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LTE-Advanced: Requirements and Technical Challenges for 4G Cellular Network

[1] Muhammed Mustaqim, [2] Khalid Khan , [3] Muhammed Usman

[1,2] College of Computer Science and Engineering. Pakistan Air Force Karachi Institute of Economics and Technology, Pakistan
[3] EPE, Pakistan Navy Engineering College, National University of Science and Technology, Pakistan

[1] abacus82@gmail.com , [2] mkhalidkhan@gmail.com, [3] musman@pnec.edu.pk

ABSTRACT

The higher peak data rates for mobile user are in demand. Audio/Video streaming, online conferences, and social media services are becoming the necessity of life. In order to fulfil the sheer amount of data need of users, robust and efficient wireless technology is needed. LTE-Advanced, which is based on Rel-10 of ITU is the solution for future mobile wireless networks. It is the promising technology for future wireless broadband network based on Rel-8 of Long term Evolution (LTE). The paper provides a higher level overview of LTE-Advanced, which includes carrier aggregation for efficient spectrum use, MIMO techniques for multiple signal transmissions and receptions, relaying and heterogeneous deployment strategy. LTE-Advanced system will be the NXGN wireless technology for years to come.

Keywords: *LTE-Advanced, Heterogeneous Network (HetNet), Multiple Input Multiple Output (MIMO), and Carrier Aggregation.*

1. INTRODUCTION

The requirement for higher data speed is exponentially increasing, main reason being the availability of smart phones, at low cost and social networking websites. Constant improvement in wireless data rate is in demand. Long Term Evolution-Advanced (LTE-A) is the solution for wireless broadband services. LTE-Advanced also known as 4G wireless networks and it is an evolution of LTE Rel-8. IMT-Advanced (International Mobile Telecommunication-Advanced) refer to a family of mobile wireless technologies, which is also known as 4G. In 2010, LTE-Advanced/4G is ratified as IMT-Advanced technology. It will allow the cellular provider to complement their 3G services by offering higher data rates, lower latency and packet –based network. Fig 3 shows the evolution of cellular technology [21]. The standard for LTE was first published in 2005 as Rel-6 by 3GPP (third generation partnership project) since then LTE-Advanced standard been in development and finally in March 2009 it was finalized by 3GPP. Table 1 provides an overview of LTE-Advanced items and its requirements. There are significant amount of improvement that were made to be qualified as LTE-Advanced. In order to achieve this significant changes are made in both the air interface and the network architecture [1] [2].

To improve the user experience 3GPP is considering various aspects which include higher order MIMO, carrier aggregation, and a deployment strategy called heterogeneous network HetNet in fig 2. HetNet combines macro-cell, microcell, relays, Pico-cell, and Femto-cell deployment in a single cell to increase spectral efficiency per unit area. It will also provide better broadband experience in a cost effective manner to users [4]. The 4G technology can also significantly increase the spectral efficiency by adapting carrier aggregation that supports the bandwidth from 1.4MHz to 20MHz. In carrier aggregation multiple component carriers can be jointly used for transmission to/from user equipment. It is done such a way that it will be compatible with the previous releases of LTE [3].

Previous releases of LTE support the use of MIMO antenna system, fig 1 where multiple antennas can be use for transmission in uplink and downlink. LTE supports up to 4 X 4 configuration but it can be enhanced to 8 X 8 for LTE-A which can be use to increase peak data rates through bandwidth expansion.

