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LTE-Advanced Carrier Aggregation Optimization

Contents

Innovation is happening right now at Nokia

Many of the innovations from previous years described in this document are still relevant today and have been developed to support the optimization of mobile broadband networks and services.

Looking ahead, Nokia will continue to focus on innovation and we will be updating this document to reflect the latest developments.

Introduction

Carrier Aggregation (CA) is the most important technology component in LTE-Advanced. CA was defined in 3GPP Release 10 and commercial network launches followed in Korea in 2013.

Carrier aggregation has proceeded rapidly in network deployments because of promising performance benefits and because it allows operators to turn their investment in additional LTE carriers into marketable, higher data rates. Carrier aggregation increases peak data rates and practical data rates, improves the downlink coverage and simplifies multi-band traffic management. The evolution of data rates through carrier aggregation is shown in Figure 1.

Commercial LTE networks started with Category 3 and 4 devices supporting 100 to 150 Mbps with continuous 20 MHz spectrum. The first version of carrier aggregation, during 2013, enabled 150 Mbps with 10 + 10 MHz allocation. The next phase with Category 6 devices has been commercially available since 2014, supporting 300 Mbps with 20 + 20 MHz. Category 9 will bring 450 Mbps with 60 MHz during 2015, and the evolution continues, with expected rates of 1 Gbps in the near future.

Carrier aggregation also provides competitive data rates on fragmented spectrum. For example, a three component carrier aggregation of 10+10+20 MHz allows operators to reach 300 Mbps. This paper discusses the practical performance of carrier aggregation, optimization steps and further evolution.

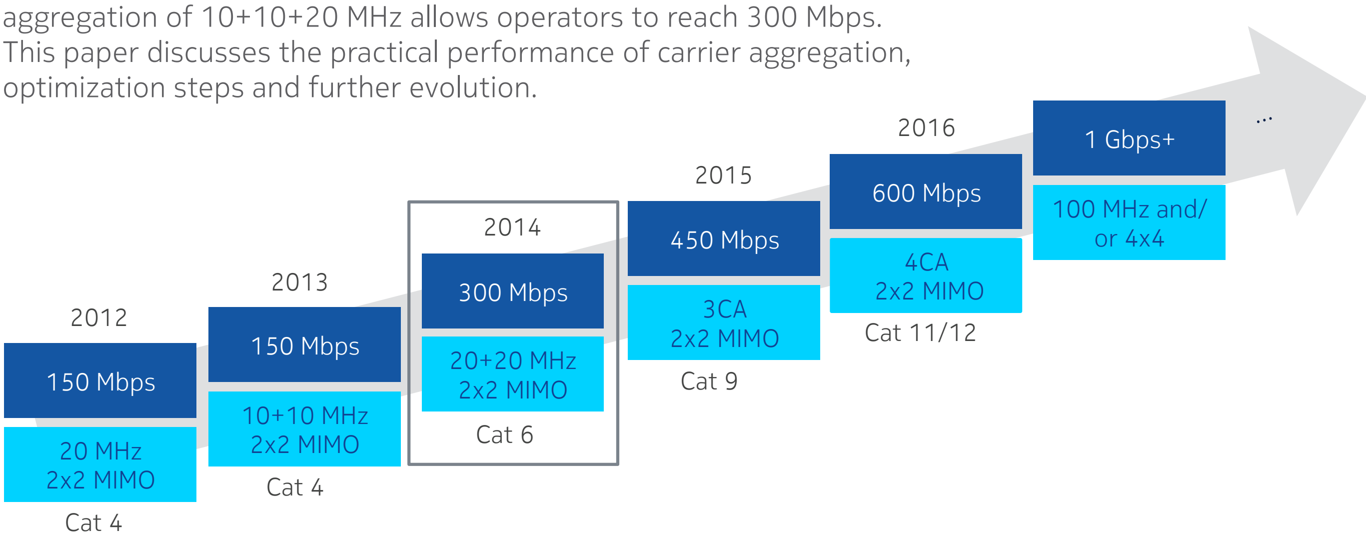


Fig. 1. Data rate evolution in downlink with carrier aggregation

Carrier Aggregation in live networks

Carrier aggregation performs well in live networks. The explanation is simple: more spectrum is allocated per connection, which results directly in higher peak and practical data rates. Figure 2 illustrates drive test results from a live network with a Cat 4 device and 10 + 10 MHz aggregation. The data rate with a single 10 MHz carrier (Primary Pcell or Secondary Scell) is approximately 30 Mbps, while the average data rate with carrier aggregation increases to 60 Mbps.

