Improvement of Security in Communication System Using Time Reversal Division Multiple Access

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Abstract: ***In broad-band communications, wide ranges of frequencies are available allowing more information to be transmitted in a given amount of time. The multi-path effect makes high speed broad-band communication a very challenging task due to the severe inter-symbol interference (ISI). To resolve this problem, multicarrier modulations are needed at the receiver to alleviate the ISI. A novel concept of time-reversal division multiple access (TRDMA) has been introduced as a wireless channel access method based on its high-resolution spatial focusing effect. Time reversal signal processing is a technique for focusing waves. This paper aims to develop a multi-user downlink system with both the single-input single-output (SISO) antenna scheme and its enhanced version with multiple-input single-output (MISO) antenna scheme and the system (MISO) performance are investigated in terms of its effective signal-to-interference-plus-noise ratio (SINR), the achievable sum rate and the achievable rates with outage. In this work, simulation of TRDMA multiuser downlink system with both single and multiple transmit antennas (SISO and MISO case) were performed. The effective SINR (by varying number of multiple antennas), achievable sum rate and achievable rate with outage for MISO case were also simulated. The simulation results confirmed that satisfying performances are achieved which makes TRDMA a promising candidate for future low complexity broad band wireless communications.***

Keywords: Time reversal, TRDMA, spatial focusing, temporal focusing

1. Introduction

Communication is the process of transmission of information from one point to another through a guided or unguided medium. The term wireless is used to describe all types of devices and technologies that use open space as signal propagating medium [8]. It is the fastest communication refers to technologies that transmit data growing segment of the communications industry. In the present world, wireless communication system has got many applications such as GPS units, garage door openers, wireless computer networks, cordless telephones, etc. All the advancements in this field are to achieve two important goals namely reliability and efficiency. Time reversal signal processing is a technique for focusing waves. Time Reversal Mirror focus waves using time reversal method. TRM transmits a plane wave towards the target and is reflected off it. The reflected wave returns to TRM, where it looks as if target has emitted a weak signal. TRM reverses and retransmits the signal as usual and a more focused wave travels towards the target. As process is repeated, waves become more and more focused on target. In time reversal signal processing, one need not know any details about the channel. The step of sending the wave through the channel effectively measures it and retransmission step uses this data to focus the wave. Thus we only need to know that the channel is reciprocal. The single-user TR wireless communications consist of two phases: the recording phase and the transmission phase. When transceiver A wants to transmit information to transceiver B, transceiver B first sends an impulse that propagates through a scattering multi-path environment and the multi-path signals are received and recorded by transceiver A; then, transceiver A simply transmits the time-reversed (and conjugated) waves back through the communication link to transceiver B. By utilizing channel reciprocity, the TR waves can retrace the incoming paths, ending up with a “spiky” signal-power spatial distribution focused only at the intended location, as commonly referred to as spatial focusing effect [2]-[4]. Also, from a signal processing point of view, in single-user communications, TR essentially leverages the multi-path channel as a facilitating matched filter computing machine for the intended receiver, and concentrates the signal energy in the time domain as well, as commonly referred to as temporal focusing effect. [9]-[11].Time reversal division multiple access is a wireless channel access method by taking advantage of the high-resolution spatial focusing effect of time-reversal structure. Time-reversal technique makes full use of a large number of multi-paths and in essence treats each path as a virtual antenna that naturally exists and is widely distributed in environments. Thus with even just one single transmit antenna, time reversal can potentially achieve a very high diversity gain and high-resolution “pin-point” spatial focusing. The high- resolution spatial focusing effect maps the natural multi-path propagation profile into a unique location-specific signature for each link, similar to the artificial “orthogonal random code” in a code-division system. The TRDMA scheme exploits the uniqueness and independence of location-specific signatures in multi-path environment, providing a novel low-cost energy-efficient solution. The TRDMA scheme accomplishes much higher spatial-resolution focusing/selectivity and time-domain signal-energy compression [3] at once, without requiring further equalization at the receiver as the antenna-array based beam-forming does.

