Implementation of New Combiner for Indoor UWB Wireless Rake Receiver

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Abstract. In wireless systems, the multipath components (MPCs) are propagated 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 problems 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 and used to capture most of the energy of the received signal. Using 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, a 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 show 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.

1. 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, made this technology suitable for many applications. In the past, UWB technology was only used in military applications till 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 large number of branches, this will increase 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 to capture all the received paths. Therefore, 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. 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: maximal ratio combining (MRC), equal gain combining (EGC) and selective combining (SC) [4].

A hybrid MRC/SC receiver was evaluated by (A Dinamani) [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. (Yawgeng A) [6] proposed A New Suboptimal SC scheme which is less complex than other selection schemes, but the BER is higher. (Twinkle Doshi) [7] evaluated UWB P-rake receiver with a novel algorithm and based on a predefined cut-off value for the multipath amplitude gain level, the results show that the performance was improved but the complexity was increased.

(HimaPradeep) [8] evaluated a hybrid MRC/EGC diversity scheme over the additive white Gaussian noise (AWGN) channel 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, a new combiner called adaptive partial-hybrid (AP-H) was proposed. 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 in comparison with the conventional types, and without increasing the complexity of design.

The remainder of the paper were 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 was used which is a rake receiver. Section 6 shows the conventional and the proposed combining techniques that used for the combiner. Section 7 shows the simulation results with the discussions, and Section 8 is concluded the work.
2. System Model

In this work, we considered UWB signal using BPSK-TH multiple access modulation scheme. The signal was transmitted through multipath channel, using IEEE802.15.3a channel model. Different transmitted signals were 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 \( W_1, W_2, ..., W_n \) are the MRC weights.

![Figure 1. Block Diagram for UWB Wireless Communication System Using Rake Receiver.](image)

3. 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 uses 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 a small UWB transceiver design which is a challenging task [10]. To generate UWB signal, impulse radio technique was 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 \((-2\pi t^2/\tau)\) is used for the UWB pulse and is given by equation (1):

\[
G(t) = (1 - 4\pi (t/\tau)^2) \exp(-2\pi (t/\tau)^2) 
\]

where \( \tau \) 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):

\[
S^j(t) = \sum_{k=-\infty}^{\infty} \sum_{l=0}^{N_c-1} G(t - kT_s - lT_f - C_l^j T_c - \tau_0^j) d_k^{(j)} 
\]

where \( S^j(t) \) is user \( j \)'s transmitted signal, \( \tau_0^j \) is the first user’s reference delay \( (0 \leq \tau_0^j \leq T_s) \), and \( N_c \) is the spreading factor as a number of chips [14].
4. 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]. 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 a 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 (σ₁), standard deviation of ray lognormal fading term (σ₂), and standard deviation of lognormal shadowing term for total multi-path realization (σ₃). The main channel characteristics are used to determine the model parameters such as: mean excess delay (τₑ), RMS delay spread (τₑₚₑ), and number of multipath components that arrive within 10 dB (NP10 dB) of the peak multipath arrival [18].

| Parameters | λ (1/μsec) | Γ | γ | σ₁ | σ₂ | σ₃ | τₑ (ns) | τₑₚₑ (ns) | NP10 dB |
|------------|------------|---|---|----|----|----|--------|-----------|---------|
| CM1        | 0.0233     | 2.50 | 7.10 | 4.30 | 3.3941 | 3.3941 | 3.0 | 5.0 | 5.0 | 12.5 |
| CM2        | 0.40       | 2.50 | 5.50 | 6.70 | 3.3941 | 3.3941 | 3.0 | 9.94 | 8 | 15.3 |
| CM3        | 0.0667     | 2.10 | 14 | 7.90 | 3.3941 | 3.3941 | 3.0 | 15.9 | 15 | 24.9 |
| CM4        | 0.0677     | 2.10 | 24 | 3.3941 | 3.3941 | 3.0 | 30.1 | 25 | 41.2 |

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

\[ h_i(t) = X_i \sum_{l=0}^{L} \sum_{m=0}^{W} a_{i,m}^l \delta(t - T_l^i - l\tau_i) \]  (3)

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

5. 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):

\[ r_i(t) = S_i(t) * h_i(t) + n(t) + F_{ISI}(t) + F_{MUI}(t) \]  (4)

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

\[ r_i(t) = X_i \sum_{l=0}^{L} \sum_{m=0}^{N} a_{k,l} d_j C(n) G(t - T_l^j - jT_f - nT_p - C_jT_c - \tau_{kl}) \]  (5)

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 separates the MPCs of the transmitted signals and then combines 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) yields to improve the reception performances, but it is considered as a challenging task because it makes the design more
expensive, more complex and bigger in size. Therefore, 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 are termed correlations [20]. The output signal from the L-th correlator ($z_{jL}(t)$) of user j can be written as in equation (6):

$$Z_L^j(t) = \int_0^T r_1(t)G(t)dt$$

(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 that provides the required synchronization between transmitter and receiver. After combination, the combined pulse is delivered to the decision circuit to decide whether the transmitted bit is 0 or 1.

