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A Survey on Evolution of Mobile Networks:1G to 4G

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Abstract

In this paper, we discuss generations of mobile networks and its step by step evolution. Mobile communications using wireless technology began in 1970s known as zeroth generation. Today it has reached till fourth Generation and several researchers are working on the designing and architectures of 5G. So here we focus on technologies associated with each generation and how the previous generations have helped the next generation to evolve and serve as a core technology by fulfilling the user's requirement.

Keywords: 0G-4G, GSM, HSCSD, GPRS, EDGE, UMTS, UTRAN, WCDMA, HSPA, OFDM, WiMAX, LTE, Vertical Handoff .

Introduction

During last few decades mobile communications have developed rapidly. The zeroth generation or pre cellular technology was analog system with limited range. With the evolution of first generation the size of the transmitter and receiver reduced and the concept of cell introduced. 2G introduced GSM architecture [6][7] that eliminated the roaming drawback of 1G with extra utility of SMS by using digital systems. After 2G, quite modifications were done to the original GSM architecture to improve and make it more efficient. 2.5G system includes HSCSD and GPRS [5]. 2.75G known as EDGE [5] was introduced which required only software upgrade to existing BS. After such modifications in architectures and transmission techniques 3G [5] came to existence, which deploys CS and PS both based on the kind of traffic available. 3.5G – HSPA [10] is the combination of HSDPA and HSUPA. 3.75G introduced HSPA+ [10] known as HSPA evolution which was 3GPP initiative to enhance performance and capabilities of HSPA. 4G network provide much higher data rates than recent 3G networks. It is a IP based PS ultra broadband standard. Focus on 4G technology is given with OFDM [12], WiMAX [12] and its architecture, LTE and its architecture [14] with security issues. At the end we discuss types of handoffs in 4G.

To contribute in current technology one must know the previous history of technology and its pros and cons. This paper helps reader to understand the previous mobile generations and its step by step evolution till 4G.

Earlier Generations

Zeroth Generation

This was the first mobile communication technology also known as pre-cellular system. Here a central antenna was mounted per region and strong transmitters and receivers were used to send and receive the data such as push to talk. This generation used half duplex and analog mode of communication [1][2].

First Generation

1G was basically an analog cellular system with circuit switched network architecture deployed in 1981. The data traffic was mainly in voice. It used FDMA as a multiplexing technique with peak speed of 1.9kbps [3,4]. The most successful standards were Total Access Communication System (TACS), Advance Mobile Phone Service (AMPS) and Nordic Mobile Telephone (NMT) [5]. The major problems associated were limited services, low data rates, inadequate fraud protection and poor security with no roaming.

Second Generation

The main difference between 1G and 2G is analog/digital split. With the introduction of GSM architecture in 1991, 2G was now capable of handling roaming with Short Message Service (SMS) facility. The main traffic in this circuit switched architecture was voice and data with FDMA and TDMA as their multiplexing techniques. In this generation the data rates were 9.6kbps – 14.4 kbps [4]. Next mobile generations are nothing but evolution of core GSM architecture.

GSM Architecture

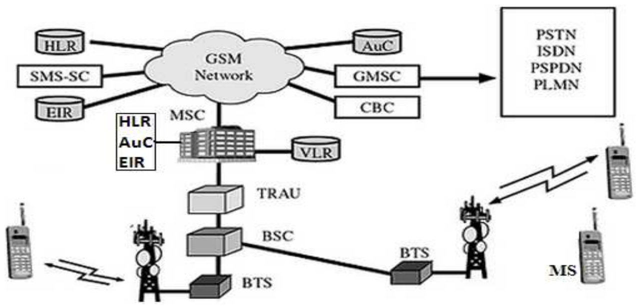

Fig. 1. GSM Architecture [6.7]

The GSM Architecture is divided into three main parts

1) The Mobile Station (MS): It consists of Mobile Equipment (ME) and the Subscriber Identity Module (SIM). A SIM contains a globally unique identifier and a secret key, used for authentication and other security procedures. ME possesses International Mobile Equipment Identity (IMEI) which identifies each ME uniquely.