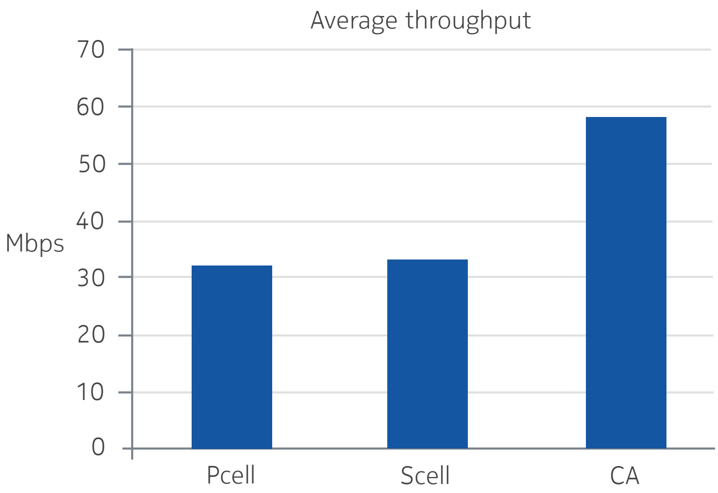


Fig. 2. Drive test data rate with 10 + 10 MHz carrier aggregation

A Cat 6 device further increases the data rate. The peak rate measurements are shown in Figure 3. The allocation of 20 + 10 MHz gives 225 Mbps, while 20 + 20 MHz gives up to 300 Mbps, illustrating the importance of allocating as much spectrum as possible to get the full benefit of the device capabilities.

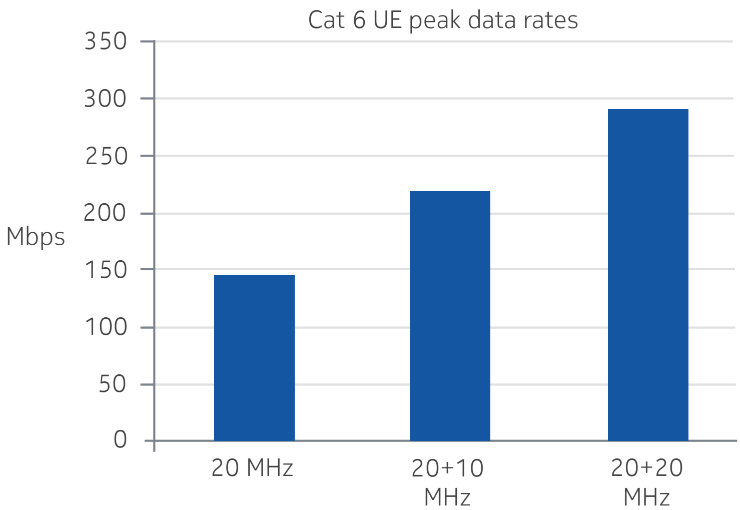


Fig. 3. Peak rate measurements with Category 6 device

The drive test data rate with a Cat 6 device in good signal conditions is shown in Figure 4. The results indicate that it is possible to achieve data rates of 250 – 300 Mbps in the field if the signal and interference conditions are favorable.

