GTI White Paper

Global TD-LTE Initiative

TD-LTE Carrier Aggregation

WHITE PAPER

V5.1

http://lte-tdd.org/

TD-LTE Carrier Aggregation

WHITE PAPER

Global TD-LTE Initiative

Version:	Draft Version 5.1
Deliverable Type	□ Procedural Document √ Working Document
Confidential Level	√ Open to GTI Operator Members √ Open to GTI Partners □ Open to Public
Working Group	Network WG
Task Force	Carrier aggregation
Contributors	CMCC, Softbank, NOKIA, Huawei, Ericsson, ZTE
Editor	Kenichi Minamisono, Jianhui Zhang, Jianhui Mao, Chunyi Wang, Jingdi Liu, Qun Pan
Last Edit Date	03-02-2016
Approval Date	DD-MM-YYYY

Document History

Date	Meeting #	Version #	Revision Contents
08-07-2014	Kick off teleconference	NA	confirm the agenda & elect the editor
28-08-2014		0.1	Initial document consolidation
06-11-2014		4.0	Addition of prioritisation on band combinations
02-01-2015		4.1	Final updates with additional operator inputs on band combinations
25-02-2015		4.2	Version for Steering Committee approval
31-03-2015		4.3	Version for publication
01-06-2015		4.4	Updates for GTI Shanghai release edition
13-09-2015		4.4bis	Updates merged for team review
24-09-2015		4.5	Final updates for GTI Budapest release edition
05-10-2015		5.0	Version for approval and release
03-02-2016		5.1	Addition of UL CA field verification results

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
DC	Dual Connectivity
HetNet	Heterogeneous Network

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.

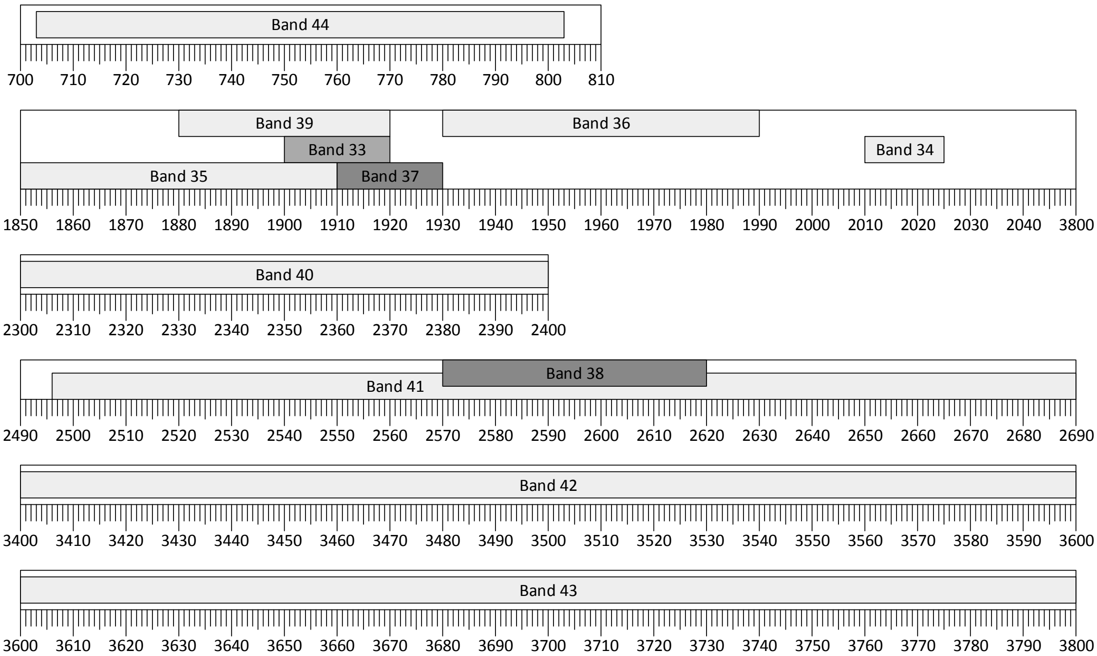


Figure 1-1: E-UTRA TDD band assignment in 3GPP

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	Argentina	DirecTV	Band 43	3.5 GHz
2	Australia	NBN	Band 40	2.3 GHz
3	Australia	Optus	Band 40	2.3 GHz
4	Bahrain	Menatelecom	Band 42	3.5 GHz
5	Belgium	B.lite	Band 42	3.5 GHz
6		On Telecomunicacoes	Band 38	2.6 GHz
7		SKY Brasil Services	Band 38	2.6 GHz
8	Canada	ABC Communications	Band 42	3.5 GHz
9	Canada	Sasktel	Band 42	3.5 GHz
10	China	China Mobile	Band 39, 40, 41	1.9/2.3/2.6 GHz
11		China Telecom	Band 40, 41	2.3/2.6 GHz
12		China Unicom	Band 40, 41	2.3/2.6 GHz
13	Colombia	DirecTV	Band 41	2.6 GHz
14	Cote d'Ivoire	YooMee	Band 40	2.3 GHz
15	Hong Kong, China	China Mobile Hong Kong	Band 40	2.3 GHz
16	India	Bharti Airtel	Band 40	2.3 GHz
17	Indonesia	PT Internux	Band 40	2.3 GHz
18	Japan	UQ Communications	Band 41	2.6 GHz
19		Wireless City Planning	Band 41	2.6 GHz
20	Nigeria	Spectranet	Band 40	2.3 GHz
21		Swift Networks	Band 40, 42	2.3/3.5 GHz
22	Oman	Omantel	Band 40	2.3 GHz
23	Peru	DirecTV	Band 40	2.3 GHz
24	Philippines	PLDT	Band 42	3.5 GHz
25	Poland	Aero2	Band 38	2.6 GHz
26	Russia	Megafon	Band 38	2.6 GHz
27		MTS	Band 38	2.6 GHz
28		Vainakh Telecom	Band 40	2.3 GHz
29	Saudi Arabia	Mobily	Band 38	2.6 GHz
30	Saudi Arabia	STC	Band 40	2.3 GHz
31	South Africa	Telkom Mobile(8ta)	Band 40	2.3 GHz
32	Spain	COTA /Murcia4G	Band 38	2.6 GHz
33	Spain	Neo-Sky	Band 42	3.5 GHz
34	Spain	Vodafone	Band 38	2.6 GHz
35	Sri Lanka	Dialog Axiata	Band 40	2.3 GHz
36		Lanka Bell	Band 40	2.3 GHz
37		SLT	Band 38	2.6 GHz
38	Sweden	Hi3G	Band 38	2.6 GHz
39	Uganda	MTN	Band 38	2.6 GHz
40	UK	UK Broadband	Band 42, 43	3.5/3.7 GHz
41	USA	Sprint	Band 41	2.6 GHz
42	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	4
		20 + 20	x		x	x	2014	4
		20 + 20		x	x	x	2015	4
B 39	B 39	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	B 40	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
		20 + 20	x	x	x		2015	2
B 42	B 43	20 + 20	x	x			2014	1
B 43	B 41	20 + 20	x	x			2015	1

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

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

(3) Planned year for the earliest operator(s)

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
B 40	B 40	B 38	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)

(3) Planned year for the earliest operator(s)

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		
B40	4 * 20 MHz	x	x	x		2016	1
B42	4 * 20 MHz	x	x	x	x	2016	3
B43	4 * 20 MHz	x	x	x		2016	2
B42+B42+B43+B43	20+20+20+20 MHz	x	x	x	x	2017	1
B40	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
B42	5 * 20 MHz	x	x	x	x	2017	2

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

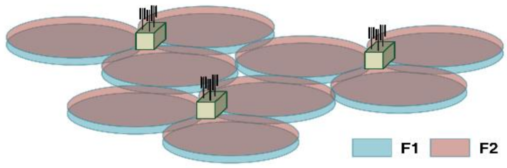
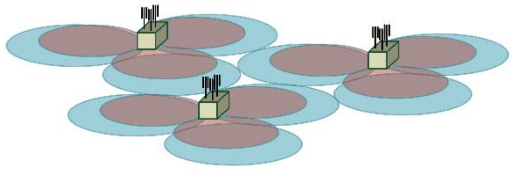
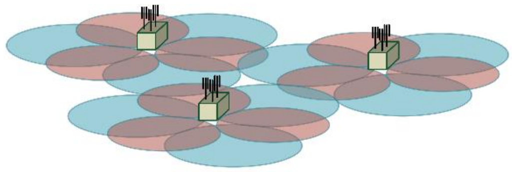
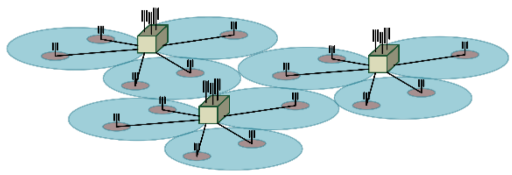
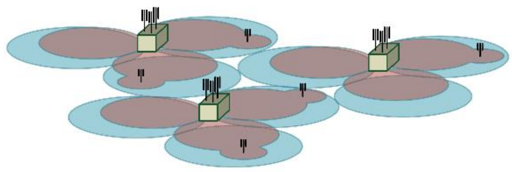
(2) Contiguous (C) or Non-Contiguous (NC)

(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 GHz, 800 MHz, 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 = {800 MHz, 2 GHz} and F2 = {3.5 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 = {800 MHz, 2 GHz} and F2 = {3.5 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., 1.7 GHz, etc. and F1 and F2 are of different bands, e.g., F1 = {800 MHz, 2 GHz} and F2 = {3.5 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.

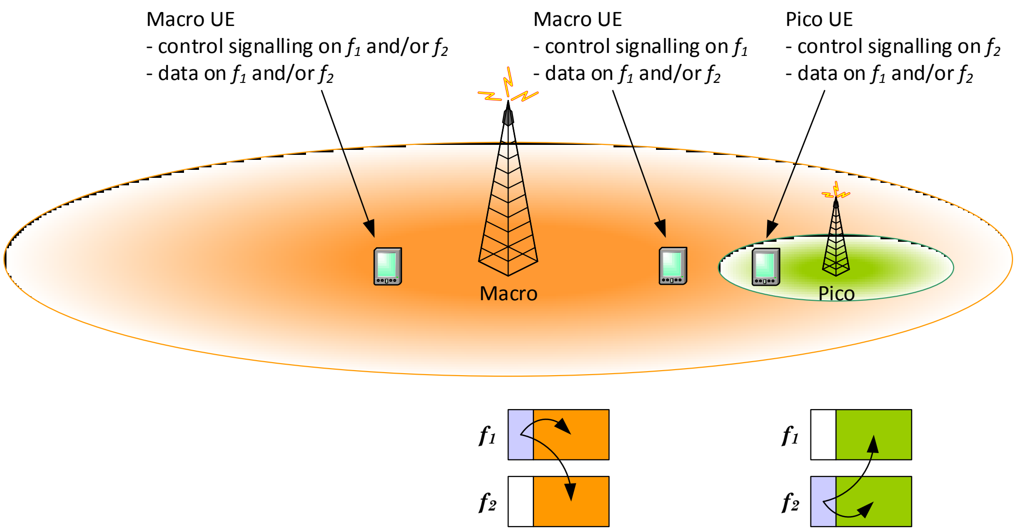


Figure 1-2: Application of CA and cross-carrier scheduling in the HetNet configuration

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.

For small cell network and/or Heterogeneous Network (HetNet), Dual Connectivity (DC) seems to be one of the attractive technologies. DC extends CA and coordinated multi-point (CoMP) to inter-eNB with non-ideal backhaul, and 3GPP is now working hard to develop specifications for this technology. In this whitepaper DC is briefly reviewed in section 5 as an alternative approach to CA.

To adapt the traffic needs in a specific cell areas, Dynamic TDD technology has begun attracting a great deal of attention. By using Dynamic TDD technology, we could improve resource utilization efficiency in TDD system. This technology is briefly introduced in section 6.

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

In the previous section it was mentioned that two or more Component Carriers (CCs) can be aggregated in order to support wider transmission bandwidths that in turn will enable a more efficient usage of resources as well as an improved in customer user experience and enhanced network performance. In the section carrier aggregation principles and technical advantages are presented in detail.

