The [r]evolution towards 4G

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***Abstract*—This paper is an overview of the next generation of mobile telephony, it will briefly describe the milestones of telecommunication during the last 20 years. As well as bring you an overview of todays LTE (release 8) networks that is being deployed as well as giving an overview what has to be done in order to upgrade the todays LTE Release 8 networks into LTE Release 10 so that the requirements for ITU-R IMT-Advance functionality will be fulfilled. It will also describe what is missing in todays so called "4G" networks in order to fulfill the IMT-Advance criterias. However, today, there is a big gap between 4G and IMT-Advanced.**

I. Introduction

The telecom market has been thriving in a way that has not been possible until the last 20 years. The rapid growth of new techniques, competitors and different standards in different countries do not make it easier for the customers. In the beginning the standards was not very hard to follow, first out was the Nordic Mobile Telephone, NMT after that the GSM standard changed the world. After the recognition of internet the demand for high speed mobile broadband was a fact. Today almost everyone carries a handset that are capable of speeds up to 28 Mbits/s, but the demand for higher speeds are still out there. 3G has been available for 10 years and like GSM that also was out for 10 years, a new standard is on the brink of being publicly available - 4G. However, the requirements for what is needed to be called 4G varies between different carriers and mobile telephone companies. In this report we will focus on the gap between LTE Release 8 and LTE Release 10, sometimes referred to as LTE Advanced because it is the only standard to date that have fulfilled all the requirements of ITU-R IMT-Advanced. Differences and comparisons between the two will be described in this report. But there is still a question out there - Is it up to the market to decide what should be called 4G or is it the responsibility of the International Telecommunication Union, ITU decide to lower the diversity of standards?

II. Background

During the past several years the technology evolution has been way greater then ever imagined. The mobile revolution started with the NMT standard, Nordic Mobile Telephone, in 1981[1]. The technology served the society well with great coverage in the country side - which was the main reason it was so popular even after the release of GSM in 1991. The main reason for the better coverage in the rural was because of the frequency and the output power, which is $\sim$3 times higher than a standard GSM set.

The NMT standard however had some limits and the world was thriving for a new standard. The new standard GSM had some extra features but was mainly the same but with the extension of Short Message Service, SMS, and later in 1997 the release of Wireless Application Protocol, WAP. After the great success of GSM which basically changed the way the world communicates the people demanded higher speeds then the WAP could deliver, the need for a IP-based protocol was also a priority[2]. GPRS released and most carriers changed the way people were charged for surfing the web. Instead of paying for each minute, like a modem based internet connection, GPRS charged for the total amount of data that was downloaded and uploaded. The speed is about $\sim$60 kbit/s and was raised to about $\sim$200 kbit/s with the EDGE standard.

With the raised demand of higher speeds the 3G standard was developed. The focus was high bit rate to satisfy the users of the thriving internet. UMTS was later developed and released in year 2001 and was standardized by 3rd Generation Partnership Project, 3GPP. Other services as video calling, video messages and positioning was introduced. During the 10 years that 3G has been available the peak speeds of the data rate has been increased massively. The technique that was used in the start is called HSPA with speeds up to $\sim$384kbit/s. With the release of HSPA+ in 2007 the speeds can be as high as $\sim$54 Mbit/s (in theory), and about $\sim$28 Mbit/s in download and $\sim$22 Mbit/s in upload[3].

This is however not enough, because of web applications demands higher and higher bit rate the evolution continuous. In 2009 the first publicly available 3G: LTE system was available in Stockholm and Oslo in 14^{th} of December 2009. However, because of the rapid growth of data-speeds in the past 10 years, from about 9kbit/s to peak speeds of 100Mbit/s. This means a the peak speeds has been multiplied about 10 000 times in the past 12 years.

