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Department of Electronics and Communications Engineering

THESIS
REPORT

On

"Distributed Cooperative Space Time Trellis Code"

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Distributed Cooperative Space Time Trellis Code

Abstract

The wireless communications industry has been undergoing tremendous changes in the last few years. There has been a spectacular growth in the internet and mobile communication services in the last decade. Wireless Internet and multimedia services are introduced in the 3G mobile phones, require much higher data rates than those available with current radio technology. Video telephony and picture messaging introduced by 3G phones generate huge uplink traffic. Given a limited Spectrum the only way to support high data rates is to develop new spectrally efficient radio communication techniques. It was shown recently that multiple input multiple output

(MIMO) system have a potential to significantly increase spectral efficiency in the wireless communications. Space Time codes are practical techniques used to approach the theoretical MIMO spectral efficiencies

Unfortunately uplink transmit diversity is not directly applicable to the cellular due to the small size of the mobile station and electromagnetic interaction of antenna elements on the small platform. Furthermore the channels corresponding to different antennas are correlated because of the miniature size of the mobile phone.

So, there is a need for such ideas to be extended to the macroscopic arena, where space-time coding is performed over transmit antennas that are not necessarily co-located. Mobile antennas are omni directional. Signals transmitted towards the destination can be "overheard" at the other MTs(Partner). Partners (Adjacent MTs) process this overheard information and re-transmit towards the destination. These Partnering mobiles form a Virtual Antenna Array. This approach successfully gives solution to the problem of just one receiving antenna in a handset. In our proposed scheme space-time trellis coding is performed over transmit antennas that are not necessarily co-located. The Idea is called Distributed Space Time Trellis Coding. Cooperative Distributed Space Time Trellis Coding have also been analysed to increase the performance of Distributed Space Time Code.

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Introduction

Since mobile cellular became commercially available in the early 1980s, it has advanced beyond imagination in terms of coverage, services, technology, handsets and regulation. Perhaps the most revolutionary change is that in the space of around 20 years, mobile subscribers surpassed fixed-telephone line subscribers in 2002, making mobile technology the predominant means of voice communications.

First generation mobile cellular networks employed analogue technology. Developments in digital technology led to second-generation (2G) systems. By the end of the 1980s, 2G networks had been developed to provide better quality services, greater capacity and additional functionality than analogue systems. At the end of 2002, the world had almost completed the transition to digital cellular networks, with analogue users accounting for a mere three per cent of total mobile subscribers. There are four 2G digital cellular radio technologies in use around the world.

- **Global System for Mobile Communications (GSM)** This is the predominant technology worldwide and the predominant system in Europe. It is also used in many nations in Africa, Asia, the Middle East and some countries in the Americas. At December 2002, there were 788 million GSM subscribers on 467 networks in 169 countries.
- **Time Division Multiple Access (TDMA)** This is the leading technology in the Americas with 109 million subscribers at December 2002.
- **Code Division Multiple Access (CDMA)** At December 2002, there were 147 million CDMA subscribers with 61 per cent in the Americas, 37 per cent in the Asia-Pacific region and less than two per cent in Europe, the Middle East and Africa.
- **Personal Digital Cellular (PDC)** This system is deployed only in Japan with 60 million subscribers at December 2002.

A significant development with 2G systems has been the increasing utilization of data-like services, for example, the short message service (SMS), which allows text messages to be sent between mobile handsets. Some 360 billion SMS were sent over GSM networks in 2002.Mobile handsets are also increasingly being used to access the Internet. This has become successful in countries such as Japan, where 80 per cent of cellular users subscribe to a mobile Internet service provider.[3]The growing use of mobile data has led to demand for faster speed than the initial transmission rate of 9.6 kbit/s for GSM. This is being accomplished by upgrading existing GSM networks with the deployment of General Packet Radio Service (GPRS) technology. In the case of cdmaOne networks, they are being enhanced with CDMA2000 1X technology. These technologies offer speeds that are equivalent to, or even faster than, conventional dial-up.

The development of 3G systems

The need for faster speed, global compatibility and multimedia services has led to the development of 3G systems. In an effort to consolidate existing incompatible mobile environments into a seamless global network, ITU adopted a family of radio access methods at its Radio communication Assembly in Istanbul in early May 2000. Known as International Mobile Telecommunications-2000 (IMT-2000), this global standard was realized after years of collaborative work between ITU and the global cellular community. At the end of May 2000, the World Radio communication Conference (also held in Istanbul) identified additional frequency bands for 3G (IMT-2000) use. IMT-2000 consists of five different radio access methods: W-CDMA (Wideband Code Division Multiple Access), CDMA20001X, TD-SCDMA, EDGE (Enhanced Data Rates for GSM Evolution) and DECT (Digitally Enhanced Cordless Telecommunications).

Outline of the thesis

This thesis proposes four communication models for the case where mobile terminals act as intermediate relays in wireless communications systems. These are referred to as the direct SISO QPSK, Relayed QPSK, Distributed Space Time Code and Cooperative Distributed Space Time Code.

Chapter 2 presents background for Problems With Wireless Communication, Diversity, Virtual Antenna Arrays, Ad-Hoc Network, Introduction to MIMO and Space-Time Codes and Space-Time Trellis Codes.

Chapter 3 presents System Description and Modelling, Distributed Space Time Coding Distributed Space Time Coding Principles and operation, Different Communication Scenario and Cooperative Distributed Space Time Coding for MRC and LOS

Finally chapter 4 describes the Result and Conclusion, Future Work and Reference

Background

- Problems With Wireless Communication
- Diversity
- Virtual Antenna Arrays
- Ad Hoc Network
- Introduction to MIMO and Space-Time Codes
- Space-Time Trellis Codes

Problems With Wireless Communication

Due to an explosion of demand for high-speed wireless services, wireless communications has become one of the most exciting fields in modern engineering. However, development of 3G products and services poses a serious challenge: how can we support the exceedingly high data rates and capacity required for these applications with the severely restricted resources offered in a wireless channel?

The characteristics of wireless communication channel between the transmitter and the receiver effects the performance of the overall system. The transmitted signal will be attenuated when it propagates from the transmitter to the receiver. Moreover, the transmitted signal could arrive at the receiver through multiple paths, which experience different attenuations, arrive at different time delays and phases. This could result in constructive or destructive summation of the transmitted signal, and could cause a significant attenuation to the signal strength. Furthermore, within a short period of time, the transmission path can vary from line of-sight to one that is obstructed by all sorts of obstacles. Hence, the transmitted signal will suddenly be attenuated significantly and the signal quality will drop from good to bad within this short period of time. This huge variation of wireless communication channel imposes severe limitations for reliable transmission.

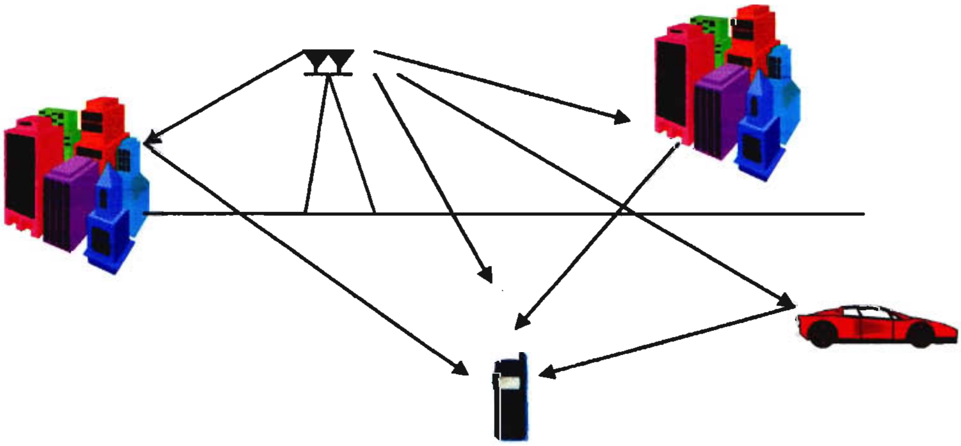


Fig2.1: Wireless environment

The obstacles associated with wireless environments are difficult to overcome. Interference from other users and inter-symbol interference (ISI) from multiple paths of one's own signal are serious forms of distortion, the latter effectively causing frequency-selective channel properties.

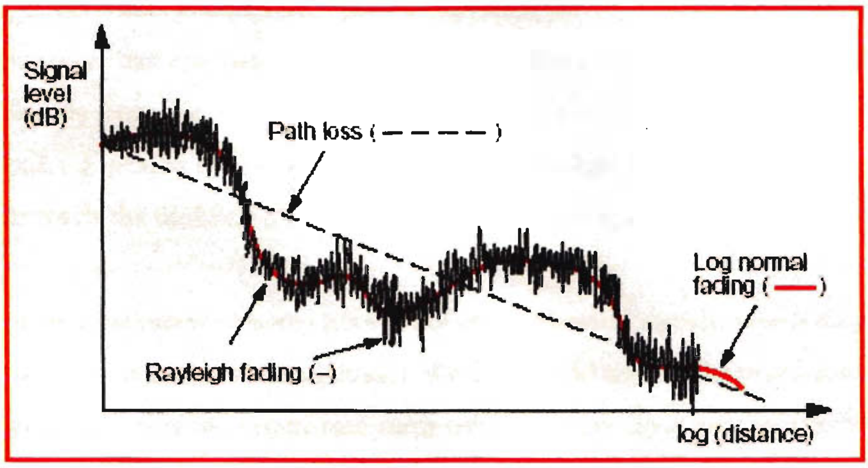


Fig2.2: Different type of fading in wireless channel

Path Loss:

Path loss is the phenomenon which occurs when the received signal becomes weaker and weaker due to increasing distance between mobile and base station. There are no obstacles between transmitting (Tx) and receiving (Rx) antenna. For the free space case we say that for a given antenna the received power density is inversely proportional to the square of the distance, d, between the Tx– and Rx–antennas.

Shadowing or lognormal fading:

However, we seldom use our mobile station in an environment without obstacles. More common is the situation where there are hills, buildings etc. between the base station and the mobile station gives rise to a shadowing effect which decreases the received signal strength. When the mobile moves around, the signal strength decreases and increases depending on whether there are obstacles or not between the Tx and Rx antenna.

Rayleigh Fading:

As mobile telephony becomes more and more popular, it is not hard to believe that the subscriber density is higher where there are a lot of people in the cities. Using a mobile station in the city gives rise to yet another disturbing effect which is called multipath or Rayleigh fading. This occurs when the signal takes more than one path from the Tx– to the Rx–antenna. The signal is not received directly from the Tx–antenna, but from a lot of other directions from where it has bounced, e.g. nearby buildings. There is no line–of–sight path between the antennas. The signals reach the mobile station via several reflections against big buildings.

This means that the received signal is a sum of many identical signals, which differ only in phase (and to some extent in amplitude). While you add signals like vectors, it can unfortunately mean that the vector sum turns out to be very close to zero which means that the signal strength also becomes very close to zero - a very severe fading dip indeed.

Furthermore, when transmit and receive antennas are in relative motion, the Doppler effect will spread the frequency spectrum of received signals . This results in time varying channel characteristics. Many systems must function without a line-of-sight (LOS) path between transmit and receive antennas, thus pure Rayleigh fading may completely attenuate a signal at times and render a channel temporarily useless.

Additionally, the usual additive white Gaussian noise (AWGN) corrupts the signal. Besides the above difficulties, there are extremely limited bandwidth and stringent power limitations on both the mobile unit (for battery conservation) and the base station (to satisfy government safety regulations). To conserve bandwidth resources, we maximize spectral efficiency by packing as much information as possible into a given bandwidth. A solution to the bandwidth and power problem is the cellular concept, in which frequency bands are allocated to small, low power cells and reused at cells far away. However, this idea alone is not enough. We must look to other means, such as space-time coding, to increase data rate, capacity, and spectral efficiency.

Diversity

Diversity is a technique to combine several copies of the same message received over different channels. Diversity is used to improve link performance

In such fading environments discussed in previous section, reliable communication is possible only through the use of diversity techniques in which the receiver is afforded multiple replicas of the transmitted signal under varying fading conditions. These techniques, therefore, reduce the probability that all the replicas are simultaneously affected by a severe attenuation. Commonly used diversity methods include:

1. **Frequency diversity,** in which the signal is transmitted on multiple RF carriers.
2. **Temporal diversity,** in which channel coding and interleaving are used to replicate and distribute the signal over time.
3. **Antenna or spatial diversity,** in which multiple antennas are used at the transmitter and/or receiver to provide multiple replicas of the signal with decorrelated fading characteristics.

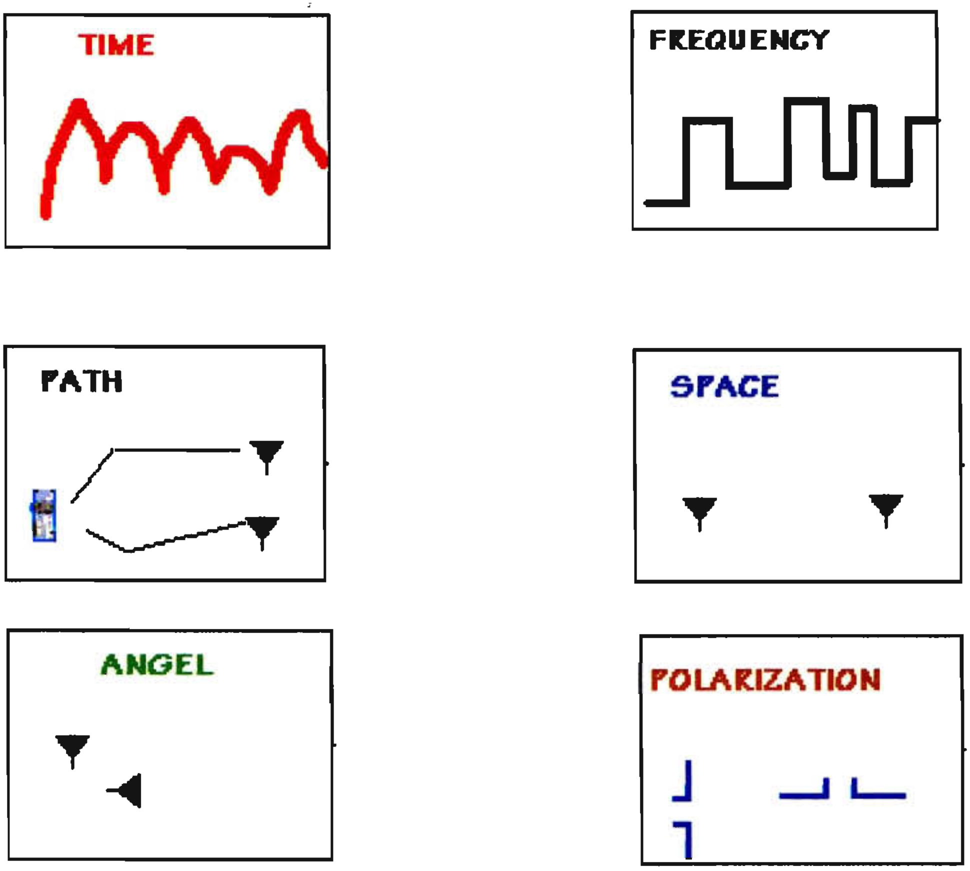


Figure2.3: Various types of Diversity

Recent information theoretic studies have shown that the spatial diversity provided by multiple transmit and/or receive antennas allow for a significant increase in the capacity.

