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'Fading is Our Friend!': A Performance Comparison of WiMAX-MIMO/MISO/SISO Communication Systems

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Abstract

Research work for some time now has shown that fading wireless channels present enormous advantages if properly exploited through a Multiple-Input Multiple-Output (MIMO) communication model. In this paper, we demonstrate the advantages of implementing the MIMO communication model by investigating three communication techniques, namely, Single-Input Single-Output (SISO), Multiple-Input Single-Output (MISO) and MIMO for WiMAX communication systems. The performances of these communication techniques are analyzed and compared for three scenarios - rural environment, TGV (high-speed train) environment and urban environment by using the models to investigate several communication parameters.

Keywords: MIMO, MISO, SISO, Wimax, Space-Time Coding, Alamouti Space-Frequency Block Coding

1. Introduction

In wireless communication systems, MIMO, pronounced my-moh or mee-moh, refers to a link for which the transmitting end as well as the receiving end is equipped with multiple antenna elements. Like MIMO, MISO is another smart antenna technology, but characterized by multiple antennas only at the transmitting end. To understand smart antenna technology, it is best to consider an example in which, say, you are in a room. Someone in the room is talking to you and, as he speaks, he begins moving around the room. Your ears and brain have the ability to track where the user's speech is originating from as he moves throughout the room. This is similar to how smart antenna systems operate. They locate the users, track them, and provide optimal RF signals to them as they move throughout the base station's coverage area. MIMO is rapidly becoming the face of smart antenna technology. On the other hand, SISO, which has a single antenna at both transmitting and receiving ends, is the simplest and cheapest to implement among the three and has been in use since the birth of radio technology. MIMO promises to resolve the bottlenecks of traffic capacity in the forthcoming high speed wireless broadband wireless internet access networks like Worldwide Interoperability for Microwave Access (WiMAX), 3G-Long Term Evolution (see [3]) and beyond.

In this paper we have limited our analysis to the WiMAX system and/or mobile-WiMAX system, which were based on the IEEE 802.16-2004 standard and IEEE 802.16e-2005 standard respectively. In essence, WiMAX is a 4G technology for a state-of-the-art ''last mile'' telecommunication infrastructure (see [4,9]). WiMAX is poised to replace a number of existing broadband telecommunication infrastructure for wireless local loop, while mobile-WiMAX can replace cellular networks.

There are several ways to implement MIMO systems, such as, BLAST described by G. J. Foschini (see [1,2]), space-time coding (see [5–7,10,11,13]) and more. However, we have stuck to the Alamouti space-time block code proposed by Siavash Alamouti in 1998 (see [12]). This code achieves transmit diversity by correlating the transmit symbols spatially across the two transmit antennas, and temporally across two consecutive time intervals. The only condition is that the channel should remain stationary over two consecutive symbols. Although the Alamouti code achieves the same rate as SISO, it attains maximum diversity for two transmit antennas. The greatest advantage it offers is that the coding and the decoding mechanisms it symbolizes are remarkably simple and equally effective. The code also provides the lowest probability of error and implementation complexity among all MIMO implementation techniques. At the receiver end we use Maximum Likelihood

(ML) detection technique which largely does an exhaustive search among all received signals in order to find the optimum received signal (see [7]). Importantly, the performance of the Alamouti code depends on an accurate estimation of the channel between the transmitter and the receiver. Transmission of training symbols is used to perform channel estimation (discussed in Section 2).

In this paper we have analyzed the performance of a WiMAX-MIMO system (by means of Bit Error Rate (BER)) vis-à-vis WiMAX-MISO and WiMAX-SISO systems using the MATLAB simulation tool. Analyses for the following scenarios have been performed.

- Rural environment: We consider an environment with no obstacles, hence no fading takes place. Also, the transmitter and the receiver are in zero relative motion (stationary).
- Train à Grande Vitesse (TGV)/High-speed train environment: We consider a doppler fading environment. The transmitter is stationary and the receiver is sitting in a TGV moving at its top speed of 574.8 km/hr.
- Urban environment: We consider a static multipath environment with a LOS link between transmitter and receiver. Again, the transmitter and receiver are in zero relative motion.

