# Performance Evaluation for Mobile WiMAX Handover with a Continuous Scanning Algorithm

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***Abstract*—With the IEEE 802.16e standard for Mobile WiMAX the course for new 4G mobile radio communication systems is set. It offers significantly higher data rates than GSM or WCDMA/UMTS and supports different handover mechanisms and QoS features in contrast to WiFi (IEEE 802.11g) on the OSI-layer 2 (L2). Since WiMAX-devices are hardly available today and protocol optimizations are strongly restricted with commercially available devices, a simulation model is not far to seek. Thus, we developed and implemented a simulation in OMNeT++ based on the INET framework in order to investigate and evaluate the performance of the new Mobile WiMAX protocol.**

**In this paper we particularly focus on the handover performance on OSI-Layer 2 (L2) for noise affected channels. Beyond the standardized handover we propose a sliding window mechanism for the channel measurements the handover decision is based on. Ultimately a performance evaluation demonstrates the reduction of handover delay for certain noise levels by introducing a continuous scanning process.**

## I. Introduction

First Mobile WiMAX (IEEE 802.16e) devices will be commercially available in the near future. In contrast to known 3G cellular technologies new capabilities concerning quality of service (QoS), bandwidth allocation or hybrid automatic repeat requests (HARQ) slip into the new standard. Since Mobile WiMAX is a fully IP based approach the handover algorithms and underlying architectures have been basically redesigned. Hence, performance measurements and protocol evaluations are an emerging research topic. In particular the intrinsic IEEE 802.16e interdependencies between handover mechanisms and QoS schemes are a prominent research field and need further investigation.

Handover support in Mobile WiMAX is designated both on OSI-Layer 2 (L2) and layer 3 (L3). The L2-handover is also known as micro mobility handover or intra-ASN-handover, that is performed within a single access service network (ASN) according to the Mobile WiMAX reference network model Enabled by Mobile IP the L3-handover is required for a handover between different ASN within a connectivity service network (CSN). Thus, the L3-handover is also known as macro mobility handover or inter-ASN-handover using MobileIP with a home agent in the CSN [4].

Quite apart from the fact that MobileIP is not part of the IEEE 802.16e standard, we focus in this paper on the L2-handover analysis using an extensive IEEE 802.16e implementation in OmNET++ [6] and the INET framework [7] according to the Mobile WiMAX reference model. Next to real world measurements as described in [3] further protocol development is easier and more comfortable with a simulation tool. Those allow for fast parametrization and are additionally flexible with respect to modifications on the algorithm. According to our present knowledge there are still no MAC-Layer implementations for OmNET++ available.

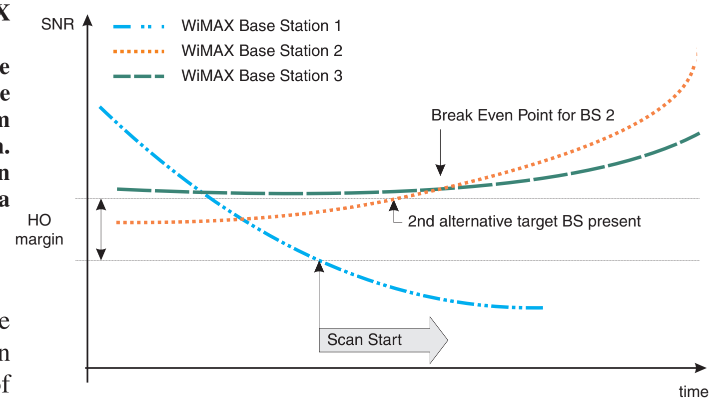



Fig. 1. Motivation for Continuous Base Station Scanning

The IEEE 802.16e handover decision is based on channel measurements during a scanning period and is initiated when a SNR-threshold is reached (Fig. 1). The subscriber station (SS) sweeps on different frequencies for a suitable target base station (BS). Typically the first detected BS with the higher SNR is suggested as the new target BS for the handover request as shown for BS 3 in Fig. 1. But the first choice is not the best one since a BS 2 appearing a short time later stays fully unconsidered though the SNR is sustainable higher (see Fig. 1). Behind the break even point BS 2 is the optimal target BS. The problem outlined here is not solved with the introduction of a handover margin as by means of this only ping pong handover can be avoided. Subsequently, the conventional scanning schemes cannot guarantee an optimal choice of a target BS. This becomes certainly probable when noisy transmissions have to be assumed.

