International Journal of Advanced Science and Technology
Vol. 41, April, 2012

Effective Carrier Aggregation on the LTE-Advanced Systems

A. Z. Yonis[1*], M. F. L. Abdullah[2] and M. F. Ghanim[3]

[1]Department of Communication Engineering, College of Electronics Engineering, University of Mosul, Mosul, Iraq

[2]Department of Communication Engineering, Faculty of Electrical and Electronic Engineering, University of Tun Hussein Onn Malaysia,Malaysia

[3]College of Engineering, Computer Engineering Department, University of Mosul, Mosul, Iraq

aws_zuher@yahoo.com, faiz@uthm.edu.my, mayada_faris@yahoo.com

Abstract

The initial release of LTE provided extensive support for deployment in spectrum allocations of various characteristics, with bandwidth ranging roughly from 1.3 MHz up to 20 MHz in both paired and unpaired bands. In LTE release 10 the transmission bandwidth can be further extended by means of so-called Carrier Aggregation (CA), where multiple component carriers are aggregated and jointly used for transmission to/from a single terminal. There are up to five component carriers, possibly each of different bandwidth, which can be aggregated, allowing for transmission bandwidth up to 100 MHz backwards compatibility where, each component carrier (CC) uses the release-8 structure. Hence, to a release-8/9 terminal, each CC will appear as an LTE release-8 carrier, while a carrier-aggregation capable terminal can exploit the total aggregated bandwidth, enabling higher data rates. In general case, a different number of component carriers can be aggregated for the downlink and uplink. Therefore, this paper highlights the carrier aggregation which supports the inter-band aggregation contiguous component carriers, intra-band aggregation non-contiguous component carriers and inter-band aggregation. This paper also presents the enhancement of LTE spectrum flexibility through carrier aggregation, further extension of multi-antenna transmission and provision of improvements in the area of inter-cell interference coordination in heterogeneous network deployments.

Keywords: *LTE-Advanced, Carrier Aggregation (CA), inter-band aggregation, intra-band aggregation*

1. Introduction

LTE-Advanced aims to support peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink [1]. In order to fulfil such requirements, a transmission bandwidth of up to 100 MHz is required; however, since the availability of such large portions of contiguous spectrum is rare in practice, LTE-Advanced uses carrier aggregation of multiple Component Carriers (CCs) to achieve high-bandwidth transmission. Release 8 LTE carriers have a maximum bandwidth of 20 MHz, therefore LTE-Advanced can supports aggregation of up to five 20 MHz CCs.

The second motivation for using carrier aggregation is to facilitate efficient use of fragmented spectrum, irrespective of the peak data rate. Carrier aggregation in LTE-Advanced is designed to support aggregation of a variety of different arrangements of CCs, including CCs of the same or different bandwidths, adjacent or non-adjacent CCs in the same frequency band, and CCs in different frequency bands. Each CC can take any of the transmission bandwidths supported by LTE Release 8, namely 6, 15, 25, 50, 75 or 100 Resource Blocks (RBs), corresponding to channel bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz respectively. For Frequency Division Duplex (FDD) operation, the number of aggregated carriers in uplink and downlink may be different (although Release 10 focuses on the case where the number of downlink CCs is not less than the number of uplink CCs). This flexibility enables a large variety of fragmented spectrum arrangements of relevance to network operators to be supported. The third motivation for carrier aggregation is the support of heterogeneous networks.

2. Carrier Aggregation Schemes in LTE and LTE-Advanced

The possibility for carrier aggregation was introduced in LTE release 10. In the case of carrier aggregation, multiple LTE carriers, each with a bandwidth up to 20 MHz, can be transmitted in parallel to/from the same terminal, thereby allowing for an overall wider bandwidth and correspondingly higher per-link data rates. In the context of carrier aggregation, each carrier is referred to as a component carrier (CC), from an RF point-of-view; the entire set of aggregated carriers can be seen as a single (RF) carrier. As mention earlier, up to five component carriers, possibly of different bandwidths of up to 20 MHz, can be aggregated allowing for an overall transmission bandwidths of up to 100 MHz. A terminal capable of carrier aggregation may receive or transmit simultaneously on multiple component carriers. Each CC can also be accessed by an LTE terminal from an earlier releases that is, component carriers are backwards compatible [2].

