Bandwidth Extension in LTE-Advanced using Carrier Aggregation

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Abstract
The technology evolution in mobile communications in last few years, has led to an exponential growth in video downloads and the increase in data usage due to smart phones. This resulted in requirement of larger air interface bandwidths. Hence, the Spectrum aggregation has recently received much attention due to the quick increasing of services. The first release of 3GPP LTE provided extensive support for deployment in spectrum allocations of various characteristics, with transmission bandwidths ranging from 1.4MHz up to 20MHz in both paired and unpaired bands. In order to achieve up to 1 Gbps peak data rate in future IMT-Advanced mobile systems, Carrier Aggregation (CA) technology is introduced by the 3GPP to support very-high-data-rate transmissions over wide frequency bandwidths (e.g., up to 100 MHz) in its new LTE-Advanced standards. This technique makes it possible for multiple spectrum bands to be utilized by the same user in order to satisfy the large bandwidth demand of the service and achieve better performance. In this paper, we have discussed the valuation of spectrum and extension of bandwidth using Carrier Aggregation (CA).

Keywords
Carrier Aggregation, Spectrum Analysis, LTE-Advanced, 4G Wireless Technologies

I. Introduction

Wireless data usage is increasing at a phenomenal rate and demands the need for continued innovations in wireless data technologies to provide more capacity and higher quality of service. A wave in Internet connectivity growth is being driven by the cellular industry, and the global number of Internet connected devices has now surpassed the number of connected computers and is growing at a much faster rate. Faster mobile broadband connections, more powerful smart phones, connected tablets; networked laptops as well as new consumer and enterprise applications are all driving the wireless industry to provide new technical capabilities. For network upgrade the operators require access to additional spectrum, because the capacity in the network is determined by the amount of spectrum. Spectrum is a finite, non-exhaustible common resource which influences the valuation, and some parts of the frequency band are more valuable than others.

Carrier aggregation is one of the most distinct features of 4G systems including LTE-Advanced, which is being standardized in Third Generation Partnership Project (3GPP) as part of LTE Release 10. It allows scalable expansion of effective bandwidth through concurrent utilization of radio resources across multiple carriers to be delivered to a user terminal. These carriers may be of different bandwidths, and may be in the same or different bands to provide maximum flexibility in utilizing the scarce radio spectrum available to operators. By combining the deployment of new radio equipment and additional spectrum operators are able to increase capacity substantially. So, in this way the Carrier Aggregation (CA) technology can support very-high-data-rate transmissions over wide frequency bandwidths i.e. up to 100 MHz [7, 8, 9]. In this paper, we have discussed valuation of spectrum and extension of bandwidth using Carrier Aggregation (CA).

II. Valuation of Spectrum

Having information about valuation of spectrum helps to apply a techno-economic approach which combines technology with economic and business aspects. The three approaches to evaluate spectrum are:

A. Economic value

The economic value of spectrum can be assessed by estimating the value of the economic activities through the contribution to the GDP by regarding spectrum as an input in the production.

B. Engineering Value

The engineering value is determined by cost savings in the infrastructure of an operator's network obtained by having access to additional spectrum. It reflects the less costly configuration of the network infrastructure obtained when more spectrum is available for an operator. It could also be expressed as the opportunity cost or the marginal value of spectrum.

C. Strategic Value

The strategic value reflects the expected position and competitive advantage an operator would achieve in the market as a result of the assigned spectrum compared to another operator that would not receive the equivalent amount of spectrum [1].

III. Need for Carrier Aggregation

The multi-antenna techniques cannot continuously increase transmission performance, because the constraints on terminal size, complexity, and cost limit the number of antennas that can be installed on a UE unit. In order to achieve the performance requirements of IMT-Advanced systems, Carrier Aggregation (CA) has been proposed in order to aggregate two or more component carriers for supporting high-data-rate transmission over a wide bandwidth (i.e., up to 100 MHz for a single UE unit), while preserving backward compatibility to legacy systems [2].

