Journal of Theoretical and Applied Information Technology
10th March 2013. Vol. 49 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

SPECTRAL EFFICIENCY ANALYSIS FOR MIMO BEAMFORMING USING ADAPTIVE MODULATION

[1]R.O. ABOLADE [2] Z. K. ADEYEMO
[1, 2] Electronic and Electrical Engineering Department,
Ladoke Akintola University of Technology, Ogbomoso. Oyo State. Nigeria.
E-mail: [1]roabolade@lautech.edu.ng, [2]zkadeyemo@yahoo.com

ABSTRACT

This paper describes the analysis of multiple input multiple output (MIMO) Beamforming with adaptive modulation using spectral efficiency as a figure of merit in multipath fading environment. Multipath fading environment causes the transmitted signals to be unreliable due to effects of tall buildings, trees, mountains, moving objects and so on. As a result of increase in demand for information communication technology which is an aspect of wireless communication, this motivated this research work.

The system model for MIMO beamforming mode is developed for a 2x2, 3x3 and 4x4 antenna systems configuration in the presence of frequency selective Rayleigh fading channel. A closed- form expression for spectral efficiency is also developed. Received signal strength indication (RSSI) is used for channel estimation in order to change the constellation sizes of the M-ary Phase Shift Keying (M-PSK) modulation scheme in accordance with the fading severity. The analysis is carried out using randomly generated data in MATLAB application package.

The results obtained show that the Spectral Efficiency increases as the SNR increases, also as the antenna configurations increase, the average spectral efficiency also increases. This indicates that bandwidth is fully optimized at higher antenna configuration. Mobile wireless designers can find the results obtained useful in the design of improved wireless systems.

Keywords: *MIMO, Beamforming Mode, Spectral Efficiency, Multipath Fading, SNR*

1. INTRODUCTION

Wireless communication involves the processing and transmission of information from one point to another via electromagnetic waves in free space. The wireless communication system growing in popularity worldwide to help people and machines communicate with one another irrespective of locations. The most common wireless method to access data or voice dialing is the use of cellular system. The wireless communications system finds application in the internet connections with the laptop computers at any location [1]. Other applications are in Global Positioning Systems (GPS) units, garage door openers, wireless computer mouse, keyboards, satellite television and cordless telephones.

However, wireless communication faces a number of challenges such as signal fading and interference which result in distorted received signal. The radio channel is the major obstacle facing the transmitted signal. The radio signals are obstructed by other obstacles like tall buildings, human beings, mountains or many other natural and artificial obstacles, which make the signal to experience reflection, refraction, diffraction or superposition. Multiple copies of the transmitted signals arrive at the receiver at different times. These copies interfere destructively and result in poor quality of service, lower network capacity and overlapping of symbols called inter-symbol interference at high data rate [2].

Previous techniques developed to eliminate the problem of high error rates associated with the transmission of information over frequency non-selective fading channels are based on increasing the transmit power of the signal to be transmitted over the channel and the diversity combining techniques. These methods have been found to be inefficient and ineffective in frequency-selective Rayleigh fading channel. The conventional MIMO is also developed to solve this problem, this method utilizes multiple antennas at the transmitters and receivers to increase the link

Journal of Theoretical and Applied Information Technology
10th March 2013. Vol. 49 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

capacity as well as link reliability in point to point wireless link but the method is not effective in frequency selective fading channel [3].

In this paper, performance analysis of adaptive MIMO beamforming is carried out to improve the effect of the frequency selective fading in wireless communication system as compared to Ergodic capacity using the spectral efficiency as the performance metric. Beamforming is employed for directional transmission and /or reception of signals in a sensor array [4], that is, the beamformer has been incorporated in the combination of Adaptive modulation and MIMO in this paper to direct the antenna beams toward the desired user while canceling signal from other users. This electronically steer a phased array by weighing the amplitude and phase of signal at each array element in response to changes in the propagation environment. The criterion to be fulfilled in choosing the weights of array elements in order to optimize the beamformer is minimum mean-square error. System architecture for MIMO beamforming is obtained for 2x2, 3x3 and 4x4 antenna systems. The system model is simulated using MATLAB application package. Received signal strength indicator (RSSI) is used for channel estimation in order to change the constellation sizes of the M-PSK signaling scheme in accordance with the fading severity. Adaptive modulation M-PSK means changing the modulation order or the number of bits transmitted per symbol in a communication system to the favourable possible order based on the channel state information (CSI).

