Wider Bandwidth of non-Contiguous Component Carriers in LTE-Advanced

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Abstract

The 3GPP Long Term Evolution-Advanced (LTE-A) system extends the capabilities of 3rd Generation Partnership Project (3GPP) LTE Rel-8 with the support of carrier aggregation, where two or more component carriers are aggregated in order to support wider transmission bandwidths up to 100 MHz and for spectrum aggregation. A user terminal may simultaneously receive or transmit one or multiple component carriers depending on its capabilities. From the User Equipment (UE) perspective, the Layer 2 aspects of Hybrid automatic repeat request (HARQ) are similar to those of Rel-8. There is one transport block (in the absence of spatial multiplexing, or up to two transport blocks in the case of spatial multiplexing) and one independent HARQ entity per scheduled component carrier. Each transport block (TB) is mapped to a single component carrier on which all HARQ re-transmissions may take place. A UE may be scheduled over multiple component carriers simultaneously, but at most one random access procedure will be ongoing at any time. This paper presents the main types of carrier aggregation and focuses on intra band non-contiguous carrier aggregation. A simulation is designed to show the main performance of intra band non-contiguous carrier aggregation for different frequencies between 30 MHz – 100 MHz.

Keywords: *LTE-Advanced, Carrier Aggregation (CA), Intra-band non-Contiguous Aggregation*

1. Introduction

LTE (Rel-8) delivers improved system capacity and coverage, improved user experience through higher data rates, reduced-latency deployment, and reduced operating costs, and seamless integration with existing systems. Further enhanced requirements, however, were approved in 2008 to allow LTE to be approved as a radio technology for International Mobile Telecommunications-Advanced (IMT-Advanced). IMT-Advanced requirements are defined by the International Telecommunication Union, which is an organization that provides globally accepted standards for telecommunications [1].

This further advancement for LTE is known as LTE-Advanced (LTE-A). Peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink must be supported. Target latencies have been significantly reduced as well. In addition to advancements in system performance, deployment and operating-cost-related goals were also introduced. They include support for cost-efficient multi-vendor deployment, power efficiency, efficient backhaul, open interfaces, and minimized maintenance tasks. A comprehensive list of LTE-A requirements can be found in [2]. In order to achieve these LTE-A requirements related to system performance, numerous physical-layer enhancements have been introduced in LTE-A [3, 4]. They include carrier aggregation, enhanced downlink spatial multiplexing, uplink spatial multiplexing, and support for heterogeneous networks. Carrier aggregation allows multiple carriers to be aggregated to provide bandwidth extension up to 100MHz.

Carrier aggregation is a feature in LTE-A to enable bandwidth extension to support deployment bandwidths of up to 100MHz. This is done by aggregating several carriers to provide a larger system bandwidth [5, 6]. It will allow LTE-A target peak data rates in excess of 1 Gbps in the downlink and 500 Mbps in the uplink to be achieved [2]. In addition to the increased peak data rates, carrier aggregation also allows advanced features such as multi-carrier scheduling, carrier load balancing, quality-of-service (QoS) differentiation, interference coordination, and heterogeneous deployment to be used to further increase the spectral efficiency of the system.

This paper is presenting the main principles of carrier aggregation in LTE and LTE-A in Section 2, the transmitter structure is explained in details in Section 3. Spectrum Aggregation for non-contiguous carrier aggregation is clarified in Section 4, while the implementation of both Evolved Node B (eNB) and User Equipment (UE) are described in Sections 5 and 6. Carrier aggregation performances are presented in Section 7. Data packets in LTE-Advanced are defined in details in Section 8. Finally, all the simulation results, discussions and conclusions are shown in Sections 9, 10 and 11 respectively.

2. Carrier Aggregation in LTE and LTE-A

LTE Release 8 provides extensive support for deployment in a variety of spectrum allocations, ranging from 1.4 MHz to 20 MHz, in both paired and unpaired bands. Beyond 20 MHz, the only reasonable way to achieve LTE-Advanced highest target peak-throughput rates is to increase the transmission bandwidth, relative to Release 8. Therefore, LTE-Advanced specifies spectrum allocations of up to 100 MHz using “carrier aggregation”, where multiple component carriers are combined to provide the necessary bandwidth. It is possible to configure all component carriers that are LTE Release 8 compatible, at least when the aggregated numbers of component carriers in the Uplink (UL) and the Downlink (DL) are the same [7].

