Space Time Spreading Assisted MC DS-CDMA System Using Parallel Interference Cancellation

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Developed by

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Supervised by

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بسم الله الرحمن الرحيم

Dedicated to my parents and teachers

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Abstract

In this dissertation we are going to study the space time and frequency domain spreading for increasing the capacity of our system over a frequency selective Rayleigh fading channel. We will study the BER performance of this system by changing different parametric values.

The receiver optimization techniques are also investigated and their results are being compared. We will use parallel interference canceller (PIC) assisted MUD instead of Decorrelating detector due to its increased complexity and noise enhancement.

We are going to accommodate an increased number of users by transmit diversity and without requiring any extra set of codes. Just a little bit extra hardware complexity will be added on both sides of the link.

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Chapter 3 Space time spreading and multi-user detection schemes

Chapter 4 Space time spreading for broadband synchronous MC DS-CDMA

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Glossary

2G	*2*nd *G*eneration
3G	*3*rd *G*eneration
AMPS	*A*dvance *M*obile *P*hone *S*ystem
AWGN	*A*dditive *W*hite *G*aussian *N*oise
BER	*B*it *E*rror *R*ate
BPSK	*B*inary *P*hase *S*hift *K*eying
CDMA	*C*ode *D*ivision *M*ultiple *A*ccess
CIR	*C*hannel *I*mpulse *R*esponse
CSI	*C*hannel *S*tate *I*nformation
DS	*D*irect *S*equence
FDMA	*F*requency *D*ivision *M*ultiple *A*ccess
FFH	*F*ast *F*requency *H*opping
GA	*G*enetic *A*lgorithm
GSM	*G*lobal *S*ystem of *M*obile
ISI	*I*nter *S*ymbol *I*nterference
ITU	*I*nternational *T*elecommunication *U*nion
MF	*M*atch *F*ilter
MMSE	*M*inimum *M*ean *S*quare *E*rror
MUD	*M*ulti *U*ser *D*etection
MRC	*M*aximum *R*atio *C*ombining
MT	*M*ulti *T*one

OFDM	*O*rthogonal *F*requency *D*ivision *M*ultiplexing
PIC	*P*arallel *I*nterference *C*anceller
SDMA	*S*pace *D*ivision *M*ultiple *A*ccess
SFH	*S*low *F*requency *H*opping
SIC	*S*uccessive *I*nterference *C*anceller
SNR	*S*ignal to *N*oise *R*atio
SSS	*S*pread *S*pectrum *S*ignal
SUD	*S*ingle *U*ser *D*etection
STS	*Space Time Spreading*
TF-domain	*Time and Frequency Domain*
TH	*T*ime *H*opping
TDMA	*T*ime *D*ivision *M*ultiple *A*ccess
TD-SCDMA	*T*ime *D*uplex-*S*mart antenna aided *CDMA*
UMTS	*U*niversal *M*obile *T*elecommunication *S*ystem
UTRA	*U*MTS *T*errestrial *R*adio *A*ccess
ZF	*Z*ero *F*orcing

CHAPTER 1

Introduction

1.1 Introduction to thesis

Multi-carrier Code Division Multiple Access (MC-CDMA) [1] [2] [3] is a novel transmission technique, which combines Direct Sequence CDMA (DS-CDMA) and Orthogonal Frequency Division Multiplexing (OFDM) [4, 5, 6, 7]. One of the basic requirements expected to be achieved by the broad band mobile wireless system is the provision of high bit rate wireless Internet services and the delivery of high speed multimedia services.

But the system capacity and data rates is being affected by numerous factors. To circumvent the effects of fading, a transmit diversity technique known as Space Time Spreading is being employed.[3,156-158] shows that a substantial diversity gain can be achieved by STS and this typically allows the throughput of the system to be increased. In the following thesis, we propose a novel STS assisted multi-carrier direct sequence code division multiple access system for supporting a wide range of bit rates.

When multiple users are communication simultaneously, on receiver end if we consider only the signal of user of interest as useful information while rest users' data as noise this sort of detection is known as Single User Detection (SUD). Similarly, the case of considering the other users' data, as useful information is known as Multi-user Detection (MUD).

Numerous Multi-user Detection schemes have been proposed in the literature [25] [26] [31]. For example, in [24], Maximum Likelihood (ML) MUD designed for MC-CDMA had been considered, while an Interference Cancellation (IC) based MUD has been proposed in [3, 26]..

From a physical perspective, the MMSE detector balances the desire to completely eliminate the MAI with the desire of avoiding the background noise enhancement problem. Since it takes the effects of the background noise into account, the MMSE detector generally provides a better performance than the Decorrelating detector. But still the MMSE detector involves complexity. That's why in this dissertation we will use Parallel Interference canceller (PIC) to avoid noise enhancement as well as complexity.

This proposed scheme could be applied to Multi-carrier CDMA receiver optimization where number of users is excessive.

1.2 Contribution

The novel contributions of this dissertation are given below:

- To accommodate a large number of users, instead of using different set of codes for each user we will apply STS (Space Time Spreading) in which a common set of codes will be used for all users in a unique way and then they will be F-domain spreaded and sent on the multiple antennas.

- Investigated the scheme for synchronous DS-CDMA system communication over frequency non-selective Rayleigh flat fading channel.
- At the receiver end we separately de-spread space time and frequency sequences and then apply different detection schemes like De-correlating detector and Parallel interference Canceller (PIC) and compare their results.
- Simulation results show that the proposed scheme can support large number of user and PIC performs better than de-correlating detector at the rate of a little overhead.

1.3 Organization

The outline of the dissertation is as follows:

Chapter 2 In this chapter I discussed the cellular concepts regarding AMPS (American mobile phone systems) and GSM (Global System for mobile) systems.

Chapter 3 In this chapter I discussed the wireless access technology along with the vitality and significance of MC-CDMA over single carrier. Further the structure of Multi-user Detectors and their history is discussed in detail. Pros and cons of each scheme are given as well.

Chapter 4 In this chapter I discussed STS assisted broadband MC DS-CDMA synchronous system. Simulation results are demonstrated for different number of simultaneous users, using Walsh Codes over *M* orthogonal carriers with different detectors.

Chapter 5 In this chapter, the thesis is concluded and future extendable dimension regarding this scheme are mentioned and references are listed in the end.

CHAPTER 2

Mobile Cellular and Multiple Access Techniques

2.1 Cellular Communication

A cellular system links Mobile subscribers to Public Telephone System or to another Mobile subscriber. It removes the fixed wiring used in a traditional telephone installation. Mobile subscriber is able to move around, perhaps can travel in a vehicle or on foot & still make & receive call.

2.1.1 Advantages of Cellular Communication

- Mobility
- Flexibility
- Convergence
- Greater QOS
- Network Expansion
- Revenue/Profit

2.1.2 What is Cellular Telephony?

Considerations

FREQUENCY

SUBSCRIBER DENSITY

COVERAGE

2.2 Analog Mobile Telephony

In the end of 1980's Analog Systems were unable to meet continuing demands due to the following reasons:

- Severely confined spectrum allocations
- Interference in multipath fading environment
- Incompatibility among various analog systems
- Inability to substantially reduce the cost of mobile terminals and infrastructure required

2.3 Digital Mobile Telephony

- Spectrum space - most limited and precious resource

- Solution - further multiplex traffic (time domain)
- Can be realized with Digital Techniques only.

2.4 GSM History and Organization

1979	Europe wide frequency band reserved for Cellular
1982	"Groupe Speciale Mobile" created within CEPT
1986	GSM had full time in Paris
1988	ETSI takes over GSM Committee
1990	The phase 1 GSM Recommendations frozen
1991	GSM Committee renamed "Special Mobile Group" and GSM renamed as " Global System for Mobile Communication"
1992	GSM is launched for commercial operations

2.4.1 GSM - IN CELLULAR TELEPHONY

- Each Cell in the Cellular Network consists of one or more RF carriers.
- An RF carrier is a pair of radio frequencies
    - One used in upward direction by MS - Uplink
    - Other used in downward direction by BTS - Downlink

  - The transmit and receive frequencies are separated by a gap of 45 MHz in GSM of 75 MHz in DCS.

- There are 124 carries in GSM Band. With each carrier carrying 7 timeslots, <u>only 124 x 7 = 868 calls can be made!</u>

- Frequency Reuse is the solution

2.4.2 Features of GSM

- Compatibility
- Noise Robust
- Increased Capacity & Flexibility
- Use of Standard Open Interfaces
- Improved Security & Confidentiality
- Cleaner Handovers
- Subscriber Identification
- ISDN Compatibility
- Enhanced Range of Services

2.5 GSM 900

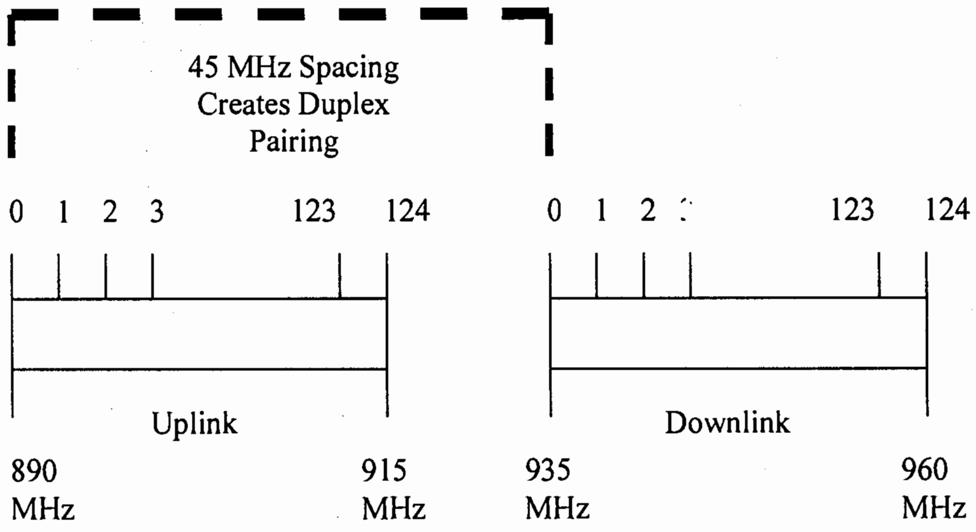

Figure 2.1 The frequency Spectrum

Total bandwidth	25MHz
Bandwidth/channel	200 KHz
Channel availability	124 ARFCN (1-124)

2.5.1 Frequency spectrum

Interference occurs when two signals are transmitting at the same frequency. But the signal with higher energy will win.

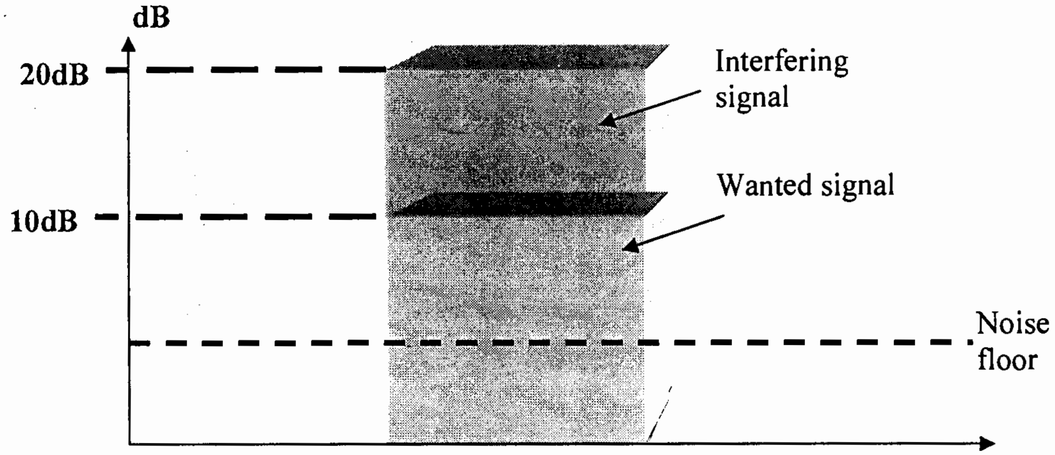

Figure 2.2 Signal Interference Level

2.5.2 How to maximize the spectrum utilization

To maximize the spectrum utilization two methods are being adopted:

- Adopt multiple access techniques
- Adopt frequency reuse

2.5.3 Frequency Re-Use

Why need Frequency Re-Use?

