Implementation of Time Reversal Technique for Energy Efficient Wireless Communication

A Thesis submitted in partial fulfilment of the Requirements for the degree of

Master of Technology
In
Electronics and Communication Engineering
Specialization: Communication and Networks

By

P.P.Priyanka

Roll No: 213EC5235

Department of Electronics and Communication Engineering

National Institute of Technology Rourkela,

Rourkela, Odisha, 769008, India

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Under the Guidance of

Prof. S.K.Patra

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May 2015

DEPT. OF ELECTRONICS AND COMMUNICATION ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
ROURKELA – 769008, ODISHA, INDIA

Certificate

This is to ensure that the work in the postulation entitled **Implementation of Time Reversal Technique for Energy Efficient Wireless Communication** by **Panidarapu Padma Priyanka** is a record of a unique exploration work did by her during 2014 - 2015 under my supervision and direction in complete satisfaction of the necessities for the honor of the level of Master of Technology in Electronics and Communication Engineering (Communication and Networks), National Institute of Technology, Rourkela. Neither this proposition nor any piece of it, to the best of my insight, has been submitted for any degree or confirmation somewhere else.

Prof. Sarat Kumar Patra
Professor
Dept. of E.C.E
National Institute of Technology
Rourkela – 769008.

DEPT. OF ELECTRONICS AND COMMUNICATION ENGINEERING
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I certify that

a) The work contained in this thesis is original and has been done by myself under the general supervision of my supervisor.

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P.P.Priyanka

May 2015

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Abstract

From the past few years, the mobile industry has developed quickly, providing network coverage to more than 4 billion users. So more network infrastructure and maintenance of network is required which increases the energy cost and energy consumption.. So "Green" wireless communication is taking much effort for improving energy efficiency and to reduce environment impact. A new energy efficient Time Reversal Technique is proposed. Time reversal is a pre-filtering/focusing signal processing technique for green wireless communication. The temporal effect and spatial focusing effects reduce the interference and receiver complexity for TR wireless communication. In multipath environment it adds all the reflected signals constructively and increase the signal strength at the receiver. It require low transmit power than the direct transmission of signal. Therefore the focusing property of TR simplify receiver design. The theoretical and simulation analysis show reduction in transmit power and improved BER.

In this thesis work, time reversal technique and its focusing properties are studied in detail. The temporal and spatial focusing effects of TR technique are simulated in MATLAB. TR technique is implemented for single user and multiuser case. A new wireless channel access method Time Reversal Division Multiple Access also implemented for multiuser downlink link system.

Contents

List of Figures

List of Tables

ABBREVIATIONS

AWGN	: Additive White Gaussian Noise
BER	: Bit Error Rate
BPSK	: Binary Phase Shift Keying
FDD	: Frequency Division Duplexing
ICT	: Information and Communication Technology
ISI	: Inter Symbol Interference
MISO	: Multiple Input Single Output
PA	: Power Amplifier
QOS	: Quality of Service
QPSK	: Quadrature Phase Shift Keying
SNR	: Signal to Noise Ratio
SISO	: Single Input Single Output
TDD	: Time Division Duplexing
TR	: Time Reversal
TRDMA	: Time Reversal Division Multiple Access

CHAPTER 1

INTRODUCTION

1

INTRODUCTION

1.1 Introduction to Energy Efficient Wireless communication

Information and communications technology industry has grown widely in developing and developed countries. Every year it deploys 1.2 lakh new base stations for providing services to the new mobile subscribers across the world. When compared with developed regions the percentage of increase in mobile subscribes is very large in developing countries. Most of the developing regions depend on diesel generators for power supply which is a more disturbing fact on carbon usages.

These diesel generators are inefficient energy sources which release CO_2 in large amount. These greenhouse gases effects the earth atmosphere. In most of the rural areas, all the base stations depend on diesel generators for power supply which increases the carbon footprint of telecommunication industry.

Each base station consumes an average power of 1kilowatt, using a total of 8.8 Megawatt-hours each year, which is equal to the power required for 1.68lakh houses in Europe. In a few information technology markets, vitality expenses represent as much as 50% of a portable administrator's working costs while more than 1% of the whole world's carbon foot print impression is because of information transfers.

The blend of rising and vitality costs and our unquenchable longing for network and information will prompt critical natural effect unless forcefully tended to by a brought together method. A low power urban cell site obliges 3kW of force (70-80kWh of energy for a 24-hour operation) and produces an expected 11 tons of carbon dioxide. Numerous provincial base stations use essentially more power because of the bigger scope range needed from every site.

Table 1.1: Energy Usage of Telecommunication

Country	**Number of Base Stations**	**Energy cost per MWh**	**Annual operating cost (Millions)**	**CO_2 emission (Annual)**
USA	**50000**	**$54**	**$150**	**Approximately 2 million tons**
EUROPE	**25000**	**$114**	**$140**	**Approximately 0.6 million tons**

1.1.1 Green House Gas emission by ICT Industry

In the past two decades, the mobile industry has grown rapidly, providing network coverage to more than 90% of the world’s population and connecting more than 4 billion people. Rapid growth of subscribers encourages fast up gradation in technologies. The development in technologies increases the number of base stations [15].

More number of base stations are deployed to provide services for the new users which require large amount of fuel for the power supply. In rural areas, base stations depend on the diesel generator for the power supply which releases CO_2 into the atmosphere.

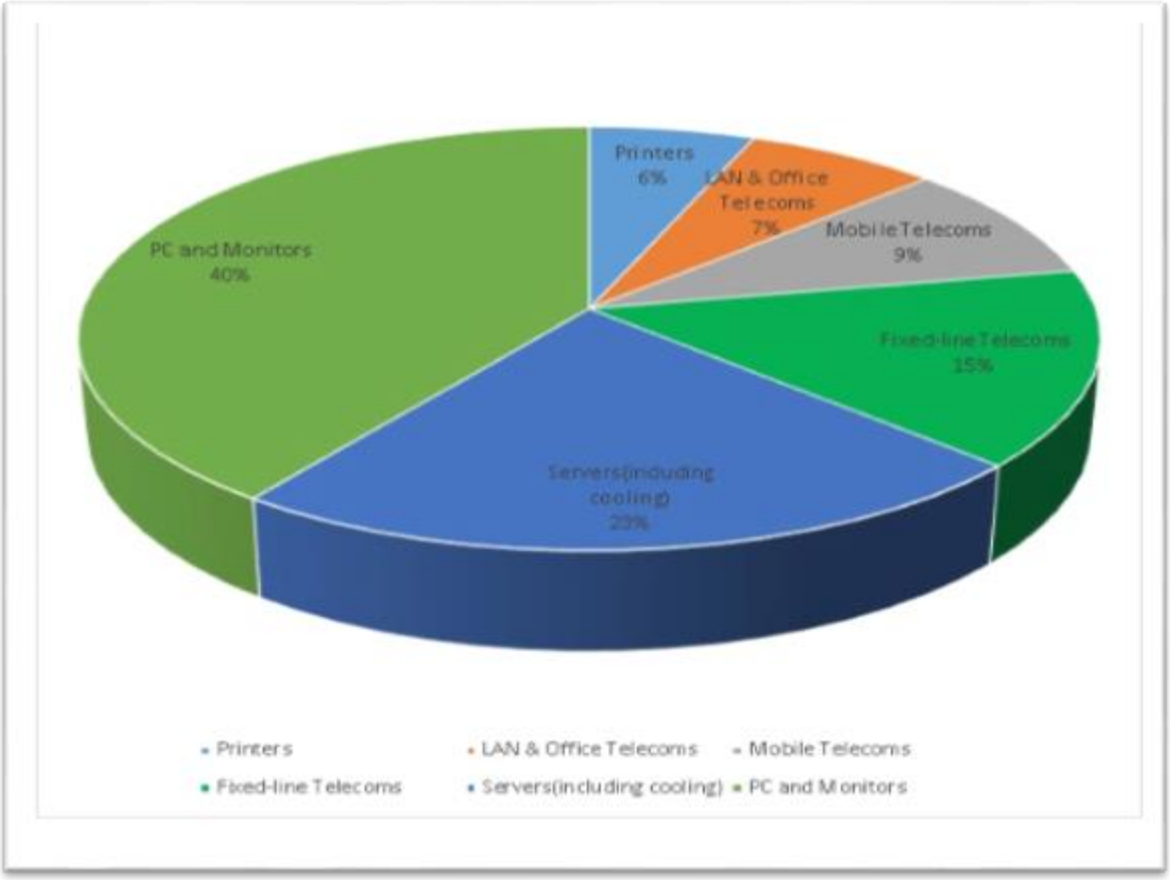


Figure 1.1: CO_2 emission of ICT industry [22]

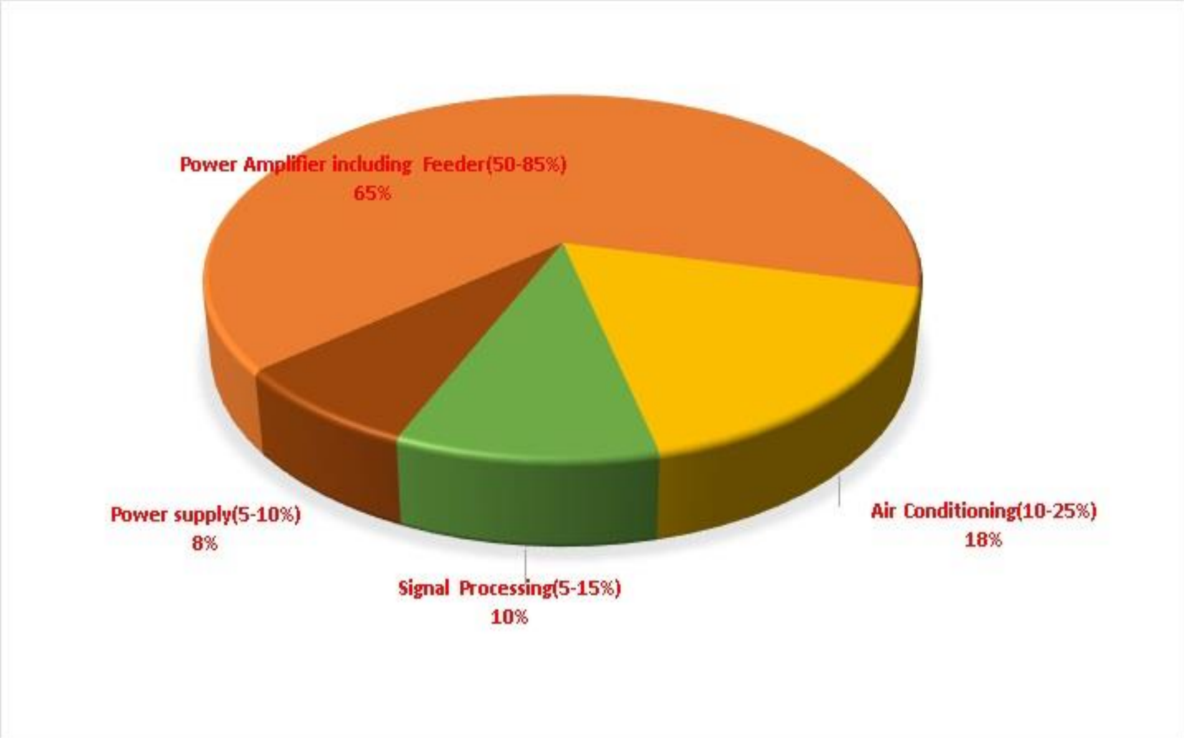


Figure 1.2 Power Consumption of a Base station [22]

The Information and Communication Technology (ICT) industry [16] contributes about two percent/860 million tons of world greenhouse gas emissions. It includes energy requirement for PC and monitors about 40%, data centres 23% , LAN and Office Telecoms 7%, Mobile Telecoms 9% , Fixed line Telecoms 15%, Printers 6% [17].