6. 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 lead to increase the receiver reliability. In this work MRC technique was 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 ($V_1, V_2, ..., V_m$) of all branches and it can be expressed by equation (7):

$$Y_{\text{tot}} = \frac{E_b}{N_0} \sum_{l=1}^{m} q_l w_l = \frac{E_b}{N_0} \sum_{l=1}^{m} V_l$$

(7)

where, $N_0$ 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):

$$Q = \sqrt{\frac{2E_b}{N_0}} = Q(\sqrt{2SNR})$$

(8)

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

$$Q = \frac{1}{\sqrt{2\pi}} \int_{\text{SNR}}^{\infty} e^{-\frac{t^2}{2}} dt$$

(9)

6.1. Conventional selective rake (S-rake) combiner
Selective rake combiner captures only the $L_s$ 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 only done by 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 ($Y_{\text{tot}}$) using MRC for S-rake scheme can be formulated as in equation (10):

$$Y_{\text{tot}} = \frac{E_b}{N_0} \sum_{l=1}^{L_s} S_l(t) w_l = \frac{E_b}{N_0} \sum_{l=1}^{L_s} V_l$$

(10)

where $S_l(t)$ belongs to the subset $S(t)$ which represents the strongest paths, $S(t) = (S_1(t), S_2(t), ..., S_{L_s}(t)).$

6.2. Conventional partial rake (P-rake) combiner
P-rake is the simplest type 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 in size, and lower in cost than S-rake receiver [21]. The output of the combiner (Ytot) using MRC for P-rake scheme can be formulated as in equation (11):

$$Y_{tot} = \frac{E_b}{N_0} \sum_{l=1}^{L_p} V_l$$  \hspace{1cm} (11)

6.3. 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 state to select. Then it combines 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 computes the value of (ϒ) every frame time; this value is equal to the sum of the La channel gain coefficients of the first received paths and is given by the equation (12):

$$ϒ = \sum_{i=1}^{L_a} a_i$$  \hspace{1cm} (12)

where ai represents the channel gain coefficient of the ith path and La 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 applies scheme-1- which selects and then combines the first Lp 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 applies scheme-2- which is hybrid combination from P-rake and S-rake schemes. In scheme-2-, the combiner shall select the first Lsp received paths and then selects the strongest Lh paths among them, where Lsp > Lh. By using AP-H scheme, the combining performance will be improved and achieve lower BER and the receiver will offer the power and time in comparison with selective rake combiner. The output of the combiner (Ytot) using MRC for AP-H scheme can be expressed as in equation (13):

$$Y_{tot} = \begin{cases} \frac{E_b}{N_0} \sum_{l=1}^{L_p} V_l, & \text{£ } \geq \text{ϒ} \\ \frac{E_b}{N_0} \sum_{l=1}^{L_h} V_l, & \text{£ } < \text{ϒ} \end{cases}$$  \hspace{1cm} (13)

**Figure 2.** Block Diagram of the Rake Receiver with the Proposed AP-H Combiner
7. Results and Discussions
The simulation flow chart diagram for the AP-S scheme is shown in figure 3. The parameters used in simulation were: 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 = 7. The SNR values range = 0: 2: 20. Figures 4 - 7 show the calculation plottings 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, Figure 4 shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner were 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. Therefore, 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.
Figure 3. Flow Chart Diagram for UWB System Using Rake Receiver with the Proposed AP-H Combiner.
Figure 4. BER vs. SNR over CM1 for selective, partial and AP-H combiners.

In CM2, Figure 5 represents that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner were 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, 10.7 dB, 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.

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

Over CM3, Figure 6 shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner were 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. Therefore, 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.
Figure 6. BER vs. SNR over CM3 for selective, partial and AP-H combiners.

In CM4, Figure 7 shows that at SNR = 0 dB, 5 dB, and 10 dB the BERs for AP-H combiner were equal to 0.05257, 0.02145, and 0.00945 respectively, and to achieve these values of 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. Therefore, 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 7. BER vs. SNR over CM4 for selective, partial and AP-H combiners.

