GTI White Paper

Global TD-LTE Initiative

TD-LTE Carrier Aggregation

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Contents

Executive Summary

This white paper provides a technical overview of carrier aggregation, including the following aspects:

1. Analyse the frequency bands allocation of different operators and the CA requirements of the operators based on the spectrum assignment.
2. Introduce the technical principle, advantages and application scenario of CA
3. Share the current status of standardization and industry.
4. Release the requirements of the operators and summarize the earliest roadmap expecting by the operators.

Terminology

Abbreviation	Explanation
3GPP	3rd Generation Partnership Project
ITU	International Telecommunication Union
LTE	Long Term Evolution
QoS	Quality of Service
RAN	Radio Access Network
RRM	Radio Resource Management
TD-LTE	Time Division Long Term Evolution
TDD	Time Division Duplex
CC	Component Carriers
CA	Carrier Aggregation
TTI	transmission time interval

1. The spectrum status of operators and Carrier Aggregation scenarios

1.1. Introduction to Carrier Aggregation

Based on the ITU requirements for IMT-Advanced systems, 3GPP set a target downlink peak rate of 1 Gbps an uplink peak rate of 500 Mbps for LTE-Advanced. One straight solution to achieve significantly higher data rates is to increase the channel bandwidth. Now, LTE supports channel bandwidths up to 20 MHz. LTE-Advanced introduces Carrier Aggregation (CA) technology that can aggregate two or more Component Carriers (CCs) in order to support wider transmission bandwidths up to 100MHz (up to 5 CCs). Because most spectrum is occupied and 100 MHz of contiguous spectrum is not available to most operators, the creation of wider bandwidths through the aggregation of contiguous and non-contiguous CCs are allowed. Thus, spectrum from one band can be added to spectrum from another band in a UE that supports multiple transceivers.

By utilizing plenty of resources on large bandwidth, network performance can be improved from the following viewpoints.

(1) Increase the peak date rate:

Terminals can transmit and receive data in a wider bandwidth.

Test result shows peak rate can reach 220 Mbps by 2 x 20 MHz CA.

(2) Increase the cell throughput:

Frequency selective scheduling on larger bandwidth can increase 10% cell throughput.

Flexible resource schedule on different CCs can Improve load balance efficiency.

(3) Improve the network KPIs:

Excellent load balance performance can reduce UE HO probability between different CCs in high load scenario.

(4) Increase Control channel capacity:

Increase Control channel capacity by using PDCCH cross-carrier scheduling to avoid the control channel interference.

1.2. Summary of the spectrum status of operators

Currently, 12 E-UTRA TDD Bands are defined by the 3GPP, though most available spectrums are concentrated at or around 1.9/2.0 GHz, 2.3 GHz and 2.6 GHz, 3.5/3.7 GHz. Figure 1-1 shows the current E-UTRA TDD band assignment in 3GPP and Table 1-1 shows the TDD band allocation in major countries and regions.

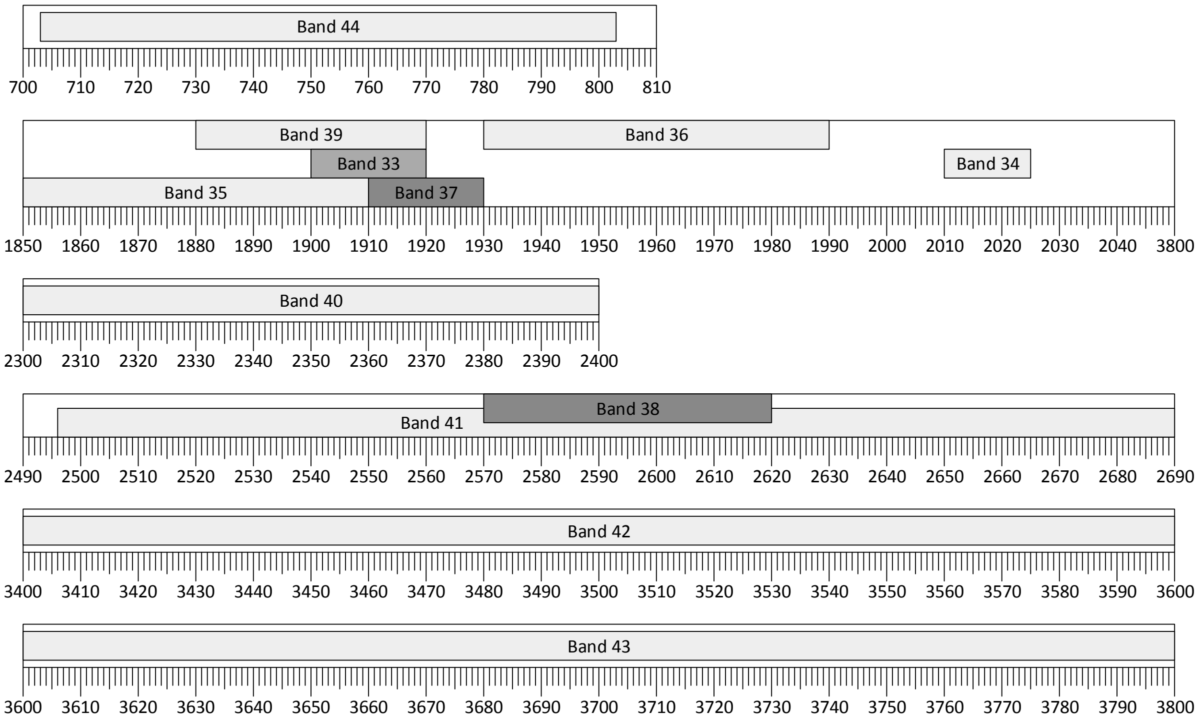


Figure 1-1: E-UTRA TDD band assignment in 3GPP

Frequency	Countries and Regions
1.9 GHz / 2.0 GHz	Australia, China, Europe, Japan, Russia, South Africa, South Asia
2.3 GHz	Africa, Australia, Canada, China, India, Latin America, Russia, South Korea, South Asia, The Middle East
2.6 GHz	Africa, Brazil, China, Europe, Japan, India, Latin America, North America, Saudi Arabia
3.5 GHz / 3.7 GHz	Australia, Europe, Latin America, North America, Russia, Japan(planned)

Table 1-1: TDD bands in major countries and regions

As of July 2014, 39 TD-LTE commercial networks have been launched and over 73 TD-LTE commercial networks are in progress or planned. List of the Global TD-LTE commercial networks is shown in Table 1-2. Many of the TD-LTE live networks are operated in 2.3 GHz or 2.6 GHz band. Furthermore, 3.5 GHz and/or 3.7 GHz bands are now the focus of attention because many of the GTI Operators hold 3.5 GHz/3.7 GHz band spectrum and have plan to introduce TD-LTE in their networks.

