Improving Peak Data Rate in LTE toward LTE-Advanced Technology

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Abstract

One straight forward possibility to reach high data rates requirements is to aggregate multiple Long Term Evolution (LTE) carrier. Two or more component carriers are aggregated in order to support wider transmission bandwidths up to 100MHz. However initial LTE-Advanced (3GPP Release 10) deployments will likely be limited to the use of maximum two component carriers, i.e. the maximum DL/UL bandwidth will be 40MHz for Frequency Division Duplex (FDD).

A relatively simple way to further increase individual data transmission speeds is to increase the channel bandwidth. To remain backward compatible with 3GPP Release 8, the maximum carrier bandwidth of 20MHz is not altered. Instead, carrier aggregation is used to combine the capacity of several individual carriers. The aggregated carriers can be adjacent or non-adjacent; they can be in a single band and also in different bands. An individual carrier is referred to in the standards as a component carrier (CC). Carriers can be aggregated asymmetrically in the downlink and the uplink directions. In the downlink direction, for example, carriers in two different bands can be aggregated to a combined 40-MHz channel, while in the uplink direction only a 20-MHz carrier in a single band is used. This paper focuses on the peak data rate which is improved depending on the number of aggregated carriers, with a related impact on the user equipment (UE) complexity.

Key words: LTE, LTE-Advanced, Peak data rate, CC.

1. Introduction

With regard to the peak data rates of cellular systems, from the onset of the introduction of cellular systems and until the mid-1991s the data peaked at approximately around 10 kbps. The peak data rate was lifted to 160 kbps with the introduction of GPRS. Only few years later, the first WCDMA systems supported peak data rates of 384 kbps. Nowadays, HSDPA supports peak data rates from 7.2 Mbps to about 14.6 Mbps (by using adaptive modulation and coding with higher-order modulation and multicode transmission. HSPA-Evolved specified by 3GPP Release 7 (Rel-7), the second phase of HSDPA, can achieve data rates of up to 42 Mbps (assuming 64-Quadrature Amplitude Modulation (QAM)). The coming technology, LTE, will see the peak data rate reaching 326 Mbps. In a few years, LTE-Advanced will theoretically push the peak rate to attain the huge throughput rate of 1Gbps (Afif Osseiran, Jose F. Monserrat, Werner Mohr, 2011). The evolution of the peak data rate from years 1991 to 2017 is shown in Figure 1.