CHAPTER 2

Green Wireless Communication

2

Green Wireless Communication

2.1 Need for Greening of Telecommunication

So "Green" wireless communication is taking much effort for improving energy efficiency and reduce environment impact. Reduction of greenhouse gases produced or caused by telecommunication sector is referred to as "Greening of Telecommunication." It is broadly classified as

i) Greening Telecommunication Networks

ii) Greening Telecommunication equipment manufacture

iii) Atmosphere friendly design of telecommunication buildings

iv) Safe telecommunication waste disposal

2.2 Green Communication Definition:

Communication causing

i) less environmental pollution

ii) less power consumption

iii) less radiation

iv) Enabling technologies for low power consumption in other systems.

Its vision is to reduce overall energy consumption by maintaining quality of service (QOS).

2.3 Existing Efforts towards Green Communication

Green Communications is characterized as endeavouring to decrease vitality expenses while as yet keeping up Quality of Service (QoS) as far as scope needs. At the point when looking at framework outlines and enhancements in vitality proficient segments the lessening of greenhouse gasses alone is not sufficient. The QoS must be considered in coupled with energy effectiveness.

A troublesome yet perhaps the most vital undertaking identified with green correspondences is measuring the effectiveness of the option approaches. In what capacity can the upgrades of such an expansive exertion be deciphered in a manner that precisely mirrors the investment funds accomplished.

While power utilization is positively a central point in decreasing the carbon foot print of framework operations, we like wise propose measurements that consider vitality utilization. By and large, the terms force and vitality are inaccurately utilized reciprocally.

The IT industry has taken an administration part in enhancing energy effectiveness in the information communications technology (ICT) ecosystem. The Green Grid relationship of IT experts has distributed productivity measurements for information focuses and requested proposition for upgraded metrics.

The introductory report proposed the metric Power Usage Efficiency (PUE) and its proportional, Data centre Efficiency (DCE) [19] to empower administrators to rapidly assess energy productivity of force hungry server farms.

The PUE represents a server farm's aggregate power consumption divided by the power utilized just by the servers, storage systems and system gear. Evaluating the execution of correspondence is significantly more troublesome than measuring the execution of equipment. Commonly in server ranches or server farms, the execution of the equipment is measured by watching the processor use.

In correspondence frameworks, execution comes in various flavours. At the most minimal level, the Bit Error Rate (BER) is a much of the time utilized quantitative gauge of the connection. The great put or application-level throughput measures the measure of usable bits that are gotten by the application.

2.4. Initiatives taken for energy efficient Communication

2.4.1 Designing energy efficient equipment and innovative technologies

Base station consists of baseband unit, radio, power amplifier and feeder network. Power amplifier consumes 50% and radio consumes 80% of the base station energy. We can reduce the energy consumption of a power amplifier, by increasing its efficiency. Non constant envelope modulation methods require linear power amplifiers for good spectrum efficiency which requires more RF power. Type of modulation also effects the linearity of PA. Therefore efficiency of PA is accomplished by DSP algorithms and energy efficient structures with different materials are designed.

2.4.2 Alternative Energy sources

Renewable vitality is vitality produced from common assets, for example, water, daylight, wind, downpour, tides, power devices and biomass sources as vitality harvests. Renewable vitality sources are vitality sources that are constantly and actually recharged in a brief time of time. Interestingly, powers, for example, coal, oil, and characteristic gas are non-renewable. Renewable Energy Technologies (RETs) are those that use vitality sources in ways that don't drain the Earth's characteristic assets and are as naturally amiable as could reasonably be expected. These sources are practical in that they can be figured out how to guarantee that they can be utilized uncertainly without corrupting nature. The accompanying methodologies have been considered separately or in mix like solar, wind, Ocean/Tidal, Pico hydro energy, Biomass, Fuel cell energy.

2.4.3 Infrastructure Sharing

Latent site sharing includes parts, for example, the tower, ground based or housetop, links, physical site or roof, cover cupboards, power supply, cooling, alert frameworks, and so forth. Notwithstanding capex sparing, tower sharing spares use of valuable normal assets like steel (more or less 10 tons), bond, solid, Zinc (500 liters utilized for galvanization), land & soil preservation and improved utilization of Power [18]. What's more, dynamic sharing of system framework, which includes the sharing of the reception apparatuses frameworks, backhaul transmission frameworks and the base station hardware itself, will permit administrators to spare an extra 40% on top of accessible investment funds from latent foundation sharing [18]. Dynamic sharing could spare portable administrators all around about US$60 billion through the following five years [18].

2.4.4 Improving Grid power

In rural and remote zones destinations utilization of diesel for telecom tower would lessen, with the increment in accessibility of grid power bringing about diminishment of carbon foot print [18]. As more energy originates from renewable sources, the foot print impression would decrease further [18].

2.4.5 Waste Management

Quick mechanical advancement has prompted the era of enormous amounts of unsafe squanders, which have further disturbed the ecological issues in the nation by draining and dirtying regular assets.

A few nations are forcing strict regulation on transfer of electronic waste that comprises of system gear and additionally handsets [18]. Reusing is on the increment driven by progressively strict regulation [18]. One illustration is the Waste Electrical and Electronic Equipment Directive (WEEE Directive) of the European Community forcing obligation regarding the transfer of waste electrical and electronic hardware on the producers of such gear which got to be European law in February 2003 [18].

This has considerably changed the way gear reusing is taken care of, principally by hardware merchant's additionally capable administrators [18]. Cell telephone reusing is lessening the ecological effect of the telecom business by diminishing CO2 discharges, as well as by restricting the arrival of harmful components into nature.

2.4.6 Planning of Network Architecture

System organizers can help decrease the carbon foot print impression in various ways. New system plan philosophies, radio strategies and site innovations have been created to diminish vitality utilization no matter how you look at it: from radio hardware, through atmosphere and force frameworks to radio access systems with an emphasis on enhancing both new system take off, and additionally the operation of existing systems.

Creative strategies like utilizing telecom towers as wind towers [18] and sunlight based boards as haven rooftops can likewise convey a few advantages. Programming based force administration frameworks can be utilized by telecom administration suppliers to do an ongoing checking and administration of vitality utilization in their offices. Appropriately arranged frameworks can spare those 15% to 35% on energy costs [18].

2.4.7 Equipment standardization

There are some current worldwide models for green telecom that telecom hardware ought to adjust to e.g. ISO 14001:2004, OHSAS 18001:1999 and EuP.[18]. The EuP is another regulation that sets eco-outline prerequisites for vitality utilizing items. The worldwide models WRI/WBCSD GHG Protocol and the ISO 14067 standard "Carbon Footprint of Products" are drawing nearer to culmination [18]. Moreover, noteworthy advancements are occurring in distinctive nations that will shape the useful execution of item carbon foot imprinting later on.

2.4.8 Process of manufacturing the equipment

The weight on organizations to create procedures which grasp environmetal supportability has expanded drastically as of late. Given both administrative and shopper weight, numerous organizations have turn out to be more proactive in their endeavors to convey items and administrations which don't unfavorably affect the earth. The portable business is looking to build up its own naturally practical organizations. Concerning versatile handsets, merchants and administrators must examine outflows over the life cycle of the handset from crude material extraction to end-of-life and after that put set up approaches to lessen immediate and backhanded outflow [18].

Telecom hardware makers need to do innovative work of environment benevolent gear which minimize discharge from conceptualization to item conveyance. The outline ought to advance natural protection, quality upgrade and productive utilization of assets. The gear ought to be intended to lower operational expenses by viably diminishing the expense of renting, power, aerating and cooling, and labor. The producer ought to utilize renewable materials to fabricate items and reused materials for bundling beyond what many would consider possible. The telecom gear ought to adjust to worldwide guidelines for green telecom[18],the effect on the earth will be considered at each phase of the item life cycle and surveyed in the parts of asset and vitality utilization, waste, reusing, and so on., in order to guarantee item quality and ecological insurance[18].

2.4.9 Monitoring the Carbon Foot Print

It is critical to devise systems for telecom industry for a decent observing framework of carbon outflow and assuring carbon foot print impression reduction. Carbon foot print impression of every last one of exercises needs to be measured and reported [18]. Consistence to worldwide principles and household regulations must be persistently confirmed, it might likewise be helpful to command suitable reporting necessity to guarantee that benchmarks and regulations are being agreed to [18].

CHAPTER 3

Introduction and implementation of Time Reversal Signal Processing Technique

3

Introduction and implementation of Time Reversal Signal Processing Technique

3.1 Introduction to Time Reversal Signal Processing Technique

Wireless communication is the most popular way of communication in ICT industry. With increased number of users, there is a great demand for high speed wireless data services which requires broadband communication. In multipath channel, the broadband communication is severely affected by ISI. So, to reduce the ISI "Equalization techniques and MC-Modulation schemes" are implemented at the receiver that require complex hardware. Due to this receiver complexity is increased which results in high cost, high power consumption [11].