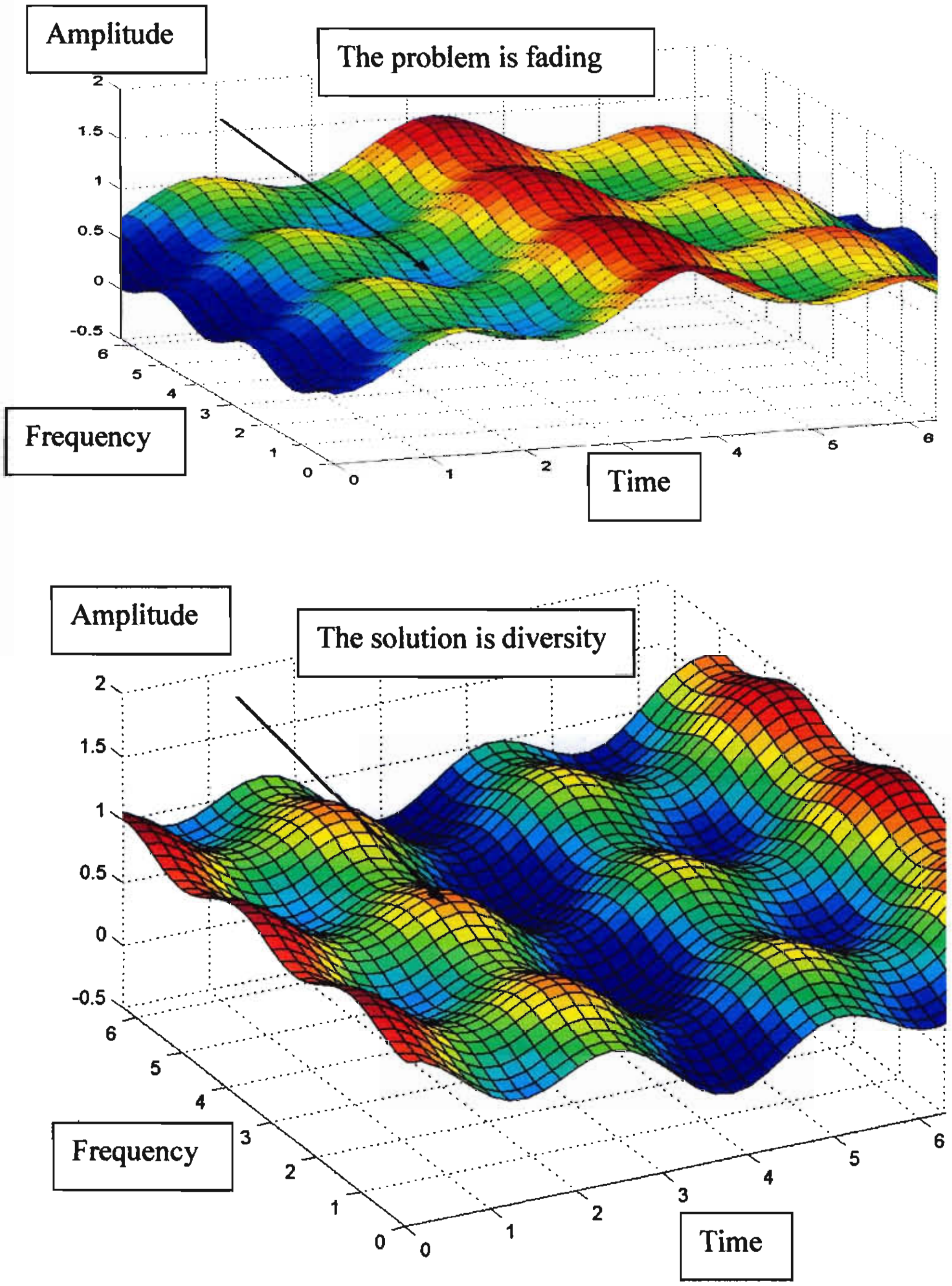


Figure2.4: To combat Fading solution is diversity

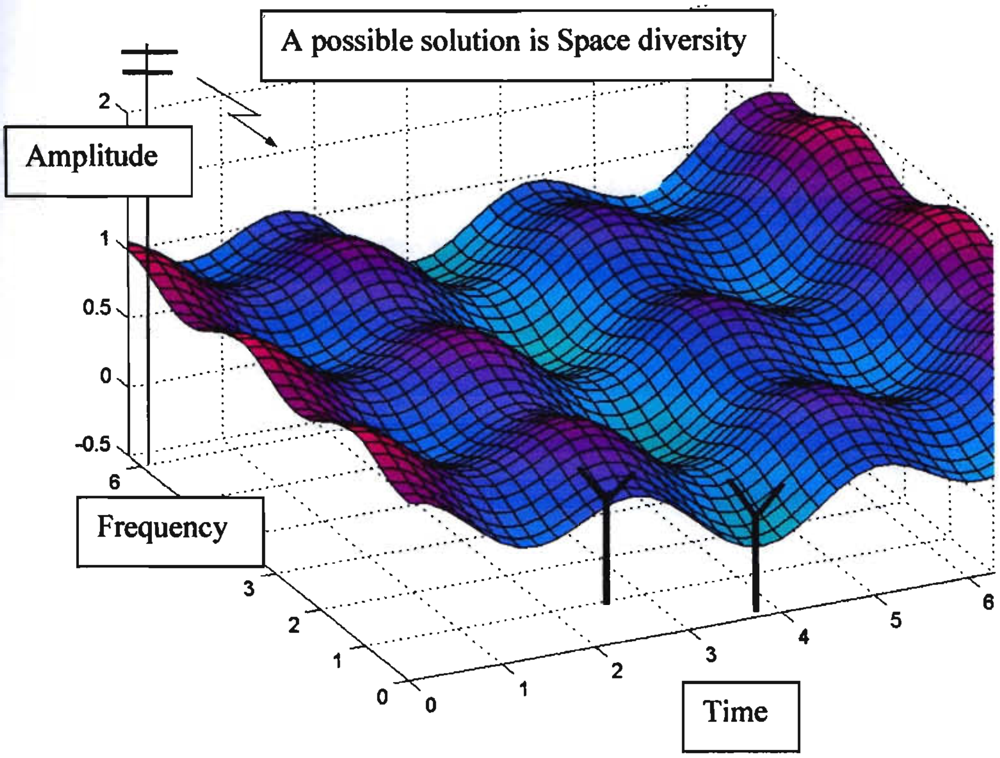


Figure2.5: A possible solution to combat Fading is Space Diversity

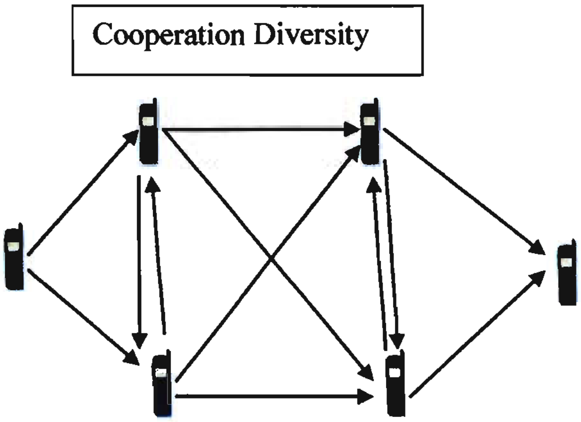


Fig2.6: Cooperative diversity

Virtual Antenna Arrays

The basic concept of Virtual Antenna Arrays is discussed here. Traditionally, each mobile terminal communicates with the BS separately. This has the obvious advantage that the BS has total control over what happens in the cell. Inherently, dynamics is kept at a very low level.

With a conventional array, then elements are closely spaced (λ/2) and connected through high bandwidth cabling. It is called Micro diversity.

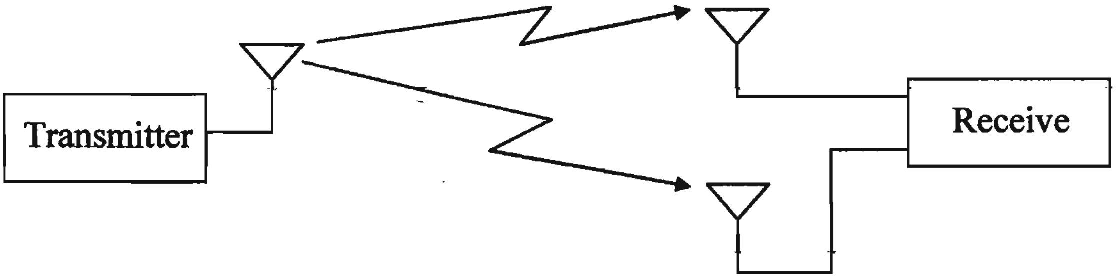


Fig2.7: Conventional Antenna Array

With a distributed array, the antennas are widely separated (e.g. different base stations) and connected through a moderate bandwidth backbone. It is called Macro diversity.

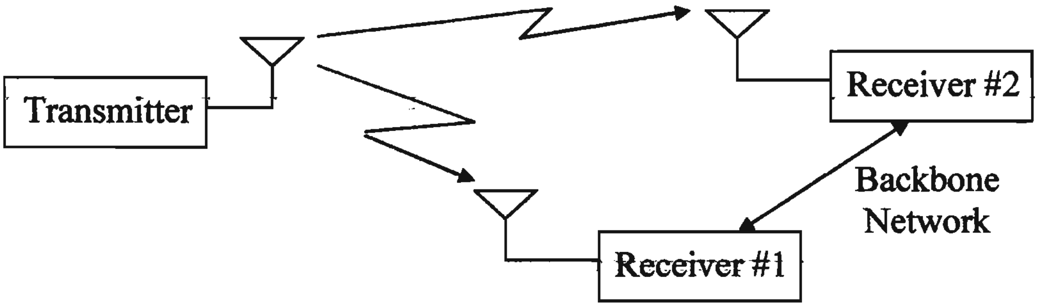


Fig2.8: Distributed Antenna Array

With a virtual array, the antenna elements are widely spaced (attached to different receivers) but are not connected by a backbone. It is called decentralized Macro diversity

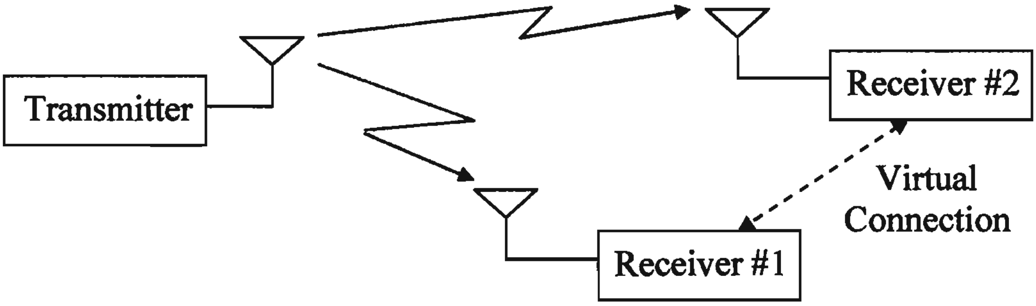


Figure2.9: Virtual Antenna Array

In virtual antenna array the users within a certain communication network communicate with base station and directly with each other. Adjacent mobile terminals form an ad-hoc VAA by means of a link between the antenna elements of each terminal.

The idea behind the VAA was to design a communication system that is capable of supporting MIMO systems and thus achieve a higher data throughput. Basically, the implementation of MIMO techniques seems to be impossible where the number of antennas in the mobile terminal is the limiting factor.

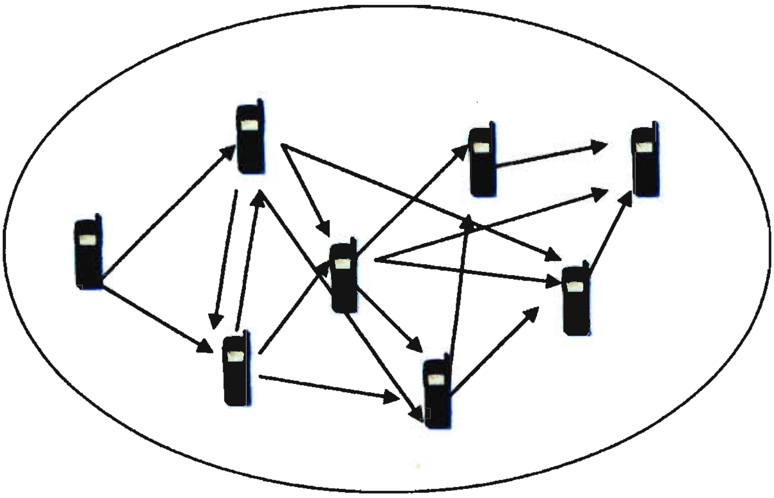


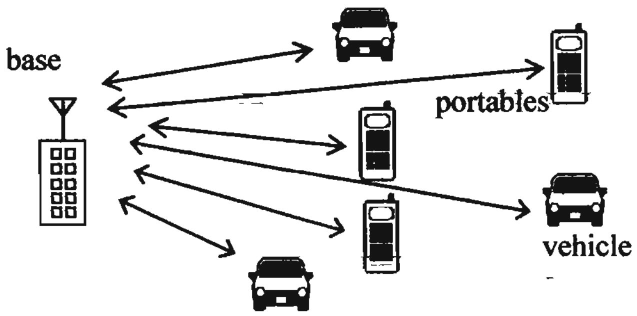
Figure2.10: Virtual Antenna Array

Figure shows typical cell with VAA deployment. It is envisaged that users form mutually supporting VAA groups, each of which emulates a MIMO channel of specific order. Communication is then accomplished by encoding the signal stream as if a MIMO channel was available. The research undertaken in this work highlights the performance gains of a VAA scheme with deployed STTC.

