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Performance Improvements in SNR of a Multipath Channel Using OFDM-MIMO

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***Abstract*—The Non Line of Sight (NLOS) broadband wireless access provided by Worldwide Interoperability for Microwave Access (WiMAX) operating in 2-11 GHz frequency is susceptible to the effects of multipath propagation, diffraction fading, vegetation attenuation, shadowing loss etc. In order to overcome these effects effective fade mitigation techniques, have to be implemented. The Orthogonal Frequency Division Multiplexing-Multiple Input Multiple Output (OFDM-MIMO) is an efficient method that helps in combatting the fading and providing higher SNR to the WiMAX system. According to the IEEE 802.16 specification, for QPSK modulation, a threshold SNR of 6 dB is required for the link to operate. In the present work the use of OFDM-MIMO achieves a SNR above this operating threshold.**

***Keywords*—WiMAX, fade mitigation, OFDM, MIMO, cyclic prefix, guard time**

I. Introduction

THE Broadband wireless services aim at providing the broadband access in a wireless context. The WiMAX technique is aimed at provision of quality services to end users with high data rate and wide coverage. The channel capacity or data rate is limited by the bandwidth, transmission power, noise, distortion and interference [1]. The NLOS WiMAX uses frequencies between 2 and 11 GHz. It specifies a range of 30 miles for channel bandwidths from 1.75 MHz to 20 MHz [2]. The operating link has a fixed or mobile Subscriber Station (SS) and a Base Station (BS) that connects to a wired network. The wireless channel is significantly affected by the various impairments that occur along its path. There is a need to mitigate these effects for the system to perform satisfactorily. Fade mitigation techniques refer to the adaptive communication systems that try and compensate the attenuation effects affecting the terrestrial link in millimetre wave communications [3]. Although various fade mitigation techniques are available, the present work has taken into account the techniques based on two criteria: Firstly, whether the technique is suitable in mitigating the propagation impairments occurring along the channel such as multipath propagation, diffraction fading, vegetation attenuation, shadowing loss etc., and secondly, whether the technique is in accordance with the WiMAX specification and that can be adapted to meet the system requirements.

Based on these criteria, certain techniques are chosen and they can be implemented individually or in combination of techniques that are apt to the situation and, which further enhance the performances.

The use of OFDM and MIMO can alleviate the multipath fading that occurs in WiMAX. The OPNET tool is utilised for determining the overall link performance in the presence of channel multipath. This work implements such a model that shows improved SNR. In the current work, section II discusses the Orthogonal frequency division multiplexing, the Multiple Input Multiple Output scheme is illustrated in section III, section IV discusses the implementation of OFDM-MIMO using OPNET and finally the conclusions are given in section V.

II. Orthogonal Frequency Division Multiplexing

A wide variety of high data rate communication systems including WiMAX have adopted multicarrier modulation technique OFDM. The spectrum of the individual carriers mutually overlaps in OFDM. If the OFDM carriers are spaced in frequency exactly at the reciprocal of the symbol interval, that is can be accomplished by using the discrete time Fourier transform (DFT) the OFDM carriers exhibit orthogonality on a symbol interval [4]. When the guard interval is longer than the maximal propagation delay, OFDM is a useful technique to overcome Inter Symbol Interference (ISI) [5]. The necessity of high data rates and ISI free channels form the basis of multicarrier modulation. OFDM can be seen as either a modulation technique or a multiplexing technique. One of the main reasons of using OFDM is for increasing the robustness against frequency-selective fading or narrowband interference. A single fade or interferer can cause the entire link to fail in a single-carrier system, while only a small percentage of the subcarriers will be affected in a multicarrier system. The few erroneous subcarriers can then be corrected using the error-correction coding.

A. Simulation of WiMAX Physical layer implementing OFDM

The OFDM implementation is shown in Fig. 1. The modulated data is converted from a serial mode to parallel mode. By dividing the channel into narrowband flat fading sub channels, OFDM is more resistant to frequency selective fading than single carrier systems. The Inverse Fast Fourier Transform (IFFT) block computes the IFFT of the channel. The outgoing signals are orthogonal. The Cyclic Prefix (CP) is added to eliminate the ISI caused by multipath. The value of CP is varied between 1/4, 1/8, 1/16 and 1/32.

