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Adaptive Rake Receiver Using Matched Filter with Three Combining Techniques

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Abstract: This paper describes the improvement of the wireless rake receiver for high speed and data rate indoor ultra wideband (UWB) propagation with two channel models (CM3 of 0 to 10 meters range and CM4 of 4 to 10 meters range). The transmitted signal system was considered to be direct sequence with binary phase shift keying modulation DS-BPSK). As the multipath is the main challenge faces the wireless rake receiver, so we need to mitigate the noise and interferences by capturing the energy which is decreased by fading and far distances. After adding the additive white Gaussian noise (AWGN), the rake receiver receives the signals from the proposed five stages matched filter and signal processing takes place to combine the output of the fingers. From the simulated results, the proposed matched filter has important role in maximizing the signal to noise ratio (SNR). The received signal is transferred to many copies according to the number of finger used in the rake receiver and each copy multiply by the generated template signal with different delay time for each finger. By limited integration, the correlation has been done to correlate the received and template signals. The rake receiver receives the signals with additive white Gaussian noise (AWGN) from the proposed matched filter and signal processing takes place to combine the output of the fingers. Combining operation is done by three main combining techniques, maximum ratio combining (MRC), equal gain combining (EGC), and selective combining (SC) to capture most of the energy of the multi-path components (MPC). The range is mentioned in this work to be up to 10 meters non-line of sight (NLOS) for indoor multi-path reception at indoor reflection and deflection. At the output of the decision circuit, the probability of bit error can be calculated according to the values of SNR. The simulated results indicate that, the MRC combining rake technique introduces the best performance compared with the other multi-path combining techniques in signal energy capturing.

Key words: UWB; ISI; MRC; EGC; SC; SNR; P-Rake receiver; MPC.

INTRODUCTION

The promising solution was proved by Ultra-wideband (UWB) communication technology to support the activity of short range, high data rate networking applications among multiple devices with different interfaces (Nikoogar H. and Prasad R. 2009). A novel rake receiver was proposed by (Norman C. Beaulieu & S. Niranjayan 2010) to mitigate the multiple access interference (MAI) using mixture of Laplacian and Gaussian noise. The range is proportional to the transmission speed in the indoor mask with the environments is standardized in to three speeds, 110 Mbps with room of nearly 10 meters dimension, 200 Mbps with room of 4m dimension and 480 Mbps with distance less than 1m (Kikuchi H. 2003). The level of power spectral density is -41.3 dBm/MHz for band of 7.5 GHz (3.1—10.6 GHz) that was proved by Federal Communications Commission (FCC) (Pendergrass M. 2003) and Figure 1 shows that. Two analytical methods (lognormal-Laplacian and lognormal- Gaussian) are proposed by (Hua Shao & Norman C. Beaulieu 2010) to evaluate the performance of MRC rake receiver and found the Laplacian model is more accurate. Low PSD leads to low power consumption and this is advantage for designing smaller signal processing circuit dealing with lower operating voltage and the UWB power less than 100 mw (Tse D. & P. Viswanath 2005). This low PSD made the UWB systems coexist with devices such as cellular systems, global positioning systems (GPS), and wireless local area networks (WALN) that based on penetration ability to overcome the obstacles for operation under both line of sight (LOS) and non line of sight (NLOS) conditions.([Nan-Yang Yen & Szu-Lin Su 2009) presented a robust matched filter algorithm to profit more benefit of DS-UWB signal over UWB dense multipath channels. In (Konstantinos B. Baltzis & John N. Sahalos 2010), optimized simulation results for half of the receiver finger settings were produced to decrease the complexity of MRC rake receiver and found that for setting 3 fingers, BER is 0.001 at 15dB SNR. The UWB transmitted signal will reach the receiver passing through the multipath channel with noises and there are number of parallel processors (RAKE). The Rake receiver will try to capture most of signal energy by combining the amplitudes of the multipath components

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(Savo G. Glisic 2003). The partial rake receiver was modified by (Win M. Z. *et al*. 2009) for UWB communication systems to add a common signal finger whose output is fed to multi-comparators distributed along the conventional partial rake fingers. In this paper, the modified adaptive rake structure (3 fingers rake) is proposed to reduce the noises and interferences with less complexity to achieve better performance.

