

MORYNE

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I. History of Versions

Version	Date	Description
1.0	03/05/2007	UASO
1.1	01/06/2007	UASO inputs
1.2	27/03/2008	<p>September 2007 consensus report remarks added:</p> <p><u>Comment:</u> "In the list of abbreviations many abbreviations are missing: UDP/IP, TCP/IP, GPS, RTP, RTCP, RTSP, FFT, DC, QPSK, QAM, ACK, NACK, QoS, CCM, TEK, DSL, MPEG, FTP, FEC."</p> <p><u>Correction:</u> About one page of missing abbreviations added.</p> <p><u>Comment:</u> "Chapter 1 contains the introduction, which equals mainly the Abstract and also the first two paragraphs of the Conclusions."</p> <p><u>Correction:</u> Chapter 1 Introduction and chapter 8 conclusion changed.</p> <p><u>Comment:</u> "In section 5.2 the statement "in the MORYNE scenario there will be some situations, where several busses need broadcast access..." is made."</p> <p><u>Correction:</u> Broadcast is never mentioned. It was always broadband.</p> <p><u>Comment:</u> "In section 5.4 the statement "redundancy is more important than higher data rates" is made, but a justification for this statement is missing."</p> <p><u>Correction:</u> A more detailed explanation in chapter 5.4 as added.</p> <p><u>Comment:</u> "An assessment of capability issues at access requests by other users (not only busses but also other private and commercial users) at the same time is missing."</p> <p><u>Correction:</u> At the end of chapter 3.2.1 were added some sentences about QoS if several users are requesting data.</p>

II. Abstract

This document analyses the potential of Mobile WiMAX in the MORYNE scenario. The MORYNE project aims at improving transport efficiency, transport safety and environmental friendliness by employing traffic management in an urban and sub-urban area. Therefore public transport vehicles, such as busses, are equipped with environmental sensors for e.g. temperature and humidity and cameras to monitor road and traffic condition. To assist traffic management the collected data has to be transferred to a traffic management center. While the sensor data could be transferred by low data rate private wireless systems, such as TETRA or TETRAPOL, the video data requires high data rate capabilities. The video data will be transmitted as compressed real-time streaming video from public transport vehicles when requested by the control management centre, e.g. if an important event is detected. This is where Mobile WiMAX claims to provide a cost efficient alternative for data transmission. Another aspect is the similar coverage and cell-structure of Mobile WiMAX compared to PMR systems like TETRA or TETRAPOL. This document analyses the potential of Mobile WiMAX to provide high data rate uplink services.

III. Definitions

The following definitions are extracted from the IEEE standards 802.16-2004 [1] and 802.16e-2005 [2] to make it easier to understand the terms and abbreviations used in this document.

adaptive antenna system (AAS): A system adaptively exploiting more than one antenna to improve the coverage and the capacity.

adaptive modulation: A system's ability to communicate with another system using multiple burst profiles and a system's ability to subsequently communicate with multiple systems using different burst profiles.

base station (BS): A generalised equipment set providing connectivity, management, and control of the subscriber station (SS).

burst profile: Set of parameters that describe the uplink or downlink transmission properties associated with an interval usage code. Each profile contains parameters such as modulation type, forward error correction (FEC), preamble length, guard times, etc.

connection: A unidirectional mapping between base station (BS) and subscriber station (SS) medium access control (MAC) peers. Connections are identified by a connection identifier (CID). The MAC defines two kinds of connections: management connections and transport connections.

downlink: The direction from the base station (BS) to the subscriber station (SS).

frame: A structured data sequence of fixed duration used by some PHY specifications. A frame may contain both an uplink subframe and a downlink subframe.

handover (HO): The process in which a mobile station (MS) migrates from the air-interface provided by one base station (BS) to the air-interface provided by another base station (BS).

mobile station (MS): A station in the mobile service intended to be used while in motion or during halts at unspecified points. An MS is always a subscriber station (SS) unless specifically excepted otherwise in the standard.

multiple input multiple output (MIMO): A system employing at least two transmit antennas and at least two receive antennas to improve the system capacity, coverage or throughput.

subscriber station (SS): A generalised equipment set providing connectivity between subscriber equipment and a base station (BS).

uplink: The direction from a subscriber station (SS) to the base station (BS).

IV. Acronyms

16QAM	16 Quadrature Amplitude Modulation
64QAM	64 Quadrature Amplitude Modulation
AAS	Adaptive Antenna System
ACK	Acknowledgement
AES	Advanced Encryption Standard
AMC	Adaptive Modulation and Coding
ARQ	Automatic Repeat Request
BE	Best Effort Service
BER	Bit Error Rate
BPS	Bits per Second
BS	Base Station
CBC-MAC	Cipher Block Chaining Message Authentication Code
CC	Convolutional Code
CCM	Counter with CBC-MAC
CID	Connection Identifier
CINR	Carrier to Interference-plus-noise Ratio
CMAC	Block Cipher-based Message Authentication Code
CQI	Channel Quality Indicator
CQICH	Channel Quality Information Channel
CTC	Convolutional Turbo Code
DC	Data Carrier
DL	Download/Downlink
DSL	Digital Subscriber Line
EAP	Extensible Authentication Protocol
ERP	Equivalent Radiated Power
ERTVR	Extended Real-time Variable Rate Service
FBSS	Fast Base Station Switching
FDMA	Frequency Division Multiple Access
FEC	Forward Error Correction
FFT	Fast Fourier Transformation
FTP	File Transfer Protocol
FUSC	Full Usage of Subchannels
GPS	Global Positioning System
HARQ	Hybrid Automatic Repeat Request

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HO	Handover
HHO	Hard Handover
HMAC	Keyed Hash Message Authentication Code
ICI	Intercarrier Interference
IP	Internet Protocol
ISI	Intersymbol Interference
IEEE	Institute of Electrical and Electronics Engineers
IETF	Internet Engineering Task Force
LOS	Line-of-sight
MAC	Media Access Control Layer
MAI	Multiple Access Interference
MAN	Metropolitan Area Network
MAP	Media Access Protocol
MCS	Modulation and Coding Scheme
MD5	Message Digest Algorithm 5
MDHO	Macro Diversity Handover
MIMO	Multiple Input Multiple Output
MPEG	Moving Picture Experts Group
MS	Mobile Station
NACK	Negative Acknowledgement
NLOS	Non-line-of-sight
NRTVR	Non-Real-Time Variable Rate Service
OFDM	Orthogonal Frequency Division Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
PDU	Protocol Data Unit
PHY	Physical Layer
PKM	Privacy Key Management
PMR	Professional Mobile Radio
PRBS	Pseudo-random Binary Sequence
PUSC	Partial Usage of Subchannels
QAM	Quadrature Amplitude Modulation
QoS	Quality of Service
QPSK	Quadrature Phase Shift Keying
ROHC	Robust Header Compression
RSSI	Receiver Signal Strength Indicator

