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Evolution of the GSM to Mobile Broadband, HSPA (3G), LTE, Comparisons and Industry focus.

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Abstract—**To comprehend the Basic Concepts, Network Evolution, Specifications, Importance and few other aspects of GSM, HSPA & LTE and a brief scenario of migration from GSM to 3G (I-HSPA) is proposed for Pakistan Telecommunication Industry with the collaboration of Nokia Siemens Network Pakistan.**

I. Introduction

The wireless telecommunication technologies have revolutionized the world as we know. The initial 1st Generation (1G) technologies introduced the mobile cellular telephones for the very first time. It changed the ways that we communicated with one another and created a great convenience for everyone. No longer were we handicapped in terms of communication and were connected with everyone where ever were.

The 1G technology included the NMTS, AMTS and the most popular one AMPS. These technologies were based on the analog process of communication. They mostly provided the voice services. But the human needs keep on soaring and soon enough the 2nd generation (2G) was introduced to the world. The initial 2G technology was the GSM; it became the most widely used cellular technology in the world. This 3rd Generation Partnership Project (3GPP) dominated the cellular ecosystem of the world. It provided the voice as well as the short messaging services (SMS) along with many others.

The internet transformed and turned the world into a global village; it further extended the possibilities of communication. The information became available at everyone's fingertips. The services such as chatting, voice calling, video conversations, online gaming, e-libraries and many such other services opened up many other possibilities and frontiers for us. Internet soon became the necessity, and everyone wanted to stay connected through internet at all times.

This created a new scope for the wireless cellular technologies; they could broaden their horizons and provide the internet facility to their users. This proved to be the motivational point for GPRS, EDGE and all the upcoming future broadband technologies. After GSM the 2nd Generation presented the General Packet Radio Service (GPRS) which provided the facilities of internet to the GSM users. The data rates were quite low (20 kbps) but were sufficient enough for the requirements of that time. Later on as the technological needs increased the motivation for the research of further new technologies was created.

The wireless telecommunication technologies entered the 3rd generation (3G) where the major motivational point was the internet. Among the technologies that sufficed the requirements of 3G were UMTS, HSPA, I-HSPA (NSN) and LTE. The Release 99 (UMTS) provided 2 Mbps in the downlink. The High Speed Packet Access (HSPA) has two further standards HSDPA & HSUPA. HSDPA provides 14 Mbps while the HSUPA 5.75 Mbps. HSPA competes with the fixed internet connections such as DSL etc.

LTE surpasses the current internet connection capabilities since it has 100 Mbps in the downlink and 50 Mbps in the uplink (Note these speeds are without MIMO). The LTE has broaden the horizons of broadband technologies even further and easily supports services like real time streaming, multi player online gaming, and many such other high requirement services.

II. GSM

GSM stands for "Global System for Mobile Communications". It is a cellular standard of 2nd Generation of Telecommunication industry. GSM was developed to cater voice services and data delivery services using digital modulation.

GSM provided users with the best solution they could get when they were previously communicating in 1st generation. What made GSM betterwere the services it provided.

Services Provided by GSM

The services provided by the GSM technology evolved telecommunication industry's generation, which previously was the 1st generation, towards the modern needs of human. Services provided by GSM can be categorized as.

- Tele-services
- Data-services or Bearer-Services
- Supplementary services (including call holding, call waiting and call forwarding and call barring)

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GSM Network Architecture

The architecture of GSM network is systematically divided into subsystems (shown in fig 1), with defining the purpose of each entity involved in it.