We will also compare the behavior of the three models to varying SNR and number of input bits in all the three environments. This paper is structured as follows. Section 2 introduces the Alamouti space-frequency block code; it's encoding and decoding scheme and how it differs from the well-known Alamouti space-time block code. In Section 3, we present our WiMAX- MIMO/ MISO/SISO communication models with a detailed description of the complete layout of each model. Section 4 is devoted to the results obtained from computer simulations for different analyses performed to compare the communication performances of the three models and also proposes a hybrid model (part SISO - part MISO - part MIMO) which can be implemented for rural environments. Finally, Section 5 presents the conclusion.

2. Alamouti Space-Time Block Code

In this paper we have focused on the Alamouti coding scheme, precisely the Alamouti space-frequency block code which is a slight variant of the Alamouti space-time block code (see [11]).

For implementing MIMO for WiMAX systems, we have employed the desired diversity differently at the reception and transmission. The reception employs Alamouti space-time block code (STBC) while the transmission employs an Alamouti space-frequency block code (SFBC). The motivation behind such a variation is that STBC requires the channel to be stationary over two consecutive OFDMA symbols (also see [14–17]). However, in a fast-fading radio channel, this is

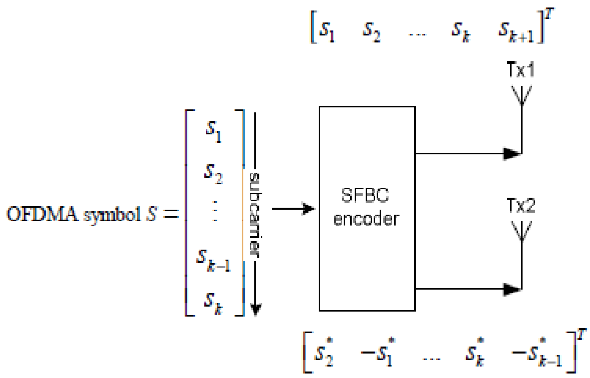


Figure 1. SFBC encoding scheme.

not always true. In SFBC, the coding is implemented across two consecutive sub-carriers in the frequency domain and thus within the OFDMA symbol. This eliminates the aforementioned handicap posed by STBC.

Figure 1 illustrates the encoding scheme for SFBC's. As clearly visible, the mapping scheme is designed in such a way that the first antenna transmits the entire symbol stream without any modification, also facilitating the system to act as a SISO system provided antenna two is switched off. However, it is assumed that two adjacent sub-carriers in the frequency domain experience correlated fading. This assumption holds in channels where the delay spread is low enough for the resulting coherence bandwidth to exceed twice the sub-channel spacing. Also, this is the reason why SFBC cannot be used for reception.

For transmitted symbols X_1 and X_2 the receiver antenna obtains the received symbol r_1 and r_2 for a 2x1 MISO system as

$$r = \begin{pmatrix} r_1 \\ r_2 \end{pmatrix} = \begin{pmatrix} x_1 & x_2^* \\ x_2 & -x_1^* \end{pmatrix} \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} + \begin{pmatrix} z_1 \\ z_2 \end{pmatrix} = Xh + z$$

where Z is the Additive White Gaussian Noise (AWGN) and h_1 and h_2 are the channel coefficients.

The optimal estimates for h_1 and h_2 can be obtained by linear processing at the receiver, and are given by

$$\tilde{h} = \begin{pmatrix} h_1 \\ h_2 \end{pmatrix} = \frac{1}{\|x\|^2} X^* r = \begin{pmatrix} h_1 + \tilde{z}_1 \\ h_2 + \tilde{z}_2 \end{pmatrix}$$

where

$$\tilde{z}_1 = \frac{x_1 z_1 + x_2^* z_2}{\|x\|^2}; \quad \tilde{z}_2 = \frac{x_2 z_2 + x_1^* z_2}{\|x\|^2}$$

These channel estimates can then be used to detect the next pair of code symbols. After the next code symbols are decoded, the channel estimate can be updated using those decoded symbols (see [9]). When the channel variation is slow, the receiver improves stability of the decoding algorithm by averaging old and new channel estimates.

The decision for the two transmitted symbols or in other words the estimate of the two transmitted symbols according to ML estimation, ~X_1 and ~X_2, is given by:

$$\tilde{x}_1 = h_1^* r_1 + h_2 r_2^*$$
$$\tilde{x}_2 = h_2^* r_1 + h_1 r_2^*$$

Similarly, the above scheme can be extended to 2 receiver antennas and hence to N_r receiver antennas.

