Mobile WiMAX Performance Measurements with Focus on Different QoS Targets

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***Abstract*—The performance evaluation of mobile communication systems for time varying environments poses a major challenge. To address this issue, in this paper we propose an approach which extends a common laboratory environment by a fading channel emulator. Hereby, we analyze OFDM based links under complex and realistic radio channel conditions including upper layer protocols. By means of this setup, the influence of velocity on the data rate and Packet Error Rate (PER) of a Mobile WiMAX system is investigated for various Signal to Noise Ratios (SNR) assuming vehicular and pedestrian channel models defined by the ITU. As a result, we analyzed the performance of Mobile WiMAX for Adaptive Modulation and Coding (AMC) dependent on the QoS target, the channel model, the user velocity and the SNR. Hereby, we assumed two partially contrary QoS targets, high data rate and target PER.**

I. Introduction

Although Long Term Evolution (LTE) is going to be the next widely spread communication system, the Mobile Worldwide Interoperability for Microwave Access (WiMAX) technology is still of great importance for special applications. These applications can be found in the area of airport data communication [1] as well as in disaster management communication [2] and Unmanned Aerial Vehicle (UAV) communications [3]. Fig. 1 illustrates such an airport scenario which can be described as typical urban/suburban area. Furthermore, the characteristic multipath propagation in such an environment is illustrated in the figure. The performance of Orthogonal Frequency-Division Multiplexing (OFDM) based links is typically investigated by means of two techniques. The first one is simulation, which is applied to evaluate the performance of these systems in large scale scenarios. Alternatively, real testbeds are used to precisely analyze different configurations and functionalities in a real world scenario and to validate simulation results. The main benefits of the simulations are high flexibility and low cost. However, a lot of effects occurring in a communication system are difficult to model using this approach. Therefore, the use of real equipment is a major advantage regarding this particular aspect. On the other hand field trials are difficult to realize in some environments. An exemplary measurement campaign that is hard to realize by means of real world measurements is the evaluation of the impact of mobility on a radio link. Typically measurement cars are used in this context. This means that for the evaluation of the impact of velocity cars have to drive with a constant and preset speed of up to several hundred km/h.

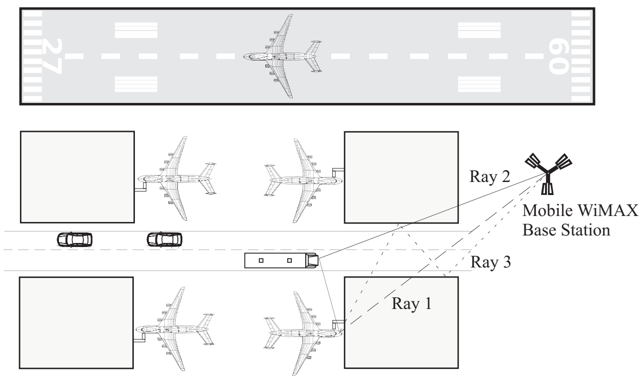


Fig. 1: Multipath propagation for Mobile WiMAX in an airport scenario

In this paper, we use an alternative approach which extends a common laboratory environment by a fading channel emulator to evaluate these scenarios. With the measurement setup described in Sec. III we observe the influence of complex radio channel models on an End-to-End connection in a laboratory environment. The major benefit of our approach/measurement setup is first of all the repeatability of the measurements, although the channel characteristics are simplified. The channel emulator uses statistical channel models, where one realization can be replayed many times. Hence, for an analysis of the influence of individual channel parameters on the overall system with all other parameters regarding the fading channel remaining constant our setup should be used. For reliable results in regard on a real radio channel field trials have advantages because the used channel is simplified for the laboratory measurements.

