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LTE Advanced: The 4G Mobile Broadband Technology

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ABSTRACT

By the design and optimization of upcoming radio access techniques and a further evolution of the existing system, the Third Generation Partnership Project (3GPP) had laid down the foundations of the future Long Term Evolution (LTE) advanced standards-the 3GPP candidate for 4G. This paper offers an overview of the research work carried out to meet the requirements of 4G. The various technology components like wideband transmission and spectrum sharing, multiantenna solutions, coordinated multiple transmission/reception (CoMP) and relaying, introduced to meet the requirements for LTE Advanced systems, have been discussed.

General Terms

LTE-Advanced, Long Term Evolution, spectrum utilization, cell edge throughput.

Keywords

LTE, LTE-Advanced, Carrier Aggregation, Coordinated Multiple Transmission/Reception, Relaying.

1. INTRODUCTION

Wireless systems can be broadly classified into two groups based on the requirements of high speed mobile wireless access services. Figure 1 shows the classification.

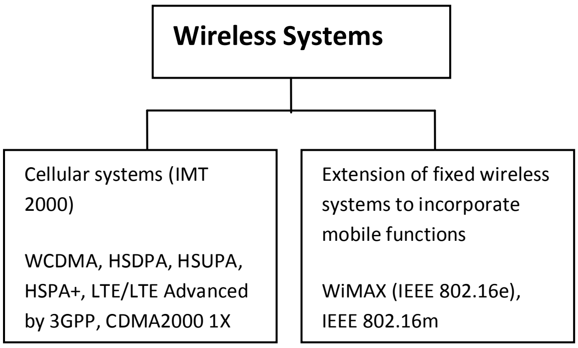

Figure 1: Classification of wireless systems

The up growing trend of data communication via mobile phones had led to the anticipation for mobile communication systems featuring higher bit rates and greater capacities. Hence studies have been carried out on 3.9G a mobile communication system which is advancement to 3G mobile communication system IMT2000. Table 1 lists the basic requirements of 3.9G mobile communication systems [1].

UMTS LTE system was designed to provide high peak data rates, low latency, improved systems capacity and coverage, multiple antenna system support and seamless integration with existing systems like WCdma, HSUPA, Cdma2000 1X etc.[2]. Substantial improvements to LTE resulted in meeting and even surpassing the IMT-Advanced requirements as defined by ITU-R [3].

Table 1. Basic Requirements of 3.9G Mobile Communications System

Maximum bit rate	Downlink: 100 Mb/s or greater Uplink: 50 Mb/s or greater
Spectrum usage efficiency	≥3 (downlink), ≥2 (uplink) times 3.5G (HSPA release 6)
Occupied bandwidth	Scalable bandwidth
Network	All-IP network
Extendibility of future systems	Smooth extendibility to 4G mobile communications system
Transmission quality	Shorter delay than current 3.5G
Global scope	International roaming and interoperability

LTE-Advanced should guarantee backward compatibility and interworking with LTE release 8 in the sense that it can be deployed in the spectrum already occupied by LTE with no impact on existing terminals [4].Table 2 lists the basic requirements of LTE and LTE Advanced [1].

Table 2. Main requirements of LTE, and LTE-Advanced

	LTE		**LTE-Advanced**	
	Downlink	***Uplink***	***Downlink***	***Uplink***
Peak spectrum usage efficiency (b/s/Hz)	>5	>2.5	30	15
Average spectrum usage efficiency (b/s/cell)	1.6-2.1	0.66-1.0	2.4-3.7	1.2-2.0
Cell-edge spectrum usage efficiency (b/s/user)	0.04-0.06	0.02-0.03	0.07-0.12	0.04-0.07
Operating bandwidth (MHz)	1.4-2.0		Up to 100	
User plane delay (unidirectional) (ms)	<5		<5	
Connection setup delay (ms)	<100		<50	

LTE-Advanced is expected to target substantial improvement in spectral efficiency and reduction in latency, i.e., reduction in transition time from idle to active mode to about 50ms in LTE Advanced system as compared to that of 100ms in LTE systems. To meet these requirements few physical layer enhancement techniques like carrier aggregation, coordinated multiple transmission and reception, relaying, uplink and downlink multiplexing of up to 4 and 8 antennas respectively, had been considered [5]. 3GPP had described these technology components in [6].

