UMTS Evolution
from
3GPP Release 7 to Release 8
HSPA and SAE/LTE

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 3rd Generation Partnership Project (3GPP) Rel-99. With the rapid progress of the evolutionary 3GPP roadmap for UMTS to HSPA, from Rel-5 (2004 white paper), to Rel-6 (2005 white paper), to Rel-7 (2006 white paper), and the commercial deployment of 200 UMTS/WCDMA networks worldwide serving more than 158 million customers as of as of December 6, 2007, the tradition continues with considerable information to update on Rel-7 and a new focus on Rel-8 in this current white paper, *UMTS Evolution from Release 7 to Release 8 – HSPA and SAE/LTE*. Some sections of this paper were updated in December 2007.

A perfect example of this growing commercialization is the progress since December 6, 2005, when Cingular Wireless (now AT&T) launched UMTS enhanced with High Speed Downlink Packet Access (HSDPA) in 16 major markets throughout the US, becoming the first operator in the world to launch this enhanced UMTS technology on a wide-scale basis. Exactly two years later, there are already 167 operators offering HSDPA services in 72 countries of the world, with 64 additional operators in stages of planning, deployment or trial as of December 6, 2007 (see *Appendix B*). As of November 2007, AT&T has deployed HSDPA technology across the company's 3G footprint, which includes more than 220 major US metropolitan markets.

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 ETSI[1] 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.

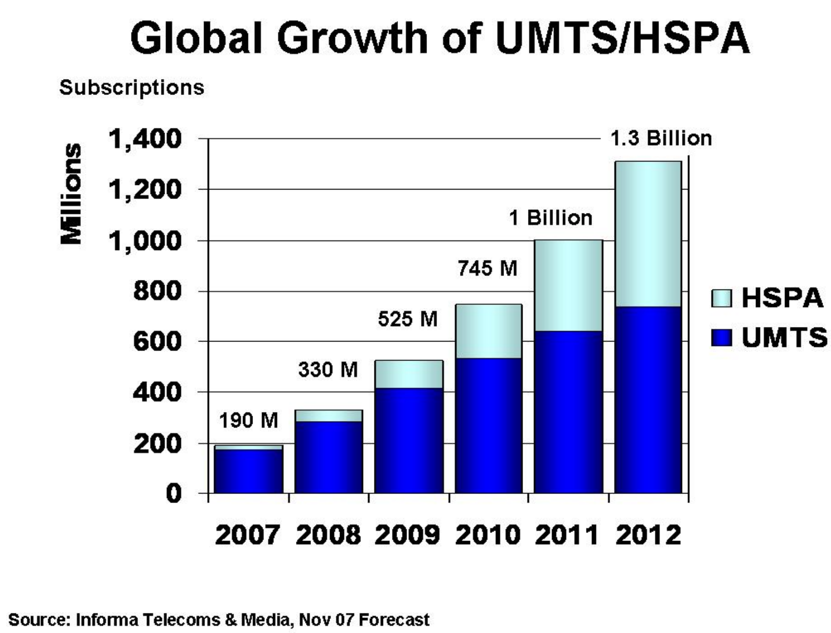

Figure 1. Global UMTS Subscriber Growth Forecast[2]

The rapid growth of UMTS led to a focus on its next significant evolutionary phase, namely, Release 5 (Rel-5). 3GPP Rel-5, initially 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 the improvements they need to offer customers higher-speed wireless data services with vastly improved spectral efficiencies through the HSDPA feature. It is expected that HSDPA Rel-5 will provide a 50% reduction in cost per megabit versus Rel-99, and HSDPA Rel-6 will further build upon reductions in

[1] ETSI: European Telecommunications Standards Institute
[2] World Cellular Information Service, Informa Telecoms and Media. May 2007.

the cost per megabit. 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 introduces the IP UTRAN concept to realize 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 Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond* December 2005 white paper 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.

Now we offer a further review of Rel-7 as it nears completion in the technology standardization process, and an introduction to the improved features of Rel-8. *UMTS Evolution from Release 7 to Release 8 – HSPA and SAE/LTE*, first published in July 2007 and now updated in December 2007, explores the growing demands for wireless data and successes already indicated for a variety of wireless data applications: the increasing Average Revenue Per User (ARPU) for wireless data services by operators worldwide, the cost per byte of UMTS data service, and technology benefits. 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 vendors. There is also a brief introduction to Evolved EDGE. In this Rel-8 white paper, the clear roadmap for UMTS evolution is defined.

This paper has been prepared by a working group of 3G Americas' member companies. The material represents the combined efforts of many experts from the following companies: Alcatel-Lucent, Andrew Corporation, AT&T, Ericsson, Gemalto, Motorola, Nokia (Nokia Siemens Networks), and Nortel Networks.

1 Introduction

Demand for wireless data services is growing faster than ever before, evident in the fact that average data ARPU in the US has increased by 50% from YE 2005 to YE 2006.[3] While demand for applications such as text messaging (SMS), Web and WAP access, multi-media 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 growing quickly. Most UMTS operators today are offering some kind of mobile broadband service and several 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, and that is driving the need for higher bit rates, lower latency and more spectrally efficient support of data services.

While there continues to be significant growth in HSDPA deployments, HSUPA is beginning to be rolled out at the same time. The combination of HSDPA and HSUPA, called HSPA, provides a very spectrally efficient wireless solution. 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, picture and video sharing, and Voice and Video over IP through the introduction of features like MIMO, 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.

In addition to the continued evolution of the HSPA technology, 3GPP has made significant progress towards the standards development and definition of 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 Network (EUTRAN). In parallel, 3GPP has progressed on the standards development and definition of 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 System (EPS) Architecture. 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 EPS will both be used to refer to the evolved flatter-IP core network. The combination of LTE and SAE provides the long-term vision for 3GPP to an all-IP, packet only wideband OFDMA system expected to

[3] Sharma, Chetan. "US Wireless Market – 2006 Update." March 2007.

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 demands for higher wireless data speeds and spectral efficiencies continues to grow.

This paper will first discuss the progress on the deployment status of the UMTS and HSPA technologies, followed by a discussion on the standards progress and expected performance benefits of the HSPA evolution to Rel-7 or HSPA+. The growing demands for wireless 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.

2 Progress of Rel-99/Rel-5/Rel-6 UMTS

Rel-99 UMTS specifications, initially standardized in early-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 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 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 167 commercial UMTS networks listed on the 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.[4] Rel-6 introduced further enhancements to UMTS including HSUPA (or E-DCH), MBMS and Advanced Receivers.[5]

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

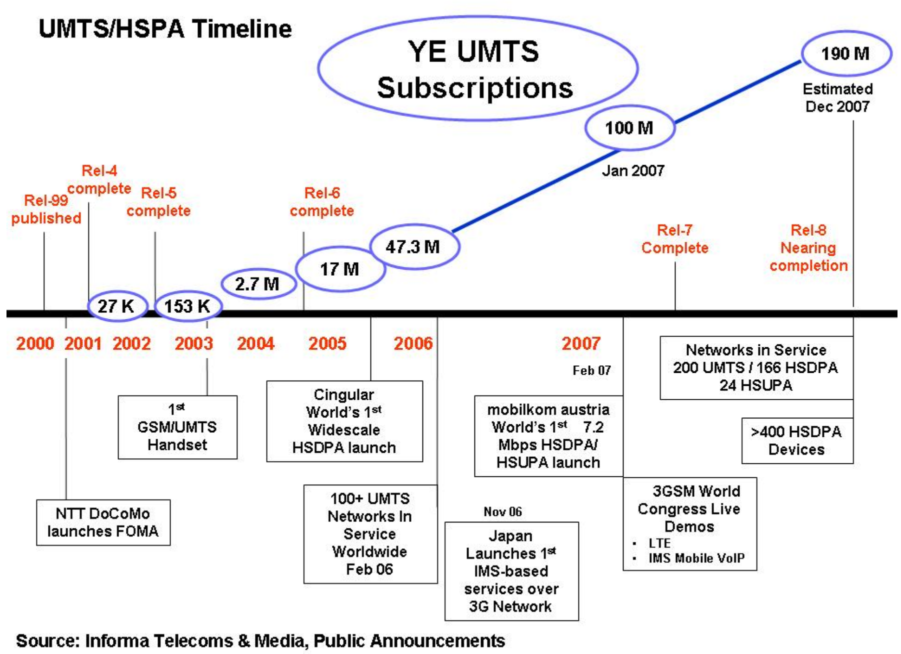

Figure 2. 3GPP UMTS/HSPA Timeline[6]

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[4] *3GPP Rel-5 and Beyond - The Evolution of UMTS*. 3G Americas. November 2004.
[5] *The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond*. 3G Americas. December 2005.
[6] 3G Americas. May 2007.

HSDPA was first demonstrated on a commercially available UMTS base station in Swindon, U.K. in November 2003, 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. In just two years, there were 167 commercial HSDPA networks in 72 countries with 64 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. There were also 25 HSUPA commercial launches worldwide as of December 6, 2007. AT&T is the first US carrier to deploy enhanced upload speeds through HSUPA in its HSPA networks with upload speeds between 500 and 800 Kbps and download speeds ranging between 600 Kbps and 1,400 Kbps.

Currently, the UMTS standard is available worldwide for use in the 850, 900, 1700, 1800, 1900, 2100, 1700/2100 and 2600 MHz bands. Additionally, it is expected the standard will be expanded for use in 700 MHz bands. The 700 MHz band auction in the U.S. is scheduled to begin in January 2008. With the introduction of LTE in later years, there will be 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 and 2600 MHz as well as the 1500 MHz band in Japan and 2300 MHz in the US. 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 encouraged operators to deploy 3G UMTS technology.

Already a reality in the market, HSDPA equipment today supports peak rates of 14 Mbps downlink and 1.4 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 are 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, 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 variety of device manufacturers [see *Appendix C*]. HSPA embedded modules in notebooks are being provided by numerous vendors to accelerate the growth of the mobile broadband and bring HSPA to every notebook. By early 2008, many notebooks will support HSPA at 7.2 Mbps downlink, 2 Mbps uplink in addition to EDGE.

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 May 2007, there were more than 250 HSDPA devices available. This list is now estimated to be more than 400 devices long as of December 2007.

Handset manufacturers are developing some strong collaborative relationships and initiating promising technologies. For instance, UMA devices have been delivered to the market and will greatly improve indoor coverage and make calls more affordable. T-Mobile USA has been trialing UMA devices in the Seattle market. Also, device manufacturers are working with financial services companies like Visa and Master Card to develop contactless payment services, or, in other words, using cell phones as credit cards. The first Near Field Communication (NFC) mobile payment trials in the US are currently ongoing. NFC-enabled mobile phones were introduced 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 February 2007, Mobilkom Austria launched the world's first commercial HSUPA and 7.2 Mbps HSDPA network, followed by commercial 7.2 USB modems in April and 7.2 data cards in May. It is expected that there will be numerous announcements of commercial network upgrades to Rel-6 HSUPA throughout 2H 2007. In fact, there are 25 commercial networks today and 132 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. Many operators have commercial or contracted IMS networks throughout the world today, and hundreds of trials of various IMS network elements are being conducted. IMS developer programs are available in Germany, USA, China and Singapore to encourage the creation of advanced IMS applications and services. IMS solutions like the 'service enhancement layer' continue to develop—this particular solution allows for integration of a set of software technologies that enable wireless, wireline, and converged network operators to create and deliver simple, seamless, secure, portable, and personal multimedia services to their customers. IMS networks are intuitive—device, application and end-user aware—resulting in the creation of an eco-system real-time multimedia applications and services.

Technology milestones and advances in the evolution of UMTS 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 advance voice applications is also demonstrating tremendous growth. Reference *Appendix A* for more detailed information on the progress of UMTS Rel-99 to Rel-8.

3 Progress of Rel-7 and HSPA Evolved/HSPA+

There has been significant progress on Rel-7 standards over the course of 2006-2007 and the standards are nearing completion at this time. In July 2006, the 3G Americas white paper, *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond* offered a detailed discussion of several of the key features introduced in Rel-7; however, due to substantial progress, an updated discussion of Rel-7 is warranted. In particular, the introduction of type 2i and 3i receivers, Higher Order Modulations (HOMs) and investigations on architecture evolutions for HSPA are all areas that have seen significant focus since the writing of last year's paper and thus will be discussed in the following sections.

Vendors are proceeding well in development of the future commercial introduction of Rel-7/HSPA+. As an example, MIMO techniques are being 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/HSDPA data services, and 'flattens' what is typically a more complex architecture. At the 3GSM World Congress 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.

Rel-7 features will soon be commercially introduced as HSPA+ with MIMO and key components of 3G mobile networks to 'flatten' what is typically a more complex architecture. Trials began as early as 3Q 2007, although there have not been any public announcements to date.

Also demonstrated live at the World Congress and CTIA in 2007 were some of the future-proof solutions that form 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. For more information on vendor progress on Rel-7 features, see the *Appendix A* in this white paper.

3.1 Background and Standards Status

In the year since July 2006, considerable progress has been made to close 3GPP Rel-7 with significant new features. On the radio side, these features include a set which falls under the "HSPA Evolution", or "HSPA+" work item. HSPA+, as it is commonly known, comprises a set of enhancements to the HSPA radio interface which increases the throughput of HSPA, taking it to the next logical level of evolution.

Rel-7, for all practical purposes, was closed for new items in March 2007. Thus, a discussion of major enhancements to Rel-7, which occurred over the last 12-18 months, specifically, features not discussed in the previous 3G Americas report on the evolution of UMTS, are provided in the following sections.

3.1.1 Radio Enhancements

This section discusses the RAN related progress in Rel-7 features over the last year.

3.1.1.1 Enhanced Performance Requirements based on Receive Diversity & LMMSE Equalizer Receiver for HSDPA UE (Type 3 Receivers)

During 2006, 3GPP has studied further improved minimum performance requirements for UMTS/HSDPA UEs. These enhanced performance requirements are release-independent (i.e. apply also to a Rel-6 terminal with advanced receivers) but have been included here since much of the work defining these minimum performance specifications has occurred since last year's paper in July 2006.[7]

Interference aware receivers, referred to as type 2i and type 3i, were defined as extensions of the existing type 2 and type 3 receivers, respectively. The basic receiver structure is that of an LMMSE sub-chip level equalizer which takes into account not only the channel response matrix of the serving cell, but also the channel response matrices of the most significant interfering cells. HSDPA throughput estimates were developed using link level simulations, which include the other-cell interference model plus Orthogonal Carrier Noise Simulator (OCNS) models for the serving and interfering cells based on the two network scenarios considered.

This type of receiver attempts to cancel the interference that arises from users operating outside the serving cell, which is also referred to as other-cell interference. Interference models/profiles were developed for this other-cell interference in terms of the number of interfering Node Bs to consider, and their powers relative to the total other cell interference power, the latter ratios referred to as Dominant Interferer Proportion (DIP) ratios. For the purposes of this study item it was determined that five interfering Node Bs should be taken into account in the interference models. DIP ratios were defined based on three criteria: median values of the corresponding cumulative density functions, weighted average throughput gain, and field data. Of these criteria, the one based on the 'weighted average' was felt to offer a compromise between the conservative, median value criteria and the more optimistic field data criteria. In addition, two network scenarios were defined, one based solely on HSDPA traffic (HSDPA-only), and the other based on a mixture of HSDPA and Rel-99 voice traffic (HSDPA+R99).

HSDPA throughput estimates were then developed using link level simulations, which included the other-cell interference models plus OCNS models for the serving and interfering cells based on the two network scenarios considered. The two-branch reference receiver, referred to as a type 3i receiver, was found to offer significant gains in throughput primarily at or near the cell edge. Link level results were developed for a wide range of operating conditions including such factors as transport format, network scenario, modulation, and channel model. For example, the gains for the DIP ratios based on the weighted average ranged from a factor of 1.2 to 2.05 for QPSK H-SET6 PB3, and from 1.2 to 3.02 for VA30 for network geometries of -3 and 0 dB[8]. This complements the performance of existing two-branch equalizers (type 3), which typically provide gain at high geometries, and thus, the combination of the two will lead to a much better user experience over the entire cell.

In addition, a system level study was conducted that indicated that a type 3i receiver provided gains in coverage ranging from 20-55% for mildly dispersive channels, and 25-35% for heavily dispersive channels, the exact value of which depends upon user location. A second system level study divided the users into two different groups depending on their DCH handover states, where the first group collected users in soft handover (between cells), and the second group collected users in softer handover (between sectors of the same cell). The results of this second study indicate that the Type 3i receiver will provide benefits for users in these two groups, increasing their throughput by slightly over 20%. With regards to implementation issues, it was felt that the type 3i receiver is based upon known and mature signal processing techniques, and thus, the complexity is minimized. With two-branch, equalizer-based receivers already available in today's marketplace, it appears quite doable to develop a two-branch equalizer with interference cancellation/mitigation capabilities. Given all of the above, 3GPP concluded that two-branch interference cancellation receivers are feasible for HSDPA.

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[7] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.
[8] Kobylinski, Majmundar, Ghosh. "Other-Cell' Interference Cancellation for HSDPA Terminals with Diversity." Globcomm 2007.

3.1.1.2 Higher Order Modulations

The use of higher order modulations (HOMs) such as 64QAM (Quadrature Amplitude Modulation) in the downlink is an attractive complement to multi-antenna techniques (MIMO) in the downlink, e.g. in scenarios where deployment of MIMO is not possible. QAM is a modulation scheme which conveys data by changing (modulating) the amplitude of two carrier waves. HOMs provide more symbols per bit in order to increase the spectral efficiency of the transmitted signal, therefore enabling more information to be transmitted during the same bit over the air. Figure 3 illustrates a typical constellation for both 64QAM and 16QAM.

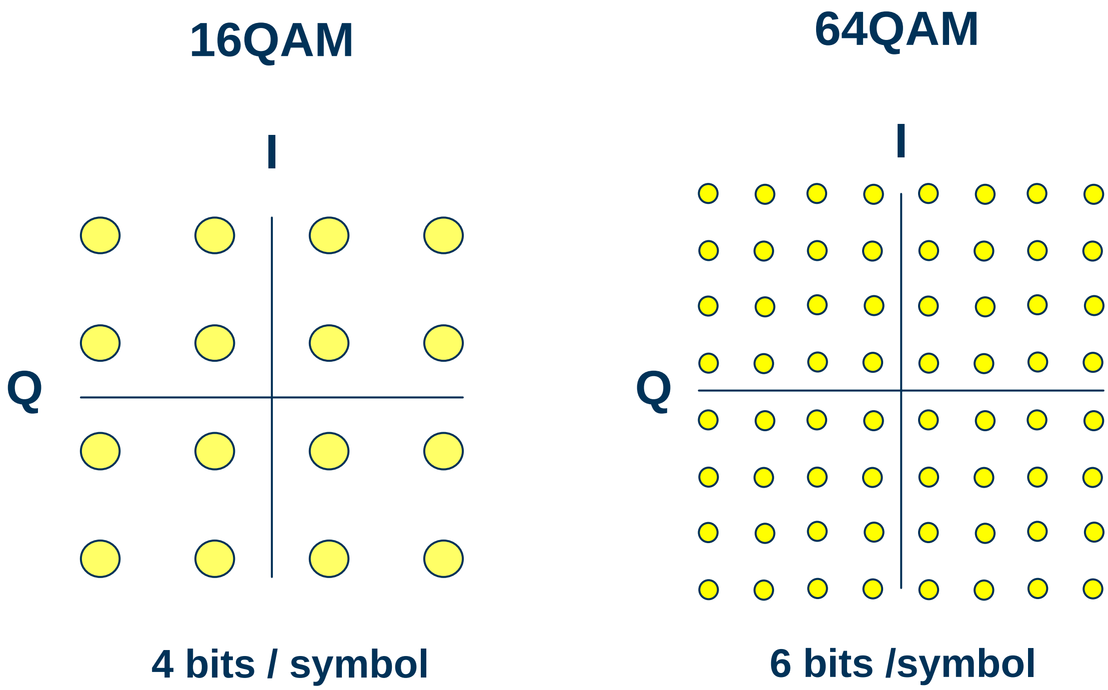

Figure 3. Typical 16QAM and 64QAM Constellations

In Rel-6 HSPA systems there is support for the use of 16QAM in the downlink and QPSK in the uplink. These modulation schemes provide higher data rates given the received symbol SNRs of macro cell environments, however, for indoor or small-cell system deployments, higher SNRs and higher order modulation can be supported. Modulation and coding scheme (MCS) tables determine the best combination of modulation and coding rate for a given SNR. With existing MCS tables, high symbol SNRs may "max out" the choice of MCS, giving the highest order modulation with the least amount of coding. As a result, these high SNR systems become peak rate limited. Besides MIMO, another means to increase this peak rate is to extend the MCS tables into higher SNRs with the introduction of even higher order modulations: 64QAM in the downlink and 16QAM in the uplink. While HOM can be used in conjunction with MIMO, it is important in its own right in those cases where deployment of MIMO systems is prohibited by physical, zoning, or budgetary limitations at the transmitter.[9]

The feasibility and performance impact of 64QAM modulation in HSDPA networks was extensively investigated in 3GPP in 2001. However, with the introduction of several new reference receivers in WG4 since then, there was renewed interest in understanding the performance and impact of the 64QAM modulation in HSDPA. The new reference receivers currently accepted by WG4 include: (a) Type-1: dual-port RAKE diversity receiver; (b) Type-2: 1-port LMMSE receiver; (c) Type-3: dual-port LMMSE receiver with inter-cell interference modelled as white noise, and (d)Type-3i receiver a dual-port LMMSE receiver.

3.1.1.3 Continuous Packet Connectivity (CPC) for Data Users

The objectives with CPC are to (1) reduce overhead for HSPA users, (2) significantly increase the number of HSPA users that can be kept efficiently in CELL_DCH state and (3) reduce latency for restart after

[9] *High Speed Packet Access Evolution – Concept and Technologies*. Ericsson. Q2 2007.

temporary inactivity. CPC was discussed in the 3G Americas' paper published in July 2006[10]. Since that time, 3GPP has worked on how to achieve the objectives and the following features have been included in Rel-7.

- Discontinuous transmission and reception (DTX/DRX), comprised of Uplink discontinuous transmission (UL DTX), CQI reporting reduction and Downlink discontinuous reception (DL DRX)
- HS-SCCH-less operation
- New DPCCH slot format

The overhead in uplink comes mainly from the continuous transmission of DPCCH when data is not being transmitted, which serves the purpose of maintaining synchronization and power control ready when needed for a rapid resumption of data transmission. This is different from the case where data is being transmitted, and the DPCCH also has to act as the phase reference for the data. The feature UL DTX and the new DPCCH slot format introduces two different ways to exploit the different functions of the DPCCH depending on whether data is transmitted or not.

With UL DTX, the UE can be configured to switch off the UL DPCCH when there is no data to transmit, (e.g. between web browsing events, or VoIP packets). This is also known as UL DPCCH gating. UL DTX reduces both the interference from inactive users, and the UE power consumption. To prevent severe impact on synchronization performance and power control, a UL DPCCH burst pattern (UE DTX cycle) is transmitted even when there is no data to transmit.

CQI reporting reduction can give a large gain in terms of reduced overhead since CQI reports (DL channel quality indicators from the UE) transmitted on HS-DPCCH require simultaneous DPCCH transmissions. After a period of HSDPA inactivity, the CQI reporting will get lower priority than the DTX pattern, CQI reports will then only be transmitted when they overlap with an UL DPCCH burst in the UL DPCCH burst pattern. As soon as there is an HSDPA transmission for the user, the CQI reporting will be restored to the (Rel-6) CQI feedback cycle.

DL DRX allows the UE to switch off its receiver after a period of HSDPA inactivity and then periodically switch its receiver on in accordance with a UE DRX cycle, while in Rel-6 the UE is required to monitor all (up to 4) HS-SCCHs continuously. The gain with DL DRX is in terms of UE power consumption.

HS-SCCH-less operation aims to reduce the overhead in downlink from HS-SCCH for transmission of small data packets, e.g. VoIP services. With this option the UE will monitor up to two HS-PDSCH OVSF codes, also known as HS codes, and perform blind transport format (TF) detection for 4 small TF. This allows the HSDPA scheduler in the base station to transmit any data packet that fits into one of the 4 TFs without using the HS-SCCH. HS-SCCH-less operation is expected to give some DL VoIP capacity gain in VoIP-only scenarios but more importantly the HS-SCCHs are freed up for other users, such as best effort users, and the total number of HS-SCCHs needed can be reduced.

