Time Reversal based TDS-OFDM for V2V Communication Systems

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Abstract: - Higher spectral efficiency and fast synchronization can be achieved by using time domain synchronous OFDM (TDS-OFDM). But unfortunately, it suffers from low bit error rate performance in long delay spread channels and its performance loss over fast time-varying vehicular channel. This paper proposed TDS-OFDM as a strong candidate for vehicle-to-vehicle (V2V) communication using time reversal technique to solve its BER performance degradation. V2V wireless channel is characterized by high mobility and dynamic environment. The time reversal OFDM assist single input multi output communication through channel achieve a high bandwidth capacity. The proposed scheme is tested for V2V tap delay multipath channels and simulation results show that TDS-OFDM based on time reversal technique can provide significant bit error rate improvement.

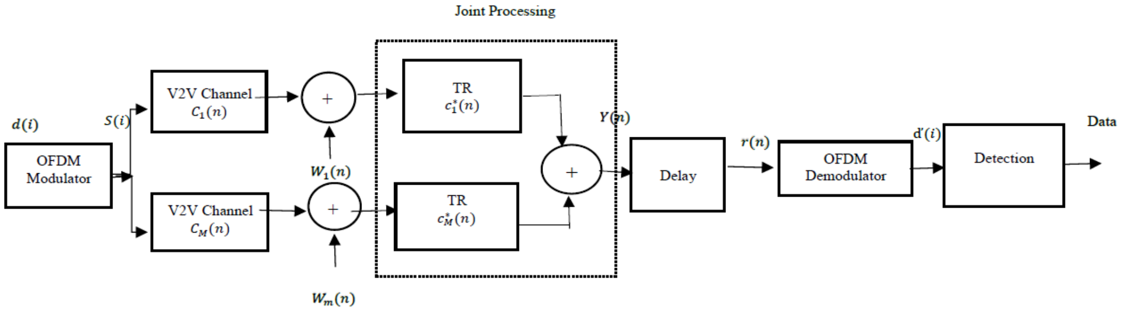
Key-Words: - OFDM, Time Reversal, Vehicle-to-Vehicle, Fading Channel, DTTB and Channel Estimation.

1 Introduction

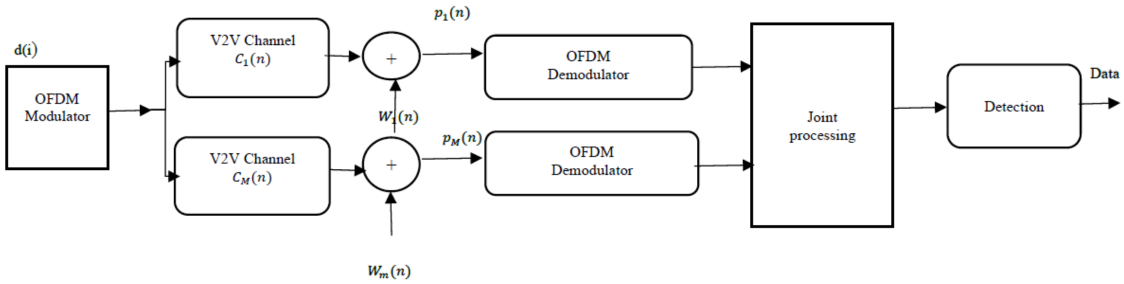
High-speed wireless communication is challenging for wireless channels spatially which with significant multipath delays. As the data transmission rate increases, the time dispersion channel significantly increases and becomes more pronounced. To realize depressed Bit Error Rates (BERs) in this channel, one favorable process is to use Single Input Multi Output (SIMO) Orthogonal Frequency-Division Multiplexing (OFDM) communication system [1]. OFDM with its outstanding robustness to multipath fading and high spectral efficiency plays an important role in emerging vehicular communications [2]. In SIMO-OFDM systems based on Time-Reversed (TR), the multiple time-dispersive fading channels switching into single channels and reduce the channel fading and time dispersion. SIMO-OFDM adopts multicarrier (MC) transmissions that relies on diversity combining (e.g., maximum ratio combining) and combats fading.

