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A MODIFIED-HOPPED SINGLE DELAY APPROACH FOR UWB TR RECEIVER USING THE MODIFIED HADAMARD MATRIX

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Abstract

The Transmitted-Reference (TR) is a technique used to improve the performance (gain) of received noisy multipath component in indoor and outdoor UWB signal. This technique is utilized by ultra-wide band (UWB) transceiver which receives very short transmitted pulses (less than 1 ns) using popular modulation and spread spectrum of time hopping. It is well-known that the inter pulse interference (IPI) is one of the most important challenges in transmitted reference impulse radio (TR IR-UWB) receiver. In this paper, a Modified-Hopped Single Delay (MHSD) TR receiver was proposed to completely remove the IPI drawback in TR and thereby increasing data rate and reducing Symbol Error Rate (SER) for better performance. This achievement requires a new modified 2^2-Hadamard matrix by using bi-orthogonal codes. The size of Hadamard matrix was then enlarged and tested. The results obtained in this study shows that a gain of about 2.7 dB has been achieved compared to conventional single delay (SD) TR receiver used in wireless techniques.

Keywords: Modified-Hopped single delay, inter pulse interference, Transmitted reference impulse radio ultra -wideband.

1. Introduction

In the last three decades, UWB has been receiving more attention as the demand for better communication is increasingly needed in industries, military, and academia. UWB technology is responsible for carrying outstanding convenience and mobility of wireless communication systems to a high speed interconnects in devices throughout the digital system at home and office [1, 2]. The increasing demand for improved UWB technology faces challenges due to the restriction imposed by

Federal Communication Commission (FCC) to limit the power used at -10 dB and fractional bandwidth greater than 20% or occupying 500 MHz minimum.

Historically, coherent rake receiver was very good but it was limited to very low data rate [2] due to its increasing complexity as more fingers are needed for extra multipath components and as rake receiver no longer successfully serves the purpose [3]. To overcome this challenge, Hoctor and Tomlinson in 2002 proposed a TR system that can take advantage of all available signal energy without requiring explicit synchronization and channel estimation. This goal is achieved by transmitting a reference pulse before each main data pulse and exploiting the channel response to the former as a template in a correlator detector. Specifically, calling the received waveform, the decision is formed by generating template signal and integrating the product over a symbol period [4]. However, in this technology a major challenge associated with the original TR approach is the inter-pulse interference (IPI) and/or achieve noise averaging over many frames, the required delay for autocorrelation has to be longer than the channel delay length [5].

Extensive studies propose solutions to remove or mitigate IPI from all TR receivers. The Inter Frame Interference (IFI) was first to be removed by introducing M-ary orthogonal coded/balanced TR system [6]. The basis of this preliminary approach is to shortening the existing time delay between the reference and data pulses [6]. In [7], Dong In Kim and Tao Jia proposed M-ary orthogonal coded/balanced TR system in which the IFI can be avoided because the frame time can be prolonged due to M-ary signalling as far as the required data rate is achieved. Based on this signalling approach, the IPI has been mitigated by using a pair balanced matched filters, which subtracts out the overlap portion between multi-path delayed pulses. On other hand, their proposed receiver is largely suffered from time jitter even for small time values. It is also too complex in terms of the number of matched filters used. In addition to this approach, the authors of [7] evaluated theoretically the simple error probability (SEP) of the increasing data rate based on IEEE standard UWB models.

The multipath environment has been developing and a new UWB-TR technology is increasingly needed. Farahmand et al. [8] proposed a new orthogonal coded/balanced signalling to adopt high rate UWB-TR. They [8] re-evaluated symbol error probability and theoretically derived an approach for M-ary balanced TR system for many multipath components. In 2009, Khani [9] proposed a novel weighted high data rate for UWB-TR system. A nearly inter-symbol interference (ISI) free-channel response was proposed along with enhancing the reference pulse quality by employing optimum power allocation and eliminates the need for equalization. The results were compared with the differential transmitted-reference (DTR) system.

Simulation study for improving the performance was conducted by Jin et al. [10] in which they developed an improved transmitted reference pulse cluster (iTRPC) scheme. The basis of this simulation is breaking both cluster reference and data and inserting a number of zeros at the end of each of them to reduce the interference. The results are compared with the traditional TR and original TPRC. The performance improvement as stated by [10] was 7 dB. However, the IPI was not completely removed which undermines the reliability of their results.