Therefore, time reversal based signal transmission technique is the best ideal model for green wireless communication because of its less complexity and low energy consumption. In multipath environment it collects all the signal energy and add coherently at the receiver. TR is advantageous because it provides high spectral efficiency, large multipath gain, reduces ISI and IUI, low transmission power. Mostly, this TR technique is used in rich scattering environment to reduce multipath.

Time Reversal is a signal processing technique which focus the wave at required receiver location. It is also called pre-filtering or focusing technique that empowers the signal to focus in both time and spatial domain. First it is implemented in acoustics and under water communication, later it is executed in wireless communication and electromagnetics for ultra wideband (UWB) systems.

Now, it has taken a very prominent role in wireless communication because it provides energy efficient communication with reduced transmission power and low complexity. The temporal and spatial focusing effects of TR reduce the interference and receiver complexity [20]. In multipath environment it adds all the reflected signals coherently and increase the signal strength at the receiver. It require low transmit power than the direct transmission of signal. Therefore the focusing property of TR simplify receiver design. The theoretical and simulation analysis show reduction in transmit power and improved BER.

3.1.1 History of TR

The first paper on Time Reversal is published in 1957 by Bogert of Bell Labs in the IRE Transactions on Communications. This paper proposed Time Reversal technique for the removal of phase delay distortion which can be seen on pictures, television while transmitting signals on telephone lines. In 1965, another IBM journal is published on TR that deals with distortion of transmission of signal over telephone networks. In the period of 1950-1990 the time-reversal systems are used to remove phase delay distortion. Later non causal digital filters are designed based on time reversal method with zero phase shifts[14].

In 1990’s. the time-reversal technique is implemented in ultrasound communication and acoustics by M. Fink. In medical field ultrasonic scanner or X-ray imaging unit can detect the stone position in the human body. In inhomogeneous medium ultrasonic waves are distorted and they cannot give exact location of the stone. Another problem is stone position is changed because of breathing. So the aim is to detect an object in inhomogeneous medium which require high focusing of a wave on reflective target. In optical field due to inhomogeneities in the channel, wave fronts are distorted. Therefore, solution to the above problem is using TR technology. To achieve high focusing in optical domain field TR technology with Time-Reversal Mirror is used. TRM consists of an array of transducers which records the reflected signal from the target, time-reversed and re-transmitted. To achieve high focusing, this process is repeated. If the medium contain more than one reflective targets, then TRM focus on most reflective target i.e., with high amplitude. Later it also implemented in underwater communication because of its ability to focus the wave at desired location in inhomogeneous medium. Now a days TR technology has become more popular in wireless communication [14].

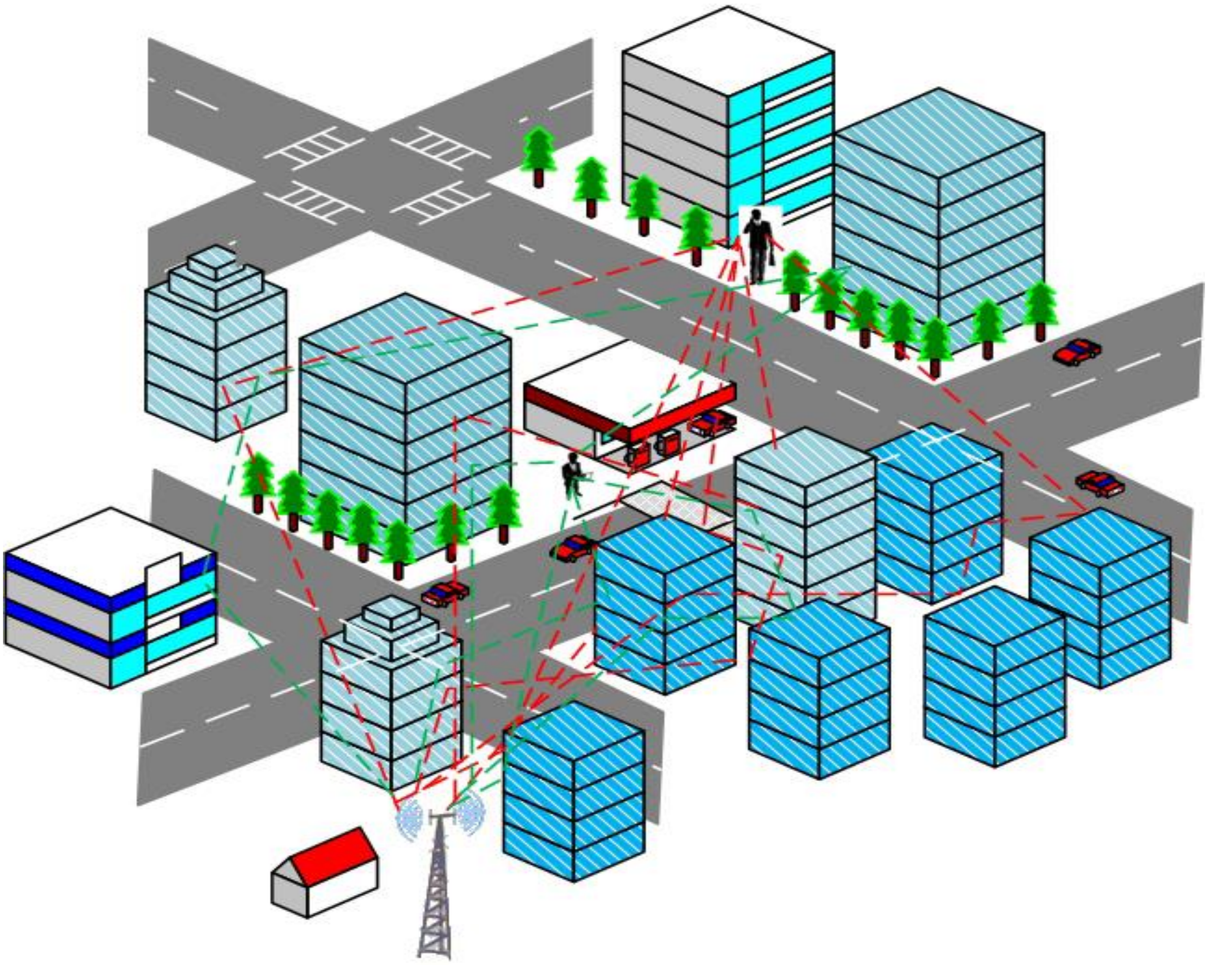


Figure 3.1: Multipath Environment

3.2 Time Reversal Concept

Time reversal (TR) is a pre-filtering/focusing signal processing technique for focusing the waves in both time and spatial domain by using time reversal mirror (TRM). TRM is a device which consists an array of transducers or transceivers. It transmits a wave towards the target and records the reflected signal coming from the target. It treats the reflected signal as a weak signal, time reverses and re transmits the reflected signal. To achieve high focusing, this process is repeated. If the medium contain more than one reflective targets, then TRM focus on most reflective target i.e., with high amplitude.

3.3 Time Reversal Mirror

This device is used for focusing the wave in highly scattered environment.it is made up of an array of transceivers or transducers. Each element consists of a transmitting and receiving antenna, amplifier, A/D converter, and shift register for storing and processing the received signal.

TRM transmits a pulse echo signal in to the inhomogeneous or scattered medium to the target and receives the reflected signal from the target. The reflected signal is stored in the shift register for processing the signal. It treats the received signal as a weak signal, time reverses and re transmits the reflected signal. To achieve high focusing, this process is repeated. In highly scattered multipath channel, this process converts divergent transmitted wave in to a convergent reflected wave, focusing on the source [4].

In the below figure explains the time reversal mirror operation. In step (a) the array of transducers or antenna elements emits a pulse echo signal into the channel. Here we assume the reflective target located at certain distance in the inhomogeneous medium. The signal reaches the target and it gets reflected.

In step (b) the reflected signal travels back through the inhomogeneous medium and reaches the TRM. The antenna elements of the TRM receives the reflected signal, time reverse and re transmits the signal.

In step(c) the time reversed reflected signal is retransmitted through the same channel and focused on the target. This process is repeated till we achieve high focusing at the target.

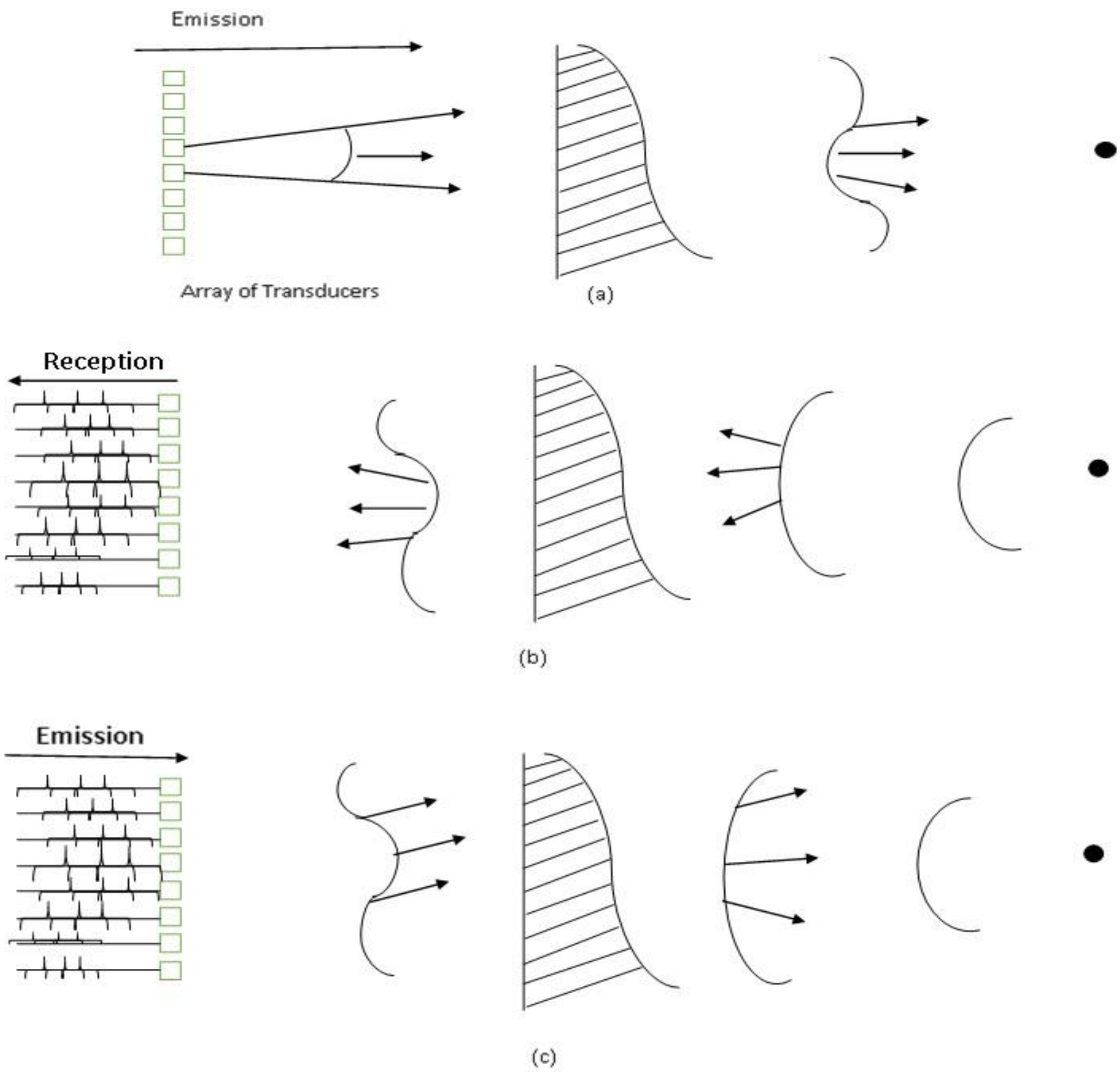


Figure 3.2: Time Reversal Mirror

3.4 Principle of TR Technique

In TR wireless communication we assume channel is reciprocal i.e., the forward and backward channel characteristics are identical and channel should be stationary for at least one transmitting cycle [3]

