LTE vs. WiMAX
4th generation telecommunication networks

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***Abstract*—This paper provides an overview of next generation telecommunication networks LTE and WiMAX. They are compared to each other and the current telecommunication networks. It also shows their availability in the world and explains which of these two networks is superior in which case and gives an outlook about their succesors LTE-Advanced and WiMAX release 2.0.**

I. Introduction

In times when mobile devices are getting more popular the mobile networks are becoming more and more important, too. Websites are not the same they used to be 10 years ago. They consist of with high quality pictures, animations, flash applications and more. Also the demand for mobile Internet grew significantly. According to Opera's mobile Webbrowser the number of pages viewed has risen from about 1.8 billion pages in January 2008 to 23 billion pages in January 2010 [1]. All those things leading to an increase of the amount of data. Even calling and messaging with the mobile phone requires more data today. There are not only simple calls and short messages anymore, there is also video telephony, multimedia messaging and emailing possible nowadays. Also netbooks and tablet pcs are becoming more popular than ever. People want to access the internet with their phones and notebooks from everywhere [2]. They want to play flash games or watch streamed videos on the internet while they are on the way to work or school. Services like the Internet Protocol television (IPTV) also highly increase the need for higher transfer rates. These examples show that the demand for higher transfer rates and better availability of mobile internet connections grows more and more. So it is just a matter of time until current telecommunication networks reach their limits.

The next generation networks Worldwide Interoperability for Microwave Access (WiMAX) and Long-Term Evolution (LTE) promise to bring better transfer rates, lower latency, better availability and more to fullfill the needs of the customers, but they also have to be more effective. They should not be too expensive for providers, they should reach more devices with less costs. Otherwise they would be unprofitable for the carriers or it would take too much time until the new communication networks would cover a large area. And maybe until then other communication networks would be developed. Thats what happened to the 3rd generation telecommunication networks. They are still not fully available everywhere and newer generation networks such as WiMAX and LTE are on the way or even already out. Will LTE and WiMAX be the next generation telecommunication networks?

The remainder of this paper is organized as follows: First, a short overview of the current generation mobile networks will be given. Then a closer look at the next generation networks WiMAX and LTE will be taken followed by a comparison of these networks and a conclusion which of these networks is superior. The final part of this paper will give an outlook of their successors LTE-Advanced and WiMAX Release 2.0.

II. Overview

Currently the mobile network infrastructure comprises overlay networks including 2G and 3G technologies.

Global System for Mobile Communications (GSM) is a 2nd generation mobile network and provides circuit-switched communication. It was enhanced by General Packet Radio Service (GPRS), also known as 2.5G, and Enhanced Data rates for GSM Evolution (EDGE), also known as 2.75G, providing IP functionality and data transfer rates up to 1.3 Mbps in the downlink and 653 kbps in the uplink.

On the side of the the 3rd generation communication networks, there is Universal Mobile Telecommunications System (UMTS) and its enhancements High-Speed Downlink Packet Access (HSDPA) and High-Speed Uplink Packet Access (HSUPA), both also known as 3.5G networks [3]. Maximum transfer rates by 3rd generation mobile networks can be reached with High-speed Data Access (HSPA) Evolution as shown on Figure 1. 28 Mbps in the downlink and 5.76 Mbps in the uplink are possible.

All these technologies have been standardized by either the 3rd Generation Partnership Project (3GPP) or the Institute of Electrical and Electronic Engineers (IEEE). 3rd generation mobile networks can reach quite high transfer rates compared to 2nd generation networks but they have higher service costs. Compared to GSM, UMTS and HSDPA do not provide full coverage.

