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Multi-User I Intrference Mitigation in TR UWB Receiver via Mid-point Impulse Correlation Technique

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Abstract

Impulse radio-ultra wideband (IR-UWB) is a wireless technology system that offers a high data rate within a short range. Therefore, IR-UWB system is regarded as an excellent physical layer solution to the multi-piconet Wireless Personal Area Network (WPAN) applications. In spite of all the advantages of IR-UWB, there are several fundamental and practical challenges that need to be carefully addressed. The big and most important one among these challenges is the interference. In this paper, to largely suppress the Multi-User Interference (MUI), a very simple novel Midpoint Impulse Correlation (MIC) technique is proposed instead of the conventional correlation. The proposed technique is programmed using Matlab R2008b software and tested in various suggested scenarios close to the realistic multi-piconet WPAN environments using the dense multipath indoor IEEE 802.15.3a CM2. The performance results for the proposed technique exhibited lower SERs values as compared with the conventional correlation.

***Keywords* : IR-UWB, MIC, IEEE 802.15.3a CM2, WPAN and SD .**

الخلاصة

أن ارسال النبضات الضيقة جدا Impulse Radio (IR) وبحزمة اتساع عريضة جدا Ultra-Wideband (UWB)هو نظام تكنولوجي لاسلكي يَعْرِضُ سعة عالية ضمن مدى قصير. لذا، يُعتَبرُ نظام IR-UWB حَلاً ممتازاً للطبقةِ الفيزياوية لتطبيقاتِ شبكات الـ WPAN المتكونة من شبكات متعددة صغيرة جدا Multi-piconets . بالرغم مِنْ كُلّ فوائد نظام IR-UWB ، هناك عِدّة تحديات أساسية وعملية والتي مِن الضَّرُوري أَنْ تعامل بعناية كبيرة. أهم وأكبر تحدي والأكثر أهميةً بين هذه التحديات هو التداخلُ بأنواعه.ولغرض تَحسين أداءِ الانظمةِ في البيئاتِ متعددة المستخدمين، تم ابتكار واقتراح طريقة إرتباط بسيطة جداً بدلاً مِنْ الإرتباطِ التقليديِ وهي إرتباط الاندفاع المنتصف Midpoint Impulse Correlation (MIC) وذلك لاخماد الـ MUI بشكل كبير جدا. الطريقة الجديدة المقترحة تم برمجتها باستخدام الـ Matlab R2008a وتم تجريبها في سيناريوهات مختلفة قريبة من بيئات شبكات الـ Multi-piconet WPANs الواقعية، وباستخدام القناة الداخلية الكثيفة متعددة الطرق نوع CM2IEEE 802.15.3a. إضافةً إلى ذلك، تم مقارنة الطريقة المقترحة بالطريقة التقليدية وأبدت قيم منخفضة للـ SERمُقارنة بها.

1. Introduction

As wireless communication systems are making the transition from wireless telephony to interactive internet data and multimedia types of applications, the desire for higher data rate transmission is increasing tremendously. As more and more devices go wireless, future technologies will face spectral crowding and coexistence of wireless devices will be a major issue. Ultra Wideband (UWB) offers attractive solutions for many wireless communication areas, including Wireless Personal Area Networks (WPANs), wireless telemedicine, and UWB wireless mouse, keyboard, and speakers [1]. With its wide bandwidth, UWB has the potential to offer much higher capacity than the current narrowband systems. From Shannon's formula for the capacity C in b/s in Additive White Gaussian Noise (AWGN), the capacity of the UWB system occupying bandwidth BW, as a function of the Signal to Noise Ratio (SNR) at a distance d between the transmitter and receiver is given by previous study [2]:

$$C(d) = BW \quad \log_2(1 + SNR(d)) \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

The function SNR (d) represents the effect of path losses on the transmitted signal. It can be seen that UWB systems offer their greatest promise for very high data rates for high BW.

The UWB system was often referred to as base-band, carrier-free or short impulse. A UWB signal is any signal whose fractional bandwidth BW_f is greater than 0.2 or occupies 500 MHz or more of the spectrum. The BW_f is given by previous study [2]:

$$BW_f = \frac{BW}{f_c} = 2\frac{(f_H - f_L)}{(f_H + f_L)} \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where f_H and f_L are defined as the highest and lowest frequencies, respectively in the transmission band and f_c is the center frequency.

UWB systems cover a large spectrum and interfere with existing users and narrow band services [3]. In order to keep this interference to the minimum, a spectral mask was specified for different applications which show the allowed power output for specific frequencies.

