UMTS EVOLUTION

FROM 3GPP RELEASE 7 TO RELEASE 8

HSPA AND SAE/LTE

JUNE 2008
UPDATE

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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 with considerable information to update on Rel-7 and a new focus on Rel-8, in July 2007, *UMTS Evolution from Release 7 to Release 8 – HSPA and SAE/LTE* was published by 3G Americas. This paper provided detailed discussion of the new Evolved EUTRA (E_UTRA) or LTE air-interface and Evolved Packet Core (EPC, formerly termed the SAE) as well as progress on HSPA+. Since the publishing of this paper and a moderate update in December 2007, 3GPP has been focused on completion of the EPC and LTE or E-UTRAN (E-UTRA refers to the air interface and E-EUTRAN refers to the radio access network or enodeB to be precise) specifications in Rel-8 which is targeted by the end of 2008. While there is a new study item in 3GPP to define evolution of the LTE technology to meet IMT-Advanced requirements (called LTE-Advanced), this work is in the early stages at this point in time. Therefore, 3G Americas plans to release a fully rewritten white paper toward the end of this year that focuses on the evolution of LTE to LTE-Advanced once this study item is more mature. The paper to be published later this year will also update the HSPA/EPC/LTE sections in the July 2007 release of the paper based on work that has occurred since its publishing.

Updates have been made to parts of this white paper. Sections fully rewritten are: The Growing Demands for Wireless Data Applications and the Appendix including Vendor Progress; major changes were made to the Preface, Introduction, and the SAE/EPC section where interface names and diagrams were updated to be accurate.

Information that will be included in the new white paper to be published in late 2008 will cover the following areas of current development at 3GPP that have occurred since June 2007:

Completion of Rel-7 HSPA+ features – Completes work on improved layer 2 support for higher data rates, enhanced Cell_FACH state and Single Frequency Network (SFN) support for MBMS.

Combination of Higher Order Modulation and MIMO in HSDPA (FDD) – Allows an increase of the downlink peak rate by combining both 64QAM and MIMO.

Enhanced Uplink for CELL_FACH State in FDD – Reduces latency, increases available peak rate and reduces state transition delays.

Improved L2 for uplink – Introduces support for flexible RLC PDU sizes, MAC segmentation and allows for smooth transitions between old and new protocol formats.

Performance requirements for 15 code reception with 16QAM/QPSK – Defines minimum performance specifications for 15 code reception for 16QAM/QPSK.

Voice over HSPA – Provides a mechanism to map CS services over HSPA channels instead of traditional DCH.

3G Home NodeB – Defines Architecture and requirements for femto-cell type applications for UMTS/HSPA/UMA.

EPC specification – Continues to evolve EPC/SAE and focus on functions and procedures to support LTE access with GTP & PMIP Functions, interoperation between LTE and legacy cellular PS accesses (LTE <-> 3GPP & 3GPP2 Radio Accesses), Single Radio Voice Call Continuity for 3GPP (for both 3GPP and 3GPP2 systems), generic support for non-3GPP accesses (including Dual radio aspects of optimized handover with WiMAX), impacts on IMS (e.g. Local Break Out aspects) and CS fallback (for Voice and SMS, for both 3GPP and 3GPP2 systems).

Common IMS – Focuses in 3GPP to prevent IMS fragmentation by pooling resources within 3GPP, TISPAN, CableLabs, etc. to maintain a single "Common IMS" architecture.

LTE-Advanced – Begins to define and analyze the performance of proposed feature content for LTE beyond Rel-8 for meeting IMT-Advanced requirements.

As the list above demonstrates, there has been significant work in 3GPP since the original publishing of this paper in July 2007. However, due to the early stage of the LTE-Advanced work, 3G Americas will release a paper later this year that includes discussions on all of the areas of work outlined above with focus on the main features being considered for IMT-Advanced.

The growing commercialization of UMTS is exemplified by 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 HSDPA on a wide-scale basis. At the writing of this paper, AT&T has deployed HSPA across the company's 3G footprint, available in more than 275 U.S. cities (with populations greater than 100,000) and by the end of 2008 will be available in nearly 350 markets, including the top 100 major markets (MSAs). Additionally, T-Mobile USA launched UMTS/HSDPA in New York City in the 1700/2100 MHz bands in May 2008 beginning their nationwide rollout.

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

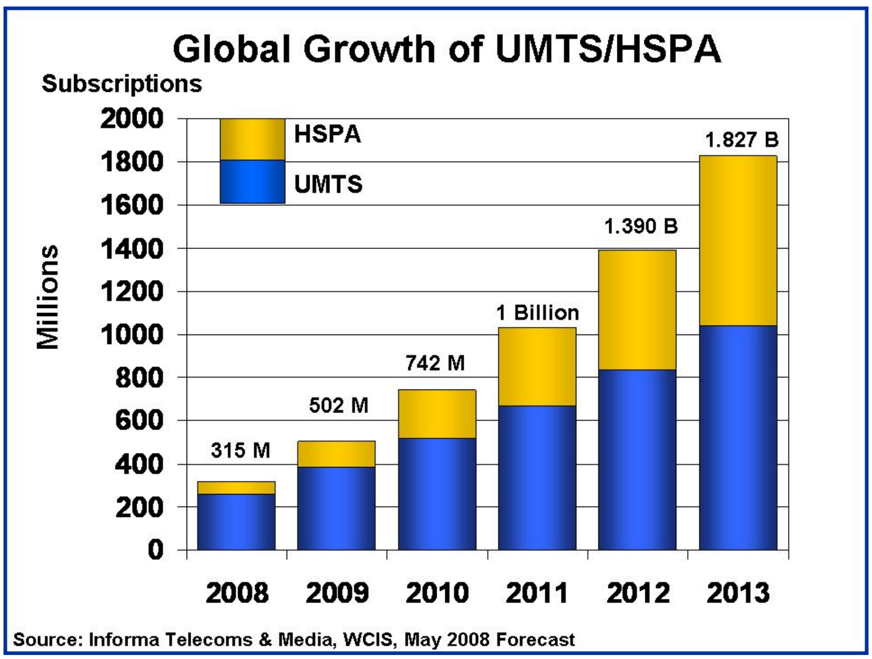

Figure 1. Global UMTS Subscriber Growth Forecast[1]

The rapid growth of UMTS led to a focus on its next significant evolutionary phase, namely Release 5 (Rel-5). 3GPP Rel-5, 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 with the improvements they need to offer customers higher-speed wireless data services with vastly improved spectral efficiencies through the HSDPA feature. In addition to HSDPA, Rel-5 introduces the IP Multimedia Subsystem (IMS) architecture that promises to greatly enhance the end-user experience for integrated multimedia applications and offer mobile operators a more efficient means for offering such services. There are many operators who have already deployed IMS architecture. UMTS Rel-5 also introduced the IP UTRAN concept to recognize transport network efficiencies and reduce transport network costs.

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

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

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

Now we offer a further review of Rel-7 upon its 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, first updated in December 2007, and now further updated in June 2008, 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 and the material represents the combined efforts of many experts from 3G Americas' membership.

1 Introduction

According to the International Data Base, the arm of the U.S. Census, the global population expands by three people a second. In the same second, 38 wireless devices will be sold. At that rate, within 24 months another billion devices will be added to the 2.5 billion currently in circulation.[2] [Note: there are 3.5 billion wireless subscriptions worldwide as of May 2008, which would indicate about that number of devices.]

Industry research forecasts have predicted that 2008 will be the year that the worldwide mobile industry becomes a one trillion US dollar industry. For an industry to go from zero to USD 1 trillion in just twenty years is a staggering achievement, equal to a CAGR of almost 30 percent sustained for twenty years, an achievement previously unequalled by any other industry at any time in human history.[3]

2007 was the year worldwide mobile handset shipments exceeded one billion for the first time, and in 2008 the world will cross the threshold of the highly significant fifty percent mobile penetration point with gross industry revenues set to reach one trillion dollars. This is truly an exciting time for the mobile wireless industry.[4]

Thus, seven years after the launch of the first 3G network (in Japan), the global number of subscribers using 3G devices has increased to more than 306 million, with most of the growth in the past two years. The key factors to ignite faster 3G adoption are finally coming together, including better network coverage, more compelling data applications, improved wireless data speeds and a wider selection of user-friendly handsets at more affordable levels, according to Paul Wuh, Lehman Global Equity Research.[5]

> Improved network coverage. After more than six years of 3G network build-outs, upwards of 293 3G networks operate through the world, with coverage approaching that of 2G networks. 3G coverage will continue to improve, in our opinion [Lehman].
> More compelling data applications. 3G carriers have developed a widening array of interesting content for subscribers, such as music downloads, mobile TV,
> gaming, location-based searches, news, etc. We believe that Apple's iPhone (and other similar terminals) will drive data usage, given their attractive user interface.
> Improved data speeds. We [Lehman] estimate that 88% of WCDMA networks have upgraded to

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[2] Cauley, Leslie. "Race is on for the Mobile Web's pot of gold." *USA Today.* 9 January 2008.
[3] *Slicing Up the Mobile Services Revenue Pie.* Portio Research. 18 April 2008.
[4] *Ibid.*
[5] Wuh, Paul. "Global 3G Developments: 3G subs accelerate; more data revenue in 2009." Lehman Global Equity Research. 23 May 2008.

HSPA 3.5G technology which provides theoretical download speeds of up to 7.2Mbps with an upgrade path to 80 Mbps. As networks continue to improve data speeds, we believe that the user experience will improve and wireless broadband usage (especially in developing markets) could become another key revenue driver.

Wider selection of terminals and lower price points. We [Lehman] estimate the ASP of WCDMA handsets at around $161 in 4Q07 (down from $400 in 2004) — which is a level more likely to be subsidized by operators. Moreover, the selection of smaller and sleeker 3G handsets is expanding — which will likely encourage upgrades. Operators are more willing to subsidize the migration to 3G, as it stands to lower network capex, given that 3G networks can handle much more voice and data traffic — necessitating less network capacity capex.[6]

Much of the incremental 3G growth is being driven by UMTS/WCDMA which accounts for about 68% of the total 3G device base at the end of 1Q 2008. Lehman Global Equity Research estimates that mobile operators are adding around 22 million new UMTS device users, per quarter, globally versus and average of 8 million per quarter for EV-DO. Going forward Lehman expects this to widen as UMTS/HSPA growth accelerates.[7]

As mobile voice prices have continued to decline and margins have come under intense pressure, network operators are increasing their revenues through the delivery of wireless data services. A wide variety of non-voice services have emerged, from messaging and mobile music, to email, mobile TV and video downloads, location based services, games, gambling and mobile payment services. In 2007, worldwide, non-voice services accounted for 18.9 percent of total mobile services revenues according to Portio Research, and this figure will keep growing, reaching more than 25.5 percent by the end of 2012. To put that in context, worldwide consumer spending on non-voice mobile services in 2012 will exceed 251 billion USD, more than a quarter of a trillion USD per annum.[8]

Demand for wireless data services is growing faster than ever before, evident in the fact that average data ARPU in the U.S. jumped 55% from YE 2006 to YE 2007 while average data ARPU grew 34% during the same time period.[9] 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/HSPA operators today are offering some type of mobile broadband service and many PC vendors offer notebooks with built-in HSDPA capabilities that will boost data usage even further. Clearly, data revenues are playing an increasingly important role for operators, which 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 roll 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 (EUTRA). 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 Core (EPC) Architecture. Note that the complete packet system consisting of the EUTRAN and the EPC is called the Evolved Packet System (EPS). In this paper, the terms LTE and EUTRAN will both be used to refer to the evolved air-interface and radio access network based on OFDMA, while the terms SAE and EPC will both be used to refer to the evolved flatter-IP core network. Additionally, at times EPS will be used when referring to the overall system architecture. The combination of LTE and SAE provides the long-term vision for 3GPP to an all-IP, packet only wideband OFDMA system expected to further improve performance by providing higher data rates, improved spectral efficiency and reduced latency. The

[6] *Ibid.*
[7] *Ibid.*
[8] *Ibid.*
[9] Sharma, Chetan. "US Wireless Market – Q4 and 2007 Update." March 2008.

ability of LTE to support bandwidths wider than 5 MHz is of particular importance as the demand for higher wireless data speeds and spectral efficiencies continues to grow.

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 200 commercial UMTS networks listed on the global deployment status list in *Appendix B* of this paper. Rel-4 introduced call and bearer separation in the Core Network, and Rel-5 introduced some significant enhancements to UMTS including HSDPA, IMS and IP UTRAN.[10] Rel-6 introduced further enhancements to UMTS including HSUPA (or E-DCH), MBMS and Advanced Receivers.[11]

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

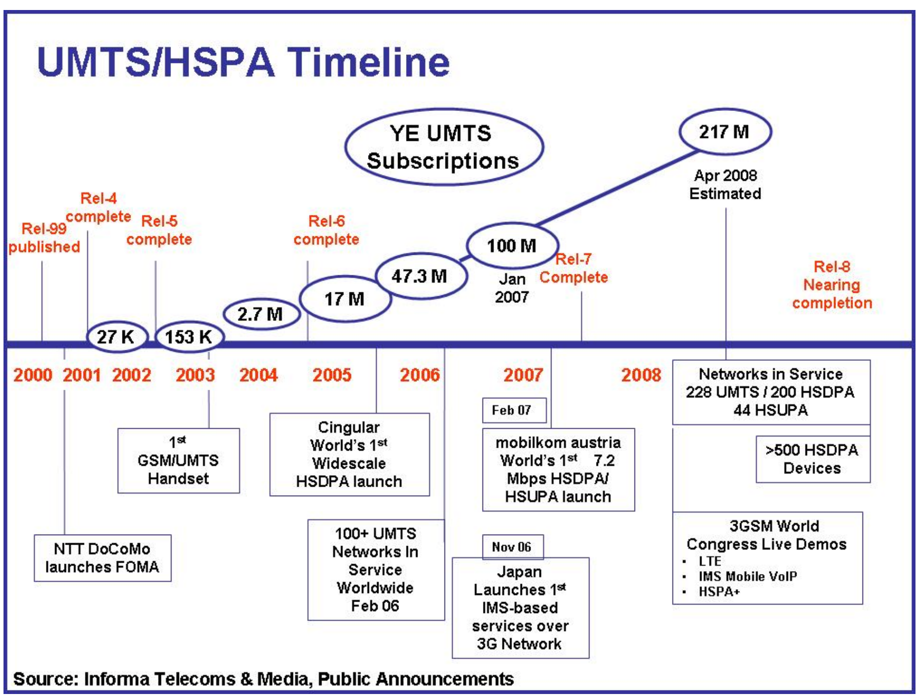

Figure 2. 3GPP UMTS/HSPA Timeline[12]

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[10] *3GPP Rel-5 and Beyond - The Evolution of UMTS*. 3G Americas. November 2004.
[11] *The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond*. 3G Americas. December 2005.
[12] 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. As of May 2008, there were more than 200 commercial HSDPA networks in 88 countries with 62 additional operators with networks planned, in deployment or in trial with HSDPA (see *Appendix B*). It is expected that almost all UMTS operators will deploy HSDPA and likewise all HSDPA operators will upgrade to HSUPA. There were 44 HSUPA commercial launches worldwide as of May 2008. AT&T is the first U.S. carrier to deploy enhanced upload speeds through HSUPA in its HSPA networks with upload speeds between 500 Kbps and 1.2 Mbps and download speeds ranging up to 1.7 Mbps.

Currently, the UMTS standard is available worldwide for use in the 850, 900, 1700, 1800, 1900, 2100, 1700/2100 and 2600 MHz bands. Additionally, the standard will be expanded for use in the 700 MHz bands which were auctioned in the U.S. in April 2008 with AT&T as one of the primary auction winners already announcing their future deployment of LTE in this band. With the commercial introduction of LTE expected in 2010, 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 U.S. One vendor cites the mobile-data throughput capability of the most cost-effective base station as more than 400 GB per day, resulting in a broadband radio network at a cost close to $1 per GB. With reportedly up to 70% lower base station site expenditure, the GSM/UMTS infrastructure costs encouraged operators to deploy 3G UMTS technology.

Already a reality in the market, HSPA 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.[13] HSPA embedded modules in notebooks, as well as other devices needing broadband connectivity, are being provided by numerous vendors to accelerate the growth of the mobile broadband. As of the writing of this paper, 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 500 devices as of May 2008[14].

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 launched UMA devices for customers on their T-Mobile @home offering. 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 began in mid 2007 following the introduction of NFC-enabled mobile phones at CES in January 2007.

Mobilkom Austria completed the first live HSUPA demonstration in Europe in November 2006. One month later, the first HSUPA mobile data connection on a commercial network (of 3 Italia) was established. In February 2007, Mobilkom Austria launched the world's first commercial HSUPA and 7.2

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[13] http://hspa.gsmworld.com/devices/default.asp
[14] *Ibid.*

Mbps HSDPA network, followed by commercial 7.2 USB modems in April and 7.2 data cards in May. There were numerous announcements of commercial network upgrades to Rel-6 HSUPA throughout 2H 2007 and in fact, there are 44 commercial networks today and 130 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 was significant progress on Rel-7 standards over the course of 2006-2007 and the standards are now finalized. The introduction of type 2i and 3i receivers, Higher Order Modulations (HOMs) and investigations on architecture evolutions for HSPA all are areas that saw significant work and thus will be discussed in this section.

Vendors are proceeding well in developing the commercial introduction of Rel-7/HSPA+. As an example, MIMO techniques were developed by vendors as well as flat-IP base stations, an innovation that integrates key components of 3G mobile networks into a single network element optimized to support UMTS/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 as well as key components of 3G mobile networks to 'flatten' what is typically a more complex architecture. Trials began as early as 3Q 2007, several announcements were made in 2007 and 2008 including AT&T, TerreStar Networks and Stelera Wireless in the U.S. and T2 Slovenia in Europe. HSPA Evolution eases the path to LTE as the two technologies use the same flat network architecture.

Speeds of up to 42 Mbps are supported by HSPA+ or HSPA Evolution. These speeds are achieved by combining new higher order modulation technology (64QAM), together with 2x2 Multiple Input Multiple Output (MIMO) antenna technology. HSPA evolution at 42 Mbps was demonstrated at CTIA 2008 using a form-factor handheld device. The improved speed will assist operators in leveraging existing network infrastructure to meet growing consumer appetite for advanced multimedia services.

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

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

Demonstrated live at the 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.

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

Some vendors offer gear that is 'software definable' for the ideal upgrade path to LTE. Beginning in the 3Q 2008, UMTS/HSPA base stations can be upgraded to LTE in the second half of 2009 via software in the same frequency band. Many bands are supported by these base stations including the 1.7/2.1 GHz AWS band and the recently auctioned 700 MHz bands in the U.S. Field trials for LTE are planned for 2008 with commercial availability by the end of 2009.

Field trials in realistic urban deployment scenarios have been made for LTE as early as December 2007, reaching with a 2X2 MIMO antenna system peak data rates of up to 173 Mbps and still more than 100 Mbps over distances of several hundred meters. The trial demonstrated that future LTE networks can run on exiting base station sites.

In April 2008, the first public announcements of LTE being demonstrated at high vehicular speeds was announced with download speeds of 50 Mbps in a moving vehicle at 110 Kmph.

For more information on vendor progress on Rel-7 features, see the *Appendix A* in this white paper.

3.1 Background and Standards Status

From July 2006 to July 2007, considerable progress was 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, or 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.[15]

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

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

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[16]. 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, and a work item has been created to standardize the performance requirements with type 3i receiver.

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.

[16] Kobylinski, Majmundar, Ghosh. "Other-Cell' Interference Cancellation for HSDPA Terminals with Diversity." Globcomm. 2007.

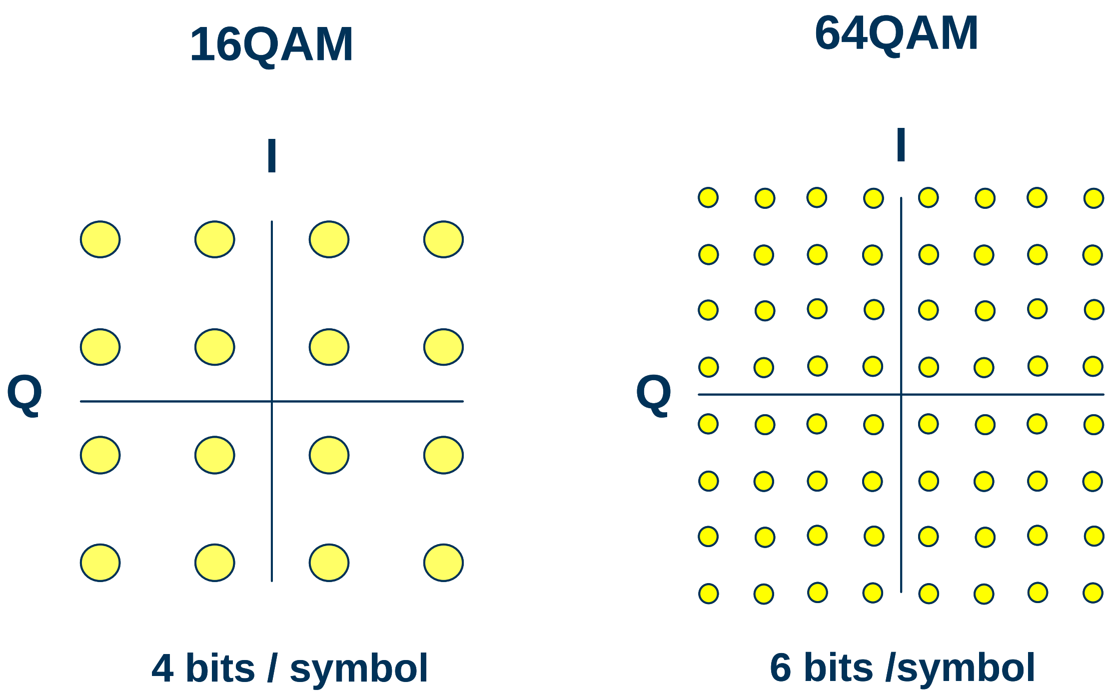

Figure 3. Typical 16QAM and 64QAM Constellations[17]

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.[18]

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 temporary inactivity. CPC was discussed in the 3G Americas' paper published in July 2006[19]. 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

[17] *HSPA Evolved*. Ericsson. CTIA 2007. 27 March 2007.
[18] *High Speed Packet Access Evolution – Concept and Technologies*. Ericsson. Q2 2007.
[19] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.

- 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 introduce 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.

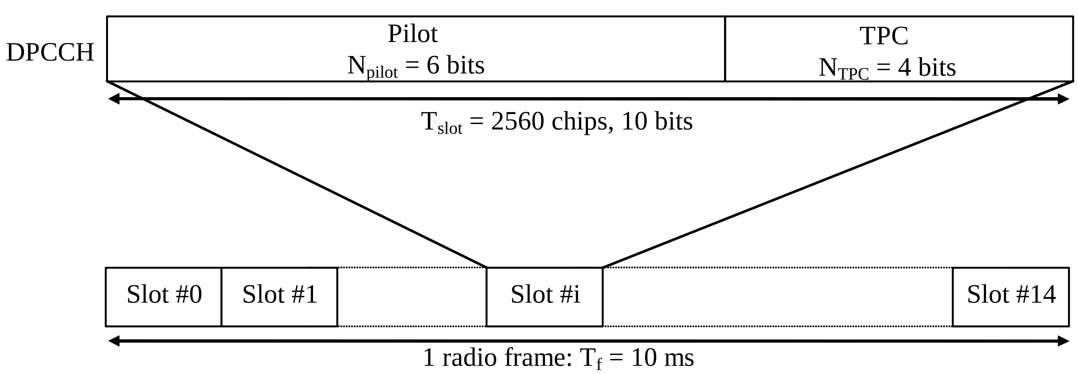

Figure 4. New DPCCH slot format[20]

[20] Ericsson. Q2 2007.

3.1.1.4 MIMO (Multiple Input Multiple Output) Antennas

MIMO Antennas were discussed in the July 2006 white paper,[21] 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.*[22] 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/EPC 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.

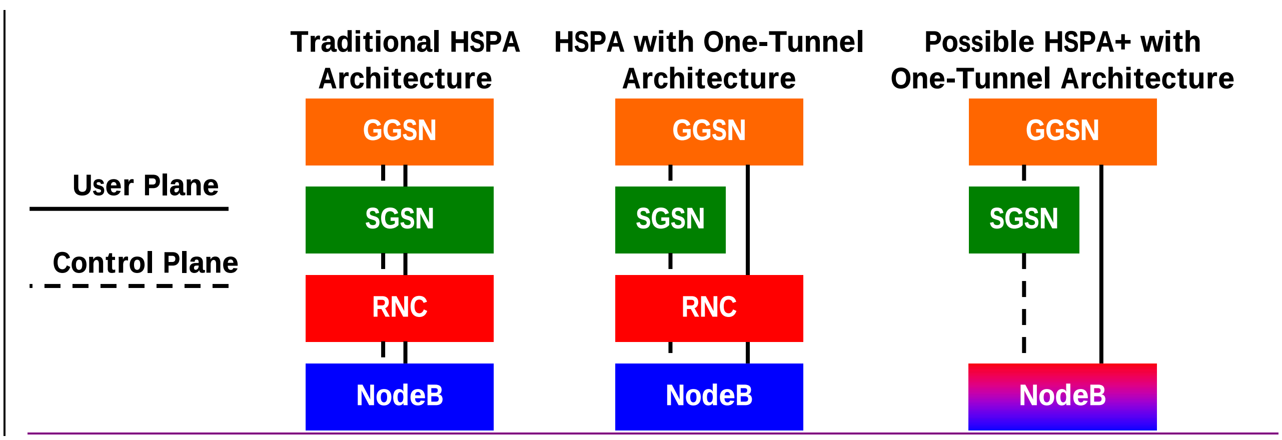

Figure 5. HSPA Architecture Options for the PS domain[23]

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.

[21] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.
[22] *Ibid.*
[23] Seymour, J.P. "HSPA+ Performance Benefits." HSPA+ Seminar. CTIA. 2007.

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. 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.*[24]

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.

3.2.1 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.

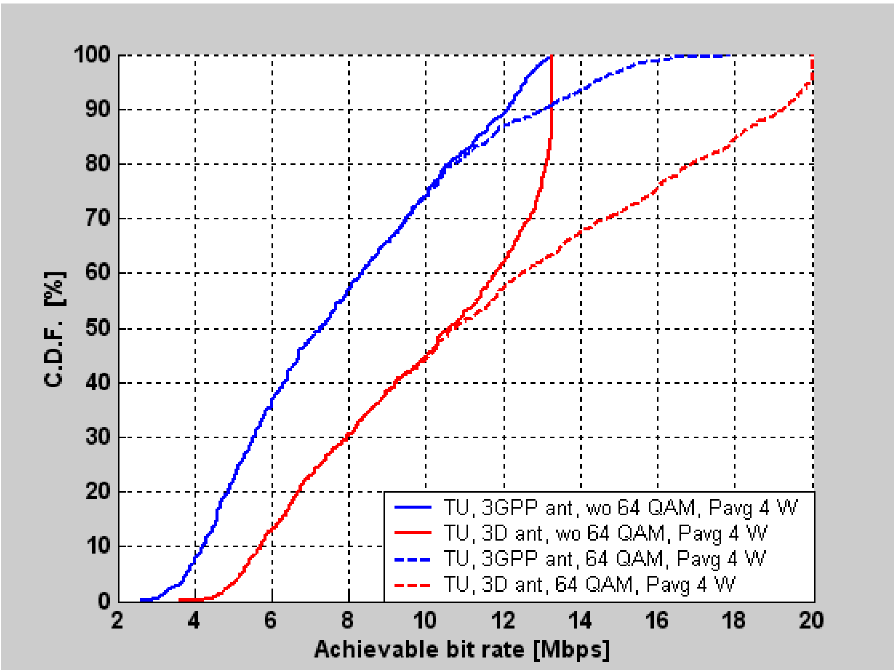

Figure 6. DL bit rate improvement with 64 QAM[25]

3.2.2 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

[24] *Mobile Broadband: The Global Evolution of UMTS/HSPA Release 7 and Beyond*. 3G Americas. July 2006.
[25] *64QAM for HSDPA System-Level Simulation Results*. 3GPP. Tdoc R1-062265.

load, where the gain decreases with the load and becomes negligible with 10 or more simultaneous users in the cell.

