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Carrier Aggregation in LTE-Advanced

Ioana-Elena Puşcaş [1]

Abstract – LTE-Advanced extends the capabilities originally defined in LTE within the 3GPP and Carrier Aggregation (CA) is the most significant, although complex, improvement provided by LTE-Advanced. Bandwidths from various portion of spectrum are logically concatenated or "aggregated" resulting in a virtual block of a much larger band, enabling increased data throughput. The aim of this paper is to present an introduction of CA in LTE-Advanced system, including current 3GPP status on CA technology, configuration and deployment scenarios and Physical, MAC and RRC (Radio Resource Control) Layers aspects of Carrier Aggregation.

Keywords: LTE-Advanced, Carrier Aggregation, 3GPP

I. INTRODUCTION

LTE-Advanced (LTE-A) aims to support peak data rates of 1 Gbps in the downlink and 500 Mbps in uplink. [1] In order to fulfill such requirements, a transmission bandwidth of up to 100 MHz is required. However, since current versions of broadband wireless systems make use of channel bandwidths of up to 20 MHz the availability of such large portions of contiguous spectrum is rare in practice. Therefore a different spectrum management scheme is necessary for next generation wireless systems in order to achieve the required bandwidth.

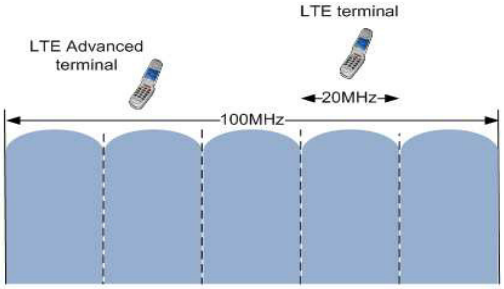

Figure 1. Concept of Carrier Aggregation

LTE-Advanced uses carrier aggregation to form a larger bandwidth by collection of multiple existing carriers in order to meet the needs of higher bandwidths. In Fig. 1 is presented CA concept in LTE-Advanced system. [2] Each aggregated carrier is referred to as a component carrier (CC). Release 8 LTE carriers have a maximum bandwidth of 20 MHz; therefore LTE-Advanced can support aggregation of up to five 20 MHz carriers.

Upon the demand on higher bandwidth and higher data rate applications and based on the expected growth of broadband users, LTE-Advanced system introduced CA technology to overcome the spectrum poverty and fragmentation problem, irrespective of the peak data rate. [3]

Carrier aggregation in LTE-Advanced is designed to support aggregation of a variety of different arrangements of component carriers including carriers of the same or different bandwidths, adjacent or non-adjacent component carriers in the same frequency band or in different frequency bands. [4] There are three types of CA, depending on CC combinations:

a) Intra-band Contiguous CA
b) Inter-band Non-contiguous CA
c) Intra-band Non-contiguous CA

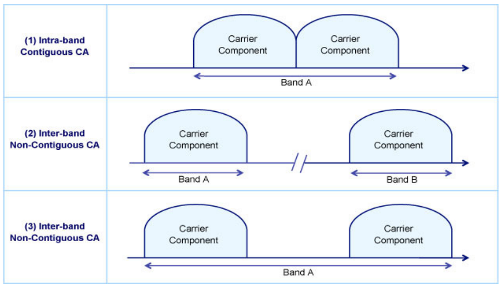

Figure 2. Types of Carrier Aggregation

The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz and, as mentioned earlier, a maximum number of five component carriers can be aggregated allowing for an overall transmission bandwidth of up to 100 MHz. CA can be used for both FDD and TDD. In FDD the number of aggregated carriers can be different in downlink (DL) and uplink (UL); however the number of UL component carriers is always equal or lower that the number of DL component carriers. The individual CC can also be of different bandwidths. For TDD the number of CCs as well as the bandwidths of each CC will normally be the same for DL and UL.