This is where things get complicated. Because of the rapid growth of new competitive techniques the standards are not fully set. The 4G standard is specified by the International Mobile Telecommunications Advanced, IMT-Advanced. IMT-Advanced is defined by the International Telecom Union Radiocommunication Sector, ITU-R. They have defined the 4G standard to have bit rates around 100Mbit/s in high mobility areas and 1Gbit/s in low mobility areas. There are also other specifications that need to be fulfilled such as all-IP packet

	LTE Release 8	LTE Release 10	IMT-Advanced
Target user rate:	~50-100 Mbit/s	~1Gbit/s	~100Mbit/s (high-mobility enviroment)
RF Channel Bandwidth:	1.4, 3, 5, 10, 15 and 20 Mhz	20Mhz-100MHz (support scalable bandwidth)	e.g. 100 Mhz (support scalable bandwidth)
Access Technology:	Down-link: OFDMA + MIMO, Up link: SC+FMDA	Down-link: OFDMA + MIMO, Up link: SC+FMDA	Down-link: OFDMA + MIMO, Up link: SC+FMDA
Potential Frequency Bands	IMT-2000 band	TBA	Higher then 3 GHz
Latency, Control/User plane	50 ms/4.9 ms	50 ms/4.9 ms	Less then 100 ms/10ms
Peak spectral density, Downlink/Uplink	16b/s/Hz, 4b/s/Hz	16.0(30)*b/s/Hz, 8.1(16.1)*b/s/Hz	15b/s/Hz, 6.75b/s/Hz

Fig. 1. System performance of LTE 8, LTE 10 and IMT-Advanced. *Value is for a 4x4 antenna configuration. Value in parenthesis for 8x8. **Value is for 2x2 antenna configuration. Value in parenthesis for 4x4.

switched network, dynamically share and use the network resources to support more simultaneous users per cell, scalable channel bandwidth 520 MHz, optionally up to 40 MHz and smooth handovers across heterogeneous networks[4].

However, none of the existing standard on the market can fulfill these requirements. The only requirement that has been fulfilled is the speed. The telephone carrier companies did not care that the standard was not fully developed before the name 4G showed up in advertisements. Today the existing standards that have been called 4G are 3GPP Long Term Evolution, 3G: LTE (LTE Release 8), and Worldwide Interoperability for Microwave Access, WiMAX, and the newest LTE-Advance (LTE Release 10) that is the standard that is being developed to fulfill the IMT-Advanced requirements.

III. Technical overview

A. Long Term Evolution Release 8

LTE was first released in 2009 and when it then was compared with 3G it indicated a significant performance increase in peak rates, spectrum efficiently, network-delay. To reduce cost and simplify operation was the LTE radio-network architecture designed as a flat distribution. The first release provides support for both frequency-division multiplexing, FDD, and time-division multiplexing, TDD. Due to different properties between up-link and down-link, different multiplexing techniques are used. For the down link were the available transmission power is considerably larger, Orthogonal frequency-division multiplexing, OFDM, is used. This means that data are divided and then transmitted on multiple narrowband sub-carriers. In the up link a discrete Fourier transform, DFT, precoded OFDM is used instead of regular OFDM. The DFT precoded OFDMA is sometimes called single carrier frequency- division multiplexing, SC-FDMA. This technique is highly power-efficient which is one of the most important factors considering the available transmission power. The use of this multiplexing techniques minimizes terminal complexity on the down link as well as on the up link, leading to an overall reduction in terminal complexity and power consumption[5] which will lead to lowered costs.

Before the data is modulated with OFDM it is also turbo coded and modulating with either QPSK, 16-QAM or 64-QAM. One of the main reasons to use OFDM is that it ensures that the signal to be inter symbol interference, ISI, free. This is a guard interval added between the signals, see figure 4. In LTE 8 a normal cyclic prefix is 4.7μs, in a highly dispersive environment this value is 16.7μs. "Note that the DFT precoder does not compromise orthogonally between sub-carriers.", according to [5]. This will provide an ISI free up link too.

The transmitted signals are divided into sub frames of 1 ms duration, 10 sub frames forming a radio frame, this i illustrated in figure 2. First transmitted in the sub frame is the control region which contains one to three OFDM symbols, used for the control signals sent from the base station. The second part of the sub frame contains the data region, used for the data signals but also cell-specific reference signals[6]. How the sub frame looks can be seen in figure 3. The purpose of the reference signals is to estimate the channel-quality and its properties in the down link, depending of cycle prefix consisting of 12-14 OFDM symbols. Each sub frame is dynamically scheduled by the scheduler in the base station. The scheduled located in the base station is a key element whose function is to determine which users are allowed to transmitted, on what frequencies and what data rate. By being fed channel-information and then evaluate it can the scheduler control both up and down-link[5].