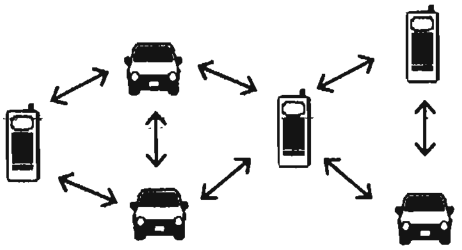
Ad Hoc Wireless Networks

Wireless ad hoc networking is basically– The art of networking without a network. It's a collection of mobile nodes forming a temporary network. It is a Dynamic topology without centralized administration or standard support services.

However, all of the current wireless communication services assume fixed infrastructures consisting of base stations and the associated links to fixed wired networks. Even two subscribers located very close make a conversation by way of a base station, as shown in Fig.1 (a), possibly located several



(a) Conventional cellular network



(b) Ad hoc network

Figure 2.11 : Networks with base station and without base station.

km apart. This wastes power and frequency utilization efficiency.. In contrast to this, so-called ad hoc network is a network without infrastructure such that mobile terminals themselves autonomously forms a network without base station to communicate each other under the distributed control as shown in Fig.1(b). In the area of wireless local area network (LAN), such an ad hoc network has already been studied and standardized, for instance, at IEEE802.11.

How will these wireless ad hoc networks affect the current wireless networks? Firstly, this type of network is expected to broaden the radio coverage of the current cellular system as proposed to 3rd Generation Partnership Project (3GPP) by the name of Opportunity Driven Multiple Access (ODMA). Around the edge of the cell, transmission channel is generally considered to be poor. Therefore, relaying messages to the inner terminals first and then making a connection with base station improve transmission performance of the terminals.

Secondly and most importantly, this type of network contributes to the large extent to the efficient use of radio resource such as frequency spectrum and transmitter power. Just think about the case where calling person and called person are located very near, yet they must communicate via a distant base station, which naturally leads to inefficient use of the radio spectrum and also the power. If two terminals can directly communicate each other, this contributes a lot to improve the spectral efficiency. In the case of multi-hop connection, one may think that total transmission power might be increased because the power is also used to relay other users' packets. However, it will be shown in the next section that this is not true. Similarly, frequency utilization efficiency will be improved mainly because frequency can be used very locally and reused more frequently, although frequency must also be used to relay the packets hop by hop.

Thirdly, this might lead to the concept of "all wireless network" without using the common carrier's network, implying that the cost of networking approaches free of charge. Imagine the world where everything is connected by wireless link. Those emerging networks such as so-called sensor networks, Bluetooth , ad hoc WLAN, inter-vehicle communications will naturally make it necessary to realize a hierarchical self-deployable wireless ad hoc network with distributed control. In the coming world of

IPv6, every device can be given an IP address and can be accessed from anywhere through the Internet.

At this moment, however, it is more reasonable to think about the wireless networks consisting of both wireless networks with infrastructure and without infrastructure. Of course, some hierarchical structure must be incorporated.

Introduction to MIMO and Space-Time Codes

MIMO systems can be defined simply.

MIMO system consists of several antenna elements, plus adaptive signal processing, at both transmitter and receiver, the combination of which exploits the spatial dimension

Frequency and time processing are at limits.Space processing is interesting because it does not increase bandwidth

- Higher capacity (bits/s/Hz)
- Better transmission quality
- Increased coverage
- Promises a vast improvement in coverage and capacity in cellular systems

A key feature of MIMO systems is the ability to turn multipath propagation, traditionally a problem of wireless transmission, into a benefit for the user. MIMO effectively takes advantage of random fading and when available, multipath delay spread for multiplying transfer rates. The prospect of many orders of magnitude improvement in wireless communication performance at no cost of extra spectrum (only hardware and complexity are added) is largely responsible for the success of MIMO as a topic for new research. This has prompted progress in areas as diverse as channel modeling, information theory and coding, signal processing, antenna design and multi antenna cellular design, fixed or mobile.

- Receive diversity: This is the configuration of uplink when one mobile terminal is transmitting with one antenna and base station has two receive antenna. Capacity increases logarithmically with the number of receive antennas.

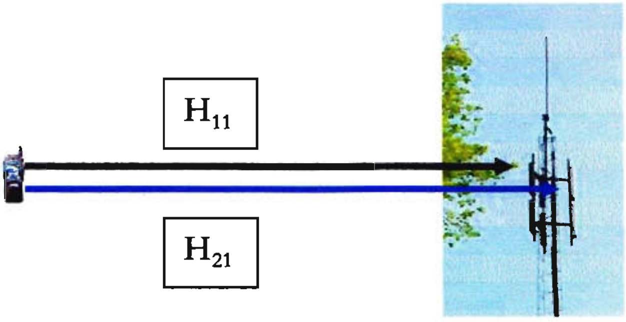


Fig2.12: Receive diversity 1transmit and 2 receive antenna

$$C = \log_2 .\det[I + \frac{P_T}{\sigma^2 n_T} HH^*] \ .$$

$$= \log_2 .\det[1 + \frac{P_T}{\sigma^2} |H\ |^2 \quad \text{[bit/(Hz·s)]} \qquad (2.1)$$

Where, **H** = [H_{11} H_{21}]

- **Transmit diversity:** This is the configuration of downlink when one mobile terminal is receiving with one antenna and base station has two transmit antenna. 3 dB SNR increase if transmitter knows **H**.Capacity increases logarithmically with n_t

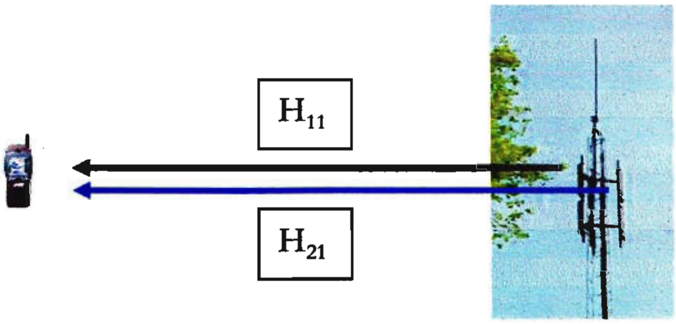


Fig2.13: Transmit diversity 1 transmit and 2 receive antenna

$$C_{Diversity} = \log_2 .\det[I + \frac{P_T}{\sigma^2 n_T} HH^*] \qquad (2.2)$$

$$C_{Diversity} = \log_2 .\det[I + \frac{P_T}{2\sigma^2} HH^*] \qquad (2.3)$$

$$C_{Beamfor\min g} = \log_2 .\det[1 + \frac{P_T}{\sigma^2} |H\ |^2 \qquad (2.4)$$

MIMO:

This is the configuration when mobile terminal has two antenna and base station has two antennas.

We consider MIMO system with n_T transmit and n_R receive antennas. The transmitted signal is represented by n_T x 1 column matrix X. The total transmitted power is constrained to P_T, regardless of number of transmit antenna n_T. We assume that the signal transmitted from the individual antenna elements have equal power of $\frac{p_T}{n_T}$. The transmitted power bandwidth is narrow enough that its frequency response can be considered as flat.

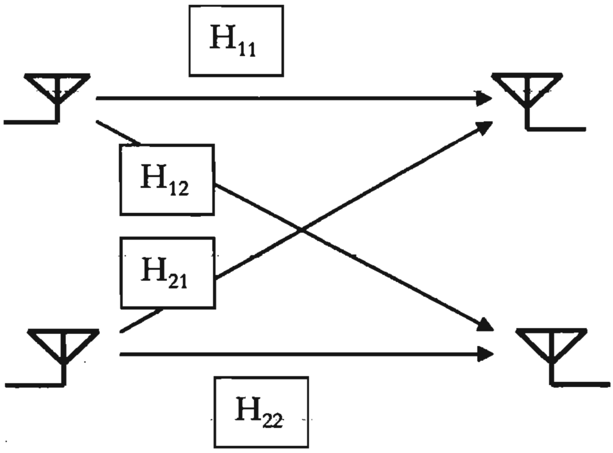


Fig2.14: MIMO 2 transmit and 2 Receive antenna

The noise at the receiver is described by an n_R x 1 column matrix , denoted by n. Its components are statistically independent complex zero mean gaussian variables. Receive antennas have identical noise power of σ^2. The received signal is represented by an n_R x 1 column matrix ,denoted by r , where each complex component refers to a receive antenna.

We denote the average power at the output of each receive antenna by P_R, The average Signal to Noise Ratio at the each receiver branch is given by,

$$SNR = \frac{P_R}{\sigma^2} \tag{2.5}$$

and it is independent of n_T.

The channel is described by an n_T x n_R complex matrix denoted by H. For normalization purposes we assume that the receiver power for each of n_R receive branch is equal to the total transmitted power. Thus we obtain the normalization constraint for the element of H,
in channel with fixed coefficients, as

$$\sum_{j=1}^{n_T} \left|h_{ij}\right|^2 = n_T \text{ where I=1,2.....} n_R \tag{2.6}$$

We will assume that the channel matrix is known to the receiver, which can be achieved for example , by transmitting a training preamble. On the other hand in most situation We will assume that the channel parameters are not known at the transmitter.

We will consider several possible scenarios for matrix H

- Matrix H is deterministic.
- Matrix H is random .We will mainly focus on Rayleigh distribution of the channel matrix elements. Channel matrix change randomly at the beginning of the each symbol interval T and are kept constant during symbol intervals , Such channels are called fast fading channel.
- Matrix H is random .Its entries change randomly and are kept constant during a fixed number of symbol interval, much shorter than a transmission blocks. Such channels are called block-fading channel.
- Matrix H is random but is fixed at the start of the transmission block, which means that symbol duration is small compared to the channel coherence time. This channel is known as slow or quasistic fading channel.

By using the linear model the received signal can be represented as,

$$r = H.x + n \tag{2.7}$$

The channel capacity is the maximum possible transmission rate such that the probability of error is arbitrarily small .

$$C_{Diversity} = \log_2 .\det[I + \frac{P_T}{\sigma^2 n_T} HH^*] \tag{2.8}$$

$$C_{Diversity} = \log_2 .\det[I + \frac{P_T}{2\sigma^2} HH^\dagger] \tag{2.9}$$

$$= \log_2\left[1 + \frac{P_T}{2\sigma^2}\lambda_1\right] + \log_2\left[1 + \frac{P_T}{2\sigma^2}\lambda_2\right] \quad (2.10)$$

Where the λ_i are the eigenvalues to $\mathbf{HH}^{\dagger}$ and

$$\mathbf{H} = \begin{bmatrix} H_{11} & H_{12} \\ H_{21} & H_{22} \end{bmatrix}$$

MIMO can be interpreted by simple Pipe analogy. We used different channel between the transmitter and receiver.

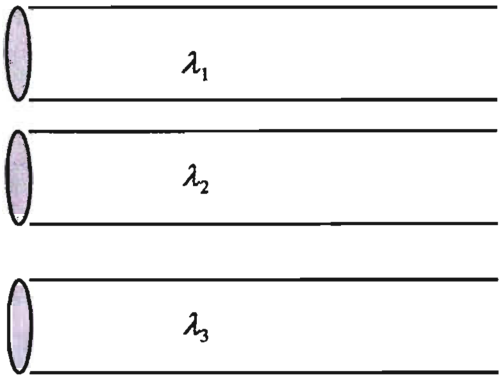


Fig2.15: MIMO with Pipe analogy

m=min(n_r, n_t) parallel channels, equal power allocated to each "pipe" or channel.

Space Time Codes are practical techniques used to approach the theoretical MIMO spectral efficiencies. It is a branch of wireless communications that utilizes the "Space Dimension" along with the traditional time dimension in modulation and coding at the transmitter and demodulation and decoding at the receiver so as to improve the link of the wireless communications

Space-Time Codes (STC) were first introduced by Tarokh et al. from AT&T research labs [1]. in 1998 as a novel means of providing transmit diversity for the multiple-antenna fading channel. Previously, multipath fading in multiple antenna wireless systems was mostly dealt with by other diversity techniques, such as temporal diversity, frequency diversity and receives antenna diversity, with receive antenna diversity being the most widely applied technique.

However, it is hard to efficiently use receive antenna diversity at the remote units because of the need for them to remain relatively simple, inexpensive and small. Therefore, for commercial reasons, multiple antennas are preferred at the base stations, and transmit diversity schemes are growing increasingly popular as they promise high data rate transmission over wireless fading channels in both the uplink and downlink while putting the diversity burden on the base station.

System Block Diagram:

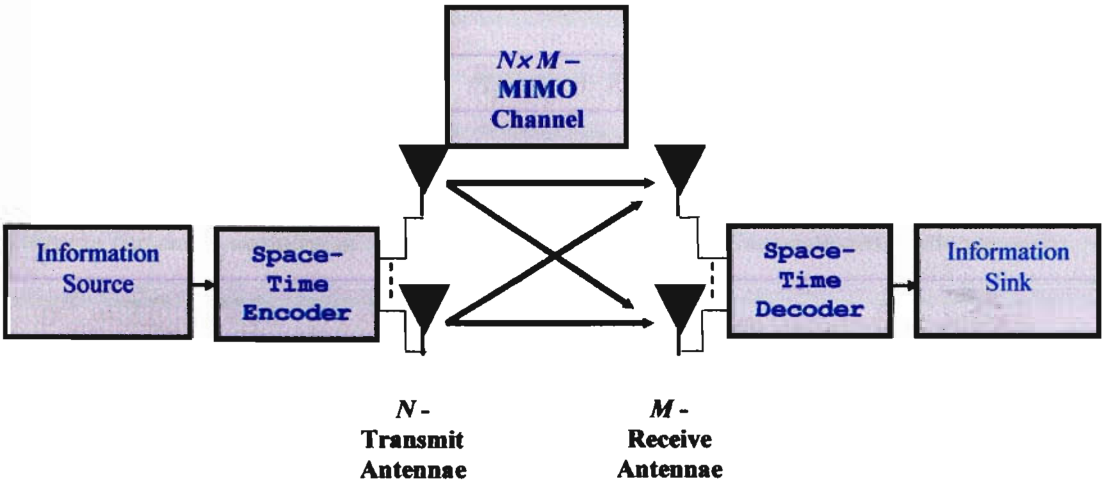


Figure2.16: Space-Time encoder and decoder

The space-time coding scheme by Tarokh et al. [1], [2], is essentially a joint design of coding, modulation, transmit and receive diversity, and has been shown to be a generalization of other transmit diversity schemes, such as the bandwidth efficient transmit diversity scheme by Witneben [4] and the delay diversity scheme by Seshadri and Winters [5].