However, not all component carriers are necessarily Release 8 compatible. Figure 1 shows Types of carrier aggregation with contiguous component carriers (Intra-band) and with non-contiguous carrier (Intra-band) and Inter-band non-contiguous component carriers respectively.

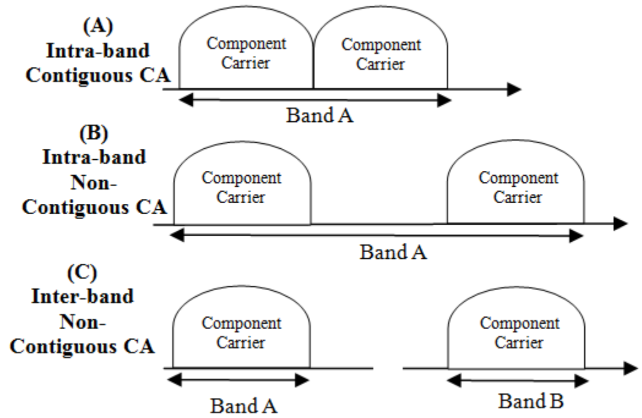

Figure 1. Three types of carrier aggregation [7]

In order, to insure the backward compatibility of eNB resource allocations, only minimum changes are required in the specifications if the scheduling, MIMO, Link Adaptation and HARQ are all performed in carrier groupings of 20MHz. For example, a user receiving information in the 100MHz bandwidth will need 5 receiver chains, one per each 20MHz block. Carrier aggregation is supported for both contiguous and non-contiguous component carriers, with each component carrier limited to a maximum of 110 Resource Blocks (RB) in the frequency domain (using LTE Release 8 numbering). It is possible to configure a UE to aggregate a different number of component carriers originating from the same eNB and possibly different bandwidths in the UL and the DL. Of course, in typical Time Division Duplex (TDD) deployments, the number of component carriers and the bandwidth of each component carrier in UL and DL will be the same.

The center frequency spacing of contiguously aggregated component carriers is in multiples of 300 kHz. This is in order to be compatible with the 100 kHz frequency increments of Release 8 while at the same time preserving the orthogonality of subcarriers with 15 kHz spacing. Depending on the aggregation scenario, the N*300 kHz spacing can be achieved by inserting a small number of unused subcarriers between contiguous component carriers. There are three scenarios for carrier aggregations:

2.1 Intra-band aggregation with frequency contiguous component carriers (CCs)

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

2.2 Intra-band aggregation with non-contiguous component carriers (CCs)

This is where multiple CCs belonging to the same band are used in a non-contiguous manner as shown in Figure 1 (B). This scenario can be expected in countries where spectrum allocation is non-contiguous within a single band, when the middle carriers are loaded with other users, or when network sharing is considered. Therefore this model would fit operators in North America or Europe, who have fragmental spectrum in one band or share the same cellular network [8].

2.3 Inter-band aggregation with non-contiguous component carriers (CCs)

Inter-band carrier aggregation implies that carriers in different operating bands are aggregated, see example in Figure 1 (C). Many RF properties within a band can, to a large extent, remain the same as for a single carrier case. For non-contiguous carrier aggregation, the component carriers are usually separated by a sufficient frequency gap; therefore, the interference between aggregated bands is negligible. However, there are still frequency bands belonging to other systems adjacent to each component carrier that may cause interference. In a high-speed mobile environment, large Doppler frequency shift, nonlinear frequency response of a power amplifier and/or the asymmetric characteristic of a crystal oscillator and the effect of frequency aliasing may affect the orthogonality between adjacent frequency bands and may potentially cause inter-band interference. The aliasing effect may significantly degrade the BER performance, especially when high-order modulation schemes are used. Therefore, for both contiguous and non-contiguous carrier aggregation, the guard bands for a component carrier should be carefully set to suppress the intra-system and/or inter-system interference, while maintaining high spectral efficiency in data transmission [9].

3. LTE-A Transmission Structure

The LTE-A transmission structure has the same basic format as LTE. However, due to the introduction of carrier aggregation, the total system bandwidth may be extended by combining multiple component carriers, each of which corresponds to an LTE compliant bandwidth.