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[1] Faculty of Electronics and Telecommunications, Communications Dept.
Bd. V. Parvan 2, 300223 Timisoara, Romania, e-mail first.author@etc.upt.ro

II. CONFIGURATION SCENARIOS OF CARRIER AGGREGATION

3GPP has defined a range of carrier aggregation scenarios for LTE-Advanced. Further we will present five potential deployment CA scenarios considering F1 and F2 two carriers to be aggregated (F2>F1). For the DL all scenarios could be supported and for the UL only scenarios #1, #2 and #3. [5]

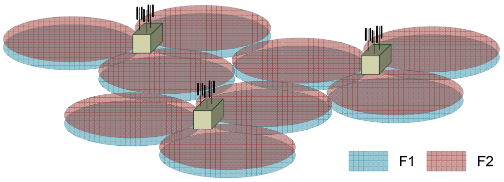

Figure 3. CA deployment scenario #1

A first possible CA configuration scenario is described by following characteristics: F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. For this scenario both carriers are generally within the same band (e.g. 2 GHz, 800 MHz, etc.) and it is expected that aggregation is possible between overlaid F1 and F2 cells. [5]

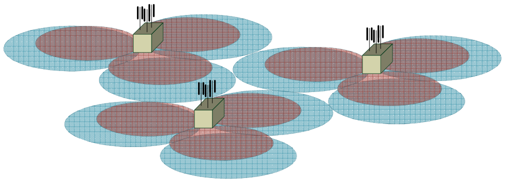

Figure 4. CA deployment scenario #2

The second possible scenario is similar with the first one, F1 and F2 are co-located and overlaid, but F2 has smaller coverage due to larger path loss. Only F1 is used to provide full coverage and F2 is used to further improve the data transfer rate for some specific area. For this scenario the two carriers are configured in different frequency bands (e.g. F1 = {800 MHz, 2 GHz} and F2 = {3.5 GHz}, etc.) and it is expected that aggregation is possible between overlaid F1 and F2 cells. [5]

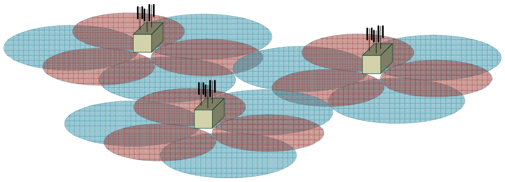

Figure 5. CA deployment scenario #3

In the third configuration scenario F1 and F2 cells are co-located, but F2 antennas are directed to the cell boundaries of F1 to increase the throughput at cell edge. In this configuration is also more likely that the two carriers are configured in different frequency bands. It is expected that F1 and F2 cells of the same base station can be aggregated where coverage overlap for higher data transmission rate. [5]

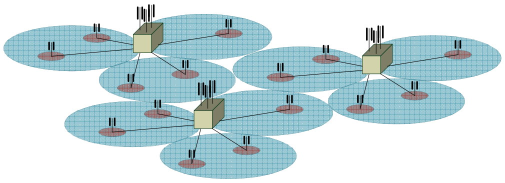

Figure 6. CA deployment scenario #4

The fourth CA deployment scenario is shown in Figure 5. F1 provides macro coverage and F2 is deployed with Remote Radio Heads (RRHs) to provide throughput at hot spots. Possible configuration is to assign two carriers on different frequency bands. It is expected that F2 cells can be aggregated with the underlying F1 macro cells. [5]

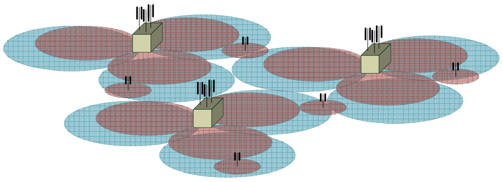

Figure 7. CA deployment scenario #5

The fifth configuration scenario is similar to scenario #2, but frequency selective repeaters are deployed so that coverage is extended for one of the carrier frequencies. It is expected that F1 and F2 cells of the same base station can be aggregated where coverage overlap. [5]

III. PROTOCOL IMPACT OF CARRIER AGGREGATION

Backward compatibility is essential for smooth system migration and maximal reuse of the previous design. The design of 3GPP LTE-Advanced carrier aggregation considers backward compatibility; thus CA feature enables concurrent data transmission on multiple CCs, with procedures largely inherited from LTE Release 8/9.