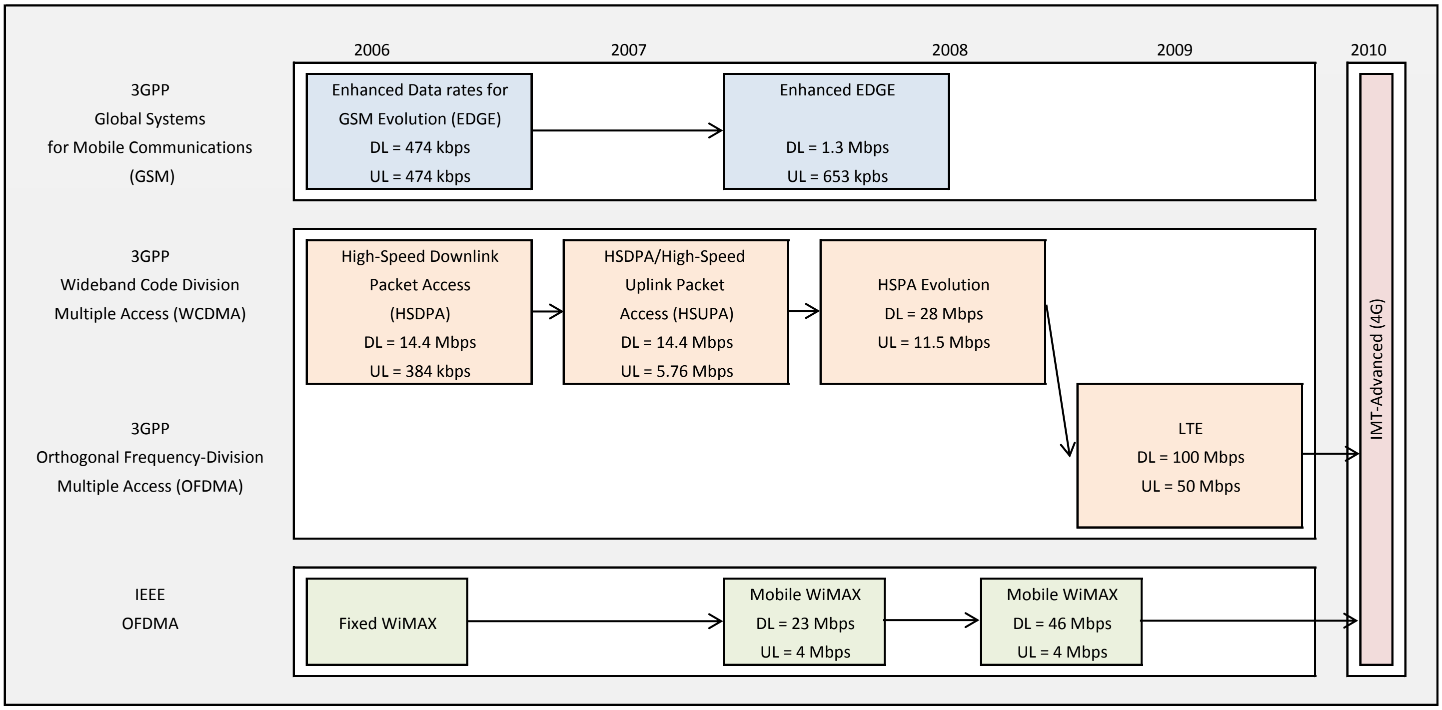

Fig. 1. Overview of the current telecommunication networks

In order to form new communication standards regarding 4G, the International Telecommunication Union (ITU) launched the International Mobile Telecommunications (IMT)-Advanced initiative [4]. WiMAX and Long-Term Evolution (LTE) meet most of the requirements of IMT-Advanced, however they are just considered as 3.9G even though telecommunication companies use the term 4G when marketing WiMAX and LTE.

III. WiMAX

WiMAX is an acronym meaning World-wide Interoperability for Microwave Access. It is part of the IEEE 802.16 standards and was developed by the Institute of Electrical and Electronic Engineers (IEEE). The first WiMAX standard was IEEE 802.16-2004 also known as 802.16d [5]. It supported fixed wireless internet service and was published in 2004. The second standard 802.16-2005 also known as 802.16e was published by IEEE at the beginning of 2006 and provided further enhancements by adding the support of mobile wireless access. [6] The WiMAX forum, an industry consortium, is promoting the 802.16 family of standards for broadband wireless access systems. Their task is to certify the interoperability of WiMAX products.