In the downlink, the number of Transport Blocks (TBs) transmitted simultaneously to each UE may be increased with carrier aggregation since the maximum two TBs per subframe are applied per component carrier.

In the uplink, the basic multiple access scheme is enhanced to support noncontiguous allocation of Resource Blocks (RBs) to each UE so called clustered DFT-spread Orthogonal frequency-division multiplexing (OFDM). This allows for improved multiuser gain since each UE can be more accurately allocated to RBs where the corresponding channel is strong. However, a side-effect is that the PAPR of the transmitted signal is slightly degraded due to the resulting discontinuities in the mapping of the DFT-spread signal to subcarriers [10].

In addition, due to the introduction of SU-MIMO spatial multiplexing in the uplink, up to two TBs may be simultaneously transmitted per subframe and component carrier. The resulting uplink transmission structure (per component carrier) is shown in Figure 2.

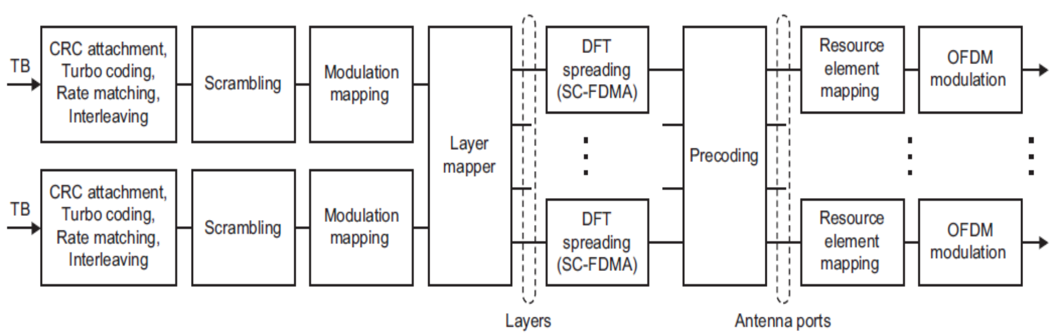

Figure 2. LTE-A Uplink transmission structure [10]

4. Spectrum Aggregation

For aggregation of non-contiguous component carriers, each carrier should meet existing LTE spectrum requirements such as emission mask, adjacent channel leakage and spurious emission to provide backward compatibility and ensure minimal interference to adjacent carriers. An example is shown in Figure 3 for the non-contiguous frequency division duplexing (FDD) [11] deployment scenario from Table 1, 40 MHz FDD using 10 MHz (1.8 GHz) + 10 MHz (2.1 GHz) + 20 MHz (2.6 GHz). In this case, each component carrier is provisioned with guard band to minimize spurious emissions into adjacent bands [12].

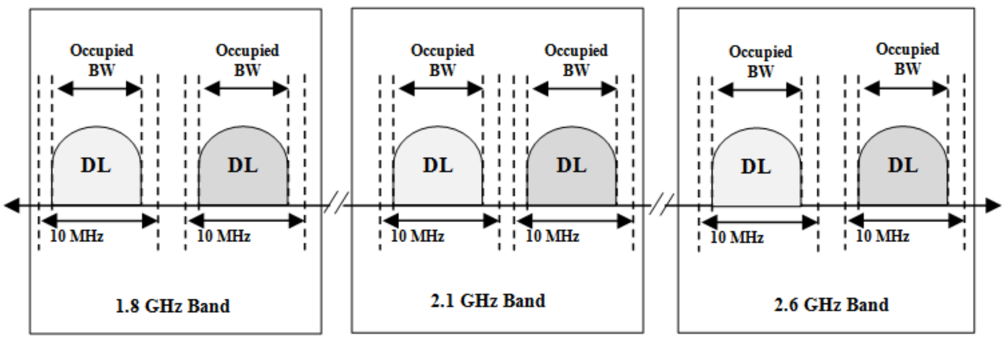

Figure 3. Non-contiguous FDD deployment over multiple bands [12]

In case of contiguous carrier aggregation, however, large guard band is not necessary. Therefore by removing or relaxing the guard band between adjacent carriers of the same eNB, a more efficient use of the available spectrum is possible. In addition, for the downlink, a single IFFT may be used, which reduces implementation complexity and provide some cost saving.