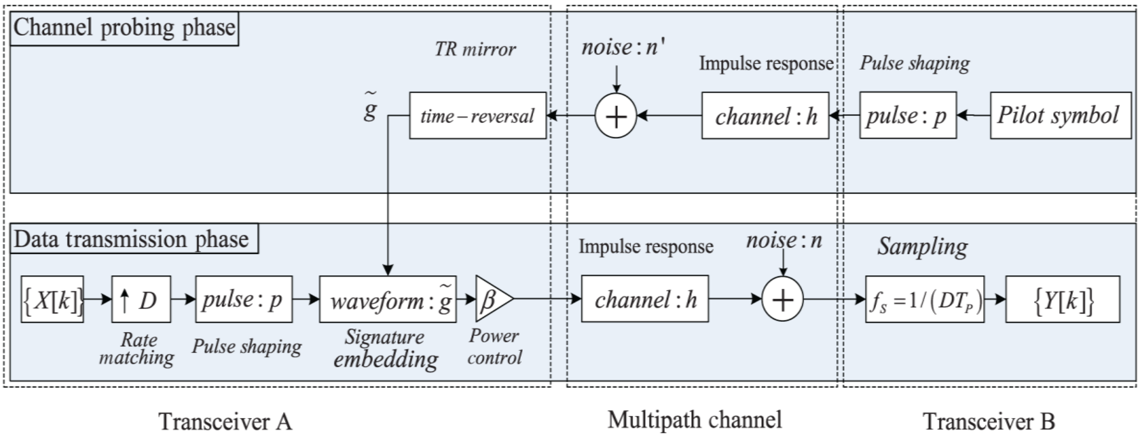


Figure 3.3: Basic Time Reversal Communication

The TR wireless communications consist of two phases:

1) The Recording or probing phase

2) The Transmission phase

3.4.1 Recording Phase

Let us assume, transceiver 'A' wants to send the information through a scattering and multi-path environment to transceiver B, then first B has to send an pilot signal (impulse) to the A through the multipath channel. On receiving the reflected waveform, the transceiver 'A' records the impulse response of the channel and store the time reversed conjugated version of the received signal [2].

3.4.2 Transmission Phase

Transceiver A, uses the normalized time reversed wave as basic wave form and retransmits it through the same multipath channel. Fig describes the recording phase and transmission phase process. The re-emitted TR waves can retrace the incoming paths due to channel reciprocity. At transceiver B the received signal from multipath channel is the constructive addition of signals from different paths i.e., strong signal is received at desired location known as *spatial focusing effect*. Time Reversal takes the advantage of multipath channel as matched filter which reduces the complexity and focus the signal in time domain which is known as *temporal focusing effect*.

3.5 Time Reversal based transmission for single user

3.5.1 System model

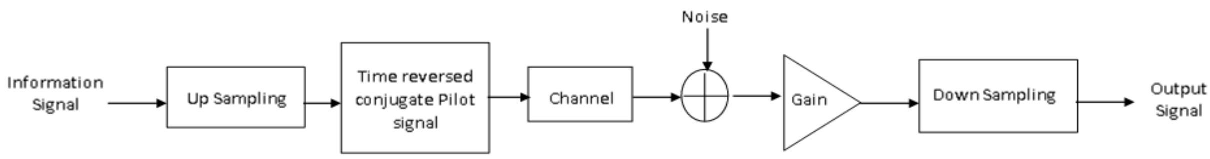


Figure 3.4: Block diagram of TR-based communication system

Let us consider a wireless channel having channel impulse response as

$$h(t) = \sum_{l=0}^{L-1} h_l \delta[t - \tau_l]$$

L is the total number of multipath, h_l is the complex channel gain of the **lth** path, τ_l is the path delay of a particular path.

In discrete time domain the channel is modelled as

$$h(k) = \sum_{l=0}^{L-1} h_l \delta[k - l]$$

Here the base station X wants to send the data to the receiver Y. in TR wireless communication the receiver Y sends impulse signal to the base station which propagates through the multipath channel, the base station receives the signal which is impulse response of the channel. The TRM at the base station time reverses the received waveform, normalize and conjugate the signal if it is complex and use it as basic waveform transmitting the signal i.e.,

$$g(k) = \frac{h^*(L-1-k)}{\sqrt{\sum_{l=0}^{L-1}|h(l)|^2}}$$

Let the base station wants to transmit the data containing information sequence X[k]. These are assumed to be complex random variables with zero mean and variance of V. The data sequences are up sampled by rate back-off factor D, convolved with g(t) and transmitted in to wireless channel. The transmitted signal is

$$S(k) = g(k) * X_D(K)$$

Where $X_D(K)$ is the up sampled sequence with rate of factor D

$$X_D(K) = X\left(\frac{k}{D}\right) \qquad if \;\; k \, mod \, D = 0$$

$$= 0 \qquad if \; k \, mod \, D \neq 0$$

In essence, by convolving the information symbol sequences with TR waveforms, TRM provides a mechanism of embedding the unique location-specific signature associated with each communication link into the transmitted signal for the intended user. The receiver B receives the signal i.e., convolution of S(t) with h(t) with addition of AWGN noise n(k) with variance σ^2 and zero mean, it recovers the signal by down sampling with same rate off factor '**D**' and one tap gain adjustment.

The signal received at B is

$$Y(k) = S(k) * h(k) + n(k)$$

$$Y(k) = X_D(K) * g(k) * h(k) + n(k)$$

After receiving the signal $\boldsymbol{Y(k)}$ **,** it is down sampled by the same rate off factor **D** and multiplied with gain ‘**a**’**.** The equation is given by

$$Y(\dot{K}) = a \sum_{l=0}^{(2L-2)/D} (h * g)[Dl]X[k-l] + an(\dot{k})$$

Where $$h(k) * g(k) = \frac{\sum_{l=0}^{L-1} h(l)h^*(L-1-k+l)}{\sqrt{\sum_{l=0}^{L-1}|h(l)|^2}}$$

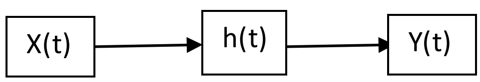
With k=0,1,2,3,4…2L-2, and $n(\dot{k}) = n(Dk)$.

Therefore the in TR wireless communication the receiver is having very low complexity.

3.6 Time Reversal Process analysis using LTI system

3.6.1 Temporal Focusing Effect

Let us consider an LTI system with an impulse response h(t) .



Where **X(t)** is the input and **Y(t)** is the output to the LTI system .

$$Y(t) = X(t) * h(t)$$

In multipath channel, the TR wireless communication adds all signals coherently at the receiver, so that its signal to noise ratio is increased which is similar to matched filter and concentrates the energy at a particular time instant in time domain. So ideally the channel impulse response should be Dirac delta function to concentrate the signal energy in time domain.

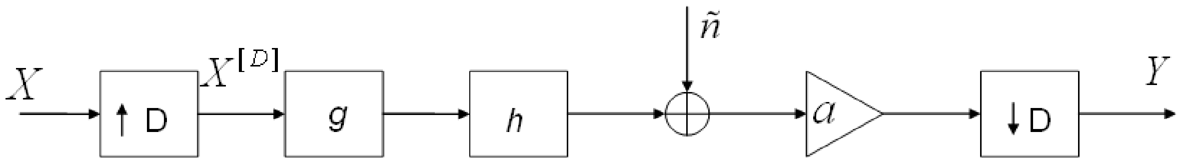


Figure 3.5: TR Model

From the above figure,

The transmitted signal is

$$S(t) = X(t) * g(t)$$

Where $g(t) = h(-t)$.

The signal received at the receiver is

$$Y(t) = X(t) * g(t) * h(t) + n(t)$$

Where $n(t)$ is the AWGN noise.

$$Y(t) = X(t) * h(-t) * h(t)\text{+n(t)}$$

$$Y(t) = X(t) * R_{hh}(t) + n(t)$$

Where $R_{hh}(t)$ is the auto correlation of the system response.

To recover the signal ideally at the receiver $R_{hh}(t) = \delta(t)$. For receiver the channel looks as $R_{hh}(t)$, so the $R_{hh}(t)$ approximation as a delta function depends mainly on the magnitude of the frequency response of $h(t)$ but not on the shape in the time domain.[antenna paper]. It is derived mathematically and shown below

The signal received at the receiver is (ignore noise)

$$Y(t) = X(t) * h(-t) * h(t)$$

Fourier transform of $h(t)$ is

$$\mathrm{F}\{h(t)\} = H(w) = |H(w)|e^{-j\emptyset(w)}$$

Fourier transform of time reversed of $h(-t)$ is

$$\mathrm{F}\{\mathrm{h}(-\mathrm{t})\} = \mathrm{H}^*(\mathrm{w}) = |\mathrm{H}(\mathrm{w})|\mathrm{e}^{+\mathrm{j}\emptyset(\mathrm{w})}$$

Where F{} is the fourier transform, superscript (*) is the complex conjugate.

$|H(w)|$ is the magnitude response and $\emptyset(\mathrm{w})$ is the phase response of the LTI system .

