Performance Comparison of OFDMA and CDMA Access Technologies in Broadband Wireless Communication Networks

Ilija Efnusev, Vesna Stojanovska, Lazar Dinov

***Abstract* — In this paper overview of the OFDMA and CDMA access technologies in variety of Broadband Wireless Communication Networks is given. It also makes comparison of advantages and disadvantages of OFDMA and CDMA as access technologies and their expected performance as well as the real measured performance and bandwidth efficiency. Furthermore a comparison the OFDMA and CDMA multiple access techniques in different standards like UMTS, HSPA, LTE, WiMAX is given as well as their Uplink and Downlink throughput and spectral efficiency performance depending on the multiple access technology used.**

***Keywords* — OFDMA, CDMA, LTE, WiMAX, HSPA, 3G, wireless broadband technologies, performance, throughput, spectral efficiency.**

I. INTRODUCTION

WITH the communication and Internet technologies and services unstoppable growth the end users demand bigger and bigger data transfer rates. The services themselves become more and more bandwidth demanding. With the new ubiquitous services people want to have access to them no matter of the place, time and the terminal they are using. The mobile devices and PDAs have become just one more gadget that everybody has just like the watch. This data rate demand for mobile devices and the limited wireless spectrum strives for more bandwidth efficient and high throughput able technologies. These two parameters are mostly controlled by the physical layer and access technology. Many technologies have been used on the radio link layer for wireless technologies like TDMA, FDMA etc. but now-days the most widely used spectral efficient and cost effective ones have shown to be CDMA and OFDMA. This is the reason why in this paper these two access technologies were chosen for comparison of their technology advances and their performance.

Ilija Efnusev, working in IT Department in T-Mobile Macedonia Orce Nikolov bb. Skopje, Macedonia (e-mail: ilija.efnusev@telekom.mk)

Vesna Stojanovska, working in LANCom Computers, bul. Kliment Ohridski 24, Skopje, Macedonia (e-mail: vesna@lancom.com.mk)

Lazar Dinov, working in TO Depratment in T-Mobile Macedonia. Orce Nikolov bb. Skopje, Macedonia (e-mail: lazar.dinov@telekom.mk)

In the same time all of the above are Master Students in Communication and Information Technologies at the Faculty of Electrical Engineering and Information Technologies on the Ss. Cyril and Methodius University in Skopje Macedonia

I. CDMA – TECHNOLOGY

The world is increasingly adapting faster and advanced ways of communication for better quality and CDMA is one of these technologies in wireless world. CDMA stands for Code Division Multiple Access. It is an access technology that operates on Spread Spectrum Technique and differentiates various communicators on the basis of codes. Spread Spectrum technique is a method that transmits a signal by spreading its bandwidth over broad range of frequencies. The bandwidth for the signal is greater than the frequency of the original content to be transmitted. Successful variation type of CDMA is wideband CDMA that uses spread-spectrum technology and special coding scheme.

A. WCDMA Principles

CDMA as basis of 3G technologies (UMTS / HSPA / HSPA+), use WCDMA for the frequency division duplex (FDD) mode of UMTS, and Time Division CDMA (TD-CDMA) for the time division duplex (TDD) mode of UMTS. W-CDMA (Wideband Code Division Multiple Access) defines the air interface access of the UMTS network [1]. Unlike GSM and GPRS, which uses time division multiple access and frequency division multiple access, W-CDMA allows all users to transmit at the same time and to share the same frequency carrier.

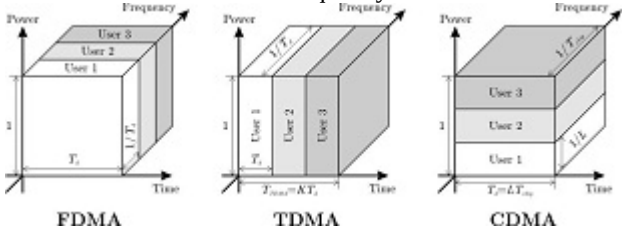

Fig. 1 Comparison of FDMA, TDMA and CDMA

Wideband CDMA uses spread-spectrum technology and special coding scheme, and has two modes: frequency division duplex (FDD) and time division duplex (TDD). In the first case two separate 5-MHz bands are used for uplink and downlink communications, and in TDD only one 5-MHz band is time-shared between uplink and downlink communications. FDD is being deployed at this time and is usually referred to as W-CDMA. With CDMA and W-CDMA technolgy instead of dividing users up by frequency or time, they are divided into codes, specific data streams assigned to particular users shown on Figure 1. All users transmit at the same time and multiple users

share the same frequency carrier. Each mobile user is uniquely identified by a specialized code and frequency.

