A Spatial Modulation based BER analysis of MIMO System under Rayleigh Fading Channel using STBC codes and Complex Wavelet Transform

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Abstract

Because of the enormous capacity upsurge a MIMO systems offer; such systems gained a lot of interest in mobile communication research. One indispensable problem of the wireless channel is fading, which occurs as the signal follows multiple paths between transmitter and receiver antennas. Fading can be mitigated by diversity, which means that the information is transmitted not only once but several times, hoping that at least one of the replicas will not undergo severe fading. There are various coding methods, a main issue in all these schemes is the exploitation of redundancy to achieve high reliability, high spectral efficiency and high performance gain for MIMO-OFDM systems earlier. In this paper, we introduce an orthogonal spatial division multiplexing in which we divide the central signal streams into both time and frequency. Also to increase the spatial diversity we introduce spatial modulation along with STBC for our new MIMO-OSDM. Experimental results show that proposed system outperform the existing MIMO-OFDM system in terms of performance measure for various modulation schemes.

Keywords: Multiple Input multiple output (MIMO) system, Orthogonal Spatial Division Multiplexing (OSDM), Space Time Block Coding (STBC), spatial modulation, 4G wireless communications.

I. INTRODUCTION

High spectral efficiency and high transmission rate are the challenging requirements of future wireless broadband communications. In a multipath wireless channel environment, the use of Multiple Input Multiple Output (MIMO) systems leads to the accomplishment of high data rate transmission without escalating the total transmission power or bandwidth [1]. Multiple-Input Multiple-Output antenna systems are a type of spatial diversity. An effective & realistic way of approaching the capacity of MIMO wireless channels is to utilize space-time block coding in which data is coded through space & time to improve the reliability of the transmission, as redundant copies of the original data are broadcasted over independent fading channels [2, 3]. Then all the signal copies are collected at the receiver end in a best possible way to extort as much information from each of them as possible. In practice, wireless communications channels are time varying or frequency selective particularly for broadband & mobile applications. To deal with these challenges, a promising amalgamation has been exploited, namely, MIMO with Orthogonal Frequency Division Multiplexing (OFDM), MIMO-OFDM, which has previously been adopted for present & future broadband communication standards such as LTE or WiMax [5-9].

OFDM can diminish the effect of frequency selective channel. This is because OFDM is a multi-carrier transmission scheme, which divides the existing spectrum into many carriers, each one of them being modulated by a low-rate data stream. One popular combination of MIMO & OFDM is the STBC-OFDM.

Furthermore, this work is encouraged from such STBC-OFDM system to build up an orthogonal spatial division multiplexing system. In STBC coding is applied across multiple OSDM blocks to improve the system Performance inherent in MIMO-OFDM system. The coding allocates symbols along different transmit antennas & time slots. In this context, the STBC-OSDM system is one of most capable system configurations that is adopted for 4th generation mobile systems [10].

Figure 1: Example of 4x2 MMO (Multiple Input Multiple Output)

The transmission of radio waves through the atmosphere including the ionosphere is not an easy phenomenon to model. Atmospheric propagation can show a wide variety of behaviours based on the aspects like frequency, bandwidth of the signal, and types of antennas utilized, terrain & weather conditions. When there is no fading, the channel can be supposed to be additive. If the samples are independent of each other the additive noise is referred to as ‘white’ & then they are correlated are known as ‘colored’. The straightforward communication channel model is the Additive White Gaussian Noise model under which the
signal is exaggerated only by a constant attenuation. In wireless communication channels there will be more than one path in which the signal can travel amid the source & destination. The presence of these paths is due to atmospheric reflections, refractions & scattering. In a multipath fading environment if a line of sight (LOS) component is present then the channel is known as a Rician channel. On the other hand if there is no LOS component then the channel will be referred as the Rayleigh fading channel.

A. Introduction to fourth generation of communication system

The first-generation (1G) radio systems put away analog communication schemes to transmit voice over radio, such as Advanced Mobile Phone Services (AMPS), the Nordic Mobile Telephone (NMT) scheme, & the Total Access Communication System (TACS), which were developed in the 1970s & 1980s. The 2G systems were accumulated in the 1980s & 1990s, & featured the execution of digital technology, such as Global System for Mobile Communications (GSM), Digital-AMPS (D-AMPS), code-division multiple access (CDMA), & personal digital cellular (PDC); among them GSM is the mostly successful & widely used 2G system. 3G mobile technologies offer users with high-data-rate mobile access, which developed rapidly in the 1990s & is still budding today.

