

**PERFORMANCE ANALYSIS OF TIME REVERSAL SPACE TIME
BLOCK CODES IN NAKAGAMI FADING CHANNEL**

Thesis submitted towards the partial fulfilment of requirement for the award of
degree of

MASTER OF ENGINEERING

IN

WIRELESS COMMUNICATION

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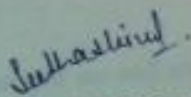
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DECLARATION

I, **Subhashini Dhiman**, hereby declare that the work, which is being presented in the thesis entitled "**Performance Analysis of Time Reversal Space Time Block Codes in Nakagami Fading Channel**" by me in partial fulfilment of the requirements for the award of degree of Master of Engineering in Wireless Communication from Thapar University (Deemed University), Patiala, is an authentic record of my own work carried out under the supervision of **Dr. Surbhi Sharma**, Assistant Professor, Electronics and Communication Engineering Department.


The matter presented in this thesis has not been submitted in any other University/Institute for the award of any other degree.

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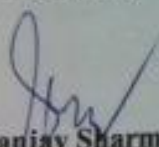

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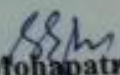
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ABSTRACT

The demand of improved spectrum efficiency, link reliability and coverage of wireless networks is increasing constantly. Meeting this demand is challenging since wireless communications systems are subjected to the effect of fading. Fading is most challenging phenomena in wireless communication to establish a reliable communication between transmitter and receiver. Use of multiple antennas along with appropriate signalling and receiver techniques in space-time wireless technology offers a powerful tool for improving the wireless performance.

Multiple antennas when used with appropriate space-time coding (STC) techniques can achieve huge performance gains in multipath fading wireless links. Space-time block codes have a most attractive feature of the linear decoding/detection algorithms and thus become the most popular among different STC techniques.

Space-time coding involves the transmission of multiple copies of the data. This helps to compensate for the channel problems such as fading and thermal noise. However, Space-time block codes (STBC) can obtain full transmit diversity gain in slow-fading environment. But it is not the case for STBC in fast-fading channel. In fast-fading, channel is no longer constant over a period of time. As a result of rapid time variation of the channel, the orthogonality of STBC is lost. This will cause error in decoding and hence the system performance is degraded. So, simple STBC transmit diversity scheme is capable of maximizing the diversity over frequency flat MIMO channel. For high data rate service, most channels cannot be considered frequency-flat anymore but are dispersive, causing inter-symbol interference. This frequency selectivity of the channel destroys the orthogonality of the transmitted STBC streams. Space-time coding for frequency-selective fading environments has attracted great attention.

TR-STBCs (Time Reversal Space Time Block Codes) extend STBCs transmission over frequency selective channels by encoding together conventionally ordered and time reversed contiguous blocks of symbols. First of all, BER performance of TR-STBC is evaluated for two transmitter and one receiver antenna and then compared with performance of STBC.

Generally, multipath fading amplitude distribution is modelled with Rayleigh channel. But, when fading is severe, Rayleigh model fails to characterize the exact channel characteristics. So, a more accurate model, named Nakagami-m model may use to represent the channel.

The BER performance of TR-STBC is simulated in Nakagami- m fading channel. A low complexity zero forcing receiver is evaluated to mitigate the effect of fading. The BER performance of TR-STBC is compared with classical zero forcing receiver. For Rayleigh fading ($m=1$) proposed scheme gives performance similar to the classical zero forcing. For slow fading ($m>1$) the BER performance of proposed scheme is improved. But for ($m<1$), its BER performance degrades.

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LIST OF ABBREVIATIONS

BER	Bit Error Rate
BLAST	Bell-Labs Layered Space Time
BPSK	Binary Phase Shift Keying
CSI	Channel State Information
DFSE	Decision Feedback Sequence Estimation
EDGE	Enhanced Data rates for GSM Evolution
FFT	Fast Fourier Transform
GSM	Global System for Mobile Communications
GPS	Global Positioning System
IEEE	Institute of Electrical and Electronics Engineers
ISI	Inter Symbol Interference
LTE	Long Term Evolution
LOS	Line Of Sight
MLSE	Maximum Likelihood Sequence Estimator
MIMO	Multiple Input Multiple Output
MISO	Multiple Input Single Output
ML	Maximum Likelihood
MRRC	Maximal Ratio Receiver Combining
MMSE	Minimum Mean Square Error
OFDM	Orthogonal Frequency Division Multiplexing
PDF	Probability Density Function
QoS	Quality Of Service
QAM	Quadrature Amplitude Modulation
QPSK	Quadrature Phase Shift Keying
Rx	Receiver
SNR	Signal to Noise Ratio
SISO	Single Input Single Output
SIMO	Single Input Multiple Output
SM	Spatial Multiplexing
STC	Space Time Coding
STBC	Space Time Block Codes
STTC	Space Time Trellis Codes

SC-FDE	Single Carrier-Frequency Domain Equalization
TR	Time Reversal
Tx	Transmitter
WLAN	Wireless Local Area Networks
WAN	Wireless Wide Area Networks
Wi-MAX	Worldwide Interoperability for Microwave Access
WCDMA	Wideband Code Division Multiple Access
ZF	Zero Forcing

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1.1 Introduction to Wireless Communication:

In recent years, requirement of high data rate wireless communication system has enlarged considerably. To assure this vast communication demand, new techniques which are utilizing the narrow resources like power and bandwidth should be as efficient as possible. For future communication systems multiple input multiple output antennas at both transmitter and receiver ends are used as a capable solution because they give high data rate by utilizing spatial domain but at the cost of restricted bandwidth and power required for transmission. By utilizing multiple transmit and receive antennas, the performance of wireless communication system can be improved, which is MIMO technique and has been included into one of the Wi-Fi systems. In recent years, Wireless communication has developed from an elective convenience to an essential need in everyday life. It has gained the consideration of the media. Vast range of wireless communication services is established by the progress in digital computing and radio transmission techniques.

Better technologies of antenna and the less costs, easy operation and more flexibility, improved reliability and the demand for mobile communication is the main cause of the increasing popularity of the wireless communication. The isolated area is one of the examples of those cases where wireless connections can be the only option. History of Fixed wireless system is elongated, but mobile wireless paging and telephony has gaining popularity recently. Phone and cable TV companies operate the networks which uses the microwave point to point connections for data and voice communication. These connections are also used by the government agencies and paging and railways companies. In future, the use of point to point microwave connections will continue to be an essential component of the communications infrastructure. Use of Higher frequencies is permitted by improved technologies and therefore antennas to be used are smaller. This result in lower cost and therefore the systems can be easily deployed.

The customers demand for high data rates has been avid. This results in another motive for the attractiveness of wireless communication systems. But the operation of fibre connections is very expensive. So because of this reason companies are turning to the fixed wireless networks. Result of expensive fibre connections has introduced the appliance of wireless networks system to host the applications from the options given as:

wireless local area networks (WLAN), wireless wide area networks (WAN), paging networks for one way and two way, communication which is laser based, global positioning system (GPS), links of satellite, radio communication for indoor and mobile communication and cellular communication. Wireless local area network replaced the wired networks in various business and campus applications. Wireless networks have a bright future.

The spectrum competency of wireless communication is gaining popularity with increasing demand for the wideband wireless services. Capacity demand in wireless local area network has developed over the last decade. A large enlargement in the throughput of information is required for the wireless multimedia and internet access in addition with maintaining reliability. So there has been witnessed a large growth in the wireless communication market. Wireless networks for First generation (analog voice) and second generation (digital voice/low-rate data) have been universally developed. Main focus of Wireless network for first generation and second generation was voice services. But for next generation wireless networks there are some new challenges. Main challenges are high-rate-data services and support of QoS (Quality of Service). Demand for expanding wireless bandwidth is also an important challenge for the future generation. As compared to the wired networks, the wireless network sources are very limited. By adding new physical resources to the wired networks, extra bandwidth can be achieved. Wireless communication obliged allocation of limited natural resource which is the radio frequency spectrum. Important hard work has been made to recover the efficiency of wireless spectrum in order to fulfil the prospective need for high-data-rate wireless communication.

Even though this demand has been fulfilled by wired communication systems , but the main reason for increasing demand of high speed wireless system is the aspiration to communicate from anyplace at anytime. The production of consumer electronics with the potential to develop a big amount of data, like cell phones along with digital camera, wireless home audio and visual networks, wireless local area network for campuses and businesses and homes etc. also increases the need of consistent high speed wireless communication. Thus, wireless communication systems data rate has improved significantly in current years. Data rate can be further improved and the reliability of wireless system can be also improved by overcoming the problems that usually occurs in the system.

The existing Second and third generation cellular systems which supports the data rates of 9,6 kbps to 2 Mbps is used by millions of people. In recent times, communication which supports the rates of 54Mbps is enabled by using IEEE 802.11 wireless LAN networks and have gathered the attention of more than 1,6 billion USD in equipment sales. In future, abilities of these technologies are supposed to support 100 Mbps - 1 Gbps range. Recently, fourth mobile generation (4G) standardization is discussed by research community and industry of wireless communication. A number of promising solutions has been introduced by the research community for considerable improvements in the performance of system. Use of multiple antenna elements at the transmitter and receiver introduced the one of the most capable future technologies in mobile radio communication. Using multiple input and multiple output antennas at both the link ends of a communication system, i.e. the transmitter and the receiver side is called MIMO (multiple input multiple output). A new dimension in the consistent communication is introduced by using multiple-antennas at the transmitter side and/or at the receiver side in a wireless communication system. By utilizing it, the system performance can be improved substantially. In MIMO the antennas at the both ends, i.e. transmitter and receiver are connected and combined in an optimum way so that the bit error rate or the data rate for each user is enhanced. So the quality of system is improved. The main idea in transmission in a MIMO system is the space time processing a signal in which the processing of signal in time is balanced by processing of signal in the spatial domain by utilizing multiple antennas which are spatially distributed at both ends of the link. The MIMO system offers a huge increase in the capacity, so this system has gained a lot of attention in the mobile communication research [1], [2].

Many challenges are introduced in the wireless channel. The problems that occur as a result of multipath fading and Doppler frequency shift are two of the major challenges for wireless communication system. By both of these problems, the received signal gets affected and thus the performance of the wireless communication system degrades.

1.2 Introduction to Fading:

Many factors in radio signal propagation influence the characteristics of a wireless channel [3], including multipath propagation, velocity of the mobile, and transmission bandwidth of the signal. The presence of surrounding objects reflecting and scattering in the channel creates a constantly changing environment that dissipates the signal energy in amplitude, phase, and time. These effects result in multiple versions of the transmitted

signal to arrive at the receiving antenna, displaced with respect to one another in time and spatial orientation.

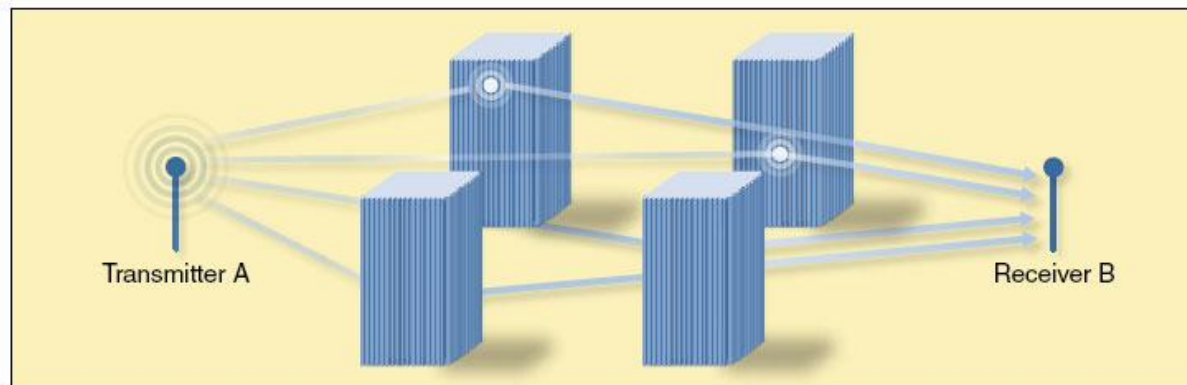


Figure 1.1: Illustration of Multipath Propagation [43]

Fading occurs because of the probable existence of multiple paths between the transmitter and the receiver with destructive combining at the output of the receiver. Under Certain conditions, the incoming signals will combine destructively and reduce the received power and make it zero or near to zero. In such case there is no possible reliable communication. Many models described fading in wireless channels [4]. Rayleigh and Rician are classical fading models. These models are classically applied to narrowband signals and do not consist of the Doppler shift which occurs because of motion induced by transmitter or the receiver. Doppler shift is introduced by vehicle motion, by which the signal spectrum gets widen. The multipath fading can completely fades away the signal in some cases, whereas in some of the cases the signal strength may not fall below the practicable strength. The major cause of fading is multipath effect. In this effect, multiple copies of the signal which are transmitted from the transmitter traverse through the different paths to reach the receiver. So, at the receiver all the multipath signals get added to achieve the received signal. The signals traversed through different paths which may be longer or may be shorter. The line of sight signal has shortest direction. At the receiver, signals interact with each other. The resultant signal would be intensified if the signals are in phase with each other. But if signals are out of phase with each other then the resultant signal would be weakened. This is known as channel fading. There are two methods available for measuring the channel fading.