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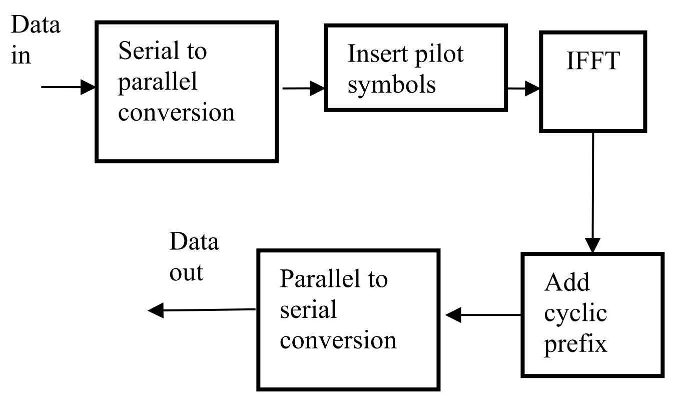

Fig. 1. OFDM implementation

B. *OFDM link design*

The OFDM parameters that are used in the link design are summarised in Table I.

TABLE I.
SUMMARY OF OFDM PARAMETERS

Symbol	Description	Relation	Value			
B	Nominal bandwidth	$B=1/T_s$	3.5 MHz			
n	Oversampling rate	From standard [11]	7/6			
F_s	Sampling frequency	F_s =floor(n.B/8000)x8000	4.08 MHz			
L	Number of subcarriers	IFFT/FFT size	256 [Data subcarriers(N_{data})=192 Pilot subcarriers(N_{pilot})=8 Guard subcarriers(N_{guard})=56]			
Δf	Subcarrier spacing	$\Delta f=F_s/L$	15.625 kHz			
T_b	Useful symbol time	$T_b=1/\Delta f$	64 μs			
T_s	Sample time	$T_s=1/B$	0.29 μs			
G	Guard fraction	% of L for CP	1/4	1/8	1/16	1/32
N_g	Number of Guard symbols	N_g=GL	64	32	16	8
T_g	Guard time (μs)	$T_g=G.T_b$	16	8	4	2
T	OFDM symbol time(μs)	$T=T_s(L+N_g)=T_b+T_g$	80	72	68	66
B_{sc}	Subcarrier bandwidth	$B_{sc}=B/L$	13.67 kHz			

C. *Bit Error Rate (BER) performance with modulation and coding, fixed OFDM symbol size and varying cyclic prefix width*

In the first stage of analysis the OFDM symbol size is fixed at 69 symbols of 5 ms duration. The modulation and coding scheme is varied along with the cyclic prefix width. Fig. 2 shows the variation in BER for various SNR values when using various modulation- schemes suitable for WiMAX specification. The simulations were carried out for a Rayleigh channel.

From Fig. 2 it is noted that there is no significant variation in the BER levels with the variation of cyclic prefix length, where the OFDM symbol size is fixed at 69 symbols. According to the WiMAX specification, the cyclic prefix width of ¼ is suitable for fixed WiMAX operations. The Guard Time (GT) length is selected such that the symbol time is greater than the channel delay spread of 8μs. Practically, the GT length is 25% of the useful symbol time, which implies a 1 dB reduction in the SNR, so GT length is two or four times the maximum anticipated delay spread [6]. In the present design, the maximum SNR loss is 0.97 dB, due to the inclusion of GT. The optimum cyclic prefix length is concluded as ¼ or 25% the useful symbol time [7].

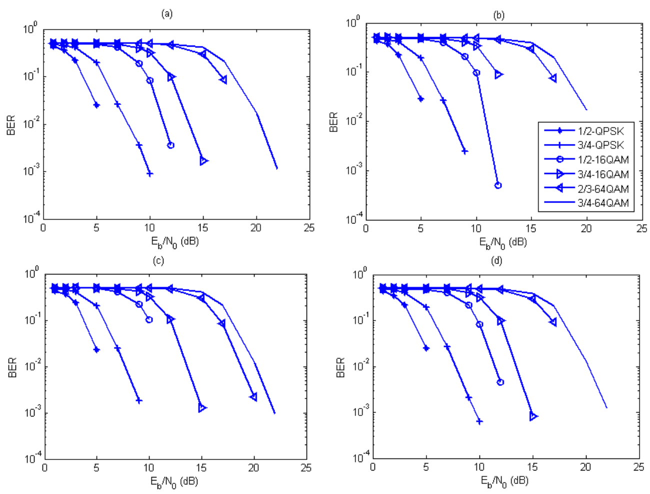

Fig. 2. BER for OFDM with fixed OFDM size and varying size of cyclic prefix (a) 1/4 (b) 1/8 (c)1/16 (d)1/32