A. Overview

The current WiMAX release supports transfer rates up to 46 Mbps in downlink and 4 Mbps in uplink using 10MHz system bandwidth [4]. The WiMAX system supports scalable system bandwidth using time division duplex (TDD). So it can use 3.5, 5, 7, 8.75 and 10 MHz as system bandwidth [6]. Maximum coverage with the technology is 50 km for fixed usage and up to 5 km for mobile usage. WiMAX focuses on nomadic mobility but it supports also vehicular speeds up to 120 kmph. WiMAX is a flat, all IP-based architecture [7]. There are currently 2 major releases of WiMAX: WiMAX release 1.0 and WiMAX release 1.5.

B. Features

All needed basic features for an all-IP architecture are supported by mobile WiMAX first release (1.0) [8]. It includes:

- Access service network (ASN) and Connectivity service network (CSN) mobility for mobility support
- Paging and location management
- IPv4 and IPv6 connectivity
- Preprovisioned/static qualitiy of service (QoS)
- Optional radio resource management (RRM)
- Network discovery/selection
- IP/Ethernet CS support
- Flexible credentials, pre- and postpaid accounting
- Roaming (RADIUS only)
- 3GPP I-WLAN compatible interworking

In the second release (mobile WiMAX release 1.5) new features were added, focusing on 3G interworking and

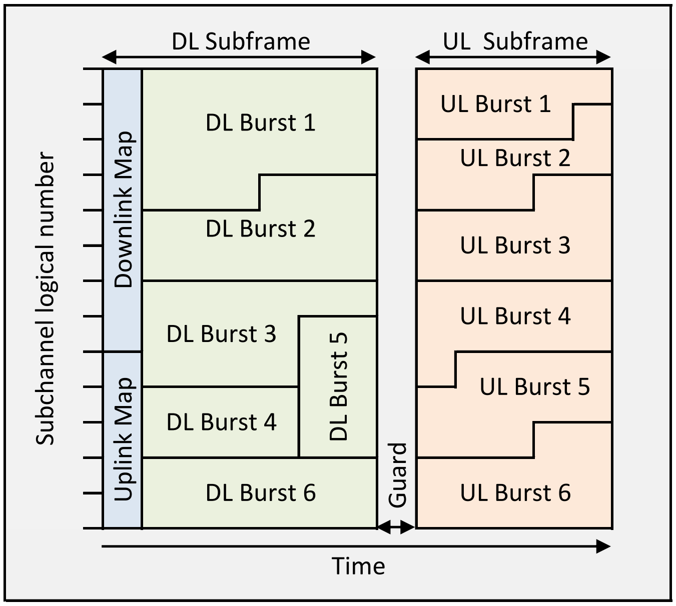

Fig. 2. WiMAX frame

commercial grade VoIP. Some of the key features are:

- Over-the-air (OTA) activation and provisioning
- Location-based services (LBS)
- Multicast broadcast service (MBS)
- IMS integration
- Dynamic QoS and policy and charging (PCC) compatible with 3GPP Release 7
- Telephony VoIP with emergency call services and lawful interception
- Full NAP sharing support
- Handover data integrity
- Multihost support
- Ethernet services, VLAN, DSL IWK
- Enhanced open Internet services
- Diameter-based authentication, authorization and accounting (AAA)

WiMAX supports quality of service (QoS). It is achieved by allocating bandwidth to users. WiMAX uses reservation-based access for it, which means that it uses frames to reserve the needed resources for a connection. A WiMAX frame as shown in Figure 2 has a duration of 2 to 20 ms and each frame is divided into two subframes, the downlink subframe and the uplink subframe. The downlink part comes from the base station and the uplink part from the mobile device. At the beginning, the base station transmits both, the downlink and the uplink map, which reserves the resources during a frame [9]. Both subframes contain data of different users in different bursts. So on Figure 2 there are resources for 6 different users allocated for example. Downlink burst 1 and uplink burst 1 belong to the same user and so on. WiMAX can allocate the traffic between downlink and uplink in any ratio, which makes it also very felxible.

