Adaptation of BPSK/TH/UWB Parameters Using RAKE Receiver with IPI in WPAN Indoor Multipath Fading Channels

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Abstract

In this paper, the performance of a PRAKE receiver for a pulse based ultra-wideband (UWB) communications system is studied in a realistic channel model that is based on an extensive set of indoor channel measurements. The adaptation of parameters of Binary Phase shift Keying/Time Hopping/Ultra Wideband (BPSK/TH/UWB) using PRAKE receiver is shown to contribute to a mitigation of the Inter-pulse interference (IPI). This work is based on the adaptation of multiple access parameters to mitigate the effect of IPI in a certain level. This study is done on the Wireless Personal Area Network (WPAN) IEEE802.15.3a, CM3 channel which is used for indoor network applications. Simulated results show the performance improvement in terms of BER. The results show improvements in the BER due to the adaptation of the values of number of pulses N_s and the number of chips per frame N_h. This is done simply by adjusting the bit rate R_b to a certain value and varies the value of N_s and N_h such that their product has a similar value. In this way the IPI is reduced because it is hardly depends on N_s and N_h

Key words: Time Hoping, PRAKE, IPI, WPAN, UWB, and BPSK.

الخلاصة

في هذا البحث ، تم دراسة أداء المستلم نوع *PRAKE* باستخدام نظام الاتصالات *Ultra-Wideband* الذي يعمل على مبدا ارسال النبضات في نموذج قناة واقعية والمستنده على مجموعة شاملة من مقاييسِ القناة الداخلية. إن تكيفَ المتغيرات لنظام *BPSK/TH/UWB* يعمل على تخفيف التداخل بين النبضات *IPI*. هذه الدراسة مستندة على تكيف البارامترات لمبدأ الوصول المتعدد لتَسكين تأثيرِ *IPI* الى مستوى محدد. هذه الدراسة تُعملُ على شبكة الـ *WPAN* لقناة نوع *IEEE802.15.3a / CM3*، والتي تستخدم لتطبيقات *WPAN*. تبين النَتائِج التي تم الحصول عليهاُ بتحسن الأداء من خلال الحصول على *BER* قليلة. تظهر النَتائِج التحسيناتَ في الـ *BER* بسبب تكيف قيمِ عدد النبضات N_s وعدد الرقائق لكلّ إطارِ N_h. هذا يعملُ ببساطة بضبط الـ *bit rate* (R_b) إلى قيمة معينة وبتغيير قيمةَ N_s وN_h بحيث ان حاصل ضربهما ينتج نفس القيمة. بهذه الطريقة فان سوف يقل *IPI* لأنه يعتمد بشكل كبير على N_s وN_h .

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1. Introduction

There has been a growing interest toward UWB communication systems for indoor and short range communications in resent years [1].

Ultra-wideband (UWB) radio is ideally suited for short range, high speed wireless personal area network (PAN) applications [2,3,4].

Another promising candidate to reduce the required signal to noise ratio is the RAKE receiver. UWB radio provides a very fine time resolution. Therefore, the RAKE receiver can efficiently make use of multipath diversity gains by resolving each multipath component individually in UWB radio [1].

UWB has been recently proposed for use in wireless personal area networks (WPANs). Ultra Wideband (UWB) is a technology which spans the entire frequency spectrum. It is capable of achieving high data rates over short distances with low power consumption.

A RAKE receiver is used to combine a subset of the resolvable multipath components using the maximal ratio combining technique.

Many problems associated with UWB system like as the inter-symbol interference (ISI) and inter-pulse interference (IPI) [1,2].

Adaptation of multiple access parameters in TH-UWB systems in terms of the number of pulses per symbol, and the frame duration is another flexible mean of exploiting system resources efficiently especially in the presence of ISI and IPI. Increasing the number of pulses per symbol increases the Signal-to-Interference-Noise –Ratio (SINR), which can be considered as a power control approach in the time domain without changing pulse amplitudes. Increasing the frame duration (which is related with the cardinality of the code) again improves the SINR in a multiuser environment, as it becomes less likely that the pulses will receive hits [5].

Adaptation of multiple access parameters has not enough studied in the literature. In [6], the authors proposed a link adaptation mechanism which can adapt TH parameters according to interference conditions. The analysis in that paper assumes the additive white Guassian noise (AWGN) only without considering the multipath scenario.