It is intended to use Mobile-WiMAX in the context of the networking of avionic robots hosting various sensors to provide real-time measurements to enable the optimization of emergency response actions (see [1]). The networking of these highly dynamic mobile clients requires high performance handover capabilities.

In this paper, we propose handover protocol improvements for AWGN and slow fading affected channels by introducing a continuous scanning with a sliding window for the SNR mean value calculation. The algorithm does not require any modifications to the existing standard. The paper is organized as follows: We start with a short overview about the related work in section II. Section III covers our concept for the improved handover algorithm. The developed IEEE 802.16e simulation architecture and implementation are provided in section IV. Then we will briefly discuss the assumed properties of the physical layer (PHY) in section V considered in the simulation framework. A clustered network topology and simple mobility model are outlined for the further analysis in section VI. Based on the presented methodology, we will delve into the handover process and handover performance evaluation in section VII.

## II. Related Work

Many research activities have been carried out concerning the handover topic in wireless cellular networks. But to this day only a few investigations have been made with respect to the specific IEEE 802.16e standard such as described in [8][9]. But preliminary findings do not sufficiently enlarge upon the scanning algorithm in Mobile WiMAX. In [10] several aspects of IEEE 802.16e operation such as ranging, authorization, and registration are taken into consideration. A special capability built into the proposed algorithm is service-flows awareness, i.e. the algorithm tries to minimize the time spent in handover based on the service flows running at the subscriber station. The scanning process in [10] has been implemented in detail according to the standard but the SS simply selects those BSs whose RSSI value is higher than a minimum threshold plus a hysteresis value (handover margin). Since the focus lies on the interaction between service flow and handover management no novel contributions regarding the scanning mechanisms are made. A group-based scanning scheme is presented in [11], in which grouping of subscriber stations by signal strength reduces the number of channels to scan so that fast scanning is achieved. To enhance the performance of the group-based scanning scheme, a dynamic neighbor base station list is proposed. Sliding window scanning schemes as provided in this paper have not been analyzed yet.

## III. Improved Handover Algorithm

This section describes our contribution to a optimized handover-algorithm for Mobile WiMAX. Major parts of the handover implementation are left to the operator or vendors. This includes the parametrization of timing intervals that are predefined and announced by the BS using broadcast messages. Particularly frame durations and scanning intervals are modifiable parameters. Channel measurements and estimations are furthermore not specified in detail. Thus, an optimization of handover algorithms is even possible according to the standardized IEEE 802.16e.

Due to the time variant channel properties, the network topology and the stochastic traffic behavior of the user, it is not possible to postulate a simple formula for evaluating the handover performance. This makes a simulation indispensable, which addresses the following requirements on a handover-algorithm:

- No noticeable handover delays or gaps (quality of user experience)
- No unnecessary ping ping handover in the overlapping cell areas
- Handover should be preferably performed at defined cell-edges

Our proposed handover-algorithm is implemented within the subscriber stations control plane (mobile station initiated handover). The algorithm may be divided into two subprocesses.

- scanning for DL channels of neighbored cells to find a adequate target BS
- handover signaling process and handover decision

### A. Scanning-algorithm and Threshold

The scanning procedure in the IEEE 802.16e protocol is designed as a periodical scanning. But a steadily periodical scanning decreases the mean data rate. Thus, we considered the periodical scanning to be active only where SNR thresholds are undershotted. Typically scanning procedures are conducted within the overlapping area of two BS.

