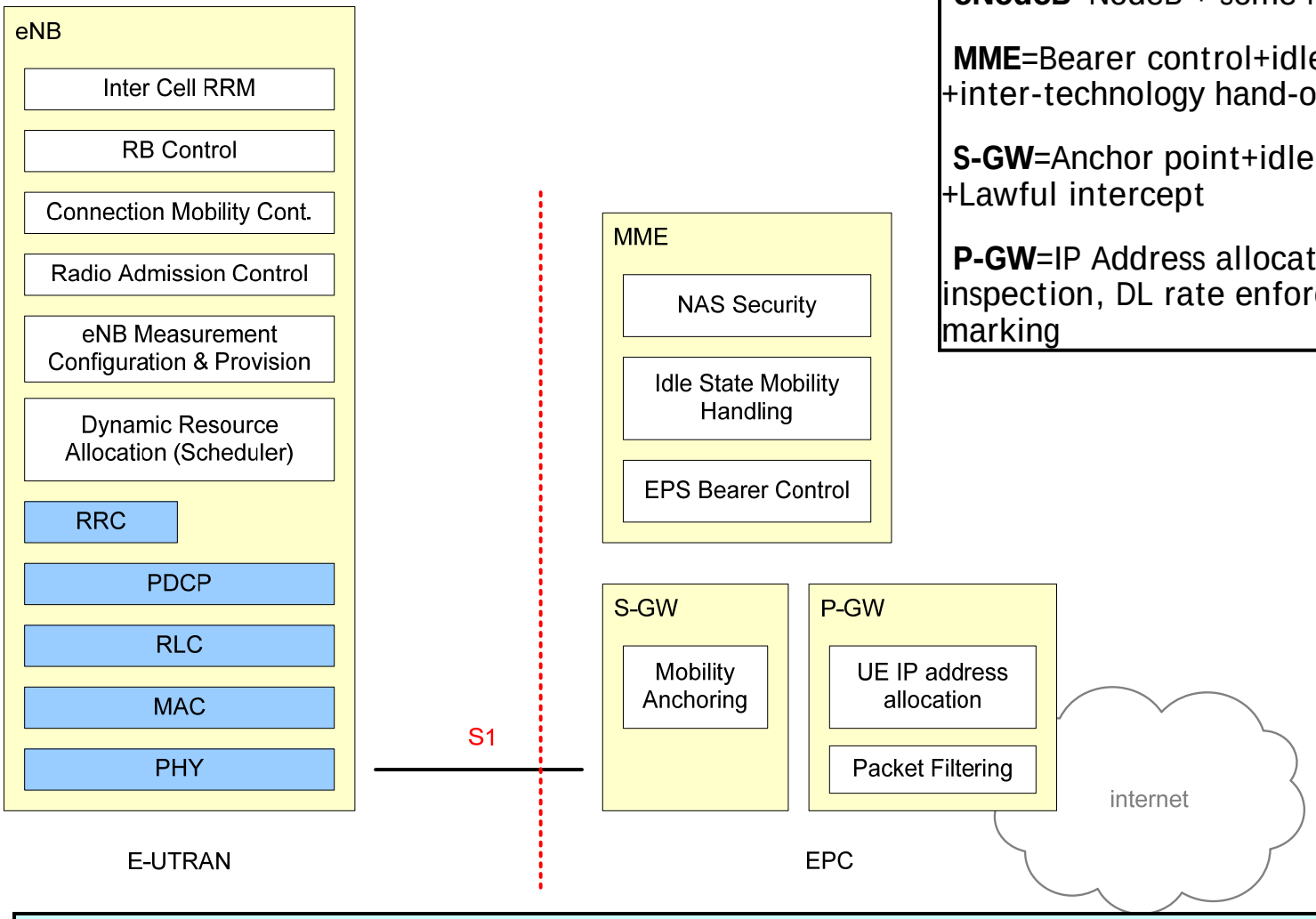
S-GW: Serving Gateway

PCRF: Policy and Charging Resource Function

PDN-GW: Packet Data Network Gateway

GANC: Global Access Network Controller

E-UTRAN and EPC Functional Split



eNodeB=NodeB + some RNC functionality