3. Wimax-MIMO/MISO/SISO Communication Model

This section presents the communication model block diagram of all the three models and talks about the nuances of each of them. It is interesting to note that the MIMO and the MISO models have a far more complex implementation than the simple SISO model (Figures 5, 6 & 7).

SISO communication systems are vulnerable to environments characterized by problems caused by multipath effects. Figure 2 illustrates a real-time model of a SISO system. On the other hand, the MISO transmission strategy maximizes the received SNR by adding up the received signal from all transmit antennas in-phase and by allocating more power to the transmit antennas. MISO wireless communication system exhibits transmitter diversity. Some of the transmitter diversity techniques include frequency weighting, antenna hopping, delay diversity and channel coding (see [8]). The real-time model of a MISO system is similar to the one in Figure 3; however, there is only one antenna at the receiver end. The MIMO system exhibits both transmitter diversity and receiver diversity. While the transmitter diversity techniques have already been discussed, some of the receiver diversity techniques include selection diversity, antenna diversity, maximal ratio combining and equal gain combining (see [11]). Figure 3 illustrates a real-time model of a MIMO system.

The advantages of using MIMO systems are increased spectral efficiency, throughput, coverage, capacity, better BER and resistivity to fading effects to name a few. However, the greatest challenge it faces is the necessity of complex DSP circuitry and the fact that its promise of better communication performance hold true most only for scattering-rich environments.

Figures 5, 6 & 7 illustrate the block diagram for urban environment for the WiMAX-SISO, WiMAX-MISO and WiMAX-MIMO communication model discussed in this paper. We have taken a 200x200 black & white image (Figure 4) as the input to the communication system.

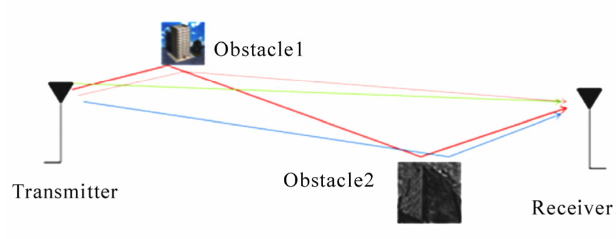


Figure 2. Real Time SISO communication model.

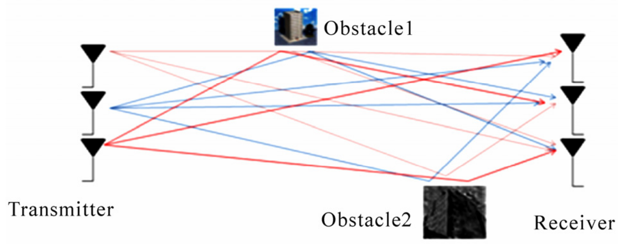


Figure 3. Real Time MIMO communication model.

Figure 4. 200×200 black&white input image.

We have used an in-built MATLAB function 'qammod (data, index) to perform 16-QAM and similarly 'qamdemod (data, index)' to perform 16-QAdeM. The SFBC encoder and decoder are designed in accordance with the equations already talked about in Section 2. The characteristics of the models for the three environments that we have used for our analysis are given below.

- Rural environment: There is no 'Multipath Rayleigh filter 'block in the block diagram and the output of 'peak power clipping' goes to the 'add Gaussian noise' block.
- TGV environment: The 'Multipath Rayleigh filter' block is replaced by the 'Doppler fading filter' block. We have used an in-built MATLAB function ''rayleighchan (sampling freq, Doppler spread, 'path-delays', 'path-gains')'' to realize the doppler fading environment by setting Doppler spread as maximum of 1300 Hz, corresponding to 574.8 km/hr. Path delay is set to zero.
- Urban environment: We again use the same in-built MATLAB function mentioned in TGV environment to realize the multipath fading environment. We have taken a total of 15 multipath delays generated randomly.

