TR-IR-UWB Performance Improvement Using Modified Hadamard Matrix

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***Abstract*—During the last three decades, ultra-wideband (UWB) has become one of the most prominent techniques encountered in the communication system. UWB brought advantages to the human community such as higher data rate, excellent time domain resolution, and immunity to both multipath and interference. The time domain resolution was earlier improved by rake receiver where a drawback was experienced due to complexity. Rake receiver was then replaced by the traditional transmitted reference (TTR)-UWB which simplifies the complexity but creates another set of drawback of inter-pulse interference (IPI) and significant reduction in data rate. To overcome these drawbacks, controlling time delay (T_d) in conjunction with the maximum delay spread (T_{mds}) became the key element in ever-lasted improving UWB system. In this work, T_d is chosen as much smaller than T_{mds} -the condition that was achieved by modifying Hadamard matrix which satisfies balance and orthogonality. The outcome of this setting, IPI was totally removed and data rate was improved. And in this work, we proposed modified TTR (MTTR) after adding a generated modified Hadamard matrix (GMHM) component to the structure of TTR transceiver. The simulation results show that the new modelling system which is based on Hadamard matrix has shown very good improvement compared to TTR. The results show that S/N of the modified TTR has shifted by about 3 dB compared to TTR. It is also observed that with a constant number of users detected by number of frames, S/N undergoes a shift of about 4 dB.**

***Index Terms*—Generated Modified Hadamard Matrix, Inter Pulse Interference, Modified Traditional Transmitted Reference, Ultra-Wideband.**

I. Introduction

The history of the UWB has started more than a hundred years ago and since then progress was made which, eventually, led to the existing Ultra-Wide Band (UWB). UWB has brought many advantages to the communication system which includes, but not limited to, higher data rate, excellent time domain resolution, and immunity to both multipath and interference [1]. UWB has encountered very severe drawback which is known as IPI. Removal of IPI has become the locus of all research work hoping an increase in data rate and reduction in noise. Removing IPI was conducted by controlling T_d, which separates the two pulses (reference and data) from each other [2]. The received data of the TTR system is limited by the T_{mds}. The precise interval between the two pulses T_d, has to be greater than or equals to T_{mds} in order to avoid interference between the reference and data pulses in a single frame [2]. The main purpose of this work, as others do, was to totally remove IPI in order to increase the data rate and reduce simple error rate (SER). In 2008, Dong In Kim [3], proposed a constraint regarding T_{mds} in which T_{mds} was much smaller than chip time (T_c). In M-ary system, the frame of time, T_f, was set at $T_f \geq 2MT_{mds}$ in order to avoid inter-frame interference (IFI) [4]. Figure 1 shows the basic doublets which contains modulated and unmodulated pulse with $T_d < T_f$. [5]. In 2011, D'Amico [6] proposed a direct relationship between T_d and T_{mds} as the delay time has to be greater than the maximum delay spread.

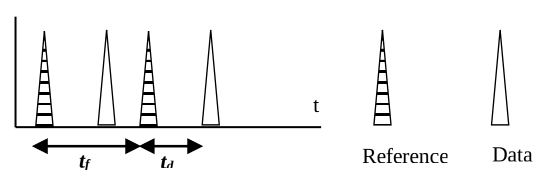


Figure 1: TTR frame structure

In this work, a severe condition is set to regulate T_d according to $T_d \ll T_{mds}$ projecting total removal of IPI and significant increase in data rate and reduce SER. The technique which is used to implement this severe condition is carried out by modifying Hadamard matrix ($H_{mod.}$) [7] which undergoes a series of modifications as shown below.
Hadamard modification could be followed starting at Equation (1) which depicts the definition of Hadamard matrix.

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

To reach the balance and bi-orthogonality, H_{2^1} should be doubled as presented by Equation (2).

$$H_{2*2} = \begin{bmatrix} H_2 & H_2 \\ H_2 & H_2 \end{bmatrix} \quad (2)$$

Hadamard is further modified to satisfy the balance (+1s, -1s) which is carried by eliminating the positive 1s in the odd rows in order to totally remove IPI as shown in Equation (3).

$$H_4 = \begin{bmatrix} +1 & -1 & +1 & -1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \quad (3)$$

By repeating H_4 four times, the final step of Hadamard matrix is concluded as presented by Equation (4). The final matrix H_{mod} represents N-ary symbol (N_s) which is characterized by its own delay (delay 1) and has NS bits.

$$H_{mod} = \begin{bmatrix} -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \begin{bmatrix} delay1 \\ delay2 \\ delay3 \\ delay4 \\ delay1 \\ delay2 \\ delay3 \\ delay4 \end{bmatrix} \quad (4)$$

The final H_{mod} contains rows which represent N-ary symbol (N_s) characterized by its own delay time (delay 1, 2, 3, and 4) [3]. The transmitted and received signals are controlled by a component known as GMHM. An example showing total IPI removal is shown in Figure (2).