- Frequency resources are very expensive.
- Frequency resources are very limited.
- However maintain the quality of service.

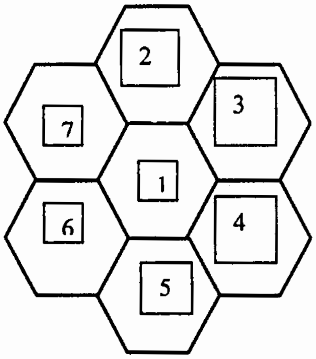

Figure 2.3 7(cell) × 1(site) re-use

2.6 Introduction to Multiple Access Techniques

The need for Multiple Access (MA) techniques arises whenever there is a limited communication channel resource that is accessed by more than one independent user (i.e., multipoint-to-point communication). In wireless PCSs, due to the scarceness of channel resource (i.e., bandwidth), MA techniques are used to share the common transmission channel among all users in the system. The MA technology should be robust to channel impairments and changing conditions and the receiver should be able to separate the desired signal from interfering signals.

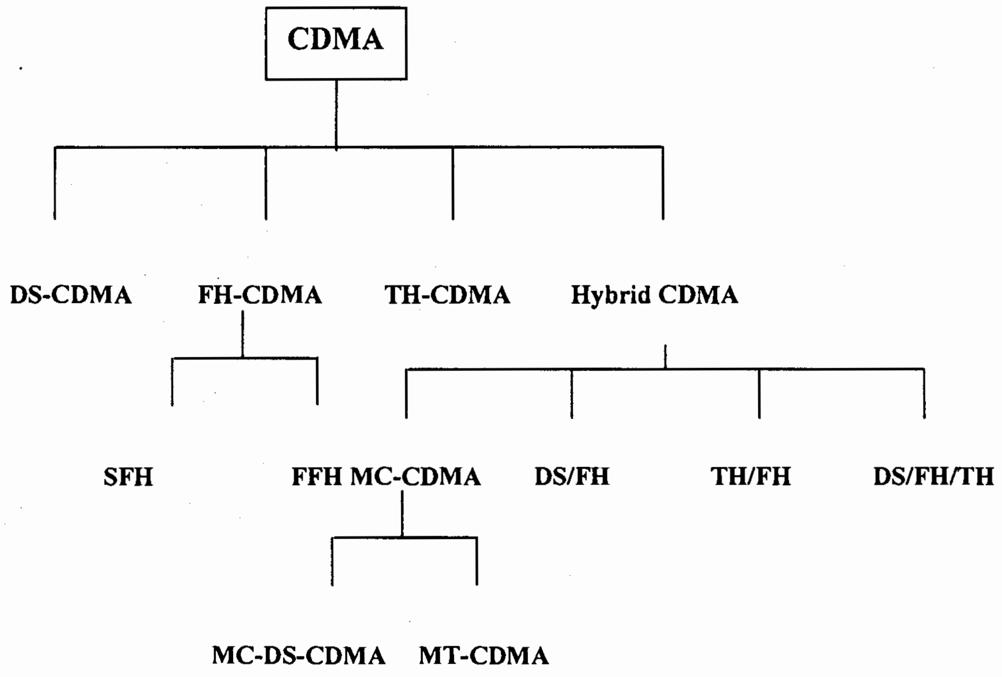

Figure 2.4 Radio Classification of the Multiple Access technology

As shown in Figure 2.3, the MA techniques can be classified into four main groups as follows [15, 20].

2.7 Scheduling Multiple Access

It avoids simultaneous access from multiple users by scheduling all transmissions. This scheduling protocol can either be implemented as a fixed assignment where the channel capacity is divided among the users in a static fashion, or as a demand assignment where the scheduled transmission takes place only if the user is active. Unlike the fixed assignment, the demand assignment does not waste channel capacity on idle users, albeit additional overhead and delay are introduced to sort out active users. Examples of demand assignment MA protocols include roll-call polling and token-passing [15].

Traditionally radio communication systems use fixed assignment MA to divide a single high-capacity MA channel into smaller orthogonal channels. This is typically done by channel partition in terms of disjoint frequency bands known as Frequency Division Multiple Access (FDMA), disjoint time slots known as Time Division Multiple Access (TDMA), or both (i.e., hybrid FDMA/TDMA). Hence, their capacities correspond to the number of channel partitions. To avoid co-channel interference (i.e., overlapping of different transmissions), guard times and bands are inserted between adjacent transmissions in TDMA and FDMA respectively.

In cellular radio systems, to avoid co-channel interference, the concept of frequency reuse is used to place a minimum distance between cells using the same frequency set. A well-designed frequency reuse plan respects a compromise between high reception quality (i.e., low reuse factor) and high spectral efficiency (i.e., high reuse factor). Both TDMA and FDMA provide a simple MA solution in a steady or slowly varying traffic network. It is noted that FDMA is simpler than TDMA, since no synchronization between users is required.

The fix assignment scheduling multiple access techniques are discussed as under.

2.7.1 Frequency Division Multiple Access

In Frequency Division Multiple Access (FDMA) the channels are *frequency bands*. The frequency range allocated for a particular application is divided into a number of non-overlapping frequency bands with each user assigned to one band. To help avoid cross-channel interference, *guard bands* are allocated between each pair of frequency bands in which there should be no component of either signal from the adjacent bands. FDMA was, for decades, the dominant multiple access technique used in analog telephone voice transmission [22].

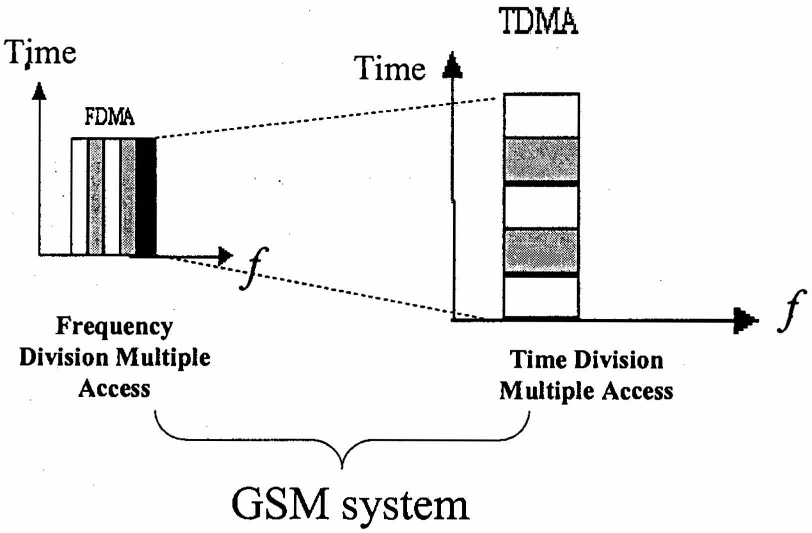

Figure 2.5 Illustration of the concept of FDMA.

In a simple FDMA system, channels comprise different frequency bands; each user is allocated one frequency band for transmission in the uplink. The Advanced Mobile Phone System (AMPS) was the first standardized cellular system and belongs to this class; it uses the 800 MHz to 900 MHz band and allocates 30 kHz for each channel [16,18]. The modulation scheme used by AMPS is analog frequency modulation (FM).

An AMPS-based system design is simpler than that of other cellular systems and can be based on analog modulation for its continuous transmission properties. The AMPS system has several drawbacks, though. An AMPS handset may need to change transmission frequency during the handoff (as the user moves from one cell to the other). Furthermore, static channel sharing of AMPS leaves the idle channels unused while making it difficult to allocate multiple channels per user.

The most serious disadvantage of the AMPS system, how ever, is the limitation that it places on system capacity [19]. Narrowband analog mobile phone service (NAMPS) was proposed as an interim solution to address the capacity limitations of AMPS. In NAMPS, each 30 kHz channel that previously carried a single voice conversation in AMPS, is utilized to carry three conversations by dividing the 30 kHz channel into three 10 kHz channels. Although capacity is increased, the channels in NAMPS remain statically shared and the idle channels remain unused.

2.7.2 Time Division Multiple Access

In Time Division Multiple Access (TDMA) the orthogonal channels are *time slots.* A transmission time frame of appropriate length is divided into a number of time slots. Each user in the given transmission environment (for example, a base station cell) is allocated one slot in each frame in which to transmit. Similarly to FDMA, to avoid cross-channel interference, guard bands are allocated between transmission slots in which neither user in the adjacent slots may transmit [32]. Bits may also be allocated within each time slot for training sequences and control flags.

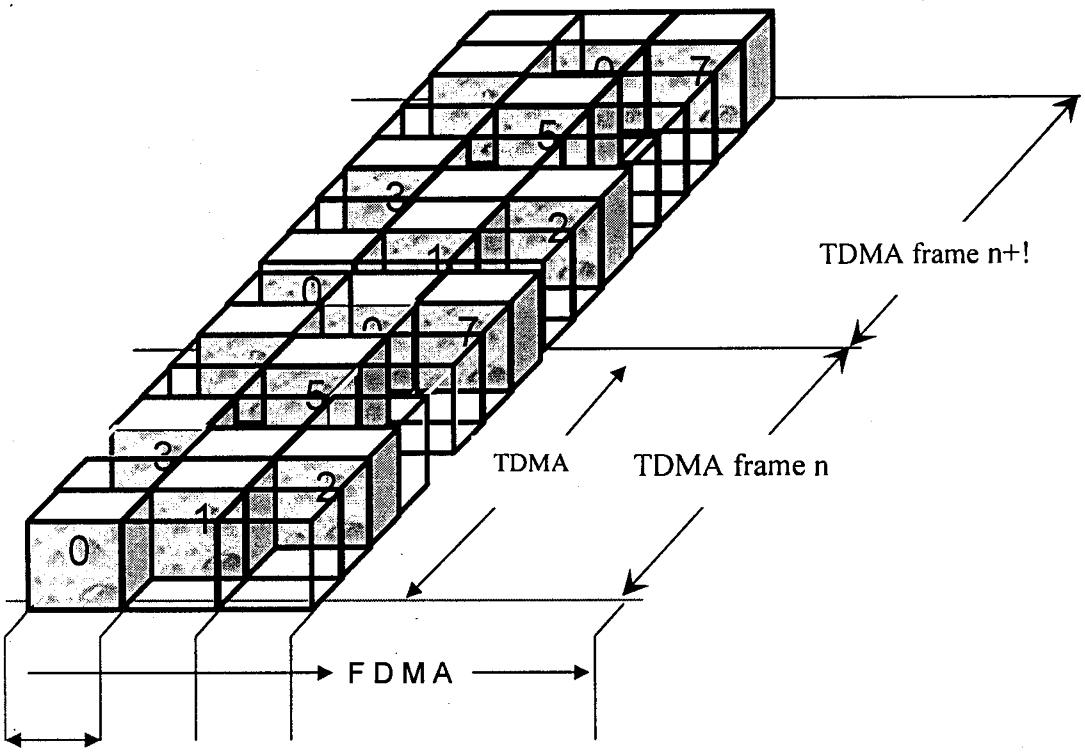

Figure 2.6 Illustration of the concept of TDMA.