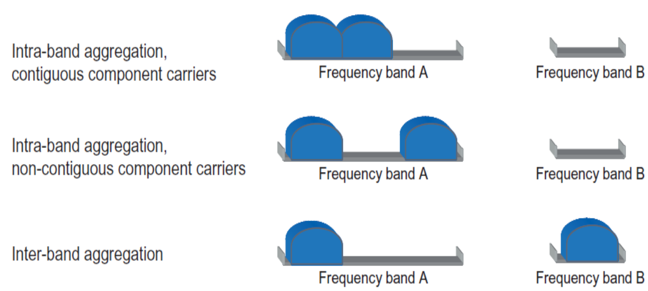


Figure 1. Different Types of Carrier Aggegation [2]

It should be noted that aggregated component carriers do not need to be contiguous in the frequency domain but rather, with respect to the frequency location of the different component carriers. There are three different cases which can be identified as shown in Figure 1:

- Intra-band aggregation with frequency-contiguous component carriers
- Intra-band aggregation with non-contiguous component carriers
- Inter-band aggregation with non-contiguous component carriers

The possibility to aggregate non-adjacent component carriers allows for exploitation of a fragmented spectrum; operators with a fragmented spectrum can provide high-data-rate services based on the availability of a wide overall bandwidth even though they do not posses a single wideband spectrum allocation. Except from an RF point of view there is no difference between the three different cases outlined in Figure 1 and they are all supported by the basic LTE release-10 specification.

However, the complexity of RF implementation is vastly different, with the first case being the least complex. Although spectrum aggregation is supported by the physical-layer and protocol specifications, the actual implementation will be strongly constrained, including specification of only a limited number of aggregation scenarios and aggregation over a dispersed spectrum can only being supported by the most advanced terminals.

A terminal capable of carrier aggregation has one downlink primary CC and an associated uplink primary component carrier. In addition, it may have one or several secondary component carriers in each direction. Different terminals may have different carriers as their primary CC that is, the configuration of the primary CC is terminal specific.

The association between the downlink primary carrier and the corresponding uplink primary carrier is cell specific and signalled as part of the system information. This is similar to the case without carrier aggregation, although in the latter case the association is trivial. The reason for such an association is, for example, to determine which uplink CC has a certain scheduling grant transmitted on the downlink relates without having to explicitly signal the component-carrier number.

All idle mode procedures apply to the primary CC only or, expressed differently, carrier aggregation with additional secondary carriers configured only applies to terminals in the RRC_CONNECTED state. Upon connection to the network, the terminal performs the related procedures such as cell search and random access following the same steps as in the absence of carrier aggregation. Once the communication between the network and the terminal is established, additional secondary component carriers can be configured.

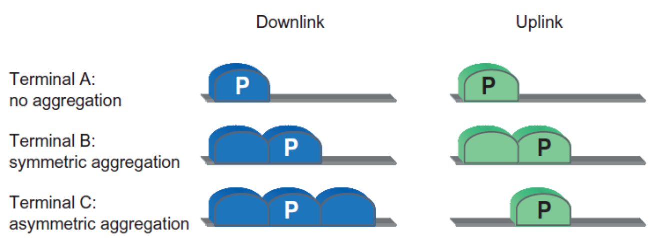


Figure 2. Examples of Carrier Aggregation ('P' denotes the primary component carrier)[2]

The fact that carrier aggregation is terminal specific –that is, different terminals may be configured to use different sets of component carriers is useful not only from a network perspective to balance the load across component carriers, but also to handle different capabilities between terminals.

Some terminals may be able to transmit/receive on multiple component carriers, while other terminals may do so on only a single carrier. This is an obvious consequence of being able to serve terminals from earlier releases at the same time as a carrier-aggregation-capable release-10 terminal, but it also allows for different capabilities in terms of carrier aggregation for different terminals as well as a differentiation between downlink and uplink carrier-aggregation capability. For example, a terminal may be capable of two component carriers in the downlink but of only a single CC that is, no carrier aggregation – in the uplink, as is the case for terminal C in Figure 2. Note also that the primary component-carrier configuration can differ between terminals. Asymmetric carrier aggregation can also be useful to handle different spectrum allocations, for example if an operator has more spectrums available for downlink transmissions than uplink transmissions.