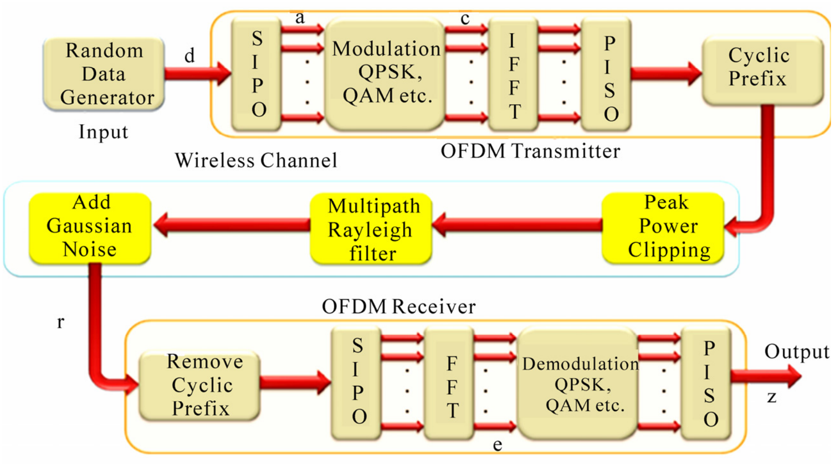


Figure 5. WiMAX-SISO communication model for urban environment.

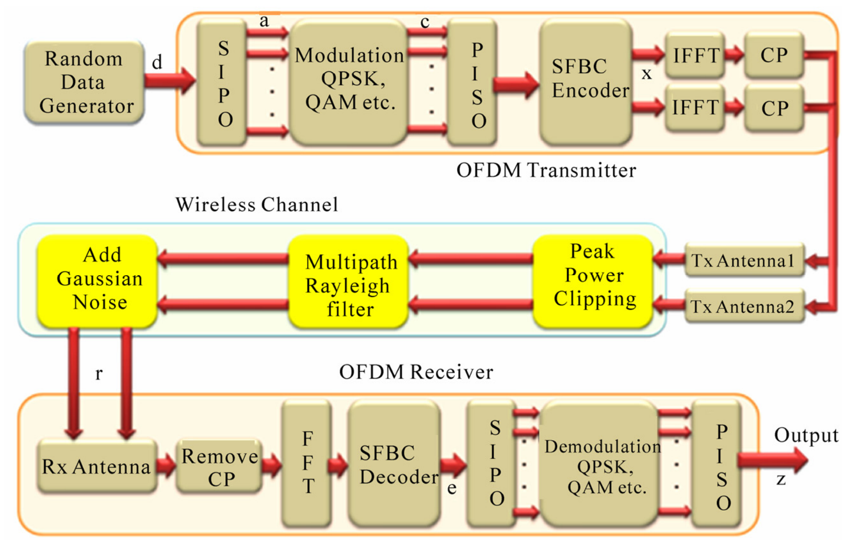


Figure 6. WiMAX-MISO communication model for urban evironment.

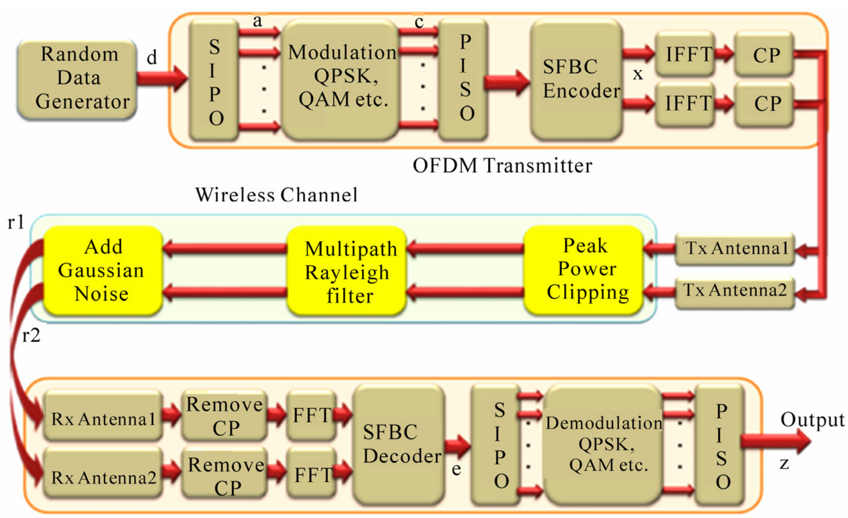


Figure 7. WiMAX-MIMO communication model for urban environment.

Figure 8. Comparison of SISO, MISO & MIMO model for rural, TGV and urban environments.

The output is compared with the input data and the BER is calculated. Also, importantly, it should be noted that we have not used channel state information at the transmitter (CSIT) for our analysis.