RTCP	Real-Time Control Protocol
RTP	Real-Time Transport Protocol
rtPS	Real-Time polling service
RTSP	Real-Time Streaming Protocol
RTVR	Real-Time Variable Rate Service
SIM	Subscriber Identify Module
SIMO	Single Input Multiple Output
SM	Spatial Multiplexing
SOFDMA	Scalable OFDMA
SS	Subscriber Station
STC	Space-time Code
TCP	Transmission Control Protocol
TDD	Time Division Duplex
TEK	Traffic Encryption State
TETRA	Terrestrial Trunked Radio
TTG	Transmit/Receive Transition Gap
UDP	User Datagram Protocol
UGS	Unsolicited Grant Service
UL	Upload/Uplink
UMTS	Universal Mobile Telecommunications System
USIM	Universal Subscriber Identify Module
VoIP	Voice over IP
VSM	Vertical Spatial Multiplexing
WiMAX	Worldwide Interoperability for Microwave Access
XML	Extensible Markup Language

1 Introduction

This document analyses the wireless technology of Mobile WiMAX in the MORYNE scenario. Mobile WiMAX is an emerging technology for broadband wireless access in urban and suburban areas. Currently two different versions of WiMAX exist: 1. fixed WiMAX which doesn't support mobility and 2. Mobile WiMAX which enables WiMAX to perform handover between cells. Because of the MORYNE scenario where a bus drives along a track of several kilometers support of mobility is necessary to get a high coverage. Therefore this document considers Mobile WiMAX.

In the MORYNE project different information are collected to improve the traffic management, safety and security. For traffic safety sensor information is used to estimate road conditions e.g. temperature or humidity. Via this road conditions it is possible to make a more precisely weather forecast also for different segments of a track. For traffic management cameras inside buses monitor and detect congestions or traffic jam. Additionally cameras could be utilized to enhance security inside the bus.

In the MORYNE scenario sensor information could be transmitted via existing networks like TETRA or TETRAPOL. But these technologies only support narrowband data rates. Therefore another technology for transmitting real time video data via a wireless link is necessary. Alternative technologies could be WiFi, UMTS or Mobile WiMAX. WiFi lacks of coverage because the cells are limited to approximately 100 meters and the costs for introducing and operating UMTS are high. Also the bandwidth of UMTS especially in the uplink direction is low in contrast to WiFi or WiMAX. Thus Mobile WiMAX should be the best solution for a wireless network in the MORYNE scenario.

After a short introduction to Mobile WiMAX this document analyses the spectrum, physical layer, medium access, mobility and system impact of the Mobile WiMAX standard on the envisioned MORYNE scenario.

2 The MORYNE scenario and requirements

The MORYNE project aims to contribute to better transport efficiency, increased transport safety and more environmental friendly transport by improving traffic management in an urban and sub-urban area [22]. MORYNE will provide a system by using public transport vehicles as elements of a network of mobile sensors, communicating with the infrastructure. The public transport vehicles shall be buses. They shall be equipped with sensors and processing devices that collect data on the vehicle environment.

2.1 MORYNE scenario

One technical objective is to capture and to understand public transport vehicle surrounding scenes with an appropriate video camera moving with the vehicle and providing real-time video analysis. At important events the control management centre can request a real-time video. The compressed video is streamed over the WiMAX, WiFi mesh or UMTS radio communication network. Snapshots can also be necessary for better traffic understanding and appropriate management decisions. Another innovative aspect of MORYNE is to transmit traffic-focused scene analyses results in real-time to the traffic control centre.

A typical MORYNE scenario is that a bus with the mobile sensors is driving or standing on the road. The most bus routes are along the urban roads, where in most cases many buildings, trees or other obstacles are in close vicinity. For the radio communication from the bus to the base station there will consequently be a lot of reflection, scattering or diffraction, and usually no direct path to the antenna of the base station.

The sensors employed in a bus are temperature sensors, humidity sensors, and one or more video cameras as example for the final MORYNE demonstration at the end of 2007. The data from the temperature and humidity sensors require low data rates. From the video cameras, different types of transmissions are defined: The data transfer for pictures and video clips, the video streaming for live video, and the service messages for set-up, status and user request processing.

2.2 MORYNE requirements

An On-Board Unit inside the bus will send periodic sensor or GPS data to the Control Centre about position, speed, temperature, humidity, status of working etc. The data could be transferred by low data rate private wireless systems, such as TETRA or TETRAPOL. However, the video data requires high data rate capabilities and this is provided by e.g. WiMAX.

The pictures and video clips are considered as files. The data transfer does not enforce time constraints and can therefore be based on TCP/IP. The selection of the transmitted pictures and video clips is set by a user request. A real-time transmission is not required.

Service messages are XML-based and communications are based on TCP/IP.

The video streaming is based on UDP/IP. The rate is defined by levels (for example low, medium and high) and each level is associated with a video compression rate. The video codec can be scaled from 64 kbps to more than 1 Mbps. Appropriate transport and application protocols – such as RTP, RTCP, RTSP – may be used. In the framework of the MORYNE project, the end – to – end delay is not essential because a visualisation slightly delayed should not lessen the quality of the service provided to the final user. But particular attention must be paid to the jitter, i.e. the variation in end – to – end delay of sequentially transmitted packets, to ensure a fluent play of the video.

In MORYNE scenario, the driving speed of the busses can be up to 50 km/h when they are driving in the city.

3 Mobile WiMAX Overview

The term “Mobile WiMAX” is used to describe wireless systems based on the IEEE Standard 802.16e-2005 [2], which is an amendment to the IEEE standard 802.16-2004 [1]. Compared to the 802.16-2004 products, the advantages offered by 802.16e products are a better link margin, support for mobility, improved indoor coverage, flexible management of spectrum resources, and a wider range of terminal form factors. The IEEE standard 802.16e-2005 added some special features to primarily support mobility and to improve the system performance. Here from, the WiMAX Forum™ is developing Mobile WiMAX system profiles that will define the mandatory and optional features of the IEEE standard that are necessary to build a Mobile WiMAX compliant air interface. The choice of profiles is driven by market demand, spectrum availability, regulatory constraints, the services to be offered, and vendor interest. While the 802.16e supports a wide range of frequencies up to 66 GHz, channel sizes from 1.25 MHz to 20 MHz and applications for line-of-sight (LOS) and non-line-of-sight (NLOS) as well as Point to Point and Point to Multipoint connections, the WiMAX Forum™ profiles narrow the scope of the IEEE Standard to focus on specific configurations. The WiMAX Forum™ itself is an industry-led, non-profit corporation formed to promote and certify the compatibility and interoperability of products using the IEEE 802.16 specifications.

The objective of this section is to give an overview about the state of the art of Mobile WiMAX. The in-depth analysis and impact on MORYNE scenario are discussed in section 5 and 6. In this section the key characteristics of the IEEE Standard 802.16e-2005 are explained.

The reader should be aware that no differentiation between mandatory and optional items is made, because this is not done by the IEEE group, but by the WiMAX Forum™ in the Mobile WiMAX system profile. For this information, please refer to Appendix A.1.

3.1 The Physical Layer

The IEEE Standard 802.16e-2005 defines multiple physical layer specifications. In this document, only the “WirelessMAN-OFDMA” physical layer will be addressed because of the special design for non-line-of-sight (NLOS) operation in the frequency bands below 11 GHz and the support of mobility.

