2009

3G migration in Pakistan

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By

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9/18/2009

Thesis submitted is in partial fulfillment of the requirements for the degree of Master of Science in Telecommunications Engineering Technology

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Date: September 18th, 2009

Dedication

I dedicate this research to my dear parents, Sardar Pervaiz Sarwar & Seema Pervaiz, for their unconditional love, support and faith in me. They instilled a deep appreciation for the value of moral ethics, self-help and helping others, and also encouraged me to take advantage of every opportunity. Thanks, Dad, for believing I could do whatever I set out to accomplish. Mom, you transferred in me the love of learning and for that I am deeply grateful.

I would also like to thank my beloved uncle and aunt, Brg Khurshid Ahmed and Perveen Khurshid; you are the best mentors a girl could ever have, especially in the culture that I came from.

Last but not the least, my siblings Arsal Pervaiz, Zeeshan Perviaz and Kanza Pervaiz who stood by me at all times, my cousins Aisha Khurshid and Amna Rasheed, for their love and support, my friends Ana, Val, Jody, Arricka ,Michelle and Katrina, for being the best of friends, and my thesis advisor Prof Roanald Fulle for his guidance and time.

Abstract

The telecommunication industry in Pakistan has come a long way since the country's independence in 1947. The initial era could be fairly termed as the PTCL (Pakistan Telecommunication Company Limited) monopoly, for it was the sole provider of all telecommunication services across the country. It was not until four decades later that the region embarked into the new world of wireless communication, hence ending the decades old PTCL monopoly.

By the end of the late 1990's, government support and international investment in the region opened new doors to innovation and better quality, low cost, healthy competition. Wireless licenses for the private sector in the telecommunication industry triggered a promising chain of events that resulted in a drastic change in the telecommunication infrastructure and service profile. The newly introduced wireless (GSM) technology received enormous support from all stakeholders (consumers, regulatory body, and market) and caused a vital boost in Pakistan's economy.

Numerous tangential elements had triggered this vital move in the history of telecommunications in Pakistan. Entrepreneurs intended to test the idea of global joint ventures in the East and hence the idea of international business became a reality. The technology had proven to be a great success in the West, while Pakistan's telecom consumer had lived under the shadow of PTCL dominance for decades and needed more flexibility. At last the world was moving from wired to wireless!

Analysts termed this move as the beginning of a new era. The investors, telecommunication businesses, and Pakistani treasury prospered. It was a win-win situation for all involved. The learning curve was steep for both operators and consumers but certainly improved over time. In essence, the principle of deploying the right technology in the right market at the right time led to this remarkable success.

The industry today stands on the brink of a similar crossroads via transition from second generation to something beyond. With the partial success of 3G in Europe and the USA, the government has announced the release of three 3G licenses by mid 2009. This decision is not yet fully supported by all but still initiated parallel efforts by the operators and the vendors to integrate this next move into their existing infrastructure.

Industry critics, however, have shown mixed emotions towards 3G. The well-tested, stable, and mature 2 and 2.5G wireless networks demonstrate excellent results in overall network performance and integration, whereas 3G wireless is still in the jittery phase of its evolution. Operators with a consumer focus on voice services face a more uncertain demand for new content-based services, and broadband 3G data transport is considered too expensive for most consumers. However, 2.5G upgrades, providing reasonably fast data transport mechanisms using the existing spectrum, are typically considered more cost effective. On the other hand, ongoing 4G talk poses a threat to the still struggling 3G network potential based on the high expected demand for IP on the go. As Arthur C. Clarke calls it, any sufficiently advanced technology is indistinguishable from magic.

> Fourth generation (4G) wireless was originally conceived by the Defense Advanced Research Projects Agency (DARPA) the same organization that developed the wired Internet. It is not surprising, then, that DARPA chose the same distributed architecture for the wireless Internet that had proven so successful in the wired Internet. Although experts and policymakers have yet to agree on all the aspects of 4G wireless, two characteristics have emerged as all but certain components of 4G: end-to-end Internet Protocol (IP), and peer-to-peer networking. The final definition of "4G" will have to include something as simple as this: if a consumer can do it at home or in the office while wired to the Internet, that consumer must be able to do it wirelessly in

a fully mobile environment. Hence, sometimes referred to as, wireless *ad hoc* peer-to-peer networking.[1]

Thus, the decision faced by Pakistan's telecommunication industry today is tricky and challenging. It is tricky because today the stakes have risen beyond mere following the footsteps of another region; with progress and development of the industry have emerged new market trends and better consumer awareness. It is challenging because with 4G evolving in parallel to 3G, stakeholders propose two arguments: first, the high investment in the 2.5G networks has yet to provide the desired revenue that would encourage future long-term investments by the financers and second, 3G is not a guaranteed success due to the lingering shadows of 4G and its potential to become a reality as 4G proves itself in the market.

Innovation and progress are indeed catalysts that trigger change and change in this case may be an upgrade, evolution or revolution in technology. The question of which technology and where or how is still unanswered. Some of the most important issues include market readiness, business issues (e.g., pricing, market segmentation), service issues (e.g., coverage, service portfolio, and QoS), and technical challenges (e.g., spectrum availability, maturity of technology, and availability of proper user terminals). This thesis will interpret such issues in regards to the expected transition in Pakistan and will justify a migration model highlighting the inevitable challenges lining up for the region's future.

[1] Mobile Streams. "YES 2 3G" - White Paper. February 2001. www.mobile3G.com

Acknowledgments

The author wishes to express sincere appreciation to Professor Ronald Fulle for his guidance and time in the preparation of this manuscript. The core idea for this research originated from his teachings and views. In addition, special thanks to Shehzad Khattak (Nokia Seimens network, Islamabad, Pakistan) and Abid Riaz (BSS and TXN Implementation – North, Pakistan) for their insightful help with telecommunication industry today in Pakistan. Thanks also to the members of RIT Libraries and RIT publishing and research center for their valuable input.

Table of Contents

List of Figures

Chapter 1 - Mobile Wireless Communication Evolution

"Mobile telephony dates back to 1920s, with the partial success with maritime vessel. Due to extremely bulky equipment and lack of sophisticated radio technology, it was not particularly suited to on-land communication. Further progress was made during the Second World War in the 1930s with the development of *frequency modulation* (FM). Developments were carried over to peacetime enabling limited mobile telephony service in the 1940s in some large cities."[2]

> The first radiotelephone service was introduced in the US at the end of the 1940s, and was meant to connect mobile users in cars to the public fixed network. In the 1960s, a new system launched by Bell Systems, called "Improved Mobile Telephone Service" (IMTS), brought many improvements like direct dialing and higher bandwidth. The first analog cellular systems were based on IMTS and developed in the late 1960s and early 1970s. The systems were "cellular" because coverage areas were split into smaller areas or "cells", each of which is served by a low power transmitter and receiver.[3]

"Until the advent of IMT-2000, discussed later in detail, cellular networks had been developed under a number of proprietary, regional and national standards, creating a fragmented market."[4]

[2] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.
[3] Source: ITU http://www.itu.int/osg/spu/ni/3G/technology/
[4] Source- ITU http://www.itu.int/osg/spu/ni/3G/technology/

1.1 Basics of Mobile Telephony

It is crucial to highlight some basic concepts in mobile telephony in order to provide grounds for building and understanding the ideas discussed hereafter. Model used is 2G since it provides ground for 3G evolution.

1.1.1 Basic Network Architecture

1. BSC: A number of base stations are connected to and controlled by a *Base Station Controller* (BSC) with the control logic embedded in the BSC. Among other tasks, the BSC manages the handoff of calls from one base station to another as subscribers move from cell to cell.
2. MSC: Connected to the BSC is the *Mobile Switching Center* (MSC), a switch that manages the set up and teardown of calls to and from mobile subscribers. In addition to numerous similarities with standard PSTN switch, it contains a number of functions that are specific to mobile communications. For example, it interacts with a number of BSCs over an interface, contains logic of its own to deal with mobile subscribers, and part of this logic involves an interface to one or more HLRs.
3. HLR: Effectively a subscriber database, home location register (HLR) contains subscription information related to a number of subscribers. It plays a critical role in mobility management, the tracking of a subscriber as he or she moves around the network. "As a subscriber moves from one MSC to another, each MSC in turn notifies the HLR. When a call is received from the PSTN, the MSC that receives the call queries the HLR for the latest information regarding the subscriber location so that the call could be correctly routed to the subscriber.[5]

[5] Source-ITU http://www.itu.int/osg/spu/ni/3G/technology/

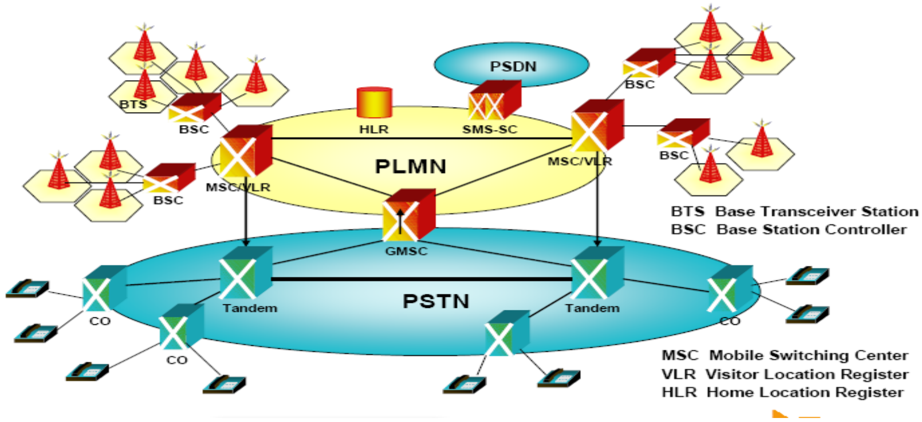


Figure 1 Basic Network Architecture

The network depicted in figure 4 can be considered as representing the bare minimum needed to provide a mobile telephony service. In addition, there are VLR and IN systems that deal with visiting subscribers and network intelligence (authentication, security, billing, etc.) respectively.

1.1.2 Cell and Sectors

The concept of cellular mobile telephony was the breakthrough that caused mobile telephony to become something viable. “Before the advent of cellular technology, capacity was enhanced through a division of frequencies and the resulting addition of available channels. However, this reduced the total bandwidth available to each user, affecting the quality of service. Cellular technology allowed for the division of geographical areas, rather than frequencies, leading to a more efficient use of the radio spectrum. This geographical re-use of radio channels is known as “frequency reuse.”[6]

[6] Source-ITU http://www.itu.int/osg/spu/ni/3G/technology/

1.1.3 Air Interface Access Techniques

"Radio spectrum is a precious and finite resource. Unlike other transmission media such as copper or fiber facilities, it is not possible to simply add radio spectrum when needed. Only a certain amount of spectrum is available and it is critical that it be used efficiently, and be reused as much as possible. Such requirements are at the heart of the radio access techniques used in mobile communications."[7]

FDMA: Frequency Division Multiple Access (FMDA) chunks up available spectrum into predefined bandwidths and then assigns one to each user. The result is a scenario where the network has one user per band of frequency or per channel as shown in figure 1. The channel, therefore, is closed to other conversations until the initial call is finished or until it is handed off to a different channel. "In most FDMA systems, separate channels are used in each direction one from network to subscriber (downlink) and the other from subscriber to network (uplink). For example, in analog AMPS 30-kHz channels implies two 30-kHz channels, one in each direction. Such an approach is known as *Frequency Division Duplex* (FDD) and normally a fixed separation exists between the frequency used in the uplink and that used in the downlink. This fixed separation is known as the duplex distance."[8]

TDMA: "Time Division Multiple Access (TDMA) improves spectrum capacity by splitting each frequency into time slots. TDMA allows each user to access the entire radio frequency channel for the short period of a call. Other users share this same frequency channel at different time slots. The base station continually switches from user to user on the channel. TDMA is the dominant technology for the second generation mobile cellular networks."[9]

[7] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.
[8] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.
[9] Source ITU http://www.itu.int/osg/spu/ni/3G/technology/

CDMA: Originating from the spread spectrum technology which involves spreading the signal over a wide bandwidth, Code Division Multiple Access (CDMA) increases spectrum capacity by allocating the entire radio band to all users in a given instant of time. User communication (voice and data) is identified based on a unique code assigned to individual user. "CDMA allows for a 'soft hand-off,' which means that terminals can communicate with several base stations at the same time."[10]

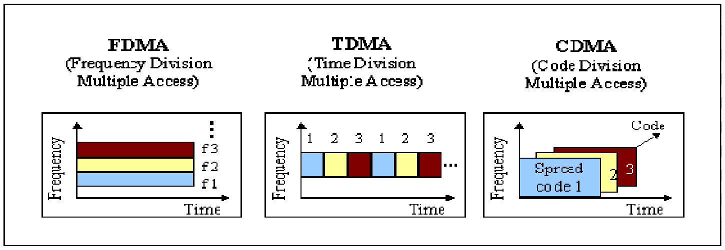


Figure 2 Access Technologies

1.1.4 Roaming

Roaming converts a wireless communication network into a mobile network. "Mobility implies that subscribers be able to move freely around the network and from one network to another. This requires that the network tracks the location of a subscriber to certain accuracy so that calls destined for the subscriber may be delivered and allow him to do so while engaged in a call."[11]

[10] Source ITU http://www.itu.int/osg/spu/ni/3G/technology/

[11] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.

1.1.5 Handoff/Handover

Defined as the ability of a subscriber to maintain a call while moving within the network, handoff implies that a subscriber travels from one cell to another while engaged in a call, and that call is maintained during the transition (ideally without the subscriber noticing any change). Depending on the two cells in question, the handoff can be between two sectors on the same base station, between two channels within the same cell, between two BSCs, between two MSCs belonging to the same operator, or even between two networks.

1.2 First Generation of Mobile Communication "1G"

1.2.1 Types

Based purely on analog communication, 1G marked the advent of wireless communication. The three major 1G technologies that gained popularity are:

1. AMPS: It began with the implementation of a trial system in Chicago in 1978 using a technology known as *Advanced Mobile Phone Service* (AMPS), operating in the 800-MHz band based on FDMA. For numerous reasons, however, including the break-up of AT&T, it took a few years before a commercial system was launched in the United States in 1983, with other cities following rapidly.
2. NMT: The Europeans 1G systems were launched in 1981 in Sweden, Norway, Denmark, and Finland using a technology known as *Nordic Mobile Telephony* (NMT), operating in the 450-MHz band. Later, another version was developed to operate in the 900-MHz band and was known as NMT900.

3. TACS: Britian introduced a modified version of AMPS in 1985 called the *Total Access Communications System* (TACS) that operated 900-MHz band.

1.2.2 Limitations

The success of 1G was beyond what anyone had expected. It was this very success that eventually exposed shortcomings like limited capacity and vulnerability to fraud. "The systems were able to handle large numbers of subscribers, but when the subscribers started to number in the millions, cracks started to appear, particularly since subscribers tend to be densely clustered in metropolitan areas. Consequently, significant effort was dedicated to the development of second-generation systems."[12]

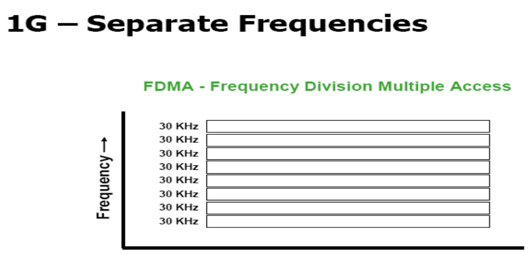


Figure 3 FDMA used in 1G

1.3 Second Generation of Mobile Communication "2G"

Formally known as the digital cellular networks, 2G systems were first developed at the end of the 1980s. Primary reason behind 2G was to increase network's voice call capacity by enabling more calls within a cell. The call capacity within a cell increases by using TDMA rather than FDMA. The 200 KHz frequency band is divided into channels, where each channel is shared among eight users by time slots,

[12] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.

one for each user. Each user could send a burst of bearer data within that one time slot assigned uniquely to him or her. These systems digitized not only the control link but also the voice signal and provided better quality and higher capacity at lower cost to consumers. The approach involves compressing the voice signal digitally and then doing modulation. Result is a significant change in the core network (introduction of the concept of intelligent network). "Intelligent Network (IN) is a telephone network architecture in which the service logic for a call is located separately from the switching facilities, allowing services to be added or changed without having to redesign switching equipment."[13]

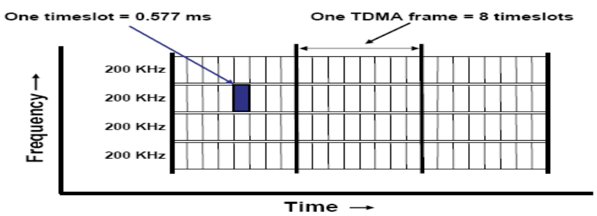


Figure 4 Air Interface in 2G

"Using FDMA, the available bandwidth is divided into a number of smaller channels as in FDMA and it is these channels that are divided into timeslots. The difference between a pure FDMA system and a TDMA system that also uses FDMA is that, with the TDMA system, a given user does not have exclusive access to the radio channel."[14]

1.3.1 Types

Based on digital communication both in radio path and between the network entities, these systems brought semi-global acceptance, and consequently roaming, to large regions.

1. Global system for Mobile Communication (GSM): Developed by ETSI, the most popular 2G standard surfaced in 1989. Early version used 25MHz frequency spectrum in the 900 MHz band.

[13] http://searchnetworking.techtarget.com/sDefinition/0,,sid7_gci212335,00.html
[14] Smith, Clint, P.E. 3G wireless networks. New York : McGraw-Hill, c2007.

This 25MHz was further divided into 124 carrier channels of 200 KHz each. A single 200 KHz channel was then used among eight users via TDMA. Of late, there are two other variants of GSM operating at 1.8 GHz and 1.9 GHz.

2. Personal Digital Communication (PDC): Immensely popular in Japan, this 2G technology works at 800 MHz and 1500 MHz frequencies. Since PDC success was limited to Japan, it is no surprise that Japan was the first one to launch a 3G network in 2001 in an attempt to work toward a 3G technology that was globally accepted.
3. IS-95: While most of the 2G technologies were based on FDMA and TDMA, Qualcomm designed a code division multiple access scheme. This scheme uses separate code to distinguish between data transmitted by different users on the same frequency.
4. US-TDMA or D-AMPS: Popular in North America, this was a digital version of First Generation AMPS technology.
5. Personal Handy Phone System (PHS): Somewhere in between a cellular and a cordless technology, it was a cheaper alternative to cellular systems used in Japan.[15]

1.3.2 Limitations

2G brought a major change in the way mobile networks were built, but they had their limitations:

1. Lower transfer rate: Designed primarily for voice services, the data transfer rate offered was low. Though the rates vary across technologies, the average rate is in the order to tens of kilobits per second.
2. Low efficiency for packet-switched services: With the immense popularity of the Internet came the demand among customers for access to the Internet while on the go. Wireless Internet access with the 2G networks is not efficiently implemented.

[15] 3G Mobile Networks- Architecture, Protocol, and Procedures

3. Multiple Standards: A multitude of competing standards allowed a user limited roaming; it was possible in regions that supported same technology. The 2G standards were semi- global and failed to allow global roaming.[16]

A series of standards, termed 2.5G, were developed later on to deal with the slow data rate issue. These standards were HSCSD - High speed Circuit-Switched Data (data rate of 57.6 Kbps), GPRS - General packet radio service (data rate of 115Kbps), and EDGE - Enhanced data rate for Global Evolution (384Kbps).

[16] 3G Mobile Networks- Architecture, Protocol, and Procedures

Chapter 2 - Third Generation of Mobile Communication "3G"

The mobile world of 2G, in spite of the increased data rates through 2.5G technologies, failed to cope with the huge demand for mobile broadband services, especially Internet. Internet access anywhere anytime!

3G talk started at ITU and in Europe as early as 1992, a year after 2G was commercially launched. "ITU, in the late 1990's, saw the growth of the Internet and other packet data applications as the key to developing third generation cellular systems."[17] The vision, initially known as Future Public Land Mobile Telecommunication System (FLMTS), "was to have a high data rate-globally accepted technology (3G) to indicate the next generation of mobile services capabilities in terms of bandwidth and network functions. These service capabilities in turn allow advanced services and applications, including multimedia."[18] It talked about having cells (Micro, Macro, and Pico) at many different scales with varying coverage areas. All were all to register under the umbrella of one standard.

Third generation (3G) systems promise faster communications services, including voice, fax and Internet, anytime and anywhere with seamless global roaming. ITU's IMT-2000 global standard for 3G has opened the way to enabling innovative applications and services such as multimedia entertainment, infotainment and location-based services, among others. 3G is the term used to describe the latest generation of mobile technology which provides enhancements to voice communications and data connectivity including wireless access to the Internet, mobile applications and multimedia content.[19]

[17] Wireless communications : evolution to 3G and beyond
[18] 3G Mobile Networks- Architecture, Protocol, and Procedures
[19] A White Paper from the UMTS Forum Mobile Broadband Evolution: the roadmap from HSPA to LTE February 2009

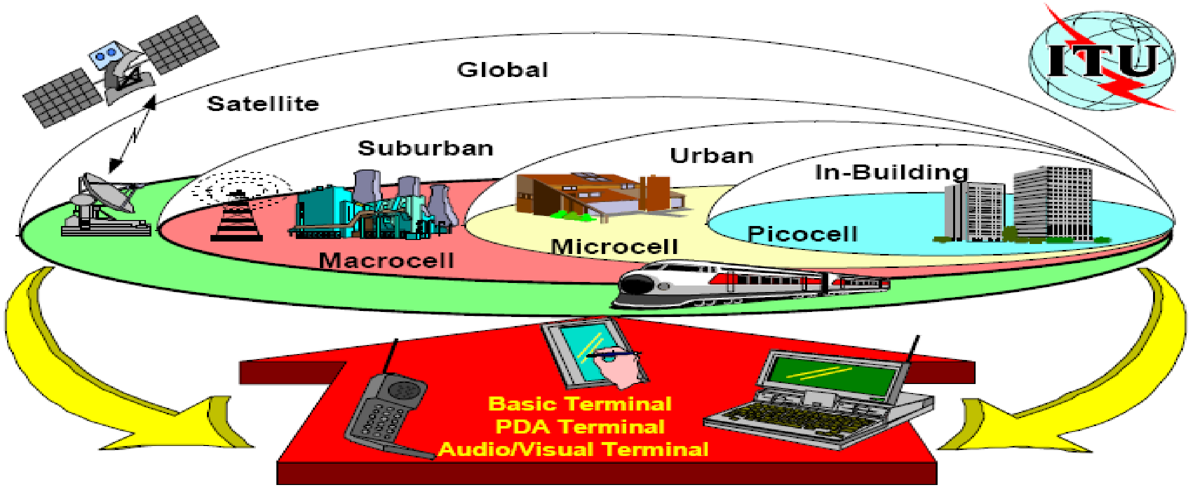


Figure 5 3G Vision

2.1 IMT-2000

IMT-2000 refers to set a radio interface standard that fulfills 3G requirements. The vision has following key characteristics:

Affordability: There was agreement in the industry that 3G systems had to be affordable in order to encourage their adoption by consumers and operators.

Compatibility with existing system: IMT-2000 services have to be compatible with existing systems. 2G systems, such as the GSM standard (prevalent in Europe and parts of Asia and Africa), will continue to exist for some time, and compatibility with these systems must be assured through effective and seamless migration paths.

Modular Design: The vision for IMT-2000 systems is that they must be easily expandable in order to allow for growth in users, coverage areas, and new services, with minimum initial investment.

Flexibility: With the large number of mergers and consolidations occurring in the mobile industry and the move into foreign markets, operators wanted to avoid having to support a wide range of different interfaces and technologies. This problem was addressed by providing a highly flexible system capable of supporting a wide range of services and applications. The IMT-2000 standard accommodates five possible radio interfaces based on three different access technologies (FDMA, TDMA and CDMA): [20]

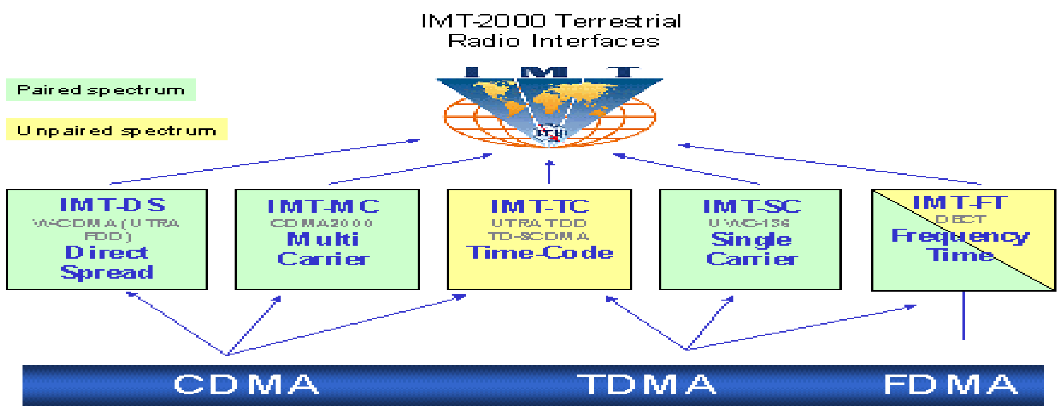


Figure 6 IMT-2000 mobile/terrestrial radio interface standards

IMT-Direct Spread (IMT-DS): CDMA direct spread is known as WCDMA and is intended for applications in public macro cell and microcell environments.

IMT-Multicarrier (IMT-MC) refers to CDMA2000 1X and CDMA20001xEV.

IMT-Time Code (IMT-TC) is a combination of WCDMA-TDD and TD-SCDMA.

IMT-Single Carrier (IMT-SC) corresponds to Universal Wireless Communication 136 and EDGE.

