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Research Article

Weighted Symbol Decision for Transmitted Reference Impulse Radio Ultra-Wideband Receiver by Modifying Hadamard Matrix

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Abstract: The UWB technique is employed in this study to exclude unusual multipath components by introducing a modified Hadamard matrix. Within the concept of this approach, IPI is totally removed and the S/N is improved. The successful UWB developments were always challenged by some external factors such as noise, interference and wrong multipath components. The challenges were treated by several researchers and, in many occasions, success was achieved in improving the data rate. The basic objectives of the improvement include removing the inter-pulse interference, distinguishing the wrong multipath components and to achieve high accuracy. Transmitted reference impulse radio ultra-wideband is only one of these techniques where it is aimed to have better detection and estimation. The analogue signals are digitalized -a crucial step that significantly pushed transmitted reference impulse radio ultra-wide to a new frontier. The basic element of this study is to digitalize the output quantities of integrable data by using analogue-to-digital convertor. The other element of this study is to modify the Hadamard matrix in transmitter and receiver to achieve total removal of inter-pulse interference. As a result, the estimation and the decision were enhanced and, on other side, a reduction in signal-to-noise ratio by amount ranges from 7.12% to about 14.42% at the receiver compared to the previous modification (modified hoped single delay). Other achievements were performed by targeting inter-pulse interference total removal and the wrong multipath error was altered which led to high accuracy, better information and less simple error rate.

Keywords: Analogue-to-digital, inter-pulse interference, multi-path components, simple error rate transmitted reference impulse radio, ultra-wideband

INTRODUCTION

Ultra-Wideband (UWB) is very advanced communication system which offers very high data rates due to transmitted pulses with very short duration and low duty cycles. Despite the fact that UWB is a very powerful technique, its performance is highly sensitive to timing error (Zhao *et al*., 2011). UWB technology has become very interesting for its ability of fine resolving multipath components in addition to implementing and generating very low complexity (Rebhi *et al*., 2012). The high degree of diversity could be obtained from resolving dense multipath components using timing resolution property. The main challenge of UWB multipath components is originated from receiving hundreds of replicas with variety of delays, amplitudes and phases (Khani *et al*., 2012). Traditionally, Rake receiver was used to resolve UWB multipath signals components collected at the receiver, however; Rake receiver is no longer able to handle such huge components due to high complexity and additional fingers which could result in high cost and channel estimation. Rake receiver was then replaced by a new technique called Transmitted Reference (TR). In this new technique, TR transmits dual pulses, modulated and unmodulated, with precise delay time. Despite the fact that TR is a new technique, it still shows a drawback as the noise induced incurs in the transmitted reference unmodulated pulse which results in degrading severely the pulse power.

The recent research in UWB has been focusing on two major changes that includes quantization and shifted frequency reference (Niu *et al*., 2011). It was proposed that a slight frequency shift could be employed with the quantization to enhance the performance (Goeckel and Zhang, 2007). Traditionally, the noise involved with the data-bearing signal has been treated statistically by correlating the average of several

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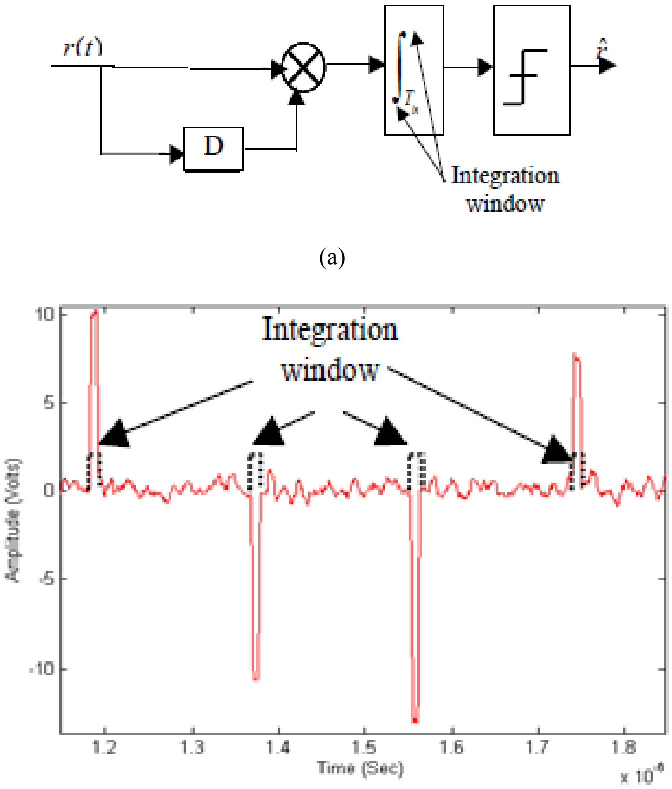
reference signals with the data signal. Niu *et al.* (2011) proposed an alternative method to treat the noise. Their approach is performed by creating a slight shift in TR receiver by using unmodulated UWB signal.