Table 1. LTE-A deployment scenarios [13]

	Deployment Scenario	Carrier Aggregation
FDD	Contiguous single band UL:40 MHz DL: 80 MHz	UL: 2x20MHz(3.5 GHz) DL:4x20 MHz(3.5 GHz)
FDD	Non-contiguous multiple bands UL:40 MHz DL:40 MHz	UL: 10 MHz(1.8 GHz)+ 10 MHz(2.1 GHz)+ 20 MHz(2.6 GHz) DL: 10 MHz(1.8 GHz)+ 10 MHz(2.1 GHz)+ 20 MHz(2.6 GHz)
TDD	Contiguous single band 100 MHz	5x20 MHz(2.3 GHz)
TDD	Non-Contiguous single band 80 MHz	2x20 MHz(2.6 GHz) + 2x20 MHz(2.6 GHz)

However, due to LTE channel raster of 100 kHz and 15 kHz subcarrier spacing, the spacing between the center frequencies of the carriers must be a multiple of 300 kHz to satisfy both conditions. This is shown in Figure 4 where a number of unused subcarriers are placed between carriers to ensure the separation between center frequencies is a multiple of 300 kHz. The reclaimed spectrum may be used to provide additional guard band. Although the above two examples are for FDD, similar conclusions may be drawn for TDD systems.

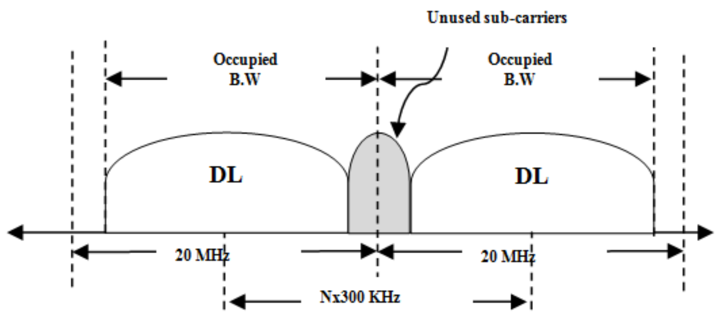

Figure 4. Contiguous FDD deployment in a single band [12]

5. Evolved Node B Implementation

A block diagram of the downlink transmitter chain is shown in Figure 5 for contiguous carrier aggregation. Because the aggregated carriers are contiguous, a single transmitter chain including one IFFT may be used. However, current Linear Power Amplifier (LPA) technologies are capable of supporting 20-30 MHz modulation bandwidth at the required efficiencies. In order to efficiently support the large bandwidth required for LTE-A, LPA combining techniques need to be considered. Techniques often considered for combining LPA resources include hybrid combining, cavity combining, coherent combining and combining using Fourier Transform Matrix. The choice of combiner techniques depends on trade-offs between design criteria such as cost, complexity, LPA bandwidth, total transmission bandwidth and whether the bands to be combined are contiguous or non-contiguous.

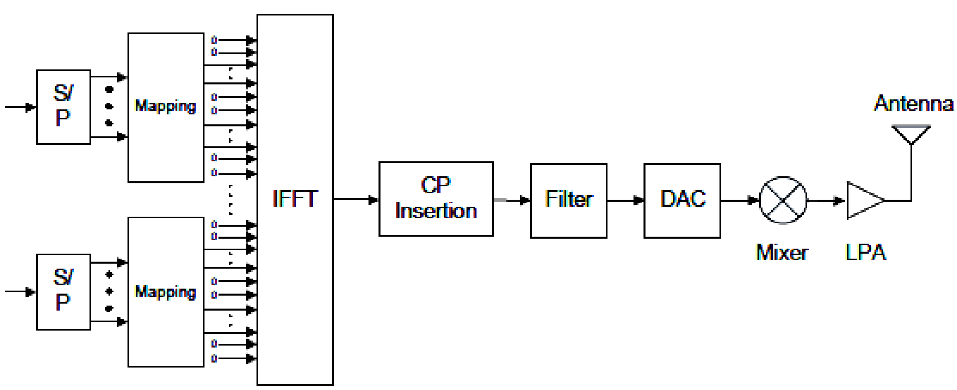

Figure 5. Transmitter block diagram for downlink carrier aggregation

For non-contiguous aggregation, LPA should not be a concern as multiple transmitter chains including IFFTs are required. In this case, however, the transmitters must be carefully designed and isolated to prevent mixing of the signals that can lead to spurious emissions.