B. Spreading and De-spreading

Due to spreading and de-spreading, signal-to-interference ratio (carrier-to-interference ratio) is lower in WCDMA than in GSM. The main principle of spreading modulation (BPSK/QPSK) is multiplication of each user data bit with a sequence of X code bits, called chips (spreading factor) shown on Figure 2[2].

This effects in processing gain (the ratio of the transmission bandwidth to the information bandwidth), which is a fundamental aspect of all CDMA systems[3]. Processing gain is what gives CDMA systems the robustness against self-interference that is necessary in order to reuse the available 5MHz carrier frequencies over geographically close distances.

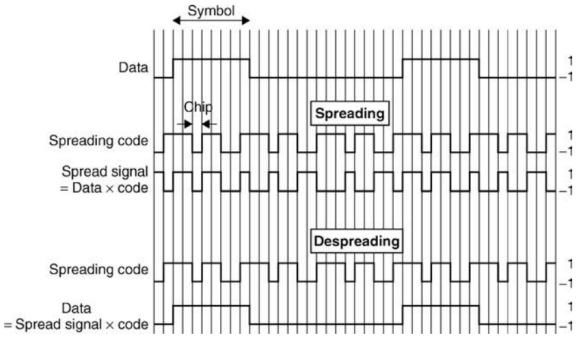

Fig. 2 Spreading and dispreading in DS-CDMA

C. MIMO in CDMA

Until HSPA is an enhancement to original UMTS data service, HSPA+ is evolution of HSPA in direction to increase throughput and capacity and to lower latency. The performance improvements in HSPA+ are achieved with introduction of MIMO [4]. This approach significantly increases the data rates of the HSPA+ and other improvements, such as higher order modulation targeted for HSPA evolution to further increase the DL data rates.

II. OFDMA- TECHNOLOGY

Orthogonal Frequency-Division Multiple Access (OFDMA) is based on orthogonal frequency division multiplexing (OFDM), a digital multi-carrier modulation scheme that is widely used in wire-lined systems such as Digital Subscriber Line (DSL) modems and cable modems, but it is pretty new in the wireless and cellular technologies.

A. OFDM Principles

OFDM achieves high data rate and efficiency by using multiple overlapping orthogonal sub-carrier signals instead of just one carrier. Because of sub-carriers orthogonally at the sampling instant of one sub-carrier all the other sub-carriers have zero value, illustrated on Figure 3 [5].

The key advantage of OFDM over single carrier modulation schemes is the ability to divide the bandwidth into multiple frequency sub-carriers which carry the information independently, what leads to higher bandwidth efficiency and flexible bandwidth allocation ([6], [7]).

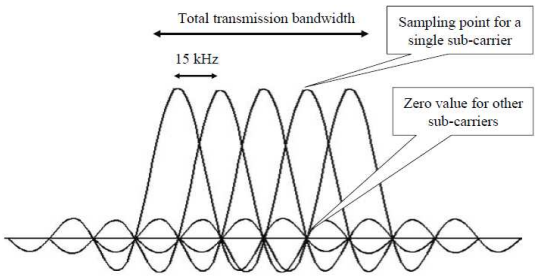

Fig. 3 OFDM orthogonal sub-carriers

Because OFDM can easily match transmission signals (sub-carriers) to the uncorrelated RF channels, the technology is well-suited to Multiple Input, Multiple Output (MIMO) as fast growing concept used by newest network technologies for increasing power gains (SNR) of the received signal [8]

B. OFDMA vs. OFDM

As mentioned before OFDMA is a variation and in the same time an improvement of the OFDM technology. With standard OFDM a user has one or couple of sub-carriers allocated, so transmissions can suffer from narrowband fading and interference in those sub-carriers. OFDMA makes a leap forward and incorporates elements of time division multiple access (TDMA). OFDMA allows subsets of the subcarriers to be allocated dynamically in time among the different users on the channel, as shown in Figure 4[9].

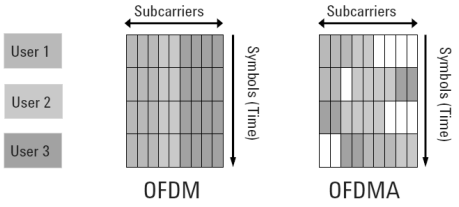

Fig. 4 OFDM vs. OFDMA sub-carrier allocation

The result is a more robust system with increased capacity and bandwidth efficiency. This is due to the possibility multiplexing low rate users which leaves more bandwidth (sub-carrier time slots) for higher rate demanding users and the ability to schedule users by frequency and time, which provides resistance to multi-path fading.