IMT-Frequency Time (IMT-FT) is the European digital enhanced cordless telecommunication proposal (DECT).

[20] www.itu.int/osg/spu/imt-2000/technology.html

“IMT-2000 is the result of collaboration of many entities, inside the ITU (ITU-R) and (ITU-T) and outside the ITU (3GPP, 3GPP2, UWCC and so on) in an effort to attain full interoperability and interworking of mobile systems.” [21] “The IMT-2000 specification is meant to be a unifying specification, enabling mobile and some fixed high-speed data services to use one or several radio channels with fixed network platforms for delivering the services envisioned:

a) Global standard, b) Compatibility of service within IMT-2000 and other fixed networks, c) High quality, d) Worldwide common frequency band, e) Small terminals for worldwide use, f) Worldwide roaming capability, g) Multimedia application services and terminals, h) Improved spectrum efficiency, i) Flexibility for evolution to the next generation of wireless systems, j) High-speed packet data rates, k) 2 Mbps for fixed environment, 384 kbps for pedestrian, 144 Kbps for vehicular traffic.”[22]

2.2 Radio Spectrum

Mobile operators use radio spectrum to provide their services. Spectrum in the cellular world is a scarce resource and is allocated as such. IMT-2000 vision necessitated finding a new globally available frequency band as well as maximizing convergence within the many existing 2G wireless technologies. At the 1992 ITU World Radio Conference, 230 MHz of new radio spectrum was identified. At WRC2000, spectrum capacity expanded significantly by allowing the use of current 2G spectrum blocks for 3G technology and allocating 3G spectrum to an upper limit of 3GHz. The result was a threefold increase in the potential IMT-2000 spectrum. The 2007 World Radio Conference made valuable strides in identifying additional spectrum for IMT, both below 1GHz and above 2 GHz. The following frequency bands are currently identified for IMT: **(Band 1)** 450 – 470 MHz, **(Band 2)** 790 – 960 MHz,

[21] http://www.itu.int/home/imt.html
[22] 3G wireless networks

(Band 3) 1710 – 2025 MHz, **(Band 4)** 2110 – 2200 MHz, **(Band 5)** 2300 – 2400 MHz, **(Band 6)** 2500 – 2690 MHz[23]

2.3 3G Standardization

The idea of one global standard for 3G was hard to apply due to the rapid growth of 2G mobile during the 1990's. With several similar technologies worldwide, it became necessary for ITU to offer a number of possible routes from the various existing 2G systems to a 3G capability. This led to the establishment of two distinct 3G families:

3GPP2: 3rd Generation Partnership Project 2 (3GPP2) was formed to help North American and Asian operators using CDMA2000 transition to 3G. 3GPP2 technologies evolved as 1XRTT, EV-DO, EV-DO Rev. A, EV-DO Rev. B and UMB.

3GPP: The 3rd Generation Partnership Project (3GPP) was formed to foster deployment of 3G networks that descended from GSM. 3GPP technologies evolved as GPRS, EDGE, WCDMA, HSDPA, and LTE. [24]

Note: GSM constitutes more than 95% of the cellular market in Pakistan (chapter x). Pakistan as the focus of this research entails 3GPPstandards as a guideline for 3G migration.

[23] http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/Spectrum-IMT.pdf

[24] http://searchtelecom.techtarget.com/sDefinition/0,,sid103_gci214486,00.html

2.4 The Myth

The frequency bands for IMT-2000 were allocated in two steps: WRC 1992 and WRC 2000. Spectrum auction in late 1990's was primarily for the newly defined high frequency bands. "Many country-specific regulations controlled which IMT-2000 family option could be deployed. Result was media focus on the 'revolutionary' members of the IMT-2000 family of standards, which led to a belief that this was the only real 3G. Many industry organizations only consider part of the IMT-2000 family of 3G standards as actual 3G technologies; in particular IMT-SC (EDGE) is excluded from most 3G mobile statistics. This is particularly unfortunate because IMT-SC is the 'evolutionary' option for the vast installed GSM (2G) base and therefore will almost certainly become the dominant 3G component in the near future. IMT-SC is typically excluded because many within the industry view CDMA as the only 3G wireless technologies."[25]

"The term 3G represents the next generation of mobile services. These services include better quality voice, higher capacity access to the Internet and high speed packet data and multimedia applications. The international 3G standards have been accepted by ITU under the name of IMT-2000"[26]. IMT-2000 offers both evolution and revolution options for migration to 3G.

Evolution: Backwards compatible evolution of a 2G standard to its 3G equivalent within an operator's existing spectrum allocation. There are essentially two widely deployed "evolutionary" IMT-2000 standards: IMT-MC (cdma2000) and IMT-SC (EDGE).

[25] http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/What_really_3G.pdf
[26] Wireless communications : evolution to 3G and beyond

Revolution: Required an operator to obtain additional spectrum, build an overlay network, and utilize dual mode/band mobile equipment. These are MT-DS (W-CDMA) because of the relatively wide channels (5 MHz), and IMT-TC (TD-SCDMA/UTRA TDD) plus IMT-FT (DECT) because a TDD frequency assignment is required. Note that it can in some cases be possible to deploy IMT-DS in existing cellular bands if sufficient spare bandwidth can be made available.[27]

2.5 Technologies

3G vision, standards, and requirements have been set. How a region embarks on this journey, however, may vary from place to place. Japan launched the very first commercial 3G network in 2001 (W-CDMA). China, not far from it, came up with its own air interface standard, TS-CDMA, in addition to the available options. In terms of technology, there is more than one path to 3G. First step, for a region and in this case Pakistan, is to identify the possible candidates among these standards. Based on the discussion so far, the starting picture would be as follows:

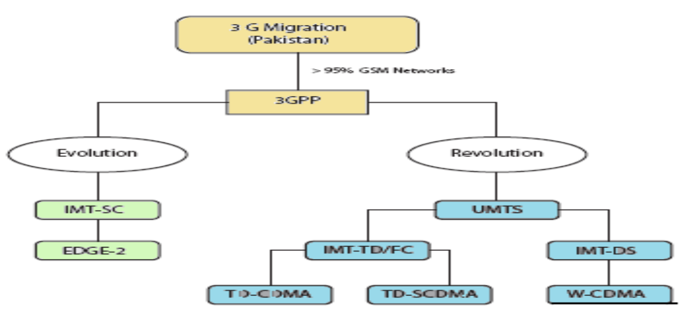


Figure 7 Migration Possibilities

[27] http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/What_really_3G.pdf

Note: IMT-MC and IMT-DT are eliminated due to fact that these technologies are irrelevant to discussion at hand. IMT-MC is for 2G networks originating from IS-95 standard one, and IMT-DT is for the European DECT.

2.6 Revolution

The options for revolution can all be categorized under the umbrella of Universal Mobile Telecommunications System. UMTS is the term coined by 3GPP, synonymous to 3G networks, and represents an evolution of GSM to support 3G capabilities. UMTS includes three of the air interfaces from IMT-2000 standard list.

1. (Direct Sequence Wideband CDMA) WCDMA-FDD: In the FDD option, paired 5-MHz carriers are used in the uplink and downlink as follows: uplink (1920 MHz to 1980 MHz); downlink (2110 MHz to 2170 MHz). Thus, for the FDD mode of operation, a separation of 190 MHz is used between the uplink and downlink.
2. (Direct Sequence Wideband CDMA) WCDMA-TDD: For TDD option, a number of frequencies have been defined, including (1900 MHz to 1920 MHz) and (2010 MHz to 2025 MHz). Of course, with TDD, a given carrier is used in both the uplink and the downlink so that no separation exists.[28]
3. (Time Division Synchronous Code Division Multiple Access) TD-SCDMA: In the second release of radio access interface for UMTS (UTRA), TD-SCDMA was included. Jointly developed by Siemens and the China Academy of Telecommunications Technology (CATT), TDSCDMA 2010

[28] 3G wireless networks

MHz - 2025 MHz in China combines an advanced TDMA/TDD system with an adaptive CDMA component operating in a synchronous mode.[29]

2.6.1 UMTS Network Architecture

The basic UMTS network bears similarities with any wireless network and is modeled along the lines of GSM/GPRS. "The RNC in UMTS networks provides functions equivalent to the base station controller (BSC) functions in GSM/GPRS networks. Node B in UMTS networks is equivalent to the base transceiver station (BTS) in GSM/GPRS networks. In this way, the UMTS extends existing GSM and GPRS networks, protecting the investment of mobile wireless operators. It enables new services over existing interfaces such as A, Gb, and Abis, and new interfaces that include the UTRAN interface between Node B and the RNC (Iub) and the UTRAN interface between two RNCs (Iur)."[30] The network may be partitioned into three broad entities.

Access network (UTRAN)

The new air interface access method, WCDMA, requires a new radio access network (RAN) which in this case is called UTMS terrestrial RAN (UTRAN). It constitutes RNC and Node B.

[29] Siemens TD-SCDMA white paper
[30] Overview+of+GSM_+GPRS_+and+UMTS

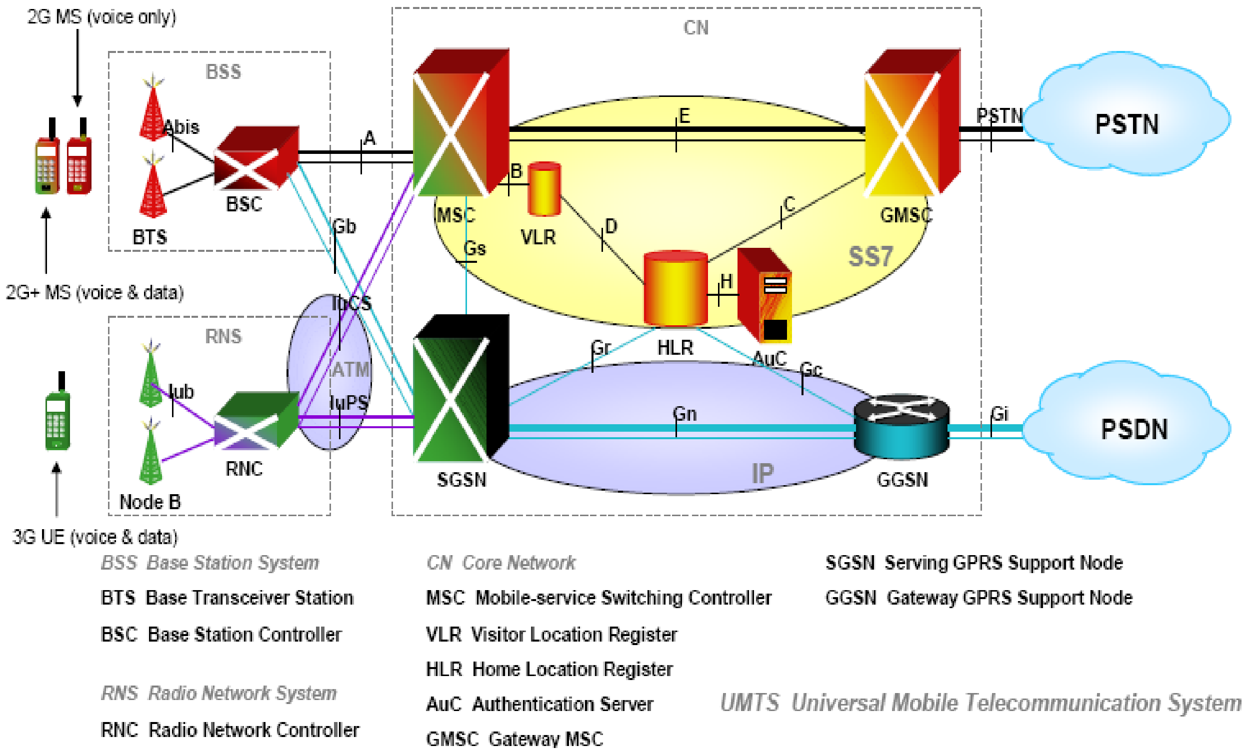


Figure 8 UMTS Architecture [31]

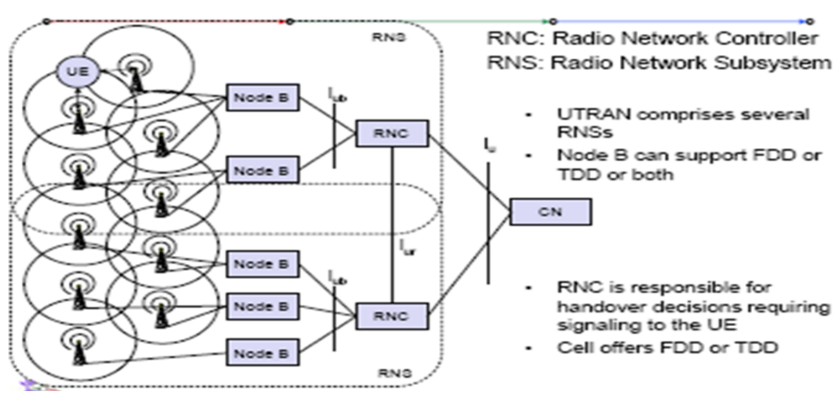


Figure 9 UTRAN Architecture

[31] www.nmscommunications.com

Radio Network Controller

“RNC functions include Radio resource control, Admission control, Channel allocation, Power control settings, Handover control, Macro diversity, Ciphering, Segmentation and reassembly, Broadcast signaling, and open loop power control.”[32] The RNC that controls a given Node B is known as the Controlling RNC (CRNC). The CRNC is responsible for the management of radio resources available at a Node B that it supports. For a given connection between the UE and the core network, RNC is in control and is called Serving RNC or SRNC. [33]

Node B

Node B is the radio transmission/reception unit for communication between radio cells. Each Node B unit can provide service for one or more cells. Node B connects to the user equipment (UE) over the Uu radio interface using wide-band code division multiple access (WCDMA), supporting FDD and TDD. The main function of Node B is conversion of data on the Uu radio interface. The functions of Node B include air interface transmission and reception, modulation and demodulation, CDMA physical channel coding, micro diversity, error handling, closed loop and power control.”[34]

User equipment

The UMTS user equipment (UE) is the combination of the subscriber’s mobile equipment and the UMTS Subscriber identity module (USIM). The USIM card has the same physical characteristics as the GSM/GPRS SIM card and provides functions like supports multiple user profiles on the

[32] Overview+of+GSM_+GPRS_+and+UMTS
[33] 3G Wireless Networks
[34] Overview+of+GSM_+GPRS_+and+UMTS

USIM, updates USIM information over the air provides security functions, provides user authentication, supports inclusion of payment methods, supports secure downloading of new applications, etc. The UMTS standard places no restrictions on the functions that the UE can provide. Many of the identity types for UE devices are taken directly from GSM specifications; such as International Mobile Subscriber Identity (IMSI) and Temporary Mobile Subscriber Identity (TMSI).[35]

Core Network

The core network requires minor modifications to accommodate the UTRAN since it is based upon the core from GSM. GSM core can support both UTRAN and GSM radio access. Logically, it can be divided into packet and circuit switched domain. "Core functions include mobility management, call control, switching, session management, routing, authentication and equipment identification."[36]

UMTS interfaces

In comparison with the preceding 3GPP GSM architecture (GSM/GPRS), UMTS defines four new open interfaces:

1. Uu interface—User equipment to Node B (the UMTS WCDMA air interface)
2. Iu interface—RNC to GSM/GPRS (MSC/VLR or SGSN)

    Iu-CS—Interface for circuit-switched data

    Iu-PS—Interface for packet-switched data

3. Iub interface—RNC to Node B interface

[35] Overview+of+GSM_+GPRS_+and+UMTS

[36] 3G Mobile Networks- Architecture, Protocol, and Procedures

4. Iur interface—RNC to RNC interface (no equivalent in GSM).[37]

2.6.2 UMTS Air Interface

DS-CDMA means that user data is spread over a much wider bandwidth through multiplication by a sequence of pseudo-random bits called chips. Figure 2.3 provides a conceptual depiction of this spreading. The user data, at a relatively low rate compared to spreading code rate, is spread over a signal that has a higher bit rate and the signal transmitted has pseudo-random characteristics. When transmitted over a radio interface, the spread signal looks like noise. If multiple users transmit simultaneously on the same frequency, then the stream of data from each user needs to be spread according to a different pseudo-random sequence. At the receiving end, the stream of data from a given user is recovered by dispreading the set of received signals with the appropriate spreading code. What is being dispread is the complete set of signals received from all users that are transmitting. As the number of simultaneous users increases, so does the interference and it eventually becomes impossible to recover a specific user's data with any confidence. In other words, for a given bit of recovered user data, the signal-to-noise ratio must be sufficiently high. In CDMA, provided that Eb/No is sufficiently large, the user data can be recovered.[38]

Modulation

[37] Overview+of+GSM_+GPRS_+and+UMTS

[38] 3G Wireless Networks; Eb is the power density per bit of recovered user data and No is the noise power density.

"The modulation used on uplink is different from the downlink. The downlink used QPSK for all transport channels. However, the uplink uses two separate channels to avoid interference and works with DQPSK."[39]

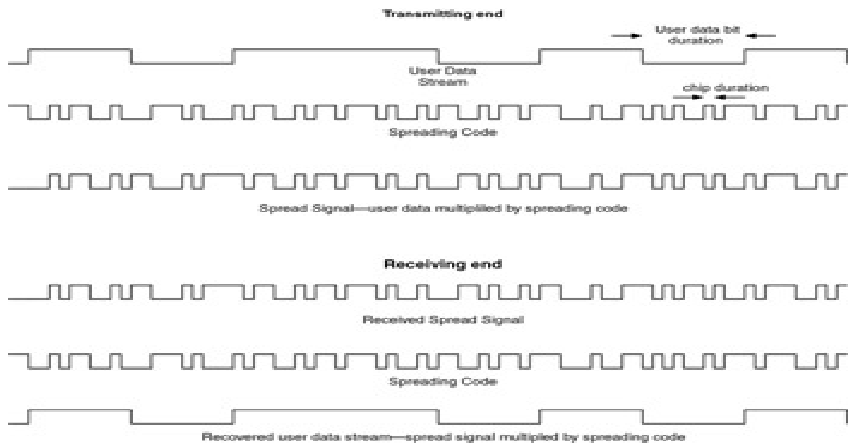


Figure 10 CDMA Basic Concept

Spreading Factor

The ratio of the chip rate to the user data symbol rate is known as the spreading factor. The chip rate in WCDMA is 3.84 x 106 chips/second (3.84 Mcps). The capability to recover a given user's signal is directly influenced by the spreading factor; the higher the spreading factor, the greater the capability to recover a given user's signal. In terms of transmission and reception, a higher spreading factor has an equivalent effect as transmitting at a higher power. Thus, the magnitude of the spreading factor can be considered a type of gain and is known as the processing gain. In dB, the processing gain is given by 10 x 10Log10 (spreading rate/user rate). In some cases, this can be quite a large number and can help to overcome the effect of interference generated by the presence of other users.[40]

[39] http://www.radio-electronics.com/info/cellulartelecomms/umts/umts_wcdma_radio.php
[40] 3G wireless Networks

Uplink

"In theory, for a speech service at 12.2 Kbps (and, for now, assuming no extra bandwidth for error correction), the spreading factor would be 3.84 x 106/12.2 x 103 = 314.75. This would equate to a processing gain of 25 dB. In reality, however, WCDMA does include extra coding for error correction. Consequently, a spreading factor as high as 314.75 is not supported, at least not in the uplink. The supported uplink spreading factors are 4, 8, 16, 32, 64, 128, and 256. The highest spreading factor (256) is used mostly by the various control channels. Some control channels can also use lower spreading factors, while user services generally use lower spreading factors."[41] A summary of the spreading factors and the corresponding data rates on the uplink is:

Spreading Factor	Gross Data Rate (Kbps)	User data rate (Kbps) (assuming half-rate coding for error correction)
256	15	7.5
128	30	15
64	60	30
32	120	60
16	240	120
8	480	240
4	960	480

Figure 11 Uplink Data Rates

"The lowest spreading factor (4) provides a gross rate of only 960 Kbps and a usable rate of only 480 Kbps. This does not meet the requirements of IMT-2000, which states that a user should be able to achieve speeds of 2 Mbps. In order to meet that requirement, UMTS supports the capability for a given

[41] ibid

user to transmit up to six simultaneous data channels. Thus, if a user wants to transmit user data at a user rate greater than 480 Kbps, then multiple channels are used, each with a spreading factor of four. With six parallel channels, each at a spreading factor of four, a single user can obtain speeds of over 2 Mbps."[42]

Downlink

"The uplink effectively uses one bit per user symbol, while the downlink effectively uses two bits per user symbol. Consequently, for a given spreading factor, the user bit rate in the downlink is greater than the corresponding bit rate in the uplink. The user rate in the downlink is not quite twice that in the uplink, however, due to differences in the way that control channels and traffic channels are multiplexed on the air interface."[43]

Downlink Spreading Factors and Data Rates

Spreading Factor	Gross air interface bit rate (Kbps)	User data rate (Kbps) (including coding for error correction)	Approximate net user data rate (Kbps) (assuming half rate coding)
512	15	3–6	1–3
256	30	12–24	6–12
128	60	42–512	21–25
64	120	90	45
32	240	210	105
16	480	432	216
8	960	912	456
4	1920	1,872	936

Figure 12 Downlink Data Rates

"An important capability of WCDMA is that user data rates do not need to be fixed. In WCDMA, channels are transmitted with a 10-ms frame structure. It is possible to change the spreading factor on a frame-by-frame basis. Thus, within one frame, the user data rate is fixed, but the user data rate can change from frame to frame. This capability means that WCDMA can offer bandwidth on demand. Note

[42] ibid
[43] 3G wireless Networks

that rate changes every 10 ms do not apply to AMR speech as each speech packet is 20 ms in duration, so that the speech rate can change every 20 ms if needed, but not every 10 ms." [44]

2.6.3 UMTS Services

The UMTS supports the following service categories and applications:

1. Internet access: Messaging, video/music download, voice/video over IP, mobile commerce (e.g., banking, trading), travel and information services.
2. Intranet/extranet access: Enterprise application such as e-mail/messaging, travel assistance, mobile sales, technical services, corporate database access, fleet/warehouse management, conferencing, and video telephony.
3. Customized information/entertainment: Information (photo/video/music download), travel assistance, distance education, mobile messaging, gaming, voice portal services.
4. Multimedia messaging: SMS extensions for images, video, and music; unified messaging; document transfer.
5. Location-based services: Yellow pages, mobile commerce, navigational service, trade.[45]

2.6.4 Traffic Types

UMTS promises high data rate capabilities, but there is more to a given service than just the data rate that the service demands. UMTS specifications define four service classes, where the services within a given class have a common set of characteristics. The service classes are as follows:

[44] ibid
[45] Overview+of+GSM_+GPRS_+and+UMTS

1. ***Conversational*** is characterized by low delay tolerance, low jitter (delay variation), and low error tolerance. The data rate requirement may be high or low but is generally symmetrical. Examples are Voice, video telephony, and video gaming.
2. ***Interactive*** consists of typically request/response-type transactions and is characterized by low tolerance for errors but with a larger tolerance for delays than conversational services. Jitter (delay variation) is not a major impediment to interactive services, provided that the overall delay does not become excessive. Interactive services may require low or high data rates depending on the service in question, but the data rate is generally significant only in one direction at a time. Examples are Web browsing, network gaming, and database access.
3. ***Streaming*** concerns one-way services, using low- to high-bit rates. Streaming services have a low-error tolerance but generally have a high tolerance for delay and jitter. That is because the receiving application usually buffers data so that it can be played to the user in a synchronized manner. Streaming audio and streaming video are typical streaming applications in addition to Multimedia, video on demand, and webcast.
4. ***Background*** is characterized by little, if any, delay constraint. Examples include E-mail, short message service (SMS), file downloading, server-to-server e-mail delivery (as opposed to user retrieval of e-mail), and performance/measurement reporting. Background applications require error-free delivery.[46]

2.6.5 QoS in UMTS

[46] 3G Wireless Networks

"An important feature of the Universal Mobile Telecommunications System (UMTS) is that information generated by independent sources can be efficiently multiplexed on the same transmission medium. A major challenge for the UMTS infrastructure is to carry various types of application on the same medium, while meeting the QoS objectives. As well as meeting the user needs in the end-to-end QoS. This requirement applies not only to the scarce radio spectrum, but also to terrestrial transmission resources, and especially the access part which must provide a cost-effective transfer service while minimizing investment and operating costs. Thus it is highly desirable to achieve some statistical multiplexing gain. In particular, transmission links and the radio interface must be loaded as heavily as possible while meeting the QoS requirements. Therefore it is important to identify mechanisms that optimize the load."[47]

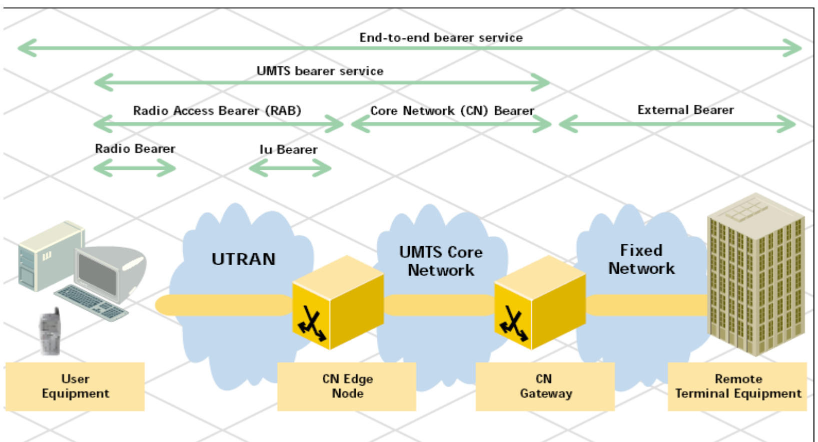


Figure 13 UMTS QoS Architecture[48]

QoS Handling in the UMTS Core Network

"There are three basic timescales for traffic management in UMTS networks:

1. Dependant on operators traffic mix, service level agreements and network topology matrix, capacity planning and network dimensioning determine the numbers and configuration of the core nodes plus required bandwidth of the UMTS interfaces.

