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Collision Problem Avoidance in Packet Acquisition for Frequency Hopped Random Multiple Access

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ABSTRACT

Random multiple access (RMA) comprises a large class of multiple access protocols, such as ALOHA. A common characteristic of all RMA protocols is that when a user transmits a data packet other users waiting until the transmission finished, so RMA can achieve very low latency and limit the network performance. In this paper a new technique that uses time and frequency hopping is proposed to solve the collision problem in packet acquisition of frequency hopped systems operating in random multiple access (RMA) environments. Moreover, the proposed scheme also improves the system performance due to the idea of dividing the time and frequency between all users in the system. Each user has a PN code pattern for any transmitted sync pulse that is responsible for selecting the frequency channel that carry the pulse and selects the time slot that the pulse uses it. We have presented an analytical approach for the proposed scheme to determine the packet acquisition performance in a RMA environment. To illustrate the accuracy of the analytical results, simulations are performed over a wide range of parameters such as the pulse length, pulse duty cycle, number of synchronization pulses and the number of users in the system.

KEY WORDS

Frequency Hopping, Packet Acquisition, Multiple Access Interference.

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I INTRODUCTION

Frequency hopping signals are suitable for anti-jamming and multiple access applications. The transmission of a frequency hopping waveform is divided into two parts, these parts are the acquisition preamble and a data payload [1]. The function of the acquisition preamble is to allow the receiver to detect and synchronize an incoming packet. Acquisition is a very important task in any frequency hopping receiver because without acquisition the receiver cannot receive any data. If the receiver succeeds to initiate the acquisition, it can tune a narrow band demodulator to the current hopping channel.

Generally, three schemes for frequency hopping signal acquisition are investigated, serial, matched filter, and two-level scheme. These schemes have been well described in [2-4]. On the condition of same detection performance, results show that the serial search scheme is relatively simple to implement but taking far longer to make a decision and matched filter detection take the shortest time to accomplish a acquisition but requiring a complex hardware structure. The two-level scheme combines the advantages of the rapid search time of the matched filter with the simple structure of the serial search.

In packet radio systems, there are limited opportunities to detect a message, so matched filter technique is suitable for these applications. Without prior information about the incoming packet, the receiver is unable to determine the specific times to tune to specific channels. Therefore, the receiver must be able to simultaneously process all acquisition channels. Thus, if the number of acquisition channels is increased, the receiver complexity will increase.

In this paper the acquisition performance is analyzed under RMA environment where each packet begins with a preamble followed by data pulses. The preamble is consists of a number of synchronization pulses that carry known data to help the receiver to determine the arrival time of a packet. In the proposed scheme, a PN code pattern must be generated for each transmitted sync pulse of a specified user. This code will be divide into two parts, the function of the first part is to select the carrier frequency that carry the pulse while the second part is responsible for selecting time slot of the sync pulse.

The remainder of the paper is as follows. Section 2 describes signal model of the system. In section 3, the acquisition performance of the proposed scheme in RMA environment is considered. Section 4, compares numerical results obtained via analysis and simulations while conclusions are presented in Section 5.

II SIGNAL MODEL

Consider the system using N synchronization pulses and N_S channels for acquisition purpose. Each of the synchronization pulses consists of M modulated chips. We examine the acquisition performance for a particular user when the acquisition channels are also used by another N_I interfering users.

In the proposed scheme, A PN code pattern is generated for each sync pulse. For example, if four sync pulses is needed to acquire acquisition and using only two channels for acquisition tacking the pulse duty cycle = 0.25 and suppose that we have two users in the system user A and B. Table.1 shows for example the states of PN code pattern for two users taking the length of PN pattern ($k = 3$). In Table.1 there are four patterns for each user equivalent to four sync pulses. The pattern of the first sync pulse is divided into two parts, the first part is used to select the channel for the pulse while the second is used to select the time slot. Thus, the sync pulses of a packet follow a frequency and time hopping pattern.