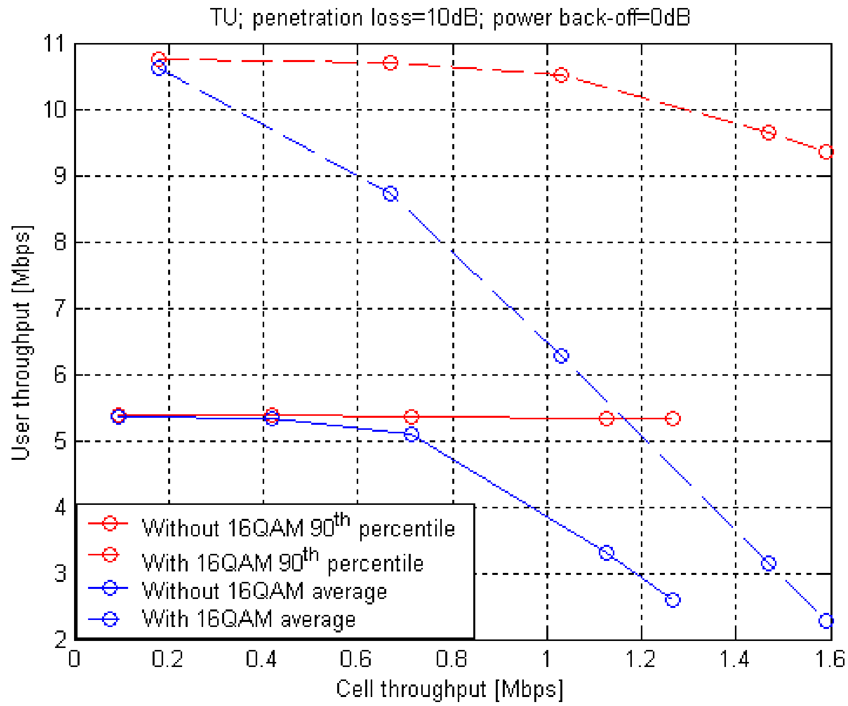

Figure 7. UL bit rate improvements with 16 QAM [26]

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. As UMTS/HSPA 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 3.1 billion GSM/HSPA mobile subscriptions worldwide by May 2008, a number that will rise to more than four billion in 2011, the tremendous opportunity for the uptake of wireless data services and applications is clear.[27]

The market indicators and predictions by many industry analysts showed 2007 as a "year of inflection" when the foundation was laid for customer uptake of wireless data applications. The devices and networks were in place and the applications plentiful. Moving forward in 2008, mobile broadband is providing the Internet experience anywhere, anytime. Ericsson CEO Carl-Henric Svanberg predicted that total broadband connections will hit 2.5 billion in five years and that mobile broadband will account for two-thirds of broadband subs by 2013.[28]

In this section, the growing demands for wireless data are demonstrated by examples of increased operator ARPU from data services, a variety of 3G applications for consumers and the enterprise and analysts predictions for their growth, and devices such as smartphones and embedded modules for PC notebooks.

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[26] *UL bit rate improvements with 16 QAM*. 3GPP. Tdoc R1-062267
[27] *Subscriber Forecast*. World Cellular Information Service. Informa Telecoms & Media. May 2008.
[28] *Ericsson CEO: Mobile to Account for Two-thirds of Broadband Subs by 2013*. GSMA Mobile Business Briefing. 14 May 2008.

4.1 Wireless Data Trends and Forecasts

"Wireless technology has deeply embedded itself into the fabric of our lives; changing the way we interact with the world around us," said Steve Largent, President and CEO of CTIA, in April 2008.

"Today more than 84% of America has embraced the wireless revolution… Year after year, the wireless industry continues to evolve, innovate, compete and grow at a rapid pace, and it looks like 2008 is right on track with this impressive trend."

In April 2008, US Wireless Association CTIA reported record-breaking six-month wireless service revenues of $71 billion. Wireless data service revenues for the entirety of 2007 rose to more than $23 billion. This represented a 53% increase over 2006, when data revenue was $15.2 billion. Wireless data revenues for the year 2007 amounted to about 17% of all wireless service revenues, representing money that consumers spent on non-voice services.

According to the CTIA survey, text messaging in the US continues to be enormously popular, with more than 48 billion messages reported for the month of December 2007 alone — 1.6 billion messages per day. This represents an increase of 157% over December 2006. Wireless subscribers are also sending more and more pictures and other multi-media messages, with nearly 4 billion MMS messages sent during the second half of 2007 alone, compared with 2.7 billion sent over the course of the entire year in 2006.

Mobile data traffic ramped up between four- and eightfold in 2007, thanks to the knockout combination of dramatically decreasing prices and faster network downlink speeds, according to a report from Heavy Reading.[29] Those operators who achieved eightfold increases typically introduced competitive flat-rate data plans and were previously not carrying much data traffic prior to their deployment of HSPA technology; for operators with a lot of pre-HSPA 3G data traffic and without competitive flat-rate data plans, three – and fourfold increases in data traffic in 2007 were common, according to the Heavy Reading report.[30] Gabriel Brown, senior analyst and the report's author, stated it's "no wonder that data usage is growing because performance is getting better and prices are coming down. 2007 was the breakthrough year. You're getting 1 Mbps to 2Mbps downlink routinely, and prices have come down tremendously."[31]

2007 became the year that worldwide mobile handset shipments exceeded one billion for the first time, and in 2008, the world also crosses the highly significant 50 percent mobile penetration point and the industry enters a year where gross industry revenues are set to reach one trillion dollars. This is an exciting time for the wireless cellular industry.

4.2 Wireless Data Revenue

Although 3G capabilities have been available to a critical mass for only a few years, the percentage of total revenue from data services had increased on average worldwide to 17% by the end of 2007 according to Chetan Sharma.[32] Most of the major carriers around the world have double digit percentage contribution to their overall ARPU from data services. Operators such as KDDI, DoCoMo, and 02 UK are topping 30%.[33]

Pyramid Research cites similar numbers in its report, *Mobile Data Best Practices.* According to Pyramid, mobile data will account for 29% of the global mobile services revenue in 2012, up from 19% in 2007. Pyramid says clearly the mobile data opportunity is soaring: 2007 mobile data revenue was more than double what it was in 2004 and is expected to double again to $300 billion by 2012.[34]

The U.S. remains a very strong market for operator revenues, and it continued its rapid growth in 2007 to $24.5 billion, up 55% from end of year 2006 according to analyst Chetan Sharma. Although SMS accounts for the greater portion of most operators' current data revenues, non-messaging data revenues

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[29] Donegan, Michelle. "Wireless Data Prices Fall, Usage Booms." Unstrung. 22 April 22.
[30] *Ibid.*
[31] *Ibid.*
[32] Sharma, Chetan. "Global Wireless Data Market Update 2007." April 2008.
[33] Sharma, Chetan. "US Wireless Data Market Update – Q1 2008." 19 May 2008.
[34] *Mobile Data Best Practices: Positioning and Revenue Opportunities in Emerging and Developed Markets*. Pyramid Research, report referenced in *Mobile Data Revenue to Double by 2012.* Cellular-News. 15 April 2008.

comprised about 50-60% of the data revenues for U.S. operators.[35] As of 1Q 2008, Sharma reports average industry percentage contribution of data to service revenues reached 20.62% in the U.S.[36]

Pyramid Research similarly reported that in 2007, U.S. mobile data revenue increased by 54%, reaching $26 billion. Pyramid expects mobile data revenue to reach nearly $70 billion in 2012 and account for more than one third of total mobile wireless revenue.[37]

AT&T, the largest carrier in the U.S., added 1.3 million net subscribers in 1Q 2008, reaching a total of 71.4 million. Wireless data revenues increased 57.3% to $2.3 billion, 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. During the first quarter, AT&T's wireless customers sent more than 620 million multimedia messages and 44 billion text messages, more than double totals in the year-earlier first quarter. Data now represents 21.5% of AT&T's total wireless service revenues, up from 16% a year prior and 10.9% two years prior. Wireless data growth has also begun to reflect wider usage of the advanced capabilities and high speeds available with AT&T's 3G UMTS/HSDPA network.[38] AT&T represented the strongest growth of all US wireless carriers in 1Q 2008, with 15% and 53% increase in data revenues from 4Q 2007 and 1Q 2007 respectively.[39] According to Chetan Sharma, AT&T is on target to exceed $10 billion in data revenues for the year 2008, a record only achieved worldwide to date by operator NTT DoCoMo.[40]

T-Mobile USA added 981,000 subscriptions in 1Q 2008. This is a huge number of additions for the fourth largest carrier in the U.S. Data service revenues continued to rise to $760 million in the first quarter of 2008, representing 16.6% of blended ARPU, or $8.50 per customer, compared to 14.3% of blended ARPU, or $7.50 per customer in the first quarter of 2007. Robust growth in messaging continued to contribute to the increase in data ARPU. The total number of SMS and MMS messages increased to 33 billion in the 1Q 2008, compared to 16 billion in the first quarter of 2007. Strong GPRS / EDGE access and usage revenues were another significant driver of the increase in data services revenues. The rapid uptake of consumer converged devices continued as well, 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.[41] With the launch of UMTS/HSPA service in the 1700/2100 AWS bands throughout 2008, and the introduction of sophisticated 3G devices, T-Mobile is poised to continue growth of data services.

Rogers Wireless in Canada added nearly 100,000 subscriptions for the three months ending March 31, 2008. Year over year, for the first quarter, they experienced 47% growth in data revenue, reaching $206 million, or 15.1% of network revenue compared to 12.3% in the corresponding period of 2007. This increase in data revenue reflects the continued growth of text and multimedia messaging services, wireless Internet access, BlackBerry and other PDA devices, downloadable ring tones, music and games, and other wireless data services. [42]

Telcel, the América Móvil operation that is market leader in Mexico, closed 2007 with data revenues reaching approximately 15% of total company revenues; up from 13% at the end of 2006 (América Móvil does not report data ARPU on quarterly reports). Telcel launched UMTS/HSDPA in February 2008, starting with four major cities in a first phase of 13 markets. In addition to the launch by Telcel, its parent company, América Móvil, completed twelve commercial UMTS/HSDPA 3G networks during 2007 and 1Q 2008 in Latin America, operated as Claro in Argentina, Brazil, Chile, El Salvador, Guatemala, Honduras, Nicaragua, Paraguay, Peru and Uruguay and operated as Comcel in Colombia. Their enhanced UMTS/HSDPA wireless networks enable clients to have access to value added services at high-speed data transmission rates, including wireless broadband accesses. As of the end of 2007, America Movil reported that in Argentina, Paraguay and Uruguay (Mercosur region) the data revenues rose by 56% annually, representing 29% of the service revenues in the region. By YE 2008, America Movil will cover the main cities of Latin America with 3G UMTS/HSDPA mobile broadband.

[35] Sharma, Chetan. "Global Wireless Data Market Update 2007." April 2008.
[36] Sharma, Chetan. "US Wireless Data Market Update – Q1 2008." 19 May 2008.
[37] *Mobile Data Best Practices: Positioning and Revenue Analysis in Emerging and Developed Markets.* Pyramid Research. 26 March 2008.
[38] *AT&T Ramps Revenue Growth, Delivers Strong First-Quarter Results*. AT&T. 22 April 2008.
[39] Sharma, Chetan. "US Wireless Data Market Update – Q1 2008." 19 May 2008.
[40] *Ibid.*
[41] *T-Mobile USA Breaks 30 Million Customer Milestone And Reports First Quarter 2008 Results*. T-Mobile. 8 May 2008.
[42] *Rogers Reports Strong First Quarter 2008 Financial and Operating Results.* Rogers Wireless. 29 April 2008.

Informa Telecoms & Media reports that the average data contribution to ARPU in Latin America is 13%. Countries with the highest data contribution to ARPU are: Argentina (30%), Venezuela (24%), Ecuador (16%), and Mexico (15%).

Although 3G (UMTS/HSPA and EV-DO) accounts for only around 9% of all mobile devices, non-voice applications have continued to become an important source of revenue for wireless carriers (mainly in the form of SMS and ring tone and other downloads) according to Paul Wuh in the Lehman Global Equity Research Report[43]. In the developed markets in Asia, Europe and North America, non-voice revenue accounts for 20-35% of the total ARPU. In Japan, the most developed 3G market in the world according to Wuh, 76% of all mobile subscribers use 3G devices, and non-voice revenue represents more than 30% of total ARPU. In order to encourage greater data usage, NTT DoCoMo first introduced unlimited data packages for its UMTS subscribers in June 2004. With more than 45% of Japans' 3G subscribers on unlimited data packages, average data usage has increased to 19 MB/month in 2007 from 0.96 MB/month in 2003. DoCoMo reported that 75% of its subscribers had data ARPU of about US $38/month and the remaining 25% had data ARPU around US $12/month in 4Q 2007. Wuh believes that many of the factors that contributed to the data growth in Japan will also help accelerate 3G adoption in other developed markets throughout the world.[44]

According to Lehman Global Equity Research, among 3G subscribers that use mobile data applications, it is estimated that monthly data ARPU is nearly twice the average data ARPU for 2G subscribers.[45]

4.3 3G Devices

UMTS/WCDMA devices continue to build momentum with shipment volumes that are up 44% year-over-year for first quarter of 2008 according to a report by ABI Research.[46] As of May 2007, there are 500 different HSPA devices from 108 suppliers including 224 phones, 42 data cards, 30 embedded modules, about 84 notebooks, 34 routers and 44 USB modems, plus other devices such as surveillance cameras.[47]

Kevin Fitchard, editor for Telephony Wireless Review, interprets carrier data revenues to be just as dependent – if not more dependent – on the devices they offer than the availability or even the speeds of the data services themselves. As an example, the iPhone helped drive AT&T data revenues even on the EDGE network. AT&T's data revenues are driving through the roof, up 57.3% year-over-year at the first quarter of 2008 with more than 2 million iPhones sold. If there is a moral to the Telephony story, it's that offering data services in and of themselves may not draw customers as strongly as offering highly appealing devices that are based around those services. It is the same story as in the wireless voice market: consumers like — and buy — cool devices. With that theory, it will not take long for the ultimate test as the iPhone with a 3G chip has now arrived to take advantage of AT&T's 3G (HSPA) service. The combination of the next-gen iPhone and 3G services represent the perfect alchemy, potentially driving iPhone sales and AT&T data revenues to altogether new heights.[48]

iPhone users have turned out to be prodigious consumers of wireless data. For example, the iPhone customers of T-Mobile in Germany consume 30 times more data than its other wireless customers, according to analyst Chetan Sharma. Sharma estimates that iPhone users in the U.S. consume two-and-a-half to three times more data than users of other cell phones. Faster [3G] networks could widen that gap and further extend the iPhone's influence in the telecommunications world. "iPhone is not only having an impact on data revenues, but also on device design, mobile advertising road maps and applications and services that are being contemplated for the future," Chetan Sharma stated.[49]

Shortly before writing this paper, Apple announced features of the 3G iPhone and an even lower price point than for the first generation of the iPhone. Priced at US$199, the 3G iPhone, which is expected to be available July 11, 2008, will surely spark further uptake in wireless data services.

Spurred by the popularity of Apple's iPhone and its elegant user interface, global shipment of touch-screen display modules are expected to more than double from 2008 to 2012 according to iSuppli.[50] iSuppli expects the market to grow from 341 million units in 2008 to 833 million units by 2013 with a

[43] Wuh, Paul. "Global 3G Developments: 3G subs accelerate; more data revenue in '09." Lehman Global Equity Research. 23 May 2008.
[44] *Ibid.*
[45] *Ibid.*
[46] *Mobile Device Market Exceeds Expectations to Deliver 289 Million in 1Q 2008*. ABI Research. 25 April 2008.
[47] http://hspa.gsmworld.com/devices/default.asp.
[48] Karpinski, Rich. "Devices drive data usage, operators find." Telephony Wireless Review. 29 April 2008.
[49] Markoff, John. "The Guessing Game Has Begun on the Next iPhone." The New York Times. 28 May 28 2008.
[50] *Touch-Screen Shipments Expected to Reach 833 Million by 2013*. iSuppli. 20 May 2008.

CAGR of 19.5% from 2008. The touch-screen market is characterized by more than 100 suppliers, in excess of 300 OEM/integrators and a wealth of technological alternatives.[51]

Many smartphones today are incorporating browsers that support the latest capabilities such as AJAX and RSS, as well as websites optimized for viewing on a mobile device. ABI Research sees this segment of the mobile browser market accounting for the vast majority of growth over the next five years, as the open-Internet browser (OIB) segment for mobile grows from 76 million in 2007 to nearly 700 million browsers delivered in 2013.[52] Michael Wolf, research director at ABI Research stated, "The focus today for mobile browser developers is to take advantage of the latest web standards while developing solutions tailored towards the unique experience of using a browser on a mobile phone." Recent commercial solutions from companies such as Openwave as well as those using open-source solutions target towards allowing customers to access content on the web without limitations due to browser constraints.[53]

According to the ABI Research titled, "Smartphone and OS Markets,"[54] the market for smartphones will grow from around 10% of the total handset market in 2007 to 31% of the market in 2013. This meteoric growth will be the product of number of complex factors including carriers' drives to grow data revenues from advanced services and the general trend to pushing "smart" operating systems down into middle tier devices.[55]

Handset transition will drive the emergence of mobile TV services, according to a market study by ARC Chart. The report forecasts that 295 million specialist handset devices – that can receive one or another format of mobile TV – will be sold by 2012. Furthermore, 61 million non-handset devices will be added, making total shipments of 356 million devices which can view mobile TV.[56]

GPS is one of the features that will become more prevalent in 3G handsets and enable increased data applications.. According to Berg Insight, there are 175 million handsets that support GPS technology as of April 2008, and this number will grow to more than a half a billion worldwide in five years.[57]

Since May 2006, the number of 3G enabled terminals has increased significantly. Also, the size, features, and weight of these units have fallen to a point where these handsets are more competitive vis-à-vis 2G handsets. Lehman estimates the average selling price of 3G handsets [not differentiating between 3G technologies] to have declined to around US$250, with the lowest priced unit at around US$125 (from Chinese vendors such as Huawei and ZTE).[58] Lehman believes that more network operators are willing to subsidize the cost of 3G handsets for their high-end customers as an encouragement to switch to 3G and thereby open up capacity on their 2G networks and reducing overall capex requirements. Lehman sees improved 3G terminal devices with more attractive pricing as a contributing factor in driving 3G subscriber growth going forward.[59]

4.4 3G Applications

Text messaging (SMS) has become the cash cow for mobile operators and soon that may be changed by instant messaging. Mobile Instant Messaging (MIM) is used by 8% of mobile customers worldwide according to a study by TNS Global Telecoms.[60] SMS accounts for roughly 70 to 80 percent of non-voice mobile revenues worldwide. Text messaging activity increased steadily over the last year, according to M:Metrics, rising from 39.2 percent of mobile users sending an SMS in February 2007 to 48.6 percent on year later.[61] M:Metrics figures that MIM has grown 19 percent in the same timeframe with 7.9 percent of U.S. mobile customers sending instant messages from their handsets. That figure mirrors European uptake of MIM which, according to Forrester Research, will triple in the next three years.[62]

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51 *Ibid.*

52 *Mobile Browser Market is Transforming and Will Grow to 1.5 Billion Units in 2013*. ABI Research. 11 April 2008.

53 *Ibid.*

54 *By 2013 One in Every Three Phones Sold Will be a Smartphone*. ABI Research. 20 March 2008.

55 *Ibid.*

56 *Mobile TV Business Models, Technologies and Markets 2008-12.* ARC Chart. May 2008.

57 *Berg Insight says GPS-enabled handset shipments will reach 560 million units in 2012*. Berg Insight. 15 January 2008.

58 Wuh, Paul. "Global 3G Developments: 3G subs accelerate, more data revenue in '09." Lehman Global Equity Research. 23 May 2008.

59 *Ibid.*

60 Gibbs, Colin. "*SMS vs. MIM.*" RCR. 3 May 2008.

61 *Ibid.*

62 *Ibid.*

Although U.S. consumers have been slow to embrace text messaging, they may not be so slow to move to instant messaging which has an installed base of 1.2 billion online IM users — low hanging fruit for MIM vendors—and is expected to grow to 1.9 billion in the next four years.[63]

As the popularity of mobile messaging services continues to grow, Gartner forecasts 2.3 trillion messages will be sent across major markets worldwide in 2008, a 19.6 percent increase from the 2007 total of 1.9 trillion messages.[64] Mobile messaging revenue across major markets will grow 15.7 percent in 2008 to $60.2 billion, up from $52 billion in 2007.[65] Gartner anticipates erosion of operator profit margins on messaging services due to competition and market saturation. The compound annual growth rate (CAGR) for Short Message Service (SMS) revenue in major markets worldwide from 2002-2006 was 29.8 percent. From 2007-2011, the CAGR for SMS revenue is forecast to be 9.9 percent. "To sustain growth over the next few years, carriers should look to social networking applications to drive traffic," advised Nick Ingelbrecht, research director for Gartner.

According to a 2007 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.[66]

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

According to a report by Strategy Analytics, total spending on mobile media services by consumers and advertisers, including web access, video and music products, will more than double – from almost $47 billion in 2007 to over $102 billion by 2012. Strategy Analytics also projects that the population of cellular users engaging in mobile content and applications delivered over cellular networks will ramp from 406 million to over 870 million in the same period.[67] Nitesh Patel, Senior Analyst, Global Wireless Practice noted, "over the next five years, we project continued growth in consumer acceptance and spending across a range of media applications distributed over cellular networks, particularly web access, video, music and mobile TV."[68]

Analysys Research defines mobile media and entertainment services as excluding messaging, mobile browsing and data charges, and reports $3.1 billion in revenue in 2007 with a forecast of growth to $6.6 billion by 2012, a compound annual growth rate of 16.3%.[69] Analysys sees 2010 as the point when the technical and market environment will improve and growth will accelerate. Analysys anticipates mobile media and entertainment services will account for 12.3% of non-voice revenue by 2012, with mobile TV and video-on-demand enjoying the most significant consumer uptake.

Mobile Internet services are accounting for a 13% increase in visitors to leading websites over home PC traffic alone, according to research by Nielsen. The study found that weather- and entertainment-related websites were the biggest beneficiaries of mobile Internet usage, both reporting a 22% increase in traffic. Gaming and music both reported a 15% increase while email-related websites showed an increase of 11%. The study also noted that of the 87 million U.S. mobile users that have access to mobile Internet services, around 13.7% actively use the mobile Internet each month.[70]

Vodafone U.K. reported that the mobile Internet was also benefiting from the popularity of social networking websites. The operator said that Facebook was the most popular mobile Internet destination while Bebo and MySpace were fifth and eighth most popular, respectively. Facebook and Bebo were also named as the two most popular search terms on Vodafone UK's mobile Internet portal.[71]

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[63] *Ibid.*
[64] *Gartner Says Mobile Messages to Surpass 2 Trillion Messages in Major Markets in 2008*. Gartner. 17 December 2007.
[65] *Ibid.*
[66] *Mobile Messaging Futures, 2007-2012*. Portio Research. February 2007.
[67] *Mobile Media and Services Spending to Reach $102 Billion in 2012. Strategy Analytics*. 17 April 2008.
[68] *Ibid.*
[69] *Forecast: Mobile Media Revs to Double by 2012*. FierceMobileContent. 22 April 22 2008.
[70] *Mobile Internet Extends the Reach of Leading Internet Sites by 13%.* Nielsen. 1 May 2008.
[71] *Ibid.*

According to Pyramid Research, there are strong forces bringing social networking sites (SNSs) and mobility together, including the industry-wide trend toward presence and personalization. The ability of members to access a social networking site from anywhere will enhance the utility of the SNS and thus boost the amount of advertising revenue that it can generate. For mobile operators, SNSs could greatly increase mobile data usage, which has so far been lackluster in most markets, and open the door to new revenue streams from subscription fees or advertising.[72] Pyramid expects 2008 will be another building year, with operators and SNSs continuing work on technical, commercial and market challenges and by 2009 and 2010, mobile social networking should become increasingly popular – with uptake seen not just in the US market, but globally. Social networking accounts for almost 40% of worldwide mobile web traffic, topping the 60% mark in some countries including the U.S., South Africa and Indonesia as of May 2008 and reported by browser development firm Opera Software.[73]

Pyramid forecasts 300 million mobile social networking users by 2010, representing 7% of worldwide mobile subscribers. By 2012, an expected 18% of mobile users, 950 million users worldwide, will be accessing at least one social networking site via their mobile device. [74]

Informa provided the following thought leadership regarding social networking in the mobile space. Social networking has experienced an explosion in popularity online: by the end of 2007 there were expected to be 230 million active memberships in such online websites.[75] MySpace, Facebook, YouTube and Flickr are some of the main social networks online, but there are many different variants. Recently, both the social networking industry and telecoms and media industries have started looking at how such services and user-generated content (UGC) can be commercialized on mobile. MySpace recently introduced an ad-supported mobile version of its site and Facebook also has expanded into mobile, allowing users to update their profiles from mobile devices and to be alerted when they receive messages from their friends. Facebook also recently unveiled a mobile platform to encourage its 80,000 developers to extend applications to phones and teamed with Research In Motion (RIM) to put its service on BlackBerry smartphones. People can tag and upload photos and send Facebook invitations from their BlackBerry's address book. Facebook's mobile user base is growing faster than the website. As of the end of October 2007, Facebook's four million distinct active users across its mobile line-up generated more than 300 million page views.

Informa reported that Google, having made acquisitions of mobile social networking start-up Zingku and blogging site Jaiku, now offers a mobile service that shares information about a user's location and helps them find friends in their local area. And in early November 2007, Google announced Android, an open platform for mobile devices that may drive the development of more interesting and context-aware social applications for mobile. This comes on the back of OpenSocial in which Google teamed with MySpace, LinkedIn and other social networks on a platform to spread social software applications across the internet.[76]

AirG, which manages social-networking communities for leading carriers including AT&T says 59% of its 20 million unique users around the world don't use or have easy access to a home PC. Mobile phones do have a few key factors that allow them to fulfill certain functions that many consider core to the success of networking applications. The ease with which users can take pictures or video clips and then upload them is far greater than doing the same using a PC. The general immediacy and convenience that mobile devices allow also alleviates some of the obstacles compared to a PC.[77]

Globally, end-user generated revenues from social networking, online dating and personal content delivery services will increase from $572 million in 2007 to more than $5.7 billion in 2012, with social networking accounting for 50% of the total by the end of the forecast period, according to Juniper Research.[78] Dr. Windsor Holden of Juniper expects that the highest levels of growth could well be experienced in developing markets with limited fixed broadband access. "In these markets, the mobile phone is becoming the predominant means by which people access the internet. Hence, the

[72] *Analyst Insight: By the End of 2012, 950m Users will be Accessing Social Networking Sites via Mobile Devices*. Pyramid Research. February 2008.
[73] *State of the Mobile Web.* Opera Software. Referenced in Opera: *Social Networking 40% of Mobile Web Traffic.* Fierce Wireless. 20 May 2008.
[74] *Ibid.*
[75] Winterbottom, Daniel. "Social networking has potential to drive mobile revenues, but also to add to network woes." Informa. 19 November 2007.
[76] *Ibid.*
[77] *Ibid.*
[78] *Mobile User-generated Content Revenues to Rise Tenfold by 2012*. Juniper Research. 13 August 2007.

overwhelming majority of online social networking will be conducted via the handset rather than the PC."[79] The number of active users of mobile social networking is expected to rise from 14 million in 2007 to nearly 600 million in 2012 according to Juniper. In fact, in February 2008, Informa forecast the number of mobile social networking users exceeded 50 million (some of these users were registered in multiple mobile communities), approximately 2.3% of the global mobile user population on December 31, 2007. Informa predicts that by 2012, there will be between 12.5% penetration of mobile social networks among mobile users globally in the most conservative scenario, approximately 23% in the high growth scenario.[80] Informa argues that with only low investments from mobile network operators, the growth in users and community registrations will continue at a CAGR of 30-50%, depending on the type of community and region. The concept of mobile social networking is fast catching on in the U.S., as all tier one and tier two operators in the U.S. currently offer social networking applications.[81]

Social networking and Internet commerce are compelling smartphone users to spend an average of four hours and 38 minutes per month browsing the mobile Web in the U.S. and two and a half hours per month in Britain, reports M:Metrics.[82] Mark Donovan of M:Metrics stated, "Among smartphone users in the U.S., mobile browsing has increased 89% year-over-year, and pageviews have increased 127%. Consumption is quickly evolving from brief transactions, such as checking the weather or flight status, to time intensive interaction with mobile Web sites- even without an iPhone."[83]

Mobile financial services (MFS) are showing signs of a promising future. From about 10 million people at the end of 2007, it is envisioned that more than 1.4 billion people worldwide will benefit from mobile financial services in 2015 by using mobile wallets—software than enables consumer to manage their money, including making and receiving payments, using their mobile phone-- according to research by Edgar Dunn, a specialist mobile banking and payments consultancy firm in partnership with the GSMA.[84]

Handsets can now be used to buy online, via 'swipe' points in retail outlets, and mobile-to-mobile. However, the phone can be used as more than a banking tool – it can serve as the location for the account, hold all the financial information, and be used as the primary security measure. Operators serving 40% of the world's subscribers are working on contactless m-payments systems according to the GSMA. Based on predictions that two billion mobile handsets will be shipped in 2012, visiongain estimates that 22.5% of these will be NFC enabled, which results in 450 million NFC handsets to be shipped in 2012.[85]

One example of HSPA delivery of mobile banking is Telstra and the National Australia Bank (NAB) which joined to offer 3G HSPA technology based mobile ATMs (cash machines) at temporary venues. The ATMs will be deployed at major sports and cultural events across Australia to provide convenient access to cash for the public.