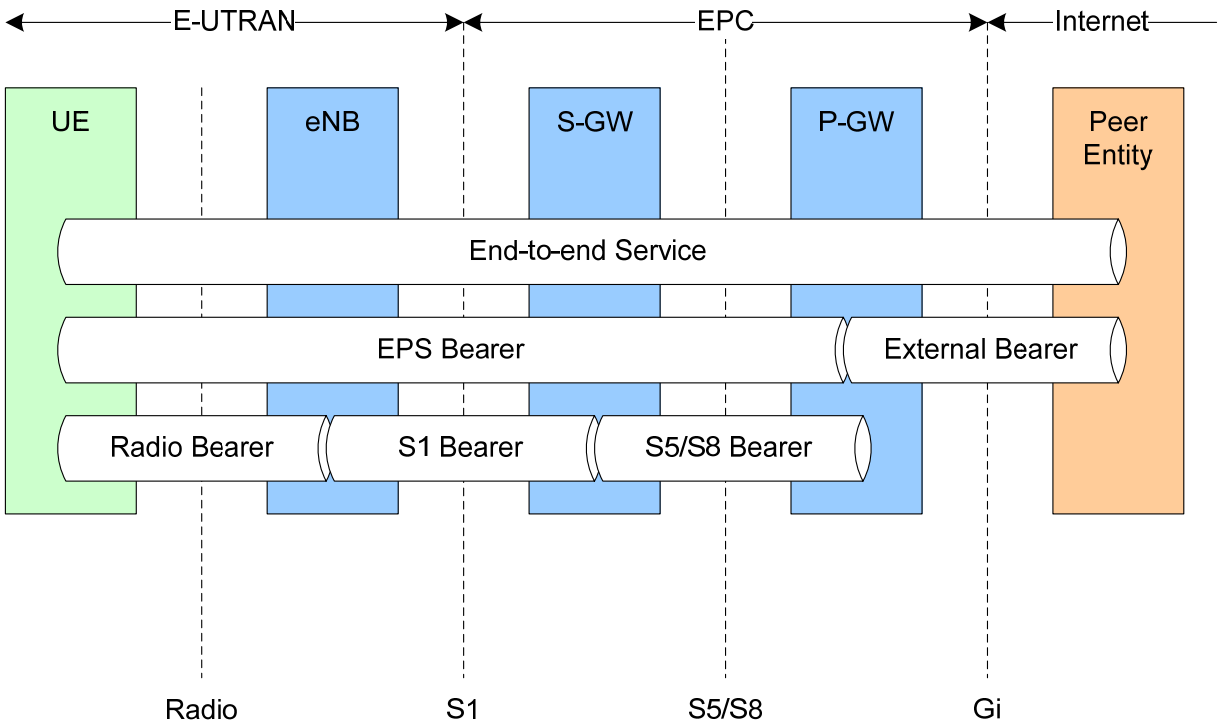
MME=Bearer control+idle state mobility +inter-technology hand-off control

S-GW=Anchor point+idle mode buffreing +Lawful intercept

P-GW=IP Address allocation+deep packet inspection, DL rate enforcement, DL packet marking

