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Wireless Communication Self-Learning Report

Understanding the evolution of the wireless telephone network technology from an analogue based network to 4G and 5G technology.

## **Introduction**

Since the introduction of the 2nd Generation wireless telephone technology (2G), Consumer expectations for mobile handsets and similar products have become more and more sophisticated. 2G technology was based on the GSM standards introduced by RadioLinja in 1991, Finland [1]. It applied digital data transmission and encryption using Time and Code Division Multiple Access TDMA and CDMA. It consequently replaced its predecessor, the analogue based wireless telephone technology, 1G. The introduction of this digital based technology enabled high quality speech service and global mobility, strongly convincing users to buy 2G terminals. It enabled various mobile phone networks to provide services like text messages, picture messages and multimedia messages MMS [2]. Using digital signals between the handsets and the towers (base stations) increased the capacity of mobile phone users drastically. Technologies such as Multiple Access Methods and re-engineering of cellular designs for low power and frequency reuse ensured capacity growth. 2G technology was a HUGE success story. Packet switched domains in addition to circuit switched domains were soon added to the technology to call it 2.5G. Its approach was to use General Packet Radio Services GPRS. Before this time, all circuits had been dedicated to a given user through circuit switching. This approach was inefficient when a channel was used for only a very short period and left dormant and inaccessible for other users. GPRS was centered on the use of packet data for efficient channel utilization. It allowed packets of data to be routed from the transmitter to the receiver instead of dedicating circuits allowing the same circuit to be utilized by several users. GPRS

soon evolved to EDGE networks, introducing 8PSK encoding while maintaining the packet symbol rate. Through EDGE, the data transmission rates improved from 50kbps (40kbps in practice) to 1Mbps (500kbps in practice). 2.5G was now called 2.75G (EDGE). EDGE was standardized by 3GPP as part of the GSM family and is an upgrade that provides a potential increase in capacity of GSM/GPRS networks [3].

## The architecture of the wireless mobile network

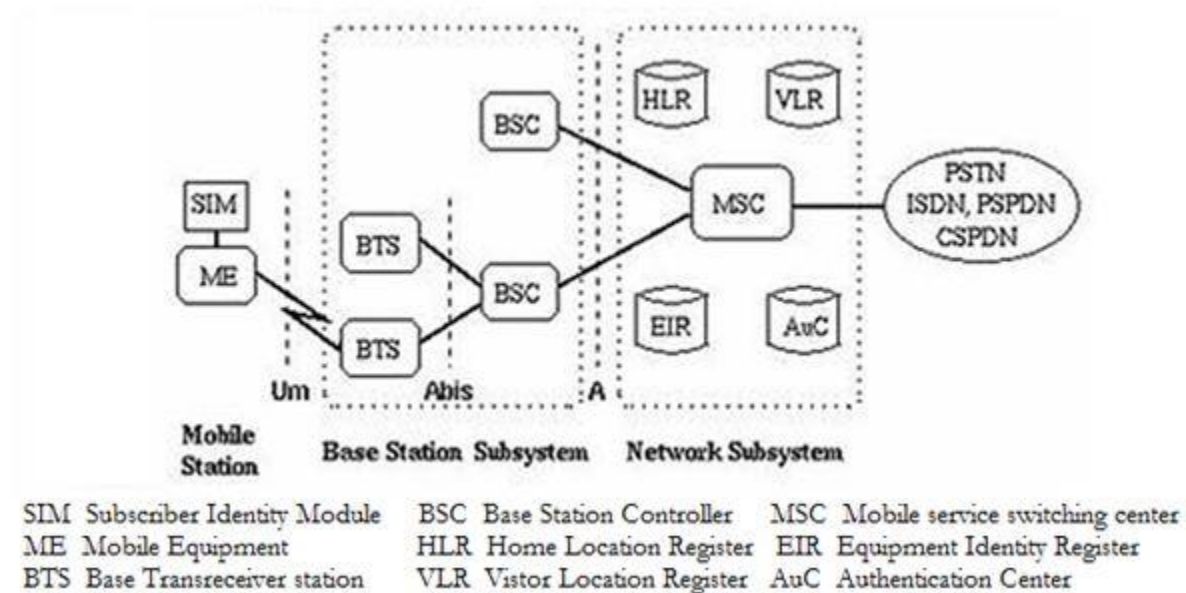


Figure 1. GSM based wireless telephone network architecture [source: <http://www.ques10.com/p/2599/gsm-explain-gsm-architecture-with-a-neat-block-d-1/>]

It comprised of the following;

- Mobile Station (MS)
- Base Station Subsystem (BSS)
- Network and Switching Subsystem (NSS)
- Operation and Support Subsystem (OSS)

### Mobile Station

These are mostly referred to as the mobile or cellular phone. These devices are meant for a mobile user to receive and send voice signal through circuit switch (Circuit Core) and mobile

data through the packet switch (Data Core). They have two main components, SIM and the hardware part itself. SIM is the subscriber Identity module which authenticates and identifies the user uniquely on the network, the hardware contains the element that of the mobile phone. It includes the peripherals, display, casing, receiver and transmitter plus other electronics that facilitate reception and transmission of radio signal.