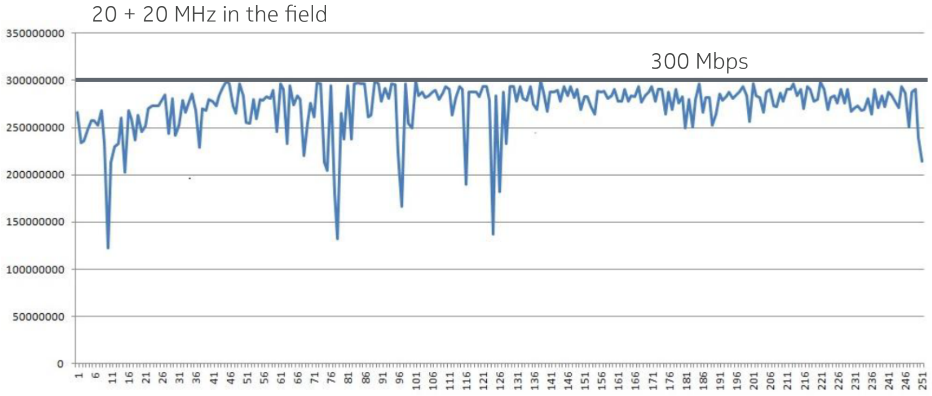


Fig. 4. Drive test data rate with Cat 6 device in good signal conditions

Multi-band traffic management

The majority of operators started LTE networks on a single frequency band at a given area, for example, 1800 MHz or 700 MHz. Most operators have meanwhile added a second and even a third LTE frequency because of capacity requirements and because of carrier aggregation data rates. The evolution continues, leading to ever more frequencies being used for LTE, in turn making the traffic management between the frequencies more challenging. The general target is to balance the loading between the frequencies and to make best use of the low band to provide better coverage.

Carrier aggregation will be the main solution for simplifying multi-band traffic management. Without carrier aggregation, traffic management must rely on handovers, which are relatively slow, taking several seconds when taking into account the measurements and procedure. Traffic management also requires proper configuration of idle mode parameters. The process becomes simpler when carrier aggregation is activated, as load balancing happens as part of the packet scheduler, within a few milliseconds.

Figure 5 illustrates the typical frequency bands that are and will be available for European mobile operators in the near future. The frequencies between 700 and 2600 MHz are preferably aggregated together to gain the benefit of fast traffic management. Even the frequencies at 3.5 GHz can be aggregated together if the site grid is dense enough to provide for sufficient coverage on 3.5 GHz.

Figure 6 illustrates the benefit of fast load balancing with carrier aggregation. The dotted line shows the user data rate as a function of system loading with 20 MHz bandwidth. The curve assumes that load balancing is done at the beginning of the packet calls. The continuous line shows the user data rates when carrier aggregation of 20 + 20 MHz is activated and all devices support the feature. The user data rate is increased considerably, in the order of 80%, even at high loading. Alternatively, the same average user data rate can be achieved while having higher offered load and more users. In this example even 40% more loading can be supported while providing the same user data rates.