The services offered by higher layers are filled by user plane and control plane function. The user plane is responsible for data communicational, and the control plane is responsible for maintaining the connection between the network and the user equipment (UE). The LTE R8/9 control plane stack also applies to LTE-A CA. From the higher layer viewpoint, each CC appears as a single cell with its own cell identifier: each UE connects to one Primary Serving Cell (Pcell) which is initially configured during establishment and provides all necessary control information and functions; besides, up to four Secondary Serving Cells (SCells) may be configured after connection establishment only to provide additional radio resources. [6]

In the user plane protocol design for LTE-A, the use of carrier aggregation is not visible above the Medium Access Control (MAC) layer.

A. Physical Layer Aspects

The exchanging of the data and control information between network and UE is the responsibility of the physical layer. LTE-A CA inherits the legacy LTE data transmission per CC, including multiple access scheme, modulation and channel coding (MCS). Additional UE functionalities are supported in LTE-A, but the main challenge in the design of CA was improving the DL and UL control signaling to efficiently support data transmission. [7]

For downlink, at the start of each subframe of each DL CC a control region is available for Physical Control Format Indicator Channel (PCFICH – transmits a control format indicator, CIF, field which specifies the number of OFDMA symbols carrying control information), Physical Downlink Control Channel (PDCCH – supports information on resource allocation, MCC, HARQ etc.) and Physical HARQ Indicator Channel (PHICH – used for transmission of the HARQ ACK/NACKs).

A key characteristic of CA is a cross-carrier-scheduling. This enables a PDCCH on a CC to be configured in order to scheduled PDSCH and PUSCH transmissions on other CCs by means of new 3-bits carrier indicator field (CIF) inserted at the beginning of the PDCCH. The main motivation for cross-carrier scheduling is to support Inter-Cell Interference Coordination (ICIC) for PDCCH in heterogeneous networks, so CA can reduce or even eliminate ICIC on PDCCH of the CC which can schedule data resources on others CCs and improve data rates. [8]

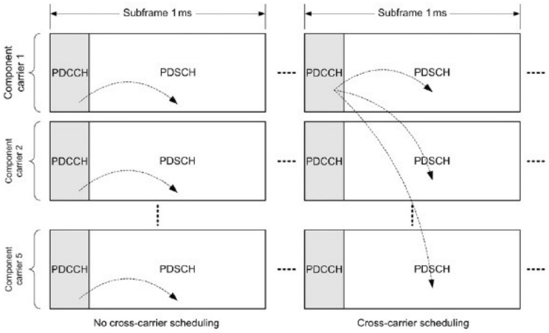

Figure 8. Cross-carrier scheduling

The normal scheduling operation where the PDCCH with the corresponding PDSCH or PUSCH are transmitted on the same cell is also maintained for backward compatibility. It is possible to transmit PDCCH scheduling a PDSCH on the same carrier frequency and PDCCH scheduling a PUSCH on a linked UL carrier frequency where the linkage of the DL and UL carriers in conveyed as system information.

Based on the decoded CFI value, UE derives the starting point of PDSCH transmission. In the case of PDSCH non-cross-carrier scheduled by PDCCH on the same component carrier, UE is required to decode the PCFICH in order to determine the starting OFDM symbol used for PDSCH. For PDSCH cross-carrier scheduled by PDCCH on another carrier, the starting OFDM symbol for PDSCH transmission is configured by the network though higher layers, and the UE is not required to decode the PCFICH on the CC of the PDSCH transmission. [9]

The design of the PHICH in LTE-Advanced CA follows the design of LTE Release 8.