The current research focuses on issues such as improving performance, achieving low-complexity, and obtaining low-power-consumption UWB transceivers. In previous studies, as mentioned above, the time delay, T_d, was proposed in conjunction with the maximum delay spread, T_{mds}, i.e., $T_d \geq Tmds + T_p$, however, this study proposes severe reduction in T_d such that $T_d \ll T_{mds}$ and, as such, the data rate will be enhanced significantly. The drawback of the enhancement is that the interference will significantly increase and the need to remove such a drawback could be performed by utilizing Hadamard matrix.

Jacques Hadamard is a French mathematician who proposed in 1893 a matrix, named after him, based on Sylvester matrix about 26 years earlier. The entries of Hadamard matrix are either +1 or -1 and whose rows are mutually orthogonal. Geometrically, the two rows in Hadamard matrix represent two perpendicular vectors. The properties of Hadamard matrix made it suitable for balanced repeated replication which is widely used in statistics [11]. Hadamard matrices have extensive applications in communication such as UWB. Studies conducted by [12] and [13] employed Hadamard matrix in communication extensively. In this research, Hadamard matrix was modified to enable transmitting N-ary signalling scheme and completely removing IPI. It is hoped that this study by reducing T_d ($T_d \ll T_{mds}$) which together with modified Hadamard matrix will achieve total removal of IPI, increase data rate and reduced SER.

2. System Model

2.1. Transmitter

The basic principal in TR wireless receiver is transmitting a reference pulse (un-modulated pulse) along with transmitting a data (modulated pulse) using pulse position modulation (PPM). Both reference and data pulse is transmitted with a delay in between. The TR transmitter sends a pulse pair or doublet instead of a single pulse, where each doublet consists of a reference pulse followed by data pulse. Each bit is transmitted over a number of frames $\mathrm{N_f}$ with each frame carrying a TR doublet. TR transceiver structure is shown by the block diagram in Fig. 1 [14].

The TR transmitter transmits signal $S(t)$ that can be written as [15]:

$$S(t) = p(t) + p(t - \delta(\alpha) - T_d) \quad (1)$$

where $p(t)$ is UWB signal with pulse duration of T_p, and delay time T_d as defined earlier, $\delta(\alpha)$ is Dirac delta function [16].

The transmitted signal, $S(t)$, was set by many authors [4, 14, 15] as shown in Eq. (2) where superscript (k) refers to the number of users, subscript (j) refers to number of frames, and T_h time hoping.

$$S^{(k)}(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{E_s}{N_s}}\, p\left(t - jT_f - c_j^{(k)} T_h\right) + \ P\left(t - jT_f - c_j^{(k)} T_h - \delta\alpha_{\lfloor j/N_s \rfloor}^{(k)}\right) \quad (2)$$

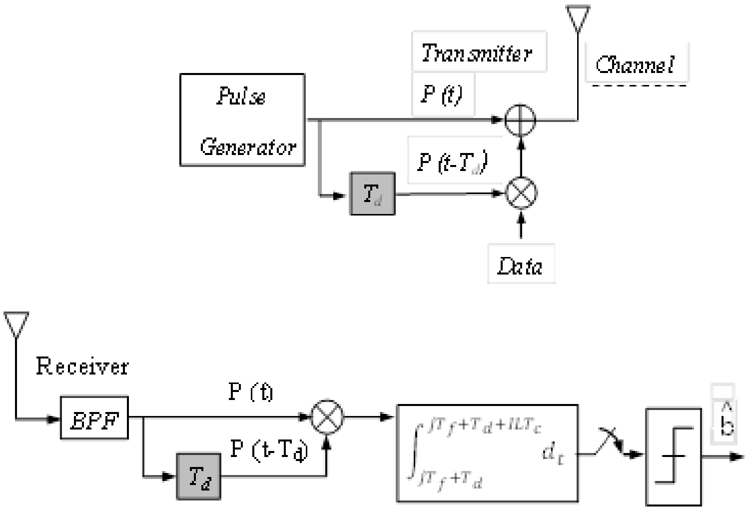

Fig. 1. Block diagram of the traditional IR-UWB TR transceiver system [14].