Index	Country	Operator	E-UTRA frequency band	
			Band number	Frequency
1	Australia	NBN	Band 40	2.3 GHz
2		Optus	Band 40	2.3 GHz
3	Bahrain	Menatelecom	Band 42	3.5 GHz
4	Belgium	B.lite	Band 42	3.5 GHz
5	Brazil	On Telecomunicacoes	Band 38	2.6 GHz
6		SKY Brasil Services	Band 38	2.6 GHz
7	Canada	ABC Communications	Band 42	3.5 GHz
8		Sasktel	Band 42	3.5 GHz
9	China	China Mobile	Band 39, 40, 41	1.9/2.3/2.6 GHz
10		China Telecom	Band 40, 41	2.3/2.6 GHz
11		China Unicom	Band 40, 41	2.3/2.6 GHz
12	Cote d'Ivoire	YooMee	Band 40	2.3 GHz
13	Hong Kong, China	China Mobile Hong Kong	Band 40	2.3 GHz
14	India	Bharti Airtel	Band 40	2.3 GHz
15	Indonesia	PT Internux	Band 40	2.3 GHz
16	Japan	UQ Communications	Band 41	2.6 GHz
17		Wireless City Planning	Band 41	2.6 GHz
18	Nigeria	Spectranet	Band 40	2.3 GHz
19		Swift Networks	Band 40, 42	2.3/3.5 GHz
20	Oman	Omantel	Band 40	2.3 GHz
21	Philippines	PLDT	Band 42	3.5 GHz
22	Poland	Aero2	Band 38	2.6 GHz
23	Russia	Megafon	Band 38	2.6 GHz
24		MTS	Band 38	2.6 GHz
25		Vainakh Telecom	Band 40	2.3 GHz
26	Saudi Arabia	Mobily	Band 38	2.6 GHz
27		STC	Band 40	2.3 GHz
28	South Africa	Telkom Mobile(8ta)	Band 40	2.3 GHz
29	Spain	COTA /Murcia4G	Band 38	2.6 GHz
30		Neo-Sky	Band 42	3.5 GHz
31		Vodafone	Band 38	2.6 GHz
32	Sri Lanka	Dialog Axiata	Band 40	2.3 GHz
33		Lanka Bell	Band 40	2.3 GHz
34		SLT	Band 38	2.6 GHz
35	Sweden	Hi3G	Band 38	2.6 GHz
36	Uganda	MTN	Band 38	2.6 GHz
37	UK	UK Broadband	Band 42, 43	3.5/3.7 GHz
38	USA	Sprint	Band 41	2.6 GHz
39	Vanuatu	WanTok	Band 40	2.3 GHz

Table 1-2: Global TD-LTE commercial networks (As of July 2014)

1.3. Operator requirements for Carrier Aggregation combinations

In order to assess the requirements for CA, GTI Network Working Group has collected the feedback from GTI Operators. Tables 1-3, 1-4 and 1-5 show the current summary of the GTI Operators feedback.

E-UTRA Band No.		Bandwidth [MHz]	DL / UL (1)		C / NC (2)		Year (3)	Number of operators
Band A	Band B	(BA+BB)	DL	UL	C	NC		
B 38	B 38	20 + 10	x	x	x		2014	2
		20 + 20	x		x		2014	1
B 40	B 40	15 + 15	x		x	x	2015	1
		15 + 15	x	x	x	x	2016	1
		20 + 10	x	x	x		2014	3
		20 + 20	x		x	x	2014	4
		20 + 20		x	x	x	2015	4
B39	B39	20+10	x		x		2014	1
		20+10		x	x		2015	1
B 41	B 41	20 + 10	x	x	x		2016	1
		20 + 20	x		x	x	2014	2
		20 + 20		x	x	x	2015	2
B 42	B 42	15 + 15	x	x	x	x	2014	2
		20 + 10	x			x	2015	1
		20 + 20	x	x	x	x	2014	8
B 43	B 43	20 + 20	x	x		x	2014	1
		20 + 20	x	x	x	x	2015	4
B38	B40	20 + 10	x	x		x	2015	2
		20 + 20	x	x		x	2015	2
B 40	B 41	20 + 10	x	x			2016	2
		20 + 20	x	x			2016	2
B 40	B 43	20 + 20	x	x			2016	1
B 41	B 39	20 + 20	x		x		2014	1
		20 + 20		x	x		2015	1
B 42	B 41	20 + 10	x			x	2016	1

Table 1-3: Summary of the CA requirement of GTI Operators (2CC cases)

E-UTRA Band No.			Bandwidth [MHz]	DL / UL (1)		C / NC (2)		Year (3)	Number of operators
Band A	Band B	Band C	(BA+BB+BC)	DL	UL	C	NC		
B 40	B 40	B 40	20 + 20 + 20	x		x		2015	1
			20 + 20 + 20		x	x		2016	1
			20 + 20 + 10	x		x		2015	1
			20 + 20 + 10		x	x		2016	1
B 42	B 42	B 42	20 + 20 + 20	x	x	x		2015	3
B 43	B 43	B 43	20 + 20 + 20	x		x	x	2016	1
B40	B40	B38	10 + 20 + 20	x	x	x	x	2015	1
			20 + 20 + 20	x	x	x	x	2016	1
B 41	B 38	B 38		x	x	x		2015	1
B 41	B 41	B 39	20 + 20 + 20	x		x		2015	1
			20 + 20 + 20		x	x		2016	1
B 41	B 41	B 41	20 + 20 + 20	x		x		2015	1
			20 + 20 + 20		x	x		2016	1
B 41	B 39	B 39	20 + 20 + 10	x		x		2015	1
			20 + 20 + 10		x	x		2016	1
B 42	B 42	B 43	20 + 20 + 20	x	x	x		2016	1

(1) Downlink (DL) or Uplink (UL)

(2) Contiguous (C) or Non-Contiguous (NC)

Table 1-4: Summary of the CA requirement of GTI Operators (3CC cases)

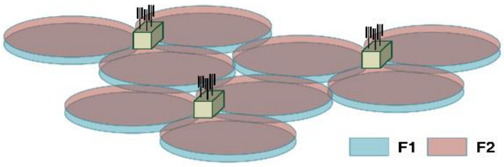
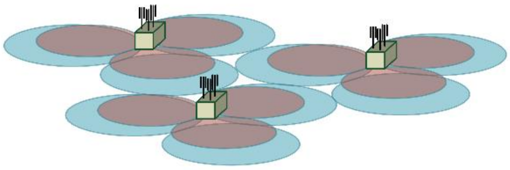
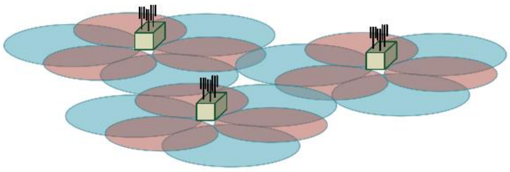
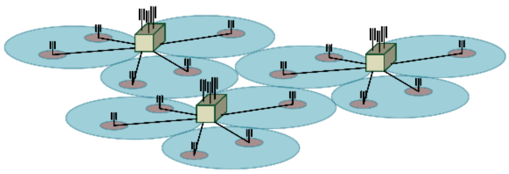
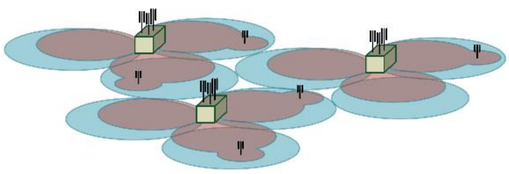
E-UTRA Band No.	Carrier combination	DL / UL (1)		C / NC (2)		Year (3)	Number of operators
		DL	UL	C	NC		
B 40	4 * 20 MHz	x	x	x		2016	1
B 42	4 * 20 MHz	x	x	x	x	2016	3
B 43	4 * 20 MHz	x	x	x		2016	2
B42+B42+B43+B43	20+20+20+20 MHz	x	x	x	x	2017	1
B 40	5 * 20 MHz	x	x	x		2016	1
B39+B41+B41+B41	20+20+20+20 MHz	x		x		2016	1
	20+20+20+20 MHz		x	x		2017	1
B39+B39+B41+B41	20+10+20+20 MHz	x		x		2016	1
	20+10+20+20 MHz		x	x		2017	1
B38+B40+B40+B40	20+20+20+20 MHz	x	x	x	x	2017	1
B39+B39+B41+B41+B41	20+10+20+20+20 MHz	x		x		2017	1
	20+10+20+20+20 MHz		x	x		2018	1
B 42	5 * 20 MHz	x	x	x	x	2017	2