Table 1: LTE Requirements

Technical Items	**LTE-Advanced, IMT Requirement**
Downlink peak data rates	1 Gbps (low mobility 15 km/hr)
Uplink peak data rates	500 Mbps (low mobility 15 km/hr)
Bandwidth	Scalable up to 100 MHz
User plane latency	10 ms
Control plane latency	50 to 100 ms
Uplink peak spectral efficiency	15 bps/Hz
Downlink peak spectral efficiency	30 bps/Hz
Access Scheme	OFDMA

The denser deployment of low power relaying nodes can decrease the distance between transmitter and receiver, hence providing higher peak data rates can be achieved. Traditional relays can simply amplify and forward the signal that it receives regardless of the node presence but smart relays can be adapted that will only relay information in the presence of the user. Even user equipment can be use as relay, like in Wireless Ad Hoc networks (WANET) [4]. Like the predecessor technologies, LTE-A is not based on CDMA (code division multiple access), it uses OFDM (Orthogonal frequency division multiplexing) as an air interface. LTE-Advanced has several key features: Peak data rates up to 300Mbps on downlink and 75Mbps on uplink, mobility support up to 300km/h to 500km/h, latency as low as 5ms, more than 200 users per 5Mhz cell, supports both FDD (frequency division duplexing) and TDD (time division duplexing), bandwidth flexibility up to 20Mhz, and MIMO support from 2 X 2 to 4 X 4 modes. Since the network is all packet based it reduces control plane latency compare to its predecessor technologies [6].

LTE-Advanced is based on several technology components includes, relaying, carrier aggregation, MIMO (multiple input multiple output), and HetNet (Heterogeneous networks) [4]. These components will enable the users to take advantage of 4G Cellular networks by guaranteeing quality of service (QoS), higher throughputs, and low latency.

2. TECHNOLOGICAL COMPONENTS AND CHALLENGES IN LTE-ADVANCED

LTE-A is also known as 4G wireless technology. It guarantees low latency, higher data rates, and all IP-based networks. There are 4 major technology components which enable LTE-A to become the Standard for Wireless broadband technology. 4 major components are Carrier aggregation, MIMO mode, Heterogeneous network, and relaying. Higher data rates as per Rel-10 can be possible by adaptation of smart antennas like MIMO (multiple input multiple output) which uses beam-forming and spatial multiplexing techniques to achieve peak data rate of 300 Mbps, aggregation of multiple LTE component carrier on the physical layer to provide necessary bandwidth to preserve spectrum compatibility, and adaptive modulation and coding schemes like QPSK and 16 QAM improves cell-edge coverage and active radio link bit rate. [1]

LTE-advanced aims to support and increase a downlink peak spectrum efficiency of more than 15bps/Hz for eight antennas (MIMO 8x8) and an uplink spectrum efficiency above 7bps/Hz with four antennas (MIMO 4x4). As compare to LTE rel-8, antenna numbers are twice. The use of beam-forming technique allows the use of antenna arrays to improve cell-edge coverage. CoMP (coordinated multipoint transmission and reception) is based on cooperation between different base stations using fast backhaul network in order to significantly improve the interference situation and thus overall system performance. In CoMP, relay node is connected to a donor cell (eNodeB or smart base transceiver system) via the Un interface and mobile set is connected to the relay node (RN) via Uu interface. RN is usually a separate cell with own physical cell ID, synchronization channels, reference symbols, and etc. Mean while carrier aggregation increases the transmission bandwidth with multiple carriers, whether being contiguous (close to each other) or not. This way HARQ (hybrid automatic repeat request) retransmission can be performed independently per component carrier.[2]

LTE-Advanced is the all IP based cellular networks that can offer higher user data rates and lower latency. In LTE-Advanced lower latency can be achieve by adopting terminal state of being idle or active which can significantly reduce control plane latency and signaling compare to earlier generation. Higher user data rates can be achieve by adopting several techniques including: MIMO support, Modulation techniques like OFDM, bandwidth flexibility, and the support of FDD (Frequency Division Duplex) and TDD (Time Division Duplex) modes of operation. The future techniques include carrier aggregation, high order MIMO and deployment of heterogeneous networks. Heterogeneous networks fig 2 will become the key feature in terms of deployment, because it blends macro-cells to Pico-cells, metro-cells, relays and Femto-cells. With the help of HetNet, user can enjoy broadband experience in cost-effective manner. In HetNet, load balancing can be easily done with the deployment of Femto or Pico cells.[3]