III. MULTIPLE-INPUT MULTIPLE-OUTPUT (MIMO) SCHEME

MIMO wireless systems with multiple antennas at both transmitter and receiver sides operate by increasing the number of antennas at both the transmitter and the receiver to satisfy the high capacity requirements of wireless systems. As the number of transmit antennas *'N_t'* and number of receive antennas *'N_r'*, satisfy the condition $N_r \geq N_t$, there is a linear increase in capacity [6]. When using spatial multiplexing for a data rate per stream *'R'*, the number of transmit antennas *'N_t'*, the transmit data rate is $N_t \, x \, R$. The same information is sent through signals along different paths and multiple independently faded replicas of the data symbol are combined at the receiver. Hence, more reliable reception is achieved, which results in diversity. By transmitting independent information streams in parallel through multiple spatial channels, there is an increase in the spectral efficiency and this is referred to as multiplexing [9].

The advantages of MIMO are to:

- Provide an increase in system reliability by decreasing the bit or packet error rate
- Provide an increase in the achievable data rate and therefore increase system capacity
- Provide an increase in coverage area
- Reduce the required transmit power.

A. *Performance of MIMO (Alamouti space time block coding)*

Space time signal processing provides diversity gain as well as increased data rates by employing multiple antennas at the transmitter and the receiver. The BER is known to decrease proportionally to SNR^{-d} in a Rayleigh fading channel, where *'d'* is the system diversity obtained by transmitting the same symbol through *'d'* independently faded channel. By repeating the transmitted symbols using multiple antennas, diversity is obtained. With spatial diversity the diversity gain is compounded by array gain, which results in a reduction of the average noise power even in the absence of fading [10].

Fig. 3 demonstrates the use of transmit and receive antenna diversity and highlights that the receive diversity outperforms the transmit diversity. The receive diversity provides a diversity gain of 2.8 dB for a BER of 10^{-3}. The same data rate and diversity order as a 1x2 diversity system with Maximum Ratio Combining (MRC) can be achieved with 2x1 Alamouti code but with a penalty of 3 dB. This occurs due to the need of removing the redundant information at the receiver that is transmitted in order to reduce the spatial interference [9]. The work by Alamouti [12] states that the Alamouti space time block coding (STBC) 2x1 scheme is 3 dB worse than the two branch MRC because the simulations assume that half the energy is radiated by each transmit antenna in order to ensure that the same total radiated energy is radiated as one transmit antenna. However, the performance would be identical if each transmit antenna in STBC radiates the same energy as the single transmit antenna for MRC. Therefore, if the BER was drawn against the average SNR per transmit antenna, then the performance curves for STBC would be shifted to 3 dB left and overlap with the MRC curves.

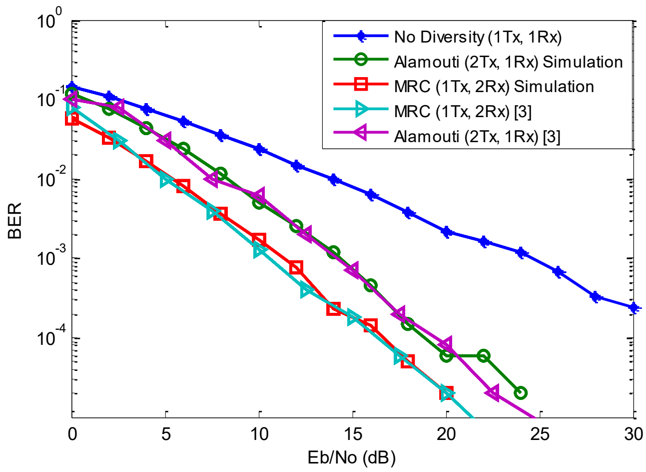

Fig. 3. Comparison of BER performance of simulation with Andrews et al. [9] for Alamouti STBC with MRC for BPSK in a Rayleigh fading channel

It is further stated by Alamouti [12] that the 3 dB reduction in power in each transmit antenna would translate to cheaper, smaller and less linear power amplifiers. In some cases, it may be desirable and the 3 dB reduction in amplifier power handling is very significant. The current simulation results are compared with the existing work carried out by Andrews [9]. The simulation curves show good agreement with the existing work.

IV. OPNET OVERVIEW

OPNET can be described as a high level event based network level simulation tool that operates at packet level. It consists of high level user interface, which is constructed from C and C++ source code blocks with a huge library of OPNET specific functions. The overall scope of the system to be simulated is specified by the network domain. The objects contained in the system, their physical locations, interconnections and configurations are described as a high level description in this domain. It consists of network, sub networks, network topologies, geographical coordinates and mobility parameters.