A possible technique for implementing UWB is the Impulse Radio (IR), which is based on transmitting extremely short (in the order of nanoseconds) and low power pulses [2]. These very short pulses in transmission result in a UWB spectrum [4]. Rather than sending a single pulse per symbol, a number of pulses determined by the processing gain of the system are transmitted per symbol.

The most popular approach for realizing UWB communications is Time Hopping(TH-IR). It allows a very simple transmitter structure that consists of only a baseband pulse generator, completely obviating the need for passband components like mixers, local oscillators, etc. However, the implementation of the receiver can be considerably more complex in a multipath environment.

2. *The IEEE 802.15.3a Channel Standard Model*

The IEEE 802.15.3a task group has evaluated a number of popular indoor Channel Models (CMs) to determine which model best fits the important characteristics from realistic channel measurements using UWB waveforms. The goal of the channel model is to capture the multipath characteristics of typical environments where IEEE 802.15.3a devices are expected to operate. Although many good models were contributed to the group, the model finally adopted was based on a modified Saleh-Valenzuela (S-V) model that seemed to best fit the channel measurements [5].

The multipath model adopted by the IEEE 802.15.3a committee for the evaluation of UWB physical layer proposals consists of the following discrete time impulse response [6]:

$$h(t) = X\sum_{k=0}^{K}\sum_{m=0}^{M}\alpha_{m,k}\delta(t-T_k-\tau_{m,k}) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3)}$$

where K is the number of clusters, M is the number of paths in the k^{th} cluster, $\alpha_{m,k}$ is the multipath gain coefficient, T_k is the delay of the k^{th} cluster, $\tau_{m,k}$ is the delay of the m^{th} MPC (ray) relative to the k^{th} cluster arrival time T_k, and {X} represents the log-normal shadowing. Furthermore, h(t) can also be written as [7]:

$$h(t) = \sum_{l=1}^{L}\alpha_l\delta(t-lT_m) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

where α_l is the multipath gain coefficient, represents the sum of all MPCs arrived in l^{th} time bin and L is the number of resolvable MPCs. Assuming that T_m is equal to the IR-UWB chip interval T_c, then h(t) becomes:

$$h(t) = \sum_{l=1}^{L}\alpha_l\delta(t-lT_c) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(5)}$$

and by letting $\tau_l = lT_c$, then h(t) becomes:

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

3. *IR-UWB Receiver Options*

High capacity, high-data rate, simple, power-efficient, low-cost, and small IR-UWB receivers design is a challenging task [1].

A generic UWB receiver structure is shown in Fig. (1) [1,6]. The optimal matched filtering implemented as Rake with a simple single correlator receivers correlate the received signal with a local template. The local template can be a pulse template, a frame template, or a template that includes multiple pulses to include the relative delays between pulses based on the TH code. In either case, the template needs to be estimated locally based on the received signal by transmitting some training sequences. This type of receiver, which correlates the received signal with a template, is often referred to as "locally generated reference" systems or simply as "correlation" receivers (switch at point 2). Alternatively, the received signal can be correlated by itself, which leads to "autocorrelation" receiver structures (switch at point 1) i.e., the TR receiver.

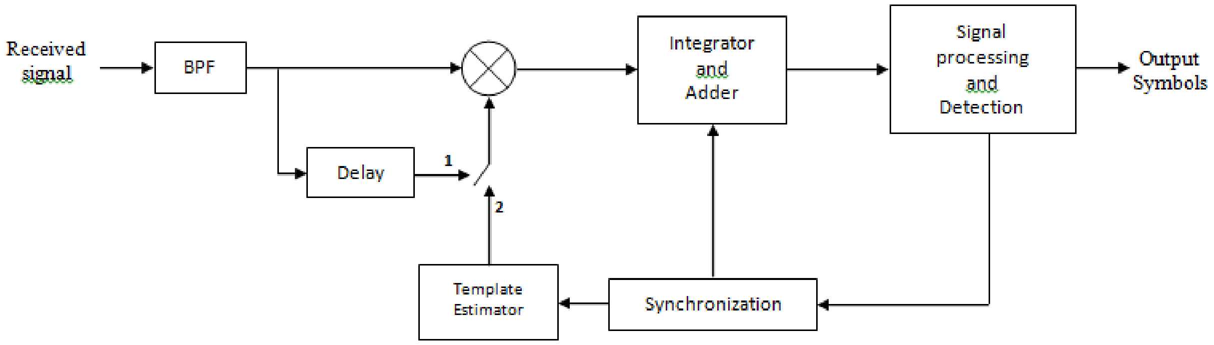


Fig. (1): A Generic IR-UWB receiver structure

4. IR-UWB TR-Based Scheme

One of the key challenges for IR-UWB system is the construction of low-cost receivers that work well in multipath environments. From the previous section, it's known that the coherent Rake receiver offers optimal performance, relying on enough fingers to accurately capture all or a significant part of resolvable MPCs.