6. User Equipment Implementation

In LTE uplink, Single-Carrier Frequency Division Multiple Access (SC-FDMA) using DFT-Spread OFDM is the physical layer access scheme. SC-FDMA has many similarities to OFDM; chief among them is frequency domain orthogonality among users. SC-FDMA also has a low power amplifier de-rating requirement, thereby conserving battery life or extending range [14]. Carrier aggregation is supported in the uplink using N×SC-FDMA. A block diagram of the uplink demonstrating N×SC-FDMA for N=2 is shown in Figure 6. Similar to the downlink, a single transmitter chain may be used since the aggregated carriers are contiguous. However, N DFT-IFFT pairs are required to implement carrier aggregation in the uplink [15].

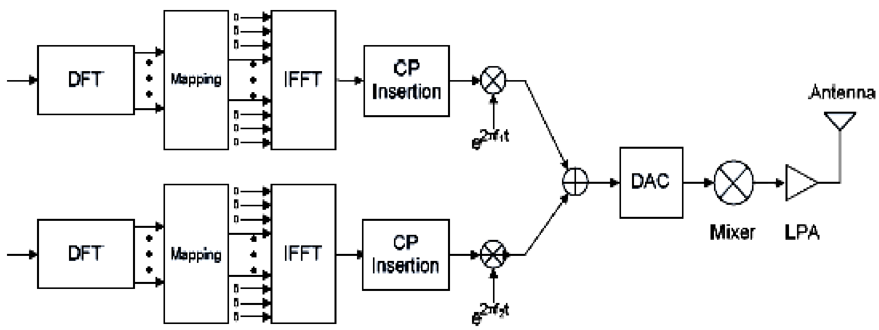

Figure 6. Transmitter block diagram for uplink carrier aggregation

Therefore, with carrier aggregation, single carrier property in the uplink is no longer preserved when transmitting on multiple carriers. As a result, the cubic metric increases which require larger back-off in the power amplifier, thereby reducing the maximum transmit power at the UE. A comparison of the cubic metric for different number of SC-FDMA carriers is shown in Figure 7.

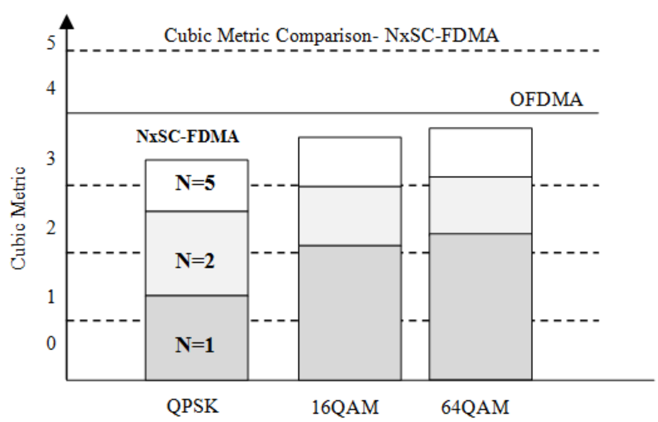

Figure 7. Cubic metric comparison for N×SC-FDMA

From the figure above, it is seen that there is a substantial increase in cubic metric when transmitting on multiple uplink carriers. However, multi-carrier transmission will generally be restricted to UEs in good channel condition; therefore should be no loss of coverage for those users. Instead, higher transmission power will be required which may impact battery life. On the other hand, users at the cell-edge will most likely be scheduled only on a single carrier. In this case, coverage may actually be improved since the eNB has the ability to dynamically assign the users to the best uplink carrier.

7. Carrier Aggregation Performance

The use of carrier aggregation benefits system performance in two ways; firstly, there is an increased peak data rate when enabling the aggregation of spectra for more than single frequency band. The theoretical peak data rate from the combination use of carrier aggregation with total of 40 MHz spectrum and up to eight antennas reaches up to 1 Gbps in the downlink and in the uplink up to 500 Mbps with the technologies. Secondly, improved average user throughput, especially when the number of users is not too high. Joint carrier scheduling in the eNodeB allows the optimal selection of the carrier to use thus leading to better performance and optimal load balancing between the carriers.