Although mobile payment is still a nascent service, it is expected to reach 32.9 million users worldwide in 2008 and grow to 103.9 million in 2011, according to a study by Gartner.[86] Gartner defines mobile payment as paying for a product or service using mobile technologies, such as Short Message Service (SMS), Wireless Application Protocol (WAP), Unstructured Supplementary Service Data (USSD) and Near Field Communications (NFC). The payment is made via the phone, although not necessarily over a wireless network, as in the case of NFC. SMS is the dominant mobile payment technology today, driven by mobile money transfers, and it will remain the dominant technology through 2011 according to Gartner. Gartner excluded telebanking or using a mobile phone to call the service center, as well as mobile ticketing where the ticket value has been prepaid and is stored on the phone. The Asia Pacific region leads the market with 28 million projected users in 2008 –85% of the world's total. North America is expected to have one million users and Western Europe half that amount in 2008.[87]

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[79] *Ibid.*
[80] *Informa: Mobile Social Networking Revenues Could Reach US $52 billion by 2012.* Informa. 19 February 2008.
[81] *Source: Strong Uptake of On-deck and Off-deck Mobile Social Networking Services Continue to Drive U.S. Mobile Social Networking Markets*. Frost & Sullivan. 28 April 2008.
[82] Marek, Sue. "Americas Spend More than 4.5 Hours Per Month Browsing on Smartphones, Nearly Double the Rate of the British." Fierce Wireless. 22 May 2008.
[83] *Ibid.*
[84] *Mobile Financial Services to Thrive with the Right Regulation*. GSMA. 6 February 2008.
[85] *MPayments 2007-2012, Commerce and Banking in the Mobile World*. Visiongain Intelligence. July 2007.
[86] *Gartner Says Worldwide Mobile Payment Users to Total 33 Million in 2008.* Gartner. 21 April 2008.
[87] *Ibid.*

Juniper Research expects that over 612 million mobile phone users will generate more than $587 billion worth of financial transactions by 2011.[88]

Today, the idea that mobile phones could become an extension of a person's wallet or purse has become a reality. The industry has settled on NFC technology as the most suitable way of transforming mobile devices into a payment method. This allows the development of proximity payment solutions, whereby mobile devices can be used in a fashion similar to other contactless payment methods. Examples of these include PayPass and PayWaves, contactless cards from respectively, Visa and MasterCard. Transit operators, for example, can use handset-based proximity payments (NFC) to achieve savings through a reduction in their operating costs. The processing cost of an electronic transaction is around 40% cheaper than that of a paper ticket.[89]

Willy Dommen, principal of consulting firm Booz Allen Hamilton, 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.[90]

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.[91] 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.[92]

"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.[93] Juniper Research reports that financial institutions are delivering an increasing variety of products in the mobile environment, from fund transfers, bill payment and presentation to account management and customer service. As a result, the annual number of global mobile banking transactions is forecast to rise from 2.7 billion in 2007 to 37 billion by 2011, as a greater number of services are deployed worldwide. Juniper expects the number of consumers accessing banking services on their mobile phones to increase tenfold over the next four years, reaching 816 million by 2011.[94]

ARC Charts believes that based on the strength of trials and pilots conducted in 2007, that in 2008, device manufacturers will begin to ship NFC-enabled handsets in earnest, forecasting shipments to increase at a CAGR of 338% for the period 2008-2012, culminating in shipment of 504 million devices in 2012.[95]

Ovum forecasts that the mobile payment market (m-payment) will grow from $12 billion in 2007 to around $150 billion in 2012. Most of the current market originates in Japan, where mobile contactless payment and online shopping services are already well advanced. Three segments of mobile payment are also forecast by Ovum. 1) Mobile contactless payments are expected to grow from $3 billion in 2007 to $52 billion in 2012. This market mainly lies in Japan, North Americas, Western Europe as well as a few developed Asia-Pacific countries. 2) Online shopping is expected to grow from $8 billion in 2007 to $41 billion in 2012. It is anticipated that as the Internet becomes mobile with a new generation of mobile devices and Internet access tariffs, a growing share of the business-to-consumer e-commerce market will take place on mobiles. 3) The money transfers sector is expected to grow from $1 billion in 2007 to $58 billion in 2012. This market opportunity lies mainly in developing countries.[96]

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88 *Financial Transactions Conducted Via Mobile Phone to Generate Over $587 billion by 2011*. Juniper Research. 30 Jan 2008.

89 *Driving Mobile Payments and Ticketing with NFC Handsets*. ARC Chart. May 2008.

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

91 White, Spencer, AT&T. Mobile Payments World speech. 26 March 2007.
Dolan, Brian. "AT&T: Mobile Payments, Past the Hype." Fierce Wireless. 26 March 2007.

92 *Ibid.,* 39

93 *US Mobile Banking: Beyond the Buzz Report Published by Celent.* Celent. 17 May 2007.

94 *Source: Juniper Research, Mobile Financial Services Banking & Payment Markets 2007-2011*. Juniper Research. February 2008. Referenced in *Mobile Banking Users to Increase Tenfold by 2011*. Telecoms.com. 17 April 2008.

95 *Driving Mobile Payments and Ticketing with NFC Handsets,* ARC Chart. May 2008.

96 *Mobile Payment Market Forecasts*. Ovum. 23 April 2008.

Juniper Research expects that over 2.6 billion mobile tickets will be delivered to just over 208 million mobile phone users by 2011. Initially trialed by mobile network operators, commercial services are now often controlled by the ticketing issuers themselves such as Ticketmaster, British Airways, and tickets.com. Benefits for the ticketing issuers include reduced cost, better security to help fight against fraud and improved environmental footprint by reducing paper usage. Early use of mobile barcode technology will be further improved by the emergence of Near Field Communications (NFC), particularly for the transportation ticketing sector. These services are already in play in the Far East, with important trials in North America and Western Europe. Juniper's report predicts savings of $500 million each year for the airline industry due to mobile boarding passes; $87 billion worth of mobile ticketing transactions by 2011; NFC will begin to get traction from 2009 onwards.[97]

The mobile entertainment market—including ringtones, mobile games, mobile music, mobile TV and video services, full track music downloads, ringback tones, and graphics/themes—is expected to account for 5.1% of the estimated $800 billion in total global wireless service revenue by 2011, and 23% of all mobile data revenue according to IDC forecasts.[98] IDC sees the vast majority of mobile entertainment revenue derived from ringtones, ringback tones and mobile TV and video services.

Juniper Research expects a rise in mobile entertainment revenues from just over $20 billion worldwide in 2007 to more than $64 billion by 2012, according to a new forecast issued in January 2008.[99] Music will represent $17.5 billion (up from $9 billion), games will represent $16 billion (up from $5 billion) and mobile TV will represent $11.9 billion (up from $4.1 billion) as the primary catalysts behind the market growth, and user-generated content, gambling, adult entertainment and infotainment will drive adoption as well.[100] According to Juniper analyst Dr. Windsor Holden, "With more widespread penetration of 3G handsets --- or entertainment-focused 2.5 G handsets like the iPhone –there is likely to be a much greater surge in both the adoption and overall usage in rich media services."

Mobile TV use is set to surge due to strong consumer demand, with the service ranked as the number one application users want on their phone, according to a consumer behavior study conducted by Ericsson and news broadcaster, CNN. The results show more than a third (34%) of respondents ranking TV as the most in-demand application and almost half (44%) of the respondents poised to adopt mobile TV by 2010.[101] Other key findings in the study revealed that photo and video messaging appear set for wide-scale adoption as consumer pricing and functionality improves. Photo technology is used by 57% of respondents on a monthly basis to send and receive images, making it the most popular activity. Mirroring this trend is CNN International's user-generated content service iReport, which launched in 2006. The service garnered 50,000 submissions, driving the worldwide trend for citizen journalism.

"Mobile operators' sustained investment in video delivery will continue to be rewarded by subscribers' growing adoption rates, particularly as they upgrade to new video-capable handsets," said Mike Wolf, research director at ABI Research. "Consumers are being increasingly enticed by better experiences through more powerful and larger screens as well as by a widening array of subscription options." ABI Research sees the total number of mobile TV service subscribers growing to 462 million over the next five years, driven in large part by the expansion of 3G networks, and flat-rate plans for mobile video. The build-out of mobile video delivery networks and increase in the amount of available content will also contribute to the market's growth.[102]

Vendors are working to extend the reach of mobile TV. One example is the recent announcement by Alcatel-Lucent and Quantum SpA of their cooperation to develop terrestrial or hybrid (terrestrial and satellite) mobile broadcast solutions adhering to the new DVB-SH mobile broadcast standard.[103] Seamless multimedia mobility for mass market Mobile TV is their goal, through Pay TV digital set-top boxes for the automotive industry, Pocket TV Portable Media Players and the software that brings together unique applications through the convergence of Mobile TV, the internet and location based services into a single personal device. Key drivers include in-car multimedia entertainment, portable

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97 *Mobile ticketing goes mainstream, with over 2.6 billion mobile tickets set to be delivered by 2011, says Juniper Research*. Juniper Research. 7 March 2008.
98 *IDC Predicts Ringback Tones Will Be the Single Largest Source for Mobile Entertainment Revenue by 2010*. IDC. 4 March 2008.
99 *Mobile Content Revenues to $64B by 2012*. Juniper Research. 23 January 2008.
100 *Ibid.*
101 *CNN and Ericsson Reveal Findings from Joint Mobile TV Study.* Cellular-News. 12 Feb 2008.
102 *Mobile TV Subscribers to Number 462 Million by 2012*. ABI Research. 25 January 2008.
103 *Alcatel-Lucent and Quantum SpA Cooperate to Extend the Reach of DVB-SH Mobile TV*. Alcatel-Lucent. 6 May 2008.

devices with larger screens and navigation services to accelerate the advent of mass market mobile TV, by providing end users with an experience that complements their traditional TV experience.

ARC Chart forecasts that 295 million specialist handset devices — that can receive mobile TV in one form or another — will be sold by 2012. Furthermore, 61 million non-handset devices will be added, totaling shipments of 356 million devices that are enabled to view mobile TV.[104]

Mobile video messaging services are at the center of the technology convergence that is allowing mobile customers to achieve greater levels of self-expression and online community participation. ABI Research expects the opportunity for mobile video services to produce a compound annual growth rate of nearly 60%, amounting to $10 billion in 2012.[105]

With the growth of sophisticated devices like the iPhone, video sites such as YouTube, and Wi-Fi and 3G networks, consumers are downloading more videos on their phones. Analyst firm ARC estimates that the mobile online video market will generate worldwide revenue of $5 billion in 2008.[106] Mobile video is being facilitated by advances in solutions that automate real-time adaptation and delivery of video content over multiple networks to any device.

Music delivered to mobile phones via operators' networks (mobile music) is on the rise, currently representing around 13% of global recorded music retail value. A report from Understanding & Solutions forecasts an increase to almost 30% by 2011, amounting to $11 billion.[107] Since most new handsets now come with built-in music functionality, and recent developments from manufacturers and operators have helped improve the user experience when searching for, purchasing and using mobile music, many barriers have been removed for this mobile entertainment segment. Interfaces and software will need to continue to improve to make the mobile experience comparable to online music.[108]

New research indicates that mobile gaming has a stronger rate of growth than in console and handheld markets, according to research firm Understanding and Solutions, although it has a smaller market share.[109] Mobile is in the second position following the online games market. Global revenues for mobile gaming were $3.6 billion in 2007 and expected to rise to $6 billion by 2011 according to analyst David Rouse of Understanding and Solutions. Games are not seen as the leading application, but increasingly important as the market continues to see major growth. An increasing number of traditional content owners are moving into the mobile games space, either by setting up their own mobile games subsidiaries like EA mobile, Konami and THQ wireless, or by licensing out content (Sega, MGM, Universal, Warner).

Worldwide subscribers to location-based communications services on mobile devices will increase by nearly 168% in 2008 while revenue will grow by 169% according to a Gartner report.[110] Gartner expects that subscribers worldwide will rise from 16 million in 2007 to 43.2 million in 2008 and revenue will rise from $485.1 million in 2007 to $1,307.3 million in 2008. Subscribers are expected to reach nearly 300 million in 2011 and revenue is forecast to top $8 billion in 2011. Annette Zimmerman, Gartner analyst says, "Growth now will be stimulated by the arrival of mobile phones with built-in, precise location sensing and the arrival of new service providers, like Google and Nokia with its service offerings, keen to exploit geographic and positioning technologies."

Mobile search gained strength in the U.S. market, where The Nielsen Company estimated 46.1 million wireless subscribers using 411 and SMS-based mobile search on their phones in the 3Q 2007. Although local listings was the most common search objective, information such as sports, weather, news and other mobile content was popular. "As more mobile users turn to their phone for the answers they need, mobile search has quickly escalated as a critical part of the mobile media and advertising landscape," said Kanishka Agarwal, vice president of Mobile Media for Nielsen Mobile.[111]

Mobile search ads will create their own sector of business in the advertising space. According to ABI Research, the market for mobile search ads is projected to jump from $813 million in 2008 to $5 billion in

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104 *Mobile TV Business Models, Technologies and Markets 2008-12*. ARC Chart. May 2008.
105 *A $10 billion Mobile Video Messaging Opportunity for 2012*. ABI Research. 9 April 2008.
106 *Dilithium Unveils Content Adaptor for Real-Time Mobile Video.* Dilithium. 13 May 2008.
107 *Mobile to Account for 30% of Music Retail Value by 2011*. Understanding and Solutions. December 2007.
108 *Ibid.*
109 *Mobile Games Revenues to Hit $6bn by 2011*. Understanding and Solutions. December 2007.
110 *Dataquest Insight: Location-Based Services Subscriber and Revenue Forecast 2006-2011*. Gartner. 12 February 2008.
111 *46 Million Use Mobile Search in US*. Neilsen Mobile. January 2008.

2013. Over the same period, SMS searches will increase nearly sixfold, from 13 billion to in excess of 76 billion.[112]

Juniper Research expects almost 30 percent of global mobile subscribers, around 1.3 billion users, to use local mobile search services by 2013.[113] Juniper believes that advertising supported local search will be the key to driving this sector, with the caveat that the effectiveness of advertising in this sector will vary widely according to local conditions. The best equipped regions are thought to be Western Europe and North America, as countries within these regions typically have good local digital information suppliers such as Yellow and White Pages, as well as good mapping data. Total mobile search revenues are expected to reach $4.8 billion by 2013 with the caution from Juniper that "advertising overload" might act as a disincentive to consumers. [114]

The Mobile Marketing Association has offered advertising guidelines for mobile web banner and text messaging, downloadable content and multimedia messaging service formats and expects to finish advertising guidelines for mobile video and TV by October 2008.[115] With guidelines in place, consumers can expect to see more ads on mobile phones. According to eMarketer, worldwide spending on mobile advertising reached nearly $2.7 billion last year and should reach $4.6 billion in 2008, rising to $19.1 billion by 2012.[116] Most ad dollars will go to text messaging; SMS, MMS text-messaging and mobile instant messaging. Mobile email will account for more than $14 billion of the $19 billion total expected in 2012; up from $2.5 billion in 2007. The expansion of display and search advertising on mobile phones worldwide is expected to reach $1.2 billion and $3.7 billion respectively by 2012.[117] In 2007, the standard cost for a mobile marketing campaign more than tripled to $100,000.[118]

Arthur D. Little predicts that in the coming years, mobile advertising is poised to be the next major digital media platform for brands to reach customers, and the key telecoms players have a great deal to gain from bringing their services to the market early.[119] Roughly 60% annual growth in mobile advertising spending over the next four years is predicted in its 2008 report. Future mobile advertising formats will be more interactive and dynamic than online advertising or mobile advertising today, including call waiting, idle-screen advertisements, mobile TV ads, games and voicemail ads. Push ads via SMS/MMS are another traditional option. The Arthur D. Little report cites the Blyk case study: Blyk, a U.K.-based Mobile Virtual Network Operator, successfully launched large-scale mobile advertising to early adopters with a 29% response rate by using highly defined target groups and user data to achieve such a positive rate compared to .05% response rate for typical online marketing campaigns.[120]

In a March 2008 report, Nielsen Mobile measured 58 million U.S. mobile subscribers who saw a mobile advertisement on their phone in the previous 30 days; this represented 23% of all U.S. mobile subscribers. Nearly half, or 28 million subscribers, claimed to have responded at least once to a mobile ad. Nielsen's survey found that 26% of those who responded to mobile ads did so by sending an SMS message — the most popular response.[121]

According to Juniper Research, mobile advertising spending will for the first time exceed $1 billion in 2008 and reach nearly $7.6 billion by 2013, with the growth credited to lucrative channels such as mobile streamed and broadcast TV services. Although SMS campaigns presently dominate the mobile adspend, mobile TV spending will rise from $335 million in 2008 to more than $2.5 billion in 2013 based on Juniper forecasts. Findings from the Juniper report: nearly 1.5 billion mobile users will receive SMS ads in 2008; and China and the Far East will remain the largest regional market for mobile adspend.

A report by Media Analyst Screen Digest examined the emerging market for rich media advertising delivered to consumers via their mobile phone in the form of TV, video, games, user-generated content (UGC) and music. Screen Digest believes the market for rich media advertising on mobile will reach $2.79 billion by 2012, with global mobile TV advertising accounting for the lion's share at $2.44 billion. By 2012, advertising will account for 20% of mobile TV revenues. The reason for success? More ubiquitous than the PC, mobile offers the opportunity to send personalized messages to people in all markets.

112 *Mobile Search Critical as Search Advertising Races Towards $5 Billion in 2013.* ABI Research. 16 April 2008.
113 *Local Mobile Search Finds Favor*. Juniper Research. 29 April 2008.
114 *Ibid.*
115 *Mobile Marketing Association Tackles Video, TV Guidelines.* eMarketer. 29 April 2008.
116 *eMarketer: Worldwide mobile ad spending to hit $19.1 billion by 2012.* eMarketer. 27 March 2008.
117 *Ibid.*
118 *Ibid.*
119 Little, Arthur D. "Report Forecasts 60% Annual Growth in Mobile Advertising over the Next 4 Years." 20 May 2008.
120 *Ibid.*
121" *Nielsen: Mobile Ads Reach 23 Percent of Users*. Nielsen. 7 March 2008.

Advertising sent via mobile phones reaches the recipient directly, wherever they are, at any time and location, offering effective targeting as well as interactivity and consumer engagement. "The potential is huge, and some of the world's largest companies are vying for control of what they see as the next major advertising medium," stated David MacQueen, co-author of the report.[122]

Gartner provides predictions that worldwide mobile advertising revenues are to surpass $2.7 billion in 2008 – a $1 billion increase from 2007.[123]

According to David Kerr, analyst with Strategy Analytics, the growth of mobile content and applications will spur interest from advertisers, "Relative growth in consumer spending on mobile media applications will be surpassed by advertisers as they look to exploit the maturing cellular content channel as a means to deliver their marketing and advertising messages to key target segments,"[124] he stated.

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," wrote Jessica E. Vascellaro of the Wall Street Journal.[125] "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,"

Another tremendous area of growth for wireless data will be in machine-to-machine (M2M) wireless mobile connections. According to Berg Insight, the number of cellular connections used for M2M communication will grow from 37.5 million connections in 2007 at a CAGR of 37.9 percent to 186 million connections in 2012.[126] As of the end of 2007, the GSM family of technologies dominates the market and account for 71% of the total number of active connections at the end of 2007. UMTS/WCDMA has primarily been adopted for M2M applications in Japan. Berg Insight finds that, in general, the number of M2M applications today correspond to between 1-3% of the reported number of mobile subscribers in developed markets.

Berg Insight forecasts that vehicle telematics applications will dominate the machine-to-machine cellular market in most parts of the world and account for more than half of all network connections in 2012. "In North America OnSTar already gives peace of mind to millions of drivers. Europe is well on the way to introducing the eCall automatic emergency call system and several Latin Americas countries are considering mandatory tracking devices on all new cars to combat epidemic vehicle crime," stated Tobias Ryberg, senior analyst.[127]

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.[128] Due to current widespread usage in many commercial vehicles as a result of legislation, 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. 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)

IMS is expected to provide mobile telephone operators with a forecasted $300 billion in extra revenue over the next five years (through 2013) according to ABI Research. "Until recently IMS was mainly the province of fixed-line operators," said senior analyst Nadine Manjaro, "But now it is essential to the success of mobile and fixed operators who are losing revenue from traditional sources. IMS enables rapid development and deployment of new services."[129]

Perhaps a remaining challenge is the integration of IMS without operators disrupting existing services. This need is being met by the major infrastructure vendors such as Ericsson, Alcatel-Lucent and Nokia-

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[122] *Mobile Advertising Using Rich Media Formats*. Screen Digest. 29 April 2008.
[123] *Focus on: Mobile Advertising.* Telecoms.com. 7 May 7 2008.
[124] *Mobile Media and Servics Spending to Reach $102 Billion in 2012*. Cellular News. 17 April 2008.
[102] Vascellaro, Jessica. "Small mobile devices lighten business load." The Wall Street Journal. 2 April 2007.
[126] *Berg Insight Says 186 Million Machines will be Connected to Mobile Networks in 2012*. Berg Insight. 6 May 2008.
[127] *Ibid.*
[128] Cory, Dr. Therese. "*Wireless Telematics & Machine to Machine: Entering the Growth Phase, 2006-2011.*"Juniper Research. 22 January 2007.
[129] *IP Multimedia Subsystems' $300 Billion Opportunity*. ABI Research. 13 March 2008.

Siemens Networks, which have been packaging IMS (at additional costs) with the network upgrades they provide to operators.[130]

Work is being done by organizations such as the GSM Association in 2008 to test our carrier ENUM services and make it easier to send IMs, MMS, emails, videos and any other IP content between mobiles and fixed line phones, as well as mobile-to-mobile transmissions. Four operators, Bharti Airtel, mobilkom Austria, Telekom Austria and Telenor are involved in the trial and it is expected to achieve full commercial service by the end of 2008.

"As we move to the end of the decade, mobile networks will emerge with a flat all-IP architecture using 3GPP standards to deliver multimedia services ad VoIP," said Ian Cox, principal analyst at ABI Research. "In the meantime operators want to offer attractive calling plans to consumer and enterprise users. This will enable a single device to use both mobile and fixed broadband network, improving business efficiency and enabling users to access directory information easily from their favorite device."[131] According to a new study by ABI Research, fixed mobile convergence market could grow to 250 million users by 2012. Converged services on fixed and mobile networks are available today and a new round of trials should be forthcoming as femtocell technology becomes available, said ABI.[132]

Informa Telecoms & Media studies mobile converged devices and expects sales of mobile phones with active SIP functionality will increase from 4 million units in 2006, reach 275 million units in 2007, with an inflection taking place between 2010 and 2011. It forecasts 435 million mobile SIP users by 2012.[133]

The growth of IMS was further confirmed by Mind Commerce stating that IMS components and User Equipments (UEs) are poised for an explosive growth in the duration 2008-2012. The IMS Component market will grow from $1.6 billion in 2008 to nearly $8 billion in 2012 at a CAGR of 49% and the UE market will grow from 3.9 billion in 2008 to 34.9 billion in 2012 at a CAGR of 73%.[134]

Based on research by Strategy Analytics, the market for enterprise Fixed-Mobile Convergence solutions are expected to grow to over $50 billion by 2012. New factors are pushing the enterprise market towards a tipping point at which companies can see the business process benefits of FMC, resulting in unreserved implementation. Analysis indicated that UMA services will initially generate the more significant revenues due to its early market entry, but this position will be eroded over time by SIP-based services. "SIP-based services will initially be implemented by large multi-nationals with the capacity to carry voice traffic on their private MPLS network. Consequently, SIP-based revenues will overtake UMA revenues toward the end of the forecast period [2012]," stated David Kerr, Strategy Analytics.[135]

4.6 In-Building Wireless Systems

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

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

ABI Research forecasts worldwide deployment revenues from in-building wireless systems to grow from $3.8 billion in 2007 to more than $15 billion in 2013. Drivers for this tremendous growth include consumers' growing dependence on wireless voice and messaging communications, as well as an

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[130] *Ibid.*
[131] *FMC Market to Count 250M Users by 2012*. ABI Research. 21 March 2008.
[132] *Ibid.*
[133] *Report: 435 Million Mobile SIP Users Projected by 2012*. Informa Telecoms & Media. 2 October 2007.
[134] *Multimedia Subsystem (IMS): The Market for Components and User Equipment*. Reportthinker.com. January 2008.
[135] *Enterprise FMC Market to Reach $50 Billion by 2012*. Strategy Analytics. 21 May 2008.

increasingly competitive mobile operator environment. However, underlying all demand drivers is a fundamental connectivity issue.[136]

When higher frequencies are used for 3G technologies, there are imposed limits on wireless coverage inside buildings based on current cell site distributions. According to Dan Shey, principle analyst with ABI Research, this creates the business case for deployment of in-building wireless systems s mobile data services are capturing a greater share of subscribers' mobile services spend. "In-building wireless networks will become more than simply an extension of the cellular macro network," he stated. "They will become the basis for delivery of a range of business services that will ultimately change how wireless telecommunications are provided indoors."[137]

Both dual-mode handsets and home base stations or femtocells will be used by operators to enable them to fulfill their strategies. Main players using UMA include BT, Orange, TeliaSonera and T-Mobile USA. Others who have deployed FMC but have not used UMA include Telecom Italia, O2 Germany and AT&T. Numerous operators are trialing femtocells as part of their convergence strategy.

4.7 VoIP over Cellular

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

The HSUPA networks initially deployed in 2H 2007, which now total 44, achieved the bidirectional capability needed to run real VoIP over Cellular.

