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A Comparative Study of OFDMA and SC-FDMA in Long Term Evolution (LTE)

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Abstract— **Long term evolution (LTE) is a 3GPP (Third Generation Partnership Project) 4G technology which enhances the development in the field of telecommunication and by improving the performance of the network for the different types of traffic flows. As it is an all IP technology so, it is the most emerging technology now a days. The fact that 3G long term evolution is a packet based networks brings some improvements in the form of higher bit rate, lower latencies and a variety of services. This paper presents a survey of LTE system and it is concluded that OFDMA technique is used in downlink and SC-FDMA technique is used in uplink. PAPR of OFDMA is higher than SC-FDMA.**

***Keywords*— LTE, PAPR, equivalent Capacity, Downlink(DL), Uplink (UL), OFDMA, SC-FDMA, Quality of Service (QoS)**

I. Introduction

Evolution of wireless access technologies is about to reach its fourth generation (4G). Wireless access technologies have followed different evolutionary paths aimed at unified target: performance and efficiency in high mobile environment. 1G has fulfilled basic mobile voice while 2G has introduced capacity and coverage. This is followed by 3G, which has quest for the data at higher speed which opens gates for mobile broadband experience i.e. it allows support for data, voice and video information at higher speeds.

Long Term Evolution (LTE), commonly referred to as 4G- or next generation wireless communications-is the new standard for nationwide public safety broadband. It provides even better support for mobile broadband.

LTE was first proposed by NTT Docomo of Japan in 2004. In May 2007, the LTE Trial Initiative (LTI) alliance was founded as a global collaboration between vendors and operators with the goal of verifying and promoting the new standard in order to ensure the global introduction of the technology as quickly as possible. The LTE standard was finalized in December 2008, and the first publicly available LTE service was launched by Telia Sonera in Olso and Stockholm on December 14, 2009 as a data connection with a USB modem. The LTE services were launched by major North American carriers as well. This standard will allow access to digital technologies and deliver expanded capabilities to public safety practitioners in the field.

It is a standard for wireless communication of high speed data for mobile phones and data terminals. It is based on GSM/EDGE and UMTS/HSPA network technology, increasing capacity and speed using different radio interface together with core network improvements. The goal was to increase capacity and speed of wireless data network using digital signal processing and modulation. A further goal was the redesign and simplification of the network architecture to an IP-based system with significantly reduced transfer latency compared to the 3G architecture.

The LTE wireless interface is incompatible with 2G and 3G networks, so that it must be operated on a separate radio spectrum. The LTE specification provides downlink peak rates of 300 Mbit/s, uplink peak rates of 75 Mbit/s and QoS provisions permitting a transfer latency of less than 5 ms in the radio access network. LTE has the ability to manage fast-moving mobiles and supports multi-cast and broadcast streams. LTE supports scalable carrier bandwidths, from 1.4 MHz to 20 MHz and supports both Frequency division Duplexing (FDD) and time Division Duplexing (TDD). The IP-based network architecture, called the Evolved Packet Core (EPC) designed to replace the GPRS Core Network, supports seamless handovers for both voice and data to cell towers with older network technology such as GSM, UMTS and CDMA2000. The simpler architecture results in lower operating costs.

A. LTE Features:

- Downlink peak rate: 300Mb/s
  Uplink peak rate: 75Mb/s
- Improved support for mobility.
- Low data transfer latencies(less than 5ms).
- Support both FDD & TDD communication systems.
- OFDMA for downlink & SC-FDMA for uplink to conserve power.
- Support all frequency bands currently used by ITU-R
- Increased spectrum flexibility: 1.4 MHz, 3 MHz, 5 MHz, 10 MHz, 15 MHz and 20 MHz.

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- Ability to manage fast moving mobiles and support multicast & broadcast streams.
- Support atleast 200 active data clients in every 5 MHz cell.
- Simplified architecture: Network side of E-UTRAN is composed of eNodeBs and each E-UTRAN support up to four times data and voice capacity supported by HSPA.
- LTE is all IP based network called evolved Packet Core (EPC).
- Packet switched radio interface.
- Low data transfer latencies.
- Supports at least 200 active data clients in every 5 MHz cell.
- Users can start a call or transfer of data in an area using an LTE standard and, should coverage be unavailable, continue the operation without any action on their part using GSM/GPRS or W-CDMA-based UMTS or even 3GPP networks such as CDMA One or CDMA2000.
- Support for MBSFN (Multicast Broadcast single-frequency network). This feature can deliver services such as mobile phones using LTE infrastructure and is a competitor for DVB-H based TV broadcast.