Carrier Aggregation (CA) has been identified as a key technology that will be crucial for LTE-Advanced in meeting IMT-Advanced requirements [9]. Without any carrier aggregation the system bandwidths are 10 or 20 MHz, the cases with more than 20 MHz of bandwidth will result in multiple 20 MHz systems working in parallel. With these assumptions the average data rates will be 20 or 40 Mbps and the peak data rates will be 100 or 200 Mbps.

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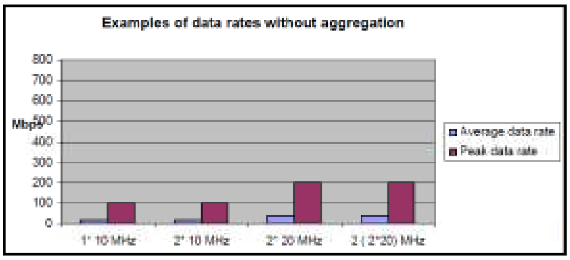


Fig.1: Data Rates without any Carrier Aggregation

Fig. 1, showing examples of data rates without any carrier aggregation assuming spectral efficiency 2 bps per Hz for average and 10 bps per Hz for peak data rate

The performance will change if carrier aggregation is introduced. The system bandwidth will increase substantially, up to 80 MHz for two cooperating operators with 2*20 MHz each. Then the average data rates can reach 80 or 160 Mbps, and the peak data rates can be up to 400 or 800 Mbps.

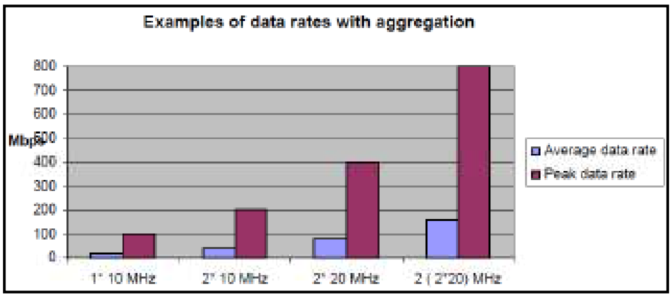


Fig. 2: Data Rates using Carrier Aggregation

Fig. 2, showing examples of data rates using carrier aggregation assuming spectral efficiency 2 bps per Hz for average and 10 bps per Hz for peak data rate [1].

IV. Types of Carrier aggregation

A. Continuous CA

when multiple available component carriers are adjacent to each other.

B. Non-continuous CA

when multiple available component carriers are separated along the frequency band.

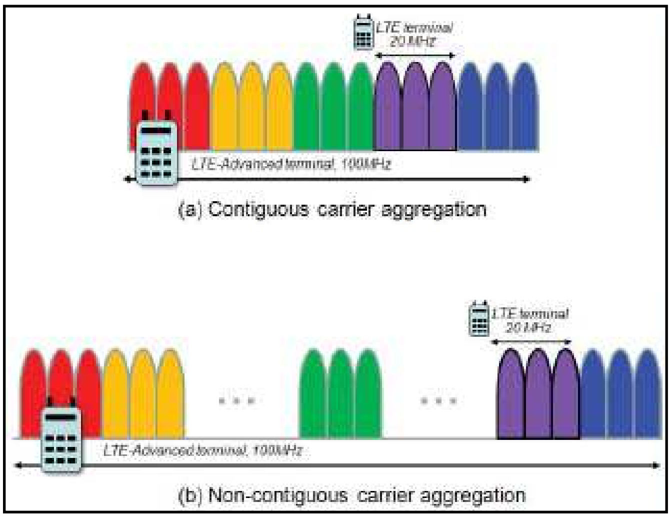


Fig. 3: Carrier Aggregation (CA), with contiguous and non-contiguous carrier allocations

In both cases multiple LTE/component carriers are aggregated to serve a single unit of LTE-Advanced UE. Regarding UE complexity, cost, capability, and power consumption, it is easier to implement continuous CA without making many changes to the physical layer structure of LTE systems. It is possible to use a single Fast Fourier Transform (FFT) module and a single Radio Frequency (RF) component to achieve continuous CA for an LTE-Advanced UE unit, while providing backward compatibility to the LTE systems. In addition, compared to non-continuous CA, it is easier to implement resource allocation and management algorithms for continuous CA [2].