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:

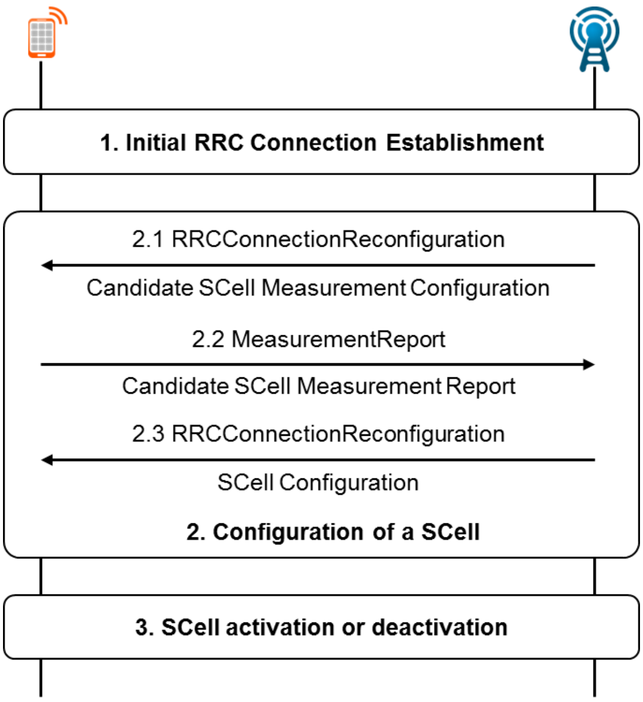


Figure 2-1: CA service procedures

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 signalling.

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

- Configured but deactivated
- Configured and activated
- Unconfigured

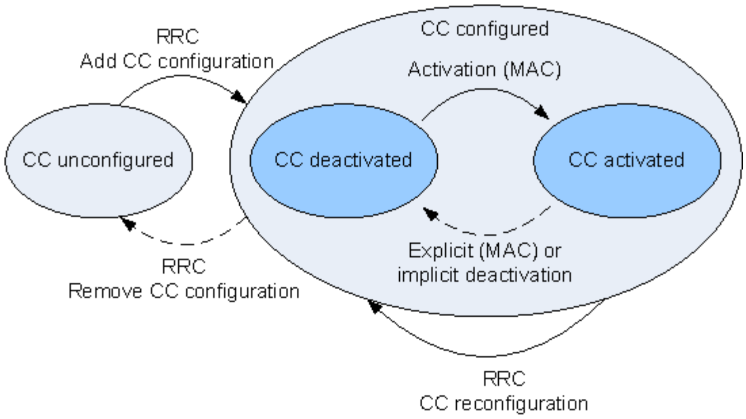


Figure 2-2: CA State Diagram

Event A4-based measurement (Neighbour becomes better than threshold) may be used as criteria to add a SCell. And event A2-based measurement (Serving becomes worse than threshold) 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.

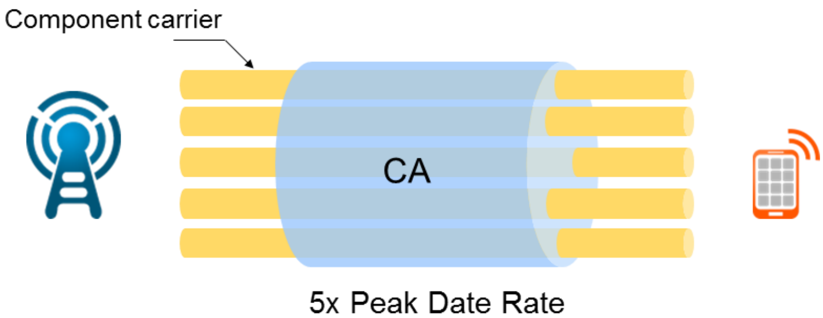


Figure 2-3: Illustration of carrier aggregation

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.

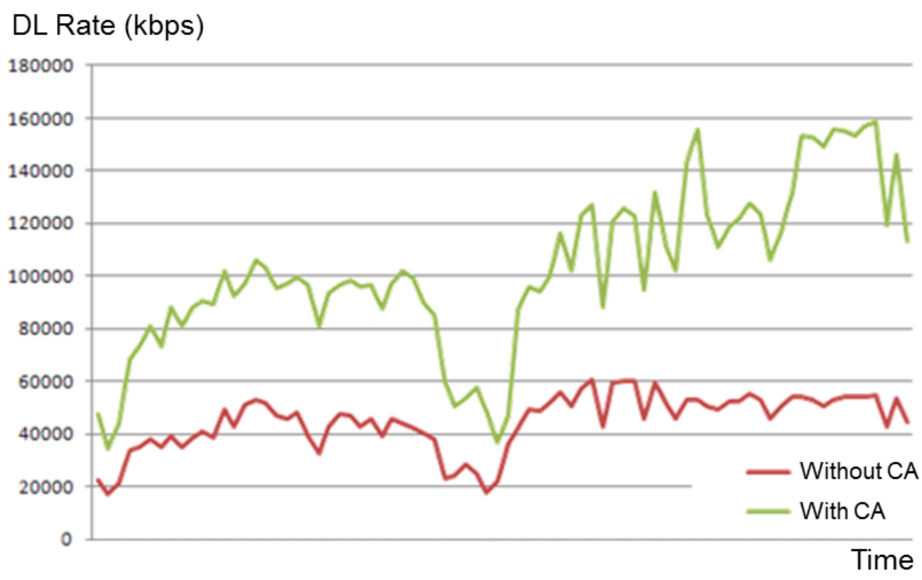


Figure 2-4: Driving Test Comparison CA vs. w/o CA

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

In case the traffic load is different between carriers, congestion may occur in one carrier while the others still have spare resource blocks not being allocated. In this particular TTI (transmission time interval), Release8 / Release9 system would waste part of radio resources. However, 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.

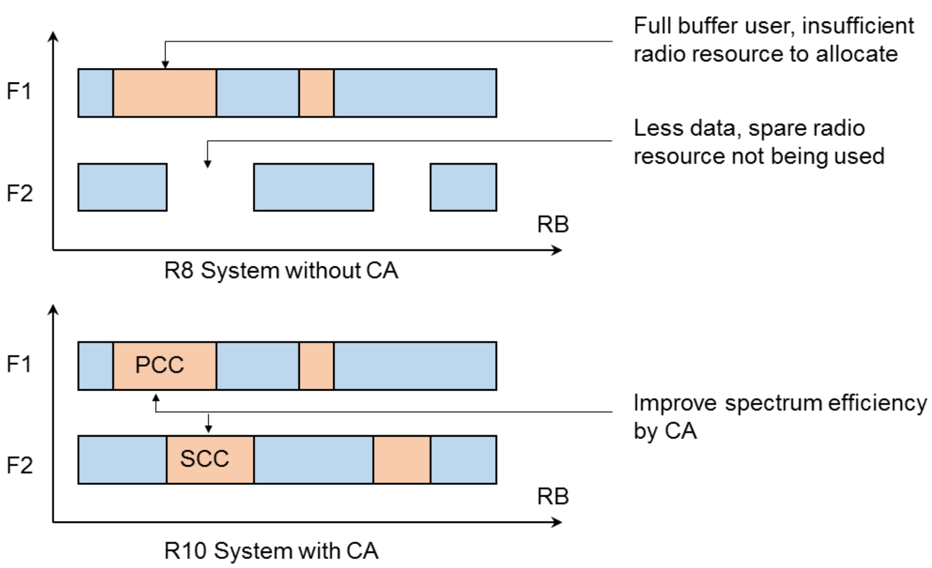


Figure 2-5: RB Utilization Principle CA vs. w/o CA

Simulations of 20MHz+20MHz intra-band CA, in 19 sites, 3 cells per site, 10 users per cell, 2x2 MIMO, and full buffer traffic, it can be seeing that after CA is enabled, 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.

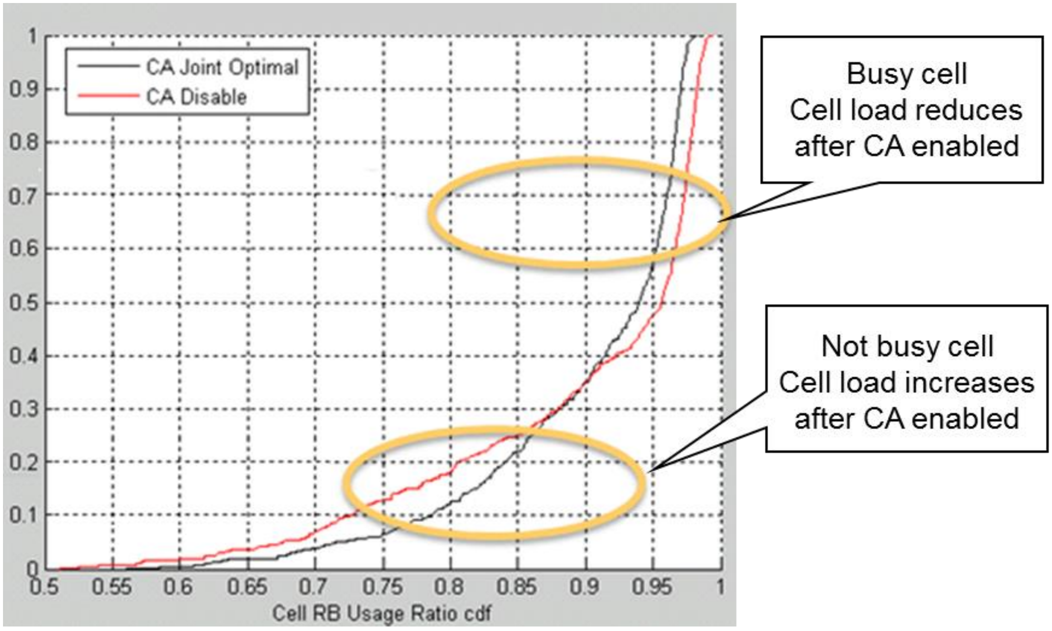


Figure 2-6: RB Utilization CDF CA vs. without CA

- **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. without 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.

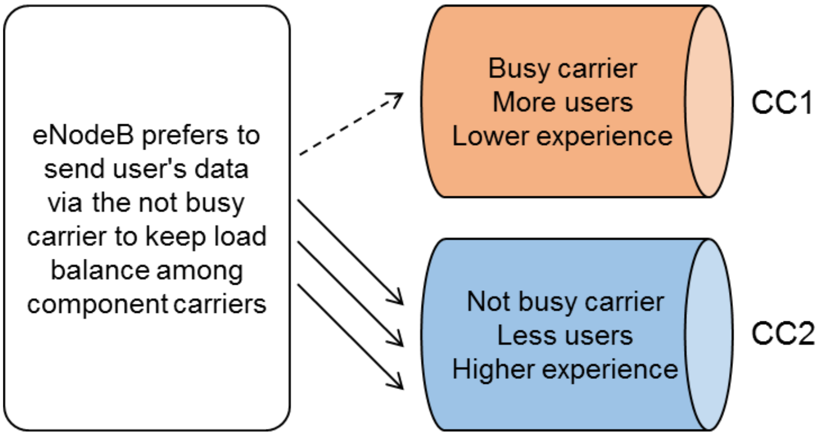


Figure 2-7: CA Load Balancing Principle

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
Signalling 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.

2.3. Evaluation of algorithms for scheduling and balancing symmetrical and asymmetrical traffic

2.3.1. Scheduling schemes in Carrier Aggregation

There are two main scheduling methods for Carrier Aggregation defined by the 3GPP. The first one depicted on the left side of Figure 2-8, schedules the resources on the same carrier as the grant is received. The second method, where the resources are scheduled on a different carrier than the carrier where the grant is received, is called as cross-carrier scheduling and it is depicted on the right side of Figure 2-8.

