Using Space Time Coding MIMO System for Software-Defined Radio to Improve BER

Mehul R Naik[#1], Abhishek Garg[#2], Aditya Aggarwal[#3]

[#1-3] *Electronics & Communication Department at Nirma University, Ahmedabad, India*

[1]mehul.naik@nirmauni.ac.in

[2]abhi08.garg@gmail.com

[3]aggarwal.aditya89@gmail.com

***Abstract* - The demand for mobile communication systems with global coverage, interfacing with various standards and protocols, high data rates and improved link quality for a variety of applications has dramatically increased in recent years. The Software-Defined Radio (SDR) is the recent proposal to achieve these. In SDR, new concepts and methods, which can optimally exploit the limited resources, are necessary. Multiple antenna system is one of those, which resort to transmit strategies, referred to as Space-Time Codes (STCs). It gives high quality error performance by incorporating spatial and temporal redundancy.**

The paper discusses the space-time block codes and highlights the trade-off between the number of transmitter and receiver antennas and the bit error rate. We simulate MIMO systems using M-ary Phase Shift Keying (PSK) and compare the results with Single Input Single Output (SISO) systems. This analysis can be helpful in choosing the desired modulation scheme depending upon the Bit error rate (BER) and Signal to noise ratio (SNR) requirements of the service.

***Keywords*- Antennas, MIMO Systems, Maximum Likelihood Detection, Space Time Coding, SDR.**

I. INTRODUCTION

The concept of integrated seamless global coverage of mobile communication systems requires that the radio support two distinct features: first, global roaming or seamless coverage across geographical regions; second, interfacing with different systems and standards to provide seamless services at a fixed location. To manage changes in networking protocols, services, and environments, mobile devices supporting reconfigurable hardware also need to seamlessly support multiple protocols. Such radios, known as Software-Defined Radios (SDR) can be implemented efficiently using software radio architectures in which the radio reconfigures itself based on the system it will be interfacing with and the functionalities it will be supporting. [1,2]. Space Time Coding and Multiple Input Multiple Output (MIMO) Antenna System are the techniques used in SDR among many techniques to improve the performance in hostile wireless environment [7].

MIMO systems refer to the use of multiple antennas at the transmitter and the receiver side. MIMO systems separate signal transmissions in a time and spatial domain. In the current mobile communication systems multipath fading presents one of the most problematic channel impairments. With the use of multiple antennas, multiple channel paths are created between the transmitter and receiver side. These channel paths are uncorrelated to each other. The probability of all the channel paths fading simultaneously is very low. Even if one of the channel paths fades away, other paths remain intact for transmission leading to low bit error rates.

The idea to exploit the multipath environment in conjunction with the use of antenna arrays on the receiver side and the transmitter side offers new ways to achieve higher capacities. MIMO systems aim to achieve capacities increasing linearly with a number N, which is the minimum of the number of antennas on the transmitter side and on the receiver side. Space-time coding [4] is a coding technique that is designed for use with multiple transmitter antennas. This technique introduces temporal and spatial correlation into signals transmitted from different antennas. The intention is to provide diversity at the receiver and coding gain over an uncoded system without sacrificing the bandwidth.

II. MIMO BASICS

A communication system, where N signals are transmitted from N transmitters simultaneously is considered. For each time slot t, signals $C_{t,n}$, $n = 1, 2, \ldots, N$ are transmitted simultaneously from N transmit antennas. The signals are the inputs of a multiple-input multiple-output (MIMO) channel with M outputs. Each transmitted signal goes through the wireless channel to arrive at each of the M receivers. In a wireless communication system with M receive antennas; each output of the channel is a linear superposition of the faded versions of the inputs perturbed by noise. Each pair of transmit and receive antennas provides a signal path from the transmitter to the receiver. The coefficient is the path gain from transmit antenna n to receive antenna m. Fig.1 depicts a baseband discrete-time model for a flat fading MIMO channel. Based on this model, the signal $r_{t,m}$, which is received at time t at antenna m, is given by

$$r_{t,m} = \sum_{n=1}^{N} \alpha_{n,m} C_{t,n} + \eta_{t,m} \qquad (1)$$

where $\eta_{t,m}$ is the noise sample of receive antenna m at time t.