1) Spectrum flexibility: In the design of the LTE system some important requirement was to be able to avoid unnecessary fragmentation, have a consistency between FDD and TDD modes of operation while maintaining possibility to fully

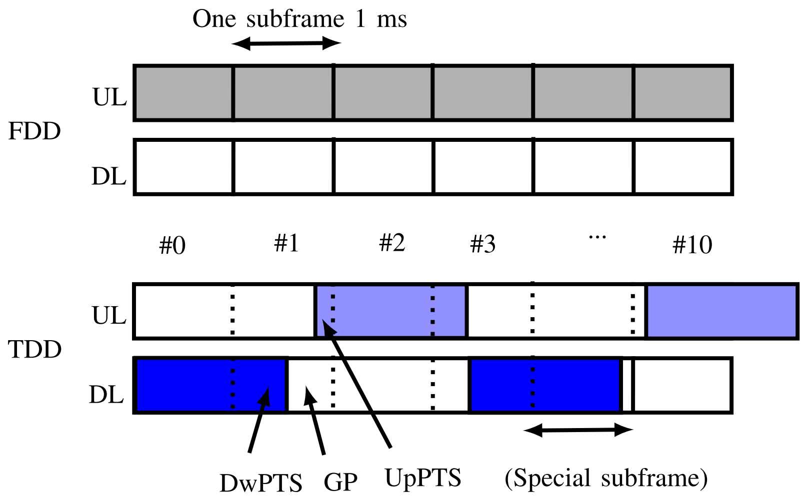

Fig. 2. LTE Frame Structure

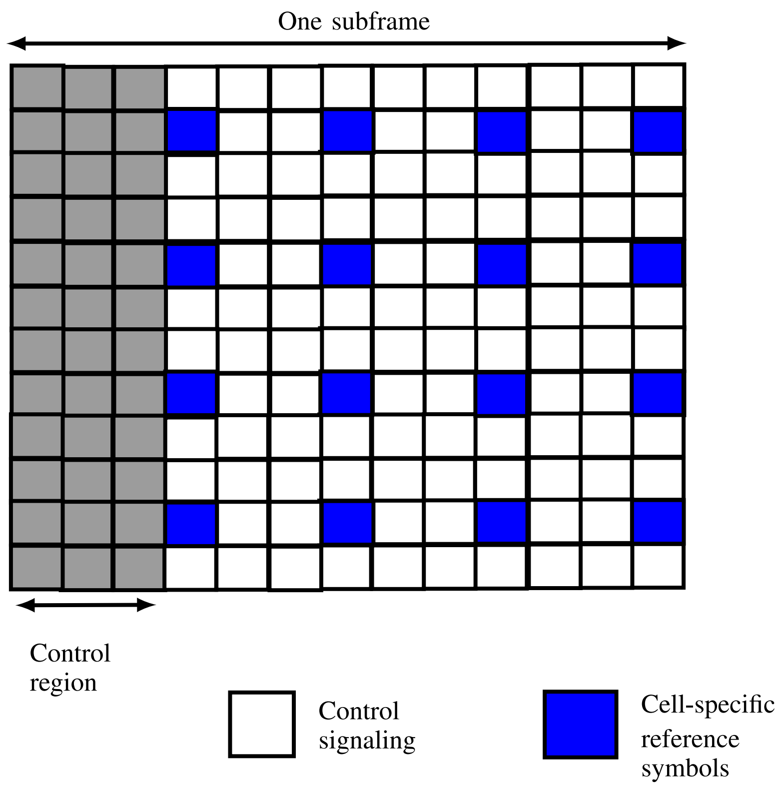

Fig. 3. The sub frame in the LTE Frame Structure

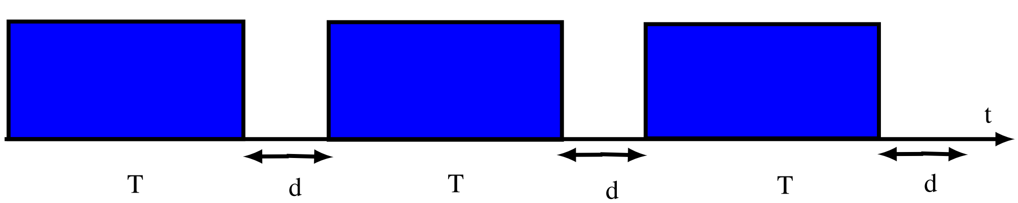

Fig. 4. Guard interval to eliminate ISI

exploit duplex-specific properties for FDD and TDD. This is done in the LTE radio access technology were one of the main properties is the bandwidth flexibility[6]. A range from 1.4 to 20.0 MHZ is defined, supporting both FDD and TDD operations, by allowing both paired and unpaired operation. Paired frequency bands means that the up link and down link are assigned seperate frequency bands for there transmission. In the unpaired case is the same frequency band shared between up link and down link. When the paired operation is used a frequency guard band required to provide sufficient isolation between up link and down link. To ensure the isolation when using a unpaired operation a so called guard period is used. Large guard period will limit capacity compared with a large guard band which does not impact capacity. Several factors affect how long the guard period have to be to ensure that the up link and down link do not interfere with each other, most important is that the guard period must be long enough to handle the prorogation delay which largely depends on the distance. Additional to avoid inter-system-interference, ISI, should the up link and down link be mutually aligned, that is, down link-up link switch-points have to coincide between the two systems.

The guard periods are created by splitting one or two sub frames into three fields; a down link part called DwPTS, a guard period called GP, and an up link part called UpPTS. These splitt sub frames are refereed to as special frames. When a terminal attempt to access a cell occupies the system information the most narrow bandwidth supported by LTE, 1.4 MHZ, and located in sub frames guaranteed to be down link sub frames. This is done so that regardless of the cell bandwidth or duplex-scheme used can the terminal re-access the cell. After the terminal have receive knowledge about the system information, then based on the knowledge on the parameters cell bandwidth and duplex-scheme can the terminal access the cell again[5].