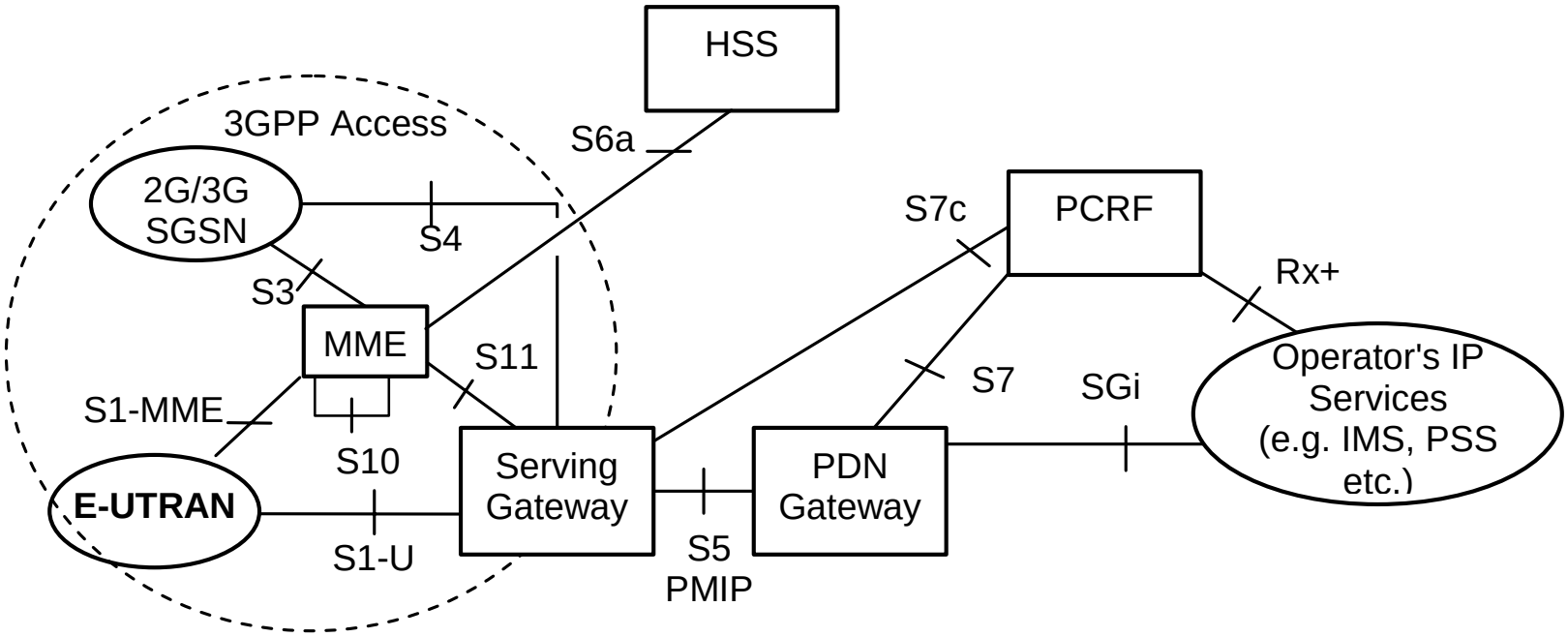
RNC functionality of UMTS/HSPA is split between eNodeB and MME/SG in LTE/EPC