1.1 Objectives

The main objective of this project is to structure a multi-user downlink system for future energy-efficient low-complexity broadband wireless communications. Motivated by the high-resolution spatial focusing potential of the time-reversal structure, several major developments have been proposed and considered in the proposed TRDMA multi-user communication system. Specifically:

(i) Introduce TRDMA multi-user downlink system with single transmit antennae (SISO case).
(ii) Introduce TRDMA multi-user downlink system with multiple transmit antennae (MISO case).
(iii) Evaluate SINR, achievable sum rate and achievable rate with outage for MISO TRDMA system.

2. Related Works

Wireless communication is a rapidly growing segment of the communication industry, with the potential to provide high-speed high-quality information exchange between portable devices located anywhere in the world. Potential applications enabled by this technology include multimedia Internet-enabled cell phones, automated highway systems, video teleconferencing and distance learning, and autonomous sensor networks, to name just a few. However, supporting these applications using wireless techniques poses a significant technical challenge.

2.1 Wireless Channel Access Methods

A limited amount of bandwidth is allocated for wireless services. A wireless system is required to accommodate as many users as possible by effectively sharing the limited bandwidth. Therefore in the field of communication, the term multiple access could be defined as a means of allowing multiple users to simultaneously share the finite bandwidth with least possible degradation in the performance of the system. There are several techniques how multiple accessing can be achieved.

2.2 Frequency Division Multiple Access (FDMA)

In FDMA, each user is assigned or allocated one or several frequency bands. FDMA is the earliest multiple-access techniques when continuous transmission is required for analog services. In this technique, each user transmits and receives at different frequencies as each user gets a unique frequency band as illustrated in figure 2.1. FDMA channels are usually implemented in narrowband systems.

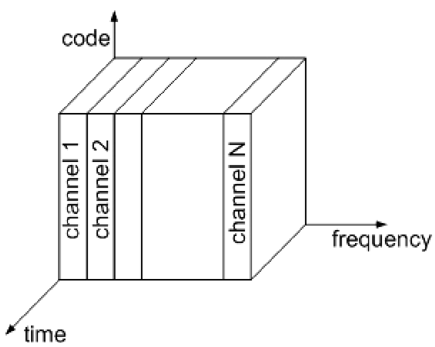

Figure 2.1: FDMA

2.3 Time Division Multiple Access (TDMA)

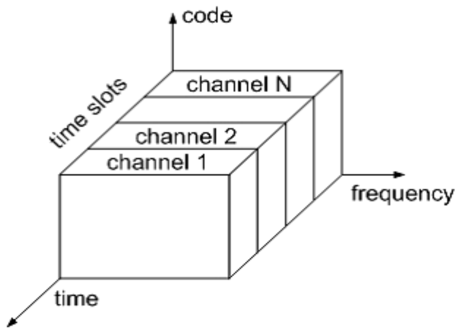

Figure 2.2: TDMA

TDMA permits the users to operate on same frequency. This method schedules the users at different time periods. In most cases the available bandwidth is divided into fewer channels and the users are allotted different time slots during which they can access the entire channel bandwidth at their disposal. This is illustrated in figure 2.2. TDMA provides no interference from other simultaneous transmission and are easily adapted for data transmission and voice communication.

2.3 Code division multiple access (CDMA)

CDMA is a multiple access technique where several users can send information simultaneously over a common communication channel. This method allows the users to share a band of frequencies; however they are all assigned separate codes, which differentiate them from each other as shown in figure 2.3. CDMA systems employ a spread spectrum technique in which a signal is transmitted on a larger bandwidth than the frequency of original information.