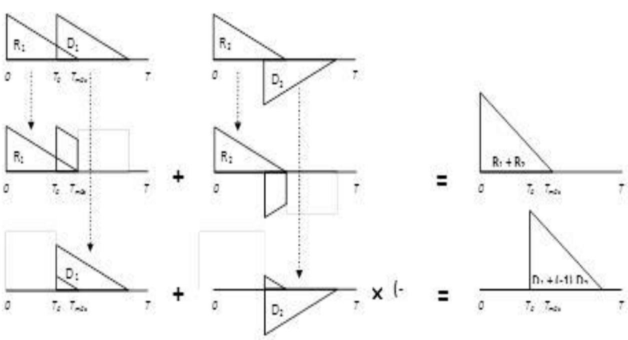


Figure 2: Removal of IPI for $N_s = 2$ coded with (+1,-1) [8]

In this paper, a condition was set according to $T_d \ll T_{mds}$ which, with the help of the H_{mod} (Equation 4) results in total removal of IPI which results in significant increase in data rate and reduction in SER.

II. Methodology

Two pulses are generated in transmitter (modulated and un-modulated) with a T_d. The transmitted signal through the channel will be transferred to the receiver through the band-pass filter (BPF) after which the correlation process is taking place. Both reference and data is then for making correlated in order to detect the information. The process continues for integration to facilitate the condition decision as shown in Figure 3.

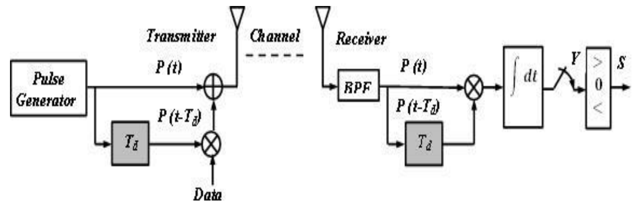
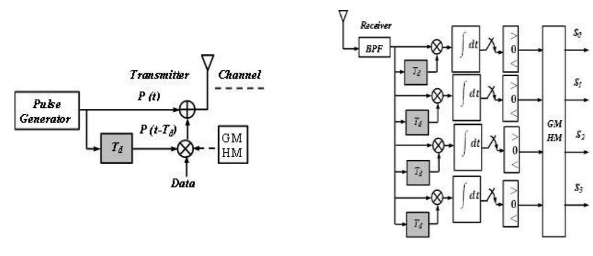


Figure 3: Block diagram of the TTR IR-UWB transceiver system [5]

In this work, a new structure is proposed by adding GMHM to the TTR as shown in Figure 4 where four pair pulses which represents a N_s with T_d arranged in four pairs (replica).



(a) (b)

Figure 4: The proposed MTTR transmitted reference transceiver block diagram, (a) transmitter, (b) receiver.

A. System model

The TTR transmitter transmits signal $s^{(k)}(t)$ is described in Equation 5.

$$s^{(k)}(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{E_s}{N_s}}\, p\left(t - jT_f - c_j^{(k)} T_h\right) + P\left(t - jT_f - c_j^{(k)} T_h - \delta\, \alpha^{(k)}_{\lfloor j/N_s \rfloor}\right) \quad (5)$$

where $p(t)$ is UWB signal with pulse duration of (T_p) and T_d as defined earlier, $\delta(\alpha)$ is Dirac delta function [9], superscript (k) refers to the number of users, subscript (j) refers to number of frames, and T_h time hoping. The corresponding time-invariant channel model based on the IEEE 802.15.3a is given by [10] and represented by Equation (6).

$$h^k_{(t)} = \sum_{l=0}^{L-1} \alpha_l^k \delta(t - \tau_l^k) \quad (6)$$

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^{th} multi-path, respectively. By inserting the response channel $h(t)$ and adding the noise, $n(t)$, in Equation 7, the general form of received UWB signals (r^k) at user k becomes:

$$r^k(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{E_s}{N_s}}\, p\left[\left(t - jT_f - c_j^{(k)} T_h\right) + P\left(t - jT_f - c_j^{(k)} T_h - \delta\, \alpha^{(k)}_{\lfloor j/N_s \rfloor}\right)\right] * h(t) + n(t) \quad (7)$$

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. Within the concept of the severe restriction on T_d, the new model for both transmitted and received signal are as in Equation (8) and (9), respectively.

$$s^{(k)}(t)=\sum_{j=-\infty}^{\infty}\sqrt{\frac{E_s}{N_s}}\,p\left(t-jT_f-c_j^{(k)}T_c\right)+P\left(t-jT_f-c_j^{(k)}T_c-\delta\alpha^{(k)}_{\lfloor j/N_s\rfloor}\right)H_{mod} \quad (8)$$

$$r^{k}(t)=\sum_{j=-\infty}^{\infty}\sqrt{\frac{E_s}{N_s}}\,p\left[\left(t-jT_f-c_j^{(k)}T_c\right)+P\left(t-jT_f-c_j^{(k)}T_c-\delta\alpha^{(k)}_{\lfloor j/N_s\rfloor}\right)H_{mod}\right]*h(t)+n(t) \quad (9)$$

