Bit Error Rate Analysis in WiMAX Communication at Vehicular Speeds Using Nakagami-*m* Fading Model

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***Abstract*—High speed wireless communication technologies such as Worldwide Interoperability for Microwave Access (WiMAX) have revolutionized the way of our day-to-day communication and opened opportunities for many innovative applications. The 802.6m version of WiMAX offers data rates up to 1 Gbps for fixed communications and supports mobility up to 350 km/h. While WiMAX technology's capacity to deliver high data rates in a fixed environment is beyond any doubt, the standard is not fully optimized yet for mobile communication at high vehicular speeds. At high vehicular speeds, rapid changes in surrounding environments, cause severe fading at the receiver, resulting a drastic fall in throughput and unless any proactive measure is taken to combat this problem, throughput becomes insufficient to support many applications, particularly those with multimedia contents. Bit Error Rate (BER) estimation is an integral part of any proactive measure and recent studies suggest that Nakagami-m model performs better for modeling channel fading in wireless communications at high vehicular speeds. No work has been reported in literature that estimates BER at high vehicular speeds in WiMAX communication using Nakagami-*m* model. In this paper, we develop and present an analytical model to estimate BER in WiMAX at vehicular speeds using Nakagami-*m* fading model. The proposed model is adaptive and can be used with resource management schemes designed for fixed, nomadic, and mobile WiMAX communications.**

***Index Terms*—WiMAX, vehicular speeds, bit error rate, Nakagami-m.**

I. Introduction

WIMAX is a popular next generation wireless technology that currently serves more than 620 million people in approximately 147 countries. WiMAX is popular for its capacity to deliver high throughput at a fixed communication environment. In a mobile communication environment at high vehicular speeds, this throughput decreases sharply, often providing a connection only service with no guaranteed data rate. The 802.16m version of WiMAX standard acknowledges this problem and indicates that the 802.16m is fully optimized for stationary and pedestrian speeds (0-10km/h) [1]. At speeds between 10-120km/h, WiMAX users experience a gradual degradation of service and at speeds above 120 km/h, only a connection can be maintained without any assurance on data rate.

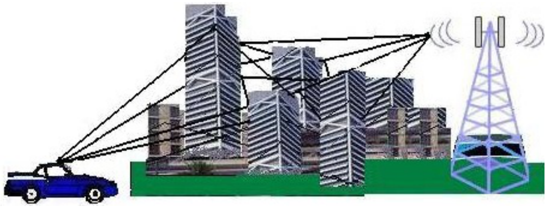

Figure 1. Multipath fading problem in wireless communication at vehicular speeds.

WiMAX standard incorporates Orthogonal Frequency Division Multiplexing (OFDM) and Orthogonal Frequency Division Multiple Access (OFDMA) [2] for achieving better spectral efficiency and data rates. The OFDM is a robust technique that overcomes the frequency selectivity problem of the channel and provides higher throughput. In OFDM systems, total bandwidth is divided into multiple sub-carriers using Fast Fourier Transformation (FFT) operation where the sub-carriers are orthogonal to each other. Sub-carriers are divided into data, pilot, DC and guard sub-carrier. The data, pilot and guard sub-carriers are used for transmitting data, pilot symbols and guard information for limiting interference, respectively. The OFDMA technique is based on OFDM, which provides multiuser access to a channel by dividing the sub-carriers into subsets of sub-carriers. For supporting mobility, mobile WiMAX extends its physical layers and incorporates the scalable OFDMA (S-OFDMA) technique. By adopting scalable PHY architecture, it can support a wide range of bandwidths. The scalability is implemented by varying the FFT from 128 and multiple of 128. Table-1 summarizes the primitives used for mobile WiMAX PHY. At high speeds, doppler shift causes inter-carrier interference (ICI) and due to small sub-carrier spacing, ICI possibilities on larger FFT is higher than lower FFT. WiMAX forum therefore recommends smaller FFT and simpler modulation at high vehicular speeds.

In a high mobility scenario, relative motion between transmitters and receivers results in rapid time variation and high doppler shift. Accumulating dynamically changed multipath effects and noise, a significant fluctuation in received signal strength is observed in the channel. Fading like this is often modelled in literature with Rayleigh fading model. Rayleigh fading model has not been challenged until very recently when researchers started to focus on the throughput problem at vehicular speeds. Rayleigh model works on the assumption that the resultant fading arises from a large number of uncorrelated partial waves with identically distributed amplitudes and uniformly $[0, 2\pi]$ distributed random phases. This assumption is highly optimistic in a mobile communication environment at high vehicular speeds and the more realistic assumption

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Table I
WIMAX FORUM SPECIFICATION PRIMITIVES FOR MOBILE WIMAX PHY.