### **Base Station Subsystem**

The base station subsystem comprises of two elements, the transceiver station and the base station controller

#### *Base Station Transceiver (BTS)*

This comprises of the radio transmitters and receivers including other antennas associated with cellular communication. It communicates directly with the mobile stations.

#### *Base Station Controller*

This controller is responsible for controlling a group base station transceivers. It is co-located with the base station transceiver. It manages the radio resource and manages network mechanisms such as handover of calls for the base station transceivers within its jurisdiction and allocates channels for calls to and from mobile stations.

### **Network Switching Subsystem**

The major elements of the Network Switching Subsystem is the Mobile Switching Center (MSC), The Home Location Register (HLR), Visitor Location Register (VLR), Equipment Identification Register (EIR), Authentication Center (AUC), Gateway Mobile Switching Center (GMSC) and SMS gateway (SMS-G)

#### *Mobile Switching Center (MSC)*

It is the main element of the network architecture. It is basically a switch node within PSTN and ISDN except it provides additional functionalities that suit the requirement of mobile stations. It is responsible for the registration of mobile stations, authentication, call location, inter-MSC

handover and routing to a mobile subscriber. It interfaces the mobile network to other networks through the Public Switched Telephone Network PSTN.

#### *Home Location Register (HLR)*

This is a database on the network switching subsystem containing all the administrative information about each subscriber along with their last location on the network. This allows calls to be placed to the right BS for the intended MS on the network. The mobile station always registers itself on the network so that calls are routed to it appropriately.

#### *Visitor Location Register (VLR)*

This database stores only a selective amount of information about the mobile station from the HLR. It stores the data for a foreign mobile station visiting the cell. The records are temporal and are deleted when the visiting mobile station returns to its usual cell where it is registered in the HLR. This register is important for faster access to the visiting mobile station as opposed to fetching its details from the HLR in a different cell.

#### *Equipment Identification Register (EIR)*

The EIR database decides whether a mobile station device should be allowed on the network. Each mobile station hardware has a unique identification number installed by the manufacturer, IMEI number. The EIR identifies all mobile stations by this number and can assign three states to a mobile device depending upon the information held; Allowed onto the network, Barred access or monitored in case of problem.

#### *Authentication Center (AUC)*

This database contains the secret key also contained on the SIM. It is responsible for authentications and ciphering the radio channel during placement of a call.

#### *Gateway Mobile Switching Center (GMSC)*

The GMSC is very useful for routing calls to a visiting mobile station. It is responsible for locating the records of a visiting mobile station from its HLR and routing the call correctly to the visited MSC.

#### *SMS Gateway (SMS-G)*

It handles SMSs directed in different directions on the network. It acts as a fixed access point for text messages being sent over the mobile network

### **Operation and Support Subsystem (OSS)**

The OSS subsystem is an element within the network architecture that is connected to components of the NSS and the BSC. It is used to control and monitor the overall network and it is also used to control the traffic load of the BSS. It must be noted that as the number of BS increases with the scaling of the subscriber population some of the maintenance tasks are transferred to the BTS, allowing savings in the cost of ownership of the system [4].

### **3G Technology**

3G was introduced soon after 2.75G in May of 2001. It was not a huge evolution as 2G but the improvement was evident. There is still unclear definition of the data rate that standardized 3G but IMT-2000 provided minimum data rates of 2Mbps for stationary or walking uses and 348 kbps for moving users at vehicle speeds. 3G also offered better and improved security compared to its predecessors. The main security technology that gave 3G finesse was KASUMI, a blocking cipher that allowed User Equipment (UE), previously referred to as just “mobile stations” to authenticate the network it was operating in and would identify impersonator networks. Later 3G releases were 3.5G which came with High Speed Packet Access (HSPA) a mixture of two mobile protocols, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA) which improved the performance of the 3G mobile telecommunication network using WCDMA. A further improvement of the 3GPP (3<sup>rd</sup> Generation Partnership Project) standard, HSPA+ was released in 2010 allowing speeds of up to 337Mbps down link and 34Mbps Uplink [5]. This became known as 3.75G.