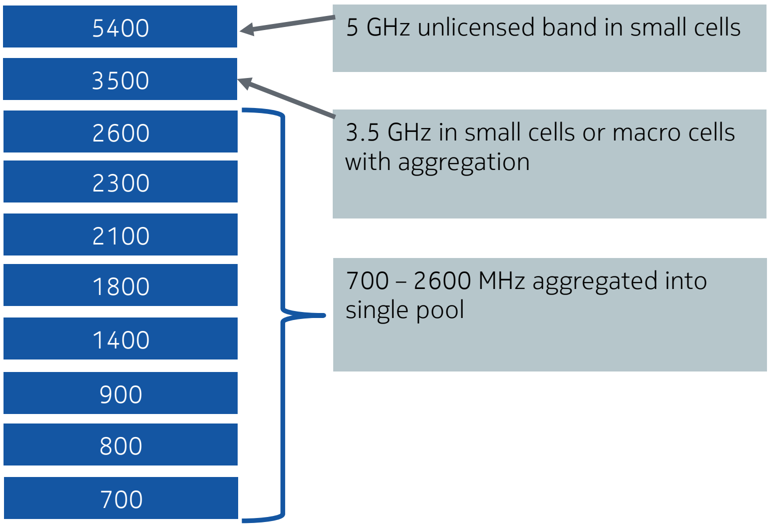


Fig. 5. Aggregation of all low bands in macro cells

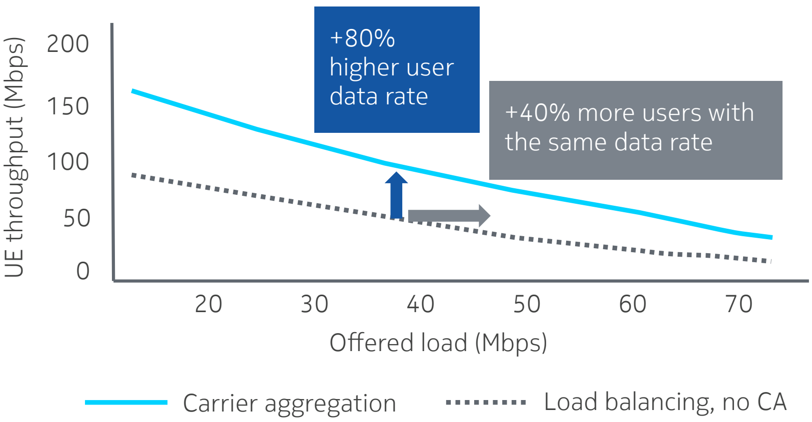


Fig. 6. Gain from fast load balancing with carrier aggregation

LTE networks will have a mixture of new CA devices and legacy non-CA devices and so fair resource sharing between these devices needs to be considered. We would like to provide enough resources for non-CA devices particularly on the low band, which has better coverage and typically a smaller bandwidth. Nokia Smart Scheduler allows the operator to allocate more resources for non-CA devices cell-by-cell because CA devices can access resources from two cells. An example case is shown in Figure 7, where a non-CA device is allocated double resources compared to a CA device on the Primary cell (Pcell), while the CA device gets resources also on the Secondary cell (Scell). The result is that the end user data rate is distributed more fairly between the different devices. Resource sharing in the advanced scheduler can be configured by the operator.

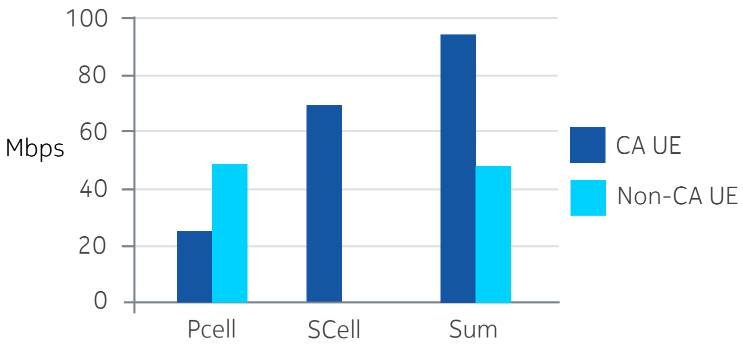
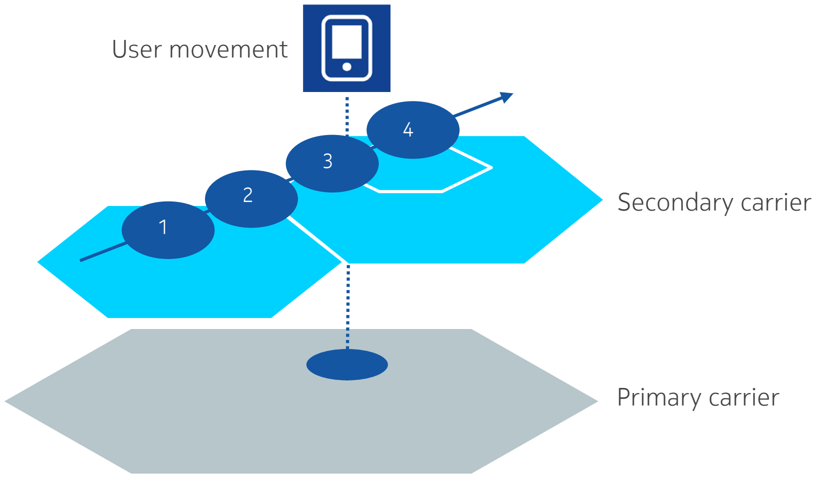


Fig. 7. Advanced resource allocation between CA and non-CA devices

The Scell's coverage area may be different to that of the Pcell in practical networks if different antennas or antenna locations are used. Such a network configuration requires flexible configuration of Scell. An example case is illustrated in Figure 8, with multiple Scells in the coverage area of a single Pcell. When the device is moving, the Scell is reconfigured dynamically. First, the carrier aggregation is activated according to the data volume in (1). The Scell is reconfigured due to mobility in (2) and again in (3). The carrier aggregation is deactivated due to inactivity in (4).



