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OPTIMAL RAKE RECEIVER MODEL UTILIZING TIME HOPPING IMPULSE RESPONSE ON UWB SYSTEM (WPAN)

Kilungu Duncan,Kinoti Mugiira, Mugo Simon

Kilungu Duncan is assistant lecturer, Technical University of Kenya. E-mail: dmanthi2010@gmail.com

Kinoti Mugiira is a Tutorial fellow, Machakos University College, and a Ph. D student Technical University of Kenya. Email: emmanuelkinoti@gmail.com

Mugo Simon is assistant lecturer, Technical University of Kenya. E-mail: smugo717@gmail.com

ABSTRACT

Impulse Radio-Time Hopping-Ultra Wideband (IR-TH-UWB) is a relatively new technology that might have a big effect on improving wireless communication. This technology uses short pulses in order to transmit large amounts of digital data over a wide spectrum of frequency bands with a very low power. This paper we derive the performance for UWB communication systems using different optimal models techniques in a RAKE Receiver. Comparisons have also been made between the techniques and conclusions have been drawn based on the requirements. We present simulation results using IEEE 802.15.3a UWB channel models. We evaluate the performances of Rake Receivers with different pulse-widths and also the effect of inter-frame interference in Ultra wideband Multipath Channels**.**

KeyWords

Rake receiver, Time Hopping Impulse response, Ultra wideband, Wireless personal Area Network

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INTRODUCTION

The focus of our work is on ultra-wideband (UWB). The world of UWB has changed dramatically in very recent history. In the past 20 years, UWB was used for radar, sensing, military communications and niche applications [1]. A substantial change occurred in February 2002, when the FCC (2002a, b) issued a ruling that UWB could be used for data communications as well as for radar and safety applications. The band allocated to UWB communications is 7.5 GHz. UWB provides its users with high data rates at a short distance [2]. The power of the transmitted signal in UWB is low. One of the enormous potentials of UWB is the ability to move between the very high data rate, short link distance and the very low data rate, longer link distance applications [3]. The very low transmit power available invariably means multiple, low energy, UWB pulses must be combined to carry 1 bit of information. In principle, trading data rate for link distance can be as simple as increasing the number of pulses used to carry 1 bit. The more pulses per bit, the lower the data rate, and the greater the achievable transmission distance

UWB characterizes transmission systems with instantaneous spectral occupancy of 500 MHz or a fractional bandwidth of more than 20%. The fractional bandwidth is defined as [5] where $f_C = (f_H + f_L)/2$ with f_H being the upper frequency of the -10 dB emission point, and f_L the lower frequency of the -10 dB emission point, as shown in the below figure. Figure 1: FCC allocated spectral mask for indoor ultra wideband communication systems as shown in the figure

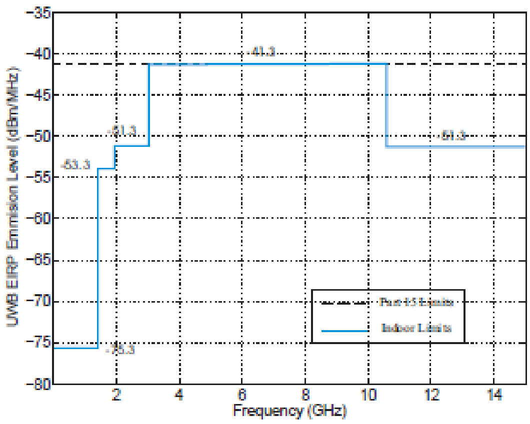

Figure 1: FCC allocated spectral mask for indoor ultra wideband communication systems [3]

This definition employs that UWB is not a specific technology anymore; it is an available license-free spectrum. The IR-UWB systems use short sub nanosecond pulses that occupy a very wide frequency spectrum. The channel capacity C (in bits per second (bps)) of the band-limited additive white Gaussian noise (AWGN) channel increases with RF bandwidth [2]

$$C = B_{RF} \log 2\left(1 + \frac{P_{rec}}{B_{RF} N_o}\right)$$

Where B_{RF} is the RF bandwidth of the channel and P_{rec} is the receivedsignal power and *No* is the noise power spectral density (PSD) in the RF bandwidth of the radio. This equation is based on an idealized rectangular filter of width B_{RF} and does not account for much effect in real systems, including interference of all sorts, receiver mismatch, and so forth. The applications of UWB can be broadly divided into two categories depending on the data rates. A wireless personal area network (WPAN) is a short-range (10-15 m) high data rate wireless communications system.