The three main radio air limit standards for 3G are wideband CDMA (WCDMA), time-division synchronous CDMA (TD-SCDMA), & CDMA 2000. The transmitted data rate of 3G is up to 144 kb/s for high-mobility traffic, 384 kb/s for low-mobility traffic, & 2 Mb/s in good condition. However, there are two restrictions with 3G. One is the tricky expansion to very high data rates such as 100 Mb/s with CDMA due to severe interference between services. The other is the difficulty of providing a phase of multirate services, all with different quality of service (QoS) & performance requirements, due to the restrictions required on the core network by the air interface standard. This design is encouraged by the growing demand for broadband Internet access. The challenge for wireless broadband access lies in providing an analogous quality of service (QoS) for similar cost contrasting wire line technologies.

B. Principles of space-time (MIMO) systems

Consider the multi-antenna system diagram shown in Figure 2. A compressed digital source in the form of a binary data stream which is supplied to a simplified transmitting block encompassing the functions of error control coding & (possibly joined with) mapping to complex modulation symbols (quaternary phase-shift keying (QPSK), M-QAM, etc.). The last produces several separate symbol streams which varies from independent to partially redundant to fully redundant. Each of them is then mapped onto one of the multiple TX antennas. Mapping can includes linear spatial weighting of the antenna elements or linear antenna space–time pre-coding. After upward frequency conversion, filtering & amplification, the signals are broadcasted into the wireless channel. At the receiver, the signals are captured perhaps by multiple antennas & demodulation & demapping operations are performed to recuperate the message. The level of intelligence, complexity, & a priori channel knowledge used in selecting the coding & antenna mapping algorithms can differ a great deal depending on the application. This determines the class & performance of the multi-antenna solution that is implemented.

Simple linear antenna array combining can present a more reliable communications link in the presence of unfavourable propagation conditions such as multipath fading & interference. A chief concept in smart antennas is that of beam forming by which one increases the average signal-to-noise ratio (SNR) through focusing energy into desired directions, in either transmit mode or receiver mode. Indeed, if one estimates the reaction of each antenna element to a given desired signal, & possibly to interference signal(s), one can optimally mingle the elements with weights chosen as a function of each element response. One can then exploit the average desired signal level or diminish the level of other components whether noise or co-channel interference.

Another dominant effect of smart antennas lies in the concept of spatial diversity. In the existence of random fading caused by multipath propagation, the probability of losing the signal fade away exponentially with the number of decor related antenna elements being used. A major concept here is that of diversity order which is defined by the number of decor related spatial branches accessible at the transmitter or receiver end. When combined together, leverages of smart antennas are shown to enhance the coverage range versus quality trade-offs offered to the wireless user.

As subscriber units (SU) are steadily evolving to become complicated wireless Internet access devices rather than just pocket telephones, the stringent size & complexity constraints are becoming somewhat more relaxed. This constructs multiple antenna elements transceivers a possibility at both sides of the link, even though pushing much of the processing & cost to the network’s side (i.e., BTS) still makes engineering sense. Clearly, in a MIMO link, the advantages of conventional smart antennas are reserved since the optimization of the multi-antenna signals is carried out in a larger space, thus providing extra degrees of freedom. In particular, MIMO systems can offer a joint transmit-receive diversity gain, and array gain upon coherent combining of the antenna elements.

![Figure 2: Space-time (MIMO) systems](image)
C. Transmission over MIMO systems

Although the information theoretical analysis can be bootstrapped to encourage receiver architectures (as was done, e.g., in [1], [2]), it usually carries a drawback in that it does not reflect the performance attained by actual transmission systems, since it only provides an upper bound recognized by algorithms/codes with an unlimited complexity or latency. The development of algorithms with a reasonable BER performance/complexity compromise necessitates realizing the MIMO gains in practice. Here, we summarize different MIMO transmission schemes, give the instinct behind them, and evaluate their performance.

D. General Principles

Current transmission techniques over MIMO channels characteristically fall into two classes: data rate maximization or diversity maximization schemes, although there has been a few effort towards unification in recent times. The first kind focuses on enhancing the average capacity behaviour. For exam ple, in the example shown in Fig, the aim is just to perform spatial multiplexing as we transmit as many independent signals as we have antennas for a specific error rate (or a specific outage capacity [2]).

More usually, however, the individual streams should be encoded mutually in order to guard transmission against errors caused by channel fading & noise and also interference. This leads to a second sort of approach in which one tries to curtail the outage probability, or equivalently exploits the outage capacity.

E. Structure of Assessment

The association steps of this paper is as follows. The Preliminary Section ends with a concise introduction of MIMO systems & its necessity in today’s communication. The part A, B, & C in introduction shows a brief description about fourth generation of communication, ideology of MIMO system & transmission over multiple input multiple output system.

Section II explains a common review & related work of different coding & multiplexing techniques in multiple antenna system, many techniques have been proposed for the MIMO systems which are classified in this section.