The shift in time, known as the time delay, severely impacts TR-UWB communication technology. TR limitation starts at the reference and data pulses time separation which has to be at least equal to the time channel delay spread to avoid IPI which could be yield 50% loss. The pulse itself is used as a reference and data at the same time by using coding and decoding through which a reasonable level of IPI is maintained (Farahmand *et al.*, 2008). When the time space becomes very close, the data rate increases. The multiple pulses maintain a certain level of Bit Error Rate (BER). When the multiple symbols per block are transmitted over identical frames, there is a possibility of increasing data rate. Each symbol in the block is assigned to a signature code orthogonal to the code of other symbols where the orthogonality codes are controlled via Walsh (Hadamard) matrix. Under such circumstances, the increase in the data rate was not affected by the performance and its relevant complexity (Farahmand *et al.*, 2008).

This study aims at improving communication in hospitals where the environment is very rich in multipath components. It is known that TR-UWB signal energy is generally composed of many multipath components and the goal is to distinguish amongst these components by using a coherent receiver in order to maximize the signal received. The optimized signals suffer from noise because of a delay-hopped TR Autocorrelation Receiver (AcR) communication system which has been recently implemented due to its simplicity and ability to synchronize and to capture all energy from all multipath channel components (Das and Das, 2010). Meanwhile, other research introduced the weighted energy in order to use utilize a set of M parallel integrators where the energy is collected over one of the M non-overlapping time intervals per symbol period. The signals from the integrators are linearly weighted and compared with the decision threshold (Wang *et al.*, 2011).

It is well-known that in rich multipath components environment, the interference becomes one of the most important challenging to the communication system. The interference amongst the multipath system could be originated from Inter-Symbol Interference (ISI). This type of interference is heavily studied (Troesch and Wittneben, 2007) and there are a few proposals to mitigate it (Tang *et al.*, 2007). Avoiding ISI could be managed by setting the TR delay to half of the symbol period without losing the output power of the signal (Troesch and Wittneben, 2007). Angelico *et al.* (2008) provided an alternative technique to reduce the ISI in



(a)

(b)

Fig. 1: Integration window in TR receiver; (a): and in received signal in noisy environment; (b): Nekoogar *et al.* (2004)

high transmission rate. A proposal to avoid such increase in ISI is performed by channel equalization scheme which results in fewer taps than the traditional TR (Nekoogar *et al*., 2004). To do so, an equivalent baseband time reversal system with multiple antennas is employed. Briefly speaking, TR performance depends, to a certain extent, on an accurate timing acquisition to enable estimating integration as shown in Fig. 1a and 1b.

The limit of the integration window shown in Fig. 1b depends on the accuracy of the time interval (Nekoogar *et al*., 2004). When the length of the integration is smaller than the pulse width, the data collected shows only a fraction of the pulse energy. Under this situation, the degradation will be more than the gain achieved by decreasing noise which results in net decrease in Signal-to Noise Ratio (SNR) output. In an alternative scenario where the time integral is larger than the pulse width, more noise will be introduced which, again, reduces the SNR output. The two cases discussed above are not suitable and therefore the integration interval should be equal to the pulse width. It is important to note here that any deviation from the precise position of the integration window could result in decreasing SNR level (Nekoogar *et al*., 2004).

In this study, a new technique is employed to improve the performance of TR-IR-UWB communication in which a decision is introduced to avoid certain unusual received strong positive or negative signals originated in the dense multipath environment due to noise, interference, or otherwise. These unusual multipath signals create an unavoidable error based on traditional receiving data. However, in this study, such error could be avoided and, consequently, the overall performance will be improved as expected. The decision is carried out individually after each integral and those signals with very high positive or negative amplitude will be converted according to a suitable threshold from Analogue-to-Digital (A/D) scheme. Away from previous approaches, which consider certain ways for estimation including the likelihood average, the estimation here is carried out on digitalizing the energy quantities. Within the digital output, the error will be significantly minimized.

