CARRIER AGGREGATION IN LTE-ADVANCED

A Thesis Submitted in Partial Fulfilment

of the Requirements for the Award of the Degree of

Master of Technology

in

Communication & Networks

by

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National Institute of Technology, Rourkela

Odisha- 769008, India

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Department of Electronics & Communication Engineering
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CERTIFICATE

This is to certify that the thesis report entitled **"CARRIER AGGREGATION IN LTE-ADVANCED"** Submitted by **Mr SATISH KUMAR TIWARI** bearing roll no. **212EC5180** in partial fulfilment of the requirements for the award of Master of Technology in Electronics and Communication Engineering with specialization in **"Communication & Networks"** during session 2012-2014 at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University / Institute for the award of any Degree or Diploma.

Prof. Poonam Singh

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ACKNOWLEDGEMENTS

First of all, I would like to express my deep sense of respect and gratitude towards my advisor and guide **Prof. Poonam Singh**, who has been the guiding force behind this work. I am greatly indebted to him for his constant encouragement, invaluable advice and for propelling me further in every aspect of my academic life. His presence and optimism have provided an invaluable influence on my career and outlook for the future. I consider it my good fortune to have an opportunity to work with such a wonderful person.

Next, I want to express my respects to Prof. S.K. Patra, Prof. S.K. Behera, Prof. S. Maiti, Prof. S.K. Das and Prof. L. P. Roy for teaching me and helping me how to learn. They have been great sources of inspiration to me and I thank them from the bottom of my heart.

I also extend my thanks to all faculty members and staff of the Department of Electronics and Communication Engineering, National Institute of Technology, Rourkela who have encouraged me throughout the course of Master’s Degree.

I would like to thank all my friends and especially my classmates for all the thoughtful and mind stimulating discussions we had, which prompted us to think beyond the obvious. I have enjoyed their companionship so much during my stay at NIT, Rourkela.

I am especially indebted to my parents for their love, sacrifice, and support. They are my first teachers after I came to this world and have set great examples for me about how to live, study, and work.

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ABSTRACT

Advancement in mobile communication technology has led to an increase in data usage due to smart electronic gadgets. Also despite of increased spectrum efficiency the required data rates (1 Gbps) for 4G LTE Advanced system cannot be attained. To attain these very high data rates it is required to increase the transmission bandwidths (up to 100 MHz) over those that can be supported by a single carrier or channel. The technique being proposed is named as carrier aggregation (CA) to aggregate two or more component carriers (CCs). These channels or carriers may be contiguous components of the spectrum, or they may be in different bands resulting in Intra-band contiguous CA, Intra-band non-contiguous CA and Inter-band CA. Carrier aggregation is supported by both formats of LTE, namely the FDD and TDD variants. This guarantees that both FDD LTE and TDD LTE are capable of meeting the high data throughput requirements placed upon them. With carrier aggregation, it is likely to schedule a user equipment (UE) on multiple component carriers simultaneously i.e. multiple spectrum bands are exploited by the same user in order to fulfil the large bandwidth requirement of the service and attain enhanced performance.

The first release of 3GPP LTE facilitated extensive support for deployment in spectrum allocations of several characteristics, with transmission bandwidths extending from 1.4MHz up to 20MHz in both paired and unpaired bands. One of the most significant features to drift from LTE system to LTE-A system is Carrier aggregation. Furthermore an LTE Advanced user is backward compatible with LTE. Carrier aggregation is a multi-carrier technique, where vacant SCC (Secondary Component Carrier) is combined with the PCC (Primary Component Carrier) that is allocated to the user equipment. Five component carriers each of 20 MHz are combined to increase bandwidth to 100 MHz for high data rates.

Each CC will act as an LTE release-8 carrier for release-8/9 UE, whereas a carrier aggregation capable UE can exploit the total aggregated bandwidth, facilitating higher data rates. Different number of component carriers can be aggregated for the downlink and uplink.

CONTENTS

CHAPTER 1

Introduction

1.1 MOTIVATION

With the growth in wireless data usage at an unusual rate there is requisite for sustained innovations in wireless data technologies to offer more capacity and higher quality of service. A trend in Internet connectivity development is being motivated by the cellular industry, and the worldwide number of Internet connected devices has now exceeded the number of connected computers and is rising at a much faster rate. Faster mobile broadband connections, more dominant smart phones, connected tablets; networked laptops as well as new consumer and enterprise applications are all motivating the wireless industry to deliver new technical proficiencies.

The multi-antenna techniques cannot always rise transmission performance, because the restrictions on UE size, complexity, and cost limit the number of antennas that can be mounted on a UE. Also spectrum is a limited, non-exhaustible shared resource which effects the valuation, and some portions of the frequency band are more valuable than others.

Hence in order to attain the performance necessities of IMT-Advanced systems, Carrier Aggregation (CA) has been projected in order to aggregate two or more component carriers for supporting high data rate transmission over a wide bandwidth, while conserving backward compatibility to inherent systems.

The inclusive aim of the Carrier Aggregation is to deliver enhanced and consistent user experience across the cell by:

- Maximizing the peak data rate and throughput by combining peak capacities and throughput performance available at different frequencies.
- Improving mobility, by reducing the relative inefficiencies that may be inherent in wireless deployments in non-contiguous carrier spread across different spectrum bands.
- Providing a better and more consistent QoS to users. A user suffering from congestion in one band can be scheduled seamlessly to access unused capacity available at another frequency or system.
- Enabling interference management with intelligent allocation of resources.

1.2 INTRODUCTION

LTE-Advanced targets peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink [1] [2]. This requirement is fulfilled by a transmission bandwidth of up to 100 MHz [3] however, since the accessibility of such large part of contiguous spectrum is uncommon in practice. High transmission bandwidth is attained in LTE-Advanced by carrier aggregation of several component carriers [3]. LTE-Advanced provisions aggregation of up to five 20 MHz CCs since Release-8 LTE carriers have an extreme bandwidth of 20 MHz [3] [4]

Regardless of the peak data rate CA enable effective use of disjointed spectrum. Aggregation of a diversity of dissimilar arrangements of CCs, containing CCs of the similar or different bandwidths, adjacent or non-adjacent CCs in the same frequency band, and CCs in different frequency bands is supported by LTE-Advanced through CA [5]. Corresponding to channel bandwidths of 1.4, 3, 5, 10, 15 and 20 MHz each CC can take any of the transmission bandwidths supported by LTE Release, namely 6, 15, 25, 50, 75 or 100 Resource Blocks (RBs) respectively [3]. The quantity of aggregated carriers in uplink and downlink can be different for FDD operation [6]. This flexibility allows a large diversity of disjointed spectrum arrangements of importance to network operators to be sustained.

Heterogeneous network is supported by CA [7]. A heterogeneous network deployment naturally comprises of a level of high-power macrocells and a level of low power small cells (e.g. picocells, closed subscriber group (CSG) femtocells or relay nodes) with at least one carrier being used by both levels. In such a deployment, communication from one cell can affect intensely with the control channels of another. Consuming separate carriers for the two levels would result in inefficient spectrum usage hence carrier aggregation permits multiple carriers to be used for a given level, while interference can be avoided by means of cross-carrier scheduling [8]. Cross-carrier scheduling permits the Physical Downlink Control Channel (PDCCH) on the CC of one serving cell to schedule transmission resources on a CC of other serving cell [4].

CCs are designed to be backward compatible in Release-10. Each CC is likely to be configured such that it is fully accessible to Release-8 User Equipment (UEs). Hence important Release-8 channels and signals such as Primary and Secondary Synchronization Signals (PSS and SSS) and System Information (SI) particular to each CC are communicated on the respective CC.

Backward compatibility also has the benefit that the technology developed for LTE Release-8 may be used again on aggregated Release-10 CCs. From the upper layer perception, each CC seems as a distinct cell with its particular cell ID.

A UE that is designed for carrier aggregation associates to one Primary Serving Cell (known as the 'P Cell') and up to four Secondary Serving Cells (known as 'S Cells'). The P Cell is defined as the cell that is configured during connection formation; it shows a vital role with respect to security, NAS mobility data, SI for configured cells, and some lower-layer tasks. S Cell is configured post connection formation, just to offer extra radio resources. The term serving cell denotes either a P Cell or S Cell. Similar frame organisation is used in all aggregated serving cells and the uplink-downlink configuration across all serving cells is similar for TDD carrier aggregation [1].

CCs corresponding to P Cell are mentioned as the Downlink and Uplink Primary Component Carriers (PCCs), whereas the CCs corresponding to an S Cell are mentioned as Downlink and Uplink Secondary Component Carriers (SCCs). All CCs that may be aggregated in a particular geographic area are expected to be synchronized and belong to the same eNodeB. UE's identity (C-RNTI) is identical in P Cell and its configured S Cells.

CA lessens interference (Dynamic Interference Management) by an idea named ACCS (Autonomous CC Selection) which states, a base station node is only permitted to use extra CCs into usage (to increase its capacity when offered traffic increases) in addition to at least one active CC with complete cell coverage only if it does not cause too much interference to the nearby cells based on downlink RSRP (Reference Signal Received Power) measurements by each HeNB [7].

CA lessens power usage by disabling secondary CCs for extremely loaded cells (as the average offered traffic per cell rises to the point where many simultaneously schedulable users are existing at all CCs for both the Release-8 and LTE-Advanced cases, the gap between experienced data rates of two user categories shrinks). Thus for extremely loaded cells, one may configure single CC per user to save terminal power usage.

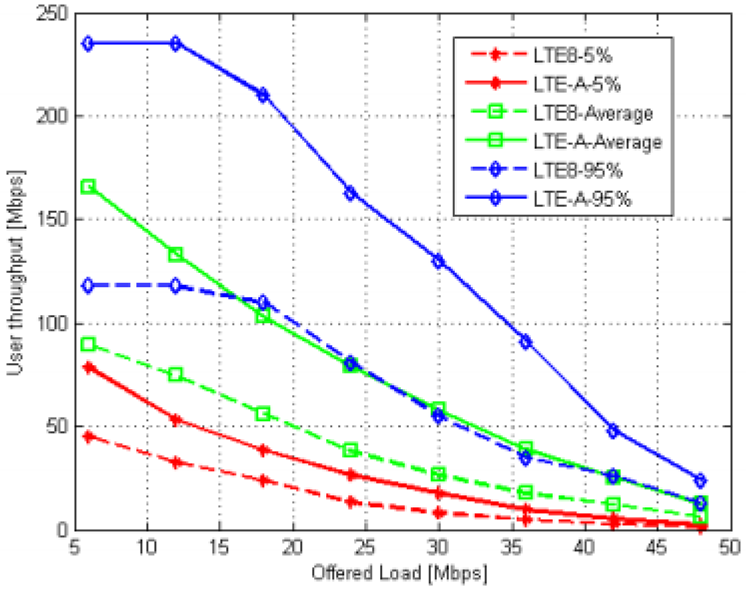


Fig. 1.1. Experienced user throughput performance versus the average offered load per cell

CHAPTER 2

Carrier Aggregation Evolution

2.1 HSPA+ EVOLUTION OVERVIEW

The Dual Carrier DC-HSDPA is a 3GPP Release-8 feature and is already a reality in numerous commercial deployments in the world. The DC-HSDPA is limited to 2 adjacent carriers of 5MHz [10]. In Release-9 the adjacent carrier limitation is overcome, to provide a Dual Band HSDPA operation with separate frequency bands with MIMO. The uplink is also considered, and the Dual Carrier HSPA is introduced [11].

In the following Release, the standardization of the structure developed during the earlier rounds of multi-carrier standardization in 3GPP is reused to provide a 4 Carrier HSDPA in Release-10 on two separate frequency bands.

A natural step in Release-11 is to provide a support up to 8-Carriers HSDPA aggregating up to 40 MHz of spectrum meeting the requirement of ITU for a real 4G/IMT-Advanced. Release-11 also brings support aggregation of non-adjacent carriers on the same frequency band [11].

Fig. 2.1: Evolution of HSPA Carrier Aggregation

The peak rate capabilities provided by each evolution is improved significantly. Carrier aggregation is one of only a few features to provide such a clear capacity improvement on the network.

As seen on fig. 2.1, from a downlink theoretical peak data rate in Release-7 of 28 Mbps, each Release doubles this peak, to reach in Release-11 a throughput of 336 Mbps with 2x2 MIMO and a throughput of 672 Mbps when combined with 4x4 MIMO

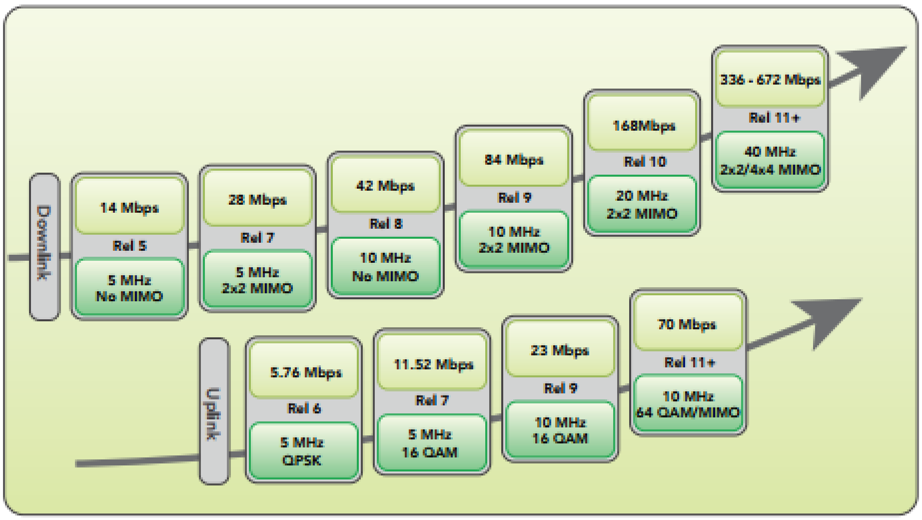


Fig. 2.2: Evolution of throughput in HSPA with Carrier Aggregation

The evolution of HSPA is pushing the peak data rates to approach LTE Advanced performances, allowing this mature technology to continue its life while LTE is deployed. The following chapter describes in details those evolutions. However the UE complexity and the power consumption related to multicarrier in W-CDMA might be slowing down further release adoption.

2.2 RELEASE-8

2.2.1 DUAL-CELL HSDPA PROCESS ON NEIGHBOURING CARRIERS

Carrier aggregation was first introduced in Release-8 with the feature called “Dual-Cell HSDPA Operations on Neighbouring Carriers”. This method doubles the peak rate (with 64 QAM) from 21 Mbps to 42 Mbps without MIMO. This feature combines two carriers of adjacent 5MHz bandwidth. A dual carrier user may be scheduled on either of the 5 MHz carriers [11].

The channel not pertaining to HSDPA technology stays in so called “primary serving cell”, the physical layer processes rely also on this primary serving cell. The transport channel chain are independent, they perform coding, modulation and Hybrid Automatic Repeat request (HARQ) retransmissions separately in a similar fashion as MIMO.

2.3 RELEASE-9

2.3.1 HSPA+ ENHANCEMENTS FOR RELEASE-9: DUAL-CARRIER HSUPA

The same needs in terms of capacity drove the support for a similar dual-carrier in Uplink. Hence, the dual-carrier HSUPA process on neighbouring uplink carriers is presented in Release-9. It relies on similar principle as DC-HSDPA: it then doubles the uplink rate up to 23 Mbps using 16QAM. Moreover it is well known that UE in uplink condition is frequently extra restricted by the bandwidth rather than by the actual transmit uplink power. The advantage of DC-HSUPA in terms of data rate and availability are then substantial.

A DC-HSUPA user can transmit over two E-DCH 2 ms TTI transport channels, one on each uplink carrier. The user is served by a same NodeB, over two different cells, on the same sector. The secondary carrier can be activated or deactivated through HS-SCCH orders. Each active HSUPA carrier mechanism are largely independent from each other, they perform their own grant signalling, power control, and soft handover.

One strong limitation of the DC-HSUPA is that it has to be configured with the DC-HSDPA operation; the secondary uplink carrier can be active only if the secondary downlink carrier is also active. The main reason is that the secondary downlink carries channel that are essential for uplink operation (F-DPCH, E-AGCH, E-RGCH, E-HICH). On the opposite the uplink secondary is not necessary for the secondary downlink operation since HS-DPCCH is mapped every time on the primary uplink carrier.