Section III provides the information about the fundamental problem definition & proposed methodology. This section is further sub-classified into numerous subsections like spatial modulation, spatial division multiplexing, space time coding scheme.

Section IV gives information about the simulation results; it also shows some comparative graphs which proved that the proposed approach surmount the traditional approach.

Section V shows the observations, discussion & tabular comparison of different researches reviewed in earlier sections & a general conclusion of the paper, regarding review is presented.

I. RELATED WORK

With the speedy improvement in wireless communications & the decreased cost of communication devices, wireless networks have become denser & denser while bandwidth efficiency becomes more & more important. It is common to consider that multiple communication devices conduct transmission & reception jointly in a distributed process.

Employing multiple-input multiple-output (MIMO) in wireless communication systems has been proven to present plenty of benefits in both increasing the system capacity and stae diness of reception in rich scattering atmosphere [11, 12]. To take benefit of these a space-time block coding (STBC)-oriented diversity scheme has been usually adopted in future wireless communication standards [13], for example 3GPP LTE, WiMax, etc. The STBC technique was originally proposed by Alamouti in [14], achieves transmit diversity exclusive of channel information. Although Alamouti’s STBC was initially designed for two transmit antennas & one receive antenna, this scheme has been generalized by Tarokh in [15] & enlarged to the system for four transmit antennas.

A space-time block coding (STBC) scheme was originally anticipated by Alamouti as an effective technique to achieve a transmit diversity gain [16]. Recently, increasing demands for high data rate wireless communication services requires data transmissions over wideband channels. The combination of STBC along with OFDM is deemed to be a promising solution for combating frequency-selective fading [17]. For both single carrier & multi-carrier transmission systems, the Alamouti scheme performs well if the channel is time-invariant over two successive symbol durations. The impact of a time-varying fading channel on the performance of Alamouti transmit technique has been explored in [18] for a single-carrier system & in [19] for an OFDM system. In both the papers, the spatial correlation amid the time-varying multipath Rayleigh fading sub-channels has not been taken into account. However, it has been revealed in [20] by simulations that the performance of a STBC-OFDM scheme depends not only on temporal correlation but also on spatial correlation.

Space time Block Coding is a set of realistic signal design techniques aimed at approaching the information theoretic capacity bounds of Multiple-Input Multiple-Output (MIMO) channels. Since the initial work of Alamouti [21], space-time coding has been a rapid growing field of research. In the last decade, numerous coding techniques have been proposed. These includes orthogonal (OSTBCs) [21]–[23], quasi-orthogonal (QOSTBCs) [24], [25] & non-orthogonal STBCs (NOSTBCs) [26]

The revolutionary works on the cooperative diversity address information-Theoretical aspects of cooperative networks examining achievable rate regions & outage probabilities. The outage analysis in [20] relies on the random coding argument & demonstrates that full
spatial diversity can be achieved employing such a rich set of codes. Laneman et al. [27] proposes the use of “conventional” orthogonal space-time block coding (STBC) in a “distributed” manner for realistic implementation of user cooperation. Nabar et al. [28], [29] evaluates distributed STBC operating in an amplify-&-forward (AF) mode through the derivation of pairwise error probability (PEP) terms. They show that the original design criterion for conventional STBC (i.e., rank & determinant criteria) still apply for the design of distributed STBC schemes under the supposition that appropriate power control rules are used at relays. A variety of equalization schemes, which were originally developed for single-input single-output (SISO) systems can be useful for distributed STBC as well. However, uncomplicated extensions result in an excessive complexity mainly for higher-order modulation schemes and/or long channel memory [30]. Among the equalization schemes studied for STBC, three of these deserve particular attention due to their low-complexity, specifically time-reversal STBC (TR-STBC) [31], single-carrier frequency-domain equalization for STBC (SC-STBC) [32], & orthogonal frequency division multiplexed (OFDM)-STBC [33].

An overview & comparison of these schemes can be found in [34]–[36]. In this paper, author extend the three abovementioned equalization schemes to a relay-assisted transmission scenario, carefully utilizing the fundamental Orthogonality of distributed STBC. Most of the existing literature on cooperative diversity assumes frequency-flat fading channel. Together with the conference version of this paper [37], there have been only a few sporadic results accounts on the broadband cooperative transmission techniques for frequency-selective channels. Yatawatta et al. [38] proposes an OFDM cooperative diversity system assuming AF relaying & derive upper bounds on the channel capacity. They also examine the achievable diversity order for distributed cooperative OFDM supposing a non-fading inter-user channel. Barbarossa et al. [39] examines the performance of a distributed OFDM-STBC technique through a simulation study considering both AF & decode-and-forward (DF) relaying. Building upon their preceding work on distributed STBC [40], Anghel et al. [41] studied the performance of a relay-assisted uplink OFDM-STBC scheme & derive an expression for the symbol error probability assuming DF with no error propagation. To the best of our knowledge, the conference version of the current paper [37] is the first effort to investigate TR-STBC & SC-STBC in a relay-assisted transmission scenario (and OFDM-STBC along with the above mentioned papers [38], [39], [41]).