The main novelty of this paper is the analysis of the performance of different Adaptive Modulation and Coding (AMC) approaches for Mobile WiMAX dependent on the QoS target, the channel model, the user velocity and the SNR. Hereby, we assumed two QoS optimization targets, high data rate and target PER. For typical real time applications (Voice over IP (VoIP) and video streaming) a PER of about 1 % is needed [4]. We show that the choice of an ideal MCS is strongly dependent on the QoS target, the channel environment, the user velocity and the SNR. The problem how to measure the user velocity is not part of this paper. However, in a closed airport scenario where every user is known by the tower it is obvious, that the approximate velocity can be detected (for example via Global Positioning System (GPS)).

II. Related Work

For the performance evaluation of Mobile WiMAX systems many simulation results can be found. For example in [5] the performance of Mobile WiMAX is analyzed via a physical layer simulation. In this paper, the authors focus on the behavior of the PER and the throughput for different channel models and various modulation and coding schemes. The investigations focus on the ITU Vehicular A channel model assuming different velocities. Furthermore, in [6] a comparison between LTE and WiMAX with focus on throughput measurements via simulation for different velocities (ITU Vehicular A model) can be found.

Beside this, field trials are often used for the analysis of the impact of velocity on the performance of OFDM based links. For example the performance of LTE is evaluated by a testbed in [7]. For throughput measurements a monitoring car with an average speed of around 30 km/h is used. Hereby, it is very difficult to drive a car with a constant and preset speed to evaluate the influence of velocity. Hence, in real world measurements often static scenarios [8] or scenarios with low velocity are considered ([9]; pedestrian 3 km/h fading channels in downlink and static channels in uplink). In [10] an evaluation of a WiMAX link with respect to higher layer protocols can be found. For this purpose an experimental WiMAX testbed has been deployed and several experiments and stress tests are carried out over this testbed in the uplink (UL) and downlink (DL) directions for various service and traffic types and at various distances from the base station.

Some papers compare results from simulations and field trials. In [11] analyses with a fully compliant Mobile WiMAX simulator are compared with experimental results from field measurements. Furthermore, in [12] performance analyses of several wireless technologies (including WiMAX) from laboratory measurements without focus on the influence of different channel conditions are presented.

In [4] Adaptive Modulation and Coding (AMC) for Mobile WiMAX is presented from the QoS point of view. The authors analyzed the throughput for User Datagram Protocol (UDP) and Transmission Control Protocol (TCP) communication. Thereby, only the Mobile WiMAX protocol stack was implemented. The influence of the transport layer is implicated by the Mobile WiMAX target PER. For a UDP connection the authors assume a maximum allowed PER of 10^{-2} and for a TCP connection a target PER of 10^{-3} is adopted.

TABLE I: Mobile WiMAX system parameterization

Parameter	Value
Carrier Frequency [GHz]	3.5
Channel Bandwidth [MHz]	10
Transmitter Power [dBm]	-15
FFT Size	1024
Modulation Schemes	QPSK, 16 QAM, 64 QAM
Coding Rates	1/2, 3/4
Coding Type	Convolutional Turbo Code (CTC)
Duplexing Scheme	Time Division Duplex (TDD)
DL/UL Ratio	35:12
Map Repetition Factors	0 (No Repetition)
SNR	0 - 30 dB

III. Measurement Setup

Instead of performing measurements in a real world environment in this paper we use an approach based on radio channel emulation. Hereby, it is possible to perform measurements of typical Key Performance Indicators (KPI) at the application layer such as data rate, delay and jitter in a controlled laboratory environment. With this method detailed analyses for different QoS targets are possible. In the following the different elements of the setup (see Fig. 2) are described in more detail:

A Base Station Emulator (BSE) allows for the creation of a mobile network cell in a laboratory environment. A detailed parameterization of the Mobile WiMAX base station is possible.

