Improving the Performance of UWB Wireless Rake Receiver By using New Combining Technique

Rashid A. Fayadh, Sabreen A.J. Mohammed

***Abstract:** In wireless communication system, the signals are arriving to the receiver in terms of general summation for several "multipath components (MPCs)" through "direct line of sight (LOS) and indirect non line of sight (NLOS)". Multipath occurs due to "reflection, diffraction, and scattering" of transmitted signal. "MPCs" are considered one of the main problem in wireless communication system especially in "ultra-wideband (UWB)" system because these "MPCs" have a different amplitudes, phases, and delays with respect to the transmitted signals and cause signal distortions and fading that degrade the quality of the received signal and lead to poor performance in wireless communication systems, However multipath phenomena is used to enhance system performance by using a dedicated wireless receiver such as wireless "rake receiver" to resolve the "MPCs" and reduce "multipath fading" effects to improve system performance. The combiner is a main part of rake receiver that coherently combines "MPCs" using one of the combining schemes to form a complete replica of a transmitted signal to capture most of the energy of the received signal. By this combiner, the system can achieve better performances that lead to maximize the average "signal to noise ratio (SNR)" to recover the transmitted signal with lower "bit error rate (BER)". This technique is suitable for "UWB" wireless devices that are commonly used for high-speed data rate through short-range indoor wireless communication. In this paper new combiner was proposed to enhance the combining performance of "UWB" wireless rake receiver named adaptive partial-hybrid (AP-H) combiner. For comparison, the two conventional combiners: "selective combiner and partial combiner" were designed. The simulation results were obtained by using MATLAB software, these results shown higher system performance when using the proposed AP-H combiner than other conventional combiners. For this work "UWB" signal was used with binary phase shift keying-Time Hopping (BPSK-TH) multiple access modulation scheme.*

***Index Terms:** "UWB" Technology, Rake Receiver, MRC Adaptive Partial-Hybrid Combiner, Multipath Components.*

I. INTRODUCTION

In "UWB communication technique", the signals are spread across a very wide range of frequencies, where a low power and narrow pulse (less than one nanosecond) is used for transmission, so these signals appear like noise. The advantages of "UWB technology" such as low-cost, low complexity, high data rate, and immunity to multipath effects, all these advantages made this technology suitable for many applications. In past, "UWB technology" was only used in military applications yet 2002, when the "Federal Communications Commission (FCC)" gave permission for commercial use of this technology and allocates frequency range from 3.1 GHZ to 10.6 GHZ providing a 7.5 GHZ of spectrum and "power spectral density of (-41.3 dBm/MHz)" [1]. "MPCs" cause constructive or destructive interference at the receiver. The phase shifting of "MPCs" causes "multipath fading", so the wireless receiver should be able to coherently separate these multiple attenuated copies of the transmitted signal and then combine them in order to collect the energy and recover the original transmitted signal. This can be done by using the diversity techniques, such as the time diversity technique, in which several sub-receivers (branches) are used and each individually delayed to make coherent with the diversity of "MPCs" and then combine these "MPCs". In this way the effects of "multipath fading" will be mitigated. A dedicated receiver is required to perform the combining process, since combining multiple branches require a phase detecting and then co-phasing process for each branch. The co-phasing process is necessary for combining to prevent the destructive addition of the SNR's values of each branch, but for a large number of branches, this will be increasing the hardware complexity and power consumption of the wireless receiver [2]. The rake receiver exploit the benefit of the diversity technique, it can collect and resolve the "MPCs". This receiver consists of multiple sub-receiver called correlators or fingers and combiner. These fingers are individually delayed to make coherent with the diversity of "MPCs". Rake receiver applies a selection scheme to select the best received paths and only the selected paths are participate in the combining process. The selection scheme is an important issue for improving the combining performance of the receiver and according to these schemes; the rake receiver is classified into three types: "all rake (A-rake), partial rake (P-rake), and selective rake (S-rake)" [3]. All rake receivers (also called ideal rake receiver) consists of many fingers equal in number to the number of "MPCs" and these give the ability to the receiver for capturing all the received paths, so the "A-rake" receiver has a high performance in term of BER and SNR comparing with the "partial and the selective rake receivers". The disadvantage of "A-rake" receiver is the large number of fingers which make it difficult to implement in practice because of the larger size and the higher complexity and cost. The "selective combiner" selects the strongest received paths (Ls) from all received propagation paths with higher signal amplitudes. So that, the SNR is maximized but it requires keeping track of all "MPCs" and estimation of the channel for each path is required. In "partial combiner", the first arrived paths (Lp) are combined within limited delay time and these arrived paths are not always the strongest paths.