Fu Hong-liang et al., has anticipated a novel cyclic space-time block code (STBC) scheme in MIMO CDMA system. In modern wireless communications multiple input & multiple output (MIMO) is a very promising scheme. MIMO functions are mainly diversity, beam forming. And the diversity can be achieved by means of space-time coding (STC). STC has two ways one is space-time trellis codes (STTC) & the other one is space-time block codes (STBC). STBC provides diversity with less encoding & decoding difficulty. STBC employs linear processing at the receiver side. In this cyclic STBC first the input symbols are broken into blocks, then each block has M symbols & these symbols are circularly encoded into M groups.

Valipour et al., has projected that space-time block codes for Multi-carrier code-division-multiple-access (MCCDMA) systems [42]. Now a day there is vast demand for wideband wireless networks, especially for wireless sensor & adhoc networks.

Min Shi et al., has proposed permutation spreading by utilizing STBC code matrix, for MIMO-CDMA systems. Assigning different spreading sequences for different antennas is known as permutation spreading. The signal can be modulated with the help of BPSK or QPSK then it is spread with the different spreading sequences. As compared to the conventional & other methods this method provides better performance and enhanced bit error rate [43].

II. PROPOSED MIMO SYSTEM

The figure below shows the transmitter side block diagram of proposed scheme

![Input Data](Image)

**Spatial Modulation**

Data encoding using
Space time Block codes

**Multiplexing using our orthogonal spatial division multiplexing**

Channel with Fading Environment

This Spatial Division is done using
Discrete Wavelet transform

**Figure 3:** Shows the transmitter side model of proposed work, we have to send only constellation points with respect to antenna number.

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Perfect Channel Estimation

De-multiplexing using orthogonal spatial division multiplexing

Data decoding using Space time Block codes

Output Data

Figure 4: Shows the receiver side model for the proposed work.

Perfect channel estimation is done to find best suited channel. Also, Channel consists with Rayleigh Fading Environment.

Furthermore, this paper also explains a detailed view of technologies used in the proposed work as follow:

III. SPATIAL MODULATION

Spatial modulation (SM) is a recently developed transmission technique that uses multiple antennas. The basic idea is to map a block of information bits to two information carrying units:

A symbol that was chosen from a constellation diagram and

A unique transmit antenna number that was chosen from a set of transmit antennas.

The use of the transmit antenna number as an information-bearing unit increases the overall spectral efficiency by the base-two logarithm of the number of transmit antennas. At the receiver, a maximum receive ratio combining algorithm is used to retrieve the transmitted block of information bits. Here, we apply SM to orthogonal spatial division multiplexing (OSDM) transmission.

In general, any number of transmit antennas and any digital modulation scheme can be used. The constellation diagram and the number of transmit antennas determine the total number of bits to be transmitted on each sub-channel at each instant.

The combination of BPSK and four transmit antennas in this illustration in a total of three information bits to be transmitted on each sub-channel. Instead, four quadrature-amplitude modulation (QAM) and two transmit antennas can be used to transmit the same number of information bits, as shown in Table below. The number of bits that can be transmitted on each OSDM sub-channel for a system that uses a QAM constellation diagram of size $M$ ($m = \log_2(M)$) and $N_t$ transmit antennas.

$$\tilde{m} = \log_2(N_t) + m$$  \hspace{1cm} (1)

This shows that the constellation diagram and the number of transmit antennas can be traded off for any number of transmitted information bits. In addition, SM increases the spectral efficiency by the base-two logarithm of the total number of transmit antennas.

In SM, a block of any number of information bits is mapped into a constellation point in the signal domain and a constellation point in the spatial domain. At each time instant, only one transmit antenna of the set will be active. The other antennas will transmit zero power. Therefore, ICI at the receiver and the need to synchronize the transmit antennas are completely avoided. At the receiver, maximum receive ratio combining (MRRCC) is used to estimate the transmit antenna number, after which the transmitted symbol is estimated. These two estimates are used by the spatial demodulator to retrieve the block of information bits.