- Doppler spread
- Delay Spread

The various signal paths between transmitter and receiver corresponds to various transmission times. At different moments, multiple copies of the signals are arrived at the

receiver. So the signal which follows the shortest path will reach first as compared to those on the longer paths. This un-simultaneous arrival of signals directly affects the original signal and causes its spread in the time domain. This spread is the **Delay Spread**. Motion of transmitter or receiver or the motion of a scatter causes the time varying fading which results in the **Doppler Spread**. Doppler spread is caused by time selective fading. Doppler Shift is the change in the frequency. Due to movement of stations, the original signal frequency and the received signal frequency are different. Doppler Spread is the measure of maximum broadening of spectrum due to Doppler shift. Some more parameters related to fading are coherence time and coherence bandwidth. Coherence Time is the time period for which amplitude of the received signals is highly correlated. Coherence Bandwidth is used to measure the up-limit bandwidth that can be transmitted for a channel to be free of Intersymbol Interference. It is the range of frequencies that are permitted to pass through the channel without causing any distortion.

1.3 Types of Fading:

- **Large scale fading:** This type of fading is caused by shadowing introduced by obstacles where a large obstruction such as a hill or large buildings obscures the main signal path between transmitter and the receiver. The amplitude change caused by shadowing is often modeled using log-normal distribution. Large scale fading is also called shadow fading.
- **Small scale fading:** Small scale fading is observed over smaller distances as compared to large scale fading. In small scale fading, different replicas of the same signal are created by reflection, diffraction and scattering. Small scale fading can be further categorized as:
 - Fast or slow fading
 - Frequency selective or flat fading

1.3.1 Flat Fading:

Flat fading is the name given to the case when the channel coherence bandwidth is larger than the signal bandwidth and hence all frequencies of the transmitted signal experience the same channel condition; i.e., over the signal bandwidth, the channel frequency response is essentially flat; and hence the name Flat Fading. When flat multipath fading is experienced, the signal will just change in amplitude, rising and falling over a period of

time, or with movement from one position to another. Flat Fading channels are also known as amplitude varying channels or narrowband channels.

1.3.2 Frequency Selective Fading:

If the channel bandwidth is narrower than the signal bandwidth, different frequency bands of the signal are affected differently. Selective fading occurs when the multipath fading affects different frequencies across the channel to different degrees. It will mean that the phases and amplitudes of the signal will vary across the channel. Sometimes relatively deep nulls may be experienced, and this can give rise to some reception problems. Simply maintaining the overall amplitude of the received signal will not overcome the effects of selective fading, and some form of equalization may be needed. In this the signal bandwidth is limited by the channel bandwidth, due to which the overlapping of successive symbols occurs in the time domain. This leads to intersymbol interference. This is caused by ISI, where the received signal contains multiple delayed and attenuated versions of the transmitted signal. Some of the effects of frequency selective fading are:

- ISI distortion
- Pulse mutilation
- Irreducible BER

1.3.3 Fast Fading:

In a fast fading channel, the rate of change of the channel is higher than the signal symbol period and hence the channel changes over one period. In other words, the channel coherence time is smaller than the symbol period. In fast fading, the channel impulse response changes rapidly within symbol duration. In practice this occurs for low data rates since the symbol duration is wide in low data rates. Some of the impacts of fast fading are:

- Severe distortion of the baseband pulse leading to the detection problems
- Loss in SNR
- Synchronization problems

1.3.4 Slow Fading:

As the name suggest, in a slow fading channel, the channel coherence time is larger than the symbol period and hence the channel remains approximately static over a symbol or

multiple symbols. In slow fading the impulse response changes much slower than the transmitted signal.

1.4 Fading Models:

Small scale fading models that have been widely used for the modelling of fading environment are:

- Rayleigh fading
- Rician fading
- Nakagami fading

1.4.1 Rayleigh Fading:

The Rayleigh distribution is the most widely used distribution to describe the received envelope value. The Rayleigh flat fading channel model assumes that all the components that make up the resultant received signal are reflected or scattered and there is no direct path from the transmitter to the receiver. The Rayleigh distribution is commonly used to describe the statistical time varying nature of the received envelope of a flat fading signal, or the envelope of an individual multipath component. In the Rayleigh fading channel model, it is assumed that the channel induce amplitude which varies in time according to the Rayleigh distribution.

When the channel impulse response is modelled as a zero-mean complex valued Gaussian process, the envelope at any instant is Rayleigh- distributed. The Rayleigh distribution of the received complex envelope of a signal is given as

$$p(x) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \quad ; \quad (x \geq 0) \quad (1.1)$$

where σ is the root mean square value of received voltage signal before envelope detection and σ^2 is the time average power of the received signal before envelope detection [5,6]. It is well known that the envelope of the sum of two quadrature Gaussian noise signal obeys a Rayleigh distribution.

1.4.2 Rician Fading:

When there is a dominant stationary (non fading) signal component present, such as line of sight path, the small scale fading envelope distribution is Rician. That is it is often used to model propagation paths consisting of one of strong line of sight component and many random weaker components. For a multipath fading channel containing a LOS

component, the complex envelope of the received signal can be given by a Rician distribution $\frac{(x^2 + A^2)}{2\sigma^2}$

$$p(x) = \left\{ \frac{x}{\sigma^2} e^{-\frac{(x^2 + A^2)}{2\sigma^2}} I_0 \frac{Ax}{\sigma^2} \right. ; A \geq 0, x \geq 0 \quad (1.2)$$

Where A denotes the peak amplitude of the dominant or LOS signal and $I_0(\cdot)$ is the zeroth order modified Bessel function of the first kind. The Rician distribution is often described in the terms of a parameter K called the Rician factor, which is defined as ratio between the deterministic signal power and the variance of the multipath or can also be defined as $K = \frac{A^2}{2\sigma^2}$ is the relation between power of LOS component and the power of Rayleigh component. For $K=0$ we have Rayleigh fading and for $K=\infty$ we have no fading (that is channel with no multipath and only a LOS component). The fading parameter K is therefore a measure of the severity of fading; a small K implies severe fading, a large K implies relatively mild fading.

1.4.3 Nakagami Fading:

The Rayleigh and Rician fading models described above fall short of describing long distance fading effects with sufficient accuracy. M. Nakagami observed this fact and then formulated a parametric gamma function. Model uses an adaptive m parameter to describe the fading conditions. It is shown that the fading conditions less or more severe than the Rayleigh and Rician fading can also be accurately modelled by Nakagami fading. Nakagami fading model assumes that the signal that has passed through the channel will fade according to the Nakagami distribution. This means that the envelope of the channel response of the Nakagami channel will be Nakagami distributed. The PDF for this can be given as:

$$p(x) = \frac{m^m}{\Omega^m} \frac{x^{2m-1}}{\Gamma(m)} e^{-\frac{m}{\Omega} x^2} \quad (1.3)$$

$\Gamma(m)$ is the gamma function and m is the shape factor with the constraint ($m \geq 1/2$)

Experimental and theoretical [6,7] works have shown that the Nakagami distribution is the best fit distribution for the data obtained from many urban multipath radio channel.

1.5 Diversity:

Different resources of diversity are offered by wireless broadband systems to mitigate fading. In diversity, the information is not transmitted for a single time rather it is transmitted for several times with a hope that at least one of the copies will not suffer harsh fading. Diversity can be utilized by a proper transmission and coding scheme. In wireless system, there are various ways for combating the effects of fading:

- Frequency diversity
- Time diversity
- Spatial diversity
- Polarization diversity

Frequency diversity utilizes the fact that in different frequency bands, the multipath structure is different. This fact can be utilized to combat the effect of fading. In this case, in the different frequency bands the copies of information signal are transmitted, and the frequency separation is more than channel coherence bandwidth. But due to bandwidth limitations, the positive effects of frequency diversity are restricted. A finite source i.e. radio spectrum is used by wireless communication and by this the number of wireless users are limited and also the amount of spectrum that is provided to each user at any time is also limited.

Time diversity utilizes the fact that different time intervals will suffer different amount of fading. Effect of bad channel coding can be diminished by good fading intervals. In this the copies of information signal are transmitted in time slots which are different. The time slots separation is more than the channel coherence time. But time diversity is difficult to exploit because of delay constraints.

In **polarization diversity**, diversity is achieved by utilizing two transmit antennas or two receive antennas with different polarization. The transmitted waves follow the same path. There are two disadvantages of polarization diversity. First disadvantage is that you can have at most two diversity branches, corresponding to the two types of polarization. The second disadvantage is that polarization diversity loses effectively half the power (3 dB) because transmit or receive power is divided between the two differently polarized antennas.

Spatial diversity utilizes the fact that more than two antennas are either differently polarized or separated in space [2,8,9]. Different multipath and fading characteristics are used by different antennas and a stronger signal can be produced by this property. If the

spacing of antennas is greater than half of wavelength then channels which are spatially uncorrelated are formed. Copies of information signal are transmitted over uncorrelated spatial channels and hence spatial diversity occurs. Spatial diversity does not include the problems that occur with frequency diversity and time diversity. But the one drawback of this diversity is that it includes use of multiple antennas at transmitter and receiver and thus makes it not feasible every time. Space diversity techniques employ multiple transmit and receive antennas. The antennas are separated far enough that the signals have significantly different propagation paths and hence experience independent fading. Space diversity techniques are preferred over time or frequency diversity because they do not incur extra time or bandwidth, which are valuable resources in wireless communication systems. Sometimes polarization diversity can be regarded as a special case of space diversity techniques. An adaptive antenna array is an example of conventional space diversity, where the intelligence of the multi-antenna algorithm lies in the selection of the weights on each signal path for signal combining at the receiver and beam forming at the transmitter. In the development of space-time coding for multiple transmit and receive antenna systems, which are generally known as multiple input, multiple output (MIMO) systems, the emphasis is to find encoding and decoding algorithms for the transceiver. Space-time codes are implemented by employing forward error control coding techniques across the time and space domains. Space or antenna diversity has been popular in wireless microwave communications and can be classified into two categories: receive diversity and transmit diversity [10], depending on whether multiple antennas are used for reception or transmission.

- Receive Diversity

It can be used in channels with multiple antennas at the receive side. The received signals are assumed to fade independently and are combined at the receiver so that the resulting signal shows significantly reduced fading. Receive diversity is characterized by the number of independent fading branches and it is at most equal to the number of receive antennas.

- Transmit Diversity

Transmit diversity is applicable to channels with multiple transmit antennas and it is at most equal to the number of the transmit antennas, especially if the transmit antennas are placed sufficiently apart from each other. Information is processed at the transmitter and

then spread across the multiple antennas. Transmit diversity was introduced first by Winters [11] and it has become an active research area [12], [13].

In case of multiple antennas at both link ends, utilization of diversity requires a combination of receive and transmit diversity explained above. The diversity order is bounded by the product of the number of transmit and receive antennas, if the channel between each transmit-receive antenna pair fades independently [14].

Diversity utilizes a significant property of wireless multiple input multiple output channels that various paths of signals can be modelled as number of detached, independent fading channels. The channels may be different in time domain or frequency domain.

Wireless systems consisting of a transmitter, a radio channel and a receiver are categorized by their number of inputs and outputs. The simplest configuration is a single antenna at both sides of the wireless link, denoted as single input single output (SISO) system. Using multiple antennas on one or both sides of the communication link are denoted as multiple input multiple output (MIMO) systems. The difference between a SISO system and a MIMO system with n_t transmit antennas and n_r receive antennas is the way of mapping the single stream of data symbols to n_t streams of symbols and the corresponding inverse operation at the receiver side. Systems with multiple antennas on the receive side only are called single input/multiple output (SIMO) systems and systems with multiple antennas at the transmitter side and a single antenna at the receiver side are called multiple input single output (MISO) systems. The MIMO system is the most general and includes SISO, MISO, and SIMO systems as special cases. Therefore, the term MIMO will be used in general for multiple antenna systems. The fundamental problem of MIMO systems is the mapping operation at the transmitter and the corresponding inversion at the receiver to optimize the overall performance of the wireless system. Mostly, researchers concentrate on the following system parameters: bit rate, reliability and complexity. The goal is to design a robust and low complex wireless system that provides the highest possible bit rate per unit bandwidth.

