Carrier Aggregation for Enhancement of Bandwidth in 4G Systems

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Abstract. Since ITU-R had officially completed the formal definition of Third Generation (3G) systems in 1997, focus has been shifted to the Fourth Generation (4G) wireless cellular systems. The paper provides an overview of the different aspects of the proposed carrier aggregation technique, which would enable LTE-A systems to fully utilize the wider bandwidths up to 100MHz and as well maintain the backward compatibility with LTE systems. The contiguous and non contiguous carrier aggregation techniques have been discussed and their deployment scenarios have been illustrated. The technique of carrier aggregation will not only provide a wide bandwidth of 100 MHz but shall also help in achieving higher peak data rates and better coverage for medium data rates.

Keywords: carrier aggregation (CA), contiguous and non contiguous component carriers (CCs), deployment scenarios, LTE-Advanced systems.

1 Introduction

Fast and more efficient mobile internet access demands, pressurize the mobile service providers to think about adopting the advanced version of IMT, i.e. IMT-advanced. The IMT-advanced requirements of the peak data rates of 1Gbps and 500 Mbps in downlink and uplink respectively, can be achieved by using the wider bandwidths of up to 100 MHz [1]. Such wider portions of continuous spectrum is rarely available in practice for cellular based mobile communication use i.e. below 3 GHz. 3GPP proposed carrier aggregation (CA) technology, in release 10, as a potential solution for increasing the LTE bandwidth [2]. In CA, multiple component carriers (CC) of smaller bandwidths, belonging to same or different spectrum bands are aggregated by the operators to scale their spectrum bandwidths so as to enable high data rates in downlink as well as uplink transmission.

These CCs follow LTE release 8 numerology and core physical layer design, there by guaranteeing the LTE-Advanced systems (release 10 and beyond) to be backward compatible with the LTE systems (release 8 and 9). Release 10 users can access multiple spectrum bands belonging to contiguous or noncontiguous frequency bands simultaneously, to send and receive data [3]. Legacy users can access the system using one of the aggregated CCs. With CA, spectrum efficiency can be increased due

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to the feature of aggregation of non-contiguous carriers, proper utilization of different carriers results in various deployments scenarios of both homogenous and heterogeneous networks. The LTE compatible CC, enable operators to migrate from LTE to LTE-Advanced systems and at the same time continue service to LTE users [4]. Apart from providing higher peak data rates, CA also provides better coverage for medium data rates. Here the use of lower orders of modulation and lower code rates, reduces the required link budget, transmission power and interference [5]. Figure 1 [6] shows the improvement in the bandwidth of LTE-Advanced with the increase in the number of CCs.

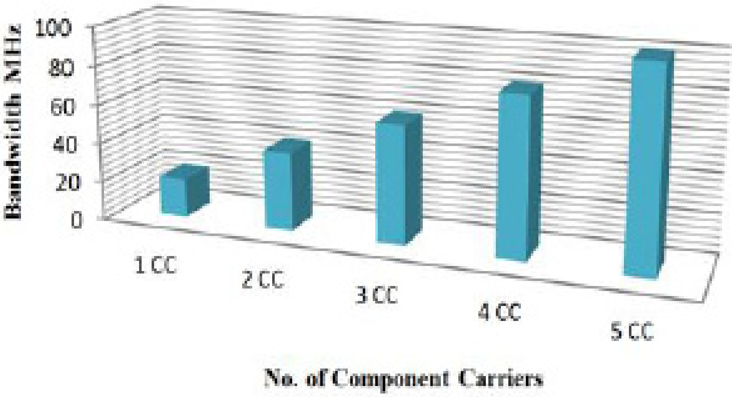


Fig. 1. Relationship between component carriers and Bandwidth MHz [6]

In spite of all these advantages, allocation of multiple CCs to power limited LTE-A user equipments (UEs), experiencing unfavorable channel condition, is not advisable. This is because when a UE has reached its maximum transmission power, increasing bandwidth does not result in increase in data rates for a UE, transmitting simultaneously over multiple CCs. The transmission power reduces due to effects of increased PAPR and peak to average power ratio and intermodulation [7].

2 Carrier Aggregation Configurations in LTE Advanced Systems

In order to ensure backward compatibility to legacy release 8 users, LTE-A systems aggregate multiple release 8 CCs for providing wider transmission bandwidth [8]. Multiple LTE carriers, with bandwidth of upto 20 MHz each, can be transmitted in parallel to/from an LTE-A supporting terminal. LTE devices which do not support LTE-A feature will use one of these 20 MHz aggregated CC.

