Performance Analysis using Time Reversal Division Multiple Access

Vidya .S, Manju Rani

Abstract*— *Inter-symbol-Interference (ISI) caused by multipath propagation has made high speed broadband communication a backbreaking task. Time reversal transmission method makes use of the behaviour of multipath environment by converging energy in the temporal and spatial domains. In this paper, a wireless channel access method named time reversal division multiple access (TRDMA) is being proposed. The system performances with multiple-transmit-antenna scheme using TRDMA is investigated in terms of the bit-error-rate, the effective signal-to-interference-plus-noise-ratio, the achievable sum rate and the outage probability. Also, the bit error rate improvement over code division multiple access method (CDMA) is also evaluated. Satisfying simulation results are obtained using the multiuser downlink systems of the proposed method which makes it a high speed broadband wireless communication method in the future.

Index Terms*— *Time reversal, TRDMA, temporal focussing, spatial focusing

I. INTRODUCTION

High speed broadband communication in a rich scattering environment is impaired by severe inter-symbol-interference and thus making it less reliable. Though it can be resolved using OFDM or complex equalization methods it often increases the complexity of end user equipments in many applications. One of the important ability of a communication system is to exploit independent channels of propagation while data is sent through a disordered medium. In the case of radio signals, multiple paths arise because of scattering and multiple reverberations on the buildings or indoors. Time reversal signal transmission exploits the multipath propagation and thereby provides a great potential for low-complexity energy efficient communications. Time reversal signal processing is used for focussing waves in which a signal is first radiated through a rich scattering medium. The signal which is scattered back is then recorded, time reversed, and retransmitted. The history of time reversal technology dates from the early 1990's .The TR technology was used first in the optical domains and then in underwater propagation environments [6]-[8]. It was later validated in Ultra-Wideband systems. It was also verified as an ideal paradigm for green wireless communication. A green wireless technology ensures low energy consumption and low radio pollution to others than the intended user [9] - [16].

The time reversal technique is based on the channel reciprocity.The single user wireless communication consists of two phases: *recording phase* and *transmission phase*. If transceiver A needs to transmit data to transceiver B, an impulse is sent by transceiver B which travels through a scattering multi-path environment and the multi-path signals are received and recorded by the time reversal mirrors of transceiver A. Transceiver A transmits the time-reversed and conjugated waves back through the communication link to transceiver B. The TR waves retraces the incoming paths by using channel reciprocity and ends up in a "spiky" signal power spatial distribution focused only at the intended receiver, which is referred to as *spatial focusing effect* [5] [12].Time reversal technology uses multipath channel as a matched filter computing machine for the meant receiver and concentrates energy of the signal in the time domain also, referred to as temporal focussing effect. Because of temporal focussing effect, received power is concentrated within few taps and equalizer design tasks become simpler. Sharpened matched filter response will reduce ISI if length of multipath pulse train is large and thus utilizes the rich multipath instead of treating it as nuisance.

Time reversal technique achieves a high diversity gain and high-resolution "pin-point" spatial focusing effect which maps the multi-path propagation profiles into unique and independent location-specific signatures in the multipath environment. The concept of TRDMA proposed in this paper is supported by several important recent works [14]–[17]. Solid simulation results concerning bit-error-ratio (BER) clearly shows the practicality of applying TR to data streams that are spatially multiplexed. In a complex environment the signal received will have undergone many multiple reflections, scattering and refractions. Received signal will be the sum of multiple attenuated and also time delayed versions of the original signal. When the received signal is time-reversed and retransmitted, the time-delayed components radiate through the same channel and converge on the original location of the source. This convergence occurs both in space and time. In this paper Time-Reversal structure is used in multi-user downlink system over multipath channels, where signals of multiple users are separated by Time Reversal Division Multiple Access (TRDMA) and evaluate a number of performance metrics such as the effective SINR, the achievable sum rate, the outage probability and the bit error rate. We also further investigate the bit error rate improvement over CDMA in Rayleigh multipath fading channels.

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II. CHANNEL MODEL

A. System Model

We consider multi-user downlink network over multipath fading channels. First, we look at the SISO case in which the users and the base station transmit using single antenna. $h_i[k]$ denote the channel impulse response (CIR) of the link between the Base Station (BS) and the i-th user with channel length L.It is assumed that the CIRs of different users are uncorrelated. This assumption can very much simplify the analysis, even though CIRs might not be perfectly uncorrelated. Real-life experimental results in [5], [12] showed that in a highly scattered environment when two locations are just several wavelengths apart, the correlation between CIRs corresponding to different locations reduces to a level that is neglectable. Each duty cycle has transmission phase and recording phase which occupy $(1-\eta)$ and η of the cycle period with value of η between 0 and 1.