High peak data rates involve the enhancement in the current deployed broadband networks like LTE Rel-8 with adaptation of heterogeneous networks which is not a technology component rather a technique i.e. how to deploy networks that has both wide area ns local area, relaying is to bring transmitters and receivers closer to each other to improve coverage and data rates, and smart antennas techniques like MIMO with 4X4 configuration with 64QAM to achieve the desired data rates as per ITU requirement. Carrier aggregation increases bandwidth and the maximum peak data rates for LTE-Advanced air interface while preserving the compatibility with LTE previous releases and legacy cellular system.[4]

To overcome and achieve the desired peak data rates of 1 Gbps DL, some technology changes are needed in Rel-8, which includes Carrier aggregation, Enhanced Multi-antenna support, and relaying. Transmission bandwidth can be significantly increased by aggregating multiple carrier components. It allows the exploitation of bandwidth by UE (user equipment). It also reduces UE power consumption by MAC signaling from base station to UE while receiving a single component carrier. SFBC (space-frequency block coding) is use for two transmitted antenna at downlink and FSTD (frequency-switched transmit diversity) is use for four transmitter antenna at downlink. Downlink in LTE-Advanced is enhanced to support eight antennas for downlink. Heterogeneous

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network is a deployment strategy not a technology component. It reduces the overall traffic from macro cell and improves cell-edge coverage. In relaying, UE communicates with the network using RN that is wirelessly connected to donor cells using LTE radio technology.[5]

The key component that guarantees higher throughput and lower latency for Rel-10 LTE-Advanced includes, carrier aggregation which joins multiple carriers components for transmission. There are three cases in carrier aggregation, includes intra-band aggregation with contiguous carrier, inter-band aggregation, and intra-band aggregation with non contiguous carrier. Intra-band aggregation with non contiguous carrier allows higher user data rates by using fragmented spectrum. Multiple antenna system in LTE-Advanced supports eight layers of transmission with the help of spatial multiplexing. Heterogeneous network deployment strategy is use to overcome cell-edge performance by adapting frequency and time domain scheme. Frequency domain scheme is used to separate control signaling for different cell layers. On the other hand, time domain scheme in heterogeneous deployment uses control signaling in the different cell layers to handle interferences.[6]

2.1 MIMO (Multiple Input Multiple Output) System in LTE-Advanced

In LTE-Advanced design, support of multiple antenna system is necessary to achieve data rates of 100Mbps in downlink and 50Mbps in uplink within a bandwidth of 20Mhz. The key requirement for LTE mobile station has a minimum requirement of 2 antennas for uplink and 2 antennas. The concept of multiple antenna system had been used for radar system but to achieve higher data rates in mobile communication is becoming popular, fig 1 gives broader picture of 2X2 MIMO antenna system, up to 8 antennas for downlink and 8 antennas for uplink can be adapted for LTE-Advanced to increase throughputs along with adaptive modulation and coding schemes. It can be denoted as 8 X 8 configurations. The access technology which can be used along with MIMO is orthogonal frequency division multiple access. The use of MIMO allow us to obtain additional transmit/receive diversity or to get spatial multiplexing to improve data rates.[7] [8]