The results obtained show that the proposed adaptively modulated MIMO beamforming system performs better than the conventional MIMO beamforming system with the same number of transmit and receive antennas over frequency selective fading channel using the spectral efficiency as a performance metric.

2. SYSTEM ARCHITECTURE

The MIMO system employs antenna array at both the transmitter and the receiver. Figure 1 shows the system model for the adaptive modulation MIMO beamforming in a Frequency selective Rayleigh fading environment with 2, 3, 4 transmit and receive antennas.

2.1 Beamforming

Beamforming (BF) is the transmission of the same signal with different gain and phase over all transmit antennas such that the receiver is maximized using channel state information available from the feedback channel [4].

Since multiple input antenna and multiple output receivers are involved, therefore, analysis is carried out in vector form. The transmitter and receiver beamforming vectors are denoted by $\mathbf{W}_T$ and $\mathbf{W}_R$ respectively, where the power constraint $|\mathbf{W}_T|^2 = P_T$ is applied to the transmit beamforming vector.

According to [5, 6, 7, 8], the transmitted vector C(n) is given as

$$\mathbf{C}\,(n) = \mathbf{W}_T\,\mathbf{S}\,(n) \quad (1)$$

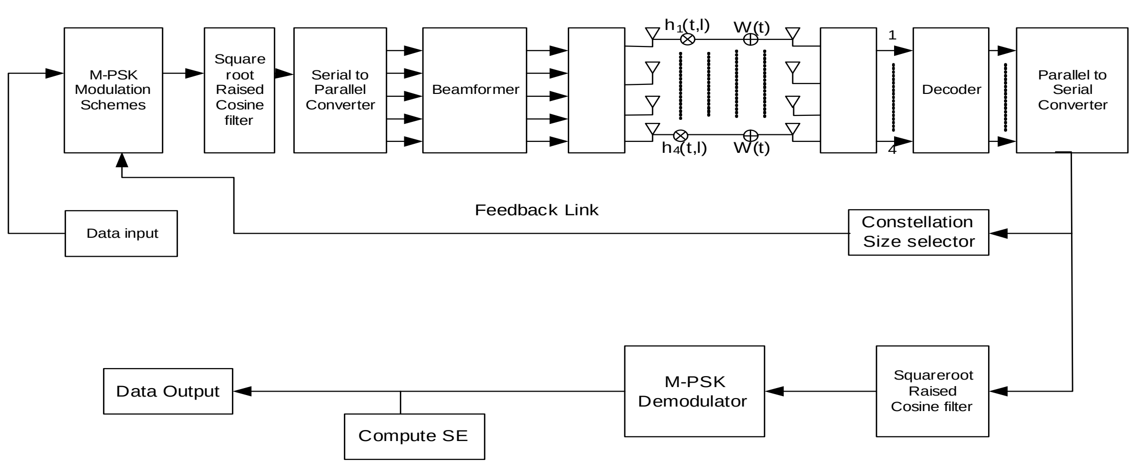


Figure 1: Simulation Model For Adaptive MIMO Beamforming For $N_T = N_R = 2, 3, 4$.

Journal of Theoretical and Applied Information Technology
10th March 2013. Vol. 49 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

2.2 Channel Prediction

Channel prediction based on pilot symbol assisted modulation (PSAM) was well documented for its merit as a counter-measure for fading channels [9, 10, 11, 12 and 13]. In this paper, the pre-known information bits are drawn as PSAM. The information bits are evaluated and from which the channel estimation is carried out. The spectral efficiency is also evaluated and the prediction is carried out.