The new DPCCH slot format is tailored to the case when the DPCCH is the only uplink channel. The DPCCH slot formats which are available in Rel-6 are primarily adapted to the case when data is being transmitted. In particular, all existing DPCCH slot formats 2 TPC bits, while the pilot field occupies between 5 and 8 bits, reflecting the need for sufficient pilot energy to give a reliable channel estimate for decoding data. The new slot format, shown in Figure 4, has 6 pilot bits and 4 TPC bits. The purpose if the new slot format is to reduce the SIR target when there is no UL transmission. Because of the larger number of TPC bits, this can be done without impacting the fast power control loop.

[10] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.

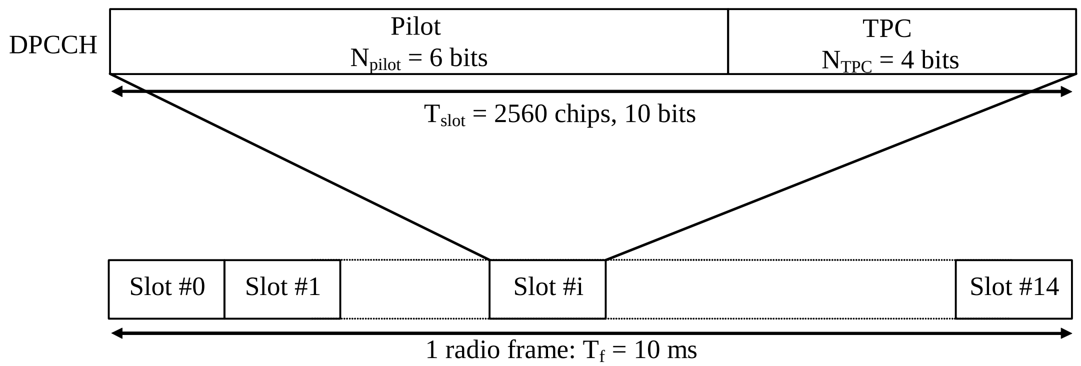

Figure 4. New DPCCH slot format[11]

3.1.1.4 MIMO (Multiple Input Multiple Output) Antennas

MIMO Antennas were discussed in the July 2006 white paper,[12] and as this information remains accurate and current, there is no additional work in this area to be presented in this paper.

3.1.1.5 RAN Architecture Improvements

In addition to PHY/MAC related enhancements, 3GPP also studies possibilities to evolve the HSPA architecture. The basis for the evolved architecture is the one tunnels solution (OTS) that is described briefly in last year's paper *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond.*[13] Initially, there were several architecture options proposed, but the RAN working groups have narrowed the options down to one potential architecture enhancement for HSPA which is an integrated RNC/NodeB option. In this option the RNC functions are integrated in the NodeB. The integrated RNC/NodeB architecture option for HSPA+ is compared to the traditional HSPA architecture and the architecture with OTS in Figure 5.

The integrated RNC/NodeB option for HSPA+ has been agreed in standards development as a viable architecture alternative for PS based services, but it will only represent an optional, complementary architecture for HSPA, (i.e. for support of CS services), HSPA+ can, and must, be deployed in the traditional hierarchical architecture as well.

One benefit of this new architecture option is that there are fewer nodes, which reduces latency, making it flatter and simpler. Further, the distribution of RNC functions out to the NodeBs could provide scaling benefits for potential femtocell HSPA deployments by not having a centralized RNC acting as the Controlling RNC for thousands of femtocells. Finally, the integrated RNC/NodeB architecture is similar to the SAE/EPS architecture to be shown later in this paper. From an architecture point of view, especially on the PS core side, the integrated RNC/NodeB option provides synergies with the introduction of LTE/EUTRAN.

[11] Ericsson. Q2 2007.
[12] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.
[13] *Ibid.*

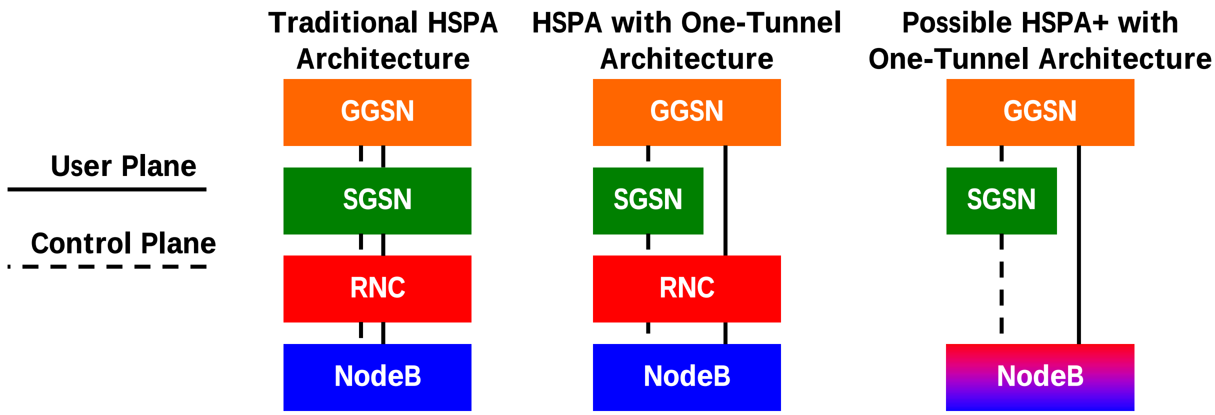

Figure 5. HSPA Architecture Options for the PS domain[14]

3.1.2 Device Related Enhancements

This section discusses device related progress in Rel-7 features over the last year.

3.1.2.1 Globally Routable User Agent URIs (GRUU)

It is common for individual users to have multiple devices that they use for different purposes. One user may carry a mobile phone, a wireless PDA and a PC with wireless capabilities. In this environment it has become important that the system provides tools to allow the different devices to be efficiently addressed and to harmonize the service presented to the user.

The GRUU feature allows the network to specify that a particular IMS transaction is related to a particular device belonging to the user. This feature enhances the experience of IMS users who wish to share a single public identity among multiple devices.

3.1.2.2 UICC Enhancements

With Rel-7, the UICC has entered a new era, dealing with multimedia and convergence reality. The high speed protocol based on USB technology is under finalization and together with the evolution of a power budget allocated to the UICC, it allows Rel-7 UICC to be considered as a secure and large storage device, integrating the latest flash technology. In addition, this secure device is efficiently connected to the network with a full IP-based communication stack, compatible with IPv6 and IPv4 standards.

A server located in the UICC, commonly named *Smart Card Web Server*, was developed by OMA standardization. Based on a strong collaboration with OMA, ETSI-SCP has amended its Rel-7 specification to allow the development of interoperable servlets, allowing operators to offer one card portal with dynamic and attractive content.

NFC-based mobile payment or transportation applications have naturally positioned the UICC as a secure and portable element and have motivated the development of a Rel-7 terminal-UICC interface dedicated to contactless exchanges. The Single Wire Protocol is the proposed interface to address the major challenges of contactless exchanges, such as transaction timing constraints and multiple applications environments, with the additional constraint to use only one UICC contact for its implementation.

Finally, *a Rel-7 security layer* is still being defined, named the secure channel, to secure local or remote exchanges between the UICC and a terminal, and thereby ensure integrity and privacy for communication over high speed interface or ISO, at an application or platform level. It relies on a key distribution mechanism defined in 3GPP SA3. This complete security feature is addressing security needs related to device management use cases when the UICC plays a role.

With Rel-7, ETSI-SCP and 3GPP also enhanced: the remote management of large files (with size larger than 32 Kilobytes) and one shot scripts based on proactive commands, the development of APIs to ensure interoperability for services based on the ISIM application, and large file management or CAT-TP transport protocol. In addition, the reference for open Operating Systems UICC based on Java Card™ technology has been upgraded to Java Card 2.2.2, the latest version recommended by Java Card Forum.

[14] Seymour, J.P. "HSPA+ Performance Benefits." HSPA+ Seminar, CTIA 2007.

Java Card 2.2.2 enables new cryptographic services and takes into account the coexistence of multiple physical interfaces.

3.1.3 Evolved EDGE

EDGE evolution consists of a number of technology improvements standardized within 3GPP Rel-7. EDGE evolution is expected to improve the user-experienced performance across all services by:

- Reducing latency to improve the user experience of interactive services and also to enhance support for conversational services such as multimedia telephony
- Increasing peak and mean bit-rates, to improve best-effort services such as web browsing or music, picture and video up-/downloads
- Improving spectrum efficiency, which will particularly benefit operators where existing frequency spectrum is used to its maximum extent and traffic volume can be increased without compromising service performance or degrading perceived user quality
- Boosting service coverage; for example, through interference reduction or more robust services. Increased terminal sensitivity improves coverage in the noise limited scenario

Latency is expected to be less than 80 ms which is achieved by reducing the Transmission Time Interval (TTI) from 20 ms to 10 ms.

Higher Symbol Rate and Higher Order Modulations are introduced for both downlink and uplink, while Downlink Dual Carrier transmission, MS Receive Diversity and Turbo Codes are introduced in downlink only. This improves the peak Rate per radio slot by 100%, to reach 120 kbps per time slot. In total the peak rate per user will be as high as 1 Mbps for downlink and 500 kbps for uplink. DL Coverage is improved by 3 dB with the introduction of MS Receive Diversity. Altogether, the EDGE evolution features will more than double the spectrum efficiency.

This improved end-user performance will stimulate mobile data usage and ensure service transparency between EDGE and HSPA as well as future LTE based services. The evolution of EDGE will also continue in Rel-8 with the addition of Turbo Codes for uplink and possibly other enhancements as well.

3.2 Performance Benefits

The evolution of HSPA as defined in 3GPP Rel-7 improves capacity, latency and peak rates. The capacity improvements are mainly related to MIMO for the DL and CPC for the UL, and were described in *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond.*[15]

With respect to latency there were some "indicative performance values" defined when the study on HSPA Evolution began. They include:

- Improved Round Trip Time from <100 ms to <50 ms
- Improved Packet Call Setup Time from ~1000 ms to <500 ms
- Improved Control Plane Latency, Dormant to Active, from ~1000 ms to <100 ms

MIMO will theoretically give 28 Mbps for peak rates and Higher Order Modulation (HOM) will give 21 Mbps for the DL. The combination of MIMO and 64 QAM would allow 42 Mbps in DL and this is being studied by 3GPP for the further evolution of HSPA in Rel-8. For UL the theoretical peak rate with 16QAM will be 11 Mbps. Significant gains can be expected by the provision of HOM in scenarios where users can benefit in terms of increased throughput from favorable radio conditions such as in well-tuned outdoor systems or indoor system solutions where there is good isolation between cells. This is further described in the following sections.

3.2.2 Higher Order Modulation, DL

The 64QAM modulation that has been introduced in the DL will improve bitrates for the most fortunate users, i.e. users with high SNR. Figure 6 shows that the bitrate for the 10% most fortunate users increases up to 45% in highly dispersive radio environments. The gain decreases as the cell load increases. For less dispersive environments, the gain is higher and there is also a gain in median bit rates for all load levels.

[15] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.

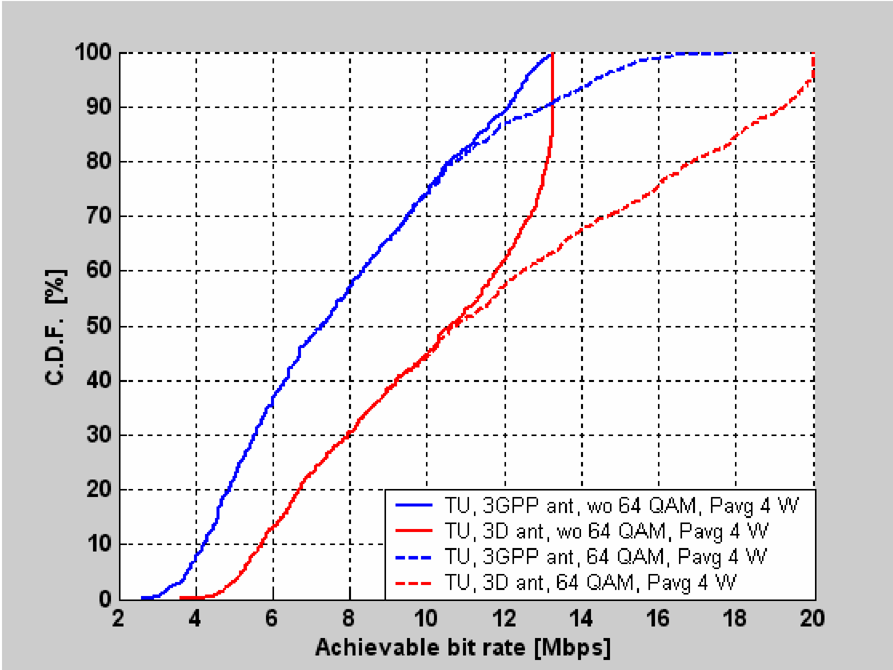

Figure 6. DL bit rate improvement with 64 QAM[16]

3.2.3 Higher Order Modulation, UL

The 16 QAM modulation that has been introduced in the UL will give a substantial improvement of bitrates. Figure 7 shows that the user throughput increases between 70% and 100%, depending on the load for the 10% most fortunate users. The median bit rate is increased up to 100% depending on the load, where the gain decreases with the load and becomes negligible with 10 or more simultaneous users in the cell.

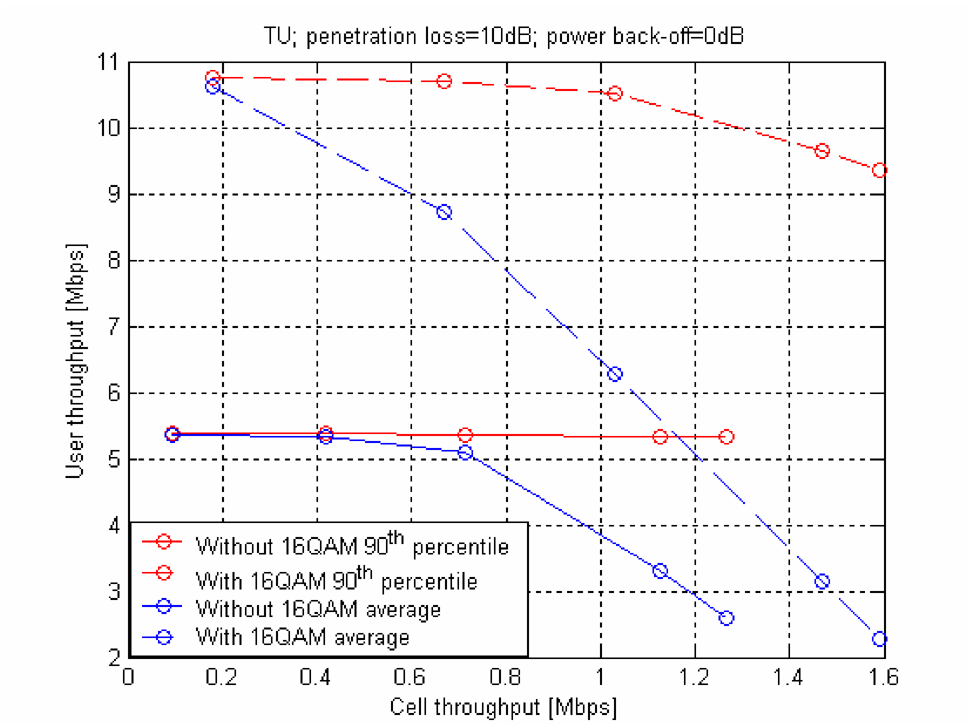

Figure 7. UL bit rate improvements with 16 QAM [17]

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[16] 64QAM for HSDPA System-Level Simulation Results, 3GPP. Tdoc R1-062265.
[17] UL bit rate improvements with 16 QAM, 3GPP. Tdoc R1-062267

4 The Growing Demands for Wireless Data Applications

Users 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. In this section, the growing demands are demonstrated by examples of increased operator ARPU from data services, a variety of 3G applications for consumers and the enterprise, and devices such as smartphones and embedded modules for PC notebooks. As 3G networks continue their rollout worldwide, the question remains how far mobile operators can leverage these technological advances to boost average revenue per users (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 MMS services.

When considering that there were more than 2.7 billion GSM/UMTS mobile subscribers worldwide by the end of 2007, a number that will rise to nearly four billion in 2011, the tremendous opportunity for the uptake of wireless data services and applications is clear.[18] According to Chris Pearson, President of 3G Americas, "Once customers realize what they can do with faster download speeds, the more they will use [wireless data services]. Customers first need to be made aware of the possibilities. Education and ease-of-use will be key."

The market indicators and predictions by many industry analysts show 2007 as a "year of inflection" when the foundation is laid for customer uptake of wireless data applications. The devices and networks are in place, and the applications are plentiful. This section of the paper reviews the growth of several applications as well as revenue predictions.

4.1 Wireless Data Trends and Forecasts

"Wireless broadband is providing mobile subscribers with the ability to access content like never before," said CTIA President and CEO Steve Largent in February 2007.[19] He continued, "Earlier this year, the Federal Communications Commission reported that 59% of all new high-speed lines [in the US] were wireless. Wireless broadband is growing faster than cable and DSL combined, and because of that fact subscribers are accessing new and exciting types of content on their mobile devices." CTIA, the USA's wireless trade association, reported that wireless data service revenues for the first half of 2007 rose to US$10.5 billion. This represents a 63% increase over the first half of 2006, when data revenue was $6.5 billion. Data revenues now represent almost 15.5% of total carrier revenue, up from 2005's 7.6%.[20] According to a CTIA survey, text messaging continues to be enormously popular, with nearly one billion text messages per day recorded in the month of June 2007 in the US. This represents a 130% increase over June 2006. Wireless subscribers are also sending pictures and other multimedia messages in droves, with more than 2.6 billion MMS messages sent in the first half of 2007, almost as many as were sent in the entire year of 2006. The foundation for these strong results is a near-record increase in wireless subscribership in the US. As of June 2007, CTIA's industry survey recorded more than 243 million wireless users. This represents a year-over-year increase of almost 24 million US subscribers. The industry's 12-month record for subscriber growth was reached in 2005, when 25.7 million new users came online.

Paralleling the CTIA survey results are those of the NPD Group, a leading consumer and retail information company, which reported that mobile phone sales in the US reached 143 million units by the end of 2006.[21] In fact, Q4 2006 sales were 14% higher than those of Q4 2005. NPD estimated $8.8 billion in total 2006 US consumer sales. Other NPD findings included a significant increase in the sale of music-enabled devices, from 18% during Q2 2006 to 32% in Q4 2006. Coupled with the growth of music-capable phones, sales on devices that support removable memory grew from just 6% in Q1 to 21% in Q4 2006. Bluetooth-capable devices grew in sales from 31% in Q1 to nearly half (49%) of all phones sold in Q4 2006. Camera phones also continue to be popular among consumers; two-thirds of all devices sold in Q4 2006 included a camera.

In the US and Europe, 76% of all mobile phones are web-enabled according to a study by the Online Publishers Association.[22] And although only 32% of consumers use their cell phones to surf the Web,

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[18] World Cellular Information Service, Informa Telecoms & Media.

[19] "CTIA–The Wireless Association® Releases New Wireless Industry Survey Results " CTIA. October 23, 2007.

[20] Palenchar, Joseph. "CTIA: Subscriber Growth Robust in '06." TWICE, April 10, 2007.

[21] "US Mobile Phone Sales Peak at $8.8 Billion in 2006." NPD Group. March 27, 2007.

[22] *Going Mobile.* Online Publishers Association. March 8, 2007.

marketers are trying to change that with compelling advertising. One in ten consumers worldwide already buys products and services through their handsets, due to the effectiveness of mobile advertising.[23] The study suggests that soon 50% of consumers will accept mobile ads; already, 60% of Japanese cell phone users present mobile coupons at the point of sale.

Randall Stephenson, now Chairman of the Board and CEO of AT&T, affirmed the growing demand for wireless data during his keynote address at CTIA when he stated, “Success does not come from technology, but from placing the user at the center of everything we do, because we are now in a user-generated industry.”[24] Stephenson cited familiar metrics to support his claim: One in five customers uses mobile data, and 45% of today’s youth are mobile data users; 12 million users voted on AT&T‘s joint contest with MySpace for most creative user-generated video. Stephenson said that because of these converged services and the importance of user-generated content (UGC), it follows that the next big application is ease of use. AT&T’s video share service is part and parcel of UGC as consumers will be enabled to broadcast full color streaming video captured live from the phone’s camera to another AT&T video share customer. Although AT&T will launch the service in the summer of 2007 in 50 markets, and it will initially be a one-to-one, peer-to-peer service, it will soon become a one-to-many broadcast technology making use of the two other screens: PC and TV.

4.2 Wireless Data Revenue

In the brief time that 3G capabilities have actually been available to a critical mass, it has increased data ARPU on the order of anywhere from 5% to 20%, according to ABI Research.[25] Fundamentally, wireless continues to push its own ceiling to new heights.

US data revenue continued its rapid growth in 2007. For the first nine months of 2007, the US wireless data service revenues stood at $17.7B jumping 59% from the same time period in 2006, according to Chetan Sharma Consulting.[26] The percentage of contribution of data to service revenues also jumped to almost 18% in Q2 2007, according to Sharma, and is expected to likely top 20% in Q4 2007. Sharma commented that US wireless carriers maintained their strong global showing vis-à-vis their peers worldwide.

AT&T, the largest carrier in the US, added a record 2 million net subscribers in 3Q 2007, reaching a total of 65.7 million. Wireless data revenues increased 63.9% versus results in the year-earlier quarter, driven by increases in both consumer and business data usage including messaging, media bundles, laptop connectivity, smart phone connectivity and enterprise vertical market solutions. This was AT&T’s fifth straight quarter with year-over-year data revenue growth above 60 percent. Wireless data growth has also begun to reflect wider usage of the advanced capabilities and high speeds available with AT&T’s new 3G UMTS/HSDPA network.[27]

T-Mobile USA added 857,000 net new customers in 3Q 2007. This is a huge number of additions for the fourth largest carrier in the US. Data service revenues continued to rise to $666 million in the third quarter of 2007, representing 15.4% of blended ARPU, or $8.10 per customer, compared to 14.7% of blended ARPU, or $7.80 per customer in the second quarter of 2007, and 11.3% of blended ARPU, or $5.90 per customer in the third quarter of 2006. Robust growth in messaging continued to contribute to the increase in data ARPU. The total number of SMS and MMS messages increased to almost 21 billion in the third quarter of 2007, compared to 18 billion in the second quarter of 2007 and 10 billion in the third quarter of 2006. Strong GPRS / EDGE access and usage revenues were another significant driver of the increase in data services revenues compared to the third quarter of 2006.[28] The rapid uptake of consumer converged devices continued, such as the Blackberry Pearl, Sidekick 3, and T-Mobile Dash, and in September 2007, the BlackBerry Curve, the first converged device enabled for T-Mobile's new HotSpot @Home service.

