CELLULAR RADIO CHANNEL CARRIER AGGREGATION MOTIVATION AND BENEFITS OVERVIEW

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Abstract: The main challenge in the evolution of cellular networks is providing increased channel capacity and data rates. Mobile operators are obligatory to boost the researching of methods for enhancing the spectral efficiency in response to the growing needs for better connectivity and signal coverage. The engineering of transmitters and receivers should be processed in a very precise manner as a matter of frequency effectiveness. An essential competitiveness is achieved having the combination of carrier frequencies as elements of one whole traffic trunk. Multicarrier techniques provide fulfillment of user requirements in the face of continuous on-line actions, fast file sharing and permanent Internet connectivity. Carrier aggregation in radio channels is seen as sophisticated technique for improving frequency usage assuring higher throughput and capacity.

Keywords: HIGH-SPEED PACKET ACCESS (HSPA+), 3.5G, LTE, 4G, CARRIER AGGREGATION, SPECTRAL EFFICIENCY, PEAK DATA RATE.

1. INTRODUCTION.

The reasons for the colossal increasing in the needs of higher data rates within mobile network communications are many and have their strong philosophy – evolution in mobile applications; need for constant broadband Internet connectivity; faster video and multimedia streaming, and the presence of low-cost smart phones as well. Cellular mobile operators must invest sufficient resources in response to the customer’s whimsical requirements. Frequency limitations are on the front line and therefore sophisticated solutions are the object of research. The challenge is to optimize the available crowded bandwidth with methods of increasing peak data rates. Optimizing unused channels with carrier frequencies in a given particular moment of time are one direction for further development. Finding a way to use the unused is no other than a perfect solution for communication network engineers and designers. The dynamic traffic splitting among multiple carriers seems to be very efficient way for improving the overall performance of the cellular network.

Mobile operators’ data traffic analysis show the flow of packets is seen difficult for prediction [1]. The packet switching technique in digital cellular networks appears to be extremely complex while having abstract modulation and signaling. Higher data rates require better error performance and optimized signal detection. As a matter of improving the signal detection, non-correlating signals should be in mind. Signal distribution play main role in extreme data loads. As an example it can be pointed that if transmission of large file is requested in a particular moment, the corresponding radio channel will get overloaded. While adjacent channels stay unused, inefficient carrier frequency distribution is present. Adjacent channels can also be in neighboring cells as well.

Avoiding such spectral inefficiencies, radio designers are to develop enhanced methods for migration toward future generation networks – 3.5G, 4G and even 5G. High-Speed Downlink Packet Access (HSDPA) and Long Term Evolution (LTE) are the available cellular networks on the market. Improving the concept of channel usage these systems migrate toward 3.5G and 4G. One main benefit chased is better spectrum usage while decreasing unused frequencies. The multi carrier systems present Carrier Aggregation and/or OFDM. Carrier Aggregation (CA) is a technique that distributes one data flow over multiple cellular radio channels achieving larger throughput and therefore faster data rates. The other technique – OFDM - is the already studied and tested way of modulation with multiple sub-carriers comprising one data stream.

2. THE CONCEPT OF CARRIER AGGREGATION.

The optimization of the available frequency bandwidth in cellular radio systems is achieved by means of a channel rescheduling technique. This channel reschedule is essential having unused channels free of charge and other channels being overloaded. To improve the existing HSDPA (3G) technology, HSPA+ and LTE-Advanced are using radio channel carrier aggregation [6]. Carrier aggregation allows expansion of effective bandwidth delivered to a user terminal through simultaneous utilization of radio resources across multiple carriers.

![Fig. 1 – Types of carrier aggregation for downlink channel.](image)

The multiple carriers are aggregated to form an overall larger bandwidth. Carrier aggregation permits the LTE radio interface to be configured with up to five “component carriers” of any bandwidth. We can assume that three types of carrier aggregation are defined: contiguous aggregation in one band, non-contiguous aggregation in one band and different band aggregation (fig. 1). In LTE-Advanced, carrier aggregation provides wider frequency bands in comparison with the previously supported in 3GPP Release 8 or Release 9 ratifications.