The base station range in urban and sub-urban areas can go up to a few kilometers depending on attributes such as terminal type, frequency band, mobility, morphology etc. In networks that are capacity constrained, the number of base stations installed depends on throughput demand, rather than range.

3.1.1 OFDMA and SOFDMA

The Physical Layer (PHY) “WirelessMAN-OFDMA” of the IEEE standard 802.16e-2005 [2] is based on OFDM modulation and is designed for non-line-of-sight (NLOS) operation in the frequency bands below 11 GHz. In an OFDM system, resources are available in the time domain by means of OFDM symbols and in the frequency domain by means of subcarriers. If the time and frequency resources are organized into subchannels for allocation to individual users, it is called Orthogonal Frequency Division Multiple Access (OFDMA). Mobile WiMAX uses OFDMA to provide multiplexing operation of data streams from multiple users onto the downlink subchannels and multiple access by means of uplink subchannels.

SOFDMA is introduced to support scalable channel bandwidths from 1.25 to 20 MHz. The scalability is supported by adjusting the FFT size while fixing the subcarrier frequency spacing at 10.94 kHz. Since the subcarrier bandwidth and symbol duration is fixed, the impact on higher layers is minimal when scaling the bandwidth.

Table 1 shows the OFDMA scalability parameters for different system channel bandwidths from 1.25 to 20 MHz.

Parameters	Values			
System Channel Bandwidth / MHz	1.25	5	10	20
Sampling frequency (F_p) / MHz	1.4	5.6	11.2	22.4
FFT Size (N_{FFT})	128	512	1024	2048
Number of subchannels	2	8	16	32
Subcarrier frequency spacing / kHz	10.94			
Useful symbol time (T_b) / μ s	91.4			
Guard time (T_g) / μ s	11.4			
OFDMA symbol duration (T_s) / μ s	102.9			
Number of OFDMA symbols	48			

Table 1: OFDMA scalability parameters

3.1.2 Sub-Channelisation

OFDM is a multicarrier modulation technique. The available bandwidth is divided into many subcarriers. An OFDMA structure consists of three types of subcarriers:

- Data subcarriers for data transmission
- Pilot subcarriers for estimation and synchronisation purposes
- Null subcarriers for guard bands and DC carriers (no transmission uses)

For a multiple-access strategy like OFDMA the data and pilot subcarriers are grouped into subsets of subcarriers called subchannels. A subchannel, as defined in the IEEE standard 802.16e-2005, is a logical collection of subcarriers. The number and exact distribution of the subcarriers that constitute a subchannel depend on the subcarrier permutation mode. The WiMAX OFDMA PHY supports sub-channelisation in both downlink (DL) and uplink (UL). The minimum frequency-time resource unit of sub-channelisation is one slot. A subchannel is the basic unit of resource allocation in the physical layer.

Subchannel allocation may be performed in the following ways: partial usage of subchannels (PUSC) where some of the subchannels are allocated and full usage of the subchannels (FUSC) where all subchannels are allocated. For these frequency-diverse subchannels the subcarriers are pseudo-randomly distributed across the bandwidth, thus subchannels are of similar quality. For each subchannel, the coding and modulation are adapted separately.

OFDMA supports multiple access, which allows user devices to transmit only through the subchannels allocated to them. Furthermore, within the same time slot more transmit power can be allocated to a user with less favourable channel conditions, while lowering the power for users in better locations.

3.1.3 Advanced Physical Layer features

Support for QPSK, 16QAM and 64QAM modulation is defined with Mobile WiMAX. Both Convolutional Code (CC) and Convolutional Turbo Code (CTC) with variable code rate and repetition coding are supported. The combination of various modulations and code rates provide a fine resolution of data rates as shown in Table 2 for 5 and 10 MHz channels with PUSC sub-channels.

Modulation	Code Rate	5 MHz Channel		10 MHz Channel	
		Downlink Rate / Mbps	Uplink Rate / Mbps	Downlink Rate / Mbps	Uplink Rate / Mbps
QPSK	1/2 CTC, 6x	0.53	0.38	1.06	0.78
	1/2 CTC, 4x	0.79	0.57	1.58	1.18
	1/2 CTC, 2x	1.58	1.14	3.17	2.35
	1/2 CTC, 1x	3.17	2.28	6.34	4.70
	3/4 CTC	4.75	3.43	9.50	7.06
16QAM	1/2 CTC	6.34	4.57	12.67	9.41
	3/4 CTC	9.50	6.85	19.01	14.11
64QAM	1/2 CTC	9.50	6.85	19.01	14.11
	2/3 CTC	12.67	9.14	25.34	18.82
	3/4 CTC	14.26	10.28	28.51	21.17
	5/6 CTC	15.84	11.42	31.68	23.52

Table 2: Mobile WiMAX PHY data rates with PUSC subchannel

Adaptive modulation and coding (AMC), Hybrid Automatic Repeat Request (HARQ) and Fast Channel Feedback (CQICH) were introduced with Mobile WiMAX to enhance coverage and capacity for WiMAX in mobile applications.

The base station scheduler determines the appropriate data rate for each burst allocation based on the buffer size, channel propagation conditions at the receiver, etc. A channel Quality Indicator (CQI) channel is utilized to provide channel-state information from the user terminals to the base station scheduler. Relevant channel-state information can be fed back by the CQICH including: Physical carrier to interference-plus-noise ratio (CINR), effective CINR, multiple input multiple output (MIMO) mode selection and frequency selective sub-channel selection.

Hybrid Auto Repeat Request (HARQ) is introduced and supported by Mobile WiMAX. It combines error correction as well as automatic repeat request, provides fast response to packet errors and improves cell edge coverage. Chase Combining and Incremental Redundancy are supported to further improve the reliability of the retransmission. A dedicated ACK channel for HARQ ACK/NACK signaling also is provided in the uplink.

3.1.4 Smart Antenna Technologies

The WiMAX physical layer has been designed from the ground up for multiantenna support. The multiple antennas can be used for diversity, beamforming, spatial multiplexing and various combinations thereof. This key feature can enable WiMAX-based networks to have very high capacity and high degree of reliability, both of which are shortcomings of current generations of cellular wireless networks.

Smart antenna technologies involve complex vector or matrix operations on signals due to the use of multiple antennas. OFDMA allows smart antenna operations to be performed on vector-flat subcarriers. Mobile WiMAX supports a full range of smart antenna technologies to enhance system performance. The smart antenna technologies supported are

- Beamforming
- Space-Time Code (STC)
- Spatial Multiplexing (SM)

Spatial multiplexing is supported to take advantage of higher peak rates and increased throughput. With spatial multiplexing, multiple streams are transmitted over multiple antennas. If the receiver also has multiple antennas, it can separate the different streams to achieve higher throughput compared to single antenna systems. With 2x2 Multiple Input Multiple Output (MIMO), SM doubles the peak data rate by transmitting two data streams. In upload direction, each user has only one transmit antenna, two users can transmit in the same slot as if two streams are spatially multiplexed from two antennas of the same user. Table 3 provides a summary of the theoretical peak data rates for various DL/UL ratios assuming a 10 MHz channel bandwidth, 5 ms frame duration with 44 OFDM data symbols and PUSC sub-channelisation.