Consider a mobile communications system where the base station is equipped with n antennas and the remote unit is equipped with m receive antennas. At each time slot t, signals C_t^i ,i = 1;2……n are transmitted simultaneously from the n transmit antennas.

The channel is flat fading and the path gain from transmit antenna i to receive antenna j is denoted by h_{ij}

The path gains are modeled as samples of independent complex Gaussian random variables with variance 0:5 per real dimension, we assume that signals received at different antennas experience independent fading. In this report, we will consider modeling the path gains in both slow and fast Rayleigh fading. For slow fading, it is assumed that the path gains are constant during a frame of length L and vary from one frame to another, i.e., channel is quasi-static. For fast fading, the path gains are constant within each symbol period and vary from symbol to symbol.

Assuming that r_t^j is the received signal at antenna j at time t, is given by,

$$r_t^j = \sum_{i=1}^{n} h_{i,j} c_t^i + n_t^j \qquad (2.11)$$

where the noise samples n_t^j are i.i.d. zero mean complex Gaussian with variance with $\sigma^2 = 2E_S / N_O$ = (1/2 SNR) per dimension. The average energy of the symbols transmitted from each antenna is normalized to one, so that the average power of the received signal at each receive antenna is n.

It is assumed that channel state information is only available at the receiver, who uses it to compute the decision metric

$$\sum_{t=1}^{l} \sum_{j=1}^{m} [\, r_t^j - \sum_{i=1}^{n} h_{i,j} C_t^i \,]^2 \qquad (2.12)$$

Over all code words $C_1^1\ C_1^2 \ldots\ldots C_1^n\ C_2^i \ldots\ldots C_2^n\ C_l^n \ldots C_l^n$ and decide in favour of codeword which minimizes the sum.

There are two main types of STCs, namely space-time block codes (STBC) and space-time trellis codes (STTC). Space-time block codes operate on a block of input symbols, producing a matrix output whose columns represent time and rows represent antennas. In contrast to single-antenna block codes for the AWGN channel, space-time block codes do not generally provide coding gain, unless concatenated with an outer code.

Their main feature is the provision of full diversity with a very simple decoding scheme. On the other hand, space-time trellis codes operate on one input symbol at a time, producing a sequence of vector symbols whose length represents antennas. Like traditional TCM (trellis coded modulation) [6] for a single-antenna channel, space-time trellis codes provide coding gain. Since they also provide full diversity gain, their key advantage over space-time block codes is the provision of coding gain. Their disadvantage is that they are extremely hard to design and generally require high complexity encoders and decoders.

Space-Time Trellis Codes

Space Time Block codes can achieve a maximum possible diversity advantage with a simple decoding algorithm. However the coding gain provided by Space Time Block codes is very limited and non-full rate space time block codes can introduce bandwidth expansion.

Space Time Trellis Coded Modulation (STTCM) is obtained by a joint design of error control coding, modulation, transmit and receive diversity to combat the effect of fading. Space Time Trellis Coded Modulation (STTCM) can simultaneously offer a substantial coding gain, spectral efficiency, and diversity improvement on flat fading channels.

In order to minimize the error probability, a code design criteria was specified in order to build optimum space-time codes; thus providing high coding gain on top of diversity gain.

The code design criteria suggests that in order to maximize the coding gain, one should maximize the rank and the determinant of the distance matrix; where the distance matrix is derived from the difference matrix which is simply the difference between the transmitted symbols from the **n**T transmit antennas and the erroneous received symbols at the receiver.

Later, it was found that if the diversity order of the system is 4 or more (where a diversity order is defined as the product of the number of transmit and receive antennas, **n**T x **n**R, then the design criteria depends on the rank and trace of the distance matrix, in order to get maximum coding gain over slow fading channels. This is consistent with the conclusions on convergence of a fading channel to an AWGN channel for a large number of diversity branches.

Space Time Trellis Code Design Criteria:

According to the system model is as follows. Assumed is a MIMO system with N transmit and M receive antennas. The channel is comprised of $N \times M$ slowly varying channels, where each channel is assumed to obey a narrowband Rayleigh fading.

Then, the following code vector is transmitted simultaneously from all N transmit antennas at time instant l:

$$\mathbf{c}_l = [c_1(l),\ c_2(l),\ \ldots,\ c_N(l)]^{\mathrm{T}} \tag{2.13}$$

The MIMO channel matrix $\mathbf{H}$ is given as:

$$\mathbf{H} = \begin{bmatrix} \alpha_{1,1} & \alpha_{1,2} & \cdots & \alpha_{1,N} \\ \alpha_{2,1} & \alpha_{2,2} & \cdots & \alpha_{2,N} \\ \vdots & \vdots & \ddots & \vdots \\ \alpha_{M,1} & \alpha_{M,2} & \cdots & \alpha_{M,N} \end{bmatrix} \tag{2.14}$$

Finally, the received signal vector can be expressed as:

$$\mathbf{r}(l) = \mathbf{H} \cdot \mathbf{c}_l + \mathbf{n}(l) \tag{2.15}$$

The probability that a ML receiver decides erroneously in favour of a signal

$$\mathbf{e} = e_1^1 e_1^2 \cdots\ e_1^n e_2^1 e_2^2 \cdots\ e_2^n \cdots\ e_l^1 e_l^2 \cdots\ e_l^n \tag{2.16}$$

Assuming that

$$\mathbf{c} = c_1^1 c_1^2 \cdots\ c_1^n c_2^1 c_2^2 \cdots\ c_2^n \cdots\ c_l^1 c_l^2 \cdots\ c_l^n \tag{2.17}$$

Was transmitted

A. Pair wise Error Probability

The pair wise error probability (PEP) is the probability that the maximum likelihood decoder selects $\mathbf{e} = e_1^1 e_1^2 \ldots e_1^n e_2^1 e_2^2 \ldots e_2^n \ldots e_l^1 e_l^2 \ldots e_l^n$ when in fact the signal $\mathbf{c} = c_1^1 c_1^2 \ldots c_1^n c_2^1 c_2^2 \ldots c_2^n \ldots c_l^1 c_l^2 \ldots c_l^n$ was transmitted. This occurs if, summing over all symbols, antennas, and time periods,

$$\sum_{t=1}^{l}\sum_{j=1}^{m}\left| r_t^j - \sum_{i=1}^{n} h_t^{i,j} c_t^i \right|^2 \geq \sum_{t=1}^{l}\sum_{j=1}^{m}\left| r_t^j - \sum_{i=1}^{n} h_t^{i,j} e_t^i \right|^2 \qquad (2.18)$$

which can be rewritten as

$$\sum_{t=1}^{l}\sum_{j=1}^{m} 2\,\mathrm{Re}\{\eta_t^{j*}\sum_{i=1}^{n} h_t^{i,j}(e_t^i - c_t^i)\} \geq \sum_{t=1}^{l}\sum_{j=1}^{m}\left|\sum_{i=1}^{n} h_t^{i,j}(e_t^i - c_t^i)\right|^2 \qquad (2.19)$$

where $\mathrm{Re}\{.\}$ refers to the real part of the argument. With the ideal channel state information at the receiver and for a given instance of channel path gains $\{h_{i,j}\}$ the term on the right of the above equation is a constant equal to $d^2(e,c)$ and the term on the left is a zero-mean Gaussian random variable with variance $4\sigma^2.d^2(e,c)$. Hence, the PEP conditioned on knowing $\{h_{i,j}\}$ is given by

$$P(c \to e | h_{i,j}, i = 1,\ldots.n, j = 1,\ldots.,m) = Q\left(\frac{d(e,c)}{2\sigma}\right) \leq \exp(-d^2(c,e)\frac{E_S}{4N_0} \qquad (2.20)$$

where Q(x) is the complementary error function given by

$$Q(x) = \int_x^{\infty} e^{\frac{-t^2}{2}}\, dt \qquad (2.21)$$

Now, $d^2(c,e)$ can be rewritten as $\sum_{i=1}^{n}\sum_{i'=1}^{n} h_{ij}\overline{h_{i'j}}(c_t^i - e_t^i)\overline{(c_t^{i'} - e_t^{i'})}$ where $\bar{x}$ is the complex conjugate of x.

$$d^2(c,e) = \sum_{t=1}^{l}\sum_{j=1}^{m}\sum_{i=1}^{n}\sum_{i'=1}^{n} h_{ij}\overline{h_{i'j}}(c_t^i - e_t^i)\overline{(c_t^{i'} - e_t^{i'})} \qquad (2.22)$$

If we denote $\Omega_j = (h_{1,j}, h_{2,j,\ldots\ldots} h_{n,j})$ we can rewrite

$$d^2(c,e) = \sum_{j=1}^{m}\Omega_j A \Omega_j^{\dagger} \qquad (2.23)$$

where $\Omega_j^{\dagger}$ denotes the Hermitian transpose of j and A = A(e;c) is an n x_n matrix independent of time and contains entries $A_{p,q} = \sum_{t=1}^{l}(c_t^p - e_t^p)\overline{(c_t^q - e_t^{q'})}$ So, the PEP becomes

$$P(c \rightarrow e | h_{i,j}, i = 1,\ldots.n, j = 1,\ldots., m) \leq \prod_{j=1}^{m} \exp(-\frac{\Omega_j A \Omega_j^{\dagger} E_S}{4N_0}) \qquad (2.24)$$

Since A is Hermitian, there exists a unitary matrix V that satisfies $V.V^{\dagger} = I$ and a real diagonal matrix D such that

$$V.A.V^{\dagger} = D \qquad (2.25)$$

The rows $v_1, v_2 \ldots\ldots\ldots\ldots v_n$ of V are the eigenvectors of A, and form a complete orthonormal basis of an n-dimensional vector space. Furthermore, the diagonal elements of D are the eigenvalues λ_i, I=1,2,3..........n of A including multiplicities, and are nonnegative real numbers since A is Hermitian.

where **c** and **e** are the originally sent and erroneously received code words, respectively; *Es* the symbol energy and *N0* the noise spectral density; *m, n* the number of receive and transmit antennas, respectively and λ_i the *ith* eigenvalue of the distance matrix A (**c**, **e**) = B (**c**, **e**) B^H (**c**, **e**), where B^H denotes the Hermitian of B. The difference matrix B for codewords of length *l* is given as:

$$\mathrm{B(c,e)}=\begin{bmatrix} e_1^1-c_1^1 & \cdots & \cdots & e_l^1-c_l^1 \\ \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots \\ e_1^n-c_1^n & \cdots & \cdots & e_l^n-c_l^n \end{bmatrix} \tag{2.26}$$

Next, we express $d^2(c,e)$ in terms of the $\{\lambda i\}$. Let $\beta_{1,j}, \beta_{2,j}, \beta_{3,j} \ldots\ldots\ldots \beta_{n,j}$ then

$$\Omega_j A \Omega_j^\dagger = \Omega_j V^\dagger D V \Omega_j^\dagger = \sum_{i=1}^{n} \lambda_i \left|\beta_{i,j}\right|^2 \tag{2.27}$$

Since $\{h_{i,j}\}$ are samples of a complex Gaussian random variable with mean E $h_{i,j}$, let

$$K^j = (Eh_{1,j}, Eh_{2,j}, \ldots\ldots\ldots\ldots Eh_{n,j}) \tag{2.28}$$

Since V is unitary, this implies $\beta_{i,j}$ are independent complex Gaussian random variables with variance 0.5 per dimension and with mean $K^j.v_i$

B. Error Probability on Slow Fading Channels:

In the case of at Rayleigh fading, E $h_{i,j}$ =0, for all i and j. To obtain an upper bound on the average probability of error, we average

$$\prod_{j=1}^{m} \exp\left\langle -\left(\frac{E_S}{4N_0}\right) \sum_{i=1}^{n} \lambda_i \left|\beta_{i,j}\right|^2 \right\rangle \tag{2.29}$$

with respect to the independent Rayleigh distributions of $\beta_{i,j}$ with probability density of $P(|\beta_{i,j}| = 2|\beta_{i,j}|\exp(-|\beta_{i,j}|^2)$. Letting $c = \frac{E_S}{4N_0}$, we get

$$E\prod_{j=1}^{m} e^{-c}\sum_{i=1}^{n}\lambda_i|\beta_{i,j}|^2 = \prod_{j=1}^{m}\prod_{i=1}^{n} E(e^{\frac{-c\lambda_i}{|\beta_{i,j}|^2}}) \tag{2.30}$$

by independence, and

$$E(e^{\frac{-c\lambda_i}{|\beta_{i,j}|^2}} = 2\int_0^\infty e^{c\lambda_i w^2} we^{-w^2} dw$$

$$= 2\int_0^\infty we^{-w^2(1+c\lambda_i)} dw$$

$$= \frac{1}{(1+c\lambda_i)}\int_0^\infty ue^{-u} du$$

$$= \frac{1}{1+c\lambda_i} \tag{2.31}$$

So

$$P(c \rightarrow e) \leq \left\langle \frac{1}{\prod_{i=1}^{n}(1+\frac{E_S}{4N_0}\lambda_i)} \right\rangle^m$$

Let r be the rank of A, then eigen value zero has multiplicity n-r.Let the non-zero eigen values of A be $\lambda_1, \lambda_2, \lambda_3 \ldots\ldots\ldots\lambda_r$,then for high SNR $(1+\frac{E_S}{4N_0}\lambda_i) \approx \frac{E_S}{4N_0}\lambda_i$

And the PEP becomes

$$P(c \to e) \le (\prod_{i=1}^{r} \lambda_i)^{-m} (\frac{E_S}{4N_0})^{-rm} = (\prod_{i=1}^{r} \lambda_i^{\frac{1}{r}})^{-rm} (\frac{E_S}{4N_0})^{-rm} \qquad (2.32)$$

Thus a diversity advantage of mr and a coding advantage of $\prod_{i=1}^{r} \lambda_i^{\frac{1}{r}}$ are obtained. Note that diversity advantage is defined as the power of the SNR in the denominator of the right hand expression of the equation and coding advantage is intuitively an estimate of the gain over an uncoded system with the same diversity advantage

C. Design criteria for Slow Rayleigh Fading STTCs

The Rank Criterion: To obtain maximal diversity, we need to maximize the minimum rank r of the matrix B over all pairs of distinct codewords. A diversity advantage of rm is achieved.