2.3 Development of Adaptive Modulation for MIMO-BF under Frequency Selective Fading Channels

Beamforming utilizes the strongest sub-channel; hence, the combined average SNR $\bar{\gamma}_i$ can be expressed as

$$\bar{\gamma}_i = \gamma_0 \sum_{l=1}^{L} E\{\lambda_i(l)\} \quad (2)$$

where λ_i λ_1 is the strongest eigen mode and L is the multipath components.

Therefore, the effective SNR, γ on the major sub channel can be expressed as

$$\gamma = \frac{\gamma_i}{N_{mm}} \quad (3)$$

where $N_{mm} = \min\{N_T, N_R\}$

The discrete rate spectral efficiency, $DR_{bf}(\gamma_0)$ $DR_{bf}(\gamma_o)$ for a MIMO beamforming system is given by [14] as

$$DR_{bf}(\gamma_0) = \sum_{1}^{k} \Delta d_k e^{-\frac{\Gamma_k}{\gamma_0}} \left[\left(-\frac{\Gamma_k}{\gamma_0} \right)^2 + A - e^{-\frac{\Gamma_k}{\gamma_0}} \right]$$

$$DR_{bf}(\gamma_o) = \sum_{1}^{k} \Delta d_k e^{\frac{\Gamma_k}{\gamma_0}} \left[\left(\frac{\Gamma_k}{\gamma_0} \right)^2 + A - e^{\frac{\Gamma_k}{\gamma_0}} \right] \quad (4)$$

where γ_0 = the input SNR.

Γ_k = the SNR threshold

A = the number of antenna at the transmitter

Δd_k = the number of bit transmitted when the SNR threshold falls between interval Γ_k and Γ_{k+1}

Γ_k is given by

$$\Gamma_k = \frac{m_k - 1}{1.5} \ln \frac{1}{5P_b} \qquad \Gamma_k = \frac{m_k - 1}{1.5} \ln \frac{1}{5P_b} \quad (5)$$

where M_k = the modulation order and P_b = the target BER.

3. MATERIAL AND METHOD

Frequency selective Rayleigh fading channel is considered in this paper because it represents the relevant behavior and properties of real-world propagation in an urban or sub-urban environment. Long sequences of random bits data are gray encoded, modulated by M-PSK modulation schemes and properly filtered using square root raised cosine filter. The filtered signal is converted to two, three and four sub channel by serial to parallel converter depending on the number of antennas used for transmitting over the channel understudy. The corrupted signals through the different antennas at the receiver decode the signal, convert them back to single channel by parallel to serial converter. This is feedback to the constellation of M- PSK signaling schemes by the RSSI algorithm which gives the information about the channel, the process continues until reliable signal is obtained and SE computed.

3.1 Parameters for Simulation and Configuration

For the purpose of evaluation of how the proposed adaptively modulated MIMO beamforming (BF) system performs over the frequency selective Rayleigh fading channel, the parameters which closely associated with this scenario are used for the simulations. These are contained in the Table 1.

Table 1: System Parameters

Simulation parameter /type	value
Modulation scheme	M-PSK
Constellation size	[2, 4, 8, 16, 32, 64]
Antenna configuration	$N_T = N_R$ = [2, 3, 4]

Journal of Theoretical and Applied Information Technology
10th March 2013. Vol. 49 No.1

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

SNR (dB) 0:2:20	
Number of packets	3000
Maximum number of error realization	200
Signal bandwidth ‘B_s’	$200e^3$
Symbol period ‘T_s’	$1/B_s$
Time delay ‘τ’	$[0.1e^{-4}, 0.2e^{-4}]$
Target BER	1e-2,
Length of Y, lens SNR	7
SNR threshold	1.22
Filter	square root raised cosine filter

4. RESULTS AND DISCUSSION

The results obtained using the aforementioned parameters and configurations over the frequency selective rayleigh fading channel using RSSI algorithm to change the M-PSK signaling schemes constellation in accordance with the fading severity are presented in Figures 2 through 6. Figures 2, 3 and 4 show the result for the adaptive MIMO beamforming system with antenna configuration of 2x2, 3x3 and 4x4 system respectively, where Figure 5 shows result for MIMO beamforming without adaptive modulation scheme for 4x4 antenna configuration.