Rogers in Canada added 195,100 postpaid subscribers in 3Q 2007 compared to 171,200 for the year-earlier quarter, and also reported increases in wireless network revenue compared to the prior year period, driven by the continued growth of its postpaid subscriber base and improvements in postpaid ARPU. For 3Q 2007, Rogers reported that wireless postpaid monthly ARPU increased 7% year-over-

[23] *Ibid.*
[24] Dolan, Brian. "AT&T not sure if mobile TV will succeed." Fierce Wireless. March 27, 2007.
Stephenson, Randall, CEO, AT&T. *CTIA 2007 keynote speech*. March 27, 2007.
[25] Wickham, Rhonda. "Pressure Intensifies on ARPU." Wireless Week. March 1, 2007.
[26] Sharma, Chetan. "US Wireless Data Market Update – Q3 2007." November 2007.
[27] "AT&T Delivers Strong 3Q Results." AT&T. October 23, 2007.
[28] "T-Mobile USA Reports Strong Results in the Third Quarter." T-Mobile USA. November 8, 2007.

year to $75.15 driven in part by the 53% growth in data revenue to $183 million. Data revenue now represents 13.6% of network revenue with monthly data ARPU in the quarter exceeding $10 for the first time, reflecting the continued rapid growth of text and multimedia messaging services, wireless Internet access, BlackBerry devices, downloadable ring tones, music and games, and other wireless data services and applications.[29]

Telcel, the América Móvil operation that is market leader in Mexico, closed 2006 with data revenues reaching approximately 13% of total company revenues, having added the staggering figure of 4.3 million subscribers in the first nine months of the year to reach a total of 47.5 million subscribers in 3Q 2007. Telcel is already testing UMTS technologies, and its CEO, Daniel Hajj, expects that before the end of 2007, América Móvil will have 3G services deployed in major cities in several countries throughout the region. This will give the company not only more voice capacity, but also enhanced data services that will continue to contribute to higher ARPUs. On a global basis, most of the major carriers around the world have double digit percentage contribution to their overall ARPU from data services. Operators like KDDI, DoCoMo, and 02 UK are topping 30%.[30]

4.3 3G Devices

Global shipments of HSDPA handsets will reach 19.6 million units in 2007, in comparison to the 1.7 million phones shipped in 2006, according to Sean Gowran, president of Ericsson Taiwan. Gowran cited data released by market research firm Signals Research Group.[31] Overall, global shipments of UMTS handsets, including HSDPA models, are likely to top 176 million units in 2007 up from last year's 107 million units. The average selling price for UMTS handsets is expected to drop to US$250 in 2007 and further decline to around US$200 in 2009, stated Gowran, who also noted that the entry level UMTS phones eventually would slide to US$170-180 this year. Additionally, volume shipments of HSUPA handsets will begin in 2008, with global shipments for the year likely to reach 3.5 million units according to the Signals Research Group study.

In the *3G for All* project of the GSM Association, emerging markets were addressed with this initiative to secure an affordably priced device with 3G functionality to bring 3G multimedia services and mobile internet access to a mass market user base around the world. That initiative was accomplished as of February 2007, and the contract was awarded to LG for their KU250 feature-rich 3G handset priced at about 30% less than the average price of a 3G handset. The KU250 will enable far more people to take advantage of 3G services such as video clips, mobile music, Internet browsing and many other multimedia applications. This will take 3G communications to a broader base of the world's population and will see the creation of an entirely new, more affordable 3G handset segment. Additionally, based on FCC filings, Samsung will release in 2007 what could be its lowest-cost 3G handset for AT&T, the A617, with a dual-band HSDPA radio, and with EDGE and GSM fallback capability for global roaming. It is expected that the 850 MHz band will also be addressed in the *3G for All* project to enable many of the operators in Latin America to offer a cost-effective 3G handset to their customers.

As of December 6, 2007, there are more than 400 different HSDPA devices from more than 60 suppliers including more than 110 phones, more than 50 PC data cards (both PCMCIA cards and embedded modules), about 50 notebooks, more than 25 routers and nearly 20 USB modems, plus other devices.[32]

Although not exclusively on 3G devices, the number of cameraphones in the United States has climbed to 160 million, passing the 50% threshold, according to mobile market analysts M:Metrics.[33] Mark Donovan of M:Metrics reported, "..the penetration of this technology has a positive impact on operator data revenues overall. Our data shows that each month more than 20% of Europeans and 14% of Americans pay for data services and photo messaging bundles to send photos somewhere over the network." With more consumers purchasing devices with this feature, it is inevitable that increasingly more users will utilize MMS services.

2007 will be a spectacular year with 60% growth for cellular PC cards and embedded 3G modems, according to research firm Strategy Analytics, which forecasts 9 million PC card and embedded 3G/3.5G

[29] "Rogers Reports Strong Third Quarter 2007 Financial and Operating Results." Rogers. November 1, 2007.
[30] Sharma, Chetan. "US Wireless Data Market Update – Q3 2007." November 2007.
[31] Shen, Daniel and Shen, Steve. "Global shipments of HSDPA phones to top nearly 20 million in 2007, says Ericsson." DigiTimes.com. March 14, 2007.
[32] See *Appendix C*
[33] "Increasing Cameraphone Ownership Forces a New Focus for Graphics Publishers." M:Metrics. April 17, 2007.

modems sales this year.[34] Their study finds that with WLAN's limitations coming into focus, and truly cost-effective mobile WiMAX still several years away, global 3G/3.5G shipments are set to grow handsomely over the next few years, with annual shipments hitting 15 million units by 2009. The study concludes that 2007 will be the high-water mark for 3G/3.5G pre-OFDM growth, as notebook OEMs will only begin to ramp up WiMAX in 2008-2009 with the help of WiMAX-ready Intel chipsets, and baked-in WiMAX support in upcoming service packs from Microsoft. Yet Strategy Analytics analysts, such as Cliff Raskind, are confident that 3G's long term role as a multi-radio, least-cost-routing future is secure. "In the early 3G card market, tech-savvy business users with sufficient need and ability to pay are finding complete freedom from location and the gratification of instant-connections to be addictive," said Raskind. "Fast forward a decade and users will come to expect options for boundless connectivity. The notion of having to 'go somewhere' to connect will be as inconvenient as it is for a voice call today. By necessity, to move the market forward, WLAN, 3G and 4G will be unknown to the user and these technologies will work in concert to provide transparent connectivity."[35]

Option, the market leader in 3G UMTS wireless data cards, first announced their product at ITU Telecom World in Geneva in October 2003. In November 2005, only 24 months later, Option shipped its millionth 3G device. Within the following sixteen months, by March 2007, two million additional 3G devices were shipped. Option's sale of three million devices represents a dramatic acceleration: double the volume in less than two-thirds of the time.[36] Technological advances mean that today, 7.2 Mbps HSDPA complemented with 2.0 Mbps HSUPA is available across the Option 3G portfolio, which (as of March 2007) consists of nine wireless data cards, four embedded modules, three USB devices and three routers. "Enterprise and consumer users are increasingly keen to liberate the notebook via a cellular network. Worldwide mobile data card sales jumped to more than 5 million units during 2006," reported Neil Mawston of Strategy Analytics.[37] Other manufacturers include Sierra Wireless, Novatel, Pantech & Curitel, Huawei and ZTE. Reference the list of HSPA devices in *Appendix C* of this document.

HSDPA is embedded in about 60 different models and manufacturers' notebooks as of December 6, 2007 including models by Acer, Clevo, Dell, Dialogue, Fijitsu-Siemens, HP Compaq, Lenovo, Panasonic, Samsung, Sony, Toshiba, Uniwill and Zepto.[38]

4.4 3G Applications

Telephia reports that mobile data usage in the US, such as text and multimedia messaging, mobile Web, and downloads reached the 50% adoption mark in Q4 2005, rising seven percentage points since the beginning of the year. According to the latest data from Telephia's Customer Value Metrics report, SMS activity leads the way for all mobile data usage with 41% of wireless subscribers using text messaging on their cell phones at the end of 2005. During Q4 2005, 22% of all cell phone users paid for accessing the Web via cell phone, 13% used MMS services (which raised 5 percentage points since Q1 2005), and 11% downloaded content from their cell phones (up 3 percentage points from the beginning of the year).[39] According to iSuppli, global premium mobile content market revenues rose to $16.4 billion in 2006, up 22% from $13.4 billion in 2005.[40].

IDC reports that text messaging remains the most popular mobile data service in the US, with nearly 50% of the data revenue derived from this service.[41] According to a recent report by Portio Research, SMS accounts for approximately 75 to 80% of non-voice service revenues worldwide. Portio predicts that SMS will remain the most widely used messaging format for some years to come, and estimates that global revenues from this service will reach US$67 billion by 2012, driven by almost 3.7 trillion messages.[42]

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[34] *Forecast: 9 Million PC Card & Embedded 3G/3.5G Modems Sales in 2007*. Government Technology's Digital Communities. February 1, 2007.
Strategy Analytics. *Liberating the Laptop: 5-Year Market Outlook on PC Cards & Embedded Wireless WAN Connectivity.* January 2007.
[35] *Ibid.*
[36] "Option Ships Three Millionth 3G Device." Option. March 30, 2007.
[37] *Ibid. 31*
[38] See *Appendix C*
[39] "Telephia Reports Mobile Data Usage Adoption Hits 50% Mark, With Text Messaging Consumption Leading the Way." Telephia. April 4, 2006.
[40] *Mobile Premium Content Market*. iSuppli. April 2007.
[41] *US Wireless Carrier Data Services 3Q05-3Q06 Vendor analysis: QView Summary and Analysis*. IDC. December 2006.
[42] *Mobile Messaging Futures, 2007-2012*. Portio Research. February 2007.

The IDC report also found that content and simple application downloads came to about 12% of total data revenue.[43] Ringtones are still the most popular type of content bought and downloaded onto mobile handsets, with about 20% of US subscribers currently purchasing at least one ringtone every quarter. IDC predicts that the total volume of ringtone sales in the US will approach the 1 billion mark by 2010 up from about 430 million in 2006.[44]

The mobile broadband multimedia market was worth US$1.1 billion in 2006, and Dilithium, a supplier of multimedia gateways that facilitates multimedia applications over 3G networks, calculates that will grow to an annual revenue figure of $23.3 billion by 2010.[45] Mobile computing grew from US$55.6 billion in 2005 to US $63.5 billion by 2006 and is predicted by BCC Research to reach more than US$88.9 billion by 2011.[46] Smartphones have the highest growth potential through the forecast period; this market is expected to reach almost US$17.8 billion by 2011. The largest market share belongs to notebook computers, which, in 2006, held 84% of the total global market. By the end of 2011, this share will be worth $69.2 billion, more than 96% of the market. Applications will clearly reflect the presence of mobile computing and advance functions throughout the period. By 2011, office-related, communications-based and global positioning applications will account for approximately 67% of total applications installed in handheld devices and mobile phones.

Moblogging, the industry term for the nascent mobile user-generated market, is expected to reap $13 billion a year in advertising and subscription revenues by 2011 according to Informa Telecoms & Media.[47] Users can send clips via video-sharing sites like YouTube where they can upload clips from their phones to the YouTube site and then watch from their personal computers and send clips to other YouTube members. “Video-sharing via mobile phones is an obvious next step for the company,” according to YouTube CEO Chad Hurley. “It's going to be a huge market.”[48]

Mobile financial services (MFS) are showing signs of a promising future. The mobile financial services market could reach $2.6 billion within five years if even 25% of today’s current financial transactions are replaced, according to Willy Dommen, principal of consulting firm Booz Allen Hamilton. Dommen characterizes businesses with low margins, where speed is important, a lot of cash is collected, and where the transactions are mostly low value, as a key market opportunity.[49]

One core value proposition for the MFS consumer is speed. AT&T Mobility’s Director of Mobile Financial Services, Spencer White, cited a study from MasterCard that found the average cash transaction takes 33 seconds, the average credit card transaction takes 22.7 seconds and the average contactless payment transaction takes a mere 12.7 seconds.[50] Two of the segments driving the adoption of MFS are the credit card companies and the fast food industry, which stand to benefit greatly. Issues for the fast food industry, such as revenue leakage, would be largely removed by MFS. In fact, any barriers to uptake due to transaction fees would be eclipsed by the recouped revenue leakage, according to Dommen.[51]

AT&T Mobility's White also noted that MFS has been hyped up in the past, but has yet to gain any traction in the market.[52] That said, he pointed to the wide availability of data services, the increased functionality of handsets and the growing dominance of online banking as signs that the market has changed dramatically in favor of MFS. White said 37 million households used online banking in 2005 and that figure is expected to double in 2009. At Bank of America, online transactions exceeded ATM, teller and phone transactions combined. "Mobile banking is a logical extension of online banking," he commented. AT&T/Cingular has been tracking this space for more than two years, and in the past six months there has been a considerable spike in enthusiasm for MFS from all segments of the value chain, White said. Typically, mobile banking allows customers to review balances and transactions, transfer

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[43] *Ibid., 38*

[44] *Ibid.*

[45] Wieland, Ken. "The 3G Search for Higher Data ARPU." Telecommunications International. February 20, 2007.

[46] *The Future of Mobile Computing.* BCC Research. April 2007.

[47] *Mobile Advertising Services: Generating Revenue Through Subsidized Content*. Informa Telecoms & Media. September 2006.

[48] Lev-Ram, Michal. "YouTube goes ‘moblogging’, The future Google unit has big plans to help consumers create and share video with their cell phones. But so do a lot of competitors." Business 2.0. November 3, 2006.

[49] Dommen, Willy, Booz, Allen, Hamilton. Mobile Payments World speech. March 26, 2007.
Dolan, Brian. "AT&T: Mobile payments, past the hype." Fierce Wireless. March 26, 2007.

[50] White, Spencer, AT&T. Mobile Payments World speech. March 26, 2007
Dolan, Brian. "AT&T: Mobile payments, past the hype." Fierce Wireless. March 26, 2007.

[51] *Ibid., 39*

[52] *Ibid., 40*

funds among accounts, pay bills, search for bank and automated teller machine locations, or connect to their bank's customer service center from a mobile device. As far as any perceived tension between those in the financial services industry and wireless carriers: White considers this an 'urban myth'. While banks are mostly concerned with security issues, the mobile industry is focused on access and around the clock availability.[53]

In April 2007, Citibank announced its mobile banking service that customers can download to their cellphone with availability throughout the US by mid-2007.[54] 'Citi Mobile' has been engineered to run on more than 100 devices and involves encryption to keep banking information secure. There were earlier announcements in March by AT&T to introduce mobile banking capabilities with four prominent banks that will also require customers to download a program on their devices; however, AT&T will begin embedding software on new handsets starting in the second half of 2007.

"The mobile banking end game will not be about 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," stated Dan Schatt, author of a report by Celent on US Mobile Banking: Beyond the Buzz.[55] "While loyalty and marketing applications are still largely confined to product roadmaps, they will make their debut in late 2008, and by 2010 we will see the fusion of mobile banking and mobile contactless payments." Celent estimates that by 2010, 35% of online banking households will be using mobile banking, up from less than 1% today. Mobile contactless payments will make up 10% of the contactless market by 2010.

The mobile entertainment market—including gambling, adult content, mobile games, mobile music, mobile TV and infotainment—was estimated to be worth more than US$17 billion by analyst firm Juniper Research in November 2006.[56] The analyst firm forecasts this to grow to $47 million by 2009 and $77 billion by 2011, as adoption of broadcast mobile TV and mass market casual games accelerates. Juniper analyst Bruce Gibson commented, "As 3G services become commonplace, sophisticated mobile entertainment products and services can reach the mass market and provide the sort of anywhere/anytime entertainment that has been predicted for some time, but not really delivered." Mobile music is currently the largest sector of mobile entertainment. Eighty percent of mobile music revenues come from ringtones. The second largest category is 'infotainment' which contains a wide variety of sport, leisure and information products, but is still dominated by wallpapers. The increasing availability of 3G services and support for high quality video is one of the drivers of mobile sports, leisure and information services over the next five years, from less than $4.2 billion in 2006 to $9.5 billion by 2011.[57] Juniper expects that the domination of these traditional core products will be diluted over the next few years as next generation mobile network technologies become commonplace, and consumers better appreciate the wide range of entertainment applications that can be enjoyed on a mobile device.

Adoption of mobile video and mobile TV is growing steadily. With more than six million users already on board in the US, up from 2.5 million at the start of 2006, and year-over-year growth of 188% last year, according to Telephia,[58] mobile television is a force to be reckoned with. Although in its embryonic stages, mobile TV has attracted 2.7% of all US wireless subscribers but more devices that are capable of playing video must be on the market before the industry reaches its targeted penetration of around 30 percent within the next five years.

As of today, only 15% of all mobile devices are video capable.[59] Iain Gillott, iGR analyst, reports that the current adoption rate of mobile television and video services is very low in the US and Western Europe is not much better, with adoption rates also less than 3%.[60] However, Gillott also reports the good news: although adoption is low, potential uptake is high, with nearly 50% of those aged 34 years or younger saying they are interested in such services. As operators develop business models, content providers, advertisers and others in the eco-system work together, there is market potential. Gillott predicts that by 2010 more than 12 million subscribers will use mobile TV and video services in the US. By 2010, global

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[53] *Ibid.*
[54] "Citibank Introduces Citi Mobile Banking Service For Cellphone." Cellular-News. April 3, 2007
[55] *"US Mobile Banking: Beyond the Buzz Report Published by Celent."* Celent. May 17, 2007
[56] " Mobile Entertainment Market has Potential to Reach $76 billion by 2011, but Question Marks Remain." Juniper Research. January 31, 2007.
[57] "Mobile Sports Content & Services to Reach $3.8bn by 2011." Juniper Research. November 16, 2006.
Mobile Entertainment Revenue Opportunities, 2006-2011. Juniper Research. January 2007.
[58] Kapko, Matt. "Mobile TV Goes Mainstream." RCR Wireless News. April 21, 2007.
Mobile Video. Telephia. March 27, 2007.
[59] *Ibid*.
[60] Gillot, Iain. "Analyst Angle: Thoughts on Mobile TV." iGR. March 12, 2007.

annual revenues from mobile TV and mobile Video on Demand (VoD) will have increased to almost 800% of the 2006 total, according to a report from Understanding & Solutions released January 2007.[61] "By 2010, we predict mobile TV and mobile VoD will achieve combined revenues of around $18 billion worldwide, and that's excluding revenues from advertising, sponsorship and added interactive services," stated Alison Casey of Understanding & Solutions.

The worldwide mobile TV broadcast market is expanding as the number of commercially launched mobile TV broadcast networks will grow from nine in 2006 to 13 in 2007, according to In-Stat.[62] "Over the next ten years, as more spectrum is made available, in many cases when analog TV signals are shut off, more mobile TV broadcast services will launch," reported Michelle Abraham of In-Stat. "Another issue limiting the market today is the small number of mobile TV broadcast enabled handsets available in many markets." Mobile TV subscribers will reach 514 million worldwide by 2011, according to ABI Research,[63] and 460 million will subscribe to broadcast services, a substantial growth from the 1.5 million broadcast service subscribers at YE 2006.

Gartner predicts a slightly higher global number of mobile TV subscribers and expects that the marketplace will vary widely by country, and will be shared between TV services delivered via both cellular and broadcast methods. TV services over 3G cellular (including MBMS) will grow from 38 million users in 2007 to 356 million in 2010. TV broadcasting will reach 133 million subscribers by 2010- due mainly due to the growing availability of broadcast-enabled phones.[64] Gartner also predicts that mobile TV has the potential to be a major overall ARPU component. "We expect TV services over cellular to show revenue of just over $100 million in 2006, growing to $15 billion by 2010," cited Carolina Milanesi, Gartner. "Revenue from broadcast TV will grow from $200 million to $10.8 billion over the same time period."[65]

As wireless handsets continue to gain computing power, they are becoming increasingly capable video-game platforms. The mobile gaming industry is set to expand threefold to $6.1 billion by 2010, rising at a Compound Annual Growth Rate (CAGR) of 27.2% from $1.8 billion in 2005, predicts iSuppli.[66] Early mobile-phone games were simply ported over from other platforms, an approach that didn't maximize the advantages of mobile gaming. However, with mobile-phone gaming revenues rising dramatically, by 80% in 2005, game publishers are now creating titles specifically designed for handsets, providing a much better experience for users. "In the coming years, expect to see mobile games that leverage multiplayer capabilities and 3D graphics," stated Mark Kirstein of iSuppli. Smartphones with additional support for multiplayer games, peer communication, and location-based networking could represent an attractive segment that should not be addressed by mobile operators.[67] iSuppli predicts the number of mobile-gaming users worldwide will grow substantially through the remainder of the decade, reaching 134 million average users a month by 2010, up from 38 million average users in 2005—an increase of more than threefold.[68]

On-portal mobile game revenue jumped 61% year-over-year to $151 million in Q4 2006. There were nearly 17.4 million mobile consumers who downloaded a mobile game in Q4, up 45% from 12 million downloaders a year ago, according to Telephia.[69] On-portal gaming revenues account for 74% of total mobile game revenue, while off-portal downloads account for the remaining 26%.

More than 34.6 million mobile subscribers accessed the Internet via their wireless devices in June 2006, according to Telephia,[70] who reports that 81% of Internet consumers have phones with browsers that support xHTML-MP, allowing for an enhanced Internet browsing experience more like what consumers are familiar with on personal computers.

The global music market is set to begin a global growth trend reversing six years of decline from a high of US $39.7 billion in 2000 to US$32.1 billion in 2006, rising again to an expected US$38.8 billion by 2011

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[61] "Mobile TV revenues are on the move." Understanding & Solutions. 2006.
[62] "Mobile TV Continues Slow, Steady Growth." In-Stat. April 11, 2007.
[63] *Broadcast and Unicast Mobile TV Services*. ABI Research. September 2006.
[64] "Consider Revenue Models for Mobile TV Carefully, Gartner Counsels." Gartner press release. March 27, 2007.
[65] *Ibid.*
[66] "Booming Mobile-Phone Gaming Market Attracts Publishers' Attention." iSuppli. January 4, 2007.
[67] *Ibid.*
[68] *Ibid.*
[69] "Mobile Game Revenue in the US Hits $151 Million in Q4 2006 with Strong Year-Over-Year Growth, According to Telephia." Telephia. March 5, 2007
[70] "Mobile Internet Populations Jumps to 34.6 Million With Email, Weather and Sport Websites Securing the Highest Reach, According to Telephia." Telephia. August 14, 2006

according to Portio Research.[71] The growth in the music market is triggered by shipment of MP3 enabled mobile handsets in some volumes by manufacturers such as Nokia, Motorola, Sony Ericsson and others in 2006. Wireless operators including T-Mobile, AT&T, DoCoMo, 02, Vodaphone, Orange and many more have started to distribute MP3 enabled phones and launch OTA (over-the-air) music download services. New entrants like Apple's iPhone, Microsoft's Zune and Sony Ericsson's Walkman are sure to further stimulate the mobile music market, thereby lifting the entire music industry. Portio Research expects that almost half of the 1 billion mobile handsets expected to ship worldwide in 2007 will be MP3-enabled. The MP3 player market will soon be totally dominated by the mobile handset vendors.

It is expected that the premium mobile content market will be more than $35 billion in 2011; the content providers' share of the premium mobile content market will exceed US$19 billion with nearly half of that total accounted for by mobile music categories according to research by iSuppli.[72] Images, the number one mobile content product consumed in 2006, will fall to fourth place as over-the-air full music track downloads, mobile games, streaming and VOD video, and ringtones become the more dominant mobile-content categories.[73]

"To date, the mobile platform is the only interactive medium where the typical user shoulders 100% of the cost of both network access and the content/service that rides on top," according to John du Pre Gauntt, eMarketer Senior Analyst. "Getting consumers to pay outright for mobile content, without ads, is a hard sell." To that end, mobile advertising in the US will approach $5 billion in 2011, according to eMarketer, up from $421 million in 2006.[74] NBC Universal plans to sell ads for its mobile video programming in May 2007, more evidence that the business of TV on cellphones is gaining momentum. For the first time, MTV Networks also signed deals for MTV and Comedy Central mobile channels with advertisers (PepsiCo and Intel) in March 2007.[75] The push of NBCU and MTVN into mobile advertising, coupled with their increased content output for mobile TV, suggests that the twin business models of license fees from carriers and advertising are coming together for mobile TV.

The world market for mobile marketing and advertising is expected to be worth about $3 billion by the end of 2007, according to a recent study from ABI Research, and is expected to reach $19 billion in value by 2011 if mobile search and video advertising is included.[76] The highest levels of spending will come in the broadcast mobile video space, with spending for broadcast mobile video advertising alone expected to hit $9 billion by 2011.[77] It is predicted by Adam Guy, wireless analyst with research firm Compete, that the market for mobile TV will move to double-digit penetration subscriber numbers by the end of this year, up from single-digit penetration at the 1Q 2007.[78]

Other modes of delivery for mobile advertising will include: via mobile music delivery, mobile game delivery, Mobile TV and video, idle-screen advert delivery, and via user–generated content and community sites. Nicky Walton of Informa says, "As operators push for new revenue streams and advertisers search for more immediate, intimate access to consumers, and the technology becomes more effective for advert delivery, we'll see dramatic growth in the space." [79]

Businesses are turning to mobile devices for much more than making calls and checking email. "A growing number of [businesses] are using souped-up cell phones for increasingly complex and critical tasks such as accessing patient medical records, closing sales, managing inventories and dispatching service representatives. Meanwhile employees can now watch training videos on a BlackBerry, or store a PowerPoint presentation on the device and display it via a wireless link to hardware connected to a projector," wrote Jessica E. Vascellaro of the Wall Street Journal.[80]

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[71] "*Digital Music Futures 2007-2011, Understanding the Clash of the Titans as the Worlds of Music and Mobile Collide."* Portio Research. January 8, 2007.