Nowadays the people daily life has become increasingly linked to vehicles such as the subway, buses, cars, trains, etc. [2]. Vehicular communication technology is used to exchange information such as position and speed between different vehicular. Pressure sensors have been used in vehicles since the 1980s to increase the road safety and security. The main objective of using the vehicular communications is decreasing the effect of transportation on the environment, decrease the number of accidents and the number of traffic jams [3]. The vehicles communication channel is a Non-Line-of-Sight (NLOS) channel due to the environments and buildings. In vehicle-to-vehicle (V2V) communications there are several destroyer properties of the radio channel, such as significant fading and high attenuation, which can cause a high bit error rates and increase latency time [4]. The differences in mobility, shadowing, and relative height of the transmitter and receiver antennas create importance difference in diffractions, reflection and scattering of the transmitted wave.

In recent years, orthogonal frequency division (OFDM) has been shown to be a technique worthy of achieving high data transfer rates through multipath fading channels. In order to avoid Inter-Block Interference (IBI) between OFDM data blocks, guard intervals are used between consecutive OFDM blocks. There are three basic types of OFDM guard intervals: The first is cyclic prefix OFDM (CP-OFDM), the second one is Zero Padding OFDM (ZP-OFDM) and the third basic type is Time-Domain Synchronous OFDM (TDS-OFDM) [5, 6]. In the CP technique, the latest samples of each OFDM block are copied and transmitted before the present OFDM block. The CP render two purposes; (1) Used to reduce Inter-Symbol Interference (ISI) and IBI; (2) convert linear convolution into circular convolution. For ZP-OFDM, zeros are used in-state of the CP (the guard interval is left empty) to reduce the energy consumption in spite of the hardware problem. In TDS-OFDM, the guard interval is full pilot symbols used in synchronization and channel estimation. Consequently, TDS-OFDM save the large sub-carrier number used as a frequency-domain pilots used in ZP-OFDM and CP-OFDM. Thus, TDS-OFDM spectral efficiency is higher than ZP-OFDM and CP-OFDM. Also, reliable and fast



(a) TR-SIMO-OFDM



(b) SIMO-OFDM

Fig. 1, TR-SIMO-OFDM / SIMO-OFDM system model.

synchronization can be done using the PN sequence. Digital Television Terrestrial Broadcasting (DTTB) standard called Digital Terrestrial Multimedia/Television Broadcasting (DTMB) [7] use TDS-OFDM as key technology. Unfortunately, TDS-OFDM technique suffering from low BER performance due to the IBI in-between the guard interval and OFDM data blocks and to warranty a perfect execution, it requires a long guard interval, which reduces efficiency in terms of both power and bandwidth. TDS-OFDM problems will be more severe in vehicular communication channels.

In this paper, time reversal (TR) is proposed to convert the V2V fading channel to be impulse like channel. The impulse like channel is used to improve the TDS-OFDM BER performance and improve energy efficiency by using short Pseudo Noise (PN) sequence. Along this line, this paper improves the TDS-OFDM system performance in V2V communication in terms of the energy efficiency and BER without affecting PN autocorrelation feature based on TR-SIMO-OFDM systems to combine the advantages of both TDS-OFDM and ZP-OFDM schemes.

The rest of this paper is organized as follows. First, proposed time reversal based TDS-OFDM scheme are addressed and discussed in Section 2. After that in Section 3 the properties of TR channel in V2V communication has been explained. Following this, the performance of the proposed scheme is analyzed and evaluated by simulations results in Section 4. Finally, Section 5 concludes the paper.