(1) Downlink (DL) or Uplink (UL)
(2) Contiguous (C) or Non-Contiguous (NC)
(3) Planned year for the earliest operator(s)

Table 1-5: Summary of the CA requirement of GTI Operators (4&5CC cases)

1.4. The main usage scenarios of CA

Some of the potential deployment scenarios of CA are summarised in 3GPP TS 36.300 [1]. In this 3GPP document, following 5 scenarios are described.

#	Description	Example
1	F1 and F2 cells are co-located and overlaid, providing nearly the same coverage. Both layers provide sufficient coverage and mobility can be supported on both layers. Likely scenario is when F1 and F2 are of the same band, e.g., 2.6 GHz etc. It is expected that aggregation is possible between overlaid F1 and F2 cells.	
2	F1 and F2 cells are co-located and overlaid, but F2 has smaller coverage due to larger path loss. Only F1 provides sufficient coverage and F2 is used to improve throughput. Mobility is performed based on F1 coverage. Likely scenario when F1 and F2 are of different bands, e.g., F1 = {2.6 GHz} and F2 = {1.9 GHz}, etc. It is expected that aggregation is possible between overlaid F1 and F2 cells.	
3	F1 and F2 cells are co-located but F2 antennas are directed to the cell boundaries of F1 so that cell edge throughput is increased. F1 provides sufficient coverage but F2 potentially has holes, e.g., due to larger path loss. Mobility is based on F1 coverage. Likely scenario is when F1 and F2 are of different bands, e.g., F1 = {2.6 GHz} and F2 = {1.9 GHz}, etc. It is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps.	
4	F1 provides macro coverage and on F2 Remote Radio Heads (RRHs) are used to improve throughput at hot spots. Mobility is performed based on F1 coverage. Likely scenarios are both when F1 and F2 are DL non-contiguous carrier on the same band, e.g., 2.6 GHz, etc. and F1 and F2 are of different bands, e.g., F1 = {2.6 GHz} and F2 = {1.9 GHz}, etc. It is expected that F2 RRHs cells can be aggregated with the underlying F1 macro cells.	
5	Similar to scenario #2, but frequency selective repeaters are deployed so that coverage is extended for one of the carrier frequencies. It is expected that F1 and F2 cells of the same eNB can be aggregated where coverage overlaps.	

Note: In 3GPP Rel-10, for the uplink, the focus is laid on the support of intra-band CAs (e.g. scenarios #1, as well as scenarios #2 and #3 when F1 and F2 are in the same band). Scenarios related to uplink inter-band CA are supported from Rel-11. For the downlink, all scenarios should be supported in Rel-10.

Table 1-6: CA Deployment Scenarios (F2 > F1). (Source: 3GPP TS 36.300)

At the initial network deployment phase, CA would be used to increase coverage area capacity and throughput. The most common scenario among GTI Operators for this objective should be the intra-band CA in scenario #1. Carriers F1 and F2 could be contiguous or non-contiguous but the most of the actual introduction scenarios would be the contiguous case. Many operators have a wide spectrum in bands 41, 42 and 43. In these bands, introduction of intra-band contiguous or non-contiguous CA should be the good solution to provide high-speed, high-performance network to their customer. Inter-band CA in scenarios #1 or #2 would also be common usage scenario because existing band allocations to an individual operator often consists of spectrum fractions in various frequency bands. The CA feature will allow flexible use of diverse spectrum allocations available in an operator network.

Heterogeneous Network is one of the solution to improve hotspot performance. After the initial network deployment, operators will suffer from high traffic area and should improve hotspot area capacity. CA is also applicable to improve hotspot performance (scenario #4). In this scenario, cross-carrier scheduling is also introduced to improve PDCCH performance.

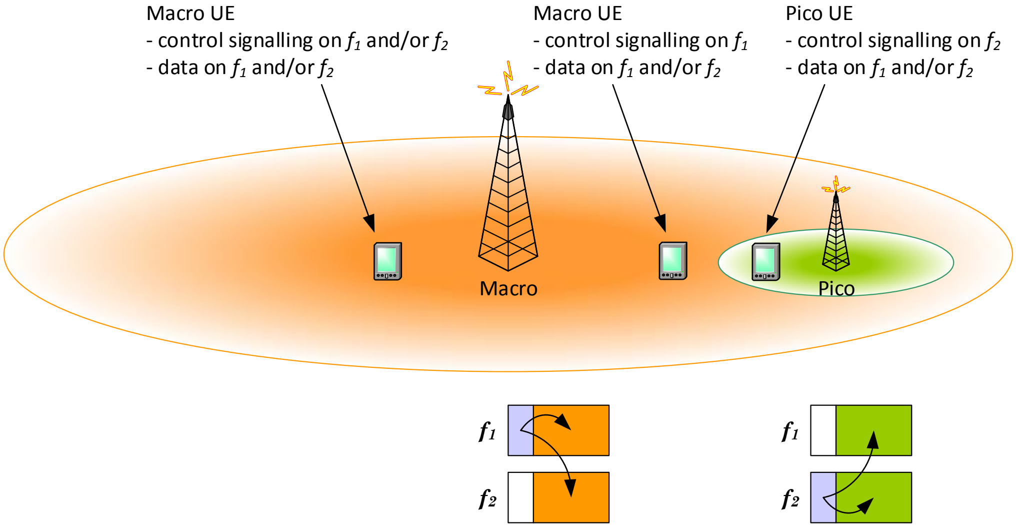


Figure 1-2: Application of CA and cross-carrier scheduling in the HetNet configuration

Above considerations are mainly for downlink CA. Demands for uplink CA would not be so high for a while because LTE/LTE-Advanced has high uplink capacity. However, as an asymmetric nature of data traffic, operator will allocate more capacity to downlink in TDD network. Therefore, once the network became highly loaded and real-time traffic such as VoLTE service is introduced, operator may suffer from uplink resource shortage. In this case, uplink CA could become a solution to enhance uplink performance.

References

[1] 3GPP, TS 36.300 V12.2.0 (2014-06), Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description; Stage 2 (Release 12).