EPS Bearer Service Architecture



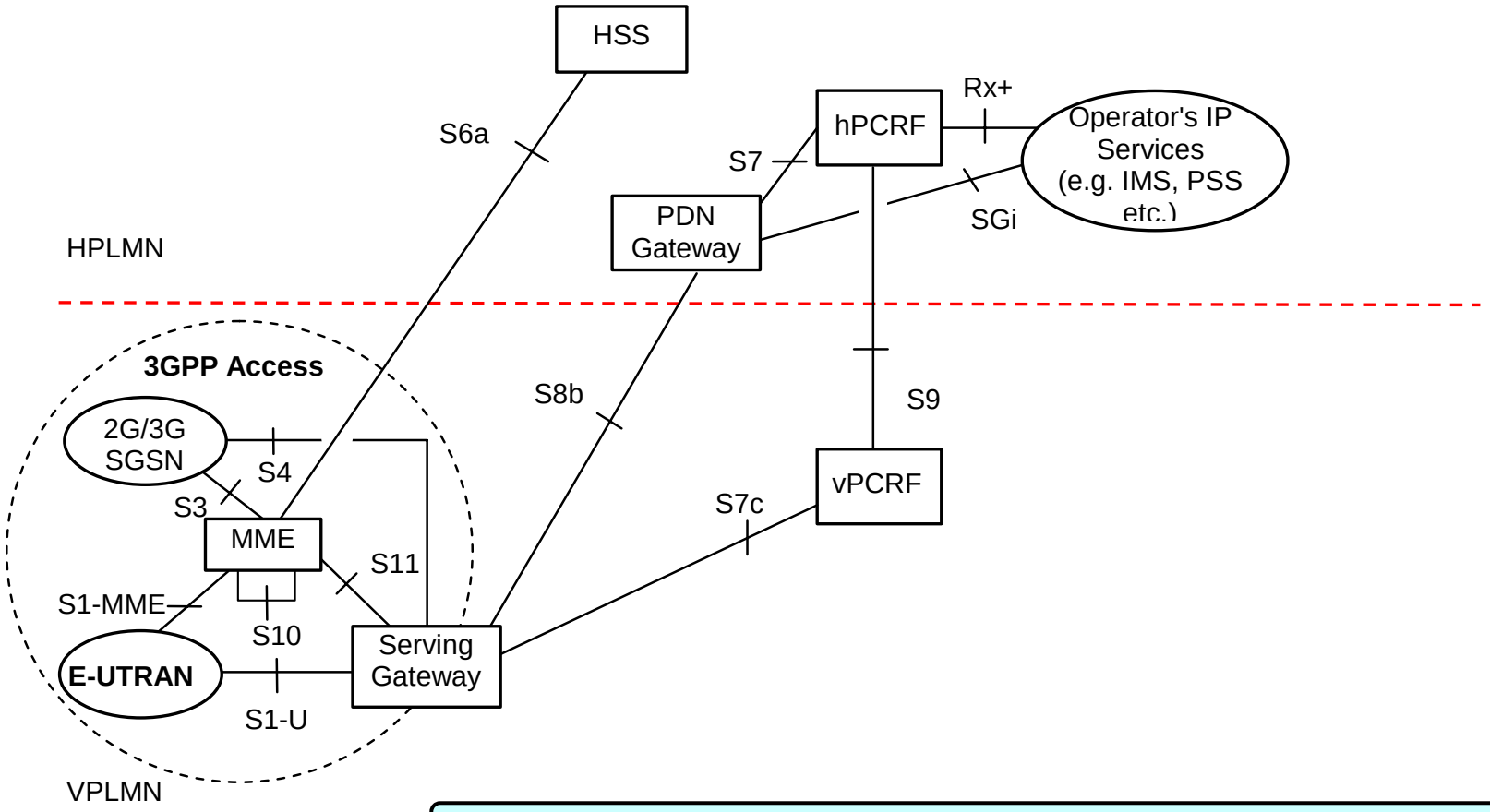
- UE creates binding between an SDF and a radio bearer in the uplink.
- PDN GW creates binding between an SDF and an S5/S8a bearer in the downlink.
- eNB creates binding between a radio bearer and an S1 bearer in both the uplink and downlink.
- A Serving GW creates binding between an S1 bearer and an S5/S8a bearer in both the uplink and downlink.

Example Non-Roaming Architecture



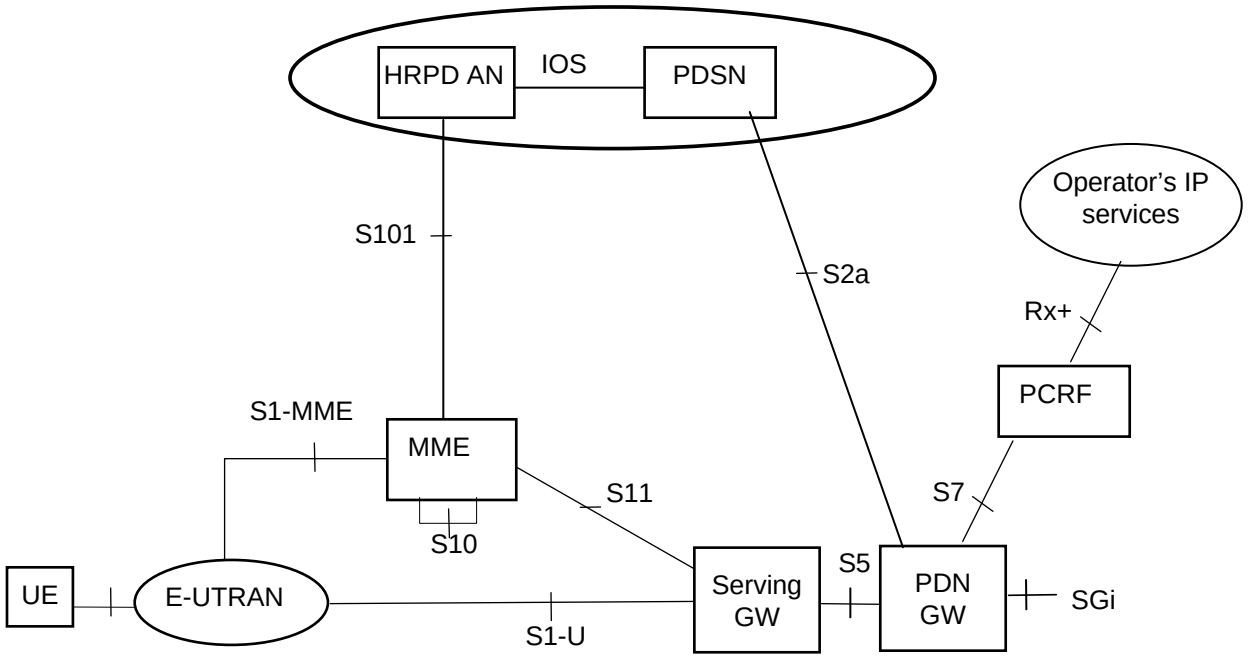
- The "3GPP Access" bubble represents a collection of functional entities and interfaces for the purpose of pictorial simplification