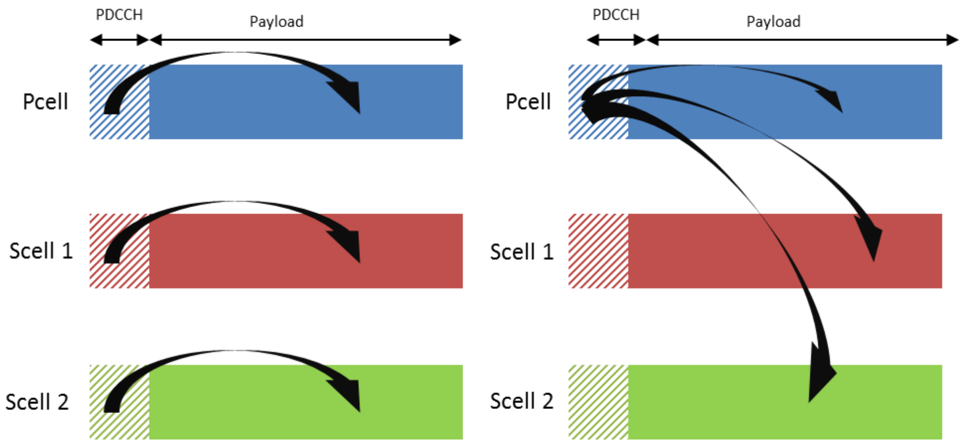


Figure 2-8: On the left, A) CA scheduling method where the scheduling is done on the same carrier as the grant is received. On the right side of the figure, B) cross-carrier scheduling.

For the first method, scheduling occurs in the same carrier as the scheduling grant is received via the physical downlink control channel (PDCCH) because of this, the PDCCH is separately coded for each carrier that server the user terminal (UE) and reuses the same PDCCH structure and downlink scheduling control information (DCI) as defined in Releases 8 and 9. The benefit of this method is that it does not require any UE specific procedure to indicate the type of scheduling. However, in some scenarios especially in the cell edge, where the PDCCH can be transmitted with higher power than the physical downlink shared channel (PDSCH) where user data is transmitted, there might be inter-cell interference. One way of avoid this kind of inference is by using the cross-carrier scheduling.

Cross-carrier scheduling, the method depicted on the right side of Figure 2-8, is an optional feature introduced in 3GPP Release 10. The UE indicates the support of cross-carrier scheduling under the UE capability transfer procedure. This scheduling method provides a good mechanism to eliminate inter-cell interference on the PDCCH especially in heterogeneous networks with macro and small cells deployed in the same carrier frequencies.

This scheduling method is only used to schedule resources on the secondary carriers without the PDCCH. Cross-carrier scheduling uses the Carrier Indicator Field (CFI) on the PDCCH to indicate which component carrier the PDSCH must allocated.

Cross-carrier scheduling does not apply to the primary cell has this is always done via its own downlink control channel.

2.3.2. Load Balancing Algorithms in Carrier Aggregation

As opposed to multi-band and multi-carrier deployments where traffic management and steering procedures, such as load balance, rely mainly on handovers, Carrier aggregation enables the possibility to balancing the load and users during scheduling. Load balancing mechanisms in carrier aggregation aim to improve average system throughput by providing an efficient distribution of carrier aggregation capable users to cells where the carrier aggregation capability can be utilized in a better way. This leads to better spectrum efficiency and improved user experience.

By implementing load balancing mechanism the traffic load will be evenly distributed by multiple carriers. In a multiple carrier deployment steering users and traffic should be done by selecting the optimal set of carriers for each user. The existence of single carrier and CA capable UEs presents a challenge to the scheduler in maintaining an even load across different carriers and, at the same time, maximize the system efficiency. This whitepaper will focus on the algorithms that distribute the load of CA capable UEs.

There are different approaches when it comes to the distribution of load and users across different component carriers. The carrier assignment and scheduler methods (described in the previous section), are the most important factors when it comes to load balancing. The assignment of carriers is done based on the UE capability and cell load at a given time whereas, in order to maximize the user experience and performance, the scheduler makes use of the feedback of parameters such as the Channel Quality Indicator (CQI) to adapt the transmission channel.

Load balancing can be done for CA capable UEs during the initial context setup by evaluating its CA utilization potential in the source cell and the available load balancing target cells. This way, the CA capable UEs are distributed during the initial context setup to the appropriate carriers.

The following methods can be used to distribute the load through the different carriers

- Load balancing during initial context setup
- CA aware Inter frequency Load Balancing

2.4. Determine best methodologies for mobility in a CA environment

CA UE mobility relied on PCell, and radio condition aware SCell handling achieved an effective CA usage in various CA deployments, especially for scenarios where the PCell and SCell(s) coverage are not totally overlapped. Link level metric and measurement event can be applied for SCell detection/addition and SCell de-configuration.

- **CA UE mobility enhancement in CA deployment scenario 2 and 4**

CA deployment scenarios 2 and 4, PCell always have a larger coverage and it contains SCell(s) coverage. When UE enter SCell coverage, A4 measurement event applied to detect SCell candidate when neighbour CC becomes better than threshold, and link level metric, e.g. MCS, can be referred to de-configure SCell(s) when radio condition worse than threshold in case UE are leaving SCell(s) coverage.

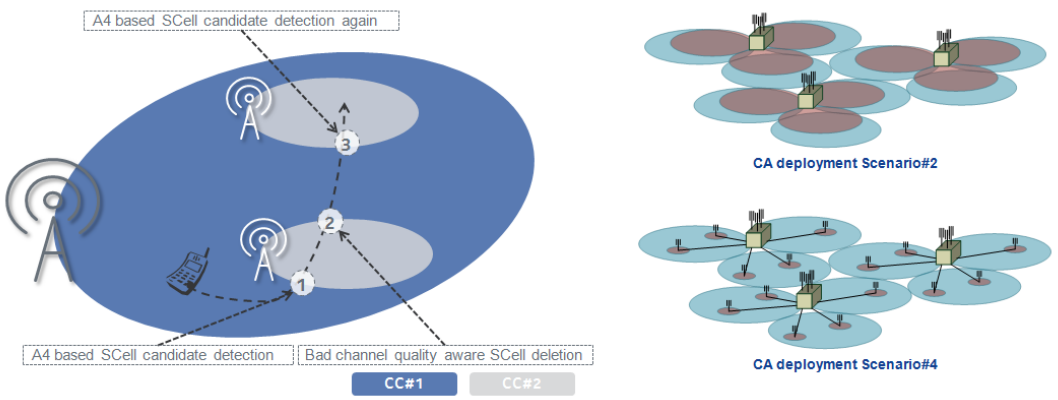


Figure 2-9: SCell handling during mobility in CA deployment 2 and 4

- **CA UE mobility enhancement in CA deployment scenario 3**

In CA deployment scenario 3, two component carrier CC#1 and CC#2 are co-located but CC#2 antennas are directed to the cell boundaries of CC#1. When CA UE moves from CC#2’s SCell#1 coverage to CC#2’s SCell#2 coverage, A6 measurement event will trigger the SCell swap when SCell#2 becomes offset better than SCell#1, thus always better coverage SCell candidate configured for CA UE.

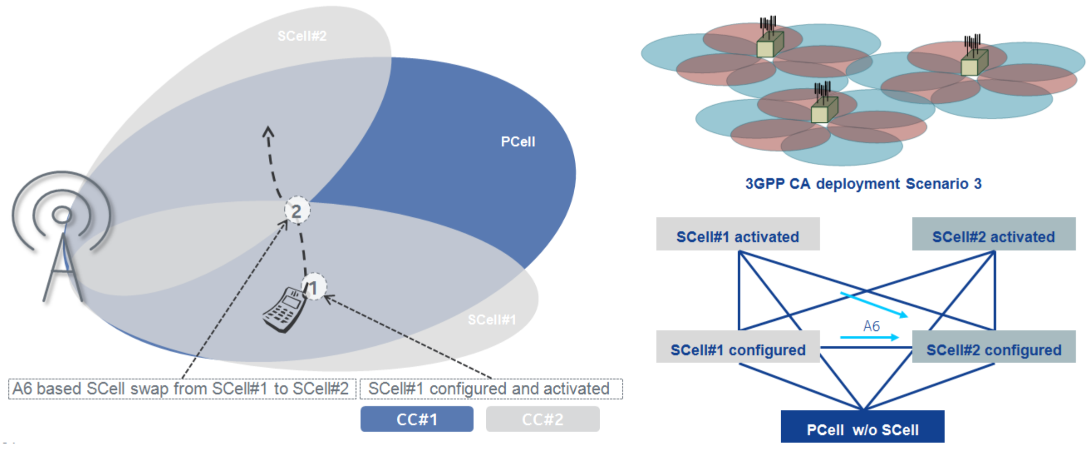


Figure 2-10: SCell handling during mobility in CA deployment 3

2.5. Carrier Aggregation achieved fast load balancing

CA operation cross multi component carriers, thus make a possibility to steering traffic load balancing cross multi carriers. Serving cell bandwidth normalized load metric will be referred for following CA operation to achieve the fast load balancing:

- Load aware SCell selection when SCell configuration
- Load aware SCell swap when load imbalance between SCell candidates
- Load aware CA UE buffer dynamic split within serving cells
- Load aware PCell swap when uplink load imbalance between PCell and SCell

Compare to handover based inter-frequency load balancing method, CA fast load balancing quick response at TTI level which is executed by packet scheduler, less RRC signalling overhead, and less service fluctuation impact.

- **Load aware SCell selection when SCell configuration**

When CA UE SCell configuration is triggered the cell load metric is referred when several SCell candidates are available. Low load SCell(s) will be selected thus steering traffic to low load cells.

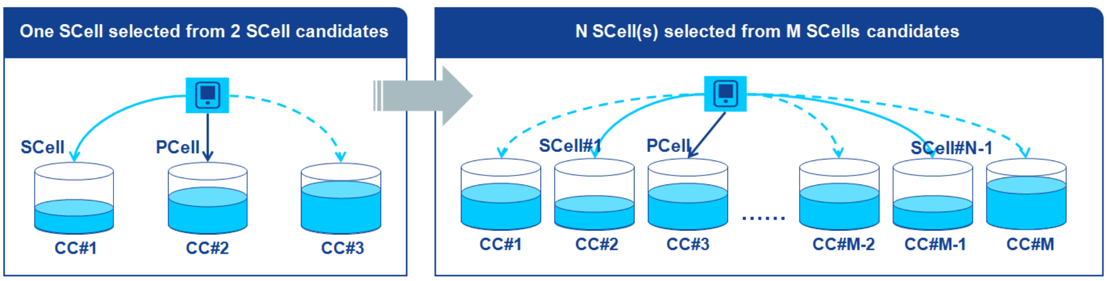


Figure 2-11: Load aware SCell selection

- **Load aware SCell swap when load imbalance between SCell candidates**

During CA operation, in case configured SCell load increase to high level e.g. load introduce by this cell non-CA increased traffic, while another SCell candidate still in low load status, load metric triggered SCell swap happen, then steering traffic to low load cells even when CA UE already served by multi serving cell.

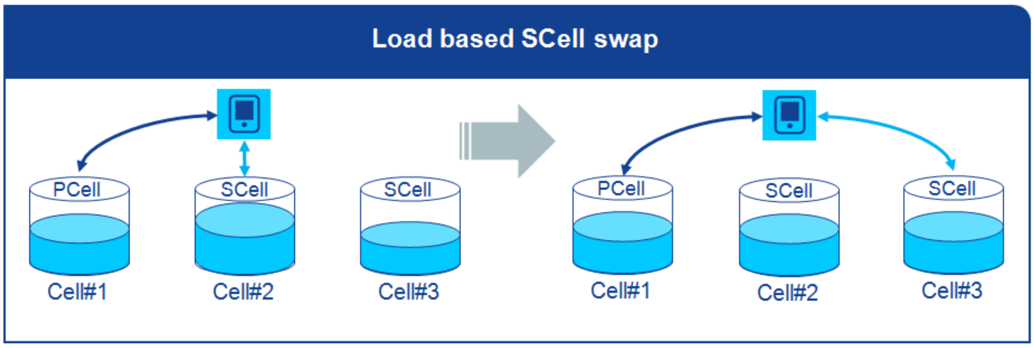


Figure 2-12: Load aware SCell swap

- **Load aware CA UE buffer dynamic split within serving cells**

When multi serving cells schedule CA UE data, load status will be referred for buffer data split within multi serving cells. Load status is exchange at scheduling interval, and dynamic adjustment of buffer split.