The evolution of mobile VoIP will rapidly eclipse voice over W-Fi and become a mainstream form of communication according to a study from Disruptive Analysis. The analyst firm predicts that the number of VoIPo3G (VoIP over 3G) users could grow from virtually zero in 2007 to over 250 million by the end of 2012. This is comfortably in excess of the expected number of FMC users with dual-mode VoWLAN/cellular phones.[138] The report demonstrates that "it will be operators themselves which will be mainly responsible for the push towards VoIP because it will enable them to fit more phone calls into their scarce spectrum allocations, reduce operating expenses by combining fixed and mobile core networks and launch new services like push-to-talk and voice integrated "mashups," VoIPo3G also fits well with the move towards femtocells. Future generations of wireless technology –3GPP LTE, 3GPP2 UMB and WiMAX — are 'all-IP", so unless mobile operators continue to run separate voice networks in parallel, they will inevitably transition to VoIP at some point."[139]

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.[140] 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.[141]

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

5 Overview of 3GPP Rel-8 – Evolved Packet System (EPS): SAE/EPC 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 EPS which consists of the SAE/EPC and the LTE/EUTRAN. As discussed in the

[136] *In-Building Wireless System to Exceed Revenue of $15 Billion by 2013*. ABI Research. 24 March 2008.
[137] *Ibid.*
[138] *Over 250m VoIP Users Over 3G Mobile Networks by 2012*. Disruptive Analysis. 13 November 2007.
[139] *Ibid.*
[140] *IMS Application Adoption Helps Fuel Nearly Tenfold Increase in Data Bandwidth Usage by 2011*. iGR. 1 May 2007.
[141] *Ibid.*

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 for 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 (Serving Gateway and the PDN Gateway). This allows for independent scaling and growth of throughput traffic and control signal processing and operators can also choose optimized topological locations of nodes within the network in order to optimize the network in different aspects. The basic EPS architecture is shown in Figure 8, where support nodes such as AAA and policy control nodes have been excluded for clarity.

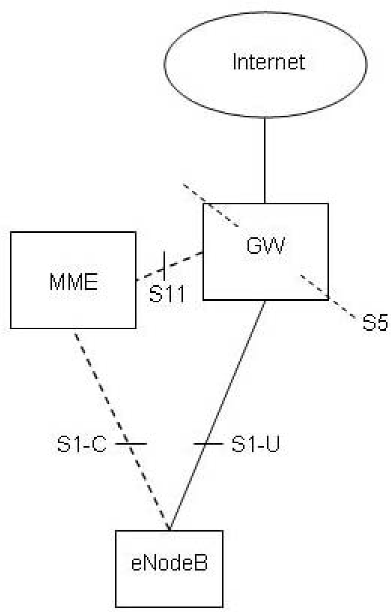


Figure 8. Basic EPS architecture[142]

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.

[142] Ericsson. Q2 2007.

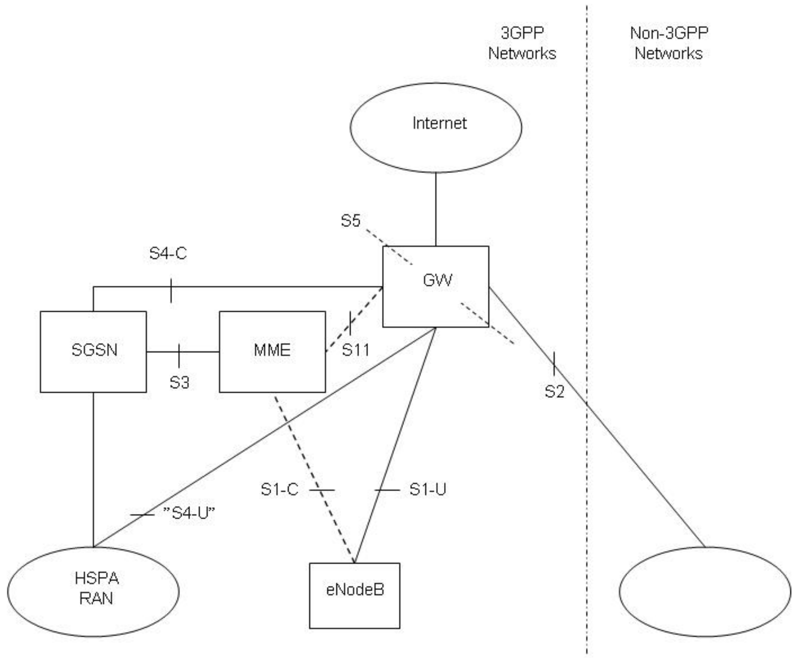


Figure 9. Example configuration for EPS support of Rel-7 UMTS/HSPA and non-3GPP accesses[143]

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.

[143] 3G Americas. Q2 2007.

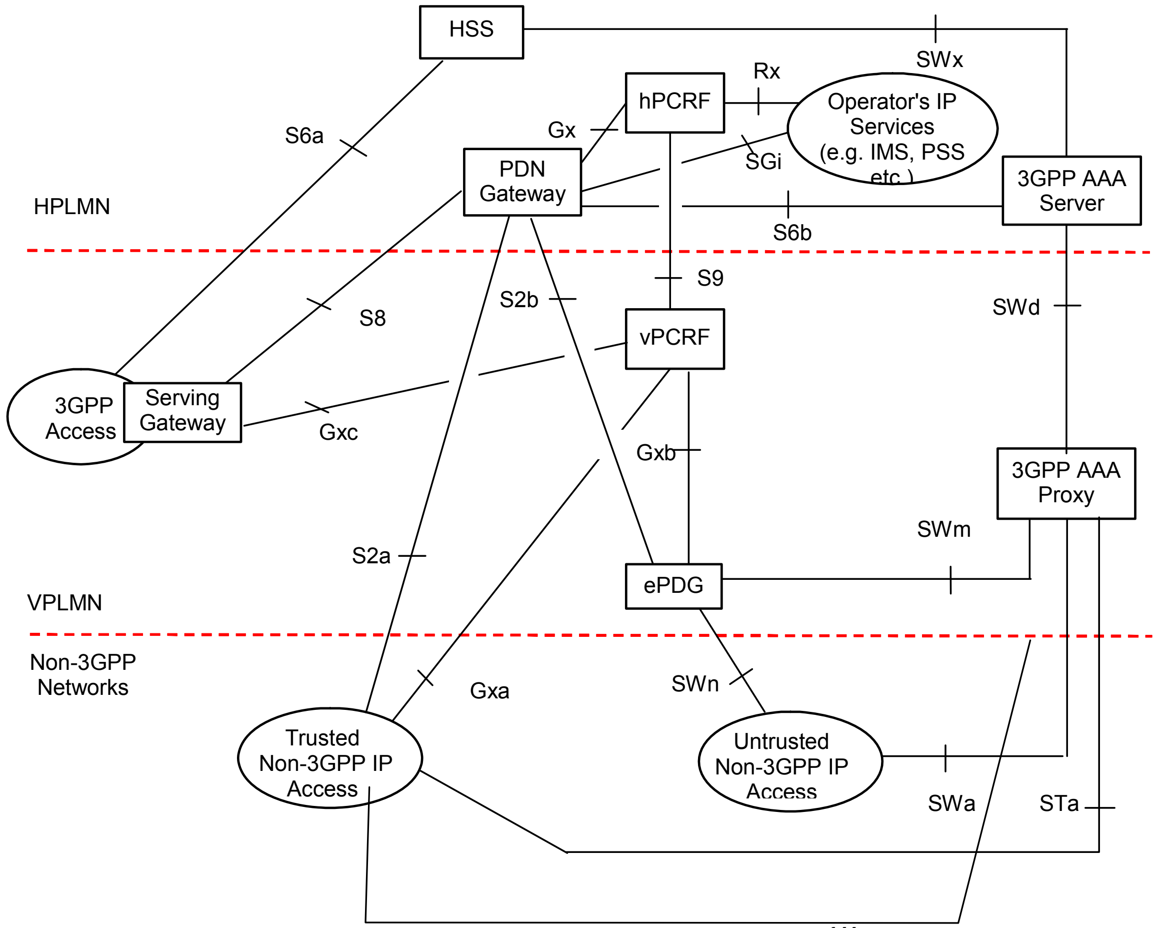


Figure 10. Detailed EPS architecture view[144]

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 include:
  - NAS signaling and related security
  - Inter CN node signaling for mobility between 3GPP access networks (terminating S3)
  - Idle mode UE Tracking and Reachability (including control and execution of paging retransmission)
  - Roaming (terminating S6a towards home HSS)
  - GW selections (Serving GW and PDN GW selection)
  - MME selection for handovers with MME change
  - SGSN selection for handovers to 2G or 3G 3GPP access networks
  - HRPD access node (terminating S101 reference point) selection for handovers to HRPD
  - 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 one single Serving Gateway. Serving GW functions include:
  - The local Mobility Anchor point for inter-eNodeB handover
  - Mobility anchoring for inter-3GPP mobility (terminating S4 and relaying the traffic between 2G/3G system and PDN Gateway). This is sometimes referred to as the 3GPP Anchor function
  - EUTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure

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

144 *Ibid.*

  - Transport level packet marking in the uplink and the downlink, e.g. setting the DiffServ Code Point, based on the QCI of the associated EPS bearer
  - Accounting on user and QCI granularity for inter-operator charging
  - Lawful Interception
  - Packet routing and forwarding

- **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
  - Transport level packet marking in the uplink and downlink, e.g. setting the DiffServ Code Point, based on the QCI of the associated EPS bearer
  - Lawful Interception
  - UE IP address allocation
  - Packet screening

- **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.
The functionality of ePDG includes the following:

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

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

5.1.3 Support of Policy Control and Charging

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

In roaming scenarios, the difference from TS 23.401, is that the vPCRF exists for the UE for the scenario of roaming with home-routed traffic in addition to the scenario in TS 23.401 of roaming with local breakout.

5.1.3.1 Home PCRF

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

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

5.1.3.2 Visited PCRF

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

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

5.1.4 Interfaces & Protocols

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

- **S1-MME:** Reference point for the control plane protocol between E-UTRAN and MME
- **S1-U:** Serves as a reference point between E-UTRAN and Serving GW for the per bearer user plane tunneling and inter eNodeB path switching during handover.
- **S3:** Enables user and bearer information exchange for inter 3GPP access network mobility in idle and/or active state. It is based on Gn reference point as defined between SGSNs.
- **S4:** Provides related control and mobility support between GPRS Core and the 3GPP Anchor function of Serving GW and is based on Gn reference point as defined between SGSN and GGSN. In addition, if Direct Tunnel is not established, it provides the user plane tunneling.
- **S5:** Provides user plane tunneling and tunnel management between Serving GW and PDN GW. It is used for Serving GW relocation due to UE mobility and if the Serving GW needs to connect to a non-collocated PDN GW for the required PDN connectivity.
- **S6a:** Enables transfer of subscription and authentication data for authenticating/authorizing user access to the evolved system (AAA interface) between MME and HSS.
- **Gx:** Provides transfer of (QoS) policy and charging rules from PCRF to Policy and Charging Enforcement Function (PCEF) in the PDN GW.
- **S8:** Inter-PLMN reference point providing user and control plane between the Serving GW in the VPLMN and the PDN GW in the HPLMN. It is based on Gp reference point as defined between SGSN and GGSN. S8 is the inter PLMN variant of S5.
- **S9:** Provides transfer of (QoS) policy and charging control information between the Home PCRF and the Visited PCRF in order to support local breakout function.
- **S10:** Serves as a reference point between MMEs for MME relocation and MME to MME information transfer.
- **S11:** Serves as a reference point between MME and Serving GW.
- **S12:** Serves as a reference point between UTRAN and Serving GW for user plane tunneling when Direct Tunnel is established. It is based on the Iu-u/Gn-u reference point using the GTP-U protocol as defined between SGSN and UTRAN or respectively between SGSN and GGSN. Usage of S12 is an operator configuration option.
- **S13:** Enables UE identity check procedure between MME and EIR.
- **SGi:** Reference point between the PDN GW and the packet data network. Packet data network may be an operator external public or private packet data network or an intra operator packet data network, e.g. for provision of IMS services. This reference point corresponds to Gi for 3GPP accesses.
- **Rx:** The Rx reference point resides between the AF and the PCRF in the TS 23.203.

5.1.5 Interfaces & Protocols for non-3GPP accesses

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

- **S2a:** The S2a interface provides the user plane with related control and mobility support between trusted non 3GPP IP access and the PDN Gateway. S2a is based on Proxy Mobile IPv6 (PMIP) and to support accesses that do not support PMIP also Mobile IPv4.
- **S2b:** The S2b interface provides the user plane with related control and mobility support between ePDG and the PDN Gateway. S2b is based on the Proxy Mobile IPv6 (PMIP).

- **S2c:** The S2c interface provides the user plane with related control and mobility support between UE and the PDN Gateway. It is implemented over trusted and/or untrusted non-3GPP Access and/or 3GPP access and it is based on the DS-MIPv6 protocol.
- **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.
- **S101**: Enables interactions between EPS and HRPD access to allow for pre-registration and handover signaling with the target system.
- **S103**: This User Plane interface is used to forward DL data to minimize packet losses in mobility from E-UTRAN to HRPD.

5.1.6 System Aspects

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

5.1.6.1 QoS and Bearer Concept

Within EPS, a logical concept of a bearer has been defined to be an aggregate of one or more IP flows related to one or more services. The bearer concept is valid for GTP, pip 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).

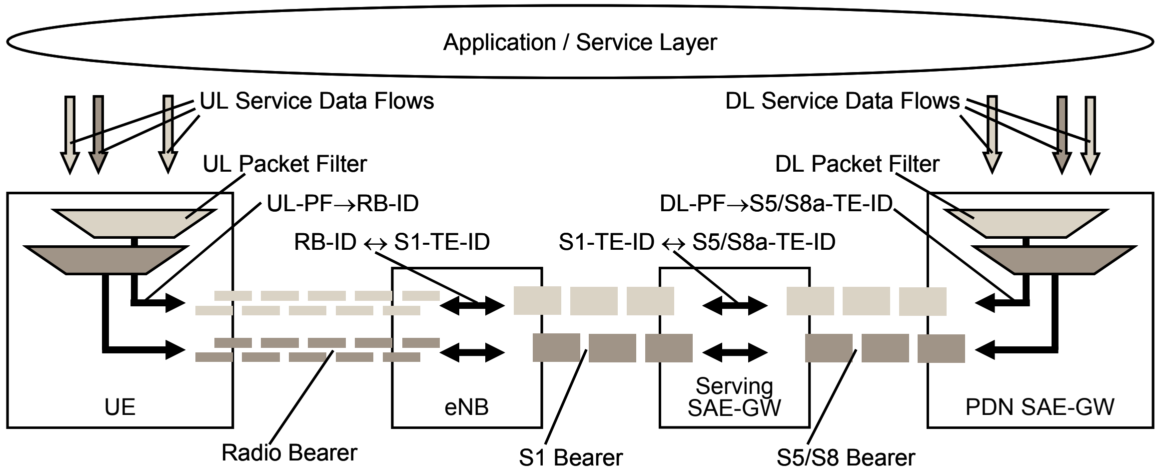


Figure 11. Two Unicast bearers (GTP-u Based S5/S8)[145]

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.

5.1.6.2 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.

5.1.6.3 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.

5.1.6.4 Security Aspects

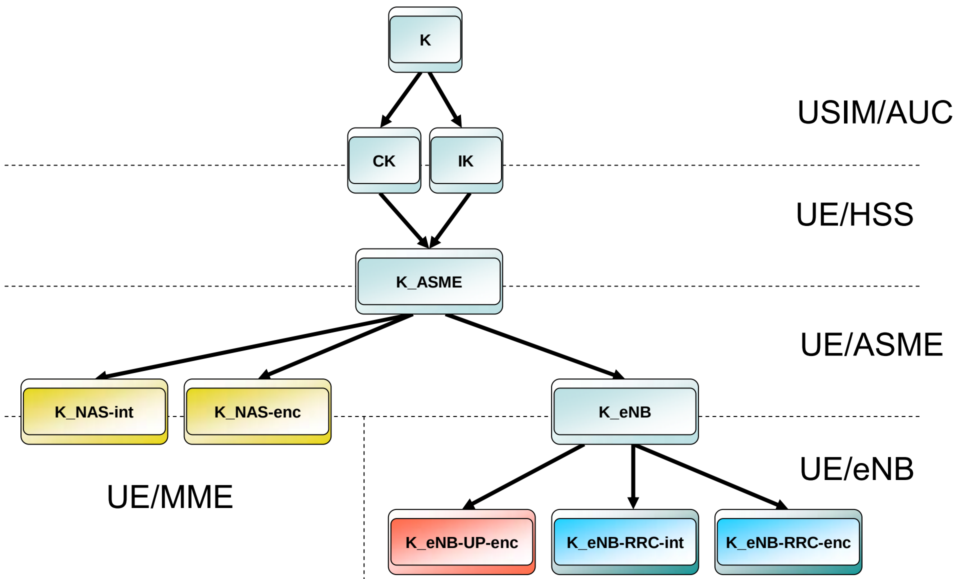
This section will discuss certain security aspects of the EPS, namely Subscriber Authentication and Traffic Protection.

<u>Subscriber Authentication</u>

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.

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

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[146]

<u>Traffic Protection</u>

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.

[146] Ericsson. Q2 2007.

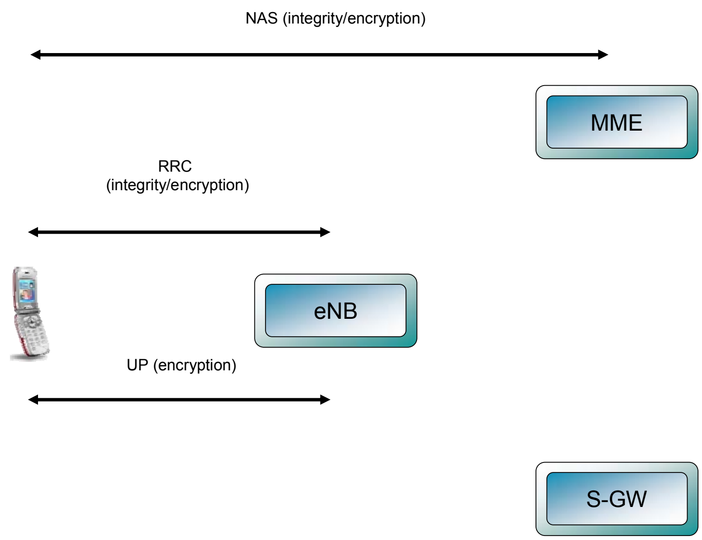


Figure 13. Security termination points for traffic to/from the UE[147]

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.

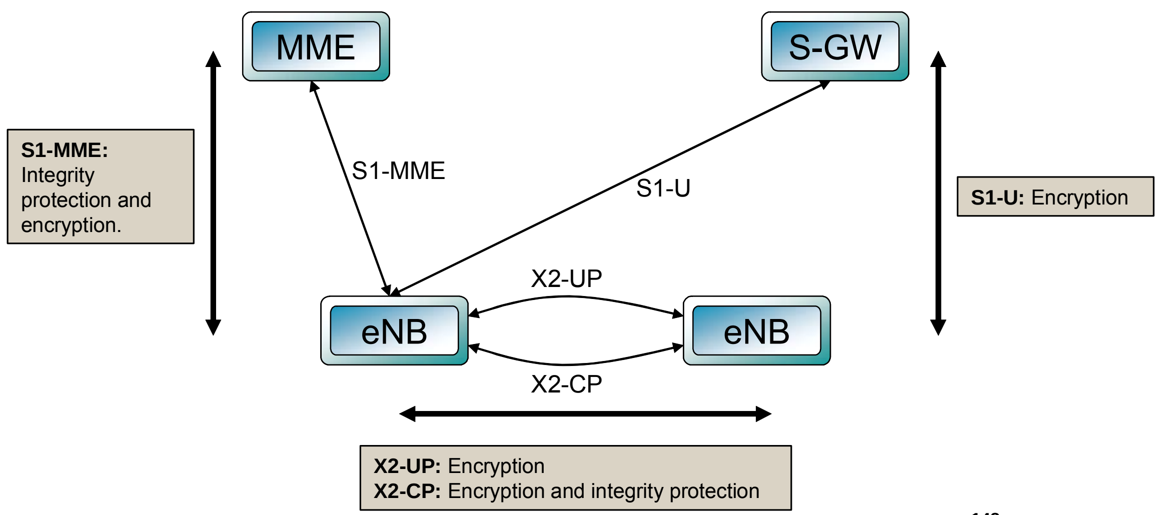


Figure 14. Security termination points for traffic internal to EPS[148]

5.1.6.5 Roaming and Non-Roaming Scenarios

One of the important aspects of the EPS is the support of roaming. Within the EPS specification, there are two documents focused on roaming aspects: TS 23.401 focuses on 3GPP access roaming (and specifically GTP based roaming, over the 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.

[147] *Ibid.*
[148] *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.

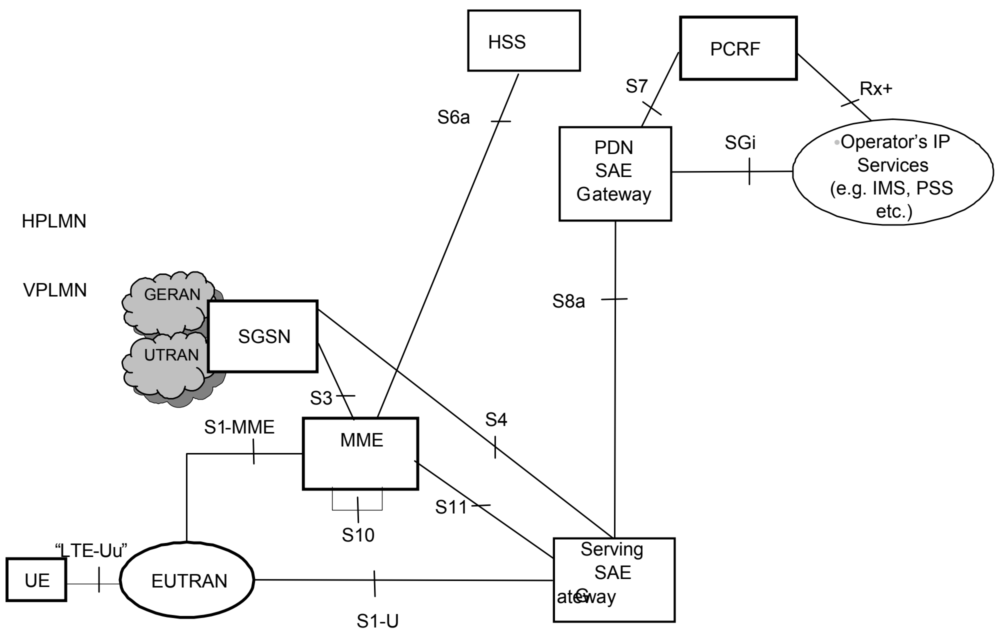
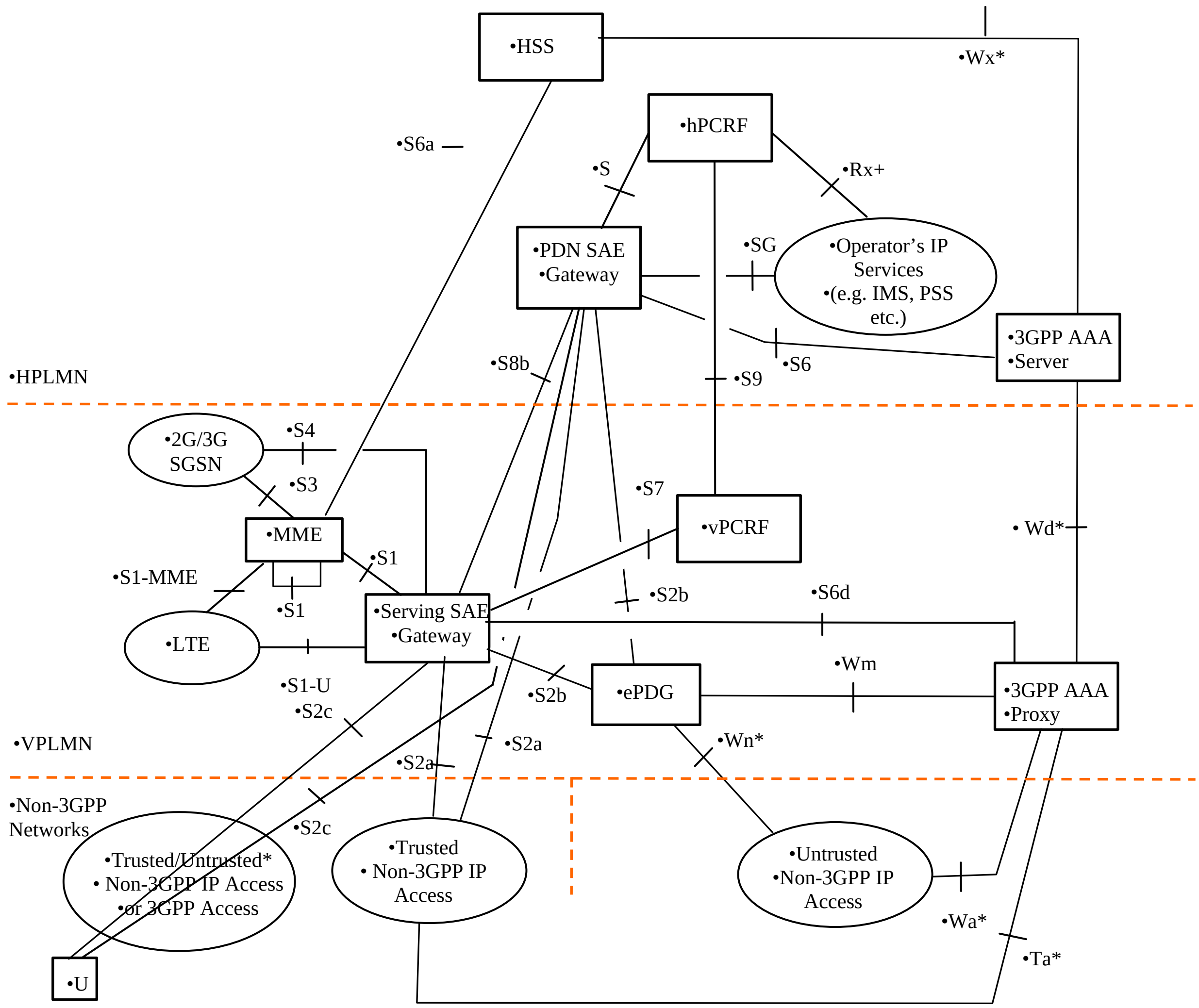


Figure 5. Roaming architecture (home routed case, 3GPP only networks)[149]

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



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

Figure 16. Roaming architecture (home routed case, including non-3GPP networks)[150]

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 focuses 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

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

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

5.2.1.1 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).

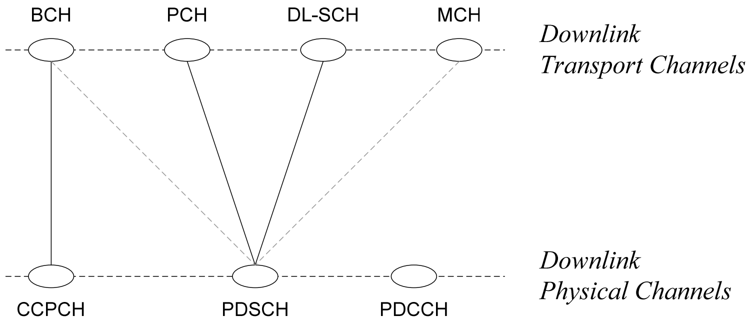


Figure 17. Mapping between downlink transport channels and downlink physical channels[151]

5.2.1.2 LTE Downlink Frame Structure and Numerology

Table 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 . Typical parameters for downlink transmission scheme[152]

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.

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

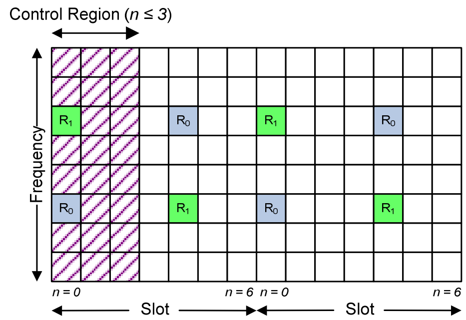


Figure 18. E-UTRA downlink sub-frame structure[153]

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 $N_{\mathrm{symb}}^{\mathrm{DL}}$ consecutive OFDM symbols in the time domain and $N_{\mathrm{BW}}^{\mathrm{RB}}$ consecutive subcarriers in the frequency domain. Thus, a resource block consists of $N_{\mathrm{symb}}^{\mathrm{DL}} \times N_{\mathrm{BW}}^{\mathrm{RB}}$ resource elements, corresponding to one slot in the time domain and 180 kHz in the frequency domain as shown in Table (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).