The RF signal provided by the BSE serves as input for the downlink channel of the channel emulator (circulators are used at the bidirectional ports for a separation of the signal components). The channel emulator afterwards manipulates the signal in a predefined manner. This includes the addition of fast fading effects as well as shadowing and Doppler shifts due to mobility in the scenario. Furthermore, it adds different kinds of interference and noise (for example Additive White Gaussian Noise (AWGN)) to the used signal. A fixed SNR can be set and the emulator calculates the needed noise power based on the measured input power for ensuring this SNR. A

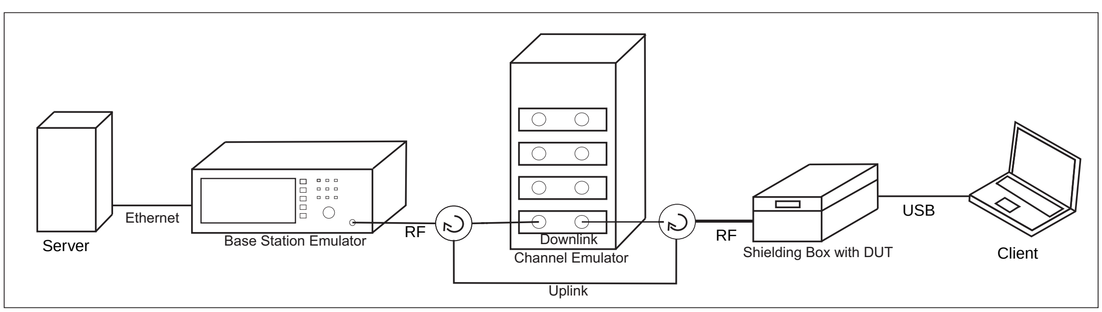


Fig. 2: Measurement setup for bidirectional performance testing

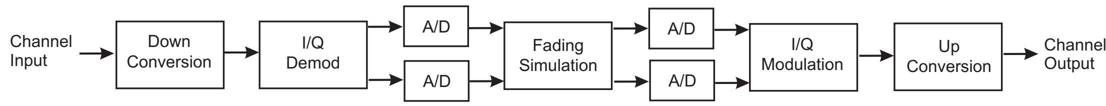


Fig. 3: Real-Time radio channel emulation in detail

method how to estimate the SNR in a real OFDM system in shown in [13]. All of these manipulations are performed in the digital base band which allows for a perfect repeatability of the measurement with exactly the same channel conditions. A detailed illustration of the method of operation can be found in Fig. 3.

The DUT is remote controlled by a client PC via USB. Due to the fact that the setup is bidirectional a real standard conform radio connection between the BSE and the DUT is established. Therefore, the uplink and downlink channel can be individually manipulated by the channel emulator. For the results presented in Sec. V of this paper only the downlink path of the signal was manipulated by the channel emulator (see Fig. 2).

For application testing we connect the BSE to an Ethernet based network in which different applications (such as for example iPerf or a video streaming server) are executed on a server. This allows for real End-to-End testing between the server and the connected client.

IV. Measurement Campaign

One key benefit of modern communication systems is that they allow for data links even at higher velocity. Nevertheless, it is a major challenge to evaluate this feature in a quantitative manner in real world measurement campaigns. The hybrid measurement approach described in Sec. III allows for such an investigation in a controlled laboratory environment.

For the emulation of the mobile radio channel the ITU channel models Vehicular A, Vehicular B and Pedestrian B are used for the downlink channel. While the A-type models for vehicular and pedestrian scenarios cover the case of a relatively small delay spread, the B-type models represent worse case characteristics of the channel [14]. Table II shows the parameterization of the models.

For the channel emulation ”Classical” fading models are used. They make use of the Rayleigh amplitude distribution and Jakes-Doppler spectrum. The Rayleigh probability density function p_{Ra} of amplitude r is given by [15].

$$p_{Ra}(r) = \frac{r}{\sigma^2} exp\left(-\frac{r^2}{2\sigma^2}\right)$$

σ^2 is the variance of both the real and imaginary components of the signal alone. In the classical model all incident angles are assumed to occur equally, leading to the normalized Doppler power spectrum formula defined below $S(f)$ [15].

$$S(f) = \frac{1}{\pi f_d \sqrt{1 - \left(\frac{f}{f_d}\right)^2}}$$

f_d is the maximum Doppler frequency shift depending on the carrier frequency f_c, the speed of light c, the velocity of the user v and α as the azimuth angle between the mobile user and the incoming radio wave.

$$f_d = f_c \cdot \frac{v}{c} \cdot cos(\alpha)$$

From the Doppler shift the influence of mobility is introduced to the channel transfer function and therefore impacts the transmitted Mobile WiMAX signal. In the measurement campaign the ITU channel model, the user velocity and the SNR of the AWGN are modified. The parameterization of the Mobile WiMAX base station emulator is given in Table I.

