

# DOFDM for Carrier Aggregation in LTE-Advanced

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**Abstract**— In Long-Term Evolution (LTE), maximum bandwidth allocation of channels in downlink and uplink is 20MHz. To meet an increasing demand of data rate for users in next generation wireless communication systems such as LTE-Advanced, bandwidth up to 100MHz or above is required. A key technology to achieve higher bandwidths up to 100MHz is carrier aggregation. To provide maximum bandwidth to the users and optimum use of radio resources for the operators, the carriers of same or different bandwidths can be aggregated using carrier aggregation. This paper presents an overview of carrier aggregation algorithms and using Matlab simulations study feasibility of using Discontiguous Orthogonal Frequency Division Multiplexing (DOFDM) for carrier aggregation. It is concluded that DOFDM enables carrier aggregation without sacrificing bit error rates for users.

**Keywords:** LTE-Advanced, Carrier Aggregation, DOFDM

## I. INTRODUCTION

LTE technology becomes a reality now and has been successfully deployed in more than 29 countries in the World. Recently, survey conducted by Informa Telecom showed that more than 60% of network operators believe small cells will be more important than macrocells in LTE networks. Deployment of LTE in small cells (e.g. Femtocells) is expected to be a key market trend by the end of 2013 [1]. Main benefits of using LTE for Femtocell include higher latency, better coverage and capacity [2]. Most of the existing equipment is able to support LTE functionality and it is expected that LTE will change the communication landscape in the near future. LTE is the evolution of technology; not for GSM/HSPA operators only but for CDMA and WiMAX operators as well[3].

The capabilities of LTE-Advanced such as higher data rates were tested for the laptop modems and it was a success. The main features of LTE-Advanced are summarised in Fig. 1. The ITU-R defined the requirements for the IMT-Advanced such that the system should be able to:

- Provides 100 Mbps peak data rate support for high mobility and up to 1 Gbps peak data rate for low mobility;
- Enabling high quality mobile services;
- Worldwide roaming capability; Flexibility to allow cost efficient support of wide range of service and applications.

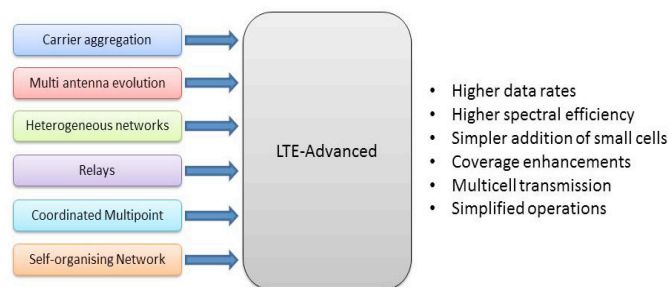


Fig. 1: Overview of LTE- Advanced features

To achieve higher data rates in LTE-Advanced, effective transmission using multiple carriers by applying Discontiguous Orthogonal Frequency Division Multiplexing (DOFDM) is an alternative solution [9]. In recent years, DOFDM has attracted attention due to its many features such as high carrier efficiency, intelligible equalisation for multipath channels etc. Carrier aggregation (CA) enables aggregation of multiple carriers and is one of the most important requirements of the LTE-Advanced as defined in Release 10 [2]. In LTE-Advanced up to 5 Carrier Components (CCs) can be aggregated and provide a wider bandwidth up to 100 MHz to help to increase the capacity of the system as defined in 3GPP in release 10 [5]. These CCs can be continuous or non-continuous carrier, so DOFDM is a potential candidate to aggregate the non-continuous carriers. Moreover, LTE-Advanced standard is supposed to develop the available radio spectrum for operators and present the requirements of the IMT-Advanced such as data rates, bandwidth, system capacity, spectrum efficiency, mobility and provide maximum flexibility [7].

In this paper, we present an overview of the CA schemes for LTE-Advanced, current state-of-the-art (SOTA) and the long

term impact of CA in LTE-Advanced systems. Our survey is followed by study of DFODM as a strong candidate for CA and we evaluated the performance of DOFDM using simulations. We compared the bit error rate (BER) performance of DOFDM as use in CA with OFDM. We conclude that DOFDM is an enabling technology for CA while maintaining similar performance as of OFDM in terms of bit error rate.

The rest of the paper is organised as follows: section II presents different types of CA techniques and structure of CA. DOFDM system for CA is described in section III and is followed by simulation results and discussion in section IV. Finally section V concludes the paper.

## II. TYPES OF CARRIER AGGREGATION

There are two types of CA techniques proposed for LTE-Advanced [7]:

- Continuous CA (CCA): available CCs are adjacent to each other;
- Non-continuous CA (NCA): available CCs are not adjacent to each other;

In both CCA and NCA, multiple CCs are combined to produce a signal unit for LTE-Advanced User Equipment (UE). In terms of energy consumption and cost, CCA is easier as to implement as compare to NCA. For CCA, there is no need to make changes in the physical layer (PHY). The fast fourier transform and a single radio frequency module is used in all UEs to achieve CCA in LTE-Advanced system. In addition, it is easier to implement resource allocation for CCA in comparison to NCA [8].