The remainder of the paper is organized as follows. Section (2) is devoted for the generated and transmitted UWB signals considering system of DS-UWB with BPSK modulation. The IEEE 802.15.4a of multipath components with indoor channel models is mentioned in section (3). In section (4) the proposed architecture partial rake receiver is produced for combining and maximizing SNR analysis. Finally, simulation results and performance analysis are discussed in section (5), while it is conclusion is remarked in section (6).

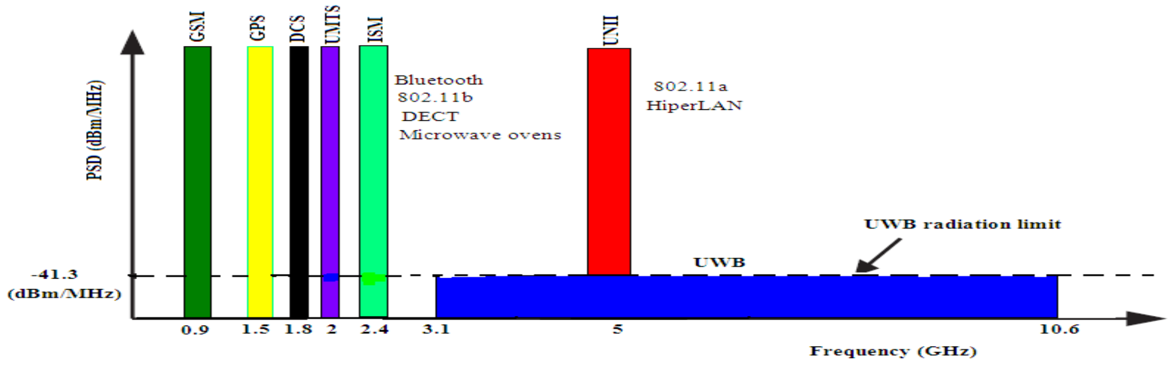

Fig. 1: The spectrum of the UWB signal and narrowband signals.

2. UWB Transmitted Signal:

We consider a DS-UWB system with binary phase shift keying BPSK modulation. The information be generated randomly by binary source as in Figure 2 that to be transmitted at a symbol rate of $1/T_b$ bits/sec (Sheng Li 2010).

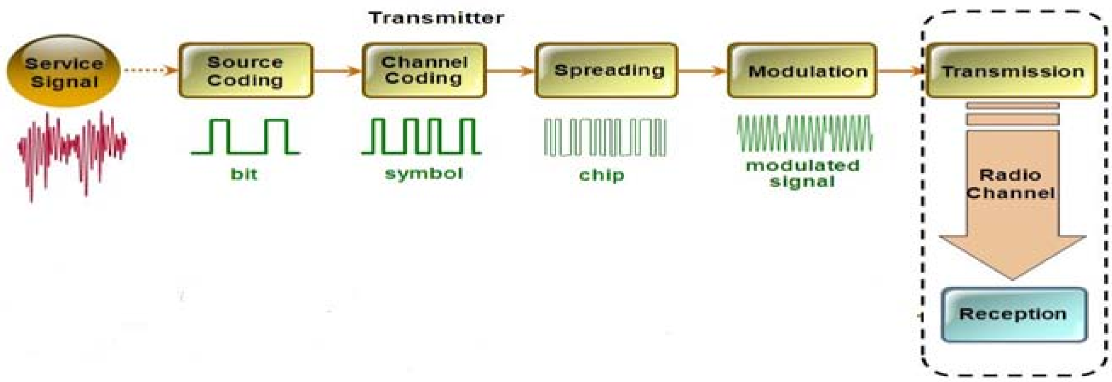

Fig. 2: DS-UWB transmition block diagram.

