Journal Of Harmonized Research (JOHR)

Journal Of Harmonized Research in Engineering
1(1), 2013, 16-23

ISSN 2347 – 7393

Original Research Article

PERFORMANCE COMPARISON OF MULTI ANTENNA OFDM SYSTEMS IN RAYLEIGH AND RICIAN FADING CHANNELS USING QPSK MODULATION

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Abstract

OFDM (Orthogonal Frequency Division Multiplexing) technique has been widely adopted in many wireless communication systems due to its high data-rate transmission ability and robustness to the multipath fading channel. OFDM may be united with antenna arrays at the transmitter and receiver side to enhance the diversity gain and to improve the system competence on time-variant and frequency-selective channels, resulting in a multiple-input multiple-output (MIMO) composition. Multiple-input and single-output (MISO) is a case when the transmitter has multiple antennas and the receiver has a single antenna. Sometimes MISO technology is also called as transmit diversity technology. In this case, the same data is transmitted simultaneously from the two transmitter antennas. The receiver is then able to receive the optimum signal which it can then use to obtain and extract the required data. In this paper a comprehensive analysis of multi antenna MISO-OFDM systems based on the Bit Error Rate performance in Rayleigh and Rician channels is discussed and analyzed. Similarly, Single Input Multiple Output (SIMO) is a form of smart antenna technology for wireless communications in which a single antenna at the transmitter and multiple antennas are used at the destination (receiver). An early form of SIMO, known as diversity reception, has been used by the military, commercial, amateur, and short wave radio operators at frequencies below 30 MHz since the First World War. The other forms of smart antenna technology include Single input Single output (SISO), Multiple Input Multiple Output (MIMO) and Multiple Input Single Output (MISO). A comprehensive literature survey on the performance analysis of different combining techniques in Rayleigh fading channels for multi antenna SIMO is also analyzed in this paper.

Keywords— MISO, Multi antenna, Rayleigh, Rician

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Received on: September 2013
Accepted after revision: September 2013

1. Introduction

The benefit of using MISO is that the multiple antennas and the redundancy coding/processing is stimulated from the receiver to the transmitter. In most instances such as cell phone user equipments, this can be an important advantage in terms of space for the antennas and decreasing the level of processing required in the receiver for the redundancy coding. This has a very positive influence on size, cost and battery life as the lower level of processing requires less battery usage.

The MIMO technology can be used for spatial multiplexing, diversity and/or beamforming, but all these goals at full scale cannot be accomplished at the same time. These objectives are always opposing one another. When a MIMO system is used in a Line of Sight (LOS) environmental background, the realizable beamforming gain is N_t / N_r, with N_t at the transmitter and N_r at the receiver, however, there is no diversity gain since there is no fading. In a heavy and deep scattering or distributed environment, the diversity order is $N_t N_r$, but the maximum beamforming gain is upper-limited by $(\sqrt{N_t} + \sqrt{N_r})^2$ [1]. Additionally, the transmit diversity and beamforming methods are two complementary and balancing techniques. The former provides diversity with no array gain, while the latter provides full array gain with no diversity.

The gain of spatial multiplexing (G_{sm}) can be defined mathematically as follows [2]

$$G_{sm} = \lim(\bar{\gamma} \to \infty) \frac{Cout(\bar{\gamma})}{\log_2 \bar{\gamma}}$$

where C_{out} is the outage capacity expressed in bits/s/Hz and $\bar{\gamma}$ is the average Signal to Noise Ratio. Similarly, the diversity gain G_d can be obtained by approximating or estimating P_e or P_{out} at high Signal to Noise Ratio and it is expressed mathematically as follows

$$P_e \approx \gamma^{-G_d} \text{ or } P_{out} \approx \gamma^{-G_d}$$

The signal is transmitted over several different propagation paths. In the case of wired transmission, this can be achieved by transmitting via multiple wires. In the case of wireless transmission, it can be achieved by antenna diversity using multiple transmitter antennas (transmit diversity) and/or multiple receiving antennas (reception diversity). In the latter case, a diversity combining technique is applied before further signal processing takes place. If the antennas are far apart, for example at different cellular base station sites or WLAN access points, this is called macro diversity or site diversity. If the antennas are at a distance in the order of one wavelength, this is called micro diversity. A special case is phased antenna arrays, which also can be used for beam forming, MIMO channels and space–time coding (STC).