1.6 Multiple Input Multiple Output (MIMO):

MIMO is effectively a radio antenna technology as it uses multiple antennas at the transmitter and receiver to enable a variety of signal paths to carry the data, choosing separate paths for each antenna to enable multiple signal paths to be used. One of the core ideas behind MIMO wireless systems space-time signal processing in which time is

complemented with the spatial dimension inherent in the use of multiple spatially distributed antennas, i.e. the use of multiple antennas located at different points. Accordingly MIMO wireless systems can be viewed as a logical extension to the smart antennas that have been used for many years to improve wireless.

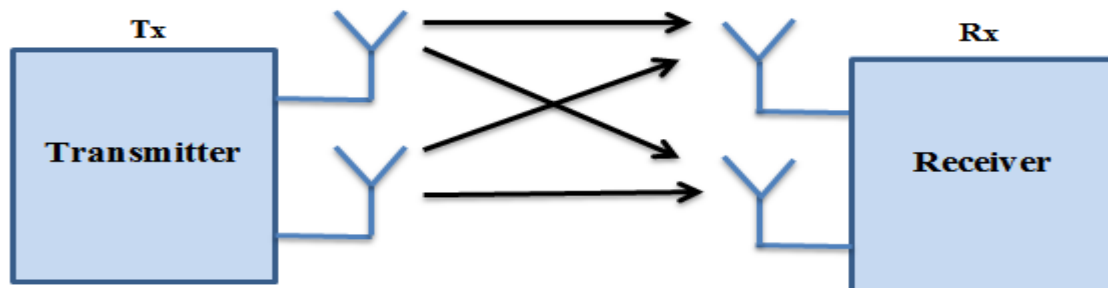


Figure 1.2: MIMO System [44]

It is found between a transmitter and a receiver, the signal can take many paths. Additionally by moving the antennas even a small distance the paths used will change. The variety of paths available occurs as a result of the number of objects that appear to the side or even in the direct path between the transmitter and receiver. Previously these multiple paths only served to introduce interference. By using MIMO, these additional paths can be used to advantage. They can be used to provide additional robustness to the radio link by improving the signal to noise ratio, or by increasing the link data capacity. The two main formats for MIMO are given below:

- Spatial diversity: Spatial diversity used in this narrower sense often refers to transmit and receive diversity. These two methodologies are used to provide improvements in the signal to noise ratio and they are characterized by improving the reliability of the system with respect to the various forms of fading.
- Spatial multiplexing: This form of MIMO is used to provide additional data capacity by utilizing the different paths to carry additional traffic, i.e. increasing the data throughput capability.

One of the key advantages of MIMO spatial multiplexing is the fact that it is able to provide additional data capacity. MIMO spatial multiplexing achieves this by utilizing the multiple paths and effectively using them as additional "channels" to carry data. The maximum amount of data that can be carried by a radio channel is limited by the physical boundaries defined under Shannon's Law.

Multiple-input, multiple-output (MIMO) antenna systems are used in modern wireless standards, including in IEEE 802.11n, 3GPP LTE, and mobile WiMAX systems. The technique supports enhanced data throughput even under conditions of interference, signal fading, and multipath. The demand for higher data rates over longer distances has been one of the primary motivations behind the development of MIMO orthogonal-frequency-division-multiplexing (OFDM) communications systems.

1.6.1 Benefits of MIMO:

- Multiple antenna configurations can be used to overcome the detrimental effects of multi-path and fading when trying to achieve high data throughput in limited-bandwidth channels.
- **Superior Data Rates, Range and Reliability:** Systems with multiple antennas at the transmitter and receiver – also referred to as Multiple Input Multiple Output (MIMO) systems – offer superior data rates, range and reliability without requiring additional bandwidth or transmit power. By using several antennas at both the transmitter and receiver, MIMO systems create multiple independent channels for sending multiple data streams.

4x4 MIMO system supports up to four independent data streams. These streams can be combined through dynamic digital beamforming and MIMO receiver processing to increase reliability and range.

The number of independent channels and associated data streams that can be supported over a MIMO channel is equivalent to the minimum number of antennas at the transmitter or receiver. Thus, a 2x2 system can support at most two streams, a 3x3 system can support three streams and a 4x4 system can support four streams.

- Achieve high channel capacity
- Minimize probability of error
- Bandwidth efficient
- Spectral efficiency: Multiplexing gain
- Link reliability: Diversity gain
- Coverage: Diversity gain and array gain
- Cellular capacity: Co-channel interference reduction

To transmit information over a single wireless link, different transmission and reception strategies can be applied. Which one of them should be used depends on the knowledge

of the instantaneous MIMO channel parameters at the transmitter side. If the channel state information (CSI) is not available at the transmitter spatial multiplexing (SM) or space-time coding (STC) can be used for transmission. If the CSI is available at the transmitter, beam forming can be used to transmit a single data stream over the wireless link. In this way, spectral efficiency and robustness of the system can be improved. It is difficult to decide which of this transmission method is the best one. It can be concluded that the choice of the transmission model depends on three entities important for wireless link design, namely bit rate, system complexity and reliability. A STC has low complexity and promises high diversity, but the bit rate is moderate. SM provides high bit rate, but is less reliable. Beam forming exploits array gain, is robust with respect to channel fading, but it requires CSI.

1.7 Receiver Decoding Techniques:

In most cases the complexity of signal processing at the transmitter side is very low and the main part of the signal processing has to be performed at the receiver. The receiver has to regain the transmitted symbols from the mixed received symbols. Several strategies can be applied at the receiver.

• Maximum Likelihood (ML) Receiver

ML achieves the best system performance (maximum diversity and lowest bit error ratio (BER) can be obtained), but needs the most complex detection algorithm. The ML receiver calculates all possible noiseless receive signals by transforming all possible transmit signals by the known MIMO channel transfer matrix. Then it searches for that signal calculated in advance, which minimizes the Euclidean distance to the actually received signal. The undisturbed transmit signal that leads to this minimum distance is considered as the most likely transmit signal.

• Linear Receivers

Zero Forcing (ZF) receivers and Minimum Mean Square Error (MMSE) receivers belong to the group of linear receivers. The ZF receiver completely nulls out the influence of the interference signals coming from other transmit antennas and detects every data stream separately. The disadvantage of this receiver is that due to cancelling the influence of the signals from other transmit antennas, the additive noise may be strongly increased and thus the performance may degrade heavily. Due to the separate decision of every data stream, the complexity of this algorithm is much lower than in case of an ML receiver.

The MMSE receiver compromises between noise enhancement and signal interference and minimizes the mean squared error between the transmitted symbol and the detected symbol. Thus the results of the MMSE equalization are the transmitted data streams plus some residual interference and noise. After MMSE equalization each data stream is separately detected (quantized) in the same way as in the ZF case. In practice it can be difficult to obtain correct parameter values of the noise that is necessary for optimum signal detection and only a small improvement compared to the ZF receiver can be obtained. Therefore, this receiver is not used in practice.

1.8 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 uncoded systems without sacrificing bandwidth. The research on STC focuses on improving the system performance by employing extra transmits antennas.

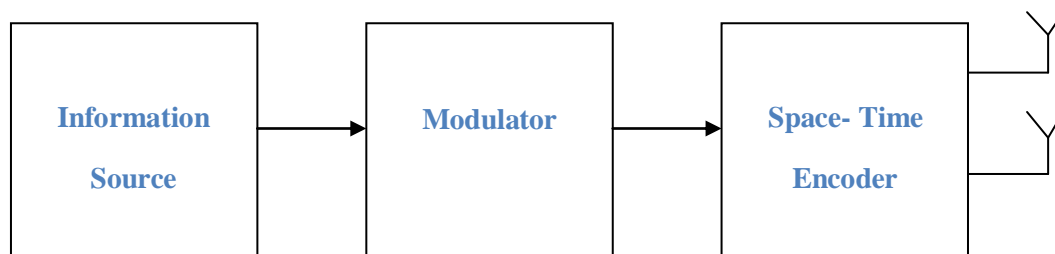


Figure 1.3: Block Diagram of Space-Time Coding [44]

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. Space-time block coding is a technique used in wireless communication to transmit multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. The fact that the transmitted signal must traverse a potentially difficult environment with scattering, reflection and refraction and so on and may then be further corrupted by thermal noise in the receiver means that some of the received copies of the data will be 'better' than

others. This redundancy results in a higher chance of being able to use one or more of the received copies to correctly decode the received signal. In fact, Space time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

1.8.1 Advantages of Space Time Coding:

- Maximum diversity
- Maximum coding gain
- Maximum possible throughput

Space time codes provides transmit diversity transmit diversity for multiple antenna fading channel. Main types of Space time coding (STC) are: STTC (Space Time Trellis Codes), STBC (Space Time Block Codes)

Space time trellis codes provide diversity gain and coding gain and achieve better bit error rate performance than the space time block codes. But these codes are more complex than STBC. In STBC, only linear processing is required at receiver and in STTC receiver Viterbi decoder is used.

Space-time block coding (STBC) has added a new dimension to broadband wireless communication systems. Applications such as wireless Internet access and multimedia require the transmission of high data rates over frequency selective fading channels. The reliability of the wireless communication system can be increased by using diversity techniques combined with an equalizer at the receiver to eliminate the inter-symbol interference caused by multipath propagation. STC involves the transmission of multiple redundant copies of data to compensate for fading and thermal noise in the hope that some of them may arrive at the receiver in a better state than others. In the case of STBC in particular, the data stream to be transmitted is encoded in blocks, which are distributed among spaced antennas and across time. While it is necessary to have multiple transmit antennas, it is not necessary to have multiple receive antennas, although to do so improves performance.

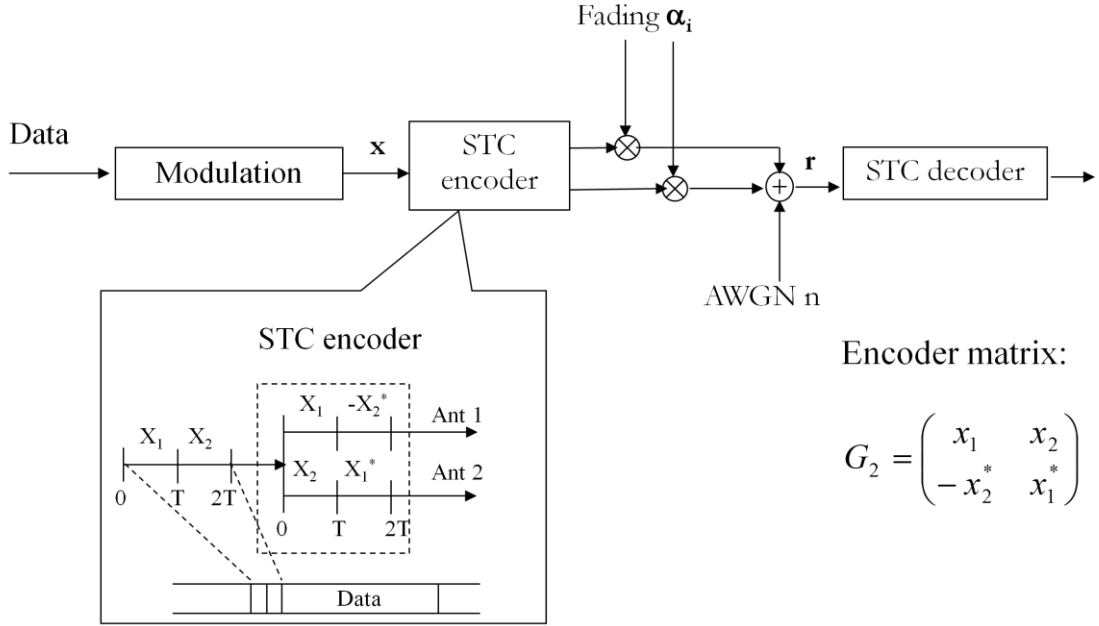


Figure 1.4: Space Time Coding Transmission [45]

Simple STBC transmit diversity scheme is capable of maximizing the diversity over frequency-flat MIMO channels. For high data rate service, most channels cannot be considered frequency-flat anymore but are dispersive, causing inter-symbol interference. This frequency selectivity of the channel destroys the orthogonality of the transmitted STBC streams.

1.9 Introduction to Time reversal space time block codes:

In a Multiple Input Multiple Output (MIMO) system, multiple transmit and receive antennas, can elevate the capacity of the transmission link. This extra capacity can be utilized to enlarge the diversity gain of the system. This results in development of Lucent's "Bell-Labs layered space-time" (BLAST) architecture [2], [1],[15] ,[9] and space time block codes (STBCs) [16]–[18] to attain some of this capacity. Space time coding has utilized diversity and coding gains to achieve high data rate transmission. STBC gained popularity because of their capability to provide simple linear processing for maximum likelihood decoding at the receiver.