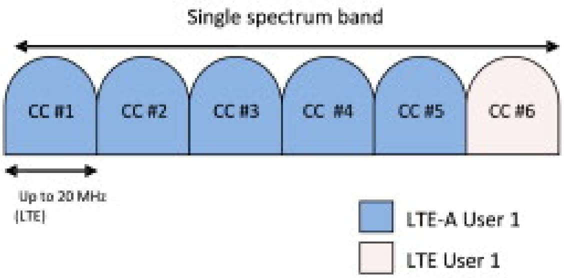


Fig. 2(a). Carrier aggregation in contiguous bandwidth

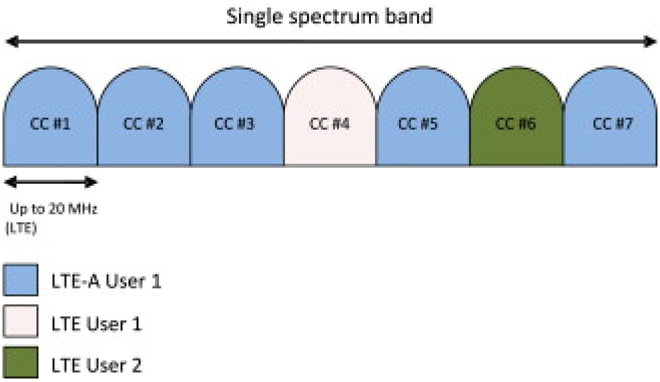


Fig. 2(b). Carrier aggregation in noncontiguous bandwidth, single band

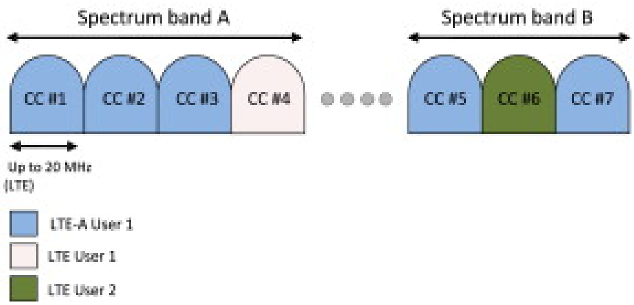


Fig. 2(c). Carrier aggregation in non-contiguous bandwidth, multiple bands

The aggregation of carriers can be done in different ways. Figure 2 (a,b,c) [5] shows the different CA types. In the Intraband aggregation with frequency contiguous CC mode, the available multiple spectrum bands of upto 20 MHz each and adjacent to each other, can be used to form a 40 MHz band single spectrum. Intra band aggregation with noncontiguous CC makes use of CCs in same frequency band e.g. 800 MHz but not necessarily adjacent to each other. Whereas in Interband aggregation with non-contiguous CCs, carriers belonging to multiple bands (located in different frequency bands) are aggregated to serve a single unit of LTE-A UE [9] e.g. 20 MHz (800 MHz) + 20 MHz (2.1 GHz) or 20 MHz (1.8 GHz) + 20 MHz (2.6 GHz) CCs aggregation combinations can be used to form a 40 MHz transmission bandwidth for downlink with interband noncontiguous CA. Thus this technique provides a practical approach for the operators to fully utilize either the current spectrum resources of frequency bands, in the frequency range below 4 GHz [10] which have already been allocated to legacy systems like GSM and UMTS, or the unused and scattered frequency bands in the range of frequencies >4GHz. Table I [5] lists the primary proposed LTE-A deployment scenarios.

Table 1. Primary LTE-Advanced Deployment Scenarios.