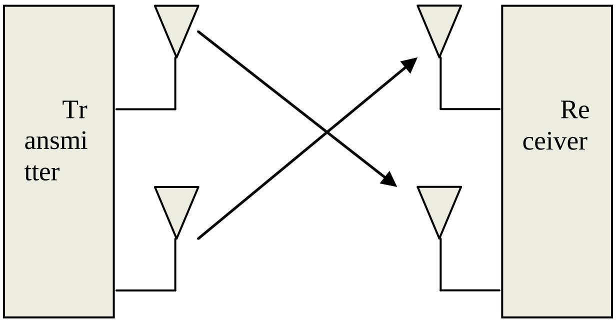

Fig 1: MIMO System in 2 X 2 Configuration

The main physical layer component in LTE-Advanced and previously releases is the use of MIMO (multiple input and multiple output) antennas to improve the overall performance of the system, [7] suggested the use of 2 X 1 and 2 X 2 antenna configuration along with (Orthogonal frequency division multiple access) OFDMA and SC-OFDMA (single carrier-orthogonal frequency division multiple access) for downlink. Space-time blocked code called Alamouti code for 2 X 2 antenna configuration to achieve the transmit diversity using redundancy in spatial and frequency domain. It is the only code that increases data rate without sacrificing the diversity gain. The idea is to jointly choose the MIMO transmission scheme and modulation/coding scheme based not only on the channel quality as determined by signal-to-noise ratio (SNR), but also on the mobility information.[7]

Multiple input multiple output technologies will improve downlink peak data rates, cell coverage, as well as average throughput of the cell. The SU-MIMO (single-user multiple input multiple output) , MU-MIMO (multiple-user multiple input multiple output), and dedicated beam-forming schemes are suggested to achieve the peak data rate. This is achieved by applying the spatial domain pre-coding on the transmitted signal taking into account the pre-coding matrix indicator reported by the user equipment. The pre-coding matrix is determined by OFDM, which enables multiple antennas to use the same transmitted power regardless of whichever pre-coding matrix which is used. Pre-coding codebook is generated for transmission of four antenna array. The use of spatial multiplexing with antenna configuration of 8 X 8 for downlink transmission and 4 X 4 for uplink transmission is being investigated.

2.2 Heterogeneous Networks and Relaying in LTE-Advanced

Decode and Forward Relay Nodes (RNs) is one of the easy ways to increase the SINR (signal-to-Interference-plus-Noise-Ratio) at the cell edge, which is based on multi-hop technologies like wireless ad-hoc networks. Enhancement in radio link technology will not solve the basic problem related to propagation loss; coverage and capacity at the cell border remain relatively small due to low SINR. To cater the problem of cell coverage and capacity, Relay Nodes (RNs) near the cell edge can be deployed to extend both the capacity and the coverage area. Conventional Amplify and Forward (AF) relays can also perform the task of coverage and capacity but related to interferences which also get amplifies along with the signal so, an alternative solution is the use of Decode and Forward (DF) Relays. DF relays detect the desired signal then encode and forward it, thus improve the capacity of the system.[9]

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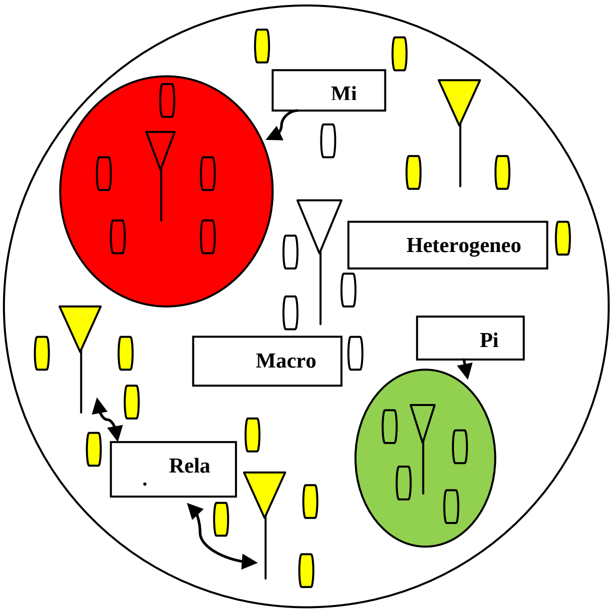