			DL/UL Ratio					
			1:0	3:1	2:1	3:2	1:1	0:1
User Peak Rate / Mbps	SIMO (1x2)	DL	31.68	23.04	20.16	18.72	15.84	0
		UL	0	4.03	5.04	6.05	7.06	14.11
	MIMO (2x2)	DL	63.36	46.08	40.32	37.44	31.68	0
		UL	0	4.03	5.04	6.05	7.06	14.11
Sector Peak Rate / Mbps	MIMO (2x2)	DL						
		UL	0	8.06	10.08	12.10	14.12	28.22

Table 3: Data Rates for SIMO/MIMO Configurations

Mobile WiMAX supports adaptive switching between these options to maximize the benefit of smart antenna technologies under different channel conditions.

3.2 The Medium Access Control Layer

The IEEE standard 802.16 was developed for the delivery of broadband services including voice, video, and data. The MAC layer can support bursty data traffic with high peak rate demands while simultaneously allowing streaming video and latency-sensitive voice traffic over the same channel. The resources allocated to one terminal by the MAC scheduler can vary from a single time slot to the entire frame. Since the resource allocation information is transmitted in a Media Access Protocol (MAP) message at the beginning of each frame, the scheduler can change the resource allocation on a frame-by-frame basis. A MAP message defines the usage of the downlink and uplink intervals in Time Domain Duplex (TDD) mode.

3.2.1 QoS support

In the Mobile WiMAX MAC layer, QoS is provided via service flows. A service flow is a MAC transport service that provides unidirectional transport of packets either to uplink packets transmitted by the MS or to downlink packets transmitted by the base station (BS). A service flow is characterized by a set of QoS Parameters such as latency, jitter, and throughput assurances.

Before providing a certain type of data service, the base station and user-terminal first establish a unidirectional logical link between the peer MACs called a connection. The outbound MAC then associates packets traversing the MAC interface into a service flow to be delivered over the connection. The QoS parameters associated with the service flow define the transmission ordering and scheduling on the air interface. The connection-oriented QoS can therefore provide accurate control over the air interface. The service flow parameters can be dynamically managed through MAC messages to accommodate the dynamic service demand.

QoS is enabled by the bandwidth-request/grant mechanism between various mobile stations and base stations. Mobile WiMAX supports end-to-end quality of service. Therefore it is possible to assign quality of service on a per user basis and/or per service flow. Real-time data should always be prioritised than e.g. FTP traffic. So if other users generate high traffic while a real-time video is about to be transmitted from a bus, then the video should not be influenced because the service flow of the video is preferred by the network. Furthermore if there are several real-time data flows at the same time, the video connection from the bus could be prioritised on a per user basis.

3.2.2 MAC scheduling

The scheduling service in Mobile WiMAX MAC is designed to efficiently deliver broadband data services including voice, video and other data over changing broadband wireless channel. The MAC scheduler must efficiently allocate available resources in response to bursty data traffic and time-varying channel conditions. The scheduler is located at each base station to enable rapid response to traffic requirements and channel conditions. The CQICH channel provides fast channel information feedback to enable the scheduler to choose the appropriate coding and modulation for each allocation. The scheduling service is provided for both downlink and uplink traffic. The MAC supports frequency-time resource allocation on a per-frame basis. The resource allocation is delivered in MAP messages at the beginning of each frame. Therefore, the resource allocation can be changed from frame to frame in response to traffic and channel conditions. The amount of resources in each allocation can range from one slot to the whole frame. The MAC scheduler handles data transport on a connection-by-connection basis. Each connection is associated with a single scheduling service that is determined by a set of QoS parameters quantifying aspects of its behaviour.

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3.2.3 Mobility management

To support mobility, Mobile WiMAX has introduced the handover process and power management.

The handover process may be used in a number of situations, as for example:

- if the Mobile Station moves and needs to change the BS (due to signal fading, interference level, etc.) to which it is connected in order to provide a higher signal quality;
- if the Mobile Station can be serviced with higher QoS at another BS.

In the IEEE standard 802.16e, there are three handover methods defined:

- Hard Handover (HHO),
- Fast Base Station Switching (FBSS),
- Macro Diversity Handover (MDHO).

The HHO is mandatory, while FBSS and MDHO are two optional modes. Hard Handover (HHO) uses a break-before-make approach, where the user device is connected to only one base station at any given time.

For the power management, Mobile WiMAX supports sleep mode and idle mode to enable power-efficient operation of the MS. Sleep Mode is a state in which the MS conducts pre-negotiated periods of absence from the Serving Base Station air interface. Sleep Mode is intended to minimize the use of MS power and Serving Base Station air interface resources. Implementation of sleep mode is optional for the MS and mandatory for the BS.

Idle Mode provides a mechanism for the MS to become periodically available for download broadcast traffic messaging without registration at a specific base station. Idle Mode benefits the Mobile Station by removing the active requirement for Handover, and all Normal Operation requirements. By restricting MS activity to scanning at discrete intervals, Idle Mode allows the MS to conserve power and operational resources. Idle Mode benefits the network and BS by providing a simple and timely method for alerting the MS to pending DL traffic directed towards the MS, and by elimination of air interface and network handover traffic from essentially inactive MS.

3.2.4 Security

Mobile WiMAX supports different state of the art security features. The most important security features are:

- Key Management Protocol: Privacy and Key Management Protocol Version 2 (PKMv2) is the basis of Mobile WiMAX security. This protocol manages the MAC security using EAP authentication, Traffic Encryption Control, Handover Key Exchange, and more messages.
- Device/User Authentication: Mobile WiMAX supports Device and User Authentication using IETF EAP protocol by providing support for credentials that are SIM-based, USIM-based or Digital Certificate or username/password-based.
- Traffic Encryption: AES-CCM is the cipher used for protecting all the user data over the Mobile WiMAX MAC interface. The keys used for driving the cipher are generated from the EAP authentication. A Traffic Encryption State machine with a periodic key (TEK) refresh mechanism enables continuous transition of keys to further improve protection.

- Control Message Protection: Control data is protected using AES based CMAC, or MD5-based HMAC schemes.
- Fast Handover Support: A 3-way Handshake scheme is supported by Mobile WiMAX to optimize the re-authentication mechanisms for supporting fast handovers. This mechanism is also useful to prevent any man-in-the-middle-attacks.

4 Spectrum Issues

4.1 10-66 GHz licensed bands

The 10-66 GHz bands provide a physical environment where line-of-sight (LOS) is required and multipath effects are negligible. In the 10-66 GHz band, channel bandwidths of 25 MHz or 28 MHz are typical.

4.2 Frequencies below 11 GHz

Frequencies below 11 GHz provide a physical environment where LOS is not necessary and multipath may be significant. The ability to support near-LOS and NLOS scenarios requires additional PHY functionality, such as the support of advanced power management techniques, interference mitigation, and multiple antennas.

The initial system performance profiles that will be developed by the WiMAX Forum for the IEEE 802.16e-2005 air interface standard are in the licensed 2.3 GHz, 2.5 GHz, 3.3 GHz and 3.5 GHz frequency bands.