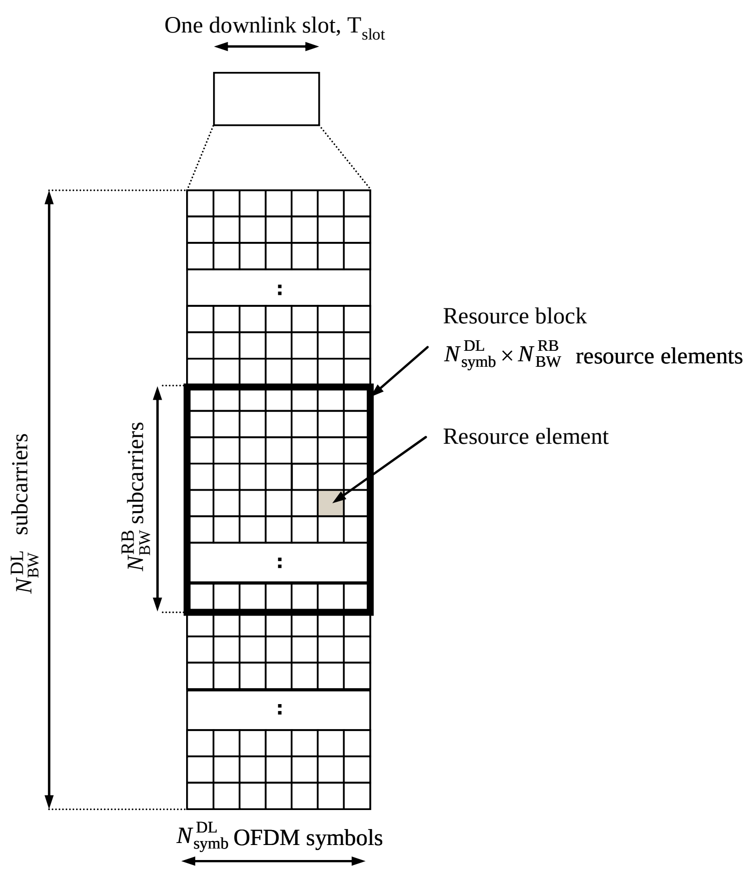


Figure 19. Downlink Resource Grid[154]

153 *Physical Channels and Modulation*. 3GPP TS 36.211.
154 *Ibid.*

Table . Resource block parameters.[155]

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

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

5.2.1.3 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.

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[155] *Ibid.*

Table 3. Example predefined coding rates[156]

#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

DL ACK Channel

The downlink acknowledgment comprises of one-bit control information sent in association with uplink data transmission. The resources used for the acknowledgment channel are configured on a semi-static basis and are defined independently of the grant channel (i.e. a set of resource elements (REs) are semi-statically allocated for this purpose). Because only one information bit is to be transmitted, a hybrid of CDM/FDM multiplexing among acknowledgments is used. Hybrid CDM/FDM allows for power control between acknowledgments for different users and provides good interference averaging. In addition, it can provide frequency diversity for different users.

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.

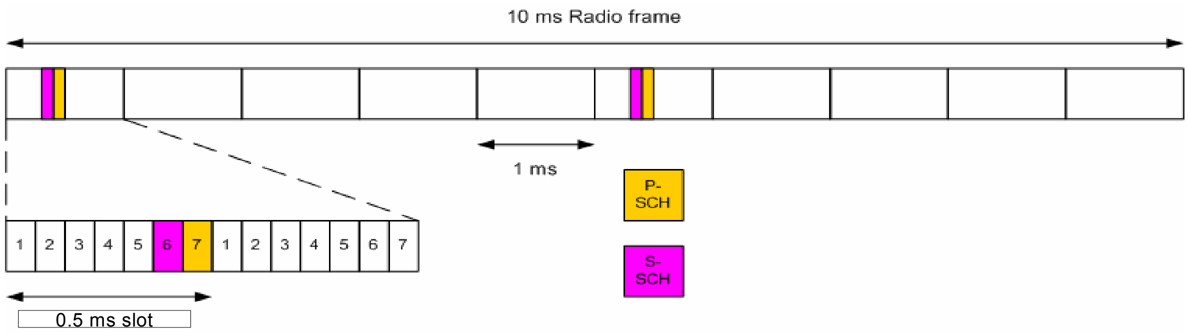

Figure 20. SCH Frame Structure[157]

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.

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

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

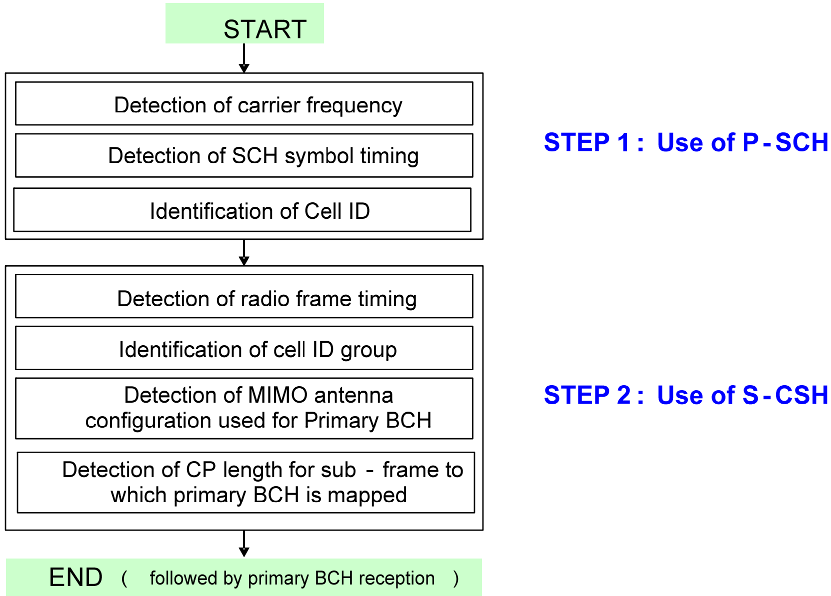

Figure 21. Cell Search Flow Diagram[158]

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 . 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.

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

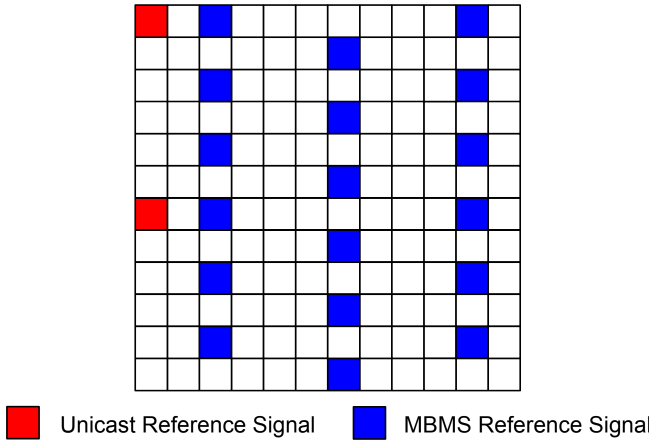

Figure 22. Reference signal structure for mixed carrier MBSFN[159]

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.

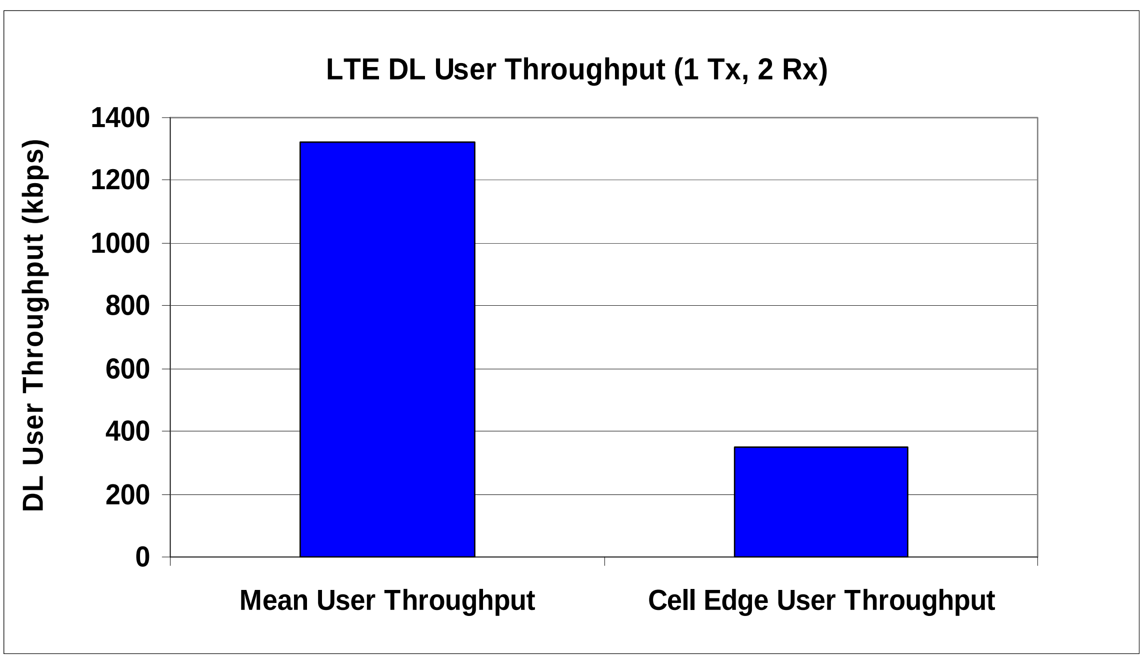

Figure 23. LTE DL User throughput[160]

[159] *Physical Channels and Modulation*. 3GPP TS 36.211.
[160] *LS on LTE Performance Evaluation Work*. 3GPP TSG R1-072580 RAN WG1#49

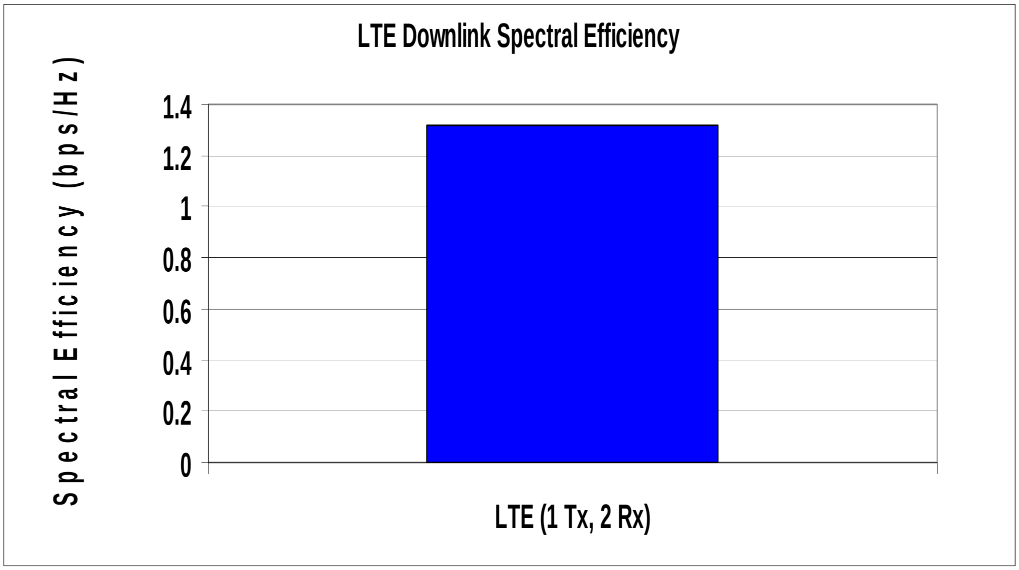

Figure 24. LTE DL Spectrum efficiency[104]

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.

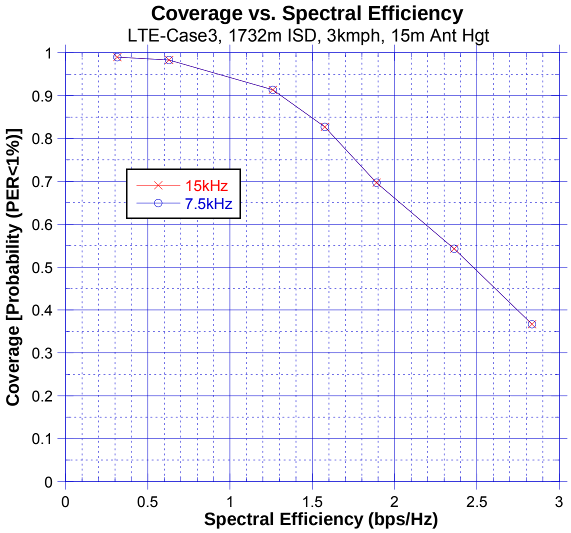

Figure 25. Coverage vs. spectral efficiency at 3km/hr[161]

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

[161] *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.

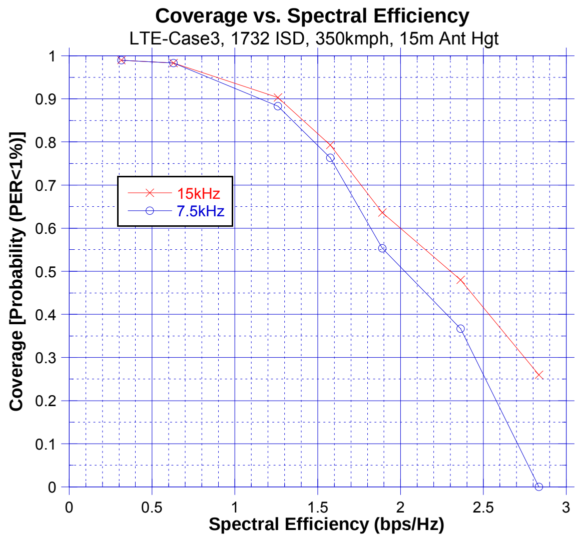

Figure 26. Coverage vs. spectral efficiency at 350kmph[162]

DL Scheduling and Resource Allocation

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

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.

[162] *Ibid.*

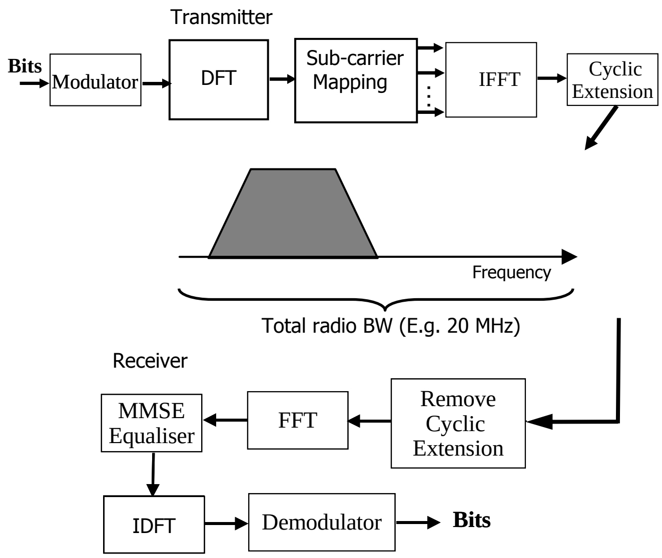

Figure 27. SC-FDMA transmitter and receiver chains with frequency domain equalization[163]

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).

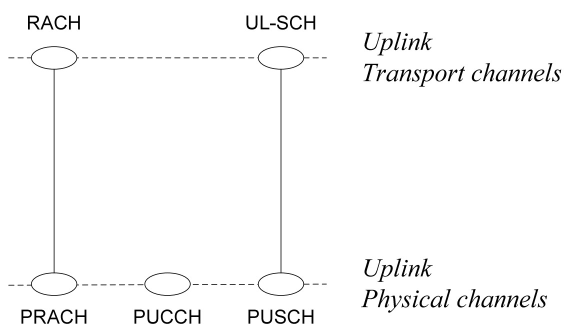

Figure 28. Mapping between uplink transport channels and uplink physical channels[164]

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

[163] 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.

[164] *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.

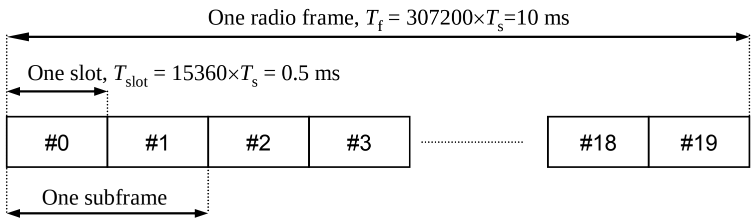

Figure 29. Frame structure type 1[165]

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

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

5.2.2.3 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 signalling;
- 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.

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

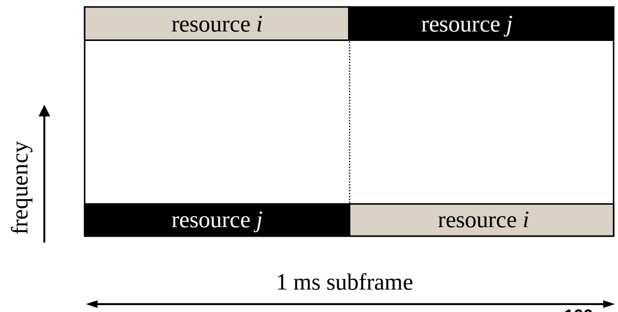

Figure 30. Physical uplink control channel[166]

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.

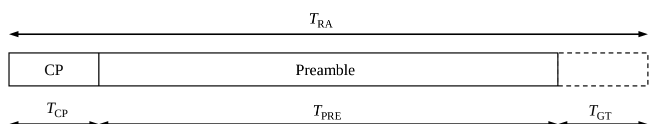

Figure 31. Random access preamble format (generic frame structure)[167]

Table 4. Random access burst parameters.[168]

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

[166] *Ibid.*
[167] *Ibid.*
[168] *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 six 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.

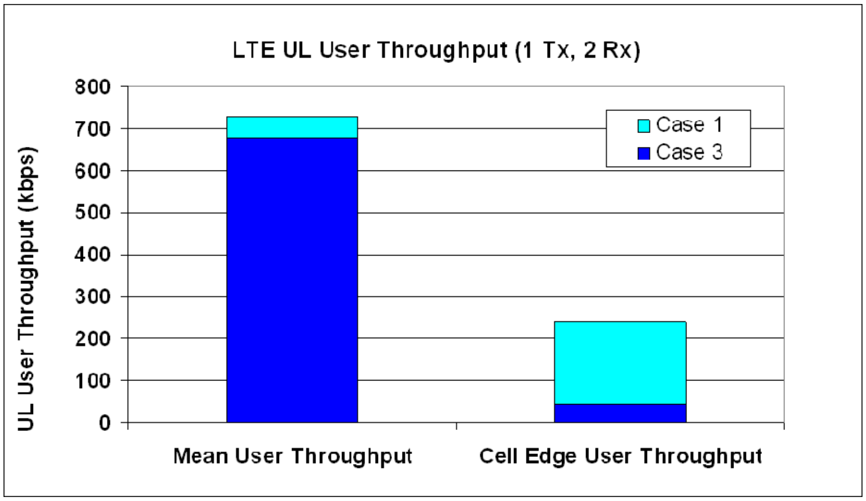

Figure 32. LTE UL User throughput[169]

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

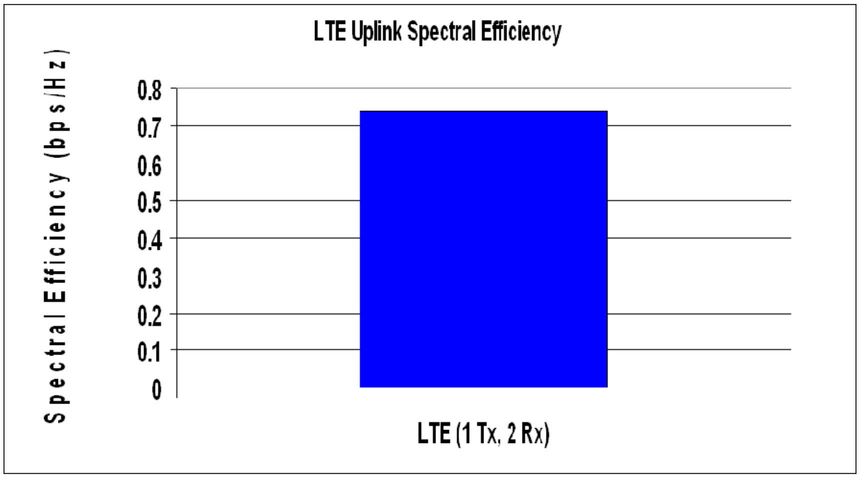

Figure 33. LTE UL Spectrum efficiency[170]

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.

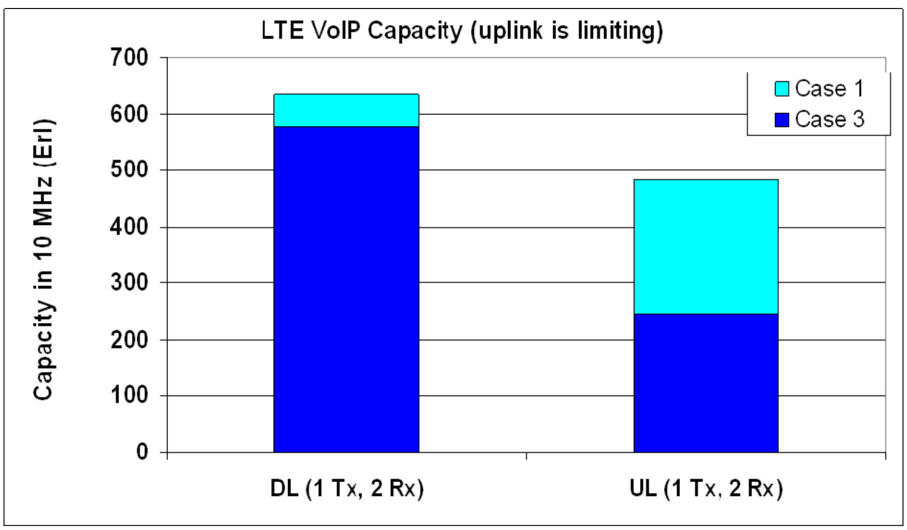

Figure 34. LTE VoIP capacity[171]

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.

[170] *Ibid.*
[171] *Ibid.*

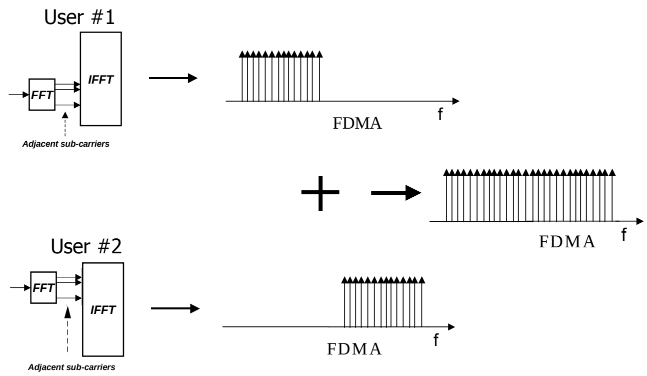

Figure 35. The principle of frequency domain scheduling in EUTRAN[172]

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.

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

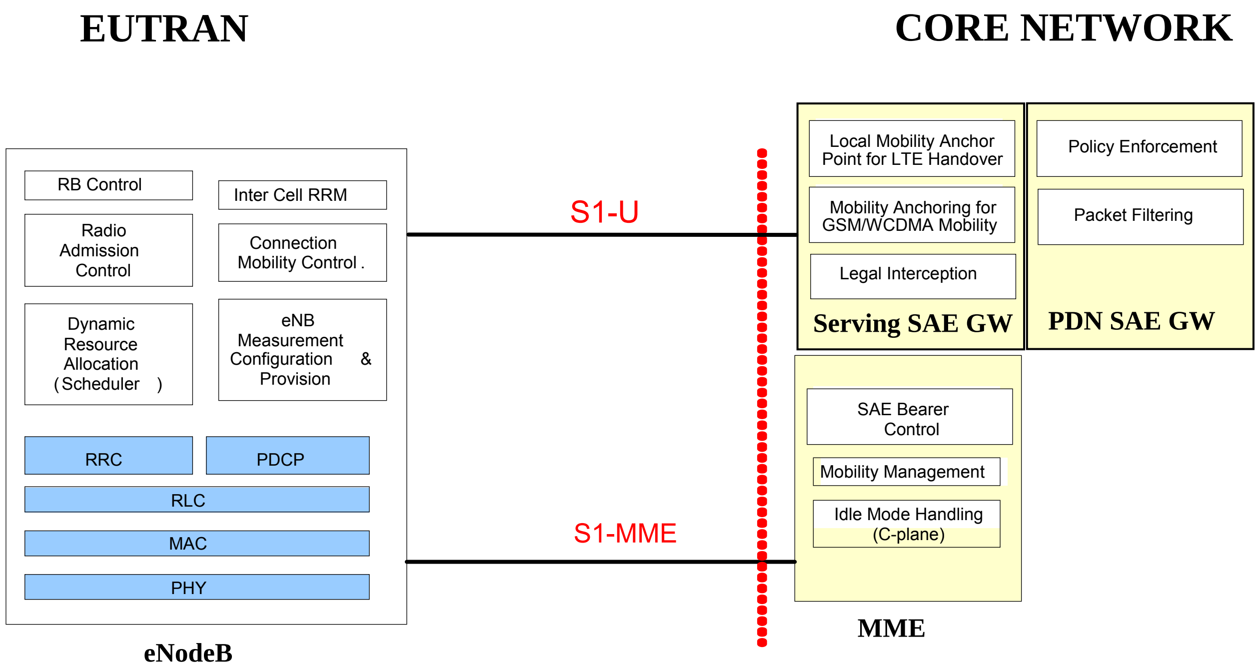

Figure 36. Functional Split between radio access and core network [173]

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, 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 that 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; more notably the current deployment of TD_SCDMA in China.

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

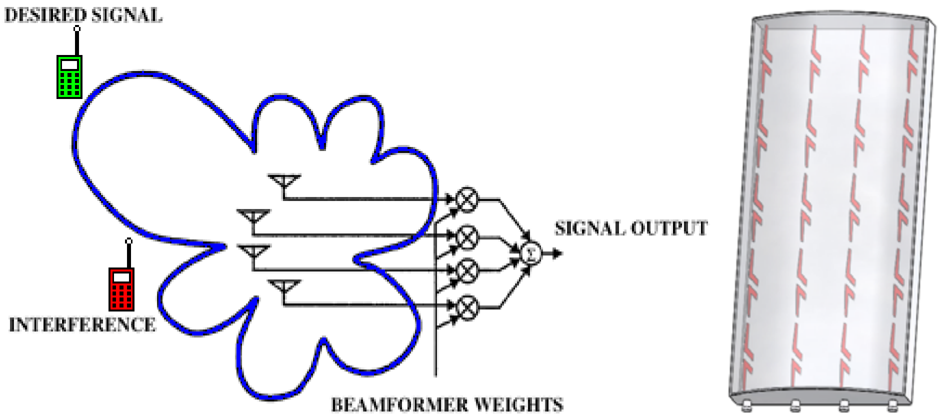

Figure 37. Conceptual depiction of an AA system implemented with 4-column, vertically polarized planar array[174]

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.

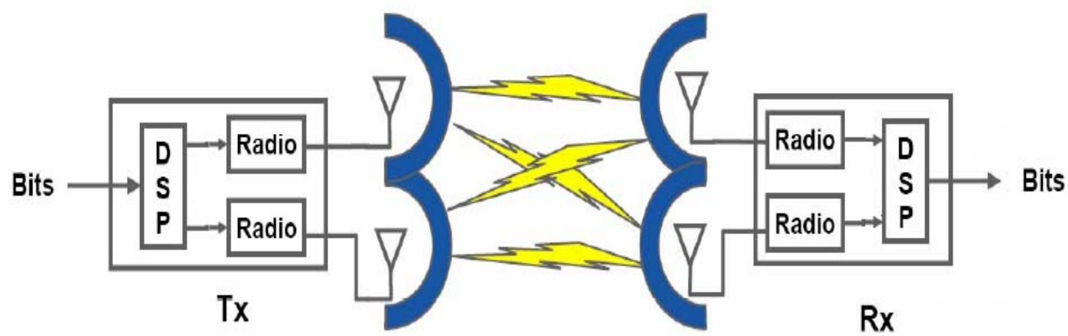

Figure 38. 2x2 MIMO system[175]

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).