In section 2, the space diversity reception methods for SIMO-OFDM systems is analyzed. In section 3, the space diversity transmission methods for MISO-OFDM are reviewed. In section 4, the performance analysis of Rayleigh and Rician Channels in different transmission and reception techniques for Multi Antenna OFDM Systems based on Bit Error Rate versus Signal to Noise Ratio is evaluated and in section 5 the performance analysis of Rayleigh channels in different combining techniques for Multi Antenna OFDM systems based on the Signal to Noise Ratio (SNR) Versus the Number of Receive Antennas is evaluated followed by the conclusion in section 6.

2. Space Diversity Reception Methods For Simo-Ofdm Systems

Space diversity, also known as antenna diversity, is one of the most popular forms of diversity used in wireless system. Conventional wireless system consists of an elevated base station antenna and a mobile antenna close to the ground. The existence of a direct path between the transmitter and the receiver is not guaranteed and the possibility of a number of scatterers in the vicinity of the mobile suggests a Rayleigh fading signal.

The concept of antenna space diversity is also used in base station design. At each cell site, multiple base station receiving antennas are used to provide diversity reception. However, since the important scatterers are generally on the ground in the vicinity of the mobile, the base station antennas must be spaced considerably far apart to achieve decorrelation. Separations on the order of several tens of wavelengths are required at the base station. Space diversity can thus be used at either the mobile or base station, or both. Space diversity reception methods can be classified into three categories:

2.1 Selection Diversity Combining:

Selection diversity is the simplest diversity technique. Here M demodulators are used to provide m diversity branches whose gains are adjusted to provide the same average SNR (signal to noise ratio) for each branch. The receiver branch having the highest instantaneous SNR is connected to the demodulator[3]. The antenna signals themselves could be sampled and the best one sent to a single demodulator. In practise, the branch with the largest (S+N)/N is used, since it is difficult to measure SNR alone. A practical selection diversity system cannot function on a truly instantaneous basis, but must be designed so that the internal time constants of the selection circuitry are shorter than the reciprocal of the signal fading rate.

2.2 Maximal Ratio Combining:

The signals from all of the M branches are weighted according to their individual signal voltage to noise power ratios and then summed. Here, the individual signals must be co-phased before being summed which generally requires an individual receiver and phasing circuit for each antenna element. Maximal ratio combining produces an output SNR equal to the sum of the individuals SNRs. Thus, it has the advantage of producing an output with an acceptable SNR even when none of the individual signals are themselves acceptable. This technique gives the best statistical reduction of fading of any known linear diversity combiner. Modern DSP techniques and digital receivers are now making this optimal form of diversity practical.

2.3 Equal Gain Combining:

In certain cases, it is not convenient to provide for the variable weighting capability required for true maximal ratio combining. In such cases, the branch weights are all set to unity, but the signals from each branch are co-phased to provide equal gain combining diversity. This allows the receiver to exploit signals that are simultaneously received on each branch. The possibility of producing an acceptable signal from a number of unacceptable inputs is still retained, and performance is only marginally inferior to maximal ratio combining and superior to selection diversity.

3. Space Diversity Transmission Methods For Miso-Ofdm Systems

The diversity of a space-time frequency selective fading channel is determined by the codeword dimensions and coherent parameters. Given a codeword duration T, the availability diversity can be up to T/T_c; for a bandwidth B, the independent frequency diversity branches can be up to B/B_c. For space diversity, the number of antennas N_t and N_r and their topology determine the diversity orders to be N_t/P_t and N_r/P_r, where P_t and P_r are the packing factors of the receive and transmit arrays, where the packing factor is the number of coherent distances occupied by at least one antenna. To achieve the maximum space diversity, the antenna arrays at both the receiver and the transmitter should be spaced apart. The maximum available diversity is thus given by [8,9] as follows

$$G_d = \frac{T}{T_c}.\frac{B}{B_c}.\frac{N_t}{P_t}.\frac{N_r}{P_r}$$

Space diversity transmission methods can be classified into three categories:

3.1 Selection Diversity Transmission:

Selection diversity transmission recognizes the site selection transmission diversity as a substitute for the full site transmission diversity which is used in the conventional Transmission Power Control (TPC) scheme. In selection diversity transmission, a Mobile Station (MS) normally chooses one of the active Base stations (BS's) having a very least path loss to the MS as a transmitting site, and then the MS sends the identity detection of this BS to all the active ones so that the output power of the non-minimum path loss BS's is reduced. The minimum or least path loss BS is focussed and addressed as the "primary BS".

The advantages of introducing Selection Diversity Transmission (SDT) are summarized as follows [4]. Firstly, since one of the BS's within an active set supplies an adequate power to the connected MS and the output power of the other BS's within the same active set is minimized to a higher extent, the enhancement in distortions can be completely neglected. In conventional TPC, since multiple BS's propagate the same forward link signal with a massive power, a number of Rake receiver fingers must be equipped in order to collect many paths given by the active BSs. Since only one active BS serves the MS as a transmitting site in STD mode, the number of paths which should be gathered by the RAKE Receiver is smaller than that necessary for conventional TPC. This feature makes the path capturing efficiency of SDT better than that of conventional TPC, given the same number of RAKE fingers. The power imbalance problems due to the TPC command reception error never happens because only one BS transmits the forward link signal during SHO state.

3.2 Maximal Ratio Transmission:

The most unfavourable propagation effect from which wireless communication systems suffer is the multipath fading. One of the common methods used by wireless communications engineers to battle multipath fadings is the antenna diversity technique [5]. A classical combining technique is maximum-ratio combining (MRC), where the signals from the received antenna elements are weighted such that the signal-to-noise ratio (SNR) of their sum is maximized finally. The MRC technique so far has been exclusively for receiving applications only. As there are more and more emerging wireless services, more and more applications may require diversity at the transmitter or at both transmitter and receiver to combat severe fading effects. Various transmit diversity techniques have been proposed in the literature. Another example of transmit diversity is a simple but effective scheme proposed by Alamouti [6], where a pair of symbols is transmitted using two antennas at first, and the transformed version of the pair is transmitted to obtain the MRC-like diversity. However, these transmit diversity techniques were built on objectives other than to maximize the SNR. That is, they are suboptimum in terms of SNR performance. Accordingly, the frame work of maximum ratio transmission (MRT) would be established here in terms of concept and principles. It can be considered the generalization of the maximum ratio algorithm for multiple transmitting antennas and multiple receiving antennas [7]. It also provides a reference for the optimum performance that a system may obtain using both transmit and receive diversity. Therefore, the focus of this document is on the analysis of the MRT scheme rather than on the implementation aspects.

3.3 Equal Gain Transmission:

The classical wireless investigations concentrated on the case where antenna diversity was deployed exclusively at either the transmitter or receiver side. When multiple antennas are only available at the transmitter, beamforming techniques such as selection diversity transmission (SDT), equal gain transmission (EGT), and maximum ratio transmission (MRT) have been used to exploit the diversity available from the multiple-input single output (MISO) wireless channel [9]. On the other hand, when multiple antennas are only available at the receiver, combining schemes such as selection diversity combining (SDC), equal gain combining (EGC), and maximum ratio combining (MRC) have been used to obtain diversity advantage from the corresponding single-input multiple-output (SIMO) wireless channel. When antenna diversity is employed at both the transmitter and receiver, the multiple-input multiple-output (MIMO) channel which came across in the memory less case is a matrix. Beamforming and combining can be used in MIMO communication channels, however the beamforming vector and receive combining vector must now be mutually designed to maximize the receive Signal to Noise Ratio. MIMO maximum ratio transmission and maximum ratio combining was addressed in [7] and shown to provide full diversity order. Systems using selection diversity transmission and maximum ratio combining were studied in [8] and also shown to provide full diversity order. Designing these vectors is non-trivial and in many cases involves an optimization problem that cannot be easily solved in real time systems. Equal gain transmission has more modest transmit amplifier needs than maximum ratio transmission since it does not require the antenna amplifiers to modify the amplitudes of the transmitted signals. This property allows the reasonably cheap amplifiers to be used at each antenna as long as the gains are very carefully coordinated.