2.3.2 PROVISION FOR DIFFERENT BANDS FOR DUAL BAND DC-HSDPA (DC-HSDPA)

To provide additional operational mode to the DC-HSDPA Release-8, where bands had to be adjacent, and Release-9 introduced supports for non-adjacent bands with the support of MIMO through a feature called dual-band DB-DC-HSDPA (DC-HSDPA) procedure.

It expands the operators’ deployments possibilities which spectrum license is often distributed over several different bands. The throughput improvement to be expected compared to DC-HSDPA operation is little as it relies on the same principle, however performance might be increased thanks to the additional capacity gains from trunking and frequency domain due to the non-collocated bands having different propagations losses and interference systems.

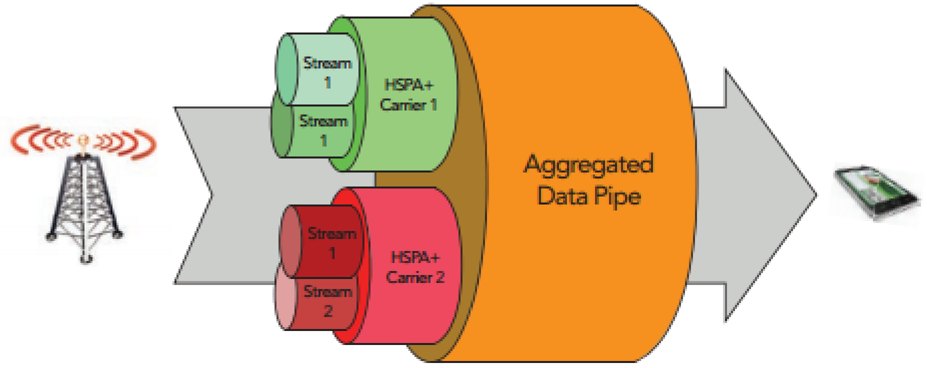
In DB-DC-HSDPA the uplink transmission is restricted to only one carrier. The uplink carrier can be arranged by the network on any of the two frequency bands.

In Release-9, dual-band HSDPA operation is specified for three diverse band combinations, one for each ITU region:

- Band 1 (2100 MHz) and Band 5 (850 MHz)
- Band 1 (2100 MHz) and Band 8 (900 MHz)
- Band 2 (1900 MHz) and Band 4 (2100/1700 MHz)

Release-9 left the possibility to add further band combination in the following releases matching Release-9 requirements. In Release-10, the new combinations were added:

- Band 1 (2100 MHz) and Band 11 (1450 MHz)
- Band 2 (1900 MHz) and Band 5 (850 MHz)



- In Rel. 9 DC-HSDC can be combined together with MIMO
- This allows achieving a peak rate of 84 Mbps in 10 MHz

Fig. 2.3: Release-9 – graphical representation of MIMO combined with CA

2.4 RELEASE-10

2.4.1 FOUR CARRIER HSDPA

The support for four carrier non- contiguous HSDPA (4C-HSDPA) process is presented in Release-10. It relies on similar principles as Release-8 DC-HSDPA and the Release-9 dual-band with MIMO. The 4C-HSDPA allows the NodeB to schedule one user transmission on up to four 5 MHz carriers at the same time.

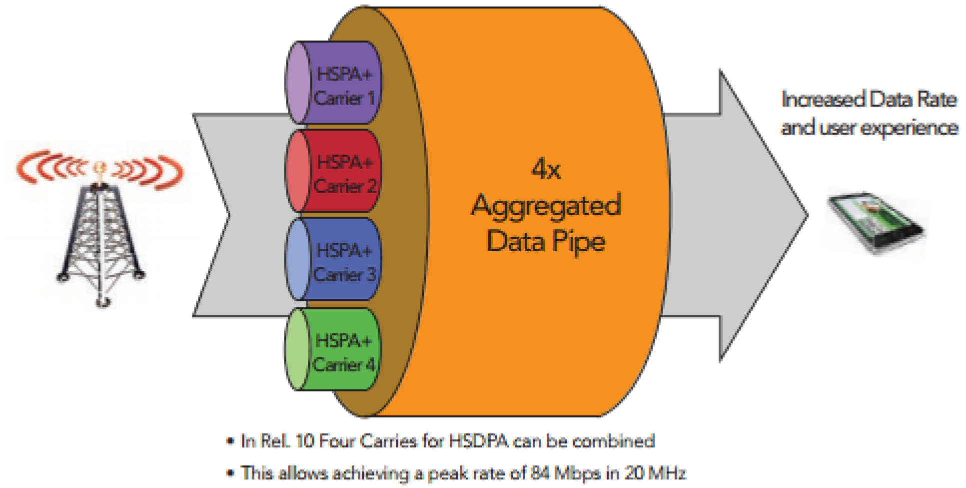


Fig. 2.4: Release-10 4C-HSDPA graphical representation without MIMO

Using the peak modulation scheme (64 QAM) and the downlink MIMO 2x2 configured on each downlink carriers it is likely to reach a theoretical peak data rate of 168 Mbps. It doubles the performance achievable with (DB)-DC-HSDPA [14].

For 4C-HSDPA the carrier usage may go over two frequency bands. The structure follows a similar structure as Release-9 DB-DC-HSDPA operation. The following band combinations are supported (one for each ITU region):

- Band 1 (2100 MHz) and Band 5 (850 MHz):
  One or two carriers in Band 1 at the same time, as one or two carriers in Band 5
- Band 1 (2100 MHz) and Band 8 (900 MHz):
  Two or three in Band 1 at the same time, as one carrier is configured in Band 8

- Band 2 (1900 MHz) and Band 4 (2100/1700 MHz):
  One or two carriers in Band 2 at the same time, as one or two carriers in Band 4

It is also likely to configure only three neighbouring carriers in Band 1 (2100 MHz).

The possible 4C-HSDPA Release-10 configurations are illustrated in Fig. 2.5

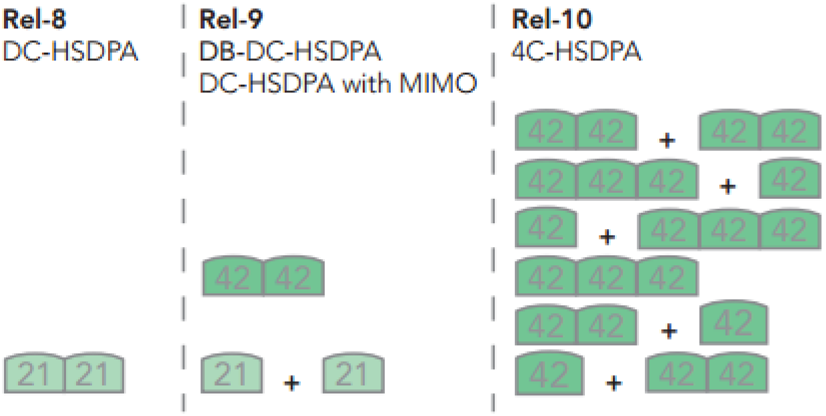


Fig. 2.5: Release-10 4C-HSDPA Band Combination

Similarly as Release-9, the further addition of band combinations is possible in the following releases.

Fig. 2.5 shows that carriers are specified to be adjacent in Release-10. This structure has been chosen for receiver integration simplicity, reducing the number of receivers required for a typical UE Release-10 compatible. However, from a protocol perspective, the specification allows non-contiguous bands.

As in earlier multi-carrier features, HARQ retransmissions, coding and modulation are implemented individually for activated downlink carriers and streams. The HS-SCCH orders transmitted by the serving NodeB also remain the mechanism to handle activation/deactivation of the secondary carriers.

In Release-10 a special work on supporting 3 carriers without MIMO was implemented.

2.5 RELEASE-11

2.5.1 CARRIER HSDPA – 40 MHz OF CARRIER AGGREGATION – 8 CARRIER HSDPA

In release 11, the potential of carrier aggregation with HSDPA is extended to up to 8 carriers with a potential use of 40 MHz aggregate within one UE. There is no need for the carrier to be adjacent, and it is likely to aggregate them in more than one frequency band.

In a similar fashion as other multi-carrier features standardized in Release-8 to Release-10 this feature is expecting to bring similar throughput gains. The peak throughput is theoretically doubled compared to the 4-carrier HSDPA from Release-10.

The deployment of 8C-HSDPA is limited to single uplink carrier. The related uplink signalling, that holds the CQI and Acknowledgements will be transmitted over two separate HS-DPCCHs. The solution standardized in Release-10 for 4C-HSDPA is reused. MIMO can be configured independently per carrier.

CHAPTER 3

LTE-A
Carrier Aggregation

CA permits LTE to achieve the goals mandated by IMT-Advanced while maintaining backward compatibility with Release-8 and 9 LTE. Release-10 CA permits the LTE radio interface to be configured with any number (up to five) carriers, of any bandwidth, including differing bandwidths, in any frequency band. Carrier Aggregation can be used for both FDD and TDD.

3.1 TYPE OF CARRIER AGGREGATION

The downlink and uplink can be configured completely independently, with only the limitation that the number of uplink carriers cannot exceed the number of downlink carriers. Each aggregated carrier is referred to as component carrier, CC. The component carrier can have a bandwidth of 1.4, 3, 5, 10, 15 or 20 MHz With a maximum of five component carriers, the maximum aggregated bandwidth is 100 MHz [12] three types of allocation have been defined in 3GPP to meet different operator’s spectrum scenario [7].

3.1.1 INTRA-BAND CONTINUOUS

The simplest way for an operator to provide aggregation would be usage of contiguous component carriers within similar operating frequency band called as intra-band contiguous. A contiguous bandwidth wider than 20 MHz is not a likely scenario given frequency allocations today, however 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 orthogonality of the subcarriers with 15 KHz spacing [13].

3.1.2 INTRA AND INTER-BAND NON-CONTINUOUS

Most operators in North America or Europe are currently facing the problem of a fragmented spectrum. The non-contiguous allocation has been specified to fit those scenarios, the allocation can be intra-band, i.e. the component carriers lie in the same operating frequency band, but has void space in between, or it can be inter-band, in which the component carriers lies in different operating frequency bands.

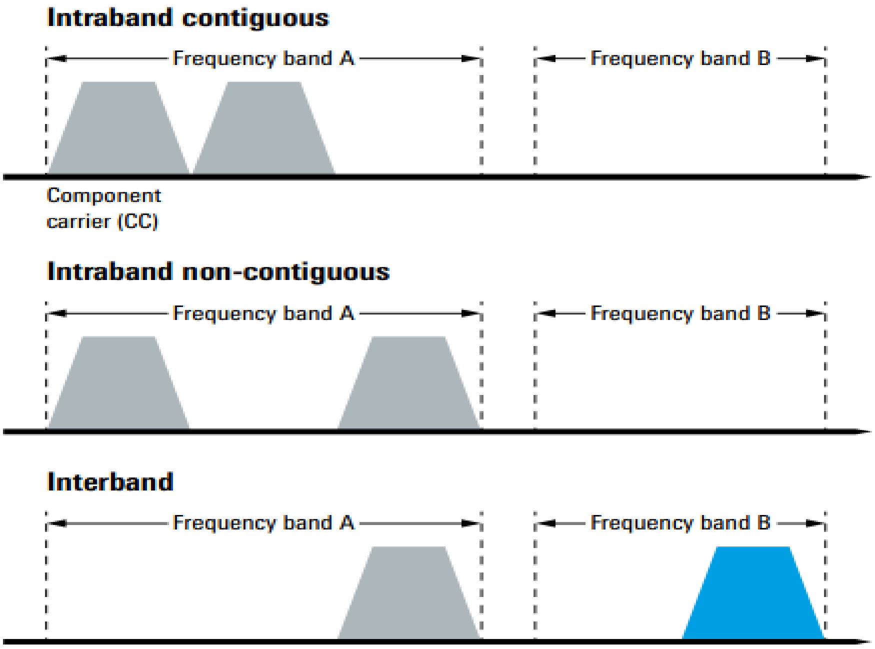


Fig. 3.1: Different type of CA allocation in LTE-A

3.2 DEPLOYMENT STRATEGIES

The possibilities enabled by the usage of several aggregated frequency bands allows a large variety of deployment scenarios for the operator. Some choices are presented as follows:-

3.2.1 INTRA-BAND CONTIGUOUS

- One of the probable scenarios is that F1 and F2 cells are co-located and overlaid, providing nearly an identical coverage. Both layers provide sufficient coverage, and mobility can be supported on both layers. Likely scenario is when F1 and F2 are on same band having a similar path loss profile.
- Another scenario would be a diverse coverage where F1 and F2 are co-located: F2 antennas are directed to the cell boundaries of F1, or in F1 holes, so that the coverage and/or the cell edge throughput is increased.

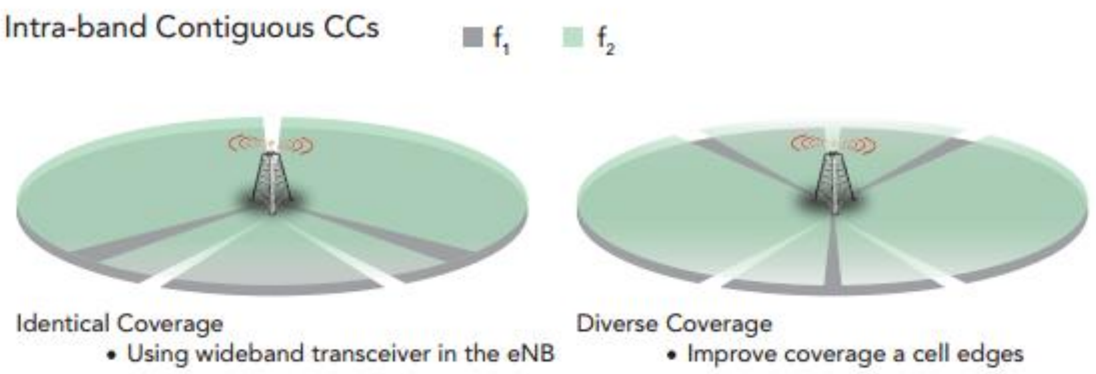


Fig. 3.2

3.2.2 INTER-BAND NON-CONTIGUOUS

The usage of non-continuous bands changes the scenario possibilities for operators due to the different band propagation profile and hardware constraints.

- A Remote Radio Heads (RRH) scenario can be considered when F1 (lower frequency) provides macro coverage and RRHs on F2 (higher frequency) are used to increase output at hot spots. The mobility is accomplished based on F1 coverage. Likely scenario is when F1 and F2 are of different bands.
- In HetNet scenario, it can be expected to see numerous small cells and relays working on various frequency bands [14].

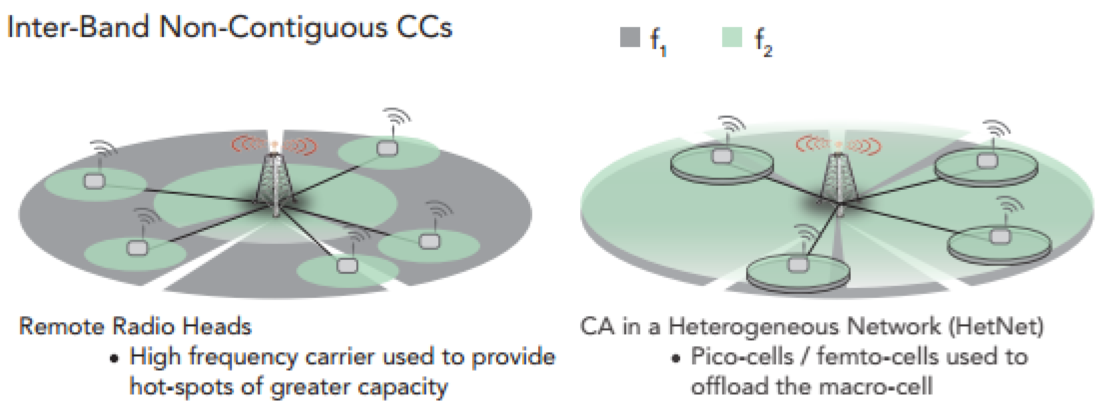


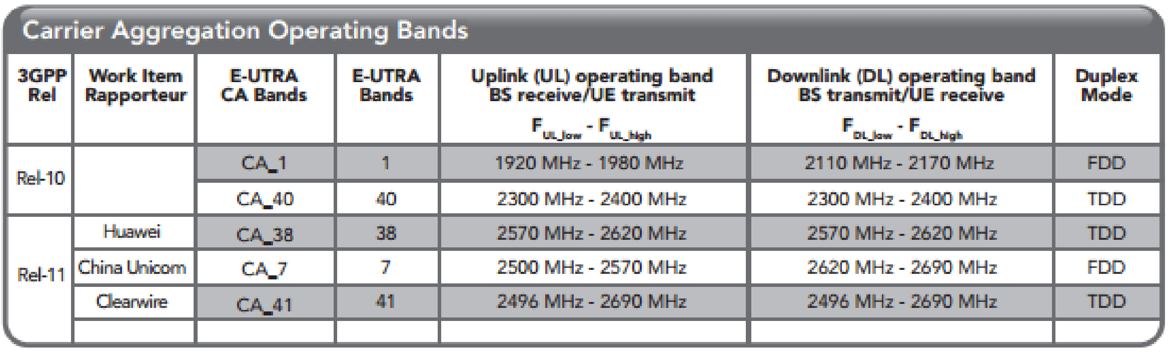
Fig. 3.3

3.3 E-UTRA CA BANDS NOTATION

With the introduction of CA in Release-10, the aggregation of bands has been specified for specific sets of CA Bands which corresponds to a combination of E-UTRA operating bands. As per the table 1 and 2, the CA configuration is mainly driven by operators who are focused on their needs based on their potential frequency blocks licencing.