4.3 Spectrum Considerations

To take best advantage of the benefits provided by WiMAX systems, large block spectrum assignments are most desirable. This enables systems to be deployed in TDD mode with large channel bandwidths, flexible frequency reuse and with minimal spectral inefficiencies for guard-bands to facilitate coexistence with adjacent operators.

The deployments of 802.16e should most likely be at 2.3 GHz and 2.5 GHz, frequencies low enough to accommodate the non-line-of-sight conditions between the base stations and mobile devices.

It must be taken into account, that in Europe the most licensed bands for WiMAX are available between 3.4 GHz and 3.6 GHz. They are preferred for Fixed WiMAX and not just for Mobile WiMAX. Furthermore the analyses made for mobile user access are addressed to frequencies below 2.5 GHz. Therefore the knowledge about the behaviour of Mobile WiMAX system performance in the higher frequency bands is poor.

One question that is to be answered regarding OFDMA is the bandwidths that will be assigned to the licensed bands, which will be between 5 and 10 MHz in the most countries. This has an important influence to the reachable data rates and the possible system capacity. E.g. in Germany, the licensed bands between 3.4 GHz and 3.6 GHz are 7 MHz wide and assigned as band pairs. The channel bandwidth is highly dependent on the spectrum allocated by regulators.

For the MORYNE scenario, mobility and non-line-of-sight conditions will be predominant. It is recommended to use the lower spectrum bands at 2.3 and 2.5 GHz because the propagation conditions at these frequencies are more appropriate to the environment of mobile users.

5 Physical Layer analysis and impact on MORYNE

Concerning the MORYNE project, some special features of Mobile WiMAX are analysed. For MORYNE it is important to know the behaviour of Mobile WiMAX in mobile urban area environments. This knowledge is essential for assessing the impact on the MORYNE scenario.

In mobile mode operation, channel quality of the link between the base station and the mobile station varies significantly over short time interval due to relative movement of surrounding scatterer objects. With mobility, the influence of the Doppler shift becomes more important and at higher speeds of the mobile stations, link quality decreases due to increased Inter-carrier Interference (ICI) between the OFDM subcarriers.

The analysis is typically done for different operating environments, for example for users moving at pedestrian speed of about 3 km/h and users moving at vehicular speeds of 30 km/h and 120 km/h respectively.

Another important aspect for MORYNE is operation under non-line-of-sight (NLOS) conditions, which are typical for urban and sub-urban areas. In most cases the mobile station equipment in the bus moving at e.g. 50 km/h will have no intervisibility to the WiMAX transmitter.

5.1 OFDM simulation at high user velocities

To analyse the physical layer properties of Mobile WiMAX, some fundamental characteristics of an OFDM multicarrier modulation technique has been pointed out. To show the behaviour of some of the parameters of an OFDM system, a link-level simulation has been set up.

The OFDM system highly depends on the choice of different design parameters. The parameters with the highest influence on the system performance are:

- channel bandwidth
- carrier frequency
- number of subcarriers
- subcarrier spacing
- cyclic prefix length
- frame length
- channel coding
- modulation and code rate
- mobile station speed
- ARQ mechanism
- error correction mode

The channel bandwidth and the carrier frequency are under control of spectrum regulation authorities. In Mobile WiMAX, the number of subcarriers is proportional to the allocated bandwidth, whereas the subcarrier spacing is kept constant. All other parameters are variables that have to be defined during system design.

To show the influence of the mobility to the link quality of a Mobile WiMAX system, some simulations were made and the results are shown in Figure 1. It can be seen that a higher velocity causes a higher Bit Error Rate (BER) or, when a certain BER is assumed, the signal power must be higher. The Bit Error Rate (BER) is plotted versus E_b/N_0 (the ratio of bit energy to noise power spectral density). Compared to a fixed terminal, the quality of the signal at a mobile user speed of e.g. 50 km/h is degraded about 6 dB when a BER of 10^{-3} is assumed.

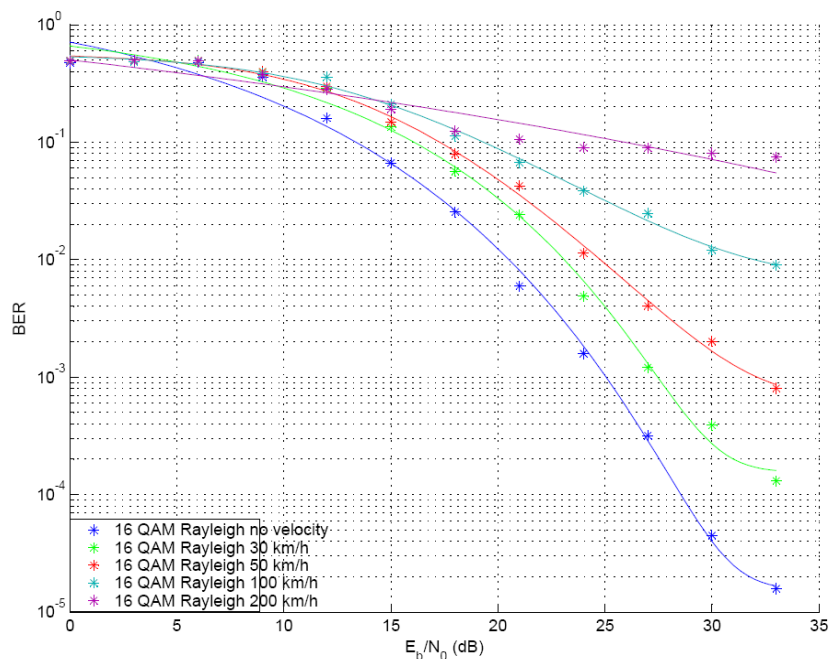


Figure 1: Simulation results for different mobile user speeds

The essential parameter settings used in the link level simulation model are:

FFT-size:	128
modulation:	16QAM
code rate:	1/2
subcarrier separation:	10.9 kHz
symbol duration:	91.4 μ s
carrier frequency:	2.3 GHz
guard interval:	22.8 μ s
max. multipath delay:	5 μ s

5.2 OFDMA and Sub-Channelisation

WiMAX presents a very challenging multiuser communication problem: Many users in the same geographic area requiring high on-demand data rates in a finite bandwidth with low latency. Multiple-access techniques allow users to share the available bandwidth by allowing each user some fraction of the total system resources. The diverse nature of anticipated WiMAX traffic – Voice over IP (VoIP), data transfer, and video streaming – and the challenging aspects of the system deployment – mobility, neighbouring cells, and high required bandwidth efficiency – make the multiple-access problem quite complicated in WiMAX. The implementation of an efficient and flexible multiple-access strategy is critical to WiMAX system performance.

Previous OFDM systems, such as DSL, 802.11a/g, and the earlier versions of 802.16/WiMAX, use single-user OFDM: All the subcarriers are used by a single user at a time. For example, in 802.11a/g, colocated users share the 20 MHz bandwidth by transmitting at different time after contending for the channel. Mobile WiMAX takes a different approach, known as OFDMA, whereby users share subcarriers and time slots. This additional flexibility allows for increased multiuser diversity, increased freedom in scheduling the users, and several other important implementation advantages. OFDMA does come with a few cost,

such as overhead in both directions: The transmitter needs channel information for its users, and the receiver needs to know which subcarriers it has been assigned.