WiMAX uses orthogonal frequency-division multiple access (OFDMA) in the downlink and in the uplink. OFDMA is a multi-user version of the orthogonal frequency-division multiplexing (OFDM) [10]. OFDM uses subcarriers, which are orthogonal to each other. That means that the peak of one subcarrier coincides with the null of the subcarriers next to it, which avoids causing interference. By using subcarriers the amount of lost data by errors or disturbance is reduced because only the data of the disturbed subcarrier gets lost. The multiple access of OFDMA is achieved by assigning subsets of subcarriers to different users. Some of the main advantages of OFDM are a high spectral efficiency, efficient implementation using fast fourier transform (FFT) and low sensitivity to time synchronization errors. But there are also some disadvantages. OFDM is sensitive to frequency synchronization problems and has a high peak-to-average-power ratio (PAPR) making it less power efficient.

Speaking of power efficiency, WiMAX provides three powersaving classes. These classes have different on/off cycles, in which they check for new data. So when a mobile station is in Power Save Class 1 mode, the window is increased from a minimum value to a maximum value. This is used for non-real-time traffic because the receiver is turned off most of the time. Power Save Class 2 has a fixed sleep window length. Power Save Class 3 is used when the mobile station knows when the next traffic is expected and so it goes into sleep mode until that moment [11]. So when having a real-time conversation for example, the radio must be enabled whenever new data arrives but after that it can be disabled and check for new data only once in a while.

Another important part of mobile telecommunication networks is the security. WiMAX provides authentication which probitis unauthoried users from using the network services. Also eavesdroppers are not able to get the data which is transmitted over the network [12]. The IEEE 802.16 standard defines a security sublayer at the bottom of the Medium Access Control (MAC) layer. In this sublayer there is a Privacy and Key Management (PKM) protocol and an encapsulation protocol. The PKM protocol sends security keys between the user and the base station to ensure a secure connection, while the encapsulation protocol handles the encryption of the data. Since WiMAX also supports multicast and broadcast, it also offers a multicast and a broadcast rekeying algorithm to refresh security keys in order to keep secured multicast and broadcast services.

WiMAX also makes use of the multiple in, multiple out (MIMO) technology which, is basically the use of multiple antenna on both, the transmitter and the receiver side, to increase the transfer rates. MIMO in WiMAX can be classified into two categories: Open loop MIMO and closed loop MIMO.

When using open loop MIMO, the transmitters do not need explicit knowledge of the channels. With closed loop MIMO on the other hand, the transmitter forms antenna beams adaptively based on the channel side information. Such technologies are also referred as transmitter adaptive antenna array (Tx-AA) techniques [13].

C. Summary

Table 1 shows all important features and specifications of the WiMAX release:

	WiMaX release 1.0
Generation	3.9G
First release	2005
Physical layer	DL: OFDMA
	UL: OFDMA
Duplex mode	time division duplex (TDD)
User mobility	60 to 120 kmph
Coverage	up to 50 km
Channel bandwidth	3.5, 5, 7, 8.75, 10 MHz
Peak data rates	DL: 46 Mbps (2 x 2 antennas)
	UL: 4 Mbps (1 x 2 antennas)
	at 10 MHz, TDD 3:1 (dl / ul ratio)
Spectral efficiency	DL: 1.91 bps / Hz (2 x 2)
	UL: 0.84 bps / Hz (1 x 2)
Latency	Link layer: about 20 ms
	Handoff: about 35 to 50 ms
VoIP capacity	20 users per sector / MHz (TDD)
other qualities	Full IP-based architecture
	3G compatible
	QoS support

TABLE I
SUMMARY OF WIMAX SPECIFICATIONS

IV. LTE

Long Term Evolution also known as LTE was developed by the 3rd Generation Partnership Project (3GPP), a collaboration between groups of telecommunication associations. It was released in the 4th quarter of 2008. The 3GPP partner from the US is the Alliance for Telecommunications Industry Solutions which members include telecommunication companies, such as AT&T, Cisco and Verizon. The LTE standard is officially known as ”document 3GPP Release 8”. LTE Release 8 is sometimes also called as 3.9G because it almost achieves full compliance with IMT-Advanced.