MODELING WMHSD

The estimation of a specific delay in a train-like pulse could be conducted by variety of methods of estimation such as least square, likelihood, or root-mean-square method. The least square method is based on statistical gathering data which requires huge amount of data as in multipath environment. The outcome of this process becomes so complex and time-consuming procedure (Zhao *et al*., 2007). In an alternative method, called maximum likelihood, the processing data requires less than what the least square method. In both methods, sampling at high rate is required, however in TR, the high sampling rate is not required and, as such, TR signaling reduces the complexity. In this case, the estimating channel impulse response, $h(t)$, serves for aggregated analog channel $s(t) * h(t)$ and consequently, the information and pilot pulses do not overlap if a proper frame duration is chosen.

Figure 2 explains the transmission model in which an input data is treated by Pulse Position Modulation (PPM) at a coefficient of δ. The transmitted pulse, $s(t)$, is sent through the transmitting antenna where the pulse undergoes some changes in the shape before transmission. In the channel, the transmitted signal is convoluted with impulse response of the channel, $h(t)$. The signal suffers of another change as the signal is processed in the received antenna which results in changing the shape of the received signal, $r(t)$. Finally, the signal is affected by certain noise, known as additive white-Gaussian noise (AWGN), $n(t)$ and for sake of analysis the *AWGN* is considered as the only noise interference component.

The TR transmitter transmits signal $s(t)$ can be written as:

$$s(t) = p(t) + p(t - \delta(\alpha) - T_d) \qquad (1)$$

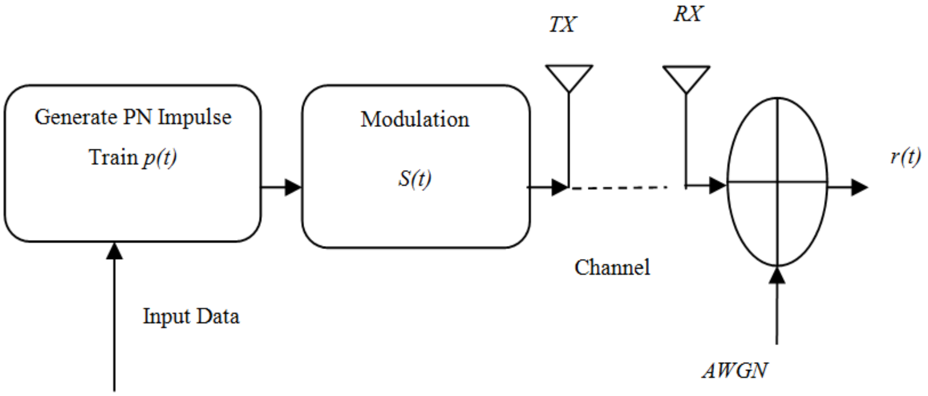


Fig. 2: Transmission model

where, $p(t)$ is UWB signal with pulse duration of T_p and delay time T_d, $\delta(\alpha)$ is the Dirac delta function (Li and Townsend, 2010).

The transmitted signal, $s(t)$, was heavily discussed (Niu *et al*., 2011; Farahmand *et al*., 2008) and the final form of $s(t)$ varies slightly; however most authors agreed on the format 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, $s(t)$ is the transmitted signal with maximum excess delay T_{mds} and the duration T_p which is subjected to $T_d \ll T_{mds} + T_p$ to fit the requirements of the current mathematical model:

$$s^{(k)}(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{\varepsilon_s}{N_s}}\, p\left(t - jT_f - c_j^{(k)} T_h\right) + P\left(t - jT_f - c_j^{(k)} T_h - \delta\right) \tag{2}$$

The received signal is attenuated by factor, α and, as such, the impulse response $h^k(t)$ is defined as:

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

where,
L = The number of multi-paths components.
τ = The offset between the users.

The received signal, $r(t)$, results from convoluted $s^{(k)}(t)$ with impulse response of the channel, $h^k(t)$ and could be described as follow:

$$r(t) = h(t) * s(t) + n(t) \tag{4}$$

Or, more in more general form which is described in Li and Townsend (2010):

$$r(t) = \sqrt{\varepsilon_p} \sum_{j=-\infty}^{j=\infty} \sum_{l=0}^{L-1} h_k p\left(t - jT_f - c_j^{(k)} T_h\right) + Pt{-}jTf{-}cjkTh{-}\delta\alpha \lfloor j/Ns \rfloor\, k{+}n(t) \tag{5}$$

where,
N_s : The number of symbols,
ε_p : The normalized pulse energy

In this study, weighted modified hoped single delay is employed using Hadamard matrix. The orthogonal codes is compromised with a code of (+1, +1) and (+1, -1) which are used in TR systems to remove IPI amongst any two successive reference and data waveform. This orthogonality code is described by Walsh-Hadamard matrix (Farahmand *et al*., 2008) as follow:

$$H_{2^0} = [1] = H_{2^1} = \begin{bmatrix} +1 & +1 \\ +1 & -1 \end{bmatrix} \tag{6}$$