In [5], adaptation of multiple access parameters in WPAN IR-UWB has been analyzed to reduce and mitigate the effect of ISI and IPI.

The mathematical framework has been developed for the analysis of IPI when the number of pulses per symbol and frame duration of each user is different. The analysis assumes multipath channels.

In this paper, the WPAN in the IEEE 802.15.3a channel model CM3 has been considered with the range of (4 – 10) m.

2. System Description

A system similar to the UWB impulse radio (UWB-IR) system analyzed in [1] is considered in this paper, see figure (1). In an UWB-IR system, the transmission of a single data bit corresponds to sending N_s monocycles over the physical channel and recombining these at the receiver (N_s is the processing gain). Each monocycle is of duration T_w and is transmitted within a chip whose duration is T_c. A frame is composed of N_h chips and its length is denoted by T_f ($N_h T_c \le T_f$). For each frame, the time hopping sequence (THS) determines the location of the chip in which the transmission takes place. The number of users (active links) is denoted by N_u. When all users have the same N_s and T_f, the data rate of a user is $R_b = 1/(N_s T_f)$.

The binary phase shift keying (BPSK) random TH-IR system with one link is considered. The processing gain of the system is assumed to be $N = N_f \cdot N_c$, where N_f is the number of pulses that represent one information symbol, and N_c denotes the number of possible pulse positions in a frame.

2.1 The Transmitter

For a single-user (device) scenario, see figure (2), the format of the transmitted TH-IR-UWB signal, S_{tx}, is given by [3]:

$$S_{tx}(t) = \sum_{j=-\infty}^{\infty} b_j \sum_{i=1}^{N_s} p(t - jT_f - c_j T_c) \quad ..1$$

where t is the transmitter's clock time; p (t) is the used UWB pulse; T_f is the time frame allocated for each UWB pulse; T_c is the time shift step used in channelization /MA together with the c_j TH code (sequence) allocated to each communication channel/user (device); b_j = {-1,+1} is the information symbol. To increase the reliability of the communication link, the same symbol can be repeated a certain number of times N_s, increasing the processing gain of the system, i.e. b_j = const. for $j = [p, \ldots\ldots, (p + N_s)]$ and any integer p. A TH sequence c_j is typically a pseudorandom sequence with period N_s, where each element of the sequence is an integer in the range $[1, \ldots\ldots, N_h]$, where N_h is the number of time hopping shifts in T_f. The time frame T_f is divided into equally spaced TH shifts, T_c , so that $T_f \ge N_h T_c$. The above signal will be transmitted via a multipath channel as seen in the next section. In order to let a multiple access system, the value of N_h in the simulation must not be smaller than (5), hence $N_{hmin} = 5$.

In fact, the probability of multi user pulse collision is decreased for higher value of N_h as soon as possible. Also, N_h must not be too small in order to let large sets of TH sequences to be incorporated. So, the value of N_{hmin} is assumed in this study for further study the system in multi user environments in future, and the study in this paper is done for single user case only.

The binary bit rate of an M-ary BPSK IR-UWB signal is given by the following expression [7]:

$$R_b = \frac{1}{T_f N_s} \log_2 M \quad \ldots.2$$

Both T_f and M are difficult to modify in an UWB system. Changing M for different transmissions is undesirable for communication systems since it leads to processing overhead. Similarly, modifying T_f for each transmission increases the complexity of the hardware design of the system. Thus, the simplest way to adjust R_b is to vary the value of N_S. The only requirement for allowing different N_S values is that the receiver of each link must integrate the correct number of pulses for each symbol received on that link. A protocol that is adaptive to network behavior should vary N_S based on interference levels in the network. More specifically, high interference levels increase the probability of pulse collisions, which requires more pulses per symbol. Note that in this work the value of M is set to 2.