Based on (1), a replica of the transmitted signal from each transmit antenna is added to the signal of each receive antenna. Although the faded versions of different signals are mixed at each receive antenna, the existence of the M copies of the transmitted signals at the receiver creates an opportunity to provide diversity gain as stated in [4].

III. TRANSMIT DIVERSITY

A. Alamouti Code :

Alamouti Code, the simplest of all the STBCs, is a code invented by S. Alamouti in 1998 [3]. The code is designed for two transmitter antennas. It provides a diversity of 2M for M receive antennas and therefore is a full diversity code as shown in [4]. It is coding technique with code rate 1 as both transmitter antennas send a block code consisting of two symbols in two time slots. Quasi-static fading channel is assumed, that is, the channel path gain doesn't change during the transmission of that block code.

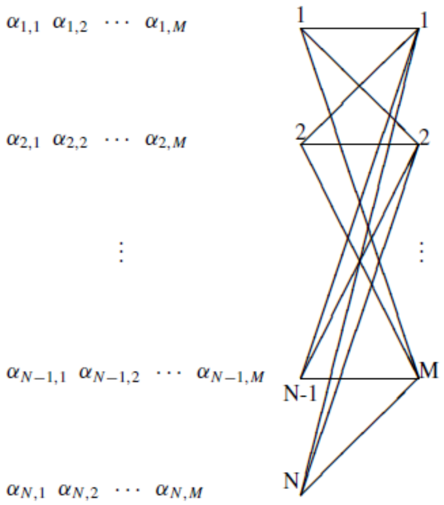

Fig.1 A Multiple-Input Multiple-Output (MIMO) channel

If s1 and s2 are the symbols to be transmitted, then the transmitter sends s1 from antenna one and s2 from antenna two at time slot one. Then at time slot two, it transmits −s2* and s1* from antennas one and two, respectively. Therefore, the transmitted codeword is

$$\mathbf{C} = \begin{pmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{pmatrix} \tag{2}$$

B. Generalised Space-Time Block Codes :

Alamouti code is a special case of STBC. It is designed only for two transmitter antennas. However in general practice the system can have any number of transmitter antennas. Hence there arises a need for codes that can be transmitted over a number of antennas. Such codes are called Generalized STBC [5, 6]. The maximum code rate that can be obtained for antennas more than 2 is ¾.

IV. RECEIVER DIVERSITY

Receive diversity places no particular requirements on the transmitter but requires a receiver that processes the received streams and combines them using algorithms such as selection combining and maximal ratio combining [4].

A. Selection Combining

Selection combining is the simplest type of combiner, in that it simply estimates the instantaneous strengths of each of the streams and selects the highest one. Since it ignores the useful energy on the other streams, SC is clearly suboptimal, but its simplicity and reduced hardware requirements make it attractive in many cases. This technique requires the receiver to continuoulsy scan the antennas and select the best one.

B. Maximum Ratio Combining

MRC uses a matched filter, which is optimum receiver, for each received signal and using the optimal weights determined from channel knowledge combines the outputs of the matched filters. MRC technique is much better compared to SC, but far complex and costly as it requires an RF block for each receiver antenna.

In our simulation, maximal ratio combining has been used. The following equations have been used to decode Alamouti code at the receiver.

$$\begin{aligned} \tilde{s}_1 &= \sum_{m=1}^{M} [r_{1,m}\alpha_{1,m}^* + r_{2,m}^*\alpha_{2,m}] \\ \tilde{s}_2 &= \sum_{m=1}^{M} [r_{1,m}\alpha_{2,m}^* - r_{2,m}^*\alpha_{1,m}] \end{aligned} \tag{3}$$

r_1 and r_2 are the signals received at receiver, α_1 and α_2 are the channel gains, $\check{s}_1$ and $\check{s}_2$ are the estimated symbols of the transmitted symbols s_1 and s_2

V. SIMULATION

A. Simulation Model

The simulated model shown in Fig. 2 works as follows:

For a particular value of SNR (Signal to Noise Ratio) a random bit stream is generated. This bit stream is converted to symbols using an M-ary PSK (Phase Shift Keying) modulation scheme. The generated symbols are encoded using space time coding and transmitted with Nt transmitters. These symbols are received by Nr receivers. Use of Nt transmitters and Nr receivers creates Nt x Nr channel paths between the transmitter side and receiver side. Each of these channel paths is represented by a channel model (mathematically represented by a path gain). White Gaussian Noise (WGN) is added to each channel randomly. The received signals are decoded by applying maximal ratio combining technique. The symbols are demodulated and the output bit stream so generated is compared with the input bit stream to calculate the number of bit errors. The number of iterations per SNR is 1000 which means that the above process is repeated 1000 times i.e. each time a random bit stream is generated and sent. The total number of bit errors divided by the total number of bits sent gives the Bit Error Rate (BER) for a particular value of SNR. The simulation is implemented using MATLAB.

B. Assumptions in the model

1) Quasi-static channel: Complex path gains remain constant for one time frame t'.
2) Path gains vary independently from one time frame to another.
3) The receiver has perfect estimate of the channel.

C. Objectives of the simulation

1) To compare the error rate performance of the conventional SISO systems with MIMO systems using Space-Time Coding.
2) To study the effect of using multiple receiver antennas on error-rate performance.
3) To demonstrate that MIMO systems along with M-ary PSK can be used to obtain an effective tradeoff between error performance and data-rates.

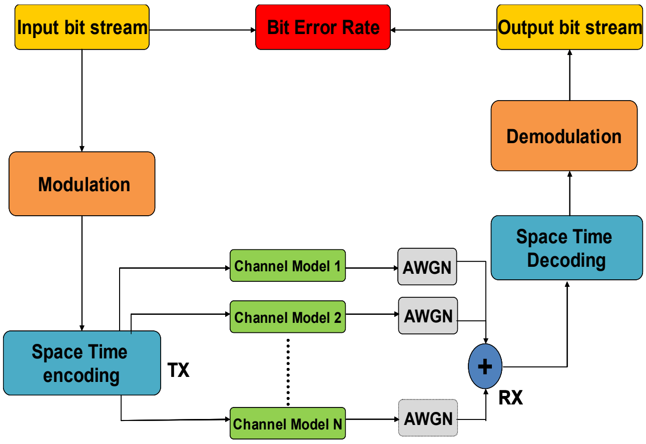

Fig.2. General block diagram of simulated model

D. Simulations

From Fig.3 it can be observed that the 2x1 MIMO system using space time coding gives better BER performance then SISO system given the same channel conditions, SNR values and data rates.

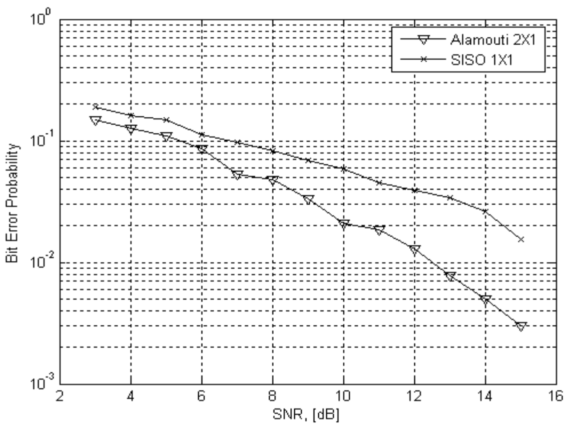

Fig.3. BER Vs SNR graph (simulated result) for 2x1 system (using Alamouti STC) and 1x1 system with QPSK modulation

Fig. 4 shows the expected theoretical result of simulation corresponding to Fig. 3 as given in [4].