This paper is organized as follows. In section 2 we discuss the wideband transmission and spectrum sharing schemes for LTE-Advanced. Multiple antenna solutions are mentioned in section 3. Section 4 describes the coordinated multipoint transmission and reception techniques. Section 5 describes the advanced repeaters/relaying schemes. Finally, conclusions are provided in section 6.

2. WIDEBAND TRANSMISSION AND SPECTRUM UTILIZATION

LTE-Advanced should support significant increase in peak data rates [7] up to 1Gbits/s in the downlink and 500Mbits/s in the uplink. To support very high peak data rates we need to further increase the transmission bandwidth to up to 100 MHz. This can be achieved with carrier aggregation. S. Parkvall et al. have shown as in Fig. 2, how LTE-Advanced terminals would exploit the total aggregated bandwidth of 100MHz [4]. Here several smaller contiguous and noncontiguous carriers can be aggregated while maintaining the backward compatibility with the legacy users. Five 20MHz component carriers can be aggregated to form 100 MHz system. This way the legacy spectrum which is being used by present operators (Vodafone, AT&T etc.) will be efficiently utilized and at the same time new frequency bands can also be utilized. Example: 40 MHz system can be deployed using 2 x 20MHz carriers in UMTS band 7 (2.6 GHz).

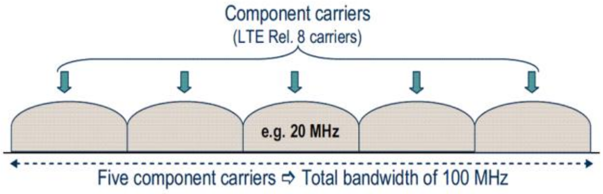

Figure 2: Carrier aggregation.

The same system may then be accessed by legacy users by making use of one of the component carriers. S. Parkvall and D. Astely of Ericson Research group had studied how carrier aggregation operates at different protocol layers. This is represented in Fig. 3 [8].

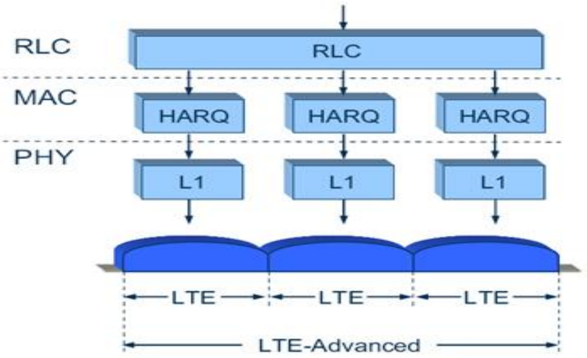

Figure 3: Carrier aggregation at different protocol layers.

3. MULTIPLE ANTENNA SOLUTIONS

Multiple antenna techniques play an important role in increasing the spectral efficiency. Advanced multiple antenna solutions help the emerging 4G cellular technologies like LTE-Advanced and WiMAX to achieve superior peak data rates over the air interface (e.g., in excess of 100 Mbps for DL and 50 Mbps for UL). LTE advanced specifies up to 8 layers in the downlink, which enables the 8 x 8 spatial multiplexing in the downlink. This will require 8 receivers in the UE. Similarly UE will be required to support up to 4 transmitters to enable 4 x 4 transmissions in the uplink when combined with 4 eNB receivers. UE specific demodulation reference signal (DMRS) pattern, defined in LTE systems, should be changed in order to support up to 8 antennas in LTE-Advanced systems. Further need arises to modify the channel state information reference signals (CSI-RS) and UE feedback in the CSC codebook design. Equivalent changes for downlink control system will have to be incorporated to meet the LTE-Advanced requirements.

Release 10 emphasizes on dual layer spatial multiplexing augmented by 4 antenna beam streaming as compared to pure 8 layer spatial multiplexing approach. This would offer higher peak rates but would also require 8 receive antennas in the UE for LTE-Advanced systems [9].