Figure 2: Overview of Heterogeneous Deployment with Relaying

Mechanical relaying where mobile nodes store and carry the information before it relay it to other nodes or BS, can resolve problems dealing with data capacity, and etc. In traditional relaying, mobile and fixed relay nodes get deployed, where messages get forwards as it receives, while in mechanical relaying nodes might delay forwarding of the message which allows highly coordinated transmission between multiple user like pedestrian node or mobile node. The use of mechanical relaying will benefit in terms of reduced energy consumption, increased spatial capacity, reduced co-channel interferences, load balancing, and better network utilization. Energy consumption can significantly improve using mechanical relaying that will allow the relay node to transmit during the good channel and network condition. Spatial capacity can be improve by employing (AMC) adaptive modulation and coding schemes. Co-channel interference can be reduced by allowing localized transmission where a node waits for mobile node to send the message to next node or BS (base station). Load balancing in traditional cellular networks is mainly achieved using the concept of cell-breathing where cell area is adjusted according to utilization but through mechanical relaying it can be achieve using node mobility to decongest highly utilized cell without affecting the cell coverage. Network utilization can also be achieved by turning off less utilized BSs.[10]

Relaying is one of the most effective and enabling component of the LTE-A standard, that will improve the data rate significantly, Wireless Terminals (WTs) to act as relays to other WTs in addition to transmitting their own signals. IWF (iterative-water filing) algorithm can be autonomously applied by the WTs to allocate their powers in a way that maximizes their instantaneous capacities. How to have fairness between different WTs requires the adaptation of joint scheduling and routing (JSR) algorithms. The design of distributed JSR schemes maximizes the network throughput without requiring feedback from the nodes. Fairness is a crucial aspect that must be considered in the joint design of scheduling and routing algorithms. In terminal relays, global fairness is hard to achieve because nodes can only communicate with immediate neighbor. Local fairness can be achieved by maximizing the harmonic mean rate of each wireless terminal.[11]

2.3 Carrier Aggregation and Handover Scheme in LTE-Advanced

CA (Carrier aggregation) defines as the use of multiple component carrier usage to transmit and receive signals from UEs in fig 1. There are two types of carrier aggregation techniques have been suggested for LTE-Advanced. First, continuous or contiguous CA use multiple carrier components adjacent to each other, second non contiguous CA, uses components that are non-adjacent and spread out in the frequency band. Continuous CA can be achieve with the help of single fast Fourier transform (FFT) using a single radio frequency, it can also provide backward compatibility with previous releases of LTE. Carrier aggregation can also resolve handover problems; it is done using continuous CA to support the continuity during the handover process across multiple cells. In non-continuous CA, component carriers required a guard between to make the interferences between the frequencies to be negligible. It is necessary for both the continuous and non-continuous CA to setup a guard-band to minimize intra and inter band interferences.[19]

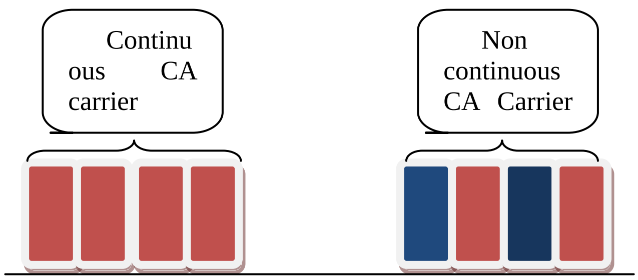

Fig 3: Continuous and Non Continuous CA carriers

Latency in IMT-Advanced systems requires advanced handover schemes called like EBB (entry before break). To support both the current and legacy technology of 802.16 three deployments scenarios were discussed green field, mixed deployment with carrier reuse, and mixed deployment with carrier overlay. In mixed deployment the frame structure is partitioned into LZone (legacy) and MZone (current) in time-division fashion.