2.2. UWB channel model

Focusing on the UWB indoor environment, the corresponding time-invariant channel model based on the IEEE 802.15.3a is given by [17]:

$$h_{(t)}^{k} = \sum_{l=0}^{L-1} \alpha_l^k \delta\left(t - \tau_l^k\right) \tag{3}$$

where L is the number of resolvable paths, $\delta(.)$ is the Dirac delta function, α_l and τ_l are the amplitude and delay of the l$^{\text{th}}$ multi-path, respectively.

2.3. Receiver

The block diagram of TR transceiver is shown in Fig. 1 with T_d delay. In the receiver, the data detection is carried out by correlating the received signal with a replica signal which has same transmitter delay and integrated over significant amount of the multipath energy.

By inserting the response channel $h(t)$ and adding the noise, $n(t)$, in Eq. 3, the general form of received UWB signals (r^k) at user *k* becomes:

$$r^k(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{E_s}{N_s}}\, p\left[\left(t - jT_f - c_j^{(k)}T_h\right) + P\left(t - jT_f - c_j^{(k)}T_h - \delta\alpha_{\lfloor j/N_s \rfloor}^{(k)}\right)\right] * h(t) + n(t) \tag{4}$$

where noise $n(t)$ represents the additive white Gaussian noise (AWGN) with double-sided spectrum. The TR transmitter sends a pulse pair or doublet instead of a single pulse, where each doublet consists of a reference pulse followed by data pulse.

In this paper Non Line of Sight (NLOS) is used with the range of 4 meters for the environments of heavy duty building such as a hospital environment.

3. The Proposed IPI Cancellation Method

The inter pulse interference (IPI) is a common draw phenomenon in transmitted reference technique and removing this IPI is a challenging issue for many studies. Removing IPI has been treated by several techniques such as appending a guard interval with duration greater than or equal to the channel's delay spread to each frame [8] and by employing a novel multi-access scheme (MA) [18]. The TR signalling scheme, combined with the balanced TR receivers, is effective against the IPI caused by the T_{mds} . This enables us to realize higher data rate transmission than conventional TR by choosing $T_d << T_{mds}$, so the minimum frame time T_f for ensuring zero IFI can be reduced accordingly. An example of how the IPI is cancelled out is shown in Fig. 2, where R_j and D_j (j = 1, 2, …N_s) represent the received multipath reference and data pulses in the j^{th} frame, respectively. The tail part of each reference pulse (beyond T_d) is overlapped with its associated data pulse. All reference pulses are added and yield a large reference pulse due to the symbol code sequence that contains an equal number of +1s and -1s (the meaning of coded/balanced). On the other hand, all data pulses are added based also on the symbol code at the receiver and get a large data pulse. The two obtained pulses are then applied to the correlator after delaying the data pulse with T_d seconds. Symbol detector is placed at the final step to estimate the transmitted symbol.

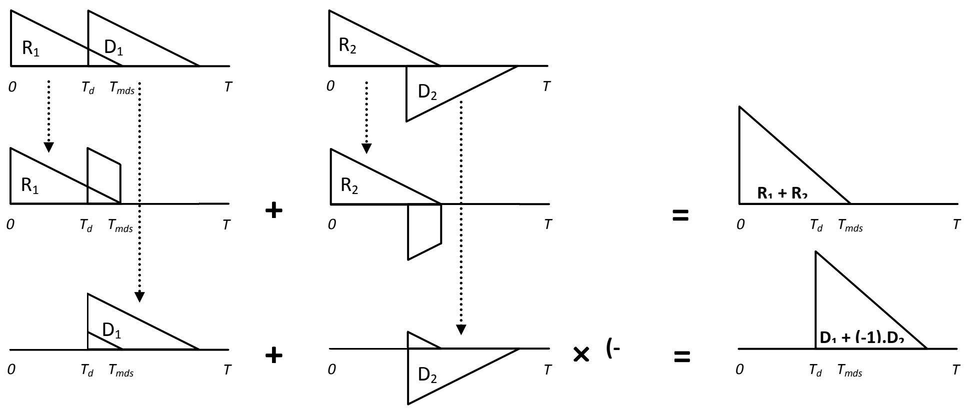

Fig. 2. IPI cancellation for N_s = 2 and symbol code (+1, -1) [15].