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This combiner has less complexity, only synchronization is required rather than full channel estimation, but optimum performance cannot be achieved. Several combining techniques can be used in the combiner to combine the output of fingers. These techniques vary in complexity and the output of combiner is the sum of all SNR's values of the received paths multiplied by a weighting factor which is determined by the combining technique. There are three main combining techniques that used by the combiner to combine “MPCs”, these techniques are: "maximal ratio combining (MRC), equal gain combining (EGC) and selective combining (SC)" [4].

A hybrid MRC/SC receiver was evaluated in [5] where two stages of combining are produced, the first stage is MRC and the second stage is SC and this multistage of combining increase the complexity. In [6] A New Suboptimal SC scheme is proposed which is less complex than other selection schemes, but the BER is higher. In [7], "UWB" P-rake receiver with a novel algorithm was evaluated and based on a predefined cut-off value for the multipath amplitude gain level, the result shows that the performance was improved but the complexity was increased. In [8], a hybrid MRC/EGC diversity scheme over "the additive white Gaussian noise (AWGN) channel" was evaluated with M number of branches uses MRC and L number of branches use EGC. This design increases the complexity, size, and the cost of the combiner because the combiner includes two hardware stages: the MRC stage and the EGC stage.

In this paper new combiner was proposed, called adaptive partial-hybrid (AP-H) combiner. In addition a conventional "partial combiner" and conventional "selective combiner" were designed for comparison. In the proposed AP-H combiner, adaptive feature was added to the combiner to make it able to adaptively select the best received paths to achieve high performance comparing with the conventional types, without increasing the complexity of design.

The remainder of the paper are organized as follows: Section 2 discusses the system model, Section 3 shows the transmitter and the generation of the transmitting signal, modulation and spreading techniques that used at the transmitter, Section 4 discusses the channel model that used in this work as reported by "IEEE802.15.3a", Section 5 represents the wireless receiver that is used which is a rake receiver and the combining techniques that used for the combiner, Section6 shows the simulation results with their discussions, and Section 7 is concluded the work.

II. SYSTEM MODEL

In this work, we consider "UWB" signal using BPSK-TH multiple access modulation scheme. The signal is transmitted through multipath channel, using "IEEE802.15.3a" channel model. Different transmitted signals are received and combined by using rake receiver in which the combining schemes are applied. The block diagram of a "UWB" wireless communication system using rake receiver is shown in figure(1) with main parameters such as, S(t) is the transmitted signal, r(t) is the received signal, and W1,W2,....Wn are the MRC weights.

III. TRANSMITTER

In this work, we used "UWB" transmitter with modulated signals by "BPSK-time hopping (BPSK-TH) multiple access modulation scheme". "UWB technology" is deferent from narrowband technology that broadcasting on separate frequencies and it use sinusoidal radio wave. In "UWB technology" signals are spread over a very wide range of frequencies and uses trains of very low power pulses and this makes "UWB signals" appear like noise to narrowband system [9]. Other benefits of "UWB" include low-cost and simple transceiver design, immunity to multipath effects, high resolution (sub-decimetre range), and small "UWB" transceiver design is a challenging task [10].To generate "UWB signal", impulse radio technique is used hence, a train of low duty-cycle, nanoseconds wide pulses, are transmitted [11]. "UWB signal" can be any one of a very wideband signals, such as "Gaussian, chirp, wavelet, or Hermite-based short-duration pulses" [12]. "The second derivate of a Gaussian function exp $(-2\pi\{t/\tau\}^2)$ is used for the UWB pulse and is given by equation(1):

$$G(t)=(1-4\pi(t/\tau)^2)\exp(-2\pi(t/\tau)^2)" \quad (1)$$

where "τ is a shape factor" and the "time hopping (TH) technique" is used for spreading to eliminate collisions in multiple access applications. In each frame time, the pulse is positioned pseudo-randomly in time with a TH sequence since the pulses are so short. There are many time slots with repeated pulses in many frames [13] and typical "BPSK-TH-UWB signal" is given by equation (2):

$$S^j(t) = \sum_{K=-\infty}^{\infty}\sum_{l=0}^{N_s-1} G(t - kT_s - lT_f - C_i^{(j)}T_C - \tau_0^j)\, d_k^{(j)} \quad (2)$$

where "$S^j(t)$ is user (j)’s transmitted signal, τ^j_o is the first user’s reference delay ($0 \le \tau^j_o \le T_f$), and N_c is the spreading factor as a number of chips" [14].