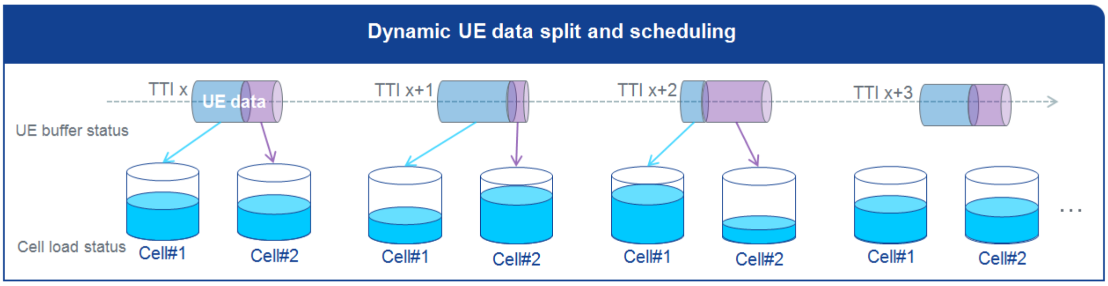


Figure 2-13: Load aware CA UE buffer dynamic split

- **Load aware PCell swap when uplink load imbalance between PCell and SCell**

In downlink only CA case, PCell uplink would be potential bottleneck as CA UEs uplink traffic and signalling reside on PCell uplink especially when PCell imbalanced distributed. Uplink load aware PCell swap expected to achieve uplink load balancing within aggregated CCs. When PCell uplink load higher than threshold while SCell uplink load is lower and qualified to be a PCell, then PCell and SCell role will be switched, thus uplink load steering to the light uplink load cell.

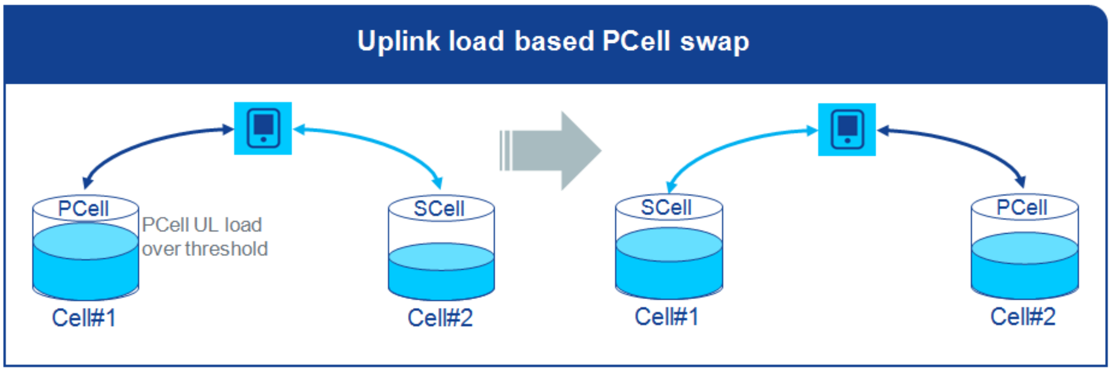


Figure 2-14: Load aware PCell swap

2.6. **Supporting large CA UE capacity**

When CA capable UE penetrations increase, we need to support large capacity of CA UEs. PUCCH resource for CA UE HARQ AN feedback, especially for TDD system, would be the bottleneck to support large CA UE capacity. Suggested countermeasure as following,

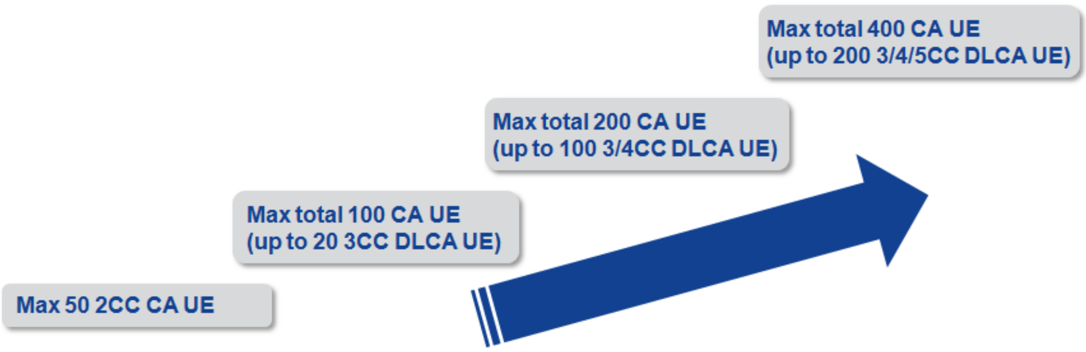


Figure 2-15: CA UE capacity boost roadmap sample

- **SCell configured on needed basis**

SCell configured on needed basis be efficient usage of CA relevant resource. Only when CA candidate UE buffer status higher than threshold, SCell configuration will be triggered. When SCell radio condition deteriorated, SCell de-configuration will be triggered. SCell configured on needed basis achieve an efficiency network usage of CA resource meanwhile benefit to UE power saving.

- **Sharable usage of CA relevant PUCCH resource**

Mount of CA UEs overbooking assigned with PUCCH resource (PUCCH format1b CS and PUCCH format3) thus boost CA UE capacity with limited PUCCH resource, and PUCCH resource conflict avoidance mechanism introduced for this sharable usage.

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 combinations in standardization are introduced. A lot of combinations with 2/3/4CC in DL have been specified; for UL some 2CC combinations have been specified with 2CC in DL. Specification work for new combinations with 3CC in DL and 3CC in UL has also started.

It should be noted that the status is for the time of writing, and there are continuous updates to the supported CA combinations in the standards, depending on the requests from operators.

The standardization work of DL CA combinations up to date is summarized in Table 3-1.

intra-band contiguous	Completed	2DL	CA_38C, CA_39C, CA_40C, CA_41C, CA_42C
		3DL	CA_40D, CA_41D, CA_42D
		4DL	-
	Ongoing	2DL	-
		3DL	-
		4DL	CA_42E
intra-band non-contiguous	Completed	2DL	CA_40A-40A, CA_41A-41A, CA_42A-42A
		3DL	CA_41A(C)-41C(A), CA_42A(C)-42C(A)
		4DL	-
	Ongoing	2DL	-
		3DL	-
		4DL	CA_41C-41C, CA_41A(D)-41D(A),

			CA_42A(D)-42D(A), CA_42C-42C
inter-band	Completed	2DL	CA_39A-41A, CA_41A-42A
		3DL	CA_39A-41C, CA_39C-41A, CA_38A-40A-40A, CA_38A-40C, CA_41A-42C
		4DL	-
	Ongoing	2DL	-
		3DL	CA_41C-42A
		4DL	CA_41C-42C, CA_39C-41C, CA_39A-41D

Table 3-1: Summary of standardization status of CA combinations

Besides DL CA, dual UL CA is also being standardized. Dual UL is supported for all the intra-band contiguous band combinations listed in Table 3-1. For intra-band combination CA_39A-41A is supported. Specification work for 3CC UL CA CA_39A-41C and CA_39C-41A in ongoing.

The detailed information including the supported bandwidth combinations for the completed combinations can be found in Table 3-2, 3-3 and 3-4 for intra-band contiguous, intra-band non-contiguous and inter-band CA, respectively.

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 [MHz]		
CA_38C （2570-2620）	15	15		40	0
	20	20			
CA_39C （1880-1920）	5,10,15	20		35	0
CA_40C （2300-2400）	10	20		40	0
	15	15			
	20	10, 20			
CA_41C （2496-2690）	10	20		40	0
	15	15, 20			
	20	10, 15, 20			
	5, 10	20		40	1
	15	15, 20			
	20	5, 10, 15, 20			
CA_42C （3400-3600）	5,10,15,20	20		40	0
	20	5,10,15			

CA_40D （2300-2400）	10, 15, 20	20	20	60	0
	20	10, 15	20		
	20	20	10, 15		
CA_41D （2496-2690）	10	20	15	60	0
	10	15, 20	20		
	15	20	10, 15		
	15	10, 15, 20	20		
	20	15, 20	10		
	20	10, 15, 20	15, 20		
CA_42D (3400-3600)					

Table 3-2: 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]	Allowed channel bandwidths for carrier [MHz]		
CA_40A-40A					
CA_41A-41A	10, 15, 20	10, 15, 20		40	0
CA_42A-42A	5, 10, 15, 20	5, 10, 15, 20		40	0
CA_41A-41C	5, 10, 15, 20	See CA_41C BW Combination Set 1 in Table 3-1		60	0
CA_41C-41A	See CA_41C BW Combination Set 1 in Table 3-1		5,10,15,20	60	0
CA_42A-42C					
CA_42C-42A					

Table 3-3: 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		

CA_39A-41C	39				Yes	Yes	Yes	60	0
	41						Yes		
	41						Yes		
CA_39C-41A	39	See CA_39C BW Combination Set 0 in Table 3-1						55	0
	41						Yes		
CA_38A-40A-40A									
CA_38A-40C									
CA_41A-42C									

Table 3-4: Summary of completed 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**

Rel-10 CA support up to 5 component carriers for all the scenarios in section 1.4 for downlink, but not scenario 4 and 5 with RRH and repeaters for uplink as different timing advance for PCell and SCell is needed for UL. Besides, TDD UL/DL configuration is required to be same in Rel-10 among the serving cells. To remove those restrictions, Rel-11 CA introduced the multiple TA feature to enable the support of scenario 4 and 5 for UL, as well as allowing different TDD UL/DL configuration for inter-band CA. In Rel-12, further enhancements were introduced to support carrier aggregation of FDD and TDD carriers to meet the requirement from operators with both FDD and TDD bands. Currently ongoing Rel-13 CA enhancement, targeting to be finished at the end of this year, will support up to 32 component carriers mainly to enable usage of un-license band as LTE carrier and PUCCH on SCell to offload PUCCH load on PCell.

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.

In 3GPP, CA combinations are introduced case by case as requested by operators, based on their spectrum allocation and deployment strategy. 3GPP evaluate the feasibility from implementation point of view, and specify the radio frequency requirements based on the agreed implementation options.

In Rel-10 where CA was firstly introduced, only intra-band contiguous combination CA_40C was defined as it was considered with least implementation issues. In Rel-11, intra-band non-contiguous combination CA_41A-41A was defined. Inter-band combinations were firstly defined in Rel-12. Also in Rel-12, combinations with 3DL CC were defined, and now in Rel-13, the first combination with 4DL CC, i.e. CA_42E, are under discussion. Dual UL CA combinations were defined in Rel-12 with 3CC UL being worked on in Rel-13.

There are and will be quite many new CA combinations coming to 3GPP, with more spectrum being allocated to operators, and with operators seeking to aggregate more deployed carriers to achieve the benefit such as higher peak rate.

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.