The output of channel coding is a vector (b) elements $\{b_m, m \in(-\infty, \infty)$ and the output of BPSK modulator is a source represented by a vector (d) with elements $\{d_m = 1\text{-}2b_m, m = \lfloor j/Nc \rfloor \in(-\infty, \infty)$. Sequence (d) is spread by PN sequence $w\{w_n, n = \mathrm{mod}(j, N_c) \in(0, N\text{-}1)\}$ which is composed of ± 1 values. When N_c is length of a PN code or block of BPSK pulses and can be 15 or 31or 63. After spreading vector (d), transform to a vector $c\{c_j = d_m. w_n, j \triangleq (m,n) \in(-\infty, \infty)\}$ that is generated at a chip rate of $1/Tc = N_c/T_b$ chips/sec and the chip period of T_c can be chosen to be five or less than five nsec. The transmitted pulse shaping form ($P_T(t)$) of duration T_p = 2 nsec and pulse energy E_p is considered as second derivative of a Gaussian function $e^{-2\pi(t/\tau)^2}$ (Huseyin Arslan *et al*. 2006).

2nd derivative is

$$P_T(t)=[1-4\pi(t/\tau)^2]e^{-2\pi(t/\tau)^2} \tag{1}$$

where τ is the shape factor or time scaling factor.

Transmitted signal is $$S(t)=\sum_{j=-\infty}^{\infty} C_j P_T(t-jT_c) \tag{2}$$

where $c_j = d_m . w_n$ …..$-\infty < m < \infty$, n=0 , 1 , 2 , …..N_c-1 (3)

$$S(t)=\sum_{m=-\infty}^{\infty} d_m \sum_{n=0}^{N_c-1} w_n P_T(t-mT_b-nT_c) \quad (4)$$

3. *Multipath Channel Model:*

The S(t) signal passes through a multipath channel and the channel model should be based on a modified Saleh-Valenzuela (S-V) channel model for indoor multipath propagation (M. Pendergrass 2003). It is proposed by IEEE 802.15 that based on this clustering phenomenon observed in several channel measurements, we propose an UWB channel model derived from the Saleh-Valenzuela model with a couple of slight modifications. We recommend using a lognormal distribution rather than a Rayleigh distribution for the multipath gain magnitude, since our observations show that the lognormal distribution seems to better fit the measurement data. In addition, independent fading is assumed for each cluster as well as each ray within the cluster. Therefore, the multipath model consists of the following, discrete time impulse response (Foerster J. & Q. Li 2012):

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha_{k,l}^{i} \delta(t - T_l^i - \tau_{k,l}^{i}) \quad (5)$$

where { $\alpha_{k,l}^{i}$ } are the multipath gain coefficients of the k^{th} ray within l^{th} cluster, { T_l^i } is the delay of the l^{th} cluster, { $\tau_{k,l}^{i}$ } is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time (T_l^i), { X_i } represents the log-normal random variable which represent shadowing, L is the number of observed clusters, and *i* refers to the i^{th} realization of the channel model.

Finally, the proposed model uses the following definitions:

T_l = the arrival time of the first path of the l^{th} cluster.

$\tau_{k,l}$ = the delay of the k^{th} path within the l^{th} cluster relative to the first path arrival time, T_l.

δ (t)= Dirac delta function.

The cluster intra- arrival times and ray intra-arrival times are described by two independent exponential PDFs and illustrated in Figure 4, by definition, we have $\tau_{0,l} = 0$.

