Overview of LTE-Advanced & it's Technologies

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Abstract **Soon after the release of 3rd generation network (3G) user become more data hungry as they start getting the good Quality of Service (QoS). As the quantity of user ascends, the QOS provided to the user descends. To maintain QoS the formation of ITU-R was made, that has put some serious guideline that actually define the network category, means which kind of network is provided whether it is 3G or 4G. With the launch of 4G the whole system architecture has changed, according to that the communication technology changes i.e. the implication of packet switching over circuit switching with the development and advancement of EPS which is a combination of EPC and E-UTRAN. As the new technology has arrived in the market, the issues were also new. Like the issue of fairness, cell edge throughput, interference handling etc. with resolving all this issues the LTE-Advanced (LTE-A) was launched. LTE-Advanced has becomes a worldwide standard for new generation cellular communications system. Which has launched with the techniques like: - Carrier aggregation, coordination multipoint and MIMO, along with the release of LTE-A the low-powered nodes get familiar in the market for the enhancement of throughput for cell edge user, for denser areas where UE are more. LTE-A significantly widened the area of cell coverage, and enhanced the overall system throughput. LTE-A standards and technologies were described in several recent research papers. In this particular research work, we worked to provide an in-detail description about LTE-A Technologies, along with the architecture of LTE.**

***Keywords* — UE; LTE; MIMO; CoMP; CA; Small Cell, Femto Cell.**

I. INTRODUCTION

As the demand regarding sharp and powerful data speed and superior quality of service (QoS) with low interference has gained interest soon after the 3rd generation (3G) system was released and accomplished at the International Telecommunication Union Radio communication Sector (ITU-R) by 2001 [1]. Some basic criteria which were then set and labeled by the ITU-R in 2001 regarding the network speed that includes 2mbps for office, 384 kbps for moving objects with low moving speed and 144 kbps for vehicular connection and some better QoS which includes no cross talk, no connection loss and so on [2]. The orientation, placement and proper functioning of network were the responsibility of International Mobile Telecommunication 2000 project (IMT-2000). Initially systems as Universal Mobile Telecommunication System (UMTS) did not directly meet the IMT-2000 norms during their deployments [3]. As the demand of QoS increases with the increase in number of users it had become impossible to provide the adequate service with the old frame work so, a new technique known as the 3.5G or High-Speed Packet Access(HSPA) that contains a combo of High-Speed Downlink Packet Access and High-Speed Uplink Packet Access, i.e. (HSDPA+HSUPA) was released. With the betterment of network, the demand of user also increases and soon the degradation of network starts. For more betterment of user experiences the 3GPP (3rd Generation Partnership Project) starts working on LTE and SAE (System Architecture evolution), this also enhances the HSPA, access network core and also includes the Evolved Packet System (EPS), which helps the telecom industry with high efficiency and more secure service with low latency [4]. The EPS is the combination of E-UTRAN and EPC, EPS was completely IP based, helps to carry both real-time service and data-communication services under the IP protocol. E-UTRAN works with OFDMA and SCFDMA technology for downlink and uplink respectively. EPC was the core part of the EPS which actually provides the connectivity with the network [6]. The issues originated in LTE were of its kind like the problem of interference, low cell edge throughput and fairness. Some of these problem are get challenged through the origination of femto cells and Multiple Input Multiple Output (MIMO) method for boasting the data rate, CA for allocation of aggregated channels at user side for sending the data with more frequently and ICIC for the interference in the cell [14]. The installation of femto cell provides the interference among macro and femto cells or sometimes while connecting the femto and femto cells. These whole issues are being addresses by the 3GPP and they also work in direction for

 DOI : 10.35291/2454-9150.2019.0390

the betterment of the networks [22]. Some of its organizations are addressed in the coming section [6], [9].

A. Organization formed under 3GPP

1. ARIB (Association of radio industries and business) Japan.
2. ATIS (Alliance for telecommunications industries solutions) United States of America.
3. CCSA (China Communication Standards Association) China.
4. ETSI (European Telecommunication standards Institutes) Europe.
5. TSDI (Telecommunication standards Development Society India) India.
6. TTA (Telecommunication Technology Association) South Korea.
7. TTC (Telecommunication Technology committee) japan.

The first project which was taken as a base and all the advancement is done on that for the betterment of the network performance, that project or the base was officially known to be the Release 8, released in 2008 by the 3GPP. In further approaching part an review of release 8 is discussed.