However, a large discrepancy in performance exists between the implementations and the theoretically optimal receivers. In IR-UWB system, the number of resolvable paths could reach tens to over a hundred in typical indoor propagation environments, which imposes technical hurdles as well as implementation difficulties. In order to capture a considerable portion of the signal energy scattered in MPCs, a conventional Rake requires an impractically large number of Rake fingers. In addition, Rake reception performance requires accurate channel and timing knowledge, which is quite challenging to obtain as the number of resolvable paths grows. The received pulse shapes of resolvable multipath are distorted differently due to diffraction, which makes it suboptimal, and one must use line-of-sight signal waveform as the correlation template in Rake reception which is impossible at all. Because of these issues unique to IR-UWB systems, an optimal Rake receiver design becomes either ineffective or very complicated [8].

The basic principle in TR-based schemes is to transmit a reference (unmodulated) pulse along with the data (modulated) pulse. The reference pulses and the data pulses are transmitted with a delay T_d between them. When the delay is less than the T_{mds}, the reference and data pulses can be assumed to be affected similarly due to the channel. Therefore, instead of using a local template, the TR scheme uses the reference pulses as the template for correlating the data pulses, and for the demodulation of the transmitted information. TR transceiver structure is shown by the block diagram in Fig. (2) [1,9].

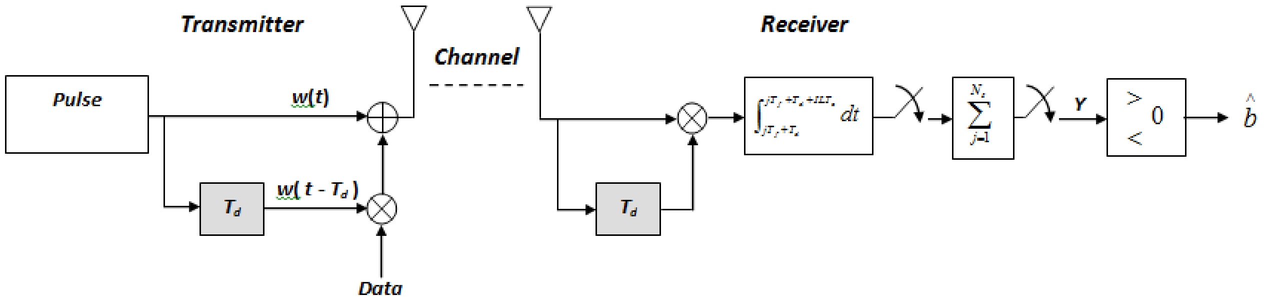


Fig. (2): Block diagram of a simple IR-UWB TR transceiver system

Another important issue in TR scheme is the use of the noisy templates for the correlation. In other words, as the TR scheme makes use of a “dirty” reference to detect the data, it still suffers from a larger performance degradation compared to a matched filter scheme [10].

In addition to single user performance, multiple accessing capabilities of TR schemes and techniques to improve multiuser performance are also important. If not designed properly, TR schemes are expected to be more susceptible to MUI and to other interference sources. First of all, the TR schemes experience more interference due to the integration of the multiplier output over a window that both desired pulses and possible interfering sources exist.

However, IR-UWB TR also has some disadvantages. It is often considered as a low data rate scheme because of implicit assumptions that the pulse spacing T_d in a doublet should be longer than the T_{mds} to prevent IPI, and the T_f should be chosen such that there is no IFI: together this leads to $T_f > 2T_{mds}$. Since both pulses in a doublet go through the same noisy channel, the correlating operation enhances the noise, which degrades the BER performance. In most IR-UWB TR schemes, signals are integrated over the full frame or symbol period, which may accumulate noise, especially at the end of the frame (or the tail of the multipath channel) where the signal strength is much weaker or even absent [11].

A conventional TR signaling carries bit information using the phase difference between the reference and data pulses occurring with fixed relative delay in a frame. The i^{th} bit’s transmitted signal of conventional TR using BPSK modulation can be written as [12]:

$$S_{tx}^{(v)}(t)=\sqrt{\frac{E_f^{(v)}}{2}}\sum_{j=iN_s}^{(i+1)N_s-1}[w_{tx}(t-jT_f-c_j^{(v)}-\tau_o^{(v)})+b_i^{(v)}w_{tx}(t-jT_f-c_j^{(v)}-T_d^{(v)}-\tau_o^{(v)})] \quad \text{.........} \ (7)$$