[72] "Mobile Enablement Platform Content Market to Grow to $7.4 billion by 2011." Cellular-News. March 14, 2007. *Mobile Content Enablement Platforms: Software Platforms Monetize & Deliver Mobile Music, Games and Video*. iSuppli. March 13, 2007.

[73] *Ibid.*

[74] *Sizing up Mobile Marketing*. eMarketer. March 29, 2007.

[75] Whitney, Daisy. "NBC plans to sell ads against mobile video in May." RCR Wireless. April 2, 2007.

[76] "Mobile Marketing and Advertising to be Worth $3 Billion by 1Q 2008." ABI Research. April 10, 2007.

[73] *Ibid.*

[78] Guy, Adam, Compete. Moderator speech at CTIA Wireless IT and Entertainment Expo 2006. September 11, 2006.

[79] *Mobile Advertising Services: generating revenue through subsidised content.* Informa Telecoms & Media. September 11, 2006.

[76] Vascellaro, Jessica. "Small mobile devices lighten business load." The Wall Street Journal, April 2, 2007.

[77] *Worldwide Mobile Enterprise Applications 2006-2010 Forecast and Analysis*. IDC. December 2006.

Faster network speeds, attributable to third generation technologies, are making it easier for mobile employees to connect to the Web and to remote databases, and with this market-research firm IDC expects the market for mobile enterprise applications to nearly triple to $3.5 billion in 2010 from $1.24 billion in 2005.[81]

Research firm In-Stat notes the dramatic growth of wireless data in commercial applications in the past decade, from $600 million in 1996 to $7.2 billion in 2006.[82] Government and healthcare have the highest adoption rates of wireless data, and the most popular applications involve enabling workers to do their job in more places.

Another tremendous area of growth for wireless data will be in machine-to-machine (M2M) wireless mobile connections. Although the automobile manufacturers in North America continue to drive demand for wireless M2M on cellular networks, Berg Insight[83] expects that other brands will soon follow GM and incorporate telematics units as standard equipment in their vehicles. According to Berg Insight, the number of machines connected to cellular networks in North America will reach 66 million by 2011. At the end of 2006, there were about 9 million active cellular and satellite wireless M2M connections in the US and Canada. Private vehicles constitute the largest vertical market segment in terms of units followed by commercial vehicles, security alarms and POS-terminals.

With businesses waking up to the operational benefits and efficiency savings of real-time data monitoring, wireless telemetry or automated meter reading will lead the evolving growth in M2M markets over the next three years. According to Juniper Research, revenues will rise from $11.6 billion in 2006 worldwide to an expected $25.3 billion by 2009.[84] This substantial 2006 revenue will quadruple by 2011 to an expected $40.8 billion, contrasted with more limited growth in telematics, from $6.4 billion to $11 billion in the same period, due to current widespread usage in many commercial vehicles as a result of legislation. Other outlets including security and surveillance, highway and public transport signs, and health care will show encouraging signs, rising from a low of $2 billion in 2006 to more than $9 billion by 2009.

4.5 IP Multimedia Subsystem (IMS)

It has been estimated that by the end of the decade, more than 400 million people will regularly use SIP-based services across IP multimedia networks. According to an operator survey done by Heavy Reading, more than half of the 140 operators surveyed said they expect mass deployment of IMS to take place by the end of 2007.[85]

In a recent report by In-Stat, it is predicted that IMS subscribers will grow from 10 million in 2007 to more than 500 million by 2011.[86] Spending on the IMS control layer equipment will hit $12 billion during the next four years. "There is no debate over whether IMS will be deployed," analyst Keith Nissan, In-Stat explains. "The question is how rapidly operators will move beyond the fixed-point solutions being deployed currently." Virtually every major vendor in the telecom industry is making a big bet on IMS, which was originally developed for 3G carriers, and is now viewed more broadly as a technology that allows users to seamlessly communicate across multiple networks. IMS basic network functionality in the US can generate over $1 billion in annual revenue.

Frost & Sullivan expects the global IMS market to jump from an estimated $200-$300 million in 2006 up to $10.4 billion in 2010. Frost & Sullivan analyst Ronald Gruia has asked, "A lot of carriers are looking at IMS as a way to cut their costs, but where are the applications?" The answer will become apparent as operators move away from their legacy systems to Next Generation Networks (NGNs). By embracing IMS solutions, carriers will be able to reduce their CAPEX spending by at least 5%-10% initially, and will realize huge savings in their OPEX as they move more applications to converged networks, according to Gruia. He notes that many operators, especially in the wireless field operators, frequently gamble large amounts of money on introducing new applications to their users. The beauty of IMS, he contends, is that

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[78] *Wireless Data in Vertical Markets: Passing the Blue Line.* In-Stat report #IN0703472MBM. February 2007.
[79] "Berg Insight says 66 million machines will be connected to North American cellular networks by 2011." Berg Insight. March 15, 2007.
[80] *Wireless Telematics and Machine to Machine: Entering the Growth Phase, 2006-2011.* Juniper Research. January 22, 2007.

[81] "Wireless Telemetry Leading Growth in M2M Revenues." Juniper Research. January 22, 2007.
[82] 3GSM: Donde esta IMS." Light Reading. February 2006.
IMS/NGN Consumer Buying Decisions. In-Stat. February 2007.

it will greatly lower the cost of these service introductions, and will allow carriers to experiment by introducing new services to their markets. [87]

4.6 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 body with major mobile telephony expertise to accomplish this standardization process.

The HSUPA networks that will be deployed in 2H 2007 will achieve the bidirectional capability needed to run real VoIP over Cellular. Several European groups were testing new mobile VoIP services in May 2006. Mobile VoIP could radically change how cellphone customers make their calls in the future. Skype and Hutchison 3 Group are in the starting blocks to launch a commercial mobile VoIP services. Hutchison will provide Skype's mobile VoIP client in a range of high-end smartphones that have Session Initiation Protocol (SIP) and run the Microsoft Windows Mobile operating system. Jajah has launched a mobile VoIP services that lets smartphone users make low-cost, and in some cases free, international calls. To make calls, users simply enter Jajah's mobile Web portal through their handset's browser and enter their usernames and passwords. Fring is another peer-to-peer VoIP service that carries calls over cell phone networks in much the same way PC-based Internet telephony services transport conversations over WiFI or fixed-line broadband connections. Unlike Jajah, Fring requires users to download a VoIP application to their handsets. As of May 2006, only Nokia's Series 60 3rd Edition phones support the service. Users can fill their contacts list with other Fring users or friends who use the other services, see when they are online and communicate directly with them.[88]

It is expected by iGR, a market strategy consultancy, that 3G mobile bandwidth usage will experience a nearly tenfold increase by 2011 fueled by IMS application adoption.[89] The model in the study suggests that in 2006, all categories of users (light, medium, heavy) sent and received more than 0.73 terabytes (TB) per month of data over radio link and backhaul network segments. iGR forecasts that number to increase by 2011 to 6.94 TB -- an increase of more than 800% in less than five years' time.[90]

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

5 Overview of 3GPP Rel-8 – SAE/EPS and LTE/EUTRAN

While work continues on the evolution of HSPA, one of the main areas of focus for 3GPP Rel-8 is the introduction of the SAE/EPS and LTE/EUTRAN. As discussed in the Introduction, while the UMTS technology evolves through Rel-8, LTE radio solutions, using orthogonal frequency division multiple access (OFDMA) radio technology will be deployed. The LTE migration may occur through a simple software upgrade based upon some of the vendors' WCDMA infrastructure currently being deployed in 2007. LTE supporting MIMO antenna technology, with speeds of up to 14.4 Mbps using a 20 MHz carrier in the 2.6 GHz spectrum, was demonstrated live at the 3GSM World Congress in February 2007. Handovers between LTE and HSPA as well as video streaming and file transfers to multiple devices were also demonstrated at the Congress. In November 2007, one of the industry's first multi-vendor over-the-air LTE interoperability testing initiatives was conducted successfully. The first field trials for LTE are planned in 2008, with commercial availability in 2009.

5.1 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. This allows for independent scaling and growth of throughput traffic and control signal

[87] "IMS at the Crossroads." America's Network. March 1, 2007.
[88] "Europe's Mobile Advances." InfoWorld. May 14, 2007.
[89] "IMS Application Adoption Helps Fuel Nearly Tenfold Increase in Data Bandwidth Usage by 2011." iGR. May 1, 2007.
[90] *Ibid.*

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 8, where support nodes such as AAA and policy control nodes have been excluded for clarity.

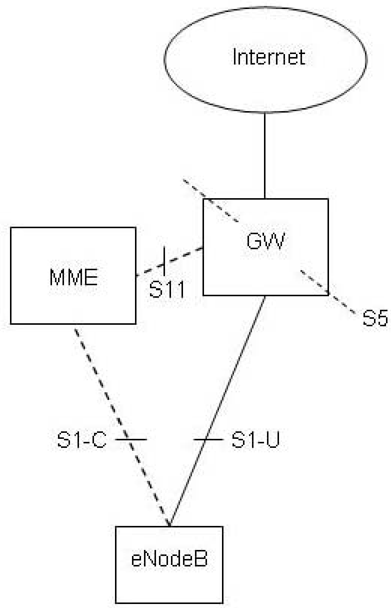


Figure 8: Basic EPS architecture[91]

The EPS architecture has a similar functional distribution as the HSPA "one-tunnel" PS core network architecture. This allows for a very easy integration of HSPA networks to the EPS, as shown in Figure 9. Note that the details of how to connect Rel-7 UMTS/HSPA networks to the EPS are still under discussion in 3GPP. The EPS is also capable of integrating non-3GPP networks.

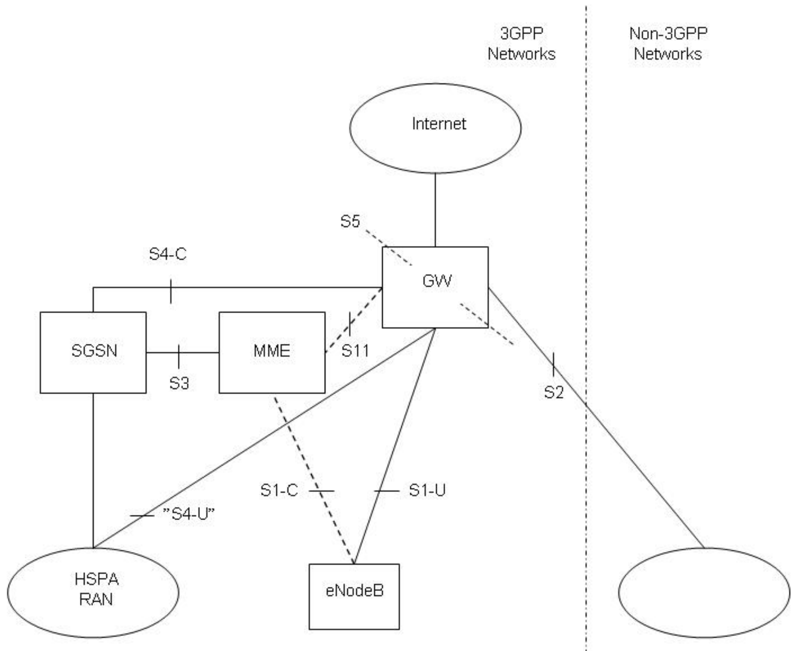


Figure 9: Example configuration for EPS support of Rel-7 UMTS/HSPA and non-3GPP accesses[92]

[91] Ericsson. Q2 2007.
[92] 3G Americas. Q2 2007.

Figure 10 shows more details of the basic architecture of the EPS. 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.

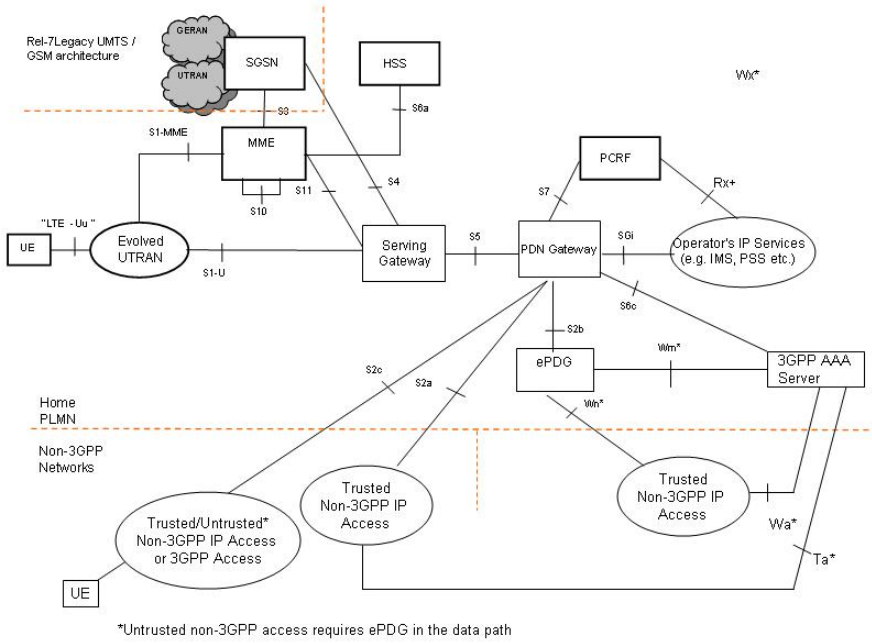


Figure 10: Detailed EPS architecture view[93]

5.1.1 Functional Nodes

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

- **Mobility Management Entity (MME):** The MME manages mobility, UE identities and security parameters. MME functions includes:
  - 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)
  - Roaming (terminating S6a towards home HSS)
  - Authentication
  - Bearer management functions including dedicated bearer establishment

- **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 [illegible] 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). This is sometimes referred to as the 3GPP [illegible]
  - [illegible] buffering and initi[illegible] triggered service [illegible]
  - [illegible]on
  - Packet routing and forwarding

Evolved UTRAN
Trusted/Untrusted* Non-3GPP IP Access or 3GPP Access
Trusted Non-3GPP IP Access
Untrusted Non-3GPP IP Access
3GPP AAA Server
Wa*
Ta*
UE

* Untrusted non-3GPP access requires ePDG in the data path

93 *Ibid.*

- **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:
  - Mobility anchor for mobility between 3GPP access systems and non-3GPP access systems. This is sometimes referred to as the SAE Anchor function
  - Policy enforcement
  - Per-user based packet filtering (by e.g. deep packet inspection)
  - Charging support
  - Lawful Interception
  - UE IP address allocation
  - Packet screening

- **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).

5.1.2 Support for non-3GPP accesses

For non-3GPP accesses the EPS also includes the ePDG. It comprises the functionality of a PDG according to 3GPP TS 23.234 that specifies inter-working between 3GPP systems and WLAN. It is unclear at this point if there will be any significant modifications to the current specification.

5.1.3 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:

- **S1-MME:** The S1-MME interface provides the control plane protocol between the Evolved UTRAN and MME.
- **S1-U:** The S1-U interface provides a per bearer user plane tunneling between the Evolved UTRAN and Serving GW. It contains support for path switching during handover between eNodeBs. S1-U is based on the GTP-U protocol that is also used for Iu user plane in the Rel-7 architecture.
- **S3:** The S3 interface enables user and bearer information exchange for inter 3GPP access network mobility in idle and/or active state. It is based on the GTP protocol and the Gn interface as defined between SGSNs.
- **S4:** The S4 interface provides the user plane with related control and mobility support between GPRS Core and the 3GPP Anchor function of Serving GW and is based on the GTP protocol and the Gn reference point as defined between SGSN and GGSN.
- **S5:** The S5 interface 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. There are two variants of the S5 interface, one based on the GTP protocol and one IETF variant based on Proxy Mobile IPv6 (PMIP).
- **S6a:** The S6a interface enables transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between MME and HSS.
- **S7:** The S7 interface provides transfer of (QoS) policy and charging rules from PCRF to Policy and Charging Enforcement Function (PCEF) in the PDN GW. The interface is based on the Gx interface.
- **S8a:** The S8a interface is the roaming interface in case of roaming with home routed traffic (see section 5.1.5.5). It provides user plane with related control between the Serving GW in the VPLMN and the PDN GW in the HPLMN. It is based on the GTP protocol and the Gp interface as defined between SGSN and GGSN. S8a is a variant of S5 for the roaming (inter-PLMN) case. There is also an IETF variant of called **S8b** that is based on Proxy Mobile IPv6 (PMIP).
- **S10:** The S10 interface between MMEs provides MME relocation and MME to MME information transfer.
- **S11:** The S11 interface is the interface between MME and Serving GW.
- **SGi:** The SGi interface is the interface 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 interface corresponds to Gi and Wi interfaces and support any 3GPP or non-3GPP access.

- **Rx+:** The Rx interface is the interface between the AF and the PCRF. It is unclear at this point if there will be any significant modifications to current Rx interface to motivate calling it Rx+.

5.1.4 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.
- **S6c:** The S6c interface is the interface between PDN Gateway in HPLMN and 3GPP AAA server for mobility related authentication if needed.
- **S6d:** The S6d interface is the interface between Serving Gateway in VPLMN and 3GPP AAA Proxy for mobility related authentication if needed. This is a variant of S6c for the roaming (inter-PLMN) case.
- **S9:** The S9 interface is the interface between hPCRF and vPCRF used in roaming cases for enforcement in the VPLMN of dynamic control polices from the HPLMN.
- **Wa*, Wd*, Wm*, Wn*, Wx*:** These interfaces are defined in 3GPP TS 23.234 and specify inter-working between 3GPP systems and WLAN. It is unclear at this point if there will be any significant modifications to the current interfaces.
- **Ta*:** The Ta* interface connects the Trusted non-3GPP IP Access with the 3GPP AAA Server/Proxy and transports access authentication, authorization and charging-related information in a secure manner.

5.1.5 System Aspects

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

5.1.5.1 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 and IETF based bearers but since some details of the IETF bearers are currently under discussion the following text focuses on GTP based bearers.

The GTP 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 11 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).

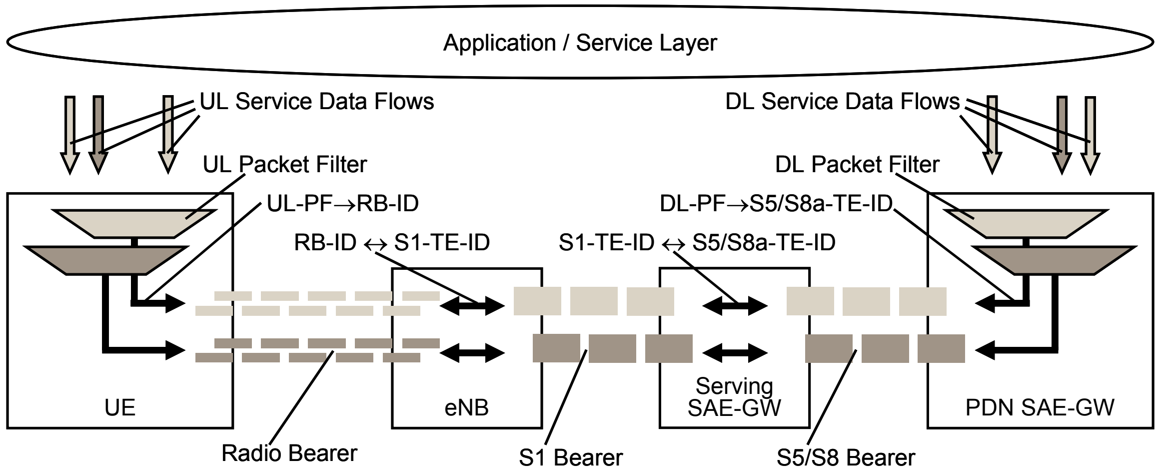


Figure 11. Two Unicast bearers (GTP-u Based S5/S8)[94]

For a bearer, QoS is defined by two parameters: Label and 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.

5.1.5.2 Network Selection

An EPS system can support a variety of access types including LTE, HSPA, eHSPA and non 3GPP access types. With the emergence of multimode devices e.g. those incorporating WiFi along with cellular technologies, it is now possible to deliver services over different access types. To this effect, the EPS system will be providing mechanisms for selection of an appropriate service delivery network that provides the best customer experience.

5.1.5.3 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 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, 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.

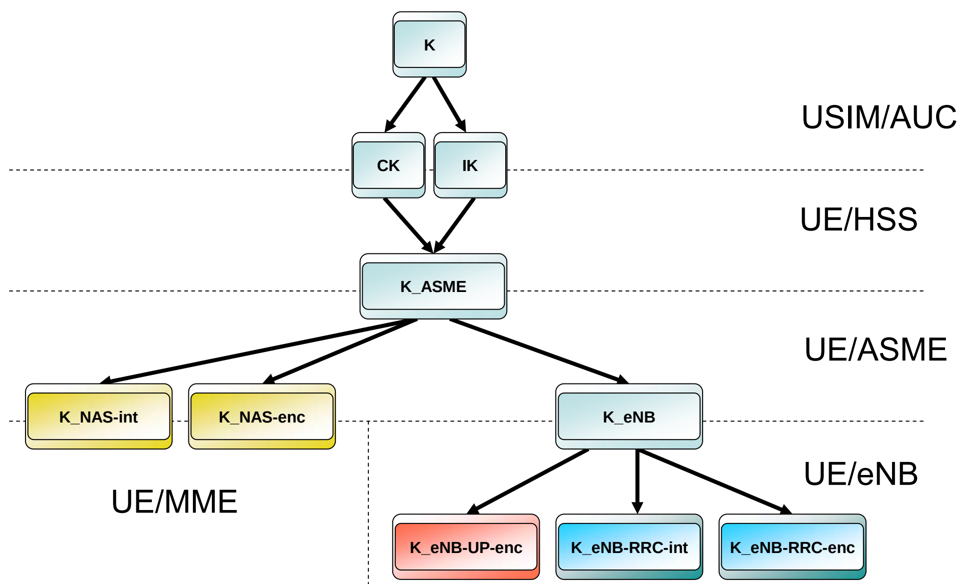
5.1.5.4 Security Aspects

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

[94].Two Unicast bearers, 3GPP TS 23.401

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 12. 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 which derives 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 still under discussion in 3GPP at the time of the writing this paper.



*Note: An **Access Security Management Entity** (ASME) is a new functional entity which receives the top-level keys in an access network from the HSS, i.e., the MME.*

Figure 12. Key Hierarchy in EPS[95]

Traffic Protection

Security termination points for various traffic types terminating at the terminal is shown in Figure 13. 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.

[95] Ericsson. Q2 2007.

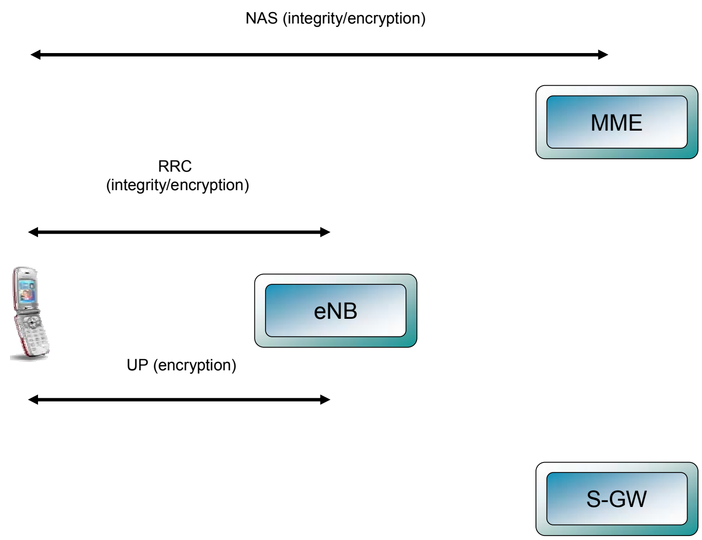


Figure 13. Security termination points for traffic to/from the UE[96]

The security termination points for traffic that is internal to EPS are shown in Figure 14. There is ongoing work in 3GPP to provide integrity protection and encryption on these interfaces, 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.

