Introduction to OFDMA and SC-FDMA for LTE System: A Review

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Abstract— *In communication systems Long Term Evolution (LTE) system is an emerging technology. It is most advantageous system over other available systems. ITU-R recommended the LTE-Advanced standard of communication. LTE system uses Orthogonal Frequency Division Multiple Access (OFDMA) technique in downlink and Single – Carrier Frequency Division Multiple Access (SC-FDMA) technique in uplink data transmission, with a guard process as cyclic prefix. The techniques OFDMA and SC-FDMA have their own advantages and disadvantages over one another and hence have limited use in data transmission. Here this paper comprises of details about starting of the era of LTE systems and recent trends and developments in the technologies. It gives a comparative study of OFDMA and SC-FDMA for LTE system.*

Keywords— LTE, OFDMA, SC-FDMA, PAPR, BER

I. Introduction

Long Term evolution (LTE) is commonly known by the name of 4G LTE in market. For high speed wireless communication for mobiles and data terminals LTE is a well known standard. It is based on the GSM/EDGE and UMTS/HSPA network technologies. LTE increases the capacity and speed of data transmission by using not only a different radio interface but also with core network improvements [1] [2]. 3GPP has developed this standard and it has specified the standard in its Release 8 and with a few enhancements in Release 9.

LTE is the natural upgrade path for carriers with both GSM/UMTS networks and CDMA2000 networks. LTE supports different frequencies and bands which means in all countries where LTE is supported, only multi-band phones are able to use LTE. Long Term Evolution (LTE) will ensure the competitiveness of UMTS for the next ten years and beyond by providing a high-data rate, low-latency and packet-optimized system. LTE as a part of Release8 document series is also known by the name E-UTRA (Evolved Universal Terrestrial Radio Access). LTE is referred as TD-LTE and LTE FDD because LTE can be operated in either mode i.e. either in frequency division duplex (FDD) or in time division duplex (TDD). The main key technology aspects of LTE are:

1) Orthogonal Frequency Division Multiple Access (OFDMA) based multiple access schemes for both LTE FDD and TD-LTE.
2) Scalable bandwidth up to 20 MHz
3) Multiple Input Multiple Output (MIMO) antenna technology is being supported by LTE.
4) New data and control channels.
5) New network and protocol architecture (two node, IP based)

Theoretically peak data rates of 300Mbps in downlink and 75Mbps in uplink are supported by LTE (3GPP Release 8).

LTE (as specified in the 3GPP Release 8 and 9 document series), however it is marketed as 4G but it does not satisfy the technical requirements the 3GPP consortium has adopted for its new LTE Advanced standard. The requirements were originally set forth by the ITU-R organization in its IMT Advanced specification. ITU later decided that LTE together with the WiMAX and Evolved HSPA technologies can be called as 4G technologies but under pressure of market and advancements in technologies these were firstly treated under 3G technology [4]. The LTE Advanced standard formally satisfies the ITU-R requirements to be considered IMT-Advanced [5]. ITU has defined LTE Advanced and WiMAX-Advanced as "True 4G"[6] [7].

In March 2008, a set of requirements for 4G standards were specified by the International Telecommunications Union-Radio communications sector (ITU-R), and these standards were named as the International Mobile Telecommunications Advanced (IMT-Advanced) specification. These standards includes setting of peak speed requirements for 4G service at 100 megabits per second (Mbit/s) for mobile communication in high speed moving vehicles such as from trains and cars and 1 gigabit per second (Gbit/s) for mobile communication in low speed moving vehicles such as pedestrians and stationary users.

The first-release versions of Mobile WiMAX and LTE are not fully IMT-Advanced compliant, since the peak bit rates supported by these are much less than 1 Gbit/s, even though these are often branded as 4G by service providers. On December 6, 2010, ITU-R recognized that these technologies do not fulfil the IMT-Advanced requirements and could never be considered "4G", until they represent IMT-Advanced compliant versions and "a substantial level of improvement in performance and capabilities with respect to the initial third generation systems now deployed"[8].