2. Principles of the CA technique and technical advantages

2.1. CA principles

Principles for LTE-A CA:

- A CA UE can be allocated resources on up to five CCs in uplink and downlink, and each carrier has a maximum of 20 MHz bandwidth.
- A CA UE supports asymmetric CA. The number of aggregated carriers can be different in downlink and uplink. However, the number of uplink CCs is never larger than the number of downlink CCs.
- The frame structure of each CC is the same as that in 3GPP Release 8 for the purpose of backward compatibility.
- The carrier aggregation can be performed between carrier in the same frequency band, i.e., intra-band carrier aggregation and carrier in different frequency bands, i.e., inter-band carrier aggregation.
- Carriers used for aggregation in 3GPP Release 10 are Release8 / Release9 compatible carriers. A Release8 / Release9 UE can transmit or receive data over any aggregated carrier.

CA service procedures:

- For a CA UE to access the network, after an RRC connection is established in a cell, the cell is regarded as the primary cell (PCell) of this UE.
- Operators may require that a certain carrier be preferentially configured as a primary component carrier (PCC). To meet this requirement, a PCC-oriented carrier priority parameters are configured in the eNodeB. In most cases, a low-band carrier is set to the PCC-oriented highest-priority carrier, which is known as the PCC anchor. This setting reduces handovers, improves service continuity, and thereby, enhances user experience.
- If a UE reports its CA capability during initial network access, the eNodeB checks whether the used carrier is the preset PCC-oriented highest-priority carrier after RRC connection establishment. If the access carrier is different to PCC-oriented

highest-priority carrier, the eNodeB instructs the UE to measure the highest-priority carrier and try to hand over to it.

The CA service procedure is described in Figure 2-1:

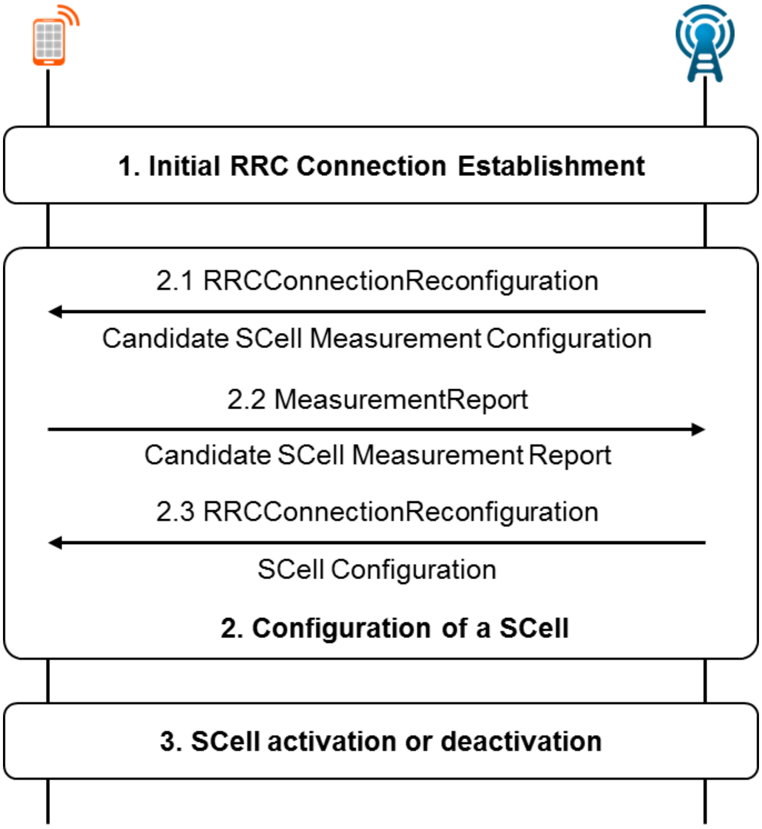


Figure 2-1 CA service procedures

1. An initial RRC connection is established in a cell, which is then regarded as the PCell of the UE.
2. The eNodeB instructs the UE to measure other candidate cells in the coverage overlay area. Based on the measurement result, the eNodeB determines the cell that can be used as a secondary cell (SCell) and then sends an RRC Connection Reconfiguration message to configure the SCell for the UE.
3. The eNodeB activates or deactivates the SCell via MAC signaling.

The SCell of a CA UE has three possible states as described in Figure 2-2:

- Configured but deactivated
- Configured and activated
- Unconfigured

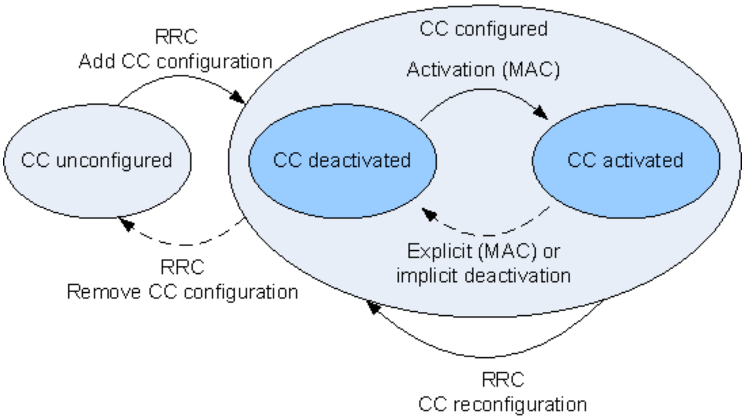


Figure 2-2 CA State Diagram

Event A4-based measurement may be used as criteria to add a SCell. And event A2-based measurement may be as criteria to remove an existing SCell.

Once the SCell is configured, eNodeB may activate or deactivate it based on the buffer data amount, system load, or other criteria.

2.2. Technical advantages of the CA technique

CA technique provides the following benefits:

- **Higher peek data rate**

Depending on how many component carriers are aggregated, CA can increase up to 5-time single user peak date rate.

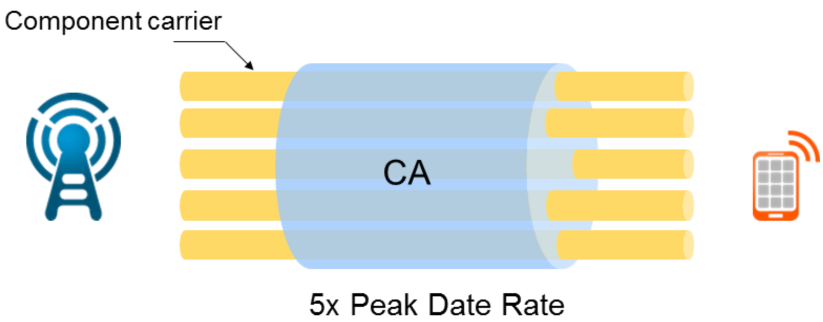


Figure 2-3 Illustration of carrier aggregation

Driving test throughput is significantly improved by CA in the trial network of Operator C.

Following Figure 2-4 shows the testing result comparison between 20MHz+20MHz CA and normal 20MHz Carrier under band 41, i.e., 2.6GHz.