The Determinant Criterion: Let rm be the target diversity advantage. Then the design goal is to maximize the minimum determinant $\prod_{i=1}^{r} \lambda_i^{\frac{1}{r}}$ of the matrix A along the pairs of distinct code words with minimum rank.

D. Case of Fast Rayleigh Fading

The analysis for slow fading channels in the previous sections can be directly applied to fast fading channels. At each time t, we define a space-time symbol difference vector F(c,e) as,

$$F(c,e) = [c_t^1 - e_t^1, c_t^2 - e_t^2, \dots\dots\dots\dots\dots\dots c_t^n - e_t^n,]^T \qquad (2.33)$$

we consider an n x n matrix C = C(c,e) defined as $c = F(c,e)F^{\dagger}(c,e)$

It is clear that C is Hermitian, so there exists a unitary matrix Vt and a real diagonal matrix Dt such that

$$V_t C V_t^{\dagger} = D_t \qquad (2.34)$$

The diagonal entries of Dt are the eigenvalues of C; the rows of Vt, are the eigenvectors of C, which form a complete orthonormal basis of an n-dimensional vector space.

Note that C is a rank 1 matrix if $c \neq e$, and is rank 0 otherwise. It follows that n-1 elements in the list $\{D_t^i, i = 1,\ldots\ldots.n\}$ are zeros, and WLOG, we can let the single nonzero element in this list be D_t^1 with corresponding eigenvector v_t^1 Since expressions for $d^2(c,e)$ are still valid here, we can directly substitute D_t^i into equation and obtain the PEP in the case of fast Rayleigh fading

$$P(c \to e) \leq \prod_{i=1}^{n} \left(1 + D_t^i \frac{E_S}{4N_0}\right)^{-m} \tag{2.35}$$

Let $v(c,e)$ denote the set of time instances such that $1 \leq t \leq l$ such that $D_t^1 \neq 0$
And , let $|v(c,e)|$ denote the number of elements of $v(c,e)$, Then

$$P(c \to e) \leq \prod_{t \in v(c,e)1}^{n} \left(D_t^i \frac{E_S}{4N_0}\right)^{-m} \tag{2.36}$$

It follows that a diversity of $|v(c,e)|$is achieved. Examining the coefficients of $(\frac{E_S}{4N_0})^{-mV}$ leads to the following design criterion.

E. Design criteria for Fast Rayleigh Fading STTCs

The Distance Criterion: To obtain a diversity of rm, we require for any two codewords c and e, that the Hamming distance between c and e be at least r.

The Product Criterion: Let $v(c,e)$ be the set of time instances such that $c_1^t c_2^t \ldots\ldots\ldots c_t^n \neq e_1^t e_2^t \ldots\ldots\ldots e_t^n$ and let $D_t^1 = \sum_{i=1}^{n} \left|c_t^i - e_t^i\right|^2$

To obtain maximal coding advantage in a fast fading environment, we maximize the minimum of the products

$$\prod_{t \in v(c,e)} \left| D_t^1 \right|^2 \qquad (2.37)$$

over distinct codeword c and e.

Encoding/Decoding of STTCs for Quasi-Static Flat Fading Channels:

The encoding for STTCs are similar to TCM, except that at the beginning and the end of each frame, the encoder is required to be in the zero state. At each time t, depending on the state of the encoder and the input bits, a transition branch is selected.

If the label of the transition branch is $I_t^1, I_t^2 ....I_t^n$ then transmit antenna **i** is used to send the constellation symbols $I_t^i, i = 1,2......n$ and all these transmissions are in parallel. An example of a STTC encoder is shown in for 4-PSK. The encoder coefficient set, denoted by

$$g^t = [(g^t_{0,1}, g^t_{0,2,......}g^t_{0,n}),(g^t_{1,1}, g^t_{1,2,......}g^t_{1,n})..........(g^t_{v1,1}, g^t_{v1,2,......}g^t_{0,n})] \qquad (2.39)$$

Consider a simple 4-PSK, 4-state code for 2 transmit antennas in order to explain how the it works. Such a code has 8 coefficients in the encoder, 4 for each antenna. The coefficients are arranged as shown in Figure.

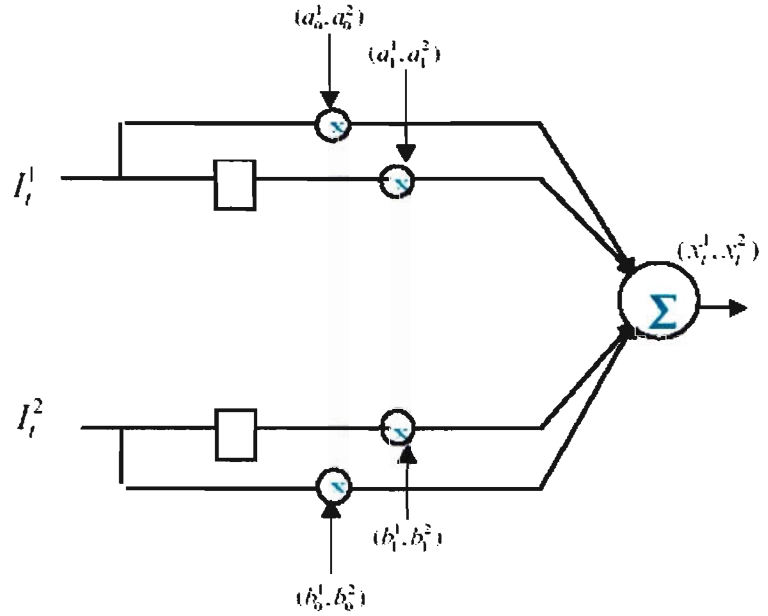


Figure2.17: Space time Trellis code encoder

At any time *t*, two binary inputs I_t^1 and I_t^2 are fed into the encoder, where I_t^1 is the most significant bit.This order may be reversed as long as we are consistent during the decoding in the receiver. The two streams of input bits are delayed as shown, and multiplied by coefficient pairs (a_p^1, a_p^2) or (b_q^1, b_q^2) respectively, where $a_p^i, b_q^i \in \{0,1,2,3\}$, i=1,2 p=0,1.....v1, q=0,1.....v2 where v1 and v2 are are the memory orders for the upper and lower branches respectively. Then, all the data after multiplication are added in modulo 4. At the output of the adder, x_t^1 and x_t^2 are transmitted simultaneously on the first and second antenna, respectively. The encoder outputs are computed as:

$$x_t^k = \sum_{p=0}^{v1} I_{t-p}^1 . a_p^k + \sum_{q=0}^{v2} I_{t-q}^2 . a_q^k \quad \textbf{mod 4,k=1,2} \qquad (2.40)$$

The encoder is initialized by flushing it with zeros, thus making it start from state '0' and is forced back into state zero by adding redundant zeros at the end of the frame. These are known as flushing zeros, and are not taken into account at the decoder. The start and end states need not necessarily be state '0', but any known states.

For the code search, the frame length L, was chosen to be twice the memory order of the encoder, i.e. 2*v*, where *v* = *v1* + *v2*. This is the average length the decoder takes to correct an error, i.e., the time it takes for two paths having diverged from a state to remerge. Although the channel may distort the symbols to anything, the decoder tries to correct it, based on maximum-likelihood but still the decoder may decide erroneously.

Let us assume that the generator sequences of a 4state QPSK scheme with two transmit antennas are:

$$G^1 = [(02),(20)] \qquad\qquad G^2 = [(01),(10)]$$

The encoder takes m=2 bits as its input at each time. There are 2^m=4 branches leaving from each states corresponding to four different input patterns.

Each branch is labeled by $I_t^1, I_t^2 / x_t^1 x_t^2$, where I_t^1 and I_t^2 are the pair of input bits to the encoder x_t^1 and x_t^2 indicate the two coded QPSK symbol transmitted through antennas 1 and 2 respectively. The Trellis has four state denoted by 00,01,10,11.
The row listed next to a state node in figure indicates the branch labels for transition from that corresponding to the input 00,01,10,11.

Assume the in-put sequence is

C=(10,01,11,00,01...........................)

The output sequence generated by the space time trellis encoder is given by

X=(02,21,13,30,01............................)

The transmitted signal from the two transmit antennas are

$$X^1 = (0,2,1,3,0.................................)$$
$$X^2 = (2,1,3,0,1.................................)$$

Considering the example shown in Figure 2 of a 2 antenna, 4-PSK, 4-state code the transmit antennas will transmit anything between 0 and 3 depending on the previous state, and current inputs at the encoder. In this particular example, if the encoder is at state '0' and the input to the encoder is '0',then '00' is transmitted, there would be an error if the decoder decides that '01' '02' or '03' was transmitted.

State **0**	**00 01 02 03**
State **1**	**10 11 12 13**
State **2**	**20 21 22 23**
State **3**	**30 31 32 33**

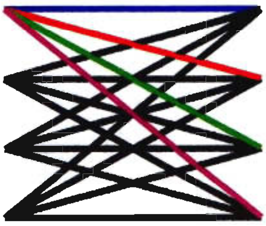


Figure2.18: Space time Trellis code for 4PSK 4 state

$$G=\begin{bmatrix} a_0^1 & a_0^2 \\ b_0^1 & b_0^2 \\ a_1^1 & a_1^2 \\ b_1^1 & b_1^2 \end{bmatrix}$$

Figure2.19: Generator Matrix

A STTC decoder can be described by a trellis diagram. The decoder is based on Viterbi algorithm which operates on the code trellis. The complexity of the decoder grows exponentially with the transmission rate and code memory order and linearly with the number of transmit antennas.

Assuming that r_t^j is the received signal at antenna j at time t, the branch metric is given by

$$\sum_{j=1}^{m}[\, r_t^j - \sum_{i=1}^{n} h_{i,j} q_t^i \,]^2 \tag{2.41}$$

The Viterbi algorithm is used to compute the path with the lowest metric. In the absence of ideal channel state information, an analysis in [9] gives the appropriate branch metrics for decoding.

System Modeling

- Distributed Space time Code
- Distributed Space time Code Principle and Operation
- Different Communication Scenario
- Cooperative Distributed Space Time Coding for MRC and LOS

Distributed Space time Coding

To employ uplink transmit diversity spatially adjacent mobile stations (MSs) have to co-operate with each other leading to diversity and coding gains.

Mobile antennas are omni directional. Signals transmitted towards the destination can be "overheard" at the other MTs(Partner). Partners(Adjacent MTs) process this overheard information and re-transmit towards the destination. These Partnering mobiles form a Virtual Antenna Array. This approach successfully gives solution to the problem of just one receiving antenna in a handset. The idea is to relay the information from the source MT to the (BS) antenna array using a variable number of relaying MTs. The effect of different possible configurations on the performance in terms of bit error rate (BER) versus signal-to-noise ratio (SNR) is analyzed. The results are very promising in the initial stage of development.

It is shown that STTCs can be implemented with VAA and Cooperative Distributed Space Time Coding shows promising performance gains as to justify the increased complexity required for relaying. Due to the spatially separated relaying mobile terminals, no correlation appears among the members of a VAA, which explains the superior performance.

Simulations could show that the double noise and concatenated wireless channels do not degrade the performance of STTCs significantly. The STTC coefficient design is accomplished according to given design criteria, communication scenario and the channel conditions. Since the deployment of VAA emulates a MIMO channel with a high number of receive antennas from the partnering MTs.

Uplink transmit diversity normally would require multiple antennas at the mobile, a requirement that may be impractical for a variety of reasons. This issue leads us to Distributed Space Time coding .We consider a scenario in which multiple nodes receive independent copies of the same message. Each node independently decodes its message and then participates. In this approach the different nodes in a network are considered as the elements of a large antenna array. Since the elements are not physically connected, this is referred to as a distributed array. All the nodes receive independent copies of a message. The nodes then make use of these independent copies in a smart manner to achieve diversity and coding gain.

Since the arrays are not physically connected, performing maximal-ratio combining (MRC) would be expensive in terms of communication overhead involved in disseminating information to all the nodes. For example, for an additive white Gaussian noise (AWGN) channel, using MRC would require sending the soft-demodulator outputs for each of the received symbols to all of the other nodes. This can drastically reduce the throughput of the system.

Distributed Space time Code Principle and Operation

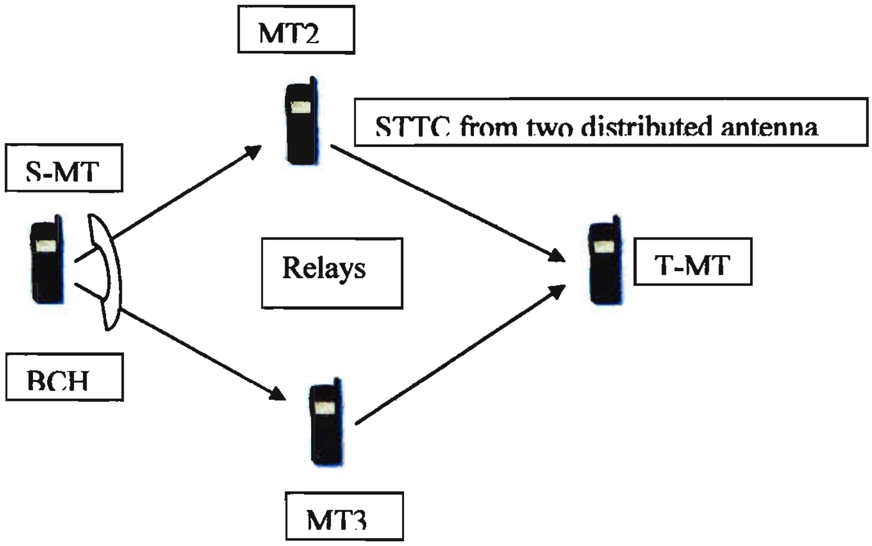


Figure 3.1 : Distributed Space Time Coding Scenario

Lets consider a two relay system. The source S-MT wants to communicate with target T-MT. In the first link it will broadcast the information to R-MT2 and R-MT3 to relay information to target mobile T-MT.