[174] Reference unknown

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

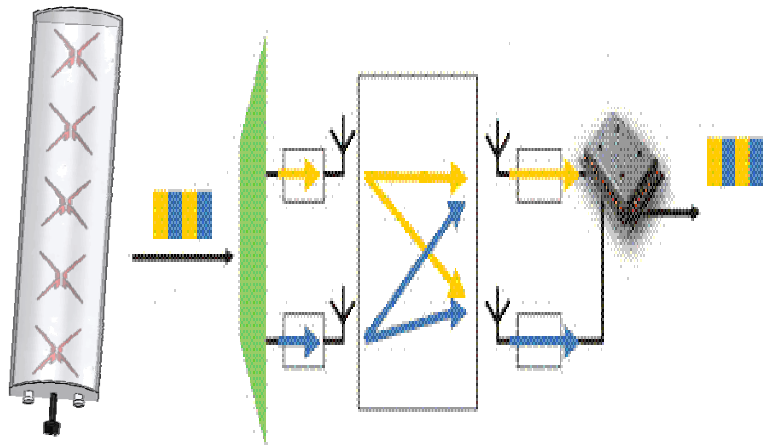

Figure 39. Conceptual depiction of a 2x2 MIMO system implemented with dual-pole, slant-45 base station antenna and two antennas in the UE[176]

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).

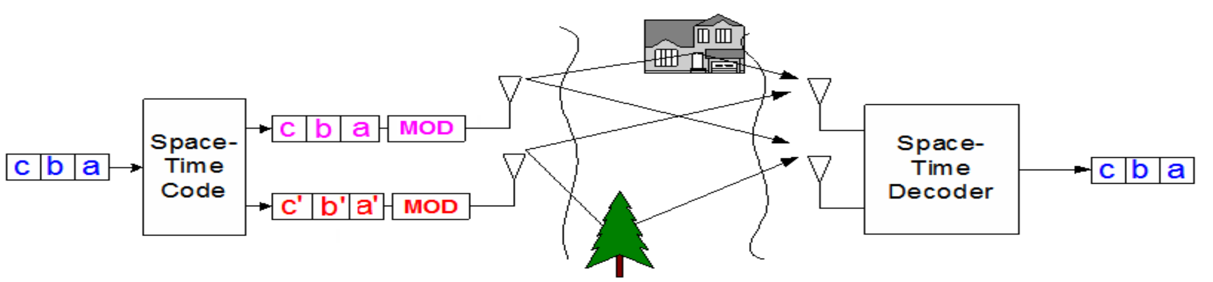

Figure 40. Illustration of Space Time Coding in a 2x2 MIMO system[177]

MIMO: Spatial Multiplexing
Spatial Multiplexed MIMO systems increase spectral efficiency by utilizing powerful signal processing algorithms to exploit multi-path propagation in the MIMO communications link. Independent data streams, using the same time-frequency resource, are each sent over a transmit antenna, providing multiplexing gain, resulting in increased system capacity (see figure 41).

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

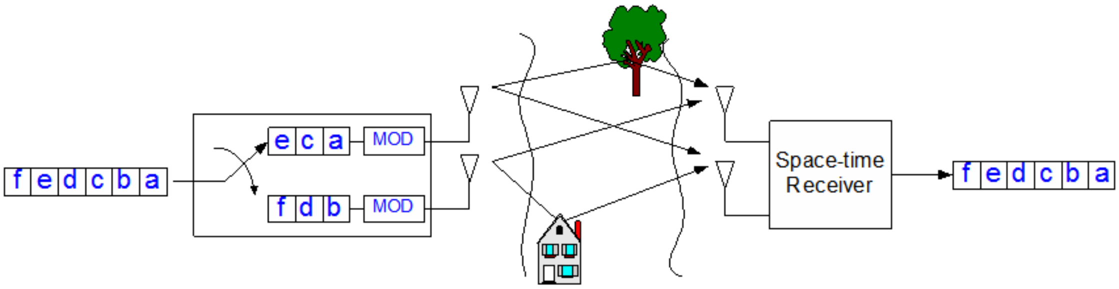

Figure 41. Illustration of Spatial Multiplexing in a 2x2 MIMO system[178]

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

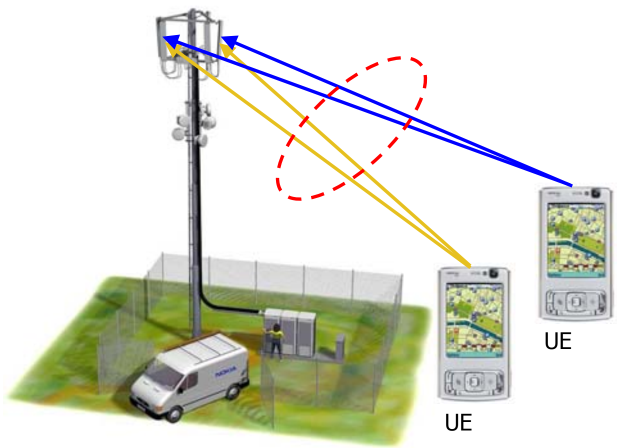

Figure 42. The basic principle of uplink MU-MIMO with 2x2 antenna configuration[179]

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.[180] 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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[178] Bhagavatula, Ramya and Dr. Robert Heath, Jr. "Analysis of MIMO Antenna Designs for 3GPP – LTE Cellular Systems." Wireless Networking and Communications Group. The University of Texas at Austin. 8 June 2007.

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

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

Downlink

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

- Precoding vector: 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 two antennas but also two parallel RF Tx chains in the UE. This implies an increase in complexity compared to MU-MIMO, which doesn't require any additional measures at the UE. Therefore, it has been agreed to incorporate only MU-MIMO in the first LTE release and to incorporate SU-MIMO in the 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.[181] 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.

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

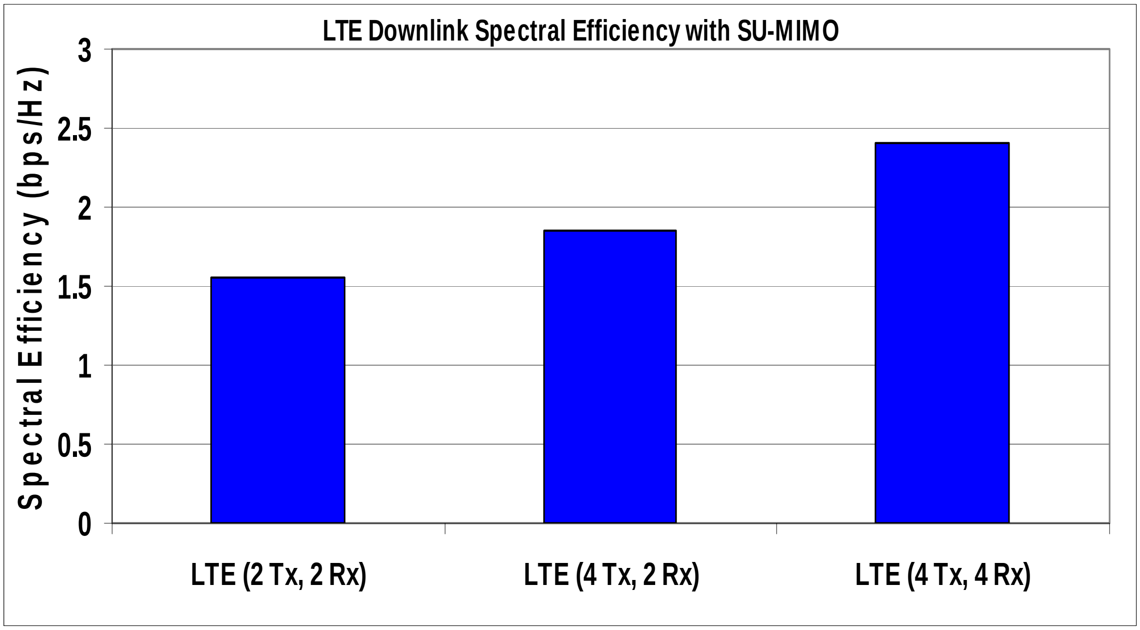

Figure 43. LTE Downlink Spectral Efficiency Performance with multi-antennas[182]

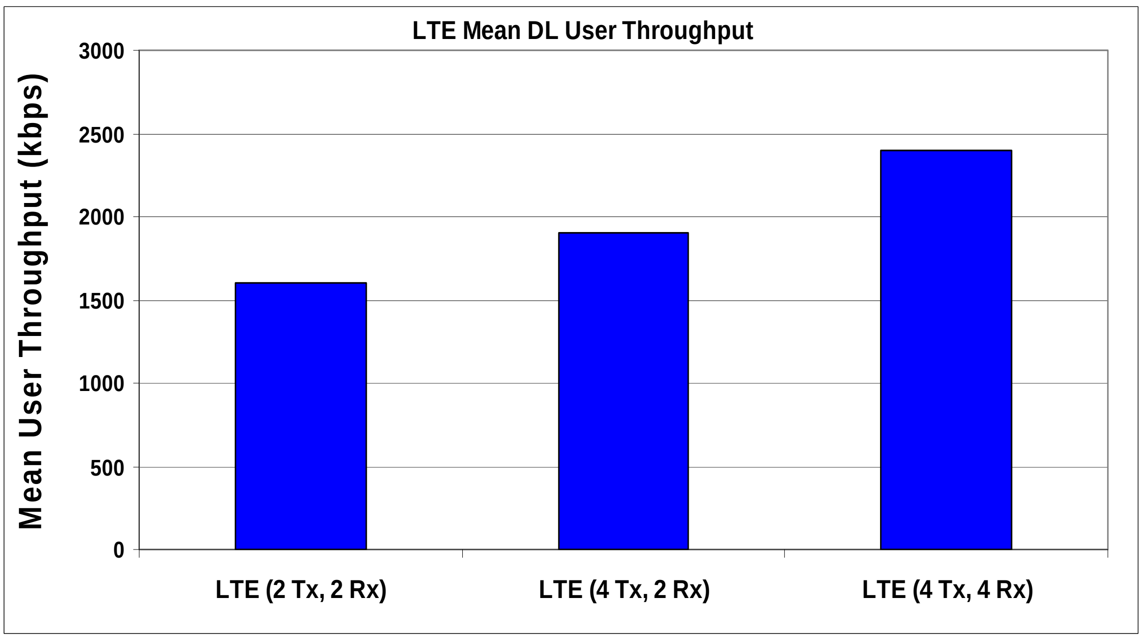

Figure 44. LTE Downlink Mean User throughput Performance with multi-antennas[183]

[182] *Ibid.*
[183] *Ibid.*

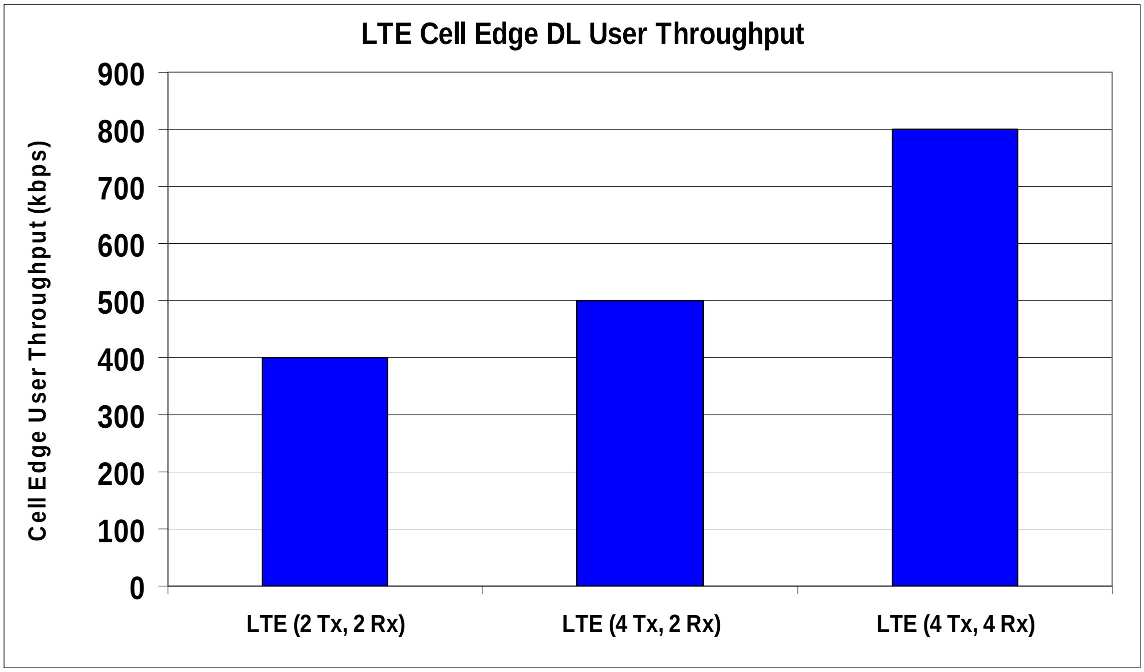

Figure 45. LTE Downlink Cell EDGE Performance with multi-antennas[184]

Uplink Performance

An aggregate performance summary of several MIMO configurations, as evaluated by various 3GPP members, has been compiled by the 3GPP.[185] 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.

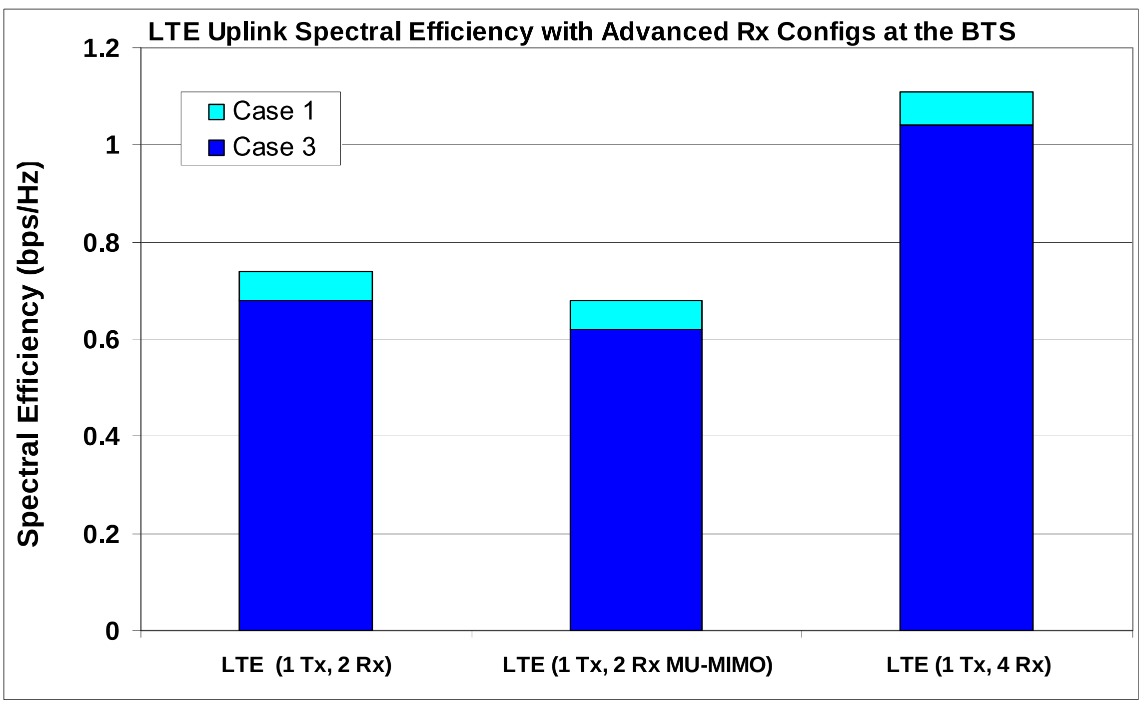

Figure 46. LTE Uplink Spectral Efficiency Performance with multi-antennas[186]

[184] *Ibid.*
[185] *Ibid.*
[186] *Ibid.*

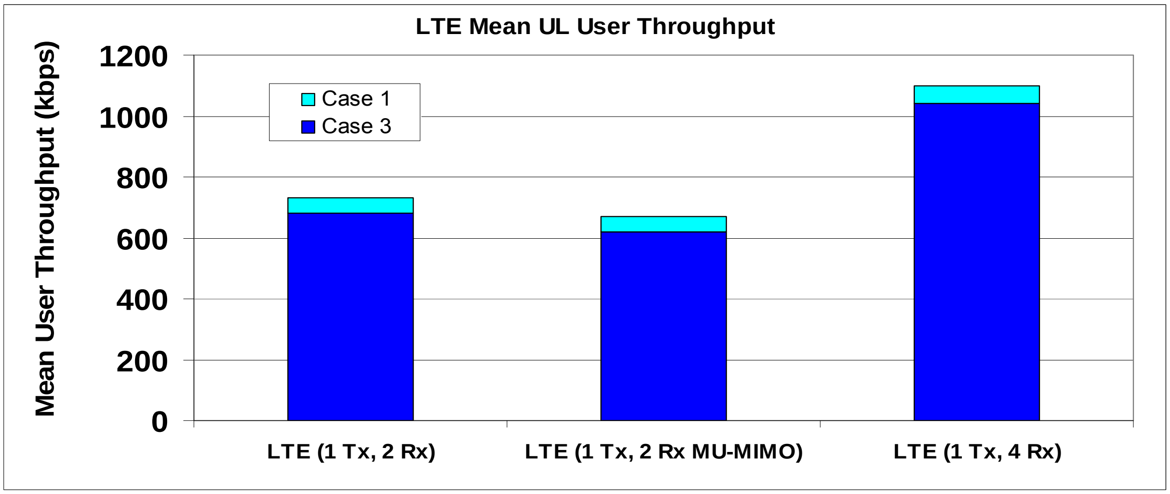

Figure 47. LTE Uplink Mean Throughput Performance with multi-antennas[187]

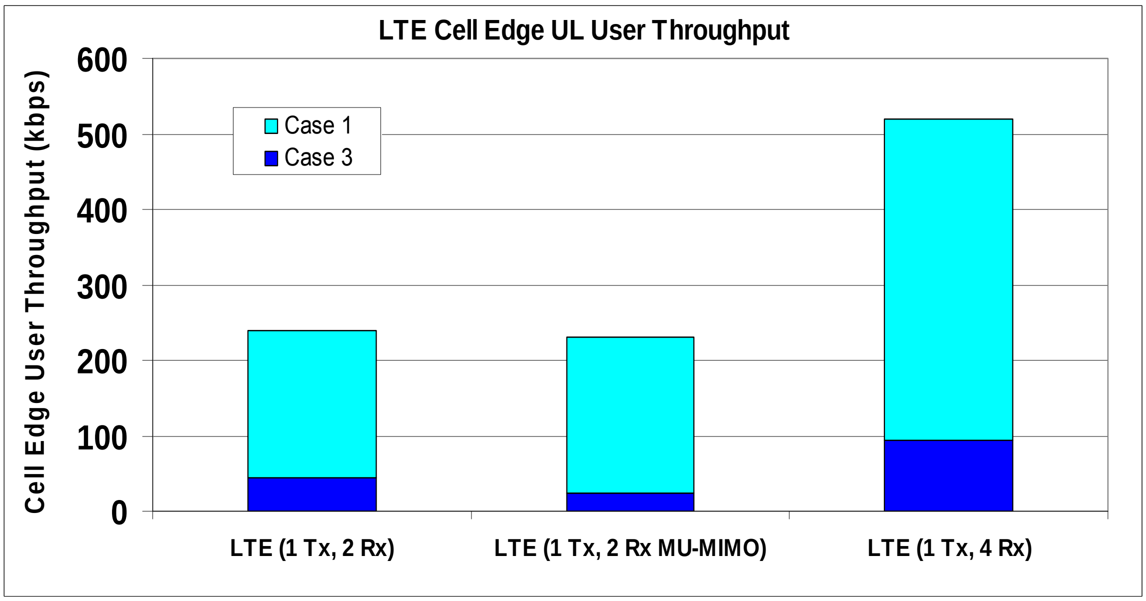

Figure 48. LTE Uplink cell edge performance with multi-antennas[188]

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).

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

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[187] *Ibid.*
[188] *Ibid.*

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).

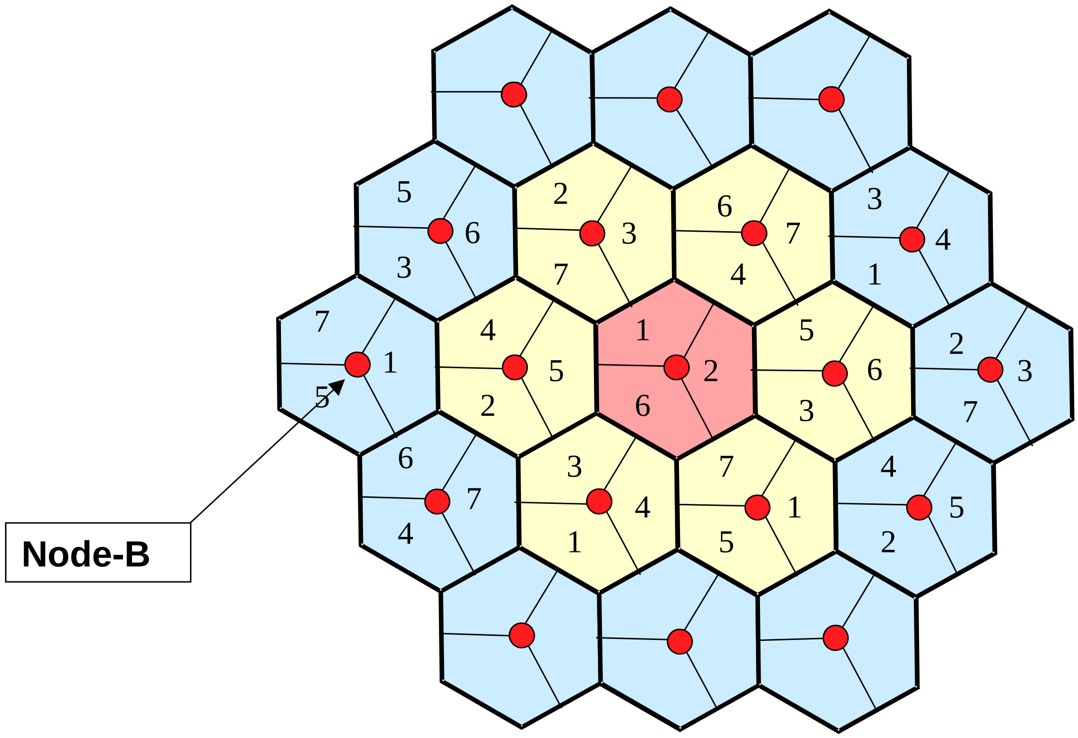

Figure 49. Cell planning for inverted re-use 7 scheme (FFR=6/7)[189]

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 act again.

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. For 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 include traffic-distribution within the different cells, downlink interference contribution from cell A to cell B, etc.) as well as the actual reconfiguration decisions. The signaling rate is in the order of tens of seconds to minutes.

[189] 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.

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

In this good-natured circle it becomes more and more important to provide an ever improving performance with higher peak rates, lower latency, etc. and above all it is important to deploy more spectrally and cost efficient systems that can handle the increasing demands with a relatively low marginal cost. This paper has described how the evolutionary 3GPP roadmap introduces new features in Rel-7 and Rel-8 to accommodate this continuous need for improvements. 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 specifications were approved by 3GPP in January 2007. The specifications are now under change control, leading to their inclusion in the forthcoming 3GPP Rel-8.

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* plays a significant role in the commercialization of the HSPA technology, from powering the first two commercial HSDPA network launches in the world back in 2005 – Cingular in the United States (now AT&T) and Manx Telecom (a wholly owned subsidiary of O2) on the Isle of Man – to supporting 30 percent of the commercial HSUPA networks deployed worldwide in early 2008. Alcatel-Lucent has seen rapid adoption of HSPA data services on its customer networks; the company saw HSDPA overtake R99 data services as of December 2006, six months before that milestone was achieved in the broader market (according to a report from Rysavy research published in September 2007).

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 already started in 2007, although none are yet publicly disclosed.

These developments, as well as expertise gained through the development of OFDM radio technology used in other standards (WiMAX, UMB, DVB-H), give Alcatel-Lucent invaluable experience in the development of best-in-class LTE 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. On November 15, 2007 Alcatel-Lucent and LG Electronics announced that the two companies have completed LTE test calls using Alcatel-Lucent's LTE solution and mobile device prototypes from LG. This accomplishment — one of the industry's first multi-vendor, over-the-air LTE interoperability testing initiatives — highlights the strength of the two companies' LTE development efforts and represents a key milestone in the commercialization of this next-generation wireless technology.

Alcatel-Lucent also demonstrated a live 2x2 LTE solution in 20MHz at both the Mobile World Congress 2008 and CTIA Wireless 2008, demonstrating our advanced development of LTE. In February 2008, Alcatel-Lucent announced a joint venture with NEC to jointly develop LTE solutions, leveraging the significant experiences of both companies and focused on leading the LTE market with best-in-class products. 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.

Alcatel-Lucent currently has more than 40 UMTS/WCDMA 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 SFR, Globacom (Nigeria), Telecom New Zealand and more. In a report published in February 2008, UBS calculated that with 12 new UMTS contracts in 2007, Alcatel-Lucent secured 24% of the contract wins available in 2007, being positioned as a strong number two in this regard.

Ericsson is the leading supplier to the world's HSPA networks. In December 2005, Cingular Wireless (now AT&T) launched the first commercial HSPA network using Ericsson equipment. By, March 2008, Ericsson equipment powered 90 of the 185 commercially launched HSPA networks worldwide, with many additional ongoing deployments.

Ericsson's HSPA mobile broadband solutions, part of Ericsson's Full Service Broadband offering, today support up to 14.4 Mbps on the downlink and 1.4 Mbps on the uplink. The advanced technology lets operators more than double their system capacity and cuts response times for interactive services. On average, users will be able to download 20 times faster than with a GSM/GPRS connection. Future evolution steps will increase the HSPA download speed to 42 Mbps and the upload speed to 12 Mbps. Ericsson offers HSPA support on many frequency bands ranging from 850 MHz to 2.6 GHz.

Ericsson conducted the world's first demonstration of end-to-end HSPA Evolution technology with speeds of up to 42 Mbps at CTIA Wireless 2008. Speeds of up to 42 Mbps represent the next phase in HSPA Evolution. These speeds are achieved by combining new higher order modulation technology (64QAM), together with 2x2 Multiple Input Multiple Output (MIMO) antenna technology. The demonstration was made using a handheld form-factor device based on Ericsson Mobile Platforms access technology.

Ericsson's WCDMA/HSPA Radio Access Network solutions offer an evolutionary path for HSPA Evolution. For example, the RBS 3000 family of Ericsson base stations has support for both HSPA Evolution and LTE.

Ericsson's next-generation radio base station family, the RBS 6000 series, offers an enhanced multi-standard solution that supports GSM/EDGE, WCDMA/HSPA Evolution and LTE, all in a single package. This energy-efficient site solution is the smallest on the market.

The RBS 6000 series products are available in indoor, outdoor and main-remote packages. The compact design requires only 25 percent of the space used by previous generations while at the same time doubling capacity. The RBS 6000 series reduces power consumption by 20 to 65 percent, compared with existing Ericsson radio base stations, and offers a simple, energy-efficient site solution that helps operators reduce costs across all areas of ownership.

The improved speed will assist operators in leveraging existing network infrastructure to meet growing consumer appetite for advanced multimedia services. Consumers can enjoy an even richer communications experience thanks to the higher speeds, while operators can reduce network operating costs via increased throughput enabled by HSPA Evolution.