B. LTE Channel Types:

In order that data can be transported across LTE interface, various channels are used to segregate different types of data & allow them to be transported across RAN. Different types of channel are:

1) Physical Channels: define where something is transmitted over the air. These channels carry user data & control messages.

2) Transport Channels: define how something is transmitted over air, e.g. what are encoding and interleaving options used to transmit data. Data & signalling messages are carried between MAC & physical layer.

3) Logical Channels: define what type of information is transmitted e.g. Traffic channels, control channels, system broadcast etc. Data and signalling are carried between RLC and MAC protocols.

The remainder of this paper is organized as follows. Section II describes the LTE Architecture and Section III surveys the related works. Sections IV present the theoretical analysis of LTE. Finally, Section V concludes the paper.

II. LTE ARCHITECTURE

The air interface between LTE network and UE supports owing to OFDM and multiple antenna techniques employed. OFDMA is used from network to UE air interface and SC-FDMA is used from UE to network air interface.

LTE SAE (System Architecture Evolution) consists UE, eNodeB and EPC(evolved packet core).

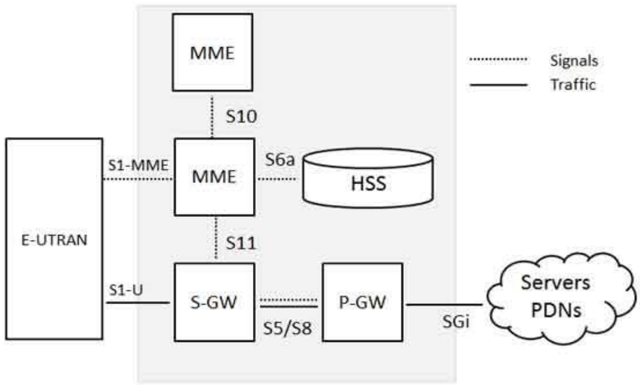

Fig1: LTE Architecture

Various interfaces are designed between these entities which include Uu between UE and eNodeB, X2 between two eNodeB, S1 between EPC and eNodeB. eNodeB has functionalities of both RNC and NodeB as per previous UMTS architecture.LTE is completely IP based network.

Basic architecture contains following network elements:
a. Evolved UTRAN
b. Evolved Packet Core

C. LTE-EUTRAN: It provides higher data rates, lower latency and is optimized for packet data. EUTRAN (Evolved Universal Terrestrial Radio) consists of eNB (Base station). EUTRAN is responsible for complete radio management in LTE. When UE powered is on, eNB is responsible for Radio Resource Management, i.e. it shall do the radio bearer control, radio admission control, allocation of uplink and downlink to UE etc. The QoS is taken care by eNB as the eNB is only entity on radio. Other functionalities include scheduling and transmission of paging messages, broadcast messages, and bearer level rate enforcements also done by eNB.

D. LTE-EPC: The LTE EPC consists of MME, SGW, PGW and HSS as described below:

1) Mobility Management Entity (MME): The MME is a control entity. It is responsible for all the control plane operations. All the NAS signalling originates at UE and terminates in MME. MME is also responsible for tracking area list management, selection of PGW/SGW and also selection of other MME during handovers. MME is also responsible for SGSN (Serving GPRS Support Node).

2) *Serving Gateway (SGW):* Serving Gateway terminates the interface towards EUTRAN. For each UE there is a single Serving GW associated with EPS at a given point of time. SGW acts as a local mobility entity for inter eNB handovers. SGW is responsible for packet routing and forwarding, buffering the downlink packets. As eNB is responsible for uplink packet marking, SGW is responsible for downlink packet marking.

3) PDN Gateway (PGW): PGW terminates SGi interface towards the PDN. PGW is responsible for all the IP packet based operations such as deep packet inspection, UE IP address allocation, Transport level packet marking in uplink and downlink, accounting etc. It is also responsible for UL and DL rate enforcement.

4) Home Subscriber server (HSS): The HSS is a central database that contains user-related and subscription-related information. The functions of the HSS include functionalities such as mobility management, call and session establishment support, user authentication and access authorization. It also holds information about the PDNs to which the user can connect. In addition the HSS holds dynamic information such as the identity of the MME to which the user is currently attached or registered. The HSS may also integrate the authentication center (AUC), which generates the vectors for authentication and security keys.