B. Overview of Release 8

In LTE release 8 which is commonly known as the LTE introduction, in that OFDMA technology is used for the Down-Link (DL) multiple access scheme and Single-Carrier Frequency Division-Multiple Access (SC-FDMA) was used like an Up-Link (UL) access scheme [4] some of the features that are supported by this are [7]: -

- It supports the bandwidth up to 20MHz to support the different deployment scenarios.
- MIMO antennas.
- The latency rate down up to 10ms.
- All IP networks
- It can operate in paired (FDD) and unpaired spectrum (TDD).

C. Network Architecture of LTE

The need of new architecture technology observed by the user and service provider in the early stage of 2000 because of existing system does not fulfill the desired requirement of user. To overcome such issues 3GPP feel to develop a new system that will be fast and accessible to more users [1], [6]. 3gpp developed a system which is based on core network and radio link, called it LTE. LTE is basically studies as EPS (evolved packet System) which comprises of E-UTRAN + EPC. All entities and their working involved in EPC and E-UTRAN are described below [4], [14], [15]. User plane is used to manage all entity and establish link among all entities, while data plane are used to transfer the data where required [3], [22]. Working process of all entities of EPC and E-UTRAN are given below in figure 1:

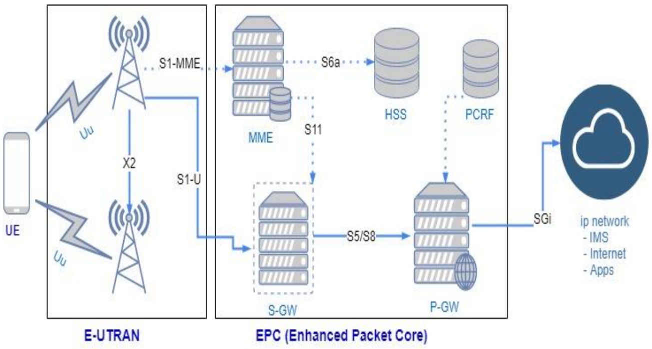

Fig. 1 Architecture of LTE

MME-> The Mobile Management Entity (MME) performs the paging, authentication of UE and functions only in control plane. It has a stored location of the user and chooses an appropriate path or a serving gateway [37]. (S-GW) is used to transfer the message. It also has some more functionality like:-Paging, Handover among various MME and also between eNodeBs, Bearer Management and Control of user plane tunnel [38]. S-GW-> Serving Gateway (S-GW) performs function like to route and forwards the user data packets from one end to the other [6]. It works as an inter-mediator between P-GW and eNodeB [14], [15]. There are some more functionalities of S-GW likewise: - Controls the GTP tunnels for Up-Link and Down-Link data delivery and User plane tunnels for Up-Link and Down-Link data delivery.

P-GW-> Packet Data Network Gateway (P-GW) works in direction to enable an IP address to the user for accessing the network and also responsible for mapping among IP packet and GTP tunnels [2], [6]. Further, we have more functionality of this like: - Packet Filtering and QCI through the rate policy and shaping. HSS-> Home Subscriber Server, has the same functionalities as HLR of 3G, like:- it contains the all the necessary user subscriptions information, the services that user has purchased, it's mobile number, IMEI number of the equipment any other extra services that user has activated on their equipment. But it also contains an AuC (Authentication Center), which works on the security information from user identity keys. That is further used for radio path ciphering. It is connected with the S6a interface with the MME [2], [13]. PCRF-> Policy and Charging Rule Function (PCRF) is a combination of both policy decision and charging rule function, the purpose of PCRF is to work on the charging and billing according to the data or the service that users are using. The other function of PCRF is to retain the quality of service [3], [14].

E-UTRAN is an evolved universal terrestrial radio access network that contains UE and eNodeB. Major functionality

 DOI : 10.35291/2454-9150.2019.0390

ISSN : 2454-9150 Vol-05, Issue-05, Aug 2019

of EUTRAN is to establish the radio link between Core and User. eNodeB is an vital inter-mediator of user and core system [1], [5]. The working details of UE and eNodeB are given bellow: UE is the user equipment, this includes any device like mobile phone, laptops, and other equipment's which are capable to access the internet [1]. eNodeB are the advance version of Nodes that were supposed to be used in 3G, the main function of the eNodeB is [2], [6]:-

- These are responsible for resource management, radio barrier control, radio emission control which was not present at the time of 3G.
- The eNodeB uses the SC-FDMA and OFDMA between the UE and the eNodeB.
- As we have in the picture, the interface between the 2 eNodeB is X2.
- These only send the message or request from one point to a destination, it only works as a medium, and no modification of the data is done by the eNodes.