4. The Proposed IPI Cancellation Method

In this proposed transceiver, Hadamard matrix is modified and then examined and subsequent construction of a transceiver design is proposed as shown in Fig. 3. Hadamard modification could be followed starting at Eq. (5) which depicts the definition of Hadamard matrix.

$$H_{2^0} = [1] = H_{2^1} = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \quad (5)$$

Based on the intended modification, Hadamard of order (H_{2*2}) is employed for modification as shown in Eq. (6).

$$H_{2*2} = \begin{bmatrix} H_2 & H_2 \\ H_2 & H_2 \end{bmatrix} \tag{6}$$

Equation (7) is a combination of Eqs. (5) and (6).

$$H_{2*2} = \begin{bmatrix} +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \\ +1 & +1 & +1 & +1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \tag{7}$$

Hadamard is modified to satisfy the balance (+1s, -1s) in which all elements in all odd rows could be removed to enable it to be used in cancelling IPI which results in a modified Hadamard as shown in Eq. (8) in which the number of (+1s) and (-1s) are equal.

$$H_4 = \begin{bmatrix} +1 & -1 & +1 & -1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \tag{8}$$

Multiplying any row by (-1) is carried out to satisfy the orthogonality requirements which yields Eq. (9) and represents the final form of modified Hadamard:

$$H_4 = \begin{bmatrix} -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 \end{bmatrix} \tag{9}$$

By repeating H_4 only once, the resulting matrix is completely biorthogonal matrix as in Eq. (10) and can cancel the IPI in which each element represents data pulse.

$$H_4 = \begin{bmatrix} -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \tag{10}$$

The data pulses and reference pulses are arranged in rows and each row is characterized by certain delay T_d as shown in Eq. (11). The final matrix contains rows which represents N-ary symbol (N_s) which is characterized by its own delay (delay 1) and has N_s bits.

$$H_{modified} = \begin{bmatrix} -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \begin{bmatrix} \text{delay1} \\ \text{delay2} \\ \text{delay3} \\ \text{delay4} \\ \text{delay1} \\ \text{delay2} \\ \text{delay3} \\ \text{delay4} \end{bmatrix} \tag{11}$$

The data rate of the conventional TR system, in general, is restricted by the multi-path delay spread T_{mds} which supposed to be much smaller than the inter-pulse distance T_d to avoid Inter Pulse Interference (IPI) which stem from the interference between the reference pulses and data pulses. In this research, a proposed UWB-TR system based on modified Hadamard matrix, Eq. (11) has been presented to increase the data rate, improve the performance of overall wireless system, reduce the SER, and to yield full removal of IPI.