2) The Base Station Subsystem (BSS): It is made up of Base Transceiver Station (BTS) and Base Station Controller (BSC). BTS maps transceivers and antennas to the cell. It is placed in the center of the cell and its transmitting power defines the size of that cell. BSC manages radio resources for one or more BTSs. It handles channel setup, frequency hopping and handover procedures when users are mobile.

3) The Network Switching Subsystem (NSS): It consists of Mobile Switching Centre (MSC), Gateway to MSC (GMSC), Home Location Register (HLR), Visitor Location Register (VLR), Authentication Centre (AuC) and Equipment Identity Register (EIR). The functional units are as follows.

- *MSC:* It acts as a switching node for a PSTN or ISDN network. The MSC deals with the registration, authentication, mobile device location updating and routing of calls between mobile user.
- *GMSC:* It is a gateway which interconnects two networks: the cellular network and the PSTN.
- *HLR:* It is a database that stores information of the subscribers belonging to the coverage area of a MSC. It also stores the current location of these subscribers and the services which they access.
- *VLR*: It holds the temporary information of registered subscriber within its vicinity. When a mobile device enters a new area it informs MSC about its arrival. MSC updates its VLR and a message is sent to HLR for its update in mobile location.
- *AuC:* It is a Database which contains a copy of a secret key present in each user SIM. It is used to enable authentication and encryption over a radio link.
- *EIR:* It is the list of all valid mobiles on the network identified by IMEI number. If a terminal has reported stolen or the equipment is not approved then it will not allow the device to operate in the network.

Generation – HSCSD and GPRS

In 1995, with the minimum data rates of 64kbps, the 2.5 Generation was introduced with all advanced upgrades over 2G networks. The biggest problem with plain 2G was its low air interface data rates. 2.5G system includes following technologies: High Speed Circuit Switched Data (HSCSD) and General Packet Radio Services (GPRS) [5].

1) HSCSD: It is enhancement over Circuit Switched Data (CSD) which gives four to six times faster data rate than GSM. High speed is achieved as a result of superior coding methods, and the ability to use multiple time slots to increase data throughput. But, since it is circuit switched it allocates the time slots when nothing is being transmitted. [5]

2) GPRS: With GPRS as the next solution, the data rates can be pushed up to 115 kbps. It is an important step towards 3G systems. This new technology made possible for the users to make telephone calls and transmit data at the same time. The GPRS architecture provides both Circuit Switched (CS) and Packet Switched (PS) data for voice and data traffic respectively. The CS data goes by traditional PSTN and PS data goes by Internet Backbone Network [5,9].

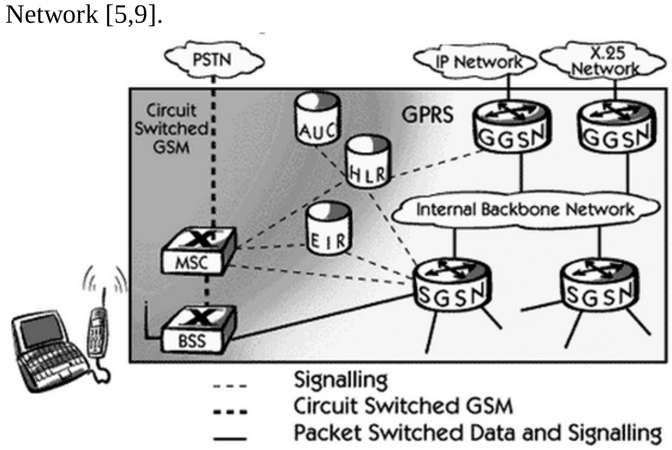

Fig. 2. GPRS Architecture [9].

The implementation of GPRS is expensive because it requires the hardware and software updates to the existing GSM architecture. Installation of new core network elements such as Serving GPRD support node (SGSN) and Gateway GPRS support node (GGSN) makes GPRS deployable[9].