D. LTE Advanced

The speed is always a concern with the sudden increase in users and quality of service that service providers are supposed to provide, that was the reason, why the telecom industry switched from 2G to 3G to LTE [4]. User was always hungry for huge data throughput and LTE was not efficient enough to satisfy this demand. Now time to move a step ahead to introduced a new technology that was the LTE-Advanced. The estimated uplink speed in LTE-A could be around 1.5 Gbps and downlink around 3 Gbps, Higher spectral efficiency and much more. The capacity and coverage of LTE-A can be enhanced through the collection heterogeneous networks which are the bunch of nodes that have less efficiency or power and spread across a network with similar frequency. The cell with low efficiency or power includes femto cells, relays, microcells, and Pico cells [37]. These all are get placed at different-different environments that include homes, enterprise environment, and other low geometric locations to revamp the basic demand of the users [38]. Consisting technology in LTE-A are described below:

- Carrier aggregation.
- MIMO.
- Coordinated Multi-Point (CoMP) operation.

D.1 CA (Carrier Aggregation)

This technique is vitally used to increase the bandwidth as well as the capacity of the channel and supports both FDD and TDD [2]. This method in LTE-A is used to increase bandwidth by aggregating one or more component carrier in order to support wider transmit bandwidth which is supposed to be extended up to 100 MHz as we know that the bandwidth of single channel is varied from 1.4,3,5,10,15 and 20MHz,to make a 100MHz channel we use around 5 channel in that we have one fixed primary component carrier channel and other 4 we have secondary component carrier channel channels for transferring the data, the maximum secondary component carrier an equipment can acquiring is only dependent on that device and informed by the device through the "UE capability information" while confirming the message to the MME [6]. The primary component carrier has the functionality to remove or add secondary component carrier and it handles all RRC and NAS (Non- Access Stratum) procedure. The carrier aggregation helps to tackle the requirement of high peak data speed and also helps for betterment of the coverage for medium data speeds as they uses the lower order modulation and code rates that lessen the needy link budget, transmission power, and interference [9]. There are various modes in Carrier Aggregation these are [7]:-

- Intra-band:- this means the primary and secondary component carrier belongs to the same frequency. The 2 main variants in these intra-band carriers are Contiguous and non–Contiguous. In intra-band Contiguous here the secondary carriers are just adjacent to the primary carrier. This is the simplest way of carrier aggregation to implement but this doesn't imply all the time as we know the spectrum allocation is not uniform. In intra-band non Contiguous carrier aggregation is like primary as well as secondary component carrier are though belongs to the same band but they are not contiguous and this is little-bit complicated than the previous one. In this, the multi-carrier signals are not be treated as a single carrier and this is the reason why need multiple transceivers and this leads to more complexity at UE and also affects its primary considerations like coast, power, and space.
- Inter-band non-contiguous:- it is the more challenging than the other types as this aggregates the carriers from different bands that may be due to improper partitioning of the band, some are up to only 10 MHz wide.

D.2 CoMP (Coordinated Multi-point)

In cellular communication, the inter-cell interference (when a single UE starts getting signal from different eNodeB that leads to inter-cell interference) was always a vital problem and an interest to study on. In 2G, operators had by parted the provided bandwidth and the areas under single nodes are in the vicinity to use various frequencies to operate on, that was called frequency-reusing [16]. But with the advancement of network the user becomes more data