2.2 The channel

The WPAN indoor multipath channel IEEE 802.15.3a is assumed. This channel is modeled as a linear, time-varying filter which is time-invariant over a frame T_f duration with impulse response *h(t)* and maximum excess delay spread T_{mds}. The IEEE 802.15.3a multipath model consists of the following discrete time impulse response [5,1]:

$$h(t) = \sum_{l=0}^{L}\sum_{k=0}^{M}\alpha_{k,l}\delta(t - T_l - \tau_{k,l}) \quad \ldots\ldots 3$$

h(t) can be written in the following form :

$$h(t) = \sum_{k=0}^{K} h_k \delta(t - \tau_k) \quad \ldots .4$$

Assuming that the minimum relative resolvable path is equal to T_c, then h(t) is becomes :

$$h(t) = \sum_{k=0}^{K} h_k \delta(t - (k-1)T_c) \quad \ldots .\ 5$$

where $\alpha_{k,l}$ is the multipath gain coefficient, T_l is the delay of the l^{th} cluster, and $\tau_{k,l}$ is the delay of the k^{th} multipath component (ray) relative to the l^{th} cluster arrival time (T_l). In addition, we assume that the channel characteristics remain unchanged over the all transmitted bits.

2.3 The Receiver

In realistic UWB multipath fading channels, the number of powerful multipath components is much more than 5 and less than 100 depending on the value of r.m.s delay (T_{rms}). Hence, about 85% of the total multipath energy is constrated in the paths having delays between (0-T_{rms}) [4].

Therefore, in practice non-perfect RAKE receivers are considered. Non-perfect RAKE receivers do not receive all multipath components and the number of fingers is less than the number of arrived components. Two main non-perfect RAKE receiver structures are used to collect most of the channel energy; they are the selective-RAKE (SRAKE) receiver and partial-RAKE (PRAKE) receiver. Whereas the All RAKE (ARAKE) receiver is considered ideal in collecting all the energy of the channel because it has a very large number of fingers. Therefore, the ARAKE is not user never in realistic systems from the view of complexity.

PRAKE receiver shown in figure (3) employs N_B UWB correlators that are located in successive bins each with duration T_c ns.

This receiver does not need to detect the multipath components with the largest gain resulting in a lower implementation complexity. It has been shown in many literatures such as [6], that the performance of the PRAKE receiver approximates the performance of a SRAKE receiver with the same number of fingers for N_B > 4. Therefore, PRAKE receiver is assumed in this work. Perfect synchronization between transmitter and receiver is also assumed. Moreover, perfect channel estimation is considered.

At the receiver side, a coherent, single user is consider, Rake receiver.

However, the number of branches of the Rake receiver is assumed to be limited to L and less than K (the max. number of path delays). The received signal is [1,2]:

$$r(t) = h(t) * s(t) + n(t) \quad \ldots\ldots 6$$

where * is the convolution operator, and *n(t)* is zero mean white Gaussian noise with two-sided power spectral density $N_0/2$.

Channel knowledge and perfect synchronization is assumed between the transmitter 1 and the receiver. Since we have *M* matched filter outputs, then *M* template waveform $w_m(t)$, $m = 0, 1, \ldots\ldots, M - 1$, matched on the signal from the first transmitter where [3,5]:

$$w_m(t) = \sum_{j=0}^{K-1} h(t) * p(t - jT_f - c_j T_c - mT_m) \ . (7)$$

$$w_m(t) = \sum_{j=0}^{K-1}\sum_{l=0}^{L-1} \alpha_l . p(t - jT_f - c_j T_c - mT_m - v_l) \ (.8)$$

Then the output $r_{j,m}$ of the m^{th} matched filter is :

$$r_{j,m} = \int_{iT_l}^{(i+1)T_l} r(t).w_m(t)dt \qquad \ldots.. 9$$

Then, the right-hand side of (9) becomes:

$$r_{j,m} = \sum_{j=1}^{N}\sum_{l=0}^{L-1}\alpha_l \sum_{k=0}^{K}\alpha_k \int_{iT_l}^{(i+1)T_l} p(t - jT_f - c_j T_c - x_j T_m - \varphi - v_l)$$

$$.p(t - jT_f - c_j T_c - mT_m - v_l)dt + n(t) \ (\ 10)$$

After few steps, the previous expression can be rewritten as:

$$r_{j,m} = s_{j,m} + n_{j,m} \quad \ldots\ldots.11$$

It is clear that, the output of the m^{th} matched filter (correlator) in the RAKE consists of following terms:

a. The first is the user contribution.
b. The second term is the AWGN.