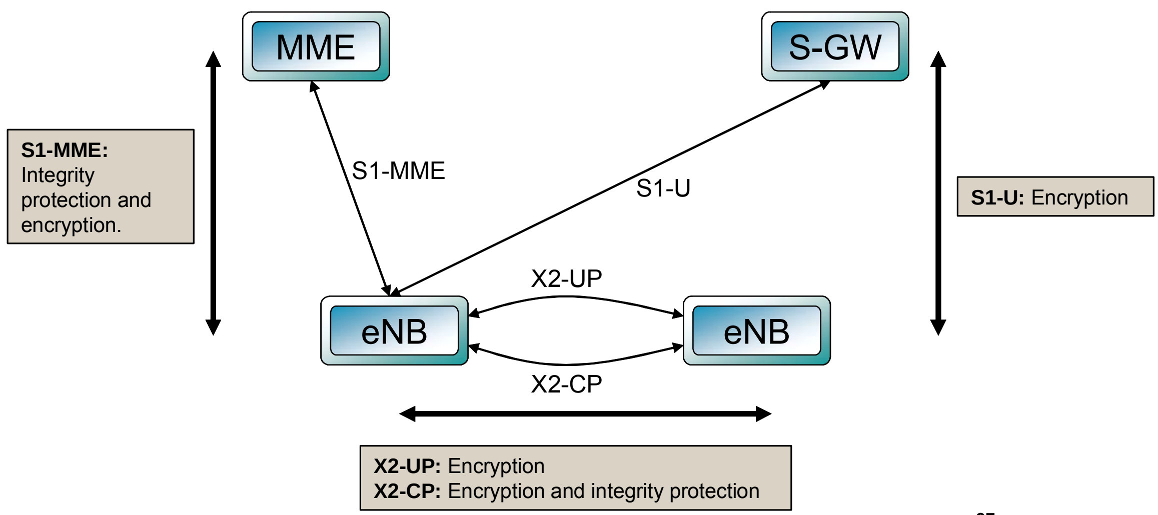


Figure 14. Security termination points for traffic internal to EPS[97]

5.1.5.5 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 S8a interface), while TS 23.402 focuses on mobility and roaming with non-3GPP access using Proxy MIP (over the S8b interface).

Figure 15 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 (S8a) towards a PDN GW in the home network.

[96] *Ibid.*
[97] *Ibid.*

Figure 16 exemplifies the roaming architecture for non-3GPP access (via S2) via S8b 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.

A distinction is also made between trusted non-3GPP networks and non-trusted 3GPP networks. Non-trusted 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 15 and 16.

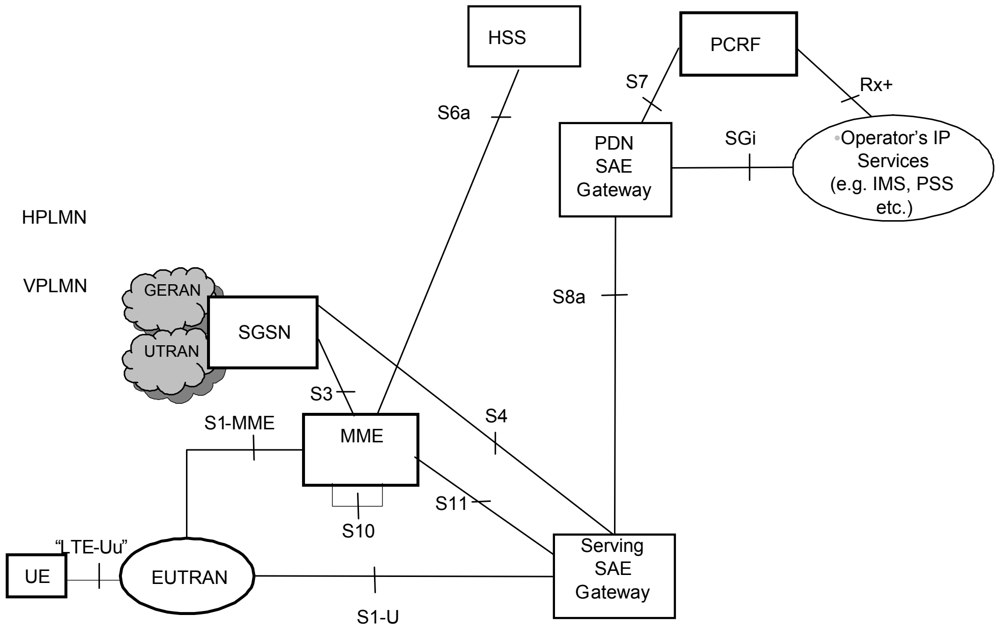


Figure 15. Roaming architecture (home routed case, 3GPP only networks)[98]

[98] GPRS Enhancements for EUTRAN. 3GPP TS 23.401.

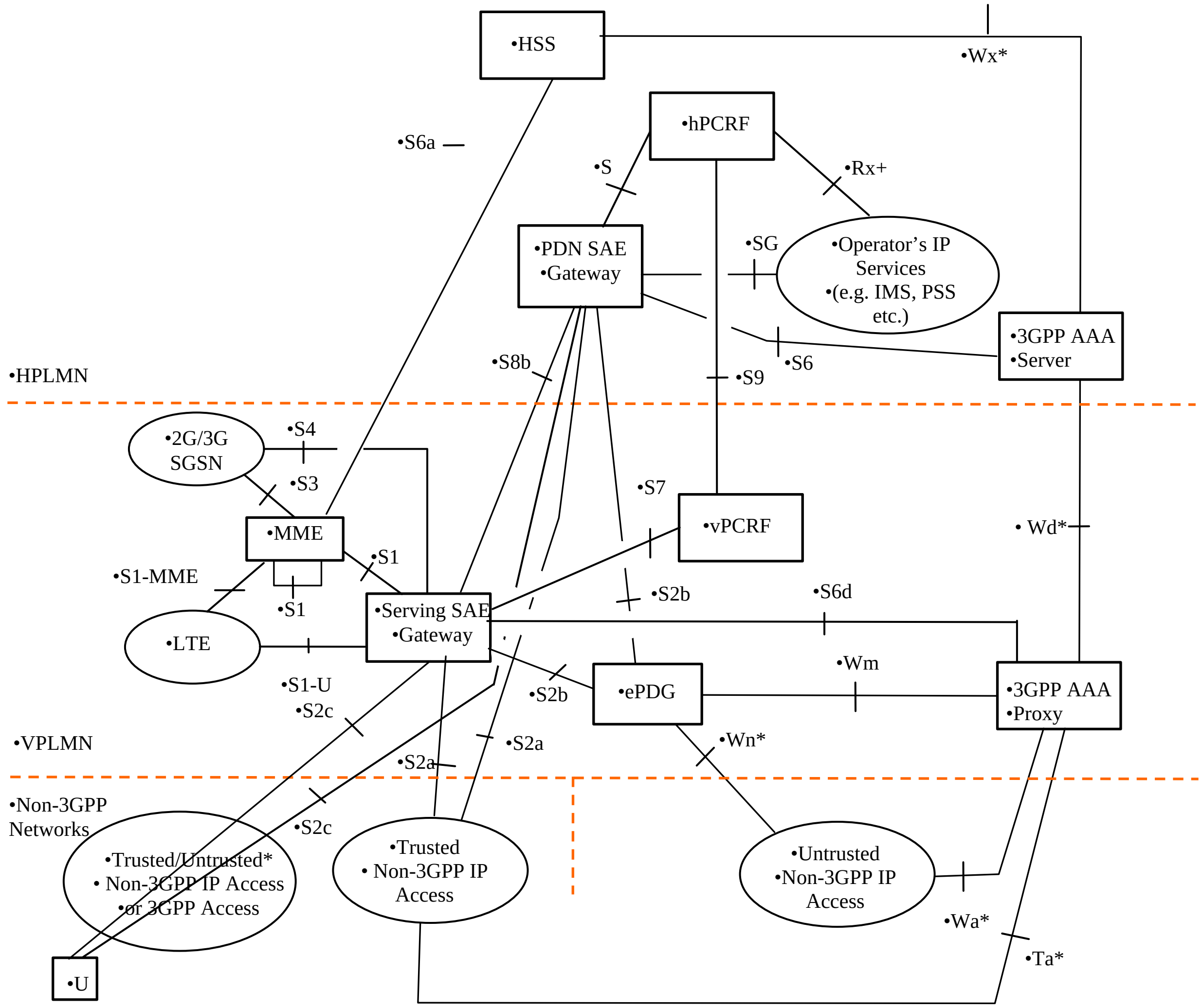


Figure 16. Roaming architecture (home routed case, including non-3GPP networks)[99]

5.2 EUTRAN Air-Interface

This section presents UTRAN Long Term Evolution (LTE) Air-interface. The work in 3GPP is defining 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 3GPP schedule, background and technology principles of UTRAN LTE physical layers, protocols and architecture. The standard is defining both FDD and TDD options for LTE, but this paper is focusing on the specifics of the FDD system.

LTE investigation began in 3GPP during 2004. The feasibility study was started 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. The 3GPP conclusion was that Orthogonal Frequency Division Multiple Access (OFDMA) is to be used in downlink 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 status in Radio Access Protocol Aspects is discussed in a corresponding section showing the latest agreements in 3GPP standardization.

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

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

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 work on LTE is targeting Rel-8 specification availability by the end of 2007, 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.

5.2.1 Downlink

This section provides some details about the downlink LTE structure defined in 3GPP. A brief introduction on mapping between the transport and physical channel is given. 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.

5.2.1.1 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. Common control physical channels (CCPCH)

The mapping between transport and physical channels are shown in Figure 17. Currently, four transport channels are defined for LTE – Broadcast Channel (BCH), Paging Channel (PCH), Downlink Shared Channel (DL-SCH), and Multicast Channel (MCH).

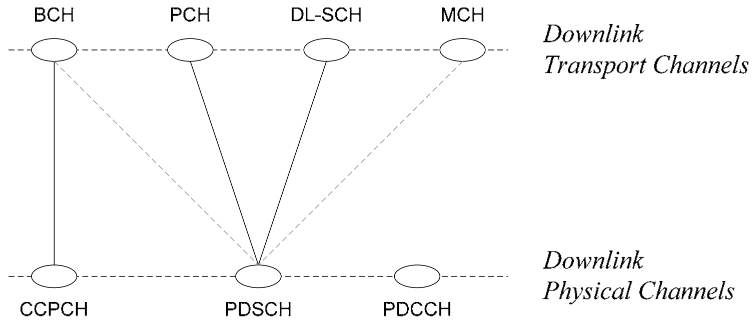


Figure 17. Mapping between downlink transport channels and downlink physical channels[100]

5.2.1.2 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. 1.4/1.6/3/3.3/5/10/15/20 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.

Table 1. Typical parameters for downlink transmission scheme[101]

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 18. Each sub-frame is comprised of two slots of length 0.5ms (either 6 or 7 OFDM symbols depending on the cyclic prefix length). Within each slot, reference symbols are located in the 1st and 5th OFDM symbols. The reference symbol structure shown in Fig. 18 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 TR 25.814, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA)" for further details on the reference symbol structure for 1 Tx, 2 Tx and 4 Tx antenna configurations. The structure shown in Fig. 18 allows a simple channel estimator to be used as well as other excellent performance, low-complexity techniques such as MMSE-FIR and IFFT-based channel estimators.

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

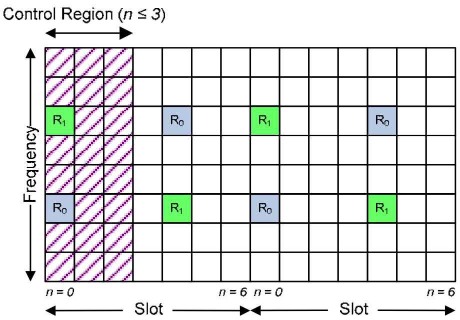


Figure 18. E-UTRA downlink sub-frame structure[102]

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 19. 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 $N_{\text{symb}}^{\text{DL}}$ consecutive OFDM symbols in the time domain and $N_{\text{BW}}^{\text{RB}}$ consecutive subcarriers in the frequency domain. Thus, a resource block consists of $N_{\text{symb}}^{\text{DL}} \times N_{\text{BW}}^{\text{RB}}$ 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).

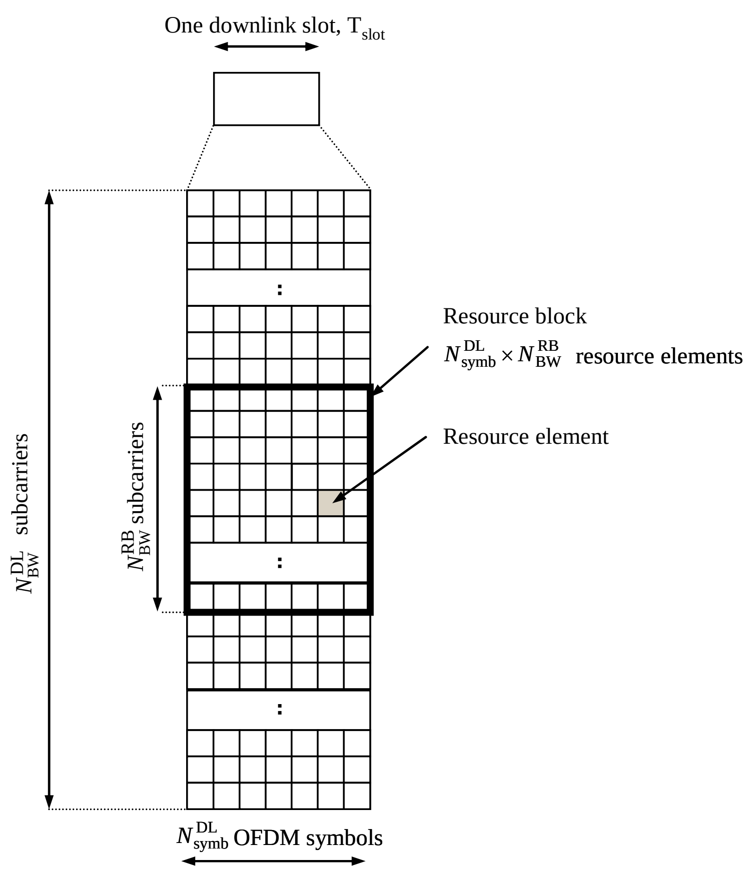


Figure 19. Downlink Resource Grid[103]

[102] Physical Channels and Modulation, 3GPP TS 36.211.
[103] *Ibid.*

Table 2. Resource block parameters.[104]

Configuration		$N_{\text{BW}}^{\text{RB}}$	$N_{\text{symb}}^{\text{DL}}$
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.

5.2.1.3 LTE Downlink Control Channel Structure

Within each downlink sub-frame, the following control signaling is required – downlink scheduling grant, uplink scheduling grant, and downlink ACK/NACK associated with uplink data transmission. 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 H-ARQ support such as process number, redundancy version, and new data indicator. Similar information is also included in the uplink scheduling grants.

Downlink control signaling is located in the first n OFDM symbols with $n \leq 3$ (as shown in Fig. 19*)*. 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. Each channel carries information associated with one ID. 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. 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 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.

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 TR 25.814, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA)" for more details on the LTE DL control channel structure.

[104] *Ibid.*

Table 3. Example predefined coding rates[105]

#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)
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

CEs combined to achieve lower Effective

<u>DL ACK Channel</u>
The downlink acknowledgment comprises 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.

5.2.1.4 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. 20. Both the P-SCH and S-SCH are transmitted on 64 active subcarriers, centered around the DC subcarrier.

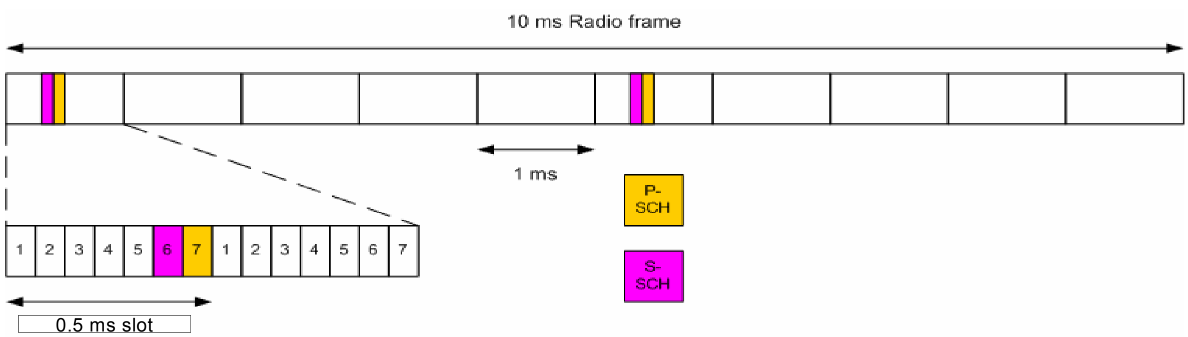


Figure 20. SCH Frame Structure[106]

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 21. The neighbor-cell search is based on the same downlink signals as initial cell search. See 3GPP TR 25.814, "Physical Layer Aspects for Evolved Universal Terrestrial Radio Access (UTRA)" for further details on the P-SCH and S-SCH structure.

105 E-UTRA DL L1/L2 Control Channel Design, 3GPP R1-070787. Motorola, RAN1#48, St. Louis, USA. February 2007.
106 Outcome of cell search drafting session, 3GPP R1-062990. Nokia et.al, RAN1#46-bis, Seoul, S. Korea. October 2006.

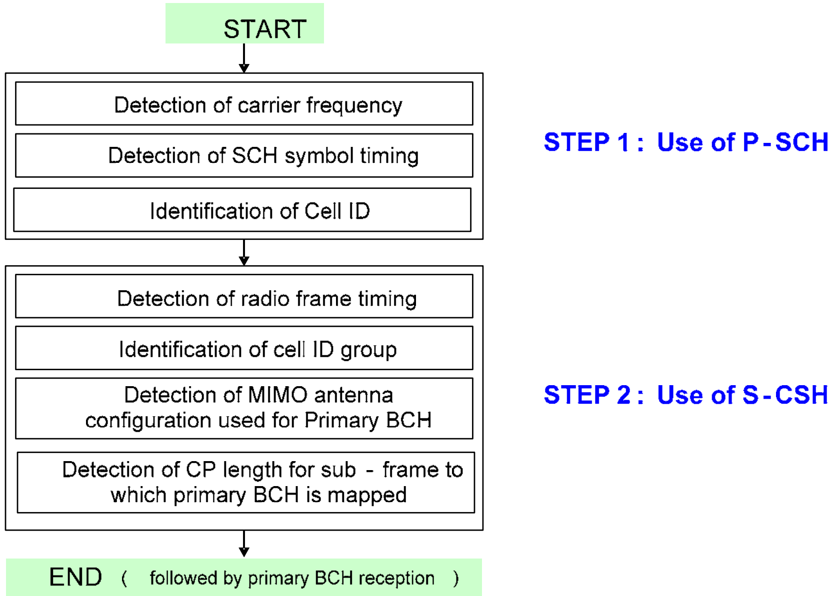


Figure 21. Cell Search Flow Diagram[107]

5.2.1.5 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, the BCH is divided into two portions – primary (P-BCH) and dynamic (D-BCH). The P-BCH contains basic L1/L2 system parameters necessary to demodulate the D-BCH which contains the remaining System Information field. The P-BCH is characterized by the following:

a. Single fixed size transport block per TTI
b. Modulation scheme is QPSK
c. CCPCH is transmitted on 72 active subcarriers, centered around the DC subcarrier
d. No HARQ

The details of the D-BCH are yet to be determined.

5.2.1.6 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 33μs 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 16.5μs. The reference signal structure for MBSFN sub-frame is shown in Figure 22. In this structure, only the first reference signal is present for unicast transmission.

[107] Three step cell search method for E-UTRA, R1-062722. NTT DoCoMo et.al, RAN1#46-bis, Seoul, S. Korea. October 2006.

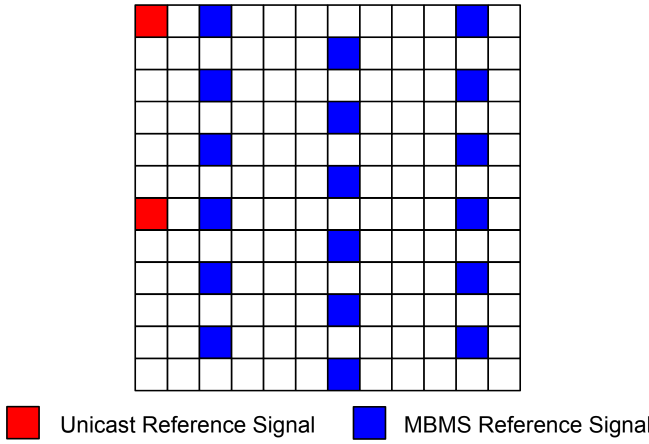


Figure 22. Reference signal structure for mixed carrier MBSFN[108]

5.2.1.7 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 26 and Spectrum efficiency results in Figure 23. 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.

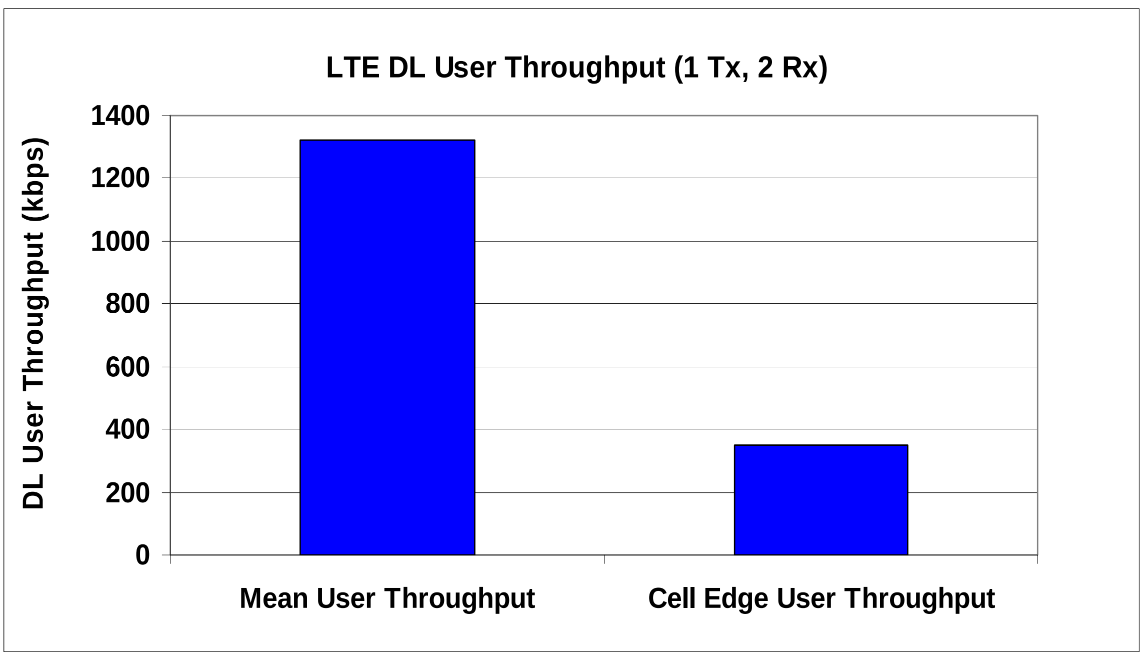


Figure 23. LTE DL User throughput[109]

[108] Physical Channels and Modulation, 3GPP TS 36.211.
[109] LS on LTE performance evaluation work, 3GPP TSG R1-072580 RAN WG1#49

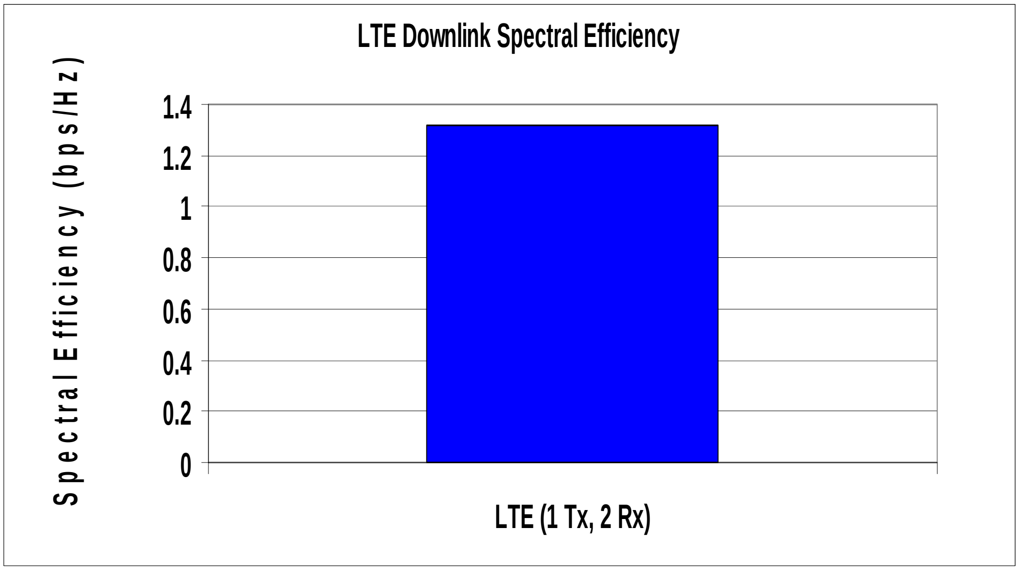


Figure 24. LTE DL Spectrum efficiency[104]

5.2.1.8 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 15kHz 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.