Where $w_{tx}(t)$ is the unit-energy transmitted pulse of duration T_p (also equal to T_c). T_f is the frame time to transmit a pair of reference and data pulses, and E_f here is defined as the frame energy. To avoid the IFI, it is assumed that $T_f \geq T_h + T_d + T_{mds}$, where T_d is the relative time delay between the reference and data pulses, and is assumed to be an integer multiple of chip time ($T_d = \Delta T_c$), where

Δ is an integer. b_i is the ith binary bit, taking on the values of {−1, +1} with equal probabilities. Note that, to allow for multiple access a user specific THS is employed to randomize the location of the pulse pair in each frame. The received signal r(t) is given by:

$$r(t)=\sum_{v=1}^{N_u} h^{(v)}(t)\otimes S_{tx}^{(v)}(t)+n(t) \quad \text{..} \ (8)$$

Assuming perfect synchronization, the sum of all correlated values over N_s frames is used as the decision statistic to detect the ith transmitted data symbol for vth user, the decision statistic ($Y_{bit}^{(v)}$) is given by:

$$Y_{bit}^{(v)}=\sum_{j=1}^{N_s}\int_{jT_f+c_j^{(v)}+T_d^{(v)}}^{jT_f+c_j^{(v)}+T_d^{(v)}+ILT_c} r(t-T_d^{(v)})\,.\,r(t)\ \ dt \quad \text{..................................} \ (9)$$

5. Integration Length Optimization

The critical design parameter for IR-UWB TR receivers is the Integration Length (IL) [13].At the integrator block - Fig. (2) -, the integration was done for the entire length of the T_{mds}. But, since indoor wireless channels change with location and distance between transmitter and receiver, it was realized that T_{mds} and thus integration time should be jointly taken into account to optimize the performance of systems. For a TR system working in an environment for example CM2 having a T_{mds}, the IL determines the amount of pulse energy as well as the noise captured, thus affecting the effective SNR of the decision variable.

The IL is assumed to be an integer multiple of the chip time, denoted by ILT_c, satisfying $0 < IL\ T_c \leq T_{mds}$.

6. The proposed Midpoint Impulse Correlation Technique

In the previous receiver, the IPI is completely removed. The multiple access technique that used is the TH. In fact, this techniqueis essentially used to distinguish between access users, but they cannot be hardly removed, mitigated, or prevented of serious MUI. In other words, they are not appropriate for concurrent schemes. The question arises here, what happens if the interferer pulses are largely overlapped with the intended pulses in the overlapped or non-overlapped portionof the reference and data waveforms? Certainly, the correlation process between the reference and data waveforms will have large errors and so the decision process will overwhelm with errors that yield a strong SER degradation. The correlator will in this case make a correlation among the reference, data, and the huge interferer pulses along the entire channel access delay that contained the replicas of pulses due to multipath channel.

The results of the correlation process will be wrong because of the collided pulses. To deal with this problem, a novel correlation technique is proposed called Midpoint Impulse Correlation (MIC). Thus, instead of performing a complete correlation between one reference and one data pulse, a special correlation can be performed between only the middle impulses (samples) of the two waveforms. The middle sample has the larger amplitude and the probability it is affected with collided pulses will be largely decreased. In doing this function, first the resulted total received reference and the delayed data waveforms, $R_{ref}(t)$ and $R_{data}(t)$ respectively are individually multiplied by a mask function $F_{mask}(t)$ which is defined as:

$$F_{mask}(t) = \sum_{k=1}^{IL} \delta(t-(k-1)T_c - T_p/2) \quad \text{...} \quad (10)$$

The principle of the mask function is illustrated in Fig. (3) that shows the multiplication with pulse replicas due to multipath effect. In fact, the multiplication is done along the IL instead of T_{mds}, and therefore this is another simplification for the mask function.