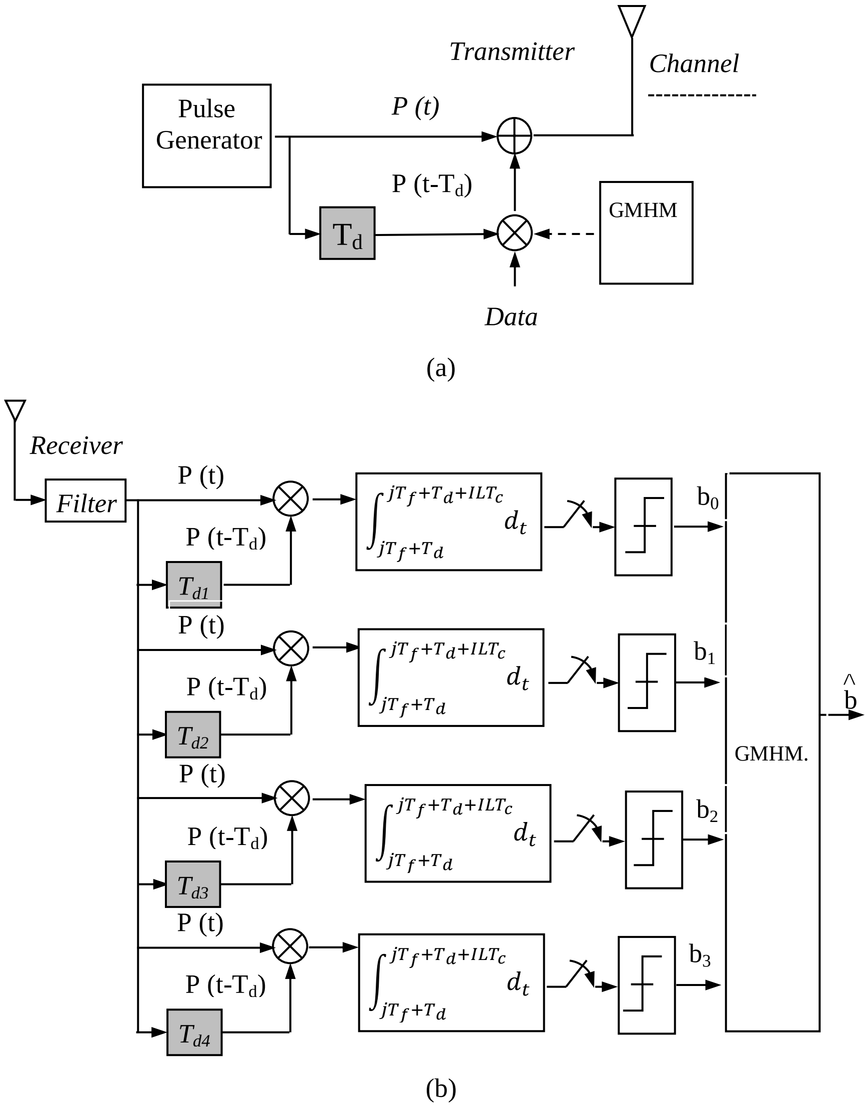

Fig. 3. The proposed MSDH transmitted reference transceiver block diagram, (a) transmitter, (b) receiver.

5. Simulation Results

A simulation code was developed using MATLAB software package version (R2013a) to evaluate the parameters of the new proposed system and compare these parameters with the conventional parameters. The wireless channel used in this study is IEEE802.15.3a [17]. This channel is a Non-Line-of-Sight (NLOS) (CM2) channel whose range is between 0 m to 4 m.

The study was conducted with N_s of 4 and 8 frames with a number of users is taken at 2, 5, and 8. The main parameter to be evaluated is SER as a function of signal-to-noise ratio (S/N). The standard signal delay of the conventional TR is compared with the new simulated results of modified hopped single delay (MHSD). All S/N levels were estimated at SER of 10^{-3} level which is traditionally accepted by researchers [19]. In Fig. 4, SER vs. S/N is shown for N_s =4 and 2 users. At SER level of 10^{-3}, the S/N was negatively shifted (improved) by about 3 dB from the conventional standard level. The MHSD outperforms the SD standard which suggests better performance. The result is in agreement with [20].

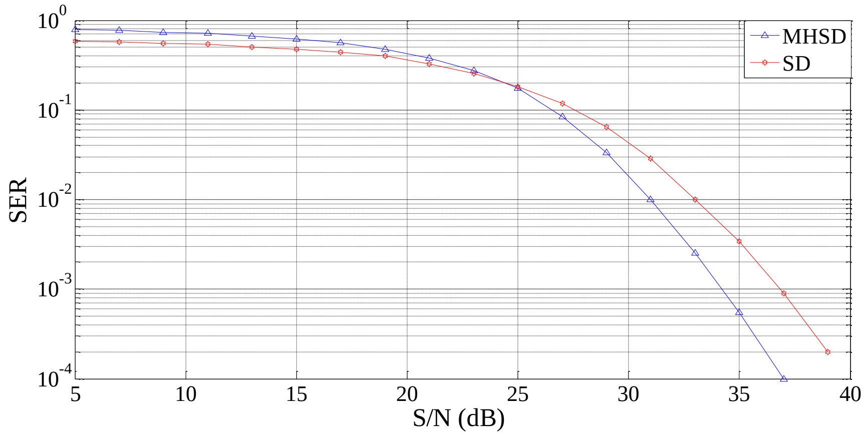

Fig. 4. SER behaviour of at number of frames N_s = 4, and 2 users.

As the number of users increased to 5, S/N slightly shows fewer shift from the conventional SD level compared to 2 users as shown in Fig. 5. This slight shift could be attributed to the fact that more users are using same number of frames, N_s.