When the fading SNR reaches the scanning threshold the SS begins with scanning process on the announced DL channels by sending the `MOB-SCN-REQ` message. The BS allows for scanning by replying with the `MOB-SCN-RSP` message, that contains the parameters for scan duration $N$, interleaving interval $P$ and the start frame $M$ (see Fig. 2). After receiving the `MOB-SCN-RSP` management-message from the target BS, the SS starts the scanning after $M$ received frames (start frame). The SS changes after $M$ frames to the next channel and stays there for a $N$ frames period (scanning interval/duration) to detect a BS and to assess its SNR. After a scanning interval the SS returns to the DL channel of the active BS. This behavior is meaningful in order to keep the interruption as short as possible since no payload transmissions are possible during the scanning process. If no preferable BS could be detected on the scanned channel, it reinitiates the scanning mode after a $P$ frames period (interleaving interval) to find a new BS. The total number of allowed repetitions of the scanning process is given with the parameter $T$.

### B. Sliding Window Enhanced Handover algorithm

For initiating a handover the SS needs information about the configuration of the neighboring target BS. These information are delivered by the the serving BS with the network topology advertisement message `MOB-NBR-ADV`. The `MOB-NBR-ADV` message contains information as it can be usually found in the DCD and UCD messages. Hence, the SS is able to synchronize to the new target BS before receiving the DCD and UCD messages from the target BS.

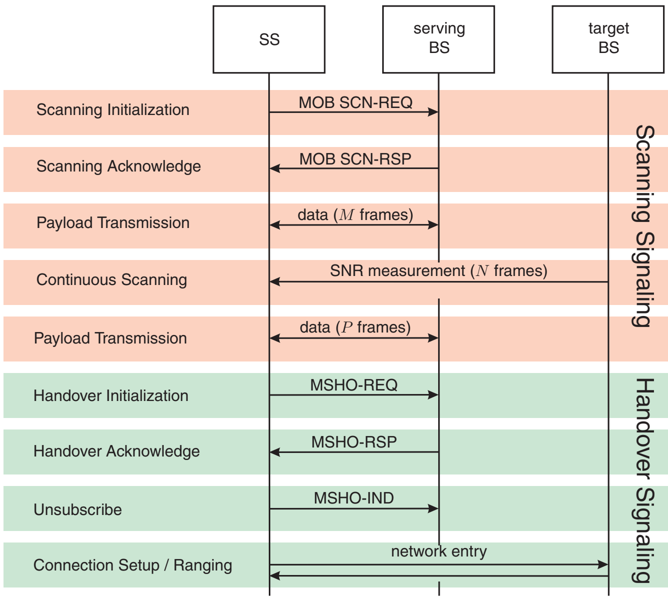



Fig. 2. Scanning and Handover process in Mobile WiMAX

The considered handover algorithm is based on signal-strength measurements based on the SNR. The handover can only be assessed within the overlapping area of two radio cells. Within this area the mobile station may build up a radio contact to both BS. The SS compares the SNR of the serving BS with the SNR of the scanned target BS. The SS initiates the handover with the `MOB MSHO-REQ` message, that contains a line-up about the scanned BS that are suitable as a target BS. The serving BS answers with the `MOB MSHO-RSP` message and advices a destination BS, which is acknowledged with a `MOB HOIND` message by the SS, if the handover is still needed and suitable. Otherwise the SS replies with a negative `MOB-HOIND` message and the handover process is started again. With a positive `MOB-HOIND` the SS leaves the old serving BS and registers at the selected target BS.

The SNR measurements and decision algorithms consider a handover margin (hysteris) in order to avoid ping pong handover. Besides the handover margin, a sliding mean value is calculated from the received SNR values. This sliding window mechanism compensates slow fading interruptions, that otherwise lead to an inefficient choice of BS, e.g.

- missed possible handover opportunity *or*
- late handover decision and initialization.

The effect of an adapted scan durations is discussed later on in section VII with respect to varying frame durations.