3. The ISI Problem

In many literature such as [1], the authors assume that $T_f = T_h + T_g$, where $T_h = N_h T_c$ is the frame's hopping time and T_g is the guard time in order to decrease intersymbol interference (ISI). But here in this work, the guard time is suggested to not be used in this study for the following reasons:

a. First, too long guard time decreases the overall throughput of the system.
b. Second, instead of inserting guard time, the increasing of N_h permits many users to multiple access the network with also ISI.

The multipath channel model and the RAKE structure that it determines, contributes to a mitigation of the ISI energy at the RAKE output [4].

Anyway, the constraint on the inter-symbol interference can be enforced by having a guard time T_g at the end of each frame, or by constraining the THS such that the minimum spacing between two consecutive chips is larger than T_g.

4. The IPI Problem

First, in this work we consider only single user case, so the multi-user effect term in eq. (11) is not appear. The first term $s_{j,m}$ of the user of interest is given by [1,3] :

$$s_{j,m} = Ns\sum_{l=0}^{K}(\alpha_l^{(1)})^2 .\Re\left[(m - x_j^{(1)})\right] \quad \ldots\ldots 12$$

where $\Re[\ ]$ is the autocorrelation of the pulse p(t) and p(t-τ)

For no IPI, m = $x_j^{(1)}$, then the special case of $s_{j,m}$ is given by :

$$s_{j,m} = Ns\sum_{l=0}^{K}(\alpha_l^{(1)})^2 .1_{\{x_j^{(1)}=m\}} \quad ....(13)$$

$$s_{j,m} = Ns\sum_{l=0}^{K}(\alpha_l^{(1)})^2 \quad ....(14)$$

Note that equation (14) is the optimum one for Maximum Ratio Combining (MRC) for RAKE receiver [1,3]. Note that the quantity $\Re\left[(m - x_j^{(1)})\right]$ is the Inter-Pulse Interference, given that its value will be between 0 and 1. This IPI can be overcome by using zero forcing (ZF) scheme [1], which yields a combining factors that exactly used by MRC rake receiver. This implies that, interesting although unexpected, even in the presence of IPI, MRC is still the optimum linear rake diversity combining scheme. But In the presence of pulse overlapping, however, the ZF optimization for pre-rake multipath combining performs worse than the MRC scheme. So, the work in [1], fail to completely remove the IPI using ZF scheme with pre-rake receiver.

In this paper, we consider how to control the effect of IPI without ZF scheme. The only way to control the effect of IPI without ZF scheme is to change TH parameters such as N_s , N_h , T_c according to different situations.

In order to discuss adaptive control of the IPI, the multiple access parameters interact with each other should be done and investigated, and how the throughput and bit error rate (BER) performance are influenced by changing these parameters. Therefore, in the following section, the relationship between link performance and these parameters is investigated by simulation.

5. Parameters Adaptation

There is an important difference between IPI and ISI which are shows in figure (4) and figure (5) respectively, which is depending on the number of pulses N_s used to represent one symbol. There are two cases:

a. If N_s = 1, then both ISI and IPI degrade the performance of the system. Hence, if any overlapping between any two pulses results in IPI. This IPI will directly cause ISI.
b. If N_s > 1, then the dominant inter-lapping is occurring between adjacent frames belongs for the same symbol; this in turn could be called Inter-Frame Interference (IFI). The TH system frame contains just one pulse, therefore if the two pulses for two frames overlap this cause IPI which does not affect the ISI but has an effect on the symbol itself. But, if IFI occurred in some T_c without IPI, then there is neither IPI nor ISI. For more explanation, figure (6) shows the multi path channel effect for the pulse in the first frame is interfere with the first five *empty* chips in the second frame. Also, the tail of the third pulse in the third frame is died out before the starting of the second symbol. Therefore, there is IFI occur whereas there is neither IPI no ISI.

In order to better exploit the system resources, it is possible to change the number of pulses N_s, and number of chips per frame N_h, based on the channel quality, and the ISI and IPI level in the system. In this section, first, synchronous communications will be considered, where the orthogonal construction of TH sequences allows interference-free communication. The adaptation of N_s and N_h is analyzed under a bit error rate (BER) constraint and for two different cases:

a. Fixed bit rate i.e., fixed bit rate for a pair of N_s and N_h, and variable frame duration (to minimize IPI).
b. Variable bit rate and variable symbol duration (to maximize the network lifetime) with acceptable bit rate value.