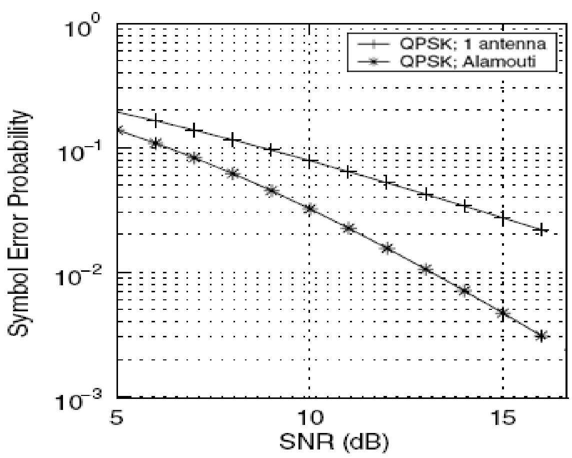

Fig.4. Theoretical result of 1x1 Vs 2x1 system

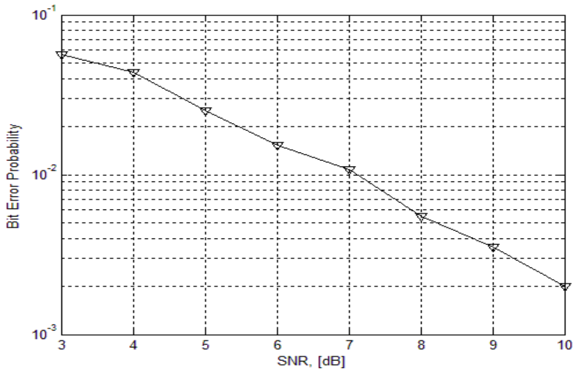

Fig.5. BER Vs SNR graph
(Simulated result) for 2x2 system with QPSK

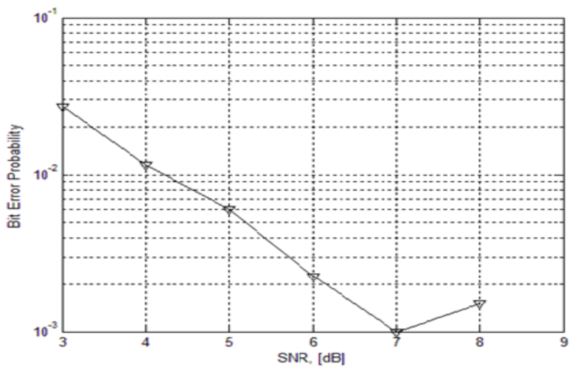

Fig.6. BER Vs SNR graph
(Simulated result) for 2x3 system with QPSK

From Fig.5 and Fig.6 it can be observed that 2x3 MIMO system gives better BER performance than 2x2 MIMO system.

While simulating space-time block codes using M-ary PSK schemes, as the value of M increases, the number of bits per symbol increase. This results in increase in bandwidth efficiency (bits/sec/Hz) accompanied by increase in error probability. This trade off between bandwidth efficiency and error probability is exploited by WiMAX systems.

1) For noisy environments where chances of transmission errors are more M is kept low (M=4) to keep error probability less even if it results in reduced bandwidth efficiency.
2) For less noisy channel where chances of transmission errors are very less M can be kept high (M=8, 16) in order to best utilize the available bandwidth.
3) Thus depending upon the BER and SNR requirement of the application, the modulation scheme can be chosen to utilize the bandwidth most efficiently.

This is the adaptive modulation employed by the Physical layer of WiMAX. Moreover, as an extension to adaptive modulation, a trade-off with power can also be done on the basis of the wireless environment i.e. one can use a variable number of antennas at the transmitter or the receiver (power consumed being proportional to the number of antennas) based on the requirement for BERs and data-rates. This is feasible with the integration of MIMO with SDR.

Fig.7 shows the simulation result of 2x1 system (Alamouti Code) using M-ary PSK schemes compared with SISO.

Fig. 8 shows the simulation of 2x2 system (Alamouti Code) using M-ary PSK schemes compared with SISO.