The Fourier transform of auto correlation $R_{hh}(t)$ is

$$\mathrm{F}\{\mathrm{R_{hh}}(\mathrm{t})\} = \mathrm{F}\{\mathrm{h}(\mathrm{t})\Theta\mathrm{h}(-\mathrm{t})\} = \mathrm{H}(\mathrm{w})\mathrm{H}^*(\mathrm{w}) = |\mathrm{H}(\mathrm{w})|^2$$

Therefore the above equation clearly shows that the autocorrelation function mainly depends on its magnitude response, it should have flat magnitude response so that it is compressed in time domain for representing a delta function. This property of time reversal is known as temporal focusing i.e., it concentrates the total energy at a particular time instant in time domain. The following figures show the impulse response and its auto correlation function.

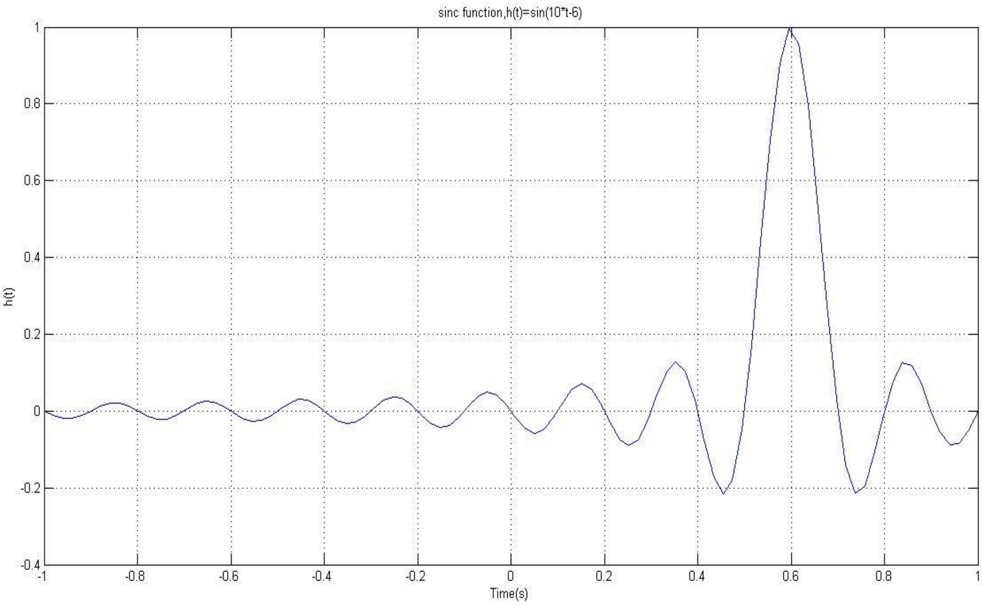


Figure 3.6: Impulse response as sinc function: h(t)=sinc(10t-6)

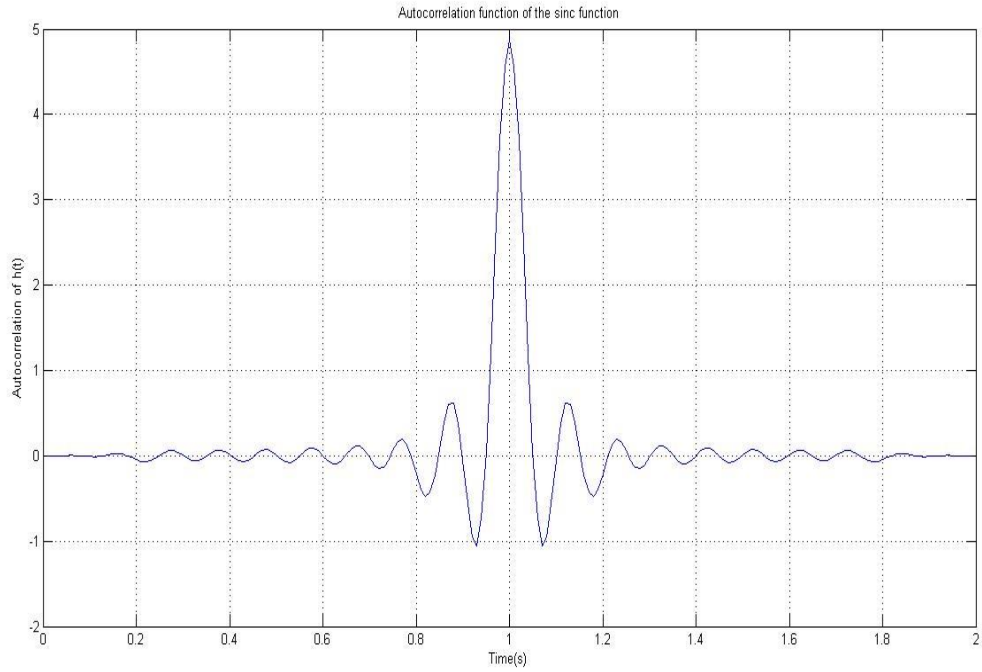


Figure 3.7: Autocorrelation function of sinc function

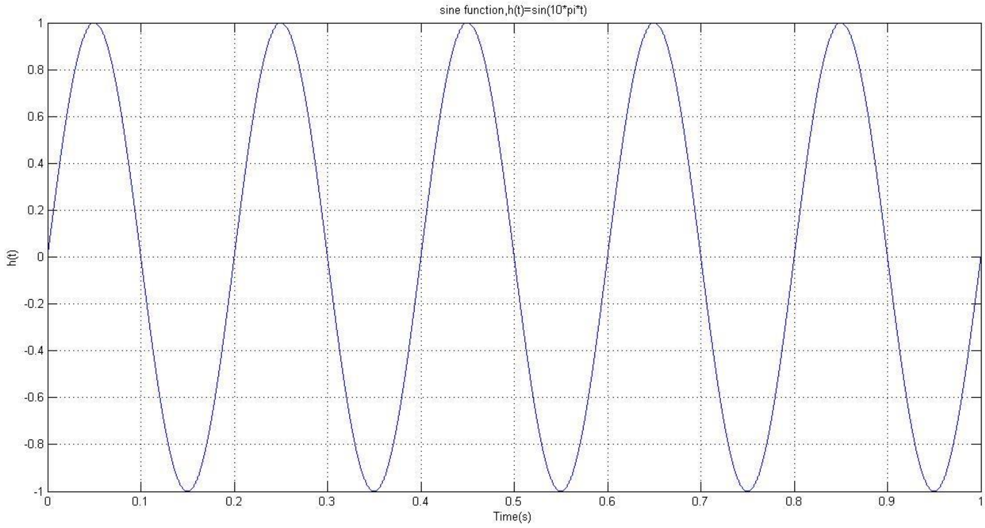


Figure 3.8: Impulse response as sine function: h(t)=sin(10πt)

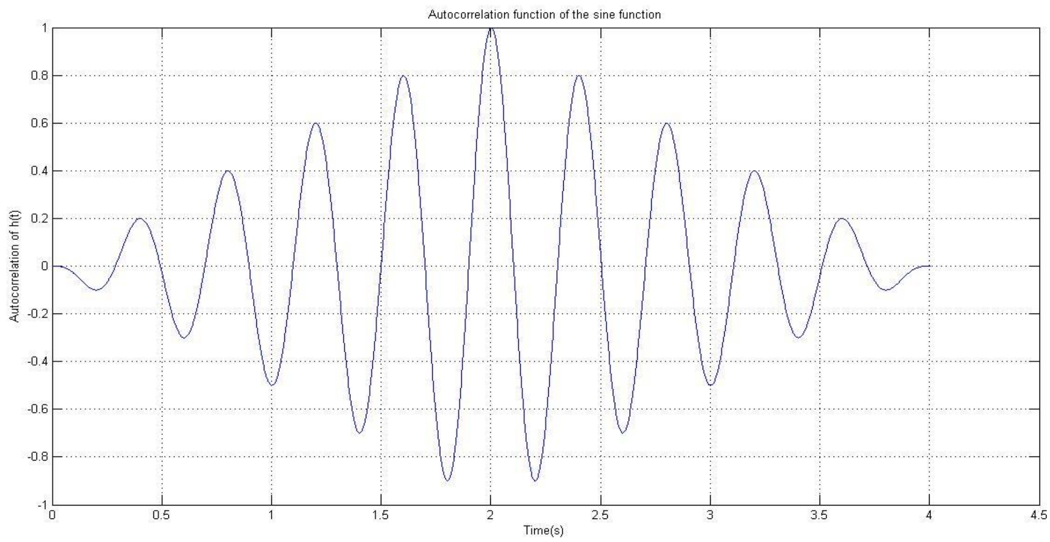


Figure 4: Autocorrelation function of sine function

The temporal focusing is similar to pulse compression technique that mainly depends on the shape of the impulse response but not on the time reversal procedure. In other words, the ability of the time-reversal i.e., the function $R_{hh}(t)$, to look like the exciting pulse,

$\delta\ (t)$, depends mainly on the complexity of the function $h(t)$, and not on the time-reversal procedure itself. The more complex $h(t)$ is, the more compressed the output, and the more one can incorrectly claim that $R_{hh}(t)$ is approximately equal to $\delta\ (t)$ [14].

3.6.2 Spatial Focusing Effect

With the help of channel reciprocity property, the retransmitted waves can retrace the incoming paths, and adds the signals of all the paths constructively at the receiver and a "spiky" signal-power distribution over the space, as commonly referred to as spatial focusing effect[3].

The spatial focusing effect concentrates the signal energy at the required user location and reduces leakage to other locations, so that it reduces the required transmitted power and co-channel interference.

Therefore due to the benefits of temporal focusing and spatial focusing property of TR waves it has large number of applications.

3.6.3 Time Reversal Bit Error rate analysis

Here we have compared time reversal transmission with direct transmission of signal with BPSK and QPSK modulation techniques. We have observed that TR transmission gives less BER for same SNR.