The orthogonal frequency division multiplexing (OFDM) transmission technique has proven its ability to mitigate the effects of frequency selective fading in multi-path radio channel with a low computational complexity by subdividing the total system bandwidth into a large number of orthogonal, non-frequency selective subcarriers [19].

But in an environment with moving terminals and therefore time-variant radio channels the orthogonality between subcarriers is degraded due to the Doppler frequencies on the different signal paths which results in Intercarrier Interferences (ICI). The bit error rate (BER) performance is decreased by this interference in case of increasing terminal mobility. In Mobile WiMAX the subcarrier spacing is fixed and can not be reduced to cope with ICI.

A combination of the OFDM transmission technique with an FDMA multiple access scheme, which is termed as OFDMA, will be required for future high performance systems. Therefore the uplink of the system especially including the subcarrier selection process can be adapted to the current channel situation by assigning the best and less attenuated subcarriers to each user achieving a large multi-user diversity gain. Applying an OFDMA technique in the uplink of a communication system is technically demanding due to the interference situation which is dominated by Intercarrier Interference (ICI) and Multiple Access Interference (MAI) between different user signals as well as the time-variance of the frequency-selective radio channel in a mobile environment. Therefore, a precise knowledge of the current radio channel is required in the equalization process at the receiver side and for the adaptive subcarrier allocation procedure at the transmitter side [15].

Subchanneling can have several positive effects on the system. The key benefits achieved by introducing subchannels include higher flexibility, better robustness and increased overall connection quality.

As coding and modulation are adapted separately for each subchannel, channel optimization can be done on a smaller scale than possible when using a single parameter set. The robustness against Intercarrier Interference (ICI) and Multiple Access Interference (MAI) is improved and the influence of frequency selective fading is mitigated by distributing it to many subcarriers [14,15]. This is useful especially for vulnerable links. The strong influence of fast fading problems that is often experienced when connecting mobile users via radio links is weakened as well. It becomes apparent, that the channel estimation method has a high influence to the quality of an OFDMA system where time-selective channels due user-mobility mainly exist.

Moreover, the orthogonality of the subcarriers increases the tolerance to multipath and self-interference effects in both UL and DL. In addition, subchanneling can improve gain by more than 3 dB, which optimizes spectrum resource use and enhances indoor coverage.

Time Division Duplex (TDD) is defined for the initial Mobile WiMAX profiles for its added efficiency in support of asymmetric traffic and channel reciprocity for easy support of advanced antenna systems.

For good physical layer performance, a guard interval is inserted between two OFDM symbols. This allows the multi-path effect of the radio channel to be absorbed. The duration of the guard interval defines the robustness of the channel. In the Mobile WiMAX profile the guard interval is adapted to cellular deployment with omni-antenna systems and high multi-path environments.

MORYNE impact: In the MORYNE scenario there will be some situations, where several buses need broadband access to the server at the same time for real-time video streaming. Many connections in the same geographic area are required with high data rates in a finite

bandwidth with low latency. The multiple access is well supported by Mobile WiMAX through the OFDMA technique and thus simultaneous broadband connections in a WiMAX cell should be possible without problems. Moreover, short bursts of bit errors can be compensated by the application of an MPEG codec for stream encoding.

5.3 HARQ and adaptive modulation and coding

The physical properties of signal propagation among which are reflection, diffraction and diffusion can be perceived as interferences at the receiving end. The effects that have to be accounted to signal propagation are fading channels, frequency selective fading, multipath effects and time variance of incoming signals. WiMAX systems use adaptive modulation and coding in order to take advantage of fluctuations in the channel.

The use of turbo codes in Mobile WiMAX based solutions can deliver 3 dB of additional gain compared to the convolutional coding [7]. Additional gain is offered by HARQ, a Chase Combining scheme, which improves retransmission efficiency and adds robustness with rapidly changing path conditions in high mobility situations. HARQ combined together with CQICH and AMC provides robust link adaptation in mobile environments at vehicular speeds in excess of 120 km/h. Messages that do not support retransmission can be sent directly in multiple instances with WiMAX 802.16e to increase maximum cell range by using repetition coding. If the repetition coding is 2, 4 or 6 the respective theoretical gain is 3, 6 or 9 dB.

Enhanced channel coding using Convolutional Turbo Code (CTC), HARQ and repetition coding can improve system gain by up to 15 dB [7].

In [13] BER simulations for IEEE 802.16e OFDM-PHY downlink are performed. It is proposed an algorithm of channel estimation and frequency equalizer to correctly detect the received data after synchronization. Also the performance degradation with different combinations of modulation schemes and code rates are evaluated.

MORYNE impact: The HARQ mechanism and the adaptive modulation and coding are supporting the transmission of the MPEG video stream. With the dedicated CQICH channel, there will be a fast reaction to the time variant quality of the physical channel when moving along the roads. If the channel quality is decreasing due to the movement of the bus, the modulation and code rate have to be changed to reach a defined bit error rate (BER). By degrading the modulation, the available uplink rate will be reduced. Then the MPEG video stream should be scale down to a lower bit rate.

5.4 Beam forming, space-time code and spatial multiplexing

Beam forming technology is used for link budget/cell range improvements, interference reduction and capacity increase. Beam forming is hence best suited for macro deployment and high-capacity coverage.

Space-Time Code (STC) is a method employed to improve the reliability of data transmission in wireless communication systems using multiple transmit antennas. STCs rely on transmitting multiple, redundant copies of a data stream to the receiver in the hope that at least some of them may survive the physical path between transmission and reception in a state good enough to allow reliable decoding.

Kurniawan et al. [11] analyses antenna selection features regarding to the gain achievable by antenna selection technique. When a base station has more than one antenna, spatial diversity can be exploited to improve transmission quality and bandwidth efficiency. In simulations, it is shown that the space time coding is able to improve the gain by up to 6 dB at 10^{-3} BER level for low Doppler spread, which allows the feedback information to be useful in im-

proving system performance. Only 0.5 dB gain is obtained for high Doppler spread and rich scattering environments, which invalidates the feedback information available at the base station.

MORYNE impact: In MORYNE, redundancy is more important than higher data rates, because real-time video data should not be repeated in case of lost packets. For a video stream it is more desired to get a higher reliability than high data rates. If the channel bandwidth is reduced first it influences only the delay of a video stream, which could be temporary counteracted with a bigger cache on the receiver side. Lost packets result in a bad video quality directly. The Space-Time Code and the spatial multiplexing are important to reach better robustness and coverage. In case of exploitation of redundant copies of a data stream the MORYNE video can be sent with a better resolution by scaling the codec. With beam forming it will be possible to reach better coverage in sub-urban areas.