Uplink control signaling, UCI, includes HARQ ACK/NACK signaling corresponding to potentially multiple PDSCHs, scheduling requests and Channel State Information (CSI). As in LTE Release 8/9, UCI can be transmitted on a physical uplink control channel (PUCCH) if there is no transmission on a PUSCH in a subframe, and transmitted on PUSCH otherwise. LTE-Advanced further supports, by network configuration, simultaneous transmission of PUCCH and PUSCH in a sub frame. This allows the base station to flexibly control the performance of the PUCCH and PUSCH independently and to avoid the UCI overhead on the PUSCH by utilizing existing PUCCH resources. The PUCCH can only be transmitted on the PCell, since it typically has more reliable link quality and coverage relative to the SCells. When applicable, UCI is always transmitted on a single PUSCH. [9]

LTE Release 8/9 PUCCH known as format 1b was only defined to support up to 4 bits (2 bits in FFD and 4 bits in TDD), so HARQ feedback can only be transmitted only for two CCs. The PUCCH format 3 was introduced in LTE-A to support HARQ feedback for a UE configured with downlink CA. This enables a full range of ACK/NACK bits to be transmitted (up to 10 Bits for FDD and up to 20 bits in TDD). [7]

Channel state information (CSI) feedback assist the network to achieve PDSCH scheduling, including resource selection, MCS selection, transmission rack indicator and precoding matrix indicator. In order to handle the different channel conditions and interface level among different CCs, the CSI is configured for each CC. In LTE-Advanced, both periodic and aperiodic CSI feedbacks are supported. LTE-Advanced supports aperiodic CSI feedback for a single or multiple CCs in a subframe in order to balance the CSI accuracy and feedback overhead. [9]

In CA, periodic CSI is reported for only one CC in a subframe. Different offsets and periodicities should be configured to minimize collisions between CSI reports of different CCs in a subframe. In case the collisions involve the multiple periodic CSI reports, the priority is according to defined prioritization rules. Aperiodic CSI feedback is transmitted on PUSCH and carries more CSI than periodic CSI feedback. In the case of a collision between periodic and aperiodic CSI for downlink CCs, the periodic CSI is dropped. [7]

B. MAC Layer Aspects

From the MAC perspective the CA simply provides additional conduits, thus the MAC layer plays the role of a multiplexing entity for the aggregated components carriers. [10] There is one MAC entity per user, which controls the multiplexing of data from all logical channels to the user, and further controls how this data is transmitted on the available CCs. Each MAC entity will provide to his corresponding CC its own Physical Layer entity, providing resource mapping, data modulation, HARQ and channel coding.

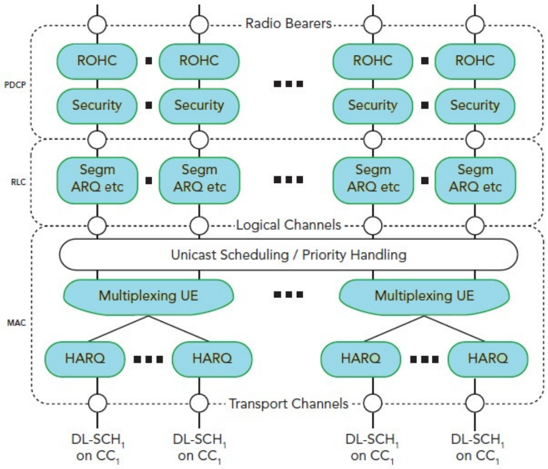

Figure 9. Downlink MAC Layer structure with CA

The interface between the MAC layer and the physical layer, which are referred to as transport channels, is also separate for each component carrier. [8]

V. CONCLUSIONS

This article provides an overview of CA in 3GPP LTE-Advanced. CA for LTE-Advanced is fully backward compatible, which essentially means that legacy LTE Release 8/9 terminals and LTE-Advanced terminals can co-exist maintaining the advantages of legacy technologies and reducing the cost per bit and saving energy.

Carrier Aggregation has much more to offer and it continues to be a significant area of work for 3GPP, equipment manufacturers and network operators and will continue to be one of the most important techniques in the next generation telecommunication system. Over the coming years there will be a number of important developments, including, for example: increasing the number of CCs and the total bandwidth supported in both the DL and the UL; supporting a greater number of frequency bands and combinations of frequency bands; supporting CA between licensed and unlicensed spectrum. [13]

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