Example Roaming Architecture



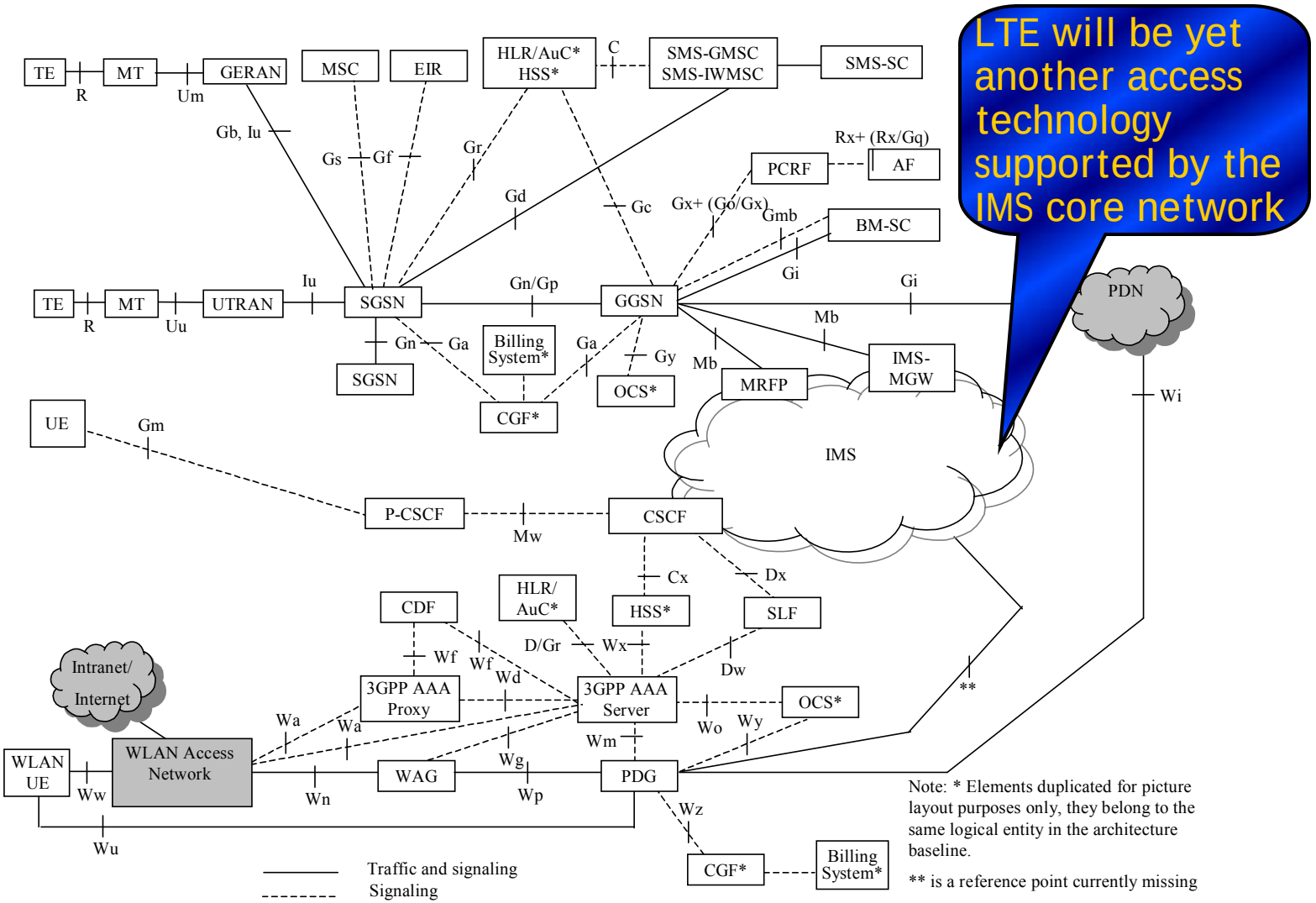
- UE uses PDN Gateway in HPLMN to access IMS applications