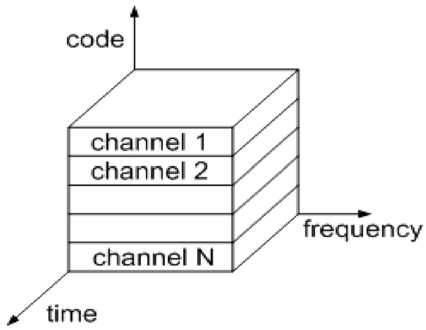

Figure 2.3: CDMA

2.4 Space division multiple access (SDMA)

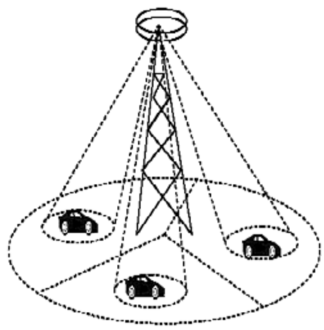

Figure 2.4: SDMA

SDMA utilizes the spatial separation of the users so as to optimize the use of the frequency spectrum. In SDMA, same frequencies are re-used in different cells in a wireless network. Figure 2.6shows three users served by SDMA using the same frequency channel within the cell. SDMA creates parallel spatial pipes next to the pipes having higher capacity. SDMA provides superior performance and provides no co-channel interference.

2.5 Orthogonal frequency division multiple access (OFDMA)

Orthogonal Frequency-Division Multiple Access is an enhanced or multi-user version of the orthogonal frequency division multiplexing digital modulation scheme. Multiple access is achieved by assigning subsets of subcarriers to individual users. The subcarriers in each OFDM symbol are orthogonal to each other and users are dynamically assigned to subcarriers.

3. System Architecture

The multi-path effect makes high speed broadband communications a very challenging task due to the severe ISI. Earlier access methods do not ensure secure communications. By concentrating energy in both the spatial and temporal domains, TR transmission technique provides a great potential of low-complexity energy-efficient communication**.** The main goal of this work is to structure a multi-user downlink system for future low complexity secure broad band wireless communication.

3.1 Block diagram of the system

Figure 3.1.1 and 3.1.2 provides a block diagram representation for the entire transmission and reception system. Three scenarios are presented: simulation of SISO TRDMA multiuser downlink system, simulation of MISO TRDMA multiuser downlink system and evaluation of SINR (signal to interference plus noise ratio), achievable sum rate and outage rate for MISO case. BER rate performances of both the system are evaluated. Block diagram of SISO TRDMA is shown in figure 3.1.1 and MISO TRDMA is shown in figure 3.1.2.

In this work, a multiuser downlink system over multipath random channel are considered and proposed the concept of TRDMA as a wireless channel access method by taking advantage of the high-resolution spatial focusing effect of time-reversal structure. Time reversal wireless communication has two phases: recording phase and transmission phase [5].

3.2 Recording phase

In the TRDMA multiuser downlink system, there are multiple users receiving statistically independent messages from the BS. TRM shown in the figure.3.1.1 and 3.1.2 is a device that can record and time-reverse the received waveform, which will be used to modulate the time-reversed waveform with input signal by convolving them together in the following transmission phase. During the recoding phase, the multiple intended user's first take turns to transmit an impulse signal to the base station. Meanwhile, the TRMs at the BS record the channel response of each link and store the time-reversed and conjugated version of each channel response for the transmission phase. The waveform recorded by the TRM reflects the true channel impulse response [1].

3.3 Transmission Phase

After the channel recording phase, the system starts its transmission phase. In the transmission phase, the input sequences are fed into the TRM and convolved with CIR. The outputs of TRM bank are added together, and then the combined signals are transmitted into wireless channels. 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 signal received at user is the convolution of transmitted signal and channel impulse response. The receiver simply performs a one-tap gain adjustment to the received signal to recover the signal. To maintain low complexity at receivers, we consider a MISO case where the transmitting BS is equipped with multiple antennas together with multiple single-antenna users. For the MISO TRDMA scheme, each antenna at the BS plays a role similar to the single-antenna BS in the basic scheme. The block diagram of MISO TRDMA system is shown in the figure.3.1.2

3.4 Time Reversal mirror

Time Reversal Signal Processing is a technique for focusing waves. A Time Reversal Mirror is a device that can focus waves using the time reversal method [4] [10]. The TRM transmits a plane wave which travels toward the target and is reflected off it. The reflected wave returns to the TRM, where it looks as if the target has emitted a (weak) signal. The TRM reverses and retransmits the signal as usual, and a more focused wave travels toward the target. As the process is repeated, the waves become more and more focused on the target.