2 Time Reversal based TDS-OFDM

The TR is a feedback wave focusing technique, used to obviously recompense multipath dispersion channel in digital communications over several types of physical propagation media, such as magnetic induction, acoustic and radio wave [8]. In a TR technique, the transmitter transmits a probe signal at the beginning of the communication, recorded at the receiver. Based on this received probe, the channel can be estimated and serving as channel information, to be used in time reversed and retransmitted at the receiver. Thus, can achieve a channel focusing at the transmitter if the change in channel is small. This process implemented as passive phase conjugation or passive TR when a receiving array is available [9]. This paper considers a passive TR system in the multipath fading channels with significant delays such as V2V communication, which consists of a single transmitter and an M element array receiver. In single-carrier (SC) communications the passive TR technique has been widely used due to its spatial and temporal focusing capability. TR communications first suggest in the early 2000s and TR-TDS-OFDM makes possible using short PN sequence for long channels [1, 10]. Adaptive TR approach can decrease moreover the crosstalk among users or multiple transmitters. TR communications can be spread easily to time-varying channels, to achieve low BERs in such channels. TR was also notified as an effective means of simultaneous channel anti-dispersion and diversity combination for SIMO-OFDM. In this paper the TR-TDS-OFDM is evaluated to the V2V communication, two cases are addressed in this work; first one with a sufficient guard interval (the PN sequence length is larger than the extreme channel tap delay); the second case is insufficient guard interval (PN sequence length is shorter than the extreme channel tap delay). The guard interval length directly impacts bandwidth efficiency spatial in the long tap delay channels [10]. Where, the signal focus can be achieved in the transmitter, if the channel does not change significantly.

TR in vehicular communication can solve the multipath problem and its time-variant channel by transmitting the received signal on an array in a time-reversed order while the array is referred to as a time-reversal mirror (TRM). TR is process where is the channel convolution in the same channel and compress the variable channel. TR-OFDM, use time reversal treatment to provide a simple way to reduce the time dispersion of the channel.

The difference between the SIMO-OFDM and TR-SIMO-OFDM in terms of how both handle or process antenna received signals are shown in Fig. 1(a, b). In conventional SIMO-OFDM, the signal received by vertical line array are individually OFDM demodulated previously jointing processed but in TR-OFDM they are together processed before the OFDM demodulation. $d(t)$ is the information data symbol, $S(t)$ is the transmitted signal after OFDM modulation, $P_M^n(n)$ is the received signal at the m-th receiver antenna, $w_n(\mathrm{n})$ is the additive noise at the m-th receiver antenna. $c_1(n)$ is the channel impulse response, $y(n)$ is the signal after joint processing, $r(n)$ is the input signal and $\mathrm{d}'(i)$ is the OFDM demodulator output signal.

Assume the channel impulse response (CIR), is given by the following formula [1].

$$c_m(l) = \sum_{\mathrm{p}=0}^{\mathrm{Lc}} c_{\mathrm{m,p}}(\mathrm{n})\ \delta(l-\mathrm{P}), m = 1, \dots, M, \quad (1)$$

where L_c is an upper bound on the channel order and its value depends on the maximum channel delay spread and the symbol interval T_s. The CIR, $c_m(l)$ includes the effects of transmitter/ receiver filtering and physical channels. The achievement of TR communications depends completely on the behavior of a q-function which combines the complexity of the channel $c_m(l)$ (i.e. the number of multipaths) [11].

The TR-OFDM transmitter employs standard OFDM modulation and its sub-carrier usage index is $\mu = \frac{K-K_p}{K+GI}$ where, K, is the OFDM data blocks length, K_p, is the frequency domain pilot's subcarriers and, GI, is the guard interval length. The TR-OFDM channel, $q(l)$, is equal to:

$$q(l) := \sum_{m=1}^{M} c_m(l) \oplus C_m^*(-l), \quad (2)$$

where $\oplus$ is the linear convolution operation, $c_m(l)$ is the linear time invariant (LTI) V2V channel and $C_m^*(-l)$ is the previous estimated one. The TR channel, $q(l)$, has a time length $[-L_c,\ L_c]$, which doubles the $c_m(l)'s$. The received signal $y(n)$ delayed by τ and $\mathrm{h}(l)$=$\mathrm{q}(l-\tau)$ is a delayed version of TR channels which with the same order.

The i-th transmitted TDS-OFDM signal frame, S_i= $[s_{i,0}.s_{i,1}.\dots.s_{i,N-1}]\mathrm{T}$ is composed of two independent parts: a known PN sequence and OFDM data respectively:

$$S_i = \begin{bmatrix} E_i \\ X_i \end{bmatrix}_{N\times 1}, \quad (3)$$

$N = K + GI$ is the total frame length.