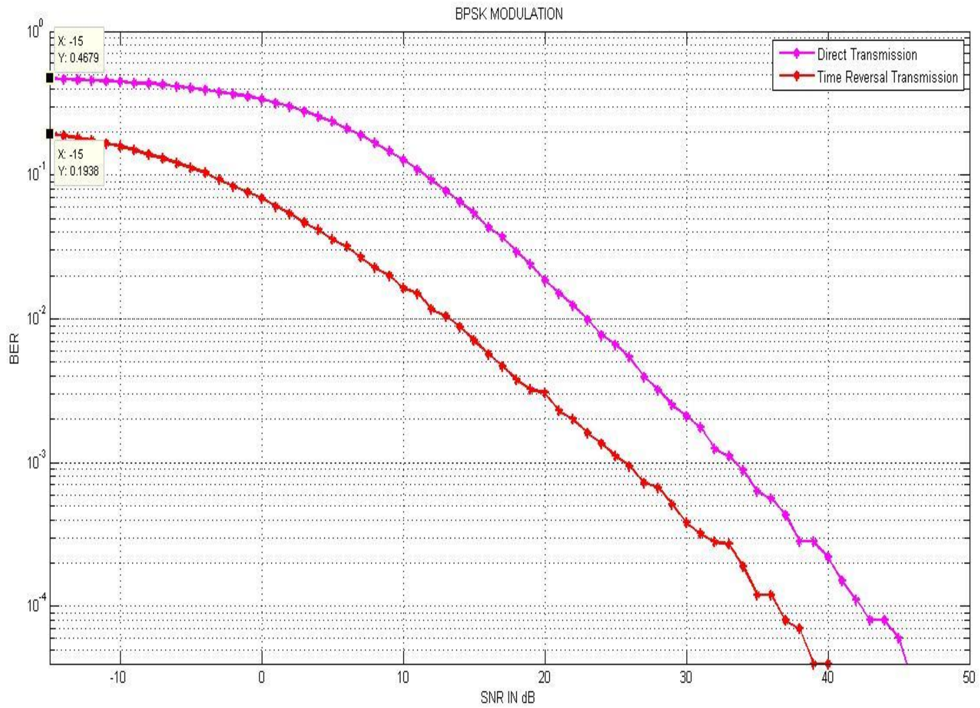


Figure 3.10: BPSK MODULATION

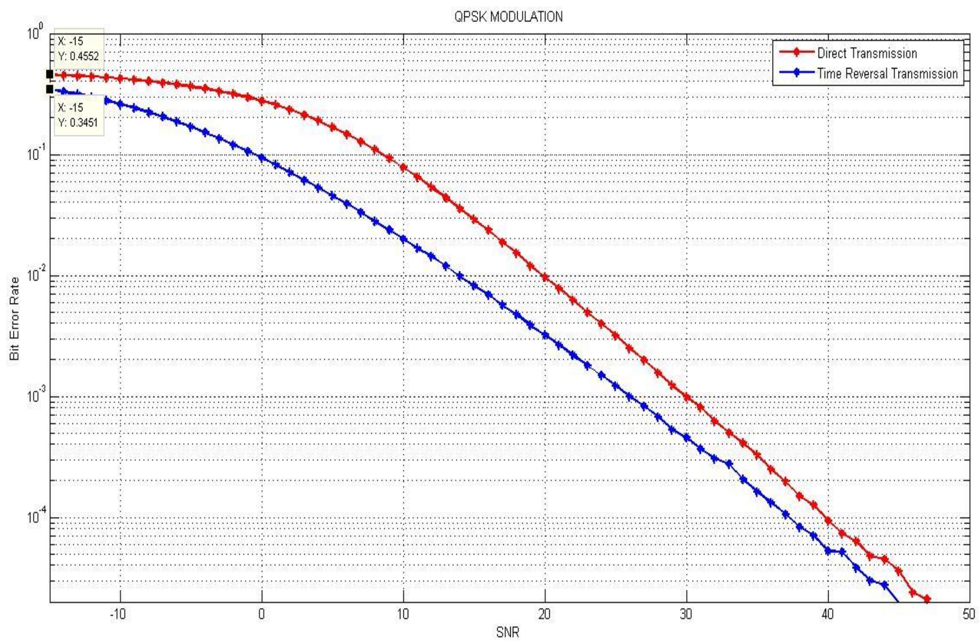


Figure 3.11: QPSK Modulation

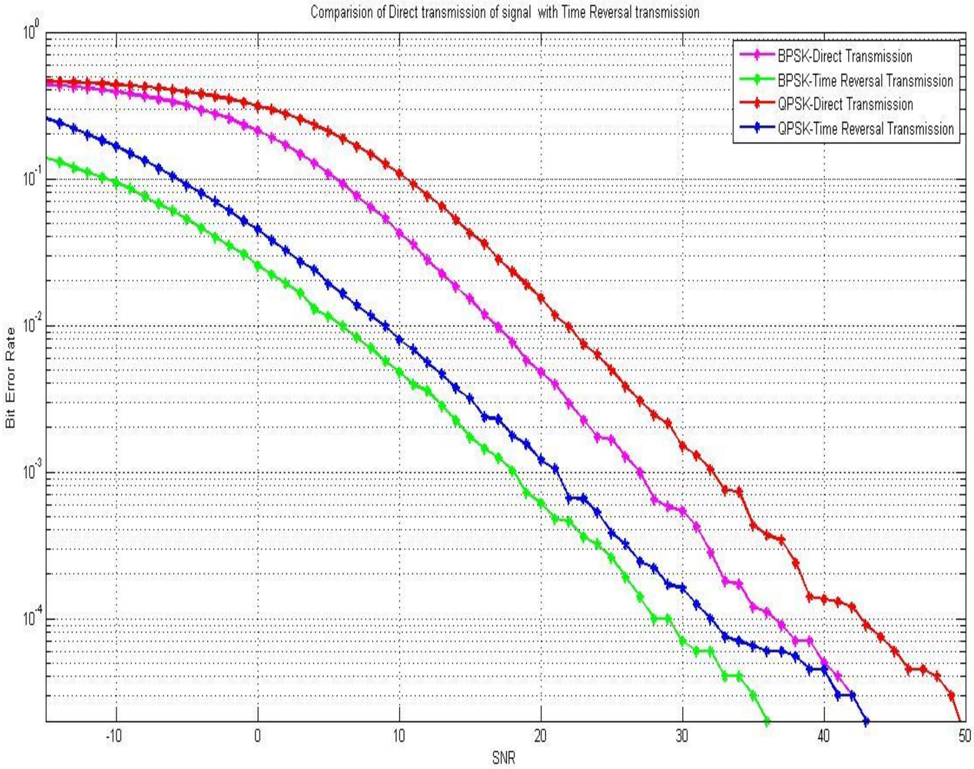


Figure 3.12: Comparison of QPSK and BPSK

CHAPTER 4

Implementation of Time Reversal Division Multiple Access Technique

4

Implementation of Time Reversal Division Multiple Access Technique

4.1 Multiple Access Techniques for wireless Communication

Different multiple access techniques are used to allow large number of mobile users to access the channel simultaneously for transmitting the data. Many users access the channel at the same time, so different techniques are proposed to avoid ISI and maintain the quality of service.

In wireless communication systems, user transmit the information to the base station and receive the information from the base station simultaneously. This is known as duplexing. There are two types of duplexing techniques:

1) Frequency division duplexing (FDD).

2) Time division duplexing (TDD).

4.1.1 Frequency division duplexing

It contains two simplex channels forward and reverse. In FDD two different channel frequencies are allotted to the user. One for transmitting the information from BS to user and the other for receiving data from user to base station. Here different users access the channel at same time with different frequency allocation.

4.1.2 Time division duplexing

It contains single simplex channel that is used for both transmitting and receiving the data at different time instances. Here the users are allocated the same channel. All users are having same frequency but are allotted different time slots for transmitting and receiving the data between base station and user.

4.2 Introduction to Multiple Access

There are three major access techniques for sharing the available channel bandwidth:

1) Time division multiple-access technique (TDMA)
2) Frequency division multiple-access technique (FDMA)
3) Code division multiple-access technique (CDMA)

4.2.1 TDMA

In TDMA, the each user is allocated a time slot for accessing the entire channel bandwidth. All users are having same frequency but are allotted different time slots for transmitting and receiving the data between base station and user. The perfect time synchronization is maintained between users for accessing the channel so as to avoid interference [21].

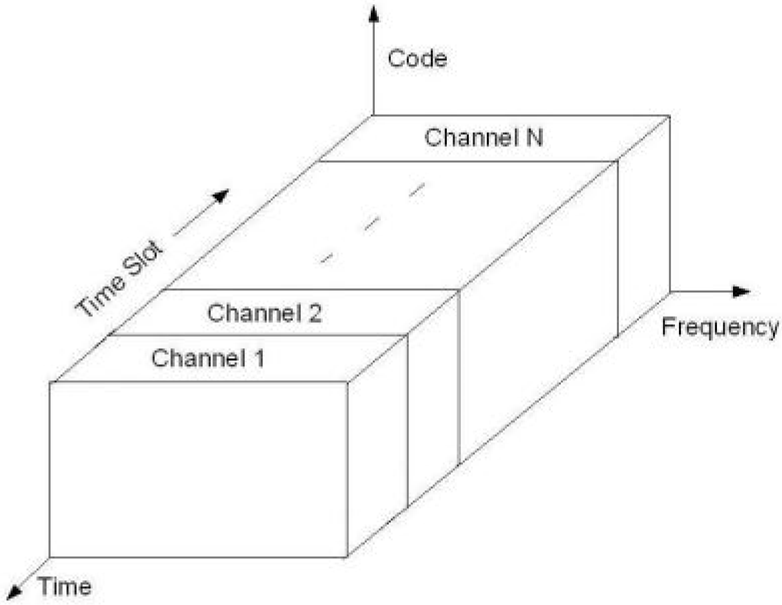


Figure 5: TDMA

4.2.2 FDMA

In FDMA all users share the channel at same time with different frequency allocation. It contains two simplex channels forward and reverse. In FDD two different channel frequencies are allotted to the user. One for transmitting the information from BS to user and the other for receiving data from user to base station. Here different users access the channel at same time with different frequency allocation.