[47] http://www1.alcatel-lucent.com/doctypes/articlepaperlibrary/pdf/ATR2001Q1/gb/09baudetgb.pdf
[48] ibid

2. Initiated with every call setup, CAC determines whether or not the new call can be accepted while guaranteeing the QoS of established calls.
3. Policing, scheduling and congestion mechanisms are performed each time a packet is sent and/or received (typically microseconds). Policing and buffer acceptance mechanisms are algorithms that decide when a packet arrives, whether or not it can be accepted. Scheduling algorithms decide when (and which) packet to send first.

The QoS features supported by the UMTS core network determine its ability to differentiate between services offered to subscribers. This capability is offered end-to end to ensure necessary resources are allocation and guaranteeing the negotiated quality of service."[49]

QoS Handling in the UMTS Terrestrial Radio Access Network

Radio access bearer services, RAB, are established dynamically to support one or several applications for a given MS. Each RAB is characterized by QoS attributes which are derived from the characteristics of the application. The UTRAN simply obtains the RAB QoS attributes from the core network when the RAB is established and maintains required QoS levels. The RAB is always established at the request of the core network, which retains ownership of the RAB throughout its life. Once the UTRAN has committed to a given QoS level, this should not be downgraded by the UTRAN without a prior modification request from the core network. In particular, this requirement applies to mobile terminals, which frequently experience varying radio conditions as they move from cell to cell. Given all WCDAM users share the same resources both in the frequency and time domains, it is essential to maintain a low level of radio interference throughout the system. To this end, power control constrains the transmission power to/from each user between appropriate limits: not too high, to preserve the UMTS cell traffic

[49] ibid

capacity and not too low, to avoid excessive transmission errors that would lower the overall bit rate. In addition, QoS monitoring is essential to ensure that the QoS requirements are met but not exceeded. Smoothing of the traffic flow and congestion avoidance is essential. Radio Admission Control (RAC), radio resource allocation and management, and radio load control functions are key features for handling QoS within UTRAN.[50]

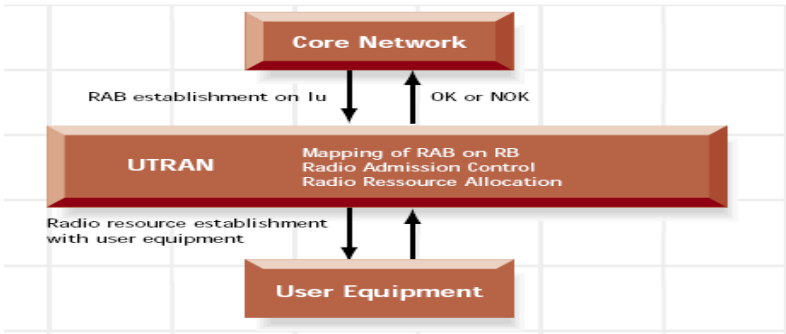


Figure 14 RAB Service Establishment Principles [51]

2.6.6 Hand Over

UTRAN interface Iur exists between the RNCs and supports inter-RNC mobility and soft handover between Node Bs connected to different RNCs. "These handovers cop with requirements of load control, coverage provisioning and offering quality of services. As a result, handover failures are reduced substantially."[52]

Hard Handover

[50] http://www1.alcatel-lucent.com/doctypes/articlepaperlibrary/pdf/ATR2001Q1/gb/09baudetgb.pdf
[51] ibid
[52] http://oldwww.com.dtu.dk/research/networks/OPNET/UMTS_handover.pdf

"Hard handover means that all the old radio links in the UE are removed before the new radio links are established. Hard handover can be seamless or non-seamless. Seamless hard handover means that the handover is not perceptible to the user. In practice a handover that requires a change of the carrier frequency (inter-frequency handover) is always performed as hard handover."[53] The mobile station performs a handover when the signal strength of a neighboring cell exceeds the signal strength of the current cell with a given threshold. To decrease blocking probabilities experienced by users entering a new cell and to avoid poor utilization of cell capacity (mobility issues in 2G networks), WCDMA offers soft and softer handovers. "Typically hard handovers are only used for coverage and load reasons, while soft and softer handover are the main means of supporting mobility."[54]

Soft Handover

"Soft and softer handover are the CDMA revolutionary features. Soft handover means that the radio links are added and removed in a way that the UE always keeps at least one radio link to the UTRAN. Soft handover is performed by means of macro diversity, which refers to the condition that several radio links are active at the same time. Normally soft handover can be used when cells operated on the same frequency are changed."[55]

Softer Handover

"Softer handover is a special case of soft handover where the radio links that are added and removed belong to the same Node B (i.e. the site of co-located base stations from which several sector-cells are served. In softer handover, macro diversity with maximum ratio combining can be performed in the Node

[53] http://www.umtsworld.com/technology/handover.htm
[54] http://oldwww.com.dtu.dk/research/networks/OPNET/UMTS_handover.pdf
[55] http://www.umtsworld.com/technology/handover.htm

B, whereas generally in soft handover on the downlink, macro diversity with selection combining is applied."[56]

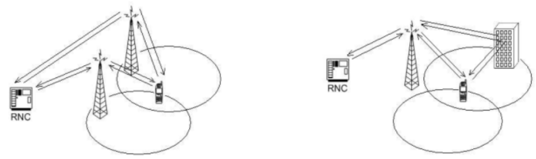


Figure 15 Soft and Softer Handover

Inter-system handover

Inter-system handovers are necessary to support compatibility with other system architectures. The signaling procedure for handing over a UMTS user to the GSM system is shown below. This example is illustrative for the general procedure followed during handovers. This procedure generally consists of carrying out of measurements, reserving resources and the performing the actual handover. When switching the connection to another system architecture there is need for a measurement on the frequency used by the other system. When there is no full dual receiver available the transmission and reception are halted for a short time to perform measurements on the other frequencies. This is called the compressed mode. As FDD and TDD mode make use of different frequencies, inter-mode handovers also make use of compressed mode to perform measurements on other frequencies needed during the handover.[57]

[56] ibid
[57] http://www.umtsworld.com/technology/handover.htm

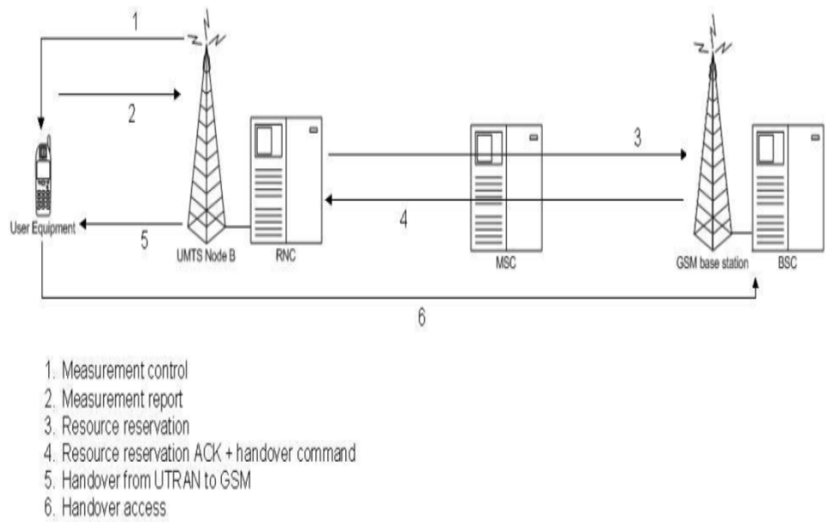


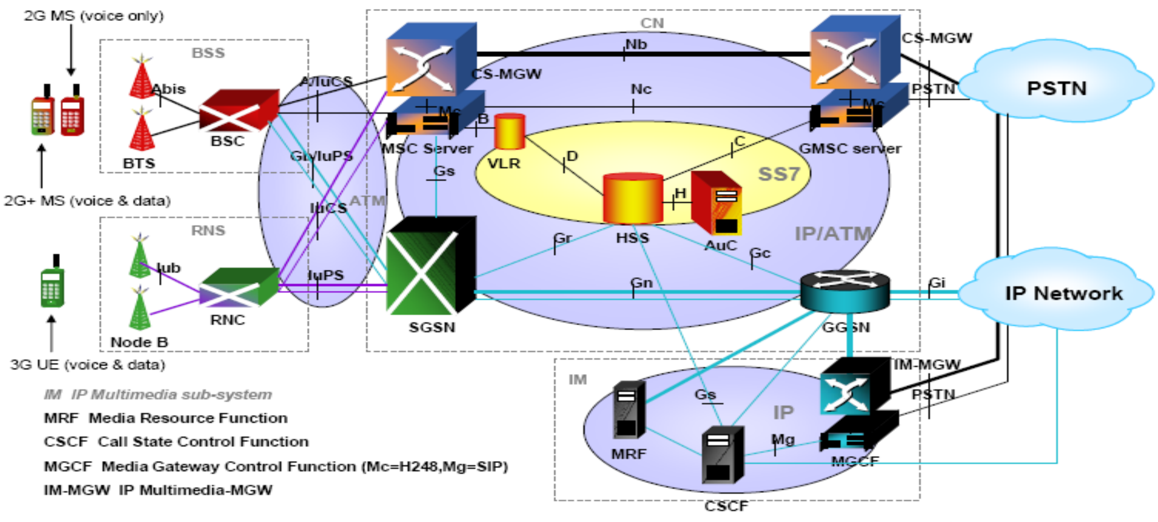
Figure 16 Inter System Hand Over

2.7 Evolution (IMT-SC/EDGE)

"EDGE provides an evolutionary path that enables existing 2G systems to deliver 3G services in existing spectrum bands. It reuses the GSM carrier bandwidth and time slot structure."[58] GSM/enhanced data rates for global evolution or GSM/EDGE standard has been taking steps to define a fully capable 3G mobile RAN. 3GPP release 5 specifies GSM/EDGE RAN (GERAN) that can connect to 3G core and provide the same set of services as UMTS UTRAN.

[58] Wireless network evolution : 2G to 3G

2.7.1 GERAN Architecture



[59]

Figure 17 GERAN Architecture

Figure 2.10 is an evolution of figure 2.1 with the addition of GSM/EDGE Radio Access Network and IMS. IP multimedia subsystem, added for maximum flexibility and independence from access technologies, falls outside the scope of this paper and hence is not discussed. Also, the core and the UE part of this network are similar to UMTS architecture as discussed.

GERAN Interfaces

Legacy Interfaces

1. **Gb Interface** connects serving GPRS support node SGSN and Base Station Subsystem (BSS)
2. **A Interface** connects BSC and MSC[60]

[59] www.nmscommunications.com

New Interfaces

The general protocol model for new interfaces is based on the protocol model used in UMTS. The logical independence of layers and planes adds additional flexibility so that transport layer protocol may be changed if needed with no impact on the radio interface.

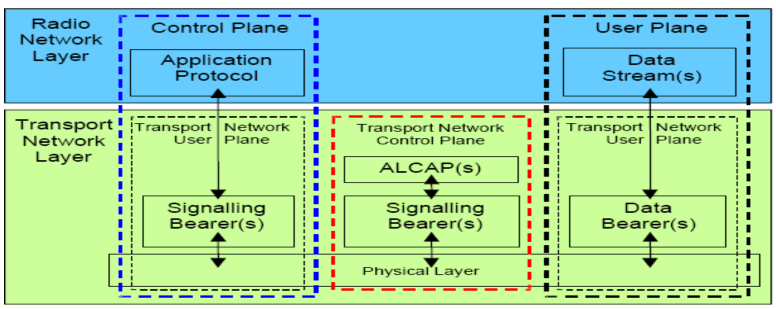


Figure 18 UTRAN/ GERAN Protocol Model

1. Iu interface similar and discussed in UTRAN.
2. Iur-g interface is based on UTRAN Iur interface and supports logical connection between any two GERAN.[61]

"The functionality split across these interfaces is aligned with UTRAN-CN split. For GERAN this means that the functionalities like ciphering and header adaptation are moved from the CN and are part of the radio access net-work. In addition the cell level mobility management tasks

[60] http://www.benoa.net/publications/ict2001.pdf
[61] ibid

are solely part of the operator deploying both radio access technologies (GERAN and UTRAN) may operate one single core network, and both access technologies can provide the same set of services. This includes provision of all the UMTS traffic classes also through GERAN. For the network and terminal manufacturers, the harmonization gives benefit in form of synergies in protocol and interface implementation. The harmonization of the GERAN and UTRAN architectures simplifies the future development of these radio access technologies, e.g., towards an All-IP system. The IP transport is expected to give benefit for the operators by bringing down the transmission costs."[62]

2.7.2 GERAN Radio Protocols

1. **Packet Data Convergence Protocol –** PDCP is for the transfer of user data using services provided by the RLC and header adaptation of the redundant network PDU control information (IP headers) in order to make the transport over the RF spectrum efficient.
2. **Radio Resource Control - RRC is** based on both GSM RR and UTRAN RRC specifications. Functions include broadcast of information related to the non-access stratum (core network) and the access stratum, paging/notification, routing of higher layer PDUs, control of requested QoS and security functions, and MS measurement reporting and control of the reporting.
3. **Link Control RLC** allows for the data transfer in various modes and in addition notifies unrecoverable errors to upper layer. When in transparent mode, RLC has no functionality and does not alter the data units of the upper layer. In non-transparent mode, the RLC is responsible for ciphering RLC PDUs in order to prevent any unauthorized acquisition of data. In acknowledged mode, Backward Error Correction (BEC) procedures are provided that allow error-free transmission of RLC PDUs.

[62] ibid

4. **Medium Access Control** – MAC allows the transmission over the physical layer of upper layer PDUs in dedicated or shared mode. A MAC mode is associated with a physical sub channel for use by one or more mobile stations (dedicated or shared mode respectively) and handles the access to and multiplexing onto the physical sub channels of mobile stations and traffic flows.[63]

2.7.3 Quality of Service

"RRC realizes the QoS requirements of the RAB by establishing a RB between MS and GERAN. For each RB, RRC allocates either a dedicated or a shared channel. In case of dedicated channels, RRC also takes care of radio resources allocations. In case of shared channels, MAC takes care of radio resource allocations."[64] As explained in UTRAN, "QoS is divided into control plane (CAC and QoS preserving) and user plane (link adaptation, traffic conditioning, packet scheduler, and power control)."[65]

2.7.4 Services and Traffic types

"As part of RAN harmonization, same services and traffic types apply to GERAN."[66]

2.7.5 Hand Over

Being a GSM evolution, the handover allowed is hard handover. Details are provided in UTRAN handover discussion.

[63] ibid
[64] http://www.benoa.net/publications/ict2001.pdf
[65] http://74.125.95.132/search?q=cache:s3_NvXfdpMIJ:www.it.lut.fi/kurssit/03-04/010990000/gsm-
[66] Advances in 3G enhanced technologies for wireless communications

2.7.6 Air Interface

Air access medium technique used is TDMA running FDMA (details provided in chapter one). "The carrier bandwidth is 200 kHz, with 8 timeslots per carrier, each containing 148 bits. The GSM Gaussian Minimum Shift Keying (GMSK) modulation scheme is supported in addition to a new 8-PSK modulation scheme."[67] "The basic goal with is to enhance the data throughput capabilities of a GSM/GPRS network or squeeze more bits per second out of the same 200-kHz carrier and eight-timeslot TDMA. The result is that EDGE can theoretically support speeds of up to 384 Kbps. Thus, it is clearly more advanced than GPRS, but still does not meet the requirements for a true 3G system (which should support speeds of up to 2 Mbps)." [68]

Air Interface Coding Schemes and Data Rates

"If a BTS supports both GMSK and 8-PSK modulation and has the same output power for both, then the cell footprint is smaller for 8-PSK than for GMSK. Recognizing this limitation, however, RF condition may change the scheme use. As a user moves towards the edge of a cell, the effect of lower signal to noise will mean that the network can reduce the user's throughput, either by changing the modulation scheme to GMSK or by changing the coding scheme to include greater error detection. All that the user will notice is somewhat slower throughput." [69]

[67] EDGE AIR-INTERFACE CAPACITY ANALYSIS
[68] 3G wireless network
[69] 3G wireless network

Scheme	Modulation	RLC Blocks per Radio Block (20 ms)	Input Data payload (bits)	Data Rate (Kbps)
MCS-1	GMSK	1	176	8.8
MCS-2	GMSK	1	224	11.2
MCS-3	GMSK	1	296	14.8
MCS-4	GMSK	1	352	17.6
MCS-5	8-PSK	1	448	22.4
MCS-6	8-PSK	1	592	29.6
MCS-7	8-PSK	2	2 x 448	44.8
MCS-8	8-PSK	2	2 x 544	54.4
MCS-9	8-PSK	2	2 x 592	59.2

Modulation and Coding Schemes for EGPRS

Figure 19 Modulation and Data Rates[70]

2.7.7 GERAN Evolution

Current EDGE peak data rates of 300 kbps cannot cope with the data rates of 7.2 Mbps provided by WCDMA/HSPA networks. Still, the enormous GSM/EDGE subscriber base motivates mobile operators to continue investing in network upgrades to provide higher data rates at minimum cost. EDGE Evolution, also standardized by 3GPP, consists of a subset of features which allow quadrupling the downlink data rates compared to legacy EDGE performance. Introduction of new modulation schemes, e.g., 32 QAM and higher symbol rate will boost data rates up to 118.4 kbps per timeslot. In combination with dual downlink carrier, mobile terminals will be able to allocate ten downlink timeslots which will enable peak data rates of 1.2 Mbps. Additional improvement of EDGE Evolution end user performance will be provided by reduced latency, turbo codes and mobile receive diversity techniques. All these features together will provide comparable performances with 3G technology and more importantly, enable true service transparency between 2G and 3G networks. Implementing EDGE Evolution improvements will

[70] 3G wireless network

mostly impact mobile terminal side. Most of the proposed enhancements can be implemented in EDGE networks only with software upgrades, without requiring any hardware modification.[71]

3GPP did major work in Release 7 in order to make GERAN networks act both as a competitor and a complement to the HSPA evolution and LTE (chapter 5). Focusing on the data rates, there are two major features: Downlink Dual Carrier (DLDC), which is only defined for DL, and EGPRS-2, which can exist for both UL and DL.

EGPRS-2

"HOM, turbo codes and HSR enhancements are bundled together by the name of EGPRS-2 Uplink and Downlink. HOM and turbo codes are already supported by latest base stations and can be implemented only with a software upgrade. Introduction of HSR will most probably require a new pulse shaping filter so transceiver boards on base stations will have to be replaced."[72]

1. Turbo code TC: Already used in 3G WCDMA networks, TC outperforms legacy convolutional codes in term of error correction, improving channel robustness, and further diminishing the drawback of higher BER for HOM.
2. Higher order modulation (HOM): Introduction of HOM schemes, such 16QAM and 32QAM, enabled via MSRD gains, will increase the bit per symbol rate to 4 and 5 respectively. HOM takes advantage of margin in the radio link, which may exist in many locations within a cell.

[71] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks
[72] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks; To maximize the fraction of legacy hardware where these features can be implemented, different ambition levels are specified: EGPRS-2A downlink: 8-PSK+16/32QAM+Turbo Codes EGPRS-2A uplink: 16QAM EGPRS-2B downlink: QPSK+16/32QAM+TC+ HSR EGPRS-2B uplink: 16/32QAM+HSR

3. Dual Symbol Rate: DSR enables the use of wider band carrier for higher average and peak bit rates. The need for higher bit rates makes favorable the use of faster symbol rate. Currently, the legacy GSM/EDGE symbol duration is 3.69 μs while EDGE evolution standardizes 3.077 μs symbol duration. This reduction of symbol duration allows a 20% increase of the symbol rate, resulting in an equivalent data throughput increase.[73]

Downlink Dual Carrier

DLDC allows one end user to be assigned the use of timeslots from two carriers, increasing average and peak bit rates. Downlink dual carrier helps to overcome a fundamental limitation of GSM, which is the 200 kHz channel bandwidth. Benefits of second carriers includes: rapid processing of data in MS leading to more responsive applications and an improved subscriber experience, increase flexibility in bandwidth allocation, more efficient use of radio resource increases system efficiency. Also, with two carriers, only half the slots need to be found on a single carrier frequency to get the same throughput. The probability of successfully using "stranded" timeslots increases which improves network efficiency. Introducing the capability to send data on two carriers simultaneously will double the data rate in a very straightforward and backward-compatible way.[74]

MSRD via Dual Antenna Interference Cancellation (DAIC)

[73] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks
[74] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks

Receive diversity capability in the mobile station increases sensitivity and robustness in areas of high interference and dense deployment implying significant downlink network capacity improvement if the mobile penetration rate is high. In case of low penetration, MS that support MSRD will see higher average throughput across the entire SNR range. This gives an increase in the average downlink throughput of around 30% compared to conventional receivers and pertains to greater coverage by MS. Hence, BTS can use power control to reduce the output power to an MSRD capable mobile station, reducing interference across the cell which increasing capacity.[75] MSRD provides better sensitivity since it mitigates effects of fast fading. Users situated in areas with poor EDGE coverage will be able to achieve satisfactory data rates.[76]

Functionality to reduce latency times

End-to-end system latency is one of the most sensitive parameters that affect data throughput. The 3GPP requirement is to achieve latency below 100ms (135 ms was reduced to 80 ms) on the radio interface. Two enhancements are combined to achieve an overall improvement in latency: reduction of the transmission time interval (TTI) and increased efficiency of acknowledging received data. Reducing the TTI gives benefits across all radio conditions, whereas improving the efficiency in acknowledged mode of operation provides the highest benefit in poor channel conditions where the number of retransmissions can be large. Reducing the overall latency has an important second order effect on mean/average and peak bit rates as well, since as the bit rate on the link becomes higher the maximum buffer window size can limit the transmission rate.

[75] 3G Americas, The case for evolved EDGE, august 2008
[76] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks

Therefore there is limited advantage to increasing the data throughput without also decreasing the latency, as the latency becomes a limiting and increasingly significant limiting factor.[77]

Data Rates

"Predictions show that by combining EGPRS2-A downlink enhancements, MSRD and dual carrier on downlink with 5 timeslots each for a total of 10 timeslots, data rates up to 1 Mbps on downlink can be achieved in the serving cell vicinity. This performance represents the fundament to guarantee seamless network operations between GSM/EDGE and WCDMA/HSPA networks. Based on EGPRS2-A enhancements, this prediction doesn't require any hardware modification in the base station. Eventual hardware constraints from terminal side can be easily surmounted due to simplicity of implementation, lower cost and shorter terminal lifetime. Considering that by using 32QAM together with HSR, data rate per timeslot can be elevated up to 118.4 kbps and for state-of-the-art handsets supporting 5 timeslots together with dual downlink carrier the theoretical peak throughput can be further boosted to the maximum value of 1.184 Mbps on downlink. Multi RAT terminals will be able to more readily incorporate features of evolved EDGE with less impact on cost and size as they leverage reuse of 3G elements, thus making them ideal fabric for a feasible implementation of EDGE Evolution features.[78]

[77] 3G Americas, The case for evolved EDGE, august 2008
[78] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks

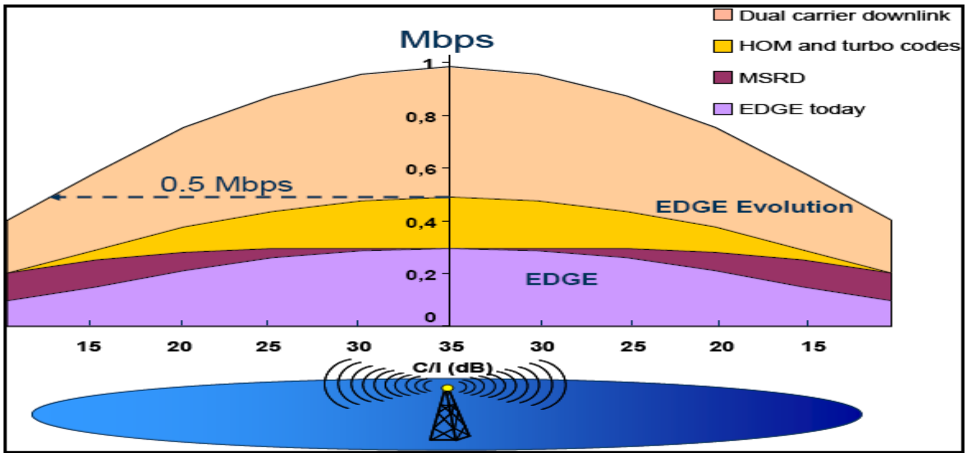


Figure 20 Predicted user throughput [79]

[79] ibid

Chapter 3 - Beyond 3G

The high data rate packet world of 3G has come a long way since its initial release and deployment. At this point in time, W-CDMA, or Evolved EDGE, is not the only candidate for providing 3G services in Pakistan. The succeeding concepts introduced by 3GPP in the recent years (HSPA, HSPA+, LTE), also referred to as 3.5 G or 3.75 G , can become equally significant candidates.