From Figures 3 and 4, it can be seen that there is a slight divergence between the ergodic capacity and the actual spectral efficiency as the SNR increases for the 2x2 and 3x3 adaptive MIMO BF but as the number of antenna configuration is increased as evident from 4x4 antenna configuration presented in Figure 4, the spectral efficiency converges toward the ergodic capacity with increased in SNR.

Figure 5 shows the spectral efficiency for MIMO-beamforming without the Adaptive Modulation. It can be seen that the actual efficiency does not diverge at same rate as in Figure 4 because the information about the channel is unknown to the signaling scheme.

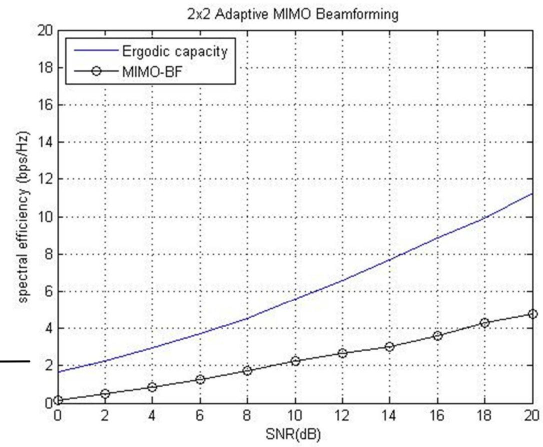


Figure 2: Adaptive MIMO beamforming curve for an 2 × 2 antenna system.

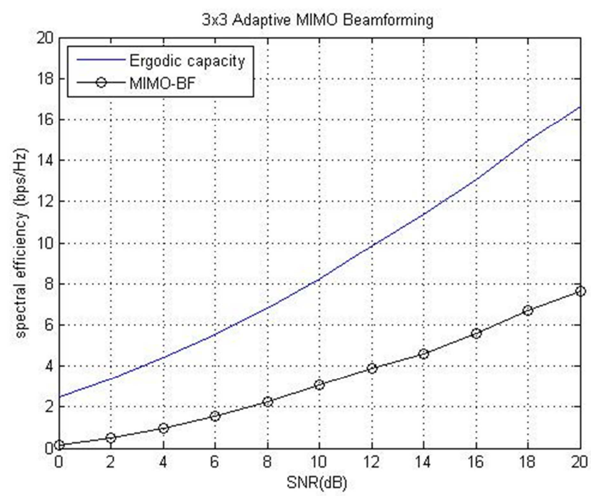
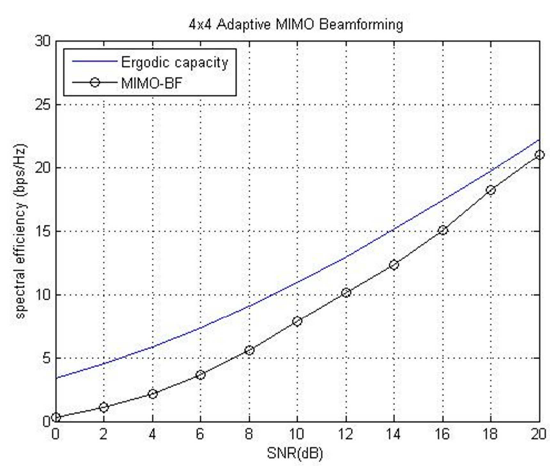


Figure 3: Adaptive MIMO beamforming curve for an 3 × 3 antenna system.



ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

Figure 4: Adaptive MIMO beamforming curve for a 4×4 antenna system.

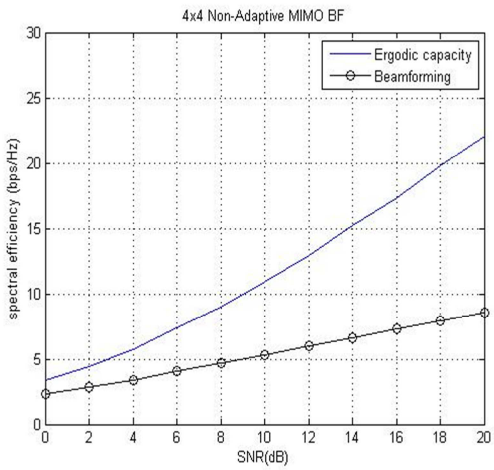


Figure 5: Non-Adaptive MIMO Beamforming Curve For An 4×4 Antenna System.