Time Division Multiple Access (TDMA) systems provide multiple access by sharing the same transmission resource at different times. Thus, end users take turns and transmit in sequence one after the other. The non-continuous nature of transmissions makes it easier to implement handoff in a TDMA system as compared to an FDMA system. Because the channels are typically wideband, inter-symbol interference (ISI) occurs. Required compensation for ISI generally is achieved by means of an equalizer [22].

In FDMA, the difficulty of allocating multiple frequency bands to a single user poses a limitation on bandwidth. Because it is easier to combine time slots than it is to combine frequency bands, TDMA systems are superior to FDMA systems in achieving high bandwidth links. In fact, the recent evolution of the Global System for Mobile (GSM) [23] for general packet radio service (GPRS) [24,25] and enhanced data rates for global evolution (EDGE) [26] capabilities makes use of this particular feature. If, for these reasons, time division multiple access is superior to FDMA, it also has its own disadvantages: TDMA systems have more stringent synchronization requirements and are less robust to multipath effects. Once again, channel sharing is static in nature while unused time slots are wasted unless dynamic access is introduced.

To enjoy benefits of TDMA without putting the AMPS infrastructure out of service, digital AMPS (DAMPS) was proposed in the United States as a TDMA "overlay" on the AMPS network [17]. DAMPS is one of the first digital cellular standards and uses the same channel bandwidth as AMPS but it time multiplexes multiple channels on each available frequency band. Other possible combinations of FDMA and TDMA are similar to NAMPS with TDMA overlays [27]. GSM [23, 28] standard, which is quite popular in Europe, uses a hybrid TDMA and FDMA system. These systems use different techniques to increase the system capacity, but all FDMA and TDMA systems and their hybrids rely on static sharing of the channel in one way or the other.

2.8 Random Access Multiple Access

It resolves the contention (or collision) that occurs when several users transmit simultaneously. The first random access system, known as ALOHA, was proposed for packet radio network in 1969 [21]. The family of ALOHA protocols assumes that there is the possibility of contention with every transmission. If the contention is detected, the user can defer its own transmission until the channel is free. Based on its access scheme, random access can be further divided into repeated random access and random access with reservation [15]. Some examples of both random access MA systems include pure-ALOHA, Carrier Sense Multiple Access (CSMA), r(eservation)-ALOHA and Packet Reservation Multiple Access (PRMA). In general, random access MA is most suitable for bursty channels whereby the probability of simultaneous transmissions of more than one user occurring is sufficiently low.

2.9 Code Division Multiple Access (CDMA)

It falls between scheduling and random access MA. It allows the number of users to be transmitted simultaneously without contention, but with increasing interference level as more users are added. It was originally developed for use in military applications due to its anti-jamming property and low probability of detection. Its central concept is the usage of the spread spectrum modulation which expands the bandwidth of information-bearing signal.

In Code Division Multiple Access (CDMA) [24, 29] orthogonal channels are formed as a consequence of signal modulation. All users transmit at the same time and within the same frequency range but each of their signals are modulated by a unique high bit-rate signature sequence.

Each user's signature sequence is statistically uncorrelated with each of the other users' sequences. Users' signals are recovered at the receiver via correlation which, ideally, completely cancels all other users' signals. Graphical depictions of CDMA techniques are shown below.

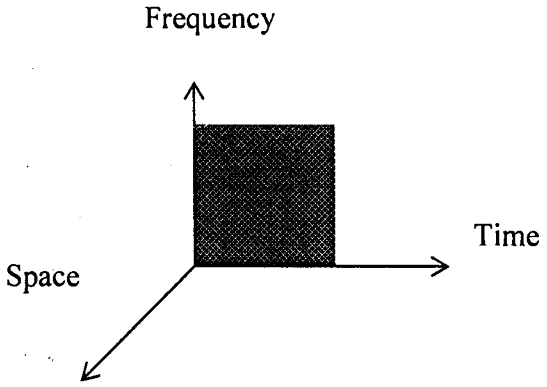

Figure 2.7 Illustration of the concept of CDMA.

In CDMA, each user is assigned a unique code such that its transmitted signal is spread into a wideband signal. At the Matched Filter based (MF) receiver (i.e., correlating the received signal with the desired user's code), assuming quasi-orthogonal codes, only the desired signal is "de-spread", and other signals remain wideband and appear as noise. Thus, CDMA is sometimes referred to as spread spectrum MA. Based on the modulation methods that generate spread spectrum signals, CDMA signals can be divided into a number of groups as follows.

2.9.1 Direct Sequence (DS)

The information-bearing signal is directly multiplied by the spreading sequence. The usual form of modulation scheme is some form of Phase Shift Keying (e.g., Binary Phase Shift Keying (BPSK)).

The one difference which sets DS-CDMA apart from all other CDMAs is the interference in the DS case is reduced by averaging it over a wide time interval, while interference in the others is reduced by avoiding it for most of the time.

2.9.2 Frequency Hopping (FH)

The carrier frequency "hops" around pseudo-randomly according to the spreading sequence. A FH-CDMA system occupies only a fraction of spread bandwidth (i.e., hop bin) at one time, while a DS-CDMA system uses the entire spread bandwidth. Because of the difficulty of maintaining phase references as the frequency hops, non-coherent demodulations are normally used. Compared with DS-CDMA, FH-CDMA has less stringent synchronization requirement and is less sensitive to channel gain and phase fluctuations.

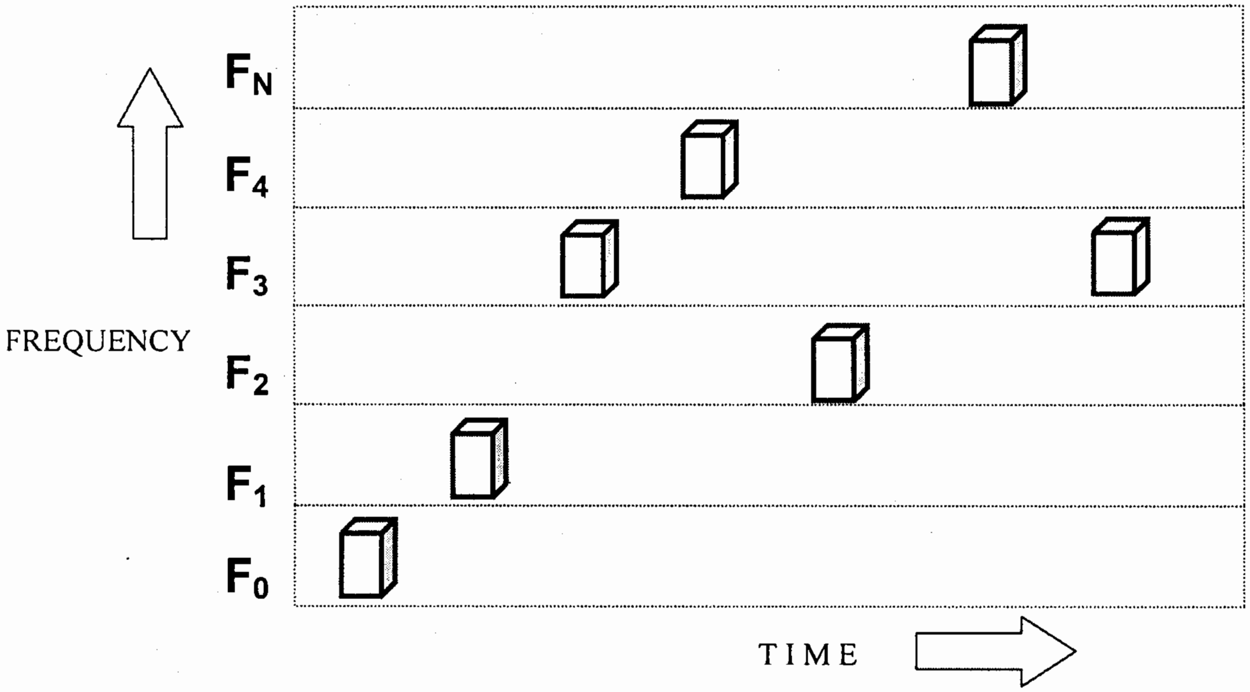

Fig 2.8 Concept of Frequency Hopping

2.9.3 Time Hopping (TH)

The information-bearing signal is transmitted in discontinuous, short bursts at time intervals determined by the spreading sequence. Although its implementation is simpler than that of FD-CDMA, the required synchronization time in TH-CDMA is longer. It is noted that if all users' transmissions are synchronized, TH-CDMA is similar to a TDMA protocol.

2.9.4 Chirp Modulation

This modulation is almost exclusively used in military radars, rather than PCSs. The radar transmits a low power signal whose frequency is varied continuously over a wide range.

2.9.5 Hybrid Modulation

This modulation combines various CDMA signaling methods, in order to mitigate some of their disadvantages. A hybrid CDMA which has received much attention recently is the Multi-Carrier (MC)-CDMA. The MC-CDMA is a combination of CDMA and orthogonal frequency division multiplex signaling. In MC-CDMA, the information-bearing signal is spread using a given code in the frequency domain, and is potentially robust to frequency selective fading channels [15].

2.6 Space Division Multiple Access (SDMA)

It controls the radiation pattern of each user in space [13, 14]. A common application of SDMA is the use of sectorized/adaptive antennas. The direction of these antennas can be fixed or adjusted dynamically, in order to steer in the direction corresponding to the desired signal. Thus, through antenna gain, the interfering signals that lie outside the antenna's main beams can be attenuated. This SDMA results in spatial separation of users and is a useful method to suppress co-channel interference.

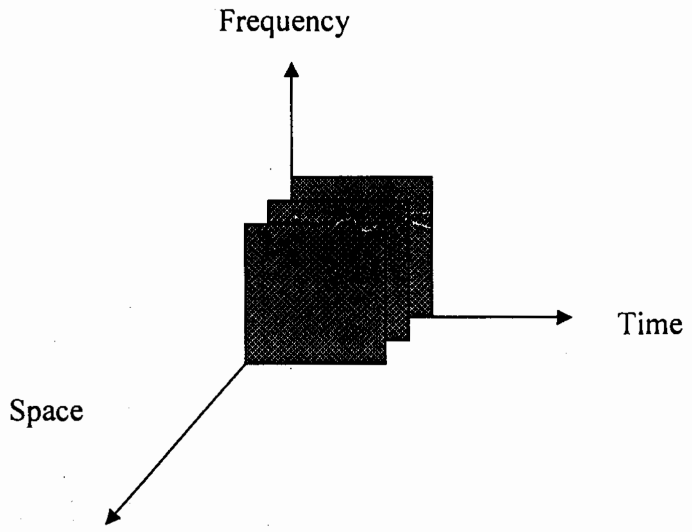

Figure 2.9 Illustration of the concept of SDMA

Space Division Multiple Access in its pure form is basically conventional beamforming applied to multiple users simultaneously. One beam pattern is allocated to each user. The main beams are quite narrow and are sometimes appropriately referred to as pencil beams. These pencil beams partition the space surrounding the antenna array receiver. This scenario is equivalent, in terms of capacity per user [33], to each user being the only transmitter in a cell (for example) with an omnidirectional antenna and no interference. Note that only a finite number of independent beams may be formed which is the same as the number of antennas [31].