Time-reversal (TR) also known as phase conjugation in frequency domain is a simple method of preparing a message such that it appears at a particular time at a particular location in space and nowhere else. In TR, a signal is pre filtered such that it focuses in space and time at an intended receiver [19]. This can be achieved by using a time-reversed complex conjugate of the channel impulse response at the receiver as a

transmitter pre filter. Several advantages come with this technique. Spatial focusing reduces co-channel interference in a multi-user system. Due to temporal focusing, the effective delay spread of the channel is dramatically reduced and thus ISI is also reduced dramatically. This leads to a reduction in the equalization task at the receiver. For example, the complexity of a maximum likelihood sequence estimator (MLSE) is proportional to m^L , where m is the size of the input alphabet and L is the length of the channel impulse response in units of T with T being the symbol separation [20]. Temporal focusing in TR reduces the equalization task by reducing the effective channel length. In a TR experiment, the intended receiver sends a training sequence to the intended transmitter(s). The transmitter(s) time-reverses the estimated channel impulse response (CIR), convolves it with the signal message that is now sent to the receiver. The emitted time reversed waves propagates through the channel retracing their former paths and this leads to a focus of power in space and time at the receiver.

STBC scheme presented by Alamouti in [16] is a transmit diversity scheme, where two transmit and one receive antenna was used. The scheme was proposed for flat fading channel where the fading is assumed to be constant over two consecutive symbols. But further same scheme approach was applied to the frequency selective channels. Particularly, methods such as time reversal [21], OFDM [22], [23], and single-carrier Frequency domain equalization [24]–[26] have gained attention. But both OFDM and SC-FDE schemes, depends on transmission of cyclic prefix, which makes the channel matrix circulant. This characteristic diagonalizes the matrices by FFT and permits effective equalization in the frequency domain. In contrast, TR-STBC applies the Alamouti's scheme on blocks instead of symbols in the time domain. At the receiver, spatiotemporal matched filter is used for transforming the received signal into block decoding and permits the perfect decoupling between the blocks [21], [26].

When coherent STBC is operated in fast-fading channel, the channel estimator provides no instantaneous channel estimate for decoding. Hence, the orthogonality is lost and the system performance is degraded.

Time reversal STBC encodes the conventionally ordered and time-reversed contiguous blocks of symbols together. In figure block structure of time reversal space time block codes is shown.

$S_1[0] \dots S_1[L_s - 1]$	$-S_2^*[L_s - 1] \dots -S_2^*[0]$
$S_2[0] \dots S_2[L_s - 1]$	$S_1^*[L_s - 1] \dots S_1^*[0]$

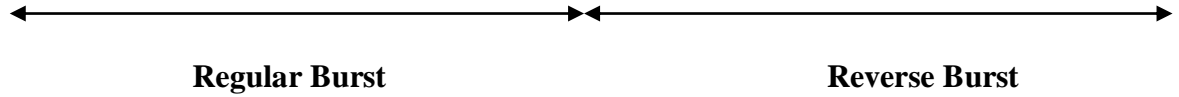


Figure 1.5: Block Structure In Time-Reversal STBC [46]

So the orthogonality between the signals is improved and the interference between the signals is also reduced.

1.10 Organization of Thesis:

The thesis is organized into five chapters.

Chapter 1: Introduces the fading in wireless communication system and brief idea of space time block codes and time reversal space time block codes.

Chapter 2: Provides an insight into literature survey related to space time block codes and time reversal space time block codes.

Chapter 3: Includes bit error rate comparison of STBC in slow fading and fast fading environment. Further the system model of TR-STBC is introduced and also the proposed scheme is applied to the TR-STBC.

Chapter 4: BER of TR-STBC is simulated and compared with BER performance of STBC in slow and fast fading environment. Further a low complexity receiver for TR-STBC is evaluated in Nakagami-m fading channel and its BER performance is simulated for different values of m and compared with classical zero forcing method.

Chapter 5: Provides a conclusion and gives recommendation for the future study.

S. M. Alamouti [16] proposed a transmit diversity scheme in which two transmit and one receive antenna was used. The diversity order of the maximal-ratio receiver combining (MRRC) with two receive antennas and one transmit antenna and this scheme are equal. This method does not need any bandwidth enlargement and computational complexity of this system and MRRC is alike. This scheme can simply have two transmit and M receive antennas which gives the diversity order of $2M$. This scheme does not need feedback by receiver.

E. Lindskog and A. Paulraj [21] proposed a scheme which attains full diversity for channels with intersymbol interference. The scheme presented by Alamouti in [1] was a transmit diversity scheme in which channel does not suffers from intersymbol interference. Alamouti scheme provides second order diversity with two transmit and one receive antenna. In this paper a new technique is obtained which handles the relative case when channel suffers from intersymbol interference. This method attains similar diversity profit with two transmit and one receive antenna as it can be attained by one transmit and two receive antennas. Over the block of the symbols the channel is constrained to be static. So this is the scheme for the channel with intersymbol interference.

Stefan Geirhofer *et al.* [27] presented two schemes which extend time reversal space time block codes in fast fading environment and then compared with different decision feedback equalizers for the high frequency channel. The performance and the complexity are investigated and time reversal space time block codes are simulated for the doubly selective environment.

Lingyang Song *et al.* [28] presented a scheme which has two successive interference cancellation signal detectors for mitigating the intersymbol interference in frequency selective fading channel of the time reversal space time block codes. In time invariant environment, the time reversal space time block codes can easily decouple the received signals at the receiver. But for frequency selective and time variant environment, intersymbol interference occurs which makes the detection of signals difficult at the receiver. So the proposed scheme used a successive interference cancellation for combating the effect of interference in time variant environment.

V. Tarokh *et al.* [17] documented the performance of transmission of space time block codes over the Rayleigh fading channels by utilizing multiple antennas at the transmitter. Signal at the receiver is superposition of the signals transmitted by transmitter antennas. Their encoding and decoding algorithms are outlined. Complexity of encoding and decoding algorithms is very less. It is exhibited that STBC and multiple transmitting antennas give exceptional performance at the cost of no additional processing.

V. Tarokh *et al.* [18] expended space time block codes theory and gave a simple scheme for transmitting symbols by utilizing multiple transmitter antennas over Rayleigh or Rician fading channel. At the receiver maximum likelihood decoding is used which involves the linear processing. Also full diversity which was given by transmit and receive antennas, was utilized. Space time block codes attain maximum diversity order with simple decoding algorithm at the receiver end.

Z. Liu *et al.* [22] presented a scheme in which precoders and decoders are used that mitigate the intersymbol interference and attain the transmit diversity gain in the multipath channel. Status information of channel is obtained blindly which depends upon constant modulus algorithm, if the channel is unknown. The space time block codes which were designed for the flat fading channel are further expanded to the frequency selective channels. Performance of the system is assessed both systematically and with simulations also.

H. Bolcskei and A. J. Paulraj [23] explored the utilization of the space time coding in broadband systems which are OFDM based. A strategy was considered which involves the coding over the OFDM tones and hence called space frequency coding. It has been shown that space time codes which are designed for attaining full spatial diversity in narrowband case, will not attain full space frequency diversity in general and the Alamouti scheme over tones cannot utilize frequency diversity. The effect of delay spread and antenna spacing was investigated on performance of space frequency codes.

N. Al-Dhahir [24] derived a scheme which combines space time block coding with single carrier frequency domain equalization. In frequency selective environment, this Alamouti- like scheme attained remarkable diversity gains with low complexity. Scheme merged the benefits of space time block coding and single carrier frequency domain equalization which is based on FFT.

S. Zhou and G. Giannakis [25] investigated space time block codes for single carrier in frequency selective environment. At the receiver linear processing is used which provides full antenna diversity. This scheme evolves transmission which enables Viterbi algorithm based maximum likelihood decoding and also the turbo decoding. This scheme attains capacity with two transmit and one receive antenna. This scheme shown that joint space-multipath diversity upgrades the performance in frequency selective fading environment.

N. Al-Dhahir [26] described and also compared various equalization techniques for space time codes in broadband wireless channels. They studied and compared three joint equalization and decoding techniques depends on Alamouti block level scheme in time domain or frequency domain. They considered enhanced data rates for global evolution and suggest an equalization scheme. It has shown that the performance of TR STBC is best among all three techniques which are studied above and OFDM-STBC is very flexible but sensitive to errors.

S. N. Diggavi *et al.* [28] proposed two methods which permits a communication that is full rate and diversity using two transmit antennas in frequency selective environment for space time transmission. First method works in frequency domain and second in the time domain. First method merges differential Alamouti scheme with OFDM in frequency domain. And the later one utilize TR-STBC to reduce the need of multiple receive antennas and temporal oversampling.

V. Tarokh *et al.* [30] proposed a scheme called group interference suppression scheme. This scheme was merged with space time coding. It reduces the complexity and provides high rates and also practicable signal to noise ratio was attained using this scheme. In this paper, the complexity of encoding and decoding decreased considerably. It involves the merging of array processing at receiver and thus gives high and reliable data rate communication for wireless channels which are narrowband.

Adel Daas *et al.* [31] derived a multiuser equalization scheme for Time reversal space time block codes over dispersive multiple input multiple output channel which is based on probability density function of equalizer output. The computational complexity of the proposed scheme is reasonable. The adaptation rate can be increased and this scheme can operate with higher rates. So this method introduces an algorithm for equalization of TR-STBC which is blind adaptive.

Pei Xiao *et al.* [32] has studied the time reversal space time block codes application for fixed wireless access systems which are broadband. This scheme combined time reversal space time block codes with outer channel code and thus it gives the coding gain. This scheme is applied with and without channel coding. Single input single output multipath channels are transformed into multiple input and multiple output multipath channel with help of time reversal space time block codes. TR-STBC utilize temporal and spatial diversities and channel coding eliminates the effect of intersymbol interference and the performance can be further improved at higher signal to noise ratio.

Kishore Mehrotra and Ian Vince McLoughlin [33] presented a paper in which a specific Time reversal space time block codes implementation is studied and outcome of accuracy of channel estimation and errors which are synchronous is examined on complete system bit error rate. First of all this paper re-prepared the time reversal equations into time domain to make them appropriate for the implementation. It was shown with help of simulation that Viterbi equalization and the time reversal space time block coding together improves the immunity from synchronization errors but on the cost of accurate estimation of channel.

Jianglin Zhang *et al.* [34] presented a time reversal space time block codes method which depends on selection of antenna in multiple input multiple output system over multipath fading environment. TR-STBC utilizes a simple matched filter which separates the transmitted data from two antennas. So, decoding of data is independent from others. When two antennas which are chosen are finest, then the higher performance can be attained. In this paper, an antenna collection and time reversal based scheme is presented in the multipath fading environment for constellations which are complex valued. So this scheme is purely antenna based scheme.

Wei Min *et al.* [35] presented a scheme that combines time reversal STBC and OFDM for multiple input multiple output. The computational complexity was decreased and it also includes the benefits in other MIMO-OFDM. The performance of the scheme presented in this paper is superior to other MIMO-OFDM schemes. Time reversal space time block codes and OFDM are merged for frequency selective channel and hence a new system for MIMO-OFDM was derived. The positions of OFDM modulator or demodulator are exchanged with space time coder or decoder by TR-STBC. This scheme attains full diversity gain.

Erik G. Larsson *et al.* [36] described transmission method of TR-STBC for frequency selective fading environment with more than two transmit antennas. The orthogonal space time block codes are extended which results in TR-STBC. At the receiver of TR-STBC linear filtering is used which decouples the space time channel into autonomous frequency selective channels and equalization can be done with any standard maximum likelihood sequence detector. Time reversal space time block codes were compared with delay diversity and the outcome shows that TR- STBC attains superior diversity order than the delay diversity always and the computational cost of TR-STBC and delay diversity are same.

Dan Wang, Ling-Ge Jiang and Chen He [37] described that a system which is single carrier frequency domain equalization ultra wide band, has utilized the multiple input multiple output methods to attain spatial and frequency diversities for ultra wide band channels in frequency selective environment. Processing of the system is block wise. In the proposed scheme, transmit diversity is attained by exploiting time reversal space time block coding. The fading consequences of ultra wide band channel can be conquered by utilizing the minimum mean squared error frequency domain equalization method and zero forcing frequency domain equalization method at the receiver. Also, the oversampling diversity and spatial diversity were simulated and their performance gain was studied.

Liu Kewen, Ma Zherui and He Ting [38] presented a combined time reversal space time block codes orthogonal frequency division multiplexing method for a system which is mobile WiMAX. The Mobile WiMAX system has a transmission model which contains a transmitter and a receiver and the mathematical model supporting receiver and transmitter processing is derived. The computational complexity is also decreased by the new proposed scheme for making it applicable to the practical Mobile WiMAX system. Also, the performance of proposed scheme is superior than the orthogonal STBC- OFDM scheme and it attained the full diversity gain, thus making this proposed scheme suitable for implementing and applying for Mobile WiMAX system.