1X EVDO and EPC



S101 enables interactions between EPS and HRPD access to allow for pre-registration and handover signalling with the target system

Operator's IP Services Network - 3GPP Release 7 Baseline Architecture with IMS



Note: * Elements duplicated for picture layout purposes only, they belong to the same logical entity in the architecture baseline.

** is a reference point currently missing

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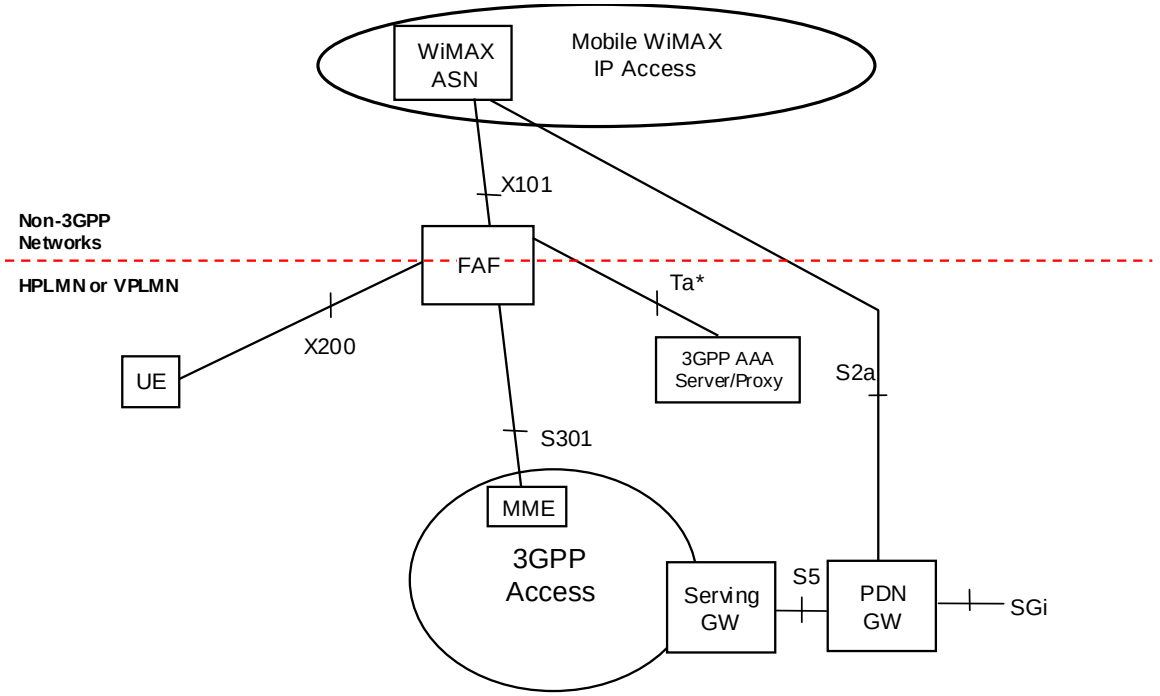
WiMax and EPC