This pure form of SDMA is naive and highly impractical. In reality it is much more likely that 1) there will be more users than the maximum possible number of independent pencil beams, 2) more than one user will occupy each partition and 3) there will be multipath signals to contend with. In addition, there is one obvious difference between SDMA and the multiple access schemes which adds an extra difficulty to achieving orthogonality. Even if the number of users does not exceed the possible number of independent beam patterns, in SDMA we have no control over allocating positions to the users as we do for frequency bands, time slots or signature sequences in FDMA, TDMA and CDMA, respectively. However, partitioning the physical environment using beamforming can aid in eliminating some of the multipath and interfering users' signals [33, 34] even with fixed beams [30] as is currently common practice in base stations for mobile communications.

CHAPTER 3

Space Time Spreading and MUD Schemes

3.1 Introduction to Space Time Spreading

Space Time Spreading STS is a technique in which each users data is being spread in a different fashion using a common set of orthogonal codes and is transmitted on their respective transmit antennas.

This technique known as STS improves the downlink performance of the broadband direct sequence code division multiple access by using a small number of antenna elements at the base and one or more antennas at the hand set, in conjunction with a novel spreading scheme inspired by space time codes. Each signal is being spreaded in a unique way over the transmitter antennas to get maximum path diversity at the receiver end. It is a practical way to increase the bit rate, quality and range in the case of large number of users. When Space Time Spreading is being invoked for spreading the signal of each sub carrier, the fading of each sub-carrier is mitigated and hence the system becomes capable of significantly reducing the effects of the time variant channel fading , provided that the number of transmit antenna is higher than one.

In other words we can say that the system will achieve higher throughput and a higher transmitted bit rate with the advent of transmit diversity. For easy understanding we will consider two transmit and one receive antenna.

3.2 Space Time Spreading Using Two Transmit Antennas

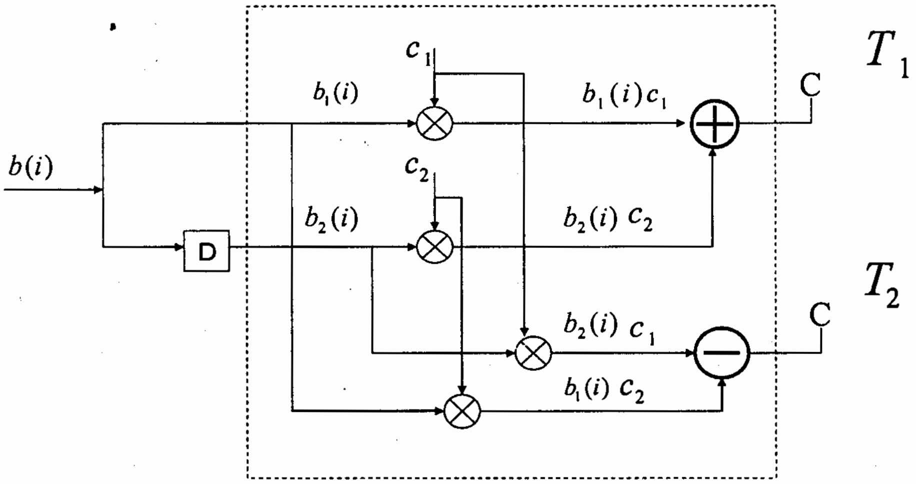

Fig 3.1 A (2,1) STS Scheme

The above figure shows a simple illustration of a (2, 1) STS scheme. Let us suppose that two bits of the same user are to be transmitted to two antennas. $b_1(i)$ and $b_2(i)$ are two data bits to be transmitted. They both will be multiplied by an orthogonal code in a unique way and then will be transmitted on the respective antennas.

Let the signal transmitted on one antenna i.e. T_1 is:

$$T_1 = \left(\frac{1}{\sqrt{2}}\right)(b_1c_1 + b_2c_2)$$

Similarly the one transmitted on T_2 is:

$$T_2 = \left(\frac{1}{\sqrt{2}}\right)(b_2c_1 - b_1c_2)$$

Where c_1 and c_2 are any set of orthogonal $2P\times 1$ unit norm spreading sequences. And also $c_1c_2=0$.

Observe that we are using two spreading codes of length $2P$ each but are employing both codes with both data symbols. Hence no extra resources are needed. We can write it as:

$$[t_1,t_2]=[c_1,c_2]\begin{bmatrix} b_1 & -b_2 \\ b_2 & b_1 \end{bmatrix}$$

The received signal after dispreading will be:

$$d_1=\left(\frac{1}{\sqrt{2}}\right)(h_1b_1+h_2b_2)+c_1n$$

$$d_2=\left(\frac{1}{\sqrt{2}}\right)(-h_2b_1+h_1b_2)+c_2n$$

'd' can be defined as:

$$d=\frac{1}{\sqrt{2}}Hb+v$$

where

$$H=\begin{bmatrix} h_1 & -h_2 \\ h_2 & h_1 \end{bmatrix}, b=\begin{bmatrix} b_1 \\ b_2 \end{bmatrix}, v=\begin{bmatrix} c_1n \\ c_2n \end{bmatrix}$$

To recover the symbol streams the mobile of interest simply has to multiply its de-spread signal d by h_1 or h_2 respectively. At this point the recovered symbols will be ready for hard or soft decoding. We call this approach STS since each user data is spread in a different fashion on each transmitter antenna.

3.3 Space Time Spreading Using Four Transmit Antennas

Similarly for 4 transmitter antennas we can write:

$$S=\begin{bmatrix} c_1 & c_2 & c_3 & c_4 \end{bmatrix}\cdot\begin{bmatrix} b_1 & b_2 & b_3 & b_4 \\ b_2 & -b_1 & b_4 & -b_3 \\ b_3 & -b_4 & -b_1 & b_2 \\ b_4 & b_3 & -b_2 & -b_1 \end{bmatrix}$$

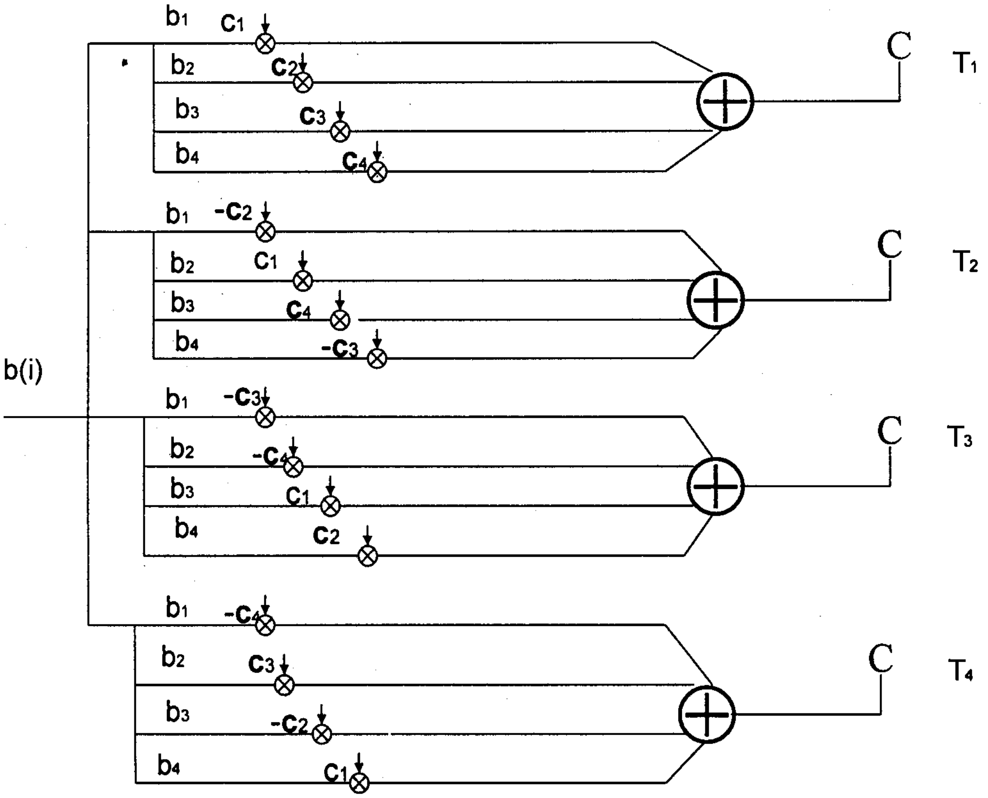

Fig 3.2 A (4,1) STS Scheme

The b's are arranged according to very famous Almouti scheme. And S is the baseband representation of the signals on the 4 antennas. This scheme is valid only for M=2, 4, 8.

The essence of the scheme is for sub-streams of each user's data to share common set of spreading codes in a different way on each transmitter antenna. Possible extra benefits of STS that remain to be quantified are the mitigation of both the power control problem, as well as the inter-cell interference problem. Increased diversity implies that adjustments to power do not have to occur as frequently.

3.4 Basic Multi-user Detector Structures

Multi-user detection (MUD) is a promising approach to provide more efficient use of the available frequency spectrum and overcoming the limitations of the conventional DS-CDMA detector.

Potential benefits of using MUD in a cellular system are significant increase in capacity. However, there are two main limitations on the benefits of MUD which are: 1) inter-cell interference and 2) multi-user receiver complexity on the downlink. In cellular DS-CDMA systems, the uplink and the downlink utilize different frequency bands. However, due to the frequency planning the same pair of frequencies are reused in neighboring cells, resulting in inter-cell interference which is added to the interference within a cell (intra-cell interference). Significant reduction in capacity can occur if this interference is not mitigated. For the sake of simplicity, we assume null inter-cell interference in the work presented in this thesis, *i.e.* only intra-cell interference is considered. A second limitation of MUD is the receiver complexity. With respect to downlink transmissions, a major concern is the constraints in cost, size and weight of the receiver. Therefore, there is a need to provide mobile multi-user receivers that have reasonable computational complexity and acceptable performance to ensure practical implementation. On the other hand, for uplink transmissions (where the detection of multiple users is required in any case) these issues are relaxed since base stations of current systems allow the extra signal processing required. Hence, improving the capacity of the uplink does not improve the overall capacity of the system. In the work presented here, multi-user receivers are only considered for the downlink of a DS-CDMA system.