2.75 Generation – EDGE

With the introduction of 2.75G in 1999 with the data rates of 384kbps, Originally known as Enhanced Data rates for GSM Evolution was changed to Enhanced Data rates for Global Evolution. The idea behind EDGE was eight-phase shift keying (8PSK) as a modulation scheme. It requires only software upgrade to existing base station and increases the data rates by threefold of standard GSM. Enhanced GPRS (EGPRS) is the combination of EDGE and GPRS techniques. If EDGE and HSCSD is combined then it is called as Enhanced Circuit Switched Data (ECSD) provides data rates three times higher than HSCSD.

Third Generation

The European Telecommunications Standards Institute (ETSI) started the work for the next generation mobile networks in the same year when GSM was launched commercially. This new system was called Universal Mobile Telecommunication System (UMTS). In the 1997 ETSI selected WCDMA as their 3G radio interface. 3G development work was carried out by Third Generation Partnership Project (3GPP) organization.

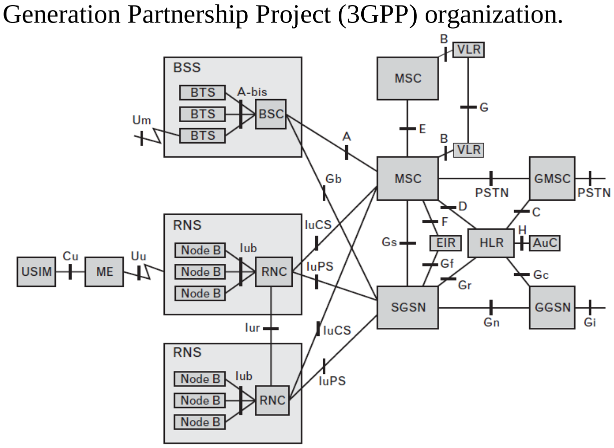

Fig. 3. UMTS network elements and interfaces [5]

The core network is divided into two parts : circuit-switched and packet-switched. Multiple technologies associated with 3G are explained with their units.

UMTS Terrestrial Radio Access Network (UTRAN)

UTRAN is the special radio access network designed for UMTS. It consists of Radio Network Controllers (RNC) and Node BS (Base Station). Together these entities form Radio Network Subsystem (RNS). In UMTS Network Evolution – Release 5, a new IP Multimedia Subsystem (IMS) domain is introduced and Home Subscriber Server (HSS) connects PS and IMS. Also the interference level of the cell affects the data rate. The User Equipment (UE) close to BS will get good traffic speed than the one which is far.

Hierarchical Cell Structure

Every where the geographical location is not same then, how can be a cell size? So based on locations and traffic density the cluster and the cell sizes may vary.

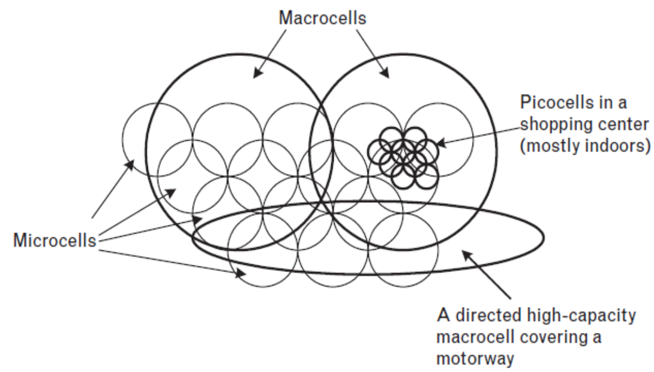

Fig. 4. Hierarchical cells [5]

A Macro cell can be as large as kilometers which can handle fast moving mobiles to reduce the number of Handoffs (HO). Microcell can range in few hundred meters covering an area of locality. While Pico cells range up to few meters. The basic aim for hierarchical cell structure is to increase the range of network in order to reach the user and provide customized services.