1 CA activation based on data volume
2 Channel quality-based reconfiguration
3 SCell swap
4 Deactivation due to inactivity

Fig. 8. Flexible configuration of secondary cell

Coverage benefits

LTE coverage in the macro cells is uplink limited because of the lower terminal output power (200 mW) compared to the typical base station power of several tens of watts. The minimum threshold for LTE is typically Reference Signal Received Power (RSRP) of -120 dBm before handing over the connection to the 3G network. The minimum threshold is limited by the uplink coverage, while the coverage could be even wider if we consider only the downlink direction. Carrier aggregation can enhance the coverage by using the low band for the uplink connection while the downlink can still be received by the device, both on the low band and on the high band. The high band connection could not be used without carrier aggregation.

The outcome is that carrier aggregation can enhance the downlink coverage of the high band. Field measurements indicate that the high band Scell can contribute to the throughput at lower signal levels down to -130 dBm. Those devices that are closer to the base station can also use LTE1800 as the primary cell and uplink transmission.

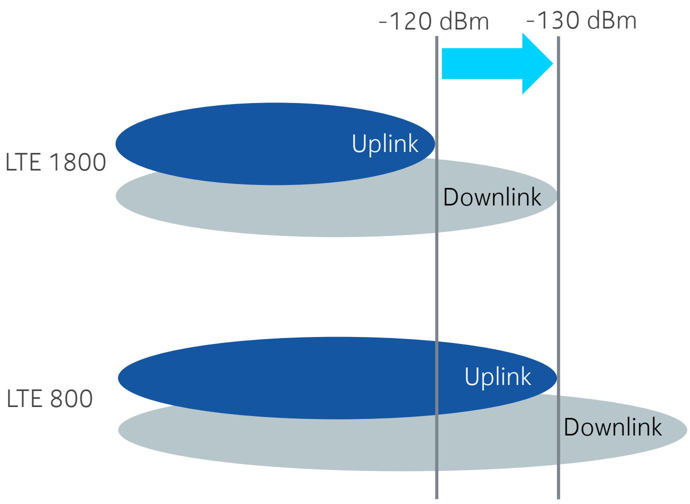


Fig. 9. Coverage benefit of carrier aggregation when using low band Pcell

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FDD and TDD aggregation

The first phase of carrier aggregation combines two FDD frequencies or two TDD frequencies. The next phase allows aggregation of the FDD and TDD frequencies together. 3GPP has defined FDD + TDD aggregation in Release 12 which allows either FDD or TDD as the Primary cell. The first practical implementations have FDD as Pcell and TDD as Scell and are expected during 2015. FDD and TDD aggregation can provide an attractive combination of low band FDD for good coverage and high band TDD with more spectrum for higher data rates.

Carrier aggregation in Heterogeneous Networks

Carrier aggregation also makes small cell deployment more attractive. First, carrier aggregation is already available in small cells supporting more than 200 Mbps. Furthermore, carrier aggregation can be obtained between the macro cell and the low power RF head that is connected to the macro cell baseband. Such a configuration is supported by 3GPP Release 10 specifications which assume that Primary and Secondary cells are transmitted from the same baseband unit.

3GPP Release 12 enhances carrier aggregation where the two cells are transmitted from two different base stations. This feature is called inter-site carrier aggregation and relies on dual connectivity where the device has two simultaneous radio connections to two base stations. The main use is heterogeneous networks where the device can maintain parallel connections to the large macro cell on some of the low bands and to the small cell at higher band. The macro cell can provide reliable mobility while the small cell can provide higher data rates and more capacity. The connection between macro cell and small cell is a X2 interface, which can also use wireless backhaul.