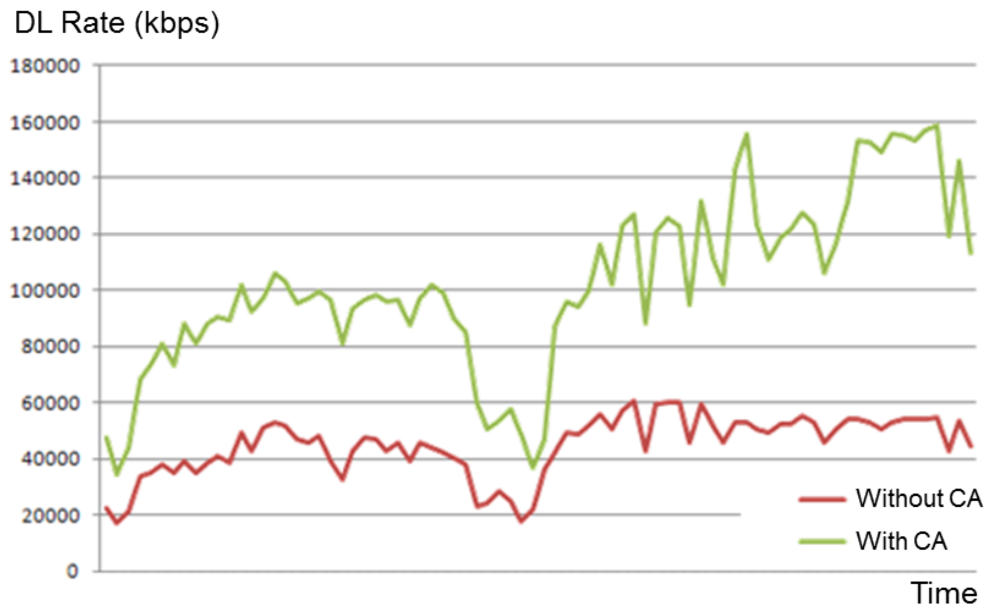


Figure 2-4 Driving Test Comparison CA vs. w/o CA

- **Effective utilization of fragmented radio resource blocks**

In condition that traffic load is different between carriers, congestion may occur in one carrier while the others still has spare RBs not being allocated. In this particular TTI (transmission time interval), Release8 / Release9 system would waste part of radio resources. But in Release10 with CA enabled, the spare resources can be used as second component carrier to increase data rate of the user under the busy carrier, hence to improve the RB usage and total network spectrum efficiency.

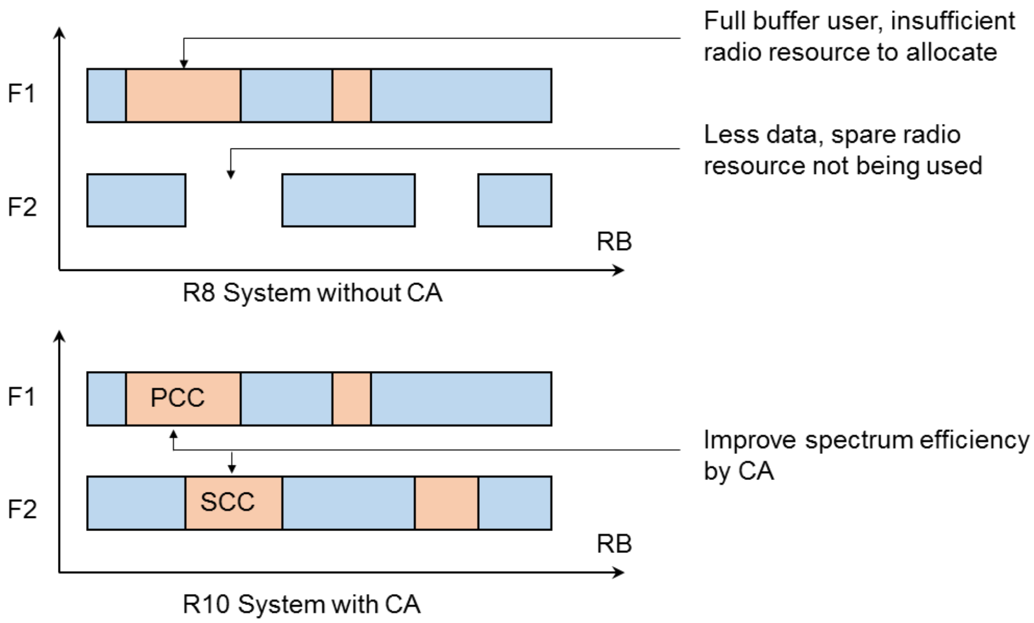


Figure 2-5 RB Utilization Principle CA vs. w/o CA

By simulation under scenario 20MHz+20MHz intra-band CA, 19 sites, 3 cells per site, 10 users per cell, 2x2 MIMO, and full buffer traffic, it shows that after enabling CA, about 70% of the total cells which are busy before with over 90% RB usage, become less loaded. While the remaining 30% non-busy cells become busier. That means CA algorithm does force the busy cells to transmit data via RBs on component carrier.

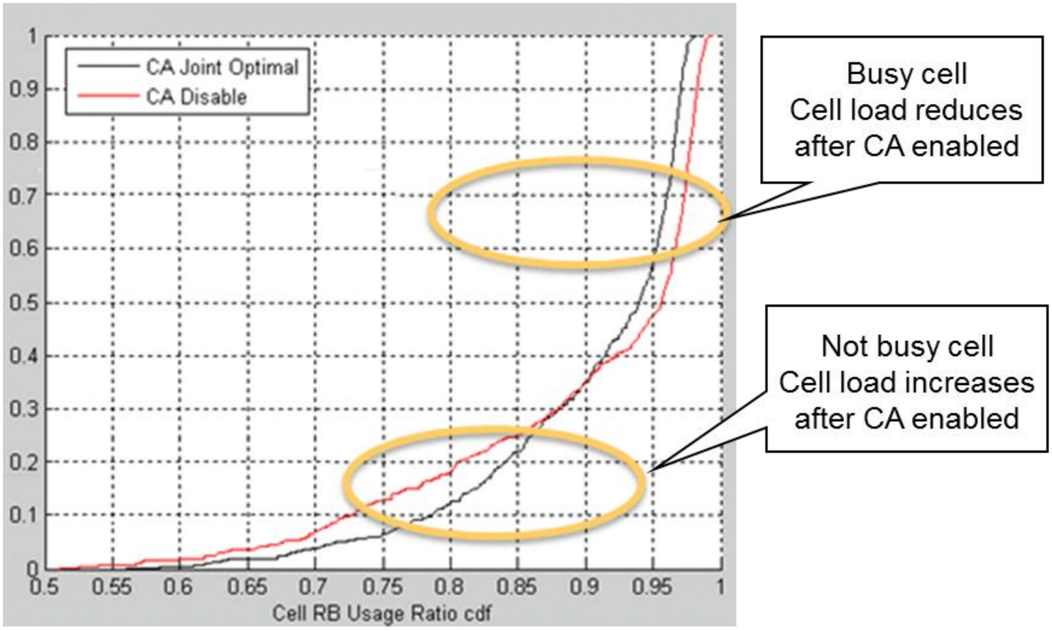


Figure 2-6 RB Utilization CDF CA vs. w/o CA

- **Cell throughput expanding**

By joint scheduling among component carriers, for a single user there will have more resource blocks to allocate. That means there will be more frequency diversity gain and improve cell average throughput and edge user's throughput.

By simulation under scenario 20MHz+20MHz intraband CA, 19 sites, 3 cells per site, 10 users per cell, 2x2 MIMO, and full buffer traffic, it is estimated that CA improves 10% cell average throughput and 15% edge user throughput (Table 2-1).