Scenario no.	**Description**	**Transmission BWs of LTE-A carriers**	**No. of LTE-A CCs**	**Bands for LTE-A carriers**	**Duplex modes**
1	Single-band contiguous spec. alloc. @ 3.5 GHz band for FDD	UL: 40 MHz DL: 80 MHz	UL: Contiguous 2x20 MHz CCs DL: Contiguous 4x20 MH CCs	3.5 GHz band	FDD
2	Single-band contiguous spec. alloc. @ Band 40 for TDD	100 MHz	Contiguous 5x20 MHz CCs	Band 40 (3.5 GHz band)	TDD
3	Multi-band non-contiguous spec. alloc. @ Bands 1, 3 and 7 for FDD	UL: 40 MHz DL: 40 MHz	UL/DL: Non-contiguous 10 MHz CC@Band 1+10 MHz CC@Band 3+20 MHz CC@Band 7	Band 3 (1.8 GHz), Band 1 (2.1 GHz), Band 7 (2.6 GHz)	FDD
4	Multi-band non-contiguous spec. alloc. @ Bands 39, 34 and 40 for TDD	90 MHz	Non-contiguous 2x20 + 10 + 2x20 MHz CCs	Band 39 (1.8 GHz), Band 34 (2.1 GHz), Band 40 (2.3 GHz)	TDD

A noncontiguous FDD deployment scenario has been shown in Figure 3. Here a 40 MHz system is formed using 10 MHz (1.8 GHz) + 10MHz (2.1 GHz) + 20 MHz (2.6 GHz). Spurious emissions into adjacent bands are taken care of by guard bands. Figure 3 illustrates the contiguous CA scenario wherein 2 x 20 MHz CCs form a 40 MHz system. Here, the available spectrum is more efficiently utilized due to narrower or no guard band between adjacent carriers of same eNB. To ensure the spacing of multiples of 300 KHz between the centre frequencies of the adjacent carriers, unused sub carriers are used [11]. Prioritized deployment scenarios for LTE-A were proposed in [12]. Aggregation in 3.5 MHz band is also planned.

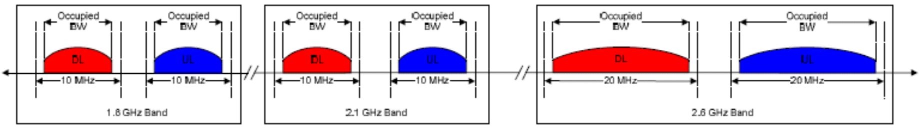


Fig. 3. Non contiguous FDD deployment over multiple bands

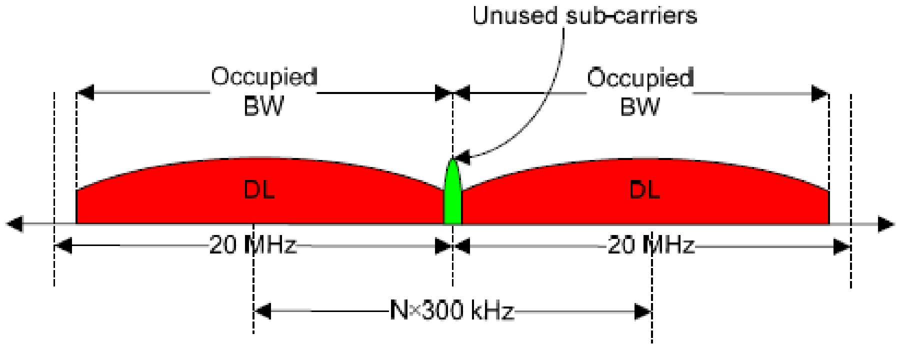


Fig. 4. Contiguous FDD deployment in single band

For a LTE-A UE unit, the contiguous CA is easier to be implemented as it can be realized with single FFT and a single radio frequency (RF) unit. Resource allocation and management algorithms can be easily implemented for this scheme. But the complexity of the LTE-A UE increases in case of noncontiguous CA, as the radio network planning phase and the design of the RRM algorithms should consider that different CCs will exhibit different path loss and Doppler shifts [13].