A. Overview

LTE supports peak data rates of 100 Mbps in downlink and 50 Mbps in uplink, both reached with 20 MHz spectrum. When using MIMO techniques LTE can even reach up to 300 Mbit/s downlink data rates. It has a variable spectrum, which can be used with 1.25, 2.5, 5, 10, 15 and 20 MHz. A cell can cover up to 100 km area [14] with slight degradation after 30 km and reach over 200 users per cell (with 5 MHz spectrum). LTE is optimized for low speeds like 0 - 15 kmph but it suppots also speeds up to 350 kmph. Round-trip times below 10 ms can be accomplished [15].

B. Features

LTE uses also orthogonal frequency-division multiple access (OFDMA) in the downlink, but it uses singlecarrier frequency-division multiple access (SCFDMA) in the uplink. [16] [17] OFDMA is power inefficient, because of the high peak-to-average-power ratio (PAPR), but since the downlink is part of the base station (e-Node-B in 3GPP terminology) it does not matter that much. In the uplink, where the transmission starts from the mobile devices that use batteries, LTE uses SCFDMA, which brings a reduced peak-to-average-power ratio (PAPR). It saves power without degrading system flexibility or performance ensuring a better mobility since the higher power efficiency is important for mobile devices [10]. SCFDMA is an alternative solution to OFDMA. [18] The performance of OFDMA can be better than SCFDMA but it is less power efficient.

LTE has also some power-saving mechanisms to turn off the transmitter whenever there is no data to transmit or receive. It uses Discontinued Reception (DRX) and Discontinued Transmission (DTX). The DRX supports an on/off cycle for the user device’s radio. When it’s on, the radio can transmit and receive data, but when it is off, it does not communicate with other devices or hardware. It is even possible to turn the radio off in the middle of a call when there are longer breaks and no data is transmitted. [19] This approach leads also to power savings.

Same as WiMAX, LTE also offers quality of service. To achieve that, it uses reservation-based access aswell and creates time frames. Each frame is 10 ms long and it contains 10 subframes of 1 ms each. Figure 3 shows an example of a LTE frame. The 0th and the 5th subframes are always reserved for the downlink so that the base station can always transmit any information to manage the transmissions. The other frames can be downlink, switchpoint or uplink. The switchpoint marks the switch from uplink to downlink or the other way around. So in the example of Figure 3, the subframe 2 is a switchpoint, then the receiver knows, that subframe 0 is always downlink, so the subframe 1 is also a downlink because there was no switchpoint frame yet, but after the switchpoint at subframe 2, the next subframe, in this case subframe 3, will be uplink. If there is no other switchpoint until subframe 5, then subframe 4 is also uplink. Since subframe 5 is always reserved for downlink and the next switchpoint in the example is subframe 6, subframes 7 to 9 are for uplink. This switchpoint method makes the transmission more dynamic in allocating resources. It is possible to switch many times in a frame, which decreases the delays in a call for example since it makes switching from receiving to transmitting data faster. [20]

LTE provides similar security mechanisms to WiMAX such as using security keys between transmitter and receiver to ensure a secure connection and encrypting the communication.