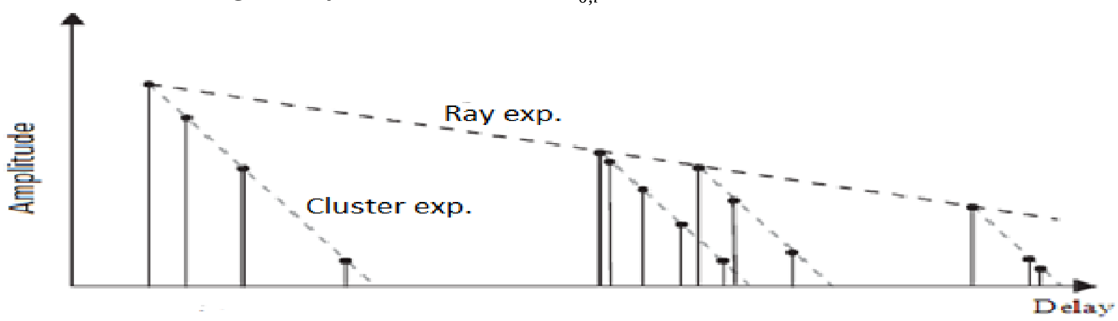

Fig. 3: The S-V channel model for exponential power decay of clusters and rays.

The multi-path model parameters are illustrated in Table 1, were used in simulation for CM3 and CM4 models that are based on NLOS (4-10m) and CM4 (Foerster J. & Q. Li 2012). Λ is cluster arrival rate, λ is ray arrival rate, i.e., the arrival rate of path within each cluster, Γ is cluster decay factor, γ is ray decay factor, σ_1 is standard deviation of cluster lognormal fading term (dB), σ_2 is standard deviation of ray lognormal fading term (dB), σ_x is standard deviation of lognormal shadowing term for total multipath realization (dB).

Table 1: the key parameters that define the channel models.

Channel Models	Λ (1/nsec)	λ (1/nsec)	Γ	γ	σ_1 (dB)	σ_2 (dB)	σ_x (dB)
CM 3	0.0667	2.1	14.00	7.9	3.3941	3.3941	3
CM 4	0.0667	2.1	24.00	12	3.3941	3.3941	3

These characteristics are based upon a 167 picoseconds sampling time and actual realizations of (100) for each channel model are provided in this research. Figure 4 shows the power decay profile for two channel models of the standard IEEE 802.15.3a that designed NLOS scenario. The considerable times for degradation the power are 200 ns over CM3 and 300 ns over CM4.

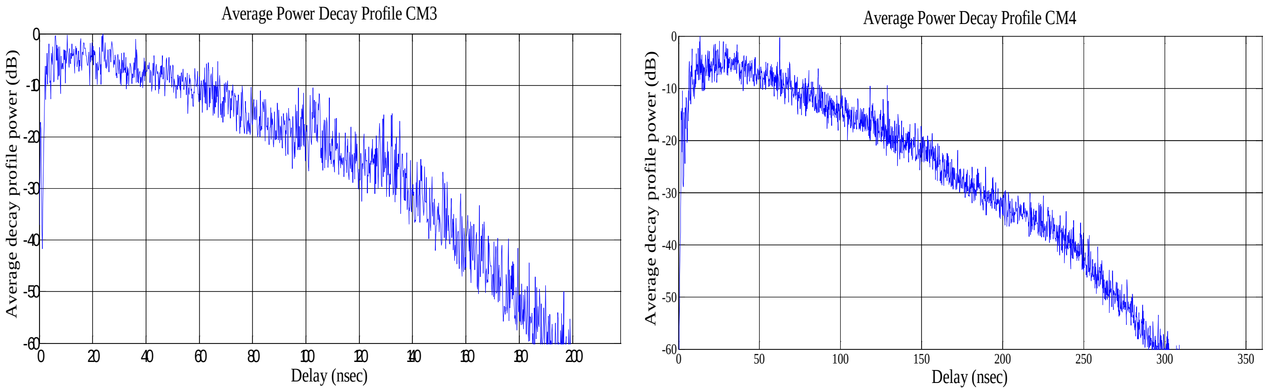

Fig. 4: The power fading based on channel models (CM3 & CM4).