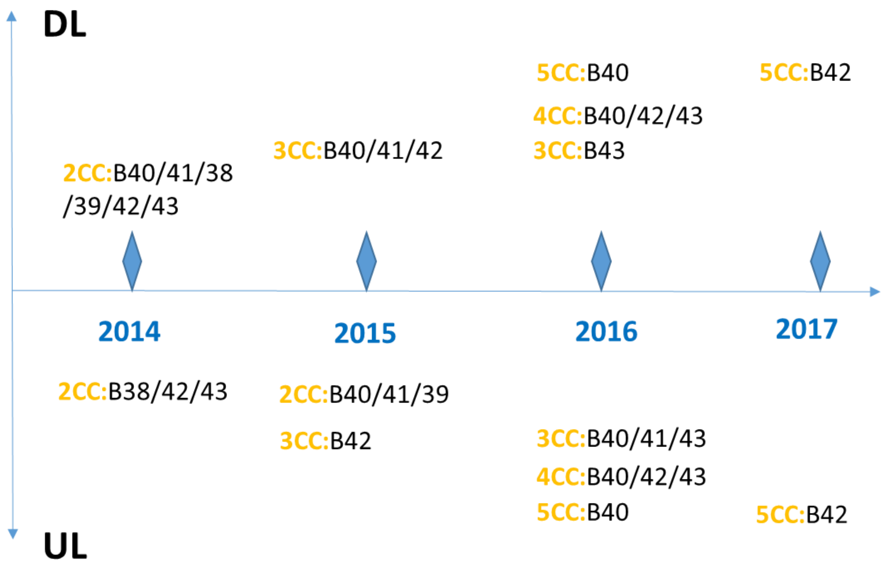


Figure 3-1: Time schedule to support intra-band CA

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

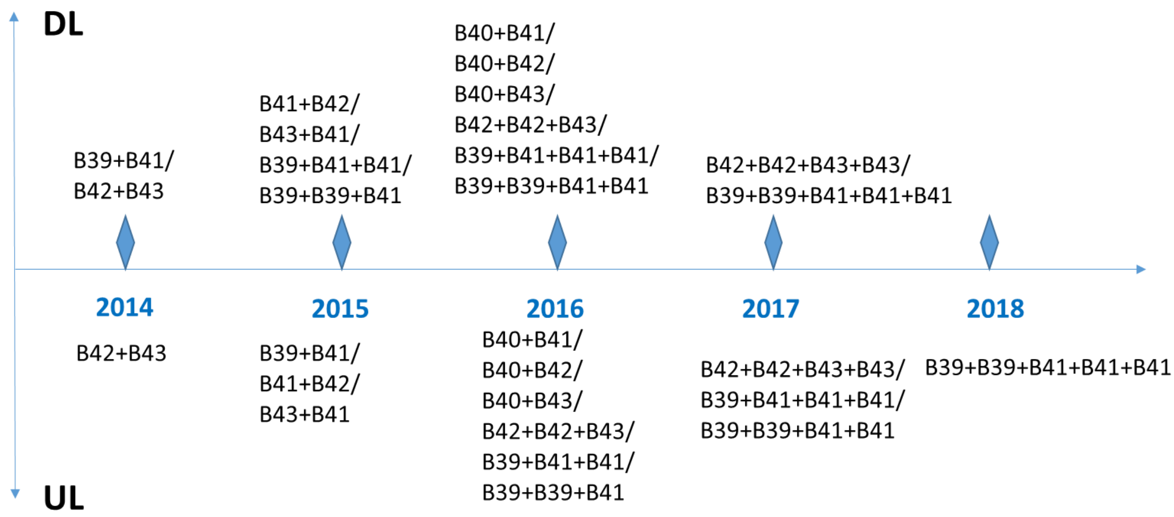


Figure 3-2: Time schedule to support inter-band CA

Following conclusions can be observed by the above figure 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
  5. 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.

3.6.1. Support for lower channel bandwidths

One of the motivations to introduce carrier aggregation is the efficient usage of fragmented spectrum held by operators. In this sense, some CA combinations are supporting aggregation of carriers with small bandwidth like 5MHz and 3MHz, as requested by operators during the standardization phase. The CA combinations supporting small bandwidth for at least one of the aggregated carriers are listed below.

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 [MHz]		
CA_39C （1880-1920）	5,10,15	20		35	0
CA_41C （2496-2690）	10	20		40	0
	15	15, 20			
	20	10, 15, 20			
	5, 10	20		40	1
	15	15, 20			
	20	5, 10, 15, 20			
CA_42C （3400-3600）	5,10,15,20	20		40	0
	20	5,10,15			

Table 3-5: Intra-band contiguous CA combinations with small bandwidth support

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]	Allowed channel bandwidths for carrier [MHz]		
CA_42A-42A	5, 10, 15, 20	5, 10, 15, 20		40	0
CA_41A-41C	5, 10, 15, 20	See CA_41C BW Combination Set 1 in Table 3-1		60	0
CA_41C-41A	See CA_41C BW Combination Set 1 in Table 3-1		5,10,15,20	60	0

Table 3-6: Intra-band non-contiguous CA combination with small bandwidth support

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_39C-41A	39	See CA_39C BW Combination Set 0 in Table 3-1						55	0
	41						Yes		

Table 3-7: Inter-band CA combination with small bandwidth support

4. Field Trial Verification Results

4.1. Field Trial Verification Results for Further Downlink Carrier Aggregation

There are two development trends of downlink carrier aggregation: downlink three-carrier aggregation and macro-micro carrier aggregation. The key technologies are secondary component carrier management based on service requirements and dynamic CA synergy. Plans to perform a field test for macro-micro carrier aggregation have been made for the end of 2015. Its verification results will be added to the next white paper edition. This document describes the field verification results of downlink three-carrier aggregation.

4.1.1. Background and Necessity of Three-Carrier Aggregation

From the perspective of TDD spectrum resources of key network operators, more and more network operators are obtaining three carriers. For example, China Mobile has obtained intra-band contiguous 60M commercial spectrum resources on its band41. China Mobile requires that the RRUs provided by equipment manufacturers must support a bandwidth of 60M. UQ Communications Japan has obtained 50M three-carrier spectrum on its band41 in 2015, and will provide 40M two-carrier spectrum on its band42 in 2016.

From the perspective of network evolution, an S222 two-carrier network will evolve to support three-carrier aggregation through software upgrade to improve user experience.

From the perspective of network performance improvement, three-carrier aggregation provides more flexible multi-carrier scheduling and improves frequency-selective gain.

From the perspective of network load, three-carrier aggregation provides more flexible load balancing policies.

From the perspective of user experience, the GAP is obviously reduced during inter-frequency measurement for secondary component carriers, and peak rates and user mobility are improved.

4.1.2. Standard-Defined Three-Carrier Frequency Band Combinations

The following frequency band combinations are defined for downlink three-carrier aggregation in the latest R12.

- Band40 DL intra-band contiguous three-carrier aggregation
- Band41 DL intra-band contiguous three-carrier aggregation
- Band41 DL intra-band non-contiguous three-carrier aggregation
- Band42 DL intra-band non-contiguous three-carrier aggregation

4.1.3. Trial Three-Carrier Verification Results of a Commercial Network

In June 2015, China Mobile and ZTE verified three-carrier aggregation performance on a commercial network. Test terminals are Qualcomm prototypes, MTP8994, and LeMAX. The chip model of the two terminals is MSM8994 (CAT9) that supports three-carrier aggregation. The terminals are used to test the rate limit for three-carrier aggregation at fixed points. The maximum throughput of downlink FTP and UDP services can reach 330 Mbps.

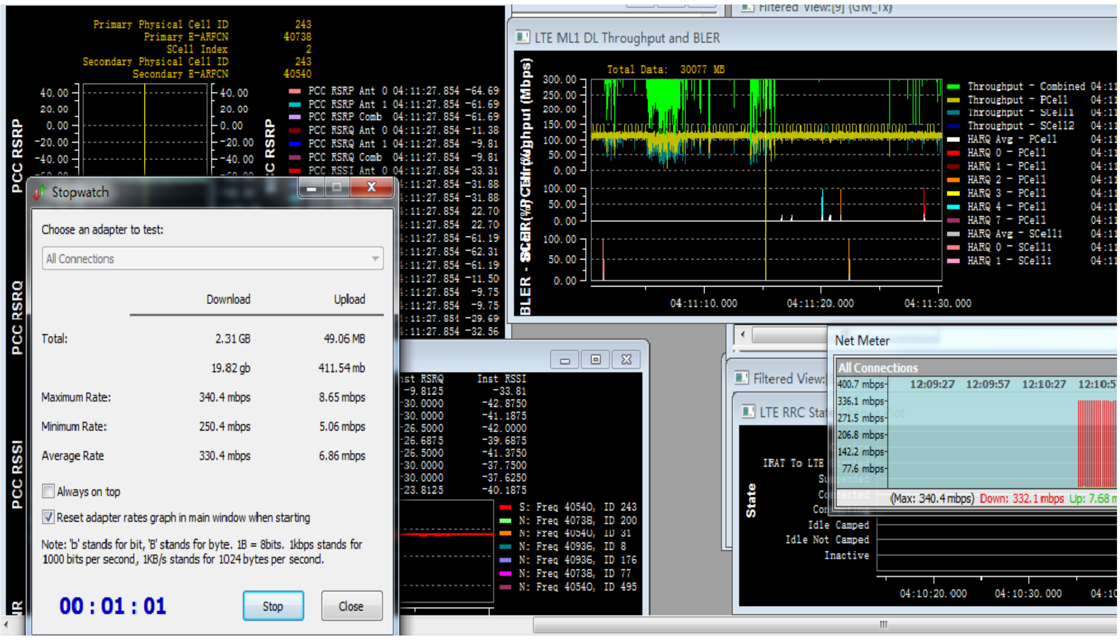


Figure 4-1: Three-Carrier Aggregation Verification Results of a Commercial Network

4.2. UL CA Commercial Field Tests

4.2.1. Test Contents and Objectives

1) Rate of a single user at a fixed point
This test verifies the rates of a single UE at good, average, and bad points while CA is enabled and disabled respectively.

2) Handover success rate
This test verifies the handover success rates of terminals R9 and R10 while CA is enabled and disabled respectively.

3) Cell throughput test
This test verifies the cell throughputs in the scenario where multiple UEs operate while CA is enabled and disabled respectively.

4) Downlink CA performance test
This test verifies the downlink CA performance while CA is enabled and disabled respectively.

4.2.2. Test Environment

This commercial network test is performed in a China Mobile network in Zhejiang Province. A downtown area with a large population of users or a typical downtown environment is selected. A total number of 30 cells with the multi-level cellular structure under wide and regular wireless network coverage are selected. The selected site provides CA in band41.

4.2.3. Basic Configuration

During the test period, the typical network configuration is as follows except for special tests.

Parameter	Configuration
Test environment	Environment with a large population of users or a typical downtown environment
Frequency	Outdoor: 2.6 GHz
System bandwidth	40 MHz
Frame structure	Uplink/downlink configuration: 2 (DSUDDDSUDD) CP: regular length Special subframe configuration: 7 (DwPTS:GP:UpPTS=10:2:2) DwPTS
CFI	3
Antenna mode	DL: auto-sensing Mode 3/Mode 8

	UL: SIMO
Uplink power control	Enabled
HARQ	Enabled
AMC	Enabled
CA	UL&DL CA is enabled.

Table 4-1: Typical Network Configuration

Name	Quantity	Model and Version (Filled in During the Tests)
Spectrum analyzer (or frequency sweep generator)	1	
IxChariot or Iperf or other service simulation software	Configured as required	Iperf
Test PC	Configured as required	Lenovo T340
TD-LTE drive testing system	⩾ 3	Test software: QXDM, terminal: Qualcomm 9X45
Test vehicle	Configured as required	
GPS and electronic map	≥ 1	

Table 4-2: Test Instruments

4.2.4. Test Results

4.2.4.1. Rate Test for a Single User at a Fixed Point

- B41+B41 intra-band dual-carrier aggregation, at an extremely good point:

Service Type	Extremely Good Point	UL/DL	UL CA Enabled /Disabled	L1 Rate (Mbps)	L1 Rate Gain
TCP	Concurrent	UL	Enabled	20.19	99.90%
			Disabled	10.1	
		DL	Enabled	220.1	91.72%
			Disabled	114.8	

- B41+B41 intra-band dual-carrier aggregation, at a good point:

Service Type	Good Point	UL/DL	UL CA Enabled /Disabled	L1 Rate	L1 Rate Gain
TCP	Concurrent	UL	Enabled	17.63	91.63%
			Disabled	9.2	
		DL	Enabled	129.2	66.49%
			Disabled	77.6	

- B41+B41 intra-band dual-carrier aggregation, at an average point:

Service Type	Middle Point	UL/DL	UL CA Enabled /Disabled	L1 Rate	L1 Rate Gain
TCP	Concurrent	UL	Enabled	14.52	76.21%
			Disabled	8.24	
		DL	Enabled	69.6	87.90%
			Disabled	37.04	

- B41 + B41 intra-band dual-carrier aggregation, at a bad point:

Service Type	Bad Point	UL/DL	UL CA Enabled /Disabled	L1 Rate	L1 Rate Gain
TCP	Concurrent	UL	Enabled	13.04	71.13%
			Disabled	7.62	
		DL	Enabled	31.15	8.92%
			Disabled	28.6	

4.2.4.2. Handover Success Rate Test

A total number of 30 cells at five CA sites in an existing network are selected for the handover success rate test. The test routes cover the 30 cells, and attempt to cover all the tested cells.