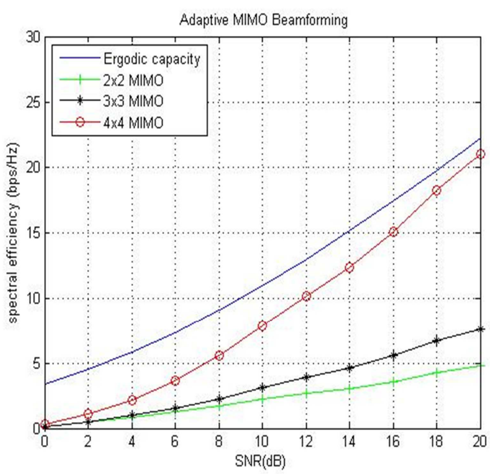


Figure 6: Adaptive MIMO Beamforming Curve For Different Antenna Configurations

The comparison results obtained in Figure 6 shows that 4×4 antenna system converges much more than with 3×3 antenna system. Also, non-adaptive MIMO system performs less compared to its adaptive counterpart MIMO system with same antenna configuration as evident in Figure 5. In fact, an adaptive MIMO system converges much in spectral efficiency with a non-adaptive system at higher antenna configuration. The same results are also contained in Table 2 for clarity.

The result obtained is justifiable in that the beamformer incorporated in adaptive modulation and MIMO improves the capacity through the effective co-channel interference cancellation. The use of statistical information of received data to select the weights also improves the performance. Also, the use of RSSI to switch the criteria to control the modulation mode due to its ability to a lower number of levels before any error occurred also adds to its improvement capacity. The proposed work in this paper is more attractive in term of implementation complexity.

Table 2: Adaptive MIMO Beamforming Systems With 2×2, 3×3, 4×4 Antenna Configurations And Non-Adaptive MIMO-Beamforming System With 4×4 Antenna Configuration

SNR (dB)	Adaptive 2×2 Antenna System	Adaptive 3×3 Antenna system	Adaptive 4×4 Antenna system	Non-adaptive 4×4 antenna system	Ergodic capacity for 4×4 antenna system
0	0.152	0.157	0.324	2.290	3.380
2	0.507	0.510	1.085	2.829	4.462
4	0.969	0.845	2.186	3.435	5.782
6	1.268	1.552	3.673	4.035	7.370
8	1.753	2.270	5.573	4.674	8.998
10	2.267	3.086	7.811	5.318	10.960
12	2.667	3.869	10.100	5.949	12.940
14	3.027	4.602	12.350	6.627	15.190
16	3.591	5.566	15.080	7.279	17.300
18	4.287	6.690	18.190	7.938	19.820
20	4.744	7.626	21.010	8.601	22.060

It is evident that as the SNR increases, the actual spectral efficiency approaches the ergodic capacity of the MIMO system as the antenna configuration is improved upon.

5. CONCLUSION

In this paper, adaptive modulation of MIMO beamforming performance has been evaluated using spectral efficiency as the performance metric over frequency selective Rayleigh fading channel. The physical

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

phenomenon has been represented accordingly 100 frame length of digital information with maximum number of packets of 300 are transmitted. Threshold for the different modulation orders are obtained with SNR, adaptive modulation of the transmit data is deployed starting from 64 as the highest constellation size. The results have shown that adaptive MIMO beamforming performs better than the non-adaptive MIMO beamforming system with the same antenna configuration. Again, the spectral efficiency improves as the number of antenna configuration increases with increase SNR.

Therefore, this paper has been able to show that by harnessing the adaptive modulation and MIMO-BF together with appropriate switching criterion to control the modulation modes in a communication system, the spectral efficiency can be greatly improved better than increasing the number of transmit and receive antenna as in conventional MIMO.