In other words, by setting the value of N_s and N_h, just enough number of pulses per symbol should be transmitted to meet the BER requirement. This is contrary to conventional systems, where the worst case parameters are used first, and then changing it according to the given value of BER hence a lower data rate is obtained. But the node can do compromising between Ns and bit rate to achieve a specific BER.

6. Simulation Results

In this section, the performance of the PRAKE receiver in various conditions and multiple access parameters is evaluated. The simulation is performed in Matlab R2006b and done over more than 100 channel realization and then averaged. The two main performance metrics in this work are the bit rate and the BER. The numerical values of the parameters of the PRAKE and physical layer that will be used in the simulation are given in Table 1.

In figure (7), the BERs were calculated with respect to node bit rate for N_s= 1,2 and with variable N_h values (6-48) and (3-24) respectively in such away that the multiplication of each corresponding pair (N_s * N_h) has the same bit rate value. In other words, the total processing gain defined by $N = N_h$. N_s is constant Therefore; we can change the number of pulses per symbol and the frame duration as long as their multiplication is fixed. Also, the value of T_c remains fixed for the two cases.

As it is noticed from the result in figure (7), for a given bit rate value the BER for the case when N_s = 1 is better than when N_s = 2. This is because the N_h value is low and smaller than the root mean square delay T_{rms} of the channel, and therefore not all paths of the previous pulse will be died out during the transmission of the next pulse. So, IPI will occur that degrades the system performance. The situation is reversed in the case when N_h is larger than the T_{rms} of the channel, i.e., there is no IPI. On the hand, at 10^{-3} BER target value, about 95 Mb/s bit rate is obtained for the case of N_s=1 (with adaptation), whereas about 70 Mb/s bit rate for case N_s=2 (without adaptation).

Another situation is given in figure (8), where the value of BER is plotted with respect to N_s for two N_h values, 6 and 30. The bit rate values are changed. The BER is increased with N_s for the two N_h values. Here the N_h values are chosen in such away that one is smaller than T_{rms} and the other is larger than T_{rms}. Again, larger BER values are obtained in the case of N_h = 30 due to the absence of IPI. As it can be seen, increasing the number of pulses with high N_h value results to a considerably good performance. Also, another interesting point shown in the figure, that the two performance (with and without adaptation) has a good performance in terms of decreasing the

BER with corresponding increasing in N_s. But, the performance of (N_h =30) (with adaptation) has lower BER than that of (N_h =6) (without adaptation).

7. Conclusion

In this paper, the performance of UWB-IR time-hopping systems with pulse position modulation in indoor fading channels was considered using computer simulation. The model employed for UWB channel is the multipath fading model. The receiver employed for the multipath fading channel, is the Partial RAKE (PRAKE) receiver with 5 fingers. The performance of the system in IPI was also considered.

In this paper we construct an adaptive procedure to mitigate and control IPI especially in very high data rates. The obtained results show that it can easily be adapted the THS system parameters in such away the effect of IPI is reduced.

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Parameter	***Symbol***	***Value***
Sampling frequency (GHz) used for pulse sampling in the receiver	f_c	*50*
Pulse duration (ns)	$T_m = T_c$	*1*
Shaping factor for the pulse (ns)	-	*0.25*
Number of bits generated by the source	-	*10000*
Time resolution [ns], i.e., the multipath channel bin duration has the same value of T_m	t_s	*1*
Number of pulses per bit	N_s	*variable*
Number of PRAKE fingers	-	*5*
Bit energy-to-Noise ratio	E_b/N_o	*variable*
Total Multipath Gain	*TMG*	*1*