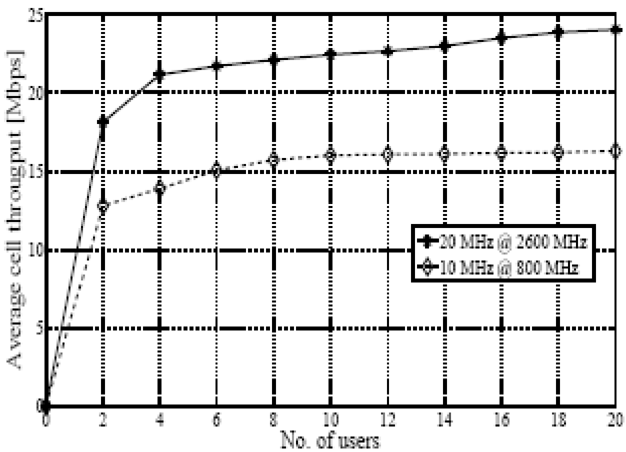


Fig. 5. Cell Throughput comparison of 20 MHz and 10 MHz

In [14], Fourat Haider and et. al have studied the effect of path losses on the cell throughput in different single carrier frequency bands. As shown in figure 5, in 2.6GHz band there is only 50% of increase in cell throughput, even when the bandwidth is doubled, as compared to operation in the 800 MHz band. Whereas, figure 6 shows that due to frequency diversity, if CA is implemented at 2.6 GHz, the throughput is 50% higher than single carrier transmission at 800 MHz and 2.6 GHz.

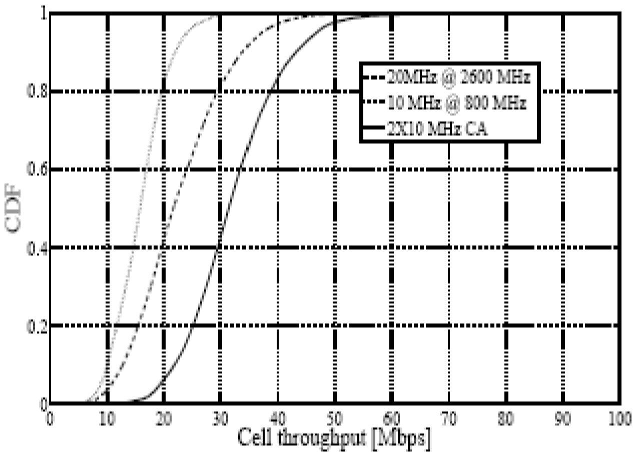


Fig. 6. CDF of Cell Throughput

Yuan G. and et. al. have discussed the effects of Doppler shifts on BER performance under different modulation schemes [10]. On account of large Doppler shifts, systems with high speed mobiles will have self interference or intersystem interference. To overcome this problem, in contiguous CA schemes, LTE technical specification [15] suggests about allocating 10% of total bandwidth specifically for inserting guard bands between adjacent component carriers. Figure 7 shows the BER performance with and without Doppler frequency shift.

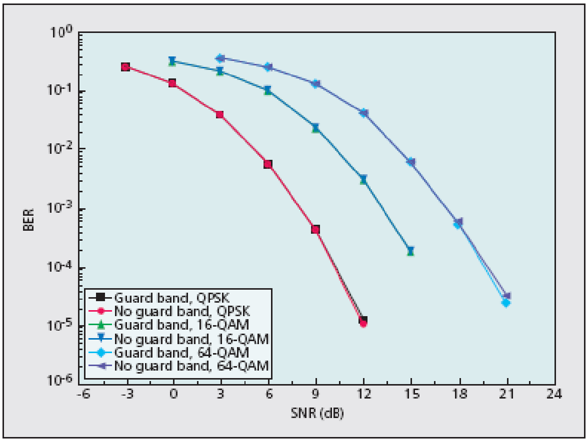


Fig. 7. BER Performance With and Without Doppler Frequency Shift

3 Downlink and Uplink Carrier Configurations in LTE-A Systems

In case of symmetric configurations, uplink and downlink carriers are always paired. In asymmetric CA configurations there are multiple downlink CCs for a UE and only one uplink CC. This causes ambiguity in the selection of downlink CC. The LTE-A eNB has difficulty in identifying the CC to which the UE will anchor in DL at the time of random access response to the UE. As per release 10, the LTE radio interface can be configured with any number of carriers (upto 5 carriers), of any bandwidth, inclusive configuration of downlink and uplink, but the number of uplink carriers cannot exceed the number of downlink carriers [16].

4 Deployment Scenarios of LTE-A Carrier Aggregation

The goal of CA is to improve the data rates for users within overlapped areas of cells. For this LTE release 10 has agreed upon several deployment scenarios [17] for design of LTE-A CA systems. Figure 8 [17] shows some of these deployment scenarios exemplifying how, in real network, CA could be deployed in flexible manner. In practice, we can consider large number of CCs and also deployments with mixed scenarios, but here only 2 CCs – CC1 and CC2 – operating at F1 and F2 frequencies respectively have been considered.