The Proposed Indoor Rake receiver:

After corrupting by a white Gaussian noise n(t), the UWB signal r(t) is received by receiver of three copy fingers. The signal passes through a matched filter to maximize the ability for suppressing most of the noise as much as possible. As shown in Figure 5 the output of the matched filter is decomposed in to $r_o(t)$ and $n_o(t)$ due to the input signal and input noise respectively. The UWB matched filter is used to maximize the amplitude of transmitted pulses at $t = t_1$ comparing to the noise amplitude at that instant (Xia J. *et al*. 2012).

$$r_0(t) = \int_0^t r(t)h(t-\tau)d\tau \tag{6}$$

$$n_0(t) = \int_0^t n(t)h(t-\tau)d\tau \tag{7}$$

In this proposed rake receiver a scheme of five stages matched filter with parameters as in (Xia J. *et al*. 2012) is used to maximized SNR in UWB pulses and to improve the signal to interference ratio from other narrow band signals. Figure 6 shows the indication of input and output for matched optimal filter. The five gain stages convert the tapped voltages to currents and add them at the output of the filter to compensate the losses due to the input stage. The received signal r(t) is passed to the sampler through a linear matched filter which is matching with the received pulse s(t). The sampler samples the received signal at chip rate and we assume the desired user is user (1). The proposed receiver is designed with three fingers and each finger has a regular delay (τ). Because of existing the indoor UWB invironments, the received signal sufers from inter-symbole interference (ISI) at the multi-path receiving of interfaced time response.

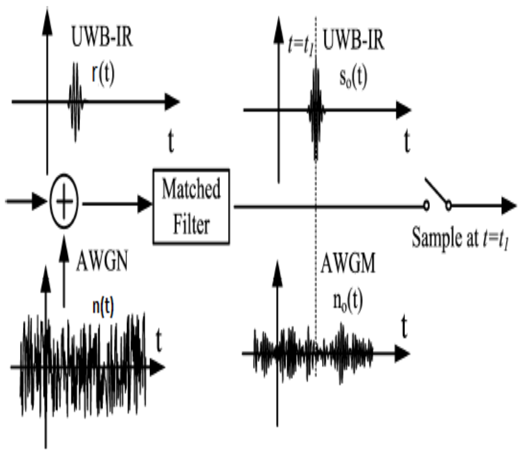

Fig. 5: Time domain scenario to improve the SNR.

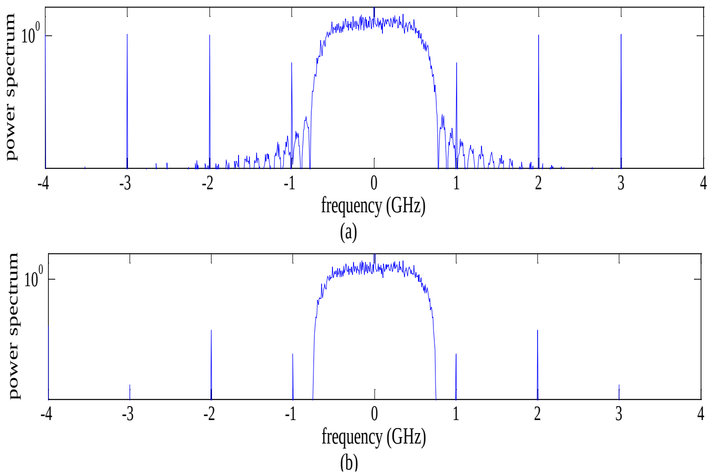

Fig. 6: (a) Matched filter input spectrum.
(b) Matched filter output spectrum.

A. Maximal Ratio Combining (MRC):

According to the strength of each path, there are three techniques to combine the output signal of the rake receiver fingers. The technique that leads to least BER is MRC after correcting the phase rotation that caused by a fading channels and summing the chips of the current symbols. Finally the chips summation is supplying in to decision circuit to detect the desired bit. As shown in the proposed rake receiver of Figure 7 the received signal by MRC is a sum of the desired signal and noise (Ian Oppermann *et al*. 2004).