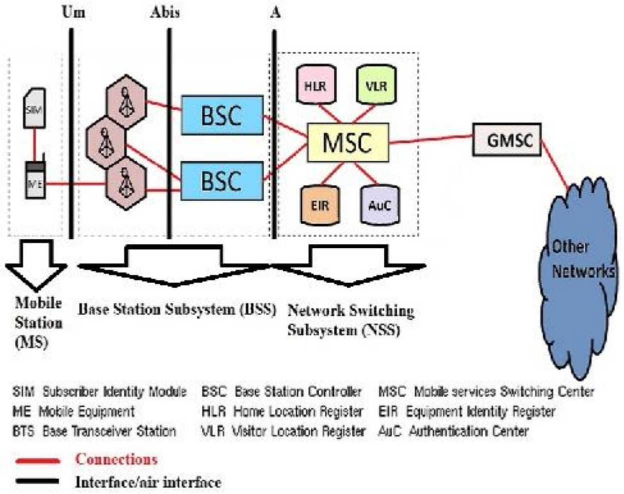

Fig 1: GSM Network Architecture

The Network Architecture of GSM consists of following components

- Mobile Station (MS) (SIM+ME)
- Base Station Subsystem (BSS) (BTS, BSC)
- Network Switching Subsystem (NSS)

The main control of RF signal throughout the architecture of GSM network is handled in NSS. Following are the components of NSS.

- o Mobile Switching Center (MSC)
- o Visitor Location Register (VLR)
- o Home Location Register (HLR)
- o Equipment Identity Register (EIR)
- o Authentication Center (AUC)

GSM Handover

When you "hand-over" to another cell while driving/moving, the HLR is automatically updated, and continues to monitor where exactly it should route your calls when u move to another BS.

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Frequencies Used in GSM

GSM 900

- Mobile to BTS (uplink): 890-915 MHz
- BTS to Mobile(downlink):935-960 MHz
- Bandwidth : 2* 25 MHz

GSM 1800

- Mobile to BTS (uplink): 1710-1785 MHz
- BTS to Mobile (downlink) 1805-1880 MHz
- Bandwidth : 2* 75 MHz

Access Method: TDMA/FDMA
Modulation Method: GMSK

GSM Radio Interfaces

In GSM Network, the radio interfaces according to point-to-point connections are listed as:

Name	Interface
Um (air)	MS <=> BTS
A-bis	BTS <=> BSC
A	BSC <=> MSC
B	MSC <=> VLR
C	MSC <=> HLR
D	VLR <=> HLR
E	MSC <=> MSC
F	MSC <=> EIR
G	VLR <=> VLR
H	HLR <=> AUC

Fig 2: GSM Radio Interface

Transmission

In GSM Network, the radio signal is transmitted through two types of links, one is radio link and other is 2Mbits/s PCM links. The RF signal is transmitted between MS and BTS through radio link (Um interface). It is then transmitted through the remaining network using PCM links.

Duplex frequency

The radio carrier frequencies are arranged in pairs and the difference between them (i.e. Uplink and Downlink) is called duplex frequency.

In GSM-900, the Uplink frequency range is 890MHz - 915MHz and this range of frequencies, as dedicated to Uplink, is separated with 200 kHz from the other frequency range which is dedicated to Downlink i.e. 935MHz – 960MHz.

As an example, if an Uplink signal varying 890.6MHz – 890.8MHz which makes the centre frequency of 890.7MHz, is transmitted. As the duplex frequency in GSM-900 is 45MHz, the centre frequency at the receiving end is 935.7MHz in this case. The signal varies 935.6MHz – 935.8MHz at the receiving end. Same is for GSM-1800 keeping the duplex frequency 95MHz.

So as a summary on transmission in GSM Network, we can conclude following results:

- 2 bands of 25MHz each, for Uplink and Downlink.
- Duplex spacing 45MHz for GSM-900 and 95MHz for GSM-1800.

Time Division Multiple Access (TDMA)

In TDMA, the radio frequency channel is divided into TDMA frames, and then each frame is further divided into timeslots. In other words, it is the sharing of timeslots between different users. GSM Network uses 8 timeslots for one TDMA frame.