TABLE I. SM MAPPING TABLE

<table>
<thead>
<tr>
<th>Input bits</th>
<th>$N_t=2$, $M=4$</th>
<th>$N_t=4$, $M=2$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Antenna number</td>
<td>Transmit symbol</td>
</tr>
<tr>
<td>000</td>
<td>1</td>
<td>+1+j</td>
</tr>
<tr>
<td>001</td>
<td>1</td>
<td>-1+j</td>
</tr>
<tr>
<td>010</td>
<td>1</td>
<td>-1+j</td>
</tr>
<tr>
<td>011</td>
<td>1</td>
<td>+1+j</td>
</tr>
<tr>
<td>100</td>
<td>2</td>
<td>+1+j</td>
</tr>
<tr>
<td>101</td>
<td>2</td>
<td>-1+j</td>
</tr>
<tr>
<td>110</td>
<td>2</td>
<td>+1+j</td>
</tr>
<tr>
<td>111</td>
<td>2</td>
<td>+1+j</td>
</tr>
</tbody>
</table>

b/symbol/subchannel

IV. ORTHOGONAL SPATIAL DIVISION MULTIPLEXING

In our work the spatial division multiplexing is performed using discrete wavelet transform as fast Fourier transform used in orthogonal frequency division multiplexing can split the signal into frequency signal only. The transform of a signal is just another form of representing the signal. It does not change the information content present in the signal. The Wavelet Transform provides a time-frequency representation of the signal. It was developed to overcome the short coming of the Short Time Fourier Transform (STFT), which can also be used to analyze non-stationary signals. While STFT gives a constant resolution at all frequencies, the Wavelet Transform uses multi-resolution technique by which different frequencies are analyzed with different resolutions.

A wave is an oscillating function of time or space and is periodic. In contrast, wavelets are localized waves. They have their energy concentrated in time or
space and are suited to analysis of transient signals. While Fourier Transform and STFT use waves to analyse signals, the Wavelet Transform uses wavelets of finite energy.

The wavelet analysis is done similar to the STFT analysis. The signal to be analyzed is multiplied with a wavelet function just as it is multiplied with a window function in STFT, and then the transform is computed for each segment generated. However, unlike STFT, in Wavelet Transform, the width of the wavelet function changes with each spectral component. The Wavelet Transform, at high frequencies, gives good time resolution and poor frequency resolution, while at low frequencies, the Wavelet Transform gives good frequency resolution and poor time resolution.

OSDM is a multi-carrier modulation (MCM) technique. The MCM scheme as the name implies is a modulation technique in which multiple carriers are used for modulating the information signals. It is a suitable modulation used for high data rate transmission and is able to mitigate the effects of inter symbol interference (ISI) and inter carrier interference (ICI). In an SFDM scheme, a huge number of orthogonal, overlapping, narrow band sub-channels, transmitted in parallel subdividing the existing transmission bandwidth. The overlapping of the sub-channels do not create any problems since the peak of one subcarrier occurs at zeroes of other subcarriers. Orthogonality between the different subcarriers is achieved by using CWT. Figure 6 depicts the spectrum for 5 different frequencies where, \( 1/NT_s \) is the subcarrier spacing. We clearly see that for the red and green peaks the dashed lines cross from the zero crossings of the other carriers [29].

![Figure 5: Frequency-time Spectrum for 5 Orthogonal Subcarriers.](image)

V. TRANSCEIVER OF PROPOSED OSDM SYSTEM

The general block diagram of an OSDM transceiver has been shown in Figure 7. The digital data if first up-converted by a modulation scheme and then the symbols are put into parallel streams that the CWT block is going to work on. After ICWT is taken an appropriately sized cyclic prefix is appended at the end of the signal. Finally, the symbol is sent into the channel. This channel is either the AWGN or the flat fading Rayleigh channel. At the receiver the first task is to remove the cyclic prefix and then apply CWT. Afterwards, the parallel streams are serialized and then the symbols put through the demodulator for obtaining the input source data.

![Figure 6: OSDM Transmitter-Receiver Block Diagram](image)

VI. SPACE-TIME CODING

Space-Time Codes (STCs) have been implemented in cellular communications as well as in wireless local area networks. Space time coding is performed in both spatial and temporal domain introducing redundancy between signals transmitted from various antennas at various time periods. It can achieve transmit diversity and antenna gain over spatially un-coded systems without sacrificing bandwidth. The research on STC focuses on improving the system performance by employing extra transmit antennas, in general, the design of STC amounts to finding transmit matrices that satisfy certain optimality criteria. Constructing STC, researcher has to trade-off between three goals: simple decoding, minimizing the error probability, and maximizing the information rate. The essential question is: How can we maximize the transmitted data rate using a simple coding and decoding algorithm at the same time as the bit error probability is minimized?