Table 1. Example for PN code pattern of length ($k = 3$) for two users

User A	010	111	011	100
User B	111	011	101	100

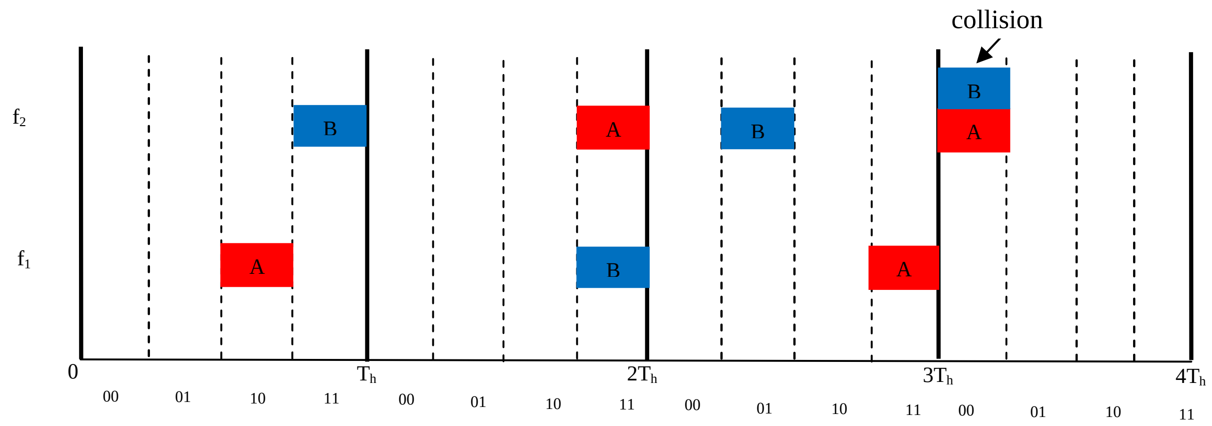

Fig.1. Example illustrates random multiple access protocol for $N_S = 2$ acquisition channels and using pulse duty cycle = 0.25 for two users A&B.

In the above example, the system uses only two channels for acquisition and the pulse duty cycle = 0.25. So, for any sync pulse there are four possible start times 1 equivalent to "00", M equivalent to "01" , $2M$ equivalent to "10" and $3M$ equivalent to "11" where M is the number of modulated chips in the sync pulse. For user A, from Table (1) the PN pattern for the first sync pulse is "010", this pattern is subdivided into two parts "0" and "10". The first part of the pattern selects the acquisition channel and the second part selects the time slot of the sync pulse. By this procedure the sync pulses of user A and B is distributed as shown in Fig.1. For a specified user, the PN pattern that selects the acquisition channel and the time slot of user sync pulses is known only to its desired receiver. This RMA protocol also assumes that all packets are slot-synchronized at the receiver of interest.

To determine the arrival time of a packet, the receiver must tune to all the frequencies that used to send the N sync pulses. The down converted received signal is sampled at the chip rate and shifted through a buffer at the same rate, while the buffer is read out at the same rate in computing the decision statistics [5]. Therefore, for the l^{th} pulse, the sampled observed signal is represented by:

$$y_l = x_l g_l + z_l + n_l \qquad (1)$$

where $l = 1, 2, ..., N$. The parameter $x_l = \left[x_{l,1}, x_{l,2}, ..., x_{l,M} \right]$ represents the sampled version of the transmitted sync pulse known a priori to the receiver and g_l is the channel gain. The term $z_l = \left[z_{l,1}, z_{l,2}, ..., z_{l,M} \right]$ represents the total interfering signal at this particular time and $n_l = \left[n_{l,1}, n_{l,2}, ..., n_{l,M} \right]$ represents the back ground WGN.