$$R_0(t)=r(t)\,h(t)+n(t) \quad (8)$$
$$h=[h_1 , h_2 , \ldots\ldots h_N]^T \quad (9)$$
$$n=[n_1 , n_2 , \ldots\ldots n_N]^T \quad (10)$$
$$Z(t)=W^H r_0=W^H\, h\, r(t) + W^H\, n \quad (11)$$

where N is the multipath component or elements of received independent copies of the same signal and r0 is a vector of received channel path coefficient. The signal power (P_s) and noise power (P_n) over a symbol period (T_s) are mathematically derived as follow with assumption r(t) to have unit power.

$$P_s = \int_0^{T_s}[W^H\, hr(t0)]^2 \mathrm{dt} = \frac{[W^H h]^2}{T_s}\int_0^{T_s}|r(t)|^2\, dt = |W^H h|^2 \quad (12)$$
$$P_{n=}E|W^H n|^2 \mathrm{E}|W^H W n n^T| = W^H E|nn^H|W = \sigma^2 W^H I_N W \quad (13)$$
$$P_n = \sigma^2 W^H W = \sigma^2 \left\|W\right\|^2 \quad (14)$$

where IN is the N×N identity matrix. By the Cachy-Schwarz inequality and the maximizing is produced when w = h.

$$SNR_{MRC} = \frac{P_s}{P_n} = \frac{\left\|W^H h\right\|^2}{\sigma^2\left\|W\right\|^2} = \frac{\left\|h^H h\right\|^2}{\sigma^2 h^H h} = \frac{h^H h}{\sigma^2} = \sum_{n=1}^{N}\frac{|hn|^2}{\sigma^2} = \sum_{n=1}^{N}\frac{E_b}{N_o}h_n \quad (15)$$

where N_o is the power spectral density of the adaptive white Gaussian noise (AWGN). E_b is the transmitted bit energy, and h_n is the gain of N^{th} path. Channel SNR over N elements is

$$CSNR_{MRC} = \sum_{n=1}^{N}(SNR_{MRC})_n \quad (16)$$

The expected value of SNR_{MRC} is therefore N times the average signal to noise ratio ($ASNR_{MRC}$) at each element and it is improved by a factor of N. $E(SNR_{MRC})=N(ASNR_{MRC})$

The bit error rate (BER) of a BPSK system is given by

$$erfc\sqrt{2SNR_{MRC}} = Q\sqrt{2N(ASNR)_{MRC}} \quad (17)$$

where Q-function is

$$Q(ASNR_{MRC}) = \frac{1}{\sqrt{2\pi}} \int_{ASNR_{MRC}}^{\infty} e^{-\frac{t^2}{2}} dt \quad (18)$$

Maximal ratio combining scheme can be improved to partial combining (PMRC) with less complexity and also uses weighted path integration with ordering of paths depending on their signal to noise ratios. The main purpose of the suboptimal scheme is to reduce the channel estimation complexity related to detect and track the strongest N paths.

B. Equal Gain Combining (EGC):

It requires a perfect estimation of the phase for each channel taps in order to correct the offset at the received signal before the detection block. The weights are chosen to remain constant and equal in all branches (Ghavami M. *et al*. 2004).

$a_1=a_2=a_3\ldots\ldots=a_m$

$$Y_{tot} = \sum_{m=1}^{M} r_m \quad (19)$$

$$SNR = \frac{Y^2 E_b}{MN_0} = \frac{E_b}{MN_0} (\sum_{m=1}^{M} r_m)^2 \quad (20)$$

where M represents the number of rake fingers and N_o the noise power spectral density.

C. Selective Combining (SC):

In this technique, the rake receiver, simply chooses the signal with highest SNR of all the signals from different fingers and use this high signal for detection. The total combined signal for SC technique can be expressed as $w_m = 1$.