Release 10 carrier aggregation in macro cell

Release 10 inter-site carrier aggregation between macro and low power RF head

Release 12 inter-site carrier aggregation between macro and small cell

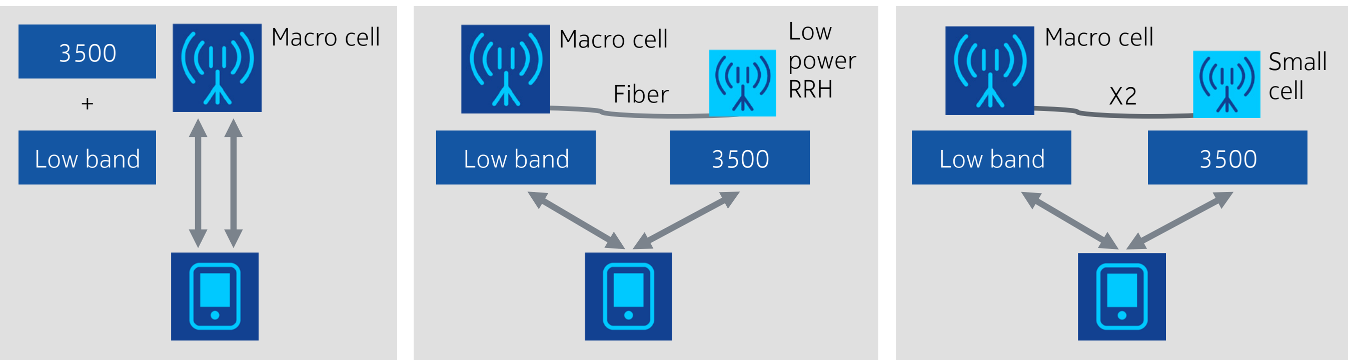

Fig. 10. Inter-site carrier aggregation between macro and small cell

Aggregation with supplemental downlink

Carrier aggregation allows the benefit of downlink only frequencies, called supplemental downlink. 3GPP has defined two supplemental downlink bands, Band 29 and 32. These bands can be used to enhance downlink data rates and capacity with carrier aggregation functionality. The concept is illustrated in Figure 11. The traffic profile in mobile broadband networks is quite asymmetric, with downlink traffic typically ten times higher than uplink traffic, which makes the downlink only frequencies attractive for matching the traffic profiles.

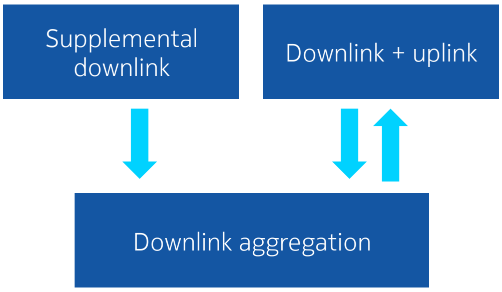

Fig. 11. Carrier aggregation with supplemental downlink

Aggregation with unlicensed frequencies

LTE can also use the unlicensed 5 GHz band to boost network capacity and data rates. This is under specification in 3GPP Release 13 and is called LTE for Unlicensed (LTE-U) or Licensed Assisted Access (LAA). The solution uses carrier aggregation between the operator's licensed frequencies and the unlicensed band.

The concept is an extension of the supplemental downlink solution. The licensed band can provide a reliable connection both in uplink and in downlink while the unlicensed band increases user data rates. The downlink data stream can be split between these two bands based on the Channel Quality Indicator (CQI) reports from the devices and based on the loading on the bands.

For the first time, there is a single technology available that can use both licensed and unlicensed bands, and undertake fast load balancing between the bands. The studies show that LTE-U with all the advanced LTE radio features can double spectral efficiency and double cell range compared to Wi-Fi technology on the same band. LTE-U is designed for smooth co-existence with Wi-Fi on the same spectrum. For more information, see the Nokia white paper on LTE-U.

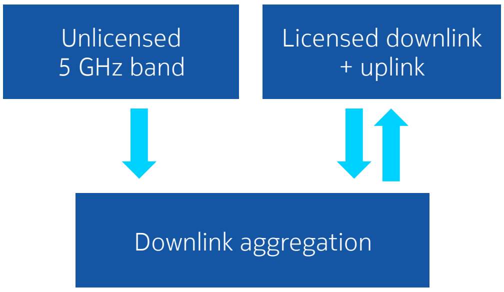

Fig. 12. Aggregation of licensed and unlicensed frequencies

Device power consumption optimization

Carrier aggregation affects smartphone battery life because the device has to monitor two frequencies, activate additional RF hardware and increase baseband activity. For large data transfers such as a file download, the power consumption with carrier aggregation increases during the time a file is downloaded. However, the higher throughput makes the download shorter, allowing the device to go back to RRC Idle state sooner, increasing the energy efficiency and saving overall battery life.