Frequency Division Multiple Access (FDMA)

All the mobile stations (MS) working at the same time in the same, or adjacent cells are separated according to frequencies they are assigned. FDMA divides the frequency channel into sub-channels, hence use multiple carrier

frequencies. In GSM-900 there are 124 sub-channels, and 374 in GSM-1800.
So, the key points are:

- 8 TDMA slots
- 124 carriers
- Suggested use is 122 carriers, (keeping top and bottom as additional guard)
- 200kHz channel

Physical and Logical Channels

Time division multiple access (TDMA) divides one radio frequency channel into consecutive time slots known as TDMA frames. Each TDMA frame is further divided into short time periods known as timeslots. As these timeslots physically move information from one place to other, these are also called physical channels.
GSM uses 26 frames = 120ms as the key number, so
1 frame = 120/26 ms
1 frame = 4.615ms
1 timeslot = 577µs
In GSM, the logical channels are divided into two types:

- Dedicated Channels
- Common Channels

From Mobile Station (MS) to BTS, BSC and then MSC/VLR, all the information is transmitted through dedicated channels. Traffic channels are also dedicated channels as each channel is dedicated to one user to carry data.

III. UMTS/HSPA

UMTS is a 3G network technology which is based on a Frequency Division Duplex (FDD) wide range of frequencies in a spectrum-CDMA on a 5 MHz carrier. UMTS is a Separate network to GSM, with well-organized devolve among GSM and UMTS. UMTS facilitate Circuit-switch (CS) and Packet-switch (PS) services through dedicated channels to each terminal, with some additions in Core network comparative to GSM. UMTS uses IP transmission, ATM. In UMTS Iu interface between RAN and core is different from A/Gb interface of GSM. [**Error! Reference source not found.**]

Release99 Networks

Release99 is a first generation of 3G/UMTS architecture. It uses WCDMA technology instead of a FDMA and TDMA over the air interface, which was a common practice for GSM. R99 specifies the need of a 3G core and a UTRAN, which is a bit different from GRAN (2G). The Release 99 eliminates the need of BTS and BSC of GSM, these entities are replaced by RNC (Radio Network Controller) and Node B in 3G/UMTS. UTRAN provides a connection between 3G CN and UE. Similarly, R99 architecture has brought a set of new interfaces fallowed by GSM naming convention; these are Iu, Uu, Iur and Iub.

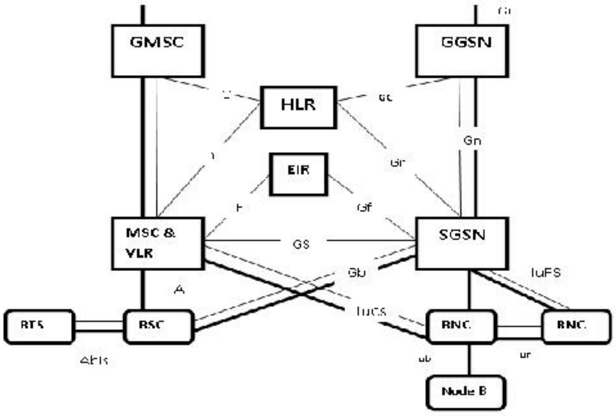


Fig: 3: R99 Network Architecture

Release4 Core Network

R4 of UMTS (released in 2001) specifies some important changes in UMTS CN, which offers the first step toward multimedia messaging and IP transport in CN. It divides MSC in MGW and MSC.
This division of 3G MSC into MGW and MSS provide battered scaling of IP core, with the separation of CP (Control Plane) and UP (User Plane). [2]

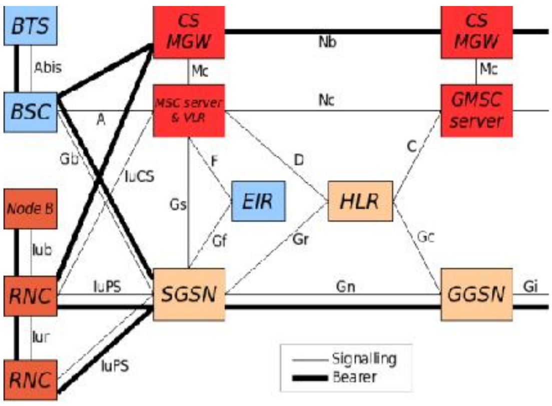


Fig 4: R4 core Network Architecture (Source: 3G America)