 DOI : 10.35291/2454-9150.2019.0390

hungry and operators have to full-fill their demands that's why operators have to provide the extra resources to users or give them more extra bandwidth, to cop up this issue frequency reuse with a factor of 1 used in 4th generation networking i.e. the similar frequency is used in all the cells, which leads to a new problem of its kind that was the user at cell edge faces the inter-cell interference problem means the users near to the eNBs have comparatively high data speed as to the user at the cell edge, that was due to the high Received Signal Strength Indicator(RSSI) value, which helps to indicate the value of efficient Channel Quality Indicator (CQI). So, the operators came up with a solution of CoMP which was proposed in 3GPP Release 9 to mitigate Inter-Cell Interference (ICI), also to escalate the overall network throughput with coordination complexity at a minimum level [18], [19]. Cell edge UEs comparative to the user near to the eNBs sends and receives the data from multiple eNBs and as in the CoMP if the signal received from various Nodes is very well ordered and coordinated this not only helps to escalate the data speed of users at the cell edge but also helps to increase the whole network with more enough coverage or network area [22], [23]. To ignore a collision between the networks while doing the scheduling and resource management for the extreme users the CoMP has to perform and follow the norms for synchronization between various nodes or the eNBs. If we talk about the prime motivation to use the CoMP are:-

- For the enhancement of the coverage of nodes.
- For the enhancement of extreme edge users throughput.
- For the enhancement of overall system throughput.

There are primarily 2 kinds of Coordinated Multi-point operations:-

1. Intra-site Coordinated Multi-point.
2. Inter-site Coordinated Multi-point.

Table1. Small cell type and descriptions

Type	Deployment	User supports	Power range Indoor Outdoor		Range
Femto	Generally in the locality and in organization environment, indoor only.	In locality between 4-15 and under organization 14-34	10-110mW	0.2-1W	10-60m
Pico	In public areas like -at bus stops, railway stations, public library, can be placed indoor and outdoor.	34-129 users	110-26mW	1-5w	90-180m
Micro	Placed at outdoor, in urban areas to fill large coverage gaps	130-2568	--	3-12W	200-500m
Metro	At outdoor, to provide additional capacity	N number greater than 250	--	12-23W	2km
Wireless Fidelity (Wifi)	Used at indoor and outdoor both in residential and in offices.	Not greater than 50 users	20-110mW	0.2-1W	10-50m

- Intra-site Coordinated Multi-point:- it enables the relation among the multiple sectors of the same cells or eNB, where the coordination is performed by multiple antenna units, which allows the synchronization between the sectors. It does have some advantage like:- a significant amount of information can be exchanged and it does not involve the backhaul [27].
- Inter-site CoMP: - it includes the mutual cooperation among multiple eNBs from various cells i.e. located at the various areas. The major drawbacks of inter-site are it gives some additional burden on backhaul because of every information exchange among the nodes through backhaul links [6].

E. Small Cell

These are low-power Radio Frequency (RF) outputs that work under the control of operators. These are generally placed indoor, functions beneath licensed spectrum or under shared i.e. unlicensed spectrum to enhance cellular bandwidth, capacity for metropolitan and for rural public spaces as we know with all grown-up of network, the demand, and data trafficking has also increased like:-66% of audio calls and 90% of data congestion exists indoors [6]. The macro-cells are not that much productive to fulfill the every user requirement so, an idea generated to deploy small cell or Femto Access Points (FAP) in those areas where the requirement of bandwidth, quality of the signal is high for the purpose to enhance indoor user experience. Now we have various types of small cells like as shown in table 1[9], [10]:-

To meet the coverage problem the deployment of Femto Access Points (FAP) was done, the reason was of its low-cost, low-power cellular base. Now with installing a huge amount of femto cells over already existing macro-cells, a new kind of issue was raised that was Electro-magnetic interference in the two-tier network and also responsible to deteriorate the whole network performance [8], [29]. This interference is classified as:-

 DOI : 10.35291/2454-9150.2019.0390

- Cross-Tier
- Co-Tier

F. Overview of OFDMA technology

LTE-A and LTE both technology are relied on OFDMA (Orthogonal Frequency Division Multiple Access), SCFDMA and MIMO (Multiple Inputs multiple outputs) antenna systems so as to communicate. OFDMA is a packed sub carrier of low rate data overlapping with each other in a frequency domain. It was imagined that they can overlap with each other as shown in figure but as they were orthogonally (90˚) separated, the chance of interfering with each other reduces and thus it allowed the use of same bandwidth without interference, also increase the efficiency [5], [11].