In release 10, only downlink-heavy asymmetries are supported that is, the number of uplink component carriers configured for a terminal is always equal to or smaller than the number of configured downlink component carriers. Uplink-heavy asymmetries are less likely to be of practical interest and would also complicate the overall control signalling structure, as in such a case multiple uplink component carriers would need to be associated with the same downlink component carrier.

Carrier aggregation is supported for both FDD and TDD, although all component carriers need to have the same duplex scheme. Furthermore, in the case of TDD, the uplink–downlink configuration should be the same across component carriers. The special subframe configuration can be different for different components carriers though, as long as the resulting downlink–uplink switch time is sufficiently large [2].

A. Intra-band aggregation with frequency-contiguous component carriers

This is where a contiguous bandwidth wider than 20 MHz is used for CA (Figure 1). Although this may be a less likely scenario given frequency allocations today, it can be common when new spectrum bands like 3.5 GHz are allocated in the future in various parts of the world. The spacing between center frequencies of contiguously aggregated CCs is a multiple of 300 kHz to be compatible with the 100 kHz frequency raster of Release 8/9 and preserving orthogonally of the subcarriers with 15 kHz spacing.

B. Intra-band aggregation with non-contiguous component carriers

This is where multiple CCs belonging to the same band are used in a non-contiguous manner (Figure 1). This scenario can be expected in countries where spectrum allocation is non-contiguous within a single band, when the middle carriers are loaded with other users, or when network sharing is considered. So this model would fit operators in North America or Europe, who have fragmental spectrum in one band or share same cellular network.

C. Inter-band aggregation with non-contiguous component carriers

Inter-Band Carrier Aggregation implies that carriers in different operating bands are aggregated (see also the last example in Figure 1). Many RF properties within a band can, to a large extent, remain the same as for a single carrier case. There is, however, impact for the UE, due to the possibility for inter modulation and cross-modulation within the UE device when multiple transmitter and receiver chains are operated simultaneously. For the base station it has very little impact, since in practice it corresponds to a base station supporting multiple bands, which is a configuration not really treated in RF specifications.

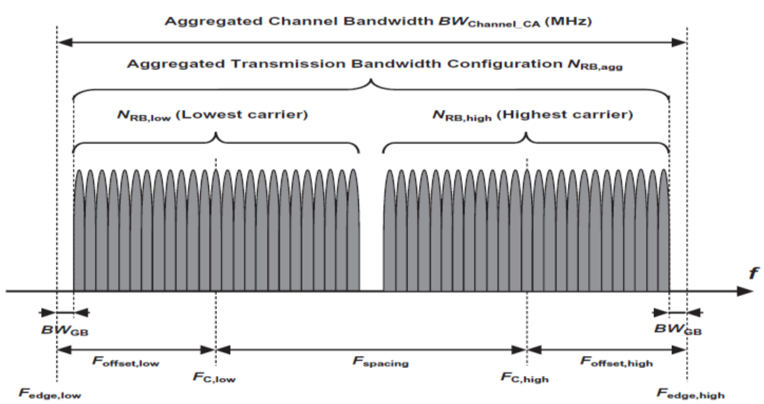


Figure 3. Definitions for Intra-Band Carrier Aggregation RF parameters, for an example with two aggregated carriers [2]

Intra-band carrier aggregation is limited to two component carriers and to one paired band (Band 1) and one unpaired (Band 40) band in release 10. Inter-band carrier aggregation is limited to the generic case of aggregating carriers between Bands 1 and 5. The next band pair for which a carrier aggregation capability is specified is a "European" scenario for Bands 3 and 7, which is planned for later inclusion in release 10. The band or set of bands over which carriers are aggregated is defined as a UE capability called E-UTRA CA Band. For the base station the band or set of bands defines what is called a Carrier Aggregation Configuration for the base station.

For intra-band carrier aggregation, the definitions of $BW_{channel}$ and N_{RB} shown in Figure 4 still apply for each component carrier, while new definitions are needed for the Aggregated Channel Bandwidth ($BW_{Channel\_CA}$) and the Aggregated Transmission bandwidth Configuration ($N_{RB,agg}$) shown in Figure 3. In connection with this, a new capability is defined for the UE called *Carrier Aggregation Bandwidth Class*. There are six classes, where each class corresponds to a range for $N_{RB,agg}$ and a maximum number of component carriers, as shown in Table 1. The classes corresponding to aggregation of more than two component carriers or consisting of more than 200 RBs are under study for later releases.