For the evaluation of the downlink performance a UDP transmission was performed with 10,000 - 100,000 packets for each modulation and coding scheme and simulated SNRs from 0 dB to 30 dB in steps of 2.5 dB. The observed connection is a bidirectional link between base station and UE. As the downlink should be analyzed the resulting parameters are the PER and the data rate from the downlink signal.

V. Results

For the UDP downlink measurement results a QoS target PER of 1 % is assumed. For this QoS target packet error rate the PER for different channel models can be found in Fig. 4. If more than one MCS at a specific SNR can achieve the QoS target PER the MCS with the highest data rate is taken. We see that for the Vehicular B channel model with 60 km/h and 120 km/h the QoS target PER cannot be achieved independent of the SNR. For the Vehicular A model with 120 km/h only the QPSK with $R = \frac{1}{2}$ fulfills the QoS target PER. Hence, there is no switching point in contrast to the Vehicular A channel model with 60 km/h and the Pedestrian B model with 3 km/h.

TABLE II: ITU channel models used [14]

Tap	**Vehicular A**		**Vehicular B**		**Pedestrian B**		Doppler Spectrum
	Relative Delay [ns]	Average Power [dB]	Relative Delay [ns]	Average Power [dB]	Relative Delay [ns]	Average Power [dB]	
1	0	0.0	0	-2.5	0	0	Classic
2	310	-1.0	300	0.0	200	-0.9	Classic
3	710	-9.0	8 900	-12.8	800	-4.9	Classic
4	1 090	-10.0	12 900	-10.0	1 200	-8.0	Classic
5	1 730	-15.0	17 100	-25.2	2 300	-7.8	Classic
6	2 510	-20.0	20 000	-16.0	3 700	-23.9	Classic

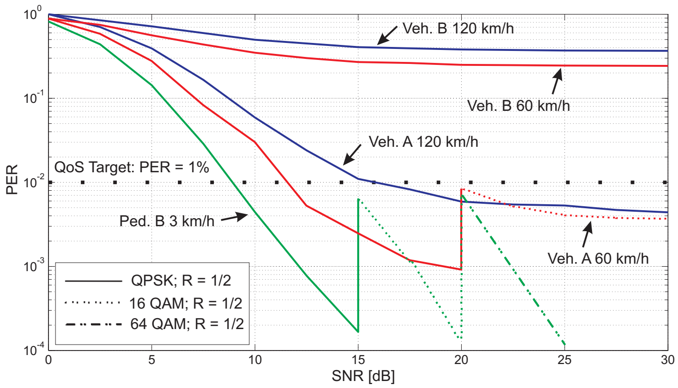


Fig. 4: PER vs. SNR for different channel models. MCS chosen for a QoS target PER of 1 %

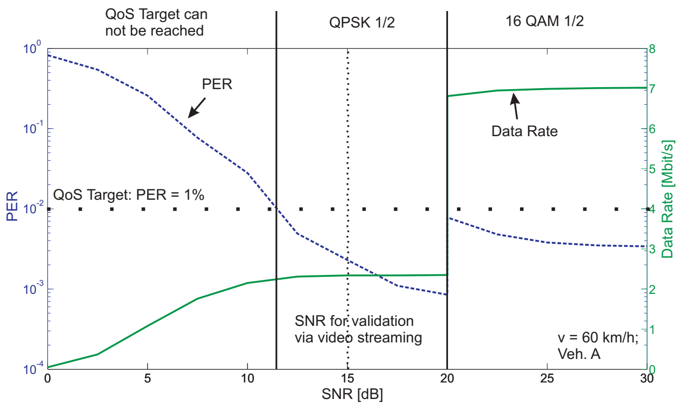


Fig. 5: PER and data rate vs. SNR for a Vehicular A channel model with 60 km/h. MCS chosen for a QoS target PER of 1 %

