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3.9G Wireless Communication System

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Abstract—*The paper studies Long Term Evolution (LTE) in detail. LTE is also referred as 3.9G because it meets only some of the requirements of IMT-advanced specifications for 4G systems. We begin by describing the EPS (Evolved Packet System) architecture for LTE systems which is completely IP based. We discuss the techniques like OFDMA and SC-FDMA which are used in downlink and uplink respectively. We understand the LTE frame structure, resource allocation and have a quick look at channel dependent scheduling. Then we try to assimilate the LTE-protocol stack and have a glance at some of the channels used in LTE systems. We conclude by studying security and mutual authentication procedures used in LTE systems and compare it with methods used in previous generations like 2G-GSM.*

1. INTRODUCTION

3rd Generation Partnership Project (3GPP) in 2009 came up with Long Term Evolution (LTE) standardization for almost 4G technology or 3.9G meaning that when 3GPP standardized LTE, they knew it was not going to meet the IMT-Advanced requirements for 4G technology [5]. However, for marketing purpose they are being sold as 4G technology. LTE offers 326Mbps for downlink, 86Mbps for uplink using 4x4 MIMO with 20MHz bandwidth. LTE works on various bands like 700/1500/1700/2100/2600 MHz bands where 2100MHz band is the most popular.

LTE is very flexible in terms of spectrum usage i.e. it supports both paired (FDD) & unpaired (TDD) spectrum and bandwidth of channel can be 3,5,10,15 or 20MHz. It uses beam forming in the downlink, which is dynamic directionality for better communication with users. One fundamental change in LTE system is the flat IP-based network architecture. Starting with the architecture, we discuss all the special features of LTE in this paper.

2. LTE-EPS ARCHITECTURE

EPS stands for Evolved Packet System which mainly comprises of two sections- Evolved UMTS Terrestrial Radio Access Network (E UTRAN) and Evolved Packet Core (EPC). [EPS = EPC+EUTRAN]

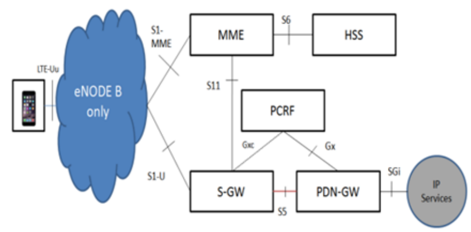

Fig. 1: EPS architecture

EUTRAN mainly consists of evolved Node B only, with X2 interface between them. It handles all the radio related functions like resource allocation, scheduling, monitoring, mobility decisions and IP header compression/decompression. MME stands for Mobility Management Entity and it handles the NAS signaling, encryption/decryption, authentication of users, tracking area management and most importantly selection of Target PDN& S-GWs.

It is also responsible for bearer management. Serving Gateway (S-GW) is mainly responsible for local mobility anchor for intra 3GPP handovers, downlink packet marking and buffering. PDN Gateway is the means how the wireless network is connected with the other internet services like IMS, PSS [1]. It mainly allocates the IP address to the user equipment and is responsible for charging and enforcement of QoS as per the QoS provisioning and charging rules defined by PCRF (Policy and Charging Rule Function).

HSS is Home Subscriber Subsystem and contains all user data information like USIM number, MNC code, etc [1]. There are different interfaces between these components and the most important one is S5 which can be either GTP/ PMIP based. This S5 is responsible for uplink/downlink bearer binding and also its verification. Depending on its nature, we may have Gxc interface between S-GW and PCRF which helps in bearer binding at S-GW only when S5 is PMIP based [1].

3. LTE-DOWNLINK

In LTE, ODFMA is used in downlink. OFDMA stands for Orthogonal Frequency Division Multiple Access which is based on OFDM where there is division of the entire bandwidth into sub carriers and then modulation of each subcarrier using QPSK, 16QAM, 64QAM, etc. All the subcarriers are orthogonal to each other in the sense that when there is peak in one, all other subcarriers have null value.

Since each sub carrier is small in frequency domain, the symbol duration is much bigger and this reduces the Inter-Symbol Interference (ISI) due to multi path fading or delay spread [2]. Therefore, OFDMA works very well with MIMO or it complements the MIMO technique. OFDMA is implemented with very simple computational methods like FFT/IFFT.