In order to continue, Hadamard matrix has to be modified to serve and to examine the nature of the new TR-IR-UWB communication. The modification, in part, is carried out by rotating H_{2^1} by 180° (π radians) which results in a new modified Hadamard matrix:

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

The other concern is about the balance which can be utilized by combining matrix 6 and 7 which results in the modified Hadamard matrix as shown in Eq. (8):

$$H_{2^1}^{m} = \begin{bmatrix} -1 & +1 \\ +1 & -1 \end{bmatrix} \tag{8}$$

where, m refers to modified matrix. The matrix in Eq. (8) could be re-arranged based on the original definition of Hadamard matrix as represented in Eq. (9):

$$H_{2*2}^{m} = \begin{bmatrix} H_{2^1}^{m} & H_{2^1}^{m} \\ H_{2^1}^{m} & H_{2^1}^{m} \end{bmatrix} \tag{9}$$

The matrix, H_{2*2}^{m}, Eq. (9), has four subsequent matrices of $H_{2^1}^{m}$. The resulting matrix is shown in the upper half of $\mathrm{H}_{2*4}^{\mathrm{m}}$ which is shown in Eq. (10). Since the original Hadamard matrix has two rows, Eq. 6, H_{2*4}^{m} should also contain two rows which are developed by inserting $\mathrm{H}_{2*2}^{\mathrm{m}}$ in the lower half of H_{2*4}^{m} as shown in Eq. (10). Therefore, the generated modified Hadamard matrix (GMHM), H_{2*4}^{m}, is used to control the transmitted signal which is shown in Eq. (2) and the received signal as represented by Eq. (5). The GMHM satisfies the following matrix:

$$H_{2*4}^{m} = \begin{bmatrix} -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \\ -1 & +1 & -1 & +1 \\ +1 & -1 & +1 & -1 \end{bmatrix} \begin{bmatrix} \mathrm{D}_1 \\ \mathrm{D}_1 \\ \mathrm{D}_2 \\ \mathrm{D}_2 \\ \mathrm{D}_3 \\ \mathrm{D}_3 \\ \mathrm{D}_4 \\ \mathrm{D}_4 \end{bmatrix} \tag{10}$$

It is shown that in the modified Hadamard matrix (Eq. 10) that the two first rows undergo same delay because they belong to same tap and the same argument is suitable to the second two rows, to the third two rows and finally to the fourth two rows. Based on this approach, the transmitted signal $s^{(k)}(t)$ and the received signal $r(t)$ can be expressed by Eq. 11 and 12, respectively. The two equations include the modified Hadamard matrix, H_{2*4}^{m} which, eventually, represent the new mathematical model (Liang *et al*., 2012):

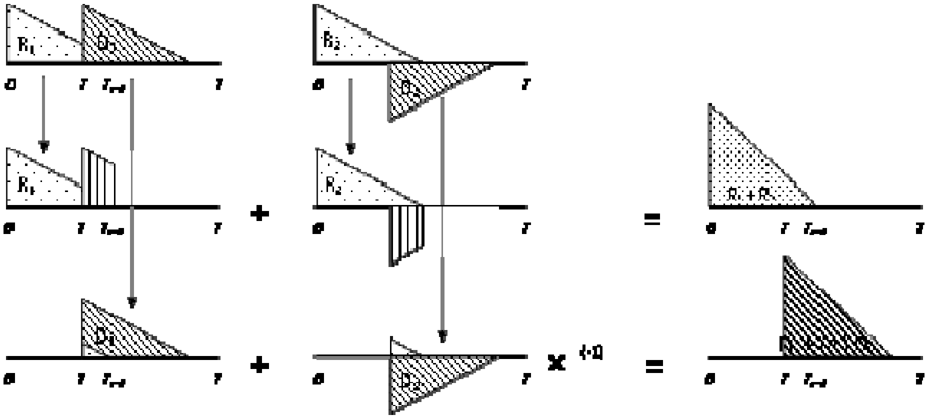


Fig. 3: IPI cancellation for N_s = 2 and symbol code (+1,-1) (Farhan and Latiff, 2016)

$$s^{(k)}(t) = \sum_{j=-\infty}^{\infty} \sqrt{\frac{E_S}{N_S}}\, p\left(t - jT_f - c_j^{(k)} T_h\right) + P\left(t - jT_f - c_j^{(k)} T_h - \delta\right) H_{2*4}^{m} \tag{11}$$