For these two models more than one MCS allow for a PER of 1 %. It can be seen, that the ideal switching points are strongly dependent on the channel model or rather on the channel environment. If a PER of 0.1 % should be achieved a more conservative AMC is needed. For example for a Pedestrian B channel model with 3 km/h a change from QPSK with $R = \frac{1}{2}$ to 16 QAM with $R = \frac{1}{2}$ is suitable for 20 dB SNR instead of 15 dB for a target PER of 1 %.

A more detailed analysis with regard to the relationship between the PER and the data rate can be found in Fig. 5 and Fig. 6. For a Vehicular A channel model with 60 km/h the QoS target PER cannot be achieved for any MCS for an SNR of less than 11 dB. For an SNR between 11 dB and 20 dB only a QPSK with $R = \frac{1}{2}$ fulfills the requirement of a PER of less than 1 %. The data rate for this robust MCS is with 2 Mbit/s relatively low. For an SNR above 20 dB also the 16 QAM with $R = \frac{1}{2}$ fulfills the target. Hence, the data rate increases to 7 Mbit/s.

We validated the results via an End-to-End video streaming application (Darwin Streaming Server [16], H.264 and Real-Time Streaming Protocol (RTSP) with UDP) with a data rate of 1.1 Mbit/s. For a Vehicular A channel model with 60 km/h and a SNR of 15 dB we propose a QPSK and $R = \frac{1}{2}$ (see Fig. 5). For this MCS a good video quality can be achieved (see

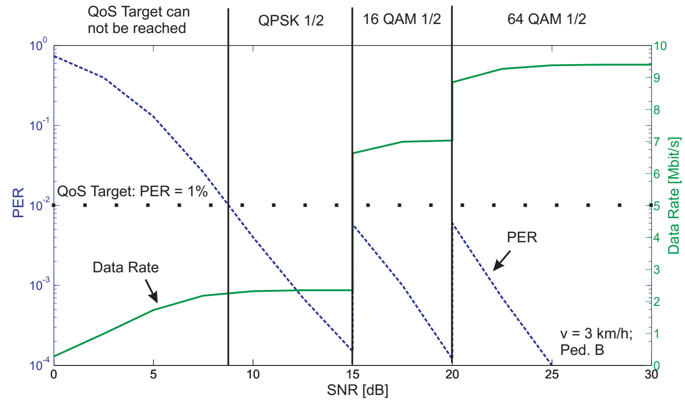
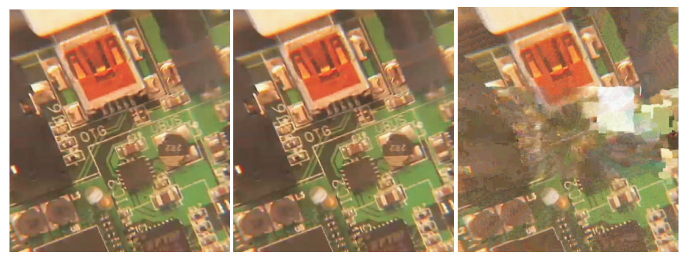


Fig. 6: PER and data rate vs. SNR for a Pedestrian B channel model with 3 km/h. MCS chosen for a QoS target PER of 1 %



(a) Original (b) QPSK and $R = \frac{1}{2}$ (c) 16 QAM and $R = \frac{1}{2}$

Fig. 7: Video quality for a Vehicular A channel model with 60 km/h and SNR of 15 dB

Fig 7). In contrast to that, for a 16 QAM and $R = \frac{1}{2}$ artifacts can be seen.