8. Data Packets in LTE-Advanced

In LTE, data is encapsulated in a medium-access control (MAC) packet data unit (PDU) and forwarded to the physical (PHY) layer for transmission over the air. The size of the supportable transmission packet is given by the transport-block-size (TBS) table using the procedure with carrier aggregation; however, the supportable data packet size will increase significantly. Instead of expanding the TBS table, LTE-A adopted the approach shown in Figure 8, whereby the physical layer remains the same as in LTE Rel-8. The MAC PDU is instead segmented into multiple packet data units such that each data packet will fit into one carrier. This interface requires minimal changes to the physical-layer specifications, and also allows individual control for the transmission of data on each of the carriers. However, separate HARQ processing and associated control signaling is required for each of the component carriers. Separate HARQ is advantageous because, if one of the segmented packets is received in error, only that packet need be retransmitted, not the entire MAC PDU. In addition, separate physical-layer processing allows individual link adaptation and MIMO support for each carrier. This can improve throughput since the amount of data transmitted on each carrier can be independently matched to the channel conditions on each carrier. However, an increase in overhead is expected due to the segmentation process. Thus, this method is not efficient for small packet size, and therefore smaller packets should not be transmitted on multiple carriers. For large packet size, however, this increased overhead is expected to be only a small fraction of the packet size. The data transmission chain in Figure 8 is valid both for the downlink and for the uplink. In the downlink, OFDM is used and multiple transmitter chains will be required for non-contiguous aggregation. With contiguous aggregation, a single transmitter chain with one IFFT may be used. In the uplink, carrier aggregation is supported using N-SC-FDMA transmission. With carrier aggregation, the single-carrier property in the uplink is no longer preserved when transmitting on multiple carriers. As a result, the cubic metric increases, which require larger back-off in the power amplifier, thereby reducing the maximum transmit power at the UE. For instance, when transmitting on two simultaneous carriers, the peak output power of the user is reduced by approximately 1–2 dB. As a result, there may be a loss of coverage of LTE-A users transmitting on multiple carriers simultaneously. This can be compensated for by smart scheduling, whereby users with poor channel conditions will be restricted to transmitting in just a single carrier [1].

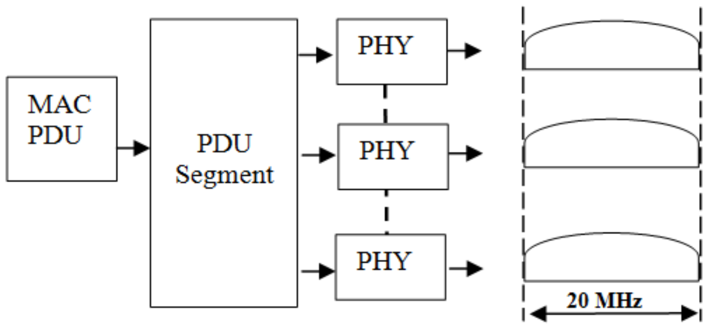

Figure 8. Data transmission for carrier aggregation

9. Simulation Results

The program SystemVue (product of Agilent Company) is used to clarify the types of Intra band Contiguous Component Carriers on LTE-Advanced. The results show the CA Spectrum Power simulation for different bandwidths of LTE-Advanced System (30 MHz and 100 MHz) [16].

10. LTE-Advanced Downlink Non-Contiguous Component Carriers to support 30 MHz -100 MHz

The program simulation is use to generate LTE-Advanced downlink signals with non-contiguous carrier aggregation within a single band, because it cannot generate multi-band carrier aggregation. The frequency band (center frequency), bandwidth of the component carrier, oversampling ratio and the number of Tx antennas can be changed in the parameter tab.

Operating bands of LTE-Advanced will involve E-UTRA operating bands as well as possible IMT bands identified by ITU-R. E-UTRA is designed to operate in the operating bands as defined in [17]. E-UTRA operating bands are shown in Table 2.