B. Recording Phase

In the recording phase, by taking turns N users transmit an impulse signal to the BS (it can be a Dirac $\delta-$function). At the BS, TRM's record each link's channel response and store the time-reversed (and conjugated) form for the transmission phase. In our analysis we assume that the waveform recorded by TRMs at the transmission side reflects the true CIR, ignoring the small degradation caused by thermal noise and quantization noise. Fig.1 shows the block diagram of SISO TRDMA multiuser downlink system. The time-reversal mirrors shown in the block diagram can be arrays of transducers which are used to focus the signal. At first, TRM transmits a plane wave which travels through the channel towards the intended user and is reflected back. The reflected waveform returns to the TRM, where it looks as if the user has emitted a (weak) signal. The signal is reversed and retransmitted by TRM and a more focused wave travels toward the target or the intended user.

C. Transmission Phase

The system starts the transmission phase after the recording phase. The information symbols transmitted are random variables. The information sequences are then fed to

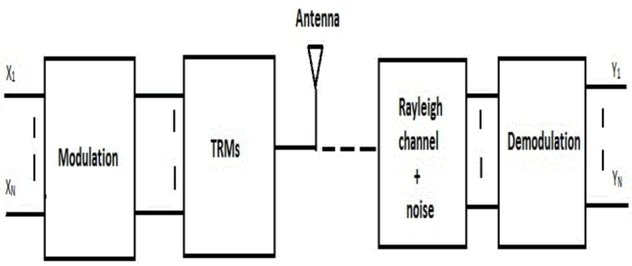

Fig.1 The block diagram of SISO TRDMA system

TRMs and the output of the i-th TRM, g_i is the convolution of i-th up sampled sequence ($X_i[k]$) and the TR waveform $(g_i[k])$ where the TR wave is expressed as

$$g_i[k] = h_i^*[L-1-k] \quad (1)$$

Then, all outputs of the TRM bank are summed together and the combined signal is transmitted through the wireless channel with

$$S[k] = \sum_{i=1}^{N} (X_i * g_i)[k] \quad (2)$$

By convolving, TRM embeds the location specific signature corresponding to each communication link into the signal transmitted for the intended user. At user i, the signal received can be expressed as

$$Y_i[k] = \sum_{j=1}^{N} (X_i * g_i * h_i)[k] + n_i[k] \quad (3)$$

where $n_i[k]$ is the additive white Gaussian noise. At the i-th receiver, the received signal consists of signal, inter-signal-interference and inter-user-interference.

D. TRDMA with Multiple Transmit Antennas

In order to maintain low complexity at the receiver side, we consider a MISO case where the BS at the transmission side is equipped with M_T antennas together with multiple single-antenna users. Fig.2 shows the block diagram of the MISO TRDMA scheme.

Let $h_i^{(m)}(k)$ denote the k-th tap of the CIR for the communication link between user i and the m-th antenna of the BS.We also assume that uncorrelated paths are associated with the different antennas. Each antenna at the BS in the MISO TRDMA scheme and the single antenna BS plays similar role.

In the following sections we evaluate a number of system performances such as the effective SINR, the achievable sum rate, the outage probability and the bit error rate. We also evaluate the bit error rate improvement of the proposed system over CDMA.

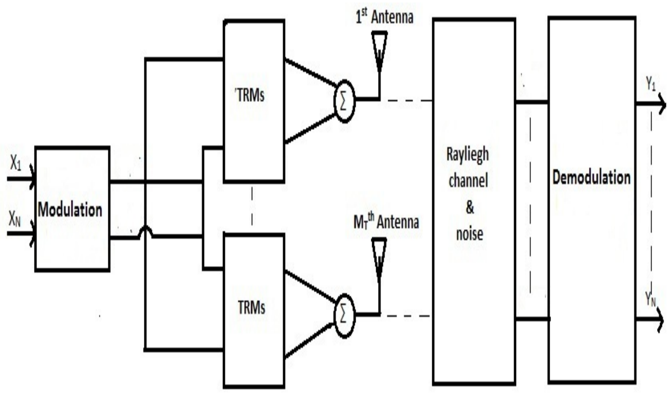

Fig. 2 The block diagram of MISO TRDMA system

III. EFFECTIVE SINR

The effective SINR of the proposed system is evaluated in the section.$Y_i[k]$ received can be categorized into signal, inter-symbol interference (ISI), noise and inter-user interference (IUI). We can calculate the signal power as