In certain definite cases, it is not very suitable to provide for the varying weighting capability required for true maximal ratio combining. In such cases, the branch weights are all set to unity, but the signals from each branch are co-phased to provide equal gain combining diversity. This allows the receiver to exploit signals that are concurrently received on each branch [10]. The possibility of producing an acceptable signal from a number of unacceptable inputs is still retained, and performance is only marginally inferior to maximal ratio combining and superior to selection diversity.

4. Performance Analysis Of Rayleigh Channels In Different Transmission And Reception Techniques For Multi Antenna Ofdm Systems Based On Ber Versus Snr.

The channel is assumed to be a flat fading, in simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication. Generally, the channel experienced by each transmit antenna is independent from the channel experienced by other transmit antennas. For the i^{th} transmit antenna to j^{th} receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number. As the channel under consideration is a Rayleigh or a Rician channel, the real and imaginary parts are Gaussian distributed having a particular mean and variance. The channel experienced between each transmitter to the receive antenna is independent and randomly varying in time. In terms of simulation, the random binary sequence of +1's and -1's are generated. Then it is grouped into pairs of 2 symbols and then the symbols are sent in one time slot. The symbols are multiplied with the channel and then white Gaussian noise is added. The minimum among the four possible transmit symbol combinations is found out. Based on the minimum the estimate of the transmit symbol is chosen. It is then repeated for multiple values of Eb/No and then the simulation results are plotted.

SIMULATION PARAMETERS

Modulation used	QPSK
MIMO System analyzed	2 x 1(MISO) and 1 x 2(SIMO)
Number of parallel channels to transmit	512
No of guard symbols	128
FFT length	1024
Phase Rotations	0 to 2π
Window function	Blackman-Haris
HPA Model	SSPA
No of frames	10
Oversampling factor	4
No of OFDM symbols/ frame	4
Bandwidth	5 MHz

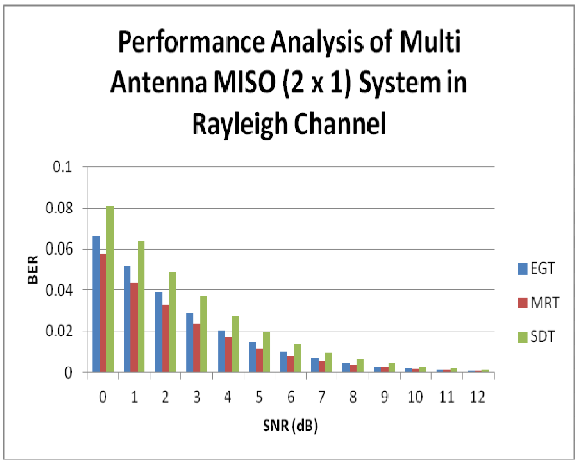

Fig. 1. Performance Analysis of Multi Antenna MISO- OFDM (2 x 1) System in Rayleigh Fading Channel.