4. COORDINATED MULTIPOINT TRANSMISSION AND RECEPTION (CoMP)

The target values of peak spectrum efficiency for LTE-Advanced systems were set to 30bps/Hz and 15 bps/Hz in downlink and uplink transmission, respectively. Apart from the multiple access schemes, enhanced multiple-input multiple-output (MIMO) channel transmission techniques and extensive coordination among multiple cell sites called coordinated multipoint (CoMP) transmission/reception were accepted as the key techniques for LTE Advanced at the Technical Specification Group- Radio Access Network (TSG-RAN) Working Group 1 (WG1) meeting in the 3GPP [10]. Spectrum efficiency can be improved with multiple antenna technologies (4 or more antennas) using spatial interference coordination methods. This concept led to the new multi-antenna technology components: uplink & downlink transmission schemes and CoMP.

Coordinated multipoint transmission and reception involves transmission/reception of signals to/from user equipments (UEs) located at multiple cell sites. In the research article on Next Generation Wireless Broadband Technology, A. Ghosh et al. had shown how CoMP interconnects antennas deployed at a number of sites that are in proximity to one another [11]. The 3GPP Technical Report on further advancements of E-UTRA physical layer aspects mentioned that the base station coordinated scheduling and beam forming (CSB) and joint processing and transmission (JPT) are the ways in which coordination is carried out in Cooperative multipoint transmission [12].

Fig. 4 shows how the coordination of signals transmitted from multiple cell sites is carried out to significantly increase the downlink performance of a system [13].

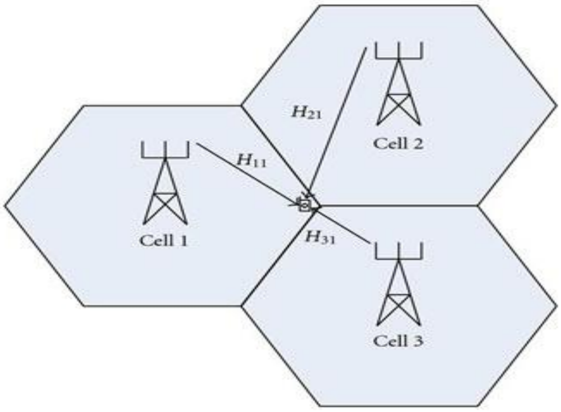

Figure 4: Coordinated multipoint transmission in downlink.

4.1 Downlink CoMP Transmission

It has been proposed that apart from the downlink CoMP transmission schemes like joint processing (JP) and coordination scheduling/beam forming (CS/CB) transmission schemes, more advanced CoMP transmission schemes, when combined with MIMO multiplexing techniques, improve the capacity and the cell edge user throughput [14]. In CoMP transmission the related control channels including the physical downlink control channel (PDCCH) are transmitted only from the serving (anchor) cell irrespective of the transmission scheme [10].

Joint transmission (JT) and Dynamic Cell Selection (DCS) are two different techniques of Joint Processing transmission scheme. Fig. 5(a) shows how Joint transmission JT is done in the downlink.

Here Physical Downlink Shared Channel (PDSCH) is transmitted from multiple cells with codebook base precoding using DM-RS among coordinated cells. The cell edge user throughput can be improved significantly by making use of transmission power resources of multiple cell sites through coherent transmission. For e.g. M. Sawahashi et al. had evaluated the cell throughput and cell edge user throughput performance applying CoMP transmission and reception schemes. For the cell throughput of 12Mb/s in the 2 x 2 antenna configuration case, the cell edge user throughput had increased approximately 58% and 53 %, as compared to single cell transmission, by applying JT and fast CS respectively. By utilizing the higher signal power from multiple cell sites through coherent combining at user equipment receiver, JT achieves higher cell edge user throughput as compared to CS. The cell edge user throughput had further improved by approximately 34 and 30 % when using JT and CS respectively for 4 x 2 antenna configuration compared to 2 x 2 antenna configurations because of the increasing precoding gain.

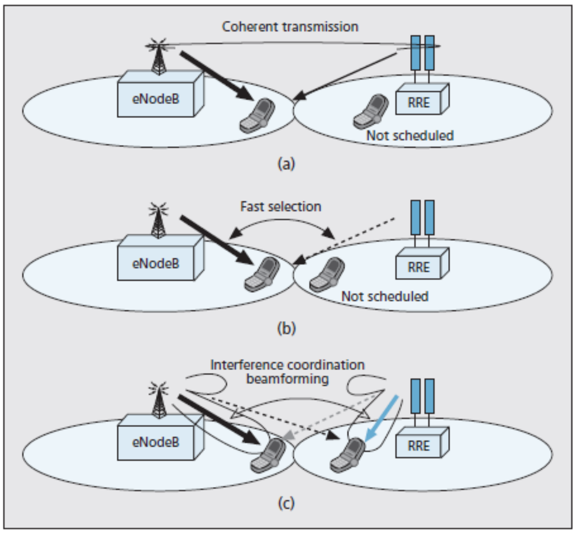

Figure 5: CoMP transmission in downlink: a) joint transmission; b) dynamic cell selection (DCS); c) coordinated beamforming.