Conclusions

In this work, an AP-H combining scheme was proposed to reduce the error bits received 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 indoor channel models are from 4.6 to 5.7 dB for AP-H selective combiner rather than for AP-H partial combiner which are from 5.9 to 8.5 dB.
References

[1] MuhibUr Rahman, Dong-Sik Ko and Jung-Dong Park 2017 A Compact Multiple Notched Ultra-Wide Band Antenna with an Analysis of the CSRR-TO-CSRR Coupling for Portable UWB Applications, Sensors vol.17.

[2] Sanja Šain 2011 Modelling and Characterization of Wireless Channels in Harsh Environments, Malardalen University School of Innovation, Design and Engineering

[3] Ville Niemelä, Matti Hämäläinen, Jarolinatti 2011 Attaphongssee and Taparugssanagorn, P-Rake Receivers in Different Measured WBAN Hospital Channels, IEEE

[4] Rashid Ali Fayyadh 2014 School of Computer and Communication Engineering, PhD Thesis, University Malaysia Perlis

[5] Dinamani A, Swagata Das, Bijendra L, Shruti R, Babina S and Kiran B 2013 Performance of a Hybrid MRC/SC Diversity Receiver over Rayleigh Fading Channel, Circuits, Controls and Communications (CCUBE) IEEE 2013 International Conference, India

[6] Yawgeng A. Chau, and Yao-Hua Chen 2013 A New Suboptimal Selection Combining with Enhanced Performance for BPSK over Rayleigh Fading Channels, IEEE Transactions on Vehicular Technology, 62(2).

[7] Twinkle Doshi and Upena Dalal 2015 Novel DS-UWB Partial RAKE Receiver over Different UWB Channels, IETE Journal of Research

[8] Hima Pradeep, and Seema Padmarajan 2016 Performance analysis of Hybrid MRC/EGC Diversity Combining Technique over AWGN Channel, International Conference on Emerging Trends in Engineering & Management, PP 25-29

[9] Ghavami, M. Michael, L. B.; and Kohno, R. 2004 Ultra Wideband Signals and Systems in Communication Engineering, John Wiley & Sons, Ltd, ISBN 0-470-86751-5

[10] Hajri, M. Issa, D. B.; and Samet, H. 2016 Low noise amplifier for MB-OFDM UWB receivers, IEEE, 17th international conference on Sciences and Techniques of Automatic control & computer engineering - STA’2016, Sousse, Tunisia, p 19-21

[11] Crăciun, F. Marghesucu, I.; and Fratu, O. 2011 RAKE receiver performances for PAM-THUWB systems, IEEE, Serbia, Belgrade, November p 22-24

[12] Patel, K. R.; and Kulkarni, R. 014 Ultra-Wideband (UWB) Wireless System, International Journal of Application or Innovation in Engineering & Management (IJAITEM), Special Issue for International Technological Conference

[13] Beaulieu, N. C. Shao, H. Niranjayan, Hosseini, S. I. and Young, D. 2012 Designing Ultra-Wide Bandwidth (UWB) Receivers for Multi-User Interference Environments, I core Alberta Informatics Circle Of Research Excellence, Faculty Of Engineering, University Of Alberta,

[14] Fayadh R. A.; and Malek, F. 2014 Enhancement of a Three Combining Techniques Rake Receiver Using Adaptive Filter of M-Max Partial Update RLS Algorithm for DS-UWB Systems, Journal of Communication and networks, Journal of Next Generation Information Technology (JNIT), vol. 5(4)

[15] Fayadh, R. A.; and Malek, F. 2014 Pulse Sign Separation Technique for the Received Bits in Wireless Ultra-Wideband Combining Approach, Mathematical Problems in Engineering.

[16] Malik, W. Q., Christopher J. Stevens, and David J. Edwards 2008 Multipath Effects in Ultra Wideband Rake Reception, IEEE Transactions on Antennas and Propagation, vol. 56(2)
[17] Goyal V. and Dhaliwal, B. S. 2015 Ultra Wideband PAM Modulation and Reception in UWB Multi Path channel Using Rake Configurations, GESJ: *Computer Science and Telecommunications*, vol. 1(45)

[18] Agrawal A., and Kshetrimayum, R. S. 2015 Transmit Antenna Selection For UWB Communication System Over IEEE 802.15.3a Channel, *IEE, CONECCT*)

[19] Goyal V., and Dhaliwal, B. S. 2015 Analyzing Pulse Position Modulation Time Hopping UWB in IEEE UWB Channel, GESJ: *Computer Science and Telecommunications*, vol. 2(46)

[20] Gold Smith, A 2004 *Wireless Communications*, Stanford University.

[21] Nikoogar, H. and Prasad R. 2009 *Introduction to Ultra Wideband for Wireless Communications, Berlin, Springer*, ISBN 978-1- 402.