3.3.1 INTRA-BAND

In Release-10, the intra-band carrier aggregation is limited to two component carriers: one paired band (Band 1) and one unpaired band (Band 40).



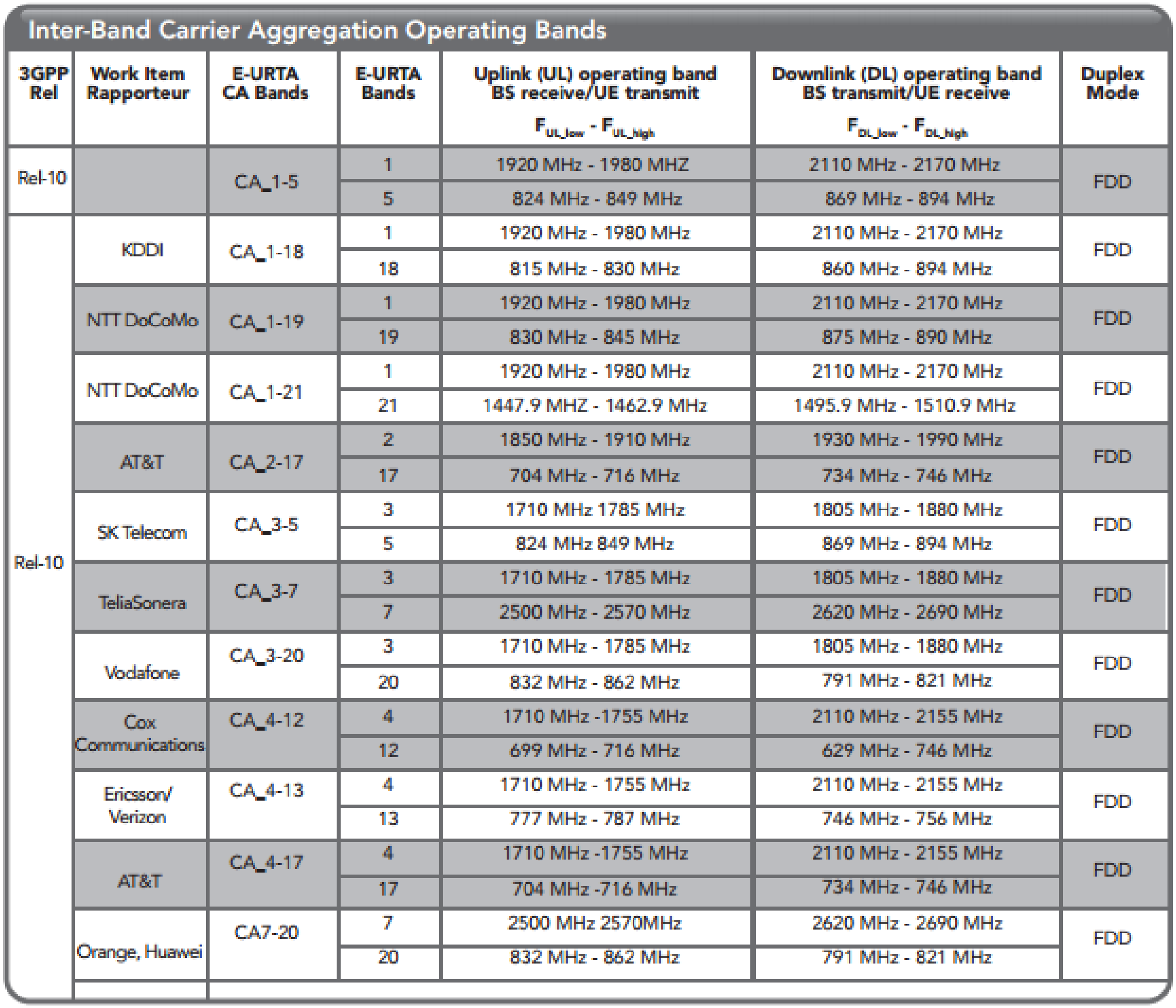
Carrier Aggregation Operating Bands

3GPP Rel	Work Item Rapporteur	E-UTRA CA Bands	E-UTRA Bands	Uplink (UL) operating band BS receive/UE transmit $F_{UL\_low} - F_{UL\_high}$	Downlink (DL) operating band BS transmit/UE receive $F_{DL\_low} - F_{DL\_high}$	Duplex Mode
Rel-10		CA_1	1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz	FDD
		CA_40	40	2300 MHz - 2400 MHz	2300 MHz - 2400 MHz	TDD
Rel-11	Huawei	CA_38	38	2570 MHz - 2620 MHz	2570 MHz - 2620 MHz	TDD
	China Unicom	CA_7	7	2500 MHz - 2570 MHz	2620 MHz - 2690 MHz	FDD
	Clearwire	CA_41	41	2496 MHz - 2690 MHz	2496 MHz - 2690 MHz	TDD

Table 1: Release Intra-Band contiguous CA operating bands

3.3.2 INTER-BAND

In Release-10, the Inter-band carrier aggregation case, the configuration is limited to bands 1 and 5. Driven by operator worldwide demands, further studies in Release-11 are considered for instance to investigate “European” scenario for Bands 3 and 7.



Inter-Band Carrier Aggregation Operating Bands

3GPP Rel	Work Item Rapporteur	E-URTA CA Bands	E-URTA Bands	Uplink (UL) operating band BS receive/UE transmit $F_{UL\_low} - F_{UL\_high}$	Downlink (DL) operating band BS transmit/UE receive $F_{DL\_low} - F_{DL\_high}$	Duplex Mode
Rel-10		CA_1-5	1	1920 MHz - 1980 MHZ	2110 MHz - 2170 MHz	FDD
			5	824 MHz - 849 MHz	869 MHz - 894 MHz	
Rel-10	KDDI	CA_1-18	1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz	FDD
			18	815 MHz - 830 MHz	860 MHz - 894 MHz	
	NTT DoCoMo	CA_1-19	1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz	FDD
			19	830 MHz - 845 MHz	875 MHz - 890 MHz	
	NTT DoCoMo	CA_1-21	1	1920 MHz - 1980 MHz	2110 MHz - 2170 MHz	FDD
			21	1447.9 MHZ - 1462.9 MHz	1495.9 MHz - 1510.9 MHz	
	AT&T	CA_2-17	2	1850 MHz - 1910 MHz	1930 MHz - 1990 MHz	FDD
			17	704 MHz - 716 MHz	734 MHz - 746 MHz	
	SK Telecom	CA_3-5	3	1710 MHz 1785 MHz	1805 MHz - 1880 MHz	FDD
			5	824 MHz 849 MHz	869 MHz - 894 MHz	
	TeliaSonera	CA_3-7	3	1710 MHz - 1785 MHz	1805 MHz - 1880 MHz	FDD
			7	2500 MHz - 2570 MHz	2620 MHz - 2690 MHz	
	Vodafone	CA_3-20	3	1710 MHz - 1785 MHz	1805 MHz - 1880 MHz	FDD
			20	832 MHz - 862 MHz	791 MHz - 821 MHz	
	Cox Communications	CA_4-12	4	1710 MHz -1755 MHz	2110 MHz - 2155 MHz	FDD
			12	699 MHz - 716 MHz	629 MHz - 746 MHz	
	Ericsson/ Verizon	CA_4-13	4	1710 MHz - 1755 MHz	2110 MHz - 2155 MHz	FDD
			13	777 MHz - 787 MHz	746 MHz - 756 MHz	
	AT&T	CA_4-17	4	1710 MHz -1755 MHz	2110 MHz - 2155 MHz	FDD
			17	704 MHz -716 MHz	734 MHz - 746 MHz	
	Orange, Huawei	CA7-20	7	2500 MHz 2570MHz	2620 MHz - 2690 MHz	FDD
			20	832 MHz - 862 MHz	791 MHz - 821 MHz	

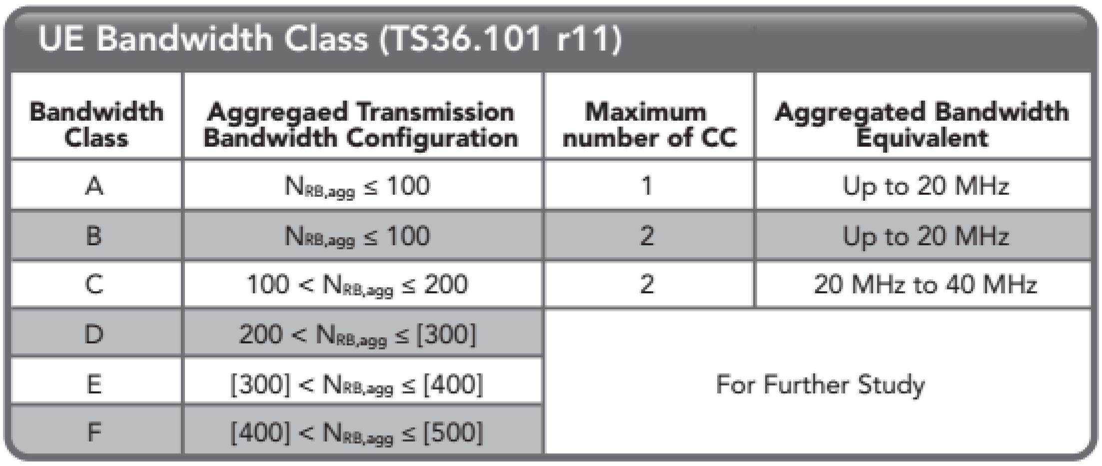
Table 2: Inter-Band CA operating bands

3.4 UE BANDWIDTH CLASS

The introduction of CA renders the previous conceptions of “frequency band” and “bandwidth” ambiguous. Indeed, LTE systems can operate on variable bandwidth for a given band ranging from 1.4 MHz to 20 MHz Therefore 3GPP has introduced terminology and notation which serve to more clearly express the radio interface configuration. The UE’s are defined by a CA Bandwidth Class [15].

For intra-band contiguous carrier aggregation, UE’s CA Bandwidth Class is defined according to their number of CCs supported and their Aggregated Transmission Bandwidth corresponding to Number of aggregated Resource Blocks (NRB, agg).

The following table summarizes the currently-defined carrier aggregation bandwidth classes in Release-11.



UE Bandwidth Class (TS36.101 r11)

Bandwidth Class	Aggregaed Transmission Bandwidth Configuration	Maximum number of CC	Aggregated Bandwidth Equivalent
A	$N_{RB,agg} \le 100$	1	Up to 20 MHz
B	$N_{RB,agg} \le 100$	2	Up to 20 MHz
C	$100 < N_{RB,agg} \le 200$	2	20 MHz to 40 MHz
D	$200 < N_{RB,agg} \le [300]$	For Further Study	
E	$[300] < N_{RB,agg} \le [400]$		
F	$[400] < N_{RB,agg} \le [500]$		

Table 3: UE Bandwidth Class

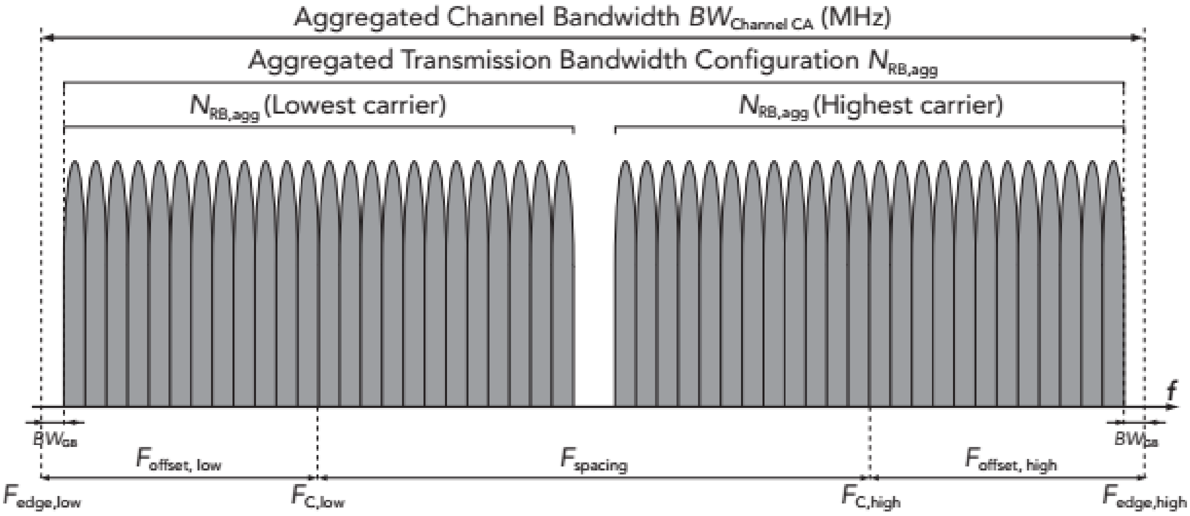


Fig. 3.4: Definition of Aggregated channel bandwidth and aggregated channel bandwidth edges

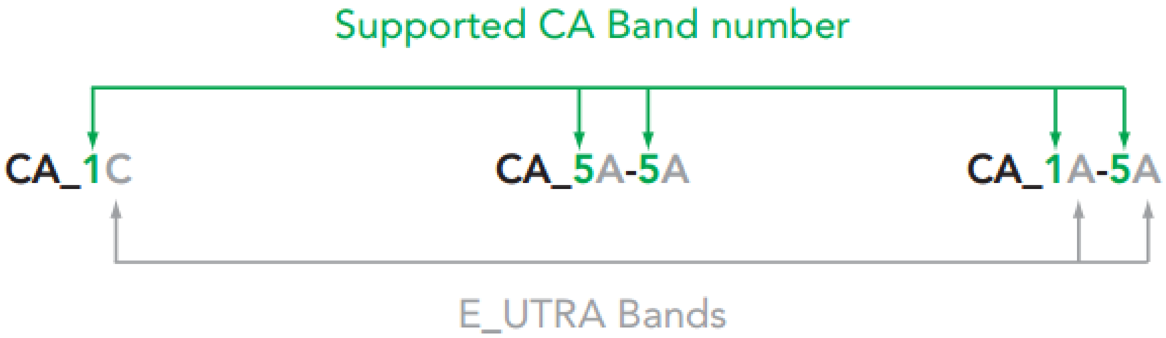
3.5 CHANNEL BANDWIDTH PER OPERATING BAND FOR CA

An LTE-Advanced capable UE will report extra information to the network regarding its CA bands support capabilities. The capabilities are notified per frequency band, independently for downlink and uplink [4]. It will define the proper carrier aggregation configuration set to be used.

The carrier aggregation structure is an amalgamation of working bands, in association with the carrier aggregation bandwidth class of the UE, for individual band. It determines which band to be used and the channel bandwidth allocated on each operating band.