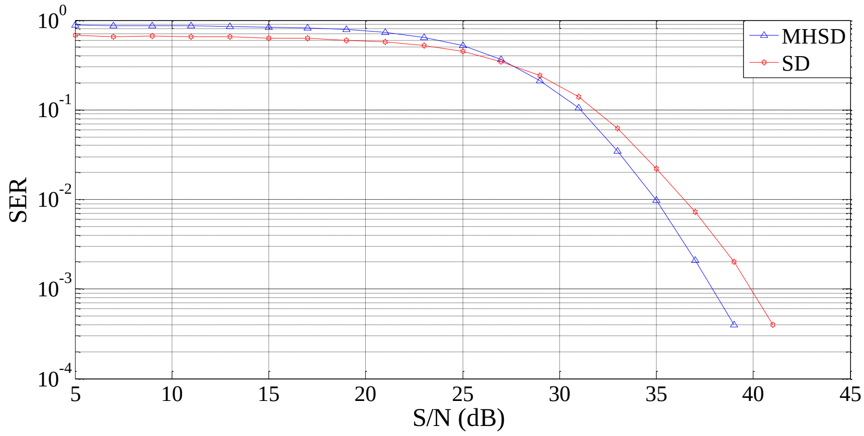

Fig. 5. SER behaviour for N_s = 4, and 5 users.

As the number of users increases again to 8 users, while N_s remains at 4 frames, the shift of S/N from the conventional SD limit is slightly decreased, compared to 2 and 5 users. Seemingly, the shift performed by the new approach MHSD shows no change and assumed to continue this systematically pattern.

As shown in Fig. 4, the level of SNR is 34 dB at SER level of 10^{-3} SER of the proposed system (MHSD) outperforms the conventional scheme by about 3 dB, which is evident that this modification is performing well. If the number of users is topped up by another 3 more users, SNR is slightly moved towards the SD conventional level closing the previous gap at about 2.8 dB compared to 3 dB as shown in Fig. 5. As the number of users increases to 8 users, the gap between the SD and MHSD at SER of 10^{-3} levels remains almost unchanged, Fig. 6. This behaviour continues as the number of users and the number of frame, N_s) .

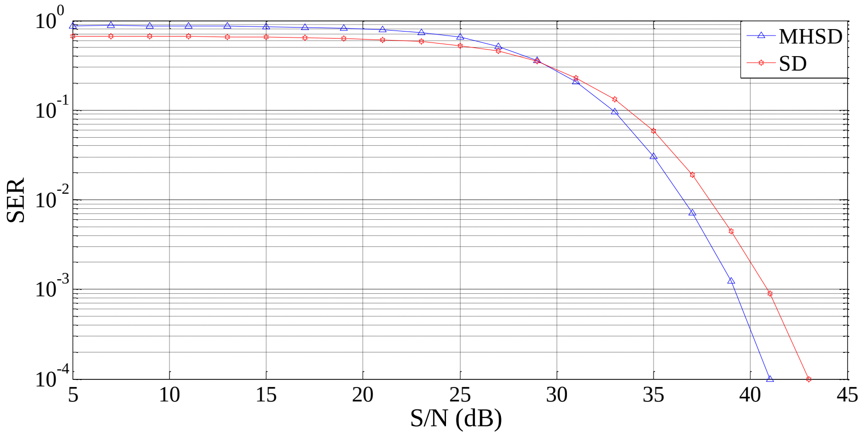

Fig. 6. SER behaviour for N_s = 4, and 8 users.

Another set of simulation was developed as N_s increased to 8 frames while the number of users is taken at 2, 5, and 8 users. The pattern of S/N shifted negatively from the conventional SD level to a new MHSD level has same pattern as the previous simulation runs as shown in Figs. 7, 8, and 9.