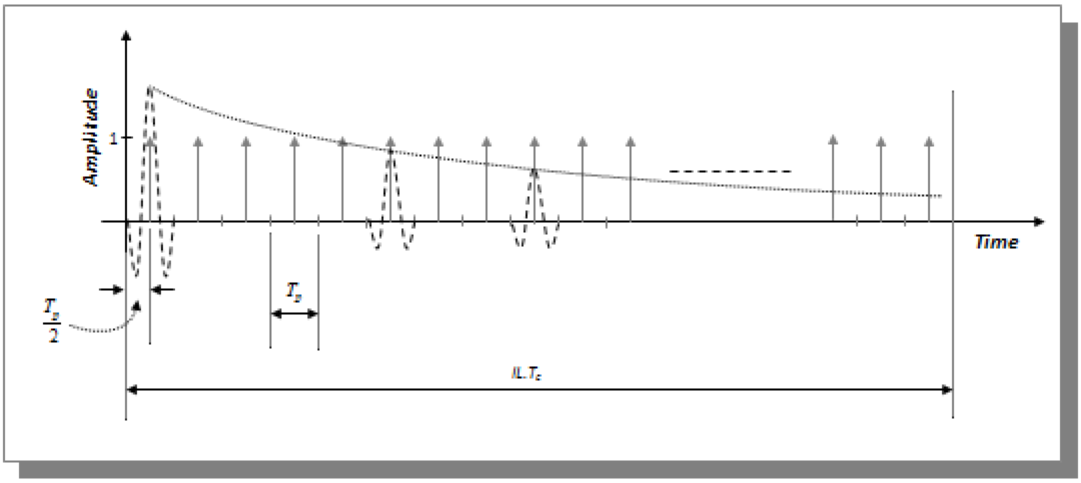


Fig. (3): The mask function

Anyway, the resulting sampled version of $R_{refe}(t)$ and $R_{data}(t)$ are then correlated to get the metric quantity. Certainly, a large portion of the signal energy will be lost due to the above process especially if there is no MUI.

7. System and Channel Models

The general block diagram of the IR-UWB indoor physical layer communication system investigated and programmed in this paper is shown in Fig. (4) with IEEE 802.15.3a indoor multipath channel and IR-UWB TR receiver.

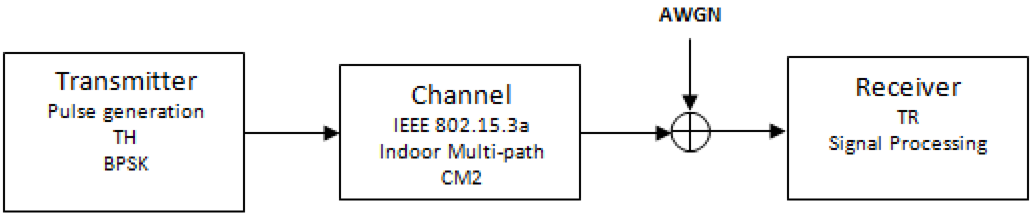


Figure (4): IR-UWB communication system used in this paper

Also, the MUI model that is used in this work is shown in Fig. (5).

The NLOS IEEE 802.15.3a indoor WPAN multipath CM2 has been used with an exponentially decaying delay profile. The CM2 is the best fit of the piconet dimension that does not exceed 4m which is the same work distance of CM2. For every new transmitted data symbol, a single CM2 channel realization is chosen among 10,000 bad and good already prepared channel realizations for each transmitted user's symbol for the desired and interferer piconets.

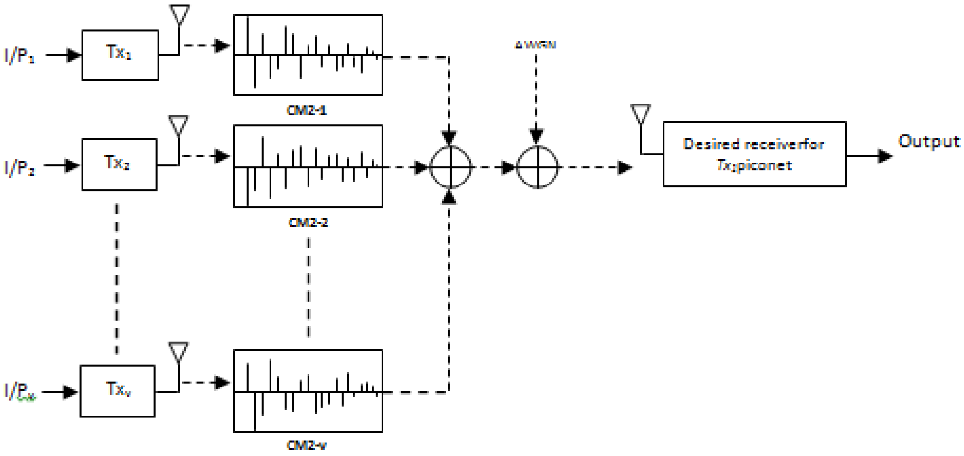


Fig. (5): The MUI model in the presence of multipath and AWGN channels

8. *Main System Parameters*

The system parameters are chosen to satisfy some of the assumptions listed in the previous sections. All parameters are fixed unless mentioned otherwise. Table (1) show the system parameters that will produce the results presented in section 9.