IV. CHANNEL MODEL

The multipath components are arriving receiver in groups, called clusters, with Poisson distribution. The path (ray) within each cluster also arrives with Poisson distribution [15].

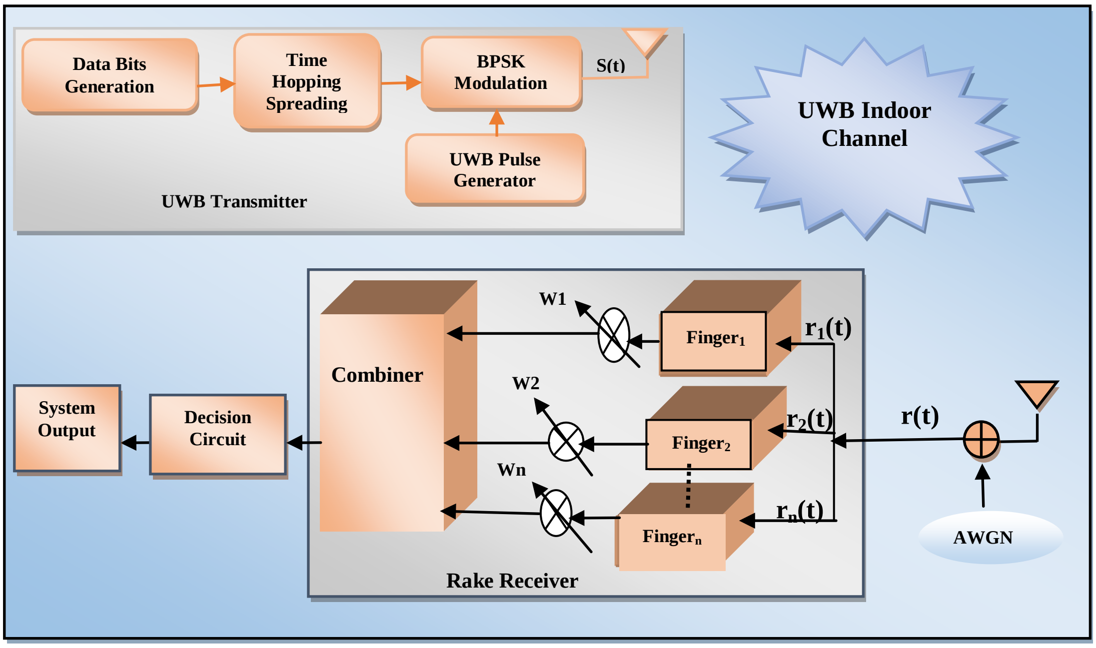

Figure (1): Block Diagram for UWB Wireless Communication System Using Rake Receiver.

The received signals are sum of both "LOS and NLOS". The "NLOS MPCs" are caused by "reflection, diffraction, and scattering" that cause signal distortion and fading [16]. These signals are also attenuated due to materials and propagation effects. The traditional channel models were reported with a constant attenuation over the bandwidth. These models are not working for the "UWB signals" because they have very large bandwidth. So that, the effects are varied over the entire band [17]. IEEE's 802.15.3a report considers the standard indoor multipath channel models during "LOS and NLOS" that is based on modified "Saleh-Valenzuela model" and the channel multi-path gain distribution is lognormal distribution, these models are: "CM1 (0-4 m LOS), CM2 (0-4 m NLOS), CM3 (4-10 m NLOS), and CM4 (≥25 m NLOS)".

The model parameters are defined in table (1) and contains: "cluster arrival rate (Λ), ray arrival rate (λ), cluster decay factor (Γ), ray decay factor (γ), standard deviation of cluster lognormal fading term (σ_1), standard deviation of ray lognormal fading term (σ_2), and standard deviation of lognormal shadowing term for total multi-path realization (σ_x). The main channel characteristics are used to determine the model parameters such as: mean excess delay (τ_m), RMS delay spread (τ_{rms}), and number of multipath components that arrived within 10 dB (NP10 dB) of the peak multipath arrival" [18].

Wireless "channel impulse response" is modelled by equation (3):

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{n=0}^{N} a_{n,l}^{i}\, \delta(\tau - T_l^i - \tau_{n,l}^{i}) \qquad (3)$$

where $a_{n,l}^{i}$ are the multipath gain coefficients and X_i represents the log-normal wireless shadowing and i refers to the i-th realization.