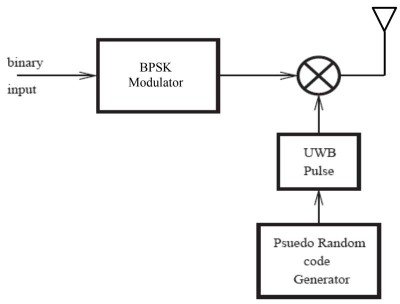

Figure (1): The IR-UWB system

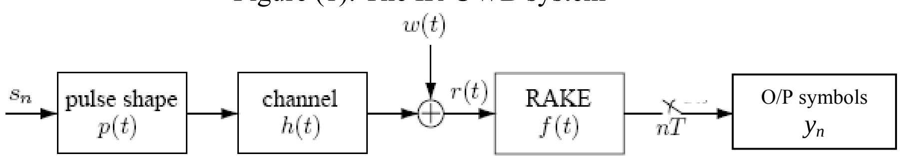

Figure (2): The IR-UWB Transmitter

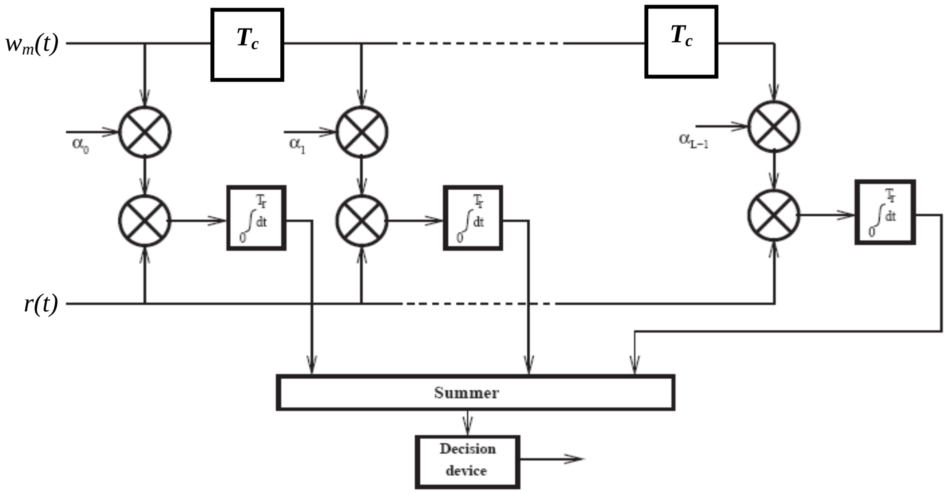

Figure (3): PRAKE receiver [2]

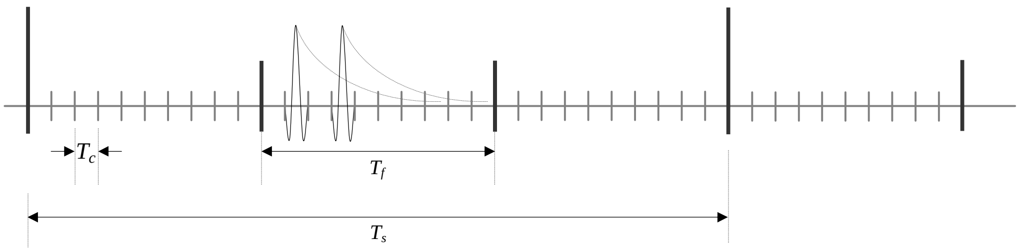

Figure (4): The IPI, where T_s is the symbol period. Note that the arc after the pulse is the replicas of the pulse due to the multipath effect**.**

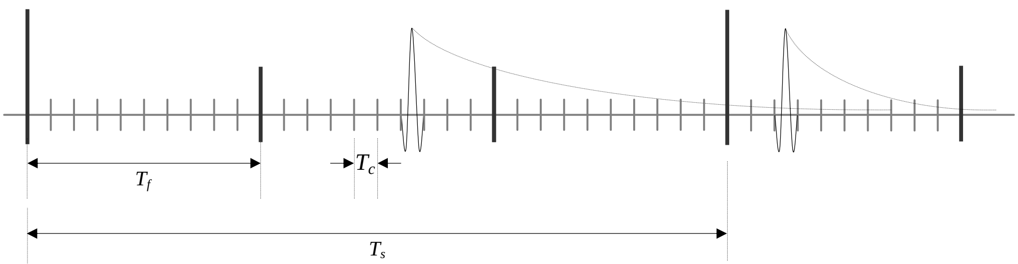

Figure (5): The ISI, where T_s is the symbol period. Note that the arc after the pulse is the replicas of the pulse due to the multipath effect.