Release5, Deployment of HSDPA

Release5 of UMTS/HSPA introduced some important developments to UMTS including, IMS (IP Multimedia Subsystem), IP UTRAN and HSDPA (High Speed Downlink Packet Access). [2] HSDPA offers theoretical data rate up to 14.4 Mbps. HSDPA employs:

- HARQ (Hybrid ARQ)
- Higher Modulation Schemes (16 QAM)
- Fast link adaptation
- Radio Resource sharing among users in code and time domains

Release6 and Release7

Release 6 of UMTS/HSPA was released in 2005 introduced major uplink and radio functioning improvements as well as additional features to the IMS specifications. Release6 also introduces HSUPA (High Speed Uplink Packet Access) technology. HSUPA offers UL speed up to 5.76 Mbps.

Release 7 of UMTS/HSPA focused on the matters directly related to market deployment and user experience. It added some important features including HSPA+, MIMO and RAN architectural changes. [2]

HSPA

3GPP has reliable packet-switched air-interfaces which are based on CDMA (UMTS) for uplink and downlink, known as **High-Speed Uplink Packet Access (HSUPA)** and **High-Speed Downlink Packet Access (HSDPA)** respectively and collectively called **High-Speed Packet Access (HSPA)**. HSPA works within R99 frequencies. In recent HSPA deployments, dedicated channels are used to carry signaling messages. Dedicated channels used in HSPA are usually low rate channels of 3.4 kbps. These channels allow larger widening factors (SF) to be used; because of this sufficient users can allot cell's resources. Today's HSPA deployments make use of channels such as, E-DCH channels on the uplink and HS-DSCH on the downlink, for carrying signals on HSPA. Because of this we not only get benefit of better use of code and power resources, but also this configuration let signaling to advantage from higher rate channels of HSPA.

3G UMTS/HSPA provides an increase in system capacity. An additional advantage of introducing an UMTS/HSPA is that it can frequently be rolled out by integrating a software update keen on the system. This shows that the employment of UMTS/HSPA carries important reimbursement to operator and consumer as well. [3]

Network Architecture of HSPA

HSPA network architecture includes:

- RNC
- NodeB
- Core network (including GGSN and SGSN).

In HSPA to provide improved data rates or user experience, some important changes are required in UMTS architecture. In order to provide batter adaptation and lower latency to persistently changing radio environment RNC functionality is burst in to Node B. RNC in UMTS network is responsible for MMC and RRM functions such as packet scheduling and admission control. Packets must be retransmitted if they are wrongly received over the wireless channel. For this delay was considered to be very high (from terminal to RNC). By permitting the Node B to handle retransmission, the radio packet length is minimized to 2ms (from 80ms), because of this fact latency is notably reduced, and Node B responsemore rapidly to rapid changes in channel quality. [4]