G. White *et al.* [39] proposed a receiver for time reversal space time block codes for the WCDMA downlink. The complexity of the proposed receiver is low. The spatial diversity gains can be attained over time variant channels by utilizing the time reversal space time block codes. In WCDMA downlink, multipath diversity and the spatial diversity can be

utilized by applying this proposed technique. The complexity of the proposed receiver is one-third of the complexity of the time-domain equivalent. The performance benefits of single input single output chip equalizers and TR-STBC RAKE receivers can be conquered by performance of proposed TR-STBC receiver in the rich-scattering urban environment.

Christof Jonietz, Wolfgang H. Gerstacker and Robert Schober [40] combined transmit beamforming and time reversal space time block codes transmission in frequency selective fading channel. If the channel state information at the transmitter is reliable, then the transmit beamforming can recover the performance of the system considerably. The consistency of the channel state information at the transmitter is taken by the proposed scheme in an optimum way. But if the channel state information at the transmitter is not reliable, then same diversity gain as time reversal STBC achieves, is obtained and if CSIT is consistent then the diversity gain of proposed scheme is superior than time reversal STBC.

R. Schober, H. Chen, and W. Gerstacker [41] proposed various decision feedback sequence estimation methods for time reversal space time block codes. These tree schemes were simulated and compared for GSM and EDGE by accepting relevant channel models. First method is unwhitened DFSE which depends on spatio-temporal matched filter output of TR-STBC demodulation. But the performance of unwhitened DFSE is acceptable only for binary modulation and small delay spread channels. Also it was shown that the modified unwhitened DFSE does not attain higher performance than unwhitened DFSE for most of the channels. Whitened DFSE is an efficient method whose computational complexity is reduced. For EDGE and trellis complexity which is low, whitened DFSE is only method that gives reasonable performance.

Nejib Ammar and Zhi Ding [42] presented an approach for channel estimation for which there is no need of training data for time reversal space time block codes encoding. The code parameters and channel matrix rank was known. For the channel estimation, a simple subspace algorithm is described which are further supported by simulation results. So a simple subspace-based scheme was investigated for the estimation of frequency selective channel which was unknown for TR-STBC modulation without training data.

SPACE TIME BLOCK CODES AND TIME REVERSAL SPACE TIME BLOCK CODES

3.1 Overview:

Spatial diversity can be achieved by transmitting several replicas of the same information through each antenna. The different replicas sent for exploiting diversity are generated by a space-time encoder which encodes a single stream through space using all the transmit antennas and through time by sending each symbol at different times. This form of coding is called space-time coding (STC). Due to their decoding simplicity, the most dominant form of STCs is space-time block codes (STBC).

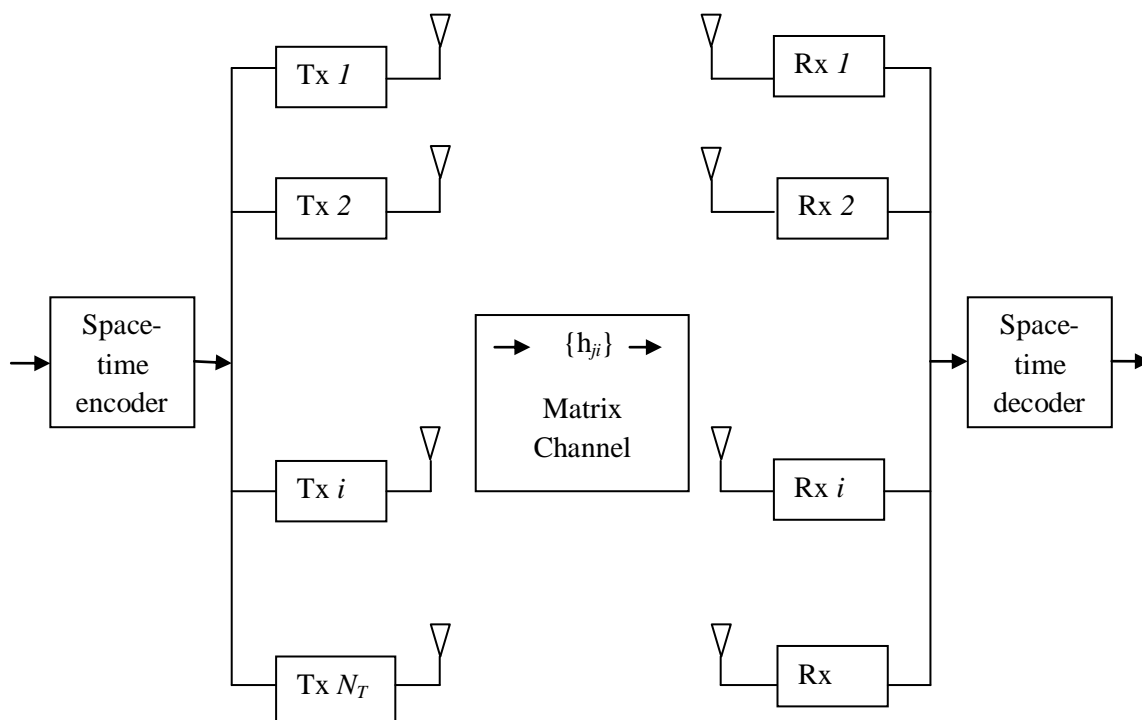


Figure 3.1: General Space Time Architecture [46]

In recent years, space-time coding techniques have attained much interest. The concept of space-time coding has arisen from diversity techniques using smart antennas. The traditional diversity techniques are receiver diversities. But, problem with receive diversity for mobile communications is that the distance between the receive antennas should be sufficient so that the signals arrived at each antenna undergoes independent fade. Due to this, it is very costly to have more than one antenna in the mobile unit because they meant to be small in size and light in weight. Therefore, the transmit

diversity at the base station is an attractive method. This also involves the complex base stations. Base stations have the advantage of using both transmit and receive diversities when they communicate with each other, in the case of multiple input multiple output (MIMO) channels. Moreover, transmit diversity could also be used when base stations need to transmit information to the mobile units which forms the channel of multiple input single output (MISO). There are many ways to communicate using a MIMO system, one of which is using Space-Time Block Codes (STBCs). One of the advantages of STBCs is that they do not require CSI at the transmitter. This is an advantage because in a time varying channel, the coherence time of the channel only needs to be long enough for transmitter to send a training sequence and the data; in systems requiring CSIT, there is the additional time to measure and relay the channel coefficients to the transmitter as well. In addition, sending the coefficients (which are prone to estimation error) to the transmitter decreases the overall data rate. While systems with CSIT have inherently higher capacity, their advantage also fades with increasing SNR. Thus STBC is a practical method of implementing a MIMO system. An STBC is usually represented by a matrix. Each row represents a time slot and each column represents one antenna's transmissions over time.

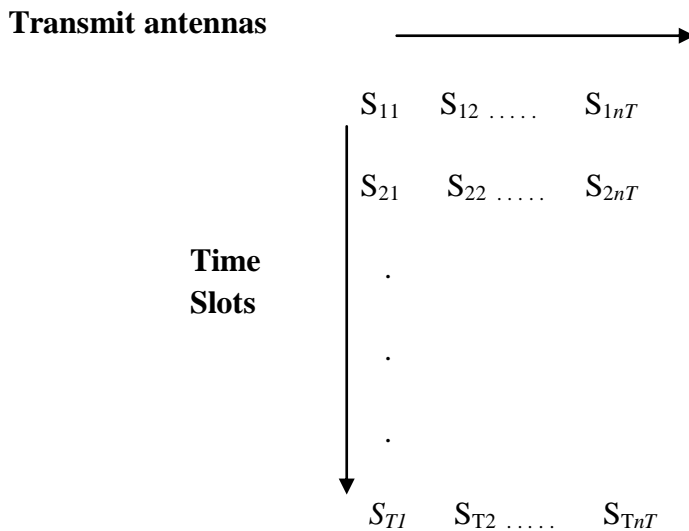


Figure 3.2: Matrix Representation of STBC [48]

Within this matrix, S_{ij} is the modulated symbol to be transmitted in time slot i from antenna j . There are to be T time slots and n_T transmit antennas as well as n_R receive antennas. This block is usually considered to be of 'length' T .

Space time block codes are orthogonal. This means that the STBC is designed such that the vector representing any pair of columns taken from the coding matrix is orthogonal. The result of this is simple, optimal, linear decoding at the receiver.

To satisfy this criterion, some portion of data rate must be sacrificed. Moreover, there exist quasi orthogonal STBC that achieve higher data rates at the cost of inter-symbol interference (ISI). Thus, their error-rate performance is lower bounded by the one of orthogonal rate 1 STBCs, which provides ISI free transmissions due to orthogonality.

Space-Time Block-Code (STBC) involves the use of spatial as well as time diversity for transmitting signal in wireless channels. In STBC, blocks of data are transmitted from different transmitter at different time instants.

Space-time block codes take advantages of multiple transmit and receive antennas to achieve the promised capacity gain [16], [18]. At the receiver, maximum likelihood decoding is achieved using a simple method by decoupling the signals transmitted from different antennas rather than joint detection. The use of orthogonal structure of STBC permits maximum likelihood decoding to be implemented with linear processing at the receiver, resulting in a less complex receiver structure preferable in practical wireless communication systems. The STBC schemes are found to be attractive solutions in industrial applications.

Space-time block codes are used for MIMO systems to enable the transmission of multiple copies of a data stream across a number of antennas and to exploit the various received versions of the data to improve the reliability of data-transfer. Space-time coding combines all the copies of the received signal in an optimal way to extract as much information from each of them as possible.

Space-time coding involves the transmission of multiple copies of the data. This helps to compensate for the channel problems such as fading and thermal noise. Although there is redundancy in the data some copies may arrive less corrupted at the receiver.

When using space-time block coding, the data stream is encoded in blocks prior to transmission. These data blocks are then distributed among the multiple antennas which are spaced apart to decorrelate the transmission paths and the data is also spaced across time.

3.2 Benefits of Space-Time Block Codes:

- ◆ Space-time block coding utilizes multiple transmit antennas to create spatial diversity.

- This allows a system to have better performance in a fading environment.
- Good performance with minimal decoding complexity.
- Can achieve maximum diversity gain equivalent to space-time trellis codes.
- Receivers that use only linear processing.

3.3 STBC System Model:

In addressing the challenge of decoding complexity, a remarkable scheme for two transmit antenna MIMO system is proposed [16], which is widely referred to as the Alamouti scheme. Alamouti code uses two transmit antennas and N receive antennas and can accomplish a maximum diversity order of 2N. Alamouti STBC uses two transmit antennas regardless of the number of receive antennas. In Alamouti scheme, rows of each coding scheme represents a different time instant, while the columns represent the transmitted symbol through each different antenna. In this case, the first and second row represents the transmission at the first and second time instant respectively.

In Alamouti scheme, by utilizing two transmit and one receive antennas, the transmitter produces the same diversity benefit at the receiver as can be achieved by using one transmit and two receive antennas in a conventional Maximal Ratio Receive Combining (MRRC) scheme [16]. Thus, the transmitter diversity is transformed into virtual receive diversity, given knowledge of the channel state information (CSI) and linear decoding at the receiver. The block diagram of the transmitter side using Alamouti space-time encoder is shown in Figure 3.2.

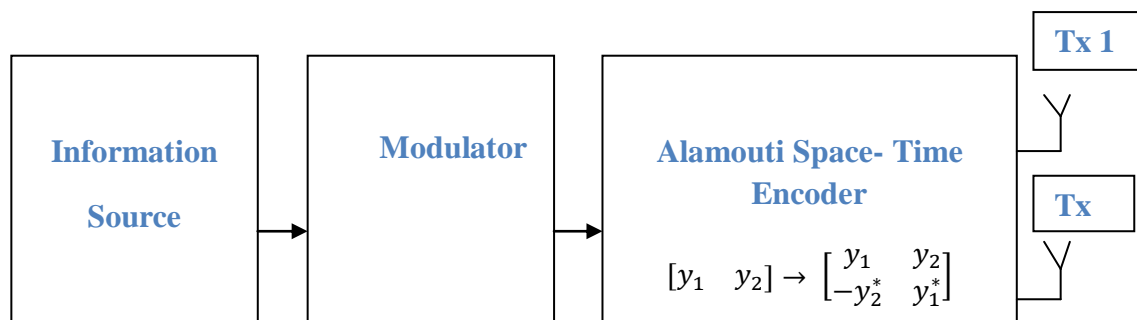


Figure 3.3: Alamouti Space Time Encoder Diagram [44]

Let us review the scheme proposed by Alamouti for a flat fading channel. We assume that the channel is static for two consecutive symbol times (known as quasi-static). The data

stream is divided into two separate streams, $y_1(t)$ and $y_2(t)$. Then, these two streams are transmitted from first antenna and second antenna in alternating time intervals. At first time interval, $y_1(t)$ is transmitted from antenna 1 and $y_2(t)$ is transmitted from antenna 2. So the corresponding received signal at the transmitter end is

$$r_1(t) = h_1 y_1(t) + h_2 y_2(t) + n_1(t) \quad (3.1)$$

where h_i is the channel between transmit antenna i and the receive antenna. And $n_1(t)$ is the noise sample at the first time interval.