In 3G the mobile station was introduced as a User Equipment and BS was replaced with “node B”, a telecommunication node that adhered to the UMTS standards. It connected the UE to the mobile phone networks. The difference between node B and the Base station was that node B utilizes the WCDMA technology which allows cells belonging to the same or different node Bs to overlap and still use one frequency pair. This came with the possibility for soft handovers. In this new technology, a group of Nodes Bs are controlled by the RNC Radio Network Controller instead of the BSC. The RNC is the governing element of the in UMTS radio access network

(UTRAN) [6]. The cell radius in 3G networks used less power and reduced cell radius, this means that a large amount of Node Bs and careful planning of the network is required. Except for the few adjustment 3G networks architecture used a similar network architecture as the one for 2G. This architecture is based on the GSM architecture standards.

## **4G networks**

In 2008, the International Telecommunication Union-Radio Communication Sector specified the requirements for 4G. Setting the peak speed at 100MBps for high speed moving user and 1Gbps for a low mobile or stationary users [7].

4G mobile telecommunication networks is designed to provide capabilities defined by ITU. Its specified applications are mobile web access, IP telephony, gaming services, high definition TV, video conferencing and 3D television.

LTE is the 3GPP standard for high speed wireless communication for mobile phone and data transfer terminals. It was the first step towards 4G, based on GSM/EDGE and UMT/HSPA technologies. It came with many improvement using different radio interfaces together with the core network improvements to increase capacity and enhance data transmission speeds [9]. LTE is the 8<sup>th</sup> release document series with few improvements in the 9<sup>th</sup>. The 10<sup>th</sup> release was known as LTE advance which was a major enhancement of the LTE standard. LTE advanced was described as 3.9G and is defined by its peak data transmission rates of 1Gbps and its backward compatibility capability. LTE advanced also introduced multicarrier to be able to use ultra wide bandwidth, up to 100MHz of spectrum supporting very high data rates [8]. The following are the research proposal have been studied as candidates for LTE-A.

- Support for relay node based stations
- Coordinated multipoint (CoMP) transmission and reception
- UE dual TX antenna solution for SU-MIMO and diversity MIMO, 2x2 MIMO
- Scalable system bandwidth of over 20MHz, up to 100Mz.
- Carrier aggregation of contiguous and noncontiguous spectrum allocations
- Local are optimization of air interface
- Nomadic / local area network mobility solutions
- Flexible spectrum usage

- Cognitive radio
- Automatic and autonomous network configuration and operation
- Support of autonomous networks and device test, measurement tied to network management and optimization
- Enhanced precoding and forward error correction
- Interface management and suppression
- Asymmetric bandwidth assignment for FDD
- Hybrid OFDMA and SC-FDMA in uplink
- UL/DL inter eNB coordinated MIMO
- SONs, self-organizing networks methodologies.

Alongside LTE advanced was WiMAX (World Interoperability for Microwave access) a family wireless communication standards based on the IEEE 802.16. It provided multiple physical layer (PHY) and media Access Control (MAC) options. WiMAX was designed for speeds of between 30 to 40Mbps with a later upgrade that achieved 1Gbps in 2011 for WiMAX 2. Both LTE-A and WiMAX 2 can use up to 8x8 MIMO and 128QAM in downlink direction with an instant performance of 100MHz aggregated bandwidth. LTE-A can provide almost 3.3Gbps peak download rates under ideal conditions. The network architectures are a combination of distributed and smart antenna technologies [9].

4G does not support circuit switched telephony service. It is entirely based on all internet protocols (IP based), supporting communication such as IP telephony. In the architecture, the EUs are connected by an enhanced version of Node Bs known as eNode Bs with very intelligent control technology. It uses OFDMA multicarrier transmission as opposed to the spread spectrum radio technology used by the predecessor generations. OFDMA makes it possible for 4G networks to transmit at very high speeds despite the extensive multipath radio propagation. The improvement in terms of data transmission rates is backed using smart antenna arrays for multiple input multiple output MIMO communication . 4G technology is set to fulfill the following requirements

- Be based on all IP packet switched network
- Have peak data transmission rates of approximately 100Mbps for high mobility users and 1Gbps for stationary users

- can dynamically share and use the network resources to support more simultaneous users per cell
- Use scalable channels with bandwidth of 5-20MHz or 40MHz.
- Have peak link spectral efficiency of 15bit/s/Hz in downlink and 6.75bit/s/Hz in the uplink
- System spectral efficiency in indoor cases of 3bit/s/Hz/cell for downlink and 2.25bits/s/Hz/cell for uplink.
- Smooth handover across heterogeneous networks

## 5G Technology

These are supposed to be the next wireless mobile networks standard to succeed 4G.