This work which considers frequency selective channel that result in ISI at high data rate with the aforementioned parameters contained in Table 1 is in agreement with Huang and Signell, (2011) where only uncorrelated Rayleigh fading was considered with 2x2 antenna configuration. This investigation can effectively be used to design a practical MIMO beamforming wireless system with adaptive modulation using RSSI switching control. The study can also be used to design a robust, high data rate transmission system, for many numbers of users amid limited spectrum.

REFERRENCES

[1] E.A. Jorswieck and Boche (2004), “Performance Analysis of capacity of MIMO Systems under multiuser Interference based on Worst Case Noise Behaviour” Eurasip Journal on wireless communications and Networking. vol. 2004, no. 2, pp 278 - 285.

[2] S. Bernard (1997), “Rayleigh fading channels in mobile digital communication system” IEEE communications magazine. vol. 35, no 7, pp 90 – 100 (Part I), pp.102 – 109 (Part II)

[3] G. J. Foschini and M. J. Gans, (1998), “On limits of wireless communications in a fading environment when using multiple antennas,” Wireless Personal Communications, vol. 6, pp.311-335.

[4] W. Mattias (2002) “On MIMO systems and Adaptive Arrays for Wireless Communications, Analysis and Practical Aspects”, Unpublished Ph.D. thesis, Signals and Systems, Uppsala University, Uppsala, Sweden.

[5] Tsoulos, G. M. Beach and J. McGeehan, (1998), “Space division multiple access (SDMA) field trials. Part 2: Calibration and linearity issues,” IEE Proceedings - Radar, Sonar and Navigation, vol. 145, no. 1, pp. 79–84.

[6] G. M. Jongren and B. Ottersten (2000), “Combining transmit beamforming and Orthogonal Space-Time Block Codes by utilizing side information,” in Proceedings IEEE Sensor Array and Multichannel Signal Processing Workshop, Cambridge, USA, pp. 153–157.

[7] R. M. Mathew, L. B. Kay, Collings, F. Antonio, and W. H. Robert (2007) “Multiplexing/Beam forming Switching for coded MIMO in Spatially correlated channels based on closed-form BER Approximation” IEEE Transactions on Vehicular Technology, vol. 56, no. 5. pp. 2555-2567.

[8] M.Yutaka, K. Kiyotaka, O. Masayuki, and M.Takashi, (2005), “Investigation of diversity Techniques considering receiver structures in MIMO systems”, IEEE Communications society, pp 391-395.

[9] K. Meena, A.P. Kabilan (2009). A Simple Adaptive beamforming Algorithm with Interference Supression.

[10] H. Bengt (2006), On the Capacity of MIMO Channel – A Tutorial Introduction [online]. Norway: Norwagian University of Technology, Department of Telecommunications.

[11] Combination of MIMO and Beamforming technology for WIMAX, ZTE Corporation. Retrieved on March 5, 2011 from http://wwwen.zte.com.cn/en/solutions/wireless/wimax/

[12] M. A. Teaneda, J. Takada and K. Araki (2001): The Problem of the Fading Model Selection, IEICE Transaction of Communication Vol. E84-B, no 3, pp. 660-666.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[13] Z.Shengli, and B.G. Georgios (2003). How Accurate Channel Prediction needs to be for Transmit-Beamforming with Adaptive Modulation over Rayleigh MIMO Channels. IEEE Transaction on Wireless communication. Pp. 1-11.

[12] J. K. Cavers "An analysis of pilot symbol assisted modulation for Rayleigh fading channels," *IEEE Trans. on Vehicular Tech.*, vol. 40, no. 4, pp. 686–693, Nov. 1991.

[13] S. Ohno and G. B. Giannakis (2002) "Average-Rate Optimal PSAM Transmissions over Time-Selective Fading Channels," *IEEE transactions on Wireless Communications*, vol. 1, no. 4, pp. 712-720, October 2002.

[14] J. Huang, S. Signell (2011) "Adaptive MIMO Systems in 2 × 2 Uncorrelated Rayleigh Fading Channel" retrieved from www.google.com/adaptive-mimo-systems-in2x2-uncorrelated-rayleigh-fading-channel on September 4, 2011.