If $|r_m| = \max.\{|r_1|,|r_2|,|r_3|,\ldots..|r_m|\}$ (21)
$=0$ otherwise

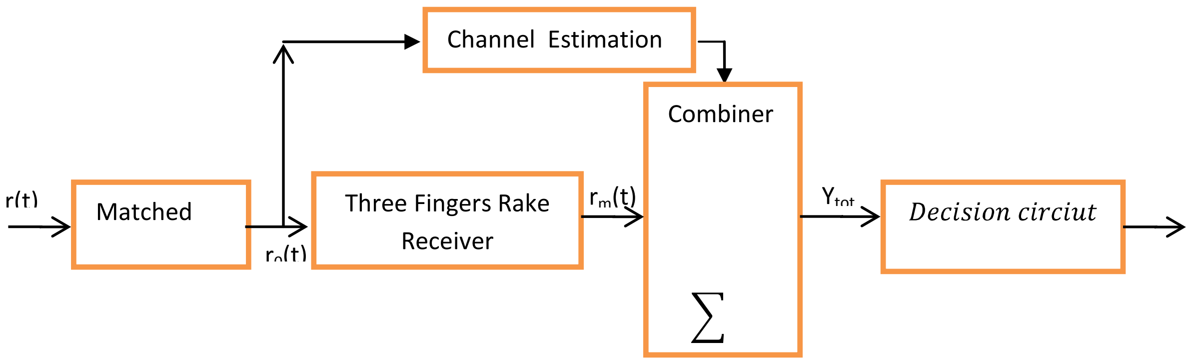

Fig. 7: Block diagram of the proposed rake receiver with M fingers.

5. The Performance Analysis and Simulated Results Discussion:

The_proposed matched filter is added in designing of rake receiver to degrade the noises that mixed with received signal r(t). Three fingers are used to capture the energy of multiple path components. The input signal to the receiver is copied to multi-copies according to the number of fingers and each copy is delayed by delay time (τ), supposing that the first delay time for the first finger is zero. These copies are multiplied by generated template signal and integrated to make dispreading and demodulation for the direct sequence spread spectrum BPSK transmitted signal. Partial rake receiver is used in this simulation rather than all rake and selective rake receivers, because of lower cost and less complexity with log-normal fading channel .In partial rake receiver, the arriving paths are selected for the first non-zero M paths and these paths are normally with high energy. The output of the fingers is signals of different attenuated, shifted, and delayed received signals. To combine these signals, three different combining techniques (MRC, EGC, and SC) are used with accurate channel estimation to find the position of the first arriving path. The output of the receiver combiner is passing through decision circuit to estimate the desired signals after declining the probability of error (BER) by proposed rake receiver.

The BER performance of the proposed rake receiver in this paper is simulated for channel models CM3, and CM4 using three main rake receiver combining techniques, MRC, EGC, and SC. The simulation is carried out using partial rake receiver by MATLAB with three fingers under each of the above channel models that received the DS-BPSK-UWB transmitted signal. The 3-fingers enhanced the reducing in complexity of receiver and decrease the optimization time. The determination and comparisons are illustrated in the following figures :

In Figure 8, the probability of error (BER) is plotted against SNR to produce the enhancement of the rake receiver for CM3 during indoor propagation (NLOS). The BER is 0.01 at 6.8 dB SNR with MRC, 7.5 dB SNR with EGC, and 8.5 dB SNR with SC rake receiver techniques. Compared to (Welelaw Yenineneh Lakew 2011), the 0.01 BER with MRC can be illustrated when SNR is 9.8 dB under partial rake receiver of 20 fingers.

Figure 9 shows the BER performance for channel model CM4 (NLOS). The bit error rate is 0.01 when SNR is 6.8 dB with MRC, 7.2 dB with EGC, and 8.4 dB with SC. From (Welelaw Yenineneh Lakew 2011), the BER of 0.01 is produced at more than 18 dB SNR using MRC technique in selective rake receiver with 10 fingers and from (Xiantao Cheng & Yong Liang 2012), it is produced at 21 dB SNR with 7 fingers.