TR is used to focus signals in time and/or space. In the context of TR-SIMO-TDS-OFDM, the received signal after the TR operation, $y(n)$, can be written as:

$$y(n) \coloneqq \sum_{m=1}^{M} p_m(n) \oplus c_m^*(-n), \quad (4)$$

for LTI channel, $c_m(l)$, $p_m(n)$ is:

$$p_m(n) = S(n) \oplus c_{\ m}(n) + w_m(n), \quad (5)$$

and $y(n)$ can be rewritten related to, $s(n)$, in the following equation:

$$y(n) = \sum_{l=-L_c}^{L_c} q(l)s(n-l) + z(n), \quad (6)$$

where, $z(n) := \sum_{m=1}^{M} w_m(n) \oplus c_m^*(\tau - n)$, represent the channel noise. The, $s(n-l)$ is the delayed version of time reversal channel with same order. After adaptive passive time reversal, the received signal, $y(n)$, is delayed by, τ, to introduce $r(n) = y(n-\tau)$, which can be written as:

$$r(n) = \sum_{l=-L_c+\tau}^{L_c+\tau} h(l) + S(n-l) + z(n), \quad (7)$$

$h(l) = q(l-\tau)$ is delayed TR channel. The TR-TDS-OFDM data model can be obtained as [10]:

$$r(i) = H_o s(i) + H_1 s(i-1) H_{-1} s(i+1) + \tilde{z}(i). \quad (8)$$

3 Properties of TR Channel in V2V Communication

Ideal TR channel assist many benefits, how much those benefits can be realized, that depends on how impulse-like a realistic TR channels. To appreciate 'impulse-likeness' of a TR channel in [1, 10] two various approaches for statistical approach of TR channel are used and the TR channel expressed as [1, 10]:

$$q(l) = \begin{bmatrix} \sum_{m=1}^{M} \sum_{p=0}^{L_C} \left|C_{m,p}\right|^2, & l = 0 \\ \sum_{m=1}^{M} \sum_{(p,\acute{p}) \in I(l)} C_{m,p} C_{m,\acute{p}}^*, & l \neq 0 \end{bmatrix}, \quad (9)$$

where $I(l)$ denotes the set of pairs $(p, \acute{p})$ satisfying $p - \acute{p} = l$ for $(p, \acute{p}) \in [0, L_C]$. The cardinality of $I(l)$ is $|I(l)| = L_C - |l| + 1$ and $q(l)'s$ treated as deterministic number. It is observed that the terms in are added coherently as a sum of real numbers and up randomly as a summation of complex numbers, respectively. Intuition suggests that $q(l), l \neq 0$ would eventually become unimportant relative to $q(0)$ and be suppressed in case of the number of terms get involved in the summations is sufficient. That mean, the good TR channel, $q_{ideal}(l)$, offers a good approximation for $q(l)$ in multipath-rich V2V channel environment.

4 Simulation Results

In this section, the performance of proposed TR-SIMO-TDS-OFDM communication system will be investigated by testing the un-coded and coded BER performance (in case of sufficient guard interval length, $GI \geq L_C$, and un-sufficient guard interval length, $GI < L_C$) via Monte Carlo simulations. Quadrature phase shift keying (QPSK) modulation technique is used in simulations, the TDS-OFDM sub-carrier number, $K = 1024$, are employed. The data generate symbols, $d(i)$, is bits generated randomly. In the coded system, the bits are first encoded by a rate-1/2 convolutional encoder with generator polynomial [65,57] [12], then it is interleaved by a block interleaver of depth 8 prior to QPSK modulation. V2V communication channel, $c_m(l)$, is established as a channel taps and generated as independent zero-mean, complex Gaussian random variables with equal variance have an order $L_c = 400$. In the receiver side, the Structured Compressive Sensing (SCS) techniques are used for channel estimation as discussed in [13], the channel estimation technique can be updated every TDS-OFDM symbol based by using the new received PN-sequence.

Test 1, (The effect of TR technique)

In this experiment, the effect of TR in BER system performance improvement are shown in Fig. 2, when TR is adopted over the V2V fast fading channel. It is clear that the conventional TDS-OFDM unable to be used in the V2V channel, where the BER performance is very high. The proposed TR-TDS-OFDM scheme has a good performance in such type of channels. The enhanced reliability over fast fading channels is contributed by TR channel used to convert V2V channel to be impulse like channel.