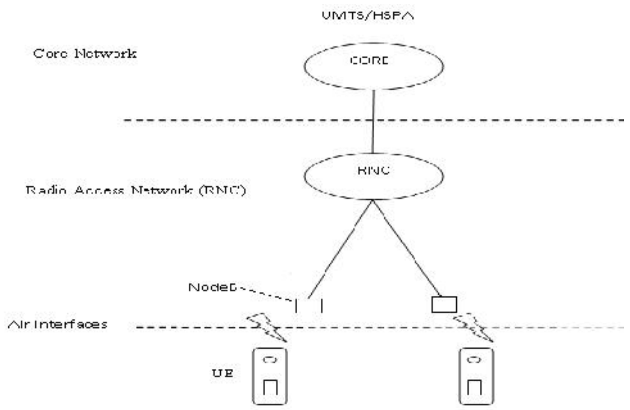


Fig: 5: UMTS/HSPA Network Architecture

Air interfaces

HSPA air interface is based on WCDMA technology. WCDMA is type of "spread spectrum" technology, and used for both DL and UL transmission. Each and every transmitted user signal is scrambled with a particular channelization code of user. This spread the signal to cover the entire accessible 5 MHz bandwidth. Because of this spreading, the signal is robust beside frequency selectivity in the channel and narrowband interference. [4]

Orthogonal variablespreading factor (OVSF) is the foundation of channelization codes. OVSF forms a hierarchal '*code tree*'. In '*code tree*' the level depends on the SF of the code. In this a service will be allotted a code, and bit rate requisite by the service determined the level in the '*code tree*'. All parent and child nodes in the '*code tree*' are blocked by occupied code.

In the DL *channelization codes* are at right angles (orthogonal) to each other. All the same, in the scenario of real environments little *orthogonality* will be lost, and this results in self-interference inside the cell.

HSDPA provides 15 channelization codes for use with 16 SF. Only one code is occupied by a channel, and in this circumstances one user may be allotted among 1 and 15 codes.

- 3.6 Mbps peak throughput can be attained by assigning 5 codes to the user.
- By assigning 10 codes to the user 7.2 Mbps peak throughput can be achieved.
- By assigning all 15 codes to the user 14.4 Mbps peak throughput can be achieved, considering 16QAM modulation.

UTRAN

Connectivity among the Core network and USER Equipment is provided by UTRAN (Universal terrestrial Radio Access Network). UTRAN contains: [3]

- Node Bs (base stations)
- RNC

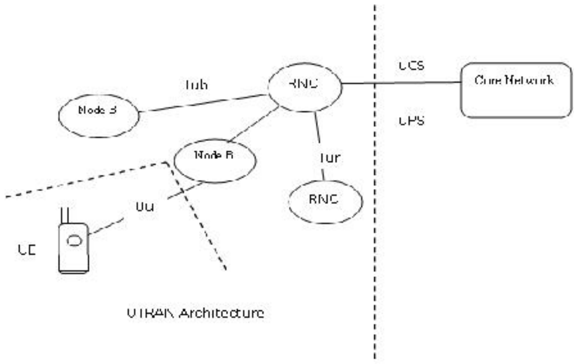


Fig: 6: UTRAN Architecture

Evolved HSPA (HSPA+)

HSPA+ also known as HSPA Evolved , HSPA Evolution and sometimes also referred as HSPA+ is infect an improved version of the 3G/HSPA or HSPA systems which was exploited to enhance the speeds of the basic 3rd Generation systems, because of the highly growing use of data, consumers wants speeds of download similar with fixed broadband. By employing HSPA+ the rates of transferring data are improved moreover those which could be attained by using HSPA. In the deployment of HSPA+ other factors like the backhaul and latency have also been considered. [3]Highlighted features of HSPA+ based on the significant enhancement in performance are:

- MIMO
- Higher Order Modulation
- Dual Carrier
- Multicarrier HSPA

NSN I-HSPA Architecture

Evolved HSPA helps presenting I-HSPA or Internet HSPA, which enhance network latency. In I-HSPA network latency is reduced because of the fact of having lesser nodes in data path. Internet-HSPA was presented in the release of 3GPP. In Interne-HSPA without changing air interface Radio Network Controller entity is amalgamated with Node B. Internet-HSPA is backward simpatico with HSUPA and HSDPA and simple architecture offers smoother evolution toward LTE. [6]