At the second time interval, $-y_2^*(t)$ is transmitted from antenna 1 and $y_1^*(t)$ is transmitted from antenna 2. Where $(\cdot)^*$ denotes the complex conjugate. So the received signal is

$$r_2^*(t) = -h_1 y_2^*(t) + h_2 y_1^*(t) + n_2^*(t) \quad (3.2)$$

where $n_2^*(t)$ is the noise sample at the 2nd time interval. Complex conjugating the received observation, we have

$$r_2(t) = -h_1^* y_2(t) + h_2^* y_1(t) + n_2(t) \quad (3.3)$$

We can rewrite (1)-(3) into blocks using the matrix form as,

$$\begin{pmatrix} r_1(t) \\ r_2(t) \end{pmatrix} = \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix} \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} + \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}$$

$$\text{Where } \mathbf{H} = \begin{pmatrix} h_1 & h_2 \\ h_2^* & -h_1^* \end{pmatrix}$$

$$\text{And } \mathbf{r}(t) = \begin{pmatrix} r_1(t) \\ r_2(t) \end{pmatrix}, \mathbf{y}(t) = \begin{pmatrix} y_1(t) \\ y_2(t) \end{pmatrix} \text{ and } \mathbf{n}(t) = \begin{pmatrix} n_1(t) \\ n_2(t) \end{pmatrix}$$

Thus, the received observation blocks have the form

$$\mathbf{r}(t) = \mathbf{H}\mathbf{y}(t) + \mathbf{n}(t) \quad (3.4)$$

In [18], as a linear decoder, Alamouti multiplies $\mathbf{r}(t)$ by \mathbf{H}^H , producing a decoupled matched filtered output.

So,

$$\mathbf{z}(t) = (|h_1|^2 + |h_2|^2)\mathbf{y}(t) + \mathbf{v}(t) \quad (3.5)$$

which perfectly decouples the decoding of $y_1(t)$ and $y_2(t)$. Since all off diagonal terms of $\mathbf{H}^H \mathbf{H}$ are zero, we can obtain

$$\mathbf{H}^H \mathbf{H} = \begin{bmatrix} h_1^H h_1 + h_2^H h_2 & 0 \\ 0 & h_1^H h_1 + h_2^H h_2 \end{bmatrix}$$

Here the off diagonal terms in above matrix are zero. So, the perfectly decoupled output can be obtained.

Where $\mathbf{v}(t) = \mathbf{H}^H \mathbf{n}(t)$

The components of $\mathbf{z}(t)$ have the form

$$z_1(t) = (|h_1|^2 + |h_2|^2)y_1(t) + v_1(t) \text{ and}$$

$$z_2(t) = (|h_1|^2 + |h_2|^2)y_2(t) + v_2(t)$$

Note that both components of $\mathbf{z}(t)$ experience the diversity gain equivalent to that of MRRC. Regarding the noise components $v_1(t)$ and $v_2(t)$, because they are jointly Gaussian and uncorrelated, they are independent. Thus, for the ideal case of perfect channel knowledge at the receiver, the decoupled matched filter outputs $z_1(t)$ and $z_2(t)$ can then be independently processed to estimate $y_1(t)$ and $y_2(t)$.

Alamouti scheme can be summarized as follows:

- No feedback from receiver to transmitter is required for CSI to obtain full transmit diversity.
- No bandwidth expansion (as redundancy is applied in space across multiple antennas, not in time or frequency).
- Low complexity decoders .
- No need for complete redesign of existing system to incorporate this diversity scheme.

3.4 Performance of Space Time Block Codes:

Alamouti space-time code is an orthogonal scheme that can achieve the full transmit diversity of $n_T = 2$. In figure 3.4, BER performance of 2 transmit and one receive is compared with two transmit and two receive antennas with BPSK modulation. It can be easily seen that the BER performance for two transmit and two receive antennas is better

than two transmit and one receive antenna because with larger number of receive antennas, the same transmitted data would be received by more than one receive antenna. This is an advantage because if one receive antenna did not recover the transmitted data correctly, the second receive antenna could. The chance that at least one out of two receive antennas would receive the transmitted data uncorrupted is always higher than if there is only one receive antenna. In addition to that, in figure 3.5 16-QAM and QPSK modulation are used in the simulation. From the figure, it can be easily seen that the BER for the Alamouti scheme using QPSK modulation is better than when 16-QAM modulation is used. This better performance is due to the fact that higher order modulation schemes do carry more bits per symbol than lower order modulation schemes. In this case, 16-QAM scheme modulates four bits per symbol and QPSK scheme modulates two bits per symbol.

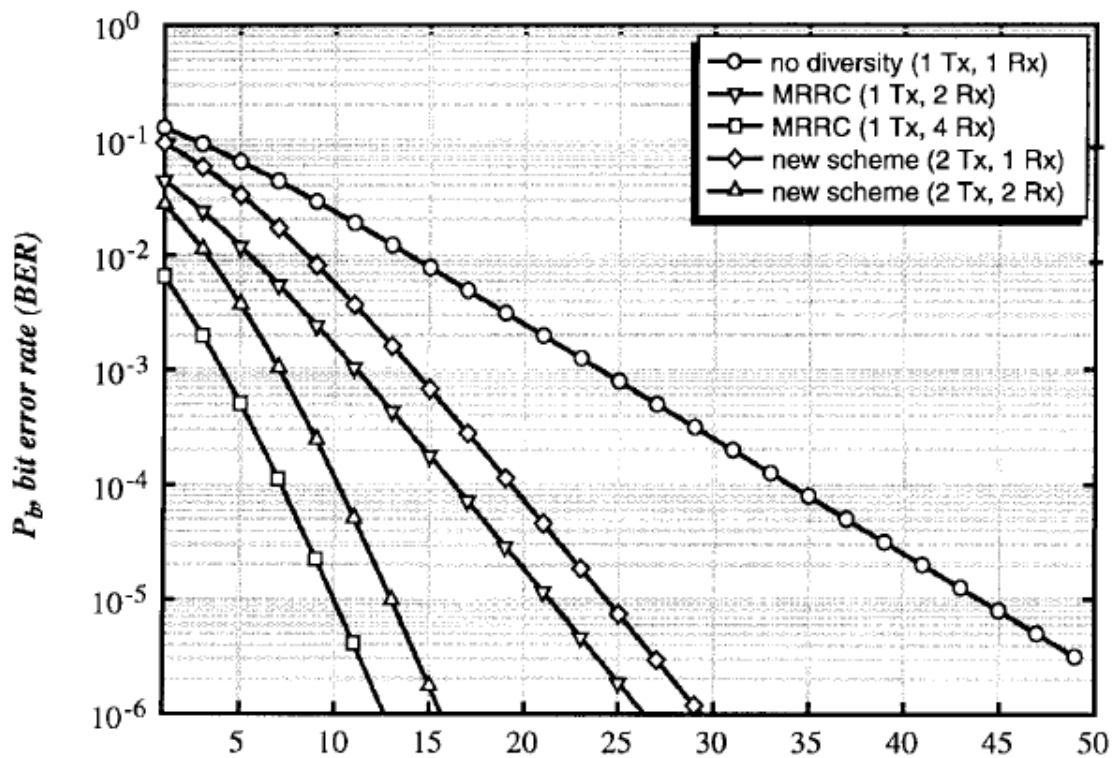


Figure 3.4: BER Performance of Alamouti Scheme Using BPSK Modulation [16]

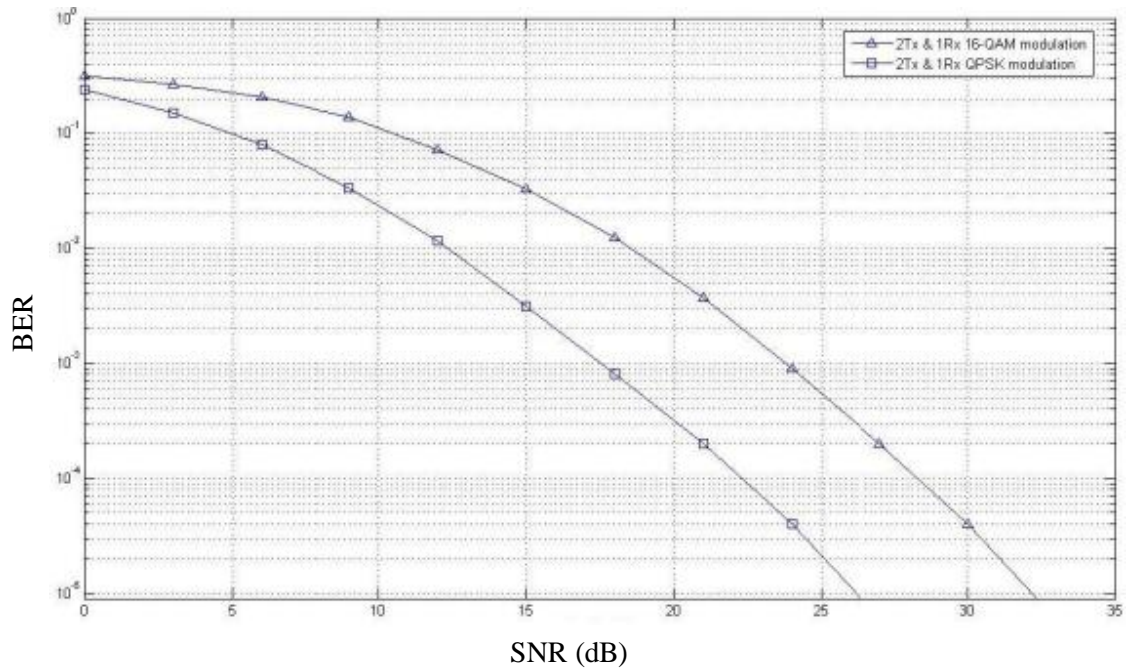


Figure 3.5: BER Performance of Alamouti Scheme Using 16-QAM and QPSK [47]

3.4.1 Fast Fading in STBC:

Space-time block codes (STBC) can obtain full transmit diversity gain in slow-fading environment. But it is not the case for STBC in fast-fading channel. As a result of rapid time variation of the channel, the orthogonality of STBC is lost. This will cause error in decoding and hence the system performance is degraded.

STBC has been widely discussed in slow-fading channel, based on the assumption that the channel is constant over a period of time (i.e. one STBC block duration for coherent detection and two STBC block durations for differential detection) and varies from one period to another. In fast-fading channel, where the channel is no longer constant over a period of time, the estimator for coherent STBC cannot trace the channel variation instantaneously. This will cause decoding in error and hence the system performance is degraded. Figure 3.6 shows comparison of BER performance of STBC in slow and fast fading environment.

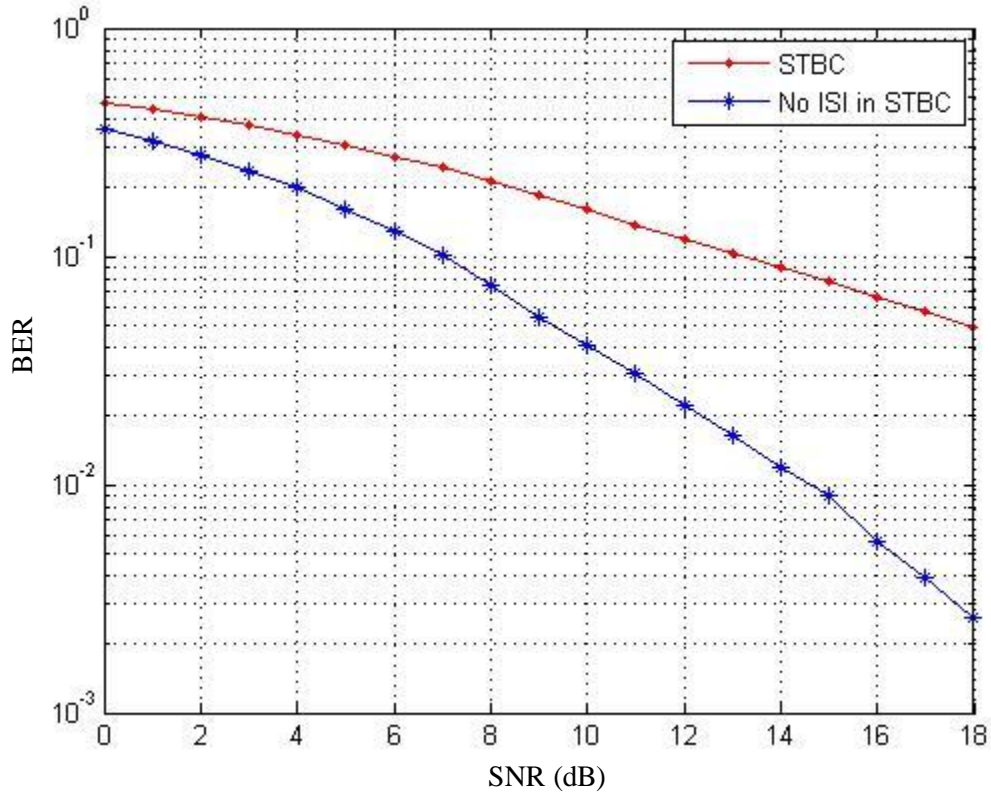


Figure 3.6: Comparison of BER Performance of STBC in Slow and Fast Fading Environment