Test 2, (The effect of the number of receiver antennas)

In this test, we test the coded and un-coded BER performance of TR-SIMO-TDS-OFDM out of the number of receiver antennas at $M = 1,2,4,8$ when the guard interval length $GI = 16$. The coded and un-coded performance results are shown in Fig. 3 (a, b), indicates that, the BER performance improves as the number of receiver antennas increase not only for diversity SIMO technique capability, but also because the TR channel is being more impulse like as the number of receiver increase. The error floor in the un-coded system is caused by the residual IBI due to insufficient guard interval length and between PN training sequence and OFDM data blocks. In practice, the error floor removed by using channel coding.

Test 3, (The effects of the cyclic prefix length)

In this test, we simulate the coded and un-coded BER performance of TR-SIMO-TDS-OFDM at different guard interval length at $GI = 16{,}180$. The performance results in Fig. 4 (a, b). Showing that the system performance becomes more better as the guard interval length increases. Where the IBI in-between the OFDM data blocks reduces as the GI lengths are sufficient. But, it reduces the OFDM sub-carrier usage index, μ. μ is the useful TDS-OFDM subcarrier (sub-carrier used in data transmission) indicator expressed the percentage of useful OFDM subcarrier number to the total number of subcarrier in OFDM frame. Hence, reducing PN sequence length improve the spectrum efficiency and improve the OFDM sub-carrier usage index. Fig. 5, show OFDM sub-carrier usage index, μ, as a function of the guard interval length, GI, out of the channel length, L_C, (the maximum sub-carrier usage index obtained when no-guard are used).

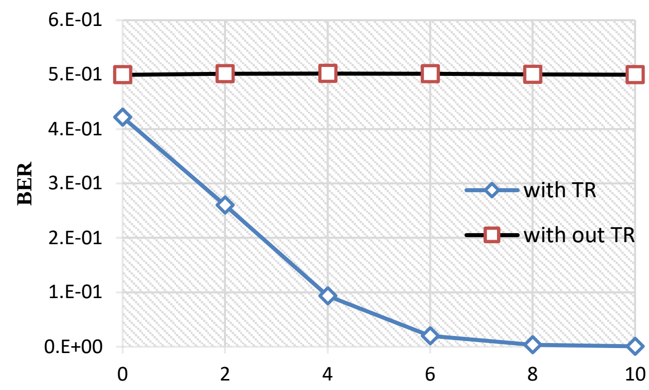
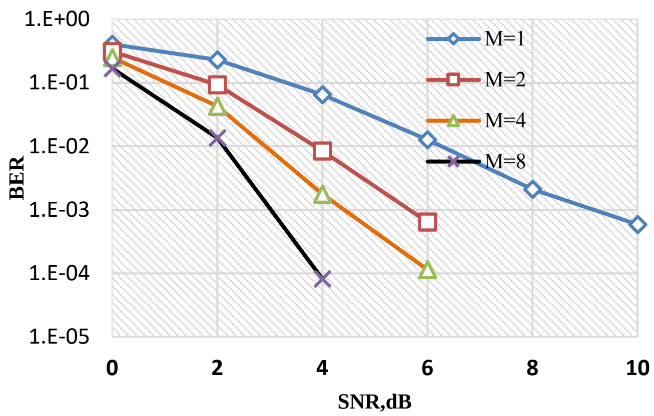
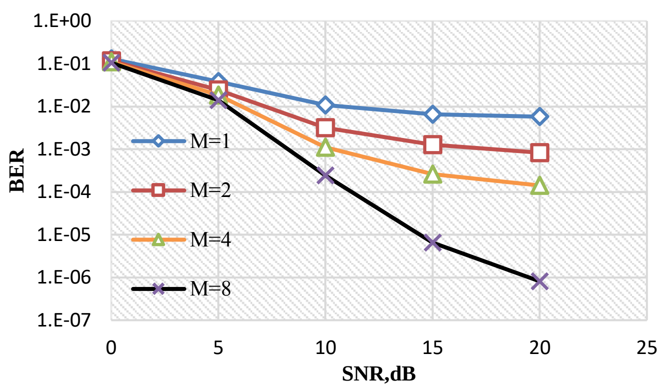


Fig. 2, BER performance of coded TDS-OFDM with and without TR technique.