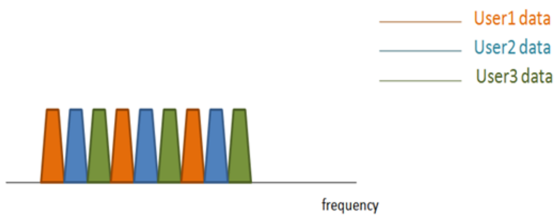

Fig. 2: OFDM signal

OFDM signal can have high variations in power levels because different carriers will have different power level. Therefore, Peak to Average Power Ratio (PAPR) is very high and we need complex amplifiers to cover these large range values. Since we cannot use such complex and expensive amplifiers in mobile stations, OFDMA is not used for uplink transmissions.

4. LTE-UPLINK

SC-FDMA is used in uplink transmissions and it stands for Single Carrier FDMA. In SC-FDMA, each user gets a contiguous part of radio channel. Since there is only one carrier now, the PAPR value is low and simple amplifiers can be used.

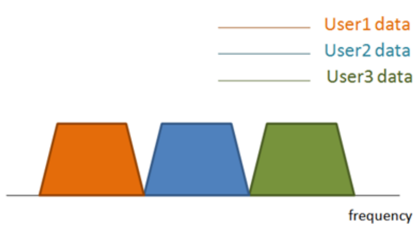

Fig. 3: SC-FDMA signal

SC-FDMA is also better for uplink since a slight mis-synchronization will not affect the decoding much. Also it uses simple mathematical computational methods like FFT/IFFT.

5. LTE-FRAME STRUCTURE

Each LTE time frame or Super Frame (SUF) is of 10 ms duration and each super frame has 10 Sub Frames (SF) each 1ms duration.

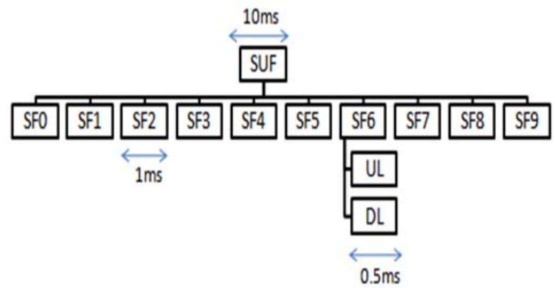

Fig. 4: LTE Frame Structure

Every sub frame has two time slots of 0.5ms duration each. One time slot can be used for uplink and other for downlink. Every time slot certain number of OFDM symbols are transmitted depending on the type of Cyclic Prefix.

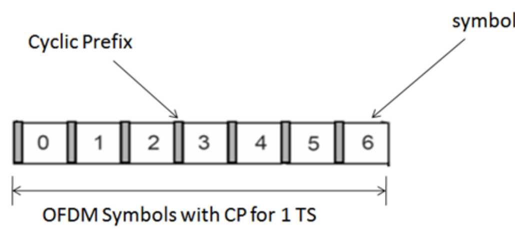

Fig. 5: Time slot with normal CP

In 1 time slot with normal Cyclic Prefix (CP), we can transmit 7 OFDM symbols with CP duration of 5.2µs for the 1st symbol and 4.7 µs for the remaining. In extended Cyclic Prefix, the CP duration for all symbols is 16.7 µs. The symbol duration is same for all i.e. 66.7 µs. Every resource block consists of 12 subcarriers with each subcarrier having 7 OFDM symbols each (assuming normal CP).

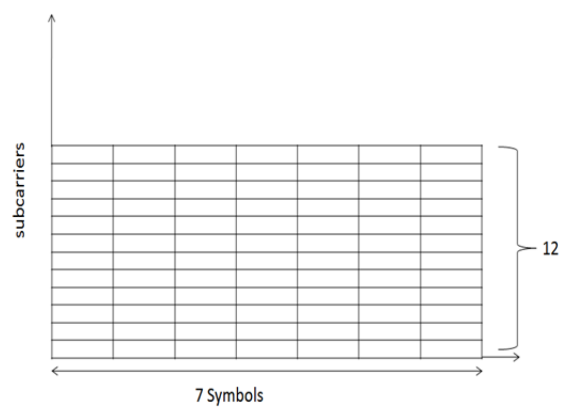

Fig. 6: Resource Block in LTE

In channel dependent scheduling [1], the number of subcarriers is allocated depending upon the user requirements, which implies there is dynamic allocation of resource blocks. Also transmission power is focused on that channel for which the user gets the best SINR value.

Resource allocation for LTE users is thus dependent on the type of user application, needs, and also on the distance from the base station as that will decide the CP length. The following table shows how resources are allocated [6].