## IV. Mobile WiMAX Simulation Architecture

In this section the general structure of the proposed IEEE 802.16e implementation in OMNeT++ will be presented and set into relationship to existing technologies like the INET framework. The INET framework yields several building blocks to simulate typical internet traffic like TCP, UDP, IP and several other lower layered traffic types like IEEE 802.11 and Ethernet. The simulation is built up strongly modular according to the INET interface architecture. The advantage of this concept lies in the simple feasibility of integrating different or new lower layer protocols where a simple exchange of the PHY profile, channel model, network topology or mobility model is possible. Building on this concept the proposed solution supports the most important functionalities of the Mobile WiMAX protocol. In contrast to IEEE 802.11 the MAC layer of the IEEE 802.16e standard consists of the following three layers as depicted in figure 3

- The *Convergence Sublayer (CS)* manages necessary adaptations for higher level protocols. It is also responsible for QoS traffic classification and the mapping of connection oriented transmission concepts.
- The *MAC Common Part Sublayer (MAC CPS)* manages the classical tasks of the MAC layer. This includes traffic control, bandwidth management, connection management, handover and MAC layer signalling.
- The *Security Sublayer* is repsonsible for authentication and data encryption. The implementation of this layer in OMNeT++ is considered to be an area of future research.

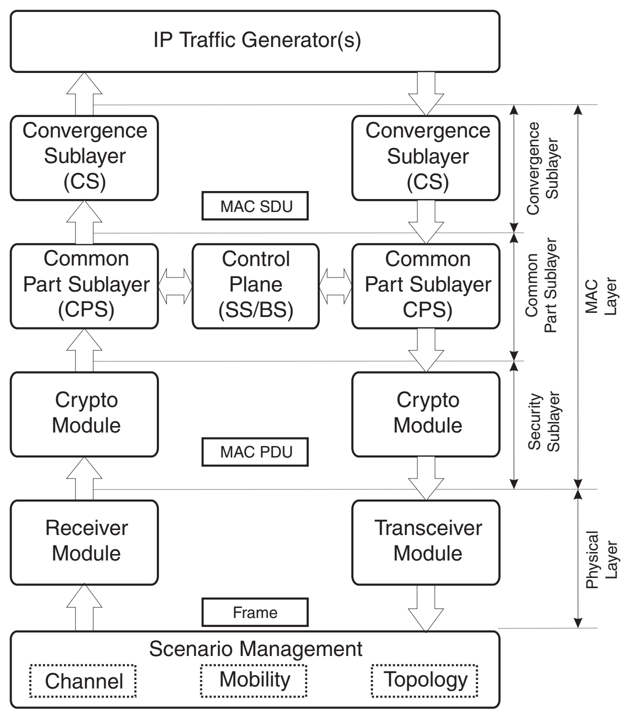



Fig. 3. Mobile WiMAX Simulation Architecture

For each layer of the IEEE 802.16e protocol a module has been implemented that is responsible for processing data packets from upper or lower layer and for forwarding this data to the opposite layer. The division of the functionality into transfer directions allows the simulation to operate in

FDD mode. The MAC CPS uses an additional module to support an easy distinction between the base station and subscriber station functionality. This is necessary because the IEEE 802.16e functions in the MAC CPS differ for mobile and base station. The proposed handover algorithm is implemented in the control plane module of our simulation.

## V. Mobile WiMAX PHY and Channel Model

Different physical layer (PHY) - profiles are defined in the IEEE 802.16e standard (modulation, coding, duplex mode, multiplex mode, etc.) in order to address the heterogeneous and region specific requirements of vendors and network operators. Some properties may be configurated in a simulation as a parameter, e.g. the RX and TX power or the frequency. On the other hand a design decision is required for the simulation architecture in order to determine the duplex (TDD/FDD) and multiplex mode. In our contribution a single carrier (SC) and FDD mode will be considered. Since we are mostly interested in the protocol performance and its improvement a OFDM(A) is not indispensable from our point of view. The TDD mode can be easily adopted by introducing receive and transmit time gaps (RTG/TTG) working on the SC in FDD mode.

For this reason, we approximated the physical layer with the standard INET radio module. This module has implemented a single carrier transmission but neither dynamic adaption of the modulation scheme nor an adaptive bitrate. This leads to the consideration of the following parameters:

- channel number,
- transmit power,
- bit rate and
- position of sender and receiver.