And,

$$r(t) = \sqrt{\varepsilon_p} \sum_{j=-\infty}^{j=\infty} \sum_{l=0}^{L-1} h_k p\left(t - jT_f - c_j^{(k)} T_h\right) + Pt{-}jTf{-}cjkTh{-}\delta\alpha \llcorner j/Ns \lrcorner\ kH2*4m+n(t) \tag{12}$$

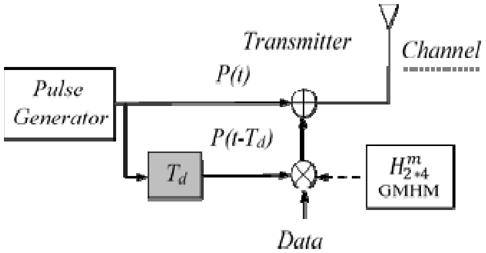


Fig. 4: The block diagram of the proposed transmitter

METHODOLOGY

Research is conducted in UTM/Malaysia during the last six months.

In Fig. 3, the modified Hadamard matrix H_{2*4}^{m} in Eq. (10) is used to totally remove IPI which results in increasing data rate and in reducing SER. The IPI removal is performed via two operations: the balance and the orthogonality. The issue here is not only the removal of IPI but how to further improve the performance (known as efficiency) of the TR-IR-UWB system.

The basic mechanism of IPI removal has already explained in Farhan and Latiff (2016). In TR-IR-UWB system each bit is transmitted over a number of frames, N_s, where each frame carries a TR doublet. In this study, the authors use a slightly modified transmitter block which is shown in Fig. 4. The block contains pulse generator and the new generated modified Hadamard Matrix (H_{2*4}^{m}) which controls transmitted data. The receiver, on other side, consists of a bandpass filter (BPF) which allows only a band-signal of interest. The estimation is performed by another set of parallel integration which has very precise limits and suitable position in the receiver.

At TR receiver, a received reference pulse is correlated with the data pulse in order to detect the transmitted signal. The output of each correlator is analog quantity which is transferred to a digital quantity by a device known as Analog-to-Digital convertor (A/D). It is well-known that the analog quantities are characterized by normal, very high, or very small intensity. Therefore the detection of these analogs will suffer of errors due to wrong multipath signals which, eventually, ruin the estimation process. To solve this drawback, the work in this field considers a statistical procedure to minimize the effect of discrepancies amongst these analogs data such as the maximum likelihood or the least square methods (Li and Townsend, 2010). However, in this study a new technique is developed and applied through which those unusual analogs data (very high or very low) are identified and then converted into digital quantities which results in significant minimized estimation error caused by such unusual multipath signals. This digital-converted signals technique improves the performance of the received data rate and reduces the SER. By summation circuit, the numbers of (+1s) or (-1s) can be allocated in order to pass these number (bits) to the detector for decision which is composed of 0 or 1 depending on transmitted message as illustrated in Fig. 5.

Under this proposal, no power is wasted as in the likelihood estimation or least-square analysis, but, instead, all signals are considered digitally for estimation. The advantage of this new technique is to avoid processes such as distinguishing the likelihood components which, by itself, adds cost for estimation process on the account of the overall performance. In summary, there are two advantages of the newly