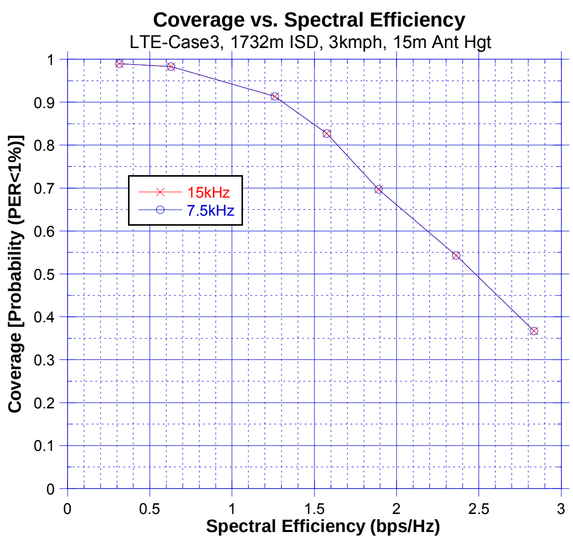


Figure 25. Coverage vs. spectral efficiency at 3km/hr[110]

Figure 25 and Figure 26 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 7.5kHz

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

numerology performance degrades compared to 15kHz 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 7.5kHz numerology.

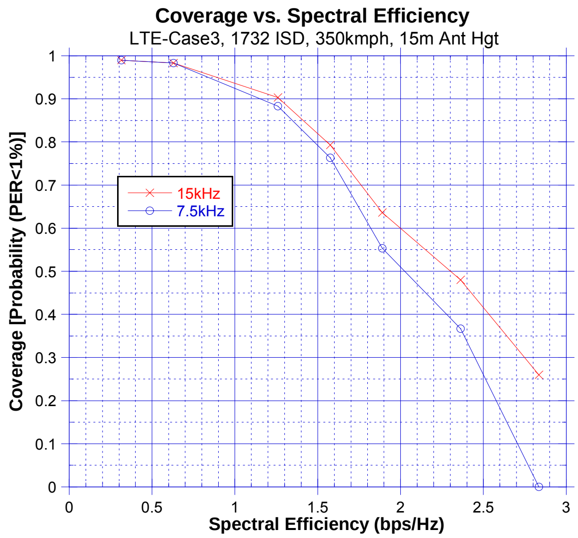


Figure 26. Coverage vs. spectral efficiency at 350kmph[111]

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 is 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.

5.2.2 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 interval 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 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 27.

[111] *Ibid.*

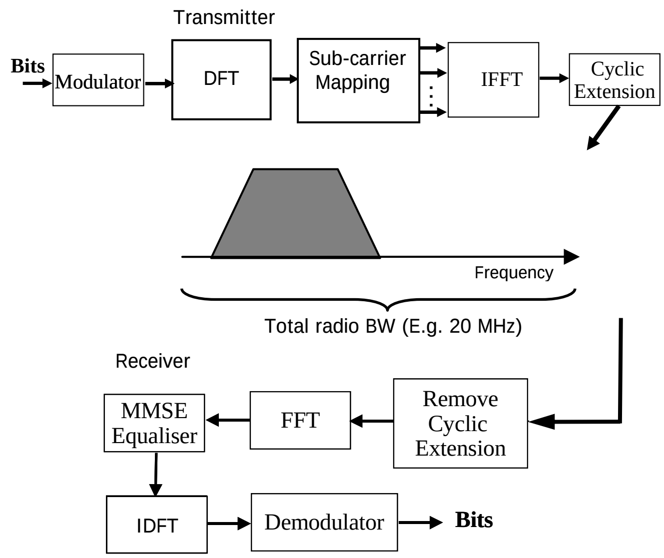


Figure 27. SC-FDMA transmitter and receiver chains with frequency domain equalization[112]

5.2.2.1 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 channels (PUSCH)

The mapping between transport and physical channels are shown in Figure 28. Currently, two transport channels are defined for LTE – Random Access Channel (RACH) and Uplink Shared Channel (UL-SCH).

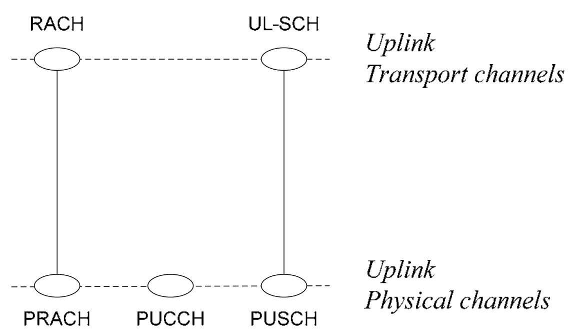


Figure 28. Mapping between uplink transport channels and uplink physical channels[113]

5.2.2.2 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

[112] 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. February 5-7, 2007.

[113] E-UTRA and EUTRAN, Overall description, Stage 2. 3GPP TS 36.300 V8.0.0 (2007-03).

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 29.

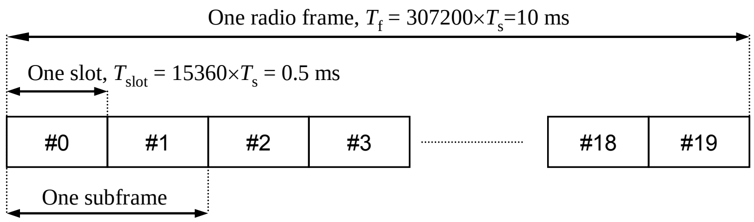


Figure 29. Frame structure type 1[114]

Other key parameters have relationship 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 allow maintaining 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.

5.2.2.3 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. Also multi-antenna uplink transmission is not specified at least 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.

5.2.2.4 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

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 a long SC-FDMA symbol.

5.2.2.5 Control Channel Structure

Physical Uplink Control Channel (PUCCH) carries uplink control information. The PUCCH is never transmitted simultaneously with the PUSCH. If scrambling is configured, the block of bits to be transmitted on the physical uplink control channel shall be scrambled with a UE-specific scrambling sequence prior to modulation, resulting in a block of scrambled bits.

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 30.

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

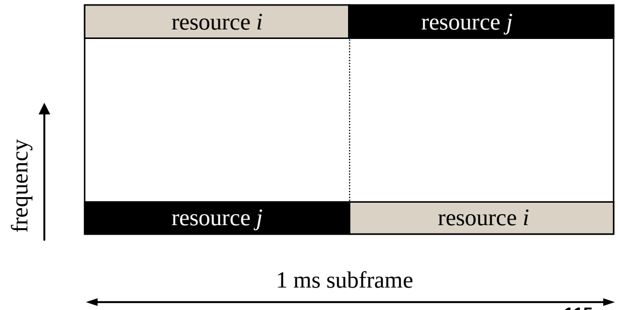


Figure 30. Physical uplink control channel[115]

Depending on 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 consists of:

- CQI
- ACK/NA
- 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 feedback. The HARQ feedback in response to downlink data transmission consists of a single ACK/NAK bit per HARQ process.

5.2.2.6 Random Access

The physical layer random access burst, illustrated in Figure 31, consists of a cyclic prefix of length T_{CP}, a preamble of length T_{PRE}, and a guard time T_{GT} during which nothing is transmitted. 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.

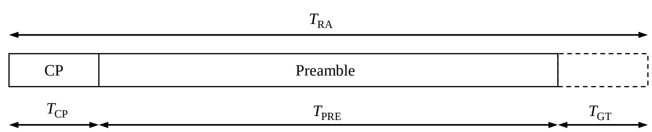


Figure 31. Random access preamble format (generic frame structure)[116]

Table 4. Random access burst parameters.[117]

Frame structure	**Burst length**	T_{RA}	T_{CP}	T_{PRE}
Generic	Normal	$30720 \times T_s$	$3152 \times T_s$	$24576 \times T_s$
Alternative	Normal	$4340 \times T_s$	$0 \times T_s$	$4096 \times T_s$
	Extended	$20736 \times T_s$	$0 \times T_s$	$20480 \times T_s$

For the alternative frame structure, the start of the random access burst depends on the burst length configured. For the extended burst length, the start of the random access burst shall be aligned with the start of uplink subframe 1.

In the frequency domain, the random access burst occupies a bandwidth corresponding to $N_{\mathrm{BW}}^{\mathrm{RA}} = 72$ subcarriers 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

[115] *Ibid.*
[116] *Ibid.*
[117] *Ibid.*

transmission by the higher layer on the shared data channel and are not considered part of the L1 random access procedure. A random access channel occupies 6 resource blocks in a subframe or set of consecutive subframes reserved for random access preamble transmissions.

5.2.2.7 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.

5.2.2.8 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 32 and Spectrum efficiency results in Figure 33. 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.

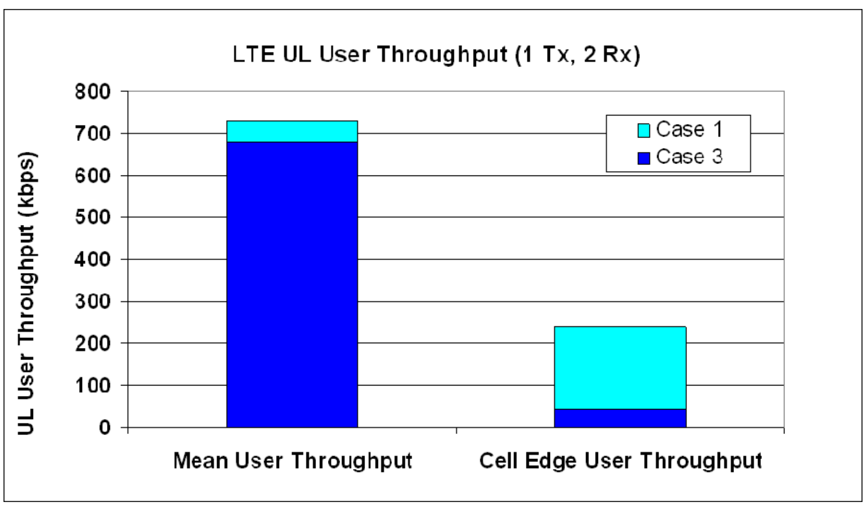


Figure 32. LTE UL User throughput[118]

[118] LS on LTE performance evaluation work, 3GPP TSG R1-072580 RAN WG1#49.

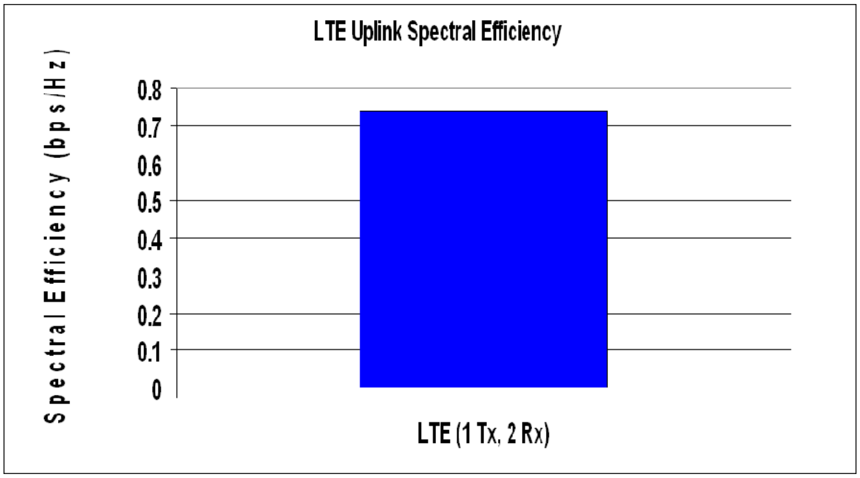


Figure 33. LTE UL Spectrum efficiency[119]

Uplink VoIP capacity results are presented in Figure 33 for 10 MHz spectrum allocation showing 634 users/sector in DL and 482 users in UL.

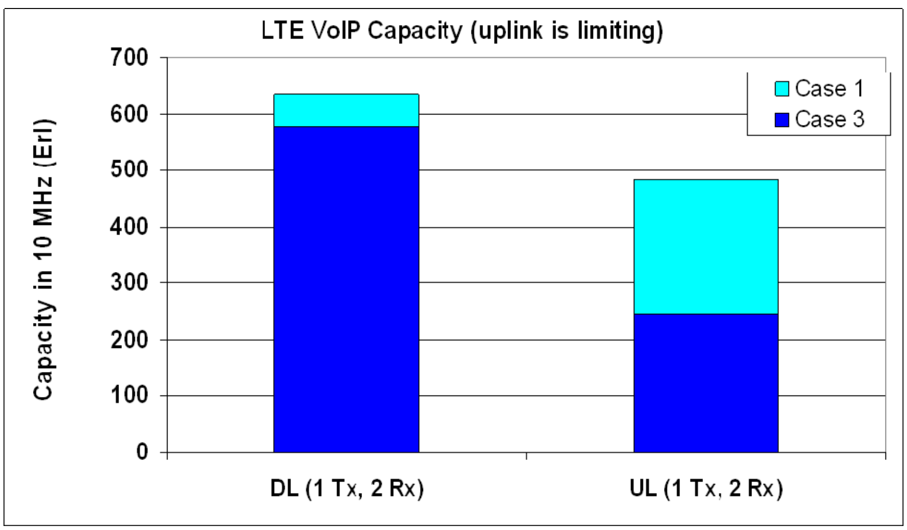


Figure 34. LTE VoIP capacity[120]

5.2.2.9 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 35. The available spectrum is divided into resource blocks (RB) consisting 12 adjacent subcarriers. The duration of a single RB is still under discussion but is assumed to be 1 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.

[119] *Ibid.*
[120] *Ibid.*

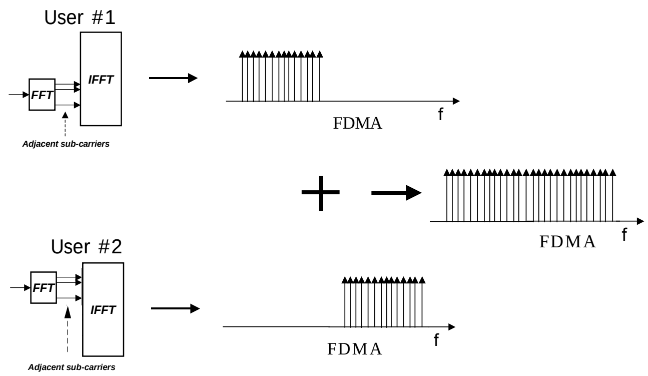


Figure 35: The principle of frequency domain scheduling in EUTRAN[121]

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 can 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.

5.2.3 Radio Access Protocol Architecture

The LTE protocol and network architecture is characterized by three special requirements:

- Support for the PS domain only. There will be no connection to circuit switched (CS) domain nodes, such as the Mobile Switching Center, but speech services are handled as Voice over IP (VoIP) calls
- Tight delay targets for small roundtrip delays; the roundtrip delay target is 5 ms for bandwidths of 5 MHz or more and 10 ms for the bandwidths below 5 MHz
- Reduced cost of the system

3GPP has defined the functional split between radio access and core network. As shown in Figure 36, 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 was 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,

[121] 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. February 5-7, 2007.

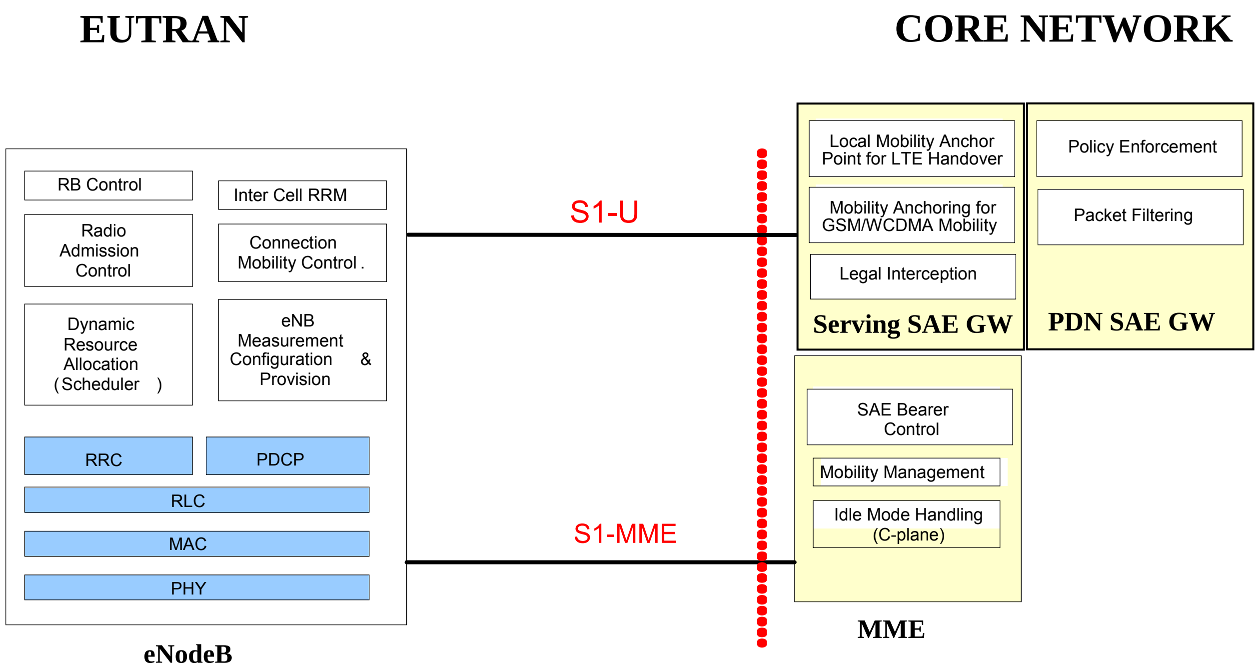


Figure 36. Functional Split between radio access and core network [122]

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.

5.2.4 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 will also be discussed.

5.2.4.1 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, Multiple Input Multiple Output, both Spatial Multiplexing and Space-Time 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 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 horizontal 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 which are controlled using digital signal processing. Smart antenna or AA (Adaptive Array) technology forms dynamic beams that are a function of the propagation channel and interference environment. See Figure 37. 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; notable is the current deployment of TD_SCDMA in China.

[122] Holma, H. and A.Toskala. *WCDMA for UMTS*. 4th edition. Wiley, 2007.

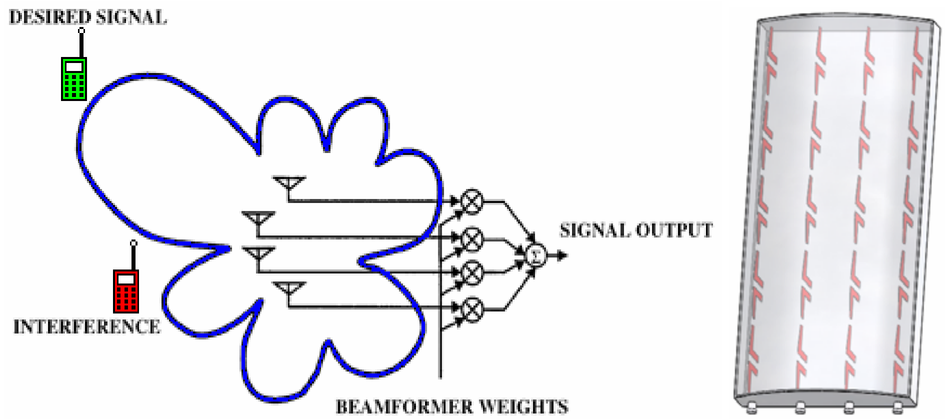


Figure 37. Conceptual depiction of an AA system implemented with 4-column, vertically polarized planar array[123]

In the last few years MIMO technology has emerged as one of the most promising approaches to achieve higher data rates in cellular systems. While multiple-input multiple output 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, 2x 2 MIMO, is shown in Fig. 38.

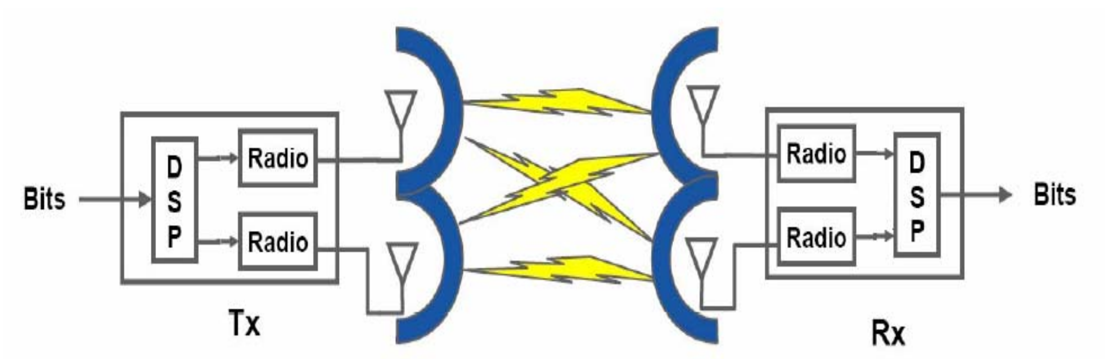


Figure 38. 2x2 MIMO system[124]

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 39.

[123] Reference pending from section owner
[124] 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, June 8th, 2007

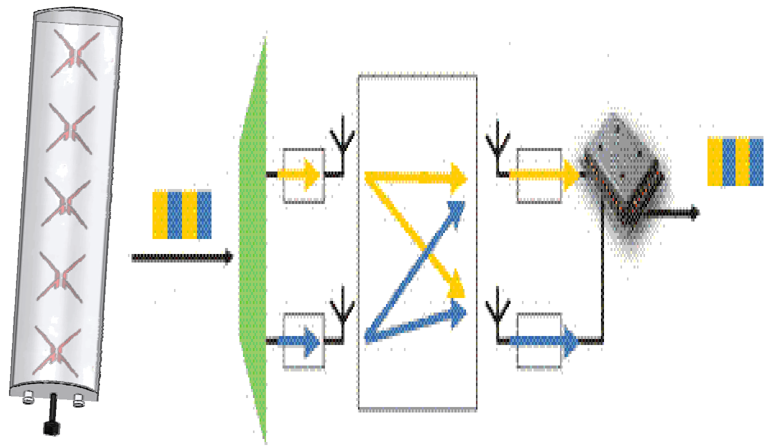


Figure 39. Conceptual depiction of a 2x2 MIMO system implemented with dual-pole, slant-45 base station antenna and two antennas in the UE[125]

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 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 40.