3.1 High Speed Packet Access (HSPA)

"HSPA is a 3.5G technology which provides theoretical download speeds of up to 7.2Mbps with an upgrade path to 80 Mbps and enables data transmission speeds of up to 14.4Mbit/s per user."[80]

"The challenge facing the mobile telecommunications industry today is how to continually improve the end-user experience, offer appealing services through a delivery mechanism which offers improved speed, service attractiveness and service interaction. HSPA is a generic term to refer to improvements in the UMTS Radio Interface, downlink (HSDPA) and uplink (HSUPA. Both can be implemented and co exists in the standard 5 MHz carrier of UMTS networks. There is no change required of the core network outside of the capacity increases that will be required to handle the expected increase in traffic generated."[81]

High Speed Downlink Packet Access (HSDPA)

HSDPA introduces a number of new technical capabilities to the radio access network, which when combined offer a significant improvement for both end users and operators. These capabilities are:

[80] http://www.webbuyersguide.com/resource/white-paper/9246/UMTS-Evolution-from-3GPP-Release-7-to-Release-8-HSPA-and-SAE-LTE
[81] *www.umts-forum.org/component/option,com.../task.../Itemid,12/*

1. A new common High Speed Downlink Shared Channel (HS-DSCH) which can be simultaneously shared by multiple users,
2. The use of a shorter Transmission Time Interval (TTI) of 2ms, which enables higher speed transmission in the physical layer,
3. The use of fast scheduling which enables accommodation of variations arising from changing radio condition,
4. The use of Adaptive Modulation and Coding (AMC), leading to a higher data rate for users with favorable radio conditions,
5. The use of fast retransmission based on fast Hybrid Automatic Response request (HARQ) techniques enables erroneous packets to be resent within a 10ms window, ensuring that the TCP throughput remains high.[82]

High Speed Uplink Packet Access (HSUPA)

"Enhanced Dedicated Channel (E-DCH), name adopted in 3GPP for HSUPA, is next step to HSDPA and the two are complimentary to one another. It seems that HSDPA is the more advanced of the two technologies, but when function side-by-side the resulting system will benefit with major data transfer speed enhancements for receiving or sending."[83] "Key technical capabilities introduced with HSUPA are; a new dedicated uplink channel, introduction of H-ARQ and fast Node B scheduling."[84] "Via E-DCH, HSUPA employs link adaptation methods similar to those employed by HSDPA including: Higher-order modulation in addition to the existing QPSK and 16-QAM. Similarly to HSDPA, there will be a packet scheduler, but it will operate on a request-grant principle where the UE (User Equipment) requests permission to send packets and the scheduler decides when and how many UEs will be allowed to do so. Unlike in HSDPA, soft and softer handovers will be allowed for packet transmissions. Both, HSDPA and

[82] *www.umts-forum.org/component/option,com.../task.../Itemid,12/*
[83] http://www.mobilecomms-technology.com/projects/hsupa/
[84] *www.umts-forum.org/component/option,com.../task.../Itemid,12/*

HSUPA, require no new infrastructure. The network equipment need only be updated with new software."[85] In a nutshell,

	ADSL	GERAN	UMTS	HSDPA
Typical Throughput (5 MHz)	1 - 15 Mbps	1 Mbps	1 Mbps	10 Mbps
Average Throughput (kpbs / user)	2048	160-200	128-300	500-700
Capacity (users/cell)*	-	8	9	40
Latency (ms for a 32 bytes ping)	5-200	260**	120	60

Figure 21 HSPA Data Rates [86]

3.2 HSPA+

"Objective is to enhance performance of HSPA based radio networks in terms of spectrum efficiency, peak data rate and latency, and exploit the full potential of WCDMA based 5 MHz operation. Important features of HSPA+ are downlink MIMO (Multiple Input Multiple Output), higher order modulation for uplink and downlink, improvements of layer 2 protocols, and continuous packet connectivity"[87]. MIMO technology is discussed in detail in LTE section.

> With MIMO technologies and higher order modulation, HSPA+ will eventually be capable of delivering 42 Mbit/s peak bit rate in the downlink and 11 Mbit/s in the uplink over a 5 MHz channel. HSPA+ introduces an optional all-IP flat architecture that reduces latency to around 10 ms and provides backhaul based on IP/MPLS transport. Base stations in IP flat architecture, evolves to an IP router that connects to the network via standard gigabit Ethernet connected to the Internet. By eliminating the need for RNC, the load on SGSN reduces, resulting in a significant reduction of the cost per bit. HSPA+ continues to evolve, and future combinations of multicarrier

[85] http://www.mobilecomms-technology.com/projects/hsupa/
[86] www.umts-forum.org/component/option,com.../task.../Itemid,12/
[87] UMTS_Long_Term_Evolution__LTE__Technology_Introduction

techniques and MIMO technologies could in principle achieve 84 Mbit/s peak on the downlink and 23 Mbit/s peak uplink. These rates could only be achieved by operators with access to multiple adjacent paired 5 MHz bands. They are the highest data rates that could be achieved in existing 3G networks based on 5 MHz WCDMA technology. Further improvements can only come with a new mobile network technology. HSPA+ is a logical development of the 3G/WCDMA approach, leveraging operator investments in HSPA and enabling a lower cost per bit. It is also the stepping stone to an entirely new radio platform called 3GPP Long Term Evolution (LTE).[88]

3.3 Long Term Evolution (LTE)

In the current (HSxPA) specifications, systems are capable of supporting high-speed packet access for both downlink (up to 14 Mbps) and uplink (up to 5.76 Mbps). Although HSxPA systems offer substantial improvement for packet data transmission over earlier UMTS systems, their designs were limited by compatibility requirements with previous generations of UMTS specifications. With the emergence of packet-based mobile broadband systems such as WiMAX 802.16e, it is evident that a comprehensive long- term evolution (LTE) of UMTS is required to remain competitive in the long term.[89]

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. "Evolved Packet System comprises E-UTRAN (Evolved UTRAN) on the access side and EPC (Evolved Packet Core) on the core side. EPC is also known as SAE (System Architecture Evolution) and EUTRAN is also known as LTE."[90]

[88] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2
[89] LTEAirInterfaceWhitePaper
[90] Long_Term_Evolution

3.3.1 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.[91] The basic architecture of the EPS contains the following network elements:

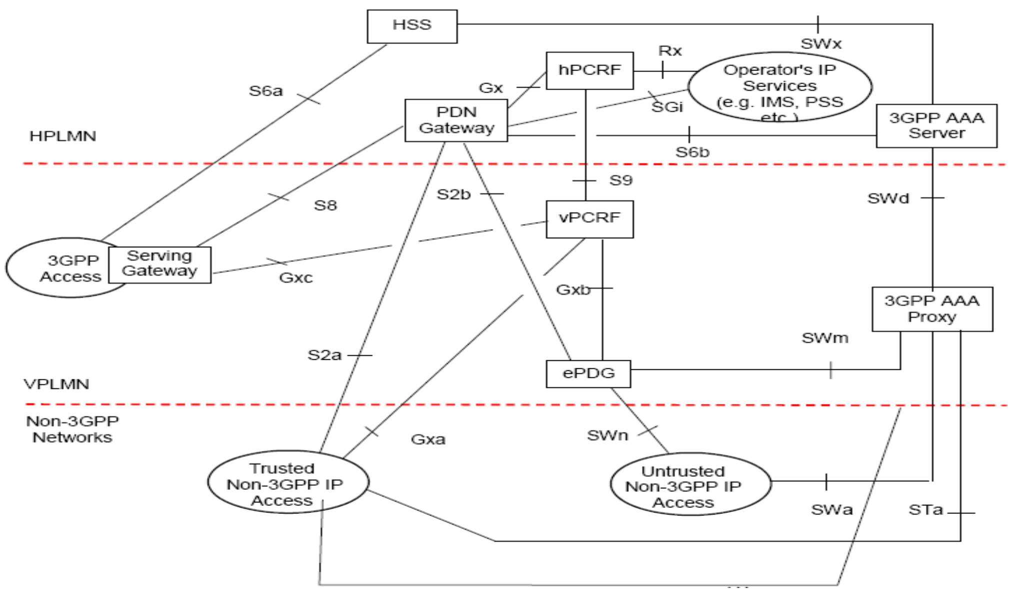


Figure 22 Detailed EPS architecture view

[91] 3GPPRel-7andRel-8_White_Paper07-08-08

1. **Mobility Management Entity (MME):** 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 Reach ability (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.
2. **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), EUTRAN idle mode downlink packet buffering and initiation of network triggered service request procedure, transport level packet marking in the uplink and the downlink, e.g., setting the DiffServ Code Point, based on the QCI of the associated EPS bearer, depending on the user and QCI granularity for inter-operator charging, lawful Interception, packet routing and forwarding.
3. **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, 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.

4. **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)[92].

Interfaces and 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:

1. **S1-MME:** Reference point for the control plane protocol between E-UTRAN and MME.
2. **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.
3. **S3:** Enables user and bearer information exchange for inter 3GPP access network mobility. It is based on Gn reference point as defined between SGSNs.
4. **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.
5. **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.
6. **S6a:** Enables transfer of subscription and authentication data for authenticating/ authorize user access to the evolved system (AAA interface) between MME and HSS.
7. **Gx:** Provides transfer of (QoS) policy and charging rules from PCRF to Policy and Charging Enforcement Function (PCEF) in the PDN GW.

[92] 3GPPRel-7andRel-8_White_Paper07-08-08

8. **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.
9. **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.
10. **S10:** Serves as a reference point between MMEs for MME relocation and MME to MME information transfer.
11. **S11:** Serves as a reference point between MME and Serving GW.
12. **S12:** Serves as a reference point between UTRAN and Serving GW. It is based on the Iu-u/Gn-u reference point using the GTP-U protocol as defined between SGSN and UTRAN and its usage is an operator configuration option.
13. **S13:** Enables UE identity check procedure between MME and EIR.
14. **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.
15. **Rx:** The Rx reference point resides between the AF and the PCRF in the TS 23.203.[93]

3.3.2 Evolved UTRAN

3GPP is developing the evolution of mobile communications systems beyond GSM/EDGE and WCDMA-HSPA systems. "3G Mobile System Long Term Evolution (LTE)" targets capacity and data

[93] 3GPPRel-7andRel-8_White_Paper07-08-08

rate speed and throughput enhancements and reduced latency to support new services and features requiring higher levels of capability and performance. Key feature include:

1. Reduced cost per bit
2. Increased service provisioning – more services at lower cost with better user experience
3. Flexibility of use of existing/new frequency bands
4. Simplified architecture, open interfaces
5. Allows for reasonable terminal power consumption
6. LTE utilizes a new radio air interface technology known as Orthogonal Frequency Division Multiple Access (OFDMA) to provide several key benefits, including significantly increased peak data rates, increased cell edge performance, reduced latency, scalable bandwidth, co-existence with GSM/EDGE/UMTS systems, and reduced CAPEX/OPEX.[94]

"LTE is backward compatible with non-3GPP as well as 3GPP technologies. Its ability to interwork with legacy and new networks, and its seamless integration of Internet applications will drive the convergence between fixed and mobile systems and facilitate new types of services. LTE heralds a new era with the transition from circuit switched approaches for voice traffic to a fully packet switched model. This transition from existing networks that combine circuit and packet switching to all-IP requires considerable simplification of the system architecture."[95]

"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

[94] lte_3gpp
[95] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

commercial availability in 2009/2010 timeframe."[96] "LTE provides downlink peak rates of at least 100Mbit/s, 50 Mbit/s in the uplink and RAN round-trip times of less than 10ms. LTE supports flexible carrier bandwidths, from 1.4MHz up to 20MHz as well as both FDD and TDD. The goals for LTE include improving spectral efficiency, lowering costs, improving services, making use of new spectrum and refarmed spectrum opportunities and better integration with other open standards."[97]

"The evolved UTRAN consists of interconnected E-Node Bs providing the evolved UTRA U-plane and C-plane protocol terminations towards the UE. The E-Node B hosts the functions for Radio Resource Management, including Radio Bearer Control, Radio Admission Control, Connection Mobility Control, and Dynamic Resource Allocation."[98]

Access Scheme

"The technology solution chosen by 3GPP for the LTE air interface uses Orthogonal Frequency Division Multiplexing (OFDM) and MIMO technologies, together with high rate modulation. LTE uses the same principles as HSPA for scheduling of shared channel data and fast link adaptation, enabling the network to optimize cell performance dynamically. In fact LTE is based entirely on shared and broadcast channels and contains no dedicated channels carrying data to specific users. This increases the efficiency of the air interface as the network no longer has to assign fixed levels of resource to each user but can allocate air interface resources according to real-time demand."[99]

LTE Downlink Transmission Scheme OFDMA

[96] 3GPPRel-7andRel-8_White_Paper07-08-08
[97] Long_Term_Evolution
[98] lte_3gpp
[99] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

Data rates in WCDMA networks are constrained by the 5 MHz channel width. At bandwidths below 10 MHz, HSPA+ and LTE provide similar performance for the same number of antennas. Use of a wider RF band, such as 20 MHz, leads to group delay problems in WCDMA that limit the achievable data rate. LTE removes these limitations by deploying OFDM technology to split the 20 MHz channel into many narrow sub-channels. Each narrow sub-channel is driven to its maximum, and the sub-channels are subsequently combined to generate the total data throughput. Assigning different sub-channels to different users results in Orthogonal Frequency Division Multiple Access (OFDMA) systems. OFDMA avoids problems caused by multipath reflections by sending message bits slowly enough so that any delayed copies (reflections) are late by only a small fraction of a bit time. Thousands of narrow sub-channels are deployed to send many low speed messages simultaneously that are then combined at the receiver to make up one high speed message. This avoids the distortion caused by multipath while maintaining a high bit rate. The narrow sub-channels in OFDMA are allocated on a burst-by-burst basis using algorithms that take account of RF environmental factors such as channel quality, loading and interference.[100]

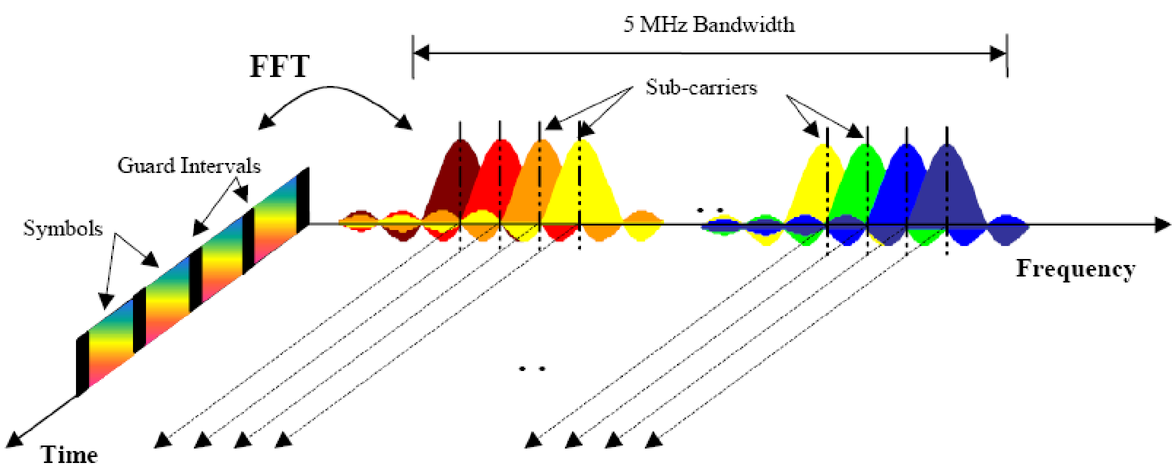


Figure 23 Frequency-Time Representation of an OFDM Signal

[100] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

The above shows a signal with 5 MHz bandwidth, but the principle is, of course, the same for the other E-UTRA bandwidths. Data symbols are independently modulated and transmitted over a high number of closely spaced orthogonal sub-carriers. In E-UTRA, downlink modulation schemes QPSK, 16QAM, and 64QAM are available. In the time domain, a guard interval may be added to each symbol to combat inter-OFDM-symbol-interference due to channel delay spread. In EUTRA, the guard interval is a **cyclic prefix** which is inserted prior to each OFDM symbol.[101]

LTE Uplink Transmission Scheme SC-FDMA

OFDMA properties are less favorable for the uplink due to weaker peak-to-average power ratio (PAPR) properties of an OFDMA signal, resulting in worse uplink coverage. Thus, the LTE uplink transmission scheme for FDD and TDD mode is based on **SC-FDMA** (Single Carrier Frequency Division Multiple Access) with cyclic prefix. SC-FDMA signals have better PAPR properties compared to an OFDMA signal. This was one of the main reasons for selecting SCFDMA as LTE uplink access scheme. The PAPR characteristics are important for cost-effective design of UE power amplifiers. Still, SC-FDMA signal processing has some similarities with OFDMA signal processing, so parametrization of downlink and uplink can be harmonized. There are different possibilities for generating an SC-FDMA signal. DFT spread - OFDM (DFT-s-OFDM) has been selected for E-UTRA.[102] "SC-FDMA is technically similar to OFDMA but is better suited for handheld devices because it is less demanding on battery power."[103]

[101] UMTS_Long_Term_Evolution__LTE__Technology_Introduction
[102] UMTS_Long_Term_Evolution__LTE__Technology_Introduction
[103] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

Requirement	Current Release (Rel-6 HSxPA)	LTE E-UTRA
Peak data rate	14 Mbps DL / 5.76 Mbps UL	100 Mbps DL / 50 Mbps UL
Spectral Efficiency	0.6 – 0.8 DL / 0.35 UL (bps/Hz/sector)	3-4x DL / 2-3x UL improvement
5% packet call throughput	64 Kbps DL / 5 Kbps UL	3-4x DL / 2-3x UL improvement
Averaged user throughput	900 Kbps DL / 150 Kbps UL	3-4x DL / 2-3x UL improvement
U-Plane Latency	50 ms	5 ms
Call setup time	2 sec	50 ms
Broadcast data rate	384 Kbps	6-8x improvement
Mobility	Up to 250 km/h	Up to 350 km/h
Multi-antenna support	No	Yes
Bandwidth	5 MHz	Scalable (up to 20 MHz)

Figure 24 Physical Layer requirements for LTE E-UTRAN

LTE MIMO Concepts

"Multiple Input Multiple Output (MIMO) systems form an essential part of LTE in order to achieve the ambitious requirements for throughput and spectral efficiency. MIMO refers to the use of multiple antennas at transmitter and receiver side."[104]

MIMO antenna systems are a magic ingredient in the quest for broadband wireless systems with higher capacity, performance and reliability. They provide a mechanism for bypassing the constraints imposed by Shannon's Law which states that there is a fundamental limit to the amount of information that can be transmitted over a communications link limited by noise. Without noise, an infinite amount of information could be transmitted over a finite amount of spectrum. But, in reality, throughput is limited because power is needed from the transmitter to overcome any noise in the channel. Today's technologies are approaching the ceiling imposed by Shannon's Law at which any further capacity gains are essentially cancelled out by noise. All technologies are approaching the theoretical limit for spectral efficiency as they all use techniques

[104] UMTS_Long_Term_Evolution__LTE__Technology_Introduction

such as efficient schedulers, higher order modulation, and adaptive modulation and coding to achieve roughly the same performance. Further gains in throughput and data rates will have to come from techniques enabling the use of higher bandwidths rather than from attempts to squeeze more bit rate into a channel. Shannon's Law applies to a single radio link between a transmitter and a receiver. But MIMO techniques create multiple radio links; each individual link is limited by Shannon's Law but, collectively, they can exceed it.[105]

Downlink MIMO

For the LTE downlink, a 2x2 configuration for MIMO is assumed as baseline configuration, i.e. two transmit antennas at the base station and two receive antennas at the terminal side. Configurations with four antennas are also being considered. Different MIMO modes are envisaged. It has to be differentiated between spatial multiplexing and transmit diversity, and it depends on the channel condition to select scheme.

1. **Spatial Multiplexing** allows transmitting different streams of data (single or multiple users) simultaneously on the same downlink resource block(s). While SU-MIMO increases the data rate of one user, MU-MIMO allows increasing the overall capacity. Spatial multiplexing is only possible if the mobile radio channel allows it.
2. **Transmit Diversity.** Instead of increasing data rate or capacity, MIMO can be used to exploit diversity. In case the channel conditions do not allow spatial multiplexing, a transmit diversity scheme will be used instead, so switching between these two MIMO modes is possible depending on channel conditions. Transmit diversity is used when the selected number of streams (rank) is one.[106]

[105] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2
[106] UMTS_Long_Term_Evolution__LTE__Technology_Introduction

Uplink MIMO

Uplink MIMO schemes for LTE will differ from downlink MIMO schemes to take into account terminal complexity issues. For the uplink, MU-MIMO can be used. Multiple user terminals may transmit simultaneously on the same resource block. This is also referred to as spatial domain multiple access (SDMA). The scheme requires only one transmit antenna at UE side, which is a big advantage. The UEs sharing the same resource block have to apply mutually orthogonal pilot patterns. To exploit the benefit of two or more transmit antennas but still keep the UE cost low, antenna subset selection can be used. In the beginning, this technique will be used, e.g., a UE will have two transmit antennas but only one transmits chain and amplifier. A switch will then choose the antenna that provides the best channel to the eNodeB.[107]

Spectrum flexibility

"The focus is now on creating more usable frequencies instead of attempts to increase spectral efficiency. Receive diversity technologies such as MIMO can do this by sending the same information from two or more separate transmitters to an equal number of receivers, cutting down on the information loss of a single transmission. Beam forming technologies are another approach, reducing interference by steering radio links towards a specific user. OFDMA is a third approach that relies on increasing flexibility in the use of spectrum. By splitting a channel into thousands of very narrow sub-channels, each on a different frequency, each carrying a part of the signal, OFDMA provides an ensuring better support for global roaming and delivering future economies of scale."[108]

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[107] UMTS_Long_Term_Evolution__LTE__Technology_Introduction
[108] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

The role of IMS

A major motivation for LTE/EPC is to support Next Generation Network (NGN) philosophies and Fixed Mobile Convergence (FMC) business models. Moving mobile networks to all-IP enables effective convergence scenarios involving mixed technology deployments. Combined with the IP Multimedia Subsystem (IMS), this greatly simplifies management and maintenance requirements. Changing access technologies today – from WLAN access to an HSPA data card for example – can require full connection, registration and authentication on each access network followed by manual intervention to switch from one to the other. Even when the mobile device supports both access technologies, the data flow cannot be handed over seamlessly without the user being aware of the change. The solution is to connect 3GPP and non-3GPP mobile networks to the core network through IMS. IMS allows seamless handover between multiple access technologies and provides the necessary mobility and routing management. The core network sees the mobile network as another IP network and does not need to manage mobility, authentication or security control as the user changes access technology. IMS uses the Session Initiation Protocol (SIP) to allow fast connection between mobile devices and the core network. Initial setup of data sessions in traditional wireless networks can take between one and 15 seconds compared with milliseconds in a fixed network. The marriage of LTE with IMS will provide operators with a cost effective network that allows integration with the core network for customer care, billing and network management. It will provide mobile users with an always connected high speed experience – truly unfettering the desktop.[109]

[109] UMTS_Forum_MBB_LTE_White_Paper_February_2009_v2

3.4 4G

"There is confusion within the wireless industry, as to what exactly constitutes 3G, because of the increasing use by some industry players of the term 4G. A number of the so called 4G technologies are in fact actually evolutions of 3G technologies, e.g., LTE, Ultra Mobile Broadband (UMB) from 3GPP2. It will clearly also be difficult to define the dividing line between 3G and 4G. One of the drivers for the popular use of 4G has been the aggressive promotion within the industry of the IEEE 802.16e (WiMax) mobile standard. A version of this standard was, however, recently accepted by the ITU as an addition to the IMT-2000 family and therefore is clearly to be considered together with the other 3G IMT-2000 technologies. The ITU is studying future broadband mobile capabilities under the name IMT Advanced, which the ITU has recently defined as the fourth generation (4G) of mobile technologies. The generic designation IMT is now used by the ITU to identify potential spectrum for administrations wishing to implement IMT-2000 (3G) or IMT-Advanced (4G)."[110]

The ITU is the internationally recognized entity chartered to produce an official definition of the next generation of wireless technologies. Its Radio Communication Sector (ITU-R) is establishing an agreed upon and globally accepted definition of 4G wireless systems that is inclusive of the current multi-dimensioned and diverse stakeholder universe. During 2008 and though 2009, ITU-R will hold an open call for the "first invitation" of 4G (IMT Advanced) candidates. Subsequent to the close of the submission period for the "first invitation, an assessment of those candidates' technologies and systems will be conducted under the established ITU-R process, guidelines, and timeframes for this IMT-Advanced first invitation. The culmination of this open process will be a 4G, or IMT-Advanced family.

[110] **http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/What_really_3G.pdf**

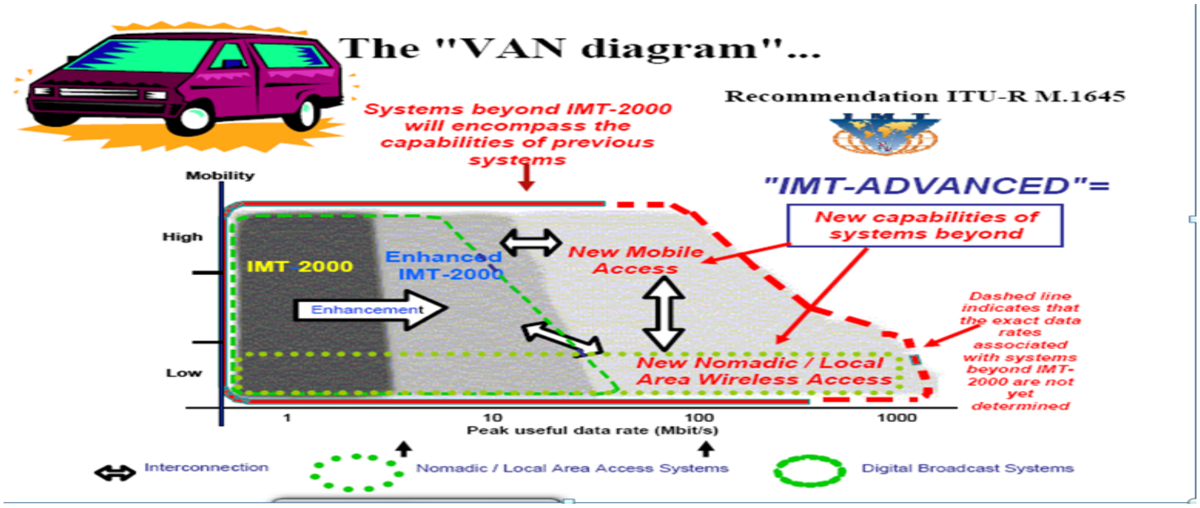

Figure 25 A Picture worth a Thousand Words in understanding the vision of 4G

Such a 4G family, in adherence to the principles defined for acceptance into this process, is globally recognized to be one which can grow to include all aspects of a marketplace that will arrive beyond 2010, thus complementing and building upon an expanding and maturing 3G business. As a defined generation of wireless, 4G is therefore only in its adolescence. As it was for 3G, 4G will be defined in stages. The 4G development work is poised to move into the next stages: establishing criteria for IMT-Advanced and ultimately screening the technologies for inclusion in the IMT-Advanced family. Only then will we understand what is and can be rightly called a 4G technology/system.[111] IMT-2000 3G wireless technologies clearly have significant future development potential, much as 2G technologies have already done, and it seems only reasonable to allow these 3G technologies to fully develop before phasing in a fourth mobile generation.[112]

[111] Defining4G2008
[112] http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/What_really_3G.pdf

Chapter 4 - Market and Consumer

Telecommunication industry in Pakistan has come a long way since the country's independence in 1947. The initial era could be fairly termed as the PTCL (Pakistan Telecommunication Company Limited) monopoly, for it was the sole provider of all telecommunication services across the country. It was not until four decades later that the region embarked into the new world of wireless communication, hence ending the decades-old PTCL monopoly.

