Introduction to Carrier Aggregation Technology in LTE-Advanced Systems

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***Abstract*—Upon the increasing application of multimedia network services, the next generation of wireless communication systems, named LTE-Advanced, have gradually towards the technological development of large broadband. Therefore, CA (Carrier Aggregation) technology becomes the most critical technology of LTE-Advanced system to achieve 100MHz bandwidth. However, there are a lot of challenges for CA technology to be adopted in LTE-Advanced systems. This paper will present an introduction of CA technology in LTE-Advanced system, including the configuration and deployment scenarios, current 3GPP status on CA technology resolution, and on-going discussion for optimization and further study issues.**

***Keywords*—Multimedia, Broadband, Carrier Aggregation, LTE-Advanced, 3GPP**

1. INTRODUCTION

LTE (Long Term Evolution)-Advanced system adopts new wireless broadband access technology MIMO-OFDMA (Multi Input Multi Output-Orthogonal Frequency Division Multiple Access) and all-IP (Internet Protocol) central office network to fulfill the requirements of downstream up to 1 Gbps and upload up to 500Mbps within a bandwidth of 100MHz. Generally, these requirements are for so-called fourth-generation wireless communication systems. Upon the demand on higher bandwidth and higher data rate applications, LTE-Advanced system introduced CA (Carrier Aggregation) technology.

That is to form a larger bandwidth by collection of multiple existing carriers. Therefore the aggregated carrier can meet the needs of higher bandwidth. Fig. 1 shows a CA example in LTE-Advanced system that five 20 MHz carriers are aggregated to realize a virtual 100MHz carrier for applications.

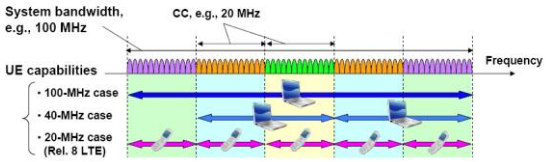

Fig. 1 Concept of carrier aggregation

The remainder of this paper is organized as follows. In section 2, we will first introduce the most popular deployment scenarios of CA from operators' point of view. Then we illustrate the CA scenarios discussed in recent 3GPP standard meetings. In section 3, we further discuss the state-of-art issues for the optimization of CA technology and make a summary introduction for related agreements in recent 3GPP standard meetings. Finally, we conclude the paper in Section 4

2. CONFIGURATION SCENARIOS OF CARRIER AGGREGATION

In this section, we will introduce the possible configuration scenarios of CA technology in a new release of LTE-Advanced system. For example, F1 and F2 denote two carriers to be aggregated. Operator NTT DoCoMo [1] proposed five possible scenarios of CA for the mutual configuration between carrier F1 and carrier F2.

- Fig. 2 depicts the first possible configuration scenario of CA for carrier F1 and carrier F2. In this configuration scenario, the coverage areas of carrier F1 and carrier F2 are almost overlapped and both carriers provide a complete and almost the same range of services. Also, the provision base station of carrier F1 and carrier F2 are collocated, i.e., located in the same position. For this scenario, both carriers are generally within the same frequency band.

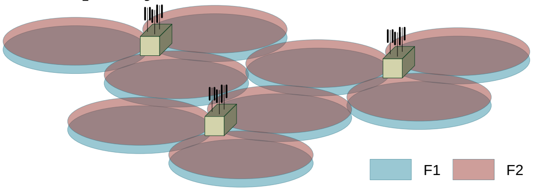

Fig. 2 CA configuration scenario #1

- The second possible configuration scenario is shown in Fig. 3. Similar to configuration scenario # 1, configuration scenario # 2 has collocated base station for carrier F1 and carrier F2 but there are different scope for each carrier. As shown in Fig. 3, only carrier F1 provides full coverage area, while carrier F2 is being used to further improve the data transfer rate for some specific area. The two carriers are possibly configured in different frequency bands, such as carrier F1 is configured in frequency band of 2 GHz, and carrier F2 is configured in frequency band of 3.5 GHz. Therefore, the action the user mobility handover process should be performed based on the coverage of carrier F1.

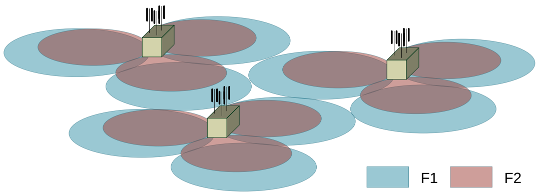

Fig. 3 CA configuration scenario #2.

- In the third configuration scenario, the base stations of carrier F1 and carrier F2 are also collocated but carrier F2 has different antenna direction with the carrier F1. As shown in Fig. 4, the antenna of carrier F2 is pointing the coverage boundaries of carrier F1 to enhance the data rate for coverage border. In this example, carrier F1 carrier supports a complete coverage while carrier F2 is majorly used to overcome the coverage holes of carrier F1. This configuration scenario # 3 is more likely to assign two carriers in different frequency bands, such as carrier F1 is configured in frequency band of 2 GHz and carrier F2 is configured in frequency band of 3.5 GHz. The major reason is to gain transmission diversity on different band for more complete coverage. Therefore, the handover process of a mobile user is majorly based on the coverage of carrier F1 as the main consideration. For those mobile users located in the overlapped coverage area of carrier F1 and carrier F2, they will be able to aggregate the capacity of two carriers for higher data transmission rate.