2) Multiple-Antenna Transmission: Already in the first release of LTE, multi-antenna transmission support was an integral part of the system. More advanced techniques that are supported are the transmit diversity and spatial multiplexing. Both these systems are capable to use up to four receive antennas. Transmit diversity is based on Space-Frequency Block Coding, SFBC, this is used for the case of two transmit antennas. To be able to use four antennas is SFBC combined with Frequency Shift Time Diversity, FFSTD[6]. The spatial multiplexing including both so-called single -user multiple-input multiple- output, SU-MIMO, and MU-MIMO and also beam forming. When using the spatial multiplexing technique, is it possible to increase the peak data rate over the radio link. This is because both the base station and the terminal are used to provide simultaneous transmission of multiple, parallel data stream, refereed to as layers over a single radio link. For example, a case where four antennas are used on both sides is it possible to send four data streams simultaneously resulting in a increasing in the data rate by a factor 4. Another technique in the spatial multiplexing, is the so-called beam-forming technology. The advantage of this is that it has a increased coverage compared with the other multiplexing techniques, hence less cells are needed to cover a specific area. The advantages of using Transmit diversity is because it creates additionally diversity in the transmission, which is disable in the case were channel dependent scheduling is not possible. This is primarily intended for a common down link. The up link and down link from one cell is orthogonal to each other and in the ideal case this implies there is no interference within the same cell between them, only with other cells[5]. See figure 5 for illustration on the different types of antenna supports.

B. Long Term Evolution Release 10

LTE Release 10 is the new technology towards the IMT-Advanced standard and is sometimes refereed as LTE-Advanced. It includes all the properties of LTE Release 8 and adds some important features to become the new IMT-Advanced standard. However the LTE release 10 does not introduce any new access technologies, the down link uses conventional ODFM and the up link uses DFTS-OFDM on the up link[8]. DFTS-OFDM also allows more efficient power-amplifier operation, thus providing a reduced power consumption at the user. By evolving LTE instead of introducing a new radio access technology is important in a operators point of view, because a LTE 10 terminal can access an old version of LTE. Later when the technology is rising one can simply do software updates to obtain the new functionality of LTE 10[6]. Some key-features of LTE Release 10 will be listed below.