The receiver must tests the hypotheses H_1 and H_0 for each chip time to determine the arrival time of a packet. The two hypothesis H_1, H_0 for each user is given by:

$$H_1 \; signal + noise \quad : \quad y_l = x_l g_l + z_l + n_l \qquad (2)$$

$$H_0 \; noise \; only \quad : \quad y_l = z_l + n_l \qquad (3)$$

In (3), $n_l \sim continous\, normal\left(0, N_l I_M\right)$, where I_M denotes the $M \times M$ identity matrix and N_l represents the noise variance for the l^{th} pulse.

III ACQUISITION PEFORMANCE OF THE PROPOSED SCHEME

Following the same procedure of [5] that is first determine the acquisition performance over an AWGN channel. Then, generalize the performance results to treat multiple access interference occurring with RMA. In the proposed scheme we detect each sync pulse individually and the pulse decision outcome is "1" if the pulse we declared is present and "0" if it is absent. Then, the sum of the N outcomes for the N pulses is compared to a final threshold. If the sum is greater than or equal the final threshold, we take a decision that the packet is present, otherwise the packet is absent.

In an AWGN channel, the detection probability of a sync pulse number l in the packet is given by [5]:

$$P_{dl} = 1 - F\left(\alpha\left(M - 1\right), 2, 2\left(M - 1\right), \lambda_l\right) \qquad (4)$$

where α is the threshold factor which can be controlled to trade off between false alarm and detection probabilities and $F\left(a, b, c, \lambda\right)$ is the cumulative distribution function of the non central- F distribution. This function can be easily evaluated using computing software packages like Matlab. The parameter λ_l is given from [5]:

$$\lambda_l = 2M \frac{E_c}{N_l} \qquad (5)$$

where $\frac{E_c}{N_l}$ is the energy to noise ratio and M is the number of chips per pulse. For packet detection probability in WGN channel we get:

$$P_d = \sum_{n=\frac{N}{2}}^{N} \binom{N}{n} P_{dl}^{n} \left(1-P_{dl}\right)^{N-n} \qquad (6)$$

Moreover, the false alarm probability of a sync pulse number l in the packet for WGN channel is given by [5]:

$$P_{fl} = f_T^{\,1-M} \qquad (7)$$

where $f_T = \alpha + 1$. Similarly the packet false alarm probability in WGN channel is given by:

$$P_f = \sum_{n=\frac{N}{2}}^{N} \binom{N}{n} P_{fl}^{n} \left(1-P_{fl}\right)^{N-n} \qquad (8)$$

In multiple access environment as shown in Fig.1, the sync pulse of any user has a duration of M chips and a width of T_h where T_h is the time of hop and $T_h \geq M$. The selection of the start time of a sync pulse is done by the second part of the PN code pattern of this sync pulse of the user as shown previously and the first part of the PN code pattern selects the acquisition channel. So, there exists a deterministic start time of any sync pulse and these times are $\left[0, M, 2M, ..., T_h - M\right]$ and assuming that no particular start time is more likely than another. So, if there is 5 possible start times of a sync pulse, the probability that a particular start time is selected is 1/5. Considering also that, the beginning of each sync pulse coincides with the first chip position of the pulse slot. Similarly, assuming that no particular frequency is more likely than another to carry a pulse, i.e., if we have N_S acquisition channels, the probability that a particular frequency is selected to carry a pulse is $1/N_S$. Finally, assuming that all packets are slot-synchronized at the receiver of interest.

To determine the acquisition performance in multiple access interference we need to consider just one particular pulse slot, say the l^{th} slot and take its lower slot boundary as the reference time. Assuming that the start time of a sync pulse coincide with the time location of the first chip of the pulse.