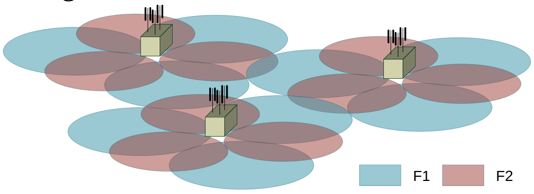

Fig. 4 CA configuration scenario #3.

- The fourth CA configuration scenario is shown in Fig. 5. To combine wireless RRH (Remote Radio Head), carrier F1 supports wide area coverage area while carrier F2 is deployed with RRH for hot spot area to enhance data transmission rate in regional area. Similarly, carrier F1 provides a more complete coverage so a mobile user would consider the handover process mainly dependent on the signal quality of carrier F1. Possible configuration scenario is to assign two carriers on different frequency bands.

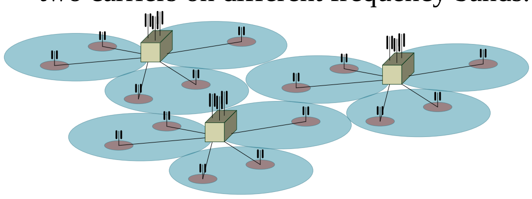

Fig. 5 CA configuration scenario #4.

- The fifth configuration scenario is similar to scenario #2. As shown in Figure 6, carrier F1 and carrier F2 have different scope of services. In addition, a frequency selective repeater may be deployed to extend the coverage of carrier F2. Therefore, mobile device could aggregate the capacity of these two carriers to improve the data transmission rate.

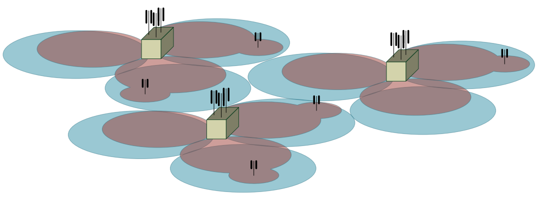

Fig. 6 CA configuration scenario #5.

The five possible CA scenarios can be adopted for both downlink and uplink but may induce different technical issues. For example, the uplink in the configuration scenarios # 4 and # 5 would lead to different uplink timing problem between different carriers. For simplicity, an agreement for 3GPP LTE Rel-10 version is to preclude the cases with multiple uplink TA (timing advance) values. In other words, LTE Rel-10 version specification will support the five CA scenarios in downlink transmissions but the CA scenarios # 1, # 2 and # 3 are priority to be considered in uplink transmissions. For CA scenarios #4 and #5, uplink CA can be considered only if there is no multiple uplink TA problems. Regardless uplink transmission through RRHs or frequency selective repeaters, the system should make sure the aggregated uplink transmissions without multiple uplink TA values

3. CA OPTIMIZATION TECHNOLOGIES

CA technology is mainly an extension of a single carrier technology. Therefore, most of technical features of single carrier technology can be directly adopted or minor revised. However, there are some specific issues considered for LTE-Advanced systems to improve some existing technologies and further optimize the system performance. In this section, we will majorly deal with the issues of activation and deactivation of mechanisms for multi-carrier operation. Also, the related handover process is discussed for system optimization under the support of CA technology.

3.1. Activation and Deactivation Mechanism) [3-6]

To minimize the power consumption on mobile devices to perform aggregation of multiple carriers, LTE-Advanced system induces the activation and deactivation mechanism for those additional carriers. While supporting multi-carrier transmissions, one of multiple carriers would be designated as the primary carrier and the others are secondary carriers. In the beginning phase, a base station would configure one or more carriers for a mobile device through the so-called RRC (Radio Resource Control) message. These configured carriers are initially set as deactivation state and the mobile device does not receive or detect signals on these deactivation carriers such like PDCCH (Physical Downlink Control Channel) and PDSCH (Physical Downlink Share Channel). Also, there is no need to perform measurement on these deactivation carriers for CQI (Channel Quality Indicator) reporting. Therefore, the mobile device can reduce unnecessary power consumption.

When these carriers are pre-configured for a mobile device, the base station can then activate one or more configured carriers by a MAC (Media Access Control) control messages, named MAC Control Element, to launch services on the activated carriers. When a carrier is activated, the mobile device has to receive corresponding PDCCH and PDSCH and perform measurement for CQI reports. If the channel quality of the activated carriers is not good for communication services or the mobile device decreases its need of transmission rate, the base station can deactivate specific carriers through same MAC Control Element. Therefore, the activation and deactivation mechanisms can help mobile devices to physically stop the corresponding processes on those temporarily unused carriers to reduce power consumption. In addition, the base station can perform quick setup through MAC Control Element to adjust corresponding parameters for better flexibility with respective to unexpected service requirements.