According to IEEE 802.15.3a standardization group, UWB technology is promising physical layer candidate for WPANs. The applications of UWB with relatively low data rates include e.g., sensor networks, wireless body area network (WBAN), imaging, ranging and radar [5].

1.2 UWB Compatibility with Other Services

UWB technology offers simultaneously high data rate communication and high accuracy positioning capabilities as it was mentioned before. These systems can utilize low transmitted signal power level with extremely wide bandwidth

The FCC recently approved the deployment of UWB on an unlicensed basis in the 3.1–10.6 GHz band [21][21].The essence of this ruling is to limit the PSD measured in a MHz bandwidth. UWB spectral mask and FCC part 15 limits are shown in the below figure:1 .In summary, UWB communications are allowed at a very low average transmit power compared to more conventional (narrowband) systems that effectively restricts UWB to short ranges . UWB is thus, a candidate physical layer mechanism for IEEE 802.15 WPAN for short-range high-rate connectivity that complements other wireless technologies in terms of link ranges. Typical Link Ranges limits of WPAN, WLAN, and Cellular Networks is shown in Figure 3. One of the main problems, according to the compatibility, is interference caused by UWB signals to other various radio systems, as well as the performance degradation of UWB systems in the presence of narrowband interference and pulsed jamming.

Using short pulses, interference in the observed frequency bands is the smallest if the pulse waveform is based on higher order Gaussian waveforms

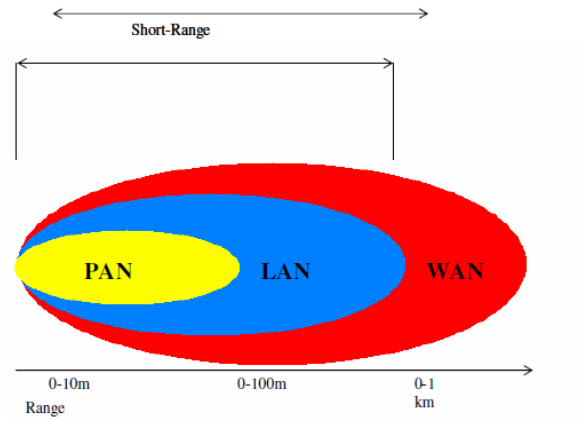

Figure: 3 WPAN, WLAN, and Cellular Networks: When the UWB system degradation is studied in the presence of an interfering and jamming radio system, results show that the system performance suffers most if the interference and the nominal Centre frequency of the UWB system are overlapping [20][21].Thus, the UWB performance depends on the pulse waveform and on the pulse width.

1.3 UWB Regulation

Industries in the US, the Federal Communication Commission (FCC) is chargers in regulating interstate and international Communication .The US was the first country to legalize the use of UWB for commercial use. The emission is defined in micro volts per meter (Uv/m) in order to express this terms of radiation power. The following formula can be used

$$P = \frac{}{}$$

Where *E* represent electric field strength(v/m)*R* is the radius of the sphere at which the field is measured, and ή=377ohms is the characteristic of the impedance of vacuum

Table1.below gives the comparison between allocations for unlicensed band in the USA [21], [20]

Unlicensed bands	**Operating frequency(GHz)**	**Bandwidth(MHz)**
ISM	2.4 to 2.4835	*83.5*
U-NII	5.15 to 5.35	*300*
UWB	3.1 to 10.6	*7500*

Types of UWB System

There are two common forms of UWB: one based on sending very short duration pulses to convey information called Impulse Radio UWB (IR-UWB) and another approach using multiple simultaneous carriers called Multicarrier UWB (MC-UWB) IR-UWB System. The concept of IR-UWB is to transmit the information using a train of pulses, either with pulse position modulation (PPM), pulse amplitude modulation

(PAM) or binary antipodal modulation. (TH) IR-UWB and direct-sequence (DS) IR-UWB are commonly used. In THIR-UWB, each pulse is positioned within frame duration according to a user-specific TH sequence.