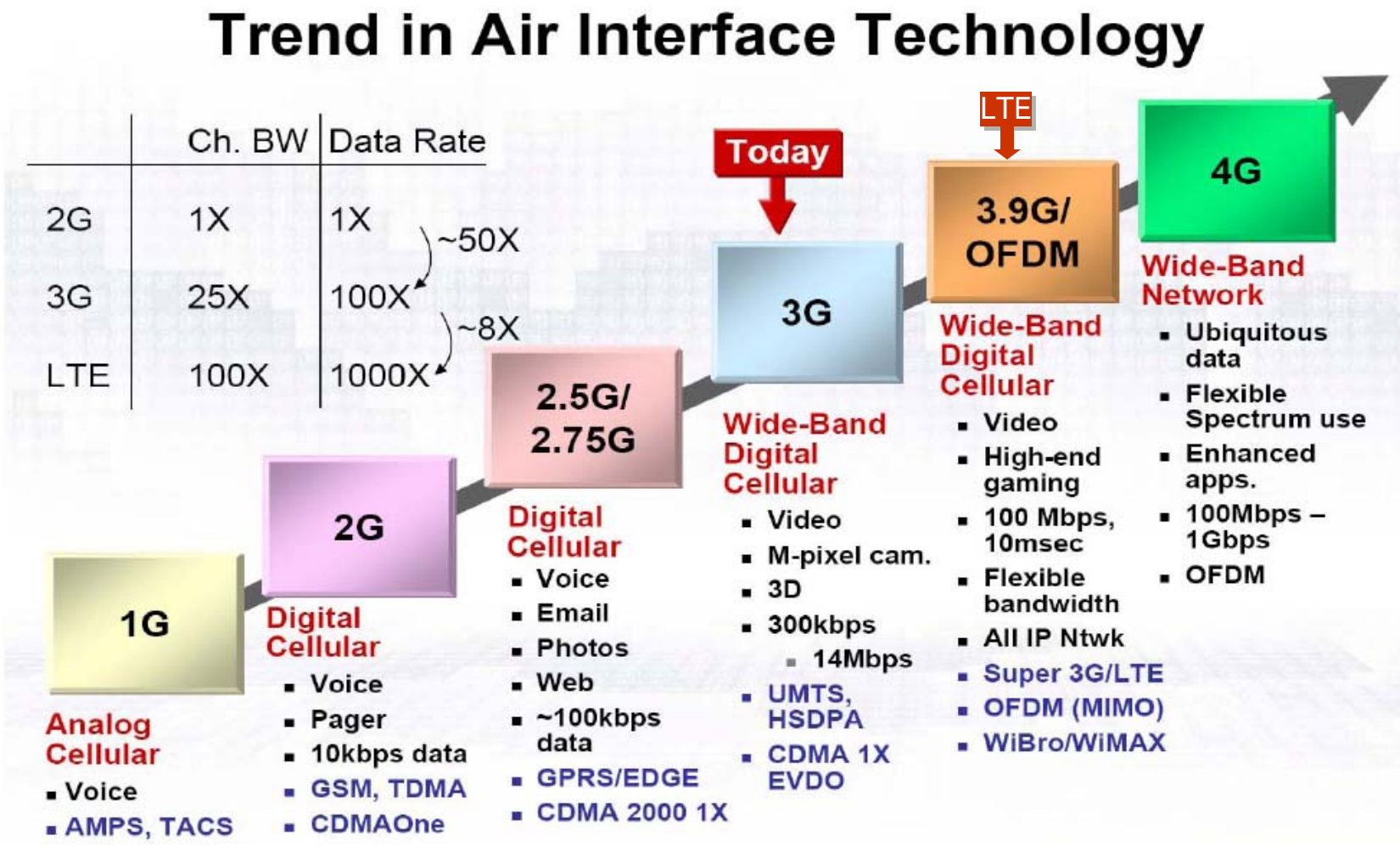


- FAF (Forward Attachment Function):The logical function which has interface with target system node using existing protocol. The UE communicates with the FAF over a generic IP access network. The UE may communicate with the FAF through mobile WiMAX IP access in order to prepare handover to a 3GPP access. Similarly, the UE may communicate with the FAF through a 3GPP access in order to prepare handover to mobile WiMAX access.

- X200:This reference point supports secure communication between the UE and the FAF through a generic IP access network, e.g. the mobile WiMAX IP access or EPS. It is used for pre-registration and for requesting resource preparation in the target access network.