Table (1): Simulation parameters

Parameter	***Symbol***	***Value***
Sampling period	T_{sam}	0.02 ns
Pulse duration	T_p	0.4 ns
Chip time	T_c	0.5 ns
Pulse shaping factor	τ_{sf}	0.24 ns
Channel bin duration	T_m	0.5 ns
Channel duration	T_{mds}	70 bins
Path loss exponent [34]	n	3.5
Number of pulses per symbol	N_s	variable
Received Signal-to-Noise ratio	$(S/N)_{RX}$	variable
Desired transmitted power in [dBm/Hz][8]	$(PT_1)_{Tx}$	variable
Interferer transmitted power in [dBm/Hz][8]	$(PT_{int})_{Tx}$	variable
User 1 distance	d_1	variable
Interferers distances	d_{int}	variable
Piconet diameter	------	4 m
Users' delays	$\tau^{(v)}$	($0-T_f$) ns
TH length	$N_{h.}$	50 chips
WPAN dimension	------	(0 – 10) m
Pulse delay for SD receiver	------	1 bin
Frame duration	T_f	variable
Number of symbols generated by the source	------	40000 sym.

9. *Performances of the Proposed TR Receivers*

9.1 Determining of Optimum IL

The first step in performing the simulation is to determine the optimum IL value at different IL range between (1-100) channel bins. The choice of optimum IL is a very important step and will be used in the next performance steps.

In addition, d_1 and d_{int} are set to 3.16 m to maintain the integer $(S/N)_{Rx}$ ratios shown in Table (1) for various PT_1 corresponding values.

The performance is evaluated in terms of average SER for the four proposed besides the SD receivers using the sets of parameters shown in Table (2):

Table (2): Various sets of parameters to determine optimum IL.

Set	$(S/N)_{Rx}$ [dB]	$(PT_{int})_{Tx}$ [dBm/Hz]	N_s	N_u
1	0	----	4	1
2	14	-98	4	2
3	14	-98	4	3
4	14	-98	4	4

In addition, d_1 and d_{int} are set to 3.16 m to maintain the integer $(S/N)_{Rx}$ ratios shown in Table (2) for various PT_1 corresponding values.

The SER versus IL for set 1 parameter is plotted in Fig. (6). In this figure it can be concluded that optimum integration interval lies in the range of (20–40) bins and this has the best performance. As an important notice, the SD receiver has the best performance in single piconet case, hence it achieved about 6×10^{-4} SER. On the other hand, the SD/MIC receiver achieved the worst performance. This is due to the low S/N value that makes the decision devices in the two receivers in a challenge task to determine the estimated symbol. On the other hand, the receiver based on MIC has achieved very high SER values due to lose of energy during the special correlation process as compared with the conventional correlation.

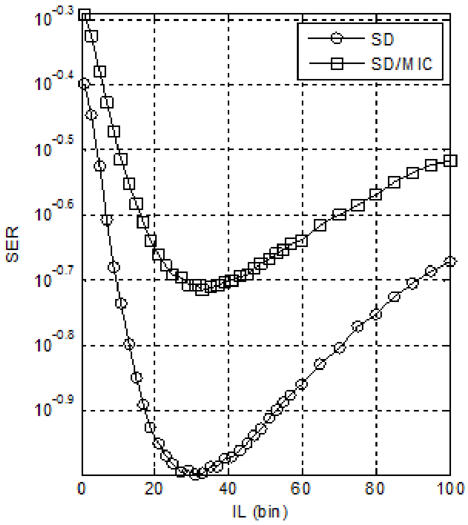


Fig. (6): The IL for set 1

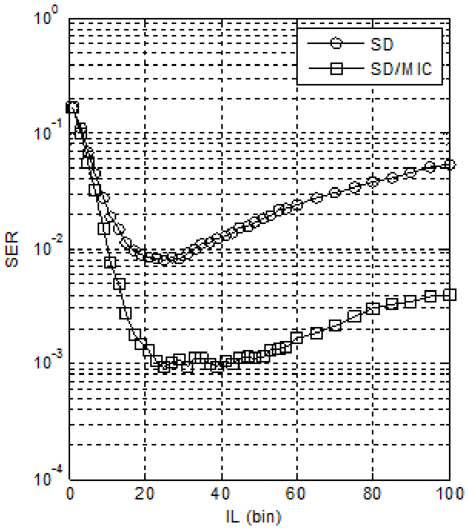


Fig. (7): The IL for set 2

In general, the performance suffers when enough energy is not captured before the integration interval. Also, the SER is increased beyond the integration interval due to the small amplitude gain of the channel (the channel tail) and therefore more noise will largely degrade the performance.

When N_u = 2,3 and 4, an inversion point is noticed in the SER performance of the SD/MIC receiver as shown in Figs. (7-9) for set 2 parameters. The optimal IL region is about (20-33) bins for the SD receiver, while it is about (22-37) bins for the SD/MIC receivers. In overall, the IL regions for all receivers are decreased due to the MUI that makes the receivers depend on the first fewer channel paths in the beginning of the multipath channel that have large gains. The worst SER is obtained for the SD receiver due to the MUI that overwhelm the correlation process to yield wrong quantities.