$$P_{sig}(i) = E\left[\left|\sum_{m=1}^{M_T}(h_i^{(m)} * g_i^{(m)})[L-1]\right|^2\right] \quad (4)$$

where E[.] represents expectation .D is the ratio of sampling rate to baud rate. The ISI and IUI powers can be obtained as follows.

$$P_{ISI}(i) = E\left[\sum_{\substack{l=0 \\ l=\frac{L-1}{D}}}^{\frac{2L-2}{D}}\left|\sum_{m=1}^{M_T}(h_i^{(m)} * g_i^{(m)}[Dl]\right|^2\right] \quad (5)$$

$$P_{IUI}(i) = E\left[\sum_{\substack{j=1 \\ j\neq i}}^{N}\sum_{l=0}^{\frac{2L-2}{D}}\left|\sum_{m=1}^{M_T}(h_i^{(m)} * g_i^{(m)})[Dl]\right|^2\right] (6)$$

SINR is a performance metric used to measure the range to which the signal is corrupted. At user i, the average effective SINR can be defined as

$$SINR_{avg}(i) = E\left[\frac{P_{sig}(i)}{P_{ISI}(i) + P_{IUI} + \sigma^2}\right] \quad (7)$$

where σ^2 is the background noise. Next we evaluate the average effective SINR versus SNR (signal-to-noise-ratio) in terms of N and M_T .Fig. 3 is plotted with N = 4 and D=2 demonstrating the impact of the number of antennas M_T to the effective SINR.From eqn.(4)-(6),one can see that average interference powers(ISI and IUI) do not depend on M_T, whereas power level of the signal increases with M_T.This is due to the enhanced focusing effect with the use of multiple transmit antennas leveraging the multipaths.This focusing effect helps in improving the average effective SINR.

IV. ACHIEVABLE SUM RATE

In this section, we evaluate the achievable rate for the TRDMA multi-user network. The achievable sum rate is an important metric of the efficiency of a wireless downlink scheme. It measures the total amount of information which can be delivered effectively.

The average achievable sum rate is a good reference of the long-term performance which can be calculated by

$$R_{avg} = E[\frac{\eta}{D}\sum_{i=1}^{N} log_2(1 + SINR(i))] \quad (8)$$

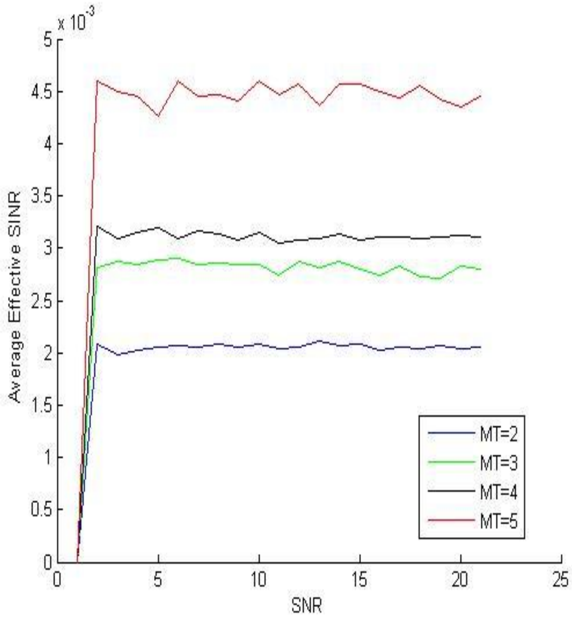

Fig.3 The impact of number of antennas on effective SINR

Without loss of generality, we use $\eta \approx 1$, ignoring the overhead caused by recording phase in each duty cycle, which is valid when the fading channels are not varying fast.

Fig.4. plots the average achievable sum rate with different transmit antennas with D=2 and N=4. From fig.4 one can see that the sum rate increases with the number of antennas due to the enhanced spatial focussing effect obtained.