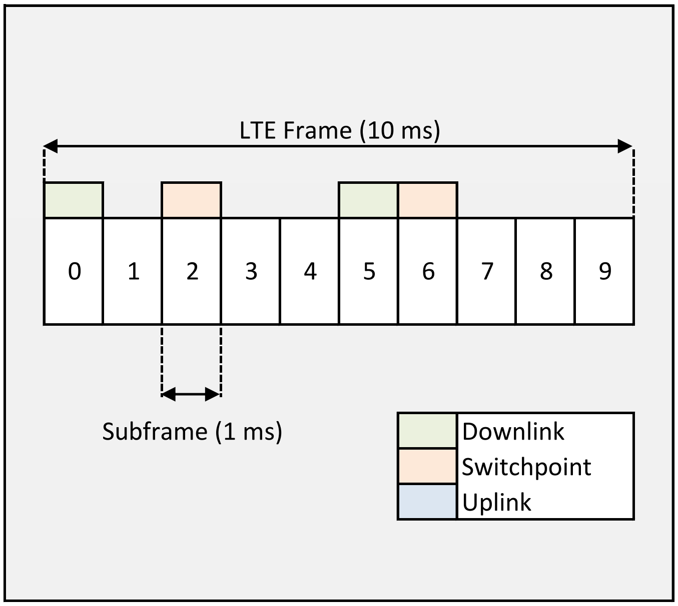

Fig. 3. LTE frame

LTE also offers a key derivation protocol, which resets the connection if corrupt keys are detected.

MIMO techniques are also used in LTE. In the downlink LTE can reach peak data rates of 300 Mbps when using 4 x 4 antennas with MIMO techniques. Figure 4 shows a 4 x 4 MIMO configuration. So there are 4 antennas on the base station and 4 antennas on the mobile station for example. Each antenna of the base station can send data to any antenna on the mobile station and the other way around. As shown in Figure 4 the antenna TX_1 can send data to antenna RX_1 via the channel h_{11}, to antenna RX_2 via channel h_{12} and so on. H is the channel matrix and h_{tr} are the complex channel gains between the transmitting antennas TX_n and the receiving antennas RX_m. In flat fading channels, the capacity increases linearly with n, where n is the minimum of the amount of receiving or transmitting antennas. The use of multiple antennas at both the transmitter and receiver improves the communication performance a lot. It increases the data rates and the coverage distance without adding more bandwidth or power. A single transmitter sends data via multiple channels. The receiver receives the signals from multiple antennas, decodes them and recovers the data. [21]

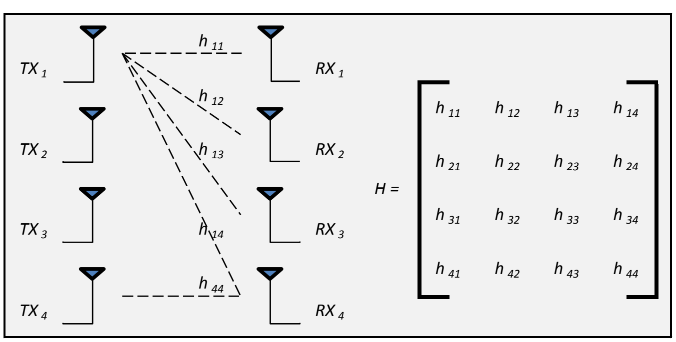

Fig. 4. 4 x 4 MIMO configuration

C. Summary

Table 2 shows all important features of Long-Term Evolution also known as the 3GPP Release 8.

	LTE (3GPP Release 8)
Generation	3.9G
First release	2009
Physical layer	DL: OFDMA UL: SCFDMA
Duplex mode	time- and frequency- division duplex (TDD & FDD)
User mobility	up to 350 kmph
Coverage	up to 100 km
Channel bandwidth	1.4, 3, 5, 10, 15, 20 MHz
Peak data rates	DL: 300 Mbps (4 x 4 antennas) UL: 75 Mbps (2 x 4 antennas) at 20 MHz, FDD
Spectral efficiency	DL: 1.91 bps / Hz (2 x 2) UL: 0.72 bps / Hz (1 x 2)
Latency	Link layer: $<$ 5 ms Handoff: $<$ 50 ms
VoIP capacity	80 users per sector / MHz (FDD)
other qualities	Full IP-based architecture 3G compatible QoS support

TABLE II
SUMMARY OF LTE SPECIFICATIONS

V. COMPARISON

A. Release and Deployment

WiMAX was developed and released in 2005, which is much earlier than LTE, which was released in 2009. Currently there are 592 WiMAX networks in 149 countries [22]. On the other hand, the commercial use of LTE just has started in 2009 and thus it is not much widespread yet [4]. This is a huge advantage over LTE's deployment, which has recently started leading to a wider spread of WiMAX.