C. SC-FDMA

The high peak-to-average ratio (PAR) associated with OFDM led 3GPP to look for a different transmission scheme for the LTE uplink.

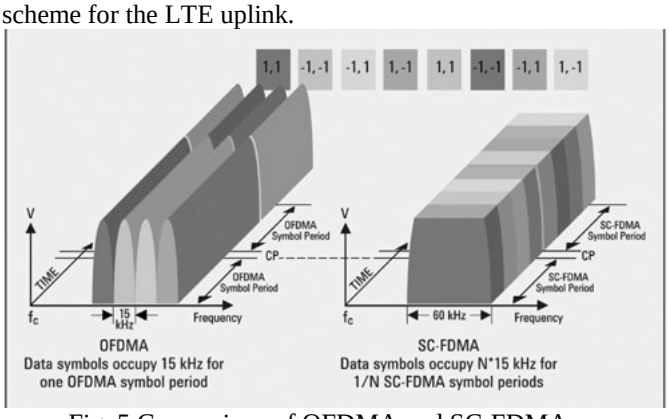

Fig. 5 Comparison of OFDMA and SC-FDMA

SC-FDMA was chosen because it combines the low PAR techniques of single-carrier transmission systems, such as GSM and CDMA, with the multi-path resistance and flexible frequency allocation of OFDMA. The idea behind SC-FDMA is shown on Figure 5[8] where it can be seen that the M symbols are transmitted with M-times shorter interval and each symbol occupies the whole single carrier which leaves the PAR rather constant.

III. OFDMA/CDMA Comparison in Different Network Technologies

OFDM has been used in communication systems for many years but due to the too demanding processing power for FFT operations it was not suitable for usage in mobile terminals earlier. That is the reason why CDMA technology was chosen in the 3GPP specification for UMTS and HSPA. With the advances in technology the cost of processing power in mobile terminals has reduced tremendously so all newer standards, like WiMAX, LTE, LTE Advanced, 802.11a/g/n empower this technology. OFDMA has many advantages over CDMA technology: resistant to fading, channel equalizers are simpler, with CP it can be totally resistant to multipath delay spread and it is better suited for MIMO [8]. However there are some disadvantages as well: sensitiveness to frequency errors and phase noise, sensitiveness to Doppler shift, high peak-to-average ratio (solved in SC-FDMA), inter-cell interference at the cell edges [8].

D. OFDMA/CDMA as Access Technologies in different Broadband Wireless Communication Networks

OFDMA and CDMA access technologies are now-days used in many different Network standards and specifications. Table 1 shows comparison of the different parameters in the most widely used Broadband Wireless Communication Networks.

TABLE I: Specifics of Broadband Wireless Technologies

Parameter	Technology			
	WiMAX	**LTE**	**HSDPA**	**UMTS**
Multiple Access DL	OFDMA	OFDMA	CDMA/ TDMA	DS-CDMA/ TDMA
Multiple Access UL	OFDMA	SC-FDMA	CDMA/ TDMA	CDMA/ TDMA
Duplexing	TDD	FDD/ TDD	FDD	FDD/ TDD
Channel Bandwidth	Scalable 3.5, 5, 7, 8.75, 10 MHz	Scalable 1.4, 3, 5, 10, 15, 20 MHz	5 MHz	5 MHz
Frame Len.	5 msec	1 msec	2 msec	10 msec
Max MIMO	2	4	2	1
Modulation	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	QPSK, 16QAM, 64QAM	QPSK, 8PSK

As it can be seen from the table OFDMA technologies have scalable channel bandwidth due to the fact that there is no single carrier but a union of sub-carriers which occupy the channel bandwidth. Also the OFDMA based technologies empower the MIMO usage at higher ranks because of its easier implementation.

E. Performance of different Broadband Wireless Communication Networks

There are many ways to evaluate the performance of different technologies but the ones that are dependent on the Access Technology in the Radio Link would be of course the throughput in uplink and downlink and the spectral efficiency in uplink and downlink.