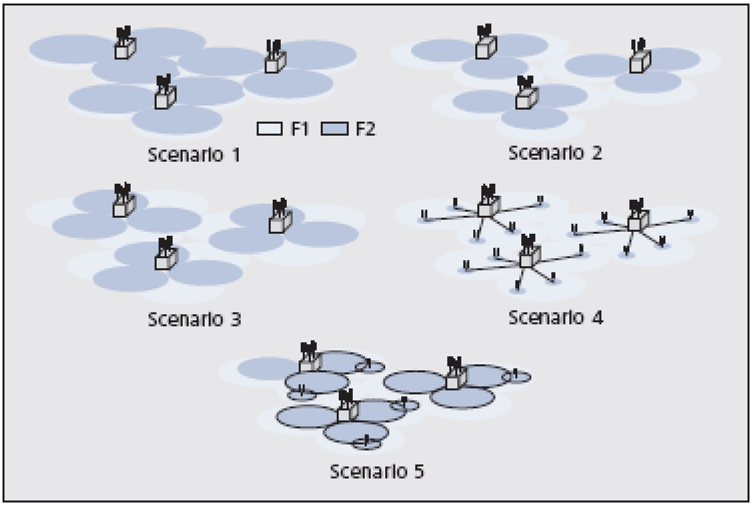


Fig. 8. Carrier aggregation deployment scenarios (F2>F1) [17]: a) scenario 1; b) scenario 2; c) scenario 3; d) scenario 4.

Various factors like the type of area involved in the existing deployed network i.e. urban, suburban or rural; usage of common antennas for all the CCs used; presence or absence of hotspots in the coverage area, determine the most efficient scenario of deployment.

Deployment Scenario 1. This is the most envisaged scenario. Here, eNB antennas with F1 and F2 carrier frequencies are collocated. F1 and F2 belong to same band. The antennas have same beam directions/patterns for both the CCs. Figure 8a shows that the antennas provide nearly same coverage on both carriers as the path loss will be similar within band. Both carriers can support mobility.

Deployment Scenario 2. Here, the collocated eNB antennas with F1 and F2 carrier frequencies operate on CCs belonging to different bands. As shown in figure 8b the coverage for a CC of higher frequency may be smaller as compared to that of the CC of low frequency because there are larger path losses in the higher frequency band. The carrier in the lower frequency band supports mobility whereas high frequency band carrier enables higher data rates and throughput. To solve the problem of intercell interference it is essential to have different coverage for the eNB antennas. For this, they are operated at different transmit power levels and CCs of same band may be deployed at the eNBs. Higher user throughputs are possible, in either cases of CA, at places where overlapping of the coverage of CCs occur.

Deployment Scenario 3. In this scenario eNB antennas operating at F1 and F2 are collocated. The CCs belong to different bands. The antennas are having different beam directions/patterns to support the different sectorization schemes (e.g. 120° sectoring or 60° sectoring). Deployment shown in figure 8c provides improved data rates and throughput at the sector boundaries of cells operating at F1. This is achieved by intentionally shifting the direction of the antenna beams, of cells operating at F2 frequency, towards the boundaries of cells of F1 frequency. CA can be implemented where the coverage area overlaps for the CCs belonging to same eNB.

Deployment scenario 4. In this case the eNB with F1 frequency CC provides macro coverage, while the remote radio heads (RRHs) of F2 frequency CC are placed at traffic hotspots to enable throughput by another CC. The coverage of eNB operating at F1 frequency determines the mobility. The CCs are of different bands. The RRH cells are connected to the eNB via optical fibers so as to enable aggregation of CCs between the macrocell and RRH cell. The operators having deployments as shown in figure 8d can improve the system throughput even with the help of low cost RRH equipments.

Deployment scenario 5. The deployment shown in figure 8e is similar to that of scenario 2 but with additional deployment of frequency selective repeaters and RRH. This scenario has the limitation that the frequency selective repeaters boost certain CCs only as a result of which there is variation in the propagation delay across boosted and non boosted CCs. This in turn requires separate transmission timing control for each CC during UL transmission. This type of scenarios are not considered for LTE release 10 for the UL transmission but are considered in a later release wherein interband CA can also be used for the UL transmission, so as to support traffic growth, spectrum allocation, and feasibility in the device implementation. As for DL transmission, release 10 does consider scenarios with RRH and repeaters [18].