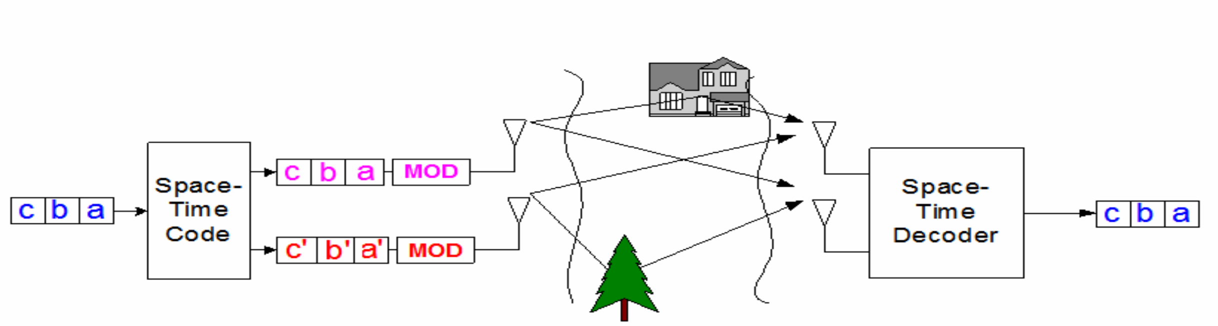


Figure 40. Illustration of Space Time Coding in a 2x2 MIMO system[126]

MIMO: Spatial Mutiplexing

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 antenna, providing multiplexing gain, resulting in increased system capacity. See figure 41.

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125 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, June 8th, 2007

126 *Ibid.*

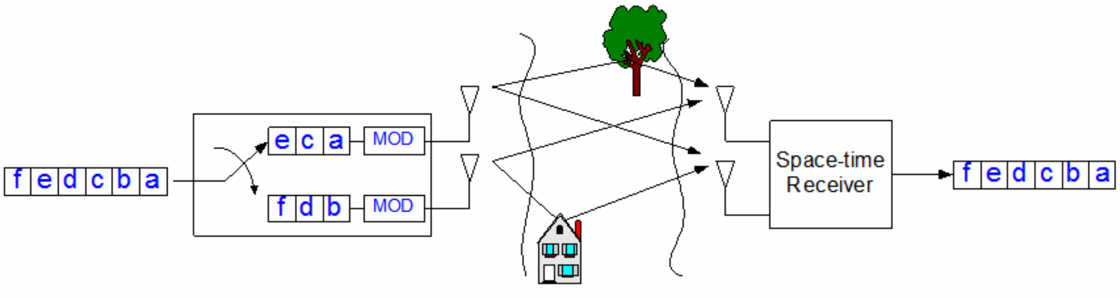

Figure 41. Illustration of Spatial Multiplexing in a 2x2 MIMO system[127]

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 42. Each of the two UEs transmit 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.

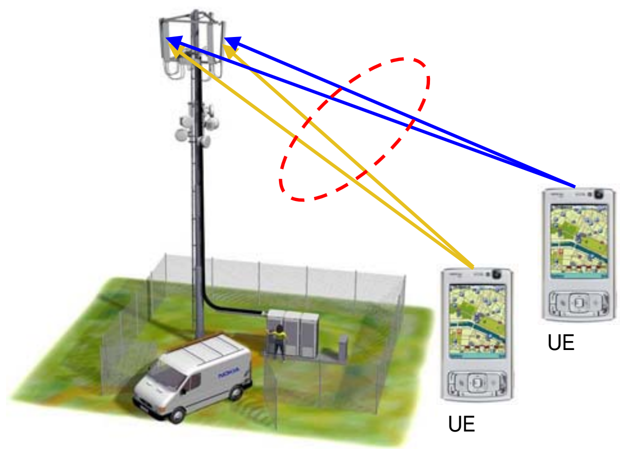

Figure 42. The basic principle of uplink MU-MIMO with 2x2 antenna configuration[128]

Uplink MU-MIMO also sets requirements for the power control. In the Single-Input Single Output (SISO) case, 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.

Currently RAN1 of 3GPP is considering various proposals for multiple antenna systems for LTE.[129] All the techniques as outlined above play a role in the ongoing LTE standardization. SU-MIMO as well as MU-MIMO techniques are considered in UL and DL. Diversity techniques and beamforming algorithms are analyzed and agreement has been reached on some of them. The status of MIMO in 3GPP LTE standardization will be discussed further in the next section.

5.2.4.2 MIMO Status in 3GPP LTE Standardization

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

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[127] 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, June 8th, 2007

[128] 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.

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

Downlink

In the downlink, MU-MIMO as well as SU-MIMO schemes are 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: 5RBs minimum, up to whole band
- Rank information: Whole band

The SU-MIMO schemes incorporate a codebook based precoding scheme with feedback. For the 2-Tx case, this codebook has already been fixed as of this paper's publication. For the 4-Tx case, agreement on the type of codebook matrix (Householder versus DFT based) has not yet been reached as of the writing of this paper. Some companies envisage two codebooks, one for single-polarised antenna configurations and another one for the dual-polarised 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 open 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 2 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 second LTE release. 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 2 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.

5.2.4.3 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.[130] Figures 43-45 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.

[130] LS on LTE performance verification work, R1-072580. 3GPP TSG-RAN WG1 #49, Kobe, Japan. May 7-11, 2007.

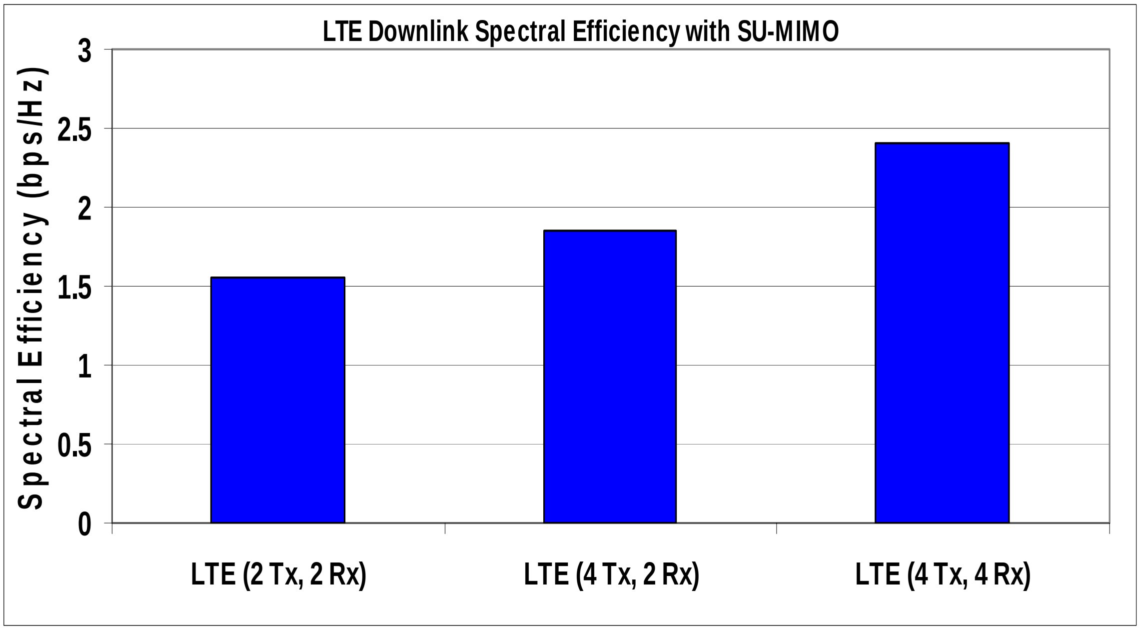

Figure 43. LTE Downlink Spectral Efficiency Performance with multi-antennas[131]

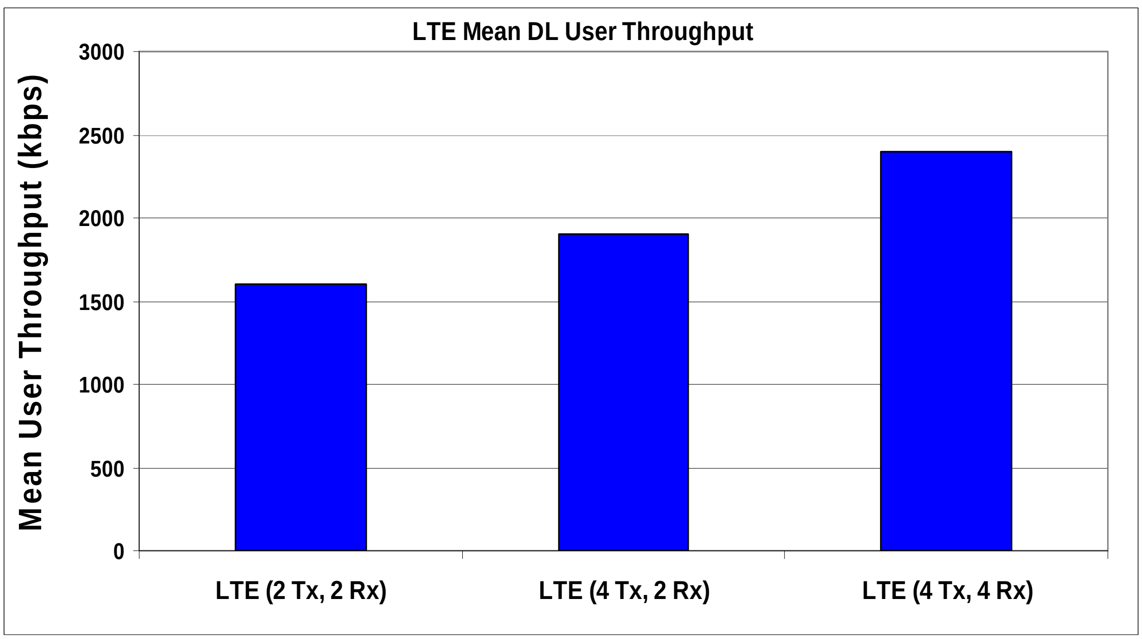

Figure 44. LTE Downlink Mean User throughput Performance with multi-antennas[132]

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[131] *Ibid.*
[132] *Ibid.*

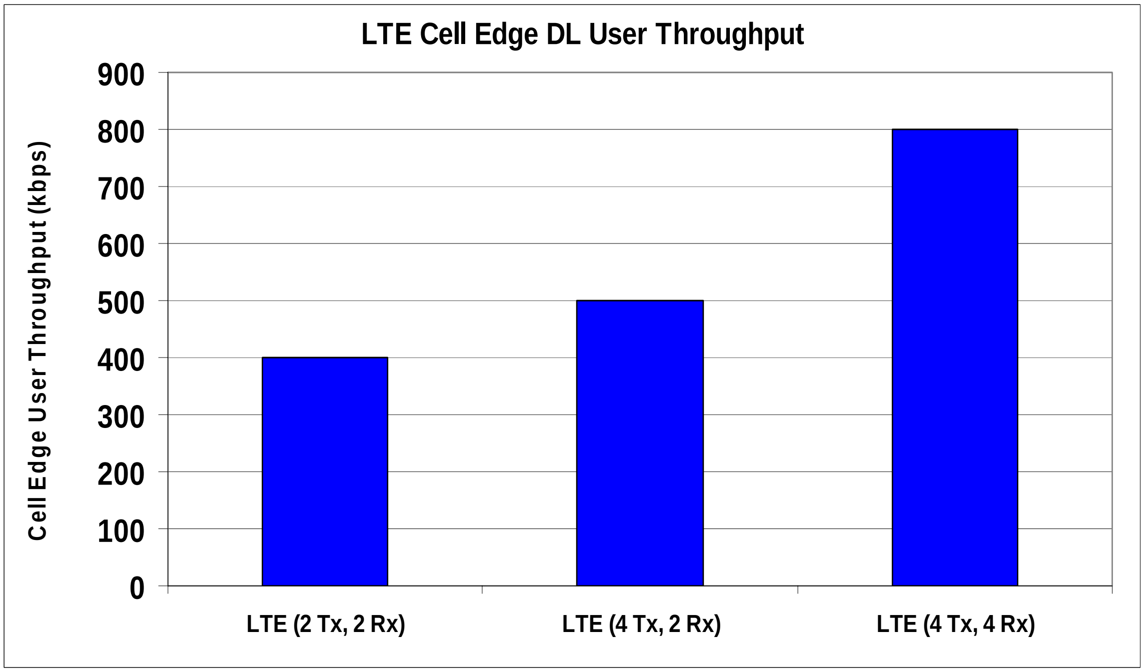

Figure 45. LTE Downlink Cell EDGE Performance with multi-antennas[133]

Uplink Performance

An aggregate performance summary of several MIMO configurations, as evaluated by various 3GPP members, has been compiled by the 3GPP.[134] Figures 46-48 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.

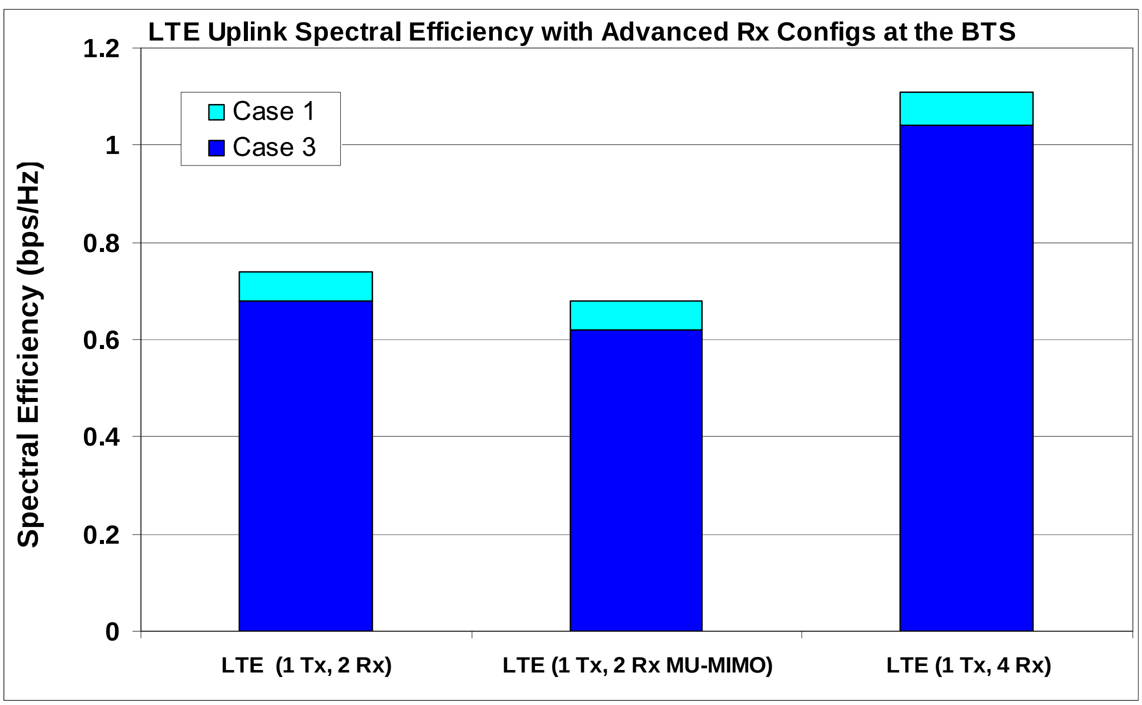

Figure 46. LTE Uplink Spectral Efficiency Performance with multi-antennas[135]

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[133] *Ibid.*
[134] *Ibid.*
[135] *Ibid.*

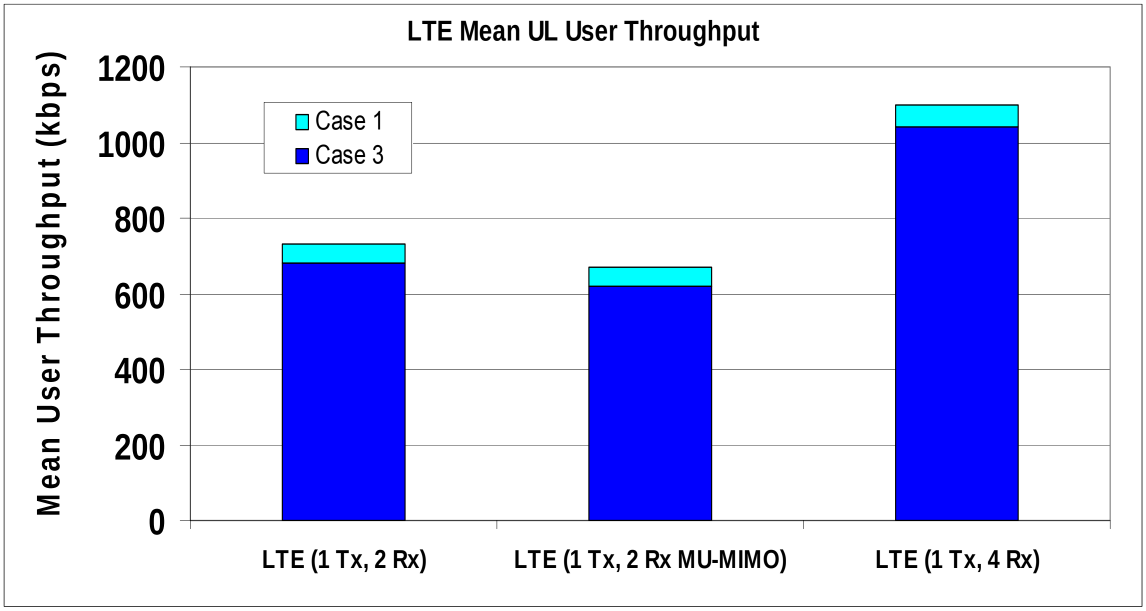

Figure 47. LTE Uplink Mean Throughput Performance with multi-antennas[136]

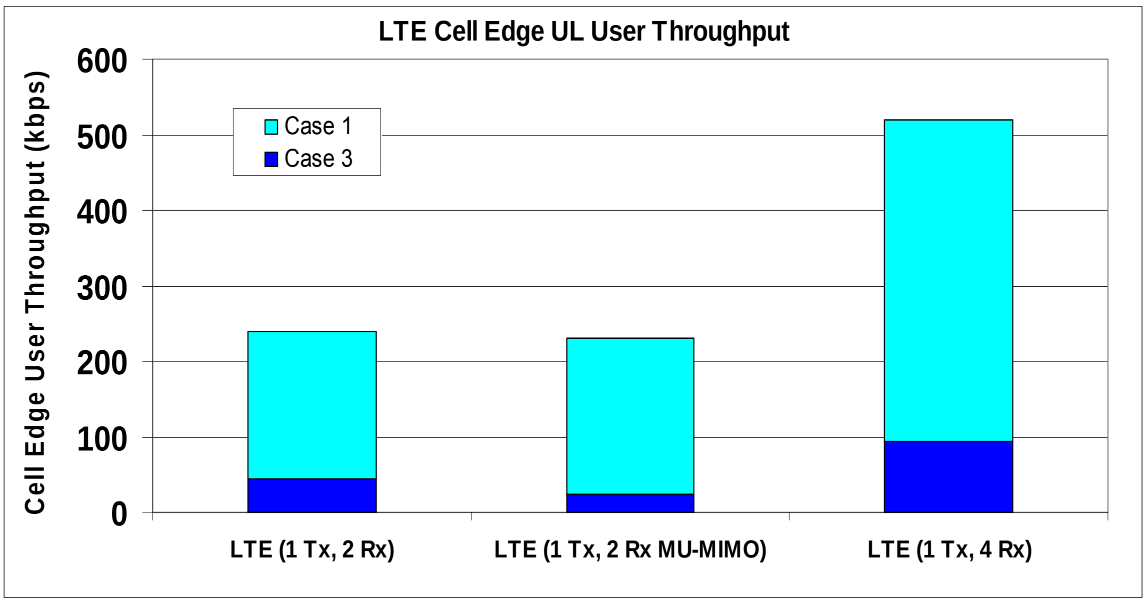

Figure 48. LTE Uplink cell edge performance with multi-antennas[137]

5.2.5 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 should 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).

[136] *Ibid.*
[137] *Ibid.*

As identified in the LTE study item 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.

5.2.5.1 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. Sometimes a spreading is also included. 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 number of users in adjacent cells (thus increasing outage).

5.2.5.2 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 necessary 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.

5.2.5.3 Interference co-ordination / avoidance

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

<u>Downlink Principle</u>
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 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.

<u>Downlink Static Schemes</u>
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. given in 50for an inverted re-use 7 scheme (FFR=6/7). See figure 49.

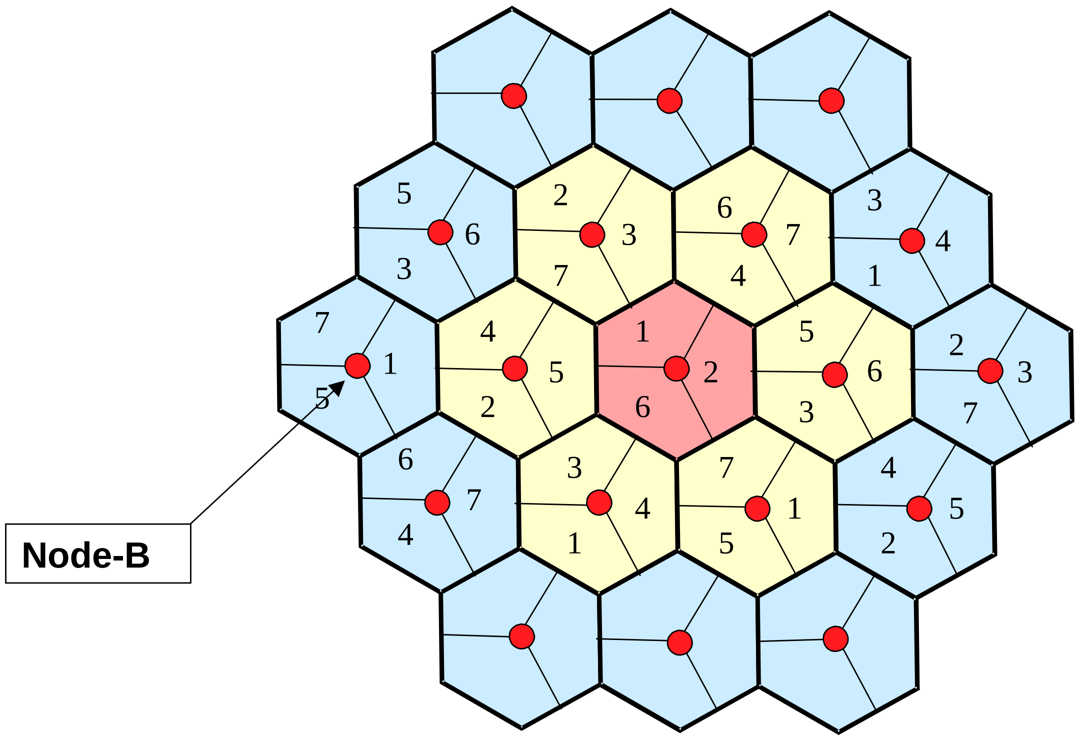

Figure 49. Cell planning for inverted re-use 7 scheme (FFR=6/7)[138]

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 these SIR improvements of certain resource blocks are stable enough and the channel quality reports are frequent enough, so that the scheduler can re-act.

By using static Interference coordination with a cell planning the SIR improvement are made more stable than the frequency selective fading and the scheduling can rely on just pathloss 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. As an example, by introducing a preference for a certain frequency subset depending on the nearest neighbor of a 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 corresponding to seconds or longer. Inter-node communication corresponds to information needed to decide on reconfiguration of the scheduler restrictions (examples of communicated information: 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.

[138] Alcatel-Lucent, Q2 2007

5.3 Other Rel-8 Enhancements

This section discusses other features in addition to EPS/LTE that are being planned for Rel-8 in the areas of IMS, Multimedia Priority Service, Packet Cable Access, VCC and UICC.

5.3.1 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.

5.3.2 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.

5.3.3 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. This work item consists of three main topics:

- Security: the cable environment requires a specific security approach driven by its particular architecture for home networking. This work item will enhance IMS security to fit in the packet cable architecture
- Cable client deployment: operational procedures in the cable industry typically involve the deployment of a "blank" client which is that customized by commands sent from the network. This work item will provide the tools needed to support this deployment model for IMS.
- 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 will provide the necessary regulatory features for cable deployment in North America and other regions. This will include support for "equal access".

5.3.4 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.

5.3.5 VCC Enhancements

There are two main areas of work related to VCC for Rel-8: IMS Centralized Services (ICS) and VCC for SAE/LTE access and CS domain. Both of these are discussed below.