An attractive aspect of time reversal signal processing is the fact that it makes use of multipath propagation. Many wireless communication systems must compensate and correct for multipath effects. Time reversal techniques use multipath to their advantage by using the energy from all paths.

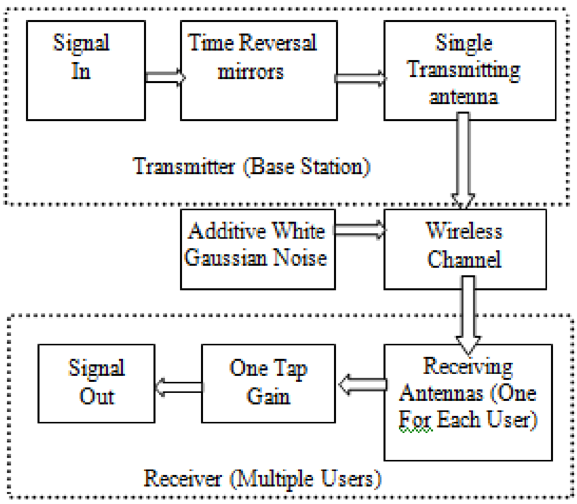

Figure 3.1.1: SISO TRDMA multiuser downlink system

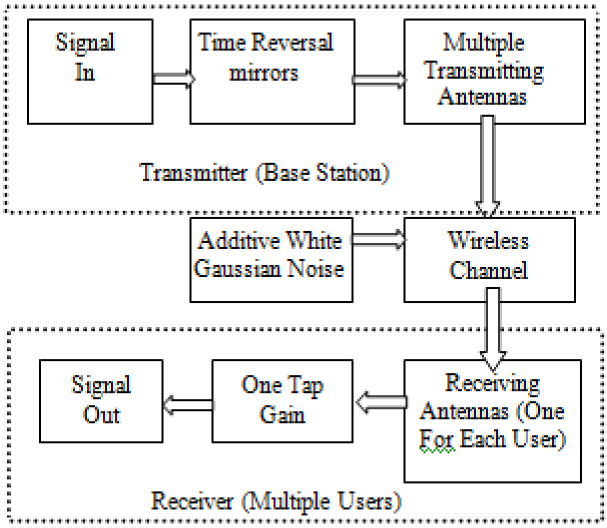

Figure 3.1.2: MISO TRDMA multiuser downlink system

3.5 Effective SINR

In this part, the effective SINR [6] at each user in this multi-user network are investigated. The average effective SINR at user i can be defined as the ratio of the average signal power to the average interference-and-noise power, i.e.

$$\mathrm{SINR}(i) = \frac{E[P_{SIG}(i)]}{E[P_{ISI}(i)]+E[P_{IUI}(i)]+\sigma^2} \quad (3.1)$$

where; $P_{SIG}(i) = \left|\sum_{m=1}^{M_T}(h_i^m * g_i^m)[L]\right|^2$ is the signal power

$P_{ISI}(i) = \sum_{l=0}^{(2L-2)/D}\left|\sum_{m=1}^{M_T}(h_i^m * g_i^m)[Dl]\right|^2$ is the power associated with inter-symbolinterference

$P_{IUI}(i) = \sum_{j=1, j\neq i}^{N}\sum_{l=0}^{(2L-2)/D}\left|\sum_{m=1}^{M_T}(h_i^m * g_j^m)[Dl]\right|^2$ is the power associated with inter-user interference

σ^2= background noise
D = rate back off factor (ratio of sampling rate to baud rate)
L = length of the channel
h_i^m =time reversed channel impulse response
g_i^m= signal transmitted

3.6 Achievable Sum Rate

The transmission rate or achievable sum rate measures the total amount of information that can be effectively delivered during transmission. The achievable sum rate for N users is a good reference of the long-term performance and can be calculated by;

$$R = \frac{\eta}{D}\sum_{i=1}^{N}\log(1+\mathrm{SINR}(i)) \quad (3.2)$$

Where η = discount factor that describes the portion of transmission phase.