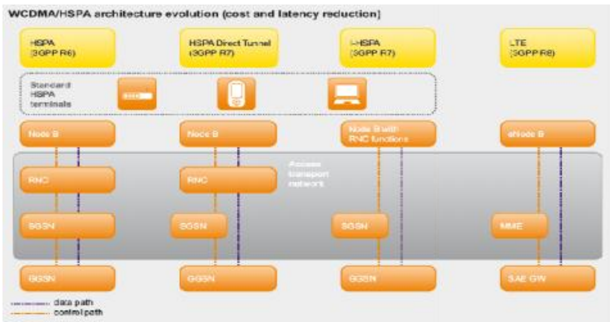


Fig 7: I-HSPA Flat Architecture (Source: NSN I-HSPA Document)

IV. LTE

3GPP technologies constitute 85% of the global telecommunication world, and GSM is one of the members of the 3GPP family. GSM is the most successful 3GPP product, since it governs the mobile telecommunication's ecosystem even after its many years of release along with the releases of many other newer and improved technologies. But now the dominance of GSM is slowly declining as the third generation (3G) and fourth generation (4G) technologies are being slowly deployed in the global telecommunication world.

The increased data traffic demands that the cost per bit should be reduced for the user as well as network operator's benefit. This challenge of reducing cost per bit demands that the Network Architecture should be simpler, which Long Term Evolution fulfills with ease. LTE has simpler/flat architecture which lessens the cost per bit as well as the data rates thus ameliorating the overall end user experience. So the main objective is to minimize system and user equipment complexities, improve data rates and co existence with the previous wireless telecommunication technologies. LTE easily satiates all these objectives since it has simpler architecture, lower latency and higher throughput thus proving to be the preferred future technology.

The LTE architecture needs to be explained at this point. Since, it has been stated to have simpler architecture than the legacy technologies.

Long Term Evolution (LTE) – Network Architecture

3GPP has developed LTE over quite a long period of time, it was first introduced in Release 8 and was continued in the next 3GPP release i.e. Release 9.

LTE architecture has changed over the period of time, it has evolved and improved. Two cases were proposed initially, for the roaming scenario and for the non-roaming scenario. Let us take a look at the roaming scenario architecture proposed by the 3GPP initially.

Architecture for the evolved system – non-roaming case

If the cell phone remains in the same network (area) where it was registered also called as the 'Home Network' then this scenario is known as the "**Non-roaming**" case/scenario. [8]In the fig 8, the basic LTE architecture has been proposed by 3GPP, the air interface is known as the Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) while the core network is called as Evolved Packet Core (EPC), which contains Mobility Management Entity (MME), 3GPP Anchor (S-GW) and the SAE Anchor (P-GW). While other services such as Multimedia services are provided by IP Multimedia Subsystem (IMS).

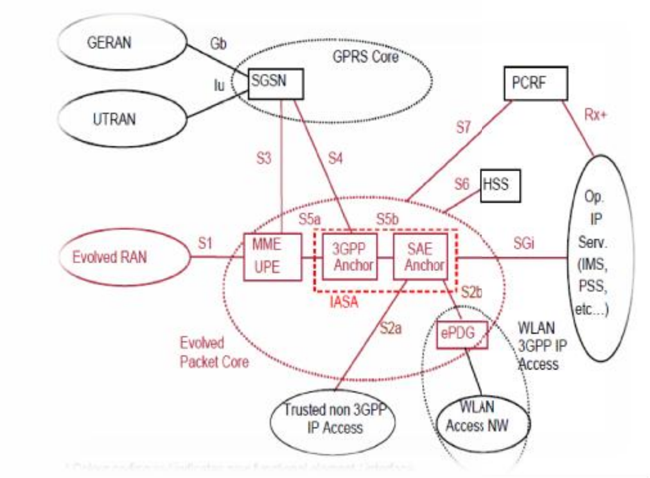


Fig 8: Architecture for the evolved system – non-roaming case

Architecture for the evolved system –roaming case [8]