Conclusion: Consecutive handovers are implemented, so the rate increases by at least 60% when UL CA is enabled at the low speed and medium speed. The gains obtained by enabling UL CA are the same for the band41+band41 network and the band41+band39 network.

4.2.4.3. Cell Throughput Test

A total number of 10 terminals are used. Three Qualcomm 9X45 terminals that support UL CA are placed at good, average, and bad points respectively, and seven R9 terminals (MIFI91S+) are placed at extremely good, good, average, and bad points of the tested CA cells. During the test, the terminals access CA cells at random.

- Band41+band41 (D+D) test result:

Throughput (Mbps)			Cell Throughput
Frequency band	Scrambling level	UL CA	
D+D	No scrambling	Enabled	12.37
		Disabled	11.32
	Scrambling level 1	Enabled	11.13
		Disabled	10.59
	Scrambling level 2	Enabled	10.33
		Disabled	9.55
	Scrambling level 3	Enabled	9.69
		Disabled	9.01

Conclusion: At different scrambling levels, when UL CA is enabled, the average throughput gain of multi-UE cells ranges from 6% to 9%. An obvious gain is obtained at good and average points, and there is no gain at bad points.

4.2.4.4. Downlink CA Performance Test

Band41+band41 test result

A drive test is performed for testing the Downlink CA (DL CA) performance, and the test routes attempt to cover all the tested cells.

- Test Result

CA	RSRP (dBm)	SINR (dBm)	RB	MCS	Bler (%)	Rate (Mbps)
UL&DL CA enabled	-87.1	15.62	68.5	15.71	6.05	73.04
DL CA enabled	-86.75	15.26	67.8	15.52	4	62.9

Conclusion: Compared with enabling DL CA, enabling UL&DL CA approximately brings a gain of 10% in both of the band41+band41 network and the band41+band39 network, conforming to the theoretical expectation.

5. Dual Connectivity –An Alternative Approach

5.1. DC deployment scenarios

This section briefly introduces typical DC deployment scenarios.

- **Scenario 1**
  Macro and small cells on different carrier frequencies (inter-frequency) are connected via non-ideal backhaul.
- **Scenario 2**
  Only small cells on one or more carrier frequencies are connected via non-ideal backhaul.
- **Scenario 3**
  TDD LTE macro and small cells as well as FDD LTE macro and small cells are provided by different equipment manufacturers, among which DC is used to increase peak rates and improve Quality of Service (QoS).
- **Scenario 4**
  A 4G network can be smoothly evolved to a 5G network. The 5G network is initially deployed in some data hotspots and supports a small number of terminals. To achieve seamless coverage and superior QoS, the DC technology is used to bundle 4G and 5G network traffic for 5G terminals. The existing terminals connected to the 4G network will not be affected. In this way, the 4G network can be smoothly evolved to the 5G network.

5.2. Principles and Technical Advantages

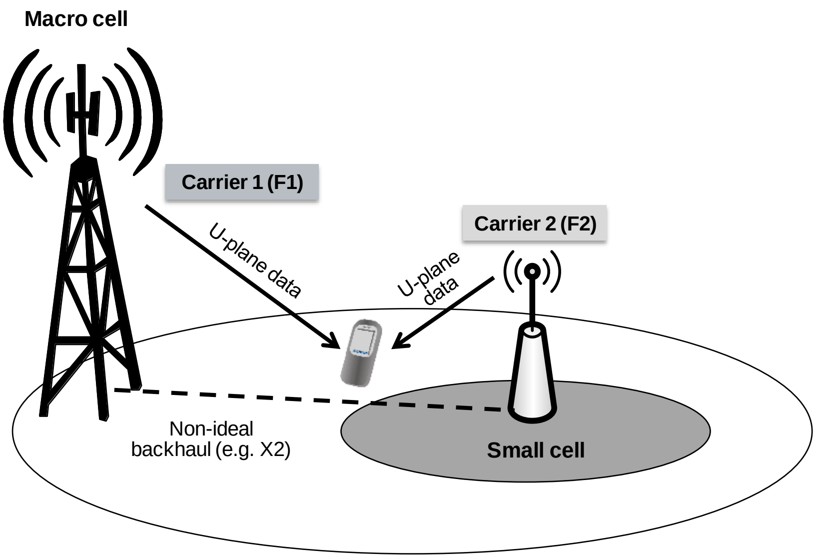


Figure 5-1: DC in HetNet/small cell deployment

In the HeNet, small cells can be added to improve network coverage. The CA is dysfunctional under non-ideal backhaul, and therefore the UE cannot be bundled with multi-carrier resources to improve QoS. With the DC technology, small cells can be aggregated; and small and macro cells can be aggregated under non-ideal backhaul.

A network operator may deploy an FDD LTE network and a TDD LTE network at different stages. If the devices of the two networks are provided by different equipment manufacturers, the CA is infeasible. The DC technology can improve per-user throughput by utilizing radio resources in more than one eNB.

There are two network architectures for the DC.

Alternative 1A is the combination of S1-U that terminates in SeNB + independent PDCPs (no bearer split).

It is depicted in the following figure (using the downlink direction as an example).

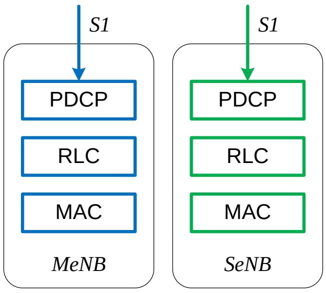


Figure 5-2: Alternative 1A

The expected benefits of this alternative are:

- no need for MeNB to buffer or process packets for an EPS bearer transmitted by the SeNB;
- little or no impact to PDCP/RLC and GTP-U/UDP/IP;
- no need to route all traffic to MeNB, low requirements on the backhaul link between MeNB and SeNB and no flow control needed between the two;
- support of local break-out and content caching at SeNB straightforward for dual connectivity UEs.

The expected drawbacks of this alternative are:

- SeNB mobility visible to CN;
- offloading needs to be performed by MME and cannot be very dynamic;
- security impacts due to ciphering being required in both MeNB and SeNB;
- utilisation of radio resources across MeNB and SeNB for the same bearer not possible;

- for the bearers handled by SeNB, handover-like interruption at SeNB change with forwarding between SeNBs;
- in the uplink, logical channel prioritisation impacts for the transmission of uplink data (radio resource allocation is restricted to the eNB where the Radio Bearer terminates).

Alternative 3C is the combination of S1-U that terminates in MeNB + bearer split in MeNB + independent RLCs for split bearers. It is depicted on Figure 5.3 below, taking the downlink direction as an example.

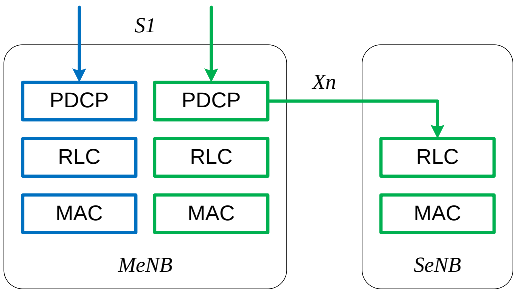


Figure 5-3: Alternative 3C

The expected benefits of this alternative are:

- SeNB mobility hidden to CN;
- no security impacts with ciphering being required in MeNB only;
- no data forwarding between SeNBs required at SeNB change;
- offloads RLC processing of SeNB traffic from MeNB to SeNB;
- little or no impacts to RLC;
- utilisation of radio resources across MeNB and SeNB for the same bearer possible;
- relaxed requirements for SeNB mobility (MeNB can be used in the meantime).

The expected drawbacks of this alternative are:

- need to route, process and buffer all dual connectivity traffic in MeNB;
- PDCP to become responsible for routing PDCP PDUs towards eNBs for transmission and reordering them for reception;
- flow control required between MeNB and SeNB;
- in the uplink, logical channel prioritisation impacts for handling RLC retransmissions and RLC Status PDUs (restricted to the eNB where the corresponding RLC entity resides);
- no support of local break-out and content caching at SeNB for dual connectivity UEs.

5.3. Industry Status and Roadmap

- Prototype: 2016Q1 TDD+TDD DC FDD+TDD DC Alternative 1A
- Commercial deployment: 2016Q4 TDD+TDD DC FDD+TDD DC Alternative 1A Alternative3C

6. Dynamic TDD -LTE

6.1. Introduction to Dynamic TDD

Dynamic TDD refers to dynamic adjustment of TDD-LTE uplink-downlink configurations for adapting to traffic needs of a specific cell area.
TDD-LTE system typically have these characteristics for supporting dynamic TDD

- In TDD uplink and downlink signals transmissions are performed on the same carrier frequency by time multiplexing of opposite transmission directions.
- In most application cases, the UL and DL traffic load is asymmetric in a cells. Seven uplink-downlink configurations are supported In TDD. These allocations can provide between 40% and 90% DL subframes.
- It is much higher flexible for TDD to handle the dynamic traffic adaptive, Since the uplink-downlink configuration is adjustable.

Although TD-LTE systems have traffic adaptation capabilities by allowing different uplink-downlink configurations in different cells, it adopt synchronous operation in the entire network with all cells using the same UL-DL configuration and ensuring time aligned transmissions of DL and UL signals. The main technical reason is the emergence of new types of interference such as

- BS-BS interference: interference between neighbouring base station (DL->UL), that leads to severely interfered uplink reception in one cell due to downlink transmission in another cell.
- UE-UE interference: interference between user terminals (UL->DL), that causes degraded downlink performance in one cell due to the uplink transmission in another cell.

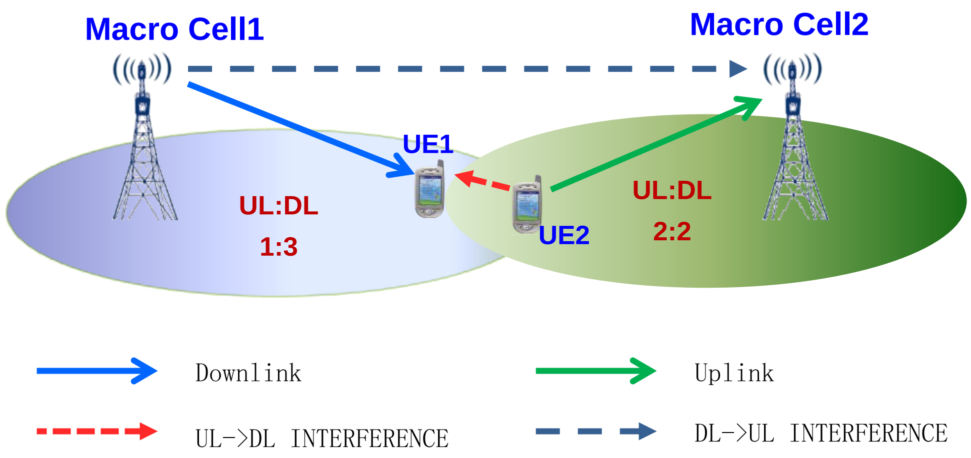


Figure 6-1: New types of interference

The usage of synchronous operation limits the application of dynamic TDD, however it prevents strong interference among opposite transmission directions that impact on system performance in typical Macro cell scenarios.

6.2. Motivations and Objectives

LTE TDD uplink-downlink subframe configurations allocation is according to average traffic load, In practical networks the amount of traffic for downlink and uplink varies significantly with time and between cells, which lead to inefficient resource utilization.