The NCA delivers a useful technique for operators to use the current resources such as unused frequency bands and those bands, which are already assigned for previous systems like 2G. As NCA supports data communications over multiple separated carriers across a large frequency range, the radio channel and transmission performance, such as propagation path loss, contrast a lot at different frequency bands, and the design of aggregation algorithm should be fully assessed and measured [9].

As NCA approach is to support data transmission, resource allocation and management structures should be developed and implemented to adjust the transmission power, modulation, and coding schemes for different component carriers [8].

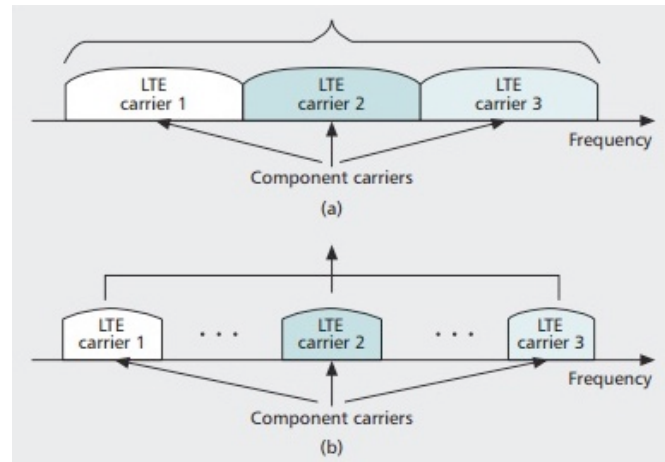


Fig. 2: Carrier Aggregation types [6]

CA supports three different types of scenarios which have been proposed in LTE-A: (1) intra-band contiguous, (2) intra-band non-contiguous and (3) inter-band non-contiguous [13]. With the expansion of RF necessities, both intra and inter-band scenarios are used in Downlink (DL) of LTE-Advanced system. But intra-band scenarios only used in uplink (UL) because of the difficulties in defining the requirement of RF for synchronized broadcast on multiple CCs with large frequency separation.

### II. a) CARRIER AGGREGATION - SCENARIOS

Several scenarios have been defined for LTE-Advanced as shown in Fig. 3. One of the most distinctive scenarios is where two CCs are collocating and overlaid, providing nearly the same coverage. Both layers provide sufficient coverage and mobility can be support on both layers (Fig. 3A). In the second scenario spectrum allocation is often dispersed across the different bands. It means both CCs are collocating and overlaid, but Frequency 1 (F1) has smaller coverage due to large path loss and only Frequency 2 (F2) provides satisfactory coverage. In this case F1 used to improve throughput and mobility is performed based on F2 coverage (Fig. 3B). In some deployments, (e.g. Fig. 3C) the eNodB antennas for different CCs can have different forms to increase the throughput at sector boundaries and in different direction the main beam of antenna originally can be rotated. As shown in Fig. 3D, coverage is guaranteed by one CC to provide continuous service, where Remote Radio Head (RRH) units are deployed at hotspots to provide extra throughput with another CC [6].

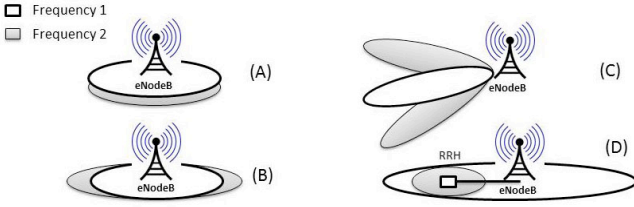


Fig. 3: Carrier Aggregation deployments

One of the fundamental technologies of carrier aggregation is the physical layer aggregation scheme, like DOFDM. DOFDM can be realised by modifying the efficient block processing of OFDM.

### III. DOFDM SYSTEM

The DOFDM is a variant of OFDM used to aggregate the non-continuous carriers [10]. To implement carrier aggregation in LTE-Advanced network, choice of a proper PHY is mandatory. A number of studies have been done on the adoption of DOFDM for LTE-Advanced PHY.[13] The DOFDM uses non-contiguous portions of spectrum or carrier to transmit data. The block diagram of DOFDM system is shown in Fig. 4 [10].

As seen from Fig. 4, the main difference between OFDM and DOFDM is ON/OFF subcarrier information block. The unoccupied or available subcarriers set to be activated and the others deactivated. We assumed that this information is obtained either from Geolocation spectrum databases or via spectrum sensing measurements [14].