By the end of late 1990's, government support and the international investment in the region opened new doors to innovationand better quality, low cost and healthy competition. Wireless licenses for the private sector in telecommunication industry triggered promising chain of events that resulted in a drastic change in the telecommunication infrastructure and service profile. The newly introduced wireless (GSM) technology received enormous support from all stakeholders (consumers, regulatory body, and market) and caused a vital boost in Pakistan's economy.

4.1 Pakistan Mobile Market

"It is Pakistan's mobile market that is driving the vibrancy of the telecommunications market, and in turn it is high levels of competition and investment, as well as low tariffs and great consumer demand that are powering mobile growth."[113] 3G migration is directly linked with the same mobile market, and for that reason it is significant to understand the current mobile industry facts and statistics. "**BMI predicted** 135mn mobile subscribers by the end of our forecast period in 2012. This means that approximately 80% of the population will have access to a mobile handset in five years time."

[113] Pakistan telecommunications report , Q1 2008, by BMI

4.1.1 Market Share

Table: Pakistan Mobile Market, September 2007

Operator	No. of Subscribers (mn)	Market Share (%)
Mobilink	28.572	40.8
Ufone	15.421	22.0
Telenor	12.578	18.0
Warid Telecom	11.867	16.9
CMPak	1.233	1.8
Instaphone	0.337	0.5
Total	**70.008**	**100**

Source: PTA, BMI

Figure 26 Pakistan Mobile Market

4.1.2 Foreign Investments

- Orascom acquired significant Mobilink shares in early 2000
- Telenor is a European firm with 22% of the market share
- SingTel purchased 30% stake in Warid Telecom at the end of June 2007
- China Mobile acquired 100% of Paktel in June 2007, rebranding the failing company as CMPak.[114]

4.1.3 Handset Market

"The growth in Pakistan's mobile market has, of course, resulted in a vibrant handset market. While Nokia remains market leader with 53% of the shipment market to Pakistan, Samsung on 20% and Sony Ericsson with 15% are also performing well. And, emerging into the marketplace are China's Huawei

[114] ibid

Technologies and ZTE, helped by a price sensitive market. Indeed, the most popular handset models in Pakistan do tend to be in the low-to-mid tier market with the following selling well – Nokia 1110/1112; Samsung E250; Sony Ericsson K750i; and the Motorola RAZR V3."[115]

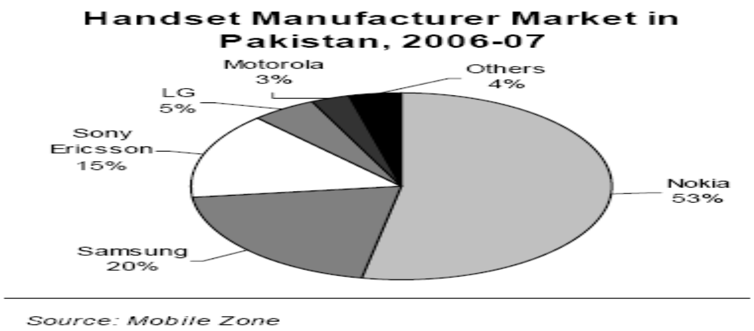

Figure 27 Mobile handset market

4.2 The Internet

With Internet being one of the driving forces in 3G developments, the Internet demand in Pakistan would play a significant role in answering questions regarding 3G migration. "Internet usage is growing all the time in Pakistan and BMI predicted 17mn Internet users at the end of 2007, with penetration at 11%. And this is despite the fact that ownership of PCs remains rare in Pakistan. Furthermore, a poor fixed-line infrastructure suggests that dial-up usage is very common, resulting in very slow download speeds. The increasing popularity of broadband services, matched by the determination of PTCL to improve the standards of its Internet business is likely to change this in time. However, high costs of broadband services in Pakistan mean that this change could be very slow, and **BMI** forecasts that penetration will remain at below 1% until well into 2012. Given the phenomenal growth in recent years of Pakistan's

115 Pakistan telecommunications report , Q1 2008, by BMI

mobile sector, this is somewhat surprising, but it does fall to the incumbent and the increasing number of alternative operators and ISPs to accelerate the speed of growth."[116]

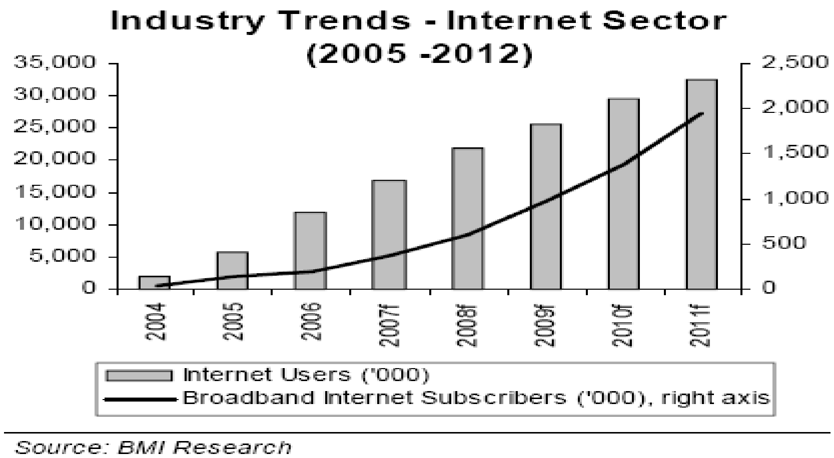

Figure 28 Internet usage in Pakistan

4.3 Business environments in Pakistan

The huge licensing fees associated with 3G spectrum, as well as the expected CAPEX and OPEX, may trigger a need for further international investments in the region. "Despite the rapid growth and the high levels of investment, Pakistan remains nearer the bottom than the top of **BMI**'s Business Environment Rankings. Aside from the surprising hike in taxation and regulatory fees on Pakistan's telecoms operators (up by 32% y-o-y in 2006-07), BMI maintain that Pakistan's telecoms market has an excellent business environment. However, there are concerns that inward investment could be moderated in the short-term at least, by political instability, which could cause economic uncertainties. The government will do all it can to ensure that Pakistan's telecoms sector retains its momentum and this it hopes to do by

[116] Pakistan telecommunications report , Q1 2008, by BMI

encouraging investment from the world's largest handset manufacturers."[117] It is imperative at this point to shed light on what it is that the region has to offer in that regard.

> On the face of it, Pakistan has a much-improved business environment, as can be seen by the evidence of considerable inward investment in the telecoms sector over the last few years. And yet, Pakistan still lies nearer the bottom of BMI Ranking table in 11th position. On the one hand, Pakistan's regulator scores very well for its role in encouraging investment, and the market is hugely competitive, offering huge potential for growth, not only in the mobile market, but also high-speed Internet, both fixed and wireless. However, the country remains in political difficulties and does not offer the most stable of markets, either politically or economically. On the positive side, Pakistan's telecoms sector currently contributes about 2% of the country's GDP and total revenues reached PKR236bn in 2006-2007. The sector received US$1.8bn of FDI in the last fiscal year, accounting for 35% of total FDI in Pakistan. These are all figures that go to suggest Pakistan's telecoms sector is in great shape and offers the investor huge opportunities. So much so that the government, having seen a number of carriers enter and transform Pakistan's mobile market in recent years, now aims to offer incentives for the manufacturers of handsets and other telecoms equipment, to make Pakistan a popular manufacturing base.[118]

[117] ibid
[118] Pakistan telecommunications report , Q1 2008, by BMI

Table: Business Environment Rankings						
	Limits of Potential Return		Risks To Realisation of Potential Returns			
Country	Telecoms Market	Country Structure	Independence of Regulator	Country Risk	Telecoms Rating	Rank
India	75	35.7	80	61.6	64.1	1
Japan	44	63.3	90	87.2	62.1	2
Singapore	37.5	93.3	80	66.1	61.9	3
Malaysia	46.3	63.3	90	74.2	61.4	4
Taiwan	42	66.7	90	76.4	60.4	5
Hong Kong	34	76.7	80	81.9	58.5	6
South Korea	40	70	70	75.5	57.2	7
China	71.5	31.7	40	70.6	56.9	8
Australia	38	66.7	70	77.3	55.7	9
Indonesia	50	66.7	60	43.2	54.6	10
Pakistan	**50**	**39.3**	**80**	**33.5**	**49.4**	**11**
Philippines	42.5	36.7	60	51.8	45.1	12
Thailand	45	32.7	40	52.6	42.4	13
Bangladesh	37.5	30	60	37.4	39	14
Vietnam	22.5	35.7	60	59.1	36.8	15

Figure 29

4.3.1 Pakistan among top 20 outsorucing Detonations

The paradox of instability in Pakistan on one hand and the rapid growth of technical expertise on the other are surprising for many. As mentioned in a business week article by Rachael King published on June 4, 2009, Pakistan has become the 20th most attractive outsourcing destination, according to consulting management firm A.T. Kearney. Even as concerns increase about Pakistan's stability and the growing displaced population due to ongoing military operations with the Taliban, the country made a significant jump on A.T. Kearney's 2009 Global Services Location Index released May 18. Pakistan went from #30 in 2007 to #20 in 2009.

"This rise in the ranks happened without much institutional support and lack of coherent policies. In my opinion, this represents the very nature of Pakistani culture. **Resilience and the will to carve out ways to**

succeed is part of the Pakistani fabric. This is one of the many ways Pakistanis are answering the challenges posed by the current security environment. Consider for example the upcoming gathering of *Pakistanis in Silicon Valley*. One session is dedicated to discussion of how can entrepreneurship promote development and stability in Pakistan?"

4.4 3G Market and Consumer

GSM world took over the country primarily due to the strong need for breaking PTCL's monopoly, as well as the unexpected popularity of voice on the go. It evolved and grew over time by penetrating the rural and remote areas. Hence, demand was created for GSM by developing consumer bases that had never had an access to any kind of communication service before. Back then, the initial era consisted of high tariffs, expensive handsets, and limited mobility. The breakthrough occurred after the technology matured and more players entered into the market; the former lead to cheaper user terminals and the later to cheaper tariffs and more coverage. Coming back to the discussion in hand, 3G migration in Pakistan, there is a world of possibilities upon which the region could embark. The market may not be present yet, as the opponents of 3G would say with less demand for broadband services, but that in no way could be taken as an indication of what the future might hold. One way to look at it is to look into applications and services that 3G could enable for the region.

3G service types and data rates offered are discussed in detail in chapters 2 and 3. Irrespective of the underlying technology, the consumer is only concerned with the applications offered and is oblivious to the access method that the network uses to provide those services and data rates. What this implies is that a technology's success in any region is linked to the changes that it invokes and how those changes are made accessible to the masses. The changes in this case will be triggered by applications.

4.4.1 Consumer Revolution in the Urban Areas

In the urban areas, the 3G talk is believed to be corporate centric. "It is often assumed that early adopters will be corporate customers for 3G, but mobile multimedia- games, entertainment and the like are much more consumer oriented than the buttoned down sober suited business people. Applications like VoIP, Moving Images, File transfer , Downloading Software , Virtual Home Environment , Web Browsing, Document Sharing/ Collaborative Working, Audio, Home Automation, Remote LAN Access, Electronic Agents, Dynamic Authoring, Job Dispatch ,Electronic commerce, Vehicle Positioning etc. are few from the current known possibilities and don't limit brand new introduced in the future."[119]

Audio

With 3G, MP3 files will be downloadable over the air directly to phone via a dedicated server. There are numerous business models to allow both the network providers as well as the copyright owners of the MP3 material to benefit financially.

VoIP

With 3G and higher rate 2.5G, technologies such as EDGE and VoIP will be available for the first time on mobile phones. VoIP can be used as an alternative to regular service but is not a replacement for standard voice services since VoIP services are bandwidth demanding.

Still Images

Still images such as photographs, pictures, letters, postcards, greeting cards, presentations, and static web pages can be sent and received over mobile networks just as they are across fixed telephone networks. Once captured, images can then be sent directly to Internet sites, allowing near real-time desktop publishing.

[119] Yes to 3G

Moving Images

Sending moving images in a mobile environment has several vertical market applications including (monitor sensor triggered) monitoring parking lots or building sites for intruders or thieves and sending images of patients from an ambulance to a hospital. Videoconferencing applications, in which teams of distributed salespeople can have a regular sales meeting without having to go to a particular physical location, is another application for moving images that is similar to the document sharing/ collaborative working applications reviewed below.

Virtual Home Environment

A service that simply lets customers have seamless access with a common look and feel to their services from home, office, or on the move and in any city as if they were at home. VHE is, therefore, aimed at roamers (a small subset of total mobile phone users).

Electronic Agent

Electronic agents are defined as "mobile programs that go to places in the network to carry out their owners' instructions. They can be thought of as extensions of the people who dispatch them. Agents are self-contained programs that roam communications networks delivering and receiving messages or looking for information or services." Orange in the UK has a vision which expects that within ten years, our mobiles will be waking us up, reading our emails, ordering our groceries, and telling us the best route to work, reminding us, and translating our conference calls.

Downloading Software

In the twenty-first century, software will increasingly be downloaded electronically from the Internet rather than purchased as boxed products in stores. Downloading software has several advantages because it is environmentally friendly (no packaging to throw away or store), quick and convenient (downloadable products are delivered direct to your computing device in minutes) and value for money (you pay no delivery charges).[120]

4.4.2 Consumer Revolution in the Rural Areas

For a developing country like Pakistan, the biggest challenges in the rural areas are health and education. There have been numerous economic and social claims that support the idea of revolution via changing these conditions. 3G holds the potential for providing means in order to bring about those changes.

Mobiles and Healthcare: Telehealth and Telemedicine Trends

Cell phones may have changed the way people communicate in the developed world, but in developing countries they're going far beyond simple communication to bring new opportunities to areas that sorely need them.

1. An example is the research at the Next Generation Intelligent Networks Research Center of FAST University, Islamabad. Their work on "Remote Patient Monitoring System" with Focus on Antenatal Care is funded by the National ICT R&D fund, Government of Pakistan, over the period of three years (2008-2010). The primary objective of this project is to develop a reliable, efficient, and easily deployable remote patient monitoring system that can play a vital role in providing basic health services to the remote village population of Pakistan at their door step.

[120] yes to 3G

2. A Pakistani researcher Jahanzeb Sherwani did doctoral-level research at CMU about using speech recognition with local languages to collect information regarding rural health care. Speech recognition is, he believes, the equalizer, the ultimate enabler. It doesn't matter if you are illiterate or if you speak a different language.
3. Due to a global shortage of some 4.4 million healthcare professionals, as estimated by the World Health Organization, many rural health centers in poor regions depend largely on community health workers who travel among clinics and villages. Due to limited facilities and the huge areas covered by them, it is often too late to bring back help to the people in need. Launched in February, FrontlineSMS:Medic aims to improve matters using FrontlineSMS, a free, open-source software program that enables large-scale, two-way text messaging using only a laptop, a GSM modem, and cell phones. Working with donations collected through Hope Phones, the initiative places a laptop running FrontlineSMS in a central clinic and then distributes cell phones to community health workers. Workers are trained in sending text messages to hospital staff to request drug dosing information or treatment instruction, for example, or provide status updates on a particular patient. Modified camera phones, meanwhile, can be used to analyze blood and sputum samples and perform critical diagnostics for conditions including HIV/AIDS, tuberculosis, and malaria. In a recent, six-month pilot test of the system at a hospital in Malawi, 150 patients received emergency care, and community health workers saved 1,000 hours of travel time—allowing them to visit more patients.The number of people being treated for tuberculosis doubled, and the hospital saved USD 3,500 worth of fuel, freeing up funds to purchase more medication. Operating the system, meanwhile, requires an investment of just USD 500, according to an article in the Guardian.
4. Of course, when it comes to developed countries, there is a lot of emphasis on reducing cost and providing connected services whereby automation and intelligence can make devices and testing smart. Here is ATT's vision for medical remote monitoring:

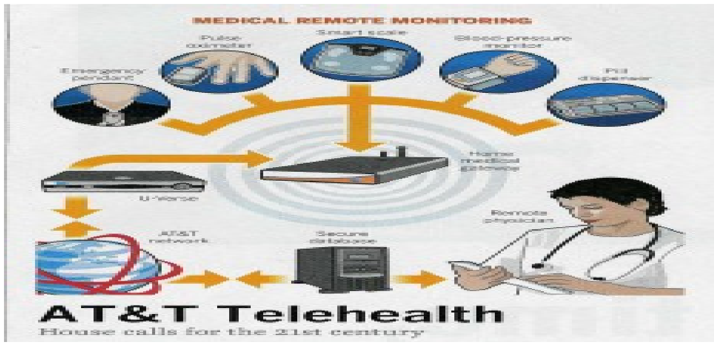

Figure 30 [121]

Improved Quality of Education

The quality of education is highly criticized with a small number of teachers available for a large mass of students. The result is minimum one-to-one communication between the teacher and the student. The slack grows over time, and the underprivileged souls with no external means to make up for this gap end up losing, falling behind, and losing interest. “Learning 2.0 platform is a new comer in the Pakistan education industry. Consider the possibilities for just-in-time learning: educators record their multi-hour lectures with a simple webcam, tag and upload them to the Learning 2.0 Platform as small interactive chunks. Students can repeatedly review the relevant information without enduring the entire session. Deep tagging metadata allows them to jump instantly to that specific section within the video for the information they need to learn”[122].

[121] http://telecompk.net/2009/06/29/mobiles-and-healthcare-telehealth-and-telemedicine-trends/#more-4513
[122] http://telecompk.net/category/pakistan/

Figure 31 education in remote sectors

"Aziz Bhatti, Principal at the Federal Government Model School for Boys G-0/4 in Islamabad was videotaped giving a lecture about Chemistry. Students tag the video while watching and their tags are indexed and made available to all who subsequently watch the presentation. Students can also comment upon their peers' tags and all comments are emailed to the teacher for response and interaction. Educators can also provide students with links to their lectures and assignments to tag as a class project. With this technology they can tag "chapters" and "topics" within the media file with a descriptive text for each tag. Additionally, all tags can be exported and distributed as a blog."[123] How do these deep technologies specifically enhance learning?

- They increase the granularity of indexed media, allowing specific parts of video lectures to be more easily remixed, linked, and reused.
- They engage students to co-create content via annotation of lectures.
- They make media as an instructional tool more efficient since reading or reviewing streaming video is more time consuming than print media.
- Also, these deep technologies enhance the educational content. The more the commenting and annotating, the more valuable the learning asset becomes as the wisdom of numerous and diverse

123 http://telecompk.net/category/pakistan/

interested parties add layers of collective intelligence to the video. Furthermore, specific moments of time within these videos can be instantaneously identified and retrieved with the Learning 2.0 Platform search engine.

- Consider the opportunity for enhancing the quality of education in Pakistan by harnessing thousands of video lectures produced by the top teachers throughout the country. This digital archive could be searched as indexed meta data by key words within the annotations. Not only would this video library complement and extend traditional learning, but it would also scale giving millions of student's access to a quality education.[124]

Distance Learning

Ghost's schools are fairly common in Pakistan. These schools exist on paper only. Reasons are more than a few but usually revolve around the distance a teacher has to commute to get to these places and the effort required by them in relation to the salaries they receive. With the 3G infrastructure in place and the right applications used, a foundation could be laid to provide quality education in remote villages and towns. The West is already using numerous custom-made tools to provide online degrees. For Pakistan, the change has to be gradual and patient. It requires additional resources for educating end user to use these tools in an optimum fashion, to provide means to access these tools (desktops connected to the world with 3G) , yearly plans to implement and monitor such system, acceptance by the HEC (higher education system), etc. Bottom line; however, is to use 3G as the last mile for making this vision a possibility.

[124] http://telecompk.net/category/pakistan/

4.4.3 Applications Impact

3G is just an evolution of current telecom services offered by cellular operators. But the missing link of applications and content conversion has the potential to convert this evolution into a revolution for Pakistan. The important factor is how and when the region would embrace this revolution.

4.5 Future Forecast of Mobile Users

The following is a summary of the expected growth in mobile users by BMI:

Mobile

Table: Pakistan Telecoms Sector – Mobiles – Historical Data & Forecasts

	2005	2006	2007f	2008f	2009f	2010f	2011f	2012f
No. of mobile phone subscribers ('000)	21,636	48,289	77,100	102,340	114,620	122,640	128,770	135,500
No. of mobile phone subscribers/100 inhabitants	14.2	31.1	49.2	63.3	69.6	73.1	75.4	77.9
No. of mobile phone subscribers/100 fixed line subscribers	390.3	703.1	1,168.2	1,574.5	1,833.9	2,078.6	2,239.5	2,398.2
No. of 3G phone subscribers ('000)	0	0	0	900	3,100	7,200	11,800	16,100
3G market as % Of entire mobile market	0.0	0.0	0.0	0.8	2.7	5.9	9.2	11.9

Source: PTA, ITU, Operator Results; f = BMI forecast

Figure 32 Wireless Statistics

"Growth will slow down partly as the market becomes saturated and partly as it reaches less accessible parts of the country. **BMI** forecasts that there will be 100mn mobile subscribers at the end of 2008, and that by the end of our forecast period in 2012, there should be more than 135mn customers, accounting for a penetration rate of around 78%. This would still represent an annual average growth rate of 8% between 2008 and 2012. With regards to our 3G forecasts, it seems likely that the PTA will run an auction for three licenses no earlier than towards the beginning of 2008, with commercial deployment either later that year, or maybe early in 2009. With GSM the main mobile technology in use in Pakistan, the preferred 3G technology would be UMTS, although China Mobile may be tempted, if it were to win a license, to usher in its homegrown TD-SCDMA standard."

Chapter 5 Regulation

5.1 Regulation Enabling the Business Environment

In the current diverse and dynamic world of Telecommunications, regulation plays far more vital role then mere allocation of frequency and technology. In research by ETSI, the key determinants of the success of 3G auctions were how well the auctions attracted entry and discouraged collusion. There is no one size fits all formula! The regulatory body needs to implement policies to overcome obstacles to growth and profitability (custom duties, handset sales taxation, service taxation, competition, low cost interconnect environment), compliance to internationally accepted stands, alignment with internationally accepted spectrum bands and allocations, and an independent regulatory body backed up by a robust legal system.

5.2 Pakistan Telecommunication Authority

The telecommunications sector in Pakistan is regulated by the PTA, which was established in 1996 following the passage of the Pakistan Telecommunication (Re-organization) Act into the statute book. PTA’s functions include:

To regulate establishment, operation, and maintenance of telecoms systems and services in Pakistan;

To receive and dispose of applications for the use of radio-frequency spectrum;

To promote and protect the interests of users of telecoms services in Pakistan;

To promote the availability of a wide range of high quality, efficient, cost effective, and competitive telecoms services in Pakistan;

To promote the modernization of telecoms systems and services;

To investigate and adjudicate complaints and claims made against licensees arising out of alleged contravention of the provisions of the above Act;

To make recommendations to government on policies with respect to international telecoms, the provision of support for participation in international meetings and arrangements to be executed in relation to the routing of international traffic and accounting settlements.[125]

"The PTA has helped Pakistan's telecoms industry to attract rising levels of FDI both from existing operators looking to enhance networks, and from foreign companies looking to enter Pakistan's telecoms market via acquisition. In the year 2006 alone, there were five major international acquisitions."[126]

5.3 3G Licenses

The 3G license auction has been delayed in Pakistan for more than three years now. "PTA initially did suggest that it would auction three 3G mobile licenses by the end of 2007."[126] Later on, the news predicted auction by last quarter of 2008. Dated 2008, Shehzada Alam Malik of Pakistan Telecommunication Authority said, "we will issue three 3G licenses to the already operational cell phone companies in the country for which bidding is expected during September to December this year. Almost all of these companies working in the country are having shown an interest in the new license." [127] "Indeed, the PTA has recommended that the licensing of 3G services be delayed and that the mobile data market in Pakistan

[125] Pakistan telecommunications report , Q1 2008, by BMI
[126] Pakistan telecommunications report , Q1 2008, by BMI
[127] http://www.itu.int/osg/spu/ni/3G/resources/licensing_policy/index.html

is insignificant. However, this is likely to remain the case until 3G services are launched, and 3G mobile telephony could suffer at the hands of WiMAX, which Mobilink and Ufone are already working on launching imminently."