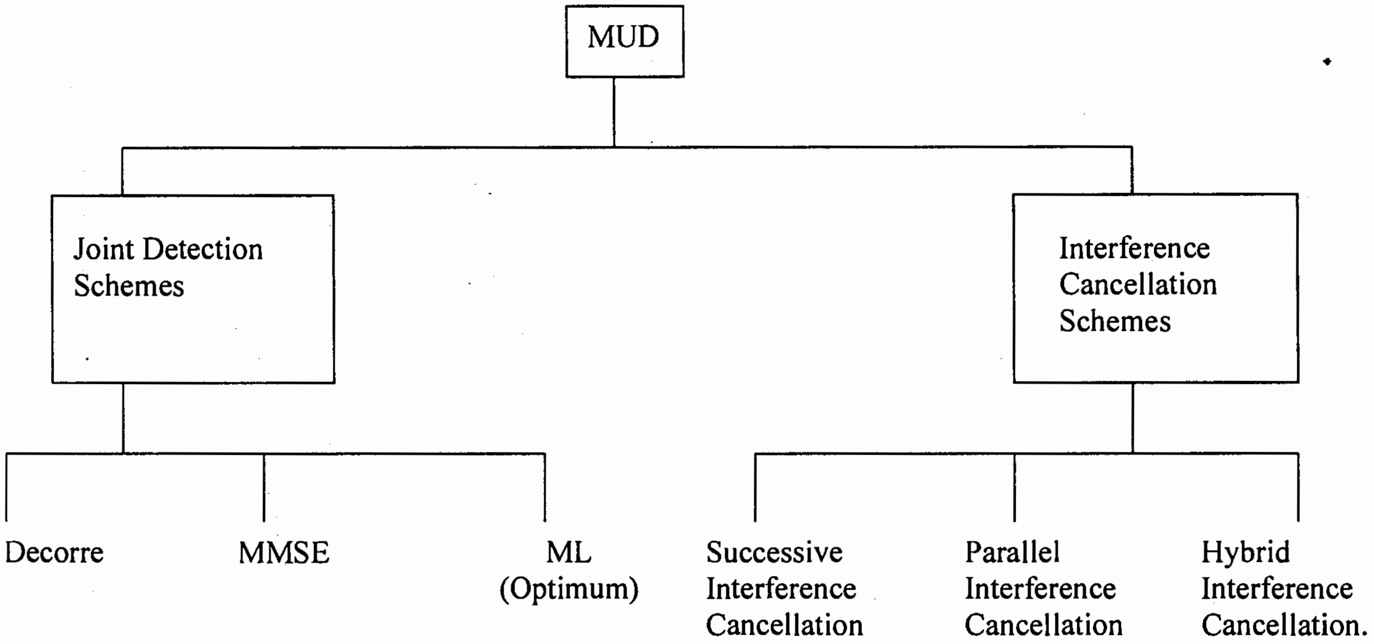

Figure 3.3 General classifications of multi-user detection structures

A general overview of MUD is presented in Figure In this section we will consider some basic MUD's structure. In discussing multi-user detection, it is convenient to introduce a matrix-vector notation based system model for describing the output of the conventional detector. We commence with a simple example considering a three-user synchronous system communicating over a non dispersive AWGN channel. The matched filter output related to each of the user can be written as:

$$\begin{aligned} y_1 &= A_1b_1 + \rho_{21}A_2b_2 + \rho_{31}A_3b_3 + n_1 \\ y_2 &= \rho_{12}A_1b_1 + A_2b_2 + \rho_{32}A_3b_3 + n_2 \\ y_2 &= \rho_{13}A_1b_1 + \rho_{23}A_2b_2 + A_3b_3 + n_3 \end{aligned} \qquad (3.1)$$

Where A_i, i=1,2,3 denotes the received signal amplitudes owing to the bits b_i, i=1,2,3 transmitted by the three users, n_i, i=1,2,3 are the corresponding noise samples and ρ_{ij}, i=1,2,3, j=1,2,3 represents the cross-correlation coefficients amongst the user-specific spreading codes. Equation 2.1 may be expressed in a more compact form as follows:

$$\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix} = \begin{bmatrix} 1 & \rho_{21} & \rho_{31} \\ \rho_{12} & 1 & \rho_{32} \\ \rho_{13} & \rho_{23} & 1 \end{bmatrix} \begin{bmatrix} A_1 & 0 & 0 \\ 0 & A_2 & 0 \\ 0 & 0 & A_3 \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} + \begin{bmatrix} n_1 \\ n_2 \\ n_3 \end{bmatrix} \tag{3.2}$$

Or as:

$$\mathbf{y} = \mathbf{RAb} + \mathbf{n} \tag{3.3}$$

In the context of a K-user system, the vector **b, n** and **y** are K-dimensional vectors that hold the users' transmitted data, the noise and the matched-filter output of all K users, respectively.

The matrix **A** is a diagonal matrix containing the corresponding received signal amplitudes, while the matrix **R** is a $K \times K$-dimensional cross-correlation matrix, whose entries contain the cross-correlation coefficient of every pair of spreading codes. Note that since the correlation coefficients of the codes satisfy $\rho_{ij} = \rho_{ji}$, the matrix **R** is clearly symmetric. Below we will briefly consider a number of multi-user detector structures in a little more detail.

3.4.1 Maximum Likelihood Sequence Estimator

The Maximum Likelihood Sequence Estimator (MLSE) detects the most likely transmitted K-bit vector **b** of K-users. The vector **b** is chosen by maximizing the *posteriori probability* of $P(\mathbf{b} \mid r(t))$, where $r(t)$ denotes the received channel-impaired signal during a bit interval. Under the assumption that all 2^K possible vectors **b** are equally probable, this detector is referred to as the MLSE. Therefore, this detector does not minimize the bit error probability of any of the *K*-users; it rather minimizes the probability of encountering erroneous *K*-bit vector. The problem associate with the MLSE approach is its high complexity. In general, there are 2^K possible vectors **b**. An exhaustive search is clearly impractical for a real time environment with high number of users.

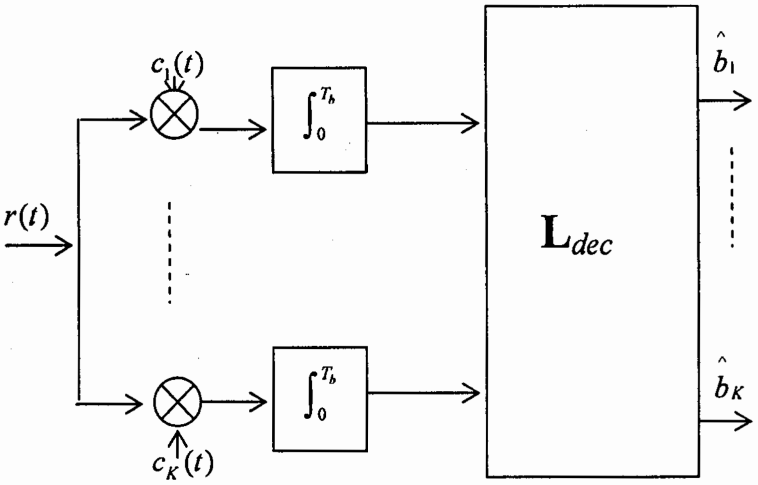

Figure 3.4 Schematic of decorrelating MUD

Hence, despite its optimum performance, owing to its excessive complexity the employment of the MLSE detector becomes impractical for real-time implementation. Therefore, numerous reduced-complexity sub-optimum multi-user detectors have been proposed in literature [3, 19].

3.4.2 Linear Decorrelating Detectors

As show in Figure 3.3, the decorrelating MUD applies the inverse of the Cross-Correlation (CCL) matrix $L_{dec} = \mathbf{R}^{-1}$ of the *K* users' spreading codes at the output of conventional matched filter based detector in order to remove the "cross-talk" among the K users' spreading codes. Hence, the decoupled output vector $\hat{\mathbf{b}}$ of the decorrelating detector is given by:

$$\hat{\mathbf{b}} = \mathbf{R}^{-1}\mathbf{y} = \mathbf{A}\mathbf{b} + \mathbf{R}^{-1}\mathbf{n} \qquad (3.4)$$

This is constituted by the decoupled data plus noise term. Thus, we can see that the decorrelating detector completely eliminates the MAI. The philosophy of this detector is very similar to that of Zero-Forcing (ZF) equalizer [5]. The advantages of the decorrelating detector are that it:

- Provides substantial performance improvements over the conventional single-user detector;
- Does not have to estimate the received signal's amplitude;
- It exhibits a significantly lower complexity than the MLSE detector;
- It exhibits near-far resistance.

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However, a disadvantage of this detector is that it imposes noise amplification. More explicitly, the powers of the noise associated with the term $\mathbf{R}^{-1}\mathbf{n}$ at the output of the decorrelating detector is always higher than that of the original noise term $\mathbf{n}$. another disadvantage of the decorrelating detector is that the complexity of inverting the CCL matrix $\mathbf{R}$ is high, in particular when number of users K is high.

3.4.3 Linear MMSE Multi-user Detector

The noise amplification problem of the decorrelating detector is circumvented by the linear MMSE MUD, which jointly minimizes the effect of the background noise and that of the MAI by exploiting the knowledge of the received signal power of K users. More explicitly, the detector minimizes the expected value of $E[\|\mathbf{Ly}-\mathbf{b}\|^2]$, and hence the decoupled matrix becomes [19]:

$$\mathbf{L}_{MMSE} = [\mathbf{R} + (\mathbf{N}_0/2)\mathbf{A}^{-2}]^{-1} \tag{3.5}$$

As seen from Equation 2.5, the MMSE detectors invoke a modified inverse of the correlation matrix, where the adjacent term of Equation 3.5 is proportional to the background noise power N_0. From a physical perspective, the MMSE detector balances the desire to completely eliminate the MAI with the desire of avoiding the background noise enhancement problem.

Since it takes the effects of the background noise into account, the MMSE detector generally provides a better performance than the decorrelating detector. As the background noise reduces, the MMSE detector's noise-related term of Equation 3.5 diminishes and hence the solution in Equation 3.5 converges to the decorrelating detector of solution of Equation 3.4.

An important disadvantage of this detector is that unlike the decorrelating detector, it requires the estimation of the K users received signal amplitudes. Furthermore, like the decorrelating detector, MMSE detector also has to invoke matrix inversion. But it exhibits more complexity than decorrelating detector.

3.4.4 Successive Interference Cancellation

The schematic of Successive Interference Canceller (SIC) is depicted in Figure 3.4, where all the K users have been ranked according to their received signal power, with the highest-power user being labeled as user 1 and the lowest-power one labeled as user K.

after power ranking, the received composite signal is processed by the matched filter or RAKE receiver of user 1 for the sake of obtaining the initial data estimates.

The transmitted signal of this user is then reconstructed using both the hard decision bits/symbols, as well as the estimate of the Channel Impulse Response (CIR) and the spreading sequence. Then the estimated reconstructed signal of this user is subtracted from the composite signal multiuser received signal. The remaining signal is then processed by the matched filter or RAKE receiver of user 2 in order to obtain its data estimate. Upon employing the estimate of the transmitted data, as well as the CIR and spreading sequence of user 2, the corresponding modulated signal is reconstructed and subtracted from the remaining composite signal that has already had the highest-power user's signals cancelled from it. This process is repeated, until the lowest-power user, namely the *K*th user's signal is processed.

The SIC detector imposes only modest additional complexity and has the potential of providing a significant performance improvement over the conventional single-user detector. It does however; pose a couple of implementation difficulties. Firstly, one additional bit delay is imposed by each cancellation stage. Thus, a trade-off has to be found between the number of users and the amount of tolerable delay. Secondly, all the users must be ranked according to their received signal power, which must be updated after each cancellation stage. A trade-off must be found between the precision of power ranking and the acceptable processing complexity. Another potential problem associated with the SIC detector occurs, if the initial data estimate of user *k* is unreliable. In this case, even if the timing, power and phase estimates are perfect, but the bit estimate is wrong, the interference imposed on the remaining users indexed from

(k+1) to K will enhances, rather than reduced. Thus, a certain minimum performance threshold must be exceeded by the matched filter based conventional detector for the SIC multi-user detector to achieve a further performance improvement.