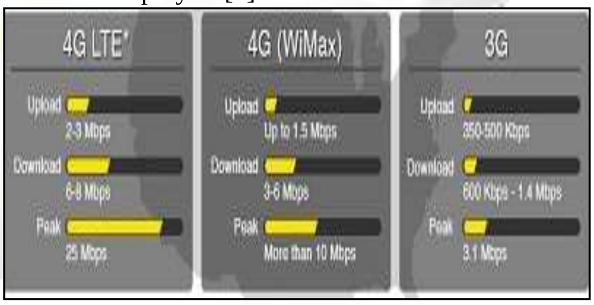

Fig. 1:

Mobile WiMAX and LTE Advanced (LTE-A) are IMT-Advanced compliant backward compatible, standardized during the spring 2011, and promising speeds in the order of 1 Gbit/s. Services were expected in 2013.

As opposed to earlier generations, a 4G system does not support traditional circuit-switched telephony service, but all-Internet Protocol (IP) based communication such as IP telephony. 3G compatible spread spectrum radio technology is also abandoned in all 4G systems. It is replaced by OFDMA multi-carrier transmission and other frequency-domain equalization (FDE) schemes, which makes it possible to transfer very high bit rates despite of extensive multi-path radio propagation (echoes). The peak bit rate is further improved by smart antenna arrays for multiple-input multiple-output (MIMO) communications.

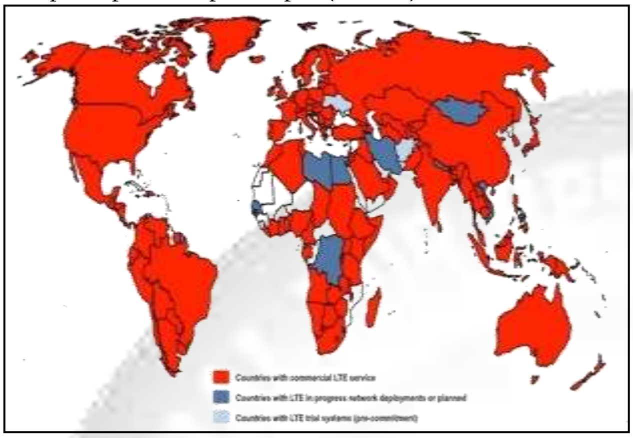

Fig. 2:

II. LITERATURE SURVEY

Performance Analysis of SC-FDMA and OFDMA in LTE Frame Structure (LTE FDD & LTE TDD) resulted that, LTE FDD has better performance than LTE TDD. PAPR of SC-FDMA and OFDMA in LTE FDD achieve lower values on average. We see that FDD has a continuous reduction of BER (Bit Error Rate) and it minimizes the BER up to a certain values of SNRs. On Comparing the Performance analysis, we can conclude that LTE FDD is the better option than in LTE TDD in uplink Transmission-SC-FDMA and downlink Transmission-OFDMA, because of its higher efficiency due to low PAPR [9].

SC-FDMA actually means “create a single-carrier waveform and shift it to the desired part of the frequency domain.” SC-FDMA provides the advantages of OFDMA — especially robust resistance to multipath — without the problem of high PAPR. However in LTE systems SC-FDMA is restricted to the uplink. The use of SC-FDMA in downlink will increase time-domain processing, which would be a considerable burden on the base station, which has to manage the dynamics of multi-user transmission.[10]

SC-FDMA offers similar performance and complexity as OFDMA. However, the main advantage of SC-FDMA is the low PAPR (peak-average-power ratio) of the transmit signal. As PAPR is a major concern at the user terminals. PAPR relates to the power amplifier efficiency at the transmitter and the maximum power efficiency is achieved when the amplifier operates at the saturation point. Lower PAPR allows operation of the power amplifier close to saturation resulting in higher efficiency. With higher PAPR signal, the power amplifier operating point has to be backed off to lower the signal distortion, and thereby lowering amplifier efficiency. Low PAPR makes the SC-FDMA the preferred technology for the uplink transmission [11].

BER is the key parameter for indicating the system performance of any data link. For different values of SNR, the BER increases for high order modulation in both the multiple access techniques (OFDMA and SC-FDMA), which means it is easily affected by the noise. BER Performance of SC-FDMA and OFDMA are very similar but for a part of them SCFDMA have good performance as compare to the OFDMA [12].