Advanced handover schemes suggested as follows: Seamless handover in which the MS is able to

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exchange (send or receive) data packet data units (PDUs) with the target BS before initiating a network reentry control message transaction, In EBB, An MS (mobile station) disconnects from the serving BS before executing handover at the target BS (base station) in BBE handover. This implies that data interruption due to handover occurs right after handover execution. When performing EBB, based on its capability, the MS performs network re-entry at the target BS during the negotiated network re-entry procedure intervals, while maintaining communications with the serving BS for data exchange up to the point of completion of network re-entry at the target BS. Thus, interruption occurs only during the negotiated network re-entry procedure intervals at the target BS, which can be finely scheduled to minimize the total interruption time during handover. In Legacy support handover, MSs with multicarrier capability can perform seamless handover by keeping connection with the serving BS and performing handover (i.e., network re-entry) at the target BS in a parallel manner. Hence, this feature and capability allow zero tolerant data interruption time during handover.[18]

2.4 Comparison with WiMAX and LTE

WiMAX stands for "World Interoperability for Microwave Access", it is based on IEEE 802.16 and is similar to WiFi/IEEE 802.11 networks with the coverage and QoS (quality of service) of cellular networks. It operates on both the licensed and un-licensed band compare to WiFi, which only operates in ISM band, thus reducing interferences problem. It can provide broadband services up to 30 miles using fixed stations and 3-10 miles on using mobile stations. LTE and WiMAX are parallel wireless broadband technologies. Table 2 provides comparison between LTE-Advanced and WiMAX [20]. Earliest versions of WiMAX focuses on Line of sight propagation (LOS) based on TDMA, but 802.11e provides non-line of sight propagation based on OFDMA (NLOS). On the other hand, LTE-Advanced has evolves from WCDMA and define the evolution of UMTS. It is also based on OFDMA for downlink and SC-FDMA for uplink.

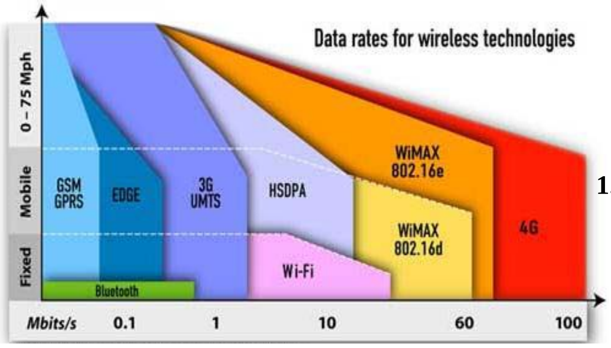

Fig 3: Gives an Overview of Wireless Technology [21].

Better radio interface means better performance, LTE radio interface make use of multi-antenna techniques along with OFDM to overcome the performance issues. LTE uses both FDD and TDD along with multiple antennas. This technique significantly increases the performance of LTE radio link in cell and cell edges.[15]

Table 2: Comparison between WiMAX and LTE-Advanced

Attributes	LTE	WiMAX
Network	WiMAX "IP based"	Evolved UTRAN based on UMTS
Access Schemes	SC-FDMA = uplink OFDMA = downlink	OFDMA = uplink and downlink
Band of Operation	700MHz, 1.9 GHz, 2.1 GHz	2.3 GHz to 5 GHz
Cell radius	5 Km	2-5 Km
Bandwidth	1.4 to 20 MHz	5, 8.75, 10MHz
Cell Capacity	200 to 400 depends on Bandwidth	100-200
MIMO antenna	Up to 4 Tx, 4 Rx	2 Tx, 2 Rx
Compatibility	IEEE 802.16a to d	GSM, UMTS, HSPA
Spectral efficiency	3.75bits/sec/Hz	5bits/sec/Hz