For example:-

INTRA-BAND CONTINUOUS	INTRA-BAND NON-CONTINUOUS	INTER-BAND



As example, the configuration CA_5A-5A indicates that the UE can receive or transmit two separate carriers in Band 5. The A gives the UE Bandwidth Class indicating, as explained previously, that the UE is capable to operate on an extreme of 100 Resource Blocks (RB) across both bands (Corresponding to a 20 MHz Bandwidth).

UE can specify support of a number of bandwidth combination sets per band combination of operating bands.

3.5.1 COMBINATION SET

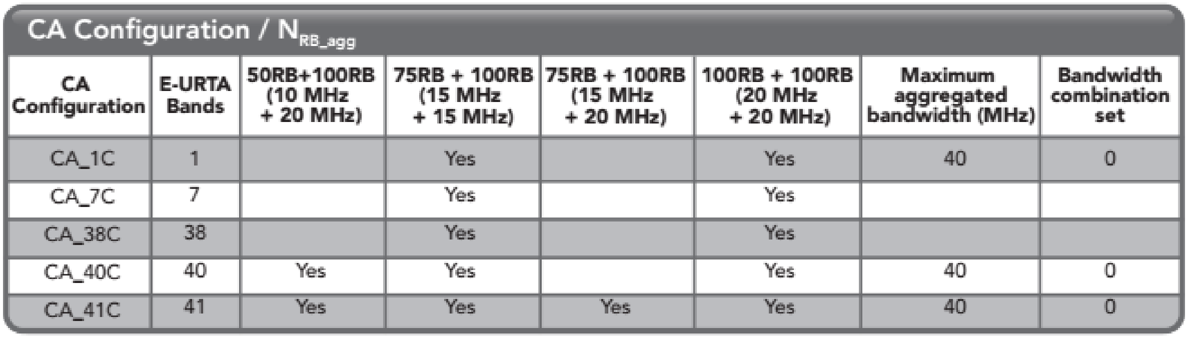
Within the aggregation configuration, the UE can report a combination set, which defines where to allocate the resource blocks.

As example, table give us two combination set for the CA_1C configuration.

1C configuration states that the UE can operate on Band 1, with 2 components carriers, with a maximum of 200 RB. The combination set then states that the allocation of those 200 RBs can be either 75 RB on both band or 100 RB on both band.

3.5.1.1 INTRA-BAND COMBINATION SET

In case of Intra-Band, the bandwidth combination set is defined by a number of consecutive resource block allocated on each component carrier. The combination are chosen among 50 RB (10 MHz), 75 RB (15 MHz), and 100 RB (20 MHz).



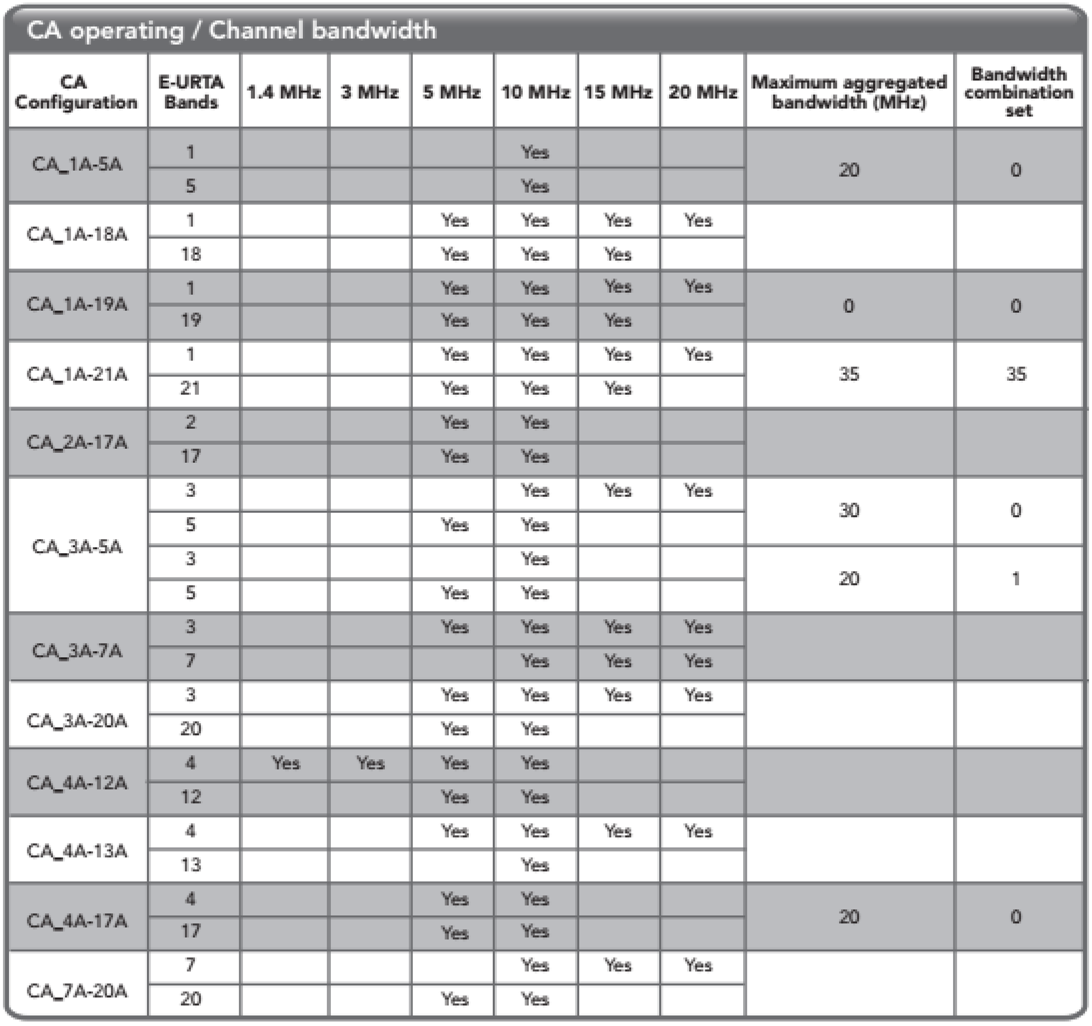
CA Configuration / N_{RB_agg}

CA Configuration	E-URTA Bands	50RB+100RB (10 MHz + 20 MHz)	75RB + 100RB (15 MHz + 15 MHz)	75RB + 100RB (15 MHz + 20 MHz)	100RB + 100RB (20 MHz + 20 MHz)	Maximum aggregated bandwidth (MHz)	Bandwidth combination set
CA_1C	1		Yes		Yes	40	0
CA_7C	7		Yes		Yes		
CA_38C	38		Yes		Yes		
CA_40C	40	Yes	Yes		Yes	40	0
CA_41C	41	Yes	Yes	Yes	Yes	40	0

Table 4: E-UTRA CA configurations and bandwidth combination sets defined for Intra-Band Contiguous

3.5.1.2 INTER-BAND COMBINATION SET

Similarly to Intra-Band, Inter-Band has a bandwidth combination set defined for each carrier aggregation configuration, however the combinations rely on the channel occupied bandwidth instead of the number of resource blocks. The 10 MHz allocation is supported by all the configurations, however the 5 MHz, 15 MHz and 20 MHz is less common, and the small bandwidth allocation, 1.4 MHz and 3 MHz, is only supported by one configuration so far in Release-11.



CA operating / Channel bandwidth

CA Configuration	E-URTA Bands	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Maximum aggregated bandwidth (MHz)	Bandwidth combination set
CA_1A-5A	1				Yes			20	0
	5				Yes				
CA_1A-18A	1			Yes	Yes	Yes	Yes		
	18			Yes	Yes	Yes			
CA_1A-19A	1			Yes	Yes	Yes	Yes	0	0
	19			Yes	Yes	Yes			
CA_1A-21A	1			Yes	Yes	Yes	Yes	35	35
	21			Yes	Yes	Yes			
CA_2A-17A	2			Yes	Yes				
	17			Yes	Yes				
CA_3A-5A	3				Yes	Yes	Yes	30	0
	5			Yes	Yes				
	3				Yes			20	1
	5			Yes	Yes				
CA_3A-7A	3			Yes	Yes	Yes	Yes		
	7				Yes	Yes	Yes		
CA_3A-20A	3			Yes	Yes	Yes	Yes		
	20			Yes	Yes				
CA_4A-12A	4	Yes	Yes	Yes	Yes				
	12			Yes	Yes				
CA_4A-13A	4			Yes	Yes	Yes	Yes		
	13				Yes				
CA_4A-17A	4			Yes	Yes			20	0
	17			Yes	Yes				
CA_7A-20A	7				Yes	Yes	Yes		
	20			Yes	Yes				

Table 5: E-UTRA CA configurations and bandwidth combination sets defined for Inter-Band CA

3.6 E-UTRAN ASPECTS

In support of CA, Release-10 introduces a distinction between a primary cell (PCell) and a secondary cell (SCell).

The PCell is the main cell with which the UE communicates as defined as the cell with which RRC signalling messages are exchanged, or equivalently by the existence of the physical uplink control channel (PUCCH), of which there is exactly one for a given UE. One PCell is always active in RRC_CONNECTED mode while one or more SCells may be active. Additional SCells can only be formed after connection formation, in CONNECTED mode, to offer additional radio resource.

All PCells and SCells are known collectively as serving cells. The component carriers on which the PCell and SCell are based are the primary component carrier (PCC) and secondary component carrier (SCC), respectively. Physical Share Channels are transmitted on both (PDSCH/PUSCH).

- A PCell is equipped with one physical downlink control channel (PDCCH) and one physical uplink control channel (PUCCH).
  - ➢ The Measurement and mobility procedure are based on PCell
  - ➢ Random access procedure is performed over PCell
  - ➢ A PCell cannot be deactivated.

- A SCell could be equipped with a one physical downlink control channel (PDCCH) or not, depending on UE capabilities. A SCell never has a PUCCH.
  - ➢ MAC layer based dynamic activation/deactivation procedures is supported for SCell for UE battery saving.

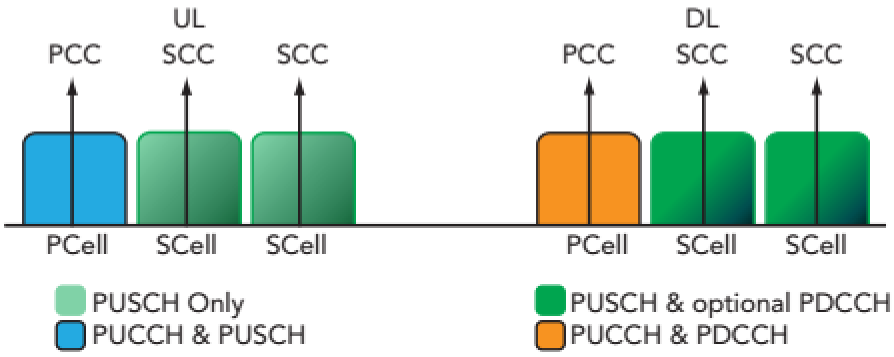


Fig. 3.5: Channel Mapping of PCell and SCell

The relation between a Primary Cell (PCC) in downlink and uplink is signalled in the system information block type 2 (SIB type 2) on the logical broadcast channel (BCCH) carried by the physical shared channel (DL-SCH). The SIB2 contains radio resource configuration information that is common for all UEs. A PCC for a given UE is not linked to the cell configuration; the allocation is device based as described previously. The PCC allocation can however be modified by the network during handover procedures. Different carrier aggregation capable UEs within a cell can have different PCC on different band.

3.7 IMPACT OF CA ON SIGNALLING ASPECTS

From the signalling aspect, the carrier aggregation is only impacting a limited number of protocol layers, the UE connected to the Primary Cell, will perceive the additional Secondary Cells as additional resource to transmit data. Indeed, the procedures as Non-Access Stratum (NAS), key exchange or mobility are carried by the Primary Cell.

For the other layer such as Packet Data Convergence Protocol (PDCP) and Radio Link Control (RLC) layer, carrier aggregation signalling is completely transparent.

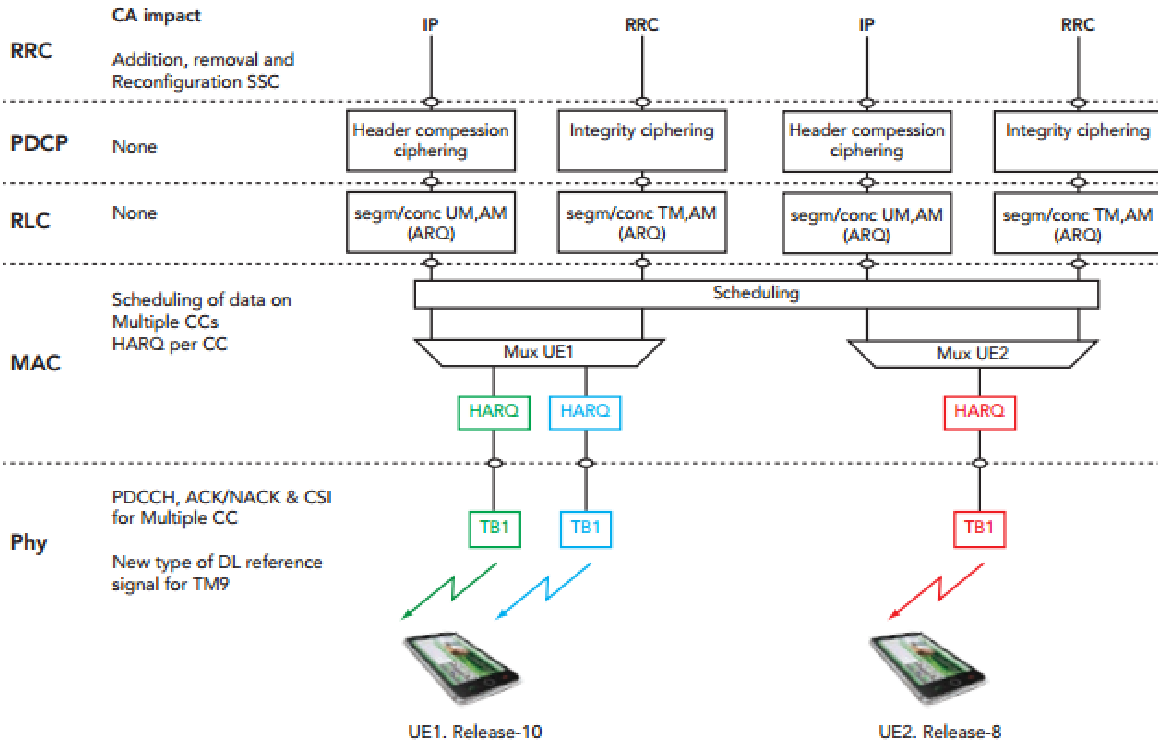
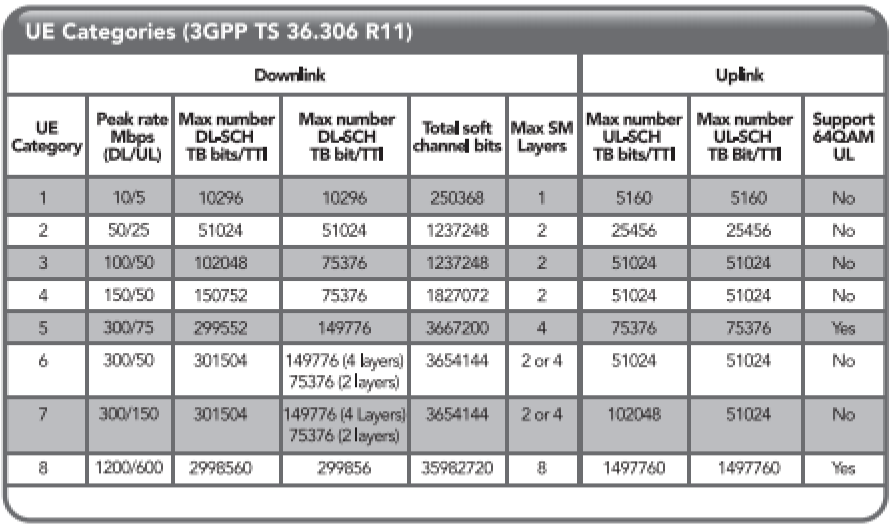


Fig. 3.6: Impact of Carrier Aggregation on transmission chain [4]

From UE design perspective a minor aspect of the RLC was changed in comparison to Rel-8, the RLC layer has now to provide higher data rates by having a larger buffer size.