4. Simulation Results

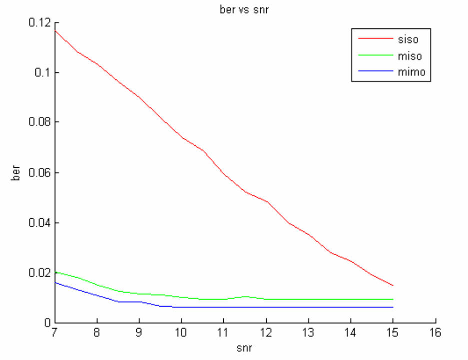
4.1. SISO / MISO / MIMO Comparison in Rural, Urban and High Speed Environments.

This section contains the results of simulations carried out to compare the communication performance (BER) of the three models in the aforementioned three environments. Also, we analyze the performance of the three models by varying the SNR and the number of input bits for all the three environments.

For the first part of our analysis, we have fixed the E_b/N_0 value to be 3dB and compared the behavior of the three communication models in all the three environments. We have used the image in Figure 4 as the input data.

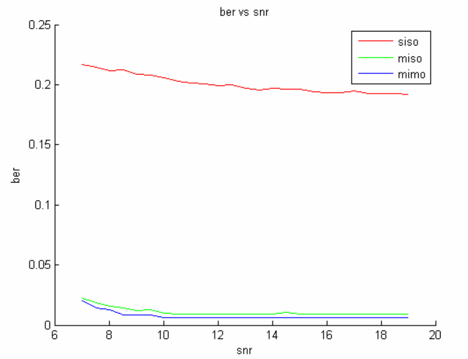
Figure 8 illustrates the results thus obtained. Here ‘q’

Rural environment



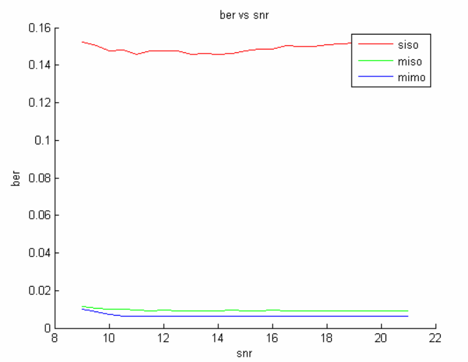
MODEL	AVERAGE	VARIANCE
SISO	0.0622	0.0011
MISO	0.0112	1.0911e-5
MIMO	0.0077	8.3562e-6

TGV environment



MODEL	AVERAGE	VARIANCE
SISO	0.2003	5.8135e-5
MISO	0.0109	1.1977e-5
MIMO	0.0075	1.0903e-5

Urban environment



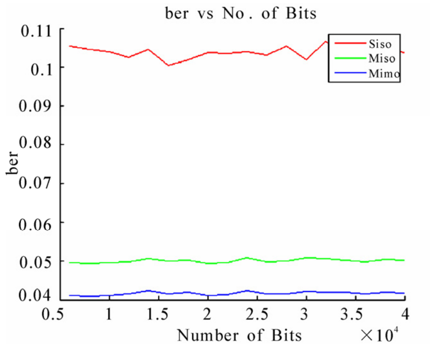
MODEL	AVERAGE	VARIANCE
SISO	0.1491	5.7380e-6
MISO	0.0094	3.0720e-7
MIMO	0.0064	8.2893e-7

Figure 9. Bervs SNR for SISO, MISO & MIMO models for rural, TGV and urban environments.

is the number of wrong bits when compared to the input data. The following conclusions can be drawn from the simulation results.

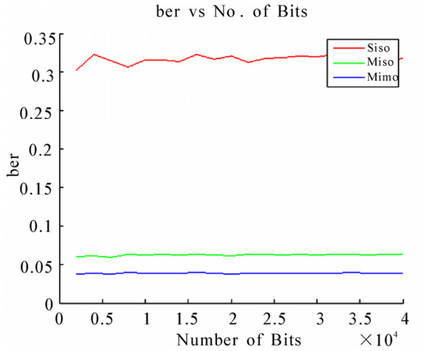
- The image is least distorted for the MIMO model followed by the MISO model and finally the SISO model for all the three environments. Also, there is a great difference between the MISO/MIMO model and the SISO model especially for the TGV and urban environment. However, there is not much difference between the MIMO model and the MISO model for any environment since the only difference between them is the inherent receiver diversity in the MIMO model.
- Another notable point is that the Bit- Error Rate (BER) for MIMO model decreases for urban and TGV environment as compared to rural environment. However, for the other two models, i.e. MISO model and SISO model, the BER increases for urban and TGV environment as compared to rural environment. However, unlike in the SISO model, the increase is a slight one for the MISO model. This result vindicates the point that a fading environment improves the performance of the MIMO model. Hence, fading is our friend!