3.7 Achievable Rate with Outage

The concept of outage rate [3] [7], allows bits sent over random channels to be decoded with some probability of errors namely the outage probability. If the achievable rate of user i, as a random variable, is less than the given transmission rate R, the system is said to be at outage. Outage probability can be calculated as;

$$P_{out} = P_r\left\{\frac{1}{N*D}\sum_{i=1}^{N}\log(1+\mathrm{SINR}(i)) < R\right\} \quad (3.3)$$

where P_{out}= outage probability
N = number of users

4. Simulation Tools

MATLAB (matrix laboratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and Fortran. In this project, MATLAB R2011a version is used.

Table 4.1: Simulation parameters

Modulation	BPSK
No: of Transmitting antennas	2,6
No: of Receiving antennas	1 for each user
Data length	400
Transmission modes	Spatial Multiplexing

5. Results and Discussion

As a part of this project, the bit error rate performance of TRDMA multiuser downlink system with both single and multiple transmit antennas was simulated. Also the effective SINR, achievable sum rate and outage rate for MISO case was also simulated.

5.1 Bit error rate for SISO case

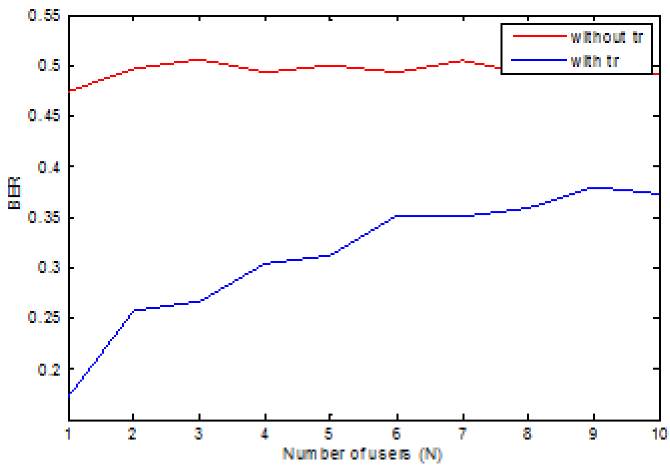

Figure 5.1: Bit Error Rate for SISO case

Figure.5.1 shows that the BER of data with time reversal is less than the data without time reversal.

5.2 Bit Error Rate for MISO case

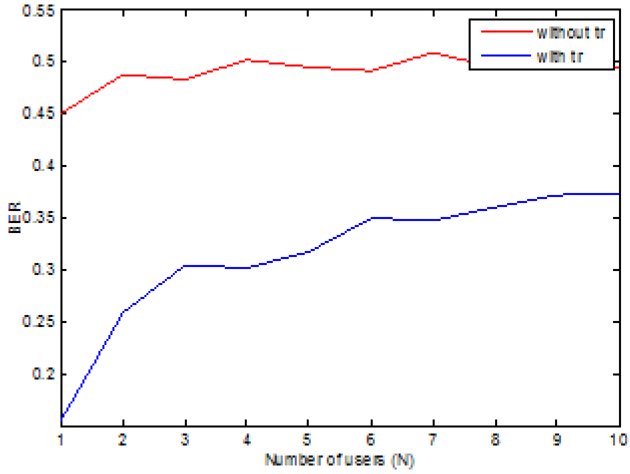

Figure 5.2: Bit Error Rate for MISO case

Figure 5.2 shows that the BER of data with time reversal is less than the data without time reversal.