For any user, considering discrete arrival times whose granularity is one chip duration, the possible arrival times are $\left[0, M, 2M, ..., T_h - M\right]$ and the possible arrival times of the last chip of the pulse are $\left[M, 2M, 3M, ..., T_h\right]$. If r_u and p_{r_u} are the random arrival time of the u^{th} interferer's pulse and its probability mass function. So, the arrival time of a sync pulse is uniform, i.e.,

$$p_{r_u}\left[r_u\right] = \begin{cases} \dfrac{1}{no\ of\ \ possible\ arrival\ times} & r_u = 0, M, 2M, ..., T \\ 0 \qquad otherwise & \end{cases} \qquad (9)$$

where $\qquad T = T_h - M \qquad (10)$

Similarly let r and p_r are the random arrival time of the desired user and its probability mass function. The collision will happen if and only if the start times of the desired sync pulse and interferer sync pulse are the same. If R denote the random number of chips that the u^{th} user overlap with the desired user. Then, R can be represented by:

$$R = \begin{cases} M & r = r_u \\ 0 & otherwise \end{cases} \qquad (11)$$

Therefore, if the hop duration $= T_h$ and the number of chips per pulse $= M$, then the possible start times of the sync pulse $tt = \dfrac{T_h}{M}$. Consider $p_R\left[\tau\right] = \Pr\left[R = \tau\right]$ denote the probability distribution of R , we get that:

$$p_{R/t}\left[\tau \mid t\right] = \begin{cases} \dfrac{tt-1}{tt} & \tau = 0 \\ \dfrac{1}{tt} & \tau = M \end{cases} \qquad (12)$$

Let U denote the random number of interferers transmitting at the frequency of the desired pulse. So, the interferers arrival times are independent $R_1, R_2, ..., R_U$ are independent given t . Given U , the total number of interfering chips from all U interferers is given by:

$$\left(R_0 \mid U, t\right) = \sum_{u=1}^{U} \left(R \mid t\right) \qquad (13)$$

The probability mass function of $\left(R_0 \mid t, U\right)$ is given by [5]:

$$p_{R_0}[\tau \mid t, U] = \left(p_{R_1|t} \otimes p_{R_2|t} \otimes ... \otimes p_{R_U|t}\right)[\tau] \qquad (14)$$

For $\tau = 0, M, 2M, ..., UM$, where $\otimes$ denotes the discrete time convolution. De-conditioning on t we get:

$$p_{R_0/U}[\tau \mid n] = \Pr[R_0 = \tau \mid U = n] = \frac{1}{tt}\sum_{t=1}^{tt} p_{R_0}[\tau \mid t, U] \qquad (15)$$

In multiple access interference environment, we get the detection probability of sync pulse number l of a packet by [5]:

$$P_{dl} = \sum_{n=0}^{N_I} p_U[n]\, P_{dl|U=n} \qquad (16)$$

where N_I is the number of interferers in the system and:

$$p_U[n] = \binom{N_I}{n}\left(\frac{1}{N_S}\right)^n \left(1 - \frac{1}{N_S}\right)^{N_I - n} \qquad (17)$$

where N_S is the number of acquisition channels used in the system and:

$$P_{dl|U=n} = 1 - \sum_{r_0=0}^{nM} p_{R_0/U}[r_0/n] \times F\left(\alpha(M-1), 2, 2(M-1), \frac{2M(E_c/E_i)}{(E_i/N_l)^{-1} + r_0/M}\right) \qquad (18)$$

where (E_c/E_i) is the desired chip to interference ratio and (E_i/N_l) is the interference to noise ratio. Then, the packet missed probability is given by:

$$P_m = \sum_{n=0}^{\frac{N}{2}-1} \binom{N}{n} P_{dl}^n (1 - P_{dl})^{N-n} \qquad (19)$$

The false alarm probability of a sync pulse number l in the packet is given by [5]:

$$P_{fl} = 1 - \sum_{n=0}^{N_I} p_U[n] \sum_{r_0}^{nM} p_{R_0/U}[t \mid n] .$$
$$\int_0^\infty \chi^2(w,2) \times F\left(\alpha(M-1)\left(1 + \frac{\varphi E_i r_0}{N_l M}\right), 2, 2(M-1), \frac{E_i r_0 w}{N_l M}\right) dw \qquad (20)$$

where $\chi^2(w,k)$ is the probability density function of a χ_k^2 variable and φ is a fine tuning factor, where $0.7 \le \varphi \le 1$[5]. Similarly the packet false alarm probability is given by equation (8).