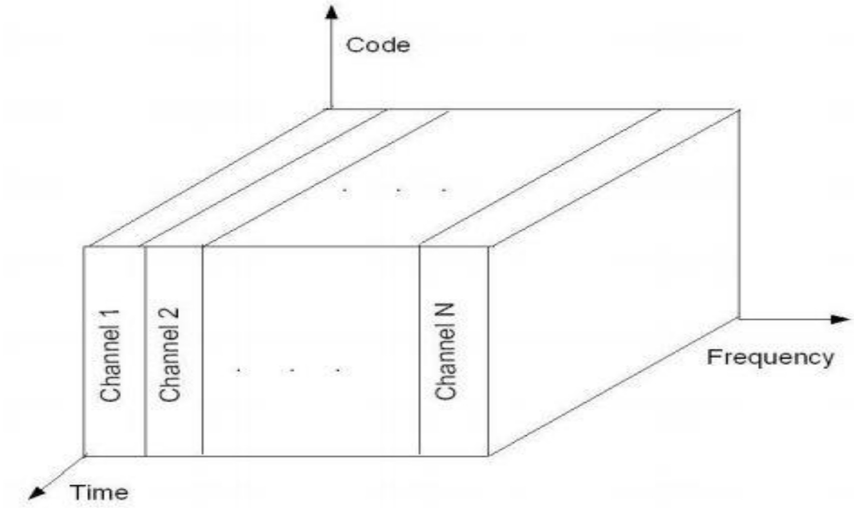


Figure 6: FDMA

4.2.3 CDMA

In CDMA each user is assigned with different code [21]. It utilizes a spread spectrum technique in which a spreading signal (which is uncorrelated to the signal and has a large bandwidth) is used to spread the narrow band message signal [21].

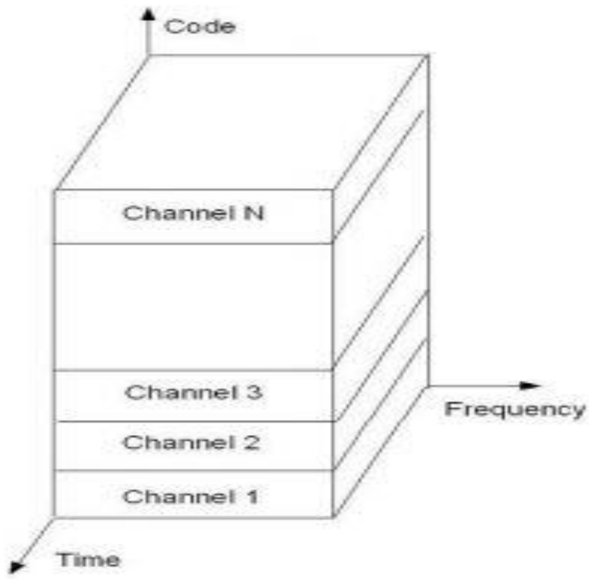


Figure 4.3: CDMA

4.3 Time-Reversal Division Multiple Access

A new wireless channel access method [22],[23] is proposed known as time-reversal division multiple access (TRDMA) by taking advantage [2] of spatial focusing effect for a time-reversal structure for a multi-user downlink system over multi-path channel [2]. TR technique makes full use of a large number of multi-paths and considers [22],[23] each path as a virtual antenna that naturally exists [22] and is widely distributed in environments [2], [22],[23].

TR can achieve very high diversity gain and high-resolution spatial focusing with one single transmit antenna [2]. The spatial focusing effect maps the natural multi-path propagation profile into a unique *location-specific signature* [2] for each link. TRDMA scheme use the uniqueness and independence of location specific signatures in multi-path environment [2], providing a low energy-efficient solution for multi user downlink [2].

4.4 TRDMA System Model for SISO and MISO

TRDMA is the ideal model proposed for multiuser downlink system in multipath Rayleigh fading channel.

4.4.1 Single input- single-output (SISO) scheme

In SISO base station and all the users are equipped with single antenna.. Here we assume that channels are reciprocal and channel impulse response of users are uncorrelated to each other.

Recording Phase

Let us assume, transceiver ‘A’ wants to send the information through a scattering and multi-path environment to transceiver B, then first B has to send an pilot signal (impulse) to the A through the multipath channel. On receiving the reflected waveform, the transceiver ‘A’ records the impulse response of the channel and store the time reversed conjugated version of the received signal [2].

Transmission Phase

Transceiver A, uses the normalized time reversed wave as basic wave form and retransmits it through the same multipath channel. Fig describes the recording phase and transmission phase process. The re-emitted TR waves can retrace the incoming paths due to channel reciprocity. At transceiver B the received signal from multipath channel is the constructive addition of signals from different paths i.e., strong signal is received at desired location known as *spatial focusing effect*. Time Reversal takes the advantage of multipath channel as matched filter which reduces the complexity and focus the signal in time domain which is known as *temporal focusing effect.*

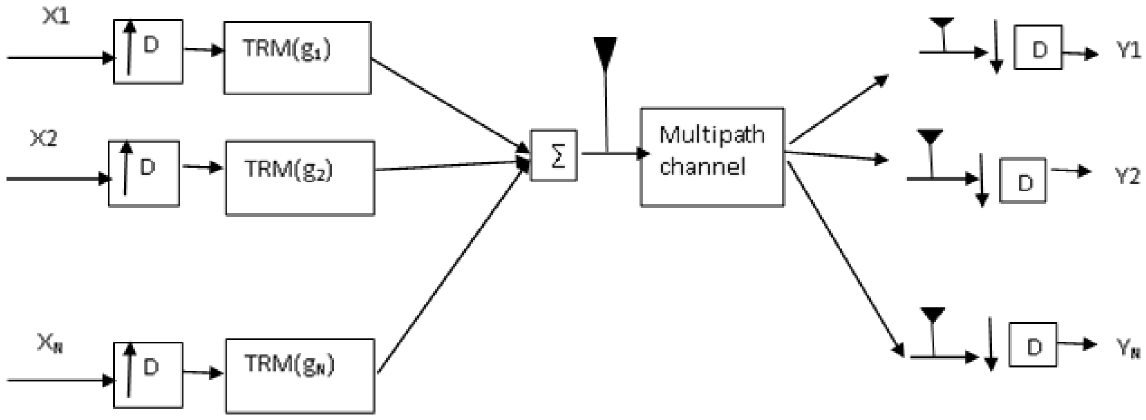


Figure 4.4: SISO TRDMA multiuser downlink system

4.4.2 Multi input- single-output (MISO) scheme

For maintaining low complexity at the receivers MISO case is proposed with M_T antennas at the base station and individual multiple single antennas with users [2] [22]. SISO is the special case of MISO with $M_T = 1$.

The signal received at user *i* is

$$Y_i(k) = \sum_{j=1}^{N} \sum_{m=1}^{M_T} \sum_{l=0}^{(2L-2)/D} \left(h_i^m * g_j^m\right)[Dl]X_j[k-l] + an(k)$$

i,j={1,2,….N users} , k,l={0,1,……L-1}, m={1,2,… M_T }

A modified SNR is defined as

$$\rho = \frac{P}{\sigma^2} E\left[\sum_{l=0}^{L-1} |h_i^m[l]|^2\right] = \frac{P}{\sigma^2} \frac{1-e^{\frac{-LT_S}{\sigma_T}}}{1-e^{\frac{-T_S}{\sigma_T}}}$$

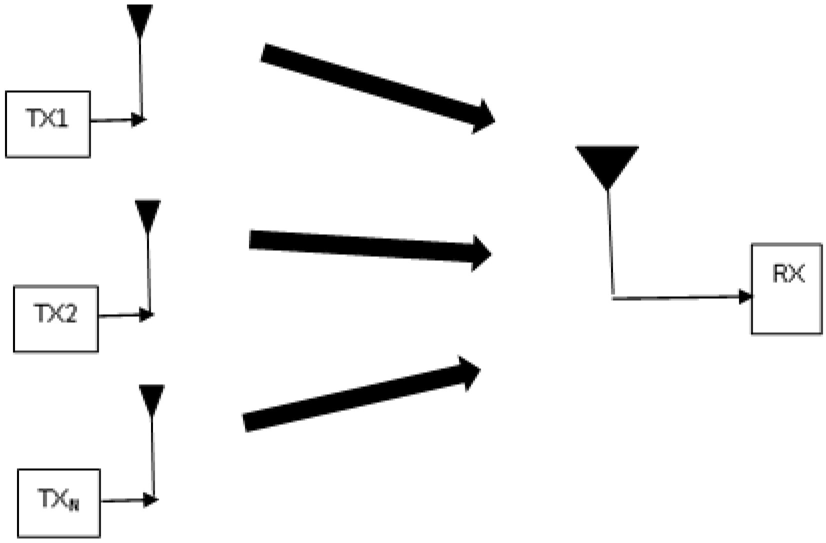


Figure 4.5: MISO TRDMA multiuser downlink system

Effective SINR

SINR is defined as the ratio of signal power to interference and noise power.

$$\textbf{SINR} = \frac{\textbf{Signal Power}}{\textbf{Interference Power} + \textbf{Noise Power}}$$

Here we analyse the signal to interference ratio for the MISO TRDMA multi user downlink system. The average SINR for user i is defines as

$$\mathrm{SINR} = \frac{\mathrm{E}\left[\mathrm{P_{Sig}(i)}\right]}{\mathrm{E}[\mathrm{P_{ISI}(i)}] + \mathrm{E}[\mathrm{P_{IUI}(i)}] + \sigma^2}$$

Where

P_{sig} is the signal power

$$P_{sig}(i) = \theta \left[\left| \sum_{m=1}^{M_T} \left(h_i^m * g_j^m \right)[L-1] \right|^2 \right]$$

P_{ISI} is the interference power

$$P_{ISI}(i) = \theta \left[\sum_{\substack{l=0 \\ l \neq \frac{L-1}{D}}}^{\frac{2L-2}{D}} \left| \sum_{m=1}^{M_T} \left(h_i^m * g_j^m \right)[L-1] \right|^2 \right]$$

P_{ISI} is the inter user interference power

$$P_{IUI}(i) = \theta \sum_{\substack{j=1 \\ j \neq i}}^{N} \left[\sum_{\substack{l=0 \\ l \neq \frac{L-1}{D}}}^{\frac{2L-2}{D}} \left| \sum_{m=1}^{M_T} \left(h_i^m * g_j^m \right)[L-1] \right|^2 \right]$$

where $\theta = E \left[\left| X_i [k - \frac{L-1}{D} \right|^2 \right]$

The average interference power is independent of number of antennas M_T, the signal power increase with number of antenna and Focusing effects of TR improves the effective SINR .

with increase in the backoff factor high quality of reception is achieved which effects the SINR.The signal power does not depend on D and interference power dominates the noise power[2] in high SINR region. Since the interference power is high compared to noise power, we neglect noise power.In high SNR regime, doubling D gives approximately 3dB gain in average effective SINR

Let us consider an example L=257, $\sigma_T = 128T_s$,

CASE1: Impact of number of antennas

Here we show that the average SINR is improved with increase the number of antenna. By doubling the number of antenna almost a 3 dB gain is achieved. Increase in the number of antenna increases the focusing capability there by increasing the signal power compared to interference and noise power.