3.5 Challenges in STBC:

The use of multiple transmit and receive antennas, commonly known as Multiple Input Multiple Output (MIMO) can increase the capacity of the transmission link. This extra capacity can be exploited to increase the diversity gain of the system. Simple STBC transmit diversity scheme is capable of maximizing the diversity over frequency-flat MIMO channels. For high data rate service, most channels cannot be considered frequency-flat anymore but are dispersive, causing inter-symbol interference. This frequency selectivity of the channel destroys the orthogonality of the transmitted STBC streams. Space-time coding for frequency-selective fading environments has attracted great attention, and it has been demonstrated that the downlink performance of wireless communication systems can be significantly improved by properly designed burst based STBCs. In order to achieve the maximum diversity in such an environment, a number of variations can be used on the classical STBC encoding. Methods such as time reversal [21], orthogonal frequency division multiplexing (OFDM) [22], [23], and single-carrier frequency-domain equalization [24],[25],[26] can be combined to combat ISI. However,

the above techniques for the frequency selective environment, by combining STBCs with other schemes, do not fully make use of the properties that orthogonal coding structures have in the time domain. OFDM can decompose a frequency-selective channel by introducing subcarriers and a cyclic prefix into a number of individual narrowband transmission channels, which can each be STBC encoded [26,29]. The drawback of OFDM systems is in general the sensitivity to synchronization errors and their large peak-to-average power ratio. Space frequency OFDM may not fully exploit frequency diversity [22], [23] if no outer codes are used; the realization of frequency diversity using OFDM only is of great interest. In TR-STBC, the ordered and time reversed blocks of symbols are encoded together.

3.6 Time Reversal Space Time Block Codes:

The type of fading experienced by a signal propagating through a mobile radio channel depends on the nature of the transmitted signal with respect to the characteristics of the channel. If the bandwidth of the transmitted signal has a bandwidth greater than bandwidth over which the frequency response of a wireless channel has a constant gain and linear phase, then it undergoes frequency selective fading. In such cases, the multipath delay spread is greater than the symbol interval. Consequently, the received signal contains multiple versions of the transmitted waveform which are attenuated and delayed in time and hence the received signal is distorted. Thus, frequency selective fading is a result of the time dispersion of the transmitted symbol within the channel. The symbol gets spread out in time resulting in Intersymbol Interference (ISI).

Time reversal (TR) space time block coding (STBC) is a novel time domain block coding approach developed to mitigate inter-symbol interference (ISI) in dispersive fading channels. The Alamouti scheme [16] is a transmit diversity technique introduced to combat flat fading channels. Further, time domain block processing schemes were applied that lend themselves to decoupled and parallel equalization for frequency selective fading channels. This scheme is known as the time reversal (TR) space time block coding (STBC) approach.

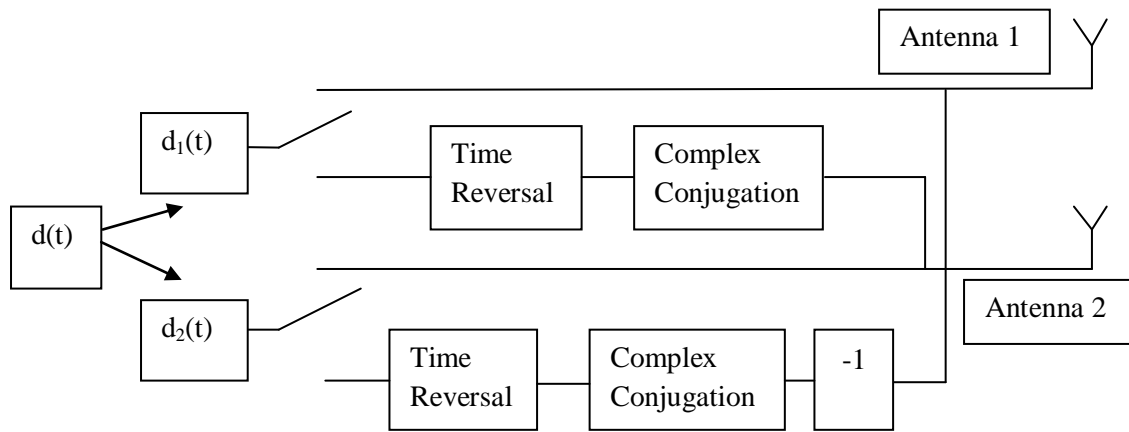


Figure 3.7: Schematic View of the Transmission in the Time-Reversal Space-Time Block Coding Scheme for Channels with Intersymbol Interference [21]

The TR-STBCs extend STBCs for transmission over frequency selective channels by encoding together conventionally ordered and time-reversed contiguous blocks of symbols. TR STBC can have any number of receive antennas. For the frequency selective channel, instead of transmitting on a symbol basis, this time we transmit on a block wise basis.

While TR-STBC is an elegant means to cope with frequency-selective channels, it makes two fundamental assumptions. First, it requires the insertion of guard intervals of greater length than the memory of the channel in order to avoid inter-block interference at the receiver. Secondly, the channel must be constant in order for the H_i to be Toeplitz and the above properties to hold.

In figure 4.2, the block diagram representation of time reversal space time block codes for two transmitter and one receiver system is represented at two different time instants t and $t+1$.

The block diagram consists of time reversal STBC encoder and time reversal STBC decoder.

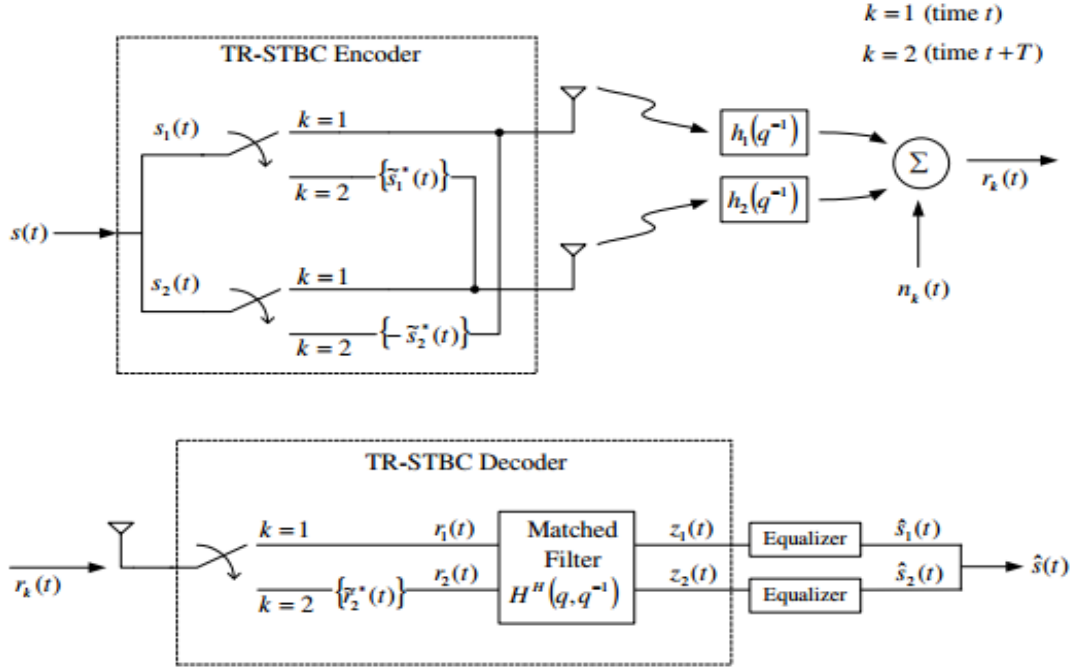


Figure 3.8: Block Diagram of 2×1 TR STBC System [46]

3.7 TR STBC System Model:

TR STBC expands transmission of Alamouti's scheme for frequency selective channels. It encodes normally arranged and time reversed blocks of symbols together [16], [27]. The data stream is divided into two separate streams, \mathbf{y}_1 and \mathbf{y}_2 . Then these two streams are transmitted from first antenna and second antenna in (alternating) time intervals. At first time interval, \mathbf{y}_1 is transmitted from antenna 1 and \mathbf{y}_2 is transmitted from antenna 2. So the corresponding received signal at the transmitter end is

$$r_{1,t} = h_{1,t}y_{1,t} + h_{2,t}y_{2,t} + n_{1,t} \quad (3.6)$$

where $h_{1,t}$ is the channel between transmit antenna 1 and the receive antenna and $n_{1,t}$ is the noise sample at the t time interval. At the second time interval, $-\overline{y_{2,t}}$ is transmitted from antenna 1 and $\overline{y_{1,t}}$ is transmitted from antenna 2. Where $(\cdot)^*$ denotes the complex conjugate. And $\overline{(\cdot)}$ represents the time reversed signal. So the received signal is

$$\overline{r_{2,t+1}} = -\overline{h_{1,t+1}} \overline{y_{2,t}^*} + \overline{h_{2,t+1}} \overline{y_{1,t}^*} + \overline{n_{2,t+1}} \quad (3.7)$$

where $\overline{n_{2,t+1}}$ is the noise sample at the t+1 time interval.

Case 1) Slow Fading

For slow fading in time we have $h_{1,t} = h_{1,t+1}$ and $h_{2,t} = h_{2,t+1}$

$$\text{So, (4.2) can be written as } r_{2,t+1} = -\overline{h_{1,t}^*} y_{2,t} + \overline{h_{2,t}^*} y_{1,t} + n_{2,t+1} \quad (3.8)$$

where \overline{hi} is the time-reversed expression of hi . So we can rewrite following:

$$\begin{pmatrix} r_{1,t} \\ r_{2,t+1} \end{pmatrix} = \begin{pmatrix} h_{1,t} & h_{2,t} \\ \overline{h_{2,t}^*} & -\overline{h_{1,t}^*} \end{pmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} + \begin{pmatrix} n_{1,t} \\ n_{2,t+1} \end{pmatrix} \quad (3.9)$$

$$\text{Where } \mathbf{H} = \begin{pmatrix} h_{1,t} & h_{2,t} \\ \overline{h_{2,t}^*} & -\overline{h_{1,t}^*} \end{pmatrix}$$

At the receiver, received signal is multiplied by \mathbf{H}^H and a decoupled matched filter output was produced.

$$\text{So, } \mathbf{z} = \mathbf{H}^H \mathbf{r} = \mathbf{H}^H \mathbf{H} \mathbf{y} + \mathbf{H}^H \mathbf{n}$$

which perfectly decouples the decoding of $y_{1,t}$ and $y_{2,t}$. Since all off diagonal terms of

$\mathbf{H}^H \mathbf{H}$ are zero, we can obtain

$$\begin{aligned} \mathbf{H}^H \mathbf{H} &= \begin{bmatrix} h_{1,t}^H h_{1,t} + h_{2,t}^H h_{2,t} & 0 \\ 0 & h_{1,t}^H h_{1,t} + h_{2,t}^H h_{2,t} \end{bmatrix} \\ &= \begin{bmatrix} J & 0 \\ 0 & J \end{bmatrix} \end{aligned}$$

So, the received signal can be written as, $z_1 = Jy_1 + n_1$ and $z_2 = Jy_2 + n_2$. So $y_{1,t}$ and $y_{2,t}$ can be separately decoded.

Case 2) Fast Fading

In this case, $h_{1k} \neq h_{1,k+1}$ and $h_{2k} \neq h_{2,k+1}$

So in matrix form it can be written as:

$$\begin{pmatrix} r_{1,t} \\ r_{2,t+1} \end{pmatrix} = \begin{bmatrix} h_{1,t} & h_{2,t} \\ \overline{h_{2,t+1}^*} & -\overline{h_{1,t+1}^*} \end{bmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} + \begin{pmatrix} n_{1,t} \\ n_{2,t+1} \end{pmatrix} \quad (3.10)$$

In this case output of matched filter is:

$$\begin{aligned} \mathbf{z} &= \mathbf{H}^H \mathbf{r} \\ &= \begin{pmatrix} h_{1,t}^H h_{1,t} + h_{2,t+1}^H h_{2,t+1} & \varepsilon_1 \\ \varepsilon_2 & h_{2,t}^H h_{2,t} + h_{1,t+1}^H h_{1,t+1} \end{pmatrix} \begin{pmatrix} y_{1,t} \\ y_{2,t} \end{pmatrix} + \mathbf{H}^H \begin{pmatrix} n_{1,t} \\ n_{2,t+1} \end{pmatrix} \end{aligned} \quad (3.11)$$

which can be written as,

$$\varepsilon_1 = h_{1,t}^* h_{2,t} - \bar{h}_{2,t+1} \bar{h}_{1,t+1}^*, \quad \varepsilon_2 = h_{2,t}^* h_{1,t} - \bar{h}_{1,t+1} \bar{h}_{2,t+1}^*$$

As the off-diagonal terms are not zero. So, the received signal cannot be decoupled separately.