From the introduction to LTE and the key components of its physical layer, this can be conversed that OFDMA is better used in downlink and SCFDMA in uplink as modulation techniques; with OFDM as the basic building block. For both the multiple access techniques (OFDMA and SCFDMA) used in LTE systems it has been noted that keeping SNR fixed, the value of BER will keep on increasing for higher order modulation techniques such as 16-QAM and 64-QAM. On the other hand, the lower order modulation schemes (BPSK and QPSK) experience less BER at receiver; thus lower order modulations improve the system performance in terms of BER and SNR. If the bandwidth efficiency of these modulation schemes is considered, the higher order modulation accommodates more data within a given bandwidth and is more bandwidth efficient as compared to lower order modulation. Thus, there exists a trade off between BER and bandwidth efficiency among these modulation schemes used in LTE. From the simulation results, it can also be noticed that the higher order modulation schemes have an impact on the PAPR of both OFDMA and SC-FDMA. For higher modulation schemes PAPR value shows a slight increase in SC-FDMA and a slight decrease in OFDMA. The overall value of PAPR in SC-FDMA is less than that of OFDMA in all modulation schemes, and that is why it has been adopted for uplink transmission in LTE system. Assuming the results it can be concluded to adopt a low order modulation scheme such as BPSK, QPSK, 16-QAM, for having a lesser value of PAPR in uplink. In nutshell, SC-FDMA is more power efficient [13].

After explaining the development from LTE to LTE-Advanced and focusing on the benefits and the key features of it, this can be illustrated that LTE Advanced will become the major cellular system for the users in next decade. One of the new concepts add to LTE-Advanced was the relaying node, where this technique add to the proposed model to support the model and to give it more credibility. An efficient model of LTE-Advanced assist the researchers to experiment the developed items of this network over different conditions and situation such as improve the congestion control algorithm for the protocol used or to derive new technique to minimize the handover among base stations[14].

A. Major Challenges for Lte

1) Spectrum Harmonization

One of the key benefits of GSM networks has been seamless roaming across countries and continents, largely because of harmonized spectrum. LTE infrastructure is being designed to operate in different spectrum bands of different sizes,[16] however, ranging from 1.25MHz to 20MHz. [For LTE max potential data rates, 20MHz FDD contiguous spectrum is required.] To truly support seamless global roaming, harmonized spectrum will be needed—otherwise the burden is shifted to terminals to support multiple frequency bands, which adds time, expense, complexity and inefficiency [17].

2) Security of data traffic over LTE networks

It requires:

- Security of the air interface to avoid eavesdropping, sniffing, theft
- Security of the all-IP core network (i.e., the EPC) [18]
- Security of the all-IP devices

3) Interoperability

A vibrant and robust ecosystem is essential for wide deployment and adoption of LTE. Deployment flexibility and lower operation cost is a very need of network operators. To achieve such needs network operators requires a strong infrastructure and device supplier base. With these issues the issue of interoperability emerges altogether. Interoperability is ensuring operators can mix and match equipment from different suppliers in their networks [19].

III. Orthogonal Frequency Division Multiple Access (OFDMA)

OFDMA is a multiple access technique which uses Orthogonal Frequency Division multiplexing (OFDM). In OFDM each user is allotted separate channel and the frequency band of each channel is divided into no. of orthogonal frequency subcarriers. These sub carriers will carry data streams onto them.

In OFDMA, the high speed serial data is firstly converted in low speed parallel data streams. These low speed parallel data streams are modulated on orthogonal frequency subcarriers. In OFDMA high data rates for each user are achieved. This can be deployed to different frequency band with little modifications to air interface. Because of modulation of each user's data over several orthogonal frequencies Multipath Fading is being reduced in OFDMA.

For avoiding inter symbol interference i.e. ISI and ICI a guard is provided here. Cyclic prefix is also used here to avoid ISI. In addition, the OFDMA is bandwidth efficient as orthogonal frequency carriers can be used with small spacing. As in OFDMA orthogonal frequency subcarriers are used and summation of orthogonal frequencies is zero so we get a minimum or zero ICI. OFDMA is comparatively advantageous, because of these advantages OFDMA is used in downlink data transmission of LTE.

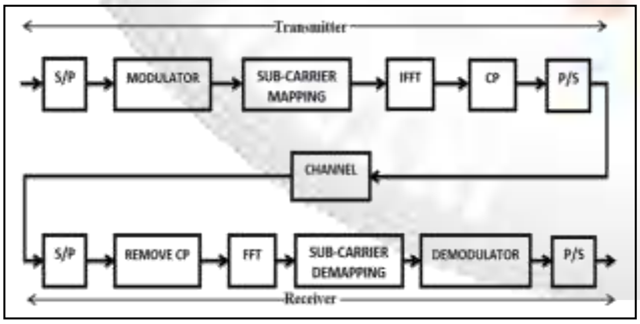

Fig. 1: Block representation of OFDMA

IV. Single carrier Frequency Division Multiple Access (SC-FDMA)

SC-FDMA is a multiple access method having same as of OFDMA with an addition of Fast Fourier Transform (FFT) block in transmission before modulation over orthogonal frequency subcarriers.