In Dynamic cell selection (DCS) as shown in Fig. 5(b), the cell transmitting the physical downlink shared channel with minimum path loss is dynamically selected through fast scheduling at the central base station, while all the cells among the coordinated cells are muted. This significantly decreased the interference from other neighboring cells and also provides maximum received signal power at the User Terminal UE [16].

Fig. 5(c) shows the coordinated scheduling/beam forming wherein PDSCH is transmitted only from one cell. Scheduling/Beam forming is coordinated among multiple coordinated cells. Hence increased SINR results in improved cell edge user throughput.

Difficulty faced in practical implementation of downlink CoMP transmission schemes, is- defining, configuring and coordinating the cooperative cell clusters from the network side and of cooperative active sets from user equipment side [17].

4.2 Uplink CoMP Reception

In CoMP reception in uplink, the physical uplink shared channel PUSCH is received at multiple cells. Scheduling is coordinated among the cells. Fig. 6 shows two methods of CoMP reception, (a) with interference rejection combining (IRC) and (b) with coordinated scheduling. In first method, multiple UE sets transmit the PUSCH simultaneously using same resource block (RB). The received PUSCHs at multiple cell sites are combined using mean squared error (MMSE) or Zero forcing (CF) algorithm.

In the second method only one UE set transmits the PUSCH using an RB and coordinated scheduling among cells. Thus increase in the received signal power results in higher cell edge user throughput. It is to be noted that CoMP reception in the uplink does not require significant change in the physical layer radio interface [16].

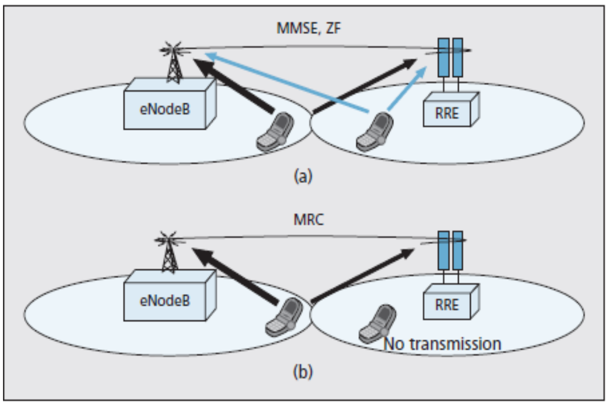

Figure 6: CoMP reception in uplink: a) multipoint reception with interference rejection combining; and b) multipoint reception with coordinated scheduling

As mentioned by L. Reya, for the uplink, appropriate signal processing is done at the receiver for coordinated multipoint reception [18]. This resembles the macro diversity schemes being used in the present cellular networks.

5. RELAYING

In the standardization process of next generation mobile communication systems, such as 3GPP LTE-Advanced and IEEE 802.16j, relay technologies have been considered and studied actively. A denser infrastructure can be achieved by deploying relay nodes in such a manner so as to reduce the transmitter-to-receiver distance and thereby allowing for higher data rates. Coverage and capacity at the cell border remains relatively small due to the low Signal-to - Interference-plus-Noise Ratio (SINR) [19]. Deploying Relay Nodes (RNs) near cell edge will help to increase the capacity [20] or otherwise, to extend the cell coverage area [21]. Other benefits of relaying in cellular networks are: providing high data rate coverage in high shadowing environments (e.g. indoors) and hotspots, reducing the deployment costs of cellular networks, prolonging the battery lifetime for UEs saving power by reducing the overall transmission power of cellular networks and enhancing cell capacity and effective throughput [22]. The basic Relaying Architecture has been shown in figure 7.

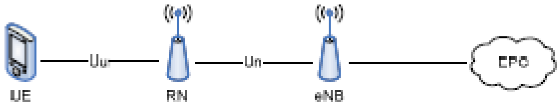

Figure 7: Relaying architecture.