	Cell Average		Cell Edge	
	Mbps	Gain	Mbps	Gain
CA Disable	18.89	-	1.31	-
CA Enable	20.81	10.2%	1.51	15.3%

Table 2-1 Cell Throughput Comparison CA vs. w/o CA

- **Quick load balancing**

Radio resources of component carriers are available for a CA UE, so that the data can be scheduled on either CC at each TTI. This quick and flexible scheduling would help to maintain the load balance among component carriers.

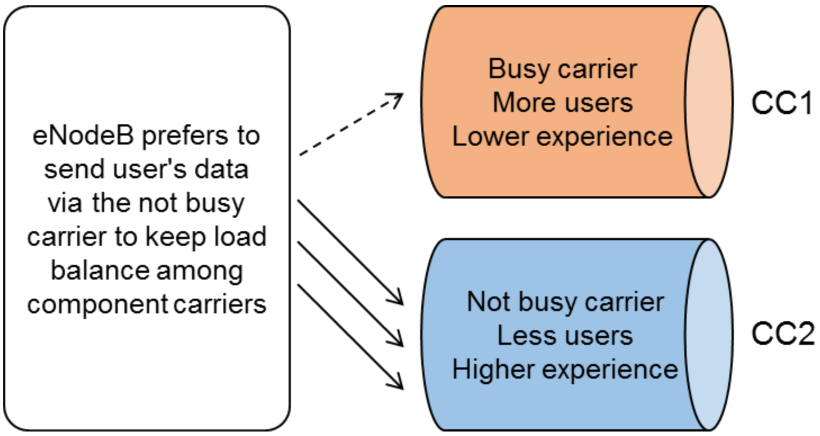


Figure 2-7 CA Load Balancing Principle

Compared to MLB, load balancing by CA is more efficient and quick (Table 2-2).

	MLB	CA
Adjustment period	Minute level	Millisecond level
Method	Handover	MAC scheduling
Signaling number	10+ RRC messages	0 RRC message
Time Delay	Large	Small
Impact on user	Fluctuant	No impact

Table 2-2 Technical Comparison CA vs. MLB

- **Control channel improvement**

The eNodeB may send a scheduling grant on one CC for scheduling the user on another CC. This is referred to as cross-CC scheduling as the scheduling grant and the corresponding data transmission takes place on different CCs. That means even if PDCCH in one CC is congested the user can also be granted via others. It may also be a way of control channel load balancing, which offers flexibility for choosing suitable grant on either CC depending on PDCCH load and interference conditions, and bring further performance gain on control channel capacity.

- **Improve user experience**

As per typical traffic module, service burst occurs randomly. CA UE has a high probability to occupy multiple carriers' bandwidth, which brings instantaneous capacity gain. So that service response delay could be shortened and user experience can be improved.

3. The requirements and technique roadmap of TD-LTE Carrier Aggregation

The requirements and technique roadmap can be various among different operators because of the different frequency resource allocation and development strategy of different region and operators. To promote the progress of system and terminal industry for carrier aggregation (CA), it is very important to summarize and classify the requirements and roadmap of the operators.

In this chapter, the current status of standardization and industry is introduced firstly. Then the annual technique roadmap for downlink CA and uplink CA is shown respectively, aiming to give a whole picture of the requirements and time schedule of CA.

3.1. Introduction of current Standardization Status

In this section, the completed and ongoing carrier aggregation standardizations are introduced. The 2CC carrier aggregation standardizations which are demanded have almost been completed, and most of the 3CC carrier aggregation standardizations are ongoing.

Take intra-band contiguous CA as an example, 3GPP has completed the standardization of CA_38C, CA_39C, CA_40C, and CA_41C. In case of intra-band non-contiguous CA, CA_41C-41C has been supported by 3GPP standardization. What’s more, inter-band CA_39A-41A has already supported by standardization and chipset. As for other 2CC cases, intra-band contiguous CA_42C, intra-band non-contiguous CA_41C-41A, CA_42A-42A and inter-band CA_41A-42A are ongoing now. The detailed information is listed as follows.

<table>
<tr><th rowspan="2">E-UTRA CA configuration</th><th colspan="2">Component carriers in order of increasing carrier frequency</th><th rowspan="2">Maximum aggregated bandwidth [MHz]</th><th rowspan="2">Bandwidth combination set</th></tr>
<tr><th>Allowed channel bandwidths for carrier [MHz]</th><th>Allowed channel bandwidths for carrier [MHz]</th></tr>
<tr><td rowspan="2">CA_38C
（2570-2620）</td><td>15</td><td>15</td><td rowspan="2">40</td><td rowspan="2">0</td></tr>
<tr><td>20</td><td>20</td></tr>
<tr><td>CA_39C
（1880-1920）</td><td>5,10,15</td><td>20</td><td>35</td><td>0</td></tr>
<tr><td>CA_40C</td><td>10</td><td>20</td><td>40</td><td>0</td></tr>
</table>

（2300-2400）	15	15		
	20	10, 20		
CA_41C （2496-2690）	10	20	40	0
	15	15, 20		
	20	10, 15, 20		

Table. 3-1 Summary of completed standardization of Intra-band contiguous CA

E-UTRACA configuration	Component carriers in order of increasing carrier frequency		Maximum aggregated bandwidth [MHz]	Bandwidth combination set
	Allowed channel bandwidths for carrier [MHz]	Allowed channel bandwidths for carrier [MHz]		
CA_41A-41A	10, 15, 20	10, 15, 20	40	0

Table. 3-2 Summary of completed standardization of Intra-band non-contiguous CA

E-UTRA CA Configuration	E-UTRA Bands	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Maximum aggregated bandwidth [MHz]	Bandwidth combination set
CA_39A-41A	39				Yes	Yes	Yes	40	0
	41						Yes		
CA_41A-42A	41				Yes	Yes	Yes	40	0
	42				Yes	Yes	Yes		

Table. 3-3 Summary of completed standardization of Inter-band CA

Considering the implementation complexity and industry requirements, 3CC carrier aggregation standardizations started from last year. Most of 3CC standardizations are ongoing when writing this white paper, for example, intra-band contiguous CA_40D, CA_41D, intra-band non-contiguous CA_41C-41C and inter-band CA_39A-41C. The detailed information is listed as follows.

E-UTRA CA configuration	Component carriers in order of increasing carrier frequency			Maximum aggregated bandwidth [MHz]	Bandwidth combination set
	Allowed channel bandwidths for carrier [MHz]	Allowed channel bandwidths for carrier [MHz]	Allowed channel bandwidths for carrier		

CA_40D (3DL)	10, 20	20	20	60	0
	20	10	20		
	20	20	10		
CA_41D (3DL)	20	15, 20	10	60	0
	20	10, 15, 20	15		
	20	10, 15, 20	20		
	……	……	……		
CA_42C	5, 10, 15, 20	20		40	0
	20	5, 10, 15			

Table. 3-4 Summary of ongoing standardization of Intra-band contiguous CA

E-UTRACA configuration	Component carriers in order of increasing carrier frequency		Maximum aggregated bandwidth [MHz]	Bandwidth combination set
	Allowed channel bandwidths for carrier [MHz]	Allowed channel bandwidths for carrier [MHz]		
CA_41A-41C (3DL)	5, 10, 15, 20	See Table 5.2A.1-1 in TS 36.101	60	0
CA_41C-41A	See Table 5.2A.1-1 in TS	5, 10, 15, 20	60	0
CA_42A-42A	5, 10, 15, 20	5, 10, 15, 20	40	0

Table. 3-5 Summary of ongoing standardization of Intra-band non-contiguous CA

E-UTRA CA Configuration	E-UTRA Bands	1.4 MHz	3 MHz	5 MHz	10 MHz	15 MHz	20 MHz	Maximum aggregated bandwidth [MHz]	Bandwidth combination set
CA_39A-41A-41A (3DL)	39				Yes	Yes	Yes	60	0
	41						Yes		
CA_41A-42A-42A	41				Yes	Yes	Yes	60	0
	42				Yes	Yes	Yes		

Table. 3-6 Summary of ongoing standardization of Inter-band CA

Finally, it should be highlighted that the capability of these carrier aggregation is release independent, which is referenced in TS36.307.