High speed data services availability on mobile devices is only possible with the deployments of WiMAX or LTE. These two key technologies guarantee data rates at cheaper cost to the user. WiMAX is basically designed to provide the broadband wireless connectivity to fixed and nomadic users for the last mile. The coverage can go up to 50 Km, allowing user to get broadband connectivity in NLOS conditions. It uses OFDMA as an access technique that allows data rates up to 75 Mbps. It is an IEEE standard 802.16e. LTE is evolved for UMTS cellular technology. It also uses OFDM technique and supports different carrier frequency bandwidths in both FDD and TDD modes. It is a 2 node architecture means only 2 nodes are involved between the user equipment and the core network.[16]

1.1.1 2.4.1 Radio Access of Air Interface

Both the technologies uses MIMO (multiple-input, multiple-output) antennas but the difference is in the uplink antenna configuration of WiMAX, which only uses single antenna system for uplink.[16]

1.1.2 2.4.2 Protocol Architecture

In WiMAX, protocol is two-layered: physical (PHY) and media access control (MAC). Every layer relies on their services provided by layer below. In WiMAX, the MAC layer is future divided into 3 sublayers. On the other hand, LTE protocol architecture is similar to WiMAX but it uses first three layers of OSI model. The radio link specific protocols, including radio link control (RLC) and medium access control (MAC) protocols are terminated in the eNB.[16

3. LTE – ADVANCED/4G BENEFITS AND DEPLOYMENT

4G cellular networks should significantly lower the bit rate cost for consumer as well as the operator. It can increase the data rates, coverage area, and cell-edge performance. Being an all IP-based network, it will provide best (quality of service) QoS. The main benefit comes in terms of spectrum efficiency; using techniques like carrier aggregation can significantly increase the spectrum efficiency. LTE-Advanced allow the users to experience same data rates wirelessly as they will experience using wired networks. LTE-Advanced deployment will provide worldwide functionality and resolve roaming issues, services compatibility, interworking with other radio network access system, and enhanced data rates to support advanced services like audio, video streaming for nomadic and mobile users with guarantee.

LTE-Advanced deployment will be in different frequency band for different country. Sweden is the first to test 4G deployment on a small scale. According to Sprint (the 3rd worldwide telecom carrier), LTE-Advanced will be deployed by mid-2012 using 800 MHz band, and by 2013 it will serve 250 million user by the mid of 2013. LTE-Rel-8, is previously deployed by both Verizon and AT&T, but Sprint will be making a switch from WiMAX to LTE-Advanced, $600 million dollars are required to launch LTE-Advanced network. Sprint will continue to operate its 3G CDMA/EV-DO for voice and 4G for data services. Sprint will soon offer VoLTE (Voice over LTE)to deliver phone calls and data services on LTE-Advanced. AT&T is planning to expand its LTE deployment into 15 markets by the end 2012. Verizon has expanded his LTE network into 178 markets. Both AT&T and Verizon have launched LTE network based on LTE-Rel-8, and will deploy LTE-Advanced network by the end of this year. From LTE to LTE-Advanced not much of an infrastructure change is required. AT&T and Sprint will deploy LTE-Advanced by the end of 2013 and Verizon is not sure of the deployment of LTE-Advanced. The deployment of LTE-Advanced is done by deploying LTE network and enhancing it to LTE-Advanced. LTE-Advanced can be deployed in different frequency band. LTE-Advanced will be commercially available in North America by 2015. LTE-Advanced will be compatible with the previous versions of LTE, and LTE older devices can be operated on LTE-Advanced network.

4. CONCLUSION AND OPEN ISSUES

The paper provides an overview of LTE-Advanced and its technological components that had been considered for 4G cellular system. Carrier Aggregation and multiple antennas techniques are based on LTE Rel-8, but coordinated multi-point transmission and reception (CoMP), relaying and Het Net are still open issues. These components can surely fulfil the requirement of 1Gbps downlink and 500Mbps uplink data rates. Cell-edge performance can be tremendously improved with the deployment of low power relay nodes within a cell network. Carrier aggregation can make use of spectrum very efficiently by aggregating multiple carrier with the help of Orthogonal Division Multiple access scheme.

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