5.4 Issues Regarding 3G Licenses

Regardless of PTA's effort and willingness towards 3G licenses, it has been a three year delay in 3G license allocations. There are two major factors, one at the government end and the second more towards the operator strategies.

5.4.1 MoITT

PTA has studied the case for 3G in Pakistan and put forward its recommendations to the Ministry of Information Technology and Telecom (MoITT). MoITT has, in turn, prepared and submitted its recommendations to the Cabinet for deliberations and approval in April 2009. Unfortunately, there is no Minister assigned to MoITT and hence the case is probably not being followed up as necessary. PTA would be unable to initiate any allocations prior to a legal affirmation by MoITT. So, until the cabinet makes some decisions, things will not move forward. In case the cabinet accords its approval, then PTA is more likely to publish the relevant legislation, regulatory processes, and requirements. In the meantime, PTA ought to be working on these, but probably their work is not available to the public at large.

5.4.2 LTE

Pakistan region, currently, is facing the inevitable dilemma of a new technology superseding an old one. The delays have led to the case where W-CDMA might be overwritten by LTE's new air access techniques. Hence, the fast approaching arrival of LTE has adopted different strategists. The result is operator's hesitance in investing huge capital in an older technology. Hence, the challenge is not only when to allow technology implementation but also what technology should be allowed.

5.5 UMTS900

Another important task for PTA at this point is to consider the option of frequency refarms. The idea of frequency reuse for higher data rates led to the introduction of UMTS-900. "There is a very strong business case and momentum for deploying UMTS900 (WCDMA-HSPA) systems in the 900 MHz band, generally used today by GSM networks, to help operators efficiently extend voice, data and mobile broadband services coverage by leveraging the advantages of lower frequencies."[128]

"Of course, there is no reason why WCDMA could not be deployed at other frequencies. In fact, the use of other frequencies may well be necessary in some countries. For instance, the frequency bands defined previously overlap significantly with frequencies used for PCS in North America. Therefore, in North America, it will be necessary to move some existing users from the PCS band and/or acquire a new spectrum in some other band. The movement of existing PCS users is likely only to happen when a given carrier that wants to implement UMTS already has an existing PCS system and uses some of the spectrum

[128] GSM/3G Market/Technology Update

for UMTS. The net result for such an operator will, of course, be limited spectrum for both PCS and UMTS."[129]

5.5. 1 UMTS900 Technical Specifications

Technical specifications for WCDMA-HSDPA in the 900 MHz band (UMTS900) were completed by 3GPP in December 2005. The 900 MHz band, denoted as Band Class VIII, is defined as paired bands in the range 880 to 915 MHz (uplink), and 925 to 960 MHz (downlink). Similar benefits and efficiencies are obtained using WCDMA-HSPA in the 850 MHz band.

5.5.2 UMTS900 Benefits

Providing full coverage using 2100 MHz would be too expensive, impractical and take too long for many mobile network operators. Radio propagation path-loss at 900 MHz is much lower. For the same service offering and coverage, the number of cell sites required using 900 MHz is significantly lower compared to that needed for 2100 MHz, with reduced rollout time. Indoor coverage is also improved with 900 MHz. UMTS900 can complement 2100 MHz deployments to improve coverage, reduce CAPEX and OPEX, improve Quality of Service and enhance the user experience. UMTS900 network operators can provide HSPA mobile broadband services in a very cost-efficient way. GSM operators can re-use existing network assets including antennas and network management systems. UMTS900 delivers the same data rates as UMTS2100, with fewer than half the number of cell sites. Operators report increases in traffic (especially data) and

[129] 3g wireless network

revenue growth where 3G is offered. All 3G applications can be provided and used cost efficiently over much larger area.[130]

UMTS900 brought 3G and mobile broadband services more cost effectively to outside the cities.

- Same coverage with 2 to 3 times fewer sites vs. 2100 MHz
- Significantly lower cost (CAPEX and OPEX)
- Allows operators to provide mobile broadband more cost efficiently
- All existing 3G applications can be provided and used cost efficiently over much larger geographical area
- Ideal for rural and suburban areas as the first step
- Same data rates using 900 MHz as for 2100 MHz
- Same cell radius for packet data services as GSM900 voice optimizes coverage and performance
- re-use GSM900 sites/spectrum to fill in areas not covered by 2100 MHz
- Improves Quality of Service and the user experience
- Drives ARPU growth in 3G services
- Indoor coverage also improves using 900 MHz; helps in urban areas[131]

It is imperative at this point to highlight a possible key enabler for 3G in Pakistan. "Regulatory approval is required to clear the way for WCDMA-HSPA 900 MHz deployments in a number of markets. An important political development in Europe concerning regulation of the 900 MHz was announced on March 24, 2009, which would remove restrictions on how the band is used by repealing the 1987 GSM

[130] GSM/3G Market/Technology Update
[131] UMTS900 Market Overview Alan Hadden, President Global mobile Suppliers Association

Directive. This is a clear signal to all regulators to prepare the path in their respective markets for a new wave of HSPA deployments in the 900 MHz band. Some countries must re-arrange band allocations in order to enable GSM and UMTS900 in 900 MHz spectrum."[132]

[132] GSA_Information_Paper_UMTS900

Chapter 6 - Issues and Challenges

Pakistan today stands at grounds similar to the West a decade ago. Hence, it is imperative to mention the industry views in the West prior to the launch of 3G.

"As with all new technology standards, there is uncertainty and the fear of displacement. Third Generation (3G) mobile is topical and contentious for several reasons:

- Because the nature and form of mobile communications is so radically changed, many people do not understand how to make money in the non voice world, and do not understand their role in it
- 3G licenses have been awarded around the world, in many cases at huge cost, necessitating that existing mobile communications companies in the 2G world think about and justify their continued existence.
- 3G is based on a different technology platform- Code Division Multiple Access (CDMA)- that is unlike the Time Division Multiple Access (TDMA) technology that is widely used in the 2G world.
- The US, Japanese and European mobile players all have different technology competences and are now unified in this single standard- the separate wireless evolution paths and European wireless leadership are thereby challenged
- Japanese network operators will be the first to implement 3G networks in the year 2001, and Japanese terminal manufacturers, who have not had much market share outside their home market, will be first with 3G terminals
- Many industry analysts and other pundits have questioned the return on an investment in 3G technology- questioning whether network operators will be able to earn an adequate return on the capital deployed in acquiring and rolling out a 3G network.

- Many media and Internet companies have shown a strong interest in using 3G technologies as a new channel to distribute their content, opening the opportunity for new entrants and new partnerships and value chains."[133]

6.1 3G Issues and Challenges in Pakistan

With no changes in the technology itself, the core challenges are more or less the same. However, the choice and time of technology, when translated into the region, needs and expectations present the following picture:

6.1.1 Regulatory

- The biggest issue encountered by the region today turns out to be neither technology nor the market but the regulatory decisions. 3G License allocation has been delayed for almost three years. PTA efforts to educate the operators (investors) on 3G required parallel work on setting grounds for its implementation. Unfortunately, the latter didn't become a reality, causing doubt and uncertainty. The operators were reluctant due to the high cost associated with the purchase of new spectrum. By the time a trust factor was established, LTE emerged as a more promising technology over UMTS due to its low cost/pit. Hence, a journey that began at the crossroad of Yes or No to 3G is now at a similar point of either UMTS now or wait for LTE. The result in both cases is a delay which may lead to more complications in making 3G a reality in the region.

[133] YES 2 3G" - White Paper www.mobilestream.com

- Another important factor to mention here is overlapping frequency bands between the operators and the defense authorities.
- Tax rate on services, handsets, and equipment is what needs to be agreed upon by PTA as well as the service providers. One-sided forced figures can discourage innovation and success by limitations imposed.
- The high cost associated with the 3G in general is now causing a shift towards infrastructure sharing among major competitors around the globe. PTA would have to provide just and promising strategies in this regard in the times to come.

6.1.2 Market and Consumer

- 3G has been often interpreted as mobile broadband anywhere and anytime. Internet being the most commonly used application has lead to 3G success in Europe and USA. The data usage in Pakistan has been a showstopper for most operators. BMI statistics of 35 million Internet and 2.5 million broadband consumers in a population of 160 million by the end of 2012 is indeed a critical fact.
- The data usage merit for 3G is a fact, but as discussed is article 4.4, the region bears high potential for supporting the world of 3G. In an underdeveloped country like Pakistan, 3G possesses the necessary traits to bring economic and social revolution. The change expected is gradual, but the outcome would be long lasting and promising.
- Foreign investment did play a crucial role in boosting telecommunication industry in Pakistan. However, recent political instability has adversely affected 3G roll out in the region. 3G spectrum fees went down since its introduction. An analyst observed a decline in the 3G license fees around the globe since 2001. But for a developing country like Pakistan, the figures could never be too low, and foreign investments would always be the financial backbone. Referring to

article 4.1.2 in chapter 4, the region does have a strong share of overseas investment, but the challenge now is to retain and increase those share.

- Last mile connectivity is what defines any technological success. Consumer access to the services in case of 3G would eventually be the handset industry. Figure 4.2 depicts Nokia dominance in the mobile market. What that means is a high customer confidence in Nokia handsets within the region. Considering the availability of Nokia 3G phone sets in international market, this may ease the transition from 2 to 3G at the customer end. But at the same time, it posts threats of overshadowing and limiting consumer exposure to a more diverse environment.

6.1.3 Technology

- It has been almost a decade since the launch of the first 3G network. UMTS-WCDMA's maturity and success is confirmed by its commercial deployment in 115 countries with 264 operators. Hence, there is no doubt about that. In fact, the technology further evolved as discussed in chapter three of this paper, and the result is the following fact sheet by GSA:

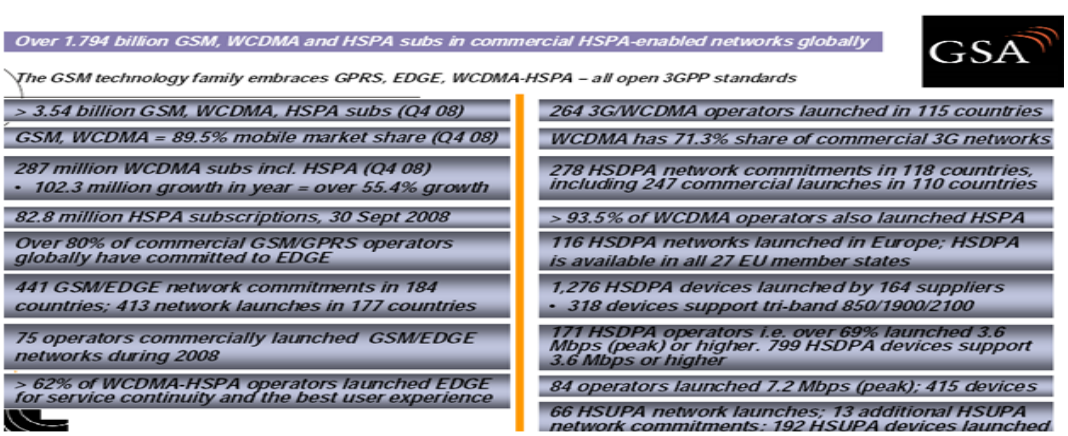

Figure 33 GSA market survey

- The next in line candidate is LTE. The theoretical findings for this technology, as discussed in chapter three of this paper, are promising. On practical grounds, as per the research by GSA, commercial networks would be available somewhere near the end of 2009.[134] So the success of LTE in various environments and industries has yet to be observed. It's a risk that regions with established 3G networks are more inclined to take. For them, with an already established base of 3G consumers and 3G revenue pouring in, LTE is worth the risk. However, for a region like Pakistan, still to embark into the world of 3G, LTE at this point in time fails to provide guarantees. Hence, immature technology popularity poses significant threats as to when and how 3G might become a reality.
- Technological myth, as discussed in chapter two, has had a great influence on the choices that are visible to interested candidates. UMTS-WCDMA is largely viewed as sole enabler of 3G. On a more generic level, purchase of new spectrum is usually referred to as an enabler for 3G. Hence the cost associated with new spectrum is what discourages investors. The result is an industry that is facing major delays in 3G, not due challenges faced by the technology but due to the myth associated with that technology.
- EDGE-2 is a highly neglected technology.

[134] www.gascom.com

Chapter 7 Transition Model

(Preface Extract)…………Innovation and progress is indeed a catalyst that triggers change and change in this case may be an upgrade, evolution or revolution in technology. The question, which technology and where or how is still unanswered. Some of the most important issues include, market readiness, business issues (e.g., pricing, market segmentation), service issues (e.g., coverage, service portfolio and QoS) and technical challenges (e.g., spectrum availability, maturity of technology, and availability of proper user terminals). This thesis will interpret such issues in regards to the expected transition in Pakistan and will justify a migration model highlighting the inevitable challenges lined up for region's future.

7.1 Model Guidelines

- The core idea behind this model stems from the notion that technology alone is not enough to penetrate an industry successfully. In terms of technology itself, an immature technology faces failure threats due to the unseen challenges lying ahead. On the other hand, an overly mature technology is shadowed by succeeding evolutions in its line. However, the success merit goes beyond technology as factors like regulation, market, and consumers play significant roles in concluding response within a certain region. These are the combined catalysts that define need and readiness of an industry as recipient. Together, they can translate failure in one region into success in another and vice versa.

- From a business perspective, it is the integration of an undeveloped model into an overly developed environment or that of a highly advanced model in a poor one. In the former case, the outcome is highly raised merit expectations that are impossible to meet. In the later case, the outcome is a non-competent product placed among highly efficient ones. The result in both cases is a chaos.[135]

- "Third generation (3G) systems promise faster communications services, including voice, fax and Internet, anytime and anywhere with seamless global roaming. 3G is the term used to describe the latest generation of mobile technology which provides enhancements to voice communications and data connectivity including wireless access to the Internet, mobile applications and multimedia content."[136] It is crucial to understand that 3G is indeed a next generation network technology. What that implies is how these services are made available to the consumer is transparent to them. The access schemes approved by ITU are there to provide last-mile connectivity. The applications and tools running on top of any 3G network require certain bandwidth and connectivity but are in no way dependant on how these requirements are fulfilled.

- Purchase of a new spectrum myth, associated with 3G, has been challenged by technologies like EDGE2, UMTS 900, and UMTS850 and to some extend LTE as well. The commercial standing and success of these networks do confirm that purchase of a new spectrum is not the only route to 3G.

- Is data-rate the only driver? In recent research into the use of unified communications and collaboration, Nemertes Research found that enterprise IT executives are concerned about the wireless standards. But why? Latency and coverage trump raw bandwidth! Carriers need to look at this evolution from the standpoint of the business customer. Transfer rates aren't always the issue. In many cases, considerations such as latency and coverage are more important than raw bandwidth. What many businesses are realizing is that the wireless standard and where it is

135 Project Management
136 White Paper from the UMTS Forum Mobile Broadband Evolution: the roadmap from HSPA to LTE February 2009

being deployed can have a profound impact on the utility of a wireless-enabled mobility application.[137]

- The migration to a new technology is more successful when changes are more consumer centric than operator centric. In other words, the flow of change ought to be from the consumer end towards the service provider and not vice versa. It is the end-user demand or expected market growth that defines the migration path.

7.2 Wireless Migration from an Operator's Perspective

"The existing wireless operators today regardless of the frequency band or existing technology deployed have or are making very fundamental decisions as to which direction in the 3G evolution they will take. The decision on 3G technology will define a company's position in the marketplace for years to come. Since the platforms to pick from utilize different access technologies, they are by default not directly compatible. The utilization of different access technologies for the realization of 3G also introduces several interesting issues related to the migration from 2G to 3G. The migration path from 2G to 3G is referred to as 2.5G and involves an interim position for data services that are more advanced than 2G, but not as robust as the 3G envisioned data services."[138] Some of the migration strategies for an existing operator involve:

Overlay: The overlay approach typically involves implementing the 2.5 technology over the existing 2G system and then implementing 3G as either an overlay or in a separate part of the radio frequency spectrum where they are allocated, spectrum segmentation.

[137] http://searchtelecom.techtarget.com/tip/0,289483,sid103_gci1319015_mem1,00.html?offer=briefcase&ShortReg=1&mboxConv=searchTelecom_RegActivate_Submit&

[138] 3G Wireless Networks

Spectrum segmentation: The choice of whether to use an overlay or spectrum segmentation is naturally dependent upon the technology platform that is currently being used, 2G, the spectrum available, the existing capacity constraints, and marketing. Marketing is involved with the decision because of the impact to the existing subscriber base and services that are envisioned to be offered.[139]

7.3 Wireless Migration from a Consumer's perspective

Unless consumers are eager to adopt mobile broadband services, the new networks and pricing regimes will have little impact. Consumer expectations and requirements for mobile broadband around the globe have evolved dramatically in recent years as users become accustomed to high speed access with fixed broadband. In Pakistan, the demand is more social and economical than personal. The opponents of 3G present the lack of notebooks and exposure to Internet as reasons behind limited data demand. The claim, although true today, is more likely to become obsolete in the future. The health and education scenarios provided in chapter four, if supported well by the government, regulators, and service providers, can bring huge data volumes into the rural areas.

In the urban parts too, the more educated class can take advantage of the diverse 3G services as discussed in this paper. Operators are accustomed to having control over new types of services coming onto their networks, but now \ services are driven by consumers and web companies. No one predicted the enormous popularity of virtual worlds, geospatial services, or instant messaging. Few anticipated the deployment, use, and impact of social networking applications. Multiple new forms of communication have materialized as people discover and explore the benefits of social networking sites and the power of instant online communication. These developing communication 'personas' are currently trapped to

[139] 3G wireless network

fixed or tethered solutions, and consumers are demanding mobility solutions that enable 'anytime anywhere' access to their communication personas.

The transition, indeed, would be slow in the beginning. However, there is no limit to how fast or big the penetration could be considering the way wireless voice took over the market a decade ago!

7.4 3G Snapshot

The following is a reproduction of research done in the field of 3G as it provides firm understanding of the grounds used to present the final model.

7.4.1 Mobile Broadband Frequency

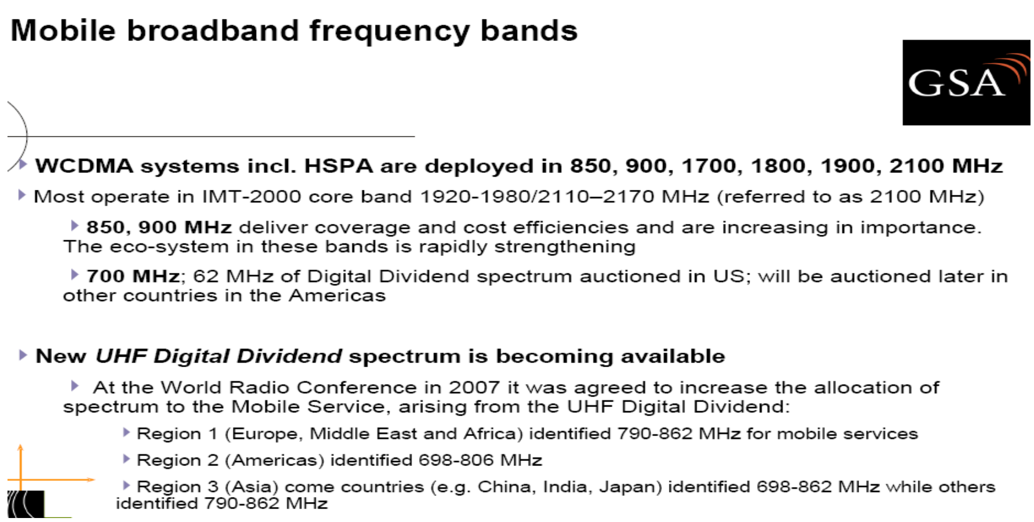

Figure 34 Mobile Broadband frequency Bands

7.4.2 Mobile Broadband Update

Commercial WCDMA networks	284	HSPA subscriptions Q4 08	104 m
Countries WCDMA launched in	120	HSDPA networks 3.6 Mbps or higher	> 73%
WCDMA subs (incl. HSPA) Q1 09	329.3 m	HSDPA networks 7.2 Mbps or higher	> 39%
WCDMA 3G network market share	72.8%	HSDPA devices launched	1,470
Commercial EDGE networks	413	Commercial HSUPA networks	72
Countries EDGE launched in	177	Networks with HSUPA launched	> 26%
GPRS networks evolved to EDGE	> 80%	HSUPA devices launched	260
Live HSPA networks with EDGE	> 64%	HSPA devices with EDGE support	> 83%
HSPA network commitments	306	HSPA+ network commitments	29
Commercial HSPA networks	267	Commercial HSPA+ networks	4
Countries HSPA launched in	114	LTE network commitments	31
Live WCDMA networks with HSPA	94%		

Source: GSA surveys and reports – up to May 14, 2009

Figure 35 3G international Market Stats

7.4.3 3G Radio Access Evolution

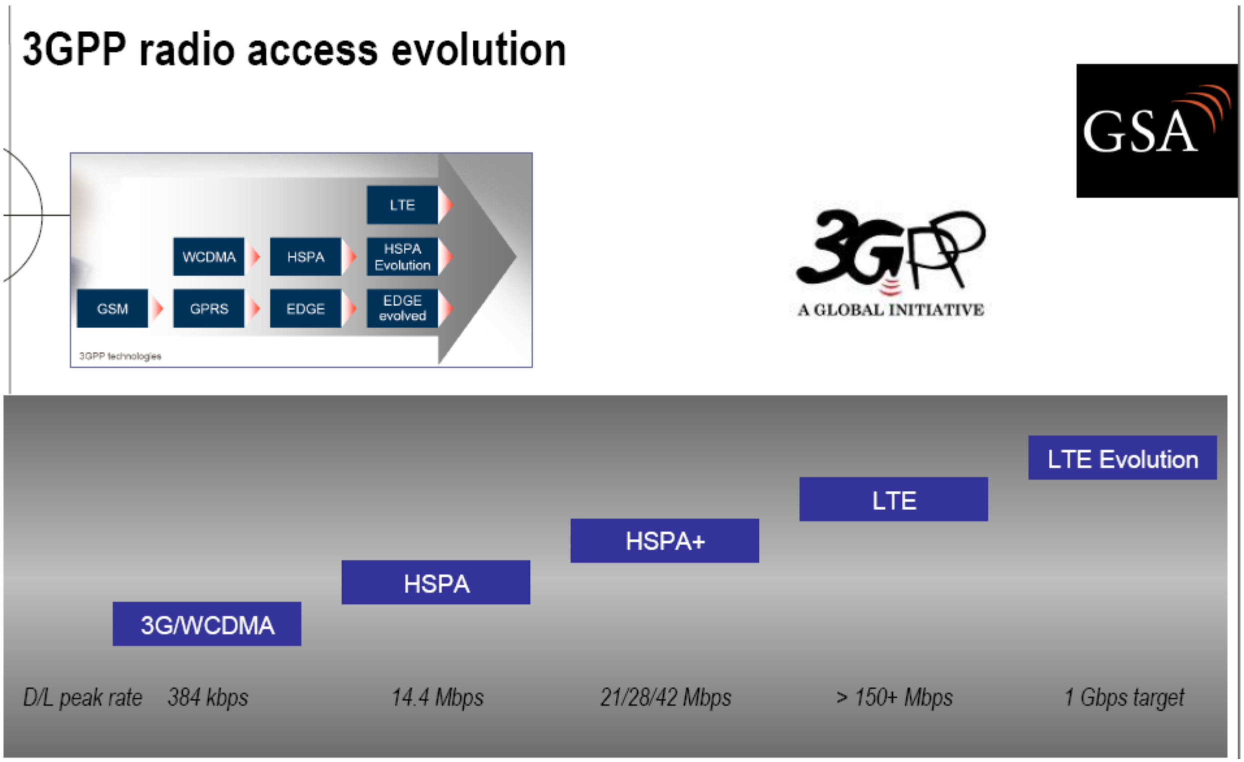

Figure 36 3G evolution

7.4.4 3G Cost, Data Rates and Delays

From the service provider's perspective, the following two charts summarize valid options in terms of investment and data rates. (The research was done by GSA and is available at www.gsa.com.)