IMS Centralized Services (ICS)

IMS Centralized Service (ICS) is an approach to the provision of communication services wherein all services and service control is based on IMS mechanisms and enablers. IMS services are delivered over 3GPP CS, VoIP capable and non VoIP capable 3GPP PS, and non 3GPP PS access networks; with provision of user transparent service continuity between these access networks.

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.

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.

Voice Call Continuity between SAE/LTE access and CS domain

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. Studies are being conducted to enable service continuity between such systems.

5.3.1.6 UICC: Internet Services and Applications

ETSI-SCP and 3GPP CT6, the major standardization bodies dealing with UICC and USIM evolution, have not completely finalized Rel-7 but have already started Rel- 8 requirements work in the following areas.

Security Model improvement

Rel-7 enhancements of interface and memory integration is opening the door to new business models, based on partnership between operators and content providers (such as Mobile Content Broadcaster, Banks, Public or Private Transportation Authorities) or based on externalization, such as a MVNO. Rel-8 will address new emerging security requirements with the *confidential application Rel-8 Work Item* that will define a technical solution for operators to share space and resources with third parties. This work item implies a revision of security model in the UICC.

Storage and data access

With the integration of flash technology, Rel-7 UICC can now offer memories up to gigabytes. Rel-8 will improve the existing memory management scheme, based on definition of elementary files and file identifiers, to ease management of multimedia and large applications in the UICC, with compatible technologies deployed in terminals or notebooks. *The Release 8 Work Item 'New type of data storage and access'* addresses requirements to define a new type of storage in the UICC for multimedia content or any type of new content identified in Rel-8. This work item is covering content access by the terminal, content management by applications residing in the UICC (such as Web Based Application or Multimedia Phonebook), and also content remote access from the operator or third party servers.

IP based remote management

The Rel-7 IP stack is a first step towards Internet based services. The remote application or file management in the UICC, based on APDUs formatting, has to be upgraded in order to fit with this new capability. *The Rel-8 Work Item 'Remote Management over IP'* targets the migration of content management to an IP-based infrastructure, replacing traditional scripts with IP compatible requests.

UICC to device communication

A Rel-7 UICC offers connectivity and large memory that can be leveraged with external peripherals plugged on the terminal such as cameras, biometric readers, GPS navigators, and external memory cards.

The *Rel-8 Work Item 'UICC external peripheral data-exchange'* is collecting requirements to allow UICC exchanging information with external peripherals plugged on the terminal.

Development of services based on UICC connectivity possibilities

Rel-8 will also have to address requirements and technical solution for developing services for web services, but also contactless based application.

6 Conclusions

The amazing uptake in commercial HSPA deployments as well as the abundance of HSPA devices that has emerged during the last two years is 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. 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-7 we have described some important additions to the concept of HSPA Evolution or HSPA+, such as Enhanced Receivers (type 2i and 3i), Higher Order Modulation and Continuous Packet Connectivity. For Rel-8, the main bulk of the work in 3GPP is focused on providing a new radio interface and system architecture 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.

The feasibility study for LTE was concluded in September 2006 and the target is to have the detailed specifications ready by the end of 2007. 3GPP recently evaluated the performance of LTE in order to make sure that it can deliver the performance requirements. After clearly passing this checkpoint, the target is within reach.

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 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. 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 40 W-CDMA customer contracts with operators including Orange, Vodafone, AT&T, Mobilkom, KTF, SK Telecom, and has announced a series of new wins since the merger with Softbank, SFR, Globacom

(Nigeria), Uganda Telecom and more. This report captures industry contributions originally attributed to Alcatel, Lucent and Nortel.

Andrew Corporation delivers products and solutions that address all areas of the UMTS RF path and coverage requirements, including a suite of UMTS tools for planning, implementation, geo-coded traffic, and performance data management.

Andrew's solutions specifically address the unique needs of wireless operators facing UMTS deployments, including:

- *Rapid development of a focused outdoor UMTS footprint* — Andrew accelerates dense urban builds with small footprint rooftop deployments, supplements macro coverage with microcell-based capacity for outdoor hotspots, simplifies greenfield site builds with kits and bundles, broadens effective cell coverage with tower-mounted amplifiers, multi-carrier power amplifiers, and Node-based interference cancelling repeaters, and provides turnkey coverage and distributed capacity for outdoor venues such as urban streets, urban canyons, road tunnels, and railways with multi-operator, multi-standard ION-based optical distribution networks and radiating cable. Andrew's cable and connector products have best in class RF performance, coupled with ease of deployment. Andrew's broadband, multiband base station antennas, with available remote electrical tilt, facilitate site optimization and simplify configuration, lowering rental costs. Andrew Institute provides world renowned training for personnel involved with RF system installation and maintenance.
- *Cost-effective indoor capacity and coverage* — Andrew helps operators and OEMs evolve beyond voice and move indoors aggressively with Pico Node B, a fully functional Node B product with HSDPA capability, that supports 40 and 80 user configurations and supports microcell applications. They offer balanced coverage and capacity in a phased, modular manner through active and/or passive distributed antenna systems. Using the Pico Node B, another base station or a repeater as a driver, an ION® series-based optical distributed antenna system distributes coverage and capacity in a cost-effective, homogonous, future proof fashion. The current ION system supports up to five frequency bands in a tightly integrated package with an extension for up to three more frequencies over a pair of single mode fiber. The new Node-A indoor or outdoor all-digital repeater provides a low cost coverage extension solution. This repeater supports up to four simultaneous frequency bands including 400MHz, 700MHz, 800MHz, 850MHz, 900MHz, 1700MHz, 1800MHz, 1900M, 2100MHz, and 2600MHz.
- *Real-time network monitoring and optimization* — Andrew makes regular, systemic drive testing and service benchmarking fast and effective with Invex3G, scanners that were among the first to support UMTS and other technologies in the same instrument, and Invex3G Autonomous, which enables lower cost data collection and higher quality drive data. Our patented remote electrical tilt base station antennas accelerate post-deployment optimization by responding quickly to changing traffic patterns and reducing interference and coverage "holes." Andrew's reconfigurable SmartBeam antennas provide remote adjustment of the elevation beamtilt, azimuth beamwidth and boresite pointing direction. This provides the operator with the ability to achieve capacity increases through load balancing and interference management. In addition, Andrew provides easily integrated element managers for the remote access and control of repeaters, TMAs, and base station antennas. These tools are aimed at enhancing the operators' ability to quickly implement optimization plans and to significantly reduce opex.
- *Effective network planning and rollout* — Andrew's network planning tools such as Odyssey™, Optum™, Omnix™, and Q.link™ help operators design and plan networks, accurately predict coverage needs, efficiently expand and deploy networks, optimize data, analyze and monitor performance, and improve efficiency.

Andrew's RF solutions enable operators to synchronize investments with revenue using scalable deployment strategies and technologies, accelerate payback by expanding macro coverage effectively while concentrating on balancing coverage, capacity and interference management in key areas such as urban settings, indoors, and along transportation corridors.

Ericsson is the primary supplier to the world's HSPA networks. In November 2007, Ericsson equipment powered 75 of the 154 commercially launched HSPA networks. In December 2005, Cingular Wireless (now AT&T) launched the first commercial HSDPA network using Ericsson equipment. One year later Ericsson and 3 Italia established the world's first HSUPA mobile data connection in a commercial network, followed by Ericsson's customer Mobilkom in Austria that was the first operator that launched HSPA in the Uplink commercially to their subscribers.

The Ericsson HSPA equipment today supports peak rates of 14 Mbps downlink and 1.4 Mbps uplink, capabilities that are added to existing networks using a simple SW upgrade. The superior performance of the Ericsson HSPA equipment allows support for mobile broadband using cell radii of up to 120 miles (200 km). This is a reality in Telstra's HSPA network in Australia where downlink speeds of 2.3 Mbps at a 120 miles range has been achieved.

Following the recent 3GPP industry standardization, Ericsson is committed to launch EDGE evolution as a software upgrade of existing infrastructure by 2009. EDGE evolution will boost data speeds by up to 300 percent 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.

Ericsson Mobile Platforms offers complete, end-to-end interoperability tested platforms for 2.5G and 3G. A common software platform for GPRS, EDGE, WCDMA and HSPA terminals enables application portability, stability and security, and ensures best-in-class outcomes regarding power consumption and size. Ericsson Mobile Platforms has the smallest, most-cost-optimized HSPA chipset in the market, making it possible for its customers to enable ultra-small HSPA phones.

In February 2007 Ericsson announced the creation of a new product area. The products, called Mobile Broadband Modules, will boost the accelerating growth of the mobile broadband market by bringing HSPA to every notebook as well as other devices needing broadband connectivity. The HSPA module, smaller than a credit card, will be included in notebooks by early 2008 and support HSPA at 7.2 Mbps downlink and 2 Mbps uplink as well as EDGE.

At the 3GSM World Congress in February 2007 Ericsson performed a series of ground breaking live demonstrations including:

- A cutting-edge LTE system supporting MIMO antenna technology with speeds of up to 144 Mbps using a 20 MHz carrier in the 2.6 GHz spectrum
- Mobile TV using Multimedia Broadcast Multicast Service (MBMS)
- IMS Mobile VoIP over HSPA for the first time on a mobile terminal

In addition, Ericsson also powered the GSMA sponsored live IMS VideoShare Interoperability Demonstration showing that the IMS VideoShare solution today works with all types of devices.

In November 2006, Softbank Mobile Corp in Japan launched the world's first IMS-based services over a 3G network. The end-to-end IMS system supplied exclusively by Ericsson allows the operator to launch new exciting 3G services on the market. Initially the launch included push-to-talk, presence and group list management. Ericsson leads the IMS market with 45 IMS system contracts for commercial launch of which sixteen were deployed and running live traffic in October 2007.

In August 2006, Telcel in Mexico and Ericsson achieved the world's first commercial implementation of 3GPP standardized MSC Pool technology. This technology is used together with the Ericsson Mobile Softswitch Solution to increase the effective softswitch capacity, while reducing operating expenses and providing efficient network-level redundancy. Ericsson is the world's leading vendor of mobile softswitch solutions with a track record of more than 200 contracts around the world, of which more than 145 were in full commercial service by October 2007. Furthermore, 76 of the Ericsson live commercial networks are based on IP-signaling (SIGTRAN) and 38 are running IP-payload.

Ericsson's technology and products are based on its global leadership of standardization work and the world's strongest intellectual property rights for 2.5G and 3G systems with more than 20,000 granted patents worldwide.

Gemalto, a 1.7b euros leader in digital security, is the largest provider of smart cards and remote management servers. In 2006, Gemalto provided close to one billion SIM and UICC to over 500 operators worldwide. Gemalto's Over-the-Air platforms and operated services were used in 60% of all installations worldwide to conduct remote updates of data but also 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 since December 2006:

- **Video streaming at 4 Mbps over TCP-IP** from the UICC (DVD quality transmission) **with parallel gaming session** via a browser session. In this demonstration presented in October 2007, a consumer launches the phone's browser and views an offline portal presented by the web server in the UICC, then selects to view a video from the offline page, and finally views a video streamed directly from the UICC with mass storage while simultaneously playing a game of Othello.

- **Operator service portals available offline based on Smart Card Web Server, presenting xHTML pages from the UICC** viewed by the phone browser pointing to a URL located in the UICC. In this demonstrations, the consumer views a storefront with top ten music and videos that can be trialed and purchased: the UICC pages directly directs the browser to wap pages, launches premium SMS services, sets up calls, or manages local UICC NFC applications. Gemalto showed two implementations of the interface with devices: one with the classic ISO commands and the BIP TCP Server, and another over TCP-IP.

- **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). Gemalto relied on the Single Wire Protocol (Release 7), HCI (under standardization), and the Smart Card Web Server for richer brand presentation during transactions. The Single Wire Protocol was demonstrated with LG, Motorola, Nokia, Sagem, and Samsung devices.

Gemalto participates in all the GSM Association Pay-Buy-Mobile trials publicly announced (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.

***Motorola*'s** solutions offerings go from strength to strength and are at the forefront of innovation. 2007 has seen Motorola successfully deploy a number of new UMTS/HSPA networks that were quickly delivering service provider revenues and subscriber delight.

Motorola's UMTS/HSPA solutions are designed to address the challenging specific needs of service providers worldwide, and make the most of today's market opportunities. Support for full 15 code HSDPA, HSUPA, IP backhaul options and a range 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 service providers' network CAPEX and OPEX figures, providing outstanding value for money and efficient ongoing cost of ownership.

Motorola's "Zero Footprint" Solution offers cost-effective options to deliver UMTS/HSPA capability, not only in areas where there is likely to be a ready return on investment, but also in areas where previously the "standard" macro equipment-related site acquisition and deployment costs meant that deployment was unfavorable. Using distributed architectures, the *"Zero Footprint" Solution* is comprised of units that are physically small and thus relatively easy to site, a major consideration in dense urban areas where space is invariably at a premium. When combined with features such as RAN site sharing, remote antenna adjustment and our various backhaul techniques, Motorola's UMTS/HSPA solutions open up a host of exciting deployment opportunities.

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 service providers 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 service providers 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 enable service providers to converge their LTE and fixed-line broadband networks giving them the ability to provide their subscribers with a seamless experience.

For LTE, Motorola is drawing upon its extensive expertise in OFDM technologies. It first demonstrated OFDM at speeds of up to 300 Mbps back in 2004 - its success as a leader in IEEE 802.16e WiMAX, expertise in collapsed IP architecture and its leadership in LTE RAN standards to offer a compelling LTE solution. In addition to LTE infrastructure, Motorola's leadership in home and video solutions, early availability of LTE chipsets, handsets and CPE, leading backhaul solutions and experience in deploying OFDM mobile broadband networks means that Motorola will bring a compelling LTE end-to-end ecosystem while offering a smooth migration path for both 3GPP and 3GPP2 service providers, traditional wire-line service providers and new entrants. Motorola will conduct LTE trials in 2008 and expects to have commercial solutions by late 2009.

Motorola was one of the first vendors to advocate the importance of in-building coverage and of dedicated indoor solutions that offer cost-effective capacity and coverage where data services are often most needed. Motorola's *Indoor Solutions* have gone beyond the enterprise; developed based on extensive customer feedback, Motorola now offers femtocell solutions for the home and SOHO environments, which provide dedicated indoor 3G coverage and backhaul via the broadband Internet connection. This solution offloads traffic from the macro network and at the same time provides improved subscriber experiences and increasing ARPU opportunities for the service provider.

Motorola provides end-to-end solutions, not just radio access technologies -- from exciting "must have" handsets through infrastructure and applications. A major and critical component of any infrastructure deployment is the core; Motorola offers not only circuit (softswitch based) and packet core solutions but also state of the art IMS, HLS, VLR and MGW platforms.

However, leading edge technology is not enough to deliver the overall solution and service requirements of today's dynamic market. During the course of its 75+ year history, Motorola has amassed a wealth of global knowledge, which today is applied with local insight and personnel to realize customer focused solutions -- solutions for success.

Nokia Siemens Networks started its operations on April 1, 2007, assuming a leading position in the global communications infrastructure market with nearly 600 customers in 150 countries. Nokia Siemens Networks is ready to meet the challenge of connecting the five billion or more people that will be "always on" by the year 2015. Nokia Siemens Networks is composed of five business units – Radio Access, Broadband Access, Service Core and Applications, IP/Transport, and Operations and Business Software – that provide a full range of solutions, products and applications for fixed, mobile and converged networks. Nokia Siemens Networks is in a unique position to bring operators and service providers an end-to-end capability from network infrastructure to devices to services and applications that will assist in differentiating their end-user services.

Nokia Siemens Networks is at the forefront of WCDMA/HSPA development. Since the first WCDMA Rel-99 networks, easy upgrades to current Rel-5/Rel-6 networks has been a key driver and benefit for the product and solution offering. Nokia Siemens Networks has a total of 99 WCDMA references worldwide. Nokia Siemens Networks HSPA is in full use worldwide, and is supplied to 85 of the 154 commercial HSDPA networks globally (as of November 2007).

The market leading Nokia Siemens Networks Flexi WCDMA base station is available for WCDMA and HSPA at 850 MHz, 900 MHz, 1900 MHz, 2100 MHz, 2000 MHz and 1700/2100 MHz. Other frequencies can and will be introduced rapidly based on market need, due to the flexible modular architecture of the Flexi BTS. In particular, 700 and 2600 MHz frequency variants will be available in time to support operator rollouts following spectrum auction and clearing.

Nokia Siemens Networks is leveraging the customer-focused research and innovation strengths of its parent companies Nokia and Siemens. It was the first company to introduce and demonstrate live at 3GSM Barcelona 2007 a fully flat network architecture with its Internet-High-Speed Packet Access (Internet-HSPA) supporting the Direct Tunnel approach in the user plane. Internet-HSPA introduces a scalable, flat network architecture by extending the 3GPP Rel-7 standardized Direct Tunnel of the Packet Switched network to the Radio Access network – consisting of a base station and single core network node on the user plane only. It supports legacy HSPA terminals that will support the 3GPP Rel-7 air interface in the future. In 2007, several operators successfully trialed I-HSPA and a deal for the first I-HSPA network was made with Terrestar in the U.S. which will have the first commercial deployment in 2008.

With Internet-HSPA, operators can ease the path to Long Term Evolution (LTE), since LTE uses the same flat network architecture as Internet-HSPA with optimal investment protection. In 2006, research teams built the world's first LTE demonstrator with MIMO, showing at the 3G World Congress in Hong Kong over-the-air data rates of up to 160 Mbps, and Nokia Siemens Networks was the world's first supplier demonstrating handovers between LTE and HSPA at 3GSM in Barcelona in 2007.

The LTE/SAE Trial Initiative (LSTI) which was initiated by Nokia Siemens Networks and Nokia together with other vendors and operators, confirmed by its commonly performed indoor and outdoor tests in the Proof of Concept phase in November 2007 that the LTE physical layer performance targets in terms of stationary and on-the-move peak data rates can be met.

Serving over 300 million subscribers worldwide, the Nokia Siemens Networks' Mobile Softswitch is the most mature platform available in the market today; first introduced in 2004, the Mobile Softswitch has been chosen by over 180 mobile operators to date. The Nokia Siemens Networks Mobile Softswitch supports a 3GPP Rel-4 compliant architecture 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).

Nokia Siemens Networks is also a leader in IP Multimedia Subsystem (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. IMS is a complement to Nokia Siemens Networks' innovative services such as VoIP, Presence, Messaging, Push-to-talk Over Cellular, MobileTV, IPTV, SDP, among many other blended services; together they all provide today a field-proven foundation for millions of mobile and fixed consumer and business users worldwide. Furthermore, Nokia Siemens Networks enables service providers to develop new business models and/or the expansion of existing access network boundaries with the support of an integrated Voice Call Continuity (VCC) solution for GSM-WLAN handover, which was demonstrated live at 3GSM Barcelona 2007 and CTIA Orlando 2007. All these solutions are future-proof and form an integral building block for the System Architecture Evolution (SAE).

Together, the strengths and businesses of Nokia and Nokia Siemens Networks offer the broadest portfolio for the industry. ***Nokia*** is the undisputed world leader in mobile devices and makes a wide range of products providing people with experiences in music, navigation, video, television, imaging, games and business mobility, for different markets around the world.

With the 6th most valuable brand in the world, (according to Interbrand) and an estimated 850+ million users of Nokia devices today, the company is also able to bring an unrivalled consumer insight in the development of behavior and new services among subscribers in different countries, growth areas for new technologies, and what new innovations are added to our products and devices. No other consumer durables company has such a wide customer base.

Reaching 90 million units last year, and expected to reach 250 million units in 2008, the market for converged devices is the fastest growing segment of consumer electronics. Within this, Nokia is by far leading this market. Nokia has over 50% market share worldwide. Nokia has estimated that there will be 3B mobile subscriptions in 2007, more than 1 billion wireless broadband subscribers by 2009, reaching 4 billion mobile subscriptions in 2010. Furthermore, Nokia Siemens Networks estimates 5 billion or more people will be "always on" by year 2015.

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 1st May 2007), 4 HSDPA enabled devices, for much faster connectivity speeds and improved downloading capabilities.

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.

In such a rapidly progressing converging industry, for many people, mobile phones and devices will enable the first connection to Internet. This has been underlined with demonstrations, launches and speeches from Nokia executives at 3GSM Barcelona 2007, CTIA Orlando 2007 and CES, Las Vegas 2007.

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.

In the US, Nokia has developed some strong collaborative relationships, and has initiated promising technologies. For instance, Nokia brought out UMA devices that greatly improve indoor coverage and make calls more affordable. Also, Nokia is working with Visa to develop contactless payment services, or, in other words, using phones as credit cards. Nokia is also working with MasterCard Worldwide in some of the nation's first Near Field Communication mobile payment trials - one is in Dallas; another is with Citigroup and Cingular Wireless in New York City. MasterCard calls this "Tap and Go". Nokia launched the Nokia 6131 NFC enabled mobile phone at CES 2007 and this device is being used in the New York trial.

Nortel believes that mobility technologies must continue to advance with increased network performance, capacity and a shift in the cost structure to drive significant business growth in the emerging highly personalized, pervasive and true broadband era. IMT-Advanced (so-called 4G) mobility technologies can deliver an order of magnitude advancement in those dimensions and support an operator's business opportunity that capitalizes on end-user demands for affordable ubiquitous broadband access and simplified mobile services in a Hyperconnected world – where any device that should be connected, will be.

Nortel views Orthogonal Frequency Division Multiplexing (OFDM) and Multiple Input Multiple Output (MIMO) as the fundamental building blocks for all future advanced wireless technologies. Practical Spatial Division Multiple Access (SDMA) technologies 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. Nortel continues to leverage its OFDM MIMO investment and experience across all IMT-Advanced technologies (3GPP LTE, 3GPP2 UMB and WiMAX) to achieve maximum synergies in these advanced wireless network product lines. In additional Nortel has been offering Adaptive Antenna Beam Selection (AABS) technology to CDMA operators since 2006 and will leverage its expertise in this space to bring SDMA technology early to the market with LTE.

Long Term Evolution (LTE) - Nortel has a clear strategy in place for early delivery of LTE networks that offers a significant time-to-market advantage for its customers. Nortel places an emphasis on technology leadership and simplicity in its LTE solution to achieve the lowest total cost of ownership for operators. The company's time-to-market leadership strategy includes early co-development and testing with LTE chipset vendors that will help accelerate interoperability testing timelines with device vendors and ensure the availability of a complete LTE ecosystem in alignment with its network solution timeline. Nortel is also partnering with leading application vendors to make sure the operators can fully exploit the network's potential to maximize revenues.

In 2005, Nortel publicly promoted the advantages of OFDM MIMO to 3GPP operators, which accelerated its introduction into the 3GPP LTE 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. In addition to being the first Uplink Multi-user MIMO LTE implementation in the industry, the 3GSM WC demonstration system was developed in collaboration with LG Electronics as the device partner, which highlights Nortel's commitment to ecosystem development.

Nortel is also delivering fully compliant 3GPP Rel-4 and Rel-5 solutions in the core network. In February 2006, Nortel was selected to deploy North America's largest 2G/3G 3GPP Rel-4 compliant network including MSC (Mobile Switching Center) Server and Media Gateway products. According to Nortel's estimate, the company's Rel-4 technology will help provide up to a 300 percent increase in call handling capacity.

Nortel has been the worldwide leader in Carrier VoIP for five 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 (source: Synergy Research "Q2 2006 Service Provider VoIP Market Share"). The company is building on this expertise, which includes 175 SIP patents, to bring a truly 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. With 100+ carrier customers world-wide, Nortel is the global leader in commercial IMS-ready deployments, and Nortel continues building on this early deployment leadership with real IMS trials in 10 wireless carriers, 6 wireline suppliers, and 2 of the largest cable operators where the minimum configuration includes CSCF, HSS, and Application Servers.

Operators not only acknowledge Nortel's contributions to 3GPP IMS, 3GPP2 MMD, TISPAN and PCMM standards, but they also recognize Nortel's leadership in industry forums, like GMI2006 Test Fest (October 2006), where Nortel was the exclusive sponsor of the event that was organized by the Multi-Service Forum. (Please visit *http://www.msforum.org/pressroom/pr/pr102406.pdf for more details on the event.)* Nortel continues focusing on delivering an open, future-proof standards-compliant IMS solution that best fits operators' profiles, increases operators' revenues, and simplifies users' lives.