Here off diagonal terms i.e. $\varepsilon_i, i=1,2$ represents the interference.

3.8 Proposed Scheme:

To remove the ISI in the fast fading, we propose a low complexity zero forcing receiver.

$$\text{So, } \mathbf{H}^{PZF} = \begin{pmatrix} h_{1,t}^* & \bar{h}_{2,t+1} / P_t \\ h_{2,t}^* & -\bar{h}_{1,t+1} / P_t \end{pmatrix} \quad (3.12)$$

Where $P_t = \bar{h}_{2,t+1} \bar{h}_{1,t+1}^* / h_{1,t}^* h_{2,t}$ and

$$\mathbf{H}^{PZF} \mathbf{H} = \begin{pmatrix} |h_{1,t}|^2 + |\bar{h}_{2,t+1}|^2 / P_t & 0 \\ 0 & |h_{2,t}|^2 + |\bar{h}_{1,t+1}|^2 / P_t \end{pmatrix}$$

So, it reduces to zero after substituting the value of P_t^* in above equation.

Hence the off-diagonal terms becomes zero. So ISI is reduced in fast fading environment. But this scheme also reduces the diversity gain.

Therefore,

$$\mathbf{z} = \mathbf{H}^{PZF} (\mathbf{H} \mathbf{y} + \mathbf{n}) \quad (3.13)$$

Estimated symbol is given by

$$\mathbf{y} = (\mathbf{H}^{\text{PZF}}\mathbf{H})^{-1} \mathbf{z} \quad (3.14)$$

3.9 Conclusion:

Two transmit and one receive antenna design was presented by Alamouti in [16], where channel coefficients at adjacent time intervals are assumed to be same. When the channel suffers from intersymbol interference (ISI) due to large delay spread, Time Reversal Space Time Block Codes (TR-STBC) achieves better performance [21]. In frequency selective Multiple Input Multiple Output (MIMO) channel environment, loss of quasi static assumption produces the ISI in TR-STBC. So, a low complexity receiver is evaluated to mitigate the effect of intersymbol interference the fast fading channel.

SIMULATION RESULTS

Simulation results shown in this chapter are verified using Matrix Laboratory v-7.5.0. The bit error rate performance of 2 transmit and 1 receive antenna system was investigated through computer simulation.

4.1 Performance of TR-STBC for 2×1 System:

First of all TR STBC is simulated for two transmitter and one receiver antenna using BPSK modulation scheme. Performance of STBC degrades in the fast fading environment because in fast fading environment the coherence time is less than the symbol period. In fast fading environment intersymbol interference occurs which deteriorate performance of STBC and reduce its bit error rate.

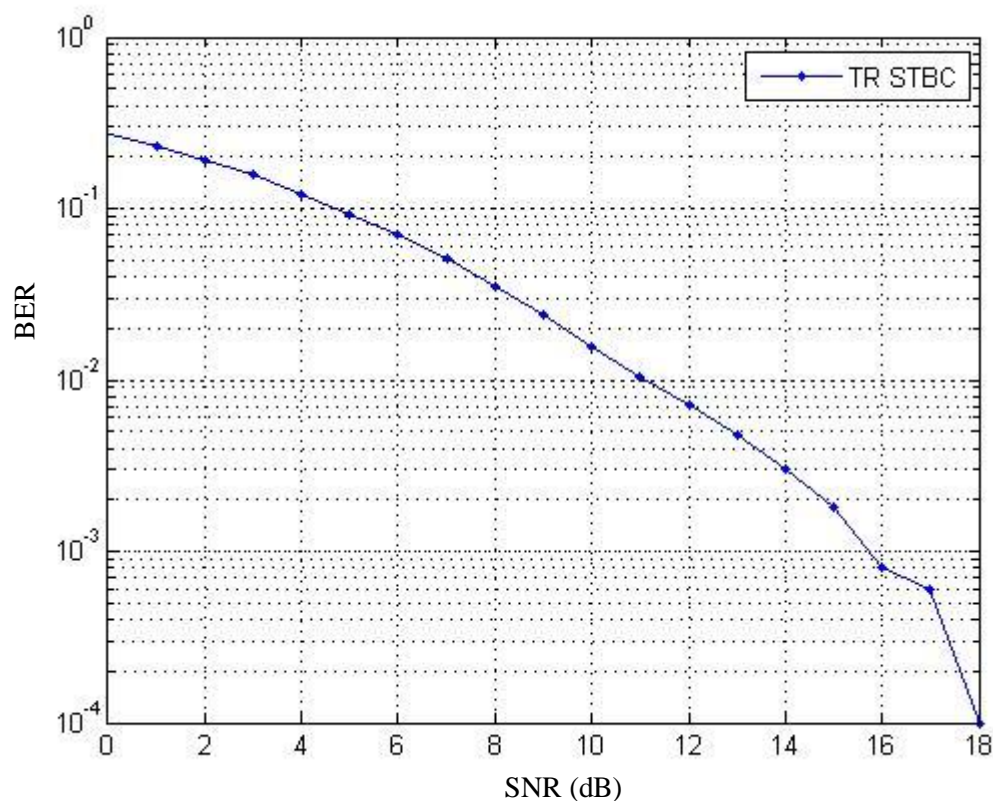


Figure 4.1: BER performance of Time Reversal STBC for 2×1 System

4.2 Comparison of STBC and TR STBC:

When STBC is operated in fast-fading channel, the channel estimator provides no instantaneous channel estimate for decoding. Hence, the orthogonality is lost and the system performance is degraded. Time reversal STBC encodes the conventionally ordered and time-reversed contiguous blocks of symbols together.

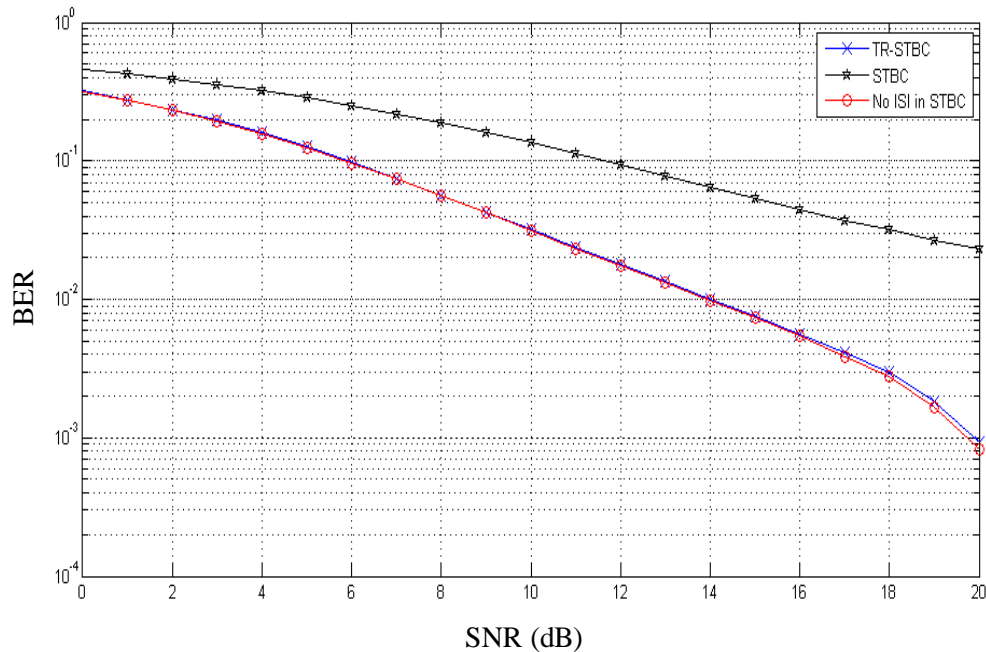


Figure 4.2: Comparison of BER of STBC and TR STBC

So due to this, the orthogonality between signals is improved and interference between the signals is also reduced. Figure 4.2 shows that in fast fading environment, TR STBC gives BER performance equivalent to STBC in slow fading environment.

4.3 Performance of TR STBC in Nakagami fading channel :

Rayleigh fading channel is special case of Nakagami-m fading channel when $m=1$. Fast fading occurs if the coherence time is smaller than the symbol duration. This is the case when $m<1$, such channels become time-varying and within a symbol duration rapid changes occur in impulse response of the channel. Therefore performance of TR-STBC degrades for $m<1$ as compared to $m\geq 1$.

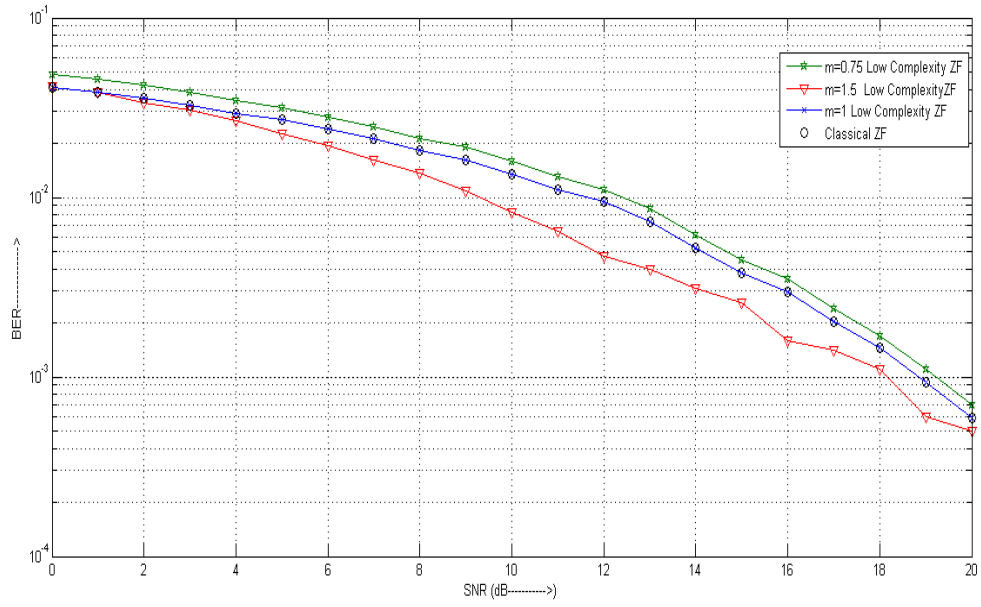


Figure 4.3: Time Reversal STBC Performance for Different Fading Channel.

CONCLUSION AND FUTURE SCOPE

5.1 Conclusion:

Space-time block codes (STBC) can obtain full transmit diversity gain in slow-fading environment. In slow fading environment, the channel coefficients at adjacent time intervals are assumed to be same. But it is not the case for STBC in fast-fading channel. As a result of rapid time variation of the channel in the fast fading environment, the orthogonality of STBC is lost. This will cause error in decoding and hence the system performance is degraded. The bit error rate comparison of space time block codes in slow fading and fast fading environment is shown in figure 3.6.

When the channel suffers from intersymbol interference (ISI) due to large delay spread, Time Reversal Space Time Block Codes (TR-STBC) achieves better performance.

Time Reversal Space Time Block Codes extends space time block codes for transmission over frequency selective channels. Time Reversal Space Time Block Codes encodes together conventionally ordered and time reversed contiguous blocks of symbols. Due to this the orthogonality between the signals is improved. Figure shows bit error rate performance of TR-STBC for 2 transmitter and one receiver antenna.

A low complexity receiver is evaluated to mitigate the effect of intersymbol interference caused due to 'quasi static' assumption in TR-STBC in Nakagami-m fading channel. The Simulation results show that in mobile environments where fading is relatively slow such as Rayleigh (special case of Nakagami-m where $m=1$), proposed low complexity receiver for TR-STBC does not give significant performance over classical zero forcing receiver for TR-STBC. More over it is observed that proposed scheme mitigates slow fading where $m>1$ more efficiently than classical zero forcing receiver for TR-STBC. Further, in the case when channel is modelled as fast fading (Nakagami-m for $m<1$), the performance degrades.

5.2 Future Scope:

- Different equalization schemes can be applied and performance can be evaluated.
- In this thesis work only BPSK modulation technique is dealt with. The effect of usage of M-QAM on TR-STBC is a subject of future research.

- Time reversal space time block codes are evaluated for two transmitters and one receiver in Nakagami $-m$ fading channel. Number of transmitter can be increased and the bit error rate performance of TR-STBC in different fading channels can be evaluated further.

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