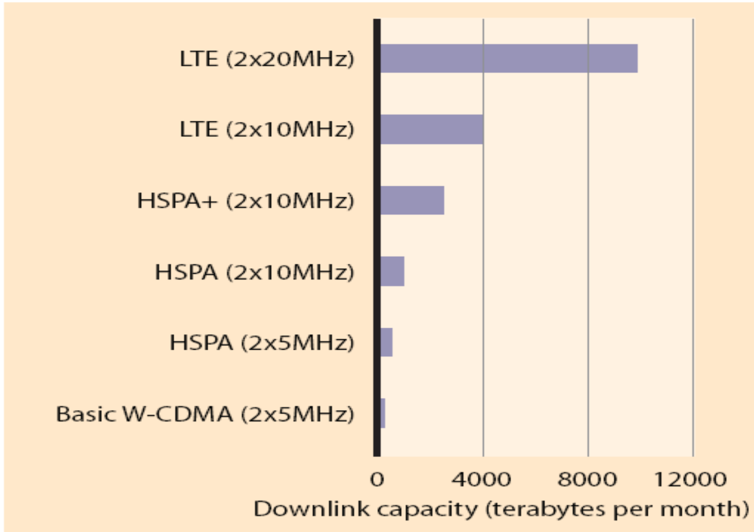

Figure 14: Estimated network capacities for WCDMA, HSPA, HSPA+ and LTE for a typical deployment of 10,000 base stations
Source: Analysys Mason, 2008

Figure 37 Data Rates

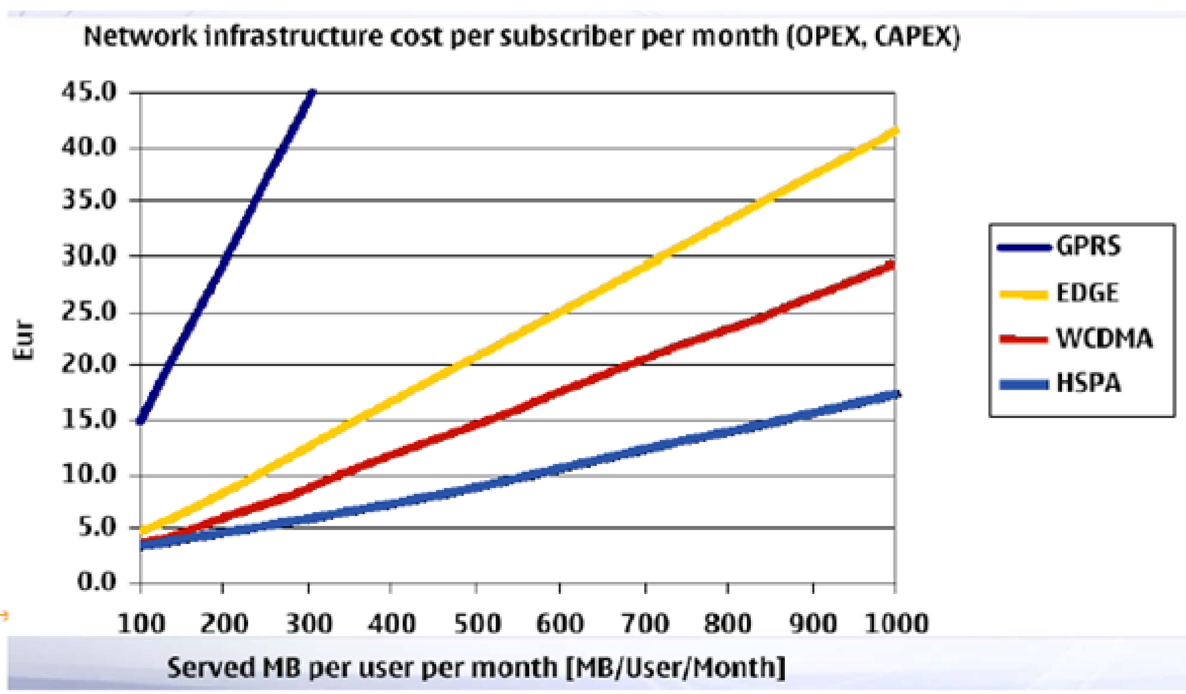

Figure 38 Cost per technology

Note: LTE, not shown in this picture, offers less cost per megabyte when compared with HSPA. The massive increase in capacity comes at a lower cost per bit. The cost per megabyte could drop by a factor of 3, from Euro 0.03 for HSPA (2x5 MHz) to Euro 0.01 for LTE (2x5 MHz), according to the Analysis Mason study.

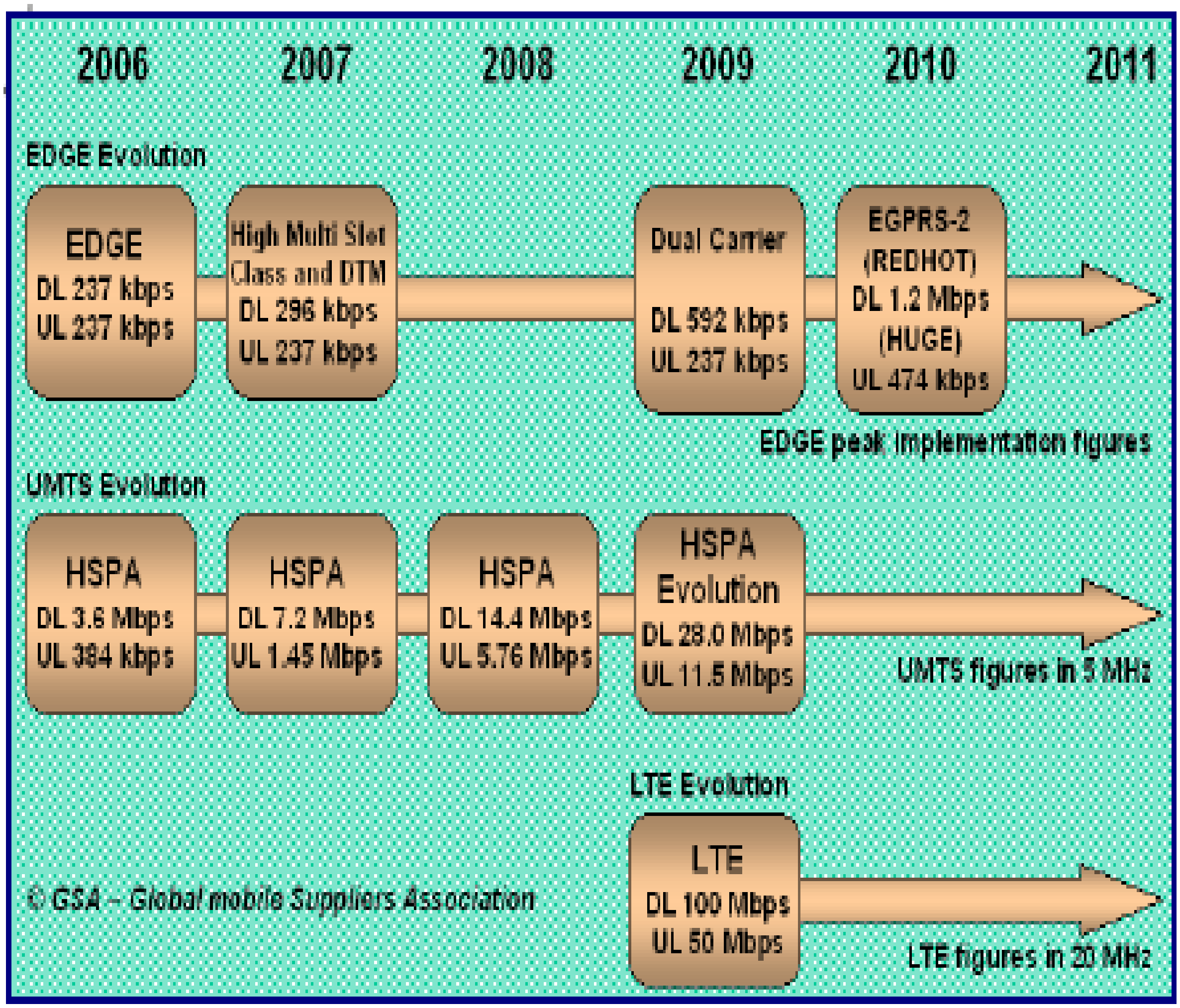

Figure 39 The evolution path for 3G

7.4.5 3G handset market

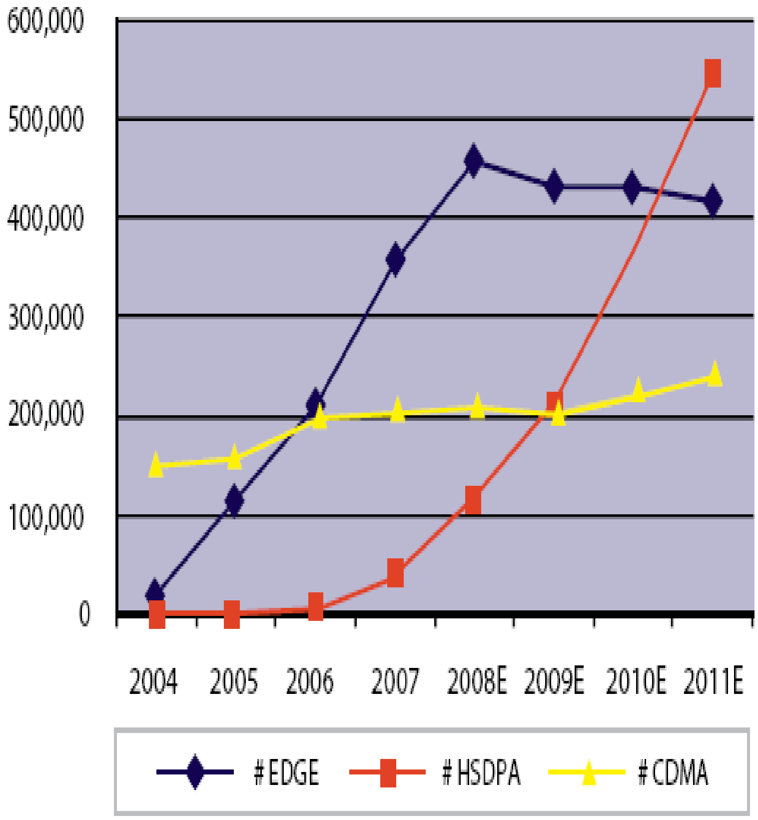

Figure 10: Handset shipments by technology
Source: Deutsche Bank

Figure 40 3G handset Industry

7.5 Migration Model

The migration, driven by the market, consumer, and the regulators, can be best visualized in a series of steps. When categorized broadly, it would be:

- Evolution
- Revolution

7.5.1 Evolution-Evolved EDGE

Going back to the model guidelines, the change ought to be consumer centric for 3G success. It is not the high data rates alone but regulation, consumer, and market readiness all together that need to be looked into. The operator's reluctance to make a high capital investment due to concerns of limited data demand is valid. However, referring to the discussion in chapter 4, the region potential for high data demand in the times to come could be anything but revolutionary. Evolved EDGE provides means to increase that demand over time with minimum changes in the existing infrastructure. In the shorter run, it can bridge and enhance user's exposure to the world of 3G. The shift would be gradual, but the impact would be more intense when higher data rates are introduced later on.

"Current EDGE peak data rates of 300 kbps cannot cope with the data rates of 7.2 Mbps provided by WCDMA/HSPA networks. Introduction of new modulation schemes, e.g., 32 QAM and higher symbol rate boost data rates up to 118.4 kbps per timeslot. In combination with dual downlink carrier, mobile terminals are able to allocate ten downlink timeslots which will enable peak data rates of 1.2 Mbps. Additional improvement of EDGE Evolution end user performance is provided by reduced latency, turbo codes and mobile receive diversity techniques. All this features together provide comparable performances with 3G technology and more importantly, enable true service transparency between 2G and 3G networks.[140] “It applies many of the techniques employed in HSPA+ to lower latency and increase the speed of EDGE. A key part of the evolution of EDGE is the utilization of more than one radio frequency carrier. This is designed to overcome the inherent limitation of the narrow channel bandwidth of GSM.”[141]

GSM high-market penetration in Pakistan, with EDGE implemented in 80% of the networks, provides an automatic means to make these changes available to the masses. With approximately 70% of the population in remote areas, where the data rate upper limit is comparatively low, this connection can indeed open new doors to revenue and innovation within the country.

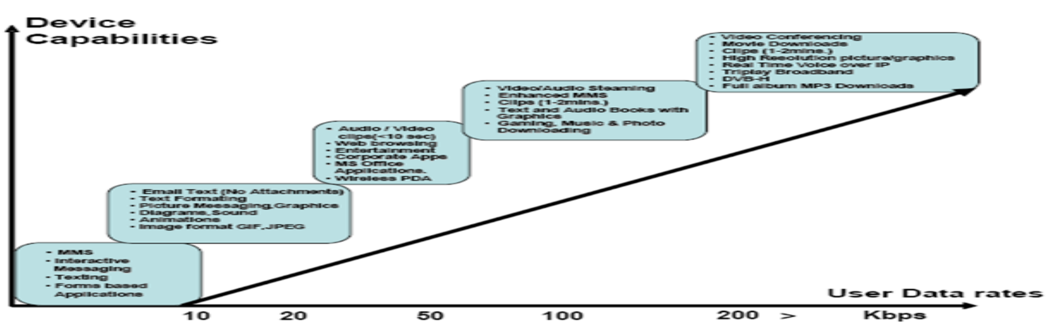

Figure 41 data rates for various services

The above figures, when coupled with the following data rates, provide promising results.

[140] Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks
[141] http://www.3gamericas.org/index.cfm?fuseaction=page&sectionid=245

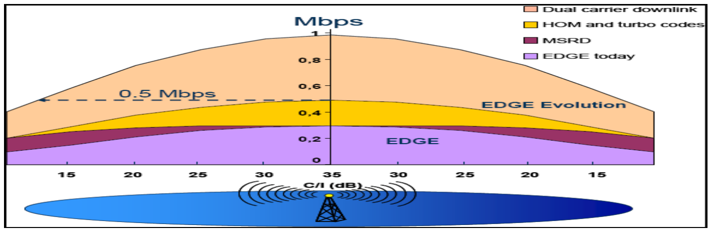

Figure 42 Evolved edge data rates

In the longer run, it can complement the future WCDMA or LTE services.

7.5.2 What will the user experience be like?

- Slightly improved throughput in normal operating interference and sensitivity scenarios and slightly better voice quality in very low signal areas.

- Possible larger handsets (greater antenna spatial separation improves diversity)

- Faster battery drain[142]

7.5.3 What will the network gains be?

Mobile will have increased ability to tolerate interference – with significant penetration of MSRD mobiles; operators may be able to optimize their cell loading and support more users with the same infrastructure.

In rural areas, MSRD-capable mobiles may experience fewer dropped calls in areas of low signal coverage and may reduce need for additional infrastructure.[143]

[142] http://www.3gamericas.org/documents/evolved_edge_update_04_2007.pdf
[143] http://www.3gamericas.org/documents/evolved_edge_update_04_2007.pdf

7.5.4 Market and Commercial Standing

Following the Rel-7 industry standardization, Ericsson and Nokia Siemens Networks are among those companies committed to launch EDGE evolution as a software upgrade of existing infrastructure in 2009. RIM has also endorsed EDGE evolution.[144]

Nortel and partner Prisma Engineering have announced end-to-end Evolved EDGE communication. The company intends to demonstrate the solution at Mobile World Congress that will include live video streaming over Evolved EDGE and LTE. This demonstrates the coupling of these technologies to deliver network-wide service continuity. A simple software upgrade for an existing EDGE network enables Evolved EDGE and can more than double the spectral efficiency. The company adds that in practice these enhancements deliver an improved end-user experience and access a full range of mobile applications including VoIP, gaming, Web browsing, e-mail, and video streaming.[145]

Evolution

Evolution provides ease in migration towards 3G by bringing data rates at the minimum end of ITU specifications at lower costs but is indeed not comparable to the advances in 3G. Revolution is the logical next step in moving towards the world of wireless broadband. However, what technology to choose from, the range discussed in chapter two and three, is still an unanswered question.

[144] http://www.3gamericas.org/index.cfm?fuseaction=page&sectionid=245
[145] http://www.astricon.net/topics/broadband-mobile/articles/20436-nortel-announces-new-evolved-edge-communication-technology.htm

7.6 Revolution

7.6.1 LTE

If the situation was simple enough to base all merits on technology alone, then the obvious choice would be LTE. The highest data rates at the lowest costs. However, LTE profits are more justified in areas of high data demands. The expensive spectrum addition is balanced by the low cost per byte triggered by high traffic volumes. In case of Pakistan, the region still has an open window before the data demand gets to the point where LTE would be mandatory to fulfill it. As discussed in the model guidelines, starting the 3G journey with LTE would be similar to placing a highly sophisticated product in very poor surroundings.

In addition, for any wireless operator the total cost of ownership could be represented as follows:

Figure 43 Operator cost of ownership

The total cost of ownership is much more than the investment in the technology. Hence, the network cost might be low, but the business-driven cost would be high and not promising at this point in time.

Consumer demand is not the only missing block. Relatively new LTE is in danger of facing the launch crisis that every new technology goes through. Hence, the grounds are not stable enough for a region like Pakistan to invest high capital in such critical times.

LTE in the long run

The stage has been set. "In December 2008, Rel-8 specification was locked. In March 2009, the ASN.1 code was locked. The standard has been complete enough that hardware designers have been designing chipsets, test equipment and base stations for some time. LTE test equipment has been shipping from several vendors since early 2008 and at the Mobile World Congress 2008 in Barcelona Ericsson demonstrated the world's first end-to-end mobile call enabled by LTE on a small handheld device. Motorola demonstrated a LTE RAN standard compliant eNodeB and LTE chipset at the same event"[146].

"GSA confirmed 31 global LTE commitments and the launch of first network in 2010. In addition, the LTE ecosystem is building too." [147] The technology offers a choice of carrier bandwidths; 1.4 MHz to 20 MHz, an operator may introduce LTE in "new" bands where it is easier to deploy 10 MHz or 20 MHz carriers eg in 700 MHz, 790-862 MHz, or 2.6 GHz bands and eventually LTE may be deployed in all bands. "A large amount of the work is aimed at simplifying the architecture of the system, as it transits from the existing UMTS circuit + packet switching combined network, to an all-IP flat architecture system."[148]

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[146] Long_Term_Evolution
[147] www.gsacom.com/gsm_3g/info_papers.php4
[148] Long_Term_Evolution

"Some regions of the world do not yet have licensed spectrum for deployment of radio technologies such as WCDMA/HSPA or LTE. The natural evolution path for GSM operators in those regions is to migrate to WCDMA/HSPA, once 3G licenses become available, and subsequently to migrate to LTE when warranted by user demand and business strategies."[149]

Thus, in the longer run, with an increase in data demand and maturity of technology, LTE indeed would be the choice for many operators.

7.6.2 UMTS

HSPA stands out in the choice from within UMTS (WCDMA) family. The show stopper for many, however, is spectrum expenses and limited surfaced demand. The few interested are challenged by the delays in allocation of new spectrum. In a situation like this, having an option to deploy 3G within the same spectrum and provide data rates better than evolved edge can bring noticeable change in the industry and also the future. Hence, the regulatory, financial, and market issues move the balance towards the idea of frequency refarm (UMTS900 and UMTS 850) .

Approved in 2005, UMTS/WCDMA-HSPA below 1 GHz 900/850 MHz, allows enabling 3G services in lower bands, less than 1G Hz, and doesn't require purchase of a new spectrum. "All existing 3G applications can be provided and used cost-efficiently over much larger geographical area. In addition, same data rates using 900 MHz as for 2100 MHz."

[149] Mobile Broadband Evolution: the roadmap from HSPA to LTE

UMTS900 Finland

In November 2007, incumbent Elisa continued its groundbreaking role by launching the world's first UMTS900 network service in the rural and suburban area. The initial deployment of UMTS2100 worked well in cities, because the high subscriber density allowed a relatively compact cell site distribution. However, in bringing 3G to suburban and rural areas, Elisa needed to find a more cost-effective method of deploying the UMTS network where sparse subscriber populations demanded greater distances between cell sites. UMTS900 was the ideal solution because it offers a cell radius that is typically almost twice that of a 2100 MHz site. It also provides the same cell radius for packet data services as GSM900 voice, optimizing coverage and performance. In addition, the performance of UMTS900 and UMTS2100 is the same with typical data rates ranging from 2 Mbps to 5 Mbps and maximum peak data rates of up to 7 Mbps, but UMTS900 provides a much larger coverage area. As a result, UMTS900 can provide the same coverage with two to three times fewer cell sites than UMTS2100. That meant that Elisa could save 50% to 70% on its build-out costs by deploying UMTS900 compared with UMTS2100. Since the commercial deployment of UMTS900 in November 2007, Elisa has seen a 300% increase in data traffic and a positive impact on ARPU.

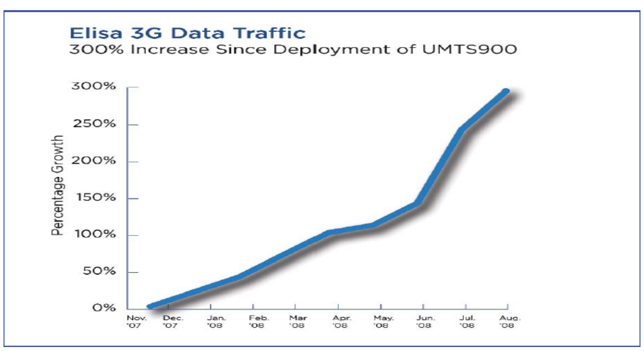

Figure 44 Elisa traffic growth chart

"Typically, 3G networks show an increase in ARPU of 5% to 10% when deployed, thanks to enhanced data performance, so we had an economic motivation to make the changeover," admits Panu Lehti, Elisa's EVP of consumer business. "The fact that we could couple it with major savings in network build out costs made the decision simple."

"By using UMTS900, we have the same coverage for mobile data as we already have for voice with GSM900," notes Dr. Eetu Prieur, Head of Access Networks for Elisa Corporation. "And we're using the existing GSM900 cell sites that we have been optimizing for 17 years, so we know UMTS900 will deliver the same coverage and quality our customers have come to expect."

"Looking ahead, once we have completed our GSM site conversion and established nationwide 3G coverage, we will expand our UMTS900 rollout into Urban areas to create a nationwide UMTS900 network," remarks Timo Katajisto, CTO of Elisa Corporation.

"We will utilize the existing UMTS2100 network as a capacity layer for urban subscribers. This is a similar approach to what many operators did years back with a GSM900 national coverage layer that dovetailed with GSM1800 as a capacity layer in cities."

In urban areas, Elisa also tested the collocation of UMTS900 with existing UMTS2100 MHz sites. The company found little that would impact future collocation opportunities when it extends UMTS900 into its current UMTS2100 markets. The only minor interoperability issue encountered was the handoff from the UMTS900 network to UMTS2100 at certain conditions, but that will be corrected in the future software upgrades. "Once we have completed our GSM site conversion and established nationwide 3G coverage, we will expand our UMTS900 rollout into urban areas to create a nationwide UMTS900 network," commented Timo Katajisto CTO, Elisa Corporation. "The number of MTS900 terminals in the market is significantly increasing over time from multiple vendors including the leading industry players," Observed Panu Lehti, EVP of Consumer Business, Elisa Corporation.

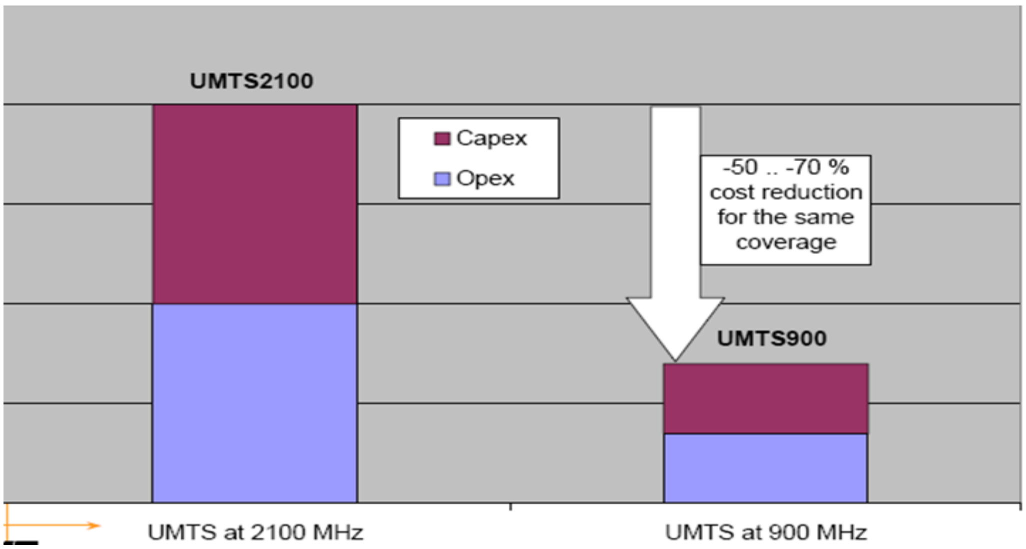

Figure 45 Reduction in capex and Opex

Pakistan's highly populated urban areas, when translated into the consumers in demand of 3G services, do produce a case similar to one discussed above. The demand in urban areas, like the rural areas in Finland, is low. Initial launch would be more for the broadband users who are limited in number. The case of high consumer concentration within a certain area, if present, does propose challenges. But when compared with the gains of 3G introduction, workarounds are needed.

Consumer's base needs to be established before operators would be confident in purchasing new spectrum. The year 2100 can then be used to add capacity layers in the urban areas. It can be the optimization in near future but certainly not the only way to enter the world of 3G.

UMTS900 Operator Case - Optus, Australia

Optus launched its UMTS900 in May 2008. Together with 2100 MHz, the Optus 3G/HSPA network now reaches over 90% of the population, covering over 500,000 sq km landmass. Majority of coverage is using 900 MHz. More than 730 UMTS900 sites are now active; over 60 more will come online by Christmas 2008, taking landmass coverage to over 650,000 sq km, 90% of which will be using UMTS900. In addition, it has excellent voice services compared to the GSM network. The benefits of building penetration compared to UMTS2100 are also notable. 900MHz offers better absorption into the wall and hence lower building penetration loss (BPL).

"Our focus on site optimization during re-farming actually gave our customers a kick up in performance for their 2G service as well as access to UMTS900. UMTS900 has been critical in bringing up that depth of coverage into people's homes, so they get a similar experience in both voice and data coverage, making it a more economically feasible solution for expansion. By having a technology that allows us to get into more places at a lower cost, we can deliver more services," notes Andrew Smith, Director, Mobile Core Engineering; Optus.

Optus strategy to increase coverage over a wider area with UMTS provides means to expand 3G in the future in Pakistan too. Once 2100 MHz becomes a reality, the existing site in the urban area may be used if needed. Or new sites can be added to the far off places. In either case, the result would be expanded broadband services into the remote and untouched places, providing means to enable the social and economic revolution as discussed in chapter four.

Options to refarm 900 MHz for UMTS900 - while maintaining the GSM quality

Option 1: There are enough channels to be taken out for UMTS900 in the rural areas where GSM is planned based on coverage, i.e. the maximum number of TRX per sector is two.

Option 2: Via GSM investments, enough channels can be allocated to deploy UMTS900 typically in suburban areas and traffic routes.

Option 3: Via migrating traffic to UMTS2100, enough channels can be allocated to deploy UMTS900 in small cities and suburban areas and high traffic routes.