Rural environment



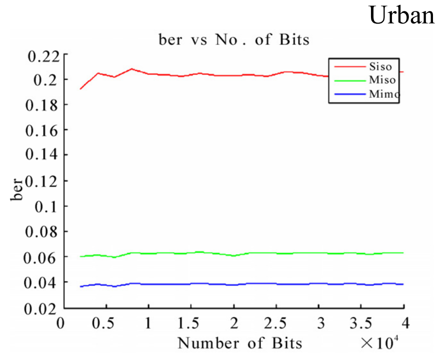
MODEL	AVERAGE	VARIANCE
SISO	0.1038	2.0936e-6
MISO	0.0500	2.1333e-7
MIMO	0.0417	1.6768e-7

TGV environment



MODEL	AVERAGE	VARIANCE
SISO	0.3165	2.6215e-5
MISO	0.0621	1.5024e-6
MIMO	0.0384	3.3734e-7

Urban environment



MODEL	AVERAGE	VARIANCE
SISO	0.2035	1.0377e-5
MISO	0.0623	1.2111e-6
MIMO	0.0384	3.7565e-7

Figure 10. Ber vs. number of bits for SISO, MISO & MIMO models for rural, TGV and urban environments.

For the second part of our analysis, we have varied the E_b/N_0 value, hence the SNR value, and found out the Bit-Error Rate (BER) value for all the three communication models each time. Again, we have used the image in Figure 4 as our input data. We have then plotted the BER vs. SNR curve for all the three models in the same graph. Also, we have performed the analysis for all the three environments. Figure 9 illustrates the results obtained from the aforementioned simulation process. The following conclusions can be drawn.

- The BER is highest for the SISO model and the least for the MIMO model for all the three environments, as can be inferred from the graph and the average BER values from the tables.
- It can also be inferred from the graphs that, as we increase the SNR values, the BER decreases for the SISO model in all the three environments with the exception of urban environment. However, for MISO and MIMO models, as we increase the SNR value, the BER decreases till a certain SNR value and then become steady at a fixed value irrespective of the SNR. The exception of the SISO model curve in urban environment can be attributed to the inability of the model to counter multipath effects.
- Another point to be noted is that, the average BER for MIMO model decreases for urban and TGV environment on comparison to rural environment. But, this is not the scenario for SISO model. Hence, we can infer

that multipath and similar fading environments truly help MIMO in its communication performance.

- Variance is not the greatest parameter to be compared for this analysis.

4.2. Influence of Data Size on Transmission Performances

For the third part of our analysis, we have fixed the E_b/N_0 value to 3 dB and varied the number of input bits and found out the Bit-Error Rate (BER) for all the three communication models each time. Here we have used randomly generated input data for this analysis. We have then plotted the BER vs. number of bits curve for all the three models in the same graph. Again, we performed the analysis for all the three environments. Figure 10 illustrates the results obtained from the aforementioned simulation process. The following conclusions can be drawn.

- The BER is highest for the SISO model and the least for the MIMO model for all the three environments, as can be inferred from the graph and the average BER values from the tables.
- Also, it can be inferred from the graphs that as we increase the number of bits, the BER values remain more or less constant for all the three models with the MIMO model providing the best results in terms of stability of the curve. Hence, we can infer that the communication performance of all the three models is irrespective of the number of bits.
- The variance of MIMO model is the least for all the three environments as compared to the SISO and MISO model. This states that the MIMO model provides us with the maximum stability in the communication performance for the aforementioned analysis.
- Also, it is interesting to note that the average BER for the MIMO model decreases for urban and TGV environments on comparison to rural environment. But, this is not the case for SISO. This again vindicates the point that multipath and other fading environments prove to be favorable for MIMO's communication performance.
- Finally, we can infer that fading environments prove to be a big downfall for the SISO model as the BER increases enormously for TGV and urban environments.

4.3. Hybrid Model for Mobile Power Saving

The purpose of this final part is to propose a hybrid model where the mobile will switch between SIMO, MISO and MIMO communications models, depending of radio transmission performances. The aim is to obtain an optimal radio performance over power consumption ratio. Using multiple antennas at the MS will utilize much power, which is a great source of concern as the MS has limited battery power. Such a hybrid model will activate antennas as a function of radio conditions.