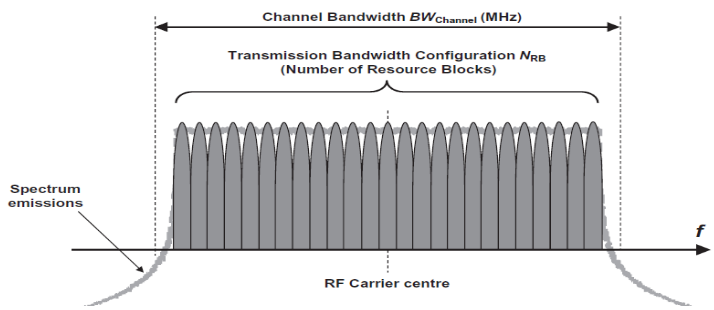


Figure 4. The Channel Bandwidth for one RF Carrier and the corresponding Transmission Bandwidth Configuration

A fundamental parameter for intra-band CA is the channel spacing. A tighter channel spacing than the nominal spacing for any two single carriers could potentially lead to an increase in spectral efficiency, since there would be a smaller unused "gap" between carriers. On the other hand, there is also a requirement for the possibility to support legacy single-carrier terminals of earlier releases.

Table 1. UE Carrier Aggregation Bandwidth Classes

Channel Aggregation Bandwidth Classes	Aggregated Transmission BW Configuration	Number of component Carriers
A	≤100	1
B	≤100	2
C	101-200	3
D,E,F	Under study (201-500)	Under study

An additional complication is that the component carriers should be on the same 15 kHz subcarrier raster in order to allow reception of multiple adjacent component carriers using a single FFT instead of an FFT per subcarrier. This property, together with the fact that the frequency numbering scheme is on a 100 kHz raster, results in the spacing between two component carriers having to be a multiple of 300 kHz, which is the least common denominator of 15 and 100 kHz.

For the specification, RF requirements are based on a nominal channel spacing that is derived from the channel bandwidth of the two adjacent carriers $BW_{Channel(1)}$ and $BW_{Channel(2)}$ as follows:

$$F_{Spacing,Nominal} = \left\lfloor \frac{BW_{Channel(1)} + BW_{Channel(2)} - 0.1\left|BW_{Channel(1)} - BW_{Channel(2)}\right|}{2 \cdot 0.3} \right\rfloor 0.3. \qquad (1)$$

In order to allow for a tighter packing of component carriers, the value of $F_{Spacing}$ can be adjusted to any multiple of 300 kHz that is smaller than the nominal spacing, as long as the carriers do not overlap. RF requirements for LTE are normally defined relative to the channel bandwidth edges. For intra-band CA, this is generalized so that requirements are defined relative to the edges of the Aggregated Channel Bandwidth, identified in Figure 3 as $F_{edge,low}$ and $F_{edge,high}$. In this way many RF requirements can be reused, but with new reference points in the frequency domain. The aggregated channel bandwidth for both UE and base station is defined as:

$$BW_{Channel\_CA} = F_{edge,high} - F_{edge,low} \qquad (2)$$

The location of the edges is defined relative to the carriers at the edges through a new parameter F_{offset} (see Figure 3) using the following relation to the carrier center positions F_C of the lowest and highest carriers:

$$F_{edge,low} = F_{C,low} - F_{offset,low} \qquad (3)$$

$$F_{edge,high} = F_{C,high} + F_{offset,high} \qquad (4)$$

The value of F_{offset} for the edge carriers and the corresponding location of the edges are, however, not defined in the same way for UE and base station.

For the base station, there are legacy scenarios where the base station receives and transmits adjacent independent carriers, supporting legacy terminals of earlier releases using single carriers. This scenario will also have to be supported for a configuration of aggregated carriers. In addition, for backward compatibility reasons, a fundamental parameter such as channel bandwidth and the corresponding reference points (the channel edge) for all RF requirements will have to remain the same. The implication is that the channel edges shown in Figure 4 for each CC will also remain as reference points when the carriers are aggregated. This results in the following base station definition of F_{offset}, for carrier aggregation, which is "inherited" from the single carrier scenario:

$$F_{offset} = \frac{BW_{channel}}{2} \quad \text{(for base station)}. \qquad (5)$$

Unlike the base station, the UE is not restricted by legacy operation, but rather from the nonlinear properties of the PA and the resulting unwanted emissions mask. At both edges of the aggregated channel bandwidth, a guard band BW_{GB} will be needed, in order for the emissions to reach a level where the out-of-band emissions limits in terms of an emission mask are applied. Whether a single wide carrier or multiple aggregated carriers of the same or different sizes are transmitted, the guard band needed will have to be the same at both edges, since the emission mask roll-off is the same. A problem with the backwards-compatible base station definition is that the resulting guard BW_{GB} is proportional to the channel BW and would therefore be *different* if carriers of different channel BW are aggregated.