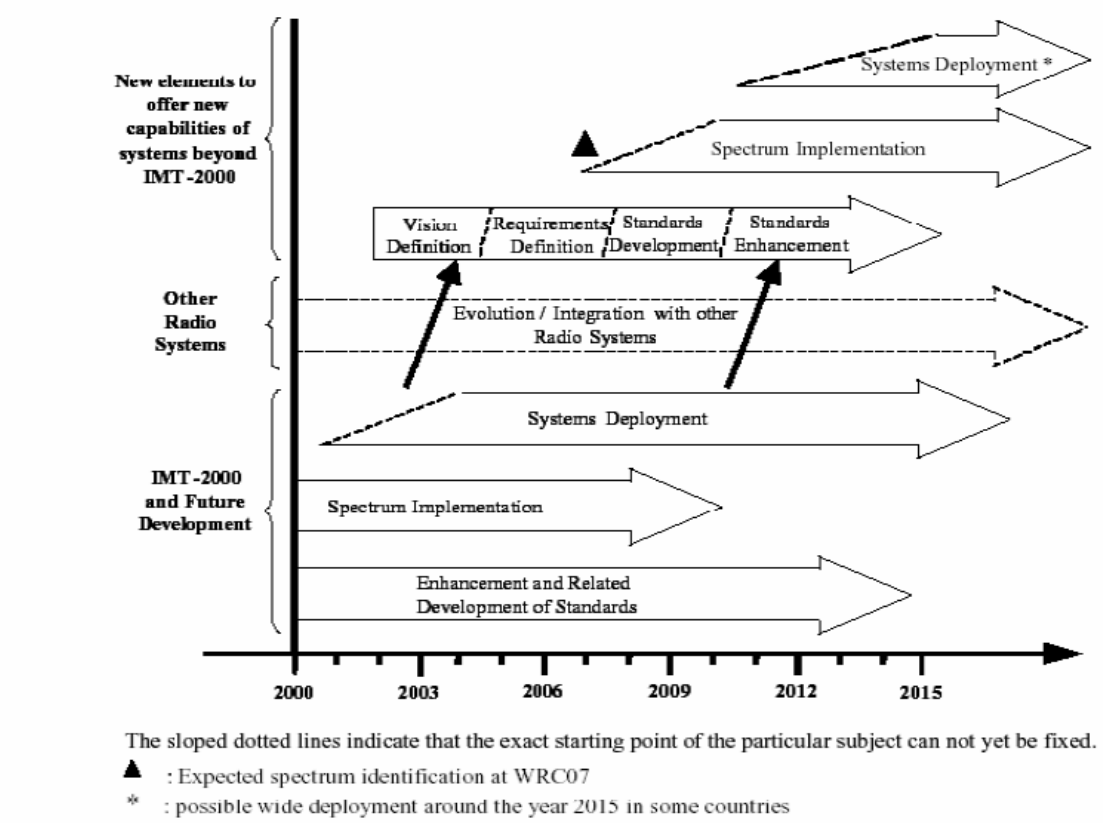
- S301:This reference point has the same functionality as the S1-MME (described in TS 23.401) and terminates to the MME inside the 3GPP Access.

Beyond LTE



Is LTE 4G or not?

IMT-Advanced:Timeline and Schedule



The sloped dotted lines indicate that the exact starting point of the particular subject can not yet be fixed.

▲ : Expected spectrum identification at WRC07

* : possible wide deployment around the year 2015 in some countries

Significant standards/technology development foreseen over the years

Summary Comparison of 3GPP Technologies

		Release 99	Release 5&6	Long-term evolution
Spectrum		3G spectrum (2GHz band and the additional bands)		
Radio aspect		W-CDMA	HSDPA, Uplink Enhancement	Evolved UTRAN
	Radio Access	Direct-Sequence CDMA		New elements (OFDM, MIMO, etc)
	UTRAN RTT	Several 100 msec	Several 10s to 100 ms	< 10ms
	Carrier Bandwidth	5MHz		1.25, 2.5, 5, 10, 20MHz
	Data Rate	384kbps - 2Mbps	14.4Mbps	50Mbps (uplink) 100Mbps (downlink)
	Mobility	-120 km/h (at least 384kbps)	- 120km/h	- 350km/h
NW aspect		Circuit Switch and Packet Switch		Packet Switch only

Minimum take away from this session

Acknowledgments

- Many colleagues at Alcatel-Lucent
- Several 3GPP contributors