Network Planning Terminologies

- Erlang is the unit to measure traffic intensity where 1 Erlang is equal to one call lasting 1 hour. For results less than 1 Erlang can be shown by mErlangs.
- Traffic density in circuit-switched voice call is measured by number of calls per kilometer square (Erlang/km^2). While for packet-switched data transfer it is Mbps/km^2.
- A spectral efficiency can be defined as traffic handled within a area and its bandwidth.

Smart Antennas

Smart Antennas are useful in WCDMA because they reduce intra cell interference levels. Generally a smart antenna is a structure which consist of more than one physical antenna and a good signal processing unit. Mobile communication can be done using multiple small antennas. A traditional omnidirectional antenna radiates evenly and uniformly in all directions but user is present at only one direction at a time, thus most of the BS energy is wasted. With the help of multiple smart antennas a BS can transmit a narrow beam signal in the direction with UE. Smart antennas increase the system capacity by reducing Signal-to-noise-ratio (SNR).

Generation – HSPA

High Speed Packet Access (HSPA) is the combination of High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA). To improve the data rates of WCDMA, it is upgraded to HSPA. It is based on shared channel transmission. It uses multi-code transmission with higher order modulation, short transmission time interval, fast scheduling along with fast link adaptation and fast Hybrid Automatic Repeat Request (HARQ). It requires only software upgrade to existing WCDMA standards.

Generation – HSPA+

Known as HSPA Evolution, it is a 3GPP initiative to enhance the performance and capabilities of the HSPA. It provides

- Better HSPA spectrum efficiency with shorter HSPA latency and higher data transmission.
- Backward compatibility
- NodeB does common resource scheduling to improve power management and data rates

Fourth Generation

Speed and reliability matters when it comes to 4G wireless networks deployed in 2010. The key feature of 4G infrastructures are accessing information anytime, anywhere with a seamless connectivity in heterogeneous environments. It is suppose to give data rates of 150Mbps to 1Gbps while moving and stationary positions. Also it should able to integrate and identify the current available technology and make use of it. 4G provides a reliable network, improved capability, increased security and global mobility. The contributing technologies to the 4G are as follows.

Orthogonal Frequency Division Multiplexing (OFDM)

In 1966, Chang from Bell labs showed that multicarrier modulation can be used to solve multipath problems without reducing data rates. In 1971, Weinstein and Ebert showed that it can be achieved by Fast Fourier Transform (FFT). Orthogonal frequency division multiplexing (OFDM) is a multicarrier modulation technique that distributes the data over a large number of carriers which are spaced apart at precised frequencies. It popular for its high data rates with flexible and efficient management of Intersymbol Interference (ISI) in highly dispersive channels.

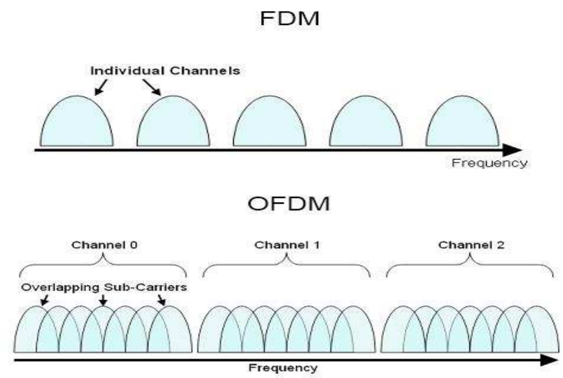

Fig.5. Sub carriers in OFDM[13]

Typically, subchannels are orthogonal under ideal conditions. To reduce ISI , the symbol time T_s is often kept significantly larger than the channel delay spread τ. Multicarrier modulation divides high rate transmit bits into L lower rate substreams, each of which has $T_S/L >> \tau$ and hence ISI in each subchannel is small. In digital OFDM implementation it can be completely eliminated by cyclic prefix. In order to keep OFDM symbol independent of each other, the guard time is introduced between OFDM symbols. The guard time T_g is kept larger than the delay spread τ, so each OFDM symbol will interfere only with itself.