5 Spectrum and Network Sharing among Service Providers

With the advancement in technology, different clients of a service provider are able to use UEs that can support various Radio Access Technologies (RATs) like the LTE, WIMAX, HSPA. This feature enables the service providers to provide a coverage to all of their users by developing different RATs [5]. It solely depends on the operator to decide as to which RAT (s) should the UE be attached to so as to achieve optimum spectrum utilization and the required QoS. Figure 9 shows the operation of Multi RAT scenarios.

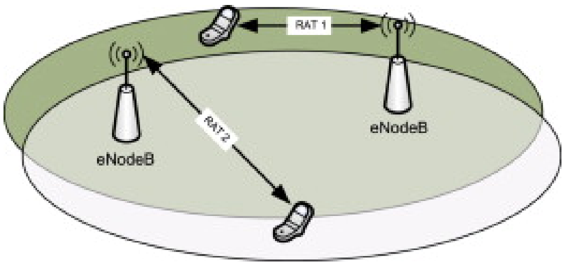


Fig. 9. Multi-RAT scenario

Every RAT will need different spectrum resources. It is the responsibility of the eNB/base stations to manage the spectrum (resources) of the RAT in use. Service providers adopt spectrum sharing concept (network sharing) which is supported by 3GPP [20,21]. Figure 10 [19] depicts the different spectrum aggregation scenarios for FDD. Herein, the service providers can get access to resources of different networks thereby reducing their initial investments. The 2 scenarios of spectrum sharing are shown in figure 11. The spectrum band is shared, between operators using either in noncontiguous carrier aggregation (case 1) or contiguous Carrier Aggregation (case 2) depending upon the way the spectrums are used by the operators. The general scenarios for multioperator network sharing are identified by 3GPP in [20]. FDD and TDD spectrum sharing on dynamic basis have been discussed in [22].

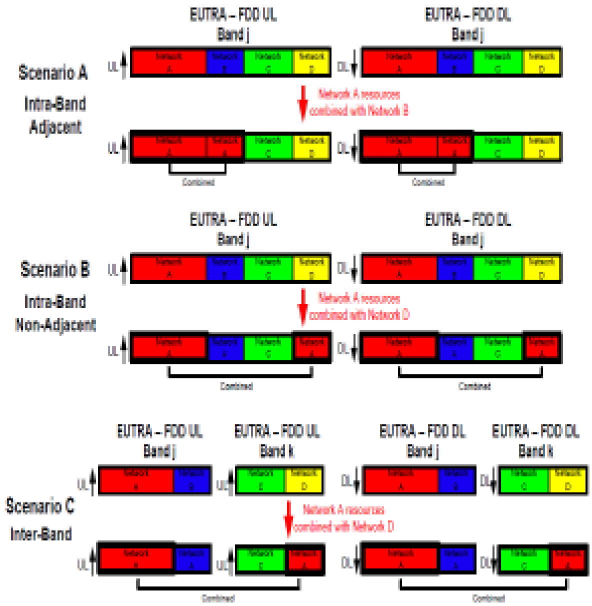
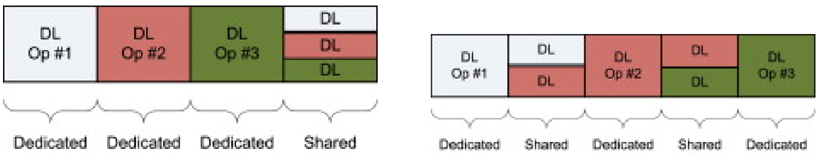


Fig. 10. Spectrum Aggregation Scenarios for FDD [19]



(a) Scenario 1 (b) Scenario 2

Fig. 11. Spectrum sharing scenarios

6 Band Aggregation

The spectrum being already overcrowded, the regulatory bodies are finding it difficult to allocate a contiguous band of 100 MHz to a single operator. The tables 2 and 3 show the bands assigned for E-UTRA (LTE) [23, 24]. It can be seen that they are not broad enough to provide a 100 MHz bandwidth which is essential to meet the basic requirement of IMT-A as defined by ITU (see figure 12). Hence it will be required by the operators to combine the various bands, as shown in table 4, as per the availability of the spectrum resources [4]. Future releases will have to support interband carrier aggregation for TDD, both UL-DL configurations, on different bands in order to ensure coexistence with the already deployed TDD systems.