For this reason, a different definition is used for the UE, based on a "symmetrical" guard band. For the edge carriers (low and high), F_{offset} is half of the transmission bandwidth configuration, plus a symmetrical guard band BW_{GB}:

$$F_{offset} = \frac{0.18\,\text{MHz} \cdot N_{RB}}{2} + BW_{GB} \quad \text{(for UE)}, \qquad (6)$$

Where 0.18 MHz is the bandwidth of one resource block and BW_{GB} is proportional to the channel BW of the largest component carrier. For the CA bandwidth classes defined in release 10 and where the edge carriers have the same channel bandwidth, F_{offset} will be the same for terminals and base stations and $BW_{Channel\_CA}$ will be the same.

It may look like an anomaly that the definitions may potentially lead to slightly different aggregated channel BW for the UE and the base station, but this is in fact not a problem. UE and base station requirements are defined separately and do not have to cover the same frequency ranges. The aggregated channel BW for both UE and base station do, however, have to be within an operator's license block in the operating band. Once the frequency reference point is set, the actual RF requirements are to a large extent the same as for a single carrier configuration.

3. Bandwidth Extension Using Carrier Aggregation

In order to achieve higher peak data rate, the bandwidth of the LTE-Advanced systems should be much wider than current 3G systems. It is expected to be as high as 100 MHz [3, 4, and 5]. Several carriers can be aggregated to form a wide bandwidth. This is known as carrier aggregation and the aggregated carriers are named as (CC)s in Third Generation Partnership Project (3GPP). Figure 5 gives an illustration of bandwidth extension by carrier aggregation technique.

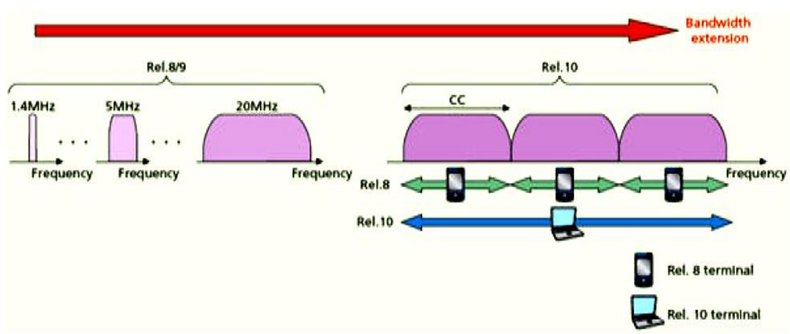


Figure 5. Bandwidth Extension by Carrier Aggregation

To support of wider bandwidth Carrier Aggregation (CA) has been identified as a key technology that will be crucial for LTE-Advanced in meeting IMT-Advanced requirements. The need for CA in LTE-Advanced arises from the requirement to support bandwidths larger than those currently supported in LTE while at the same time ensuring backward compatibility with LTE. Consequently, in order to support bandwidths larger than 20 MHz, two or more component carriers are aggregated together in LTE-Advanced. An LTE-Advanced terminal with reception capability beyond 20 MHz can simultaneously receive transmissions on multiple component carriers. An LTE Rel-8 terminal, on the other hand, can receive transmissions on a single CC only, provided that the structure of the CC follows the Rel-8 specifications.

The spectrum aggregation scenarios can be broadly classified into three categories: Intra-band adjacent, Intra-band non-adjacent and Inter-band as Examples of these scenarios are provided in Figure 6.