Fig.5 shows average achievable sum rate achieved with different users when D =2 and M_T=4. From fig.5 it's clear that a larger N gives rise to a larger achievable sum rate. As N increases the concurrent data streams increases but due to stronger interference between users, individual achievable rate of each user degrades. But this degradation comes inside the logarithm function and so results in higher sum rate.

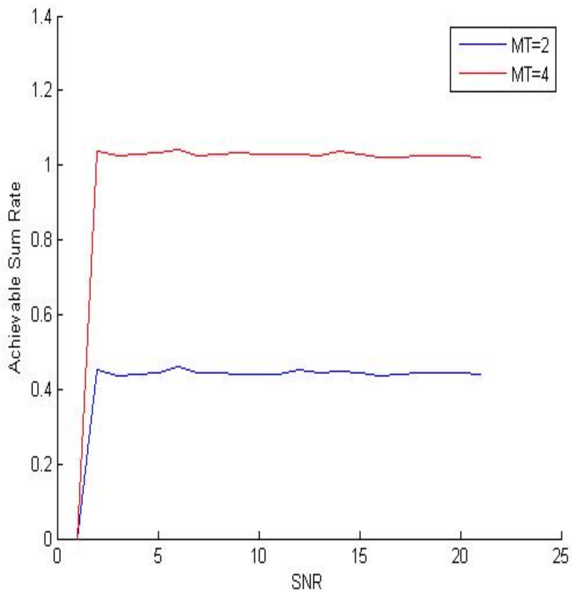

Fig.4 Average achievable sum rate versus SNR with *N*=4

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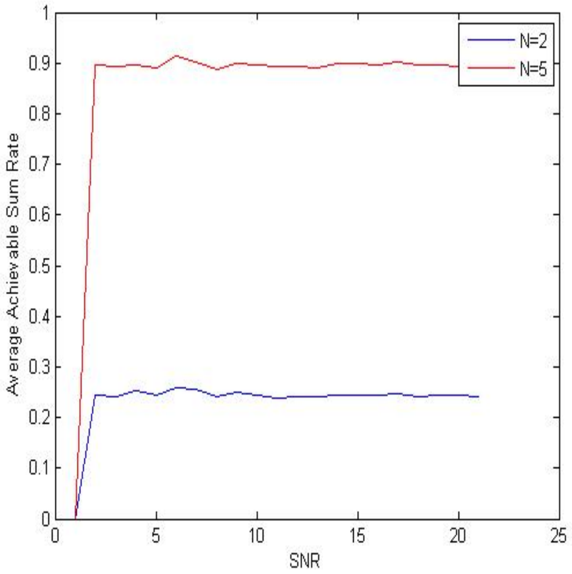

Fig.5 Average achievable sum rate versus SNR with MT=4

V. OUTAGE PROBABILITY

The outage probability refers to the bits sent over the channels to be decoded with some error probability.If achievable rate at user *i* is less than the given transmission rate *R*, outage probability of user *i* can be formulated as

$$P_{out}(i) = P\left\{\frac{1}{D}\log_2(1 + SINR(i)) < R\right\} \qquad (9)$$

where transmission rate R,

$$R = \frac{\eta}{D}\sum_{i=1}^{N} log_2(1 + SINR(i)) \qquad (10)$$

Fig.6 plots outage probability as function of transmission rate with *D*=2 and M_T =4.One can see that the N has a discounting effect on the achievable rate due to the larger IUI.

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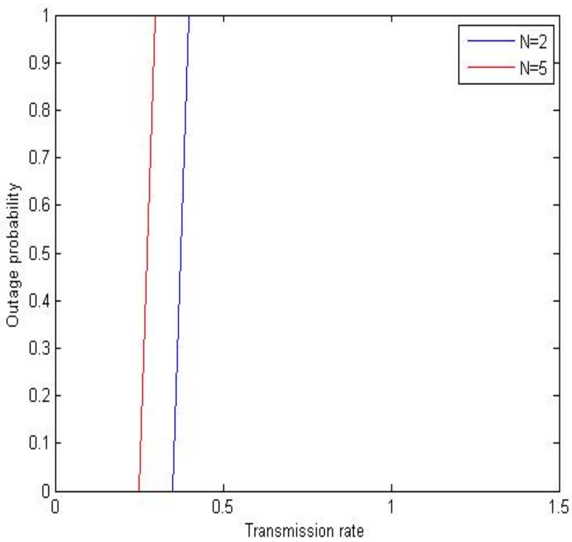

Fig.6 Outage Probability versus transmission rate

VI. BIT ERROR RATE OF TRDMA OVER CDMA

In this part, we investigate TRDMA's improvement of bit error rate over CDMA by taking benefit of the high resolution and pin-point spatial focusing effect. If large amount of errors occur when data is sent through the data link, integrity of the system might have to be compromised. Hence, it's important to access the performance of a system and BER provides an ideal way in which this can be achieved. Bit error rate is calculated the total number of bit errors in the amount of bits sent. Here, Rayleigh channel model is considered. System model is same as that of the MISO scheme.