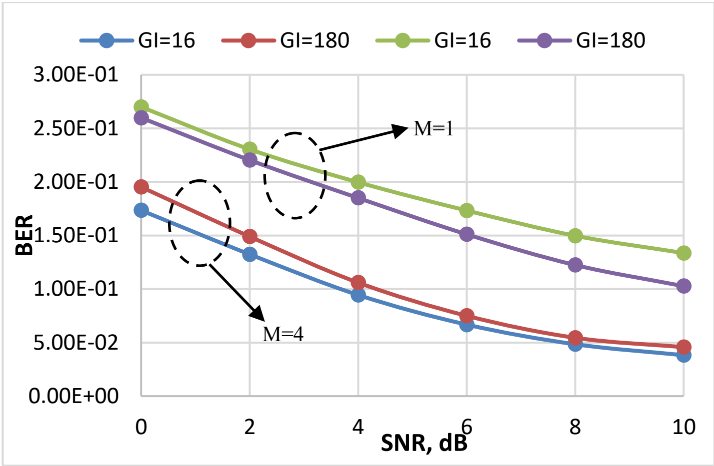


(a)

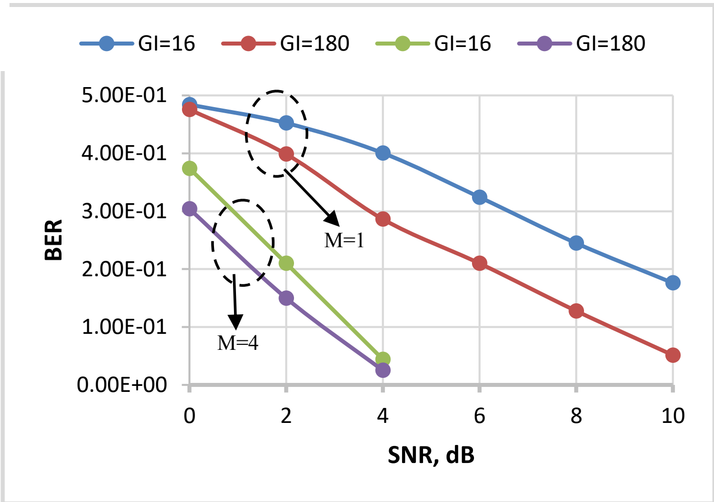


(b)

Fig. 3, TR-SIMO-TDS-OFDM BER performance over V2V channel at different number of receiver antennas, M, (a) Coded system (b) Un-coded system.



a



b

Fig. 4 BER performance for VC channel with different cyclic prefix lengths.

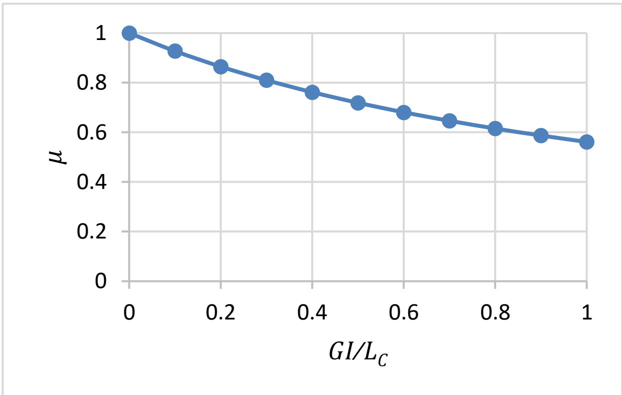


Fig. 5 TDS-OFDM sub-carrier usage index, μ, as a function of the guard interval length, out of the channel length.

5 Conclusion

In this paper, the time reversal based, TDS-OFDM is proposed for V2V communication system. TDS-OFDM is used to improved spectrum and energy efficiency. Using time reversal technique, the multipath fading V2V channel is converting to be impulse like channel and the TDS-OFDM degradation in BER performance due to IBI is significantly improve. Thanks to the time reversal technique, TDS-OFDM use guard interval length shorter than the channel to improve the sub-carrier usage index and high spectrum and energy efficiency can be achieved. Our work also led to new insights in the TR operation and resulted in a better understanding of the applicability of TR-OFDM in various V2V channel. In the future work, an optimal receiver will be design for TR-SIMO-TDS-OFDM to be used in mobility V2V communication systems.

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