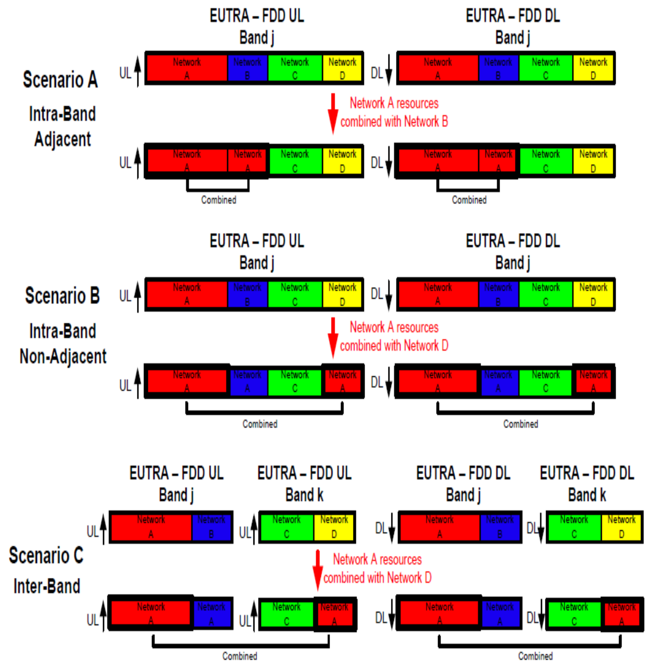


Figure 6. Spectrum Aggregation Scenarios for FDD[6]

4. Band Combinations for LTE-CA

Specifically for the LTE-CA combinations, a large number of combinations will need to be studied in order to support the needs of the various operators throughout the world according to 3GPP R4-101062. It is clear that the large amount of work needed to complete this will not be done before the plan release date for LTE Rel-10. Consequently, it was decided that in LTE Rel-10, RAN 4 will complete the specification for a set of generic scenarios (Tables 2 and 3). It was also agreed that the additional CA scenarios will be completed in a release-independent fashion. The Table 2 and 3 are based upon the table in 3GPP RP-100661 [6].

Table 2. Intra Band Contiguous CA

E-UTRA CA Band	E-UTRA Operating Band	Uplink (UL) band				Downlink (DL) band				Duplex Mode
		UE transmit/ BS receive $F_{UL\ low}$(MHz)-$F_{U\ high}$ (MHz)			Channel BW MHz	UE receive/ BS transmit $F_{DL\ low}$(MHz)-$F_{D\ high}$ (MHz)			Channel BW MHz	
CA_40	40	2300	-	2400	50[1]	2300	-	2400	50	TDD
CA_1	1	1920	-	1980	40	2110	-	2170	40	FDD
Note 1:BS requirement will be developed for both50 MHz and 40 MHz aggregated channel BWs for the CA_40 scenario in release-10 timeframe										

Table 3. Inter-band Non-contiguous CA

E-UTRA CA Band	E-UTRA Operating Band	Uplink (UL) band				Downlink (DL) band				Duplex Mode
		UE transmit/ BS receive			Channel BW MHz	UE receive/ BS transmit			Channel BW MHz	
		$F_{UL\ low}$(MHz)-$F_{U\ high}$ (MHz)				$F_{DL\ low}$(MHz)-$F_{D\ high}$ (MHz)				
CA_1-5	1	1920	-	1980	10[1]	2110	-	2170	10	FDD
	5	824	-	849	10[1]	869	-	894	10	
Note 1 Only one uplink component carrier is used in any of the two frequency bands at any time										

5. User Equipment (UE) Transmitter and Receiver Aspects

In LTE-Advanced Release 10 the spacing between the centre frequencies of contiguously aggregated CCs is a multiple of 300 kHz. The rationale behind this choice is to preserve backward compatibility with the 100 kHz frequency raster used in LTE Release 8 as well as preserving the orthogonally of the subcarriers with the 15 kHz spacing. Depending on the aggregation scenario, the actual spacing (a multiple of 300 kHz) may be facilitated by insertion of a number of unused subcarriers between contiguous CCs [7].

6. User Equipment (UE) Transmitter Aspects of Carrier Aggregation

The output power dynamics are impacted by the UE architecture, which may be based on single or multiple Power Amplifiers (PAs). Figure 7 [8] illustrates various options for Power Amplifier (PA) architectures at the UE which can be used to support carrier aggregation.

When considering the PA configuration, it is necessary to take into account any additional back-off requirements that may exist. The Cubic Metric (CM) is only a good predictor of the additional power back-off required if the third-order Inter Modulation (IM3) distortion product lands in the Adjacent Channel Leakage Ratio (ACLR) band (as it does, for instance, for LTE Release 8 with full resource allocation or for WCDMA-based system such as UMTS and HSPA).