6 Medium Access Control analysis and impact on MORYNE

Quality of Service (QoS) was a specific design aspect for Mobile WiMAX from the beginning. The following QoS parameters would provide a scheduling service to support data streams for which no minimum service level is required and therefore may be handled on a basis of available capacity:

- Maximum sustained traffic rate (in bps)
- Request/Transmission Policy
- Scheduling type: Best Effort Service (BE)

Compared to the minimum service level the following QoS parameters would provide a scheduling service to support real-time data streams consisting of variable-sized data packets that are issued at periodic intervals, such as MPEG video:

- Maximum latency (in ms)
- Minimum reserved traffic rate (in bps)
- Maximum sustained traffic rate (in bps)
- Traffic priority (0..7)
- Scheduling type: Real-Time Polling Service (rtPS)
- Unsolicited polling interval (in ms)

Hence in MORYNE a specific data rate can be reserved for the video transmission from the bus. Depending on the knowledge about the available buffer size different maximum latencies can be allowed.

The scheduling type rtPS is designed to support real-time uplink service flows that transport variable sized data packets on a periodic basis, such as MPEG video. The service offers real-time, periodic, unicast request opportunities [2]. In the MORYNE scenario the scheduling type rtPS can be employed by the traffic management centre to request periodically recorded video stream from different busses.

The MAC performance of IEEE 802.16e is evaluated in [20] by changing different parameters, such as MAC frame size, MAC protocol data unit (PDU) size, and number of connections on MAC. The most important result in this evaluation is, when increasing the number of connections, the MAC efficiency is decreasing by 30% to 40%. Generally in case of higher system loads, the scheduling algorithm is more important and has a higher impact on the overall system performance and WiMAX capacity. The scheduling algorithms are not defined by the IEEE nor the WiMAX Forum™. They will be open and defined by each WiMAX vendor.

To perform a successful network access and a stable data transfer with reasonable throughput, a minimum Carrier to Interference plus Noise Ratio (CINR) of about 1 dB is necessary. This is ensured by an admission control functionality implemented in the base station, which has to avoid system overload and packet call blocking. Automatic link adaptation selects the most appropriate modulation and coding scheme (MCS) thus optimizing the user throughput for given radio conditions in terms of CINR. WiMAX link adaptation can react very fast to varying radio conditions due to the very small MS-BS round-trip time. Typical switching periods of about 10 ms have been assumed [21].



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MORYNE impact: In the MORYNE scenario, the scheduling service for supporting real-time data streams is preferred because MPEG video streams have to be transmitted. For hard handover, the goal is to keep layer 2 handover delays below 50 ms. The worst case effect that such a handover could have on a real time MPEG video stream would be a small disturbance or some artefacts in the video. Also the fast reaction of the link adaptation to varying radio conditions such as of a moving bus has a positive influence to the link quality and causes a more seamless mobility. The introduction of service flows and the support of end-to-end quality of service allow real-time services to be used in a dynamic environment.

7 System Performance analysis and impact on MORYNE

The system performance analysis of an IEEE 802.16e Mobile WiMAX network is done by system level simulations. In [3], [8], [9] and [12] the system performance of OFDMA networks is evaluated with different system parameters all based on the first profile of Mobile WiMAX.

System simulations in [8] were used to determine the throughput performance of 802.16e OFDMA based on the simulation assumptions as follows:

cell layout:	Hex grid, 19 cell sites, 3 sector sites, 2.8 km site-site distance, 1 cell reuse
path loss:	$L = 128.1 + 37.6 \log_{10}(R)$, R in km
lognormal shadowing:	8 dB stdev, 50 m correlation distance
shadowing correlation:	0.5/1.0 between cells/sectors
penetration loss:	10 dB
antenna model (horizontal):	70° (-3 dB), Antenna Gain: 14 dB
channel models:	3 km/h pedestrian B, flat fading
traffic models:	full buffered (2 Mbyte packets)
basestation transmit power:	20 W ERP
overhead:	cyclic prefix: 1/8, pilot power: 16 %, 3 symbol control
number of data subcarriers per symbol:	DL: 384 at 5 MHz, 768 at 10 MHz
number of OFDM symbols:	DL: 31, UL: 15
subchannelization:	DL: abstracted FUSC
operating frequency:	not specified
MIMO support:	not specified

Downlink capacity: The first simulation was done with download full buffer throughput with 3 km/h flat fading channel and without overhead. All 49 OFDM symbols within every 5 ms frame were used for the downlink. The absolute sector throughput in downlink determined by the peak rate of the system is between 8 and 9 Mbps with 16QAM and a code rate of 0.638. The user throughput is about 1 Mbps at 10 users/sector and about 400 kbps at 25 users per sector.

When introducing control and pilot channel overhead, the sector throughput with 20 users per sector and 5 MHz bandwidth is about 6 Mbps.

Uplink capacity: In the second simulation the OFDMA uplink system performance with full buffer traffic and 15 allocated OFDM symbols for uplink transmission within a 5 ms frame is evaluated. The user throughput for flat fading channels is between 1100 kbps and 1400 kbps and for frequency selective fading channels between 950 kbps and 1280 kbps.

Also in [3] simulations have been performed to assess the performance of Mobile WiMAX. The performance simulation assumes heterogeneous users with a mix of mobile users with different channel models and different speeds. The system parameters and Mobile WiMAX configuration assumptions are:

cell configuration:	3 sectors/cell
number of 3-sector cells:	19
frequency reuse:	1 BS sites, 1 unique frequency channels, 3 sectors per BS
users/sector:	10

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traffic type:	full buffer
channel estimation:	ideal
scheduler:	proportional fair
antenna configuration:	1x2, 2x2
MIMO support:	DL: Alamouti STC, Vertical Spatial Multiplexing (VSM), UL: Collaborative SM
MIMO switch:	adaptive STC/VSM switch
HARQ:	CC, 3 retransmissions
coding:	CTC
frame overhead:	11 OFDM symbols (7 DL, 3 UL, 1 TTG)
data symbols per frame:	37
operating frequency:	2500 MHz
duplex:	TDD
channel bandwidth:	10 MHz
BS-to-BS distance:	2.8 km
minimum MS-to-BS distance:	36 m
antenna model (horizontal):	70° (-3dB)
BS height:	32 m
mobile terminal height:	1.5 m
BS antenna gain:	15 dBi
MS antenna gain:	-1 dBi
BS maximum power amplifier power:	43 dBm
mobile terminal maximum power amplifier power:	23 dBm
number of BS Tx/Rx antenna:	Tx: 2 or 4; Rx: 2 or 4
number of MS Tx/Rx antenna:	Tx: 1; Rx: 2
BS noise figure:	4 dB
MS noise figure:	7 dB
propagation model:	COST 231 sub-urban
lognormal shadowing:	8 dB
BS shadowing correlation:	0.5
penetration loss:	10 dB

There are 10 users per sector. The traffic is assumed to be full buffer FTP traffic. Ideal channel estimation and realistic link adaptation is also assumed. The frame overhead to account for preamble, MAP overhead, and upload control channel is 7 OFDMA symbols in the DL and 3 in the UL. One symbol is allocated for TTG for a total of 11 overhead symbols and 37 data symbols for both DL and UL. The simulations are made with different antenna configurations (SIMO and MIMO) and with different DL/UL ratios of 28:9 and 22:15.

Download capacity: With a DL/UL ratio of about 3:1, the download sector throughput is 8.8 Mbps for SIMO and 13.60 Mbps for MIMO. With a DL/UL ratio of 3:2, the DL sector throughput is 6.6 Mbps for SIMO and 10.63 Mbps for MIMO.