CDMA is another multiple access method which allows several users to communicate over a single channel. To undue interference between users CDMA employs a special coding scheme where each user is assigned a code. Here we spread the sequences using Walsh codes. Walsh codes are mutually orthogonal.Hadamard matrices can be used to generate Walsh codes of orders with power of 2. Before transmission we append cyclic prefix to each user which is discarded by the receiver. The cyclic prefixes used tend to eliminate inter-symbol-interference from previous symbols and also allows simple frequency domain processing such as channel estimation and equalization. The user signals are then combined and transmitted .Fig.7 shows the block diagram of CDMA system.Fig.8 shows the plot of bit error rate of TRDMA.Fig.9 shows the bit error improvement over CDMA. Bit error rate improvement over CDMA is due to the reduced ISI obtained with the help of high resolution spatial focusing effect and the diversity gain achieved.

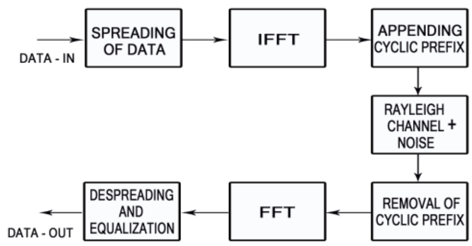

Fig. 7 The block diagram of CDMA system

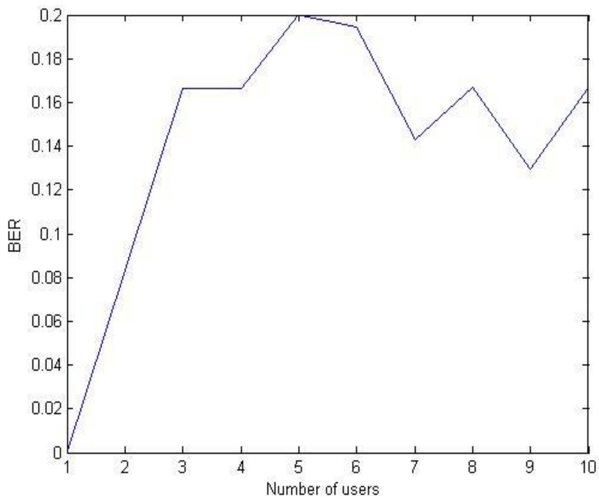

Fig.8 The bit error rate of TRDMA multiuser system

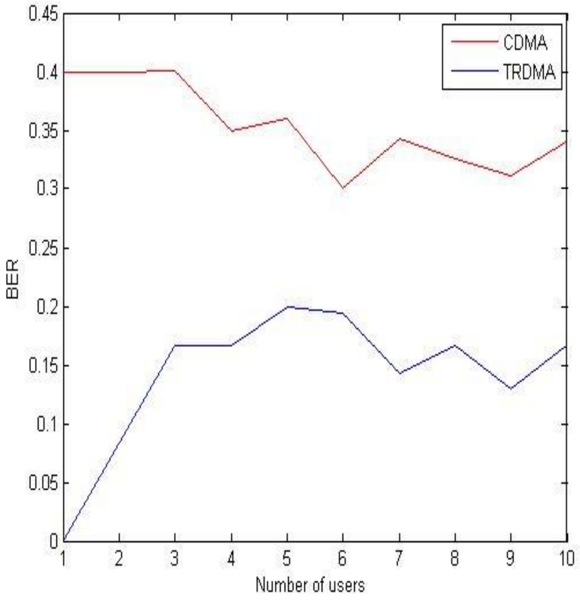

Fig.9 BER of TRDMA over CDMA

VII. CONCLUSION

In this paper, we proposed a TRDMA scheme for the multi-user downlink network over multi-path channels. By utilizing the location-specific signatures that exist in the multi-path environment we develop both single antenna and multiple antenna system model. We simulated and evaluated a variety of performance metrics such as bit error rate, effective SINR and achievable sum rates. We also demonstrated the TRDMA's improvement of bit error rate over CDMA over uncorrelated channels. Based on the nice properties obtained while simulation one can say that this can be used to transmit data to objects without knowing the correct location of the object since time-reversed signals follow the same path in the backward propagation. Thus TRDMA can be a promising candidate for future low complexity energy efficient wireless communications.