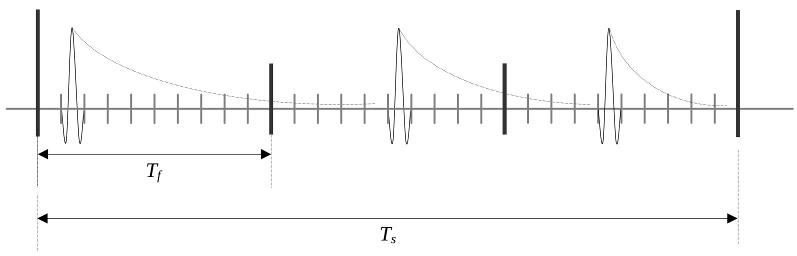

Figure (6): The IFI without IPI and ISI

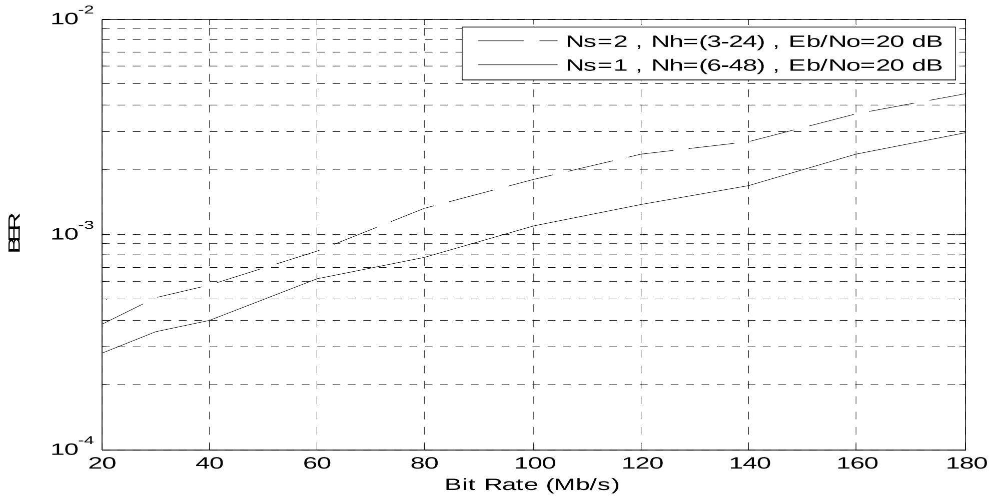

Figure (7): BER verses Bit Rate

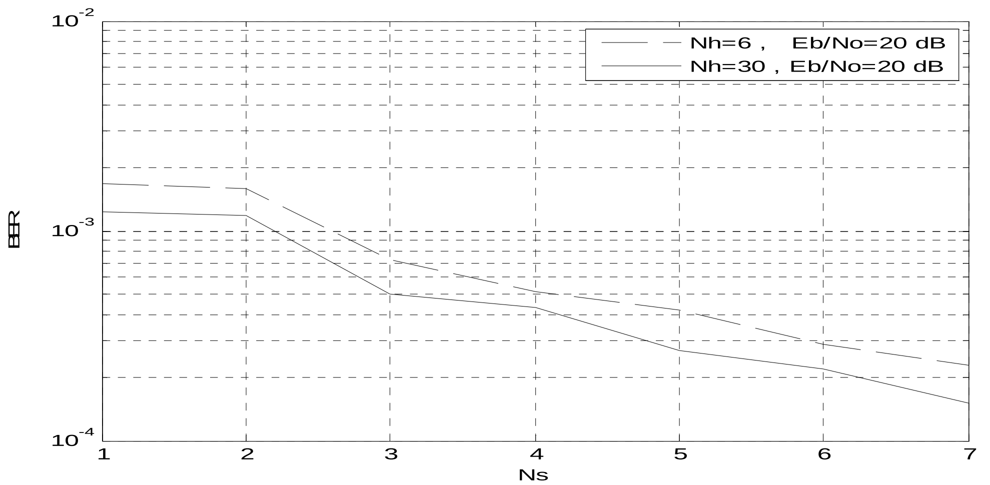

Figure (8): BER verses Number of pulses