A. Space-Time Coded Systems

Let us consider a space-time coded communication system with \( n_t \) transmit antennas and \( n_r \) receive antennas. The transmitted data are encoded by a space-time encoder. At each time slot, a block of \( m \cdot n_t \) binary information symbols

\[
\mathbf{c}_t = [c_{t1}, c_{t2}, \ldots, c_{t(m-n_t)}]^	op
\]
are fed into the space-time encoder. The encoder maps the block of m binary data in to nt modulation symbols from a signal set of constellation M = 2^m points. After serial-to-parallel (SP) conversion, the nt symbols
\[ s_t = [s_1^t, s_2^t, \ldots, s_N^t]^T \quad 1 \leq t \leq N \] (3)
are transmitted simultaneously during the slot t from nt transmit antennas. Symbol \[ s_i^t \quad 1 \leq i \leq n_t \] is transmitted from antenna i and all nt transmitted symbols have the same duration of T sec. The vector in equation above is called a space-time symbol and by arranging the transmitted sequence in an array a of nt x N space-time code-word matrix.

\[ S = [s_1, s_2, \ldots, s_N] = \begin{bmatrix} s_1^1 & s_2^1 & \cdots & s_N^1 \\ s_1^2 & s_2^2 & \cdots & s_N^2 \\ \vdots & \vdots & \ddots & \vdots \\ s_1^n & s_2^n & \cdots & s_N^n \end{bmatrix} \] (4)

Can be defined as The i-th row \[ s_i = [s_1^i, s_2^i, \ldots, s_N^i]^T \] is the data sequence transmitted from the i-th transmit antenna and the j-th column \[ s_j = [s_1^j, s_2^j, \ldots, s_N^j]^T \] is the space-time symbol transmitted at time j, 1 to N.

As already explained, the received signal vector can be calculated as
\[ Y = HS + N \] (5)
The MIMO channel matrix H co responding to n_t transmit antennas and n_r receive antennas can be represented by an n_r x n_t matrix:

\[ H = \begin{bmatrix} h_{1,1} & h_{1,2} & \cdots & h_{1,n_t} \\ h_{2,1} & h_{2,2} & \cdots & h_{2,n_t} \\ \vdots & \vdots & \ddots & \vdots \\ h_{n_r,1} & h_{n_r,2} & \cdots & h_{n_r,n_t} \end{bmatrix} \] (6)

Where the j-th element denoted by \( h_{j,i} \) is the fading gain coefficient for the path from transmit antenna i to receive antenna j. We assume perfect channel knowledge at the receiver side and the transmitter has no information about the channel available at the transmitter side. At the receiver, the decision metric is computed based on the squared Euclidian distance between all hypothesized receive sequences and the actual received sequence:

\[ d_H^2 = \sum_{t=1}^{n_t} \sum_{j=1}^{n_r} [y_j - \sum_{i=1}^{n_t} h_{j,i}^* s_i^t]^2 \] (7)

Given the receive matrix YS with smallest Euclidean distance \( d_H^2 \).

There are several distributions used to model the fading statistics. The most commonly used distribution functions for the fading envelopes are Rice, Rayleigh and Nakagami-m. Rayleigh is a special case of Nakagami-m, when m equals one. The fading models are related to some physical conditions that determine what distribution that best describe the channel.

- The Rayleigh distribution assumes that there are a sufficiently large number of equal power multipath components with different and independent phase.
- The Nakagami one distribution equals the Rayleigh distribution above. It is a general observation that an increased m value corresponds to a lesser amount of fading and a stronger direct path.

In Figure 8, a MIMO 4x4 system with Alamouti STBC algorithm is shown. The MIMO channels are shown in four colors to split them into four groups. The choice of a 4x4 MIMO instead of usual 2x1 or 2x2 is motivated by the necessity of increasing diversity in the space domain (and therefore robustness against fading effects) together with the spectral efficiency. Nowadays, a 4-element MIMO array can be implemented with affordable cost and the yielded performance improvement in terms of spectral efficiency may justify such an additional (non-prohibitive) cost.

**Figure 7:** The 4x4 MIMO-STBC system

### VII. RESULTS & DISCUSSION

In this section we will be presenting the link level performance of STBC and SM coded OSDM using either BPSK or QPSK modulation. All simulations have been carried out using the readily available MATLAB platform and writing dedicated functions for different parts. The simulation results obtained have been presented in four parts. The first part provides the bit error rate performance for BPSK modulated data transmitted over a Rayleigh fading channel. This is then followed by a performance analysis of OFDM over the AWGN channel using either BPSK or QPSK modulation. Third part demonstrates the BER vs. SNR for Alamouti STBC and Spatial modulation coded data transmitted over a Rayleigh fading channel without using OSDM. Finally, part four will provide STBC and SM coded OFDM performance when BPSK and QPSK are the preferred modulation and the channel is again the Rayleigh fading channel.