QUALCOMM designed and initial chip in October 2016, the snapdragon x50 5G modem. It supported operations in the 28 GHz band also known as millimeter wave (mmW) spectrum. With 800MHz bandwidth support peak download speed of up to 35.46Gbps [10].

The aim of 5G is to reach higher capacities than the predecessor for high density of mobile broadband users. It also must support device-to-device, ultra-reliability and massive machine communication. Low latency and power consumption will also be very essential for better implementation of the internet of things. There is now no standards set for 5G. However, the Next Generation Mobile Network Alliance defines the following requirements to be achieved by 5G.

- Data rates of tens of megabits per second for tens of thousands of users
- Data rates of 100 megabits per second for metropolitan areas
- 1 Gb per second simultaneously to many workers on the same office floor
- Several hundreds of thousands of simultaneous connections for wireless sensors
- Spectral efficiency significantly enhanced compared to 4G
- Coverage improvement
- Signaling efficiency enhanced
- Latency reduced significantly compared to LTE [11].

The introduction of 5G will bring about the reality of the internet of things, broadcast like services and lifeline communication. This technology is in very high business and consumer

demand and is expected to be launched officially in the year 2020 as promised by the Next Generation Mobile Network Alliance. Since 5G will require fast application processors, basebands and RF devices, companies like Advance Semiconductor Engineering (ASE) and Amkor Technology Inc. have been preparing in advance for this eminent technology. 5G is envisioned to be a super-efficient mobile network that delivers better performing networks for low cost, a super fast mobile network comprising the next generation of small cell density clustered to give contiguous coverage with dynamic spectral access, A converged fiber wireless network that uses wireless internet access at millimeter wave bands (20 – 60GHz) allowing very wide bandwidth radio channels to be able to support speeds of up to 10Gbps. 5G is essentially comprises of “short” wireless links on the end of local fiber optic cable. It will be more nomadic like Wi-Fi unlike the traditional wide areal mobile network [12]. Several technologies and are set out to facilitate the implementation of 5G.

### **Millimeter Wave**

This is an extremely high frequency band designated for radio frequencies in the electromagnetic spectrum from 30 to 300GHz found between super high frequency and far infrared band also known as the terahertz gap. The wave length in this band is from ten to one millimeter hence the name millimeter band/wave [13]. With this band, 5G devices can use very tiny antennas and allow the implementation of massive MIMO. Since the band is of extremely high frequency, security will be improved.

### **Massive MIMO**

This is the transmission module with many antennas that serves multiple users at the same time. With massive MIMO, several messages can be transmitted for various terminals at the same time-frequency. This will maximize beamforming gain while minimizing interference [13].

### **Three-Dimensional Beam forming (3DBF)**

This utilizes hundreds of antennas at the base station to perform in millimeter wave spectrum resulting highly direction antenna beam that can be directed in desired directions and can optimize performance of the network.

### **Multiple-hop networks**

This technology will address the challenge of making high bit rates available in large portion of the cell.

### **Wireless network Virtualization**

This will be extended to 5G mobile networks. This will introduce<sup>4</sup> the possibility to decouple the network infrastructure from the services it provides, where differentiated services can coexist on the same infrastructure hence maximizing its utilization.

### **Cognitive Radio technology**

This is also known as smart radio. It allows different radio technologies to use the same spectrum efficiently through adaptively finding unused spectrum and adapting the transmission mechanism to the requirements of the technology currently sharing the spectrum. Cognitive technology utilizes AI to read and understand its environment. It will be very useful tool for 5G [14].

### **LI-FI (light and Wi-Fi)**

It is a Massive MIMO visible light communication network. It uses light emitting diodes to transmit data instead of the use of radio waves. Li-Fi is said to advance 5G.

### **IPv6**

It will use the IPv6 internet protocol. Visiting mobile IP care-of address is assigned according to location AND connected network. It offers sufficient capacity unlike the IPv4.

### **Conclusion**

Understanding the wireless mobile telephone networks is the beginning of a journey through the core of the real master of technology. From an analogue based network, 1G - telephone network to a super network, 5G - *the internet of things*. This technology is what is around us and will always be. It is in the handset in your pocket, the PC on your desk, the Laptop in you backpack or the smart watch on your wrist. With the anticipation of the network of things wireless

telephone networking will be the master of all technology utilizing AI, smart antennas, cognitive radio, Li-Fi and many other technologies, some we are yet to see.

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