A complete HSPA-based mobile broadband network with a wide range of commercially available services is on display in Ericsson's Experience Center located in its North American headquarters in Plano, TX.

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.

Ericsson has a long term vision to bring mobile broadband to all notebooks and connected devices. Market projections indicate that in 2011, approximately 200 million notebooks will ship annually, and Ericsson anticipates that 50 percent of those notebooks will feature a built-in HSPA mobile broadband module.

Mobile Broadband Modules, designed and manufactured by Ericsson, support HSPA, EDGE, GPRS and GSM. HSPA modules will initially offer peak rates of 7.2Mbps in the downlink and 2Mbps in the uplink. Ericsson's Mobile Broadband Modules boost the accelerating growth of the mobile broadband market by expanding the HSPA ecosystem.

Ericsson's mobile broadband modules provide the end user with a simple and cost effective solution for broadband access while on the go. Seamlessly integrated with and optimized to work within the notebook, the built-in mobile broadband module provides superior downloading and uploading performance and takes less power from the battery. The module also has a GPS receiver, to be used together with positioning applications. Leveraging Ericsson's in-house HSPA chipset technology, and the company's economies of scale and longstanding operator relationships, Ericsson offers a very competitive mobile broadband module solution that will help further drive a mass market for mobile broadband.

In February 2008, Ericsson announced that Lenovo would be its first mobile broadband module customer and select Lenovo ThinkPad notebooks would include mobile broadband modules beginning in 2008.

In May 2008, Ericsson announced that Dell would offer built-in HSPA mobile broadband modules from Ericsson in their next-generation laptops beginning in Q2 2008 to support seamless roaming on tri-band HSPA mobile broadband networks.

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

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

- **DVD quality video streaming at 4 Mbps over TCP-IP** from the UICC **with parallel gaming** via a browser session: In this demonstration presented in October 2007, a consumer launches the phone's browser and views a video streamed directly from the UICC while simultaneously playing a game of Othello.
- **Offline operator services portal based on Smart Card Web Server technology:** In this demonstration, the consumer views xHTML pages with top ten music and videos that can be trialed and purchased. These xHTML pages, stored in the UICC, can be browsed using the wap browser of the handset and provide shortcuts to launch premium SMS services, set up calls, or manage local UICC NFC applications. Gemalto demonstrated two implementations of the interface: one with the BIP TCP Server over classic ISO and another with TCP-IP over USB-IC.
- **Contactless transit, payment, and smart poster applications processed in the UICC for NFC trials**. Overall, Gemalto demonstrated that the UICC can run the MasterCard Paypass, Visa Paywave, JCB, and PBOChina contactless payment applications in separate security domains, with multiple instantiations (i.e. multiple credit cards using the same application), and remote personalization (i.e. credit card remote issuance in the UICC). For richer brand presentation during transactions, Gemalto relied on the Single Wire Protocol (Release 7), HCI and the Smart Card Web Server. The Single Wire Protocol was demonstrated with LG, Motorola, Nokia, Sagem, and Samsung devices.

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

Huawei Technologies is a global organization and a leader in innovative telecommunications products and technology, providing next generation networks for 70% of the world's top 50 operators and enabling telecommunications services for well over 1 billion subscribers. Huawei's R&D strengths and innovative products have resulted in their being ranked as one of the top tier mobile network providers. As of the end of 2007, Huawei has won more than 151 3G commercial contracts comprising 86 UMTS/HSPA contracts. In 2007, Huawei won 44 newly-added UMTS commercial contracts holding the No.1 position with 45% share. Moreover, Huawei's 3G-oriented EnerG GSM solution also made great strides and as of the end of 2007, the shipments of GSM BTS exceed 1.5 million TRXs.

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

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

- January 2006: Huawei launched the first HSDPA commercial network in Europe in Portugal for Optimus, supporting downlink speeds of 14.4Mbps following the success of a pilot trial begun in May 2005.
- April 2006: Huawei demonstrated the first UMTS base station solution for the AWS band at CTIA Wireless.
- June 2006: PCCW launched its first 3G MobileTV service using Huawei's innovative Cell Multimedia Broadcast (CMB) technology over a Huawei deployed HSDPA network.
- January 2007: A new international high speed benchmark was established after a successful test on Shanghai's Maglev Railway, demonstrating strong HSDPA performance at a speed of 430 km/h. Huawei-patented Doppler Frequency Shift Cancellation technology along with robust handover algorithms were instrumental in demonstrating average HSDPA throughputs of 1.8 Mbps (Category 6 UE) and 1.3 Mbps (Category 3 UE).
- February 2007: Huawei, partnering with Qualcomm, showcased the first demonstration of MBMS at the 3GSM World Congress. The solution was based on the MSM7200 chipset and demonstrated reception of TV programs at 256 Kbps over a UMTS/HSPA network. In the same timeframe, Huawei released the world's first HSUPA USB modem with ability to support 7.2 Mbps downlink and 2 Mbps uplink data rates. These achievements were followed by the deployment of the first commercial HSUPA-network in Asia-Pacific for StarHub in Singapore.

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

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

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

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

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

***Motorola*'s** UMTS/HSPA solutions are designed to address the very specific needs of service providers worldwide and make the most of today's challenging market environment. 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 opportunities to minimize Total Cost of Ownership. For example Motorola's solutions employ the latest design and technologies such as power amplifiers that feature Digital Pre-Distortion and Doherty techniques to maximize efficiency, minimize running costs and ultimately reduce the network's impact on the environment.

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 also 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 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.

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

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

Motorola started operator lab trials in 2007 and is currently involved in a number of operator field trials and working with LSTI on additional trial and interworking activities. In March 2008, Motorola introduced its new OFDM common broadband solution (for LTE); this 3rd generation OFDM platform leverages Motorola extensive OFDM mobile broadband expertise and will be commercially available for LTE networks by end of 2009, giving Motorola the advantage of deploying LTE technology on a field proven platform.

Nokia Siemens Networks started operations on April 1, 2007, assuming a leading position in the global communications infrastructure market with nearly 600 customers in 150 countries, meeting the challenge of enabling five billion people to be connected by the year 2015. Nokia Siemens Networks provides a full range of solutions, products and applications for fixed, mobile and converged networks across its five business units – Radio Access, Broadband Access, Converged Core, IP Transport, and Operations and

Business Software. Leveraging the customer-focused research and innovation strengths of its parent companies, Nokia and Siemens, NSN is in a unique position to deliver 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.

At the forefront of UMTS/HSPA development, Nokia Siemens Networks is the global UMTS/HSPA industry leader with over 120 UMTS/WCDMA radio network references worldwide, and its HSPA solution is in full use worldwide and enables over 100 HSPA networks globally (as of April 2008).

At the heart of Nokia Siemens Networks' evolution in HSPA is its Flexi Base Station platform. The revolutionary and modular platform supports GSM/EDGE, UMTS/HSPA, WiMAX and in the near future LTE radio technologies. It is the smallest, most energy efficient multi-technology base station platform with the highest power, which minimizes deployment and operational costs for operators. Due to its small size and unique modular, waterproof design it can be deployed virtually anywhere, which makes site acquisition easier and more affordable, and provides a faster, more economic rollout.

The newest member of the market-leading Flexi Base station family, the Flexi Multimode Base Station was launched in February 2008. The new software-definable Flexi Multimode Base Station offers the ideal upgrade path to LTE. Service providers can roll out the base station with the UMTS/HSPA software release beginning in the third quarter of 2008 to serve existing UMTS/WCDMA customers. The unique quality of this product lies in its fully software definable upgrade to LTE, which means operators can deploy the base station with UMTS/HSPA technology and then upgrade to LTE via software in the same frequency band beginning in the second half of 2009. The Flexi Multimode Base Station supports most IMT frequency bands including the 1.7/2.1GHz AWS band and the recently auctioned 700 MHz band in the United States.

With Internet-HSPA (I-HSPA), Nokia Siemens Networks has led the industry in flat network architectures that deliver superior value for high volume traffic. This 3GPP-standardized innovation by Nokia Siemens Networks enables cost-efficient scaling of the network for rapidly growing data traffic volumes, works with all HSPA devices and improves the end user experience by reducing latency. In 2007, several operators successfully trialed I-HSPA, and in 2007 and 2008 the first I-HSPA network deals were announced with TerreStar Networks and Stelera Wireless in the United States and T2 Slovenia in Europe. I-HSPA also eases the path to LTE, as the two technologies use the same flat network architecture.

Nokia Siemens Networks is a pioneer in LTE research and technology development, a frontrunner in 3GPP standardization, and is actively driving the early test of LTE technology within the LTE/SAE Trial Initiative (LSTI).

In 2006, research teams built the world's first LTE demonstrator with MIMO, showing at 3G World Congress in Hong Kong over-the-air data rates of up to 160 Mbps. In December 2007, Nokia Siemens Networks demonstrated LTE in a Multi-user field trial under realistic urban deployment scenarios in the center of Germany's capital Berlin, reaching with a 2x2 MIMO antenna system peak data rates of up to 173 Mbps and still more than 100 Mbps over distances of several hundred meters. This trial also successfully demonstrated that future LTE networks can run on existing base station sites.

In December 2007, Nokia Siemens Networks and Panasonic Mobile Communications were also selected by NTT DoCoMo to be their Super 3G / Long Term Evolution vendor. Verizon Wireless, the first CDMA operator selecting LTE as their next generation mobile broadband technology, selected Nokia Siemens Networks as a vendor in their LTE trials.

Nokia Siemens Networks has already demonstrated LTE on the Flexi Multimode Base Station at Mobile World Congress 2008. In addition to the Flexi Multimode Base Station, NSN launched its Mobility Management Entity (MME) and System Architecture Evolution (SAE) Gateway as further parts of its LTE /SAE end to end solution.

Nokia Siemens Networks has made remarkable achievements in reducing energy consumption throughout its base station portfolio. Nokia Siemens Networks' Energy Efficiency solution can reduce the energy consumption of a base station site by up to 70 percent. This significant reduction in energy consumption creates a more environmentally friendly network operation by reducing CO2 emissions and lowering operating costs for operators. Nokia Siemens Networks' base station portfolio is achieving energy consumption levels of 800W and 500W for typical GSM and UMTS/WCDMA base stations respectively. Going forward, the company has set the ambitious target to further reduce the energy consumption of its GSM and UMTS/WCDMA base stations to 650W and 300W respectively by 2010. A step forward is the new Nokia Siemens Networks Flexi Multimode Base Station. This cutting-edge base station is more energy efficient than previous versions of Flexi UMTS/WCDMA base stations, as a 3-sector Flexi UMTS/WCDMA base station site will now consume on average only 430W. Furthermore, Nokia Siemens Networks provides solutions for renewable energy sources like solar cells, wind and hybrid solutions on site.

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 190 mobile operators to date. The Nokia Siemens Networks Mobile Softswitch supports an architecture that is compliant with 3GPP Release 4, 5, and 6 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 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 World Congress and CTIA Wireless in 2007. All these solutions are future-proof and form an integral building block for the System Architecture Evolution (SAE), which Nokia Siemens Networks introduced at Mobile World Congress 2008 in Barcelona.

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 true broadband era. IMT-Advanced (so-called 4G) mobility technologies can deliver an order of magnitude advancement in those dimensions and support 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 connected.

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 (LTE 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 is accelerating the evolution of current 2G/3G Networks to LTE with a solution that offers a significant value to service providers while providing revolutionary user experience. 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 and device vendors that will help accelerate interoperability testing timelines and ensure the availability of a complete LTE ecosystem. Nortel is also partnering with leading application vendors to make sure the operators can fully exploit the network's potential to maximize revenues. Solutions from partnerships with vendors like Microsoft and IBM will provide a compelling business case for driving global mobile broadband evolution.

Back 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.

Most recently, at Mobile World Congress 2008 in Barcelona and CTIA 2008 in Las Vegas, http://www2.nortel.com/go/news_detail.jsp?cat_id=-8055&oid=100238524&locale=en-US Nortel was demonstrating to many customers LIVE AIR LTE at various spectrum bands, including the new North American AWS band (1700/2100 MHz), running a variety of applications, including high definition video streaming, Live TV, multi user video collaboration and video surveillance, as well as Nortel-Microsoft Unified Communications and examples of social networking tools. These live-air demonstrations included advanced RF and MAC features showing the implementation of the LTE standard (3GPP Rel-8) in practical configuration to show the significant progress Nortel has made in LTE with industry's most advanced solution. In April, Nortel also made the first public announcement of LTE being demonstrated at high vehicular speeds, as customers visiting Nortel's LTE Center of Excellence in Ottawa witnessed download speeds over 50 Mbps in a moving vehicle at 110 Kmph. http://www2.nortel.com/go/news_detail.jsp?cat_id=-8055&oid=100238613&locale=en-US 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.

Nortel's new AGW, built on ATCA, includes a next-generation Gateway GPRS Support Node (GGSN) and LTE Evolved Packet Core Functionality.

Nortel has been the worldwide leader in Carrier VoIP for six consecutive years according to Dell'Oro Group and Nortel is the recognized leader in design and deployment of Next Generation VoIP and SIP Multimedia networks. The company is building on this expertise, which includes extensive portfolio of SIP patents, to bring 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.

Operators acknowledge Nortel's contributions to 3GPP, 3GPP2 (aligning CDMA evolution towards LTE), MMD, TISPAN and PCMM standards. Nortel is also driving LTE SAE Trial Initiative (LSTI) by leading several key milestones as an activity manager by collaborating with service providers and other vendors to ensure timely launch of LTE.

Nortel Strengthens the Case for Deployment of LTE by Publishing Competitive Patent Royalty Rates that Fosters the LTE Ecosystem http://www2.nortel.com/go/news_detail.jsp?cat_id=-8055&oid=100240037&locale=en-US

Nortel is accelerating the evolution to LTE with a focus on reducing the total cost of ownership for service providers and providing revolutionary user experiences.

www.hyperconnectivity.com

www.nortel.com/lte

Appendix B: Global UMTS and HSPA Operator Status – May 29, 2008

GLOBAL UMTS AND HSPA OPERATOR STATUS		UMTS Summary			HSPA Summary		
29-May-08		UMTS OPERATORS IN SERVICE	229		HSDPA OPERATORS IN SERVICE		200
		COUNTRIES IN SERVICE	98		HSDPA COUNTRIES IN SERVICE		88
Source: Informa Telecoms & Media, WCIS and 3G Americas		COUNTRY COMMITMENTS	120		HSDPA COUNTRY COMMITMENTS		100
		PLANNED + IN DEPLOYMENT	55		HSDPA PLANNED + IN DEPLOYMENT		59
Red = commercially available		TRIAL	2		HSDPA TRIALS		3
Information accurate to the best of our knowledge as of date published		POTENTIAL & LIC. AWARDED	42		HSUPA OPERATORS IN SERVICE		44
Please send updates to info@3gamericas.org		EDGE + UMTS COMMERCIAL	174		HSUPA PLANNED		130
Country	**Operator**	**UMTS Status**	**Start Date**	**EDGE**	**HSDPA Status**	**Start Date**	**HSUPA**
Albania	Eagle Mobile	In Service	Mar-08		Planned	Dec-08	Dec-08
Algeria	Algérie Telecom /Mobilis	Planned	Jun-08	EDGE	Planned	Jun-08	
Algeria	Orascom Telecom Algeria Djezzy	Planned	Jun-08	EDGE	Planned	Jun-08	
Algeria	Wataniya Telecom Algeria Nedjma	Potential License	Q2 2008	EDGE			
Andorra	STA	In Service	Dec-06		Planned	Jun-08	Dec-08
Angola	Unitel	In Service	Jun-07	EDGE	In Service	Jun-07	
Argentina	Claro (America Movil)	In Service	Nov-07	EDGE	In Service	Nov-07	
Argentina	Telecom Personal	In Service	May-07	EDGE	In Service	May-07	
Argentina	Telefonica Moviles (Movistar)	In Service	Jul-07	EDGE	In Service	Jul-07	
Aruba	SETAR	In Service	Dec-07		In Service	Dec-07	
Armenia	K-Telecom/Vivacell	Planned	Q1 2009				
Armenia	Armentel	Planned	Q1 2009				
Australia	Hutchison 3G (3)	In Service	May-03		In Service	Mar-07	Jun-08
Australia	SingTel/Optus	In Service	Nov-05		In Service	May-07	Dec-08
Australia	Telstra	In Service	Sep-05	EDGE	In Service	Oct-06	Sep-07
Australia	Vodafone	In Service	Oct-05		In Service	Oct-06	Dec-08
Australia	Virgin Mobile	In Service	Jul-07		In Service	July-07	

Austria	Connect Austria (ONE)	In Service	Dec-03		In Service	Jun-06	Jun-08
Austria	Hutchison 3G (3)	In Service	May-03		In Service	Sep-06	Jun-08
Austria	Mobilkom Austria	In Service	Apr-03	EDGE	In Service	Jan-06	**Feb-07**
Austria	T-Mobile Austria	In Service	Dec-03	EDGE	In Service	Mar-06	Jun-08
Bahrain	Batelco	In Service	Dec-07	EDGE	In Service	Dec-07	
Bahrain	Zain (ex-MTC Vodafone)	In Service	Dec-03	EDGE	In Service	May-06	
Bangladesh	BTTB	Potential License	Dec-10				
Bangladesh	GrameenPhone	Potential License	Mar-10	EDGE	Planned	Dec 2010	
Bangladesh	PBTL	Potential License	Jun-10				
Bangladesh	Sheba Telecom	Potential License	Jun-10				
Bangladesh	TM International	Potential License	Jun-10	EDGE			
Bangladesh	Warid Telecom	Potential License	Dec-10	EDGE			
Belarus	MTS Belarus	Planned	Mar-09	EDGE	Planned	Mar-09	
Belgium	KPN BASE (Orange)	In Deployment	Jun-08	EDGE	Planned	Jun-08	Jun-08
Belgium	Belgacom Mobile (Proximus)	In Service	Sep-05	EDGE	In Service	Jun-06	Jun-08
Belgium	Mobistar	In Service	Dec-06	EDGE	In Service	Jun-07	**Jan-08**
Belgium	-tba-1	Potential License	Q4 2008				
Bhutan	Bhutan Telecom - B-Mobile	In Service	May-08	EDGE	In Service	May-08	Jun-09
Bhutan	Tashi Infocomm	Planned	Dec-08				
Brazil	Amazonia Celular	Potential License	Q1 2009	EDGE			
Brazil	Brasil Telecom	In Service	May-08	EDGE	In Service	May-08	
Brazil	CTBC	In Service	Apr-08	EDGE	In Service	Apr-08	
Brazil	Sercomtel Celular	Potential License	Q1 2009	EDGE			
Brazil	Claro (America Movil)	In Service	Nov-07	EDGE	In Service	Nov-07	
Brazil	Telemar PCS (Oi)	Potential License	Q1 2009	EDGE			
Brazil	Telemig Celular	In Service	Nov-07	EDGE	In Service	Nov-07	
Brazil	TIM Celular	In Service	Apr-08	EDGE	In Service	Apr-08	
Brunei/Borneo	B-Mobile	In Service	Sep-05				

Brunei/Borneo	DST Com	In Service	May-08	EDGE	In Service	May-08	Dec-08
Bulgaria	BTC (Vivatel)	In Service	Apr-07	EDGE	In Service	Apr-07	Jun-08
Bulgaria	Cosmo Bulgaria Mobile/Globul	In Service	Jun-06		In Service	Sep-06	Jun-08
Bulgaria	MobilTel (M-TEL/Vodafone)	In Service	Mar-06	EDGE	In Service	Mar-06	**Aug-07**
Bulgaria	-tba-1	Potential License	Q4 2009				
Cambodia	Cambodia Shinawatra	In Service	Oct-07				
Cambodia	Cambodia GSM (MobiTel)	In Service	Oct-06	EDGE	In Service	Oct-06	
Canada	Rogers Wireless	In Service	Nov-06	EDGE	In Service	Nov-06	Jun-08
Chile	Entel PCS	In Service	Dec-06	EDGE	In Service	Dec-06	
Chile	Claro (America Movil)	In Service	Jan-08		In Service	Jan-08	
Chile	Telefonica Moviles / Movistar	In Service	Dec-07	EDGE	In Service	Dec-07	
China	China Mobile	In Deployment	Jun-08	EDGE	In Deployment	Jun-08	
Colombia	TIGO (Colombia Movil)	Trial	N/A	EDGE			
Colombia	Comcel (America Movil)	In Service	Jan-08	EDGE	In Service	Jan-08	
Colombia	Movistar (Telefonica Moviles)	Planned	Q4 2008	EDGE	Trial	N/A	
Costa Rica	ICE Telefonia Celular	Planned	Q4 2010		Planned	Jun-08	Jun-08
Cote D'Ivoire	Atlantique Telecome (Moov)	Potential License	Q4 2008				
Cote D'Ivoire	MTN Cote d'Ivoire	Potential License	Q4 2008				
Cote D'Ivoire	Orange Cote d'Ivoire	Potential License	Q2 2008				
Croatia	Tele2	Planned	Mar-08		Planned	Jun-08	
Croatia	T-Mobile	In Service	Jan-06	EDGE	In Service	Nov-06	
Croatia	Tele2	Planned	Dec-08		Planned	Dec-08	
Croatia	VIPNet	In Service	Oct-05	EDGE	In Service	Apr-06	**Apr-07**
Cyprus	MTN (Areeba)	In Service	Oct-05	EDGE	In Service	Mar-08	Sep-08
Cyprus (Northern)	KKT Cell	Planned	Oct-08		Planned	Oct-08	
Cyprus	CYTA Mobile	In Service	Mar-06		Planned	Jun-08	Jun-08

Czech Republic	Telefonica O2 (Eurotel)	In Service	Dec-05	EDGE	In Service	Apr-06	Jan-09
Czech Republic	T-Mobile	In Service	Dec-06	EDGE	In Deployment	Sep-08	
Czech Republic	Vodafone	In Deployment	Sep-08	EDGE	Planned	Sep-08	
Dem Rep Congo	Celtel DRC	Potential License	Q4 2008				
Dem Rep Congo	Vodacom Congo	Potential License	Q4 2008				
Denmark	3	In Service	Oct-03		In Service	Nov-06	Jun-08
Denmark	Sonofon	In Service	Sep-06	EDGE	In Service	Sep-07	Jun-08
Denmark	TDC Mobil	In Service	Nov-05		In Service	Jan-08	Jun-08
Denmark	TeliaSonera	In Service	Dec-07	EDGE	In Service	Dec-07	**Mar-08**
Ecuador	Conecel / Porta	Potential License	Q1 2008	EDGE			
Ecuador	Otecel (Movistar)	Potential License	Q1 2008	EDGE			
Egypt	Etisalat Misr	In Service	May-07	EDGE	In Service	May-07	
Egypt	MobiNil (ECMS)	Planned	Jun-08	EDGE			
Egypt	Vodafone Egypt	In Service	May-07		In Service	May-07	
El Salvador	Claro (America Movil)	In Service	Jan-08		In Service	Jan 08	Jun-08
Estonia	Elisa / Radiolindja	In Service	Jun-06	EDGE	In Service	Jan-08	Jun-08
Estonia	Bravocom	In Service	July 06	EDGE	In Service	Jul-06	
Estonia	EMT	In Service	Oct-05	EDGE	In Service	Apr-06	**Dec-07**
Estonia	Tele2 Eesti	In Service	Nov-06		In Service	Nov-06	Jun-08
Estonia	ProGroup Holding	In Deployment	Jun-08		In Deployment	Jun-08	Jun-08
Fiji	Vodafone Fiji	Planned	Jun-08		Planned	Jun-08	Oct-08
Finland	Alands Mobiltelefon	In Service	Jun-06	EDGE			
Finland	Finnet / DNA Finland	In Service	Dec-05	EDGE	In Service	Feb-07	Jun-08
Finland	Elisa	In Service	Nov-04	EDGE	In Service	Apr-06	Aug-08
Finland	Sonera	In Service	Oct-04	EDGE	In Service	May-07	Jun-08
France	Bouygues Telecom	In Service	Apr-07	EDGE	In Service	Apr-07	**Nov-07**
France	Orange France	In Service	Dec-04	EDGE	In Service	Oct-06	**Jan-08**
France	SFR	In Service	Nov-04	EDGE	In Service	Jun-06	Jun-08
French Polynesia	Tikiphone (VINI)	In Service	Dec-08	EDGE	Planned	Jun-08	Dec-08
French West Indies	Outremer Telecom	In Deployment	Jan-08		In Deployment	Dec-08	Jan-13
Georgia	Geocell	In Service	Dec-06				
Georgia	Telecom Invest Georgia	License Awarded	Q1 2008				

Georgia	Magticom	In Service	Jul-06	EDGE			
Germany	E-Plus	In Service	Aug-04		In Deployment	Jun-08	Sep-08
Germany	O2	In Service	Jul-04		In Service	Dec-06	Sep-08
Germany	T-Mobile Deutschland	In Service	May-04	EDGE	In Service	Mar-06	**Nov-07**
Germany	Vodafone D2	In Service	May-04	EDGE	In Service	Mar-06	**Jul-07**
Greece	Cosmote	In Service	May-04	EDGE	In Service	Jun-06	**Apr-08**
Greece	Panafon (Vodafone)	In Service	Aug-04		In Service	Nov -06	Jun-08
Greece	WIND Hellas (TIM)	In Service	Jan-04	EDGE	In Deployment	Nov-08	Nov-08
Guatemala	Claro (America Movil)	In Service	Apr-08	EDGE	In Service	Apr-08	
Guernsey	Wave Telecom	In Service	Jul-04	EDGE	In Service	Nov-06	Dec-08
Guernsey	C&W Guernsey /Sure.mobile	In Service	Sep-07	EDGE	In Service	Sep-2007	Dec-08
Guernsey	Airtel-Vodafone	Planned	Jun-08				
Honduras	Claro (America Movil)	In Service	Feb-08		In Service	Feb-08	Jun-09
Hong Kong	Hong Kong CSL (New World)	In Service	Dec-04	EDGE	In Service	Sep-06	Dec-08
Hong Kong	3HK - Hutchison	In Service	Jan-04		In Service	Nov-06	Dec-10
Hong Kong	SmarTone Vodafone	In Service	Dec-04		In Service	Jun-06	**Dec-07**
Hong Kong	PCCW Mobile (ex-Sunday)	In Service	Jul-06	EDGE	In Service	Aug-07	Dec-08
Hungary	Pannon GSM	In Service	Oct-05	EDGE	In Service	Aug-07	Jun-08
Hungary	T-Mobile	In Service	Aug-05	EDGE	In Service	Sep-06	**Sep-07**
Hungary	Vodafone	In Service	Jun-06		In Service	Jun-07	Jun-08
Iceland	NOVA	In Service	Sep-07		In Service	Dec-07	Jun-08
Iceland	Iceland Telecom / Siminn	In Service	Sep-07	EDGE	In Service	Sep-07	**Sep-07**
India	Aircel	Potential License	Dec-09	EDGE			
India	Bharti Televentures	Planned	Mar-08	EDGE	Planned	Dec-08	
India	BPL Cellular	Planned/In Deployment	Dec-09	EDGE			
India	BSNL	In Deployment	Dec-09	EDGE	Planned	Mar-09	Mar-09
India	Dishnet Wireless	Potential License	Dec-09	EDGE			
India	Essar Spacetel	Potential License	Dec-09				