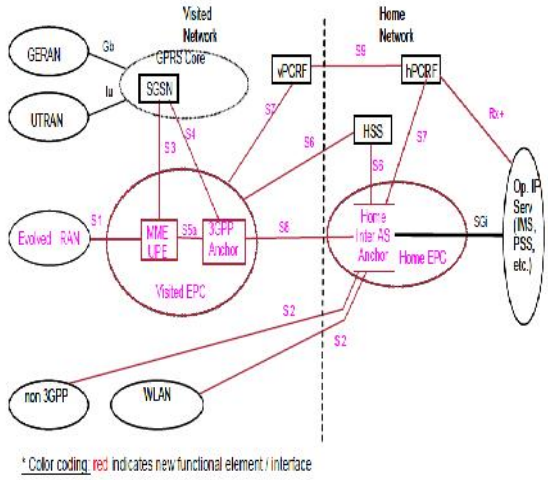


Fig 9: Architecture for the evolved system –roaming case [8]

Evolved RAN (E-UTRAN)

The air interface of Long Term Evolution (LTE) is Evolved Terrestrial Radio Access Network (E-UTRAN) which consists of the User End (UE) and the e Node B. The e Node B (eNB) has multi functionalities entrenched it such as the Physical, MAC, RLC and Packet Data Control Protocol (PDCP). These mentioned functionalities belong to user-plane while the Radio Resource Control (RRC) belongs to the control plane. E-UTRAN performs various functions including resource management, admission control etc.

Performance Objectives of E-UTRAN

Data Rate:

Instantaneous downlink peak data rate of 100 Mb/s within a 20 MHz downlink spectrum allocation (5bps/Hz).

Instantaneous uplink peak data rate of 50 Mb/s (2.5 bps/Hz) within a 20MHz uplink spectrum allocation)

Coverage (Cell range):

- 5 km - Optimal size.
- 30km - With reasonable performance.
- Up to 100 km.

Control Plane Capacity (Cell Capacity):

Control Plane Capacity is Up to 200 active users per cell i.e. 200 active data clients.

Latency:

- User Plane < 5ms
- Control Plane <50m

Spectrum flexibility

E-UTRAN will have Scalable bandwidth.

- 5, 10, 20 and possibly 15 MHz
- [1.25,] [1.6,] 2.5 MHz: to allow flexibility in narrow spectral allocations where the system may be deployed.

Adaptive Modulation and Coding

DL Modulations: QPSK, 16QAM, and 64QAM

UL Modulations: QPSK and 16QAM (optional for UE)

Rel.6 Turbo code: Coding rate of 1/3, two 8-state constituent encoders, and a contention-free internal interleaver.

ARQ within RLC sub layer and Hybrid ARQ within MAC sub layer.

Advanced MIMO Spatial Multiplexing techniques:

- (2or4) x (2or4) downlink and uplink supported.
- Multi-layer transmission with up to four streams
- Multi-user MIMO also supported.
- Support for both FDD and TDD.