IV NUMERICAL RESULTS

All P_d values obtained from analytic and simulations with P_f fixed at 2×10^{-5} for an AWGN channel. We see from all results that the simulation results confirmed the analytical results. Fig.2 and Fig.3 shows the packet missed detection probability vs. $(E_c / E_i)dB$. In Fig.2 we use $N = 12$ sync pulses to acquire acquisition tacking the number of chips per pulse $M = 32$ and using $N_S = 4$ acquisition channels to transmit these sync pulses. The final threshold to acquire acquisition is $N / 2$. Considering the pulse duty factor $\delta = 0.2$ and the number of interferers $N_I = 7$. As shown in Fig.2, if we increase the interferer to noise ratio, E_i increased and the ratio E_c / E_i decreased, so the packet missed probability improved.

In Fig.3 we study the effect of increasing the number of chips per sync pulse from 32 to 64 but we decrease the sync pulses from 12 to 8 and decrease the acquisition channels from 4 to 2. The number of interferers $N_I = 10$. It is shown that that if we duplicate length of sync pulses, we can get approximately the same performance of Fig. 2 although if we decrease the number of sync pulses, number of acquisition channels and increase the number of interferers.

Fig.4 and Fig.5 shows the false alarm probability vs. f_T . We see from these figures that increasing the number of interferers N_I has a little effect on the false alarm probability and increasing the length of a sync pulse has a good improvement on the performance of the system.

V CONCLUSION

We have investigated a model to solve the collision problem in packet acquisition of frequency hopped RMA by dividing the time and frequency between all users. A PN code pattern is generated for each transmitted sync pulse of any user. This pattern selects the time slot that the sync pulse uses it and also selects the frequency channel that carries the pulse. Only the desired receiver has a priori knowledge about this pattern. The packet acquisition performance of the proposed scheme in an RMA environment is determined. The simulation results confirmed the analytical results.

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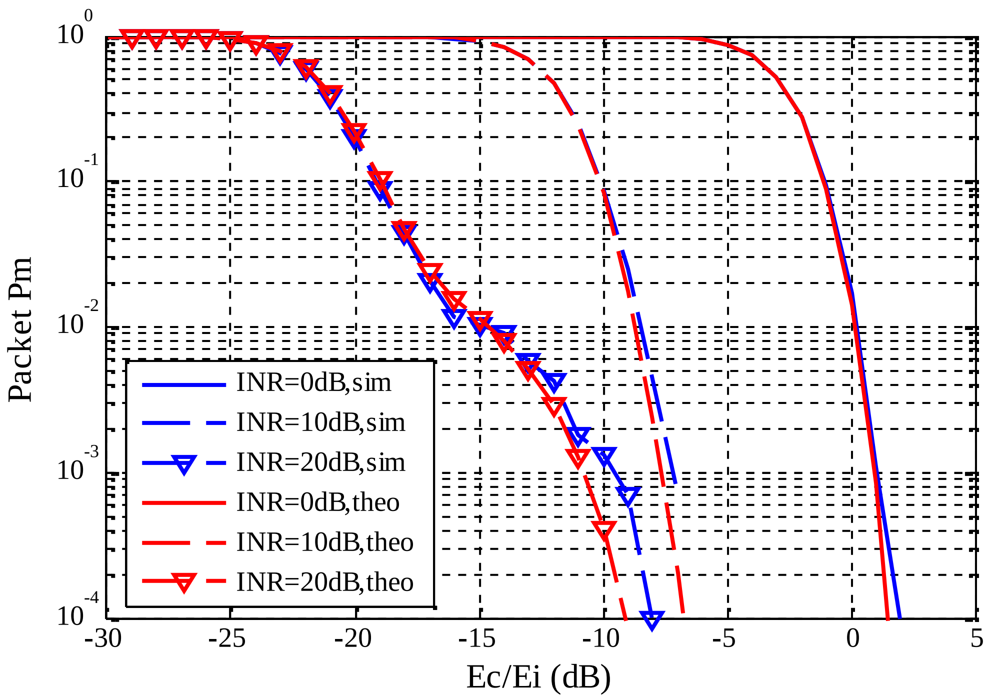

Fig.2. Packet missed detection probability vs. $(E_c / E_i)dB$ for $N = 12$, $M = 32$, $N_S = 4$, $N_I = 7$, $\delta = 0.2$ and threshold=$N/2$.