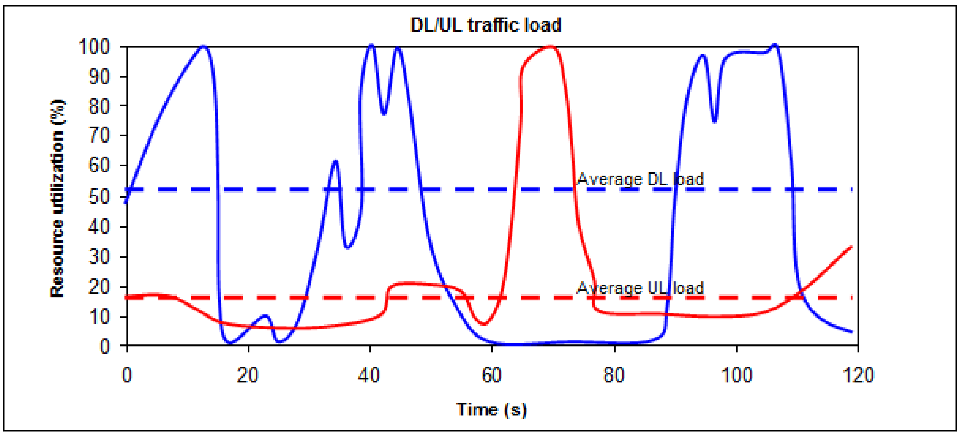


Figure 6-2: DL/UL traffic load

Traffic adaptive UL-DL subframe configuration mainly focus to

- improve DL/UL resource utilization efficiency
  the service requirements can not be satisfied if the traffic in one direction surpasses the capacity of the pre-assigned in that direction. However, the traffic another direction is lower.
- reduce network-side energy consumption by configure more UL when traffic burden is low
- Improve Uplink coverage by TTI Bundling in configure more UL

6.3. usage scenarios

the possible application scenarios are identified for scenario co-existence analysis in 3GPP TS 36.828[1] study item.

- Scenario 1: Co-channel multi-cell Femto scenario;
- Scenario 2: Adjacent-channel multi-cell Macro-Femto scenario;
- Scenario 3: Co-channel multi-cell Pico scenario;
- Scenario 4: Adjacent-channel multi-cell Macro-Pico scenario;
- Scenario 5: Co-channel multi-cell Macro-Femto scenario;
- Scenario 6: Co-channel multi-cell Macro-Pico scenario;
- Scenario 7: Adjacent-channel multi-cell Macro-Macro scenario;
- Scenario 8: Co-channel multi-cell Macro scenario.

Single layer scenarios (small cells only)	Two layer scenarios (HetNet) (Macro and Small Cells)		Single layer (Macro Cells – Multiple Operators)	
	Adjacent channel	Co-channel	Adjacent channel	Co-channel
Sc.#1. Femto layer only Sc.#3. Pico only	Sc.#2. Macro+Femto Sc.#4. Macro+Pico	Sc#5. Macro+Femto Sc#6. Macro+Pico	Sc#7. Macro (different carriers)	Sc#8. Macro (same carrier)

Table 6-1: 3GPP Scenario Category

6.3.1. Single layer (small cells) scenarios

In accordance with the 3GPP classification, single layer scenarios includes scenario 1 and scenario 3,i.e. co-channel multi-cell Femto and Pico scenario.

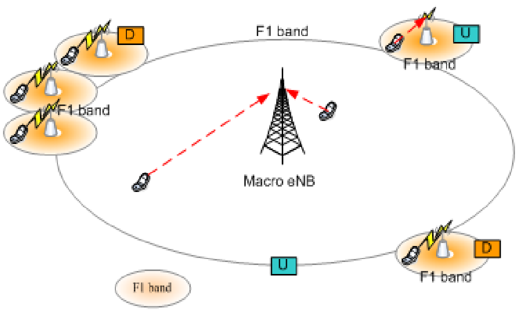
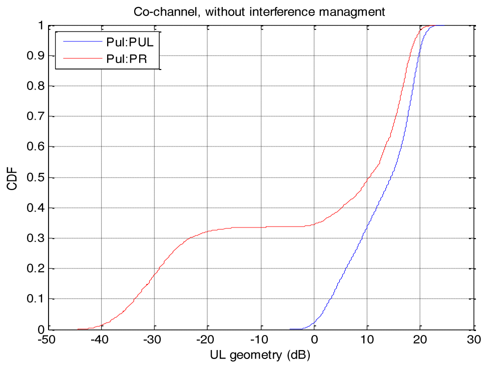
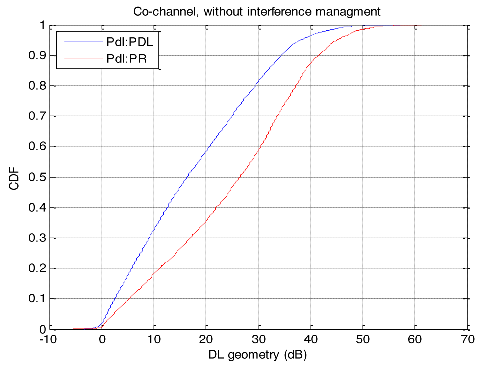


Figure 6-3: Single layer scenarios（small cell only）

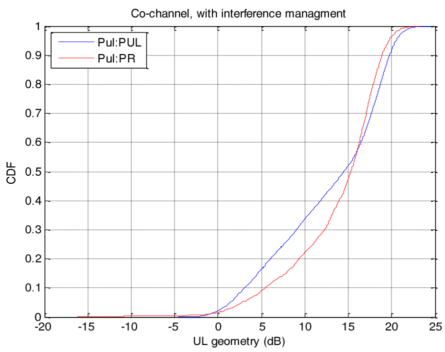
The evaluation results by system simulations for single layer small cell only scenario are shown in Figures.

Pico-Pico co-channel without any interference mitigation scheme





Pico-Pico co-channel with interference mitigation scheme



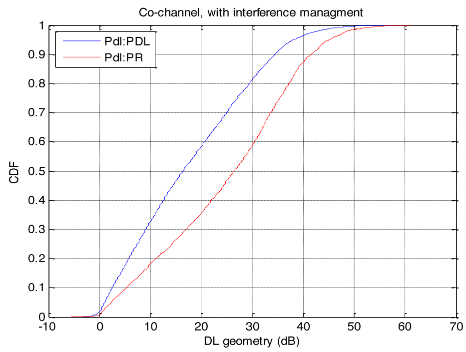


Figure 6-4: Pico-Pico co-channel UL/DL Geometry

For the performance evaluated single layer small cell scenario, TDD UL-DL reconfiguration based on traffic conditions without interference mitigation provides benefits over a fixed reference TDD UL-DL configuration.

- The benefits at least include improved average packet throughput in the low cell traffic load region.
- The less number of DL (or UL) subframes in the fixed reference TDD UL-DL configuration, the higher DL (or UL) packet throughput gain (if any) achieved by TDD UL-DL reconfiguration
- Faster TDD UL-DL reconfiguration provides larger benefits on average packet throughput than slower TDD UL-DL reconfiguration
- The 5% UE average packet throughput may be increased or decreased.

With interference mitigation, TDD UL-DL reconfiguration based on traffic conditions provides higher packet throughput in UL than without interference mitigation. Meanwhile, depending on the interference mitigation scheme and cell traffic load, TDD UL-DL reconfiguration with interference mitigation may provide higher or lower packet throughput in DL than without interference mitigation, and for the latter case, the increase in UL packet throughput can be higher than the loss in DL packet throughput.

6.3.2. Two layer scenarios

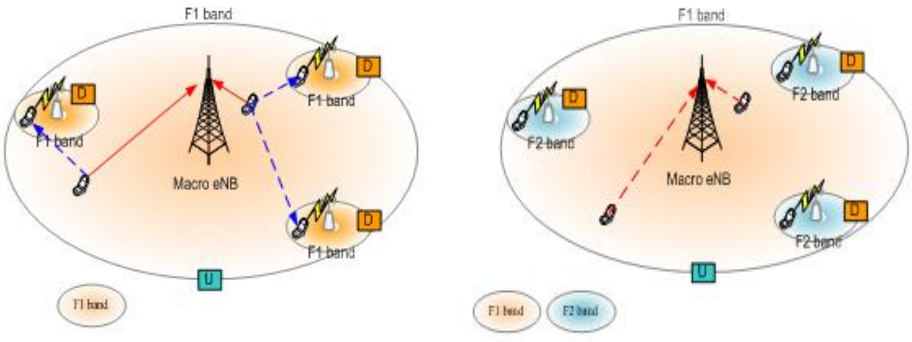
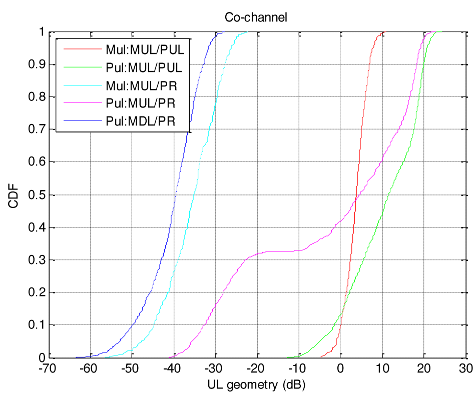


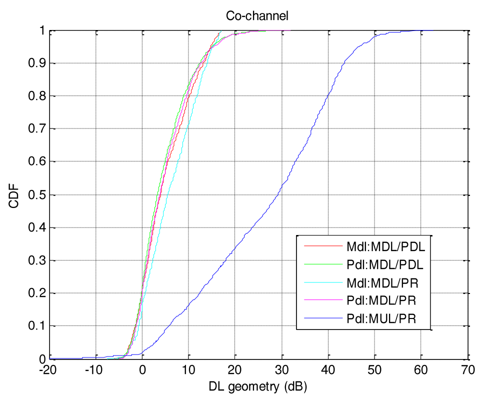
Figure 6-5: two layer scenarios (Co-channel and Adjacent channel)

6.3.2.1. Co-channel

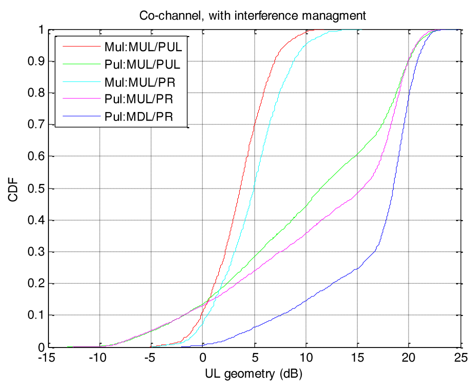
The evaluation results by system simulations for Co-channel are shown in Figures.

Pico-Macro co-channel without interference mitigation scheme





Pico-Macro co-channel with interference mitigation scheme



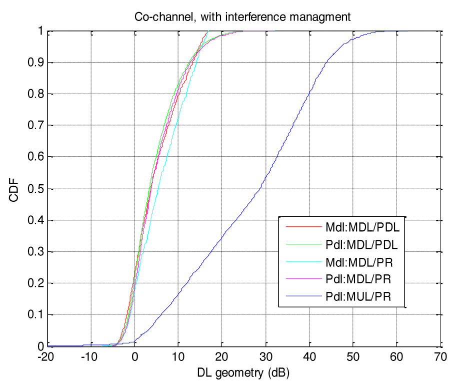


Figure 6-6: Pico-Macro co-channel UL/DL Geometry

For the performance evaluated co-channel multi-Macro/Pico cell scenario, the following observations are made for TDD UL-DL reconfiguration based on traffic conditions without interference mitigation compared to a fixed TDD UL-DL configuration:

- Improved or reduced DL packet throughput for Pico cells;
- Similar DL packet throughput for Macro cells;
- Significantly decreased UL packet throughput for both Macro and Pico cells.

For the performance evaluated co-channel multi-Macro/Pico cell scenario, the following observations are made for TDD UL-DL reconfiguration based on traffic conditions with interference mitigation compared to without interference mitigation:

- Improved UL packet throughput for both Macro and Pico cells;
- Similar DL packet throughput for Macro cells;
- Improved or decreased DL packet throughput for Pico cells depending on the interference mitigation scheme.