For the ITU Pedestrian B channel model which describes a typical outdoor to indoor and pedestrian test environment the PER and data rate are illustrated in Fig. 6. Due to the lower velocity the channel conditions are better than for an ITU Vehicular A channel with 60 km/h. Hence, the QoS target PER can be achieved for MCSs with a higher spectral efficiency. Therefore, a data rate of up to 9.4 Mbit/s can be achieved for an SNR of 25 dB and the QoS target PER of 1 %. For the same target and the same SNR the data for a Vehicular A channel model with 60 km/h is only 7 Mbit/s (see Fig 5).

The data rate for an optimization of the MCS towards a maximum throughput for different channel models can be found in Fig. 8. The data rate is measured in steps of 2.5 dB. Therefore, the curves for the data rate jump if the optimum switching point is not exactly one of the measured samples but lies between two measurement points. We see that there is a major different between different channel models in terms of achievable throughput and PER (see Fig. 8). From this one can conclude, that for a good AMC it is very important to know the channel environment. However, not only the environment plays a major role. For maximizing the data rate it is suitable to change the MCS for a Vehicular A channel model with 60 km/h at an SNR of 20 dB from 16 QAM with $R = \frac{1}{2}$ to 64 QAM with $R = \frac{1}{2}$. However, for the same channel model with 120 km/h the change to the 64 QAM with $R = \frac{1}{2}$

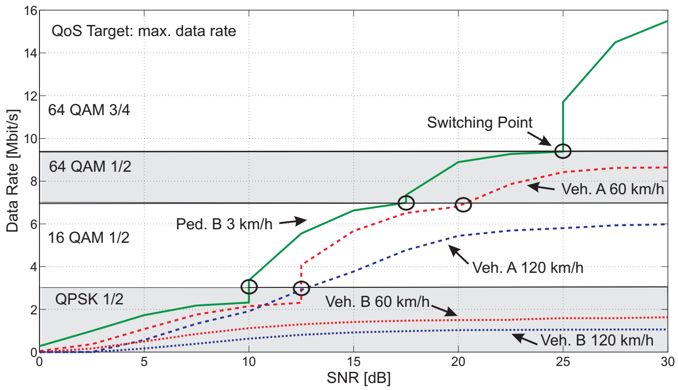


Fig. 8: Date rate vs. SNR for different channel models. MCS chosen for the QoS target maximum data rate

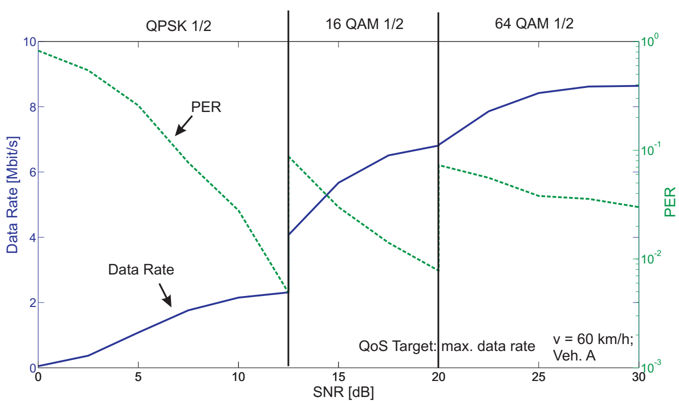


Fig. 9: Date rate and PER vs. SNR for a Vehicular A channel model with 60 km/h. MCS chosen for the QoS target maximum data rate

is not reasonable for an SNR up to 30 dB. This means that the suitable choice of a MCS for the same fading channel characteristics is strongly dependent on the user velocity, too.

A detailed presentation of the correlation between the data rate and PER for a Vehicular A channel model with 60 km/h is shown in Fig. 9. The drawback of optimization towards the highest data rate is a high PER. For most of the SNR the PER is higher than 1 %.