For the bandwidth $B = 7MHz$ and for the temperature $T = 290K$ is assumed. The foundation of the overall calculation is the sum of the path loss and slow fading effects

$$L = L_m + L_a \tag{1}$$

The path loss is calculated with the recommended formula from *ITU m.1225* for vehicular testing environments:

$$\begin{aligned} L_m =& 40 \cdot (1 - 4 \cdot 10^{-3} \Delta h_b) log_{10} R \\ & - 18 \cdot log_{10} \Delta h_b + 21 \cdot log_{10} f + 80dB \end{aligned} \tag{2}$$

where

$R$ : base station - subscriber station distance (km)

$f$ : carrier frequency

$\Delta h_b$ : base station antenna height (m) above rooftop level

The slow-fading effects are modeled as a logarithmic scale around the mean path loss $L_m(dB)$. It is characterized by a log-normal distribution with zero mean and a variable standard deviation $\sigma$ in our simulations as we explain later on. The used density function of the log-normal distribution is given with

$$f_l(m) = \frac{1}{\sqrt{2\pi\sigma^2}x} exp\left(\frac{-(lnx - \mu)^2}{2\sigma^2}\right) \tag{3}$$

## VI. Network topology and Mobility Model

For our investigations of the handover-performance a cellular network of consisting of seven basis stations is considered as shown in figure 4. These build a cluster of the size seven $BS_i (i = 1 \dots 7)$ that are positioned homogeneously in the topology. Each of the basis stations uses disjunct channels for the UL and DL (FDD mode). The overlapping width $O$ describes the maximum distance in the elliptic overlapping area. This is correlated with the maximum TX power of each BS.

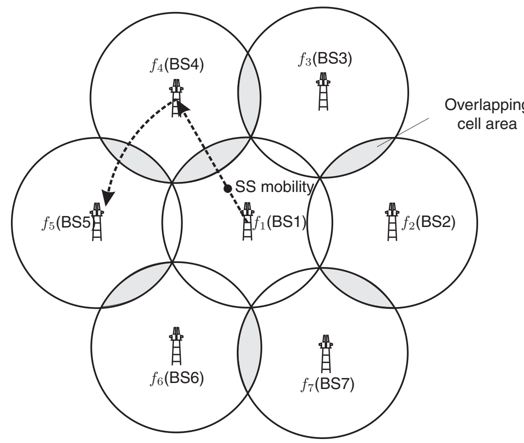



Fig. 4. Network Topology and Mobility Model for Handover Analysis

The mobility model is represented by a a single subscriber station that moves linearly from the center cell to a randomly chosen cell and afterwards in a circle through all cells at the edge of the cluster. At each received airframe SNR measurements are conducted in order to estimate, whether a handover is indicated or not. Figures of merit are the handover processing delay, scan duration and throughput with respect to varying frame durations and channel properties.

## VII. Results: Handover Performance Evaluation

### *A. Effect of Frame Duration and Scan Interval on the HO Delay*

An exemplary handover process with its periodical scanning intervals is shown in fig. 5(a). The scanning process starts, when the serving BS SNR at the receiver reaches the defined threshold. Then scanning intervals and data transmissions alternate until a target BS is found in the topology. The SS comes back for last payload transmissions and handover signaling before it registers at the new target BS. The preferred target BS is chosen on the basis of a mean value which is calculated from multiple channel measurements within the sliding window interval.

When the SS sweeps for DL channels of neighbored BS, it has to interrupt the active transmission. The influence of the scanning interval is shown in fig. 5(b) for varying frame durations $T_f = \{2ms, 5ms, 10ms, 20ms\}$ at a scan interval of $N = 1$. Due to the time variant noise on the channel, the frames can be corrupted within the scanning phase, which leads to a longer scanning period. The data rate decreases with a higher frame duration, but never breaks completely down since the SS returns periodically to the serving BS for temporarily payload transmissions. The maximum loss in data rate is 36% for $N = 1$. It has to be noted, that the overall data rate of the used traffic generator has been set to $128kbit/s$ for simulating a speech encoded transmission with G.711.