III. Results And Discussion

An analysis of SER versus S/N at SER an accuracy level of 10^{-3}, which is highly accepted amongst engineers, was performed using MATLAB software package ver. (R2013a) to simulate the results of four cases based on IEEE802.15.3a, [10]. Figures 5 and 6 show the analysis of the first two cases of $N_s=4$ while the number of users is taken at 2 and 8 users. The S/N is improved by about 3 dB compared to the traditional results. The trend of the curves of SER vs S/N agrees with other prediction [5]. When the number of users increases to 8, S/N is shifted by about 1.9 dB. Regarding the shift, the results presented here are in agreement with the work done by Liang et al. and [11]. One possible interpretation to the decrease in S/N level as the number of user increasers is due to fit more users in the same number of frames which results in more noise expected compared to only 2 users.

The other results are presented in Figures 7 and 8 where $N_s=8$ at same number of users, namely 2 and 8. The SER vs S/N results of $N_s=8$ and 2 users show that S/N is shifted by about 2 dB while the shift was about 1 dB for 8 users. For same number of users, either 2 or 8, and the number of frames either 4 or 8, it is observed that the shift of MTTR compared to the traditional shift remains almost unchanged; however, the level of S/N is improved by about3.5 dB. The same trend was observed for the second case of 8 users.

IV. Conclusion

As Hadamard matrix is modified and implemented in the transmitter and receiver structure, the time delay T_d is controlled according to $T_d \ll T_{mds}$. Hadamard matrix was modified in order to satisfy the balance and bi-orthogonality conditions enabling total removal of IPI. As a result of modifying Hadamard matrix and implementing the condition of $T_d \ll T_{mds}$, it becomes feasible that S/N is improved and data rate increased in reasonable amount. The new modification, with the assistance of MATLAB, was tested by simulation at different N_s and number of users. The results presented in this work suggest that S/N is shifted (improved) to lower values when the parameters are evaluated at SER of 10^{-3} -the level which is accepted by engineering community. It is also observed that as N_s increases at a fixed number of users, S/N shifts towards lower values suggesting improvement in the data rate and reduction in SER traditional results. The trend of the curves of SER vs S/N agrees with other prediction [5]. When the number of users increases to 8, S/N is shifted by about 1.9 dB. Regarding the shift, the results presented here are in agreement with the work done by Liang et al. and [11]. One possible interpretation to the decrease in S/N level as the number of user increasers is due to fit more users in the same number of frames which results in more noise expected compared to only 2 users.

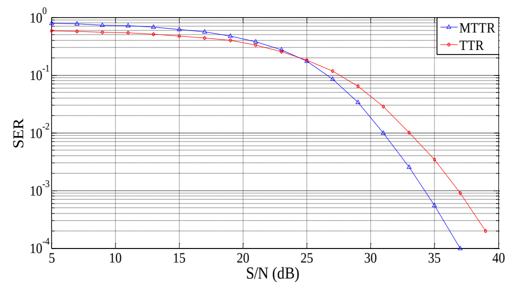


Figure 5: S/N and SER behavior of at number of frames N_s = 4 for 2 users

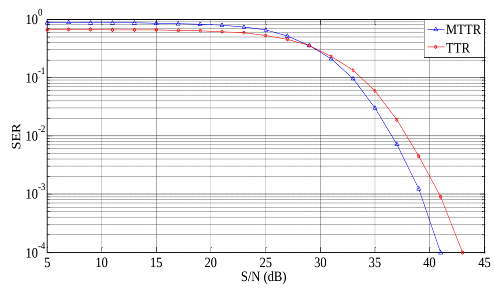


Figure 6: S/N and SER behavior of at number of frames N_s = 4 for 8 users

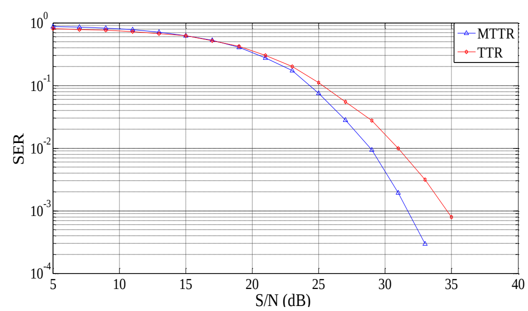


Figure 7: S/N and SER behavior of at number of frames N_s = 8 for 2 users

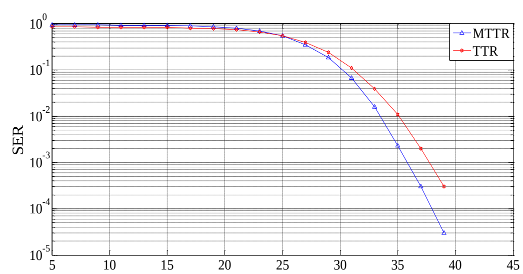


Figure 8: S/N and SER behavior of at number of frames N_s = 8 for 8 users

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