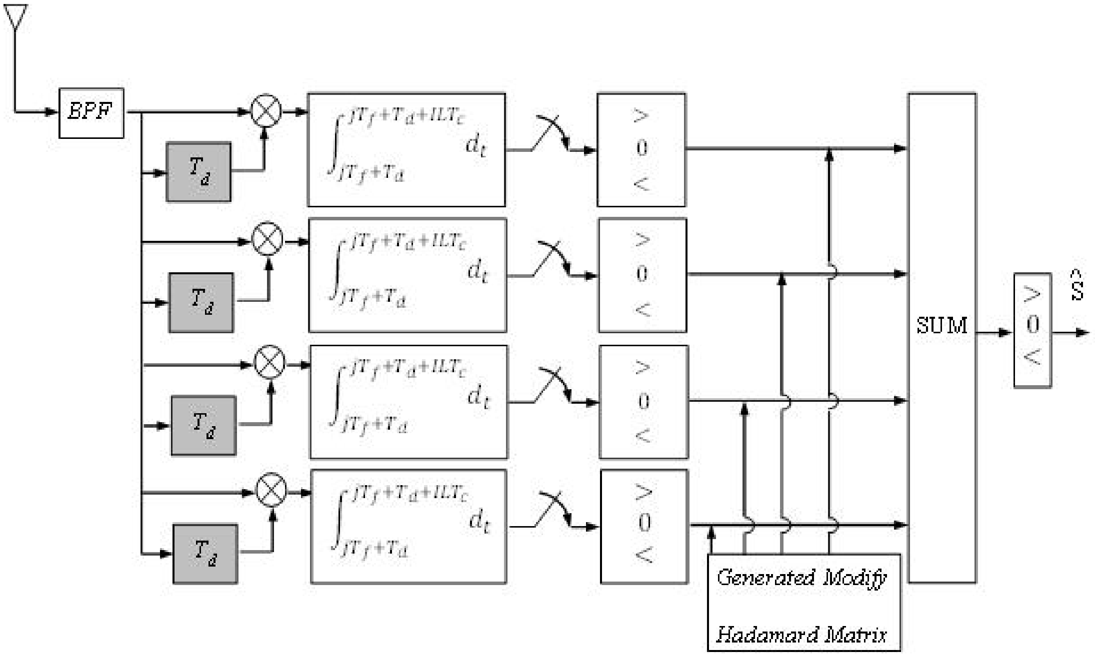


Fig. 5: The block diagram of the proposed (WMSDH) receiver

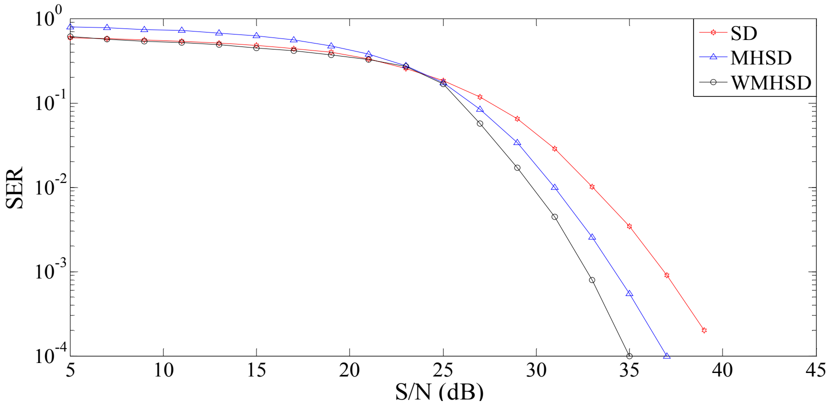


Fig. 6: Simple error rate versus signal to noise ratio for N_s = 4 and 2 users

modified Hadamard matrix: first is to massage all unusual multipath signal energies whose magnitudes are much higher than the average of the likelihood components of the total multipath component signals and secondly, to preserve any performance from further deterioration due to ignoring those unusual components.

RESULTS AND DISCUSSION

In this part the Weighted Modified Hoped-Single Delay (WMHSD) and the Modified Hoped Single Delay (MHSD) results are compared with the traditional results (SD) (Farhan and Latiff, 2016). In Fig. 6 the Simple Error Rate (SER) is plotted against signal-to-noise ratio (S/N) for $N_s = 4$ and for two users. Generally, there are two important factors underline the goal of the TR-IR-UWB research work: SER and S/N ratio. The accepted level of SER amongst most researchers is 0.1% (10^{-3}) or below. In Fig. 6, S/N is reduced by about 1.4 dB which is less than the S/N estimated by MHSD and by about 5 dB from SD. The improvement of 1.4 dB has an important impact on the quality and feasibility of the TR-IR-UWB under new modified system. The improvement also results in avoiding unusual multipath components which is considered as the cornerstone of the new modification. Briefly, in this study, the drawback of the MHSD approach is swept away by employing the digital instead of analogue (A/D).

In Fig. 7, where the number of users increases to 5 and for same $N_s = 4$, the S/N shows an improvement of about 1.2 dB which is slightly less than the improvement shown in Fig. 6 where the number of users was only two. Seemingly, as the number of user increases, the noise increases, too which suggests that more noise incurred and reflects on the improvement of the S/N.