Fig. 5(c) shows the overall handover delay for shortest possible frame duration of $2ms$ for different scanning intervals. The part of the initial ranging process (network entry) and the handover process as described before add a constant delay to the overall process. The impact of the handover itself is low in comparison both to the network entry, which is performed after the handoff, and the overall scan duration. The scan duration depends plausible linearly on the the choice of the scan interval $N$. The higher the scan interval, the higher is the overall handover delay. Fig. 6(a) shows the handover delay for all different frame durations $T_f$ and increasing scan durations $N$.

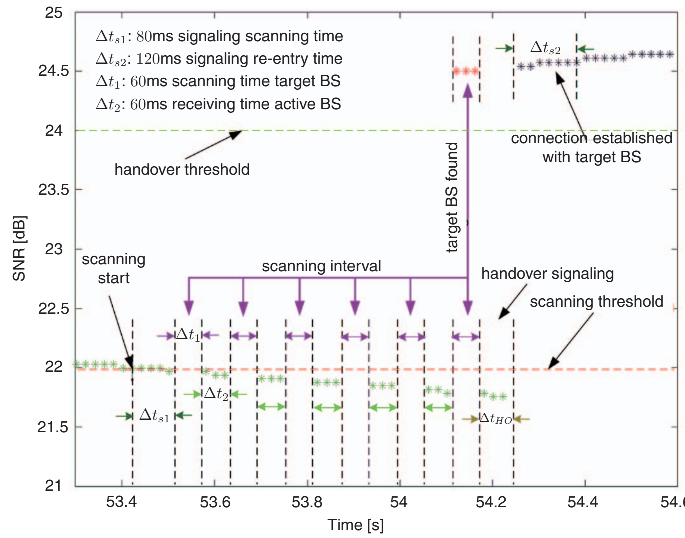
### B. The Effect of the Sliding Window on the HO Delay

The channel characteristic has got a major impact on the handover decision process. Thus, we introduced an log-normal channel to the simulation as described in section V. Fig. 6(b) shows the overall handover processing delay for an log-normal channel with a standard deviation of $\sigma = 0.75dB$ for the noise. The significant effect of the proposed sliding window can be seen for a length of $N = 8$. The handover delay for is $N = 8$ is shorter, than for $N = 1$ although the SS needs more time for the scanning process. The reason is that the reliability regarding the quality of the selected target BS increases the better the mean value for the SNR measurements is. If a DL channel has only be scanned once, the probability is very high that the selected target BS is not suitable in reality and the scan process has to be repeated several times. The 95% confidence intervals shown in fig. 6(b) are determined with a student's t-distribution for 20 samples with $t(1-\frac{a}{2}; N-1) = t(0.95; 19)$.

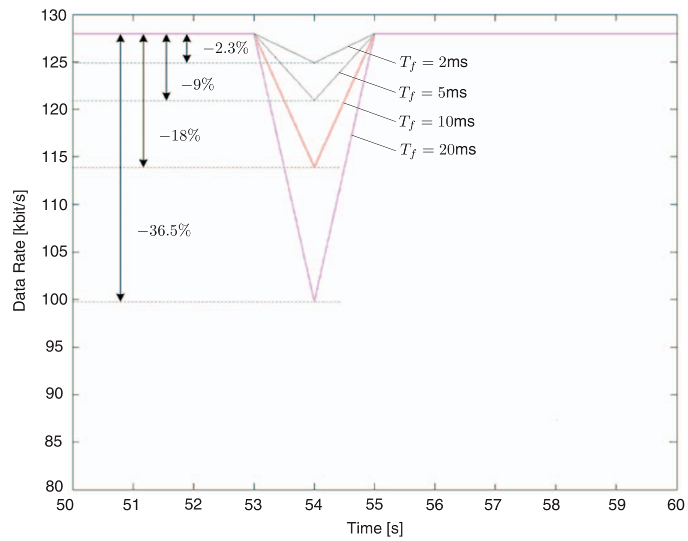
The optimization with the sliding window is shown in Fig. 6(c) for different standard deviations $\sigma$ and scan durations. The improvement is easing for a standard deviation of $\sigma = 1dB$ and higher, since the channel characteristic then becomes too stochastic and the sliding mean value is not capable to compensate those fluctuations.