III. RELATED WORK

In 2014, authors analysed the user accommodation capabilities of LTE-A systems with carrier aggregation for the LTE users and LTE-A users, respectively [1]. The adopted performance metric was equivalent capacity (EC).Two bandwidth allocation strategies were studied, i.e., the fixed-weight strategy and the cognitive-weight strategy, where the bandwidth weights of different user classes were prefixed under the former and dynamically changing with the cell load conditions under the latter. For each strategy, closed-form expressions of ECs of different user classes were derived for LTE and LTE-A users, respectively. A net-profit-maximization problem was further formulated. It was concluded that only a slightly higher spectrum utilization of LTE-A users than LTE users can result in a significant EC gain when the user traffic is busty. Moreover, the cognitive-weight strategy was shown to outperform considerably the fixed-weight one due to stronger adaptability to the cell load conditions.

In 2014, authors proposed Radio Resource Management process, which aims at distributing physical resources among users and it is performed by the packet scheduler entity [2]. The implementation of enhanced radio resource methodologies improved the overall network capacity and the quality of service offered to mobile terminals. Three dimensional schedulers was proposed by them which were built on 3 different layers interact each other to optimally distributing radio resources by taking into account users' position, the experienced channel qualities, and requirements of active requirements. The proposed solution provided the highest throughput, the lowest packet loss ratio, and the lowest packet delays.

In 2014, authors proposed a CC selection algorithm to efficiently utilise available radio resources while balancing total loss across multiple component carriers [3]. Results obtained via simulations had demonstrated efficiency of proposed algorithm in optimising system capacity without compromising with Quality of service (QoS) requirements of delay sensitive Guaranteed Bit Rate (GBR) application.

In 2014, authors presented a survey of the different proposed scheduling algorithms under variable conditions and accordingly, the variation in their results in terms of the performance metrics like throughput, packet loss, delay time, spectral efficiency, fairness etc. [4].

In 2013, authors proposed new scheduling algorithm that optimises resource assignment in overbooking scenarios [5]. This algorithm serves available resources by doing trade-off between spectral efficiency, QoS requirements and fairness. It allowed a good level of fairness while improving at the same time the overall system capacity and performances of users having strict QoS requirements.

In 2013, authors designed optimum physical layer architecture of high data rate LTE uplink transceiver using SC-FDMA multiple access scheme with error correction mechanism using LDPC codes to provide less BER and avoiding packet loss by interleaving [6]. This architecture was more power efficient and support high data rates.

In 2012, authors determined the performance analysis of SC–FDMA and OFDMA in LTE Frame Structure [7]. It is inferred from their work that SC–FDMA is less sensitive to frequency offset than OFDMA. SC–FDMA has less PAPR ratio than OFDMA and hence it is more power efficient than OFDMA.

In 2011, authors diagnosed that low dense parity check codes (LDPC) shall be used in higher order modulations like 64 QAM [8]. LDPC will increase the spectral efficiency and reliability by approaching the theoretical Shannon limit while ensuring reduced complexity. Bit error rate (BER) performance of the LDPC codes is better and is more power efficient.

In 2009, authors proposed various techniques for reducing the PAPR and the selection criteria for choosing these techniques had been discussed [9]. The goal was to convey the fundamental ideas and intuitive understanding of the concept introduced. This was done primarily to give an overview of the various techniques known today for PAPR reduction. Several techniques had been proposed such as clipping, windowing, coding, pulse shaping, tone reservation, tone injection, companding etc.

In 2007, author proposed an efficient technique for reducing the PAPR of OFDM signals. The proposed technique was data-independent and thus, does not require new processing and optimization for each transmitted OFDM block [10]. The reduction in PAPR of the OFDM signal was obtained through a proper selection of a precoding scheme that distributes the power of each modulated symbol over the OFDM block. The obtained results showed that this precoding scheme was an attractive solution to the PAPR problem of OFDM signals. The good improvement in PAPR given by the present technique permitted the reduction of the complexity

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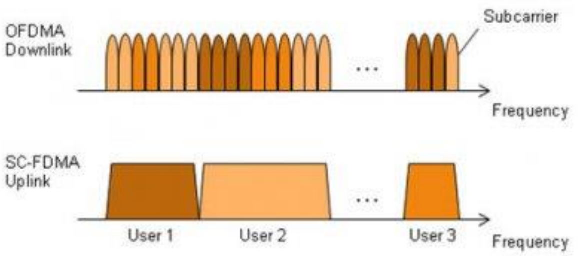
and cost of the transmitter significantly. The precoding schemes also take advantage of the frequency variations of the communication channel and can pro- vide considerable performance gain in fading-multipath channels.