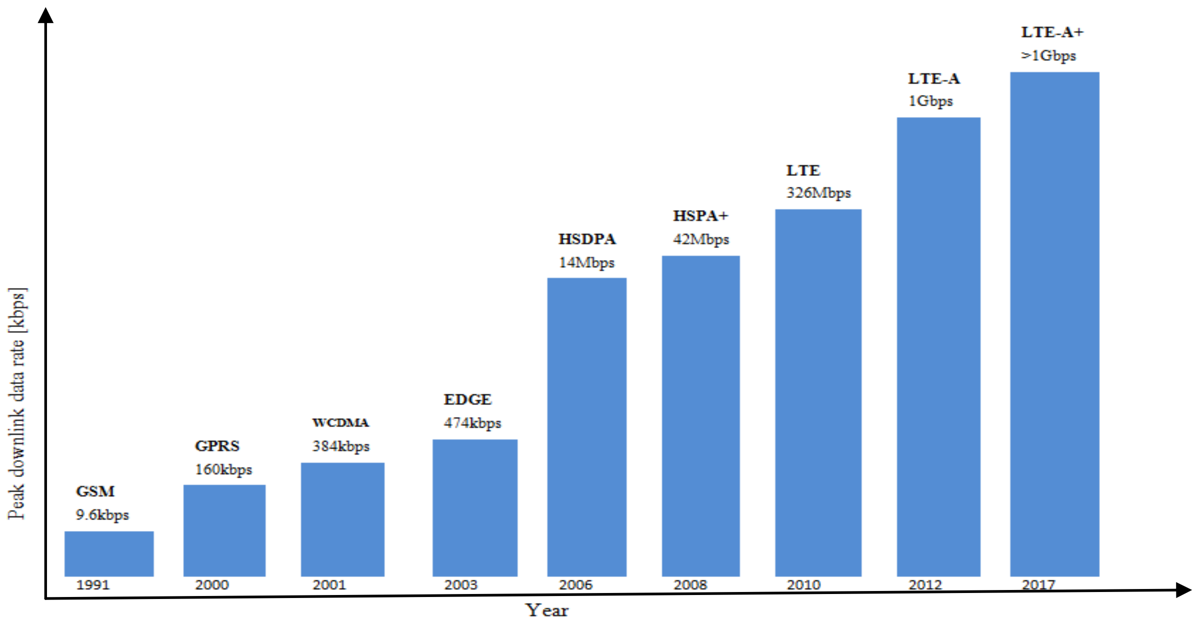

Fig. 1: Evolution of downlink peak rate from years 1991 to 2017

Finally, the LTE-A+ or 4.5G wireless broadband systems will be standardized in 3GPP Rel-12 in the 2013–2017 timeframe. It is clear that 4.5G systems will further enhance the 4G systems in terms of user experience, sector spectral efficiency, and peak rates, but the exact features for 4.5G systems are still being decided (Amitabha Ghosh and Rapeepat Ratasuk, 2011).

2. Peak data rate in LTE

The (LTE Rel-8) system supports high peak data rates and provides low latency, improved system capacity and coverage, reduced operating costs, efficient multi-antenna support, efficient support for packet data transmission, flexible bandwidth of up to 20MHz, and seamless integration with existing systems.

From a system and user performance perspective, the peak data rates have been defined. For the downlink, peak data rates of at least 100 Mbps must be supported for a system bandwidth of 20 MHz, while for the uplink, peak data rates of at least 50 Mbps must be supported (Amitabha Ghosh and Rapeepat Ratasuk, 2011).

The system supports a downlink peak data rate of 326 Mbps with 4 ×4 MIMO within 20 MHz bandwidth (EKRAM HOSSAIN, DONG IN KIM and VIJAY K. BHARGAVA, 2011).

Since uplink MIMO is not employed in the first release of the LTE standard, the uplink peak data rate is limited to 86 Mbps within 20 MHz bandwidth. In addition to the peak data rate improvements, the LTE system provides 2-4 times higher cell spectral efficiency than the Release 6 high-speed packet access (HSPA) system. Similar improvements are observed in cell-edge throughput while maintaining the same site locations as deployed for HSPA. In terms of latency, LTE radio-interface and network are capable of delivering a packet from the network to the UE in less than 10ms (FAROOQ KHAN, 2009).

3. Peak data rate in LTE-A

Rel-8 LTE 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.

This further advancement for LTE is known as LTE-Advanced (LTE-A). The LTE-A requirements are shown in Table 1 and focus mainly on improvements in system performance and latency reduction. From Table 1, it can be seen that the target cell and user spectral efficiencies have increased significantly. 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 (Amitabha Ghosh and Rapeepat Ratasuk, 2011).

Feature	Requirements
Peak data rate	Downlink – 1 Gbps
	Uplink – 500 Mbps
Peak spectral efficiency	Downlink – 30 bps/Hz (8 × 8)
	Uplink – 15 bps/Hz (4 × 4)
Average cell spectrum efficiency	Downlink – 3.7 bps/Hz (4 × 4)
	Uplink – 2.0 bps/Hz (2 × 4)
Cell-edge user spectral efficiency	Downlink – 0.12 bps/Hz (4 × 4)
	Uplink – 0.07 bps/Hz (2 × 4)
C-plane latency	50 ms from camped to active state
	10 ms from dormant to active state
U-plane latency	Reduced compared with Rel-8

Table 1: LTE-A Requirements

The key features of LTE-A include, in particular, enhanced peak data rates to support advanced services and applications (100 Mbps for high mobility and 1 Gbps for low mobility (Dan Forsberg, Günther Horn, Wolf-Dietrich Moeller and Valtteri Niemi, 2010).Also, the cell throughput or spectral efficiency target is set at around two times higher than existing LTE systems. In order to meet the peak data rate and spectral efficiency targets set by LTE-Advanced, the air interface needs to be evolved by incorporating new radio technologies as well as improving performance of the existing techniques.

4. Peak Rates and Peak Spectral Efficiency

Data rate; Many services with lower data rates such as voice services are important and still occupy a large part of a mobile network's overall capacity, but it is the higher data rate services that drive the design of the radio interface. The ever increasing demand for higher data rates for web browsing, streaming and file transfer pushes the peak data rates for mobile systems from kbit/s for 2G, to Mbit/s for 3G and getting close to Gbit/s for 4G (Erik Dahlman, Stefan Parkvall, and Johan Sköld, 2011).

For marketing purposes, the first parameter by which different radio access technologies are usually compared is the peak per-user data rate which can be achieved. This peak data rate generally scales according to the amount of spectrum used, and, for MIMO systems, according to the minimum of the number of transmit and receive antennas.