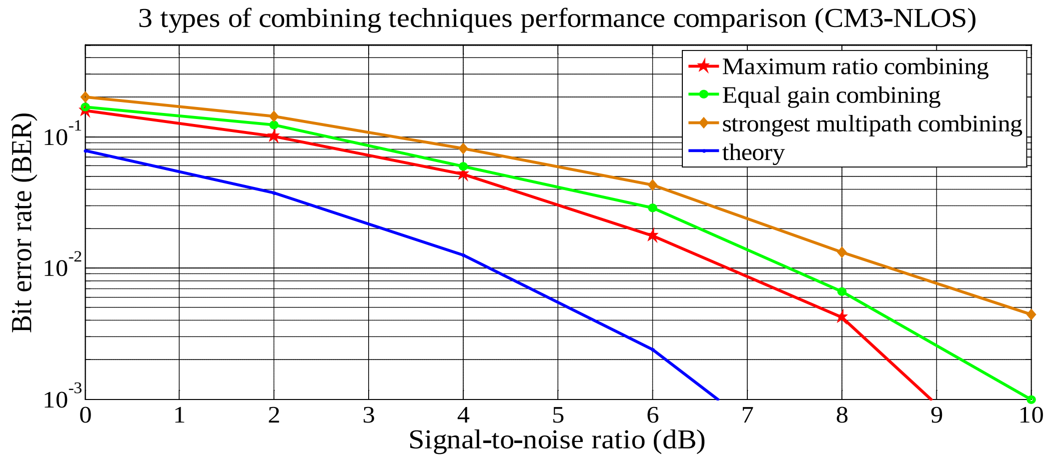

Fig. 8: The BER performance against SNR of 3 different combining techniques during CM3.

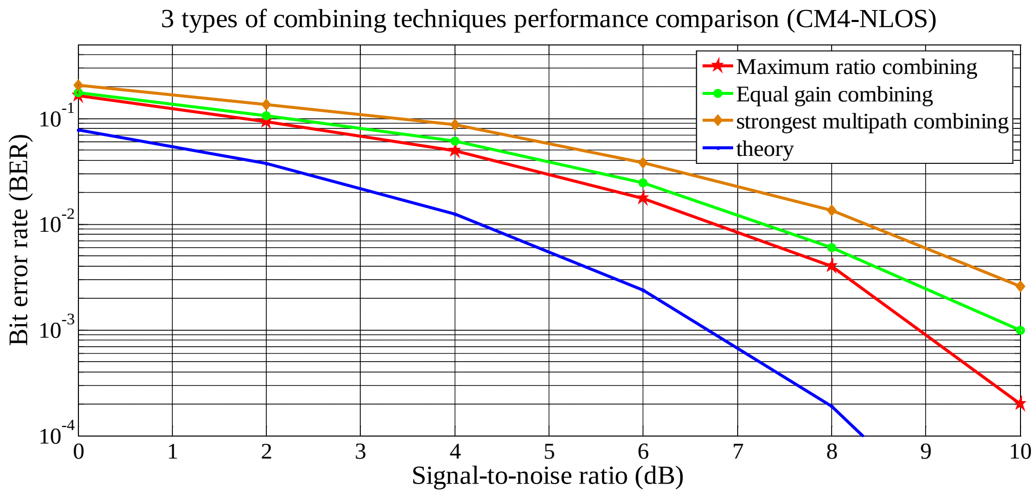

Fig. 9: The BER performance against SNR of 3 different combining techniques during CM4.

Conclusion:

The partial rake (P-Rake) receiver was presented and analyzed for DS-UWB wireless communication systems throughout two channel models (CM3 and CM4). There are many progress and attention have been seen in UWB research, but still many challenges face the performance of rake receiver during multi-path indoor propagation. One of these challenges is the inter-symbol interference (ISI) that effects on rake receiver, so matched filter is used at the input of the rake receiver to improve the signal to noise ratio (SNR) with decreasing in probability of error. The simulation results showed the improvement of three fingers rake receiver compared with theoretical, refs.[8] and [17] for three different combining techniques (MRC, EGC, and SC). From simulation results, the MRC rake receiver structure produces better performance than the other rake multi-path combining techniques in capturing as much energy as possible of the received signal.

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