The UE category specified in TS 36.336 defines this buffer size. Three new categories, category 6, 7 and 8 are specified in Release-10 to support this buffer increase.



UE Categories (3GPP TS 36.306 R11)

Downlink						Uplink		
UE Category	Peak rate Mbps (DL/UL)	Max number DL-SCH TB bits/TTI	Max number DL-SCH TB bit/TTI	Total soft channel bits	Max SM Layers	Max number UL-SCH TB bits/TTI	Max number UL-SCH TB Bit/TTI	Support 64QAM UL
1	10/5	10296	10296	250368	1	5160	5160	No
2	50/25	51024	51024	1237248	2	25456	25456	No
3	100/50	102048	75376	1237248	2	51024	51024	No
4	150/50	150752	75376	1827072	2	51024	51024	No
5	300/75	299552	149776	3667200	4	75376	75376	Yes
6	300/50	301504	149776 (4 layers) 75376 (2 layers)	3654144	2 or 4	51024	51024	No
7	300/150	301504	149776 (4 Layers) 75376 (2 layers)	3654144	2 or 4	102048	51024	No
8	1200/600	2998560	299856	35982720	8	1497760	1497760	Yes

Table 6: UE Categories (3GPP 36.366 r11)

It should be noted that category 6, 7 & 8 implicitly implies carrier aggregation support, however earlier UE category from 2 to 5, specified in Release-8, can also be capable of carrier aggregation.

3.8 TRANSPORT (MAC) LAYER ASPECTS

From the Medium Access Control (MAC) viewpoint, the carrier aggregation brings just additional pipelining, so MAC layer plays the part of multiplexing unit for the aggregated component carriers [7].

Each MAC entity will provide to its corresponding CC its own Physical Layer (PHY) entity, providing resource mapping, data modulation, HARQ, and channel coding.

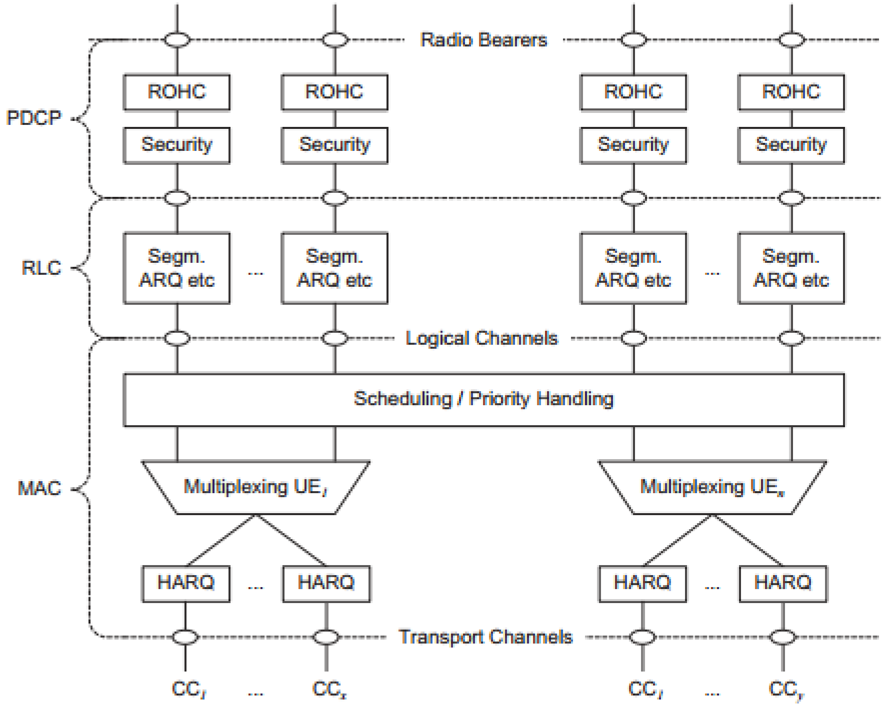


Fig. 3.7: Layer 2 protocol organisation for downlink carrier aggregation [4]

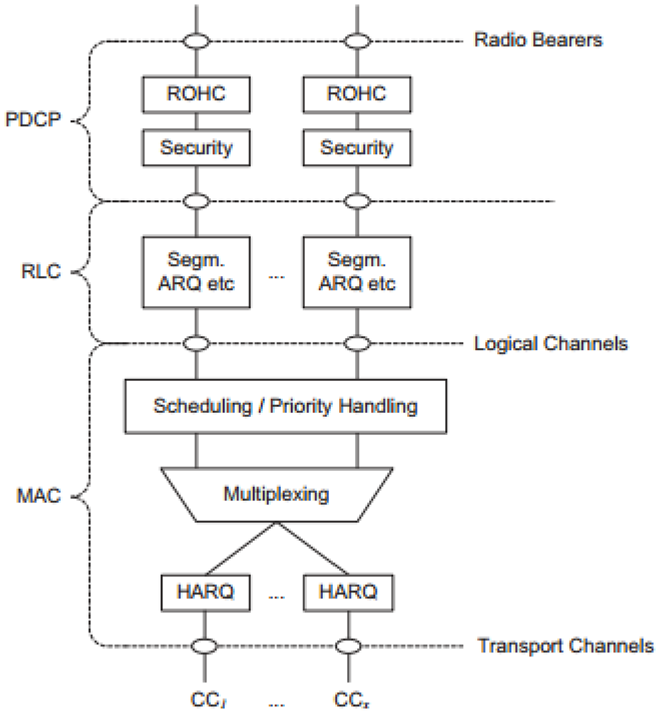


Fig. 3.8: Layer 2 protocol organisation for uplink carrier aggregation [4]

Clearly, in order to take advantage of the aggregated bandwidth and produce the desired throughput increase, the base station's MAC layer scheduler must have knowledge of all active CCs. This differs from pre-Release-10 LTE schedulers, which considered only one cell- carrier at a time.

In order for a CA-enabled base station's MAC scheduler to sequence downlink allocations and uplink grants optimally, it must consider the downlink and uplink channel conditions across the entire aggregated bandwidth. This increases the complexity of the base station scheduler and could result in some unusual scheduling outcomes. For example, the scheduler could decide to send all of a given UE's downlink transport blocks on CC1, but to receive all of that UE's uplink transport blocks on CC2.

In the absence of MIMO, a CA-enabled scheduler allocates, at most, one transport block per SCH per TTI. The HARQ processes delivering the various transport blocks within a TTI (across SCHs) are independent.

3.8.1 CARRIER ACTIVATION / DEACTIVATION AND DISCONTINUOUS RECEPTION DRX

The activation of an additional CC is done through MAC control element. When an additional CC is activated for a given subframe, the actual resource for scheduling is available 8 subframes later (8 ms). At this point, a new timer called SCell Deactivation Timer-r10 will also start, if no scheduling information is provided by the PDCCH within this timer, the SCell will be deactivated at the MAC layer.

The RRC configured timer is the same timer for all SCells. The UE deactivates SCell if there is no activity before timer expires however, the deactivation of a given SCell can also be controlled by the network using MAC header elements.

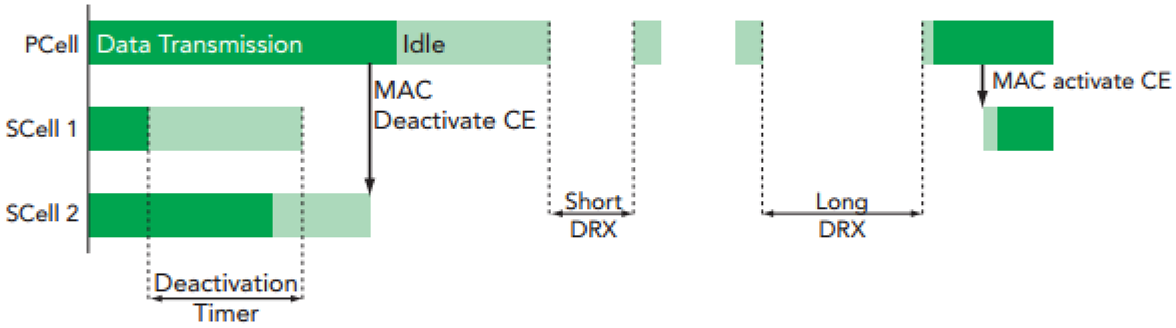


Fig. 3.9: SCell activation/deactivation RRC timer

Even with no traffic a PCell will always be active or in DRX mode.

3.9 PHYSICAL LAYER ASPECTS

3.9.1 DOWNLINK CHANNEL QUALITY

Downlink channel quality in LTE Release-8 and 9 is estimated at the UE via the channel state information (CSI) Information Element (IE) [15]. In the absence of MIMO, CSI reduces to the familiar channel quality indicator (CQI). Release-10 does not change this, but the existence of multiple CCs means that CQI must be evaluated and reported for each CC individually when CA is active.

The CQI, as well as downlink HARQ ACK/NACK indicators and other information, is reported to the base station via the uplink control information (UCI) IE. As well known, there is exactly one PUCCH and it is on the PCell regardless of the number of CCs, hence the UCI for each CC should be reported via this PUCCH if the terminal does not have a PUSCH configured. In order to distinguish which UCI belongs to a given CC, the header of the UCI contains a carrier indicator field (CIF).

Since it is possible for UE to report CQI periodically, and since UEs do not necessarily support simultaneous transmission of PUCCH and PUSCH, CQI could also be reported on the PUSCH, if PUSCH happens to be active at the time of a periodic reporting instance.

In the context of CA, it means that CQI can be transmitted on a SCell if SCell uplink burst is ongoing while a PCell burst is not.

3.9.2 UPLINK CONTROL SIGNALLING

Uplink control signalling carried by the single PUCCH, when the terminal does not have a valid scheduling grant, had to be changed to support the increase HARQ Acknowledgements of the additional carriers. The Release-8 PUCCH known as format 1b was defined to support up to 4 bits, can only support a maximum of 2 CCs.

To enable terminals capable of more than two downlink component carrier and 4 bits of acknowledgement, a new PUCCH known as “format 3” in Release-10 has been defined.

It permits a complete range of ACK/NACK transmission bits up to 10 ACK/NACK bits for FDD and up to 20 ACK/NACK bits for TDD.

Instead of using Zadoff-Chu sequences as other PUCCH format it uses similar to PUSCH transmissions (DFT-S-OFDM). The HARQ are concatenated with scheduling bit request, block coding is applied, followed by cell specific scrambling. [1] [8]

3.9.3 UPLINK CHANNEL QUALITY

Uplink channel quality, as per LTE Release-8 and 9, is estimated at the base station via sounding reference symbols (SRS) transmitted by the UE. CA implies that channel sounding could be required on multiple CCs. Release-10 introduces enhancements to permit the base station to request periodic SRS transmission on SCell in addition to PCells, though function is optional at the UE.

3.9.4 UPLINK TRANSMIT POWER CONTROL

Uplink transmit power control (TPC) commands are transported to the UE via the downlink control information (DCI) IE. The one PUCCH and one or more PUSCHs can be power controlled independently. TPC commands for the PUCCH are always received on the PCell's PDCCH.

But the TPC commands for the SCells could be received either through the SCell's PDCCH, or through the PCell's PDCCH. Again, component carrier distinction is accomplished through the presence of the CIF in the DCI IE.

3.9.5 DOWNLINK RADIO LINK MONITORING

When operating in CA mode, the UE evaluates radio link quality and declares radio link failure only through the PCell. This is intuitive as the SCell represents only additional traffic channel bandwidth rather than a pipeline for the channel control information.

From an operator network design perspective, it could be a performance advantage, due to superior propagation characteristics, to use the lower frequency cells as PCells and the higher frequency cells as SCells, particularly in the context of Inter-Band CA.

3.9.6 TIMING AND SYNCHRONIZATION

The PCell and the SCells are normally to be transmitted by the same base station. The path length between the base station and the UE therefore is normally to be the same for all carriers. This is the case regardless of frequency band. Thus, there is single timing advance value applied to all uplink transmissions, regardless of whether they occur on the PCell or a SCell [4].

In case of non-collocated cells belonging to the same NodeB such as HetNet scenario using Inter-Band carrier aggregations where antennas are distributed and connected via fibre links, the use of multiple timing advance is necessary.

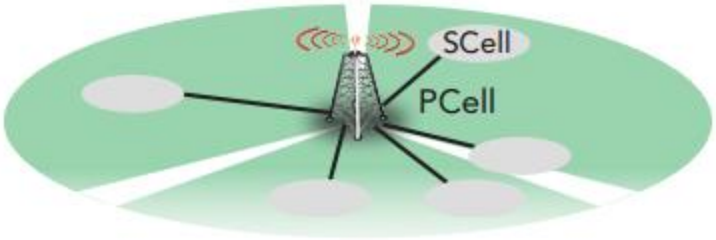


Fig. 3.10: Non co-located site, carrier aggregation

Once the UE is synchronized with the PCell, it has to obtain synchronization from the SCells situated in a different physical location. Immediately after the SCell activation, the NodeB PCell will request a RACH on the SCell. This RACH request is carried over PDCCH signalling from the PCell [15]. This RACH is then used to measure the timing offset of the SCell.

In the case of multiple component carriers having same timing requirements, they will be grouped under a timing advance group in order to save control signalling. More than on timing advance group might be used in HetNet deployment scenario.

3.9.7 CROSS-CARRIER SCHEDULING

The Cross-Carrier Scheduling is an optional feature for the UE introduced in Release-10, its activation is possible through the RRC during the UE capability transfer procedure. The objective of this feature is to reduce interference (ICIC) in HetNet scenarios with carrier aggregation where a combination of macros, small-cells and relays is used. Usage of Cross-Carrier Scheduling is to schedule resources on SCell without PDCCH [8].

The carrier responsible for delivering scheduling information in the context of cross-carrier scheduling is indicated by the Carrier Indicator Field (CIF) in the Downlink Control Information (DCI). This scheduling also supports HetNet and asymmetric configurations.

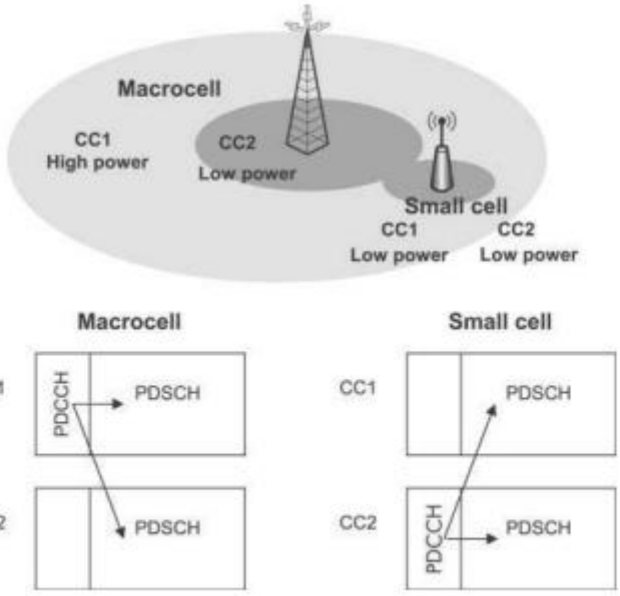


Fig. 3.11 Macro cells and small cells sharing 2 CCs for heterogeneous network deployment.

It should be noted that a PCell cannot be cross scheduled; it is always scheduled through its own PDCCH.

Figure 3.11 illustrates a typical heterogeneous network situation where macro cells and small cells share two downlink CCs [4], represented by CC1 and CC2. The small cells use both CCs at low transmit power, and the macro cells use CC1 at high power and CC2 at low power. The macro cells' communications on CC1 would result high interference to the small cells, and hence it is advantageous for the small cells to be capable of using PDCCH messages on CC2 to accomplish cross-carrier scheduling for data transmissions on CC1. To enable this, the macro cells can abstain from transmitting PDCCHs on CC2 (or transmit only with low power), rather using CC1 to schedule data transmissions on both CC1 and CC2, with cross-carrier scheduling for the latter. This efficiently offers ICIC for the PDCCH, however the Release 8 ICIC mechanisms may be applied for PDSCH data.