A. Design of OPNET model for a multipath channel

The multipath network model is designed with a BS and four SSs. Among the four SSs, two are vehicular and two pedestrians. All the SSs are located with the same cell. The multipath channel models used are 'ITU Vehicular A' for vehicular SSs and 'ITU Pedestrian A' for pedestrian SSs. The list of significant parameters used for the link design is shown in Table II.

TABLE II.
MOST SIGNIFICANT PARAMETERS IN OPNET MODEL DESIGN

PHY profile	WirelessOFDMA 20 MHz	Duplexing technique	TDD
Frame duration	5 ms	Base frequency	5.8 GHz
Symbol duration	100.8 µs	Channel bandwidth	20 MHz
Number of subcarriers	512	Multipath channel model	ITU Vehicular A
Allocation quantum	1 PS	Vehicular SS path loss model	Vehicular environment
Frame preambles	1 symbol	Multipath channel model	ITU Pedestrian A
TTG	100.8 µs	Pedestrian SS path loss model	Outdoor to Indoor pedestrian environment
RTG	302.4 µs	Terrain type	Terrain type A

B. Performance of the multipath channel without OFDM-MIMO

Fig. 4 and 5 show the Cumulative distribution function (CDF) of the downlink SNR and uplink SNR of the BS respectively for the designed network without OFDM-MIMO. According to the IEEE 802.16 specification [11], for QPSK modulation, a threshold SNR of 6 dB is required for the link to operate. In Fig. 4, x-axis denotes the SNR and y-axis denote the time %. Fig. 4 and 5 demonstrate that under multipath condition the 6 dB threshold SNR cannot be achieved. In a downlink multipath channel, for 80% of time the SNR is less than 6 dB. In an uplink multipath channel for 60% of time the threshold SNR is not attained.

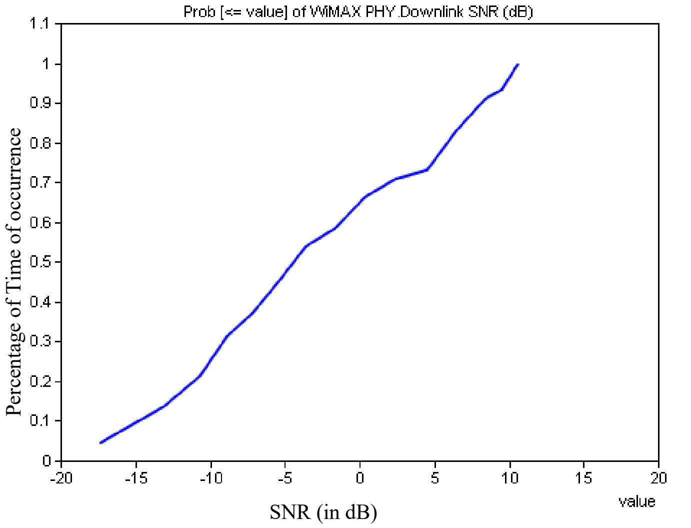

Fig. 4. Cumulative distribution function of the SNR of the Base station in the Downlink multipath channel

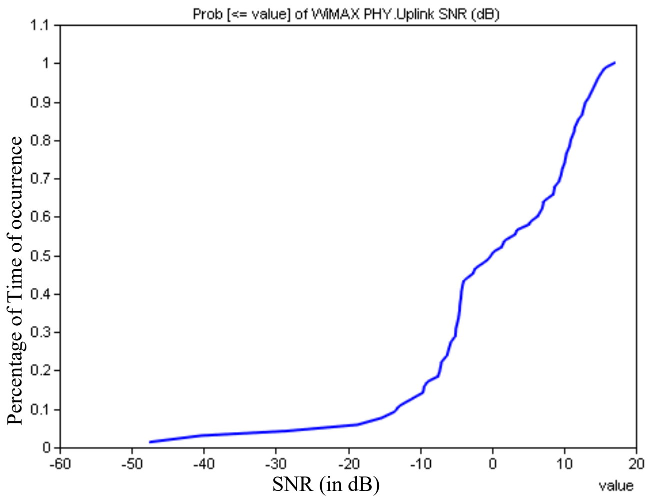

Fig. 5. Cumulative distribution function of the SNR of the Base station in the Uplink multipath channel

C. Performance of the multipath channel with OFDM-MIMO

The OFDM-MIMO technique discussed in sections II and III helps in reducing the overall SNR as demonstrated in Fig. 6 and 7. The SNR in both downlink and uplink channels are high with the use of OFDM-MIMO. For QPSK modulation a threshold SNR of 6 dB is required for the link to operate according to the IEEE 802.16 specification. In the present work in both uplink and downlink cases, the SNR is above 6 dB threshold value is obtained during 100% of time. Hence OFDM-MIMO technique improves the channel SNR and helps in operating with guaranteed link margins. For 1% of time, up to 20 dB SNR is obtained. For data networks a SNR of 20 dB is recommended. However, this ideal conditions cannot be met in realistic propagation channels.