1) *Data throughput*: There are more methods of representing the technology's throughput:

- Peak throughput (also known as peak network speed) - the fastest possible transmission speed over the radio link, generally based on the highest order modulation and the least amount of coding overhead (error correction overhead).
- Peak user rate – high end real throughput measured in deployed networks with applications such as FTP (File Transfer Protocol) under ideal conditions (light network loading that means one active data user in the cell sector and favorable signal propagation).
- Typical throughput rates – Real rates based on throughput tests that the operators have done across their operating networks with incorporated higher level of network loading.

The peak throughput in different technologies is shown in Table 2.

TABLE III: Peak Throughput of Different Technologies

Technology	**Downlink**	**Uplink**
UMTS WCDMA Rel'99	2.048 Mbps	768 kbps
HSDPA	14.4 Mbps	384 kbps
HSPA	14.4 Mbps	5.76 Mbps
HSPA+ (DL 64 QAM, UL 16 QAM)	21.6 Mbps	11.5 Mbps
HSPA+ (2X2 MIMO, DL 16 QAM, UL 16 QAM)	28 Mbps	11.5 Mbps
HSPA+ (2X2 MIMO, DL 64 QAM, UL 16 QAM)	42 Mbps	11.5 Mbps
LTE (2X2 MIMO)	173 Mbps	58 Mbps
LTE (4X4 MIMO)	326 Mbps	86 Mbps
802.16e WiMAX (10 MHz TDD DL/UL=3, 1X2 SIMO)	23 Mbps	4 Mbps
802.16e WiMAX (10 MHz TDD, DL/UL=3, 2x2 MIMO)	46 Mbps	4 Mbps

From the table it is obvious that using MIMO technology improves greatly the maximum throughput in Downlink and Uplink in any technology.

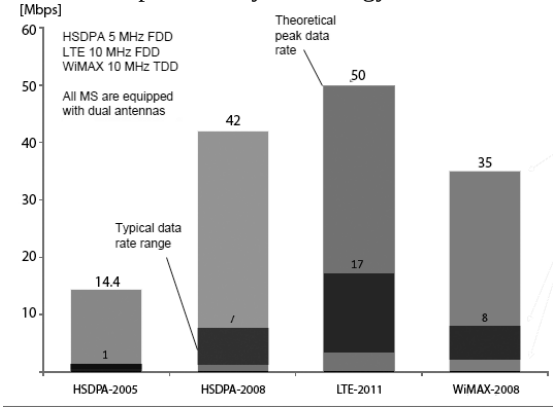

Fig. 6 Comparison of peak and typical data rates in DL

Also the scalable channel bandwidth in the OFDMA technologies enables the higher peak data rates although

the typical ones are not so record-breaking which can be seen form Figure 6 [10]

2) *Spectral Efficiency*: It refers to the ability of a given channel encoding method to utilize bandwidth efficiently and is becoming the most valued parameter due to the limited resources of the spectrum in the wireless technologies. It is defined as the average number of bits per unit of time (bit rate) that can be transmitted per unit of bandwidth (bits per second per Hertz).

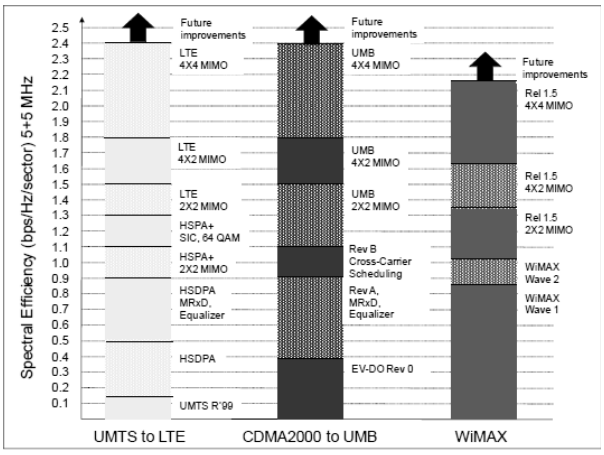

Fig. 7 Comparison of Downlink Spectral Efficiency

In Figure 7 [1] the comparison of the Downlink Spectral efficiency is shown. It can be seen that the networks that use the OFDMA access technology like LTE, WiMAX and UMB have higher spectral efficiency because of the flexible bandwidth allocation possibilities.

The same conclusion could be drawn from the Figure 8 [1] which is showing the spectral efficiency in Uplink of the same technologies.

From both figures it is obvious that the spectral efficiency is still growing and has taken a great step forward with the MIMO technologies which brought us to the 3dB margin from the Shannon bound [1].