Enhancing consistent user experience across the network cell appears to be the main purpose of Carrier Aggregation. The multi carrier traffic splitting idea is to achieve better resource utilization and spectrum efficiency. On one hand, aggregation is achieved by:
• combination of peak channel capacities and available throughput performance in adjacent and non-adjacent carrier frequencies;
• avoiding the relative spectral inefficiencies that may be inherent in wireless deployments in non-contiguous carriers, often spread across different frequency bands;
• performing consistent QoS and highly efficient load balancing across frequencies and systems (cells);
• immediate rescheduling over unused channels at another carrier or system while data congestion occurs;
• smart interference management system with dynamic resource allocation.

On the other hand, mobile operators are saving financial resources with the increase of network capacity provided by cost effective solution in the face of already deployed equipment and just a few software upgrades.

2.1. 3GPP RELEASE 8.

The first concept of carrier aggregation was introduced in 3GPP Release 8 in 2009 announcing that two adjacent carriers can operate together to serve one user [3]. That is two adjacent channels, serving one user in one frequency band, can operate simultaneously while one of them is not busy. This version of carrier aggregation is called “Dual-Cell HSDPA Operation on Adjacent Carriers”. Two carriers of 5MHz bandwidth are combined and with the use of 64QAM the peak data rate is doubled to 42Mbps. MIMO antennas here are still not included. Resources can be assigned at the same time on both carriers with the Dual-Cell capable HSPA user equipments.

The dual carrier is a natural evolution of HSDPA allowing theoretically doubling the 15 user peak data rate. The Dual Carrier DC-HSDPA is already a reality in numerous commercial deployments in the world. The DC-HSDPA is limited to 2 adjacent carriers of 5 MHz.

2.2. 3GPP RELEASE 9.

The adjacent carrier limitation is overcome in 3GPP Release-9. The uplink is also considered and the Dual Band Dual Carrier HSPA is introduced. The same principles as DC-HSDPA are standing at the foundation: to double the uplink data rate up to 23 Mbps using 16QAM. Moreover, it is well known that UE in uplink condition is often more limited by the bandwidth rather than by the actual transmit uplink power. Here the advantages of DC-HSUPA in terms of data rate and availability are well expressed.

A DC-HSUPA user can transmit over two E-DCH 2 ms TTI transport channels, one on each uplink carrier [10]. The user is served by the same eNodeB over two different cells on the same sector [1]. The secondary carrier can be activated or deactivated through special HS-SCCH protocol orders. In Release-9, dual-band HSDPA operation is specified for three different band combinations, one for each ITU region:

- Band I (2100 MHz) and Band V (850 MHz);
- Band I (2100 MHz) and Band VIII (900 MHz);
- Band II (1900 MHz) and Band IV (2100/1700 MHz).

2.3. 3GPP RELEASE 10.

In Release 10 the number of carriers is proposed to four. Uplink and downlink may be independently configured, but the number of uplink carriers must be less than or equal to the number of downlink carriers. Each component carrier is equivalent to a Release 8 or Release 9 carrier.

Fig. 2 – Uplink and downlink channel carrier aggregation

The channel non-related to HSDPA technology stays in so called “primary serving cell”, the physical layer procedures rely also on this primary serving cell. The transport channel chains are independent and perform coding, modulation and Hybrid Automatic Repeat request (HARQ) retransmissions separately in a similar fashion as MIMO.

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2.4. 3GPP RELEASE 11.

A natural step in Release-11 is to provide a support up to 8-Carriers HSDPA aggregating up to 40 MHz of spectrum meeting the requirement of ITU for a real 4G system [12]. Release-11 also brings support aggregation of non-adjacent carriers on the same frequency band.

Fig. 4 - Evolution of HSPA Carrier Aggregation.

The standardization of the framework developed during the previous rounds of multi-carrier standardization in 3GPP is reused to provide a 4-Carrier HSDPA on two separate frequency bands.