## VIII. Conclusions

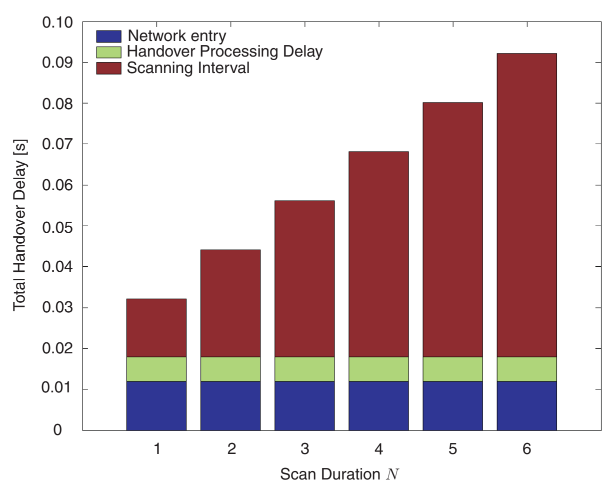
An extensive OmNET++ simulation for Mobile WiMAX (IEEE 802.16e) has been presented in this paper. The FDD/SC-simulation architecture depicts the standardized reference model with the specified protocol processes. The simulator is




(a) Continuous Scanning and Handover Decision

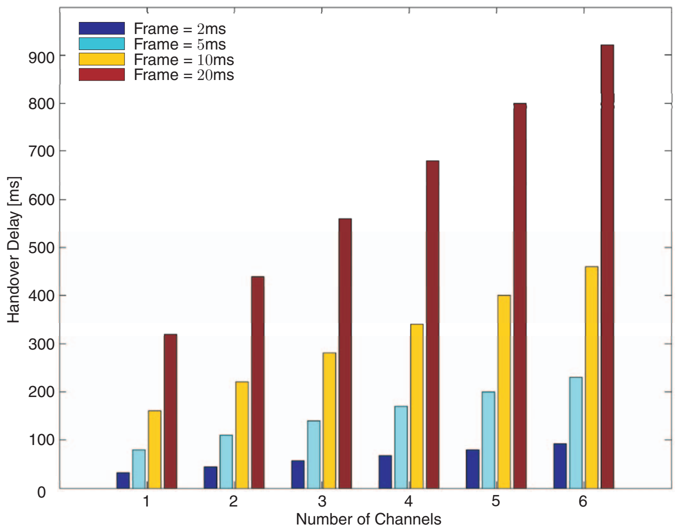



(b) Data Rate at Handover Process

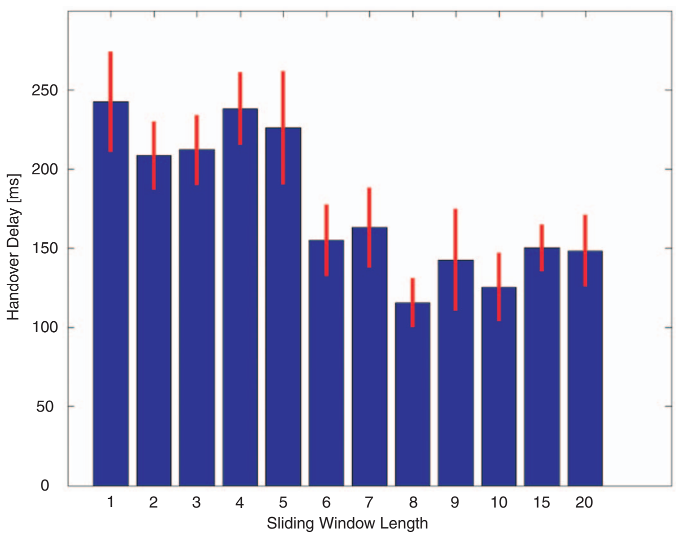



(c) Composition of Overall HO Delay

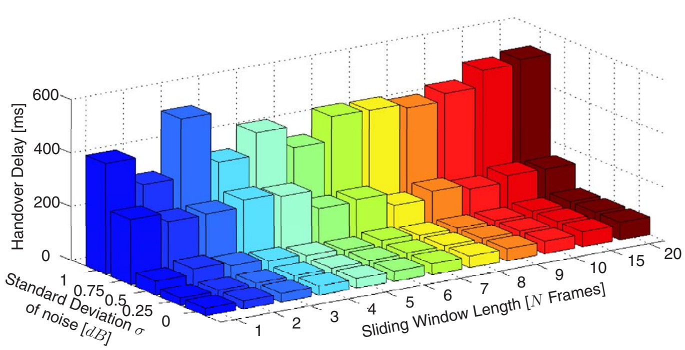
Fig. 5. Handover Delay Analysis for Free Space Propagation




(a) Handover Delay for Different Frame Durations




(b) Sliding Window Effect for a Log-Normal Channel ($\sigma = 0.75dB$)




(c) Impact of Noise and Scan Durations on the HO Delay

Fig. 6. Handover Delay Analysis

capable of mobility, hard handover and QoS. The L2-handover is detailed modelled and works on the specified WiMAX propagation loss overlayed with a slow fading lognormal-channel.

The effect of different scan durations and frame durations on the L2-handover delay for Mobile WiMAX has been shown in this paper. The handover processing delays depend linearly on the configured frame duration and amount of channels in the system. The introduction of a sliding window for the SNR measurements during the scanning process leads to shorter overall handover delays due to the higher reliability of the measurements. In future we will work on the integration of further channel models and a multiscalar integration as described in [2] in order to allow for macromobility with MobileIPv6 [4].

## IX. Acknowledgments

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## References

[1] K. Daniel, B. Dusza, A. Lewandowski, C. Wietfeld: *AirShield: A System-of-Systems MUAV Remote Sensing Architecture for Disaster Response*, IEEE International Systems Conference (SysCon), Vancouver, March 2009