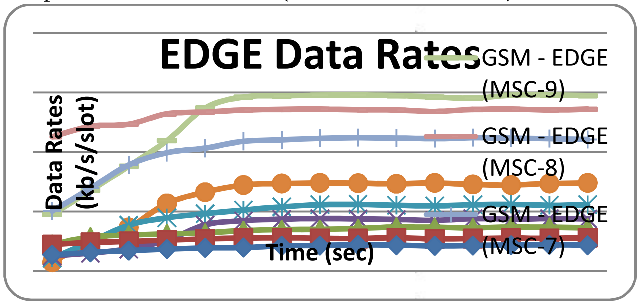
V. COMPARISON OF GSM, HSPA AND LTE

Table: 1Relationship of GSM, HSPA and LTE

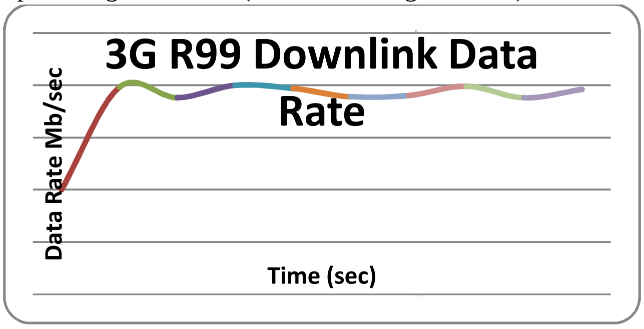
GSM (GERAN)	**HSPA (UTRAN)**	**LTE (E-UTRAN)**
Mobility: Low Mobility.	**Mobility:** High Mobility as compared to GERAN.	**Mobility:** • 0 – 15 Km/h (Optimized) • 15 – 120 Km/h (High Performance) • 120 – 350 Km/h (Maintains Mobility) • Even 500 km/h (Freq. Band Dependent) • Supports voice & real time services over entire speed range.
Spectrum Flexibility: It does not offers spectrum Flexibility	**Spectrum Flexibility:** 15 – 20 MHz (in case of dual carrier dual cells i.e. HSPA+)	**Spectrum Flexibility:** Scalable bandwidth 5, 10, 20 & maybe 15 MHz

VI. Simulation (Evolution of Data rates)

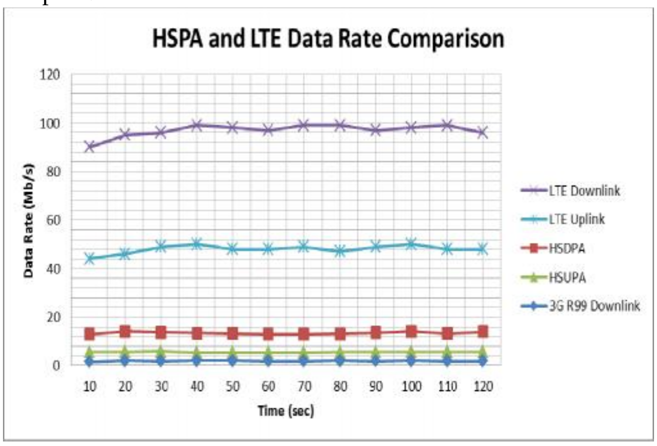
Graph 1: GSM date Rates (CS1, CS2, CS3, CS4)



Graph 2: Edge data rates (different coding Schemes)



Graph 3: 3G R99 DL data rates



Graph 4: HSPA and LTE data rates comparison

VII. Proposed Scenario for Telecommunication Industry

After the comparison of three main technologiesGSM (GPRS), HSPA and LTE, we come to the point that I_HSPA is a best recommended solution for current telecommunication industry, because of its high end performance and other quality parameters. I-HSPA not only provides high network connectivity and availability, infect it also reduces latency and enhances throughput. In I-HSPA network throughput is boosted because having lesser nodes in data path. I-HSPA is a 2 node network architecture (I-BTS and SGSN), and data traffic directly moves from I-BTS (nodeB/RNC) to GGSN. Internet-HSPA was presented in the release 7 of 3GPP. In Interne-HSPA without changing air interface Radio Network Controller entity is amalgamated with Node B. Internet-HSPA is backward simpatico with HSUPA and HSDPA. I-HSPA betters the scalability for higher data capacity of broadband networks. [6]

The architecture of I-HSPA is simple and similar to WCDMA and release 8 of LTE. Hence, it provides ahorizontal evolution or migration towards LTE; therefore it diminishes the cost of migration towards LTE[9].

VIII. Conclusion

The understanding of the three technologies i.e. GSM, HSPA & LTE lead to the evolution of these technologies, which were further proved through the simulations performed at Nokia Siemens Networks Test Bed – Pakistan, along with the practical experience. Although LTE is the superior most technology but we recommended I-HSPA for the current situation in Pakistan Telecommunication Industry; reasons, logical conclusion & details can be seen in the thesis work.

IX. Acknowledgment

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