In 2006, author considered the interleaver design in bit-interleaved coded modulation (BICM) with low-density parity-check (LDPC) codes [11]. The design paradigm was to provide more coding protection through iterative decoding to bits that are less protected by modulation (and are thus less reliable at the output of the demodulator). The design was carried out by an ad hoc search algorithm over the column permutations of the parity-check matrix. Simulations showed that the proposed reliability-based coded modulation scheme can improve the error-rate performance of conventional BICM schemes based on regular LDPC codes by a few tenths of a decibel, with no added complexity.

IV. THEORETICAL ANALYSIS

LTE is composed of many new technologies compared with the previous generation of cellular systems. These new technologies are used to generate more efficiency with regards to spectrum and higher data rates.

1) To achieve high radio spectral efficiency as well as enable efficient scheduling in time and frequency domain, a multicarrier approach for multiple access was chosen by 3GPP. In order to gain high data bandwidth when transmitting packets, LTE integrates OFDM technology which can provide high-degree resilience to reflections and interference at the same time. Furthermore, the access schemes can be divided into two access approaches used in the DL and UL respectively. The first one for the DL is OFDMA (Orthogonal Frequency Division Multiple Access); the second one for the UL is SC-FDMA (Single Carrier- Frequency Division Multiple Access), which has the advantages of smaller peak to average power ratio and more constant power able to get high RF power amplifier efficiency in the mobile handsets. The OFDMA solution leads to high Peak-to-average Power Ratio (PAPR) requiring Expensive Power amplifiers with high requirements on linearity, increasing power consumption for the sender. Hence SC-FDMA solution generates a signal with single carrier characteristics and results in low PAPR.



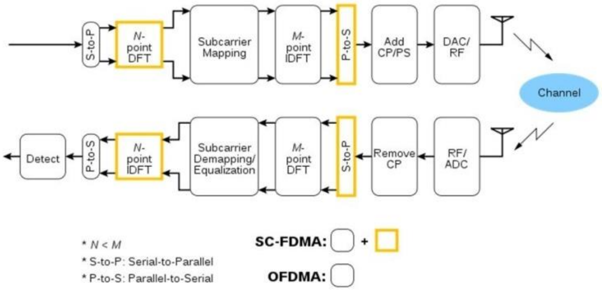


Fig 2: Block Diagram

2) MIMO (Multiple Input Multiple Output) increases the throughput via the additional signal paths after those operations. MIMO requires two or more different antennas with different data streams to distinguish the different paths, such as the schemes using 2 x 2, 4 x 2, or 4 x 4 antenna matrices.

E. PERFORMANCE CALCULATION PARAMETERS

1) Calculation of PAPR:

The PAPR is calculated by representing a CCDF (Complementary Cumulative Distribution Function) of PAPR. The CCDF of PAPR is the probability that the PAPR is higher than a certain PAPR value PAPR0 (Pr {PAPR>PAPR0}).

PAPR= Peak value of Signal/ mean square value

$$\text{PAPR} = \frac{|x|_{peak^2}}{x_{rms^2}}$$

2) BER :

The BER is ratio of errors bits to the total number of bits transmitted during the time interval i.e.

BER = (error bits) / (number of transmitted bits)

3) LTE Capacity:

It can be defined as the maximum number of users allowed in the system given the user QOS requirements.

V. CONCLUSIONS

Single Carrier Frequency Division Multiple Access (SC–FDMA) and Orthogonal Division Multiple Access (OFDMA) are the two major techniques used in LTE. The main drawback of OFDMA over SC–FDMA is its high peak to average power ratio (PAPR). Hence OFDMA is used in the downlink of the fourth generation (4G) wireless communication systems for its high spectral efficiency and high PAPR. SC–FDMA is used in the uplink of the fourth generation (4G) wireless communication systems since it is more power efficient. PAPR can be reduced by various methods like filtering, precoding, pulse shaping, windowing, clipping etc. Equivalent capacity can be increased by using carrier aggregation.

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