Table(1): "IEEE802.15.3a Report" of Indoor Parameters for Channel Models [18].

Parameters / Models	Λ (1/nsec)	λ (1/nsec)	Γ	γ	σ_1 (dB)	σ_2 **(dB)**	σ_x (dB)	τ_m (ns)	τ_{rms} (ns)	NP 10 dB
CM1	0.0233	2.50	7.10	4.30	3.3941	3.3941	3.0	5.0	5	12.50
CM2	0.40	0.50	5.50	6.70	3.3941	3.3941	3.0	9.94o	8	15.30
CM3	0.0667	2.10	14	7.90	3.3941	3.3941	3.0	15.9o	15	24.90
CM4	0.0677	2.10	24	120	3.3941	3.3941	3.0	30.1o	25	41.20

V. WIRELESS RECEIVER

For multi-user (i-th user) process, "UWB signals" pass through channel and then can be received by multiple diversity channel and these multiple copies of the same signal ($s^i(t)$) are convoluted with channel impulse responses ($h^i(t)$) and added to "AWGN (n(t))". In addition, interferences can be mitigated by receiver which are "inter symbol interference (ISI) and multi-user interference (MUI)". So, the noisy received signal can be represented as in equation (4):

$$r^i(t) = s^i(t) * h^i(t) + n(t) + F_{ISI}(t) + F_{MUI}(t) \qquad (4)$$

Then, the noisy received signals with "BPSK-TH modulation technique "can be written as:

$$r_i(t) = X_i \sqrt{\frac{E_S}{N_S}} \sum_{j=-\infty}^{\infty} \sum_{l=0}^{L} \sum_{k=0}^{K} \sum_{n=0}^{N_c-1} a_{k,l} d_j C(n) G(t - T_l - jTf - nTp - CjTc - \tau k,l) + nt + FISIt + FMUIt \qquad (5)$$

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where $r^i(t)$ is the received signal, $F_{ISI}(t)$ is "the inter-symbol interference", and $F_{MUI}(t)$ is "the multi-user interference". The wireless receiver must efficiently separate the "MPCs" of the transmitted signals and then combined them to improve the SNR. This process can be done by using rake receiver, which consist of multiple sub receivers (correlators) with each individually delayed to achieve the coherency with the diversity of "MPCs" [19]. Increasing the number of correlators (fingers) yield to improve the reception performances but it is considered a challenging task because it makes the design more expensive, more complex and bigger in size, so there is a trade off between improving the performance and the design complexity. In each correlator, a template signal is used to reshape the received pulse; the result of multiplication is integrated giving one sample output. This multiplication and integration is termed correlation [20]. The output signal from the L-th correlator ($z^j_L(t)$) of user j can be written as in equation (6):

$$z^{j}_{L}(t) = \int_0^T r_i\,(t) G'^{(t)} dt \qquad (6)$$

where G'(t)is the generated template signal that multiply by the received signal as shown in Figure (2) of rake receiver structure with combining techniques. In addition, path search is a process which provides the required synchronization between transmitter and receiver. After combining the combined pulse is delivered to the decision circuit to make decision whether the transmitted bit is 0 or 1.

VI. THE COMBINER

The combiner is defined as a part of receiver to combine the output symbols from fingers. The combiner integrates the powers from the co-phased paths of the received signal, this technique is done by weighting of these paths to estimate and recover the sent information accurately in the rake-receiver. The wireless channel usually has random and time-varying changes, so a continuous estimation process is required to adapt these changes. Channel estimation processes include multi-path coefficients, multi-path delays, and the received pulse estimations due to channel effects and signal phase correction. Phase rotation includes multiplying the outputs from correlators with a complex conjugate of the channel estimate. The combining techniques are used to increase the SNR and decrease the BER that is leading to increase the receiver reliability, in this work MRC technique is used. In MRC the higher SNR branches should be weighted higher than others, and the combiner's output is a sum of the weighted SNRs ($V_1, V_2, \ldots V_m$) of all branches and it can be expressed by equation (7):

$$Y_{tot} = \frac{E_b}{N_o} \sum_{l=1}^{m} q_l w_l = \frac{E_b}{N_o} \sum_{l=1}^{m} V_l \qquad (7)$$

where, "N_o is the spectral density of the noise power, E_b is the bit signal energy, w_l is the weighting factor of each l-th finger which is equal to channel fading coefficient , m is the number of incident MPCs, and q_l is the corresponding path magnitude output signal of each finger". The BER is the "Q-function" of the SNR and is given by equation (8):

$$Q = \sqrt{\frac{2Eb}{N0}} = Q\left(\sqrt{2SNR}\right) \qquad (8)$$

where, the "Q-function" is given by equation(9):

$$Q = \frac{1}{\sqrt{2\pi}} \int_{SNR}^{\infty} e^{-\frac{t^2}{2}} dt \qquad (9)$$