Table 2. Operating Bands for LTE FDD

LTE Operating Band	Uplink (UL) Operating Band (MHz)	Downlink (DL) Operating Band (MHz)	Main Regions of Use
1	1920 - 1980	2110 – 2170	Asia, Europe
2	1850 - 1910	1930 – 1990	Americas, Asia
3	1710 - 1785	1805 – 1880	Americas, Asia, Europe
4	1710 - 1755	2110 – 2155	Americas
5	824 - 849	869 – 894	Americas
6	830 - 840	875 – 885	Japan
7	2500 – 2570	2620 – 2690	Asia, Europe
8	880 – 915	925 – 960	Asia, Europe
9	1749.9 – 1784.9	1844.9 – 1879.9	Japan
10	1710 – 1770	2110 – 2170	Americas
11	1427.9 – 1452.9	1475.9 – 1500.9	Japan
12	698 – 716	728 – 746	USA
13	777 – 787	746 – 756	USA
14	788 – 798	758 – 768	USA
15	Reserved	Reserved	Reserved
16	Reserved	Reserved	Reserved
17	704 – 716	734 – 746	USA
18	815 – 830	860 – 875	Japan
19	830 – 845	875 – 890	Japan
20	832 – 862	791 – 821	Europe
21	1447.9 – 1462.9	1495.9 – 1510.9	Japan
22	3410 – 3500	3510 – 3600	

Table 3. Operating Bands for LTE TDD

LTE Operating Band	Band Allocation (MHz)	Main Regions of Use
33	1900 – 1920	Asia (not Japan), Europe
34	2010 – 2025	Asia, Europe
35	1850 – 1910	Americas
36	1930 – 1990	Americas
37	1910 – 1930	
38	2570 – 2620	Europe
39	1880 – 1920	China
40	2300 – 2400	Asia, Europe
41	2496 – 2690	USA

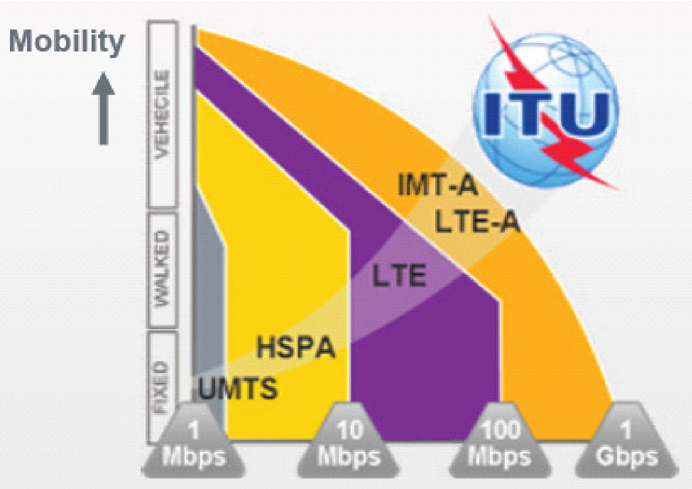


Fig. 12. Data Rates Requirements of IMT-A defined by ITU

Table 4. CA Band or Band Aggregation

CA Band or Band Aggregation	Operator	Duplex Mode
Band 4 + Band 17	AT&T	FDD
Band 2 + Band 17	AT&T	FDD
Band 4 + Band 5	AT&T	FDD
Band 5 + Band 17	AT&T	FDD
Band 41	Clearwire	TDD
Band 38	CMCC	TDD
Band 20 + Band 7	Orange	FDD
Band 3 + Band 7	Telia Sonera	FDD
Band 4 + Band 12	US Cellular	FDD
Band 5 + Band 12	US Cellular	FDD
Band 4 + Band 13	Verizon	FDD

7 Conclusion

This article provides an overview of the carrier aggregation technique used in LTE-Advanced systems for increasing the bandwidth and thereby improving the data rates of LTE-Advanced users. The deployment of CA based system enables efficient spectrum utilization and also increases the cell and user throughput significantly. The fully backward compatibility feature of CA for LTE-Advanced enables the coexistence of legacy Rel. 8 terminals and LTE-Advance terminals. To meet the IMT-Advanced peak data rate requirements, the initial focus of 3GPP was on intraband CA. Release 10 supports interband CA in Downlink for a limited number of bandwidth combination whereas Release 11 will provide full support for non-contiguous carrier aggregation.