An example shows that for an SNR of 25 dB a data rate of 8.1 Mbit/s can be achieved if the MCS which allows for the highest data rate (64 QAM with $R = \frac{1}{2}$) is chosen. Assuming this constellation the PER is $3 \cdot 10^{-2}$. For the same channel conditions and a QoS target of less than 1 % PER the data rate is 7 Mbit/s (see Fig. 5; 16 QAM with $R = \frac{1}{2}$) with a PER of $4 \cdot 10^{-3}$. This means an optimization towards the highest data rate provides an enhancement of around 16 % but with the costs of a 7.5 times higher PER.

For a Pedestrian B channel model with 3 km/h a data rate of up to 15.5 Mbit/s for an SNR of 30 dB can be achieved (see Fig. 10). If the SNR is higher than 25 dB the maximum data rate is achieved via a 64 QAM and $R = \frac{3}{4}$.

The relationship between the user velocity and the optimal AMC switching point for different QoS targets and a constant SNR of 30 dB is illustrated in Fig. 11 and Fig. 12. It can be

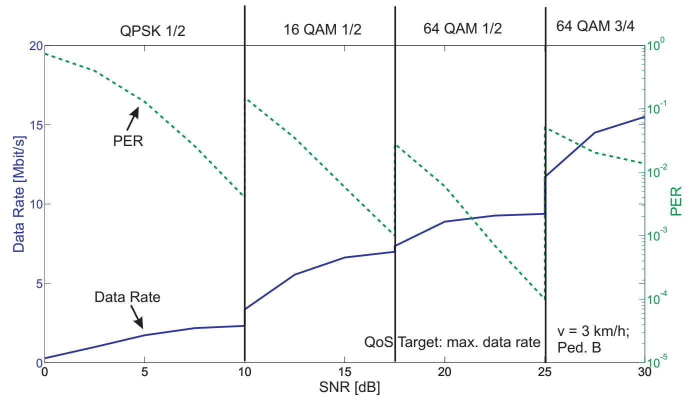


Fig. 10: Date rate and PER vs. SNR for a Pedestrian B channel model with 3 km/h. MCS chosen for the QoS target maximum data rate

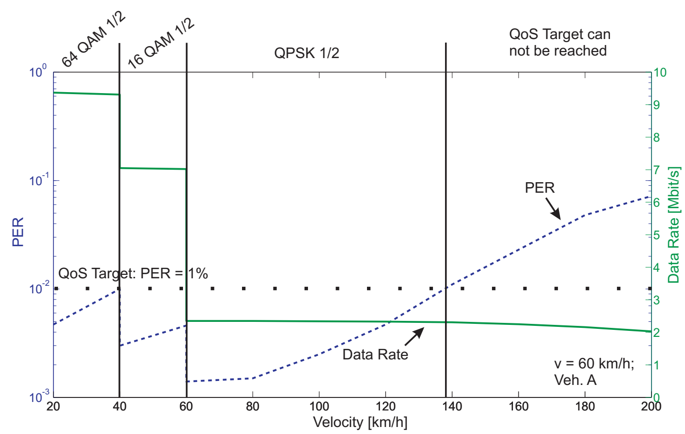


Fig. 11: PER and data rate vs. velocity for a Vehicular A channel model with 60 km/h and a constant SNR of 30 dB. MCS chosen for a QoS target PER of 1 %

seen, that for a QoS target PER of 1 % the QPSK with $R = \frac{1}{2}$ has to be chosen for a velocity above 60 km/h to achieve the PER target (see Fig. 11). For a velocity above approximate 140 km/h the QoS target cannot be fulfilled. In contrast to that a 16 QAM with $R = \frac{1}{2}$ is suitable for velocities up to 200 km/h to maximize the data rate. With these observations it is obvious, that the switching points and therefore the data rates are dependent on the QoS target and the user velocity. For a QoS target PER of 1 % and a velocity of 120 km/h the data rate is 2.3 Mbit/s. For the same conditions a maximum data rate of 6 Mbit/s can be achieved with the drawback of the PER of 7 %. This means that the data rate can be more than doubled if there is no PER restriction.