1) Carrier Aggregation: LTE 8 provides extensive support for deployment of spectrum allocations of various characteristics with bandwidths ranging from 1.4 up to 20 MHz in both directions. In LTE 10 the transmission bandwidth can be further extended by means of so called carrier aggregation where multiple component carriers are aggregated and jointly used for transmission to or from a single user equipment. Up to five component carriers can be aggregated, possibly on different channels allowing bandwidths up to 100 MHz. This provides backward compability and all the LTE handsets will look like a release 8 LTE device, but the LTE devices that allows carrier aggregation can exploit the total bandwidth[8]. See figure 6 for an illustration of carrier aggregation.

2) Relaying: LTE Release 10 extends the radio-access technology with support for relaying functionality. With relaying the user equipment communicates with the network via a relay node that is using the LTE radio-interface technology. The donor cell may also serve user equipment on its own. The donor-relay may operate on the same frequency as the relay user equipment link, usually refereed to as inband- or outband relaying.

The main advantages with relays is to provide better coverage without but minimal power used. In essence the relay is a low-power base station that is connected wirelessly to the rest of the network. This will provide better coverage for problematic areas i.e. indoor environments such as large shopping malls, train stations and airports, or where the mobile internet demand is greater then usual.

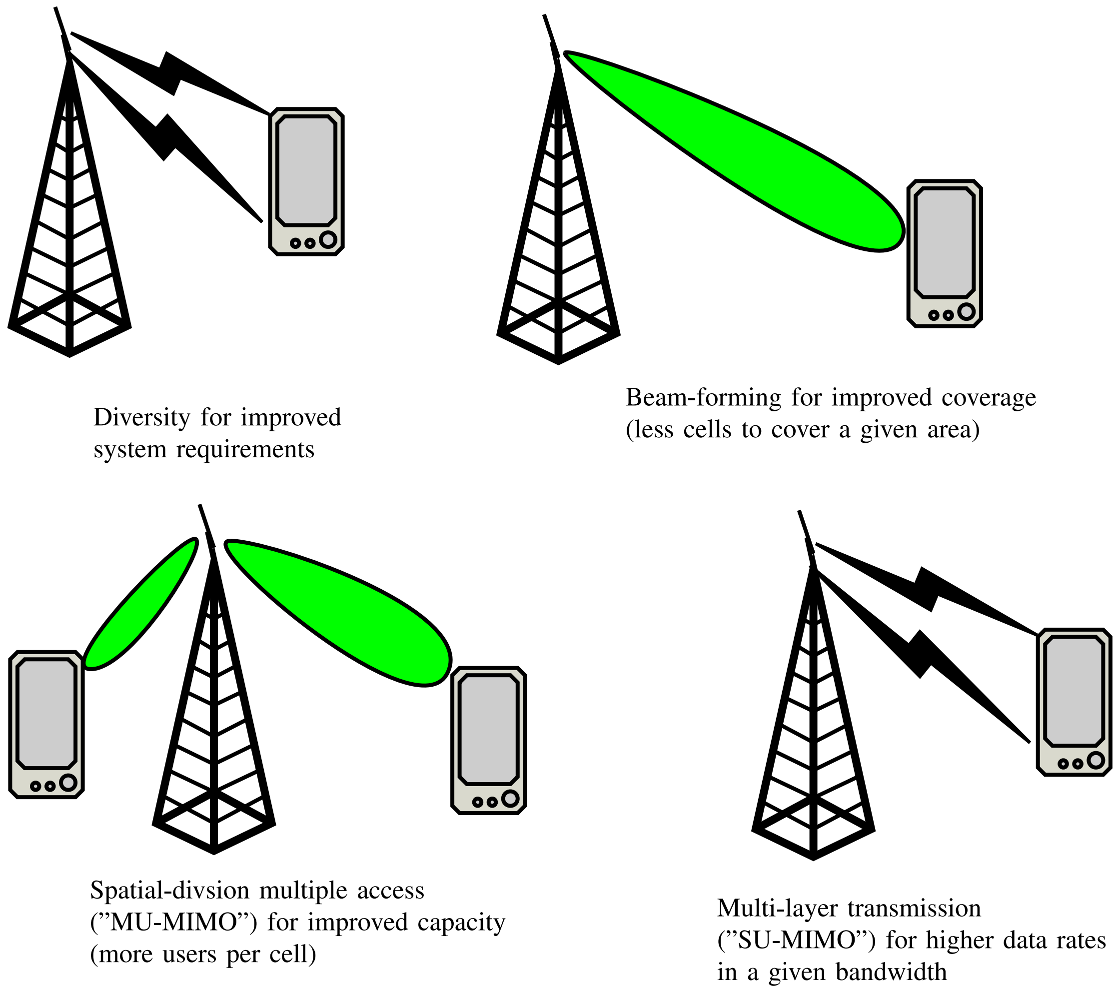

Fig. 5. Multiple-antenna techniques in LTE.

Even at later stages when demand have risen even higher, the connection between the relay and main base station do not have to be wireless but could instead be replaced with a optical fiber[8].