The signal will go through two different fading h1 and h2 and receive by R-MT2 and R-MT3 respectively. So the signal received by R-MT1 and R-MT2 will be

R-MT2 receives, $r_2 = Sh_1 + n_1$ (3.1)

R-MT3 receives, $r_3 = Sh_2 + n_2$ (3.2)

Each mobile terminal will decode the information received from the broadcast channel by the source mobile.

Now Space-time coding is performed over transmit antennas of MT2 and MT3 that are not necessarily co-located. These Partnering mobiles will form a Virtual Antenna Array. Both relay1 and 2 will have their own generator matrix but separated by different geographical location and it will still able to form Space Time Trellis code.

Both of the Mobile terminals have their Space Time Trellis encoder. It will do the encoding and Transmits the one symbol using its one antenna.

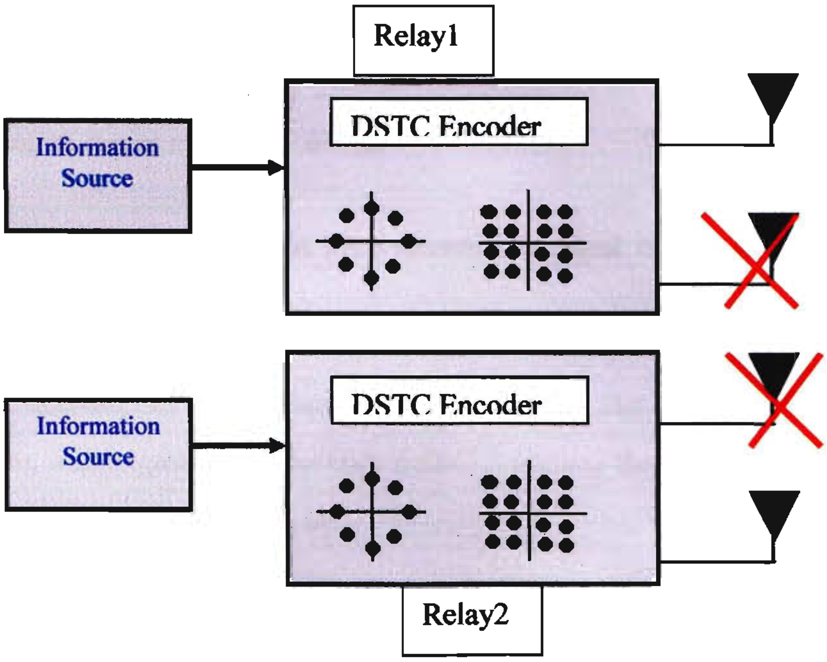


Figure 3.2: Distributed Space Time Encoder

Our proposed scheme for this scenario is 4 PSK, 4state and 2antenna for Distributed Space Time Coding.

At any time *t*, two binary inputs I_t^1 and I_t^2 are fed into the encoder, where I_t^1 is the most significant bit. The two streams of input bits are delayed as shown, and multiplied by coefficient pairs (a_p^1, a_p^2) or (b_q^1, b_q^2) respectively, where $a_p^i, b_q^i \in \{0,1,2,3\}$, i=1,2 p=0,1.....v1, q=0,1.....v2 where v1 and v2 are the memory orders for the upper and lower branches respectively. Then, all the data after multiplication are added in modulo 4. At the output of the adder, x_t^1 is transmitted simultaneously on the first antenna. The encoder outputs are computed as:

$$x_t^k = \sum_{p=0}^{v1} I_{t-p}^1 . a_p^k + \sum_{q=0}^{v2} I_{t-q}^2 . a_q^k \quad \textbf{mod 4,k=1} \qquad (3.3)$$

Encoder1 of relay1 will transmit with its antenna1 and shutting antenna2 off.
The encoder is initialized by flushing it with zeros, thus making it start from state '0' and is forced back into state zero by adding redundant zeros at the end of the frame. These are known as flushing zeros, and are not taken into account at the decoder. The start and end states need not necessarily be state '0', but any known states.
Same encoding will be performed for relay R-MT3.

Decoding at target mobile terminal:

Then the target mobile terminal MT4 received the signal from antenna 1 of MT2 and antenna 2 of MT3.

A STTC decoder can be described by a trellis diagram. The decoder is based on Viterbi algorithm, which operates on the code trellis. Assuming that r_t^j is the received signal at MS4, the branch metric is given by

$$\sum_{j=1}^{m}\left[\, r_t^j - \sum_{i=1}^{n} h_{i,j} q_t^i \,\right]^2 \qquad (3.4)$$

The Viterbi algorithm is used to compute the path with the lowest metric.

Power normalisation for fair comparison :

The total output power is normalised to be able to compare different relaying scheme It was assumed that total transmitted power in the system is limited to S_{TX} the path loss model was assumed to follow traditional exponential behaviour where the received power, S_{RX} can be expressed in terms of the pathloss co-efficient as

$$S_{Rx} = S_{Tx}.\frac{C}{d^n} \tag{3.5}$$

where d= Distance between the transmitter and receiver

n= Pathloss co-efficient

C= Constant

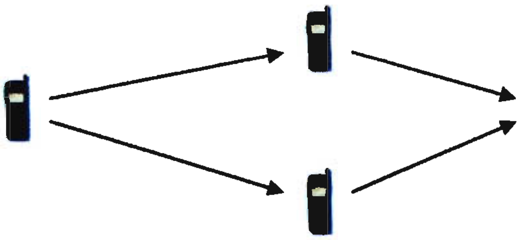


Figure 3.3: communication scenario

Denoting the receiver signal to noise ratio (SNR) as

$$SNR_{DIRECT} = \frac{S_{Rx}}{N_{Rx}} \tag{3.7}$$

Where N_{RX} is the receiving noise power then SNR of the relaying links i=1,2 can be expressed as,

$$SNR_{RELAYING} = \alpha_i(\frac{d_{direct}}{d_{relaying,i}})^n \frac{S_{Rx}}{N_{Rx}} \tag{3.8}$$

Where α_i is the fraction of power allocated to the i-th relay and $\sum_{i=1}^{n} \alpha_i = 1$. For the communication scenario it is assumed that $d_{relatying,i} = \xi_i d_{dirct}$, where ξ_i is the fractional distance.

This guarantees a fair comparison between all, possible relaying schemes as the the total power is normalised to the same values

Distributed Space Time Trellis code with two relays for fast fading chnnel:

Our proposed scheme for this scenario is 4 PSK, 4state and 2antenna for Distributed Space Time Coding.

We assume channel is fast fading which means, Matrix H is random .We will mainly focus on Rayleigh distribution of the channel matrix elements. Channel matrix change randomly at the beginning of the each symbol interval T and are kept constant during symbol intervals, Such channels are called fast fading channel.
The total output power is normalised to be able to compare different relaying scheme
Path loss co-efficient, n=3 is used for indoor propagation environment.

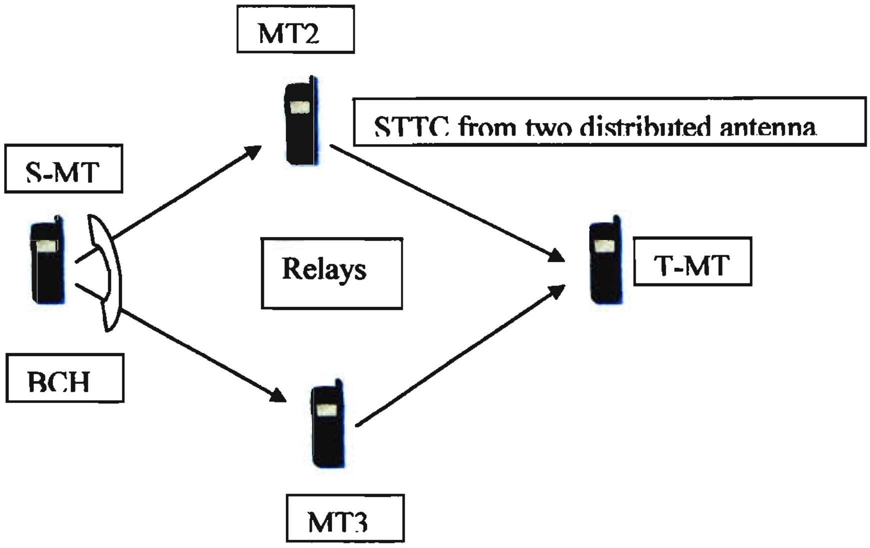


Figure 3.3: communication scenario: communication scenario

Lets consider a two relay system. The source S-MT wants to communicate with target T-MT. In the first link it will broadcast the information to R-MT2 and R-MT3 to relay information to target mobile T-MT.

Encoder1 of relay1 will transmit with its antenna1 and shutting antenna2 off.
Space-time coding is performed over transmit antennas of MT2 and MT3 that are not necessarily co-located. These Partnering mobiles will form a Virtual Antenna Array.

Both relay1 and 2 will have their own generator matrix but separated by different geographical location and it will do Distributed Space Time Trellis code.

Simulation result:

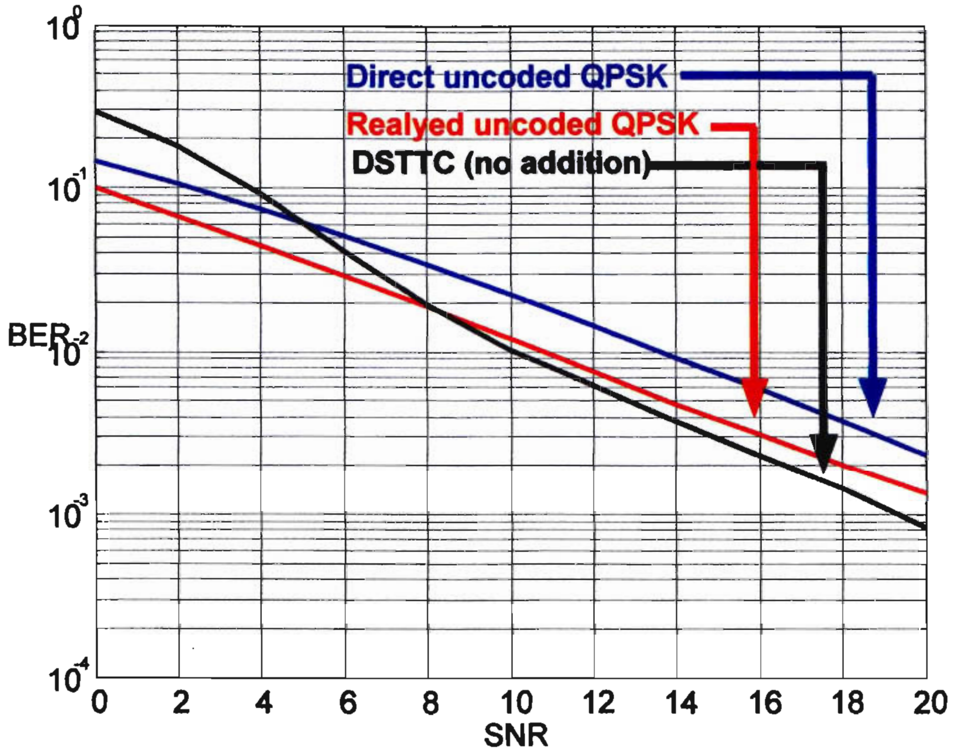


Figure3.4: BER versus SNR of direct link for direct, SISO and MIMO relaying scenarios for fast fading channel.

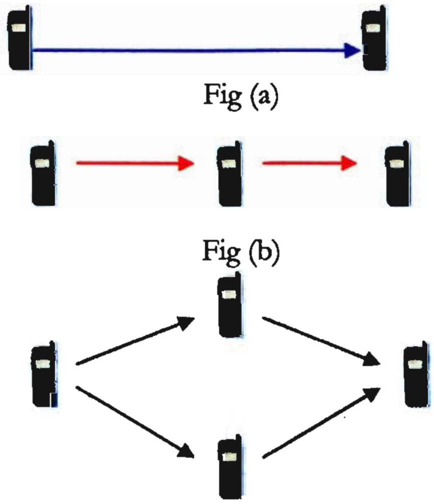


Fig (a)

Fig (b)

Fig (c)

Figure3.5: Communication scenario for the fast fading simulation.

Discussion:

End-to-end BERs for various multi-stage relaying scenarios have been simulated for fast Rayleigh fading channel. The total power is normalized for a fair comparison between different relaying scenarios.

For the Direct SISO link we have simulated uncoded QPSK modulation. The distance between the source and destination mobile terminal is d. Total transmitted power is normalized to 1.

For the Relayed SISO link we have simulated uncoded QPSK modulation. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total transmitted power is normalized to 1.

For the Relayed MISO link we have simulated for Distributed Space Time Trellis Code for 4PSK, 4State and 2 Antenna system. Pathloss coefficient n=3 is used assuming indoor propagation environment. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1. In this case we are transmitting with 0.9 power for the first link and 0.1 power is allocated for the relaying link.

Relayed SISO link have better performance over Direct SISO link.

It is clear from the plot that Distributed Space Time Trellis Code certainly gives better performance with simple 4 state 4PSK 2 antenna configuration than Relayed SISO and Direct SISO link. The BER decreases linearly with high SNR. Distributed Space Time Trellis Code has BER of 0.0006 at 20dB.

Distributed Space Time Trellis code with optimum power allocation for fast fading channel:

Our scheme for this scenario is 4 PSK, 4state and 2antenna for Distributed Space Time Coding for fast fading channel. We have allocated different power to verify the performance of the Distributed Space Time Trellis Code.

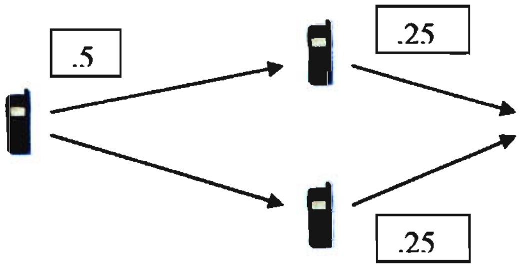


Figure 3.6: Communication Scenario a) When 1/2of the power is given to First broadcast link and ¼ power given to each relay MT.