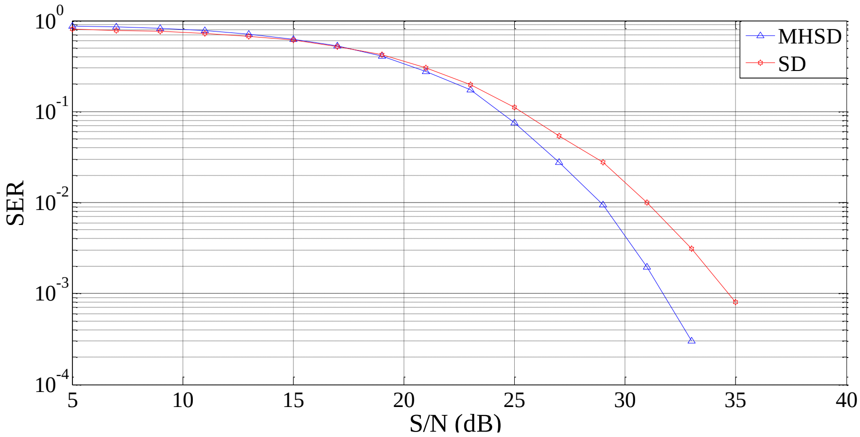

Fig. 7. SER behaviour for N_s = 8, and 2 users.

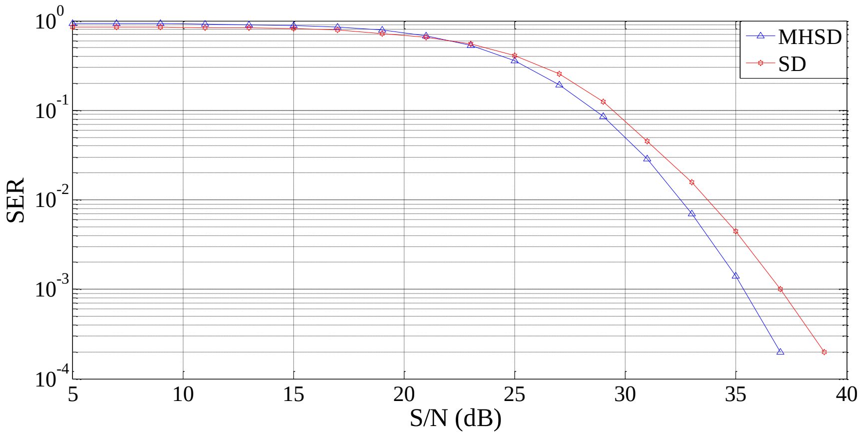

Fig. 8. SER behaviour for N_s = 8, and 5 users.

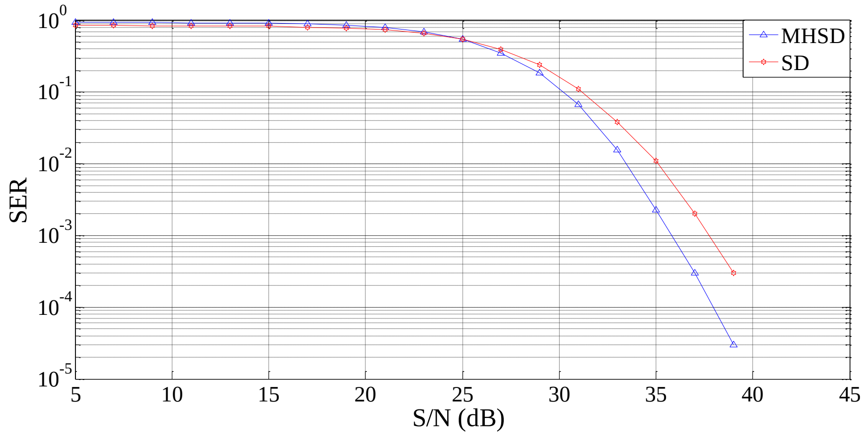

Fig. 9. SER behaviour for N_s = 8, and 8 users.

As shown in Fig. 9, the performance of the proposed structure (MHSD) needs 35 dB at 10^{-3} SER level while the conventional structure (SD) needs about 37.5 dB with a gain performance of about 2.5 dB. The simple error rate (SER) is plotted versus number of users at fixed $N_s = 8$ and S/N of 25 dB. Figures 10 and 11 show that the SER behaviour according to the number of users and the number of frames N_s, respectively for both conventional and proposed systems. All data clearly suggest that the new proposed structure outperforms the conventional structure by an average of 2.7 dB.