Table 1: OFDM Resource allocation

Cyclic Prefix	Subcarrier per resource block	Symbols per resource block	Cyclic prefix duration	Application
Normal	12	7	5.2 and 4.7 µs	Short distance
Extended	12	6	16.7 µs	Long distance
Extended	24	3	33.3 µs	MBMS

6. LTE-PROTOCOL STACK

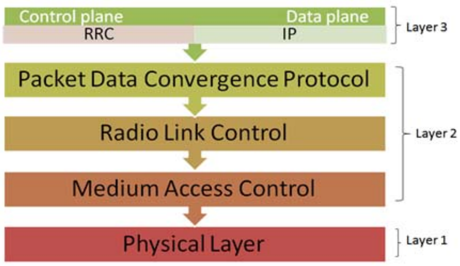

Fig. 7: LTE Protocol Stack

Layer 3 comprises of RRC (Radio Resource Control) and IP which are used for control and data plane respectively. RRC handles control plane functions like connection establishment/break, mobility & QoS management and paging.

Layer 2 comprises of Packet Data Convergence Protocol (PDCP), Radio Link Control (RLC) and Medium Access Control (MAC). Three main functions of PDCP are: IP header compression/ decompression, maintain integrity using authentication code and ciphering the user data. RLC performs segmentation/ reassemble of the PDCP PDUs depending upon the size dictated by MAC layer. MAC layer ensures QoS by indicating the size to RLC. Also, MAC layer manages hybrid ARQ and power.

Layer 1 is the Physical Layer which does modulation/demodulation and encoding/decoding.

7. LTE- CHANNELS

Successive frames that provide information forms some sort of channel. In LTE systems channels are defined between the different layers of the protocol stack. There are mainly three channel types:-

7.1 Logical channels

These are used to distinguish between control and user data flows. It is the top most channel layer.

7.2 Transport channels

It prepares the data frames so that they can be transmitted over the air interface by dividing them into smaller parts. Some examples of transport channel are Broadcast channel (BCH) which is used to broadcast the important system parameters to all mobile equipments, Paging channel (PCH), Multi cast channel (MCH), Random Access Channel (RACH) which responds to paging message.

7.3 Physical channels

For one or more transport channel, a physical channel is responsible for creating a physical medium for transmission. Some examples are Physical BCH (PBCH), Physical Downlink Shared Channel (PDSCH), and Physical Uplink Shared Channel (PUSCH).

Channels are mapped between the adjacent layers. One example can be:

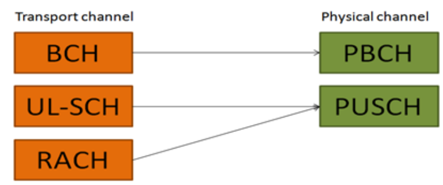

Fig. 8: LTE Channel Mapping

8. LTE- MUTUAL AUTHENTICATION

In previous wireless cellular network generation such as 2G-GSM, the authentication was only one way i.e. only the network used to authenticate UEs. They used a long term shared key. To enhance the security and reduce the burden on network side at the same time, mutual authentication is introduced in LTE systems. In mutual authentication, both the user and network authenticate each other.

First, the process is initiated in the network side and it generates the authentication vector (AV) which comprises of-RAND, AUTN, XRES, and Kasme [4]. The UE already has AUTN i.e. authentication token and it first authenticates the network if and only if their authentication tokens are matching. Then user equipment computes the authentication vector. At last, the network authenticates the UE by verifying the RES=XRES. The complete process is explained in the Fig. below:

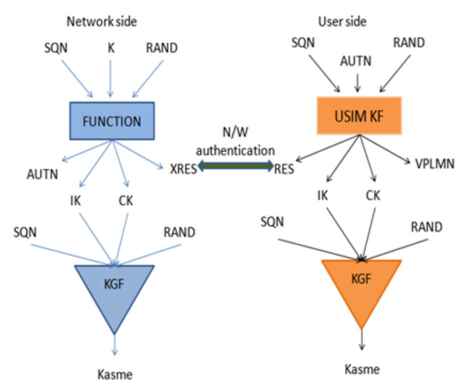

Fig. 9: Mutual Authentication

The end result of the algorithm is Kasme which stands for Key for Access Security Management Entity. This key is used for encryption/decryption of user data. With this algorithm the shared key is only for a short duration and hence it makes the LTE system very robust and highly secure.

9. CONCLUSION

We have discussed all LTE concepts and key features. It should be noted that all these concepts and specifications are similar for Wi-MAX except that it uses OFDMA in both downlink and uplink [3]. The LTE concepts have proven to give better results in terms of high data rate transmissions, security, better spectral efficiency, and better user experience. All the new and latest cellular generations are expected to include these features in them.

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