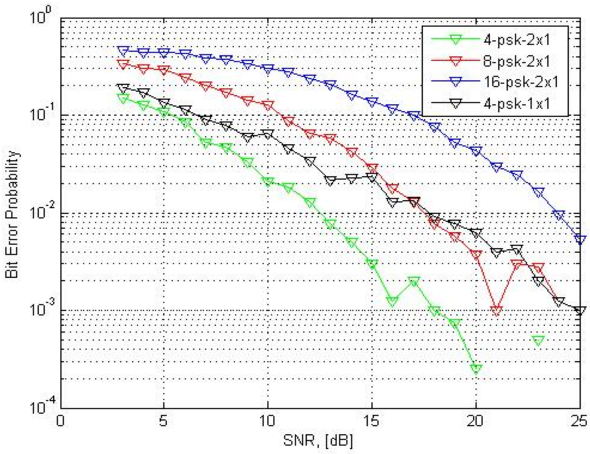

Fig.7. BER Vs SNR graph (simulated result) for 2x1 system with M ary PSK compared with 1x1 implemented through 4-PSK

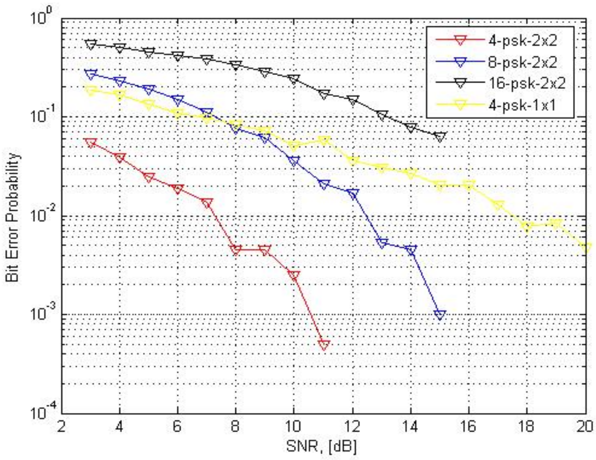

Fig.8. BER Vs SNR graph (simulated result) for 2x2 system with M ary PSK compared with 1x1 implemented through 4-PSK

TABLE I
OBSERVATIONS FROM SIMULATIONS

Simulation	Observation
Fig. 5 and Fig. 6 BER vs SNR graphs (simulated results) for 2x2 MIMO and 2x3 MIMO systems respectively	2x3 MIMO system gives better BER performance than 2x2 MIMO system.
Fig. 7 BER Vs SNR graph (simulated result) for 2x1 system with M-ary PSK compared with 1x1 implemented through 4-PSK	The 2x1 system using 4-PSK has a superior performance over 1x1 SISO system using same modulation scheme. 2x1 system using 8-PSK and 1x1 SISO system have similar BER performance above 17 dB SNR. As the modulation scheme used by 2x1 system is 8-PSK and that used by the 1x1 system is 4-PSK, it can be inferred that the data rate of the 2x1 8-PSK system would be double that of the 4-PSK SISO system while maintaining the same BER in this range of SNR.
Fig.8. BER Vs SNR graph (simulated result) for 2x2 system with M-ary PSK compared with 1x1 implemented through 4-PSK	The 2x2 system using 4-PSK has a superior performance over 1x1 SISO system using same modulation scheme. 2x2 system using 8-PSK and 1x1 SISO system have similar BER performance below 8 dB SNR. As the modulation scheme used by 2x2 system is 8-PSK and that used by the 1x1 system is 4-PSK, it can be inferred that the data rate of the 2x2 8-PSK system would be double that of the 4-PSK SISO system while maintaining the same BER in this range of SNR. Above 8 dB SNR, the 2x2 system with 8-PSK scheme gives better BER performance than the 1x1 SISO system. Thus, in range of SNR, it can be inferred that the 2x2 system with 8-PSK gives better BER as well as throughput.

From Fig.7 it can be observed that the overall BER performance of 2x1 MIMO system (using STC) is much better than the performance of 1x1 SISO system and Fig.8 shows that the overall BER performance of 2x2 MIMO system (using STC) is much better than that of 1x1 SISO system.

VI. CONCLUSION

- MIMO systems employing space time coding result in reduced bit error rates as compared to conventional SISO systems (Fig.3)
- Increase in number of receiver antennas increases the error performance since it results in greater number of channel paths existing between transmitter and receiver side (Fig.5 and Fig.6).
- Reduction in bit error rates with MIMO systems allows higher M-ary PSK schemes to be used which results in greater bandwidth efficiency (Fig.7 and Fig.8). This can allow an effective tradeoff between error rates and data rates.

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