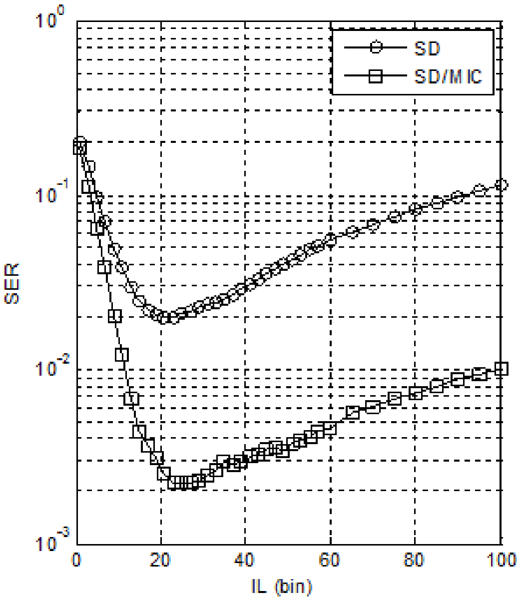


Fig. (8): The IL for set 3

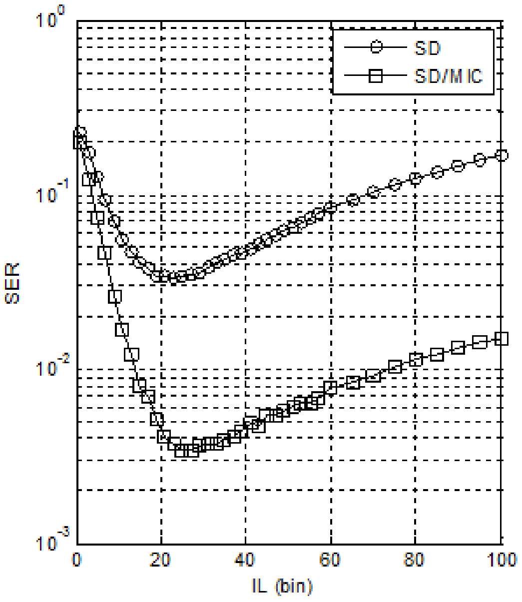


Fig. (9):The IL for set 4

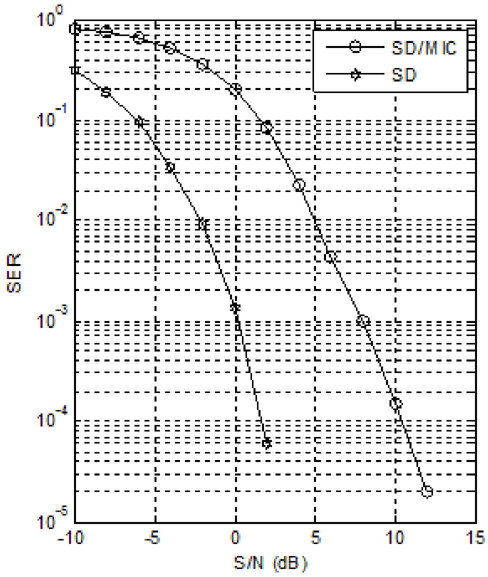
Now, the ILs selected values is based on the minimum ones whatever the SER values which somehow reduces receiver complexity (shorter and fixed IL) without causing too much performance loss. This is because of the nature of the multi-piconets concurrent transmission. In other words, the expectation that only a single piconet is active in a multi-piconet WPAN is very weak. Therefore, IL = 22 bins is a good choice and may be chosen for SD receivers, whereas IL = 29 bins is also a good choice and may be chosen for the SD/MIC receiver as an optimum ones.

The choice of the optimal IL values is very important step for the next performance simulations as will be seen later.

9.2 Performance with Single-piconet w/o IFI and ISI

A simulation is done to study the performance of the proposed receivers as a function of the received S/N per frame at the receiver input for N_s = 4. Fig. (10) shows the performance without the effects of IFI and ISI for a single piconet (N_u=1). The T_g in this case is set 50 bins. Remember that inthese cases the channel response to the transmitted pulse is completely died out before the transmission of the next pulse. It's clear from the result of the simulation that the SD receiver outperforms the others. Hence, at 10^{-4} target SER, it needs about 2 dB of S/N.

The performance with the effects of hard IFI and soft ISI for the same single piconet (N_u = 1) is shown Fig. (11). The T_g is reduced to 25 bins. In this case each adjacent frame belongs to a certain symbol is overlapped resulting in hard IFI. Besides, the last frame for symbol (i) is overlapped with the first frame of symbol (i+1) resulting in the so called soft ISI. Certainly, the data rate is also increased due to the reduction in T_f. Anyway, it's interesting to notice that there are very low degradations in the achieved SER values for all receivers as compared with the case without IFI and ISI and these low degradations are hardly noticeable.