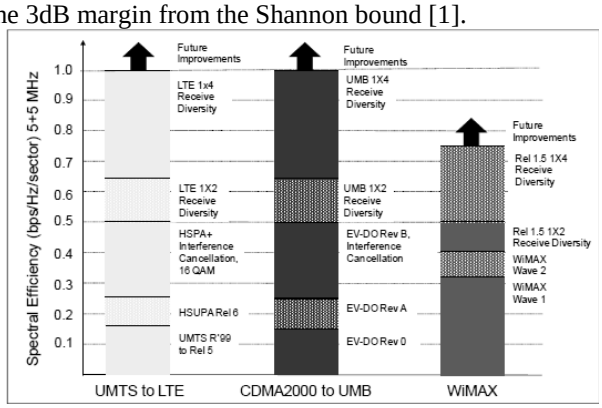

Fig. 8 Comparison of Uplink Spectral Efficiency

The spectral efficiency gain of LTE over HSDPA can be explained by a few characteristics in the LTE system design shown in Table 3[5]. For the downlink LTE uses orthogonal modulation to avoid intra-cell interference providing a major boost in capacity compared to HSDPA. The CDMA transmission in HSDPA suffers from intra-cell interference caused by multi-path propagation. The CDMA codes are orthogonal but only in the single path channel. The LTE benefit over HSDPA depends on the amount of multi-path propagation.

TABLE IIIII: LTE BENEFITS OVER HSDPA RELEASE 6

LTE Benefit over HSDPA Release 6	**Gain**
OFDM with frequency domain equalization	+70%
Frequency domain packet scheduling	+40%
MIMO	+15%
Inter-cell interference rejection combining	+10%

Another major benefit in LTE is the frequency domain scheduling, which is not possible in a CDMA based system. The CDMA systems transmit the signal using the full bandwidth. MIMO provides some efficiency benefit in LTE since MIMO was not included in HSDPA Release 6. The inter-cell interference rejection gives some further capacity boost for LTE. Adding these factors together gives the result that LTE is indeed expected to provide approximately three times higher efficiency than HSDPA Release 6[5].

IV. CONCLUSIONS

Generally, OFDMA can provide advantages over a CDMA based system for wider bandwidths, so dealing with variety of data rates in the same system is more flexible with OFDMA. It doesn't mean that OFDMA gets the position of completely successful access technology of the future, still the future of broadband wireless technologies is providing tri-mode-supporting (GSM/UMTS/LTE) cellular networks and devices with using of multiple radio technologies in a single device like 3G, WiMAX WLAN etc. The already well established and used CDMA technology in variety of wireless networks like UMTS, HSDPA, HSPA, HSPA+ and the pretty new and challenging OFDMA technology used in LTE, LTE Advanced, WiMax, WLAN, WBA can be said will be here to stay for the next years. The key of success in the future would be integrating these technologies together and creating technologies like MC-CDMA (4G Candidate together with OFDMA) that incorporates the power efficiency of CDMA and the spectral flexibility of OFDMA and creating even more spectral and power efficient technologies.

REFERENCES

[1] 3G Americas, Rysavy Research, *EDGE, HSPA, LTE: Broadband Innovation*, September 2008.

[2] J. V. Gómez, A. Rantala, T*hird Generation Mobile Technology and its evolution towards Fourth Generation*, Tampere, Finland February, 2009.

[3] H.Holma, A. Toskala, *WCDMA for UMTS – HSPA Evolution and LTE Ed. 4*, John Wiley & Sons 2007

[4] 3GPP , *Overview of 3GPP Release 7 V0.9.7* (2009-09)

[5] H, Holma, A. Toskala, *LTE for UMTS: OFDMA and SC-FDMA Based Radio Access*, 2009 John Wiley & Sons, Ltd. ISBN: 978-0-470-99401-6

[6] 3GPP TR 25.892 V6.0.0 (2004-06*), Feasibility Study for Orthogonal Frequency Division Multiplexing (OFDM) for UTRAN enhancement (Release 6)*, 3GPP TSGRAN.

[7] A. S. Pagès, J. J.Olmos Bonafé, *A Long Term Evolution Link Level Simulator*, Universitat Politècnica de Catalunya, February, 2009.

[8] J. Whitacre, *Long Term Evolution (LTE): a New Air Interface for Wireless Access*, Agilent Technologies.

[9] D. Whipple, *Concepts of Orthogonal Frequency Domain Modulation (OFDM)*, Agilent Technologies

[10] Jeffrey G. Andrews, *3G and 4G Cellular Standards*, The University of Texas at Austin, November 5, 2008.