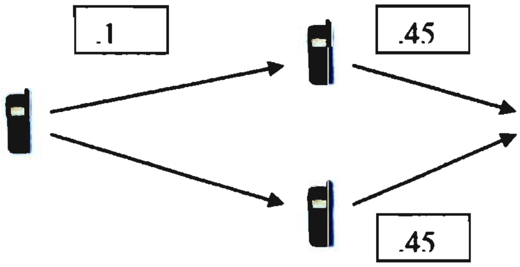


Figure 3.7: Communication Scenario b) When 0.1 of the power is given to First broadcast link and 0.45 power given to each relay MT.

Simulation result:

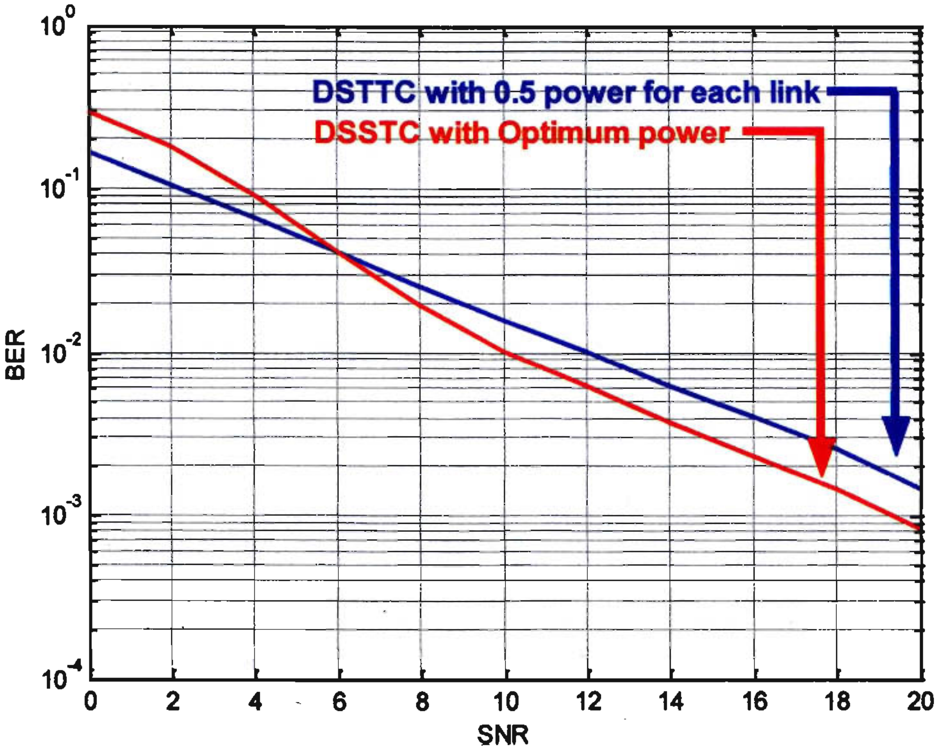


Figure3.8: BER versus SNR of Distributed Space Time Trellis Code for different power allocation.

Discussion:

We have simulated for Distributed Space Time Trellis Code for 4PSK, 4State and 2 Antenna system for fast fading channel. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1. First case we are transmitting with 0.5 power for the broadcast link and 0.5 power is allocated for the relaying link which is not optimum. In the second case we transmit with 0.9 power for the first link and 0.1 power for the relaying link which gives better performance.

So allocating power plays an important role for the performance of distributed space time coding.

Cooperative Distributed Space Time Trellis code with two relays with cooperation (Maximum ratio combination) for fast fading channel:

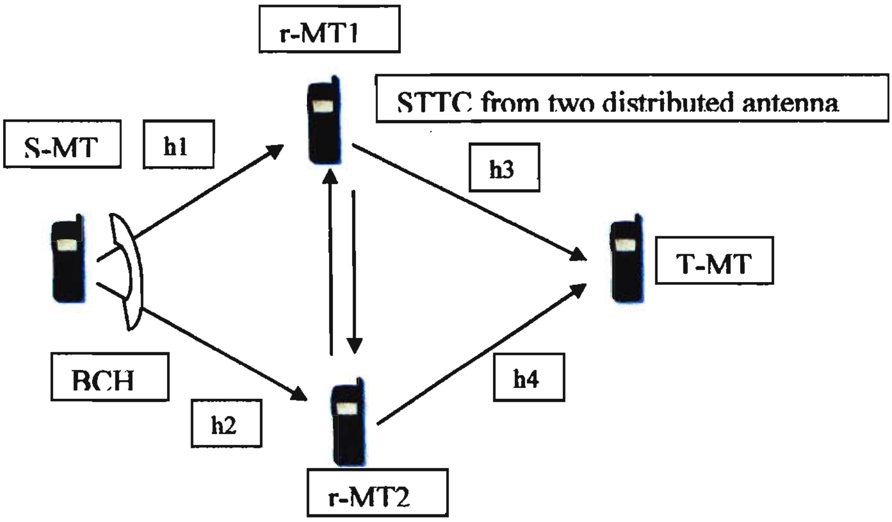


Figure 3.9: communication scenario

Lets consider a two relay system. The source S-MT wants to communicate with target T-MT. In the first link it will broadcast the information to R-MT1 and R-MT2 to relay information to target mobile T-MT. Two relay in the middle exchange their information which promises better performance We are describing the exchange of information as cooperation between relay MT.

We are assuming that two relay mobiles are very close to each other. MT2 and MT3 perform Maximum ratio combination.

First, signal will go through two different fading h1 and h2 and receive by R-MT2 and R-MT3 respectively. So the signal received by R-MT1 and R-MT2 will be

R-MT2 receives, $r_2 = Sh_1 + n_1$ (3.9)

R-MT3 receives, $r_3 = Sh_2 + n_2$ (3.10)

Each received signal is multiplied by complex conjugate of the fading and combined.

Input of the DSTTC encoder1 will be, $\left(|h_1|^2 + |h_2|^2\right)S + n_1 + n_2 + n_3$ (3.11)

Input of the DSTTC encoder2 will be, $\left(|h_1|^2 + |h_2|^2\right)S + n_1 + n_2 + n_4$ (3.12)

Now Space-time coding is performed over transmit antennas of MT2 and MT3 that are not necessarily co-located.

Simulation result:

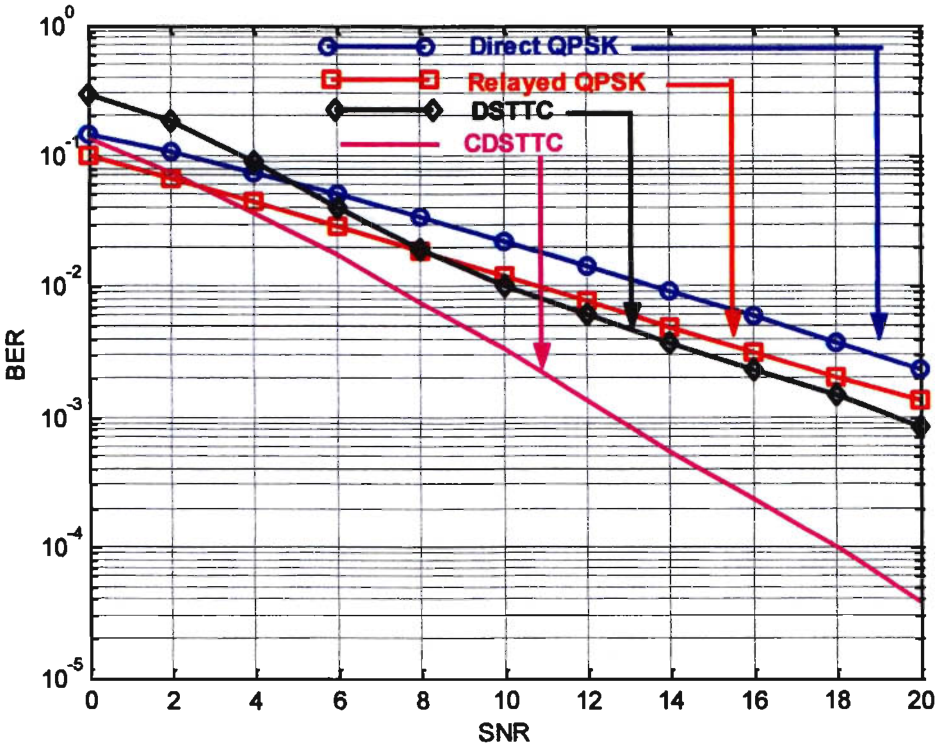


Figure 3.10: BER versus SNR of direct link for direct QPSK, relayed QPSK,DSTTC and Cooperative MIMO relaying scenarios for fast fading channel.

Discussion:

End-to-end BERs for various multi-stage relaying scenarios have been simulated for fast Rayleigh fading channel. The total power is normalized for a fair comparison between different relaying scenarios.

For the Direct SISO link we have simulated uncoded QPSK modulation. The distance between the source and destination mobile terminal is d. Total transmitted power is normalized to 1.

For the Relayed SISO link we have simulated uncoded QPSK modulation. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total transmitted power is normalized to 1.

For the Relayed MISO link we have simulated for Cooperative Distributed Space Time Trellis Code (MRC) for 4PSK, 4State and 2 Antenna system.. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1.

Relayed SISO link have better performance over Direct SISO link.

Cooperative Distributed Space Time Trellis Code certainly gives better performance with simple 4 state 4PSK 2 antenna code than Distributed Space Time Trellis Code ,Relayed SISO and Direct SISO link.

It is clear from the plot that Cooperative Distributed Space Time Trellis Code certainly outperforms DSTTC. It gives BER of 0.00003 for 20dB SNR.

Cooperative Distributed Space Time Trellis code for two relays with different power allocation to broadcast and Distributed Space Time Trellis link:

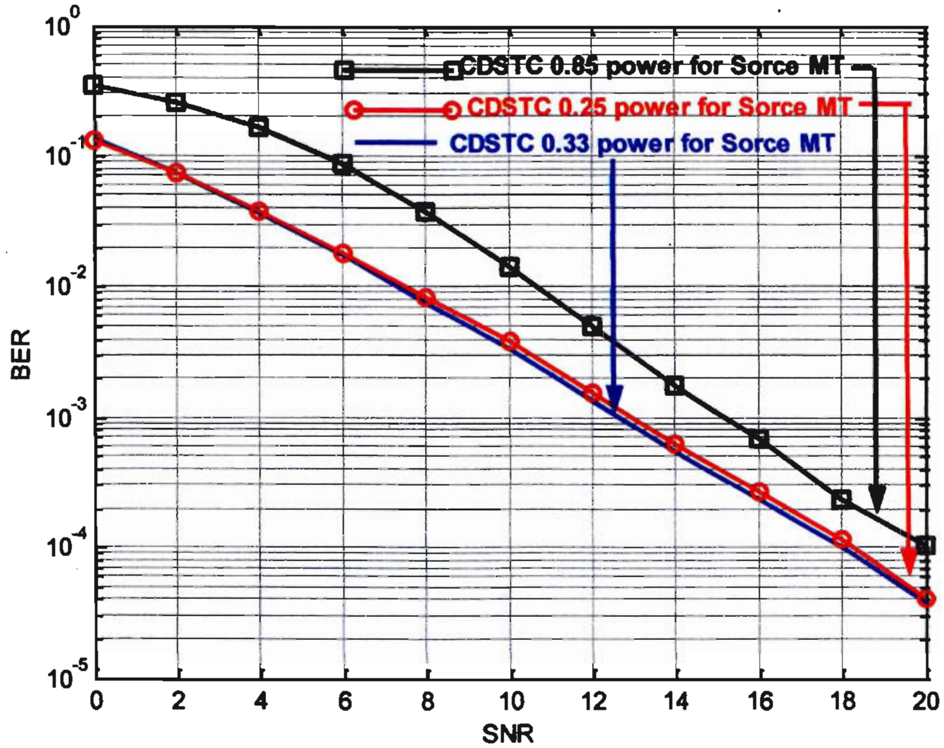


Figure3.11: BER versus SNR of Distributed Space Time Trellis Code for different power allocation

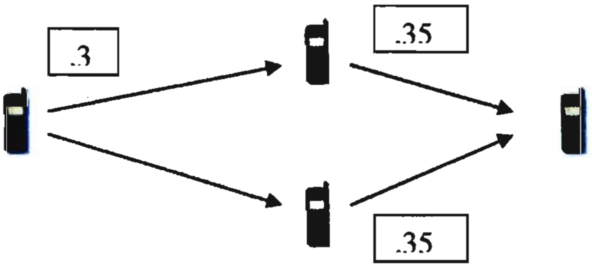


Figure 3.12: Communication Scenario When .3 of the power is given to First broadcast link and .35 power given to each relay MT.

Discussion:

We have simulated for Cooperative Distributed Space Time Trellis Code for 4PSK, 4State and 2 Antenna system for fast fading channel. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1. In this case we are transmitting with 0.3 power for the first link and 0.35 power is allocated for the relaying link is optimum which performs better than other power allocation.
Different power allocation configuration has been analyzed to get optimum power for this scenario.

So allocating power plays an important role for the performance of distributed space time coding.

Distributed Space Time Trellis code with two relays are in line of sight(Ricean) for fast fading channel:

Lets consider two relay system. The source S-MT wants to communicate with target T-MT. In the first link it will broadcast the information to R-MT1 and R-MT2 to relay information to target mobile T-MT. Two relay in the middle exchange their information and the channel between the relays are Ricean channel which promises better performance We are describing the exchange of information as cooperation between two line of sight relay MT.

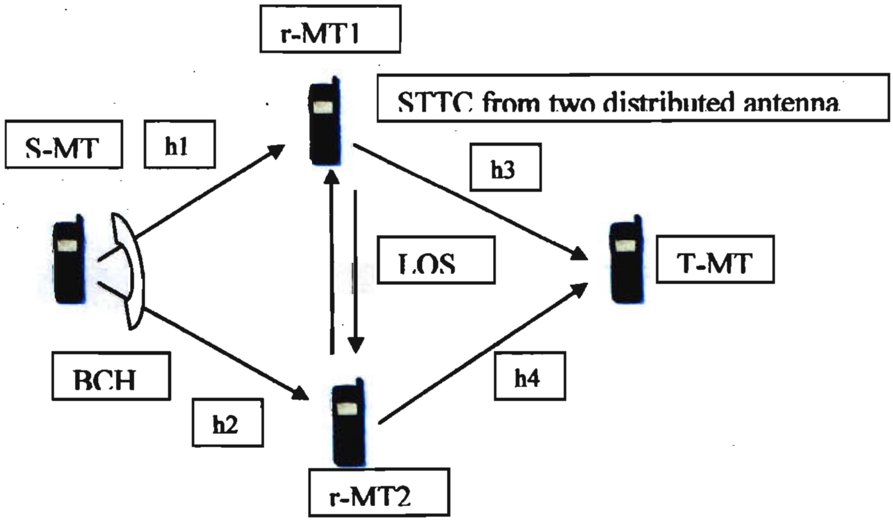


Figure 3.13: communication scenario

First, signal will go through two different fading h1 and h2 and receive by R-MT2 and R-MT3 respectively. So the signal received by R-MT1 and R-MT2 will be

R-MT2 receives, $r_2 = Sh_1 + n_1$ (3.13)

R-MT3 receives, $r_3 = Sh_2 + n_2$ (3.14)

Then relays exchange their information through the ricean channel and combined the signal .