A. Conventional ″Selective rake (S-rake) Combiner″

"Selective rake combiner" captures only the Ls strongest paths from all of the "MPCs" to maximize the SNR at the combiner's output and the receiver performance will be improved. This improvement is done by only the fingers with the highest SNRs will be chosen to participate in the combining process. S-rake requires a large number of fingers and a channel estimation process to estimate the CIR required to perform the paths selection [21].

The output of the combiner (Y_{tot}) using MRC for S-rake scheme can be formulated as in equation (10):

$$Y_{tot} = \frac{E_b}{N_o} \sum_{l=1}^{L_S} S_l(t) w_l = \frac{E_b}{N_o} \sum_{l=1}^{L_S} V_l \qquad (10)$$

where, $S_l(t)$ belongs to the subset S(t) which represent the strongest paths, $S(t) = (S_1(t), S_2(t), \ldots\ldots S(t)_{LS})$.

B. Conventional ″Partial rake (P-rake) Combiner″

P-rake is the simplest type of combiner, P-rake selects only the first L_p received paths in a limited delay time, but these paths may not be the strongest path, therefore the SNR at the output of the combiner will be low and the performance will be lower than that for S-rake combiner. However P-rake combiner does not require large number of fingers that make the receiver less complex in design, smaller size, and lower cost than S-rake receiver [21]. The output of the combiner (Y_{tot}) using MRC for P-rake scheme can be formulated as in equation (11):

$$Y_{tot} = \frac{E_b}{N_o} \sum_{l=1}^{L_P} V_l \qquad (11)$$

C. The Proposed AP-H combiner

To enhance the combining performance, we proposed an Adaptive combiner. Block diagram of the rake receiver with AP-H combiner is shown in figure (2).This combiner can adaptively run either scheme-1- or scheme-2- depending on the estimated SNR threshold (ϒ) that vary depending on the channel stateto select and then combine the best received paths that are the paths with the higher SNRs in order to achieve better SNR sum at the output of the combiner and decrease the average BER. The combiner shall compute the value of (ϒ) every frame time; this value is equal to the sum of the L_a "channel gain coefficients" of the first received paths and is given by the equation (12):