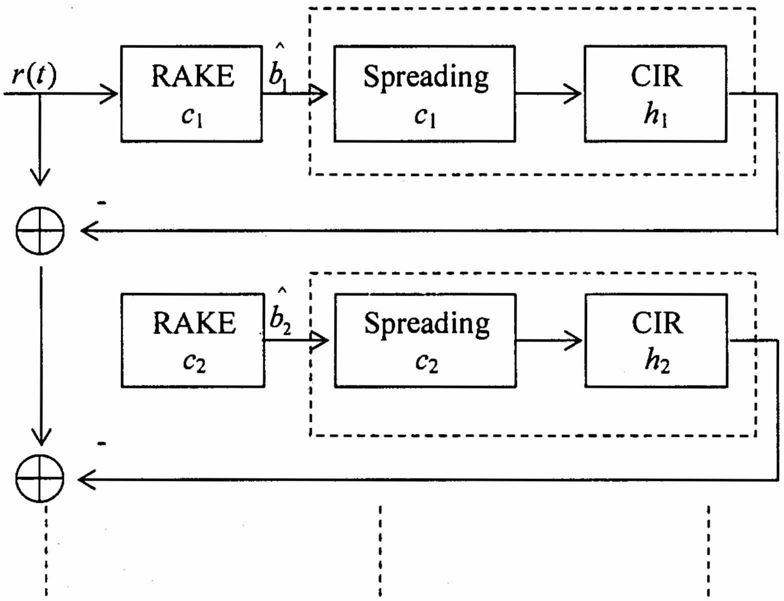


Figure 3.5 Schematic of Successive Interference Canceller

3.4.5 Parallel Interference Cancellation Multi-user Detector

In contrast to the SIC based multi-user detector, the parallel interference cancellation (PIC) aided detector estimates and subtracts the MAI imposed by all interfering users from the signal of desired user in parallel. Figure 3.5 shows a single cancellation stage of on user. In each cancellation stage, the signal of each user is reconstructed by invoking the data estimates from the previous cancellation stage. Then, for each user, the reconstructed signals of all the other users are subtracted from the received composite signal and the resultant signal is processed by the matched filter or RAKE receiver.

So that a new set of data for each of the K users to be used in the next interference cancellation stage can be obtained. The reconstruction, cancellation and re-estimation operations are repeated as many times as the affordable complexity of system allows. The advantages of PIC in comparison to SIC is that it does not require the power estimates of all users to be updated after each cancellation stage, and that all the users have the same processing delay.

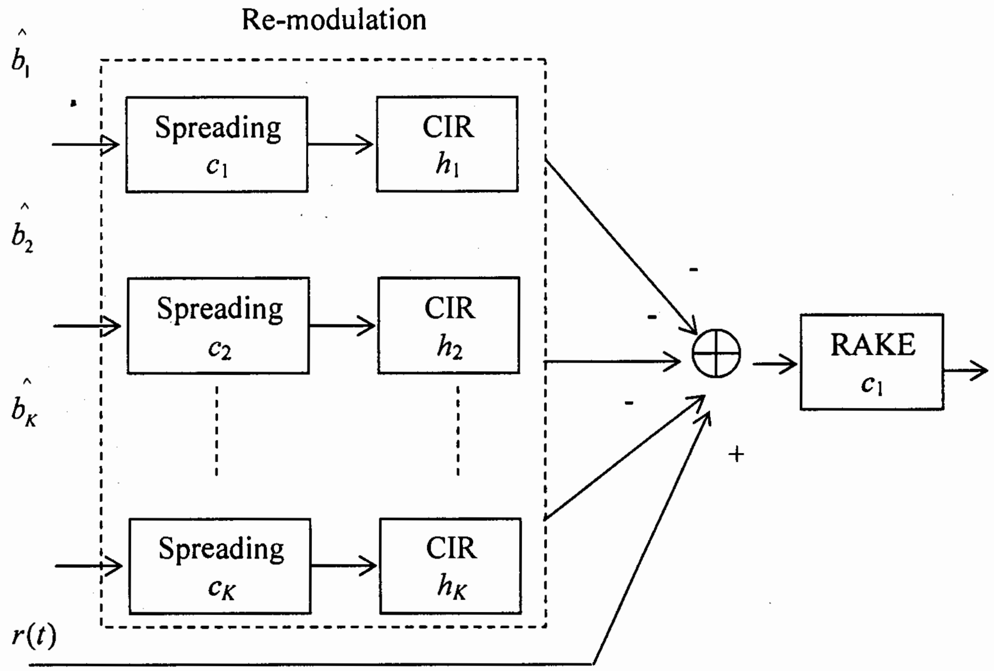


Figure 3.6 Schematic of parallel interference canceller

However, again, a certain minimum performance threshold has to be exceeded by the conventional detector in the context of the PIC multi-user detector for the sake of attaining a further performance improvement.

3.4.6 Hybrid detector

This group of subtractive interference cancellation schemes combine certain positive features of the SIC and PIC detector into a hybrid scheme. The main advantage of these schemes is that at the expense of some performance degradation, they offer significant delay and hardware reduction over the conventional SIC and PIC.

CHAPTER 4

Space Time Spreading for Synchronous MC DS-CDMA

4.1 Introduction

Multi-carrier Code Division Multiple Access (MC-CDMA) is a novel transmission technique, which combines Direct Sequence CDMA (DS-CDMA) and Orthogonal Frequency Division Multiplexing (OFDM).The number of users that can be accommodated in MC-CDMA systems, can be increased by using space time spreading assisted transmit diversity.

When multiple users are communicating simultaneously, on receiver end if we consider only the signal of user of interest as useful information while rest users' data as noise, this sort of detection is known as Single User Detection (SUD). Similarly, the case of considering the other user's data as useful information is known as Multiuser Detection (MUD).

In this system we consider K number of users that will transmit synchronously. The channels are assumed to be frequency non selective Rayleigh fading channels. First each bit of each user is being space time spreaded using Almouti scheme and is then transmitted on their respective antennas. In doing so no extra spreading codes or transmits power is required at the transmitter end. To accommodate an increased number of users' frequency domain spreading is applied so that each STS signal is being transmitted on S number of sub-carriers rather than one. This will allow them to achieve maximum frequency domain diversity.

4.2 System Model

Following are the component of the system assumed.

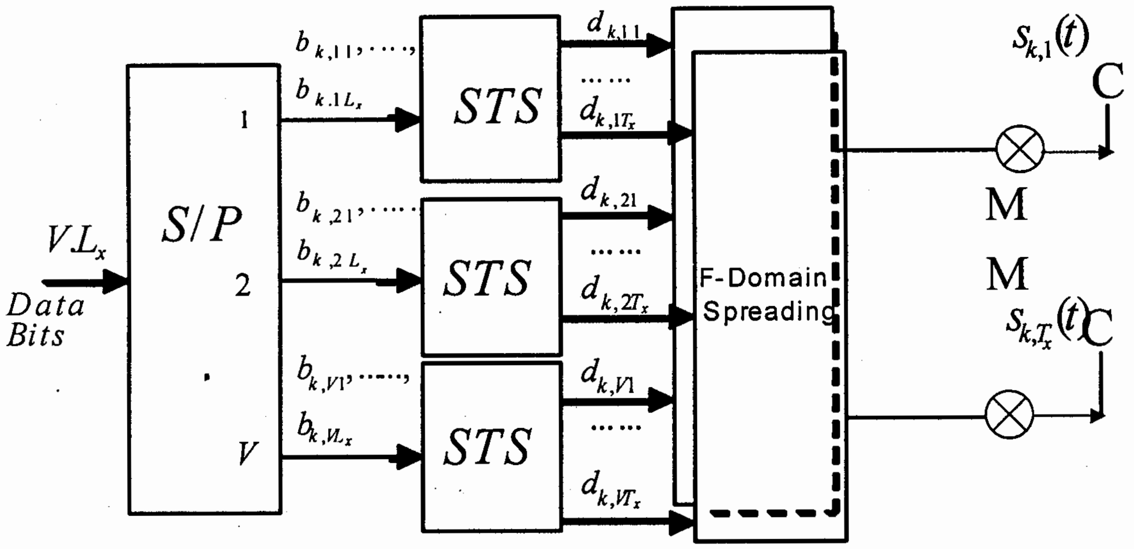
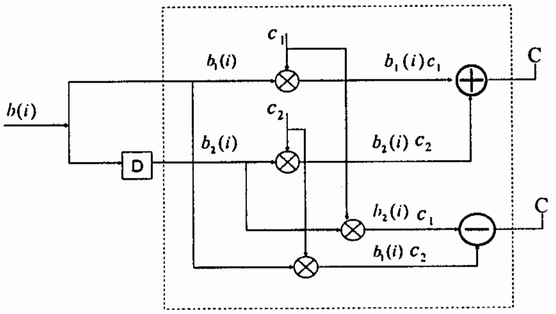


Fig 4.1 Transmitter model of MC DS-CDMA using STS

4.2.1 Transmitter

We consider an orthogonal bit-synchronous MC DS-CDMA system illustrated in Figure 4.1.We are using $V.S$ number of sub carriers , T_x number of transmitter antennas and one receiver antenna. K user signals are transmitted synchronously in this MC DS-CDMA scheme. In fig 4.1 we are investigating the *k*th user where real valued data symbol using BPSK modulation and real valued spreading is considered. A block of $V.L_x$ data bits each having bit duration of T_b is serial to parallel converted to V parallel sub blocks. Each parallel sub blocks have L_x data bits, which are space time spread using the scheme described in chapter 3.



A (2,1) STS Scheme

With the aid of M_x number of orthogonal spreading codes e.g. Walsh codes, $\{c_{k,1}(t), c_{k,2}(t), ...c_{k,M_x}(t)\}, k = 1,2,.....K$ and then mapped on T_x transmit antennas. The symbol duration of STS signal is UL_xT_b, and the discrete period of the orthogonal codes is $\frac{UL_xT_b}{T_c} = UL_xN$ as $\frac{T_b}{T_c} = N$ and T_c represents the chip duration of the orthogonal spreading codes that is Walsh codes in our case.

Now it can be shown from the figure that the output coming out from the STS blocks are then mapped on the T_x transmit antennas. These V STS signals are then spread in the frequency domain using an orthogonal sequence $\{c''_k[0], c''_k[1], c''_k[2], ..., c''_k[S-1]\}$ so that each space time spreaded signal is then transmitted on S number of sub carriers, the main purpose of F-domain spreading is to achieve maximum frequency spacing in order to avoid fading. Inverse fast Fourier transform is then applied on the STS and F-domain spreaded signals to carry out multicarrier modulation. The IFFT block output is then transmitted using one of the transmitter antennas.

The signal that is being transmitted from the T_x number of transmit antennas can be expressed as:

$$s(t)=\sum_k s_k(t)$$

$$s_k(t)=\mathrm{Re}\left\{\sqrt{\frac{2E_b}{VT_bSM_xT_x}}[C_kB_k]^T Gw*\exp\left(j2\Pi f_c(t)\right)\right\} \tag{4.1}$$

Where $\frac{E_b}{VT_b}$ is the transmitted power per sub-carrier. The factor S in the denominator is due to the S fold F- domain spreading , while the factor of M_xT_x represent STS using M_x number of orthogonal codes and T_x number of transmitter antennas. G in equation (4.1) represents V*VS dimensional F-domain spreading matrix,

$$G=\left[C_K{}^{II}[0],C_K{}^{II}[1],C_K{}^{II}[2],........,C_K{}^{II}[S-1]\right] \tag{4.2}$$

Where $C_k{}^{II}[s], s=0,1,......,S-1$ are matrices of rank V which can be expressed as

$$C_k{}^{II}[s]=diag\left\{c_k{}^{II}[s],c_k{}^{II}[s],c_k{}^{II}[s],.....,c_k{}^{II}[s]\right\} \tag{4.3}$$

Furthermore, C_k is a $V\times VM_x$ dimensional matrix constituted by the STS orthogonal codes, which can be expressed as:

$$C_k^T = \begin{pmatrix} c_{k,1}(t) & 0 & \cdots & \cdots & 0 \\ c_{k,2}(t) & 0 & \cdots & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ c_{k,M_x}(t) & 0 & \cdots & \cdots & 0 \\ 0 & c_{k,1}(t) & 0 & \cdots & 0 \\ 0 & c_{k,2}(t) & 0 & \cdots & 0 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 0 & c_{k,M_x}(t) & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \cdots & c_{k,1}(t) \\ 0 & 0 & \vdots & \vdots & c_{k,2}(t) \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ 0 & 0 & \cdots & \cdots & c_{k,M_x}(t) \end{pmatrix} \tag{4.4}$$

B_k is a $VM_x \times T_x$ is dimensional matrix mapping the data of V sub-blocks to T_x antennas. This is done according to requirements space time spreading described in chapter 3.The matrix B_k can be expressed as;

$$B_k = \left[B_{k1}{}^T, B_{k2}{}^T, \ldots\ldots\ldots, B_{kV}{}^T\right]^T \tag{4.5}$$

Where $B_{ku}, u = 1, 2, \ldots\ldots, V$ are $M_x \times T_x$ dimensional matrices.