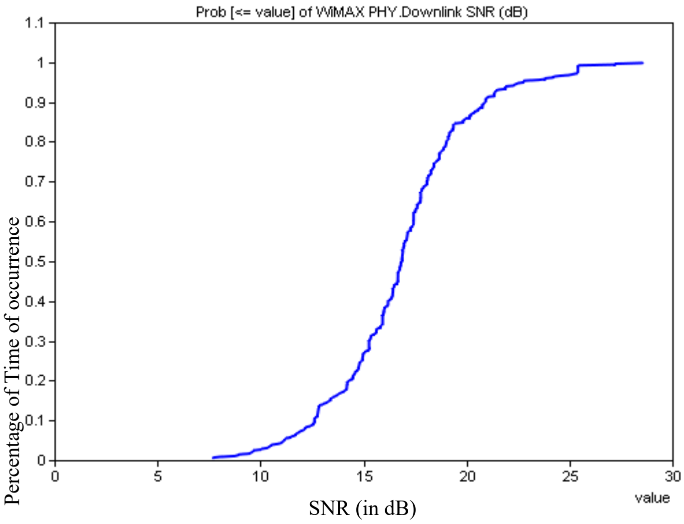

Fig. 6. Cumulative distribution function of the SNR of the Base station in the Downlink channel using OFDM-MIMO

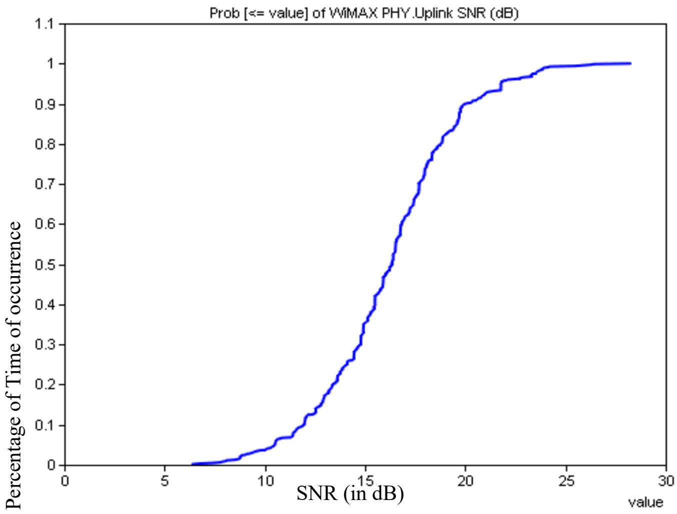

Fig. 7. Cumulative distribution function of the SNR of the Base station in the Uplink channel using OFDM-MIMO

V. CONCLUSION

Multipath fading is considered as the major contributor of signal loss in a NLOS WiMAX environment. The fade mitigation techniques that can alleviate multipath fading are implemented in this work. As the modulation and coding scheme gets to a higher order, the coverage range decreases. This has been demonstrated in the results obtained. A detailed design of an OFDM link is carried out based on the IEEE 802.16 specification. Based on the design, the OFDM technique is implemented for WiMAX. The simulations were carried out for varying levels of cyclic prefix length, OFDM symbol sizes and modulation and coding schemes. The results show that there is no significant variation in BER performance with variation in cyclic prefix length. This is due to the reason that CP is primarily used to eliminate the ISI due to multipath and any increase in size of CP doesn't improve the BER. When varying the OFDM symbol sizes, the increased symbol size marginally improves the BER. The optimum cyclic prefix length is concluded as ¼ or 25% the useful symbol time. The transmit and receive antenna diversities are implemented. The Alamouti STBC scheme provides a gain of 10 dB on a channel operating with no diversity. The 1x2 MRC scheme achieves a gain of 3 dB over STBC. This is owing to the need of removing redundant information at the receiver that was sent across two transmitting antennas for reducing the effect of spatial interference. Based on the channel conditions the MIMO scheme has to be adapted in mobile WiMAX to achieve good spectral efficiency. In the final stage of analysis, the OFDM-MIMO technique is implemented using OPNET software. The multipath channel in the absence of OFDM-MIMO performs with a low SNR which leads to high outage. When the OFDM-MIMO is introduced into the system, it provides high SNR in both uplink and downlink channels which can provide acceptable link margins.

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