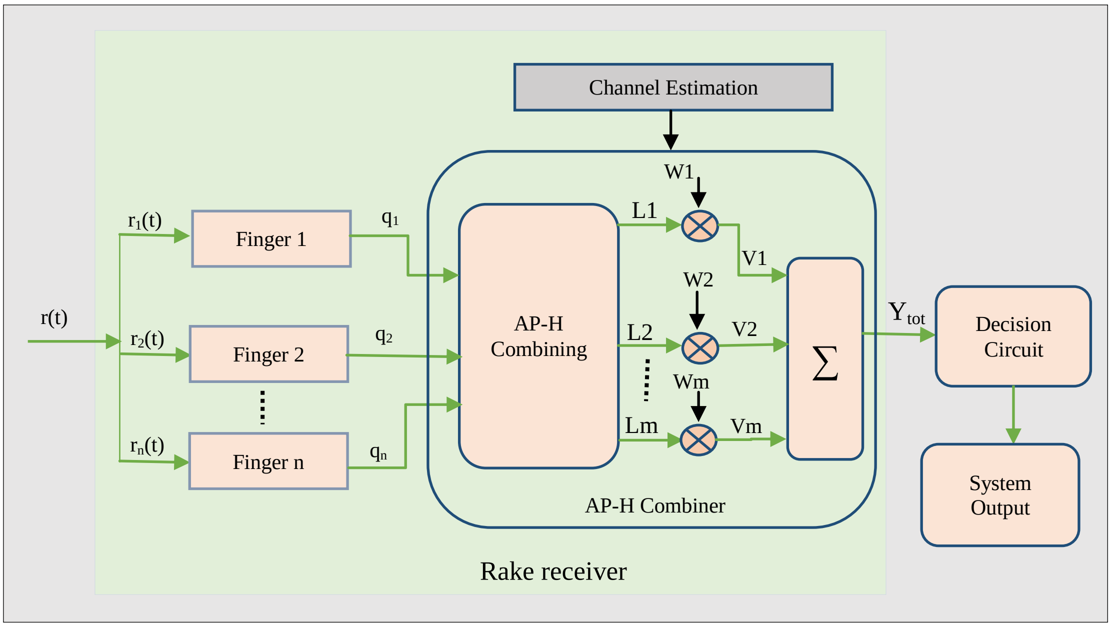

Figure (2): Block Diagram of the Rake Receiver with the Proposed AP-H Combiner

$$£ = \sum_{l=1}^{La} a_i \tag{12}$$

where, a_i represents the "channel gain coefficient" of the i^{th} path and L_a is the number of "channel gain coefficients" and it is equal to the number of incident paths.

If £ is greater than ϒ which means that these paths are strong paths and include most of signal energy, then the combiner shall apply scheme-1-which select and then combine the first L_p received paths and there is no need for many number of "MPCs", i.e. many number of fingers just like the P-rake scheme. So that, the spending power and time will be reduced. Otherwise if this sum (£) is lower than (ϒ) which means that these paths are weak, the combiner shall apply scheme-2- which is a hybrid combination from P-rake and S-rake schemes. In scheme-2- the combiner shall select the first L_{sp} received paths and then selects the strongest L_h paths among them, where $L_{sp}>L_h$. By using AP-H scheme, the combining performance will be improved and achieving lower BER and the receiver will offer the power and time comparing with "selective rake combiner".

The output of the combiner (Y_{tot}) using MRC for AP-H scheme can be expressed as in equation (13):

$$Y_{tot} = \begin{cases} \frac{E_b}{N_o}\sum_{l=1}^{L_P} V_l & , £ \geq \Upsilon \\ \frac{E_b}{N_o}\sum_{l=1}^{L_h} V_l & , £ < \Upsilon \end{cases} \tag{13}$$

VII. RESULTS AND DISCUSSION

The simulation flow chart diagram for the AP-S scheme is shown in figure (3). The parameters used in simulation are: the number of random bits = 100000 bit, Ns = 10 pulses per bit, number of channels = 50, the shaping factor = 0.22 ns, the number of users = 3, and the number of paths participated in the combining process for each combiner are seven paths. The SNR values range = 0: 2: 20. Figures (4)-(7) are shown the calculation plotting for the BER against SNR for the "partial combiner", "selective combiner", and AP-H combiner using the four channel models of "IEEE802.15.3a (CM1, CM2, CM3, and CM4)".

Through CM1, Fig.(4) shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner are equal to 0.00634, 0.003, and 0.0011 respectively. In addition, to achieve these values of BER, the "selective combiner" requires higher SNR values equal to 4.72 dB, 9.6 dB, and 15 dB respectively and "partial combiner" requires 7 dB, 11.1 dB, and 15.9 dB respectively, so for "CM1 channel model", the SNR gain for AP-H combiner rather than "selective combiner" is between 4.6 dB and 5 dB, and it is between 5.9 dB and 7 dB rather than "partial combiner".

In CM2, Fig.(5) represents that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner are equal to 0.02065, 0.00919, and 0.00428 respectively, and to achieve these values of BER, the "selective combiner" requires higher SNR values equal to 4.7 dB, 10.7dB, and 15.2 dB respectively and "partial combiner" requires 6.6 dB, 12.5 dB, and 16.6 dB respectively. So that, for "CM2 channel model", the SNR gain for AP-H combiner rather than "selective combiner" is between 4.7 dB and 5.7 dB, and is between 6.6 dB and 7.5 dB rather than "partial combiner".

Over CM3, Fig.(6) shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner are equal to 0.03277, 0.01410, and 0.00650 respectively and to achieve these values of BER, the "selective combiner" requires higher SNR values equal to 3.4 dB, 10.1 dB, and 15.6 dB respectively and "partial combiner" requires 5.5 dB, 12. 25 dB, and 17.7 dB respectively, so for "CM3 channel model", the SNR gain for AP-H combiner rather than "selective combiner" is between 3.4 dB and 5.6 dB, and it is between 5.5 dB and 7.7 dB rather than "partial combiner".