Option 4: Deployment of UMTS900 is not yet possible in downtown or other densely populated urban areas.[150]

UMTS900 Commercialization

"130 devices announced by 23 suppliers, as of may 2009. So far 10 UMTS900 networks have been launched. In addition, the 900/2100MHz combination for WCDMA-HSPA is expected to become much more Commonplace."[151]

PTA Approvals

The means to make UMTS900 a possibility again start by the regulation industry. The following is the global standing today:

[150] UMTS900 Market Overview Alan Hadden, President Global mobile Suppliers Association

[151] *www.gsacom.com/gsm_3g/wcdma_databank.php4*

Country	Re-farming status
Australia	UMTS900 is allowed
Belgium	UMTS900 is allowed
Estonia	UMTS900 is allowed
Finland	UMTS900 is allowed
France	UMTS900 is allowed
Germany	Under consideration
Greece	Under consideration
Iceland	UMTS900 is allowed
Indonesia	UMTS900 is allowed
Ireland	Under consideration
Italy	UMTS900 is allowed
New Zealand	UMTS900 is allowed
Norway	Under consideration
Portugal	Under consideration
Romania	Under consideration
Russia	Under consideration
Saudi Arabia	UMTS900 is allowed
Singapore	UMTS900 is allowed
Spain	Under consideration
South Africa	Under consideration
Sweden	UMTS900 is allowed
Switzerland	Under consideration
Thailand	UMTS900 is allowed
UAE	UMTS900 is allowed
UK	Under consideration
Venezuela	UMTS900 is allowed

Figure 46 UMTS900 Global Status

7.7 Concluding Remarks

"The combination of GSM/EDGE and WCDMA under a seamlessly integrated UMTS multi-radio network should yield the best possible radio performance both for speech and data services." Provided multiple bands availability, GSM/EDGE can play an efficient technology in the already deployed cellular network bands (800, 900, 1800 and 1900) and WCDMA in the new 2100 band (IMT-2000) or other coming bands over 2 GHz (as it is likely the case in the US). For operators licensed with multiple bands a joint operation of GSM/EDGE and WCDMA could be the optimum scenario with a UMTS multi-radio deployment."[152] Due to the present regulatory and market conditions, UMTS900 comes into the picture as 3G enabler prior to the purchase of new spectrum. Its role becomes significant as the region suffers from delays in regulation and limited consumer demand. The UMTS specifications include support for a hard handover from UMTS to GSM and vice versa. This is an important requirement, since the widespread

[152] http://library.books24x7.com.ezproxy.rit.edu/book/id_4860/viewer.asp?bookid=4860&chunkid=956045739

rollout of UMTS coverage will take time to complete, and if holes exist in UMTS coverage, it is desirable that a UMTS subscriber should receive service from the more ubiquitous GSM coverage. Last but not least, LTE bears high potential in becoming region's future based on the market, operator, and regulator response.

The major delays in 3G reality in Pakistan are more towards the regulating end than towards the technical or market side. Hence, it is not a surprise that the proposed ideas can become reality by efforts beginning at the same end. PTA's parallel efforts, enabling 3G within the same spectrum and in new spectrum, are needed in order to set ground work for a 3G-supporting industry prior to the long awaited spectrum allocation. The auction itself needs to be innovative to encourage cost and infrastructure sharing among big players in order to cope with the tremendous fees associated with it. The job of PTA doesn't end there, as discussed in article 5.1; the enabling of the business environment is the biggest challenge of the regulatory bodies.

Consumer market is the ultimate merit of success or failure for 3G in Pakistan. The trends observed in the next few years would define regions' response to it. The challenges in this regard are bigger than technology or regulation. The region bears high potential for applications that could bring high revenues for the investors and social and economic revolution for the public. The challenge is not only the access of 3G to masses but also the availability of relative applications and devices. The existing infrastructure does possess deep roots that, when supported by the regulation, technology, and operators, can make this task easier. 3G is more than Internet or notebook; it is a revolutionary step towards the world of wireless broadband. It opens doors to possibilities that can be translated into as many tools, services, and applications as the region needs.

Innovation and progress is indeed a catalyst that triggers change, and change in this case may be an upgrade, evolution, or revolution in technology. The question, which technology and where or how, is still unanswered. This paper presented a possible journey that the region could embark upon and the challenges lying ahead as the journey begins!

Bibliography

Asif, Saad Z. *Wireless communications : evolution to 3G and beyond.* Boston: Artech House, c2007.

Bannister, Jeffrey. *Convergence technologies for 3G networks* . Chichester: Wiley, c2004.

Fulle, Professor Ronald. "Telecom Policy."

Garg, Vijay Kumar, 1938-. *Wireless network evolution : 2G to 3G.* Upper Saddle River, NJ : c2002.

Karim, M. R., 1939-. *W-CDMA and cdma2000 for 3G mobile networks* . New York: McGraw-Hill, c2002.

Project Management. 2008.

Smith, Clint, P.E. *3G wireless networks.* New York : McGraw-Hill, c2007.

Sumit, Kasera and Nishit Narang. *3G Mobile Networks- Architecture, Protocol, and Procedures.* NewYork: McGraw-Hill, 2005.

Wang, Jiangzhou, and Tung-Sang Ng. *Advances in 3G enhanced technologies for wireless communications.* Boston: Artech House, c2002.

References

White Papers

1. Mobile Streams. "YES 2 3G" - White Paper. February 2001. www.mobile3G.com
2. NMS Communications. 3G Tutorial. Brough Turner and Marc Orange. Originally presented at Fall VON 2002
3. TD-SCDMA – China's chance
4. Defining 4G: Understanding the ITU Process for the Next Generation of Wireless Technology 3G Americas June 2007
5. Defining 4G: Understanding the ITU Process for the Next Generation of Wireless Technology 3G Americas Revised August 2008
6. HSPA: High Speed Wireless Broadband From HSDPA to HSUPA and Beyond
7. 3GPP Long Term Evolution Retrieved from http://en.wikipedia.org/wiki/3GPP_Long_Term_Evolution"
8. 3G Business Prospects – Analysis of Western European UMTS Markets Jarmo Harno Nokia Research Center Helsinki, Finland
9. Global mobile Suppliers Association. Information Paper. GSM/3G MARKET/TECHNOLOGY UPDATE. July 17, 2009
10. Global mobile Suppliers Association. Information Paper. GSM/3G MARKET/TECHNOLOGY UPDATE. July 10, 2009
11. Global mobile Suppliers Association. Evolution of Network Speeds. GSM/3G MARKET/TECHNOLOGY UPDATE. May 2009
12. Global mobile Suppliers Association. Information Paper. GSM/3G MARKET/TECHNOLOGY UPDATE. April 15, 2009
13. Global mobile Suppliers Association. Information Paper. GSM/3G MARKET/TECHNOLOGY UPDATE. January 30, 2008
14. Global mobile Suppliers Association. Information Paper. GSM/3G MARKET/TECHNOLOGY UPDATE. July 2007
15. Global mobile Suppliers Association. Eastern Europe. GSM/3G MARKET/TECHNOLOGY UPDATE. December 2007
16. Global mobile Suppliers Association. Mobile Universal Access. GSM/3G MARKET/TECHNOLOGY UPDATE. December 1, 2006
17. 3G Long Term Evolution. Aricent White Paper Long Term Evolution (LTE): Overview of LTE Air-Interface Technical White Paper
18. Technical Overview of 3GPP LTE May_18,_2008 Hyung_G._Myung_
19. A White Paper from the UMTS Forum Mobile Broadband Evolution: the roadmap from HSPA to LTE February 2009
20. Rohde and Schwarz. UMTS Long Term Evolution (LTE) Technology Introduction
21. Long-Term Broadband Evolution – Forecasts and Impact of New Technologies K J E L L S T O R D A H L
22. ETSI. From hype to reality Alan Hadden Lemesos, Cyprus 15 – 16 March 2007
23. Distributed Computing Group MOBILE COMPUTING R. Wattenhofer
24. Overview of the Conditions that drive Universal Access Alan Hadden President, GSA Global mobile Suppliers Association
25. ELECTRONIC COMMUNICATIONS COMMITTEE ECC Decision of 18 March 2005 on harmonised utilisation of spectrum for IMT-2000/UMTS systems operating within the band 2500 – 2690 MHz
26. GSA REPORT TO 3GPP PCG #22 Kyoto April 27, 2009
27. Cisco Mobile Exchange (CMX) Solution Guide. Chapter 2 Overview of GSM, GPRS, and UMTS.
28. Ojanpera, T. and Gray, S.D. "An Overview of cdma2000, WCDMA, and EDGE"
29. Mobile Communications Handbook Ed. Suthan S. Suthersan Boca Raton: CRC Press LLC, 1999
30. 3G AMERICAS UMTS EVOLUTION FROM 3GPP RELEASE 7 TO REALEASE 8 HSPA AND SAI/LTE JUNE 2008
31. 3G Americas The Evolution of UMTS/HSDPA 3GPP Release 6 and Beyond December 2005
32. Wireless Tutorial Brough Turner NMS Communications October 9, 2008
33. The Future of UMTS A services perspective Steve Hearnde UMTS Forum
34. WRC-07 Outcome and some views... Håkan Ohlsén and Lasse Wieweg Ericsson Group Function
35. GERAN Evolution for Increased Speech Capacity Andr´e N. Barreto, Luis G. U. Garcia and Edgar Souza
36. EGPRS2 Uplink Performance for GERAN Evolution Mikko S¨aily, Jari Hulkkonen, and Eduardo Zacar´ıa
37. Evolution of GSM in to the Next Generation Wireless World Prabhakar Chitrapu1, Member, IEEE and Behrouz Aghili
38. 3G Americas THE CASE FOR EVOLVED EDGE AUGUST 2008
39. 3G Americas Evolved EDGE Update (EDGE II) April 2007
40. Capabilities and Impacts of EDGE Evolution toward Seamless Wireless Networks D. Mužić, D.Opatić Mobile Networks Ericsson Nikola Tesla d.d.
41. Paving the Path for High Data Rates by GERAN Evolution EDGE2 with Dual-Carrier K. Ivanov, C. F. Ball, R. Mullner and H. Winkler
42. Evolution to IMT-SC (EDGE)
43. EDGE Overview and update on EDGE Evolution Alan Hadden, President, GSA Global mobile Suppliers Association Barcelona, October 19, 2005
44. GSM/EDGE Radio Access Network (GERAN) – Evolution of GSM/EDGE towards 3G Mobile Services Shkumbin Hamiti, Eero Nikula, Janne Parantainen, Timo Rantalainen, Benoist Sébire, Guillaume Sébire. Nokia Research Center
45. UMTS900 – A Case Study Optus June 2009
46. UMTS900 Market Overview Alan Hadden, President Global mobile Suppliers Association UMTS900 Workshop, Cape Town AfricaCom: November 20, 2008
47. UMTS900 Market Overview Alan Hadden, President Global mobile Suppliers Association UMTS900 Workshop, Dubai GSM>3G Middle East: December 17, 2008
48. 3G Handsets and Devices Alan Hadden, President Global mobile Suppliers Association (GSA) LTE World Summit Berlin: May 18 – 20, 2009
49. Spectrum for Mobile Broadband – Low Frequency Options Alan Hadden, President Global mobile Suppliers Association (GSA)
50. The Digital Dividend: Ensuring a Legacy of Personal Broadband for All Alan Hadden, President, GSA Global mobile Suppliers Association

51. GSMA Digital Dividend Seminar, MWC 2009, Barcelona
52. UMTS900 – A Case Study September 2008 www.gsacom.com
53. UMTS-TDD Retrieved from http://en.wikipedia.org/wiki/UMTS-TDD
54. 3G/UMTS Towards mobile broadband and personal Internet A WHITE PAPER FROM THE UMTS FORUM - OCTOBER 2005
55. QoS implementation in UMTS networks Alcatel Telecommunications Review - 1st Quarter 2001
56. Universal Mobile Telecommunications System Retrieved from http://en.wikipedia.org/wiki/Universal_Mobile_Telecommunications_System
57. Study of soft handover in UMTS Stijn N. P. Van Cauwenberge COM – Center for Communications, Optics and Materials31 July 2003
58. 3G Policy Update Sheriar Irani
59. Pakistan Telecommunications Report Q1 2008 by BMI
60. Infrastructure Sharing and Shared Operations for Mobile Network Operators From a Deployment and Operations View Dr. Thomas Frisanco, Member, IEEE Rachel Ang
61. The Evolution of Rel-7 to Rel-8—HSPA and SAE/LTE by 3G Americas
62. The Global Evolution of UMTS/HSDPA - 3GPP Release 6 and Beyond 3G Americas dec 2005

Books

1. Advances in 3G enhanced technologies for wireless communications
2. Wireless communications : evolution to 3G and beyond
3. Wireless network evolution : 2G to 3G
4. 3G wireless networks
5. Convergence technologies for 3G networks [electronic resource] : IP, UMTS, EGPRS and ATM
6. W-CDMA and cdma2000 for 3G Mobile Networks: by M.R. Karim and Mohsen Sarraf
7. 3G mobile networks: architecture, protocols, and procedures
8. QoS in integrated 3G networks.
9. Project management

Internet links

1. 1 http://74.125.95.132/search?q=cache:s3_NvXfdpMIJ:www.it.lut.fi/kurssit/03-04/010990000/gsm-
2. 1 http://www.astricon.net/topics/broadband-mobile/articles/20436-nortel-announces-new-evolved-edge-communication-technology.htm
3. 1 http://www.benoa.net/publications/ict2001.pdf
4. 1 http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/What_really_3G.pdf
5. 1 http://www.radio-electronics.com/info/cellulartelecomms/umts/umts_wcdma_radio.php
6. 1 http://www.umtsworld.com/technology/handover.htm
7. 1 http://www.webbuyersguide.com/resource/white-paper/9246/UMTS-Evolution-from-3GPP-Release-7-to-Release-8-HSPA-and-SAE-LTE
8. 1 http://www1.alcatel-lucent.com/doctypes/articlepaperlibrary/pdf/ATR2001Q1/gb/09baudetgb.pdf
9. 1 http://www1.alcatel-lucent.com/doctypes/articlepaperlibrary/pdf/ATR2001Q1/gb/09baudetgb.pdf
10. 1 www.umts-forum.org/component/option,com.../task.../Itemid,12/
11. 1 YES 2 3G" - White Paper www.mobilestream.com
12. http://oldwww.com.dtu.dk/research/networks/OPNET/UMTS_handover.pdf
13. http://www.3gamericas.org/index.cfm?fuseaction=page&sectionid=245
14. http://www.itu.int/ITU-D/imt-2000/DocumentsIMT2000/Spectrum-IMT.pdf
15. http://www.mobilecomms-technology.com/projects/hsupa/
16. http://www.umtsworld.com/technology/handover.htm
17. Source-ITU http://www.itu.int/osg/spu/ni/3G/technology/
18. www.itu.int/osg/spu/imt-2000/technology.html
19. www.nmscommunications.com

Glossary

Acronym List

1xEV-DO 1x Evolution-Data Optimized or Evolution-Data Only
3GPP Third Generation Partnership Project
AA Adaptive Array
AAA Authentication, Authorization and Accounting
ACK/NAK Acknowledgement/Negative Acknowledgement
ADSL Asynchronous Digital Subscriber Line
AGPS Assisted Global Positioning System
AMBR Aggregate Maximum Bit Rate
AMC Adaptive Modulation and Coding
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
C/I Carrier to Interference Ratio (CIR)
CAGR Compound Annual Growth Rate
CAZAC Constant Amplitude Zero Autocorrelation Waveform
CCE Control Channel Elements
CCPCH Common Control Physical Channel
CDM Code Division Multiplexing
CDMA Code Division Multiple Access
CK/IK Ciphering Key/Integrity Key
CN Control Network
CN Core Network
CPC Continuous Packet Connectivity
CQI Channel Quality Indications
CS Circuit Switched
CSCF Call Session Control Function
CSI Combination of Circuit Switched and Packet Switched services
CTIA Cellular Telecommunication Industry Association
DBCH Dynamic BCH
DCH Dedicated Channel
DFT Discrete Fourier Transformation
DIP Dominant Interferer Proportion
DL Downlink
DL-SCH Downlink Shared Channel
DMB Digital Multimedia Broadcasting
DPCCH Dedicated Physical Control Channel
DRX Discontinuous Reception
DSCH Dedicated Shared Channel
DSL Digital Subscriber Line
DSL Digital Subscriber Line
DS-MIPv6 Dual Stack – Mobile Internet Protocol version 6
DTX Discontinuous Transmission
D-TxAA Double Transmit Adaptive Array
E2E End to End
E-MBMS Enhanced Multi Broadcast Multicast Service
eNodeB Evolved Node B
EPC Evolved Packet Core; also known as SAE (refers to flatter-IP core network)
EPDG Evolved Packet Data Gateway
EPRE Energy Per Resource Element
EPS Evolved Packet System is the combination of the EPC/SAE (refers to flatter-IP core network) and
ETSI European Telecommunication Standards Institute
ETSI-SCP ETSI – Standard Commands for Programming
E-UTRAN Evolved Universal Terrestrial Radio Access Network
EUTRAN Evolved Universal Terrestrial Radio Access Network (based on OFDMA)
EV-DO Evolution, Data Optimised
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
flatter-IP core network)
FMC Fixed Mobile Convergence
FOMA Freedom of Mobile Multimedia Access: brand name for the 3G services offered by Japanese
FSS Frequency Selected Scheduling
FTTH Fibre to the Home
GB Gigabyte
GBR Guaranteed Bit Rate
GERAN GSM EDGE Radio Access Network
Gn IP Based interface between SGSN and other SGSNs and (internal) GGSNs. DNS also shares this
GPON Gigabit Passive Optical Network
GPRS General Packet Radio System
GRUU Globally Routable User Agent URIs
GSM Global System for Mobile communications
GSMA GSM Association
GTP GPRS Tunneling Protocol
GUP Generic User Profile
GW Gateway
HARQ Hybrid Automatic Response reQuest
HD High Definition
HLR Home Location Register
HOM Higher Order Modulation
HPCRF Home PCRF
HPLMN Home PLMN
HSDPA High Speed Downlink Packet Access
HS-DSCH High Speed Downlink Shared Channel
HSPA + High Speed Packet Access Plus (also known as HSPA Evolution)
HSPA High Speed Packet Access (HSDPA + HSUPA)
HSPA+ HSPA Evolution
HS-PDSCH High Speed- Physical Downlink Shared Channel
HSS Home Subscriber Server
HS-SCCH High-Speed Shared Control Channel
HSUPA High Speed Uplink Packet Access
ICS IMS Centralized Services
IDs identifies
IETF Internet Engineering Task Force (www.ietf.org)
IMSI International Mobile Subscriber Identity
IMT International Mobile Telecommunications
IN Intelligent Networking
interface. Uses the GTP Protocol.
IP TV Internet Protocol Television
ISIM IMS SIM
ISP Internet Service Provider
ITU International Telecommunication Union
J2ME Java 2 Micro Edition
kHz Kilohertz
LCS LoCation Service
LMMSE Least Minimum Mean Squared Error
LSTI LTE SAE Trial Initiative
LTE Long Term Evolution
LTE Long Term Evolution (Evolved Air Interface based on OFDMA)
M2M Machine to Machine
MAC Media Access Control
MAC=Medium Access Control, part of layer 2 in the OSI model
MBMS Multimedia Broadcast/Multicast Service
MBR Maximum Bit Rate
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
MMS Multimedia Messaging Service
MMSE Multimedia Messaging Service Environment
mobile phone operator NTT DoCoMo.
MPLS Multi-Protocol Label Switching
MRFP Multimedia Resource Function Processor
MSA Metropolitan Statistical Area

MU-MIMO Multi-User Multiple Input Multiple Output
NAI Network Access Identifier
NFC Near Field Communications
NGMN Next Generation Mobile Networks
NGN Next Generation Network
NGN Next Generation Network
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
P2P Peer-to-Peer
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 Digital Assistant
PDSCH Physical Downlink Shared Channel
PHY/MAC PHY: common abbreviation for the physical layer of the OSI model.
PLMN Public Land Mobile Network
PMIP Proxy Mobile IPv6
PoC Push-to-talk over Cellular
PoS Point of Sale
POTS Plain Old Telephone Service
PRACH Physical Random Access Channel
PS Packet Switched
P-SCH Primary Synchronization Signal
PSI Public Service Identities
PSTN Public Switched Telephone Network
QAM Quadrature Amplitude Modulation
QAM Quadrature Amplitude Modulation
QPSK Quadrature Phase Shift Keying
RAB Radio Access Bearer
RACH Random Access Channel
RAN Radio Access Network
RAT Radio Access Technology
RB Radio Bearer
RE Resource Elements
REL-X Release '99, Release 4, Release 5, etc. from 3GPP standardization
RIT Radio Interface Technology
RNC Radio Network Controller
RRC Radio Resource Control
SAE System Architecture Evolution also known as Evolved Packet System (EPS) Architecture (refers to
SBLB Service Based Local Policy
SC-FDMA Single Carrier – Frequency Division Multiple Access
SD Standard Definition
SDMA Spatial Division Multiple Access
SF-16 Spreading Factor 16
SFBA Switch Fixed Beam Array
SFBC Space Frequency Block Code
SFN Single Frequency Network
SGSN Serving GPRS Support Node
SGSN Serving GPRS Support Node
SIM Subscriber Identity Module
SIMO Single Input Multiple Output
SIR Signal-to-Interference Ratio
SISO Single Input Single Output
SMS Short Message Service
SNR Signal-to-Noise Ratio
SON Self-Organising Network
SRNC Serving Radio Network Controller
S-SCH Secondary Synchronization Code
STTD Space-Time Transmit Diversity
SU-MIMO Single-User Multiple Input Multiple Output

TCP/IP Transmission Control Protocol/Internet Protocol
TDD Time Division Duplex
TDD Time Division Duplex
TDS Time Domain Scheduling
TF Transport Format
TFC Transport Format Combination
the LTE/EUTRAN
TPC Transmit Power Control
TTI Transmission Time Interval
UE User Equipment
UGC User Generated Content
UICC User Interface Control Channel
UL Uplink
UL-SCH Uplink Shared Channel
UMTS Universal Mobile Telecommunication System
UPE User Plane Entity
URI Universal Resource Identifier
USB Universal Serial Bus
USIM UMTS SIM
UTRA Universal Terrestrial Radio Access
UTRAN UMTS Terrestrial Radio Access Network
UTRAN Universal Terrestrial Radio Access Network
VoD Video on Demand
VoIP Voice over Internet Protocol
VoIP Voice over IP
VPCRF Visiting PCRF
VPLMN Visiting PLMN
VPN Virtual Private Network
WAP Wireless Application Protocol
WCDMA Wideband Code Division Multiple Access
WiMAX Worldwide Interoperability for Microwave Access
WLAN Wireless Local Area Network
WLAN Wireless Local Area Network
WRC'07 World Radiocommunication Conference 2007
xHTML-MP xHyper-Text Markup Language - Mobile Phone

Abbreviations

3GPP 3rd Generation Partnership Project
ACK Acknowledgement
ACLR Adjacent Channel Leakage Ratio
ARQ Automatic Repeat Request
AS Access Stratum
BCCH Broadcast Control Channel
BCH Broadcast Channel
CAPEX Capital Expenditures
CAZAC Constant Amplitude Zero Auto-Correlation
CCDF Complementary Cumulative Density Function
CCPCH Common Control Physical Channel
CP Cyclic Prefix
C-plane Control Plane
CQI Channel Quality Indicator
CRC Cyclic Redundancy Check
DCCH Dedicated Control Channel
DFT Discrete Fourier Transform
DL Downlink
DL-SCH Downlink Shared Channel
DRX Discontinuous Reception
DTCH Dedicated Traffic Channel
DTX Discontinuous Transmission
DVB Digital Video Broadcast
eNB E-UTRAN NodeB

EPC Evolved Packet Core
E-UTRA Evolved UMTS Terrestrial Radio Access
E-UTRAN Evolved UMTS Terrestrial Radio Access Network
FDD Frequency Division Duplex
FFT Fast Fourier Transform
GERAN GSM EDGE Radio Access Network
GSM Global System for Mobile communication
HARQ Hybrid Automatic Repeat Request
HSDPA High Speed Downlink Packet Access
HSUPA High Speed Uplink Packet Access
IFFT Inverse Fast Fourier Transformation
IP Internet Protocol
LTE Long Term Evolution
MAC Medium Access Control
MU-MIMO Multi User MIMO
NACK Negative Acknowledgement
NAS Non Access Stratum
OFDM Orthogonal Frequency Division Multiplexing
OFDMA Orthogonal Frequency Division Multiple Access
OPEX Operational Expenditures
PAPR Peak to Average Power Ratio
PAPR Peak-to-Average Power Ratio
PCCH Paging Control Channel
QAM Quadrature Amplitude Modulation
QoS Quality of Service
QPSK Quadrature Phase Shift Keying
RACH Random Access Channel
RAN Radio Access Network
RAT Radio Access Technology
RB Radio Bearer
RF Radio Frequency
RLC Radio Link Control
RRC Radio Resource Control
S1 Interface between eNB and aGW
S1-C S1-Control plane
S1-U S1-User plane
SAE System Architecture Evolution
SC-FDMA Single Carrier – Frequency Division Multiple Access
SCH Synchronization Channel
SU-MIMO Single User MIMO
TDD Time Division Duplex
TS Technical Specification
TTI Transmission Time Interval
UE User Equipment
UL Uplink
UL-SCH Uplink Shared Channel
UMTS Universal Mobile Telecommunications System
UPE User Plane Entity
U-plane User plane
UTRA UMTS Terrestrial Radio Access
UTRAN UMTS Terrestrial Radio Access Network
VoIP Voice over IP
WCDMA Wideband Code Division Multiple Access
WLAN Wireless Local Area Network
X2 Interface between eNBs
X2-C X2-Control plane
X2-U X2-User plane