Worldwide Interoperability for Microwave Access (WiMAX)

WiMAX is based on Wireless Metropolitan Area Networking (WMAN) standards developed by IEEE 802.16 group, in 1988.The initial focus was to develop point-to-multipoint wireless broadband system in Line Of Sight (LOS) environment in 10-66GHz band. The group produced 802.16a, an amendment to the standard which includes Non-LOS environment in 2-11GHz band using OFDM. In 2004, IEEE 802.16-2004 was deployed for fixed applications known as fixed WiMAX. The amendment to this was IEEE 802.16e-2005, referred as mobile WiMAX for nomadic and mobile applications.

IEEE 802.16 STANDARDS[12].

	802.16	802.16-2004	802.16e-2005
Status	Completed December 2001	Completed June 2004	Completed December 2005
Frequency band	10GHz-66GHz	2GHz-11GHz	2GHz-11GHz for fixed, 2GHz-6GHz for mobile applications
Application	Fixed LOS	Fixed NLOS	Fixed and Mobile NLOS
MAC Architecture	Point-to-multipoint, mesh	Point-to-multipoint, mesh	Point-to-multipoint, mesh
Transmission scheme	Single carrier only	Single carrier,256 OFDM or 2,048 OFDM	Single carrier,256 OFDM or scalable OFDM with 128, 512, 1,024, or 2,048 subcarriers
Modulation	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM	QPSK, 16 QAM, 64 QAM
Gross data rate	32Mbps-134.4Mbps	1Mbps-75Mbps	1Mbps-75Mbps
Multiplexing	Burst TDM/TDMA	Burst TDM/TDMA/OFDMA	Burst TDM/TDMA/OFDMA
Duplexing	TDD and FDD	TDD and FDD	TDD and FDD
Channel Bandwidths	20MHz,25 MHz,28MHz	1.75MHz,3.5MHz,7MHz,14 MHz,1.25MHz,5MHz,10 MHz,15MHz,8.75MHz	1.75MHz,3.5MHz,7MHz,14 MHz,1.25MHz,5MHz,10 MHz,15MHz,8.75MHz
Air-interface designation	WirelessMAN-SC	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessMAN-HUMAN[a]	WirelessMAN-SCa WirelessMAN-OFDM WirelessMAN-OFDMA WirelessMAN-HUMAN[a]
WiMAX implementation	none	256 – OFDM as Fixed WiMAX	Scalable OFDMA as Mobile WiMAX

WiMAX Network Architecture

IP-based WiMAX architecture is logically divided into three groups.

Mobile Station (MS): Used by the end users to access the network.

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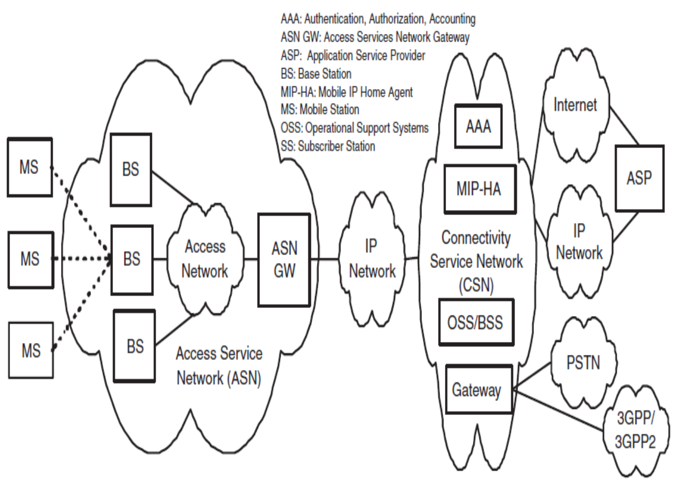

Fig. 6. IP-based WiMAX architecture [12]

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Access Service Network (ASN): It comprises of BSs which provides air interface, mobility management such as handoff, DHCP, traffic classification, tunneling, and radio resource management with QoS. ASN-GW is a gateway of ASN to the Connectivtiy Service Network.