2. LITERATURE SURVEY

In the previous papers we have gone through, derivation of the proposed adaptive minimum mean Square error (MMSE) Rake receiver for DS-CDMA UWB multipath channels to cancel multi access interference (MAI). The receiver works on chip level equalization and it does not require the spreading code to compute equalizer filter coefficients. While the proposed Optimum combined TH-UWB rakes [20][21] employs different combining techniques MRC and MMSE to show which can achieve low bit error probability with respect to SNR in UWB multipath channel in the presence of additive white Gaussian noise(AWGN).

Rake Receiver, directive antenna are employed to improve the system performance. The BER performance of Rake Receiver with, varying the number of users, spreading factor, Rake fingers, Interfering Cells, and the value of directivity of antenna at base Station. The proposed model is integrated in UWB environment with PPM modulation techniques and combining in rake receiver is done using MMSE .Performance of different rakes in proposed model are varied with parameters during simulation and results achieved are based on BER vs SNR.

3. System model

TH-IR) UWB system

Considering a binary antipodal modulation and time-hopping impulse radio (TH-IR) UWB system as multiple-access scheme, the transmitted signal from a user in the system can be represented as

$$S_t = \sqrt{\ } \sum_{i=-\infty}^{\infty} b_i b_{\lfloor j/\ \rfloor} b\, p(t - jT_f - c_i T_c),$$

Where P_t is the transmitted UWB pulse, E_b is the symbol energy of the user , T_f is the frame duration, T_C is the chip duration, N_f is the number of pulses representing one binary information symbol $b_{\lfloor j/\ \rfloor} \in \{1 - 1\}$ trans- mitted by the user. Fig. 3.1 shows an example of the transmitted sequence or a single bit. The pseudorandom time-hopping (TH) sequences (C_i) are assigned to each user that shares the UWB media to avoid catastrophic collisions among the pulses of different users. If the number of chips in a frame is denoted as *Nc* then the chip interval is chosen to satisfy $T_c = {}^{T}/_{N}$ This avoids pulses of different users from overlapping

The polarity randomization codes also help to get a zero-mean output and shape the transmit spectrum according to

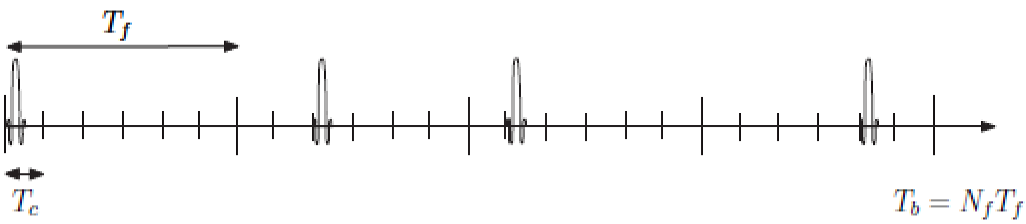

Figure 3.1 Transmit spectrums [17] An example of the transmitted sequence for a single bit, N_f= 4

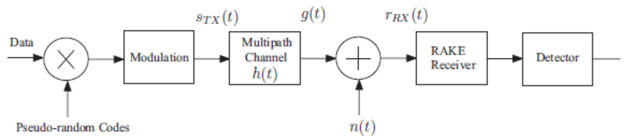

Figure 3.2 Block diagram of the system model (single-user) FCC rules.