Further, Carrier Aggregation (CA) may be classified in three different spectrum scenarios:

1. Intraband contiguous carrier Aggregation

This is where a contiguous bandwidth wider than the 20MHz is used for carrier aggregation. Although this may be a less likely scenario given frequency allocations today it can be common when new spectrum bands like 3.5GHz are allocated in the future in various parts of the world.

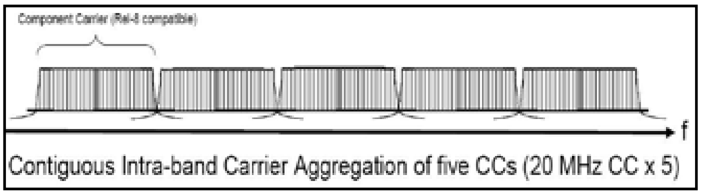
2. Intra band Non Contiguous Carrier Aggregation

This is where multiple CCs belonging to the same band are used in a none contiguous manner this can be common in countries where spectrum allocation is non contiguous within a single band

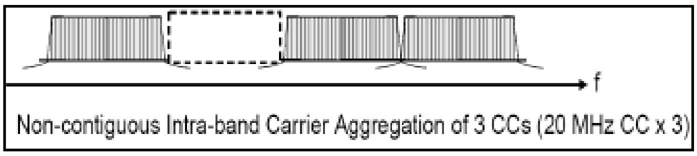
3. Interband Non contiguous carrier Aggregation

This is where multiple component carriers belonging to different bands e.g., 2GHz and 800MHz are aggregated.

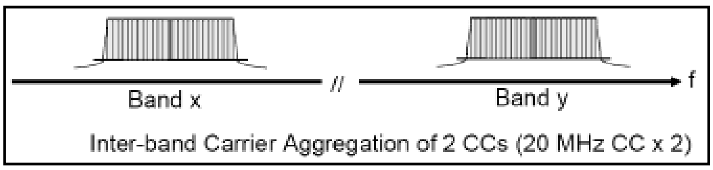
In the LTE release 10, for the UL the focus is on intraband Carrier Aggregation as illustrated below, due to difficulties in defining RF requirements for simultaneous transmission on multiple CCS with large frequency separation considering realistic device linearity [11].



(a)



(b)



(c)

Fig. 4: Illustration of (a). Intra-band Continuous Aggregation. (b). Intra-band Non-Continuous Aggregation. (c). Inter-band Non-Continuous Aggregation [10]

V. Challenges

The spectrum bands in spectrum aggregation have the same property while different spectrum bands differ greatly in real networks, so the problem is how to provide homogeneous information communication by taking advantage of discontiguous spectrum bands with different properties. Considering the utilization of discontiguous spectrum bands with different properties to fulfill bandwidth requirement of users, the most difficult tasks of the problem are maximizing information flow as well as ensuring reliability of information flow by spectrum aggregation and scheduling. An ideal scheduling scheme is necessary to facilitate the communication using discontiguous spectrum bands with the same average error and delay performance as that using contiguous spectrum communication in a statistical sense. So,the carrier aggregation is a communication method which makes transmission of integral information flow through discontiguous spectrum bands with different properties possible [3].

From a baseband perspective, there is no difference if the component carriers are contiguous in frequency or not. This could allow for aggregating non-contiguous spectrum fragments by allocating different fragments to different component carriers. For an LTE-Advanced terminal capable of receiving multiple component carriers, it can be sufficient if the synchronization signals are available on one of the component carriers only. Hence, an operator can, by enabling/disabling these signals, control which part of the spectrum that should be accessible to LTE terminals [4].