A thorough frame structure of OFDMA radio downlink LTE (DL LTE) can be seen in the figure [32]:

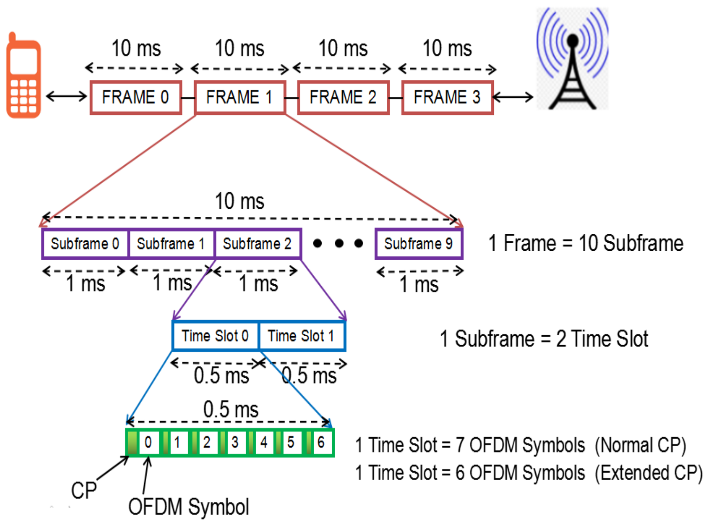

Fig. 2 Resource Block Allocation Structure

OFDMA radio frame is the largest radio resource unit in Down-Link (DL) that has 10 blocks or sub-frames (0-9). Each sub-frame (block) has duration of 1ms. The least allocable element in Scheduling is observed to as slot (frame) and also known as Transmission Time Interval (TTI). Each frame gets further fragments into 2 consecutive resource Blocks (RBs) of 0.5 msec. Further, these R-Blocks get fragmented into 12×7 matrixes like format, where the vertical dimension denoted with frequency domain and the horizontal with the time domain. On frequency domain side the R-Block is divided into 12 subcarriers having 15 kHz sub-carrier spacing in every element, thus to hold a total of 12×15(180) kHz, and on time domain side it gets fragmented into 6 or 7 OFDM. The selection of 6 or 7 OFDM on time domain side based on which the kind of extension in the cyclic prefix get selected i.e. normal or extended. If the normal extension is chosen then the 12×7(84) resource elements is formed per R-Blocks and if the Extended one is selected then 12×6(72) resource elements are formed per R-Blocks [6], [28]. The work of these extensions is to perform as guard interval among the two successive symbols and work in the direction to remove the unused inter-symbol interference (ISI), is a kind of deformation signal in which one symbol interferes with successive symbols, this problem occurs when the signal propagates through multiple paths [5]. The 15 kHz i.e. the frequency of one resource element is given to particular User equipment (UE) and this is done through resource allocation process, these were described in LTE-A section [14], [39].

OFDMA is the common technology used in both LTE and LTE-A. As this OFDMA technology is used in both femto and macro cell nodes [9]. This usage of same technology sometimes leads to the issue of interference in between these 2 cells; interference is of various types as described in the small cell section. The methods used to mitigate the interference are described in following figure [17]:

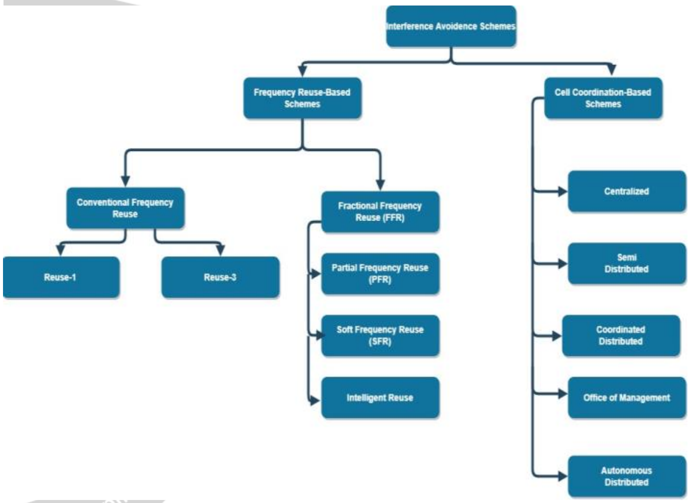

Fig. 3 Interference Mitigation Methods

The solution chosen from the above-justified figure is- interference Avoidance Scheme- and further in that the main discussion is on (Frequency Reuse) FR-Based methods.