3.2. **Standardization Roadmap**

Considering the standardization progress and products implementation complexity, the earliest time for the same number of component carrier products may be one year after finishing standardization.

As mentioned in section 3.4, the deployment time of 2CC intra-band CA_40C is 2014 and 2015, and the standardization has been finished now. Other detailed description of deployment time schedule of intra-band CA is given in section 3.4.

Similarly, inter-band CA_39A-41C may be supported in standardization this year, if operator X wants to deploy the network in 2015. More detailed information on annual deployment roadmap of inter-band carrier aggregation is given in section 3.5.

3.3. Introduction of Current Industry status

In this section, the current industry status is analyzed from the aspect of system industry, terminal industry and lab verification. The current development of system equipment and terminal equipment focus on downlink 40M intra-band CA in band 40/41, inter-band CA in band 39 plus band 41 and 30M intra-band CA in band 39 scenario.

In the following, the vendor which can support each feature is listed respectively. For the vendors which cannot support the feature now, the potential time schedule is also shared.

3.3.1. System Industry

For downlink CA, plenty of carrier combinations can be supported by most of the major vendors. The progress for uplink CA is not as well as the downlink case. Only two vendors can support 40M uplink CA currently. The details are list in the following:

- For downlink 40M intra-band CA in band40/41, all the major system vendors can support this feature. In addition, the testing and verification for this scenario has been completed.
- For downlink 40M inter-band CA in band 39 plus band 41, four system vendors can already support this feature. The other system vendors can support this feature in 2014 Q3 by estimate.
- For downlink 30M intra-band CA in band 39, major system vendors can support this feature in 2014H2.
- For UL 40M intra-band CA, three vendors can support this feature.

3.3.2. Terminal Industry

The development situation of terminal industry is similar to system industry, i.e., the progress of downlink CA is much faster than the progress of uplink CA. The details are as follows:

- For downlink 40M intra-band CA in band40/41, chips from three vendors can support this feature.
- For downlink 40M inter-band CA in band 39 plus band 41, chips from two vendors can support this feature.
- For downlink 30M intra-band CA in band 39, one vendor can support this feature.
- For UL 40M intra-band CA, one vendor can support this feature

3.3.3. Technique Verification

The testing and verification work includes the lab testing and field testing. The concrete progress is shown below:

- IOT testing for downlink transmission between all system vendors and the three chip vendors is ongoing in the lab.
- All the system equipment vendors has been finished verification and testing in the lab for downlink 40M intra-band CA in band 41/40 respectively. The peak data rate can reach 220 Mbps with 3DL:1UL time configuration and 10:2:2 special subframe structure. The mobility and Scell activated and deactivated capability has been verified. All the system vendors should finish field testing by the end of this year mainly for intra-band CA in band 41/40/39 and inter-band CA between band 41 and band 39.

3.4. Requirement Roadmap of intra-band Carrier Aggregation

Generally speaking, intra-band CA is easier to be implemented than inter-band CA. So for most of the operators, intra-band CA is considered as the first step for CA, i.e., no later than inter-band CA. So the requirements of intra-band CA is basic and important to promote the CA industry.

In this section, the technique requirement, i.e., number of component carrier, continuous/non-continuous CA and time schedule for the requirements is released for downlink CA and uplink CA respectively based on our latest survey results in last GTI meeting among the member operators. In this survey, the earliest time to support each CA scenario is investigated among the operators, which can express the requirement of the operators and provide a reference to the system and terminal industry

The aggregated bandwidth can range from 30M to 100M by the using of intra-band CA, which can significantly increase the peak data rate and network KPI.

The frequency bands related to intra-band CA include band 40, band 41, band 39, band 38, band 42 and band 43. For the number of component carrier, 2CC intra-band carrier aggregation is required in all bands. Other number of component carrier, e.g. 3CC, 4CC and

5CC is required in some of the bands. At most 5CC carrier aggregation is required by some aggressive operators.

3.4.1. Downlink Intra-band Carrier Aggregation

Considering the high traffic load requirement in downlink transmission, downlink CA is considered earlier or no later than uplink CA.

Considering the time schedule for different numbers of component carrier in DL intra-band CA, generally speaking, the number of component carrier will increase by one each year .

In detail, the earliest time for 2CC DL intra-band CA is supposed to be finished in 2014 and the 3CC case is supposed to be finished in 2015 or 2016. For 4CC and 5CC case, since maybe the current plan is not very clear in the operators, only some of the operators share their plan for the 4CC and 5CC case. The potential time schedule to complete 4CC and 5CC scenario is 2016 and 2016 or 2017 respectively.

3.4.2. Uplink Intra-band Carrier Aggregation

Generally speaking, considering the implementation complexity and traffic load requirement, the implementation of UL CA will be no earlier than DL CA, e.g., one year later than the DL CA case or in the same year of the DL CA case.

In detail, the earliest time schedule for 2CC UL intra-band CA is 2014 or 2015. The 3CC case is considered 2015 or 2016. For the 4CC and 5CC case, the earliest implementation time schedule is 2016 and 2016 or 2017 respectively.

3.4.3. Summary of schedule for DL and UL intra-band CA

The following figure summarize the time schedule to support 2CC CA in each band with different number of component carrier.

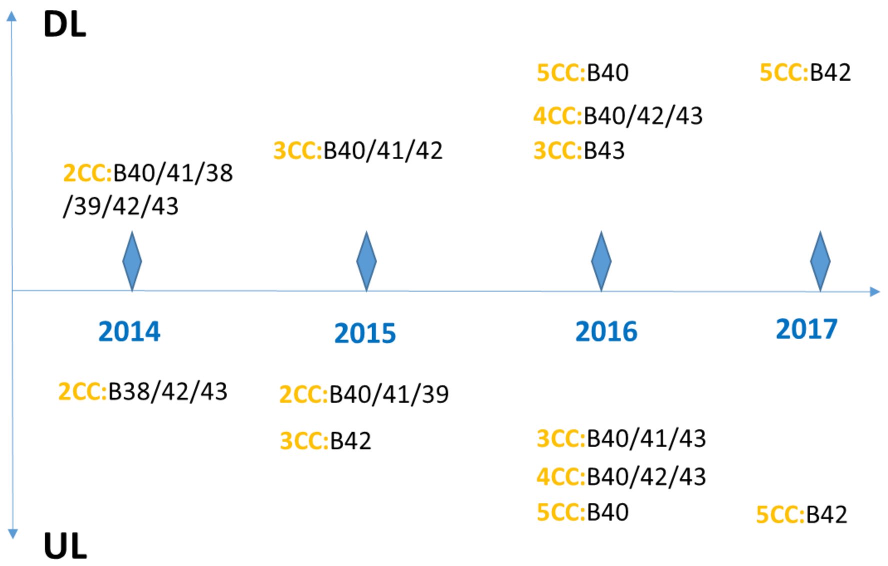


Figure 1. Time schedule to support intra-band CA

In conclusion, based on the survey result among the operators, at least observations can be got:

- The time schedule for intra-band CA range from 2014 to 2017 for 2CC to 5CC case
- 2CC CA is the basic scenario which is required by most of the operators. For the time schedule to support 2CC scenario, the earliest time should be 2014 for DL and 2014 or 2015 for UL.