The matrix structure of this matrix is as follows:

$$B_{ku} = \begin{pmatrix} a_{11}b'_{k,11} & a_{12}b'_{k,12} & \cdots & a_{1L_x}b'_{k,1T_x} \\ a_{21}b'_{k,21} & a_{22}b'_{k,22} & \cdots & a_{2L_x}b'_{k,2T_x} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M_x1}b'_{k,M_x1} & a_{M_x2}b'_{k,M_x2} & \cdots & a_{M_xL_x}b_{k,M_xT_x} \end{pmatrix} \tag{4.6}$$

In the above given matrix a_{ij} is the sign of the element in the i^{th} row and j^{th} which is determined by STS design rule that is given in chapter 3.

The w in the equation represents the IFFT multi-carrier modulated vector of length VS and it can be written as:

$$w = \left[\exp\left(j2\Pi f_1 t\right), \exp\left(j2\Pi f_2 t\right), \dots\dots\dots, \exp\left(j2\Pi f_{SV} t\right)\right]^T \qquad (4.7)$$

Equation (4.1) shows the general form of the transmitted signal regardless of the values of L_x, M_x, T_x. The study of space time spreading STS in chapter 3 shows that $L_x = M_x = T_x$ gives the best results as this combination provides maximum transmit diversity utilizing a common set of codes. Hence no extra set of set of codes is required. Now talking about the number of users supported by this broadband MC DS CDMA system using STS and F-domain spreading the analysis is given as follows:

Total number of orthogonal codes used by the STS is VL_xN and the total number of users supported by this is $K_{\max} = \frac{VL_xN}{M_x}$. Now as compared to this the number orthogonal codes used by F-domain spreading is S. This shows that the S number of signals can share a common set of STS codes. These S users are distinguishable by the help of S number of F-domain codes. It means that the total number of users supported by this MC DS-CDMA system using STS and F-domain spreading are $SK_{\max} = \frac{VSL_xN}{M_x}$.

Now the orthogonal code assignment can be done as follows: If the total numbers of users are in the range of $0 \le K \le K_{\max}$, they will be assigned the same number of orthogonal STS codes and the same S number of F-domain orthogonal spreading codes. However if the number of users increased sufficiently that is if they are in the range $sK_{\max} \le K \le (s+1)K_{\max}, s = 1, 2, \dots\dots, S-1$, then these s or $s+1$ users are assigned the same set of STS codes but the $s+1$ users are assigned different orthogonal F-domain spreading codes. In doing so multi-user interference is introduced which affects the BER performance.

4.2.2 Channel

The channel assumed in this context is slowly varying frequency non-selective Rayleigh flat fading channel. Each sub carrier signal will experience flat fading.

Now let us assume that $0 \le K^{l} \le S$ be the number of users sharing the same set of STS orthogonal codes. We can also say that any set of M_x orthogonal STS codes is shared by same K^{l} number of users. When the $K^{l}K_{\max}$ signals as seen by equation (4.1) are transmitted over frequency non selective Rayleigh flat fading channel, the received equivalent low pass can be written as:

$$R(t)=\sum_{k=1}^{K^{l}K_{\max}}\sum_{i=1}^{T_x}\sqrt{\frac{2E_b}{VT_bSM_xT_x}}\left(\left[C_kB_k\right]^{T}G\right)_i Hw+N(t) \tag{4.8}$$

Where $N(t)$ represents additive white Gaussian noise (AWGN) having a double sided spectral density of $N_{\circ}$.

4.2.3 Receiver

On the receiver side the inverse operations are being carried out. As can be seen in the figure the received signal is first down converted using FFT multi-carrier demodulation. After the FFT based demodulation we obtain $V.S$ number of parallel streams corresponding to the signal transmitted on $V.S$ sub carriers , and then each stream is space time de-spread , in order to obtain L_x variables $\left\{Z_{u,1},Z_{u,2},Z_{u,3},........,Z_{u,L_x}\right\}_{u=1}^{VS}$, corresponding to the L_x data bits transmitted on the u^{th} stream, where $u=1,2,......,VS$ respectively.

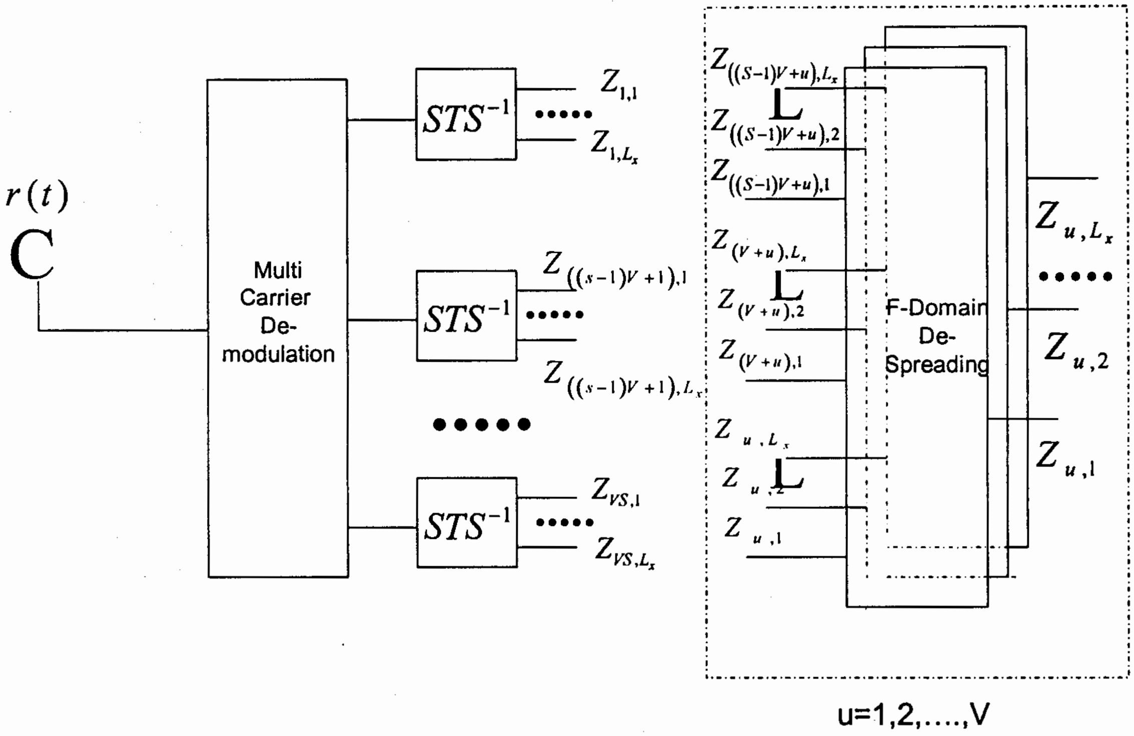


Fig 4.2 Receiver schematic of MC DS-CDMA using STS

After space time de-spreading a decision variable is formed for each transmitted data bit $\left\{b_{u1}, b_{u2}, \ldots\ldots\ldots\ldots, b_{uL_x}\right\}_{u=1}^{V}$ by dispreading the variables by using F-domain spreading sequences.

Here we are discussing the case of $L_x = M_x = T_x = 2,4,8$ etc so we can write:

$$z_{u1} = \left[Z_{u,1}, Z_{(V+u),1}, \ldots\ldots\ldots\ldots, Z_{(S-1)V+u,1}\right]^T \tag{4.9}$$

$$A = diag\left\{\sum_{L=1}^{T_x} h_{uL}^2, \sum_{L=1}^{T_x} h_{(V+u)L}^2, \ldots\ldots\ldots, \sum_{L=1}^{T_x} h_{((S-1)V+u)L}^2\right\} \tag{4.10}$$

$$Q=\begin{pmatrix} q_1^{II}[0] & q_2^{II}[0] & \cdots & q_{K'}^{II}[S-1] \\ q_1^{II}[1] & q_2^{II}[1] & \cdots & q_{K'}^{II}[S-1] \\ \vdots & \vdots & \ddots & \vdots \\ q_1^{II}[S-1] & q_2^{II}[S-1] & \cdots & q_{K'}^{II}[S-1] \end{pmatrix} \tag{4.11}$$

$$b=\left[b_{1,u1},b_{2,u1},\ldots\ldots\ldots\ldots\ldots,b_{K',u1}\right]^T \tag{4.12}$$

$$n=\mathrm{Re}\left[N'_{u,1},N'_{(V+u),1},\ldots\ldots\ldots\ldots\ldots,N'_{((S-1)V+u),1}\right] \tag{4.13}$$

Now the decision variable can be expressed as:

$$z=\sqrt{\frac{2VE_bT_b}{S}}AQB+n \tag{4.14}$$

4.3 Detection

In the detection of Space Time Spreading STS based MC DS-CDMA signals we investigate correlation based single user detector, decorrelation based multi-user detector and parallel interference canceller. The decision statistics are obtained after both STS and F-domain dispreading.

4.3.1 Correlation Based Single User Detector

In the context of single user correlation based detector, we define the decision variables as:

$$z=\left[Z_{u1},Z_{u2},\ldots\ldots\ldots\ldots,Z_{uK'}\right]^T$$

These decision variables can be obtained by multiplying both sides of equation (4.14) with Q^T of equation (4.11). It can be shown as:

$$z=\sqrt{\frac{2VE_bT_b}{S}}\left(\sum_{s=1}^{S}\sum_{L=1}^{T_x}h^2_{((s-1)V+u)L}\right)Rb+Q^Tn \tag{4.15}$$

Where R represents the correlation matrix of the K' user signals, and it can be written as:

$$R = \begin{pmatrix} 1 & \rho_{12} & \cdots & \rho_{1K'} \\ \rho_{21} & 1 & \cdots & \rho_{2K'} \\ \vdots & \vdots & \ddots & \vdots \\ \rho_{K'1} & \rho_{K'2} & \cdots & 1 \end{pmatrix}$$

Where ρ_{ij} represents the correlation factor between users i and user j. It can be defined as:

$$\rho_{ij} = \sum_{s=1}^{S} \left(\frac{q_i^{//}[s-1]\, q_j^{//}[s-1] \sum_{L=1}^{T_x} h^2_{((s-1)V+u)L}}{\sum_{s=1}^{S} \sum_{L=1}^{T_x} h^2_{((s-1)V+u)L}} \right) \qquad (4.16)$$

Equation (4.15) shows that multi-user interference is introduced since the channel time varying characteristics impair the orthogonality of the sequences $\{q_k^{//}[0], q_k^{//}[1], \ldots\ldots\ldots\ldots, q_k^{//}[s-1]\}$. Finally the corresponding data bits, $b_{k,u1}, k = 1,2,\ldots\ldots\ldots, K'$, are decided according to:

$$\hat{b}_{k,u1} = \operatorname{sgn}\left((z)_k\right), k = 1,2,\ldots\ldots\ldots, K',$$

Where $(z)_k$ represents the k^{th} row of z, while $\operatorname{sgn}(.)$ is the sign function.