FR-Based Scheme

The reuse of frequency mechanism comes into existence when a question of inter-cell interference (ICI) or co-channel interference comes into existence [6]. The issue of ICI is because of increase in the number of user in a specific cell or area which increases the traffic load on the node, which further degrades the quality of services in the cell [7]. Before the issue of co-channel interference, the nodes have unlimited access to use the whole bandwidth as 1 and there was no requirement to fragment the frequency or bandwidth as the number of users was very less. This frequency reuse based schemes were further classified into 2 parts [12]:

1. Conventional frequency reuse

The most basic one and most widely used in CDMA (Code

 DOI : 10.35291/2454-9150.2019.0390

Division Multiple Access) for allocating the frequencies in a cellular network, is to take the whole provided bandwidth as one and use this frequency in each sector for the user without implying any kind of restriction on it [29]. This approach benefits only to the user near to the node, not to the extreme ones i.e. cell edge users. This approach is studied to be the Reuse-1. That further increases the issue of ICI in the cell [30].

Reuse-3

The frequency reuse factor-3 defines that fragmenting the allocated geographical area for the allocated band in such a way like suppose if the reuse factor is 3, divide in the area in a group of 3 and named that as a sector [25]. Use the fragmented frequency in a sector in such way that the 2 adjacent cells don't get the same frequency, and in given geographical area also the 2 adjacent cell is not to be permitted, to use the same frequency as it leads to ICI (Inter-Cell Interference). The cells or sectors which are significantly far from each other can reuse the same frequencies [35]. Though it reduces the ICI (Inter-Cell Interference) but the utilization of bandwidth is low, it uses only 1/3 of the total resource because of the restriction imposed on reusability of allocated resource. So the FFR method is proposed for proper utilization of allocated bandwidth [36].

2. Fractional Frequency Reuse (FFR)

The FFR is proposed to fragment the provided bandwidth or the cell in 2 parts named as a major & minor groups [1]. The major group is used to entertain the user which is far from the node especially the user at the extreme end and the minor group is used for the users nearer to the node. The purpose of using the FFR is for the fulfilment of some basic needs of user like: - to mitigate the interference on edge user from the neighboring cell, Interference to the interior cell user from the user in the exterior cell of a same macro cell, proper utilization of allocated spectrum [26].

3. Partial Frequency Reuse (PFR)

PFR has some of the frequencies in its reserve in a condition that it can use that resource in further need of time and it is meant not to be used in other sectors [6]. The remaining frequency is used to enable quality service to the user. Let suppose the total bandwidth provided γ and it is further divided into A and B, A uses the frequency reuse of factor 1 in minor region and B uses the frequency reuse of factor 3 in the outer zone or the major region. The prediction in this case for effective frequency reuse factor is $\frac{\gamma}{A+\left(\frac{B}{3}\right)}$, which shows that the effective reuse factor for partial frequency reuse will always be grater then 1 [17]. While allocating the frequency in minor region or cell, coordination between the neighboring cells is done in response to put a curb on Inter-cell Interference [35].

4. Soft Frequency Reuse (SFR)

In case of FFR the whole spectrum was fragmented into 2 parts i.e. the major and minor subcarriers. The minor subcarrier is used in the areas nearer to the nodes, they have lower transmitting power as compare to major subcarriers and major subcarrier are used for the user in the extreme edge with a higher transmitting power [1], [9]. The vital reason for using the SFR is, in this major region subcarrier frequency can be used by the users that are present in minor region but has a low priority as if the resources are not used by the user in major region then only the minor region user can use it but the transmitting power has to be low [33]. But the frequency in the minor region is only used by the users present in this region only. The major region subcarriers are orthogonal to the neighboring major region subcarriers. In SFR the power ratio is termed as the ratio among major and minor subcarrier. The loss of spectrum efficiency is negligible as the frequency reuse factor used is very less nearer to 1 [34]. This achievement is because of power control method used for the users which uses the similar bands. Low power allocation in the minor region and high power is allocated to the major region [36].

II. CONCLUSION

In this paper, we tried to provide an overview of new communication technology which was required to develop and established as per the requirement of user. Primarily we described reasons behind to design this new technology with its background detail and organization structure. In further section described brief introduction of LTE network architecture, OFDMA structure and its entities. Major problems like ICI, Cell edge problems, throughput enhancement, coordination environment and small cell deployment are described in detail with the advancement in LTE to LTE-Advanced. Concluded with this for the improvement in LTE system LTE-A is a key step to enhance the system throughput, spectral efficiency, cell edge problem and frequency reuse problem.

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