The new multiple SC-FDMA and clustered DFT-S-OFDM waveforms supported in Release 10 (due to carrier aggregation and the concurrent transmission of PUSCH and PUCCH) impose more stringent linearity requirements on the PA than was the case for LTE Release 8.

The factors that determine the necessary UE PA back-off are compliance to the ACLR, Spectrum Emission Mask (SEM), spurious emissions and Error Vector Magnitude (EVM) requirements [8, 9].

Small resource assignments at the band edge behave as tones and hence produce highly concentrated Inter Modulation Distortion (IMD) products. Therefore, for the concurrent transmission of PUCCH and PUSCH, the SEM is expected to be the limiting requirement.

7. UE Receiver Aspects of Carrier Aggregation

For the baseband aspects of the UE receiver, the main impact of carrier aggregation is on the soft buffer allocation, where the total HARQ buffer has to be shared between the configured CCs.

For the RF aspects, two options were considered for the baseline UE receiver architecture as part of the carrier aggregation feasibility study:

- Option A: Single RF, and baseband processing with bandwidth ≥ 20 MHz;

- Option B: Multiple RF, and baseband processing with bandwidth ≤ 20MHz.

Clearly, Option A is only applicable for intra-band aggregation of contiguous CCs, but it has the advantage of keeping the UE receiver complexity low. Option B is applicable for intra-band and inter-band aggregations for contiguous or non-contiguous scenarios, but this flexibility comes at the expense of increased complexity.

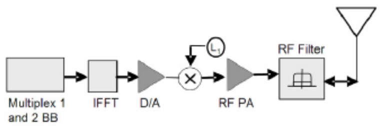
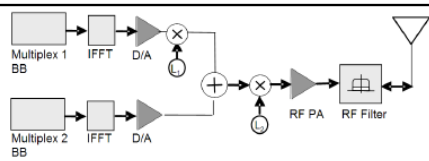
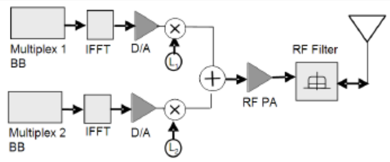
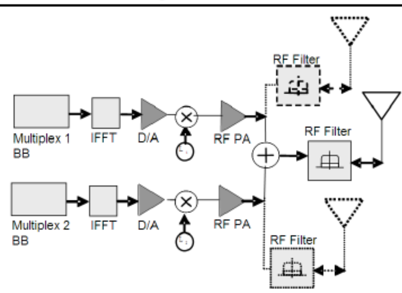
	Transmitter architecture	Aggregation Scenarios
A	 Single (baseband + IFFT + DAC + mixer + PA)	Intra-band contiguous CCs
B	 Multiple (baseband + IFFT + DAC), single (stage-1 IF mixer + IF combiner + stage-2 RF mixer + PA)	Intra-band contiguous CCs Intra-band non-contiguous CCs
C	 Multiple (baseband + IFFT + DAC + mixer), low-power RF combiner, and single PA	Intra-band contiguous CCs Intra-band non-contiguous CCs
D	 Multiple (baseband + IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna	Intra-band contiguous CCs Intra-band non-contiguous CCs Inter-band non-contiguous CCs (depending on the specific bands being aggregated)

Figure 7. Some Examples of PA Confirution Options for Carrier Aggregation. Reproduced by Permission of 3GPP [8]

8. Conclusions

There are three main motivations in introducing carrier aggregation for LTE-Advanced in Release 10, due to its support of high data rates, efficient utilization of fragmented spectrum, and support of heterogeneous network deployments by means of cross-carrier scheduling. A combination with other features defined in LTE Release 10, such as higher order MIMO, CA provides a powerful means to boost the peak user throughput in LTE Release 10 and to meet the IMT-Advanced requirements set by the ITU-R. CA allows aggregation of CCs dispersed across different bands as well as CCs having different bandwidths. CA also allows aggregation of cells having different coverage, thereby enabling flexible network deployments according to traffic demands. In exploiting cross-carrier scheduling, efficient interference management is possible in heterogeneous network deployments, thereby improving system capacity. Moreover, each CC is backwards compatible with LTE Release 8/9, allowing smooth upgrade and migration of LTE networks towards LTE-Advanced. Further evolution of CA is expected in future releases of LTE to include more advanced features such as inter-band CA for the UL and separate timing control for different UL CCs, to support additional deployment scenarios.