4.3.2 Multi-user De-Correlating detector:

For the de-correlating multi-user detector, the decision variables associated with $b_{k,u1}, k = 1,2,\ldots\ldots, K'$ are obtained by multiplying both sides of (4.15) with the inverse of R i.e. with R^{-1}. The resultant expression can be written as:

$$R^{-1}z = \sqrt{\frac{2VE_bT_b}{S}}\left(\sum_{s=1}^{S}\sum_{L=1}^{T_x} h^2_{((s-1)V+u)L}\right)b + R^{-1}Q^T n \tag{4.17}$$

The corresponding data bits are then decide according to hard decision i.e.

$$b_{k,u1} = \operatorname{sgn}\left(\left(R^{-1}z\right)_k\right), k = 1, 2, ..., K'$$

This shows that each user's data can be decided independently and the diversity order is $T_x S$.

The main problem of using decorrelating detector is its noise enhancement which can be seen by the factor shown in equation (4.17) as $R^{-1}Q^T n$. The complexity increases as we have to calculate the inverse of correlation matrix. In order to avoid these complexities•we will employ Parallel Interference canceller.

4.3.3 Parallel Interference canceller

In contrast to the SIC based multi-user detector, the parallel interference cancellation (PIC) aided detector estimates and subtracts the MAI imposed by all interfering users from the signal of desired user in parallel.

We know that

$$Z = \left[z_{u1}, z_{u2}, z_{u3}, ..., z_{uK'}\right]^T \tag{4.18}$$

We can define $z_{u,k}$ as:

$$z_{uk} = \sqrt{\frac{2VE_bT_b}{S}} AQb + n \tag{4.19}$$

$$z_{uk} = A_{u,k}b_{u,k} + \sum_{\substack{j=1 \\ j\neq k}}^{K'} A_{u,j}b_{u,j}\rho_{uj,k} + n \tag{4.20}$$

So for Conventional PIC we can write:

$$\hat{b}_{uk} = \operatorname{sgn}\left[z_{uk} - \sqrt{\frac{2VE_bT_b}{S}} \sum_{\substack{j=1 \\ j \neq k}}^{K'} A_j b_j \rho_{j,k} \right] \tag{4.21}$$

We can clearly see that there is parallel cancellation of interference.

This is the required proposed scheme for PIC. The rest of the details regarding PIC are given in Chapter 3

4.4 Simulation Results

Figures shown below compare the BER versus SNR per bit or E_b / N_o performance of STS assisted MC DS-CDMA system. Figure 4.3, 4.4 and 4.5 shows the performance of different detectors in the case of increased number of users.

We can see from the fig. 4.3 that PIC based detector is better compare to Decorrelating detector which is further better than simple correlator with simple maximum ratio combiner followed by a hard decision detector. Since noise factor is not circumvented in this scheme. In Decorrelating detector results are good for higher SNR, since the problem associated with Decorrelating detector of noise amplification make it less charming. Also with increase in number of users, due to MUI detection in all three detector is somewhat decreased that can be shown in 4.3, 4.4 and 4.5.

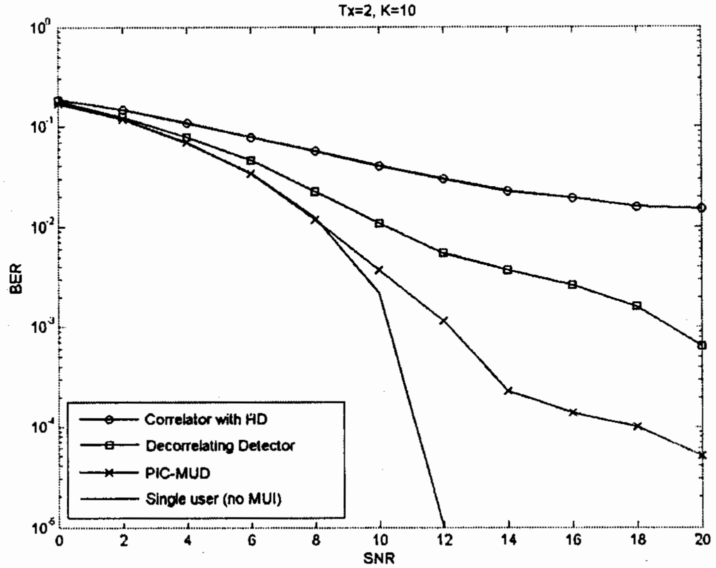


Figure 4.3 Demonstration of all three schemes with two transmit antennas and K=10 users supported

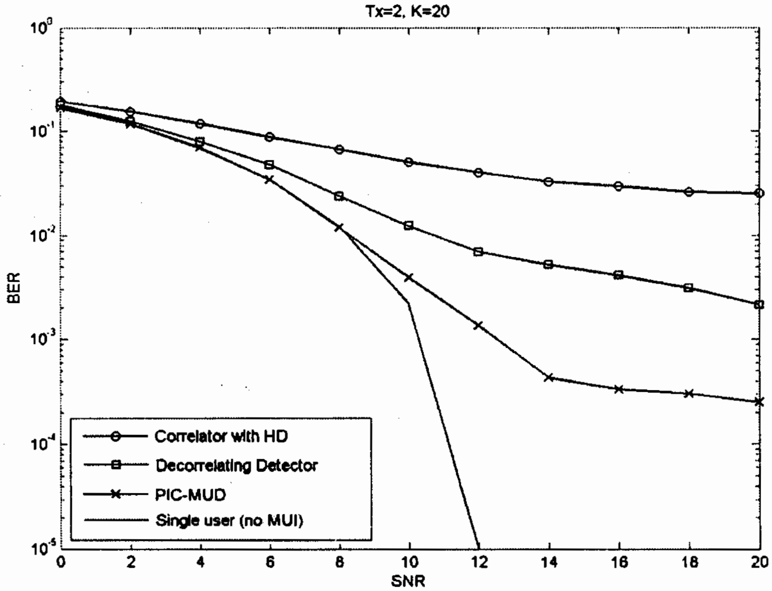


Figure 4.4 Demonstration of all three schemes with two transmit antennas and K=20 users supported

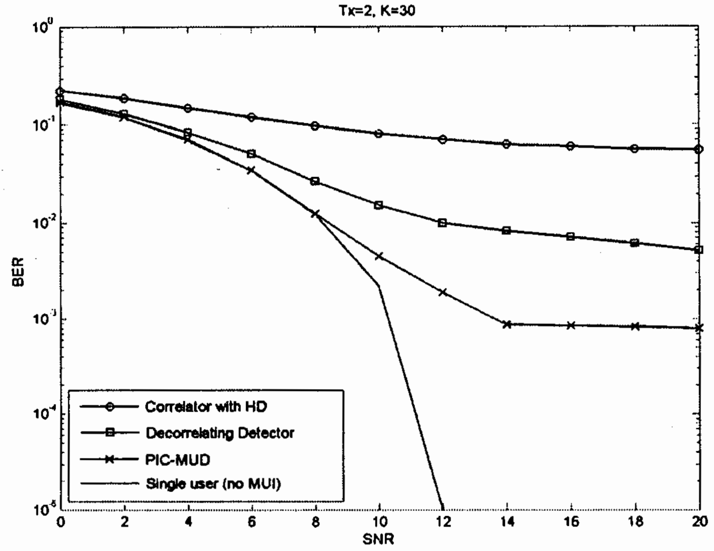


Figure 4.5 Demonstration of all three schemes with two transmit antennas and K=30 users supported

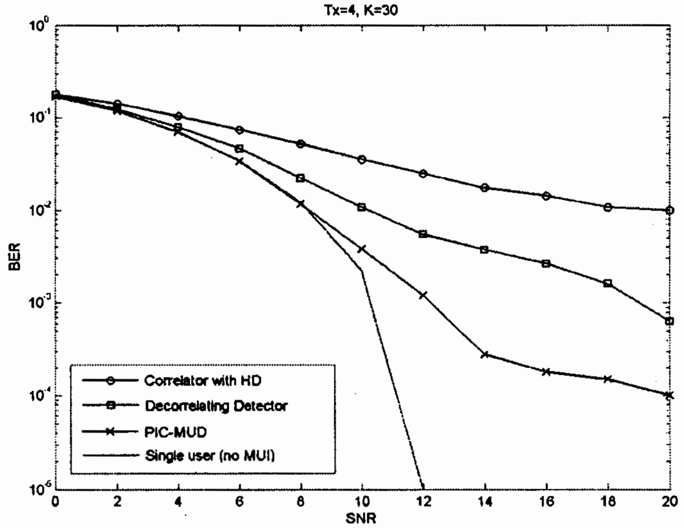


Figure 4.6 Demonstration of all three schemes with four transmit antennas and K=30

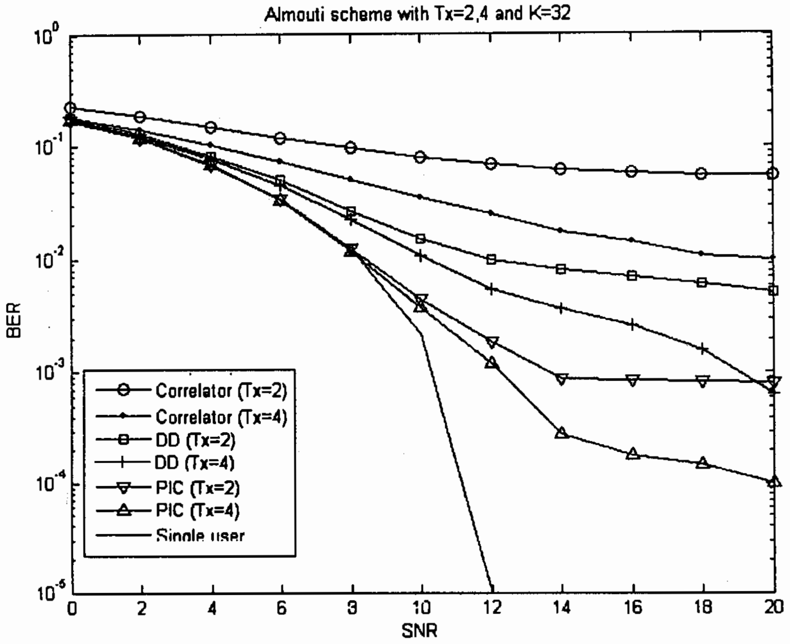


Figure 4.7 Demonstration of all three schemes with Tx=2, 4 transmit antennas and K=32

Another aspect can be seen by increase in number of transmit antennas (transmit diversity), we can see there is a significant betterment in performance. So even with high number of users (30) results are identical to that of with 10 number of users. So we can readily deduce that by increasing number of transmit antennas and PIC based detector number of supported users can be increased significantly.

CHAPTER 5

Conclusions

Summary

From the comparative study of different MUD schemes, we come upon the following conclusions.

- PIC assisted MUD outperforms than Decorrelating detector and correlator with hard decision; the comparison is more significant for higher SNR values.
- The improvement from simple correlator to DD is approximately same as DD to PIC based MUD.
- With increase in number of users the performance is reduced due to MUI, but PIC based MUD gives still reasonable comparison; further this issue can be overcome by increase in number of transmit antennas (transmit diversity).
- So more number of users can be entertained by using PIC assisted MUD, changing the length of frequency domain spreading codes, increase in SNR, or increase in number of transmit antennas for more power propagation and good signal recognition and lesser BER.

Further this scheme can be investigated with different detectors like MIC, SIC assisted MUDs. Concatenated or product codes can be used to entertain more number of users and easy decoding. Also different channels can be investigated.

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