The peak data rate can be defined as the maximum throughput per user assuming the whole bandwidth being allocated to a single user with the highest modulation and coding scheme and the maximum number of antennas supported. Typical radio interface overhead (control channels, pilot signals, guard intervals, etc.) is estimated and taken into account for a given operating point. For TDD systems, the peak data rate is generally calculated for the downlink and uplink periods separately. This makes it possible to obtain a single value independent of the uplink/downlink ratio and a fair system comparison that is agnostic of the duplex mode.

The maximum spectral efficiency is then obtained simply by dividing the peak rate by the used spectrum allocation.

The target peak data rates for downlink and uplink in LTE Release 8 were set at 100 Mbps and 50 Mbps respectively within a 20 MHz bandwidth, 7 corresponding to respective peak spectral efficiencies of 5 and 2.5 bps/Hz. The underlying assumption here is that the terminal has two receive antennas and one transmit antenna. The number of antennas used at the base station is more easily upgradeable by the network operator, and the first version of the LTE specifications was therefore designed to support downlink MIMO operation with up to four transmit and receive antennas.

When comparing the capabilities of different radio communication technologies, great emphasis is often placed on the peak data rate capabilities. While this is one indicator of how technologically advanced a system is and can be obtained by simple calculations, it may not be a key differentiator in the usage scenarios for a mobile communication system in practical deployment. Moreover, it is relatively easy to design a system that can provide very high peak data rates for users close to the base station, where interference from other cells is low and techniques such as MIMO can be used to their greatest extent. It is much more challenging to provide high data rates with good coverage and mobility, but it is exactly these latter aspects which contribute most strongly to user satisfaction.

In typical deployments, individual users are located at varying distances from the base stations, the propagation conditions for radio signals to individual users are rarely ideal, and the available resources must be shared between many users. Consequently, although the claimed peak data rates of a system are genuinely achievable in the right conditions, it is rare for a single user to be able to experience the peak data rates for a sustained period, and the envisaged applications do not usually require this level of performance.

A differentiator of the LTE system design compared to some other systems has been the recognition of these ‘typical deployment constraints’ from the beginning. During the design process, emphasis was therefore placed not only on providing a competitive peak data rate for use when conditions allow, but also importantly on system level performance, which was evaluated during several performance verification steps.

System-level evaluations are based on simulations of multicell configurations where data transmission from/to a population of mobiles is considered in a typical deployment scenario. The sections below describe the main metrics used as requirements for system level performance. In order to make these metrics meaningful, parameters such as the deployment scenario, traffic models, channel models and system configuration need to be defined (Stefania Sesia, Issam Toufik and Matthew Baker, 2011).

The improvement in downlink sector spectral efficiencies on going from 2G to 4.5G systems is shown in Figure 2 (Amitabha Ghosh and Rapeepat Ratasuk, 2011).

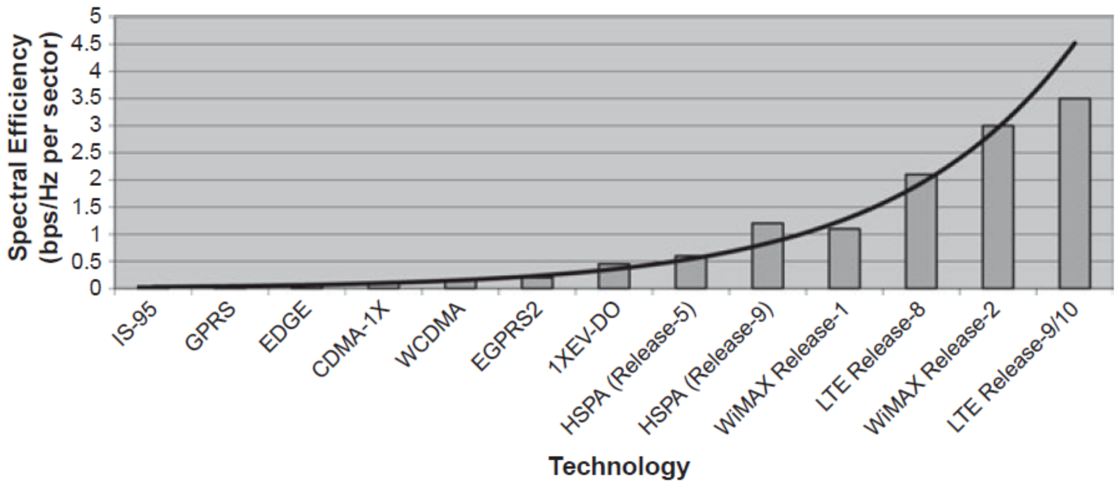

Fig. 2: Improvement in downlink spectral efficiency going from 2G to 4G system

5. Research Methodology

The main objective of this paper is to show the improvement of peak data rate in long term evolution release 8 toward release 10 (aggregated LTE) in modern wireless communications.