[2] A. Lewandowski, R. Burda, S. Subik, C. Wietfeld: *A Multiscale Simulation Environment for Performance Evaluation of high reliable heterogeneous Communication Networks*, European Simulation and Modelling Conference (ESM), Le Havre, France, October 2008

[3] F. Z. Yousaf, K. Daniel, C. Wietfeld: *Performance Evaluation of IEEE 802.16 WiMAX Links With Respect to Higher Layer Protocols*, IEEE International Symposium for Wireless Communication Systems, Trondheim, October 2007

[4] F. Zarrar Yousaf, C. Bauer, C. Wietfeld: *An Accurate and Extensible Mobile IPv6 (xMIPV6) Simulation Model for OMNeT++*, 1st International OMNeT++ Workshop on the ACM SIMUTools Conference, Marseille, March 2008

[5] R. Rouil, N. Golmie: *Adaptive Channel Scanning for IEEE 802.16e*, Military Communications Conference, MILCOM 2006

[6] Andras Varga: The OMNeT++ Discrete Event Simulation System, Proceedings of the European Simulation Multiconference, 2001

[7] I Vari: INET Framework for OMNeT++, http://www.omnetpp.org/doc, last visited Jan. 2008

[8] S.K. Ray, A. Mandal, K. Pawlikowski, H. Sirisena: *Hybrid predictive base station (HPBS) selection procedure in IEEE 802.16e-based WMAN*, Australasian Telecommunication Networks and Applications Conference (ATNAC), December 2007

[9] B. Liu, P. Martins, P. and , A.E. Samhat, P. Bertin: *A Layer 2 Scheme of Inter-RAT Handover between UMTS and WiMAX*, Vehicular Technology Conference (VTC), September 2008

[10] H. Fattah, H. Alnuweiri, H.: *A New Handover Mechanism for IEEE 802.16e Wireless Networks*, Wireless Communications and Mobile Computing Conference, 2008. IWCMC '08. International, August 2008

[11] J. Choi, N. Hao, S. Yoo: *Fast group scanning scheme with dynamic neighbor base station list in IEEE 802.16e networks*, 8th Conference on Computer and Information Technology (CIT), July 2008