Table 2. Operating bands for LTE-Advanced (E-UTRA operating bands) [18]

E-UTRA Operating Band	Uplink (UL) operating band BS receive UE transmit			Downlink (DL) operating band BS transmit UE receive		
	F_{UL_low}	–	F_{UL_high}	F_{DL_low}	–	F_{DL_high}
1	1920 MHz	–	1980 MHz	2110 MHz	–	2170 MHz
2	1850 MHz	–	1910 MHz	1930 MHz	–	1990 MHz
3	1710 MHz	–	1785 MHz	1805 MHz	–	1880 MHz
4	1710 MHz	–	1755 MHz	2110 MHz	–	2155 MHz
5	824 MHz	–	849 MHz	869 MHz	–	894MHz
6 Note 1	830 MHz	–	840 MHz	875 MHz	–	885 MHz
7	2500 MHz	–	2570 MHz	2620 MHz	–	2690 MHz
8	880 MHz	–	915 MHz	925 MHz	–	960 MHz
9	1749.9 MHz	–	1784.9 MHz	1844.9 MHz	–	1879.9 MHz
10	1710 MHz	–	1770 MHz	2110 MHz	–	2170 MHz
11	1427.9 MHz	–	[1447.9] MHz	1475.9 MHz	–	[1495.9] MHz
12	698 MHz	–	716 MHz	728 MHz	–	746 MHz
13	777 MHz	–	787 MHz	746 MHz	–	756 MHz
14	788 MHz	–	798 MHz	758 MHz	–	768 MHz
15	Reserved			Reserved		
16	Reserved			Reserved		
17	704 MHz	–	716 MHz	734 MHz	–	746 MHz
18	815 MHz	–	830 MHz	860 MHz	–	875 MHz
19	830 MHz	–	845 MHz	875 MHz	–	890 MHz
20	832 MHz		862 MHz	791 MHz		821 MHz
21	1447.9 MHz		1462.9 MHz	1495.9 MHz		1510.9 MHz
22	[3410] MHz		[3500] MHz	[3510] MHz		[3600] MHz
...						
33	1900 MHz	–	1920 MHz	1900 MHz	–	1920 MHz
34	2010 MHz	–	2025 MHz	2010 MHz	–	2025 MHz
35	1850 MHz	–	1910 MHz	1850 MHz	–	1910 MHz
36	1930 MHz	–	1990 MHz	1930 MHz	–	1990 MHz
37	1910 MHz	–	1930 MHz	1910 MHz	–	1930 MHz
38	2570 MHz	–	2620 MHz	2570 MHz	–	2620 MHz
39	1880 MHz	–	1920 MHz	1880 MHz	–	1920 MHz
40	2300 MHz	–	2400 MHz	2300 MHz	–	2400 MHz
[41]	[3400] MHz		[3600] MHz	[3400] MHz		[3600] MHz
Note 1: Band 6 is not applicable.						

10.1. Simulation of non- Contiguous CCs to support Channel Bandwidth 30 MHz

LTE-Advanced system is built using simulation and necessary tools and after execution bandwidth channel is calculated. It is clear that 30 MHz is the maximum bandwidth with transmission bandwidth configuration 30 MHz LTE-Advanced non-contiguous carrier aggregation (5 MHz+5 MHz component carriers) and data of the designed system is broadcasted over the operating band 6 which is included as one of the bands of LTE-Advanced in Table 2.

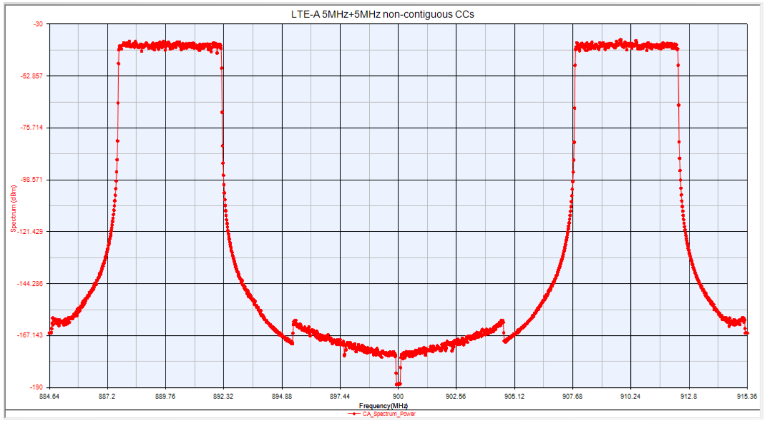

Figure 9. LTE-A non-contiguous CCs with channel bandwidth 30 MHz

10.2. Simulation of non-Contiguous CCs to support channel bandwidth 100 MHz

Through carrier aggregation technique (which is supported by LTE-Advanced) bandwidth channel can be calculated for the system. In this case, Simulink and tools are used to build the current system to support 100 MHz LTE-Advanced non-contiguous carrier aggregation (2x20 MHz+2x20 MHz component carriers) is simulated. Figure 10 shows the downloading of 80 MHz transmission bandwidth configuration LTE-Advanced signal and data of the designed system is broadcasted over the operating band 41 (3400 MHz- 3600 MHz) which is included as one of the bands of LTE-Advanced in Table 2.