To investigate this hybrid model, we have considered the transmitted power and the received power for various E_b/N_0 values. Then, for each power value thus calculated we have found the distance between the transmitter (base station-BS) and the receiver (mobile terminal-MS) by using the relation given below (also see [18])

$$P_r = P_t G_t G_r \frac{h_t^2 h_t^2}{d^4}$$

The above expression is valid for flat-terrain mobile communication environments and hence can be applied for our rural environment. The values for Pr (received power) and Pt (transmitted power) are found from the model using MATLAB. We assume Gt and Gr to be19dBi and 10dBi respectively, while ht and hr are assumed to be 50m and 1.5m respectively. All the as-

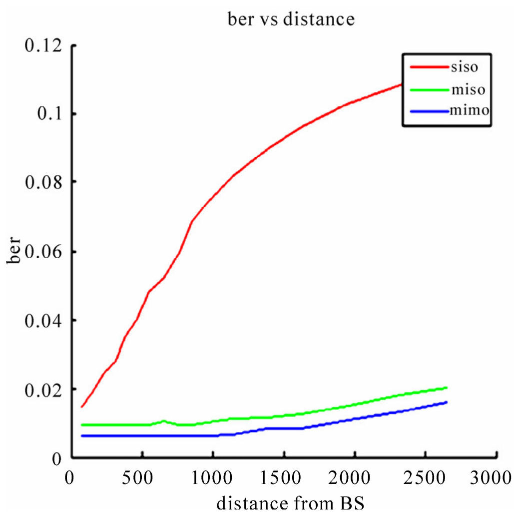


Figure 11. Ber vs distance for SISO, MISO &MIMO.

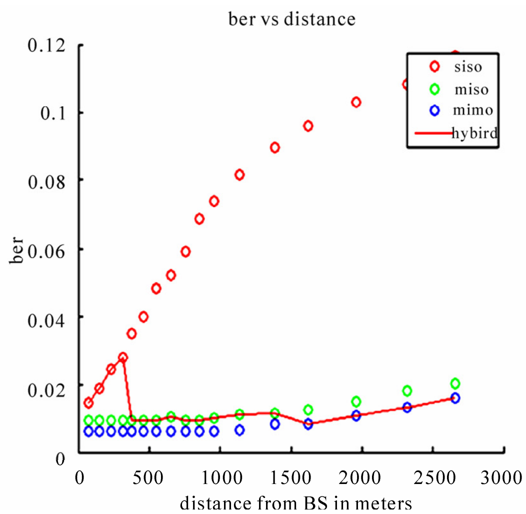


Figure 12. Ber vs distance for hybrid model.

sumed values are in accordance with the WiMAX standards (see [4,9]). We have then plotted the BER vs. distance curve for all the three models in the same graph, as illustrate in Figure 11.

As a result, a hybrid model scenario for rural environment is proposed in Figure 12. Depending of the MS-BS distance, the BER and the power consumption, the mobile choose the optimal system: SISO, MISO or MIMO.

5. Conclusions

This paper shows the use of Alamouti space-frequency block codes, a slight variant of the well-known Alamouti space-time block code, to design MISO and MIMO communication models for WiMAX systems for three environments, namely, rural, TGV/high-speed train and urban environment. The performances of the three models (SISO, MISO & MIMO) are compared for all the three environments with MIMO model clearly surpassing the other two models in every environment. This paper also notifies the improvement in the performance of MIMO systems in fading environments and also how such environments prove to be a downfall for the other models. The simulation results obtained from BER vs. number of bits analysis confirm that the MIMO model offers the maximum stability even if we have large input data bits. While those obtained for the BER vs. SNR analysis emphasize on the growing need for implementing MIMO enhanced communications systems (in this paper WiMAX system) especially for fading environments similar to urban and TGV (high-speed train) environment discussed in this paper. Such a step, if taken, will not only increase the coverage area of the communication system, but also allow for uninterrupted communication service to be possible even at the edges of the hexagonal cell. However, such an implementation would increase the power consumption at the user end. To counter this problem we have proposed our hybrid model, as of now for the rural environment, where-in, the communication system can switch from a SISO to MISO to MIMO depending upon the communication parameters (here BER). Hence this will ensure controlled power consumption as well as good communication performance. However, more research in this direction needs to be done especially at the various network layers (MAC layer). Also, such a system needs to be expanded to the urban environments as well.

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