In addition to the explicit mechanism through MAC Control Element to deactivate a carrier, timer-based mechanism is also adopted for the base station to perform implicit deactivation of a carrier. Based on current agreement in 3GPP meeting, both the base station and the mobile device will initiate a deactivation timer while a carrier is activated by receiving MAC Control Element. When the deactivation timer countdown to zero, both the base station and the mobile device will regard the carrier becomes deactivated where the mobile device can stop to receive the corresponding downlink channel on the deactivated carrier and the base station is also not to transmit any information for the mobile device on the deactivated carrier. The deactivation timer will be initialized or reset if the following situations occur.

- When a carrier is activated, the corresponding deactivation timer is initialized.
- When the mobile device receives PDCCH on an activated carrier which contains resource allocation information for the mobile device, the corresponding

deactivation timer should be reset to initial value.

- When the mobile device receives PDCCH on an activated carrier which contains data reception indication for the mobile device, the corresponding deactivation timer should be reset to initial value.

Currently, specification of activation and deactivation mechanisms is only on downlink carrier. To adopt activation and deactivation on uplink is still a undetermined item in 3GPP standard meeting [7]. The main reason is that a mobile device has to complete the setting of corresponding parameters on uplink carrier within 3 ms after it detects uplink resource assignment from receiving PDCCH. Therefore, it is obviously activated and unnecessary to have any additional signalling for activation. On the other hand, deactivation of uplink carrier seems unnecessary because a mobile device can stop uplink operation if it is no longer to transmit on uplink carrier. However, since uplink SRS (Sounding Reference Signal) is mandatory for a configured carrier, deactivation can help mobile device to stop the unnecessary transmission of SRS for power saving while activation ask the mobile device to resume the transmission of SRS. Therefore, it may be helpful and need further evaluation and discussion to clearly define the activation and deactivation operation for uplink.

3.2. Enhancement of Current Handover Procedure for CA Supporting [8-10]

Mobile device may be configured with multiple carriers to support simultaneous transmission for its high bandwidth and high data rate transmission requirements. While a multi-carrier mobile device handover from a base station to another one, the target base station has to take over the service continuity and most likely configure multiple carriers for the mobile device. In this subsection, we will discuss the issue to improve the current LTE handover process for support of CA configuration before completion of the handover procedure.

The detailed LTE handover procedure is specified in [2]. To ensure the service continuity of the handover mobile device with CA supporting, current base station will send a handover command to the mobile device for the multiple carrier configuration in target base station. During handover preparation phase, current base station shall send a handover request to the target base station. The handover request contains a list of candidate carriers with latest measurement results so target base station can determine a new CA configuration by jointly considering the measurement results and the carrier loading. The available CA configuration of target base station is then acknowledged to current base station and forward to the handover mobile device through handover command.

The mobile device starts to progress handover procedure after receiving the handover command. During the handover procedure, all carriers in new CA configuration are naturally in deactivation state until the handover completion. However, there are two options for the state of carriers in new CA configuration: one is that these carriers should be automatically activated after handover completion and the other is to wait for activation by MAC control messages from target base station. Fig. 7 illustrates the two options for a new configuration at handover completion [11-17]. Now, the current resolution is to adopt option #2 to keep the carriers of new CA configuration in deactivation state. The purpose is to leave the control authority for target base station. The target base station can decide the usage of the configured carriers based on carrier loading to achieve the mobile device's data transmission rate under maximization of its overall system efficiency.

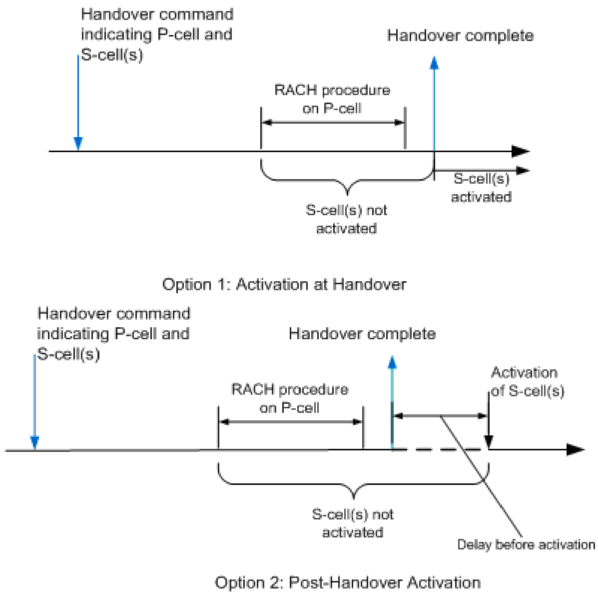

Fig. 7 Status of new CA configuration after handover completion

4. CONCLUSIONS

In this paper, we introduce the carrier aggregation technologies adopted for next generation LTE-Advanced systems. Five possible carrier aggregation configuration scenarios are illustrated and then we discuss two issues for further optimization: activation and deactivation mechanisms for carriers and enhancement for corresponding handover procedures.

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