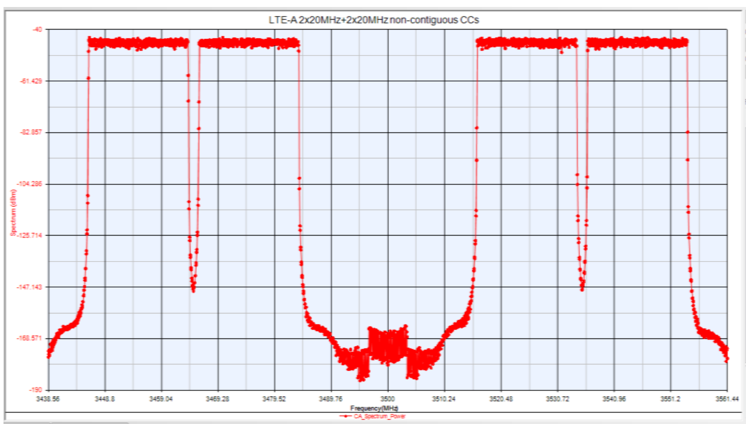

Figure 10. LTE-A non-contiguous CCs with channel bandwidth 100 MHz

From the deployment scenarios for LTE-Advanced it is clear that single–band non-contiguous shown in Figure 9 has the number of LTE-A component carriers equal to 2 (1x5+ 1x5 MHz) while Figure 10 has the number of LTE-A component carriers equal to 4 (2x20 + 2x20 MHz) and the bands for LTE-A carriers is 3.5 GHz. The used modes of duplex are FDD only.

The simulation results presented demonstrate the high potential of LTE-Advanced in terms of both, overall spectral efficiency which benefit all of operators and high cell-edge performance that benefit the end-user. In addition, this research proved that enhancement of LTE-A which includes bandwidth equal to 100 MHz and peak data rate 1 Gbps. The new implemented LTE-A presented better performance, larger bandwidth and better peak data rate at the same level of efficiency of LTE-A system; The new design supports bandwidths of 30 MHz and 100 MHz with progressive peak data rate exceeds 4 Gbps. The main advantages of designed system is because, they are getting better coverage and improve spectral efficiency (cell edge and average) which is achieved through robust interference management and greater flexibility with wideband deployments by employing wider bandwidth by carrier aggregation across bands.

11. Conclusions

As mentioned earlier, there are two types of carrier aggregation: contiguous; and non-contiguous. Noncontiguous carrier aggregation can be in the form of intra-band or inter-band. The different types of carrier aggregation will result in different deployment scenarios. LTE-A non-contiguous downlink system has been designed and simulated using SystemVue 2011 Program to show the main performance of intra band non-contiguous carrier aggregation for different frequencies between 30 MHz - 100 MHz. In practice, a mobile station is typically able to measure two carriers at the same time in active mode. The mobile station's battery consumption may be increased due to the activation of several carriers which required continuously monitored and measured. While the cost and complexity of some hardware and software components may only depend on the total bandwidth, the cost/complexity, in general, would scale with the number of component carriers. This paper discussed the types of carrier aggregation and focused on non-contiguous type. In fact non-contiguous subcarrier allocation is supported in clustered DFT-S-OFDM. In contrast, SC-FDMA supports contiguous subcarrier allocation. Clustered SC-FDMA transmission can provide more flexible scheduling than SC-FDMA in LTE. The practical results which are shown in the above figures are expected in countries where spectrum allocation is non-contiguous within a single band, where the middle carriers are loaded with other users, or when network sharing is considered. Therefore this model would fit operators in North America or Europe, who have fragmental spectrum in one band or share the same cellular network.

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