In relay transmission a relay node (RN) enables the forwarding of user information from neighboring User Equipment (UE)/mobile station (MS) to a local eNodeB (eNB)/base station (BS). The eNodeB is connected to RN via the Un interface and the UE is connected to RN via the Uu interface. RN has its own ID and synchronization channels, reference symbols etc. The Uu control plane and user plane protocols are limited to RN. Resource partitioning with time division multiplex for Un and Uu (only one active at a time)is adopted here[23]. The RN thereby improves the overall throughput performance of a wireless communication system by extending the signal and service of an eNB [24, 25].

5.1 Types of Relays

3GPP LTE Advanced and 802.16j standards have defined two types of RSs (Relay Stations). LTE-Advanced uses Type 1 and Type 2 Relay Stations [23] while IEEE 802.16m uses non transparency and transparency Relay Stations [24].

Type 1 (or non transparency) RS helps a remote UE unit, located far away from an eNB (or a BS) to access the eNB by transmitting the common reference signal and the control information for the eNB. The goal of extending signal and service coverage is met by enabling communication services and data transmissions for remote user terminals which is shown in Fig. 8.

Type 2 (or transparency) RS improves the service quality and link capacity of a local user terminal (falling within the coverage of an eNB or a BS) by having a direct communication link with the eNB.

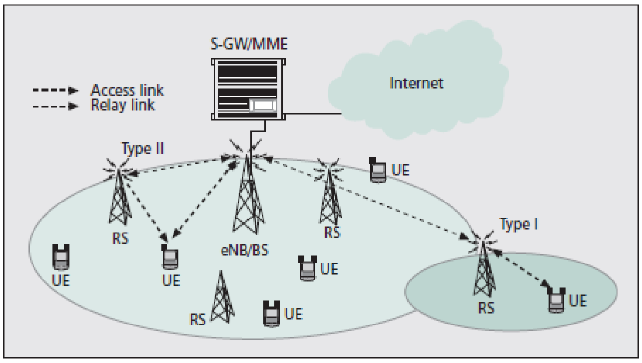

Figure 8: A network scenario with multiple RSs and multiple UE units.

Transmission of common reference signal or control information is not done by Type 2 RS. Overall system capacity is achieved by multipath diversity and transmission gains for local UE. 3GPP LTE-Advanced supports only two hop relay transmission which leads to shorter delay [27].

5.2 Relay Transmission Schemes

The two hop communication between eNB and UE unit through an RS can be established by different relay transmission schemes [24-26].

Amplify and Forward: RS receives signal from the eNB (or UE), amplifies this signal and forwards it to the UE (or eNB). This AF relays though being simple and having short delay are beneficial in most noise limited system deployment as they amplify both interference and noise along with desired signal.

Selective decode and forward: DF relays detects the desired signal and then encodes the signal and forwards the new signal. Though processing delay is quite long DF relays are employed in interference limited environments.

The transmission efficiency in two-hop relay transmission can be maximized if RSs, eNB, and the UE carry out effective link adaptation. Here it is considered that the RS has accurately measured and estimated the instantaneous channel conditions of the links to an eNB and its neighboring UE units.

6. CONCLUSION

LTE-Advanced meets the performance requirements set by ITU-R for IMT-Advanced and altogether it is an *evolution* of LTE and not a new system in itself. Keeping in view the idea of backward compatibility, LTE-Advanced terminals are designed to be able to access networks built according to the first release of the LTE specifications; and also, terminals from the first LTE release will be able to access LTE-Advanced networks. Various technology components are currently been studied about by the participants of 3GPP for the performance enhancement of IMT-Advanced technologies like LTE-Advanced. Carrier Aggregation technology, for both contiguous and non-contiguous spectrum, would support bandwidth up to 100MHz and also enable a more flexible spectrum utilization. The peak spectral efficiency of 30bit/s and 15bit/s/Hz for DL and UL respectively, can be achieved by the MIMO(Multiple input Multiple output) technique. Coordinated Multipoint Transmission/Reception, an evolution of the inter-cell interference coordination, is yet another technology to enhance the performance of the LTE-Advanced systems. Enhanced coverage and higher cell edge data rates requirements of 4G systems could be met by the relaying technology. LTE release 10 will support these technology components with more enhancements being incorporated in latter releases.

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