In CM4, Fig. (7) shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner are equal to 0.05257, 0.02145, and 0.00945 respectively, and to achieve these values of

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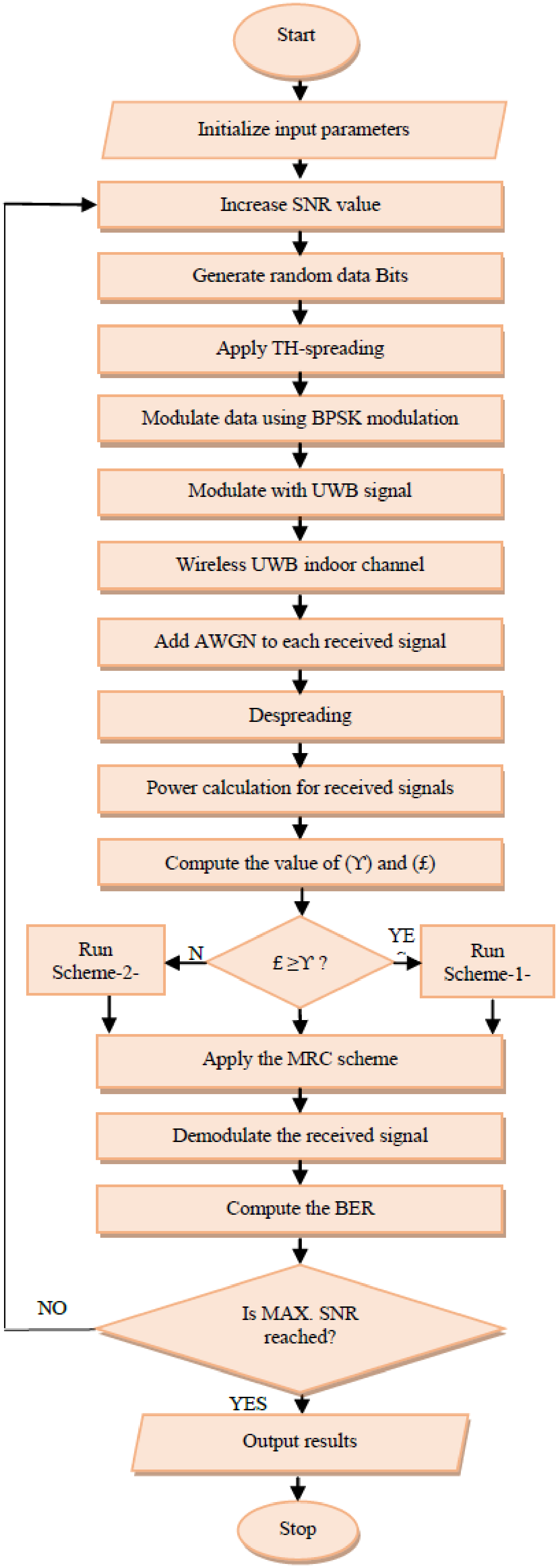

Figure (3): Flow Chart Diagram for UWB System Using Rake Receiver with the Proposed AP-H Combiner.

BER, the "selective combiner" requires higher SNR values equal to 1.6 dB, 8.4 dB, and 14.25 dB respectively and "partial combiner" requires 4.7 dB, 11.5 dB, and 18.25 dB respectively, so for "CM4 channel model", the SNR gain for AP-H combiner rather than "selective combiner" is between 1.6 dB and 5 dB, and is between 4.7 dB and 8.5 dB rather than "partial combiner".

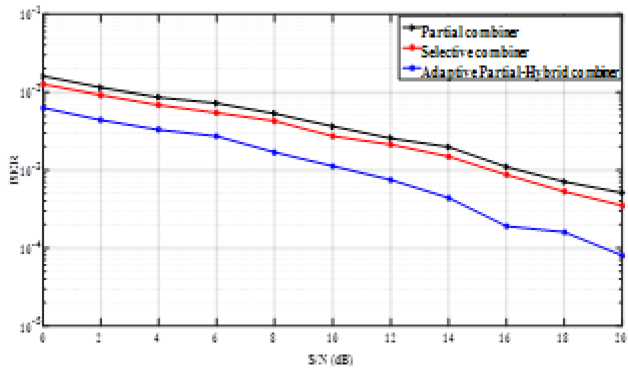

Figure (4): BER vs. SNR over CM1 for "selective, partial" and AP-H combiners.