A comparison of S/N measured at SER level of 10^{-3} and N_s of 4 frames and 8 frames as the number of users varies from 2 to 5 and then to 8, is shown in Table 1. The results show a very similar trend for each set as the percentage variation of S/N reduced from 7.3% to 4.7% for 4 frame as the number of users varies from 2 to 8. For the other set when the number of frames increased to 8 and same number of users, S/N is reduced from 8.7% to 5.6%. The reduction in S/N suggests an increase in the received data rate which means increase in the performance.

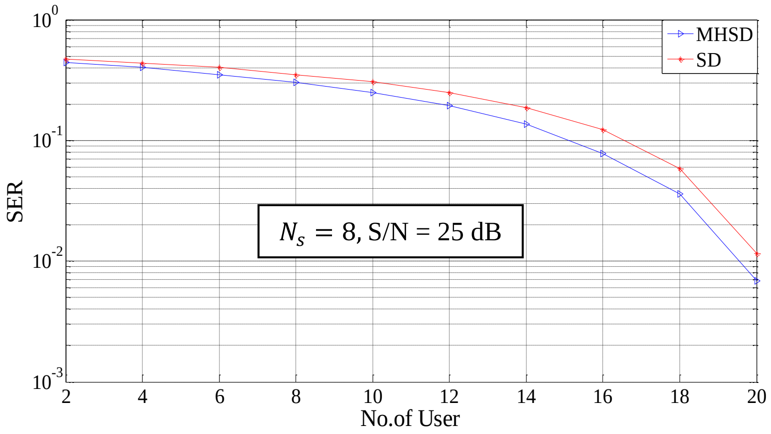

Fig. 10. The behaviour of SER vs. varying number of users at SNR of 25 dB.

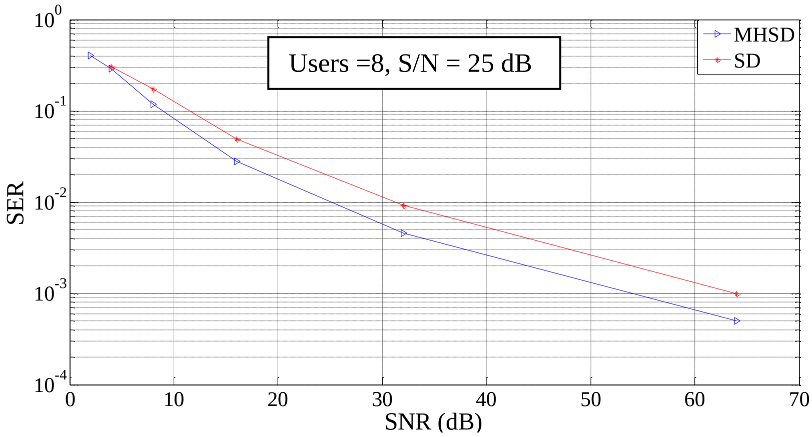

Fig. 11. The behaviour of SER at varying Ns for SD and MHSD systems.

Table 1. Comparison of S/N improvement for MHSD vs. SD.

SD at SER 10^{-3}			MHSD at SER 10^{-3}			S/N Variation
N_s	Users	S/N (dB)	N_s	Users	S/N (dB)	% (dB)
4	2	36.8	4	2	34.1	7.3
4	5	40.5	4	5	38.2	5.7
4	8	41.8	4	8	39.8	4.7
8	2	34.8	8	2	31.8	8.7
8	5	37.6	8	5	35.1	6.7
8	8	38.8	8	8	36.6	5.6

6. Conclusions

In this study, Hadamard matrix was modified and employed as a basis for constructing a new technique named as MHSD UWB transceiver system. In the proposed scheme, the IPI is completely removed by using biorthogonal codes which are generated by a modified Hadamard matrix. The study was conducted by utilizing simulation and the results are promising as the S/N has shifted backwards (showing less S/N) based on the SD conventional level. The shift was averaged at about 2.7 dB which is, by itself, could be considered a very good step towards enhancing the performance of UWB-TR communication systems. The new structure enables us to reduce the simple error rate (SER) and increase the data rate and maintaining complexity. Researchers have been trying to reduce S/N level even much lower than what is achieved in this study. Unfortunately, previous studies have variety of improvement which all is targeting this goal but not even two studies have exactly the same methodology. Overall, the results here constitute another reason to believe that there is always a room for improvement. In addition, the complexity of the transceiver does not change which yields a system with efficient performance and low complexity.

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