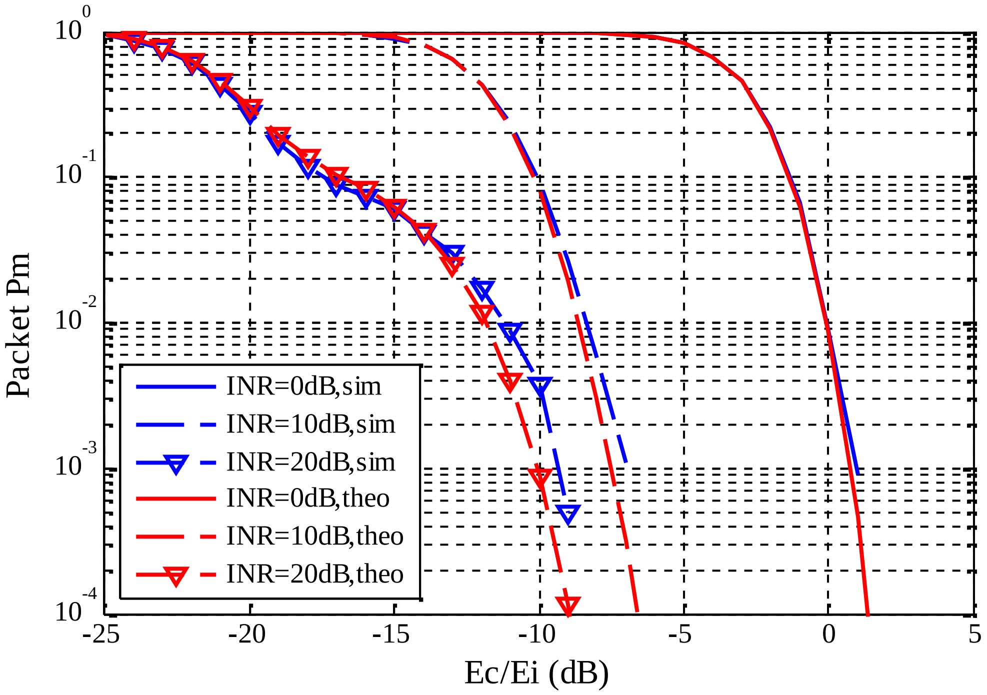

Fig.3. Packet missed detection probability vs. $(E_c/E_i)dB$ for $N=8$, $M=64$, $N_S=2$, $N_I=10$, $\delta=0.2$ and threshold=$N/2$.