India	Idea Cellular	Potential License	Dec-09	EDGE				
India	MTNL	Planned	Dec-08		Planned	Dec-08	Mar-09
India	Reliance	Planned	Mar-08				
India	Spice Telecom	Planned	Jun-08		Planned	Dec-08	
India	Tata Teleservices	Planned	Mar-08				
Indonesia	Excelcomindo Pratama ProXL	In Service	Oct-06		In Service	Jan-07	Jun-08
Indonesia	Hutchison CP Telecommunications	In Service	Dec-06		In Service	Jun-07	Jun-08
Indonesia	Indosat IM2 /Matrix/Mentari/IM3	In Service	Nov-06		In Service	Oct-07	Sep-08
Indonesia	Satelindo (Indosat)	In Service	Dec-06	EDGE	In Service	Mar-07	Sep-08
Indonesia	Telkomsel	In Service	Aug-06	EDGE	In Service	Apr-07	Dec-08
Ireland	Hutchison (3)	In Service	Jul-05		In Service	Dec 06	Jun-08
Ireland	O2	In Service	Mar-05	EDGE	In Service	Jul-07	Jun-08
Ireland	Vodafone Ireland	In Service	Nov-04		In Service	Dec-06	Dec-08
Ireland	Meteor Communications	In Deployment	Q1 2008	EDGE			
Isle of Man	Manx Telecom	In Service	Nov-05		In Service	Nov-05	Jun-08
Israel	Cellcom Israel	In Service	Jun-04	EDGE	In Service	Jun-06	**Sep-07**
Israel	Pelephone (CDMA to HSDPA)	In Deployment	Dec-08		In Deployment	Dec-08	
Israel	Partner Comm. (Orange)	In Service	Nov-04		In Service	Mar-06	Dec-07
Italy	H3G (3)	In Service	Mar-03		In Service	Feb-06	**Jul-07**
Italy	TIM	In Service	May-04	EDGE	In Service	May-06	**Oct-07**
Italy	Vodafone Italia	In Service	May-04		In Service	Jun-06	**Sep-07**
Italy	Wind	In Service	Oct-04	EDGE	In Service	Jun-07	Jun-08
Japan	eAccess / eMobile	In Service	Mar-07		In Service	Mar-07	Mar-10
Japan	Softbank (ex-Vodafone)	In Service	Dec-02		In Service	Oct-06	
Japan	NTT DoCoMo (FOMA)	In Service	Oct-01		In Service	Aug-06	Jun-08
Jersey	Cable & Wireless /sure.Mobile	In Service	Sep-06	EDGE	In Service	Dec-07	Dec-08
Jersey	Jersey Telecoms	In Service	Jun-06		In Service	Sep-07	Dec-08

Jersey	Airtel-Vodafone	In Service	Jun-07	EDGE	In Service	Jun-07	
Kenya	Safaricom	In Service	Dec-07	EDGE	In Service	Mar-08	
Kuwait	Zain	In Service	Mar-06	EDGE	In Service	Jan-07	Jun-08
Kuwait	Wataniya Telecom	In Service	Mar-06	EDGE	In Service	Mar-06	
Latvia	Bité	In Service	Jun-06	EDGE	In Service	Jul-07	**Feb-08**
Latvia	LMT	In Service	Dec-04	EDGE	In Service	Aug-06	Jul-08
Latvia	Tele2	In Service	Dec-05		In Service	Mar-07	Sep-08
Libya	El Madar Tel. Company (Orbit)	In Deployment	Jun-08	EDGE			
Libya	Libyana	In Service	Sep-06		In Deployment	Sep-08	
Liechtenstein	Orange	In Service	Feb-07		In Service	June-07	Sep-08
Liechtenstein	mobilkom	In Service	Mar-07		In Service	Mar-07	Sep-08
Liechtenstein	Telecom FL (Swisscom)	In Service	Feb-07	EDGE	In Service	Jun-07	Jun-08
Liechtenstein	Tele2 (Tango)	In Deployment	Jun-08		In Deployment	Jun-08	Sep-08
Lithuania	Bité	In Service	Apr-06	EDGE	In Service	Jun-06	**Feb-08**
Lithuania	Omnitel	In Service	Feb-06	EDGE	In Service	Jun-06	Jun-08
Lithuania	Tele2 (Tango)	In Service	Mar-07		Planned	Jun-09	Mar-09
Luxembourg	LUX Communications (VOX)	In Service	May-05	EDGE	In Service	Jun-07	Jun-08
Luxembourg	P&T Luxembourg (LUXGSM)	In Service	Jun-03	EDGE	In Service	May-07	Jun-08
Luxembourg	Tele2 (Tango)	In Service	Jul-04		Planned	Jun-08	Mar-09
Macau	CTM	In Service	Jun-07		In Service	Jun-07	Jun-09
Macau	Hutchison (3)	In Service	Oct-07		In Service	Oct-07	
Macedonia	Cosmofon	Planned	Mar-09				
Macedonia	Mobimak	Potential License	Q4 2009				
Malaysia	Maxis	In Service	Jul-05	EDGE	In Service	Sep-06	Sep-08
Malaysia	Telekom Malaysia/Celcom 3G	In Service	May-05	EDGE	In Service	Sep-06	Jun-08
Malaysia	Umobile	In Deployment	Jun-08		In Deployment	Jun-08	
Malaysia	DiGi	Planned	2008	EDGE			
Maldives	Dhiraagu	Potential License	2010				
Maldives	Wataniya	In Service	Apr-08	EDGE	In Deployment	Jun-08	Dec-08
Malta	MobIsle Comm. (go mobile)	In Service	Apr-07	EDGE	In Service	Apr-07	Dec-08
Malta	Vodafone	In Service	Aug-06		In Service	Dec-06	Dec-08
Mauritius	Orange	In Service	Mar-06		Planned	Jun-08	

Mauritius	Millicom Mauritius (Emtel)	In Service	Nov-04		In Service	Sep-07	
Mexico	Telcel (America Movil)	In Service	Feb-08	EDGE	In Service	Feb-08	Jun-09
Mexico	Telefonica Moviles/Movistar	Planned	Mar-08	EDGE	Planned		
Monaco	Monaco Telecom / Monacell	In Service	Jun-06		Planned	Jun-08	Jun-08
Mongolia	Mobicom	Potential License	Dec 2009				
Mongolia	Skytel	Potential License	Dec 2009				
Montenegro	T-Mobile	In Service	Jun-07	EDGE	In Service	Jun-07	Dec-08
Montenegro	ProMonte	In Service	Jun-07	EDGE	In Service	Jun-07	Sep-08
Montenegro	M:Tel (Telekom Srbija)	In Service	Jul-07	EDGE	In Service	Jul-07	
Morocco	Ittissalat Al-Magreb / Maroc Telecom	In Service	Jan-08		In Service	Jan-08	
Morocco	Medi Telecom (Meditel) Mobile ADSL	In Service	Apr-07		In Service	Apr-07	
Mozambique	mCel	Planned	Dec-08		Planned	Dec-08	
Namibia	MTC	In Service	Dec-06	EDGE	In Service	Dec-06	Jun-08
Namibia	Powercom -Cell One	In Service	Mar-07		In Service	Jun-07	
Nepal	Nepal Telecom Corp	In Service	May-07		In Deployment	Jun-08	
Nepal	Spice Nepal	Potential License	Sep 2012	EDGE			
Netherlands	KPN Mobile (Telfort)	In Service	Oct-04	EDGE	In Service	Dec-06	**Feb-08**
Netherlands	Orange	In Service	Nov-06		In Deployment	Jun-08	Jun-08
Netherlands	T-Mobile Netherlands	In Service	Jan-06	EDGE	In Service	Apr-06	Jun-08
Netherlands	Vodafone Libertel	In Service	Jun-04		In Service	Jul-06	Jun-08
New Zealand	Econet Wireless / NZ Comm.	Planned	Sep-08		Planned	Jun-08	Jun-08
New Zealand	Vodafone	In Service	Aug-05		In Service	Oct-06	Jun-08
New Zealand	Telecom New Zealand	In Deployment	Dec-08	EDGE	In Deployment	Dec-08	Dec-09
Nicaragua	Claro (America Movil)	In Service	Apr-08		In Service	Apr-08	

Nigeria	Globacom - GloMobile	In Service	Dec-07		In Service	Dec-07	
Nigeria	MTN Nigeria	In Service	Dec-07		In Service	Dec 07	
Nigeria	V-Mobile (Celtel)	Planned	Q3 2007		Trial	N/A	
Norway	Hi3G Access	Planned	Mar-09		Planned	Mar-09	Mar-09
Norway	Netcom (TeliaSonera)	In Service	Jun-05	EDGE	In Service	Apr-07	Jun-08
Norway	Telenor Mobil	In Service	Dec-04	EDGE	In Service	Nov-07	Jun-08
Oman	Nawras Telecom (TDC)	In Service	Dec-07	EDGE	In Service	Dec-07	
Oman	Oman Mobile / Omantel	Planned	Dec-08		Planned	Dec-08	Dec-08
Pakistan	PMCL - Mobilink	Potential License	Sep-09	EDGE			
Pakistan	PTML - Ufone	Potential License	Sep-09	EDGE			
Pakistan	Telenor	Potential License	Sep-09	EDGE			
Paraguay	Claro (America Movil)	In Service	Nov-07		In Service	Nov-07	
Paraguay	Personal	In Service	Mar-08		In Service	Mar-08	
Peru	Claro (America Movil)	In Service	Apr-08	EDGE	In Service	Apr-08	
Philippines	Globe Telecom	In Service	May-06	EDGE	In Service	May-06	Sep-08
Philippines	SMART / Piltel	In Service	May-06	EDGE	In Service	Jan-07	Dec-08
Philippines	Digitel/ Sun Cellular	In Service	Jul-06	EDGE	Planned	2007	
Poland	Centertel (Orange)	In Service	Jun-06	EDGE	In Service	Dec-06	**Dec-07**
Poland	P4 (Play)	In Service	Mar-07		In Service	Mar-07	Jun-08
Poland	Polkomtel / Plus GSM	In Service	Sep-04	EDGE	In Service	Oct-06	**Dec-07**
Poland	Polska Telefonia Cyfrowa (Era)	In Service	Apr-06	EDGE	In Service	Oct-06	Jun-08
Portugal	Optimus	In Service	Jun-04		In Service	Dec-06	Dec-08
Portugal	TMN (Telemovel)	In Service	Apr-04		In Service	Apr-06	Dec-08
Portugal	Vodafone Telecel	In Service	May-04		In Service	Mar-06	**Sep-07**
Puerto Rico	AT&T	In Service	Nov-06	EDGE	In Service	Nov-06	Sep-08
Qatar	Q-TEL	In Service	Jul-06		In Service	Jul-07	
Romania	MobiFon / Vodafone	In Service	Apr-05		In Service	May-06	**Mar-08**
Romania	Orange Romania	In Service	Jun-06	EDGE	In Service	Jun-07	**Oct-07**

Romania	ZAPP Mobile (ex-CDMA)	In Service	May-08		In Service	May-08	
Romania	DigiMobile (RCS&RDS)	In Service	Feb-07		Planned	Jun-08	Jun-08
Russia	VimpelCom	In Deployment	Sep-08		In Deployment	Sep-08	
Russia	MegaFon	In Service	Oct-07	EDGE	In Service	Oct-07	Dec-08
Russia	Mobile TeleSystems (MTS)	In Service	May-08		In Service	May-08	
Rwanda	RwandaTel	Planned	Jan-09		Planned	Jan-09	
Saudi Arabia	Etisalat / Mobily	In Service	Jun-06	EDGE	In Service	Jul-06	
Saudi Arabia	STC/ Al Jawwal	In Service	Jun-06	EDGE	In Service	Jun-06	
Saudi Arabia	Zain	In Deployment	Jun-08	EDGE	In Deployment	Jun-08	Sep-08
Serbia	Telenor (Ex-Mobtel)	In Service	Mar-07	EDGE	In Service	Mar-07	
Serbia	Telecom Srbija	In Service	Dec-06	EDGE	In Service	Dec-06	
Serbia	VIP Mobile (TopNet)	In Service	Jul-07				
Seychelles	Telecom Seyshelles (AIRTEL)	In Service	Dec-06	EDGE	In Service	Dec-06	Dec-08
Singapore	MobileOne	In Service	Feb-05		In Service	Dec-06	Jun-08
Singapore	SingTel Mobile	In Service	Feb-05		In Service	May-07	Jun-08
Singapore	StarHub	In Service	Apr-05		In Service	Aug-07	**Aug-07**
Slovak Republic	Orange Slovensko	In Service	Mar-06	EDGE	In Service	Sep-06	**Nov-07**
Slovak Republic	T-Mobile Slovakia	In Service	Jan-06	EDGE	In Service	Aug-06	Dec-09
Slovak Republic	Telefonica O2 Slovak Republic	Planned	Q4 2008	EDGE			
Slovenia	Mobitel	In Service	Dec-03	EDGE	In Service	Sep-06	**Dec-07**
Slovenia	Si.Mobile (Vodafone)	In Service	Sep-07	EDGE	In Service	Sep-07	Jun-08
Slovenia	T-2	Planned	Dec-08		Planned	Dec-08	
Slovenia	Tus Mobile	Planned	Dec-08		Planned	Dec-08	Dec-08
South Africa	3C Telecom. Cell C	In Service	Jun-06	EDGE			
South Africa	MTN	In Service	Jun-05	EDGE	In Service	Mar-06	Jun-08
South Africa	Vodacom	In Service	Dec-04	EDGE	In Service	Apr-06	Jun-08
South Korea	KTF SHOW	In Service	Dec-03		In Service	Jun-06	**Jun-07**
South Korea	SK Telecom 3G+	In Service	Dec-03		In Service	May-06	**Oct-07**
Spain	Amena / Orange	In Service	Oct-04		In Service	Jun-06	**Apr-08**

Spain	Telefónica Móviles (Movistar)	In Service	May-04		In Service	Oct-06	**Aug-07**
Spain	Vodafone España	In Service	May-04		In Service	Jun-06	**Sep-07**
Spain	Xfera (Yoigo)	In Service	Dec-06		In Service	Dec-07	Dec-08
Sri Lanka	Bharti Airtel	In Deployment	Sep-08	EDGE	In Deployment	Dec-08	Dec-08
Sri Lanka	Dialog GSM	In Service	Aug-06	EDGE	In Service	Aug-06	Sep-08
Sri Lanka	Hutchison	Planned	Dec-08	EDGE			
Sri Lanka	Mobitel	In Service	Dec-07	EDGE	In Service	Dec-07	**Dec-07**
Sudan	Bashair Telecom / Areeba	In Service	Q1 2006	EDGE			
Sudan	Zain	Planned	Q4 2008	EDGE			
Sweden	HI3G	In Service	May-03		In Service	Nov-06	**Sep-07**
Sweden	TeliaSonera	In Service	Mar-04	EDGE	In Service	June-07	
Sweden	Svenska UMTS-Nät (Tele2)	In Service	Mar-04		In Service	April-07	Jun-08
Sweden	Telenor Sverige AB (Vodafone)	In Service	Jul-04		In Service	Jun-07	Jun-08
Switzerland	Orange	In Service	Sep-05	EDGE	In Service	Apr-07	Jun-08
Switzerland	Swisscom Mobile	In Service	Dec-04	EDGE	In Service	Mar-06	**Feb-08**
Switzerland	TDC Switzerland (sunrise)	In Service	Dec-05	EDGE	In Service	Feb-07	**Mar-08**
Switzerland	Team 3G	License Awarded					
Syria	MTN	Planned	Dec-08	EDGE	Planned	Dec-2008	
Syria	SyriaTel	In Deployment	Jun-08	EDGE	In Deployment	Jun-08	
Taiwan	Chunghwa Telecom	In Service	Jul-05		In Service	Sep 06	Mar-09
Taiwan	FarEasTone	In Service	Jul-05		In Service	Sep 06	Mar-09
Taiwan	Taiwan Mobile Co. (TWM)	In Service	Oct-05		In Service	Jan-07	Mar-09
Taiwan	VIBO	In Service	Dec-05		In Deployment	Sep-08	Mar-09
Tajikistan	Josa Babilon Mobile	In Service	Jun-05		Planned	Dec-08	
Tajikistan	Indigo Tajikistan	In Service	Sep-06		Planned	Mar-09	
Tajikistan	Tacom	In Service	Sep-06		Planned	Sep-08	
Tajikistan	TT Mobile	In Service	Jun-05		Planned	Jun-09	
Tanzania	Vodacom	In Service	Feb-07		In Service	Feb 07	Jun-08
Thailand	AIS	Potential License	Q4 2008	EDGE			
Thailand	DTAC	Potential License	Q4 2008	EDGE	Planned	N/A	

Thailand	TOT	Potential License	Q4 2008				
Tunisia	Tunisie Telecom	Potential License	Q2 2008	EDGE			
Turkey	AVEA	Potential License	Q4 2009	EDGE			
Turkey	Telsim	Potential License	Q4 2009				
Turkey	Turkcell	Potential Licence	Q4 2009	EDGE			
UAE	Etisalat	In Service	Jan-04	EDGE	In Service	Apr-06	
UAE	Du	In Service	Feb-07	EDGE	In Service	May-07	
Uganda	Uganda Telecom Ltd	In Service	Nov-07	EDGE	In Service	Mar-08	
UK	Hutchison 3G (3)	In Service	Mar-03		In Service	Aug-06	Sep-08
UK	O2	In Service	Mar-05		In Service	Feb-07	Sep-08
UK	Orange	In Service	Dec-04	EDGE	In Service	Feb-07	**Apr-08**
UK	T-Mobile UK	In Service	Oct-05		In Service	Aug-06	Sep-08
UK	Vodafone	In Service	Nov-04		In Service	Jun-06	**Sep-07**
Ukraine	Ukrtelecom	In Service	Nov-07		In Service	Nov-07	
Uruguay	Ancel	In Service	Jul-07	EDGE	In Service	Jul-07	Dec-08
Uruguay	Claro (America Movil)	In Service	Nov-07		In Service	Nov-07	
Uruguay	Telefonica Moviles /Movistar	In Service	Jul-07	EDGE	In Service	Jul-07	
USA	AT&T	In Service	Jul-04	EDGE	In Service	Dec-05	**Nov-07**
USA	Cincinnati Bell Wireless	Planned	Jul-08	EDGE			
USA	Edge Wireless	Planned	Sep-08	EDGE	In Deployment	Sep-08	Sep-08
USA	Stelera Wireless / Data Only	In Service	Dec-07		In Service	Dec-07	**Dec-07**
USA	T-Mobile USA	In Service	May-08	EDGE	In Service	May-08	Dec-08
USA	Terrestar	In Deployment	2008		In Deployment	2008	
Uzbekistan	Unitel (Beeline)	Planned	Q1 2009				
Uzbekistan	Coscom	Planned	Q1 2009				
Uzbekistan	Uzdunrobita	Planned	Q1 2009				
Zimbabwe	Econet Wireless	Planned	Q4 2008				

In Service: Operator has commercially launched its network to both consumer and enterprise market, with handsets and/or data cards available in retail outlets.

In Deployment: Operator is building the network or has launched limited non-commercial trials, including those with "friendly" users.

Planned: Licensee is in planning stages of deploying network.

Trial: Used when the operator has no specific license, but is conducting some sort of network trial, likely to be 3G.

License Awarded: License has been awarded, but licensee has not announced date to deploy network or roll-out.

Potential License: Some level of speculation. Government policy or privatization process indicates that licensing opportunities may become available. Operator may have announced that if they receive spectrum, they may deploy the technology.

Appendix C: Acronym List

1xEV-DO	1x Evolution-Data Optimized or Evolution-Data Only
1xEV-DV	1x Evolution-Data Voice
3GPP	3rd Generation Partnership Project
AA	Adaptive Array
AAA	Authentication, Authorization and Accounting
ACK/NAK	Acknowledgement/Negative Acknowledgement
AGPS	Assisted Global Positioning System
AMBR	Aggregate Maximum Bit Rate
AMR	Adaptive Multi-Rate
ARPU	Average Revenue Per User
ASME	Access Security Management Entity
ATM	Automated Teller Machine
BCH	Broadcast Channel
BTS	Base Transceiver Station
CAGR	Compound Annual Growth Rate
CAZAC	Constant Amplitude Zero Autocorrelation Waveform
CCE	Control Channel Elements
CCPCH	Common Control Physical Channel
CDM	Code Division Multiplexing
C/I	Carrier to Interference Ratio (CIR)
CK/IK	Ciphering Key/Integrity Key
CN	Control Network
CPC	Continuous Packet Connectivity
CQI	Channel Quality Indications
CS	Circuit Switched
CSI	Combination of Circuit Switched and Packet Switched services
CSCF	Call Session Control Function
CTIA	Cellular Telecommunication Industry Association
D-TxAA	Double Transmit Adaptive Array
DTX	Discontinuous Transmission
DRX	Discontinuous Reception
DBCH	Dynamic BCH
DCH	Dedicated Channel
DFT	Discrete Fourier Transformation
DIP	Dominant Interferer Proportion
DMB	Digital Multimedia Broadcasting
DL	Downlink
DL-SCH	Downlink Shared Channel
DPCCH	Dedicated Physical Control Channel
DSCH	Dedicated Shared Channel
DSL	Digital Subscriber Line
DS-MIPv6	Dual Stack – Mobile Internet Protocol version 6
E2E	End to End
E-DCH	Enhanced Dedicated Channel (also known as HSUPA)
E-DPCCH	Enhanced Dedicated Physical Control Channel
E-DPDCH	Enhanced Dedicated Physical Data Channel
EDGE	Enhanced Data for GSM Evolution
EPC	Evolved Packet Core; also known as SAE (refers to flatter-IP core network)
EPS	Evolved Packet System is the combination of the EPC/SAE (refers to flatter-IP core network) and the LTE/EUTRAN
EPDG	Evolved Packet Data Gateway
EPRE	Energy Per Resource Element
E-MBMS	Enhanced Multi Broadcast Multicast Service
ETSI	European Telecommunication Standards Institute
ETSI-SCP	ETSI – Standard Commands for Programming
EUTRA	Evolved Universal Terrestrial Radio Access
EUTRAN	Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
FBC	Flow Based Charging
FBI	Fixed Broadband access to IMS
FDD	Frequency Division Duplex
FDM	Frequency Division Multiplex
FDS	Frequency Diverse Scheduling

FFR	Fractional Frequency Re-use
FOMA	Freedom of Mobile Multimedia Access: brand name for the 3G services offered by Japanese mobile phone operator NTT DoCoMo.
FSS	Frequency Selected Scheduling
GB	Gigabyte
GBR	Guaranteed Bit Rate
Gn	IP Based interface between SGSN and other SGSNs and (internal) GGSNs. DNS also shares this interface. Uses the GTP Protocol.
GPRS	General Packet Radio System
GRUU	Globally Routable User Agent URIs
GSM	Global System for Mobile communications
GSMA	GSM Association
GTP	GPRS Tunneling Protocol
GTP-U	The part of GTP used for transfer of user data
GUP	Generic User Profile
GW	Gateway
HARQ	Hybrid Automatic Repeat Request
HLR	Home Location Register
HOM	Higher Order Modulation
HPLMN	Home PLMN
HPCRF	Home PCRF
HS-PDSCH	High Speed- Physical Downlink Shared Channel
HS-SCCH	High-Speed Shared Control Channel
HSDPA	High Speed Downlink Packet Access
HSPA	High Speed Packet Access (HSDPA + HSUPA)
HSPA +	High Speed Packet Access Plus (also known as HSPA Evolution)
HSS	Home Subscriber Server
HSUPA	High Speed Uplink Packet Access
HTML	Hyper-Text Markup Language
IDs	identifies
ICS	IMS Centralized Services
IETF	Internet Engineering Task Force (www.ietf.org)
NAS	Non Access Stratum
IMS	IP Multimedia Subsystem
IMSI	International Mobile Subscriber Identity
IN	Intelligent Networking
IP	Internet Protocol
IP TV	Internet Protocol Television
ISIM	IMS SIM
ISP	Internet Service Provider
ISUP	ISDN User Part
ITU	International Telecommunication Union
J2ME	Java 2 Micro Edition
kHz	Kilohertz
LCS	LoCation Service
LMMSE	Least Minimum Mean Squared Error
LTE	Long Term Evolution (Evolved Air Interface based on OFDMA)
M2M	Machine to Machine
MAC	Media Access Control
MBMS	Multimedia Broadcast/Multicast Service
MBR	Maximum Bit Rate
MBSFN	Multicast Broadcast Single Frequency Networks
MCS	Modulation and Coding Scheme
MFS	Mobile Financial Services
MHz	Megahertz
MIMO	Multiple Input Multiple Output
MIP	Mobile IP
MITE	IMS Multimedia Telephony Communication Enabler
MRFP	Multimedia Resource Function Processor
MME	Mobility Management Entity
MMS	Multimedia Messaging Service
MMSE	Multimedia Messaging Service Environment
MSA	Metropolitan Statistical Area
MU-MIMO	Multi-User Multiple Input Multiple Output
NAI	Network Access Identifier
NAS	Non Access Stratum

NFC	Near Field Communications
NGN	Next Generation Network
OCNS	Orthogonal Carrier Noise Simulator
OFDMA	Orthogonal Frequency Division Multiplexing Access (air interface)
OMA	Open Mobile Architecture
OP	Organizational Partner
OPEX	Operating Expenses
OTA	Over The Air
OVSF	Orthogonal Channel Noise Simulator
PAR	Peak to Average Ratio
PARC	Per-Antenna Rate Control
PBCH	Primary BCH
PC	Personal Computer
PCC	Policy and Charging Convergence
PCMCIA	Personal Computer Manufacturers' Card Interface Adapter
PCRF	Policy and Changing Rules Function
PCS	Personal Communication System
PDA	Personal Desktop Assistant
PDCCH	Physical Downlink Control Channel
PDCP	Packet Data Convergence Protocol
PDN	Public Data Network
PDSCH	Physical Downlink Shared Channel
PHY/MAC	PHY: common abbreviation for the physical layer of the OSI model. MAC=Medium Access Control, part of layer 2 in the OSI model
PoC	Push-to-talk over Cellular
PLMN	Public Land Mobile Network
PMIP	Proxy Mobile IPv6
PoS	Point of Sale
POTS	Plain Old Telephone Service
PRACH	Physical Random Access Channel
PS	Packet Switched
PSI	Public Service Identities
P-SCH	Primary Synchronization Signal
PSTN	Public Switched Telephone Network
PUUCH	Physical Uplink Access Channel
PUSCH	Physical Uplink Shared Channel
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
QoS	Quality of Service
RAB	Radio Access Bearer
RACH	Random Access Channel
RAT	Radio Access Technology
RB	Radio Bearer
RE	Resource Elements
REL-X	Release '99, Release 4, Release 5, etc. from 3GPP standardization
RLC	Radio Link Control Layer
RNC	Radio Network Controller
RRC	Radio Resource Control
SAE	System Architecture Evolution also known as Evolved Packet System (EPS) Architecture (refers to flatter-IP core network)
SBLB	Service Based Local Policy
SC-FDMA	Synchronization Channel – Frequency Division Multiple Access
SDMA	Spatial Division Multiple Access
SGSN	Serving GPRS Support Node
SFBA	Switch Fixed Beam Array
SFBC	Space Frequency Block Code
SFN	Single Frequency Network
SIM	Subscriber Identity Module
SIMO	Single Input Multiple Output
SIP	Session Initiated Protocol
SIR	Signal-to-Interference Ratio
SISO	Single Input Single Output
SMS	Short Message Service
SNR	Signal-to-Noise Ratio
SRNC	Serving Radio Network Controller
S-SCH	Secondary Synchronization Code
STTD	Space-Time Transmit Diversity

SU-MIMO	Single-User Multiple Input Multiple Output
TDD	Time Division Duplex
TDS	Time Domain Scheduling
TF	Transport Format
TFC	Transport Format Combination
TPC	Transmit Power Control
TTI	Transmission Time Interval
UE	User Equipment
UGC	User Generated Content
UICC	User Interface Control Channel
UL	Uplink
UMA	Unlicensed Mobile Access
USB	Universal Serial Bus
UMTS	Universal Mobile Telecommunication System, also known as WCDMA
UPE	User Plane Entity
URI	Universal Resource Identifier
UL-SCH	Uplink Shared Channel
USIM	UMTS SIM
UTRA	Universal Terrestrial Radio Access
UTRAN	UMTS Terrestrial Radio Access Network
VCC	Voice Call Continuity
VoD	Video on Demand
VoIP	Voice over Internet Protocol
VPCRF	Visiting PCRF
VPLMN	Visiting PLMN
VPN	Virtual Private Network
WAP	Wireless Application Protocol
WCDMA	Wideband Code Division Multiple Access
WIM	Wireless Internet Module
WLAN	Wireless Local Area Network
xHTML-MP	xHyper-Text Markup Language - Mobile Phone

Acknowledgments

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