5.3 SINR vs. SNR for MISO case (MT as a parameter)

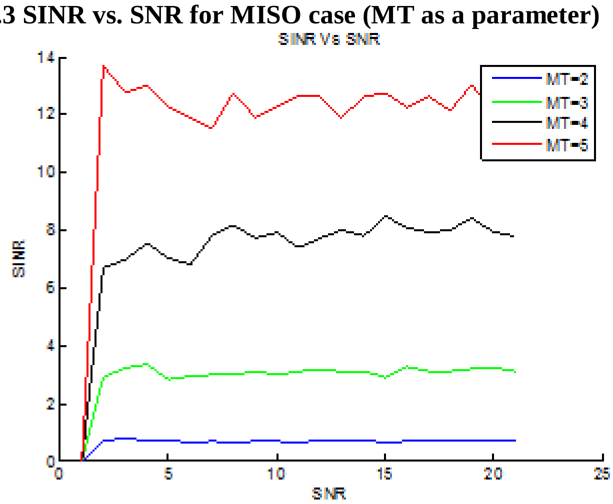

Figure 5.3: SINR vs. SNR with MT (number of multiple antennas) as parameter

As MT (number of multiple antennas) increases, SINR also increases, since signal strength increases with increase in number of antennas.

5.4 Achievable sum rate for MISO

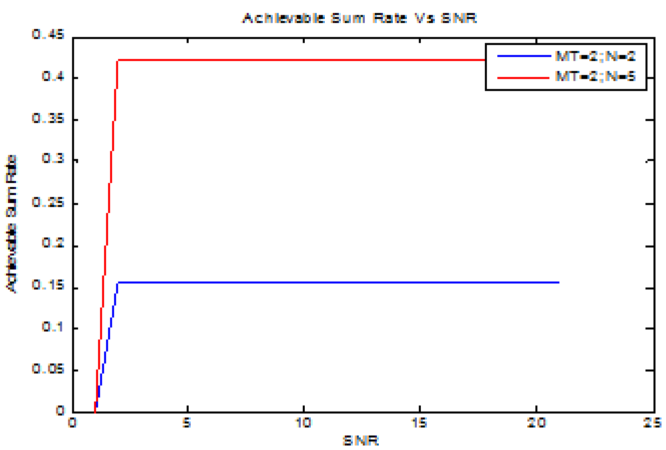

Figure 5.4: Achievable sum rate vs. SNR

Figure 5.4 shows Achievable sum rate vs. SNR for MISO case keeping number of transmitting antennas a constant and varying the number of users (N). As the number of users increases, achievable sum rate increases.

5.5 Outage rate for MISO

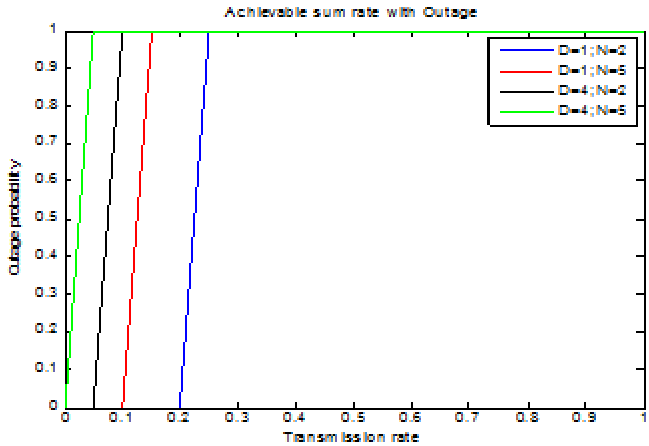

Figure 5.5: Achievable rate with Outage

Figure.5.5 shows Outage probability vs. transmission rate. A larger N reduces the individual achievable rate with same outage probability due to severe inter-user interference. A larger D also results in reduced individual achievable rate of the user as it lowers the symbol rate of the transmitter.

6. Conclusion

TRDMA is a wireless channel access method by taking advantage of the high-resolution spatial focusing effect of time-reversal structure. TR signal transmission technique can provide a great potential of low-complexity energy-efficient communications, which can make full use of the nature of multi-path environments. In this work, simulation of TRDMA multiuser downlink system with both single and multiple transmit antennas (SISO and MISO case) was performed. The effective SINR, achievable sum rate and achievable rate with outage probability for MISO case was also simulated. The simulation results confirm that the BER performance of time reversed data is less than the data without time reversal, the effective SINR increases with increase in number of multiple antennas and achievable sum rate increases with number of users. The simulation results also confirmed that the probability of a system that moves to outage occurs rapidly with increase in number of users and rate back-off factor.

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