Connectivity Service Network (CSN): It provides connectivity, AAA server, policy management, and roaming support between ASN's. It acts as a gateway to other networks.

Long Term Evolution

Long Term Evolution/System Architecture Evolution (LTE/SAE) was specified by 3GPP as a important step towards 4G. LTE (3.9G) and LTE-Advanced (4G) architectures are designed to support flat IP based connectivity and full internetworking in heterogeneous wireless access networks. The LTE systems are designed with less network elements, hence resulting in high performance, improved capacity, coverage with high data rates, low access latency, seamless integration with other wireless systems and flexible bandwidth operations. It also provides many new types of base stations such as pico/femto base stations and relay nodes in macro-cellular networks.

LTE Network Architecture

It comprises of Evolved Packet Core (EPC) which is fully PS backbone network and does mobility and session management. The traditional voice traffic which was fully CS, is handled by IP multimedia subsystem (IMS) network. When a UE connects to the EPC, the Mobility Management Entity (MME) represents EPC and performs mutual authentication and load balancing. MME, Serving Gateway (SGW), a Packet Data Network Gateway (PDN-GW) together with Home Subscriber Server (HSS) makes EPC. E-UTRAN is Evolved Universal Terrestrial Radio Access Network Base Stations, called eNode Bs (eNB) which communicates with UEs.

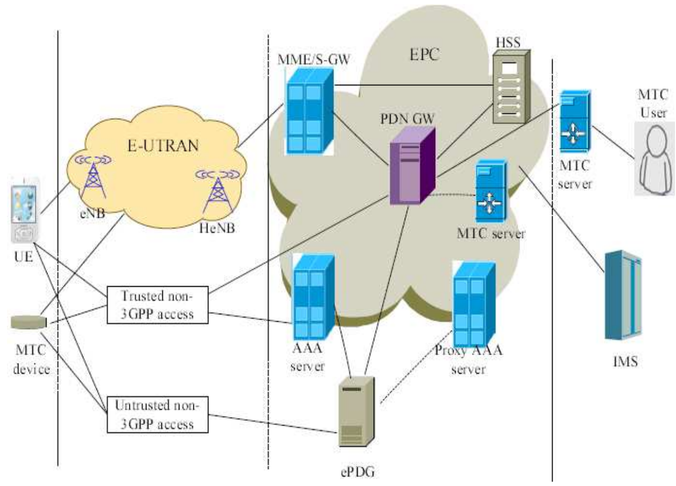

Fig. 7. LTE network Architecture [14]

A new type of base station named HeNB is used to improve indoor coverage and network capacity. It is a low power access point. LTE-A system supports non-3GPP access such as WLAN, WiMAX and CDMA 2000 systems. There are two types of non-3GPP networks, trusted and untrusted. For non trusted networks AAA server plays an important role. The new type communication between entities are supported in LTE by Machine Type Communication (MTC). MTC server provides data services and MTC user makes use of it.

LTE Security Architecture

From the LTE architecture , 3GPP committee has specified five levels of security. [15]

Network Access Security: It provides secure access between UE and EPC and protects against different kinds of radio link attacks. This feature includes ciphering between USIM, UE, EPC and E-UTRAN.

Network Domain Security: It defines security for connected wired networks. Each element should authenticate itself before data sharing or any signaling technique.

User Domain Security: The set of security mechanism which allows mutual authentication between USIM and UE.

Application Domain Security: This feature enables applications in UE and Service Provider domain for data exchange securely.

Non 3GPP Domain Security: It allows UE to securely transfer the data to untrusted non-3GPP network elements.