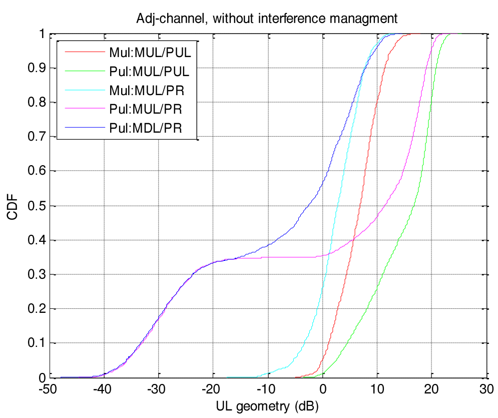
For the performance evaluated co-channel multi-Macro/Pico cell scenario, the following observations are made for TDD UL-DL reconfiguration based on traffic conditions with interference mitigation compared to a fixed TDD UL-DL configuration:

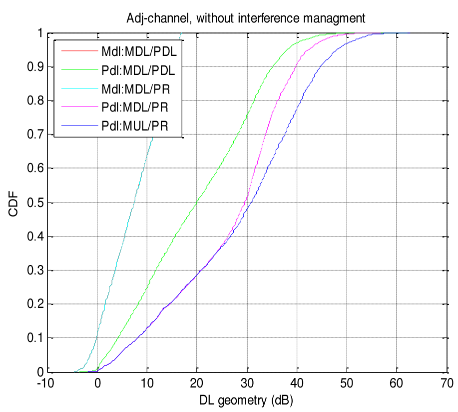
- Reduced UL packet throughput for Macro cells;
- Improved or decreased UL packet throughput for Pico cells, partly depending on the interference mitigation scheme.

6.3.2.2. Adjacent channel

The evaluation results by system simulations for adjacent channel are shown in Figures.

Pico-Macro adjacent channel without any interference mitigation scheme





Pico-Macro adjacent channel with interference mitigation scheme

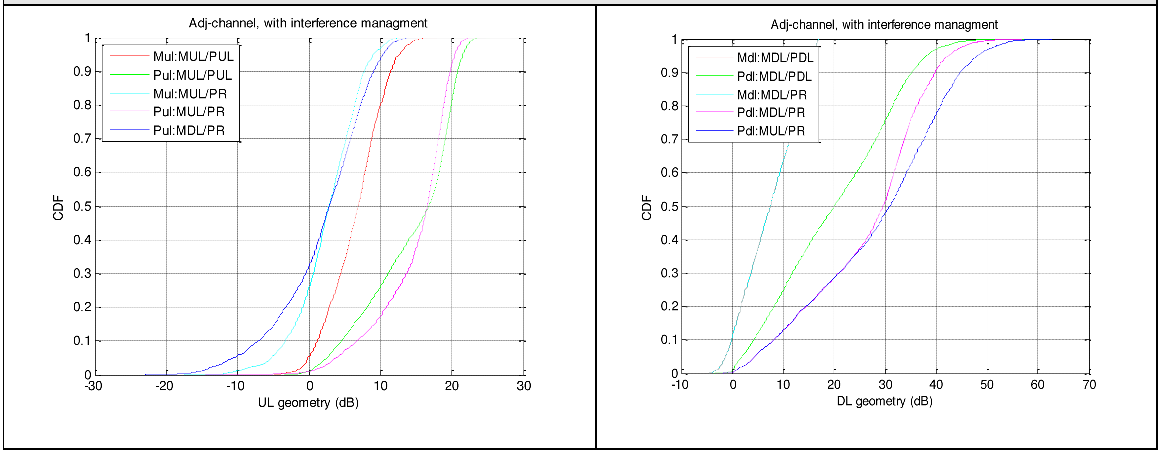


Figure 6-7: Pico-Macro adjacent channel UL/DL Geometry

For the performance evaluated adjacent channel multi-Macro/Pico cell scenario, the following observations are made for TDD UL-DL reconfiguration based on traffic conditions without interference mitigation compared to a fixed TDD UL-DL configuration:

- Improved DL packet throughput for Pico cells;
- Similar DL packet throughput for Macro cells;
- Similar UL packet throughput for Pico cells in low cell load;
- Significantly decreased UL packet throughput for Pico cells in medium to high cell load and for Macro cells.

6.3.3. Single layer (Macro cells) scenarios

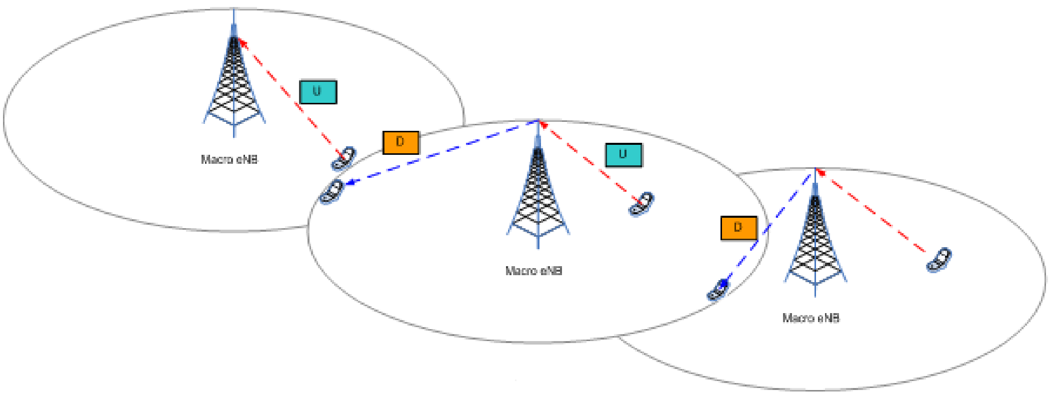


Figure 6-8: Single layer (Co-channel and Adjacent channel Macro-Macro)

The evaluation results by system simulations for adjacent channel Macro-Macro cell are shown in Figures

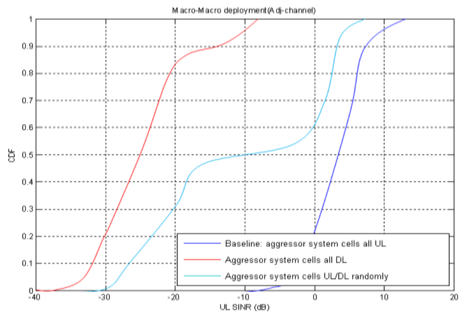
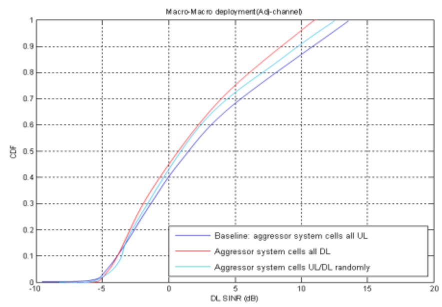
Macro-Macro adjacent-channel	
	

Figure 6-9: Macro-Macro adjacent channel UL/DL Geometry

For the performance evaluated adjacent channel Macro-Macro scenario, the following observations are made without interference mitigation

- In aggressor system Cells UL/DL randomly, the performance of UL and DL for victim cell is between aggressor system cells all UL and all DL.
- UL is more sensitive to interference of aggressor cells than DL.

For the co-channel Macro-Macro, Minimum BS separation distance will be greater than 10000km without interference mitigation, the results are calculated based on the Macro BS-BS pathloss model PL=98.45+20*log10(R), R in km.

6.3.4. Summary of performance evaluation

- Faster TDD UL-DL reconfiguration provides larger benefits on average packet throughput than slower TDD UL-DL reconfiguration, PHY signalling or MAC signalling is preferred.
- TDD reconfiguration is suitable for the low cell traffic load.
- Interference management is very important to improve cell-edge performance, especially for UL.

6.4. Interference mitigation schemes

The interference mitigation schemes provided in this section, Interference mitigation for both data and control channels shall be considered.

6.4.1. Scheduling Dependent Interference Mitigation (SDIM)

The eNB can adjust the scheduling strategies based on the variation of the observed interference, the estimation of induced interference, inter-cell interference coordination information exchange, and/or cell load to resist the inter-cell interference.

- link adaptation (MCS);
- resource allocation: blank in strongly interfered subframes or frequency bands;

- UL/DL transmit power;
- transmission direction selection of a subframe

6.4.2. Cell clustering interference mitigation (CCIM)

The cells are divided into cell clusters. Within one cell cluster, the transmission direction of all active subframes should be the same, so the BS-BS interference and UE-UE interference can be mitigated within the cell cluster

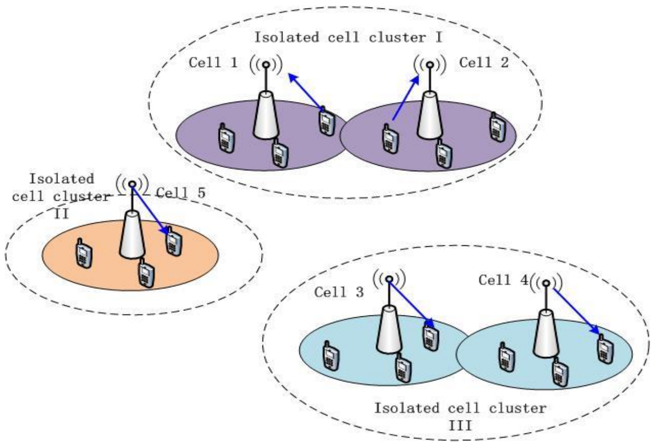


Figure 6-10: Cell clustering

6.4.3. Interference mitigation based on eICIC/FeICIC schemes

Rel-10/11 eICIC/FeICIC has been made to cope with the interference conditions caused in the HetNet deployment.

- almost blank subframes;
- restricted RLM/RRM measurements;
- dual CSI measurement reports.

6.4.4. Interference suppressing interference mitigation (ISIM)

ISIM may be considered for UL transmission of either Pico or Macro cells. Suppression of one or more of the dominant eNB-to-eNB interfering signals may be possible, e.g. by enhanced receiver such as MMSE-IRC, or by joint transceiver technologies such as interference alignment or interference nulling.

6.5. Methods to support different time scales for TDD UL-DL reconfiguration

6.5.1. Methods for reconfiguring UL-DL configuration

- System information SIB1
- dedicated RRC signalling
- MAC signalling
- PHY signalling
- PBCH (reusing 3 reserved bits in MIB)

6.5.2. Candidate solutions of UL-DL configuration signalling mechanisms

	System information	Dedicated RRC	MAC	PHY	PBCH
Minimum time scale	640ms	e.g. 200ms	e.g. 20ms	10ms	40ms
Packet throughput gain	Low	Medium	High	High	High
Signalling reliability	High	High	Medium	Low	High
Interference mitigation feasibility	High	High	Medium	Low	Medium
UE power consumption	Low	Low	Low	Low	High
Standardization impact	Low (for SIB1 defined in Rel-8)	High (include reconfiguration signalling, Backward compatibility, HARQ timing, DL measurement and interference mitigation, etc.)			

6.6. Requirement Roadmap of Dynamic TDD

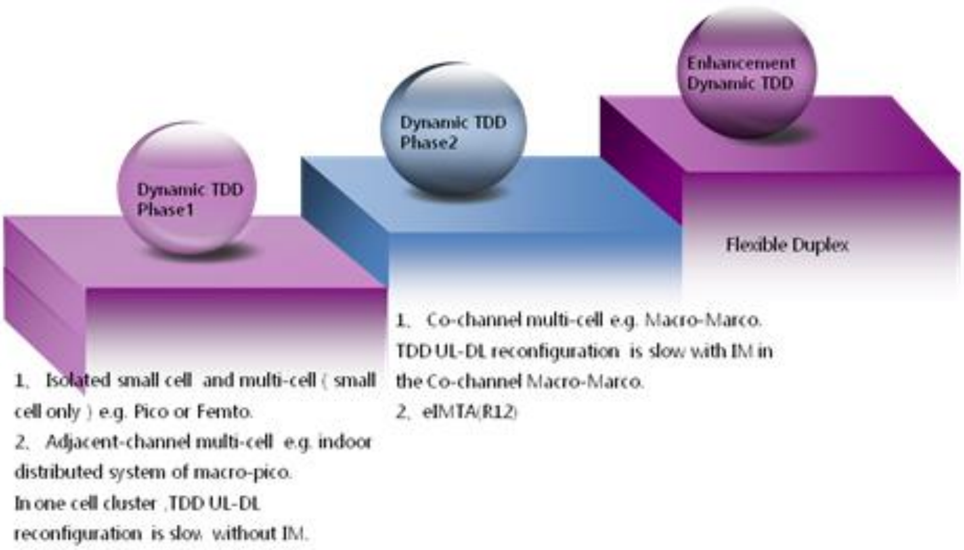


Figure 6-11: Roadmap in dynamic TDD

7. 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.