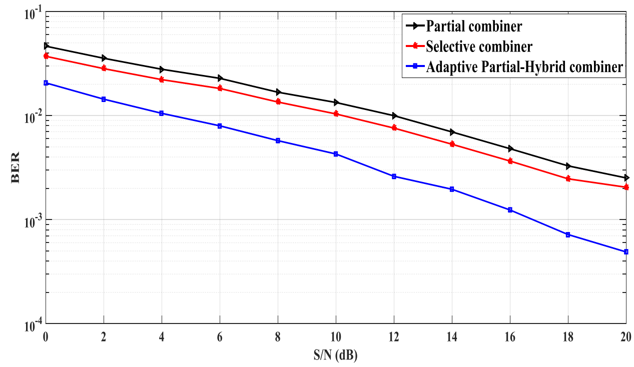

Figure (5): BER vs. SNR over CM2 for "selective, partial" and AP-H combiners.

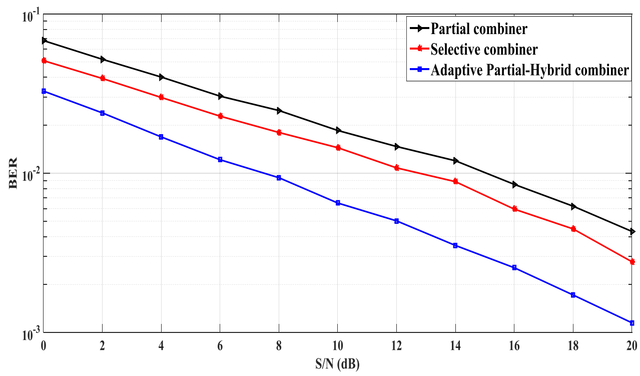

Figure (6): BER vs. SNR over CM3 for "selective, partial" and AP-H combiners.

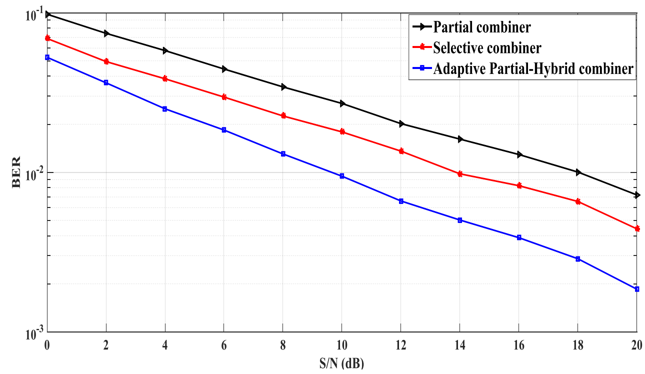

Figure (7): BER vs. SNR over CM4 for "selective, partial" and AP-H combiners.

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VIII. CONCLUSION

In this work we proposed AP-H combining scheme and for comparison the two conventional schemes: S-rake and P-rake are evaluated. The results proved that the performance of the proposed AP-H scheme outperforms both the S-rake and P-rake schemes in the four "channel models CM1, CM2, CM3, and CM4". The proposed AP-H combiner has lower BER than that for "partial combiner and selective combiner" over all of the four channel models for all SNR values obtained in the simulation. The gains in SNR over "CM1, CM2, CM3, and CM4" rather than "selective combiner" are in the ranges: 4.6 dB to 5 dB, 4.7 dB to 5.7 dB, 3.4 dB to 5.6 dB, and 1.6 dB to 5 dB respectively, and rather than "partial combiner" are in the ranges: 5.9 dB to 7 dB, 6.6 dB to 7.5 dB, 5.5 dB to 7.7 dB, and 4.7 dB to 8.5 dB respectively. In this work we proposed AP-H combining scheme and for comparison the two conventional schemes: S-rake and P-rake are evaluated. The results proved that the performance of the proposed AP-H scheme outperforms both the S-rake and P-rake schemes in the four "channel models CM1, CM2, CM3, and CM4". The proposed AP-H combiner has lower BER than that for "partial combiner and selective combiner" over all of the four channel models for all SNR values obtained in the simulation. The gains in SNR over "CM1, CM2, CM3, and CM4" rather than "selective combiner" are in the ranges: 4.6 dB to 5 dB, 4.7 dB to 5.7 dB, 3.4 dB to 5.6 dB, and 1.6 dB to 5 dB respectively, and rather than "partial combiner" are in the ranges: 5.9 dB to 7 dB, 6.6 dB to 7.5 dB, 5.5 dB to 7.7 dB, and 4.7 dB to 8.5 dB respectively.

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