The serial data is first converted into parallel data streams. These parallel data streams are then passed from an FFT, and these real time data streams are then converted into frequency samples. These samples are then modulated on orthogonal frequency subcarriers. Because of this the SC-FDMA is also called DFT pre-coded OFDMA. After modulation the modulated data streams are transmitted the same as in the OFDMA. Similarly a guard process is required i.e. CP (cyclic prefix). The data streams are now transmitted using MIME antennas.

Modulation of data stream using subcarriers makes the main difference between the two technologies viz. OFDMA and SC-FDMA. In OFDMA each data symbol is transmitted over separate subcarriers. While in SC-FDMA multiple subcarriers carry each data symbol. SC-FDMA has advantages same as of OFDMA, instead of thus SC-FDMA is advantageous over OFDMA because it has lower PAPR value due to spreading of each data symbol over multiple subcarriers. PAPR is a useful parameter for uplink; hence SC-FDMA is preferably used in uplink data transmission of LTE system [15].

Instead of having lower PAPR value for SC-FDMA it is not preferred in downlink. Since in downlink data transmission, SC-FDMA will cause burden on base stations, because of the extra circuitry and extra process involved in SC-FDMA

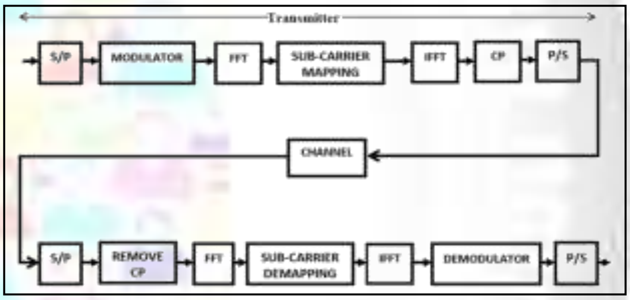

Fig. 2: Block representation of SC-FDMA

V. Parameters used for LTE testing

A. Bit Error Rate (BER)

BER is the ratio of number of error bits and total number of bits transmitted. It is given by the following formula [2].

$$BER = \frac{Number\ of\ Error\ Bits}{\text{Total Number of Transmitted Bits}}$$

The BER plot is plotted for different values of BER for different SNR values versus values of SNR ratio for the simulated model. The procedure was repeated for different modulation techniques for both OFDMA and SC-FDMA for their comparison.

B. Peak to Average Power Ratio

We calculated PAPR for both OFDMA and SC-FDMA system using the following formula [2].

$$PAPR = \frac{\text{Peak power of transmitted signal}}{\text{Average power of transmitted signal}}$$

Where peak and average power of transmitted signal was calculated by:

$$\text{Peak power of transmitted signal} = \{\text{Maximum}(\text{xt} \times \text{conjugate of xt})\}$$

$$\text{Average power of transmitted signal} = \{\text{Mean}(\text{xt} \times \text{conjugate of xt})\}$$

Where, 'xt' represent transmitted signal.

To plot PAPR, Complementary Cumulative Distribution Function (CCDF) of calculated PAPR values is used. The CCDF of PAPR is the probability that the PAPR is higher than a certain PAPR value PAPR0 (Pr {PAPR>PAPR0}).

VI. Future scope

The next generation of mobile network has a long way to go before it's a reality, but tests and plans are underway to set the terms for such an upgrade. By achieving Low latency means that not only will download and upload speeds be fast, but the response times for starting those data transfers will be similarly snappy .The other benefit relates to the biggest issue with current mobile network standards - a critical lack of bandwidth. The radio frequencies that our 4G networks operate on are overcrowded to say the least. With more and more people and devices set to be connected over the next five years or so to deliver 5G, carriers will need to boost network capacity between phones and the base stations need to install every few miles. Radio waves vibrate with a frequency measured in megahertz or even faster gigahertz. Today's phones communicate at lower frequency band; 5G will require higher frequency bands. But with the presence of high buildings and walls and mountains it is harder to transmit high frequencies. To compensate this reality and requirement, carriers will rely on advanced antenna technologies.

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