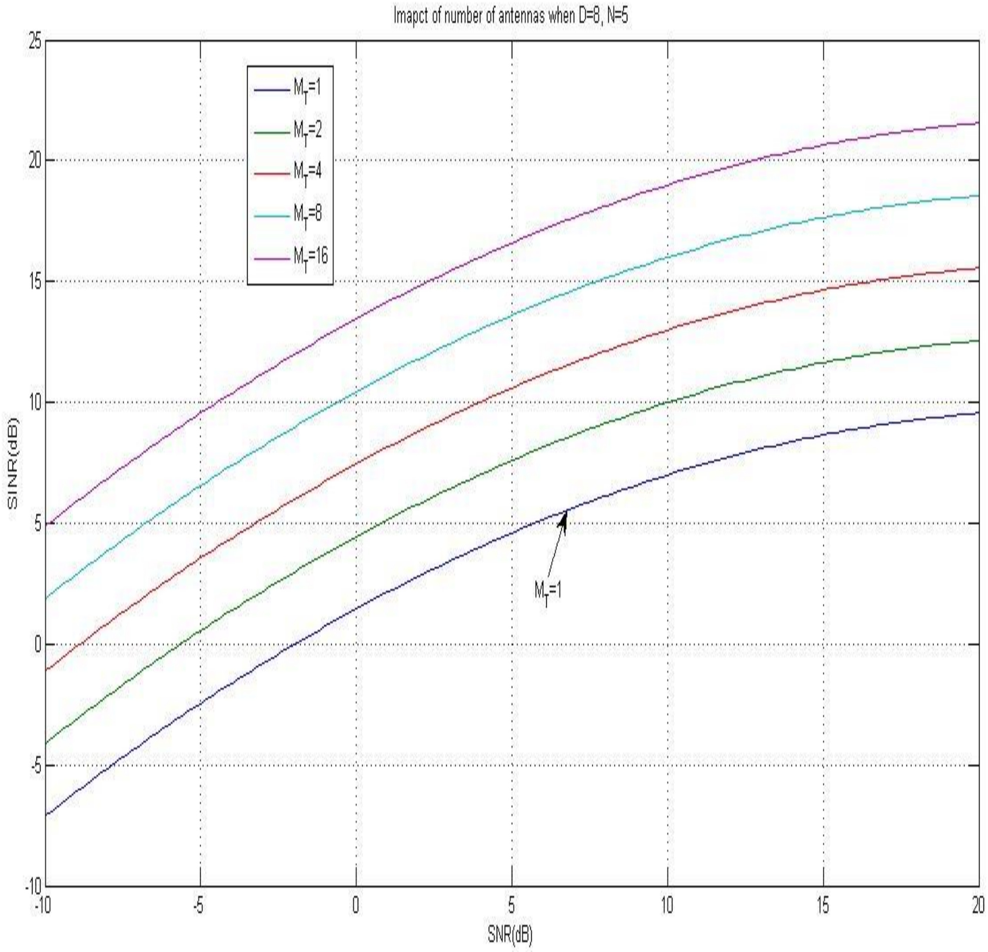


Figure 4.6: Impact of number of antennas D=8,N=5

CASE 2: Impact of Rate back off factor

Larger D can reduce the ISI and IUI while maintaining the signal power[2]. with increase in the backoff factor high quality of reception is achieved which effects the SINR.The signal power does not depend on D and interference power dominates the noise power[2] in high SINR region. Since the interference power is high compared to noise power, we neglect noise power.In high SNR regime, doubling D gives approximately 3dB gain in average effective SINR.

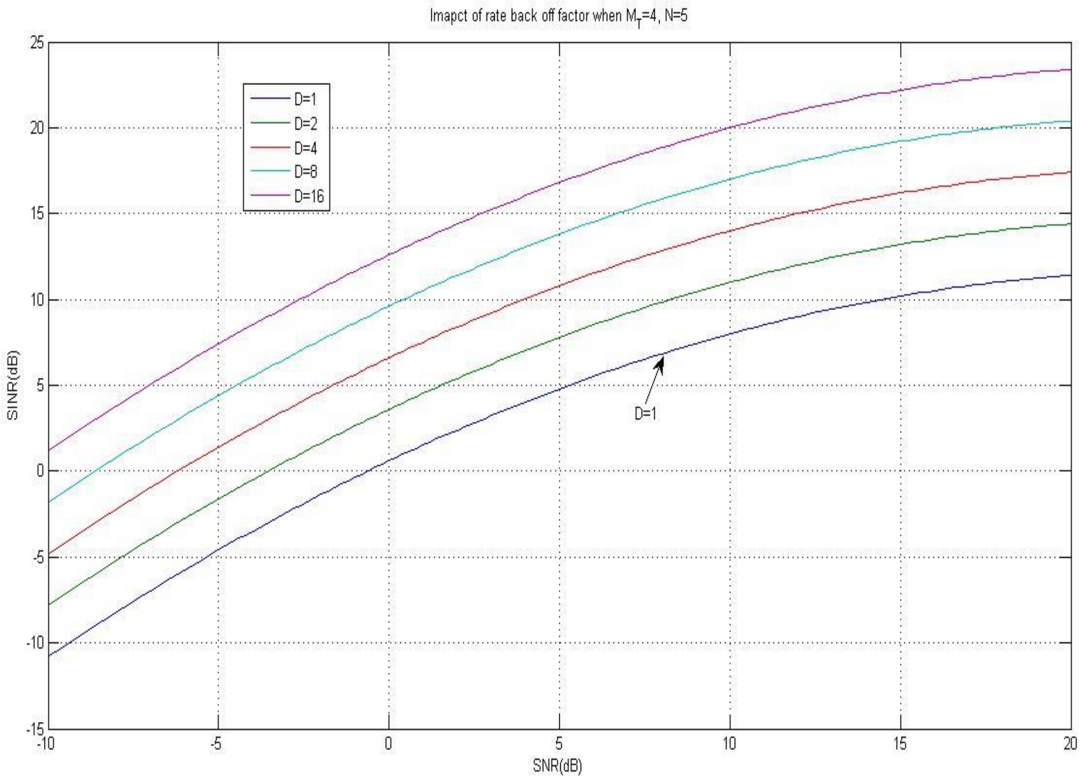


Figure 4.7: Impact of rate back off factor M_T=4, N=5

CASE3: Impact of number of Users

Increase in the number of users will increase the interference resulting in to Inter User Interference (IUI). So there is a trade off between number of users and signal reception quality.

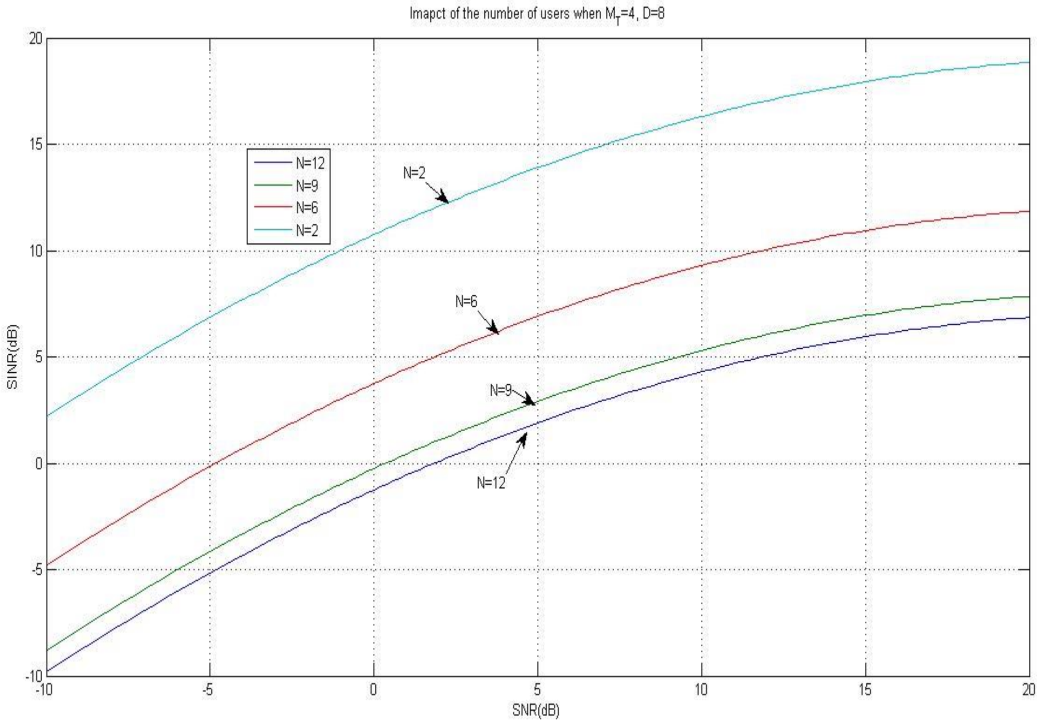


Figure 4.8: Impact of number of users M_T=4,D=8

CHAPTER 5

Conclusion and Future work

5

Conclusion and Future work

5.1 Conclusion

In this thesis we show that time reversal signal processing technique is an energy efficient technique. We have compared time reversal transmission with direct transmission of signal with BPSK and QPSK modulation techniques. We have observed that TR transmission gives less BER for same SNR. We have implemented TRDMA scheme for multi user downlink system and plotted effective SINR vs SNR and following observations are made.

Here we observed that the average SINR is improved with increase the number of antenna. By doubling the number of antenna almost a 3 dB gain is achieved. Increase in the number of antenna increases the focusing capability there by increasing the signal power compared to interference and noise power. Larger D can reduce the ISI and IUI while maintaining the signal power [2]. With increase in the back off factor high quality of reception is achieved which effects the SINR. The signal power does not depend on D and interference power dominates the noise power [2] in high SINR region. Since the interference power is high compared to noise power, we neglect noise power. In high SNR regime, doubling D gives approximately 3dB gain in average effective SINR. Increase in the number of users will increase the interference resulting in to Inter User Interference (IUI). So there is a trade-off between number of users and signal reception quality.

5.2 Limitations of the present work

The present thesis is focused on reduction of transmit power and interference between users in multipath environment. We assume that the channel impulse response of different users are independent and the cross correlation between them is zero. But practically cross correlation cannot be zero and there exist co-channel interference between the users.

5.3 Future work

This technique gives less ISI and IUI which conserves the transmission power in rich scattering multi path environment. So practical testing and hardware implementation of Time Reversal signal processing technique should be done.

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