We have shown that the choice of an ideal MCS is strongly dependent on the QoS target, the channel environment, the user velocity and the SNR:

$$\text{MCS} = f(\text{QoS target}, \text{channel environment}, \text{velocity}, \text{SNR})$$

A list of all ideal switching point for different QoS targets can be found in Table III. There is a significant difference between the switching points. For example a change from

TABLE III: Ideal switching points for different QoS targets

QoS target	**1 % PER**				**Maximum data rate**			
Model	**Veh. A**		**Ped. B**	**Veh. A (SNR=30dB)**	**Veh. A**		**Ped. B**	**Veh. A (SNR=30dB)**
Velocity	60 km/h	120 km/h	3 km/h	20-200 km/h	60 km/h	120 km/h	3 km/h	20-200 km/h
QPSK 1/2	SNR=12.5dB	SNR=17.5dB	SNR=10dB	v=120km/h	SNR=0dB	SNR=0B	SNR=0	v>200km/h
QPSK 1/2 → 16QAM 1/2	SNR=20dB	-	SNR=15dB	v=60km/h	SNR=12.5dB	SNR=12.5dB	SNR=10dB	v>200km/h
16QAM 1/2 → 64QAM 1/2	-	-	SNR=20dB	v=40km/h	SNR=20dB	-	SNR=17.5dB	v=100km/h
64QAM 1/2 → 64QAM 3/4	-	-	-	-	-	-	SNR=25dB	v=60km/h

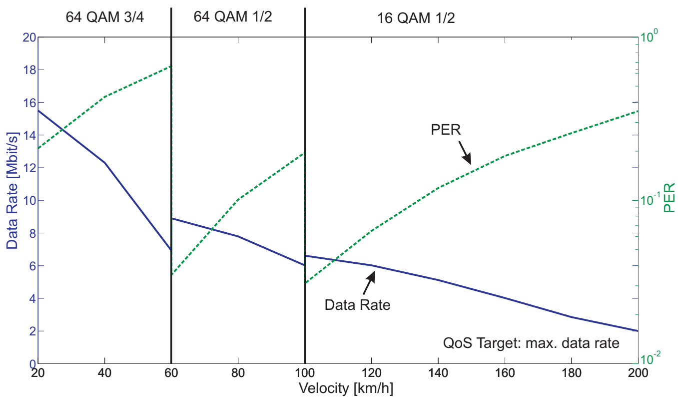


Fig. 12: Data rate and PER vs. velocity for a Vehicular A channel model with 60 km/h and a constant SNR of 30 dB. MCS chosen for the QoS target maximum data rate

QPSK with $R = \frac{1}{2}$ to 16 QAM with $R = \frac{1}{2}$ varies between 10 dB and 20 dB SNR. We also measured the data rate and PER for a QPSK with $R = \frac{3}{4}$ and a 16 QAM with $R = \frac{3}{4}$. However, these MCSs are not reasonable for the analyzed QoS targets. This means that for fading channels and high user mobility the choice of a strong coding scheme is more important than the choice of a robust modulation scheme.

VI. Conclusion

In this paper, we have shown a method to evaluate the performance of OFDM communication systems under realistic channel conditions in a laboratory environment. Thereby, a measurement setup based on a radio channel emulator and a base station emulator together with typical commercially available user devices is used.

As main issue we analyzed the performance of Mobile WiMAX for Adaptive Modulation and Coding (AMC) dependent on the QoS target, the channel model, the user velocity and the SNR. Hereby, we assumed two QoS optimization targets, high data rate and target PER. It could be shown, that the optimal switching points for AMC and therefore the maximum data rate and the achieved PER is strongly dependent on the speed-dependent channel conditions but also on a given QoS target. For example it is possible to double the data rate if there is no PER restriction in contrast to an QoS target PER of 1 %.

Acknowledgment

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