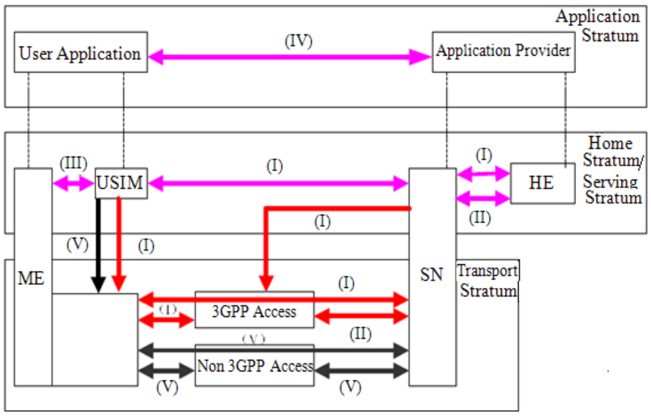

Fig. 8. LTE security architecture [15]

LTE Security Enhancements

LTE security enhancement makes it more secure than the current 3G technologies. The following chart describes some new security enhancements. [16]

Secure storage: LTE's SIM card securely stores user credentials and secure data needed to access the network services.

Mutual Authentication: Each device will authenticate itself before connection which protects from attacks by rogue base stations.

Root Key Length: The traditional key used is 64 bit but a new 128 bit long key requires a greater effort to break security algorithm.

Security Context: For each session a set of keys are used. For new session new set of keys are assigned. Handover to a new site occurs after the security is initiated.

Integrity Protection: Integrity tag is appended with each data messages to make sure that the data is not been modified.

Airlink Encryption: New encryption algorithms are used for airlink encryptions such as AES, SNOW3G.

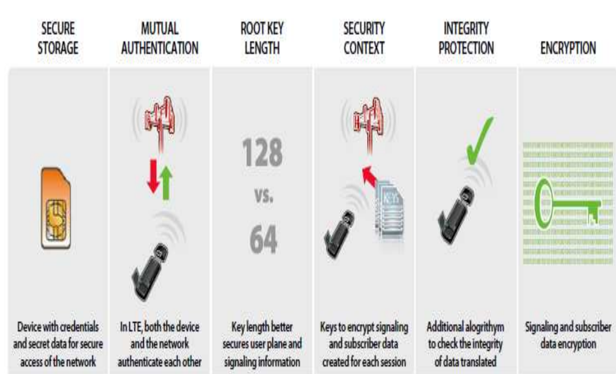

Fig. 9. LTE Security Enhancement [16]

Handoffs in 4G

In cellular communications, the term handover or handoff refers to the process of transferring an ongoing call or data session from one channel to another connected to the network core [1]. Mainly handoff process is of three stages that includes handoff decision, radio link transfer and channel assignment. But 4G is to provide data anytime, anywhere, so in this aspect there are two types of handoffs. Horizontal handoff is performed when terminal moves from one cell to another cell in same wireless systems. That is in same G network but across different cells and providers.

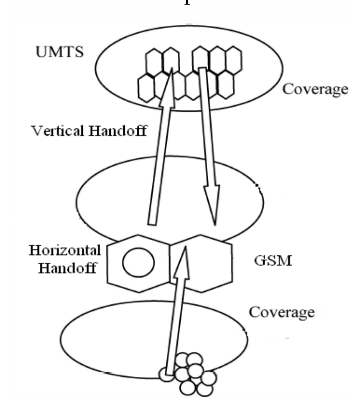

Fig.10. Vertical and Horizontal Handoff [17]

While Vertical handoff is performed when technology changes in terminal switching, like a 4G mobile user roams in 2G, 3G and 4G wireless systems [17]. Traditional handoff processes are insufficient for challenges of 4G systems because it only considers signal strength and does not include user selection for networks, congestion relief, different data traffic and interoperable network devices in heterogeneous network environments. So with the help of artificial intelligence, neural network and fuzzy logic systems, a new optimal vertical handoff technique can be developed which incorporates parameters like service type, monetary cost, network conditions, system performances and mobile node conditions.

Conclusion

This paper presented a brief description of different mobile generations and its evolution. Amongst all generations 4G provides high speed data transfer. It is the seamless integration which provides global mobility with enhanced security. Thus this paper helps the reader to understand the concepts of mobile generation networks. It also helps the researchers who are keenly working on the design and architecture of 5G.

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