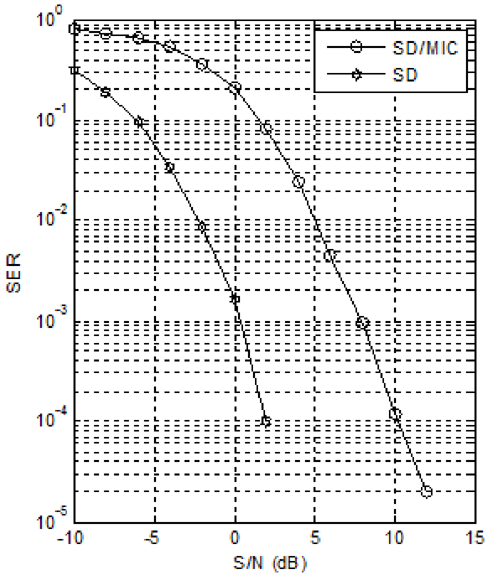
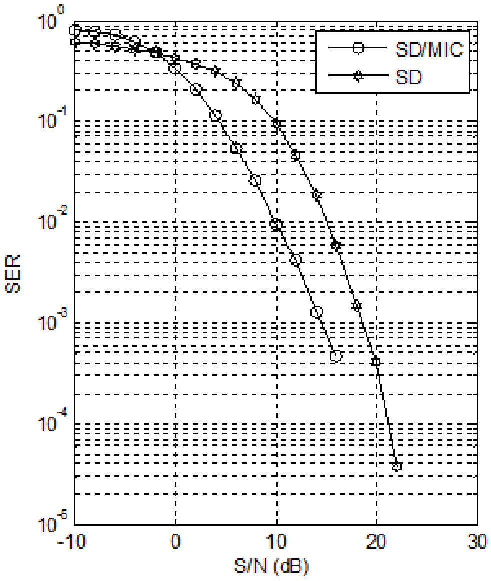


Fig. (10) Without IFI and ISIFig. (11) With IFI and

9.3 Performance with Multi-piconets w/o IFI and ISI.

In general, it is not difficult to see that increasing the number of interfere piconets ($N_u = 2$) can degrade the performance of all receivers as shown in Fig. (11) for the same value of N_s. This is Because of more MUI pulses which mean more collision pulses with the IR-UWB signal of the desired piconet.

The performance of the receivers without IFI and ISI is shown Fig. (12). It's very obvious that the SD/MIC receiver outperform the SD receiver due to the MIC technique which hardly mitigates the MUI.



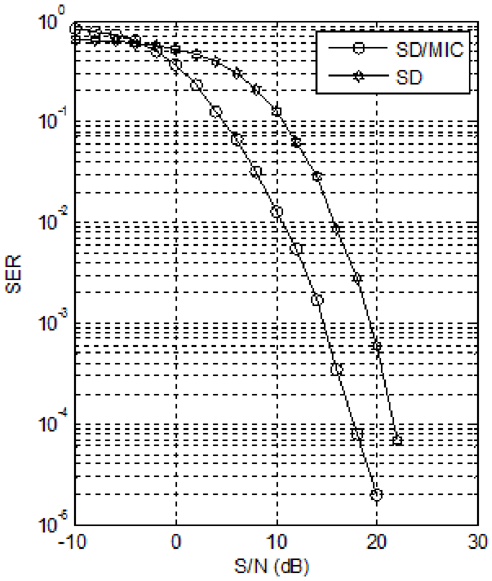


Fig. (12) Without IFI and ISIFig. (13) With IFI and

In another test, the two receivers were subjected to hard IFI and soft ISI. The performance was plotted and shown in Fig. (13) for two piconets ($N_u = 2$). The T_g was also reduced to 25 bins. It's clear that there were very low degradations in the achieved average SER for all receivers as compared with the case without IFI and ISI and these degradations are noticed in the plot. It should be kept in mind that an increase in the information rate was obtained due to the reduction in T_f.

10 Conclusions

The objectives of this paper are to design, semi-analyze and investigate the performance of multi-piconet WPAN IR-UWB receivers. The performance was evaluated in the presence of MUI, ISI, IFI, IPI, indoor dense multipath IEEE 802.15.3a CM2, and AWGN. Also, a novel multiple access method and a very simple novel correlation technique will also proposed in this paper to mitigate the MUI in UWB TR receivers.It's shown also and concluded that the MIC technique is a very simple method to largely mitigate hard MUI and clearly it is a feasible solution for practical TR implementations.

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