So the combined signal received at rely MT2 is

$$r_3 = Sh_1 + n_1 + (Sh_2 + n_2)h_3 + n_3 \qquad (3.15)$$

So the combined signal received at rely MT3 is

$$r_4 = Sh_2 + n_2 + (Sh_1 + n_1)h_4 + n_4 \qquad (3.16)$$

Where h3 and h4 are assumed to be ricean channel between the two relays..

For ricean channel,

$$h_{ricean} = \sqrt{\frac{k}{1+k}} + \sqrt{\frac{1}{1+k}}.h_{rayleigh} \qquad (3.17)$$

The K factor is taken as 10.

Now Space-time coding is performed over transmit antennas of MT2 and MT3 that are not necessarily co-located.

Simulation result:

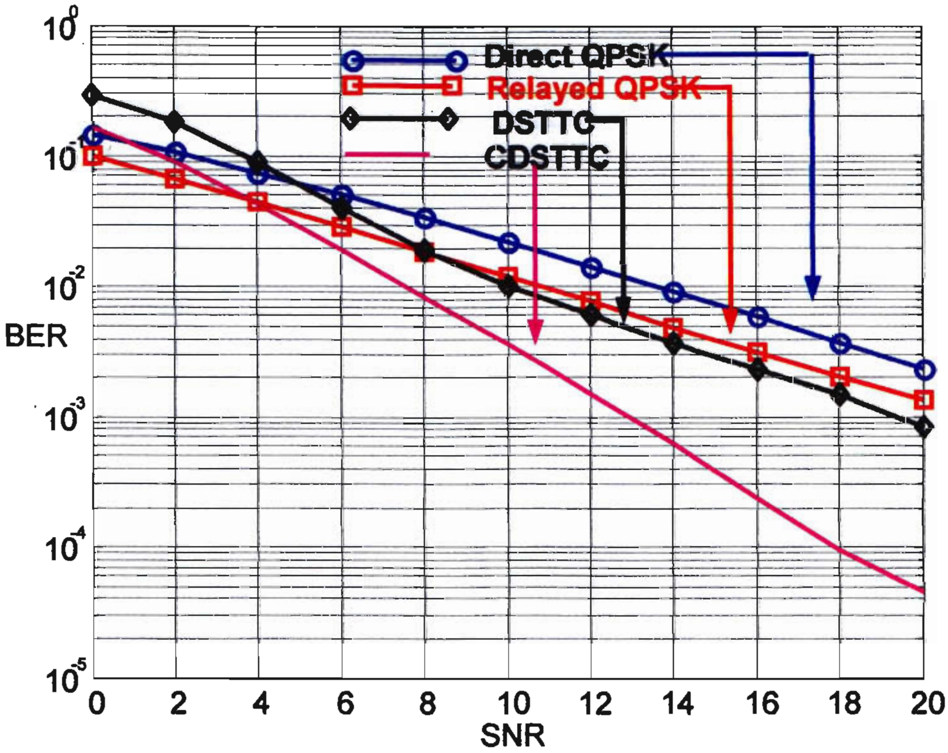


Figure: BER versus SNR of direct link for direct QPSK, relayed QPSK,DSTTC and Cooperative MIMO relaying scenarios for fast fading channel.

Discussion:

End-to-end BERs for various multi-stage relaying scenarios have been simulated for fast Rayleigh fading . The total power is normalized for a fair comparison between different relaying scenarios.

For the Direct SISO link we have simulated uncoded QPSK modulation. The distance between the source and destination mobile terminal is d. Total transmitted power is normalized to 1.

For the Relayed SISO link we have simulated uncoded QPSK modulation. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total transmitted power is normalized to 1.

For the Relayed MISO link we have simulated for Cooperative Distributed Space Time Trellis Code for 4PSK, 4State and 2 Antenna system.. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1.

Relayed SISO link have better performance over Direct SISO link.

Cooperative Distributed Space Time Trellis Code certainly gives better performance with simple 4 state 4PSK 2 antenna code than Distributed Space Time Trellis Code Relayed SISO and Direct SISO link.

It is clear from the plot that Cooperative Distributed Space Time Trellis Code certainly outperforms DSTTC. . It gives BER of 0.00003 at 20dB SNR

Distributed Space Time Trellis code for two LOS relays with different power allocation to broadcast and Distributed Space Time Trellis link:

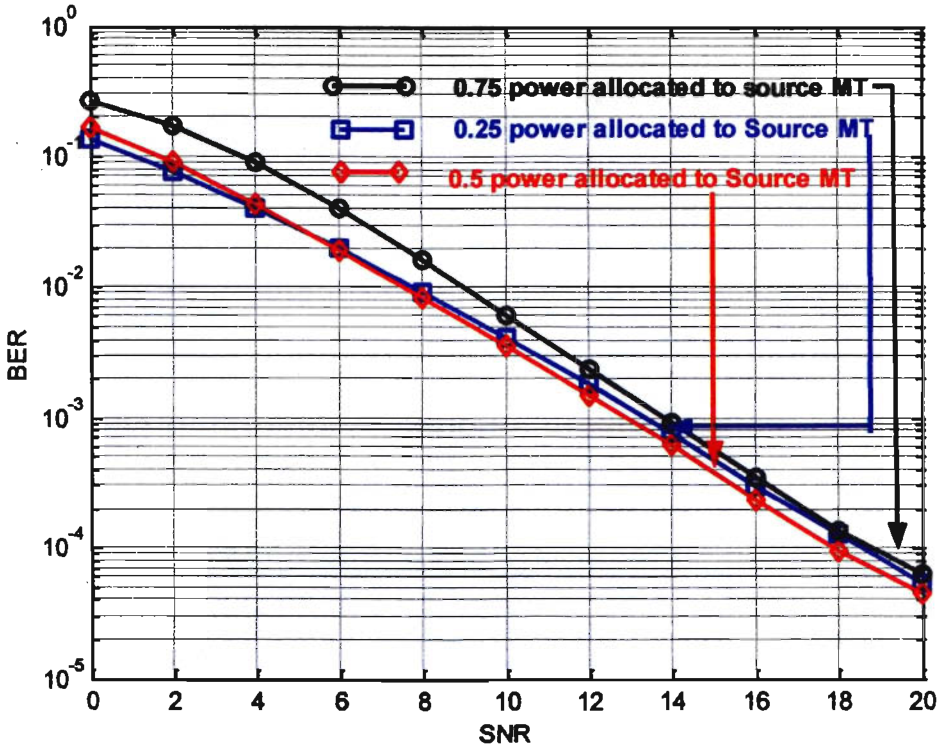


Figure3.14: BER versus SNR of Distributed Space Time Trellis Code for LOS between the relays

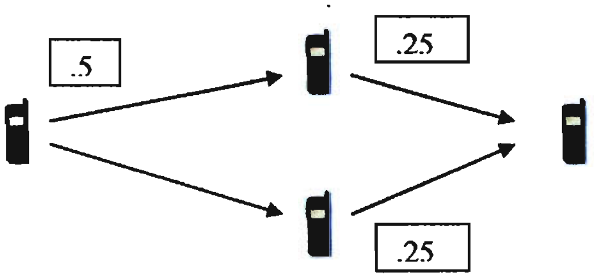


Figure 3.15: Communication Scenario When ½ of the power is given to First broadcast link and ¼ power given to each relay MT.

Discussion:

We have simulated for Distributed Space Time Trellis Code for 4PSK, 4State and 2 Antenna system.. The distance between the source and relay mobile terminal is d/2 and relay to the destination is d/2. So the total distance is d. Total power is normalized to 1. In this case we are transmitting with 0.3 power for the first link and 0.35 power is allocated for the relaying link is optimum which performs better than other power allocation.

So allocating power plays an important role for the performance of distributed space time coding.

Result and Conclusion

The idea of Cooperative MIMO relaying has been suggested as a means for data rate enhancements in cellular networks. The proposal uses relay mobile stations, in the vicinity of the target mobile. The target mobile and its relay stations would operate as one MIMO transmitter/receiver. At the same time, the concept also exhibits strong similarities to multihop networks as signals are forwarded in a relaying manner.

Concept of data relaying at physical layer is introduced which primarily overcome the disadvantage of having only one antenna in the MT.

Cooperative Distributed Space Time Coding is an effective way to achieve distributed spatial diversity and MIMO capacity.

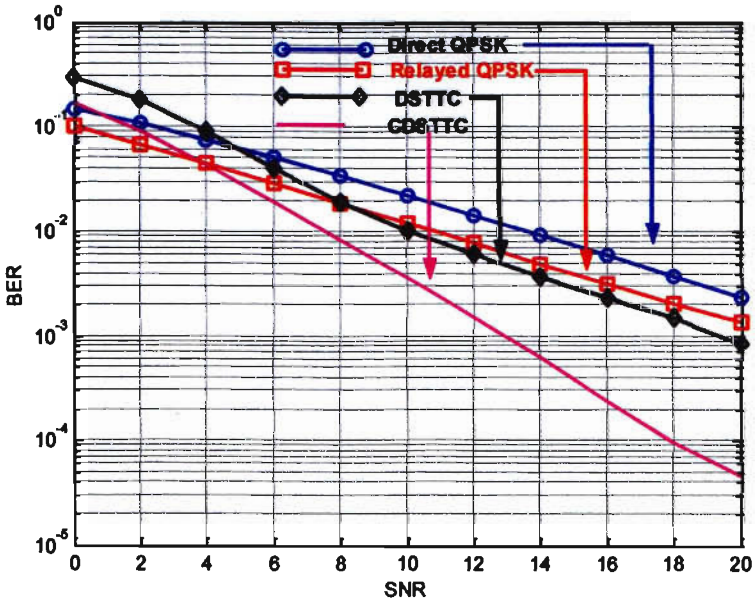


Figure4.1: BER versus SNR of direct link for direct QPSK, relayed QPSK,DSTTC and Cooperative DSTTC scenarios for fast fading channel.

It drastically improves the performance. Energy efficiency is possible by relays to assist the communication. Significant performance gains can be achieved when comparing a direct link with relaying link

Cooperative DSTTC gives a 6 dB gain when compare with simple QPSK SISO system.

Cooperative DSTTC has the potential to provide significant improvement in the wireless system.

Flow chart of the simulator:

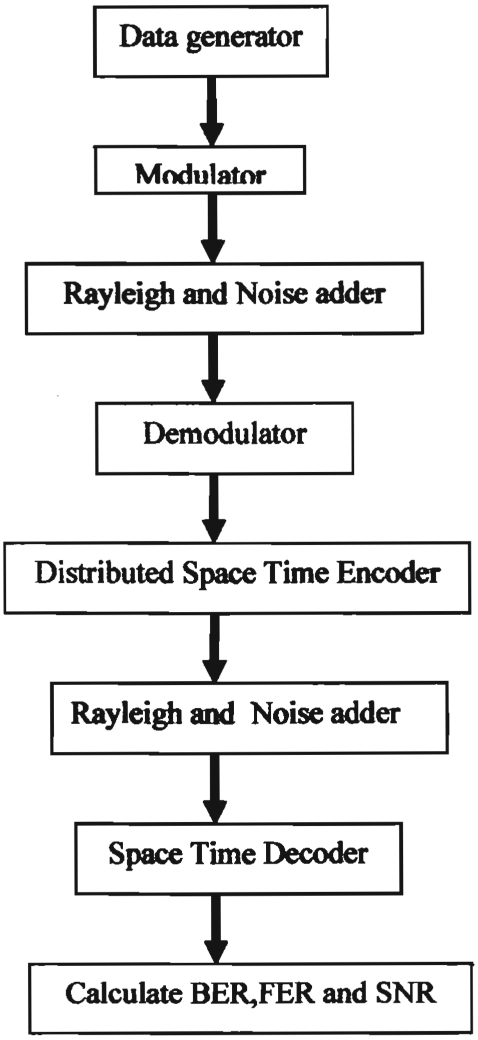


Figure4.2: Flowchart of the simulator.

Future work:

There are a variety of fruitful areas for future research on cooperative diversity and related topics. We have mentioned many issues in earlier chapters, but we repeat some of the larger and more important ones here.

In the thesis we have analyzed the performance for fast fading channel. It will be interesting to see the results of the slow fading channel.

More strong code with increasing number of state and number of transmit and receive antenna can be verified which would certainly give better performance than two hop relaying scheme.

Different communication scenario can be verified.

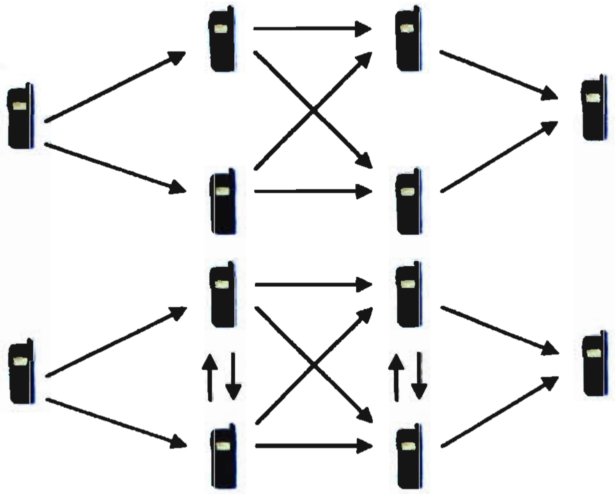


Figure4.3: Different possible scenario for the future work

For the broadcast channel strong code can be used to improve overall BER.
Different distance between the source-relays-target MT can be investigated.

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