Upload capacity: With a DL/UL ratio of about 3:1, the upload sector throughput is 1.38 Mbps for SIMO and 1.83 Mbps for MIMO. With a DL/UL ratio of 3:2, the UL sector throughput is 2.2 Mbps for SIMO and 3.05 Mbps for MIMO.

Additionally with an optimized Mobile WiMAX system, where the subchannelisation is improved, where frequency selective scheduling gain is taken into account, also the frequency selective AMC subchannelisation is considered and the overhead of the OFDMA symbols is reduced, the throughput can be improved by 20 to 30 %. Under consideration of these im-

provements and with a typical DL/UL ratio range between 3:1 and 1:1, the DL sector throughput can vary between 10 Mbps and 17 Mbps, the UL sector throughput can vary between 2 Mbps and 4 Mbps.

For all these results, it has to be taken into contrast that the capacity of the upload channel has to be shared by all connected mobile users. Moreover, the upload rate decreases when the distance to the center towards of the cell increases. The bigger the cell size, the smaller the data rate that can be achieved at the borders of the cells.

MORYNE impact: The minimum and maximum data rates required by the streaming video applications have to be determined as well as the maximum number of concurrent uploads that can be considered realistic.

At the time of this writing, no studies on the uplink data rate available to mobile users moving across the network cells were available to the authors. An analysis of these properties should make statements on the maximum throughput rate available over time or present a probability density function for the different rates. Results of this kind will be very helpful for the prediction of data transmission quality in the MORYNE scenario.

8 Conclusion

This document analyses the potential of Mobile WiMAX in the MORYNE scenario. In the MORYNE scenario sensor data like temperature or humidity is used to get a higher transport safety in public transport environments. Additionally video cameras are used to analyze road and traffic conditions. This traffic evaluation is used for traffic management and traffic forecasts. For sensor information only a narrowband connection is necessary. But video transmission requires a broadband connection up to 2Mbps. This is where Mobile WiMAX claims to provide a cost efficient alternative for data transmission.

After a short introduction to Mobile WiMAX this document analysed the spectrum, physical layer, medium access, mobility and system impact of the Mobile WiMAX standard on the envisioned MORYNE scenario.

The initial Mobile WiMAX deployment will be based on the TDD mode. TDD can be optimally adapted to asymmetric traffic. This matches well the MORYNE scenario where high data rate uplink capacity for video streams is needed. The non-line-of-sight conditions and mobility in an urban environment demand for lower spectrum bands. It is recommended to deploy 802.16e at 2.3 GHz and 2.5 GHz, frequencies that are low enough to accommodate the non-line-of-sight conditions between the base stations and mobile devices. In any case MORYNE should leverage on the fortune size of its “mobile device”, being a city bus, by employing antennas that can exploit spatial diversity.

OFDM is insensitive to frequency selective fading. However, mobility increases inter carrier interference (ICI). In Mobile WiMAX the subcarrier spacing is fixed and can not be reduced to cope with ICI. (Please note that the number of subcarriers is proportional to the Mobile WiMAX bandwidth). Therefore with increased mobility the Mobile WiMAX modulation index has to be limited. To ensure the required minimum bit error rate for the MORYNE scenario a modulation not higher than 16QAM is recommended.

Mobile WiMAX provides strong error correction mechanisms. However, if FEC and HARQ can not compensate for bad channel conditions, the application has to take care of lower bandwidth. In MORYNE the use of scalable video codecs that can adapt to varying channel bandwidth should be supported.

802.16e was standardized in 2005 and first products will become available on the market in 2007. MORYNE plans to measure the performance of selected Mobile WiMAX testbeds. The results of this analysis will be used to guide the performance measurements. The set-up of the measurements and the results will be described in later deliverables.

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A Appendix

A.1 Mobile WiMAX System Profile Release 1.0

In this section some selected characteristics of the Release 1.0 System Profile [4] are listed.

A.1.1 PHY Profile

- System parameters:
 - o PHY Mode: OFDMA
 - o Duplexing Mode: TDD
 - o Frequency bands:
 - 2.3..2.4 GHz (5, 8.75, 10 MHz channel bandwidth)
 - 2.30..2.36 GHz (3.5, 5, 10 MHz channel bandwidth)
 - 2.5..2.7 GHz (5, 10 MHz channel bandwidth)
 - 3.3..3.4 GHz (5, 7, 10 MHz channel bandwidth)
 - 3.4..3.8 GHz (5, 7, 10 MHz channel bandwidth)
 - 3.4..3.6 GHz (5, 7, 10 MHz channel bandwidth)
 - 3.6..3.8 GHz (5, 7, 10 MHz channel bandwidth)
 - o Cyclic prefix: 1/8
 - o Frame length: 5 ms
- Subcarrier allocation:
 - o DL subcarrier allocation: PUSC, FUSC, AMC 2x3
 - o UL subcarrier allocation: PUSC, AMC 2x3
- Channel Coding:
 - o Repetition
 - o Randomisation
 - o Tail Biting
 - o Convolutional Turbo Code
 - o Interleaving
- HARQ-Support
 - o Chase Combining with CTC
 - o ACK Channel
- Channel measurement:
 - o CINR
 - o RSSI
- Modulation:

- PRBS (subcarrier randomization)
- Downlink: QPSK, 16-QAM, 64-QAM
- Uplink: QPSK, 16-QAM
- STC/MIMO:
 - 2-antenna, matrix A
- Transmit requirements:
 - BS Tx dynamic range: 10 dB
 - MS Tx dynamic range: 45 dB
- Receiver requirements:

Modulation	coding rate	Receiver SNR / dB
QPSK	1/2	2.9
	3/4	6.3
16-QAM	1/2	8.6
	3/4	12.7
64-QAM	1/2	13.8
	2/3	16.9
	3/4	18.0
	5/6	19.9

Table 4: Minimum SNR requirements for BER=10⁻⁶ with CTC in AWGN channel

A.1.2 MAC Profile

- IPv4
- IPv6
- IPv4 with Header Compression (ROHC)
- IPv6 with Header Compression (ROHC)
- Multicast traffic connection
- ARQ implementation
- HARQ support
- QoS support
- data delivery services for mobile network
 - Unsolicited Grant Service (UGS)
 - Real-Time Variable Rate Service (RTVR)
 - Non-Real-Time Variable Rate Service (NRTVR)
 - Best Effort Service (BE)
 - Extended Real-Time Variable Rate Service (ERTVR)

- general handover support (only HHO)
- sleep mode
- idle mode
- PKMv2 support
- EAP-based authorization
- supported cryptographic suites:
 - o no data encryption, no data authentication, 3-DES with 128 bit key
 - o CCM-Mode 128 bit AES, CCM-Mode, AES key wrap with 128 bit key
- message authentication code mode:
 - o no message authentication
 - o CMAC
- security association
 - o support of static SA
 - o support of dynamic SA
 - o support of primary SA

A.1.3 Power Class Profile

Class Identifier	Transmit power for 16QAM / dB	Transmit power for QPSK / dB
Power Class 1	18..21	20..23
Power Class 2	21..25	23..27
Power Class 3	25..30	27..30
Power Class 4	>30	>30

Table 5: Power Class Profiles