3.10 RADIO RESOURCE CONTROL (RRC) ASPECTS

3.10.1 RRC UE CAPABILITY TRANSFER PROCEDURE

Given the flexibility of CA, the E-UTRAN must be informed of the details of the UE's support for CA. this is accomplished via the RRC UE Capability Transfer procedure during the establishment of an EPS bearer. The CA-related information sent by the UE related to this procedure is summarized below:

UE category – CA support is implied by UE category 6, 7 and 8. However it does not indicate the support for a particular carrier aggregation configuration, which is signalled separately.

Cross-carrier scheduling support – Indicates that the UE can receive scheduling orders regarding SCells from the PCell.

Simultaneous PUCCH and PUSCH transmission support – For CA capable UEs, implies that the UE can support simultaneous PUCCH and PUSCH transmission on different CCs.

Multi-cluster PUSCH within a CC support – Indicates baseband (non-band-specific) support for multi-cluster PUSCH transmission within CCs.

Non-contiguous uplink resource allocation within a CC support – Indicates RF (band-specific) support for non-contiguous uplink resource allocations within CCs.

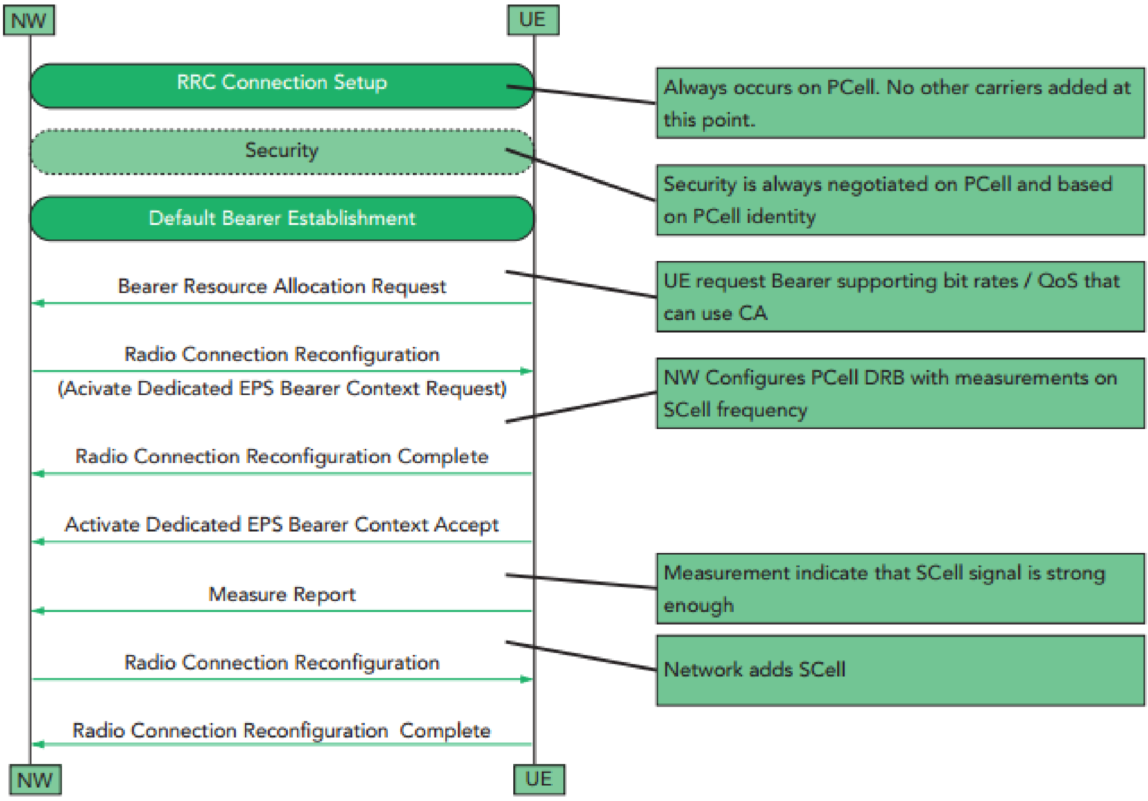
Supported band combinations – Indicates the specific frequency band and channel bandwidth configurations that the UE can utilize in support of CA.

Event A6 reporting support – Indicates that the UE is able to report Event A6, which occurs when a neighbour PCell becomes stronger than a serving SCell by an offset.

SCell addition during handover to E-UTRA support – Indicates that the UE can support E-UTRAN inter-radio access technology (IRAT) handover directly into CA mode.

Periodic SRS transmission on all CCs support – Indicates that the UE can transmit periodic SRSs on all SCells.

The message exchanged can be summarized as follows [1]:



3.10.2 SCell ADDITION AND REMOVAL

At the time of RRC establishment extra SCells cannot be activated immediately. Thus, there is no facility in the RRC Connection Setup process for SCells.

SCells are added and detached from the set of serving cells by the RRC Connection Reconfiguration process [15]. Since intra-LTE handover is taken as an RRC connection reconfiguration, SCell “handover” is allowed. CA-related data transmitted by the base station resulting to this RRC Connection Reconfiguration process is briefed below.

- **Cross-carrier scheduling configuration** – Specifies, amid other things, if scheduling for the referenced SCell is controlled by that SCell or by other cell.
- **SCell PUSCH configuration** – Specifies, amid other things, whether resource block group hopping is used on the SCell.

- **SCell uplink power control configuration** – Transmits a number of primitives pertaining to SCell uplink TPC, comprising the path loss reference linking parameter.
- **SCell CQI reporting configuration** – transmits a number of primitives pertaining to CQI measurements reporting for SCells.

3.10.3 HANDOVER

Handover processing for LTE in Release-10 is largely the same as Release 8 and 9, except that clarifications are made to refer to PCell in the measurement-related RRC signalling messages.

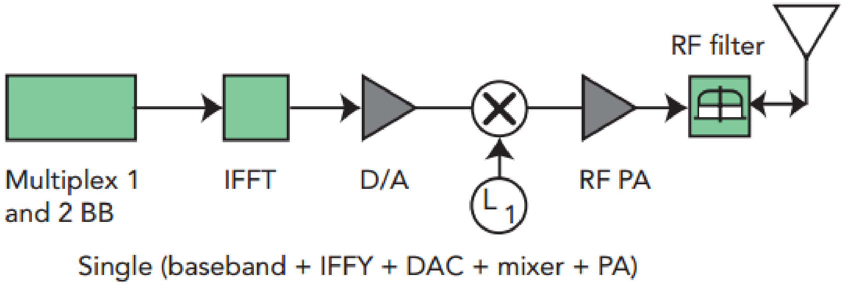
Release-10 introduces one new measurement event: Event A6. Event A6 occurs when a neighbouring cell's strength becomes better than a SCell's strength by an offset.

In the case of Intra-Band SCells, this event is less useful, as the strength of the PCell and the SCells usually is very similar. However, with Inter-Band serving cells, the strength of a neighbouring PCell could be significantly different from a serving SCell. Depending on network conditions – such as traffic load distribution – it could be advantageous to execute a handover to the cell identified by Event A6.

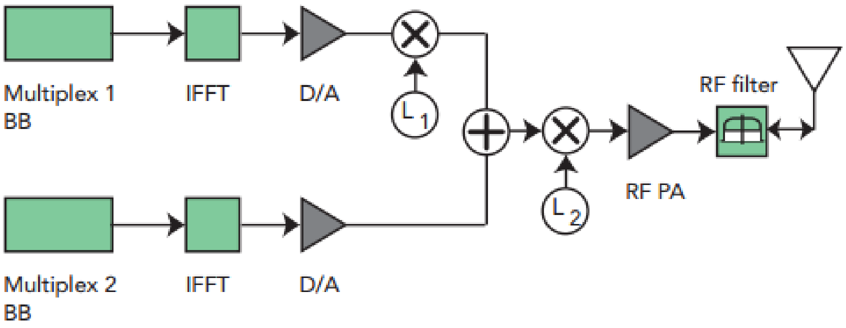
3.11 UE TRANSMITTER AND RECEIVER ASPECTS OF CA

The output power dynamics are correlated to UE architecture chosen, which can be based on a single or multiple Power Amplifiers (Pas). The following figures illustrate a mixture of options considered by 3GPP as possible implementation for Power Amplifier (PA) architectures at the UE to support the different type of carrier aggregation [10].

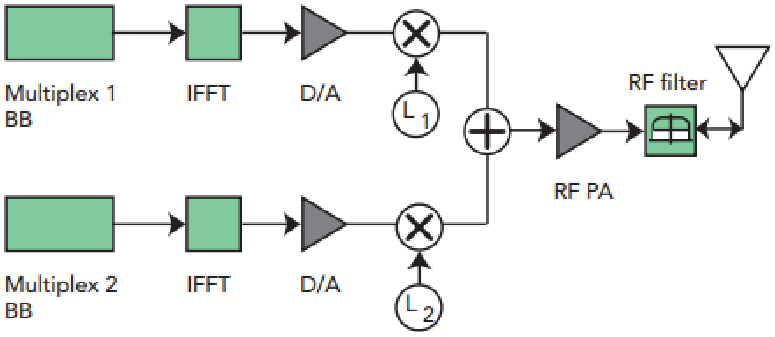
INTRA-BAND CONTIGUOUS



INTRA-BAND CONTIGUOUS AND NON-CONTIGUOUS

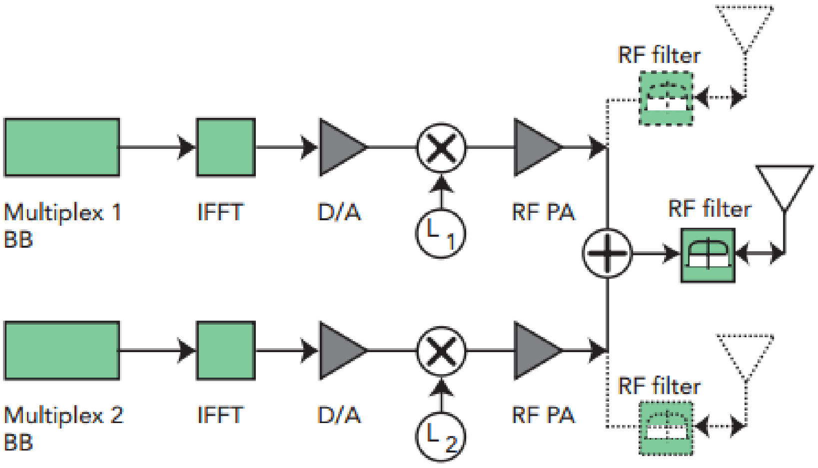


Multiple (baseband + IFFT + DAC),
Single (stage-1 IF mixer + combiner @ IF + stage-2 RF mixer + PA)



Multiple (baseband + IFFT + DAC + mixer),
Low power combiner @ RF, and single PA

INTER-BAND SCENARIO



Multiple (baseband +IFFT + DAC + mixer + PA), high-power combiner to single antenna OR dual antenna (MIMO) 3GPP TR 36.815 further advancements for E-UTRA; LTE-Advanced feasibility studies in RAN WG4

The fundamental choices when it comes to carrier aggregation design are basically either wideband or narrowband approach:

Wideband transceiver to cover all bands implying that usage of expensive wideband RF components and ultra-high performance ADCs/DACs with a baseband processing with bandwidth ≥ 20 MHz Designing wideband transceivers brings numerous challenges:

- Different path loss frequency dependent: with higher frequencies the path loss increases nonlinearly.
- Doppler frequency shift: Doppler effects are more impacting at higher frequencies.
- Noise power: The effective noise increases with the bandwidth.
- Receiver input signal: The usage of a wider bandwidth implies receiving more unwanted signals from other services.
- Component nonlinearities in analogue receiver: Demodulation can be affected by distortion and intermodulation created by additional signals.
- Maximum input signal: The receiver must have a sufficient dynamic range to avoid overload conditions.

Clearly, the coverage of all the bands by only one chain is only applicable for intra-band aggregation of contiguous CCs, but it has the advantage of keeping the UE receiver complexity low.

Multiple narrowband transceivers to cover each band with the expense of an increased complexity and cost for each band with a baseband processing bandwidth ≤ 20 MHz This design is applicable for intra-band and inter-band aggregations for contiguous or non-contiguous scenarios.

As Inter-Band requires a second transmit chain it leads inevitably to a more complex device design and of course higher power consumption impacting the device battery consumption.

In Release-10 a complete narrowband approach could lead to use of 16 transceivers assuming 2 CCs and 8x8 MIMO in the downlink.

From RF perspective, Intra-Band contiguous aggregated carriers have similar properties as a corresponding wider carrier being transmitted and received. The Inter-Band architecture represents a major challenge for the UE design as multiple simultaneous chains have to co-exist.

The radio environment and frequency plan in terms of intermodulation and cross-modulation within the UE device is also challenging.

CHAPTER 4

Simulation Results

4.1 LTE-A COMPONENT CARRIER GENERATION

4.1.1 PARAMETER CALCULATION for 20 MHz CC

Sampling frequency $f_S = 30.72$ MHz

Cyclic prefix duration $T_{CP} = 4.7\mu sec \approx 5\mu sec$ (Short CP)

$= 16.7\mu sec \approx 17\mu sec$ (Long CP)

Sampling period $(T_S) = 1/f_S$

$= (1/30.72)\ \mu sec$

1 Radio frame duration = 10msec.

1 Radio frame contains 10 equally sized sub-frames or TTI (Transmission Time Interval) of duration = 1msec each.

Each TTI is further divided into 2 slots of duration = 0.5 msec each.

Each slot has 6 or 7 OFDM symbols.

Subcarrier spacing $(\Delta f) = 15$ kHz.

OFDM symbol duration $(T_u) = 1/(\Delta f)$.

$= (1/15000)$ sec $= 66.7\mu sec$.

$(T_{CP}) \times (\Delta f) = 4.7\mu \times 15k = 0.0705 < 1$

Hence spectral efficient.

Number of samples in one slot $= 0.5 \times 30.72 \times 1000 = 15360$ samples.

Number of samples in an OFDM symbol duration $(T_u) = 66.7 \times 30.72 \approx 2048$

Number of subcarrier used = (20MHz)/(15kHz)

≈ 1333

4.1.2 PARAMETER CALCULATION for 10 MHz CC

Sampling frequency f_S = 15.36 MHz

Cyclic prefix duration T_{CP} = 4.7µsec ≈ 5µsec (Short CP)

= 16.7µsec ≈ 17µsec (Long CP)

Sampling period (T_S) = $1/f_S$

= (1/15.36) µsec

1 Radio frame duration = 10msec.

1 Radio frame contains 10 equally sized sub-frames or TTI (Transmission Time Interval) of duration = 1msec each.

Each TTI is further divided into 2 slots of duration = 0.5 msec each.

Each slot has 6 or 7 OFDM symbols.

Subcarrier spacing (Δf) = 15 kHz.

OFDM symbol duration (T_u) = $1/(\Delta f)$.

= (1/15000) sec = 66.7µsec.

$(T_{CP}) \times (\Delta f) = 4.7\mu \times 15k = 0.0705 < 1$

Hence spectral efficient.

Number of samples in one slot = 0.5×15.36×1000 = 7680 samples.

Number of samples in an OFDM symbol duration (T_u) = 66.7×15.36 ≈ 1024

Number of subcarrier used = (10MHz)/(15kHz)

≈ 666

4.1.3 PARAMETER CALCULATION for 5 MHz CC

Sampling frequency f_S = 7.68 MHz

Cyclic prefix duration T_{CP} = 4.7µsec ≈ 5µsec (Short CP)

= 16.7µsec ≈ 17µsec (Long CP)

Sampling period (T_S) = $1/f_S$

= (1/7.68) µsec

1 Radio frame duration = 10msec.

1 Radio frame contains 10 equally sized sub-frames or TTI (Transmission Time Interval) of duration = 1msec each.

Each TTI is further divided into 2 slots of duration = 0.5 msec each.

Each slot has 6 or 7 OFDM symbols.

Subcarrier spacing (Δf) = 15 kHz.

OFDM symbol duration (T_u) = $1/(\Delta f)$.

= (1/15000) sec = 66.7µsec.

$(T_{CP}) \times (\Delta f) = 4.7\mu \times 15k = 0.0705 < 1$

Hence spectral efficient.

Number of samples in one slot = 0.5×7.68×1000 = 3840 samples.