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REFERENCES

1. G. J. G. Proakis, *Digital Communications*, 4th edition. McGraw-Hill, 2001.
2. G. L. Stuber, *Principles of Mobile Communications*, 2nd edition. Kluwer, 2001.
3. A. J. Goldsmith, *Wireless Communication*. Cambridge University Press,2005.
4. D. Tse and P. Viswanath, *Fundamental of Wireless Communication*.Cambridge University Press, 2005.
5. B. Wang, Y. Wu, F. Han, Y. H. Yang, and K. J. R. Liu, "Green wireless communications: a time-reversal paradigm," *IEEE J. Sel. Areas Commun.*, vol. 29, no. 8, pp. 1698–1710, Sep. 2011
6. W. A. Kuperman, W. S. Hodgkiss, and H. C. Song, "Phase conjugation in the ocean: experimental demonstration of an acoustic time-reversal mirror," *J. Acoustic Society America*, vol. 103, no. 1, pp. 25–40, Jan.1998.
7. H. C. Song, W. A. Kuperman, W. S. Hodgkiss, T. Akal, and C. Ferla,"Iterative time reversal in the ocean," *J. Acoustic Society America*, vol. 105, no. 6, pp. 3176–3184, June 1999.
8. D. Rouseff, D. R. Jackson, W. L. Fox, C. D. Jones, J. A. Ritcey, and D. R. Dowling, "Underwater acoustic communication by passive-phase conjugation: theory and experimental results," *IEEE J. Oceanic Eng.*, vol. 26, pp. 821–831, 2001.
9. A. Derode, A. Tourin, J. de Rosny, M. Tanter, S. Yon, and M. Fink "Taking advantage of multiple scattering to communicate with timereversal antennas," *Phys. Rev. Lett.*, vol. 90, pp. 014301-1–014301-4,2003.
10. D. Rouseff, D. R. Jackson, W. L. J. Fox, C. D. Jones, J. A. Ritcey, and D.R. Dowling, "Underwater acoustic communication by passive-phase conjugation: theory and experimental results," *IEEE J. Oceanic Eng.*, vol. 26, pp. 821–831, 2001.
11. G. F. Edelmann, T. Akal, W. S. Hodgkiss, S. Kim, W. A. Kuperman, and H. C. Song, "An initial demonstration of underwater acoustic communication using time reversal," *IEEE J. Oceanic Eng.*, vol. 27, pp.602–609, 2002.
12. S. M. Emami, J. Hansen, A. D. Kim, G. Papanicolaou, and A. J. Paulraj, "Predicted time reversal performance in wireless communications,"*IEEE Commun. Lett.*, 2004.
13. M. Emami, M. Vu, J. Hansen, A. J. Paulraj, and G. Papanicolaou, "Matched filtering with rate back-off for low complexity communications in very large delay spread channels," in *Proc. Asilomar Conf. Signals, Syst. Comput.*, vol. 1, pp. 218–222.
14. H. Nguyen, Z. Zhao, F. Zheng, and T. Kaiser, "Pre-equalizer design for spatial multiplexing SIMO UWB systems," *IEEE Trans. Veh. Technol.*,vol. 59, no. 8, pp. 3798–3805, Oct. 2010.
15. T. K. Nguyen, H. Nguyen, F. Zheng, and T. Kaiser, "Spatial correlation in SM-MIMO-UWB systems using a pre-equalizer and pre-rake filter,"*2010 IEEE International Conf. Ultra-Wideband*.
16. T. K. Nguyen, H. Nguyen, F. Zheng, and T. Kaiser, "Spatial correlation in the broadcast MU-MIMO UWB system using a pre-equalizer and time reversal pre-filter," 2010 International Conf. Signal Process. Commun. Syst.
17. Feng Han,Yu-Han Yang,Beibei Wang,Yongle Wu,and K. J. Ray Liu,"Time reversal division multiple access over multipath channels".*IEEE transactions on communications, vol. 60, no. 7, july 2012.*

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