Acknowledgment

This research is funded by the Postgraduate Incentive Grant, University Tun Hussein Onn Malasyia (Vot 0894). The authors are grateful to Faculty of Electrical and Electronic Engineering for the technical support in carrying out this study.

References

[1] 3GPP Technical Report 36.913, “Requirements for further advancements for Evolved Universal Terrestrial Radio Access (E-UTRA) (LTE-Advanced)”, www.3gpp.org.

[2] E. Dahlman, S. Parkvall and J. Sköld, “4G LTE/LTE-Advanced for Mobile Broadband”, First published, Elsevier Ltd. UK, **(2011)**, pp.132-358.

[3] S. Parkvall, E. Dahlman, A. Furuskar, Y. Jading, M. Olsson, S. Wanstedt and K. Zangi K., “LTE-Advanced–Evolving LTE towards IMT-Advanced”- Vehicular Technology Conference, 2008. VTC 2008-Fall. IEEE 68th, **(2008)** September.

[4] A. Hashimoto, H. Yoshino and H. Atarashi, “Roadmap of IMT-advanced development”, NTT DoCoMo Inc., Tokyo- Microwave Magazine, IEEE, **(2008)** August.

[5] S. Ahmadi, “An overview of next-generation mobile WiMAX technology”, Intel Corporation-Communications Magazine, IEEE, **(2009)** June.

[6] 4G Americas, “4G Mobile broadband evolution: 3GPP Release 10 and beyond HSPA, SAE/LTE and LTE-Advanced”, **(2011)** February, pp. 51-52.

[7] S. Sesia, I. Toufik and M. Baker, “LTE–The UMTS Long Term Evolution from Theory to Practice” 2nd Ed., John Wiley, United Kingdom, **(2011)**, pp. 648.

[8] 3GPP Technical Report 36.815, “LTE-Advanced Feasibility Studies in RAN WG4 (Release 9)”, www.3gpp.org.

[9] 3GPP Technical Specification 36.101, “Evolved Universal Terrestrial Radio Access (E-UTRA); User Equipment (UE) Radio Transmission and Reception (Release 10)”, www.3gpp.org.

Authors

Aws Zuheer Yonis graduated from department of Computer Engineering at the Technical College in 2003 and completed his Master on Electrical and Electronics-Telecommunication Engineering at University Tun Hussein Onn Malaysia (UTHM) in 2011. Currently he is studying doctorate of Telecommunication Engineering at UTHM from 2011. Since 2006 he became an engineer at the University of Mosul-Iraq. He has published about 9 refereed international journal and conference papers. He is a member of IAENG, SCIEI, SIE, CBEES, SDIWC, IACSIT, and Syndicate of Iraqi Engineers.

Mohammad Faiz Liew Abdullah received BSc (Hons) in Electrical Engineering (Communication) in 1997, Dip Education in 1999 and MEng by research in Optical Fiber Communication in 2000 from University of Technology Malaysia (UTM). He completed his PhD in August 2007 from The University of Warwick, United Kingdom in Wireless Optical Communication Engineering. He started his career as a lecturer at Polytechnic Seberang Prai (PSP) in 1999 and was transferred to UTHM in 2000 (formerly known as PLSP).

At present he is a senior lecturer in the Department of Communication Engineering, Faculty of Electrical & Electronic Engineering, University Tun Hussein Onn Malaysia (UTHM). He had 10 years' experience of teaching in higher education, which involved the subject Optical Fiber Communication, Advanced Optical Communication, Advanced Digital Signal Processing and etc. His research area of interest are wireless and optical communication and robotic in communication.

Mayada Faris Ghanim graduated from Computer Engineering Department / College of Engineering at University of Mosul in 2004 and completed her Master in Computer Engineering at the same college in 2007. Currently she is studying doctorate of Electrical and Electronics Engineering at University Tun Hussein Onn Malaysia (UTHM) from 2010. Since 2006 she is working as engineer at the University of the Mosul-Iraq. She has published about 11 refereed journal and conference papers. She is a member of IAENG, SIE, SDIWC, IACSIT.