In OFDM transmitter (Fig. 4), the modulated symbols are mapped to the activated subcarriers, while zeros are inserted in the deactivated subcarriers. For the purpose of simulations we use QPSK as underlying modulation scheme. For DOFDM all the subcarriers are not active as in OFDM system, so the On/OFF subcarrier information key is using to activate and deactivate the subcarriers. After that, the Inverse Fast Fourier Transform (IFFT) is applied to the data streams to modulate subcarriers to dissimilar subcarrier and a cyclic prefix (CP) is applied to the DOFDM symbols [12].

The receiver performs in the opposite way of the transmitter, first using S/P converter the signal is changed into parallel streams, the CP is detached, and the Fast Fourier Transform (FFT) is applied to transform the time domain data into the frequency domain. The OFDM system uses IFFT and FFT blocks. Though, the DOFDM system has several subcarriers, which are deactivated to avoid the interference to the current user. Zero value inputs would result with the deactivated subcarriers to the IFFT and FFT blocks. So, the hardware resources of the FFT are not totally used since the additions

involving zeroes are unnecessary. Hence, the efficient implement of the FFT blocks is needed when the subcarriers are deactivated.

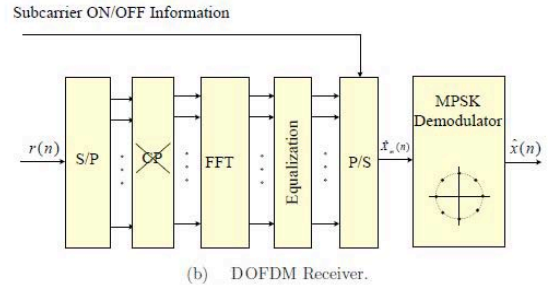
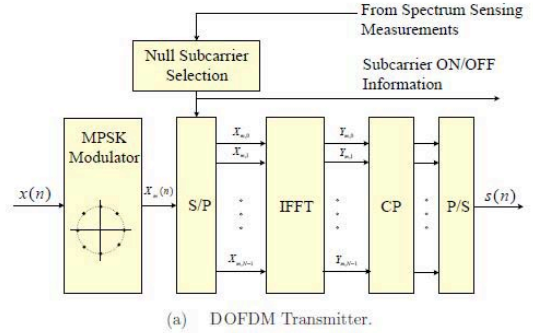


Fig. 4: DOFDM Block Diagram

The active subcarriers are then multiplexed using a P/S converter, and the original high-speed input,  $x(n)$  is demodulated. DOFDM techniques propose the important advantage, i.e. the proficient and dynamic carrier pooling for high data rate transmissions is supported. [12]

In a basic OFDM system the input data symbols are supplied into a channel encoder where data are mapped onto BPSK/QPSK/QAM constellation.

### IV. SIMULATION RESULTS

We used following parameters for the simulations of DOFDM and OFDM: transmission bandwidth = 8 MHz, IFFT/FFT size = 256 and number of subcarriers as  $N = 1705$ . DOFDM symbol time ( $T_u$ ) is 224 $\mu$ s. We used Additive White Gaussian Noise (AWGN) channel for simulations and BER was used as a metric to evaluate system performance.

Fig. 5 illustrates BER versus SNR for AWGN channel, which is employed with QPSK modulation schemes for both OFDM and DOFDM technique. As seen from Fig. 5, with increase in SNR BER decreases for both for DOFDM and OFDM system. Further, it can be observed from Fig. 5 that for a given BER e.g.  $10^{-3}$  SNR required for DOFDM and OFDM is 7dB and 6dB respectively. Hence, it is concluded that BER performance for OFDM and DOFDM is similar while DOFDM enables carrier aggregation; a desirable feature of LTE-Advanced.

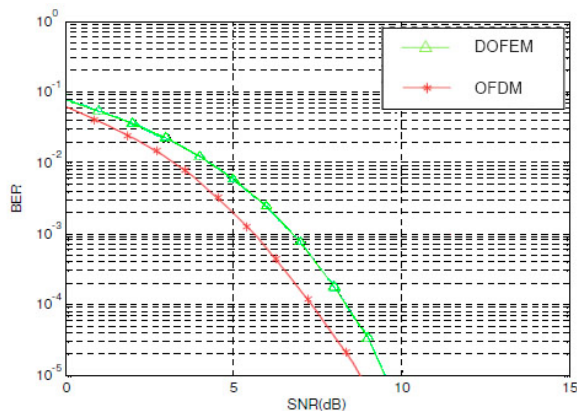


Fig 5: BER of DOFDM and OFDM system

## V. CONCLUSIONS

This paper presents a summary of CA technique for the high data rate communicates of wireless systems. Two techniques of continuous and non-continuous CAs and the deification of these schemes is reviewed and compared against each other. Structure of carrier aggregation and data aggregation schemes based on MAC and PHY layer is described. The main goal of our work is to investigate BER for non-contiguous bands of OFDM based LTE-Advanced system. A simulation result of BER for OFDM and DOFDM technique has shown.

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