Number of samples in an OFDM symbol duration (T_u) = 66.7×7.68 ≈ 512

Number of subcarrier used = (5MHz)/(15kHz)

≈ 333

Practically only 300 subcarriers are modulated with data.

For Carrier Aggregation following steps are followed:

1. Individual component carriers are generated by configuring eNodeB for each CC and calculating CC parameters.
2. Resampled (oversampled) to common sampling rate.
3. Frequency modulated to the appropriate center frequency.
4. Added together to get the aggregated signal.

4.2 CA_40C INTRA-BAND CONTIGUOUS CA (RELEASE-10)

4.2.1 SIMULATION RESULTS

4.2.1.1 COMBINATION SET (50RB+100RB)

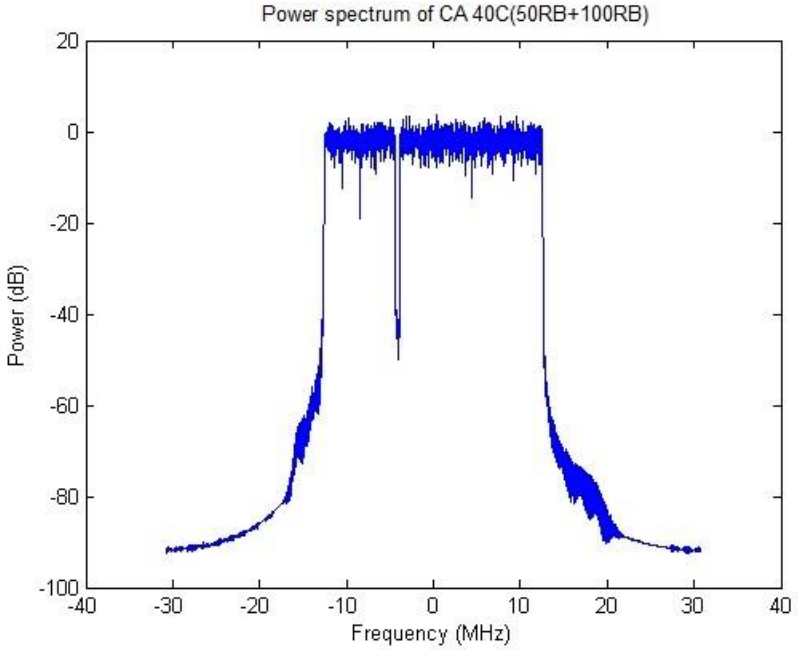


Fig. 4.1: Power Spectrum of Intra-Band Contiguous CA for Combination Set (50RB+100RB) in Band 40

4.2.1.2 COMBINATION SET (75RB+75RB)

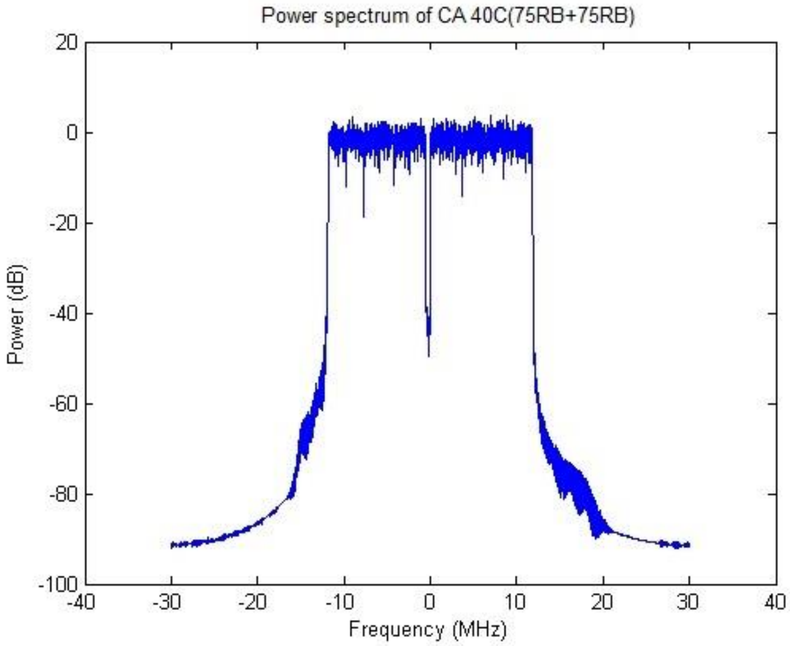


Fig. 4.2: Power Spectrum of Intra-Band Contiguous CA for Combination Set (75RB+75RB) in Band 40

4.2.1.3 COMBINATION SET (100RB+100RB)

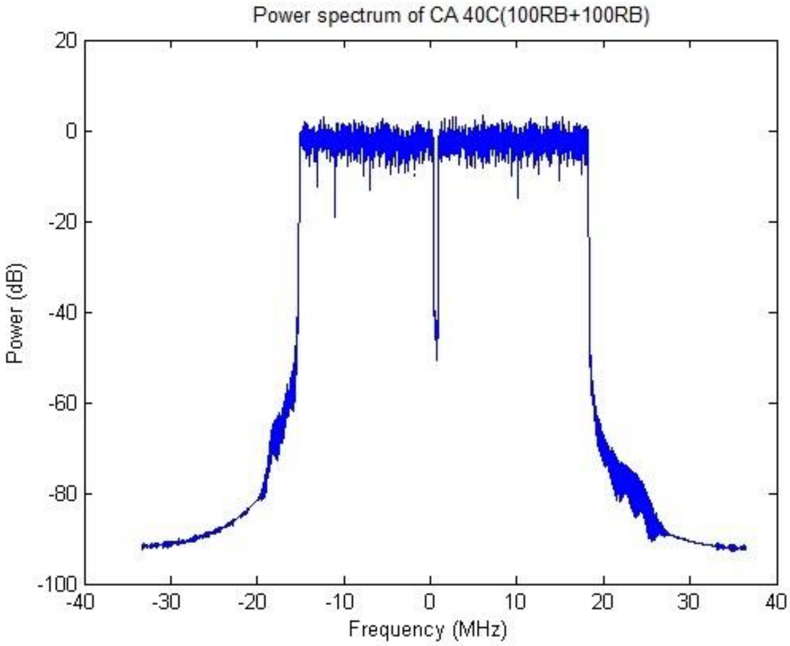


Fig. 4.3: Power Spectrum of Intra-Band Contiguous CA for Combination Set (100RB+100RB) in Band 40

CHAPTER 5

Conclusions

5.1 CONCLUSIONS

Due to provision for high data rates, effective use of fragmented spectrum, and support of heterogeneous network deployments by means of cross-carrier scheduling, carrier aggregation for LTE-Advanced is included in Release 10. An amalgamation with other features defined in LTE Release 10, such as higher order MIMO, CA offers a powerful means to increase the peak user throughput in LTE Release 10 and to meet the IMT-Advanced requirements set by the ITU-R. CA permits aggregation of CCs spread across different bands as well as CCs having different bandwidths. CA also permits aggregation of cells having different coverage, thereby allowing flexible network deployments according to traffic demands [9]. In exploiting cross-carrier scheduling, effective interference management is probable in heterogeneous network deployments, thereby increasing system capacity. Furthermore, each CC is backwards compatible with LTE Release 8/9, permitting smooth upgrade and relocation of LTE networks towards LTE-Advanced. Further evolution of CA is expected in future releases of LTE to contain more advanced features such as inter-band CA for the UL and distinct timing control for different UL CCs, to support additional deployment scenarios.

5.2 SCOPE FOR FUTURE WORK

CARRIER AGGREGATION ENHANCEMENT

As spectrum accessibility changes for different network operators around the world, new amalgamations of adjacent and non-adjacent carriers and bands will continue to become significant. RF necessities will be developed for such amalgamations and typically introduced in a release-independent manner so that user equipment of any release may support them.

[1] Djukic, Petar, Mahmudur Rahman, Halim Yanikomeroglu, and Jietao Zhang." Advanced Radio Access Networks for LTE and Beyond", Evolved Cellular Network Planning and Optimization for UMTS and LTE, 2010.

[2] ITU-R, “Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s),” Tech. Rep. M.2134, Dec. 2008.

[3] 3GPP Carrier Aggregation explained, May 2012. http://www.3gpp.org/Carrier - Aggregation - explained.

[4] Stefania Sesia, Issam Toufik, Matthew Baker “LTE-The UMTS Long Term Evolution, from Theory to Practice” 2nd Ed., John Wiley, UK, (2011), pp. 623-650.

[5] Yonis, Aws Zuheer and Liew Abdullah, Mohammad Faiz. "Wider Bandwidth of non-contiguous Component Carriers in LTE-Advanced”, International Journal of Future Generation Communication & Networking, 2013.

[6] 3rd Generation Partnership Project; Technical Specification Group Radio Access Network; Further advancements for E-UTRA; LTE-Advanced feasibility studies in RAN WG4 (Release 9).

[7] Montojo, Juan, and Jelena Damnjanovic. “Carrier Aggregation”, LTE - The UMTS Long Term Evolution from Theory to Practice, 2011.

[8] Iwamura, Mikio, Kamran Etemad, Mo-han Fong, Ravi nor y, and Robert Love. “Carrier Aggregation framework in 3GPP LTE-Advanced [WiMAX/LTE Update”, IEEE Communications Magazine, 2010.

[9]] ITU-R, “Requirements Related to Technical Performance for IMT-Advanced Radio Interface(s),” Tech. Rep. M.2134, Dec. 2008.

[10] 3GPP, “Dual-cell High Speed Downlink Packet Access (HSDPA) operation,” TR 25.825, 3GPP, June 2008.

[11] 3GPP TS 25.825 v1.0.0, “3GPP Technical Specification Group Radio Access Network; Dual-Cell HSDPA Operation,” May 2008.

[12] ITU-R, Radio Regulations. No. V. 4, 2012.

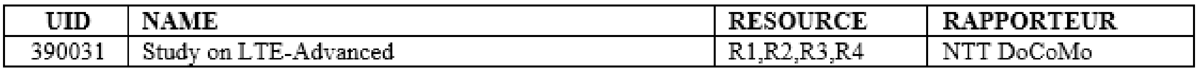
[13] Yonis, Aws Zuheer and Liew Abdullah, Mohammad Faiz. "Wider Bandwidth of non-contiguous Component Carriers in LTE-Advanced”, International Journal of Future Generation Communication & Networking, 2013.

[14] Zhou, “Carrier Aggregation”, LTE- Advanced Air Interface Technology, 2012.

[15] Ahmadi, Sassan. "Carrier Aggregation”, LTE-Advanced, 2014.

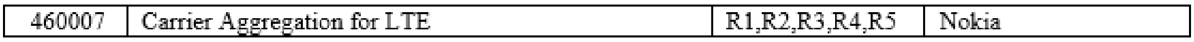
LTE ADVANCED CARRIER AGGREGATION WORK ITEMS

RELEASE-9



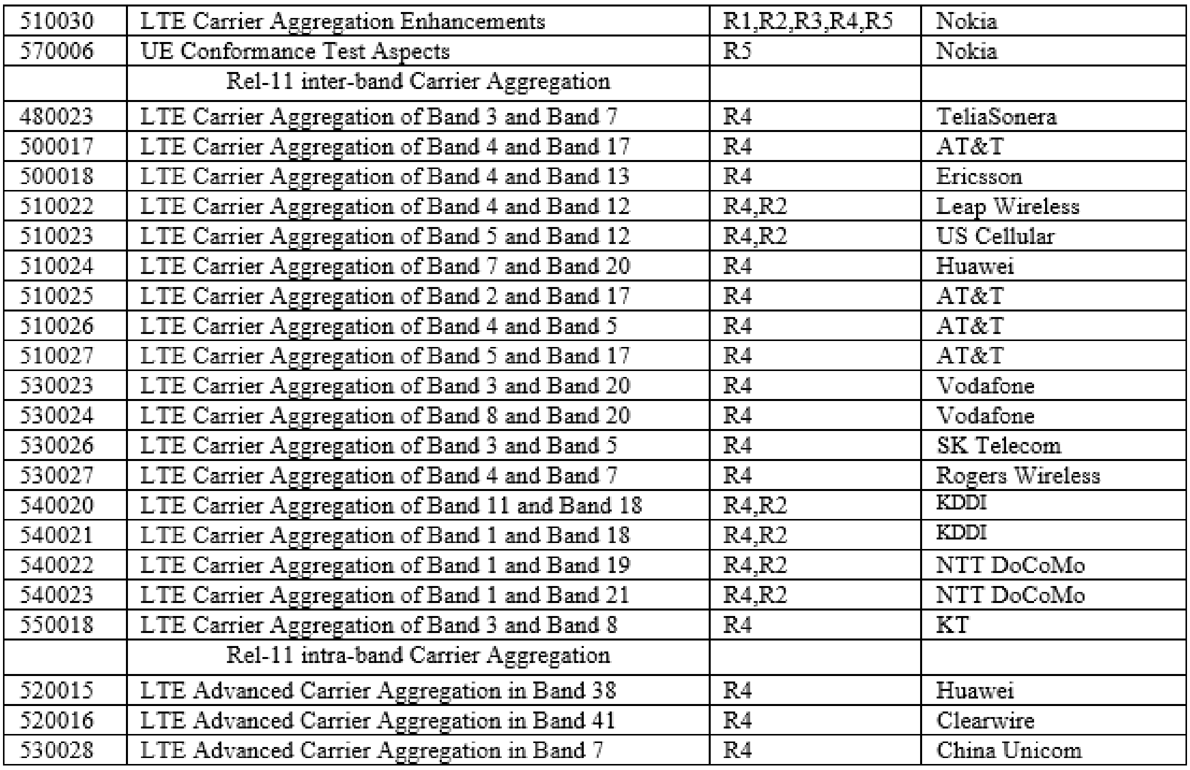
UID	NAME	RESOURCE	RAPPORTEUR
390031	Study on LTE-Advanced	R1,R2,R3,R4	NTT DoCoMo

RELEASE-10



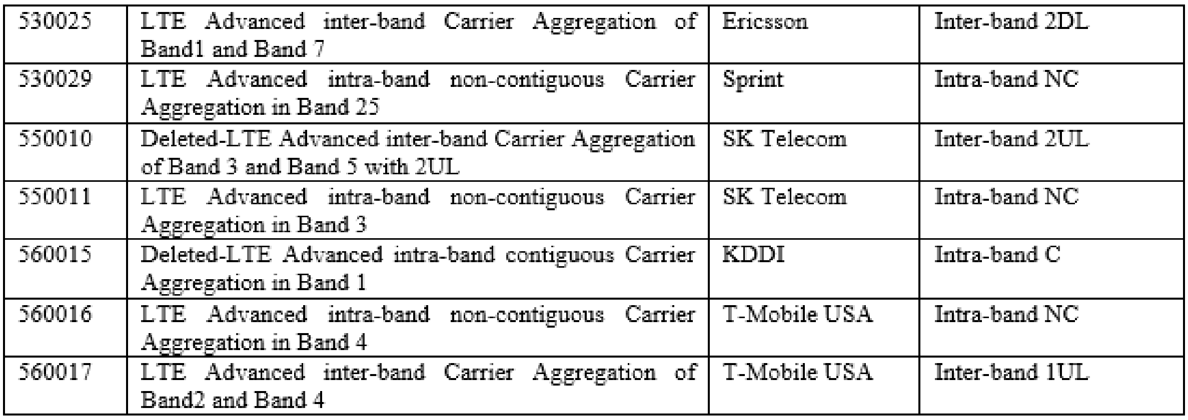
460007	Carrier Aggregation for LTE	R1,R2,R3,R4,R5	Nokia