Parameters	Value .	Value
Number of Sub-carriers	512	1024
Bandwidth (BW)	3.5, 5	7, 8.75, 10
Sampling Factor (n)	BW is multiple of 1.75 is 8/7, multiple of 1.25, 1.50, 2, and 2.75 is 28/25 not otherwise specified then n=8/7	
Cyclic Prefix time ratio (G)	1/8	
Used sub-carriers	433	865
Pilot Sub-carriers	48	96
Guard sub-carriers, Left	40	80
Guard sub-carriers, Right	39	79
DC sub-carrier	1	1
Data sub-carriers	384	768

is to have many partial waves with amplitudes that follow distributions that are not identical, yet partially correlated [3], [4]. In an environment like this, signal fluctuations are better modelled by Nakagami-*m* distribution [4], [3] and as a result, estimated BER is more accurate in Nakagami-*m* model than in Rayleigh model. Moreover, Nakagami-m model can be made adaptive to suit fixed, pedestrian and high speeds mobility environments by changing the fading parameter m, which is used to reflect the fading severity. The parameter value $m < 1$ is considered as Nakagami/sub-Rayleigh fading and the fading process is considered as a product of complex Gaussian process and a square root beta process. Rayleigh distribution ($m = 1$) and Rician distribution ($m > 1$) are considered as a special case of Nakagami distribution [4], [5]. In this paper, we develop and present an analytical model for BER estimation in WiMAX communication systems using Nakagami-*m* fading model.

II. PREVIOUS WORKS

Wireless communication at vehicular speeds in general has attracted increasing attentions in recent years mainly because of its relevance to intelligent transportation system. Onsy $et\ al.$ [6] conducted a simulation study in the IEEE 802.16e at high vehicular speeds for channels with Additive White Gausian Noise (AWGN). Dong *et al*. conducted a comparative study of channel estimation for mobile WiMAX at high mobility [7] and proposed a piecewise linear interpolation based channel estimator. Ahmad $et\ al.$ investigated the BER performance in WiMAX at high vehicular speeds using Rayleigh fading and proposed a mathematical scheme to compute the optimum packet size based on the estimated BER [8]. Ahmad $et\ al.$ conducted another study [9] to develop an adaptive error correction scheme based on estimated BER in WiMAX communications. Boudali *et al*. evaluated the BER in a convolutional coded OFDM system for the return link in a mobile environment. [10]. Aguado *et al*. performed a simulation study on mobile WiMAX deploying CCTV on a public transport [11].

Subotic $et\ al.$ [12] analysed the BER for an equalized OFDM system using Nakagami, m< 1 distribution using pilot assisted linear channel estimation and channel equalization. A BER analysis for frequency selective slow fading channel has been conducted by Zhang $et\ al.$[13] using Nakagami–m distribution . Performance of maximal-ratio diversity systems in a correlated Nakagami fading environment is analysed by Aalo [14] for urban and vehicular communications. A research was conducted by He $et\ al.$ [5] to estimate the BER on QAM and MPSK in Nakagami fading channel with space time transmit diversity. Guo $et\ al.$ [15] conducted a research to analyse the BER for MIMO-OFDM system over Nakagami-m fading channels using Rate Compatible Punctured Convolution (RCPC) and Space Time Block Code (STBC) at transmitters and maximum ratio combining (MRC) at receivers. Statistical characteristics of ICI and BER performance of OFDM system has been analysed by Vivek $et\ al.$ [16] over a correlated Nakagami fading channel using MRC at receiver. BER analysis for OFDM-BPSK and QPSK over a flat fading channel using Nakagami-m distribution has been conducted by Neetu $et\ al.$ [17]. There is no research reported in the literature that presents BER estimation in WiMAX communication at vehicular speeds using Nakagami-m model. An analytical model is required for estimating BER at various vehicular speeds for efficient resource management, which provides the motivation for this research.

Table II
DERIVED PARAMETERS FOR IEEE 802.16M.

Parameters	Equations
Sampling frequency (F_s)	$F_s = floor(n.BW/8000).8000$
Sub-carrier spacing (∇f)	F_s/N_{fft}
Useful symbol time(T_b)	$1/\nabla F$
Cyclic Prefix (CP) time (T_g)	$G.T_b$
OFDMA symbol time $ofdmT_s$	$T_b + T_g$
Sampling time (T_s)	Sampling time T_b/N_{fft}

III. CHANNEL MODEL FOR SUB-RAYLEIGH FADING

When mobile nodes move at high vehicular speeds, doppler shift and dynamic multipath effects cause complex fading and reduce throughput. Following [4], [12], this complex fading process $x(t)$ can be modelled as a product of two independent processes $y(t)$ and $z(t)$ where $y(t)$ is the zero mean complex gaussian random process and $z(t)$ is exponentially correlated random process. The correlation function $\Re_x(\tau)$, of the process $x(t)$ is a product of correlation process of $y(t)$ and $z(t)$, which can be given as

$$R_x(\tau) = |y(t)y(t+\tau)z(t)z(t+\tau)| = R_y(\tau)R_z(\tau) \tag{1}$$

The marginal distribution $p_x(x)$ of $x(t)$ does not depend on the correlation of these component. Therefore, the marginal distribution $p_z(x)$ of the modulation component $z(t)$ affects on the desired distribution. If γ is the symbol energy to noise ratio at the receiver, then the pdf of Nakagami process is given by

$$pdf(\gamma) = \frac{2m^m\gamma^{2m-1}}{\Gamma(m)\Omega^m} exp\left(-\frac{m}{\Omega}\gamma^2\right), \quad \gamma \geq 0, 0.5 \leq m < 1 \tag{2}$$