Keeping the trend shown in Fig. 6 and its subsequent analysis, it is expected that the S/N shows less improvement compared to the case of 5 users as shown in Fig. 8. S/N is improved only by about 0.8 dB compared to 1.2 dB for 5 users and 1.4 dB for 2 users.

As the numbers of frames increases from 4 to 8, there will more room for users to fit and, consequently, S/N should, based on the trend mentioned earlier, improve. Figure 9 to 11 show that S/N improves by 2, 1.5 and 1.1 dB, for 2, 4 and 8 users, respectively.

The S/N data at SER level of 10^{-3} shown in Table 1 is taken from Fig. 6 through Fig. 11 for MHSD and WMHSD compared to the traditional S/N-SD values. For $N_s = 4$ and the number of users at 2, 5 and 8, S/N improvement at level of 10-3 ranges from 8 to 7.1% for the previous modification (MHSD) while it ranges from 12.86 to 9.26%. As an average, the improvement

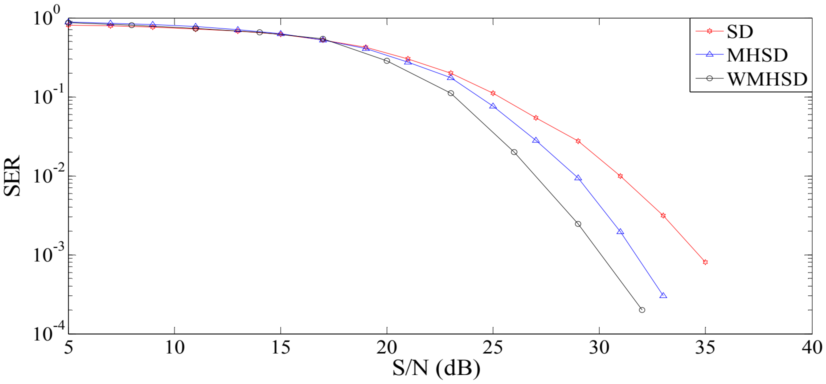


Fig. 7: Simple error rate versus signal to noise ratio for N_s = 4 and 5 users

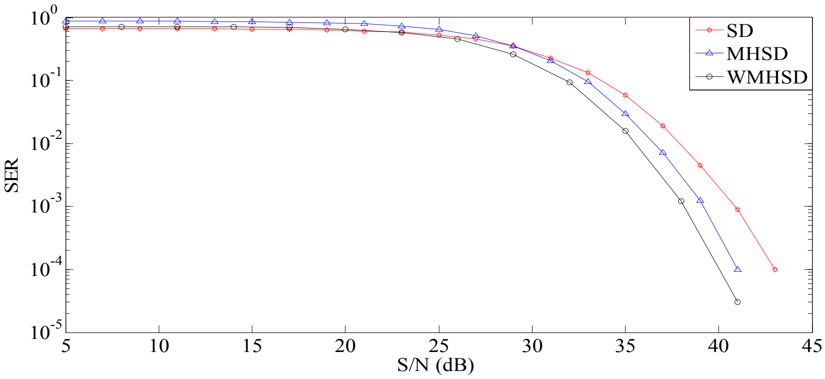


Fig. 8: Simple error rate versus signal to noise ratio for N_s = 4 and 8 users

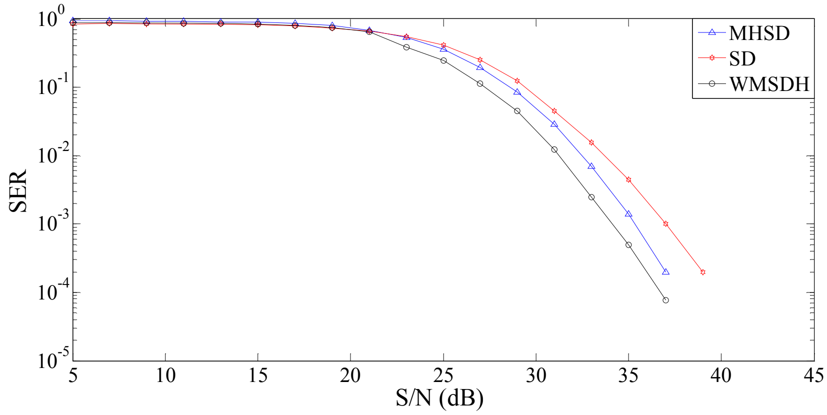


Fig. 9: Simple error rate versus signal to noise ratio for N_s = 8 and 2 users

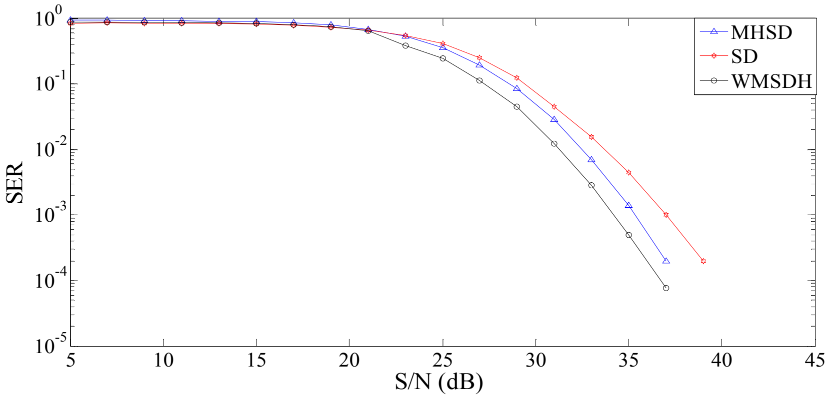


Fig. 10: Simple error rate versus signal to noise ratio for N_s = 8 and 5 users

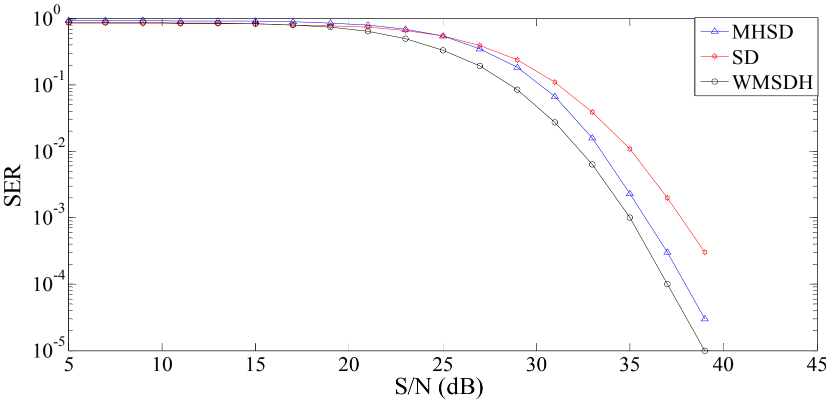


Fig. 11: Simple error rate versus signal to noise ratio for N_s = 8 and 8 users

Table 1: Improvement of S/N of MHSD and WMHSD versus SD

User	Symbols	SD@10^{-3} S/ NdB	MHSD@10^{-3} S/N dB	WMHSD@10^{-3} S/D dB	$\frac{\text{SD}-\text{MHSD}}{SD}$ %	$\frac{\text{SD}-\text{WMHSD}}{\text{SD}}$ %