3) Multiple-Antenna Support: LTE release 8 already supports a wide range of antenna techniques. This includes down link transmit diversity based on Space-Frequency Block Coding, SFBC, for the case of two transmit antennas and a combination of SFBC and Frequency-Switched Transmit Diversity, FSTD, with four transmit antennas. This includes the possibility to rank-adaption down to single-layer adaption, leading to codebook-based beam forming and a basic form of multi user MIMO where different layers in the same time-frequency resource can be assigned to different terminals[7]. In release 10 the down link multiplexing is enhanced to support eight transmission layers together with an enhanced reference signal structure. See figure 5 for illustration on the different types of antenna supports.

C. IMT-Advanced

IMT-Advance was first defined in April 2008, it was called "Requirements for Further Advancements for E-UTRA.", E-UTRA is today often refereed to as LTE-Advanced, or LTE Release 10[6]. The goal of LTE Advance is not to create a new radio access technique but instead focus on *carrier aggregation* which will provide very high data rates, *relaying* to improve coverage and deployment costs, *extended multi-antenna support*, to increase the number of data layers in the up link to 8 and in the down link to 4 in order to improve data rates further. Again, it can not be stressed enough that LTE-Advance is not a new radio access technique but instead an evolution of a existing technique. Today the main competitor to be accepted as the new standard is LTE Release 10 which not only have fulfilled the requirements, but surpasses them on many points.

IV. The 4G Race

Ever since KT of South Korea released their WiMAX technology in Seoul in 2005 the 4G technology have been seen in the horizon. But the 4G hysteria did not start until Sprint