B. Transfer rates

WiMAX reaches peak transfer rates of 46 Mbps in the downlink and up to 4 Mbps in the uplink, whereas LTE offers up to 300 Mbps in the downlink and 75 Mbps in the uplink. LTE is definitely supperior to WiMAX in this case. It also supports a bigger range of channel bandwidths from 1.4 MHz to 20 MHz than WiMAX with 3.5 MHz to 10 MHz.

C. Mobility

WiMAX and LTE are mobile telecommunication networks, so they have to offer good mobility features. The coverage of cells and the power efficiency of the devices are some of the most important factors.

1) Coverage: WiMAX signals can reach up to 50 km but this is only acquirable with much loss in signal quality. WiMAX is more optimized for shorter distances like 1.5 to 5 km. LTE, on the other hand, can cover up to 100 km, which is twice as much as WiMAX' coverage. LTE also offers connectivity with speeds up to 350 kmph. So, it's even possible to be connected on a LTE-network when sitting in a high speed train. On the other hand, WiMAX supports speeds up to 120 kmph, because of its optimization for nomadic speeds.

2) Power efficiency: Both LTE and WiMAX offer power saving mechanisms. They can be both sent into an off-state where less or even no power is needed. LTE can even turn the transmitter off while having a call when there are longer breaks. Also LTE uses SC-FDMA in the uplink, which is more power efficient than OFDMA. This makes mobile devices use less power, which increases their battary life.

D. Quality of service

WiMAX and LTE use both reservation-based access to achieve quality of service, which allows services like video telephony and VoIP. A WiMAX frame is seperated in a downlink and an uplink subframe that allocates resources for different users. LTE frames don't seperate their frames in uplink and downlink subframes. Each frame contains 10 subframes and only 2 of them are always reserved for the downlink. The other 8 subframes can either be uplink, downlink or switchpoint. LTE frames are more dynamic, so they reach smaller delays.

E. Security

Concerning security aspects both, LTE and WiMAX, are on the same level. They both offer techniques and use protocols, which ensure safe connections.

All in all, Long-Term Evolution is superior to WiMAX when it comes to the technology. But there are also downsides. LTE was released several years after WiMAX, so that many telecommunication companies already invested in WiMAX and already offer commercial services. For some telecommunication companies it is not rentable to switch from WiMAX and invest into a new technology.

VI. Conclusion

WiMAX benefits from earlier development, it has much more deployments worldwide and many telecommunications companies are involved in WiMAX activities. On the other hand, LTE's developement picked up, which made some telecommunications companies switch away from WiMAX and start using LTE. Cisco announced that it will discontinue offering WiMAX solutions [23]. Alcatel-Lucent made a similar announcement. This does not mean that carriers will have to discontinue their WiMAX offerings. WiMAX and LTE can still coexist. But since LTE has been developed by telecommunication companies, it has the advantage that these companies can choose which technology they will deploy. Being developed by the 3GPP gives LTE another advantage because the 3GPP also developed previous generation telecommunication networks such as GSM and UMTS. This makes it easier to implement features like a hand-over from LTE to UMTS or GSM in areas where the is no LTE radio reception. In those cases it is better to have a slower 2G or 3G connection instead of having no connection at all.

WiMAX has been targeting emerging markets with little infrastructure. It is cheaper to deploy a WiMAX network than laying a wired infrastructure. Also Intel has announced that it will embed WiMAX chips in its mobile platform. This will make incentive to adopt these network more and more. So WiMAX will stay at least in niche applications.

Many telecommunication companies see the future of mobile communication networks in LTE. Some telecommunicatoin companies already switched from WiMAX to LTE, other companies are planning to do the change.