Higher utilization efficiency is provided with the use of dual carriers. Dynamic user multiplexing and improvement of the load sharing allows theoretically doubling the instantaneous data rates by assigning all the code and power resource to a single user in a network cell. By increasing transmission speeds, the round trip delay time is reduced. The 10 MHz bandwidth is also used to schedule user terminals (UEs) more efficiently around fading
conditions bringing frequency selectivity gain and improved QoS gain from joint scheduling.

The peak rate capabilities provided by each evolution is improved significantly. Carrier aggregation is one of only a few features to provide such a clear capacity improvement on the network. From a downlink theoretical peak data rate in Release-7 of 28 Mbps, each release doubles this peak, to reach in Release-11 a throughput of 336 Mbps with 2x2 MIMO and a throughput of 672 Mbps when combined with 4x4 MIMO antenna. It is possible to reach a theoretical peak data rate of 168 Mbps using the highest modulation scheme (64QAM) and the downlink MIMO 2x2 configured on each downlink carriers. It doubles the performance achievable with (DB)-DC-HSDPA [12]. The study Item called “LTE and HSDPA Carrier Aggregation” is currently under investigation as part of 3GPP release 12 [14].

3. CERTAIN BENEFITS AND CHALLENGES.

Carrier aggregation enables high data rates by aggregating multiple Release 8 carriers to support transmission bandwidths of up to 100 MHz [14]. This approach provides the following advantages:

- backward compatibility with release 8 and 9 capabilities;
- dynamic scheduling over different carriers to mitigate varying channel conditions;
- higher throughput rates;
- a practical solution for the LTE spectrum fragmentation issue.

Data rate improvement of LTE networks through aggregated spectrum is just one of the many advantages of CA. Network coverage and network access performance enhancement through better capacity and coverage management are also affected. CA could also help to avoid interferences induced by heterogeneous networks where small cells and macro cells operate in the same carrier frequency. If interference exceeding certain threshold is detected, the cell can reschedule a mobile terminal to a different carrier.

![Fig. 5 - Increased data rates.](image1)

Having the flexibility to schedule data across multiple carriers to the same device provides spatial and frequency diversity, allowing for more reliable communication to the terminal. All carriers with cross carrier scheduling can be managed by one cell. This option introduces Inter Cell Interference Coordination (ICIC).

While the concept of carrier aggregation is simple, the feature has significant impact on transceivers. Mobile device developers implementing carrier aggregation need to consider impacts on the Radio Resource Control (RRC), Medium Access Control (MAC) and PHY layers as well as receiver design. From the device point of view, the user plane and layers above RRC are not impacted. UEs are classified according to their carrier aggregation aggregate bandwidths.

The LTE CA-ready devices have to support data downloading at rates up to 150Mbps and should also be packed with advanced features such as Full-HD video and audio, sophisticated computational imaging all without compromising the terminal battery life [9]. Therefore terminal powering schemes should be a very careful choice having components like SC-HSDPA/LTE modems and multimedia processors. Real-time media streaming like Ultra-HD content and quality videoconferencing will be available when the modem and the multimedia processor are closely integrated.

Another challenge facing the implementation of CA is the use of two transceivers and related upfront components to detect the two/four/eight aggregated carriers. Receiving information from two and more (up to 8) cellular radio channels and converting them into a single stream should be designed in baseband frequencies. These considerations complicate the overall design of the smartphone and compromise its power consumption, its form factor and its overall cost. In addition Carrier Aggregation could add more burdens to the already-fragmented environment of HSPA+/LTE spectrum as vendors will have to anticipate multiple CA combinations across various bands. This could have a dramatic impact on economies of scale, which in turn could have a significant impact on the overall device market price.

4. CONCLUSION.

After deploying the carrier aggregation technology, good amount of benefits are provided. Such are maximization of the peak rate and throughput performance; higher and consistent QoS; seamless access to unused channel capacity and also mitigation of relative inefficiencies in non-contiguous and narrow channel bandwidths. Of course the evolution to multicarrier also comes at the expense of UE and eNode B complexity, for which hardware implementation is challenging.

Carrier aggregation seems to be cost effective solution since expensive investments are avoided. Finding a way to utilize the frequency spectrum more efficiently, channel aggregation provides prolonged functional services from the deployed equipment and infrastructure.

5. REFERENCE.