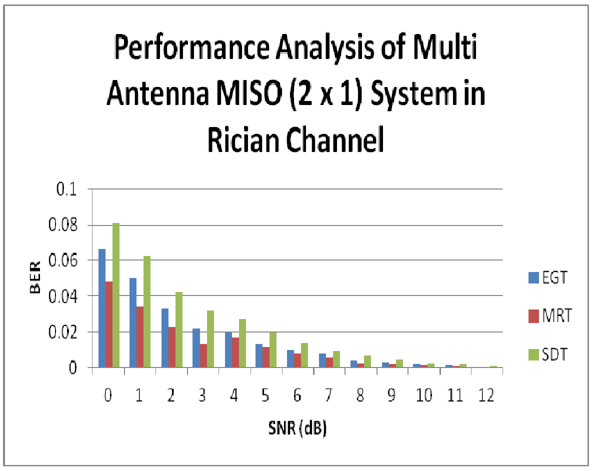

Fig. 2. Performance Analysis of Multi Antenna MISO-OFDM (2 x 1) System in Rician Fading Channel

On the careful analysis of the figures 1 and 2 it is apparent that the Maximal Ratio transmission produces a lower Bit Error Rate followed by Equal Gain transmission and then the Selection diversity transmission in both the Rayleigh and Rician Fading Channel conditions.

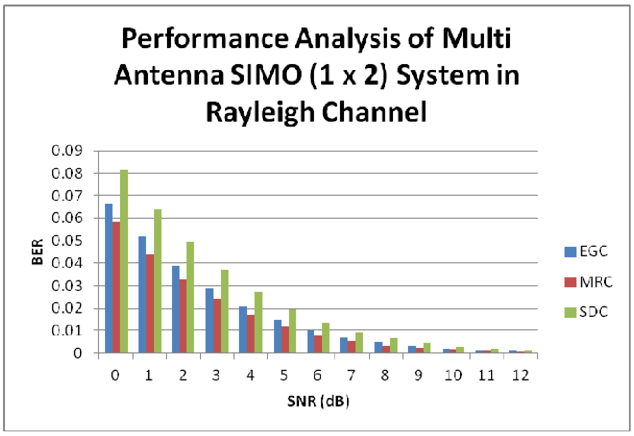

Fig. 3. Performance Analysis of different Combining Techniques in Multi Antenna SIMO Systems in Rayleigh Channel

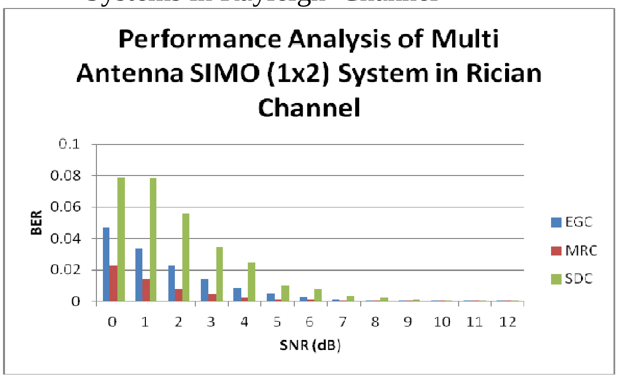

Fig. 4. Performance Analysis of different Combining Techniques in Multi Antenna SIMO Systems in Rician Channel.

On the careful analysis of the figures 3 and 4 it is apparent that the Maximal Ratio Combining produces a lower Bit Error Rate followed by Equal Gain combining and then the Selection diversity technique in both the Rayleigh and Rician Fading Channel conditions.

5. PERFORMANCE ANALYSIS OF RAYLEIGH CHANNELS IN DIFFERENT COMBINING TECHNIQUES FOR MIMO SYSTEMS BASED ON SNR VERSUS THE NUMBER OF RECEIVE ANTENNAS

The channel assumed here is a flat fading Rayleigh or Rician multipath channel and the type of modulation engaged here is Binary Phase Shift Keying. The scenario is considered that N receive antennas and one transmit antenna is present. The channel is flat fading, that is, in simple terms, it means that the multipath channel has only one tap. So, the convolution operation reduces to a simple multiplication. The channel experienced by each receive antenna is randomly varying in time. For the i^{th} receive antenna, each transmitted symbol gets multiplied by a randomly varying complex number . As the channel under consideration is a Rayleigh or Rician channel, the real and imaginary parts are Gaussian distributed having a particular mean and variance. The channel experience by each receive antenna is independent from the channel experienced by other receive antennas. On each receive antenna, the noise 'n' has the Gaussian density function. The noise on each receive antenna is independent from the noise on the other receive antennas. At each receive antenna, the channel is known at the receiver. In the presence of channel, the instantaneous bit energy to noise energy is considered and computed. In terms of simulation, initially the random binary sequences of +1's and -1's are generated. Then the symbols with the channels are multiplied and then the white Gaussian noise is added. The received path is chosen and then the received symbols per Maximal Ratio Combining or Equal Gain Combining or Selection Diversity Combining are equalized. Then hard decoding is performed and finally the bit errors are counted. For multiple values of Eb/No it is repeated and then the simulation results are plotted and the theoretical results are compared with the practical results.