Simulations are carried out in MATLAB R2013b (Version 8.2.0.703), graphical user interface is created for the simulation of proposed work on MIMO systems. When there is a direct path between the transmitter and receiver the channel is usually referred to as the Rician channel and when LOS component is missing it will be referred to as the Rayleigh fading channel. In this section we demonstrate the BER performance of BPSK modulated data over a single path Rayleigh fading
channel. The analytical expression for the BER for BPSK modulated data in a Rayleigh fading channel is

\[
P_b = 0.5 \left( 1 - \sqrt{\frac{E_b}{N_0}} \right)
\]

And for the AWGN channel \(P_b\) is defined as:

\[
P_b = 0.5 \text{erfc} \left( \frac{E_b}{N_0} \right)
\]

The advantage in multiple antenna schemes is that they use a new dimension called space in addition to time. Multiplexing gain, antenna gain and diversity gain are three main benefits of MISO and MIMO type systems. Alamouti scheme is known as the first STBC. It uses two transmit antennas and \(N_r\) receive antennas. Alamouti STBC has a unity rate and can attain a diversity order of \(2^*N_r\). Spatial modulation (SM) is a recently developed transmission technique that uses multiple antennas. The basic idea is to map a block of information bits to two information carrying units: A symbol that was chosen from a constellation diagram and a unique transmit antenna number that was chosen from a set of transmit antennas.

SM is generally used when no information is available about the channel. In SM since two successive transmitted symbols are encoded into phase differences, then it is possible for the receiver to recover the transmitted information by comparing the phase of the current symbol with that of the previously received symbols.

This section will provide BER analysis for Alamouti STBC and SM over slow fading Rayleigh channels. For both schemes the simulations have been carried out using two transmit and one receive antenna.

**Figure 8:** Comparison of Bit error probability and symbol error probability with respect to signal to noise ratio in case of 4 antenna quadrature amplitude modulation.

**Figure 9:** Comparison of Bit error probability and symbol error probability with respect to signal to noise ratio in case of 2 antenna quadrature amplitude modulation.

**Figure 10:** Comparison of Bit error probability and symbol error probability with respect to signal to noise ratio in case of 4 antenna binary phase shift keying modulation.

**Figure 11:** Comparison of Bit error probability and symbol error probability with respect to signal to noise ratio in case of 2 antenna binary phase shift keying modulation.
OSDM BER performance was obtained over a Rayleigh fading channel. The usage of a multi-carrier modulation technique was seen to further improve the BER results obtained when data was transmitted after encoding by STBC or SM. For both BPSK and QPSK modulations the boost introduced to the BER performance by combining OSDM with the chosen transmit-diversity technique would become more significant after 6dB. At a BER of 10^-3 this difference in gain is around 4.5dB for STBC OSDM using BPSK and ~6dB for STBC OSDM using QPSK modulation. Then 2×1 DSTBC and OSDM is used back to back similar behavior is experienced however the BER performances are higher due to the fact that detection is done incoherently.

The improvement in BER performance when OSDM is used mainly comes due to the use of the guard interval. When the duration of the guard interval is selected larger than the maximum excess delay time of the radio channel this will help reduce the inter-symbol interference in a fading environment and help improve the BER results. Secondly since OSDM splits a broadband channel into multiple sub-channels this changes the behavior of each sub-channel to be flat fading and hence better performance can be observed.

I. FUTURE WORK

The work described herein mainly concentrated on MIMO-OSDM based systems for 4G. However the higher Generation communication systems must adopt OSDMA, a multi user version of OSDM as the IMT-Advanced standard dictates. Therefore the future work will involve simulating OSDMA physical layer along with MIMO transmit and receive diversity techniques.

Also some effective channel coding schemes like Convolutional Coding (CC), Turbo Coding (TC) or Low Density Parity Check (LDPC) coding could be employed for providing the flexibility of detecting and correcting errors that may occur during transmission. In information theory, TCs are a class of high-performance forward error correction (FEC) codes developed by Berrou in 1993. Via the use of these TCs performances that approach the channel capacity are possible. TCs have found use in 3G mobile communications and (deep space) satellite communications as well as other applications where designers seek to achieve reliable information transfer over bandwidth- or latency-constrained communication links in the presence of data-corrupting noise. A good competitor of TCs is the LDPC codes, which provide similar performance...
### TABLE II. Tabular Comparison on Some Surveyed Literature