RELEASE-11



510030	LTE Carrier Aggregation Enhancements	R1,R2,R3,R4,R5	Nokia
570006	UE Conformance Test Aspects	R5	Nokia
	Rel-11 inter-band Carrier Aggregation		
480023	LTE Carrier Aggregation of Band 3 and Band 7	R4	TeliaSonera
500017	LTE Carrier Aggregation of Band 4 and Band 17	R4	AT&T
500018	LTE Carrier Aggregation of Band 4 and Band 13	R4	Ericsson
510022	LTE Carrier Aggregation of Band 4 and Band 12	R4,R2	Leap Wireless
510023	LTE Carrier Aggregation of Band 5 and Band 12	R4,R2	US Cellular
510024	LTE Carrier Aggregation of Band 7 and Band 20	R4	Huawei
510025	LTE Carrier Aggregation of Band 2 and Band 17	R4	AT&T
510026	LTE Carrier Aggregation of Band 4 and Band 5	R4	AT&T
510027	LTE Carrier Aggregation of Band 5 and Band 17	R4	AT&T
530023	LTE Carrier Aggregation of Band 3 and Band 20	R4	Vodafone
530024	LTE Carrier Aggregation of Band 8 and Band 20	R4	Vodafone
530026	LTE Carrier Aggregation of Band 3 and Band 5	R4	SK Telecom
530027	LTE Carrier Aggregation of Band 4 and Band 7	R4	Rogers Wireless
540020	LTE Carrier Aggregation of Band 11 and Band 18	R4,R2	KDDI
540021	LTE Carrier Aggregation of Band 1 and Band 18	R4,R2	KDDI
540022	LTE Carrier Aggregation of Band 1 and Band 19	R4,R2	NTT DoCoMo
540023	LTE Carrier Aggregation of Band 1 and Band 21	R4,R2	NTT DoCoMo
550018	LTE Carrier Aggregation of Band 3 and Band 8	R4	KT
	Rel-11 intra-band Carrier Aggregation		
520015	LTE Advanced Carrier Aggregation in Band 38	R4	Huawei
520016	LTE Advanced Carrier Aggregation in Band 41	R4	Clearwire
530028	LTE Advanced Carrier Aggregation in Band 7	R4	China Unicom

RELEASE-12



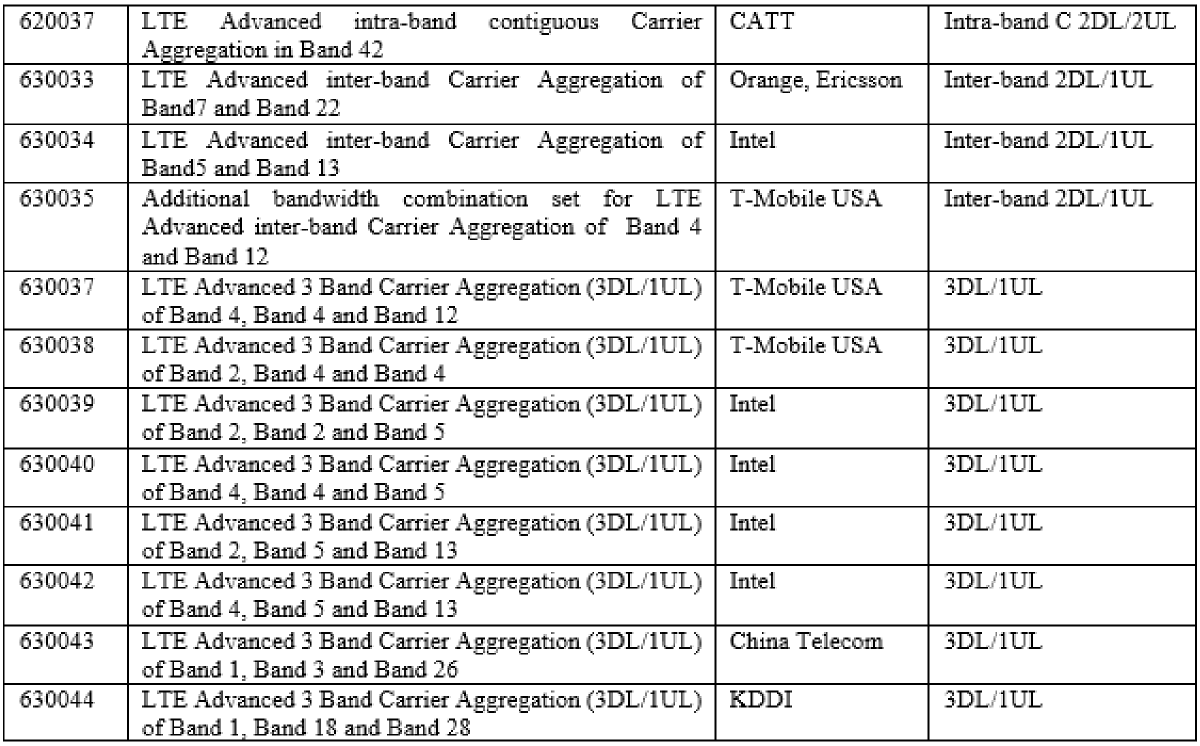
530025	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 7	Ericsson	Inter-band 2DL
530029	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 25	Sprint	Intra-band NC
550010	Deleted-LTE Advanced inter-band Carrier Aggregation of Band 3 and Band 5 with 2UL	SK Telecom	Inter-band 2UL
550011	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 3	SK Telecom	Intra-band NC
560015	Deleted-LTE Advanced intra-band contiguous Carrier Aggregation in Band 1	KDDI	Intra-band C
560016	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 4	T-Mobile USA	Intra-band NC
560017	LTE Advanced inter-band Carrier Aggregation of Band2 and Band 4	T-Mobile USA	Inter-band 1UL

570012	LTE Advanced inter-band Carrier Aggregation of Band23 and Band 29	DISH Network	Inter-band 1UL
570013	LTE Advanced inter-band Carrier Aggregation of Band3 and Band 26	KT	Inter-band 1UL
570014	LTE Advanced inter-band Carrier Aggregation of Band3 and Band 19	NTT DOCOMO	Inter-band 1UL
570015	Deleted-LTE Advanced inter-band Carrier Aggregation of Band 38 and Band 39	China Mobile	Inter-band 1UL
570016	LTE Advanced intra-band contiguous Carrier Aggregation in Band 3	China Unicom	Intra-band C CA
570018	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 8	Softbank Mobile	Inter-band 1UL
570026	LTE Advanced inter-band Carrier Aggregation of Band3 and Band 28	eAccess	Inter-band 1UL
580032	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 26	KDDI	Inter-band 1UL/2DL
580033	LTE Advanced inter-band Carrier Aggregation of Band39 and Band 41	China Mobile	Inter-band 2DL
580034	LTE Advanced inter-band Carrier Aggregation of Band2 and Band 12	US Cellular	Inter-band 2DL
580035	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 7	Ericsson	Intra-band NC
580036	LTE Advanced intra-band contiguous Carrier Aggregation in Band 27	NII Holdings	Intra-band C 2DL/1UL
590022	LTE Advanced inter-band Carrier Aggregation of Band2 and Band 13	Ericsson	Inter-band 1UL
590024	LTE Advanced inter-band Carrier Aggregation of Band19 and Band 21	NTT DOCOMO	Inter-band 1UL
590025	Deleted-LTE Advanced inter-band Carrier Aggregation of Band 8 and Band 26	KT	Inter-band 1UL
590029	LTE Advanced Dual uplink inter-band Carrier Aggregation Class A1	Huawei	Inter-band 2UL
590028	LTE Advanced Dual uplink inter-band Carrier Aggregation Class A2	Qualcomm	Inter-band 2UL
590023	LTE Advanced Dual uplink inter-band Carrier Aggregation Class A3	Ericsson	Inter-band 2UL
590031	LTE Advanced Dual uplink inter-band Carrier Aggregation Class A4	Nokia	Inter-band 2UL
590026	LTE Advanced Dual uplink inter-band Carrier Aggregation Class A5	Renesas	Inter-band 2UL
590027	LTE Advanced intra-band contiguous Carrier Aggregation in Band 39	China Mobile	Intra-band C 2DL/2UL
600022	LTE Advanced intra-band non-contiguous Carrier Aggregation : framework requirements for 2UL	Nokia	Intra-band NC 2UL
600023	Deleted-LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 41 for 2UL	Sprint	Intra-band NC 2UL
600024	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 4 for 2UL	T-Mobile USA	Intra-band NC 2UL
600025	LTE Advanced intra-band contiguous Carrier Aggregation in Band 23	DISH Network	Intra-band C
600026	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 23	DISH Network	Intra-band NC 2DL
600028	LTE Advanced inter-band Carrier Aggregation of Band12 and Band 25	US Cellular	Inter-band 1UL/2DL
600029	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 18 – Additional bandwidth combination set	KDDI	Inter-band 1UL/2DL
600030	LTE Advanced inter-band Carrier Aggregation of Band2 and Band 5	AT&T	Inter-band 2DL

600031	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 5 and Band 30	AT&T	Inter-band 3DL
600032	Deleted-LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 17 and Band 30	AT&T	Inter-band 3DL
600033	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 29 and Band 30	AT&T	Inter-band 3DL
600034	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 5 and Band 30	AT&T	Inter-band 3DL
600035	Deleted-LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 17 and Band 30	AT&T	Inter-band 3DL
600036	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 29 and Band 30	AT&T	Inter-band 3DL
600037	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 4 and Band 13	Verizon	Inter-band 3DL
600038	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 2 and Band 13	Verizon	Inter-band 3DL
600039	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 4 and Band 13	Verizon	Inter-band 3DL
610017	LTE Advanced inter-band Carrier Aggregation of Band7 and Band 28	Huawei	Inter-band 1UL/2DL
610018	LTE Advanced inter-band Carrier Aggregation of Band5 and Band 25	US Cellular	Inter-band 1UL/2DL
610019	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 11	Softbank Mobile	Inter-band 2DL
610020	LTE Advanced inter-band Carrier Aggregation of Band8 and Band 11	Softbank Mobile	Inter-band 2DL
610021	LTE Advanced inter-band Carrier Aggregation of Band5 and Band 7	LG Uplus	Inter-band 1UL/2DL
610022	LTE Advanced intra-band contiguous Carrier Aggregation in Band 41 for 3DL	Alcatel-Lucent	Intra-band C 3DL
610023	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 2	Ericsson	Intra-band NC 2DL
620018	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 3	China Unicom	Inter-band 2DL
620019	LTE Advanced inter-band Carrier Aggregation of Band1 and Band 28	KDDI	Inter-band 2DL
620020	LTE Advanced inter-band Carrier Aggregation of Band2 and Band 4 – Additional bandwidth combination set	T-Mobile USA	Inter-band 2DL
620021	LTE Advanced inter-band Carrier Aggregation of Band4 and Band 27	NII Holdings	Inter-band 2DL
620022	LTE Advanced inter-band Carrier Aggregation of Band3 and Band 27	KT	Inter-band 2DL
620023	LTE Advanced inter-band Carrier Aggregation of Band8 and Band 27	KT	Inter-band 2DL
620072	LTE Advanced inter-band Carrier Aggregation of Band8 and Band 20 – Additional channel bandwidth	Vodafone	Inter-band 2DL
620024	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 1, Band 3 and Band 8	KT	Inter-band 3DL
620025	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 1, Band 5 and Band 7	LG Uplus	Inter-band 3DL
620026	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 4 and Band 5	US Cellular	Inter-band 3DL
620027	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 4 and Band 12	US Cellular	Inter-band 3DL
620028	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 5 and Band 12	US Cellular	Inter-band 3DL
620029	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 12 and Band 12	AT&T	Inter-band 3DL

620030	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 2, Band 12 and Band 30	AT&T	Inter-band 3DL
620031	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 3, Band 7 and Band 20	Vodafone	Inter-band 3DL
620032	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 3, Band 8 and Band 27	KT	Inter-band 3DL
620033	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 5 and Band 12	US Cellular	Inter-band 3DL
620034	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 12 and Band 12	AT&T	Inter-band 3DL
620035	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 4, Band 12 and Band 30	AT&T	Inter-band 3DL
620050	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 1, Band 3 and Band 5	SK Telecom	Inter-band 3DL
620051	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 1, Band 3 and Band 20	Vodafone	Inter-band 3DL
620052	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 1, Band 7 and Band 20	Vodafone	Inter-band 3DL
620053	LTE Advanced 3 Band Carrier Aggregation 3DL of Band 7, Band 8 and Band 20	Vodafone	Inter-band 3DL
620036	LTE Advanced intra-band contiguous Carrier Aggregation in Band 7 – Additional bandwidth combinations	Orange	Intra-band C 2DL/2UL
620038	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 41 for 3DL	Sprint, Alcatel-Lucent	Intra-band NC 3DL
620039	LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 42	Huawei	Intra-band NC 2DL
630022	Additional bandwidth combinations for LTE Advanced inter-band Carrier Aggregation of Band 2 and Band 29 and of Band 4 and Band 29	AT&T	Inter-band 2DL/1UL
630023	Additional bandwidth combination set for LTE Advanced inter-band Carrier Aggregation of Band 3 and Band 20	NSN	Inter-band 2DL/1UL
630024	Additional bandwidth combination set for LTE Advanced inter-band Carrier Aggregation of Band 7 and Band 20	NSN	Inter-band 2DL/1UL
630025	Additional bandwidth combinations for LTE Advanced inter-band Carrier Aggregation of Band 3 and Band 20	Qualcomm	Inter-band 2DL/1UL
630026	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 3, Band 7 and Band 7	NSN	3DL/1UL
630027	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 1, Band 19 and Band 21	NTT DOCOMO	3DL/1UL
630028	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 3, Band 3 and Band 7	TeliaSonera	3DL/1UL
630029	LTE Advanced intra-band contiguous Carrier Aggregation in Band 40 for 3DL	China Mobile	Intra-band C 3DL
630036	LTE Advanced inter-band Carrier Aggregation of Band 41 and Band 42	Huawei	Inter-band 2DL/1UL
630045	Additional bandwidth combinations for LTE Advanced intra-band non-contiguous Carrier Aggregation in Band 25	Huawei	Intra-band NC
610013	UE Conformance Test Aspects – Further Rel-12 Configurations for LTE Advanced Carrier Aggregation	Nokia	-

RELEASE-13



620037	LTE Advanced intra-band contiguous Carrier Aggregation in Band 42	CATT	Intra-band C 2DL/2UL
630033	LTE Advanced inter-band Carrier Aggregation of Band7 and Band 22	Orange, Ericsson	Inter-band 2DL/1UL
630034	LTE Advanced inter-band Carrier Aggregation of Band5 and Band 13	Intel	Inter-band 2DL/1UL
630035	Additional bandwidth combination set for LTE Advanced inter-band Carrier Aggregation of Band 4 and Band 12	T-Mobile USA	Inter-band 2DL/1UL
630037	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 4, Band 4 and Band 12	T-Mobile USA	3DL/1UL
630038	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 2, Band 4 and Band 4	T-Mobile USA	3DL/1UL
630039	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 2, Band 2 and Band 5	Intel	3DL/1UL
630040	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 4, Band 4 and Band 5	Intel	3DL/1UL
630041	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 2, Band 5 and Band 13	Intel	3DL/1UL
630042	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 4, Band 5 and Band 13	Intel	3DL/1UL
630043	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 1, Band 3 and Band 26	China Telecom	3DL/1UL
630044	LTE Advanced 3 Band Carrier Aggregation (3DL/1UL) of Band 1, Band 18 and Band 28	KDDI	3DL/1UL

OPERATING BANDS FOR LTE-ADVANCED

Operating Band	Uplink (UL) operating band BS receive/UE transmit			Downlink (DL) operating band BS transmit /UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz	FDD
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz	FDD
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz	FDD
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz	FDD
5	824 MHz	–	849 MHz	869 MHz	–	894MHz	FDD
6	830 MHz-	–	840 MHz-	865 MHz	–	875 MHz-	FDD
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz	FDD
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz	FDD
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz	FDD
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz	FDD
11	1427.9 MHz	–	1447.9 MHz	1475.9 MHz	–	1495.9 MHz	FDD
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz	FDD
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz	FDD
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz	FDD
15	Reserved			Reserved			-
16	Reserved			Reserved			-

Operating Band	Uplink (UL) operating band BS receive/UE transmit			Downlink (DL) operating band BS transmit /UE receive			Duplex Mode
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}	
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz	FDD
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz	FDD
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz	FDD
20	832 MHz	–	862 MHz	791 MHz	–	821 MHz	FDD
21	1447.9 MHz	–	1462.9 MHz	1495.9 MHz	–	1510.9 MHz	FDD
22	3410 MHz		3500 MHz	3510 MHz		3600 MHz	FDD
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33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz	TDD
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz	TDD
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz	TDD
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz	TDD
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz	TDD
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz	TDD
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz	TDD
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz	TDD
41	3400 MHz	–	3600 MHz	3400 MHz	–	3600 MHz	TDD