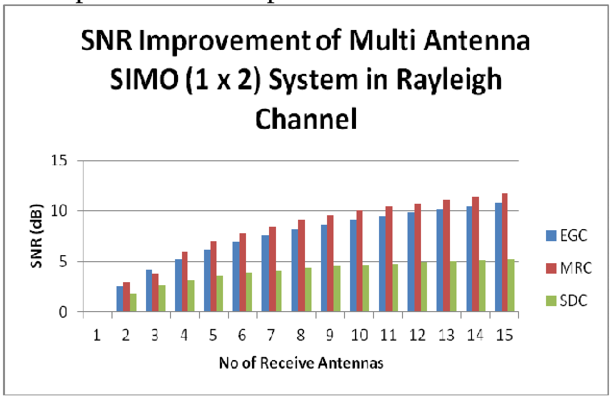

Fig. 3. Performance Comparison of SNR Improvement for Multiple Antenna (SIMO) in Rayleigh Channel

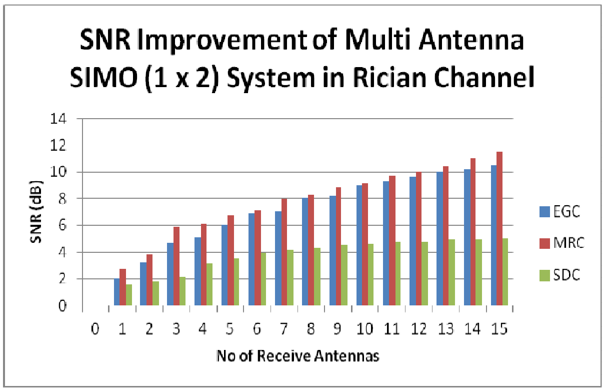

Fig. 4. Performance Comparison of SNR Improvement for Multiple Antenna (SIMO) in Rician Channel.

On the careful analysis of figure 4 and figure 5 it is evident that out of the three combining techniques, only Maximal Ratio Combining technique has a good signal to noise improvement when the number of receive antennas are increased when compared to the other two schemes in both the Rayleigh and Rician Fading Channels.

6. Conclusion

This paper gives an overview of the SIMO multi antenna OFDM techniques used in the wireless communication networks. A short survey on space diversity reception methods is also provided. Further the performance analysis of Rayleigh and Rician fading channels in different combining techniques based on the SNR versus BER is computed. It is concluded that the Maximal Ratio Combining scheme produces a very low Bit Error Rate when compared to the other two schemes. Also the performance analysis of Rayleigh and Rician fading channels with respect to the SNR improvement with different combining techniques is evaluated. It is observed that in the case of Maximal Ratio combining scheme when the number of receive antennas increase the corresponding SNR also shows great improvement when compared to the other two schemes. Also this paper gives a short introduction to MISO-OFDM Systems. A short survey on space diversity transmission methods is also provided. Further the performance analysis of Rayleigh and Rician fading channels in different transmission techniques based on the SNR versus BER is computed. It is observed that the Maximal Ratio transmission scheme produces a very low Bit Error Rate when compared to the other two schemes. Future works may incorporate the use of different modulation schemes under different channel conditions to produce a low Bit Error Rate. When comparing the SIMO-OFDM systems with the MISO-OFDM systems, the former produced a very low Bit Error Rate when compared to that of the latter. Future works may incorporate the study analysis of MIMO-OFDM Systems under different Channel conditions and under different modulation schemes.

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