<table>
<thead>
<tr>
<th>Author</th>
<th>Title</th>
<th>Summary</th>
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<tbody>
<tr>
<td>Christoph Studer</td>
<td>Energy-Efficient Spectrum Sensing for Cognitive Radio Networks</td>
<td>Author investigate an orthogonal frequency-division multiplexing (OFDM)-based downlink transmission scheme for large-scale multi-user (MU) multiple-input-multiple-output (MIMO) wireless systems. The use of OFDM causes a high peak-to-average (power) ratio (PAR), which necessitates expensive and power-inefficient radio-frequency (RF) components at the base station. In this paper, author present a novel downlink transmission scheme, which exploits the massive degrees-of-freedom available in large-scale MU-MIMO-OFDM systems to achieve low PAR.</td>
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<tr>
<td>Bang Hun Park</td>
<td>Efficient spectrum sensing in cognitive Radio using energy detection method with new threshold formulation</td>
<td>In this paper, author propose the Channel sounding scheme which is made for ideal communication between some application as well as the short distance of high speed data transmission in MIMO-OFDM system for Wireless PAN.</td>
</tr>
<tr>
<td>Linglong Dai</td>
<td>An energy efficient cooperative spectrum sensing scheme for cognitive radio networks</td>
<td>In this paper, author propose the time-frequency training OFDM (TFT-OFDM) transmission scheme for large scale MIMO systems, where each TFT-OFDM symbol without cyclic prefix adopts the time-domain training sequence (TS) and the frequency-domain orthogonal grouped pilots as the time frequency training information.</td>
</tr>
<tr>
<td>The-Hanh Pham&quot;</td>
<td>Energy-efficient spectrum sensing by optimal periodic scheduling in cognitive radio networks</td>
<td>In this paper authors consider two-way relaying systems consisting of two end users, N1 and N2, which exchange their information with the help of a relay y, R. The three terminals are equipped with multiple antennas.</td>
</tr>
<tr>
<td>Yuansheng Jin</td>
<td>Energy-Efficient Distributed Spectrum Sensing for Wireless Cognitive Radio Networks</td>
<td>In this paper, a new interference nulling based channel independent precoding for MIMO-OFDM systems of ntransmit and nr receive antennas with insufficient cyclic prefix (CP) is proposed.</td>
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<tr>
<td>Karthik Muralidhar</td>
<td>Energy-Efficient Cooperative Spectrum Sensing by Optimal Scheduling in Sensor-Aided Cognitive Radio Networks</td>
<td>In this letter, author present the VSSO Kalman channel estimator for doubly-selective multiple-input-multiple-output OFDM (DS-MIMO-OFDM) systems. Unlike the VSSO estimator in a DS-OFDM system, where all the pilot symbols had the same value, the pilot symbols need to be designed in a specific way to enable the feasibility of a VSSO estimator for a DS-MIMO-OFDM system.</td>
</tr>
<tr>
<td>Pierluigi Salvo Rossi</td>
<td>Energy-Efficient Spectrum Sensing and Access for Cognitive Radio Networks</td>
<td>This paper proposes two low-complexity two-dimensional channel estimators for MIMO-OFDM systems derived from a joint time-frequency channel estimator. The estimators exploit both time and frequency correlations of the wireless channel via use of Slepian-basis expansions. The computational saving comes from replacing a two-dimensional Slepian-basis expansion with two serially concatenated one-dimensional Slepian-basis expansions.</td>
</tr>
<tr>
<td>Johannes Georg Klotz</td>
<td>Energy and throughput efficient strategies for cooperative spectrum sensing in cognitive radios</td>
<td>In this paper, author consider a multiple-input-multiple-output-orthogonal frequency division multiplexing (MIMO-OFDM) downlink scenario, where each receiving mobile station has quality of service requirements, namely minimum rate requirements. For this problem author propose three heuristic resource allocation algorithms, which have a much lower complexity than the existing optimal solution (opt).</td>
</tr>
<tr>
<td>Y. Mlayeh</td>
<td>Cluster-Based Energy Efficient Cooperative Spectrum Sensing in Cognitive Radios</td>
<td>This paper proposes an advanced OFDM-MIMO reconfigurable architecture that uses an adaptive switching algorithm between diversity and spatial multiplexing. The transmitter blocs’ specifications such as the MIMO technique and the modulation scheme are adjusted according to the channel state, which gives a practical cognitive radio strategy. The</td>
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<tr>
<th>Md. Masud Rana</th>
<th>Energy-efficient cooperative spectrum sensing with relay switching based on decision variables for cognitive radio</th>
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<td>system cost- efficiency is performed by the application of the Software Defined Radio (SDR) technology. Based on the Demmel condition number criterion, an indicator bit exchange between the transmitter and the receiver allows selecting the adapted MIMO configuration and improving the whole system performances.</td>
<td></td>
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**II. REFERENCES & ALLUSIONS**