This can be seen in Figure 13 and Figure 14. The carrier aggregation case provides the lowest average power consumption when calculated over the total period of 185 seconds including the active download and idle time. Carrier aggregation increases power consumption if it is configured or activated even if no data is transferred. The higher power consumption is explained by the device monitoring two frequencies. Therefore, for short data transfers, where the RRC connection will spend most of the time waiting for the inactivity timer to expire, the power consumption may increase up to 80% when 10 MHz + 10 MHz carrier aggregation is configured, compared with a 10 MHz single carrier. This result indicates that carrier aggregation should preferably be configured only when the transferred data volume is large but should not be configured for small background data transmissions.

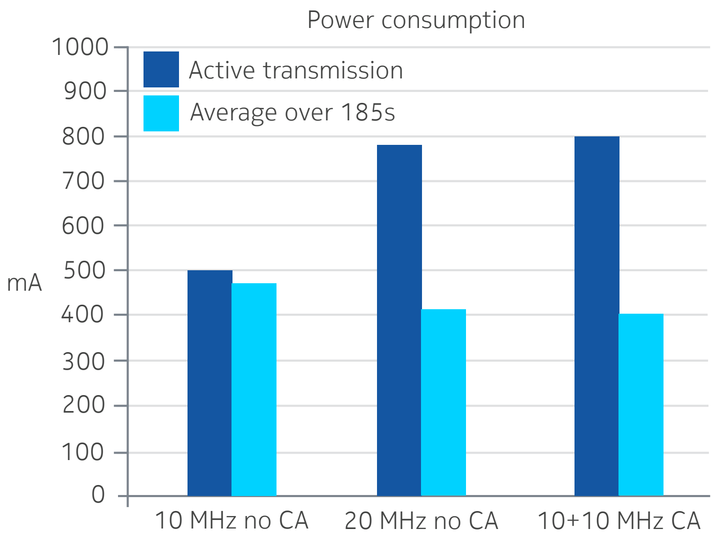

Fig. 13. Measured device power consumption with carrier aggregation

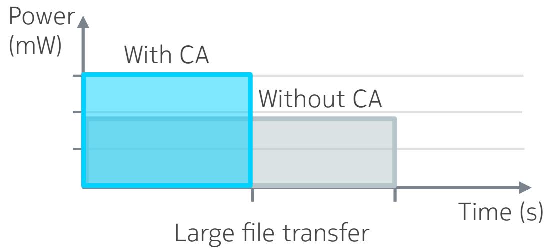

Fig. 14. Power consumption for a large file transfer

Evolution of Carrier Aggregation

Carrier aggregation is evolving further. 3GPP Release 10 supported a maximum of five component carriers while the signaling capability was extended beyond five carriers in Release 12. Many operators have even more than 100 MHz of spectrum available for LTE deployment. At the same time, device baseband and RF processing capability continues to improve, making it feasible to support even higher data rates in the devices.

Nokia demonstrated an impressive data rate of 4 Gbps by aggregating ten carriers, combined with Multiple Input Multiple Output (MIMO) technology. Both FDD and TDD frequencies were aggregated. The demonstration was completed with commercial Flexi Multiradio 10 base station hardware. So far, carrier aggregation has focused on the downlink direction. The uplink aggregation with two component carriers is expected to start soon in order to provide a better match with the rapidly increasing downlink data rates.

Summary

Carrier aggregation is the most important feature in LTE-Advanced because it improves the practical data rates, enhances the network capacity, simplifies the traffic management and extends the coverage area. Carrier aggregation started commercially in 2013. The peak data rate has increased to 300 Mbps during 2014 and will hit 450 Mbps during 2015. Carrier aggregation has turned out to be able to provide a very robust performance in live networks.

Carrier aggregation can combine both FDD and TDD frequencies together as well as licensed and unlicensed frequencies. Nokia Smart Scheduler can take full benefit of carrier aggregation and provide fair treatment between different device capabilities while minimizing device power consumption.

Further reading

LTE-Advanced white paper

LTE Release 12 white paper

Smart Scheduler white paper

LTE-U white paper

4 Gbps Carrier Aggregation press release

Small Cell Carrier Aggregation press release

FDD-TDD Carrier Aggregation press release

Three-band Carrier Aggregation press release

LTE-Advanced Carrier Aggregation video

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