References

1. 3GPP TR 36.913 v8.0.0: Requirements for further advancements for E-UTRA (LTE-Advanced) (June 2008)
2. Recommendation ITU-R.M.1645: Framework and overall objectives of the future development of IMT 2000 ans systems beyond IMT 2000 (June 2003)
3. Dahlman, E., Parkvall, S., Skold, J.: 4G LTE/LTE-Advanced for Mobile Broadband, pp. 132–134. Elsevier, UK (2011)
4. Shen, Z., Papasakellariou, A., Montojo, J., Gerstenberger, D., Xu, F.: Overview of 3GPP LTE-Advanced Carrier Aggregation for 4G wireless Communications. IEEE Communications Magazine (2012)
5. Akyildiz, I., Gutierrez-Estevez, D., Chavarria, R.: The evolution to 4G cellular systems: LTE-Advanced. Physical Communication 3, 217–244 (2010)
6. Yonis, A., Abdullah, M., Ghanim, M.: Design implementation of Intra band Contiguous Component Carriers on LTE-A. International Journal of Computer Applications 41(14) (March 2012)
7. 3GPP R4-091910: LTE-A MC RF requirements for contiguous carriers (May 2009)
8. Wang, H., Rosa, C., Pedersen, K.I.: Performance Analysis of Downlink Inter-band Carrier Aggregation in LTE-Advanced. In: IEEE Vehicular Technology Conference, September 1-5 (Fall 2011)
9. 3GPP, TR 36.815 V9.1.0: Further advancements for E-UTRA LTE-Advanced feasibility studies in RAN WG4, Rel. 10 (June 2010)
10. Yuan, G., Zhang, X., Wang, W., Yang, Y.: Carrier aggregation for LTE-Advanced mobile communication systems. IEEE Communications Magazine 48(2), 88–93 (2010)
11. Ratasuk, R., Tolli, D., Ghosh, A.: Carrier Aggregation in LTE-Advanced. In: IEEE 71st Vehicular Technology Conference (VTC 1010- Spring) (2010)
12. Krouk, E., Semenov, S.: Modulation and coding techniques in wireless communications, pp. 600–603. Wiley, UK
13. Ingemann, K., Frederiksen, F., Rosa, C., Nguyen, H., Garcia, L., Wang, Y.: Carrier aggregation for LTE-Advanced: Functionality and Performance Aspects. IEEE Communication Magazine (June 2011)
14. Haider, F., Hepsaydir, E., Binucci, N.: Performance Analysis of LTE-Advanced Networks in Different Spectrum Bands. In: Wireless Advanced (WiAD) Conference, July 20-22 (2011)
15. 3GPP TS 36.104 v. 9.1.0: Base Station (BS) RadioTransmission and Reception, Tech. Spec. Group Radio Access Network, Rel. 9 (September 2009)
16. Anritsu: LTE-Advanced: Carrier Aggregation, white paper (September 2011)
17. 3GPP TS 36.300 v10.3.0: Evolved Universal Terrestrial Radio Access (E-UTRA) and Evolved Universal Terrestrial Radio Access Network (E-UTRAN), Overall description, stage 2 (Release 10), TSG RAN
18. Iwamura, M., Etemad, K., Fong, M., Nory, R., Love, R.: Carrier Aggregation Framework in 3GPP LTE-Advanced. IEEE Communication Magazine (August 2010)
19. 4G Americas: 4G Mobile broadband evolution: 3GPP Release 10 and beyond HSPA, SAE/LTE and LTE-Advanced, pp. 51-52 (February 2011)
20. 3GPP, TR 22.951 Service aspects and requirements for network sharing, Tech. Rep., (December 2009), `http://ftp.3gpp.org/specs/html-info/22951.htm`

21. 3GPP, TS 23.251 Network sharing; architecture and functional description, Tech. Rep. (March 2010), http://ftp.3gpp.org/specs/html-info/23251.htm
22. CELTIC/CP5-026 WINNER+, D1.2 initial report on system aspects of flexible spectrum use, Tech. Rep. (January 2009)
23. Georgoulis, S.: How to Test Carrier Aggregation in LTE-Advanced Networks, White Paper (2012), http://www.eetimes.com/design/test-and-measurement/4376129/How-to-test-carrier-aggregation-in-LTE-Advanced-networks
24. Rhode & Schwarz: LTE-Advanced Technology Introduction Application Note (March 2010)