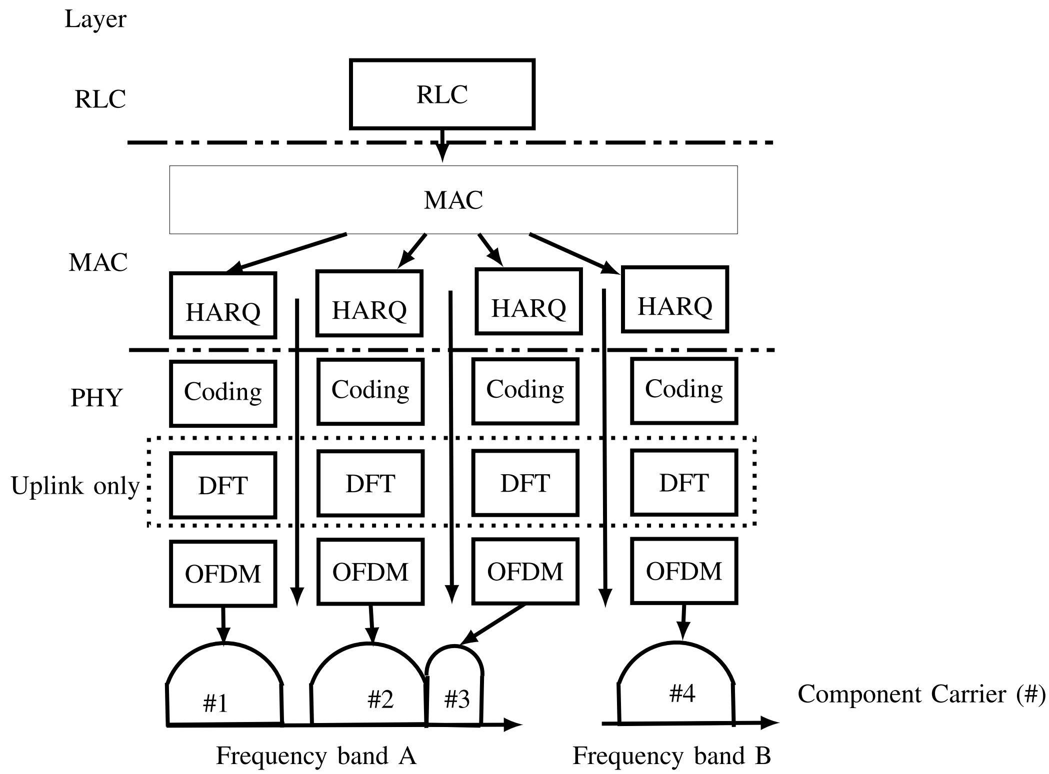

Fig. 6. Illustration of carrier aggregation.

released their so called ”4G network” in USA in mid 2008 under the consortium Open Patent Alliance. The companies that formed the consortium was Intel, Clearwire, Alcatel-Lucent, Cisco, Samsung and Sprint. The problem with this was that the so called 4G network was based on an early WiMAX candidate that did not manage to break the HSDPA speeds in Europe, which was still called 3G. The speeds were approximately 3-6 Mbit/s. Ever since this point, a lot of carriers around the world have been eager to implement 4G-network. However, the 4G standards had been described by ITU at this point and Wimax did not fulfill any of these requirements. The strategic vision for 4G was laid out in 2002 by ITU and in early 2008 ITU established the detailed performance requirements of IMT-Advanced, by issuing a Circular Letter calling for candidate Radio Access Technologies for IMT-Advanced[4].

In November 2008 HTC released their phone HTC Max 4G that should work with WiMAX networks. Lithuania released their ”4G” network, based on WiMAX in 2009, same with TeliaSonera that rolled out their LTE release with the 4G brand. TeliaSonera started the LTE network in Oslo and in Stockholm where Huawei and Ericsson based systems was used respectively.

In Estonia the carrier EMT also opened their LTE network as 4G, same with the carrier LMT in Latvia. At this point, in December 2010 during a conference called ITU World Radiocommunication Seminar, it was decided that evolved 3G standards could be considered 4G, even if it did not fulfill any of the requirements of IMT-Advanced. This got pretty confusing when carriers started to name their networks to ”4G LTE” in USA, for example Verizon[9] because of the existing 4G brand under the WiMAX technology. To make consumers aware of an upgrade and to make sure it was known that WiMAX and LTE was not the same, Verizon felt that it needed to be branded as 4G LTE. However, it is to date unclear how evolved 4G standards will be called.

V. Conclusion

The goal of this article was to provides a basic knowledge about LTE Release 8, LTE Release 10 and what is required to fulfill the IMT-Advanced requirements. Clearly LTE Release 8 has offered a good foundation for the evolution of LTE Release 10 with its key components - carrier aggregation enhanced, multi-antenna support and relaying. LTE Release 10 fulfills the specification for IMT-Advanced in every aspect, unlike LTE Release 8 that have only managed to achieve some decent speeds. However, since ITU-R have choosen to accept LTE Release 8, as well as WiMAX, to be concidered as 4G. The result of this have degraded the 4G term. How the doployment of LTE Release 10 will look in a marketing point-of-view is hard to tell. It will not have the same type of breakthrough as 3G once had and today ordinary people do not know what the new technichal features really will be between the current LTE Release 8 and LTE Release 10.

Perhaps will the consumers not keep in mind that the phone will automatically use the best internet service available at the local spot, i.e. use WLAN instead of the LTE network. The history tells us that the consumer do not care how things work - it just has to work. If it is branded as 3G: LTE, 4G, 4G LTE or even 5G, does not matter to the consumer.

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