All in all, Long-Term Evolution will take the lead as next generation telecommunication network, also because it was developed by the 3GPP which already specified GSM, UMTS and their enhancements. Still this does not mean that WiMAX has no future. WiMAX will stay as a competitor for a while, at least in niche applications.

VII. Outlook

LTE and WiMAX often were labeled as 4G but after the International Telecommunication Union Radiocommunication Sector (ITU-R) decided the specifications of 4G, both, LTE and WiMAX did not meet all requirements. [24] These 4G specifications, also known as IMT-Advanced (International Mobile Telecommunications Advanced) require:

- max. data rates up to 100 Mbitps for mobile access
- max. data rates up to 1 Gbitps for fixed access
- all-IP architecture
- scalable channel bandwidth

WiMAX and LTE both don't meet the requirement of supporting peak data rates of 1 Gbitps in fixed connectivity. But there are already succesors of LTE and WiMAX announced. Table III and Table IV provide an overview of LTE's successor LTE-Advanced and WiMAX' next release.

A. LTE-Advanced

Long-Term Evolution Advanced also officially known as 3GPP Release 10, is still in developement by the 3GPP, but it is expected to be finalized in 2011. LTE-Advanced aims to fulfill all the requirements of IMT-Advanced, which makes

LTE-Advanced a real 4G telecommunication network. It is planned that LTE-Advanced will support higher transfer rates up to 1 Gbitps in downlink. LTE-Advanced also targets faster switching between power states and higher bandwidth. Other main goals are compatibility with first release LTE equipment, a scalable system bandwidth with higher frequencies than 20 MHz, possibly up to 100 MHz and a hybrid OFDMA and SC-FDMA solution to combine the advantages of both, OFDMA with its performance and SC-FDMA with its power efficiency.

B. WiMAX release 2.0

WiMAX release 2.0 also known as IEEE 802.16m is the IEEE candidate for the 4th generation of telecommunication networks. Its goal is to meet all the specifications of IMT-Advanced. The standardization of WiMAX release 2.0 is expected to be completed by 2011 [25]. Same as LTE, WiMAX release 2.0 will increase the transfer rates by supporting higher channel bandwidths and bringing better mobility aspects, such as supporting higher speeds up to 350 kmph.

Both technologies are still in development and thus far from being completed. They promise even higher transfer rates and will fullfil all IMT-Advanced requirements. It will take a while until they become available for everyone but until then, there are still the current LTE and WiMAX releases.

	WiMAX Release 2.0
Generation	4G
Expected release	2011
Physical layer	DL: OFDMA UL: OFDMA
Duplex mode	time- and frequency division duplex (TDD & FDD)
User mobility	up to 350 kmph
Coverage	up to 50 km
Channel bandwidth	5, 10, 20, 40 MHz
Peak data rates	DL: >350 Mbps (4 x 4 antennas) UL: > 200 Mbps (2 x 4 antennas) at 20 MHz FDD
Spectral efficiency	DL: > 2.6 bps / Hz (2 x 2) UL: > 1.3 bps / Hz (1 x 2)
Latency	Link layer: < 10 ms Handoff: < 30 ms
VoIP capacity	>30 users per sector / MHz (TDD)
other qualities	Full IP-based architecture 3G compatible QoS support

TABLE III
OVERVIEW OF WIMAX 2 SPECIFICATIONS

	LTE-Advanced (3GPP Release 10)
Generation	4G
Expected release	2011
Physical layer	DL: OFDMA UL: SCFDMA
Duplex mode	time- and frequency division duplex (TDD & FDD)
User mobility	up to 350 kmph
Coverage	up to 100 km
Channel bandwidth	up to 100 MHz
Peak data rates	DL: 1 Gbps UL: 300 Mbps
Spectral efficiency	DL: 30 bps / Hz UL: 15 bps / Hz
Latency	Link layer: < 5 ms Handoff: < 50 ms
VoIP capacity	>80 users per sector / MHz (FDD)
other qualities	Full IP-based architecture 3G compatible QoS support

TABLE IV
OVERVIEW OF LTE-ADVANCED SPECIFICATIONS

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