VI. Implementation of Carrier Aggregation (CA)

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 Carrier aggregation is the only reasonable way to increase the transmission 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 UL and the DL are the same. However, not all component carriers are necessarily Release 8 compatible. Carrier aggregation achieves extra-wide frequency bandwidth transmission by bundling multiple 20 MHz-wide bands, i.e., Component Carriers (CC), for the uplink and downlink. By using link adaptation and channel coding, as well as Hybrid Automatic Repeat-reQuest (HARQ), for each component carrier, the transmission data rate can be increased efficiently. It allows up to five component carriers to be aggregated to extend the transmission frequency bandwidth to 100 MHz for the downlink, and two can be aggregated to achieve a 40 MHz bandwidth for the uplink.

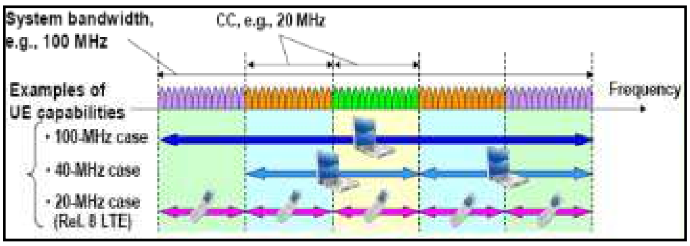


Fig. 5: Implementation of Carrier Aggregation

So, in the method of carrier aggregation, several carriers in LTE system can be aggregated into one wider channel in LTE-advanced system which is wide enough for 100MHz, even though these carriers in LTE are in different frequency bands. On the aggregated wider channel, LTE-advanced terminal can access several spectrum fragments simultaneously, and meanwhile LTE terminal can access only one spectrum fragment of them, which not only meets the needs of spectral compatibility, but also reduces the cost of bits. The main advantage of this technology is that by the use of the direct aggregation of LTE carriers, there's no need to make large changes in the physical layer of LTE system, which reduces the design difficulty of LTE-advanced system greatly [3].

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.

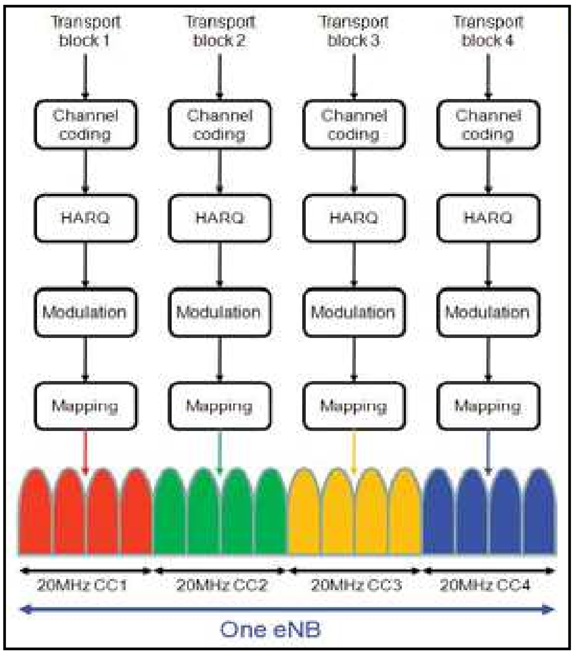


Fig. 6: Carrier allocation in contiguous carrier aggregation [5]

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 con-figure 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 [5].

In the process of spectrum aggregation, each carrier corresponds to independent data stream. Aggregation of the component carriers can be done at different layers in the protocol stack, In LTE Advanced, the data streams from the different component carriers are aggregated above the MAC layer. This implies that hybrid-ARQ retransmissions are performed independently per component carrier.

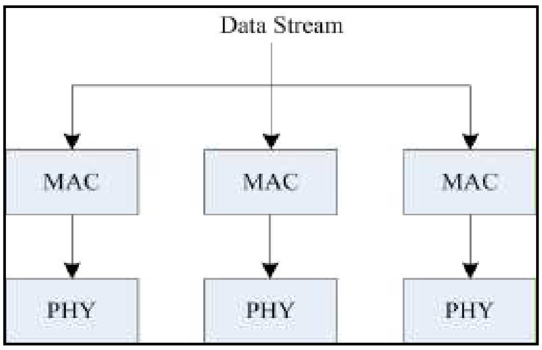


Fig. 7: Data streams aggregated in MAC layer

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The transmission parameters such as modulation scheme and code rate could also be selected per component carrier. Such independent operations per component carrier are especially useful in case of aggregating component carriers from different frequency bands with different radio-channel quality [4].