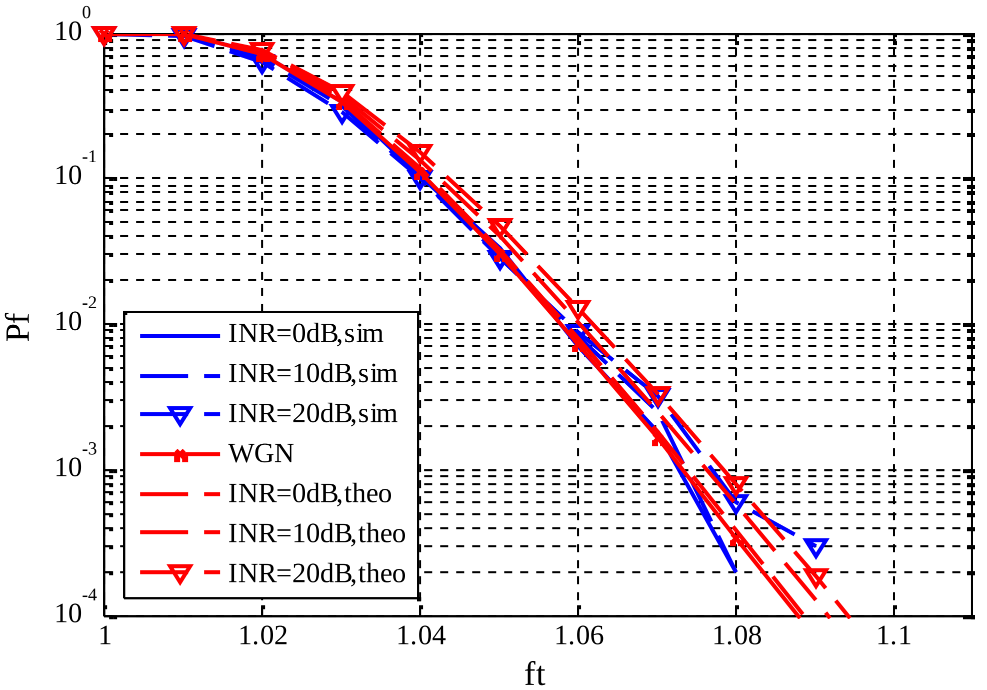

Fig.4. false alarm probability vs. f_T for $N=12$, $M=32$, $N_S=4$, $N_I=7$, $\delta=0.2$ and threshold=$N/2$.

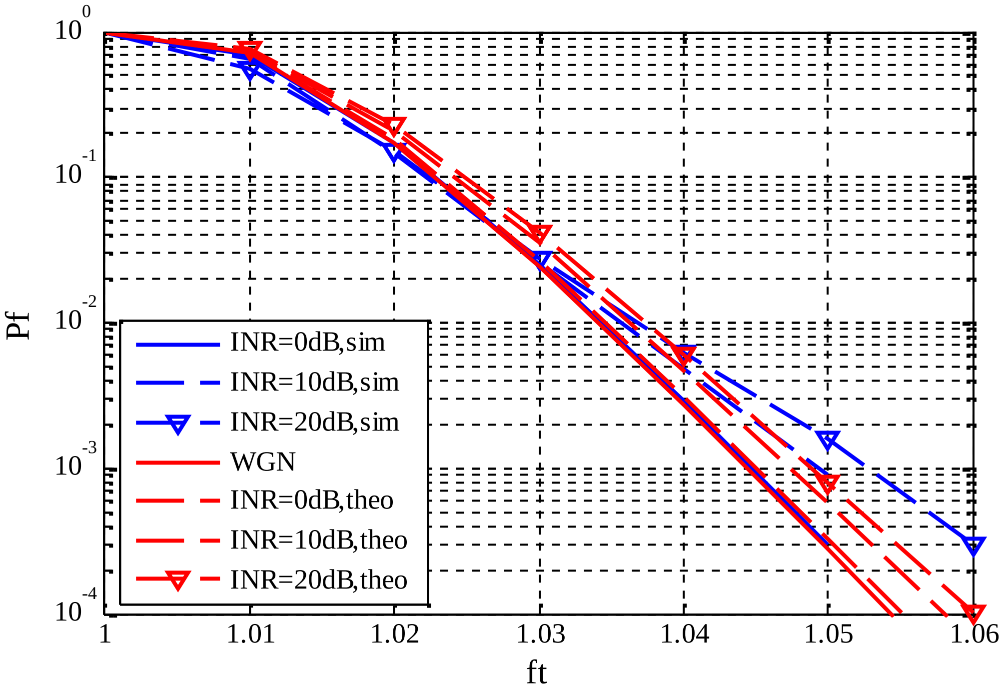

Fig.5. false alarm probability vs. f_T for $N = 8$, $M = 64$, $N_S = 2$, $N_I = 10$, $\delta = 0.2$ and threshold=$N/2$.