3.5. Requirement Roadmap of inter-band Carrier Aggregation

On one aspect, the inter-band CA can bring more flexible usage of the frequency band and more frequency selective gain. On the other aspect, inter-band CA also require more implementation complexity. So sufficient frequency band combination is considered and the time schedule for inter-band CA is no earlier than intra-band CA.

The number of component carrier for inter-band CA range from 2CC to 5CC, which can provide 40M to 100M frequency resource.

The combinations of frequency band for inter-band CA include band(39+41), band(40+41), band(40+42), band(40+43), band(41+42), band(42+42+43), band(42+42+43+43), band(42+43) and band(43+41).

3.5.1. Downlink Inter-band Carrier Aggregation

Considering the standardization progress and implementation complexity, the earliest time for the same number of component carrier may be different between different frequency bands.

In detail, 2CC is supposed to provide 40M aggregated frequency resource, which should be deployed in 2014/2015/2016 depends on different frequency band. For the other number of component carrier, some of the operators also provide their plan. For a instance, 2015/2016 is the required time to support 3CC, 2016/2017 is the required time to support 4CC. And even a few operators have the plan to support 5CC case, which is expected to be finished in 2017.

3.5.2. Uplink Inter-band Carrier Aggregation

The situation for UL inter-band CA is similar to the UL intra-band case, i.e., the time schedule to support UL inter-band CA is no earlier than the DL inter-band CA.

In detail, 2CC scenario is supposed to be supported in 2015/2016 depends on the specific frequency band combination. 3CC scenario is expected to be supported in 2016. The earliest time to support 4CC and 5CC scenario should be 2017 and 2018.

3.5.3. Summary of schedule for DL and UL inter-band CA

The following table summarize the time schedule to deploy inter-band CA in each band with different number of component carrier.

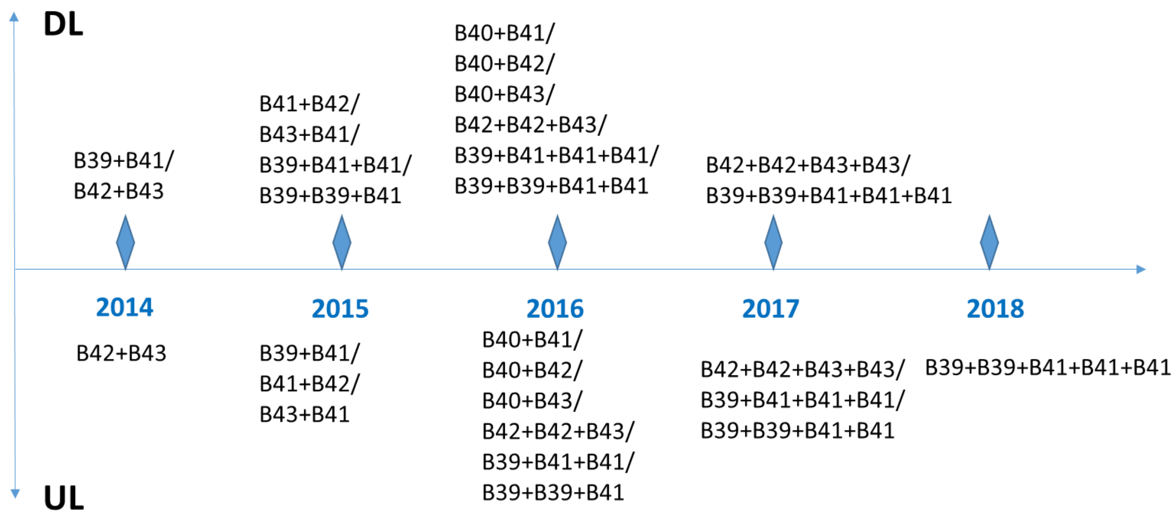


Figure 2. Time schedule to support inter-band CA

Following conclusions can be observed by the above table and analysis:

- The time schedule for inter-band CA range from 2014 to 2018 for 2CC to 5CC case. 2CC scenario is request in most of frequency bands
- At least 9 kinds of combinations of frequency bands should be supported in inter-band CA

3.6. **Priority of frequency band combinations**

Based on the operator feedback summarised in section 1.3, we can analyse the combinations that have the highest interest.

2 Carrier Combinations – Downlink

1. B42+B42 Contiguous
2. B40+B40 Contiguous
3. B41+B41 Contiguous
4. B42+B42 Non-contiguous

There were a number of further combinations requested by more than one operator: B38+ B38 Contiguous; B42+B42 Contiguous; B41+B42; B40+B41 and B38+B40.

2 Carrier Combinations – Uplink

1. B40+B40 Contiguous
2. B41+B41 Contiguous
3. B43+B43 Contiguous

4=. B38+B38 Contiguous

B42+B42 Contiguous

3 Carrier Combinations

Only two combinations were requested by more than a single operator – downlink and uplink contiguous aggregation in B42.

4 Carrier Combinations

Here also only two frequency bands were requested by multiple operators for carrier aggregation – intra-band contiguous aggregation for both downlink and uplink in band 42 and band 43.

5 Carrier Combinations

The only frequency band of interest to more than one operator in this case was Band 42.

4. Summary

Carrier aggregation is a very promising technique which can significantly increase the UE peak rate and network quality. So it can be applied in lots of scenarios to improve the user experience and network performance.

Considering the capability to increase the network performance of CA, most of the operators have requirement to deploy CA in their network. To prompt the deployment of CA, the standardization work, product development, testing and verification work need to be promoted jointly.

Currently, most of the system and terminal vendors have started the development for CA, especially the downlink CA. The development and verification work for system equipment for downlink 40M intra-band CA in band40/41 has been already completed. And several chip vendors have finished the development work for intra-band and inter-band CA in some frequency bands.

In this whitepaper of CA, the spectrum status of operators and CA scenarios are introduced to the current spectrum allocation and possible application scenario of CA. Then principle and advantage of CA is generally explained and analysed. The third chapter shows requirements and technique roadmap of CA, which can guide the development work of system equipment, terminal and testing instrument. For the next step, we should continue to push the system industry, terminal industry and the lad/field test joint to support CA. As for the time schedule for the development of CA in the industry, it could be better that the industry can follow the earliest requirements of the operators so that the requirement roadmap from the operators can be realized.