VII. Selection of Carrier Bandwidths

In the process of spectrum aggregation, it should be taken into consideration that both the aggregated carriers in LTE and the wider channel in LTE-advanced have different bandwidth. Consequently, there are several methods of aggregation, e.g. 30MHz = 20MHz + 10MHz = 20MHz + 5MHz + 5MHz. In order to reduce the design complexity of transceivers, a concept is proposed called bandwidth factor, which indicates the multiple relationship between bandwidth of aggregated carriers in LTE, e.g., when the bandwidth factor is 2, we can only choose the solution that 30MHz = 20MHz + 10MHz, for 20 is twice as large as 10. Obviously, the proposal of bandwidth factor can restrict the methods of aggregation successfully and reduce the design complexity of transceivers greatly [3].

VIII. Future Scope

A natural evolution from HSPA multicarrier, LTE carrier aggregation and handovers between the two radios would appear to be to extend the carrier aggregation to support aggregating carriers operating on different radio technologies.

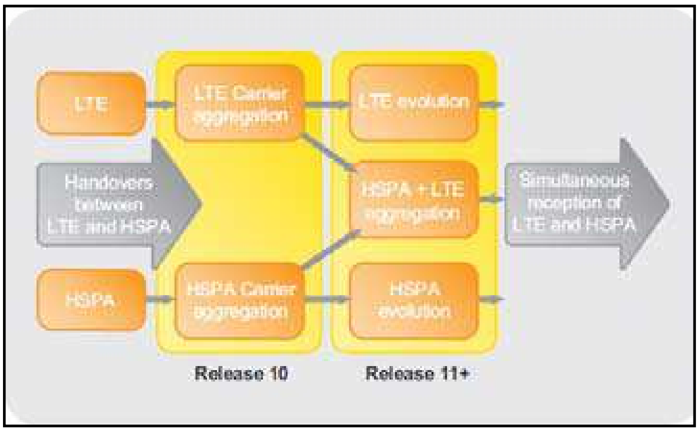

Fig. 8: 3GPP Evolution of LTE and HSPA radio interworking

Fig. 8 shows potential 3GPP evolution of LTE and HSPA radio interworking from inter-RAT handovers to simultaneous reception through aggregation. A practical deployment benefit with HSPA+LTE carrier aggregation can be obtained in an environment where the operator deploys multi-radio base stations capable to both HSPA and LTE, and similarly multimode devices are, as expected, commonplace. This leads to the fact that there is no need for additional hardware in either the network or in the device to be able to support the aggregation. The same hardware in the device just needs to be designed so that it is capable of operating with both receivers at the same time, and this is already needed in limited occasions when the device is doing mobility related measurements towards the other radio technology than it is already connected to. A multi-radio base station is by definition anyway required to be able to operate on both radio systems simultaneously, so aggregating the two radios towards a single user can be seen to be more close to be a configuration question than a new base station type [6, 7, 8].

IX. Conclusion

Wireless data usage continues to increase at an unprecedented pace. The use of tablets greatly increases the demand for wireless video applications which puts tremendous stress on the wireless network, thus higher user rates are required over larger coverage areas, which in turn is driving the wireless industry to provide new technical capabilities. In order to achieve up to 1 Gbps peak data rate in the downlink and 500 Mbps in the uplink in future IMT-Advanced mobile systems, Carrier Aggregation (CA) technology is introduced by the 3GPP to support very-high-data-rate transmissions over wide frequency bandwidths (e.g., up to 100 MHz) in its new LTE-Advanced standards. In CA, communication is achieved through the simultaneous use of multiple LTE carriers called Component Carriers (CCs) enabling broadband transmission exceeding 20MHz. In this paper, we have discussed the valuation of spectrum and the extension of bandwidth using Carrier Aggregation (CA).

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