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.

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.

In Rel-8, the peak data rate is 300 Mbps in the downlink with four layer spatial multiplexing and 75.4 Mbps in the uplink, achieved using a system bandwidth of 20MHz. With carrier aggregation, these peak rates will increase with the aggregated bandwidth. Thus, using four 20-MHz downlink carriers, a peak data rate in excess of 1 Gbps can be achieved using carrier aggregation alone. In the uplink, however, a peak data rate in excess of 500 Mbps cannot be achieved even at an aggregated bandwidth of 100MHz using just carrier aggregation. In this case, LTE-A uplink spatial multiplexing can be used in conjunction with carrier aggregation to increase the peak data rate beyond 500 Mbps.

In Rel-10 LTE, the downlink spatial multiplexing is extended to support eight data layers (8 × 8 MIMO), thus increasing the peak data rate by a factor of 2 over LTE Rel-8 for single-carrier transmission (Amitabha Ghosh and Rapeepat Ratasuk, 2011).

4. Performance comparison of LTE/LTE-A

Very high peak data rates: LTE is capable of supporting very high peak data rates. In fact, the peak PHY data rate can be as high as downlink peak data rate of 100 Mb/s within a 20 MHz downlink spectrum allocation (5 bps/Hz), while it provides uplink peak data rate of 50 Mb/s (2.5 bps/Hz) within a 20MHz uplink spectrum allocation (Tara Ali-Yahiya, 2011).

Parameter	LTE	LTE-Advanced
Peak data rate downlink DL	300 Mbps	1 Gbps
Peak data rate uplink UL	75 Mbps	500 Mbps
Transmission bandwidth DL	20 MHz	100 MHz
Transmission bandwidth UL	20 MHz	40 MHz
Mobility	Optimized for low speeds (<15 km/h), high performance at speeds up to 120 km/h, and maintain links at speeds up to 350 km/h	Same as that in LTE
Coverage	Full performance up to 5 km	Same as LTE requirement
Scalable bandwidths	1.4, 3, 5, 10, 15, and 20 MHz	Up to 20–100 MHz

Table 2: LTE and LTE-Advanced comparison

The peak data rates supported by LTE and LTE-A are summarized in Tables 3. Although the peak rates do not have true values with respect to system performance, they are of significant value from a marketing point of view.

Link type	Bandwidth	LTE and LTE-A	Peak rate (Mbps)
Downlink	20 MHz	2 × 2 SU-MIMO	82.9
	20 MHz	4 × 4 SU-MIMO	164.8
	20 MHz	8 × 8 SU-MIMO (Rel-10)	329.5
	40 MHz	2 × 2 SU-MIMO (Rel-10)	165.8
	40 MHz	4 × 4 SU-MIMO (Rel-10)	329.6
	40 MHz	8 × 8 SU-MIMO (Rel-10)	659.0
Uplink	20 MHz	1 × 2 SIMO	30.2
	20 MHz	2 × 2 SU-MIMO (Rel-10)	60.3
	20 MHz	4 × 4 SU-MIMO (Rel-10)	119.8
	40 MHz	1 × 2 SIMO (Rel-10)	60.4
	40 MHz	2 × 2 SU-MIMO (Rel-10)	120.6
	40 MHz	4 × 4 SU-MIMO (Rel-10)	239.6

Table 3: Summary of peak data rate in LTE and LTE-A

5. Conclusions

LTE has been standardized to provide higher data rate services. Its target peak data rates are 100 Mbps and 50 Mbps for downlink and uplink, respectively. Although LTE can provide a wireless multimedia service, its data rate is still limited. In order to provide richer multimedia services via wireless, 4G mobile communications (LTE-Advanced), need to use a much broader bandwidth; 100MHz bandwidth is required to achieve a higher data rate in conjunction with advanced wireless access technologies, MIMO technologies, hybrid ARQ.

The LTE-advanced targets support of peak data rates of 1 Gbps in the downlink and 500 Mbps in the uplink for low-mobility scenarios. It is important to note that LTE-advanced is also moving to supporting these rates in a greater part of the cell with the use of devices such as relays. The paper has discussed Transmission peak date rates depending on the number of antennas on the transmitter and the receiver, the used bandwidth and the configuration of radio parameters like the resource allocation for control channels. The maximum peak data rates vs. the number of transmitter and receiver antennas. The usage of carrier aggregation helps to achieve higher peak data rates and this led to achieve better coverage for medium data rates. For these data rates, it allows the use of lower orders of modulation and lower code rates, which would reduce the required link budget, transmission power, and interference.

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