2		37.3	34.3	32.5	8.01	12.86
5	$N_s = 4$	40.7	37.5	36.5	7.86	10.03
8		42.1	39.1	38.2	7.12	9.260
2		35.4	32.1	30.3	9.32	14.44
5	$N_s = 8$	38.2	35.1	33.5	8.11	12.31
8		39.2	36.2	35.5	7.65	9.020

of WMHSD is higher than that of MHSD by 2 and 4%depending on the number of users. When N_s increases to 8 while the number of users is same as in previous case, S/N improves between 7.65 and 9.32% for MHSD and from 9.02 to 12.30% for WMHSD. Overall, there is a slight improvement in S/N reduction which agrees with other published literatures in this regards (Farhan and Latiff, 2016). It is observed from the data that as N_s increases, the level of noise decreases due to less noise possible as the number of symbols increases. It is also noted from the data that the S/N level is sensitive to the number of users.

CONCLUSION

The TR-IR-UWB communication system has undergone significant improvement due newly modified Hadamard matrix and by digitalizing data by A/D technique. SER and S/N parameters were adjusted by simulation approach to evaluate the outcome of the modifications. So far, Hadamard matrix has encountered two recent modifications: one was discussed earlier in a separate published paper in which MHSD was utilized, while in the current study, a WMHSD was introduced. The new process was achieved by converting all receiving multipath signals from analogue to digital and, at the same time, the unusual multipath components were digitalized to either +1 or -1. By doing so, the estimation and the decision are well-performed which results in reduction in S/N ratio by 7.12% to as high as 14.41% depending on the number of symbols and the number of users.

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