The signal for a user is transmitted through a multipath channel with the impulse response given by

$$h(t) = \sum_{k=0}^{K-1} \alpha_k \, \delta(t - \tau_k), \qquad (3.2)$$

Below is the figure show the channel with impulse response:

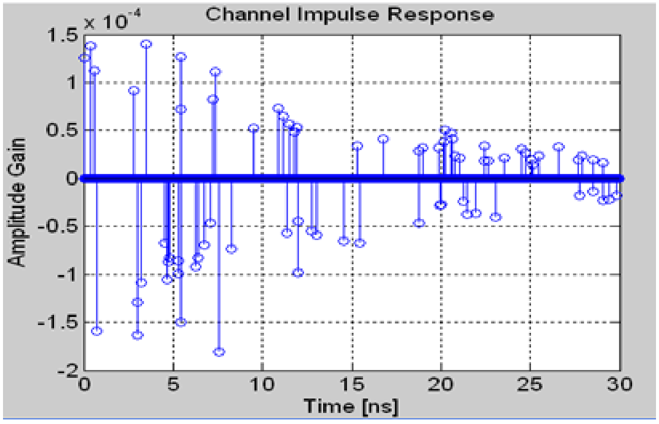

Figure 3.3 channel Impulse Response

4. Channel characteristic in uwb system

4.1: Fading- is one of the most challenging problems faced in a mobile or wireless signal propagation system [22].Fading is the time variation of the received signal power caused by the changes in the transmission medium or paths.

Hence we observe a slow fading if

$T_S << T_C$

and

$B_s >> B_d$

4.1.1 Slow Fading:-If the channel impulse response changes at a rate much slower than the transmitted baseband signal, let say *s(t)*, then it's a slow fading channel . The channel may be static over one or several reciprocal bandwidth intervals.

4.1.2: **Fast Fading: -**If the channel impulse response changes rapidly within the symbol duration, the channel is known as fast fading channel

Hence we say that a signal undergoes fast fading.

TS > *TC*$T_s > T_c$

and

$B_s < B_d$

4.1.3 Flat Fading:

A received signal will undergo flat fading if the mobile radio channel has a linear phase response over a bandwidth which is greater than the bandwidth of the transmitted signal and constant gain [22]. To summarize the flat fading let us have the following equations

$B_S << B_C$

and

$T_S >> \sigma_\tau T_S$

4.2 UWB RAKE Receivers

The amount of multipath energy that can be collected at the receiver and the receiver complexity are commonly used to determine the performance and robustness of a wireless communication system [6]. The RAKE receivers are used in many kinds of spread spectrum communication system to accumulate the energy in the significant multipath components. In order to enable *symbol-rate* sampling, the received IR-UWB signal can be correlated with a symbol-length template signal, and the correlators output can be sampled once per symbol [26]. The drawback of RAKE receiver is that the number of multipath components that can be utilized in a typical RAKE combiner is limited by power consumption issues, design complexity, and the channel estimation [24]. Secondly, each multipath undergoes different channel in UWB systems, which causes distortion in the received pulse shape and makes the use of a single LOS path signal as a suboptimal template [25]. A tapped delay line channel with *K* number of delays provides us with *K* replicas of the same transmitted signal at the receiver. Hence, a receiver that processes the received signal in an optimum manner will achieve the performance of an equivalent *K*th order diversity system. In practice, only a

4.1 Types of RAKE receivers:

The three common types of RAKE receivers are as follows:

i. All RAKE receiver (A-RAKE)

ii. Selective combining RAKE receiver (S-RAKE)

iii. Partial combining RAKE receiver (P-RAKE)

4.1.1 All RAKE Receivers:- Since the number of resolvable multipath components increases with the spreading bandwidth, the number of correlators required for the A-RAKE receiver may be quite large for UWB channels. However, the number of multipath components that can be utilized in a typical Rake combiner is limited by power consumption, design complexity and channel estimation.

4.1.2 Selective Combining RAKE Receiver:

"The S-Rake selects the L_b best paths (a *subset* of the L_r available resolved multipath components) and then combines the selected subset using MRC. This receiver makes the best use of its L_b available fingers, but - in order to do a proper selection of which paths to use - requires keeping track of all multipath components. Due to the propagation characteristics of UWB signals, a good tradeoff of performance degradation vs. receiver complexity is provided by the simpler P-Rake".

4.1.3 Partial Combining RAKE Receiver:

"The P-Rake uses L_m paths out of L_r available diversity paths, but it combines the *first* Lp arriving paths, which are not necessarily the best. The complexity reduction with respect to the S-Rake is due to the absence of the selection mechanism. Thus it alleviates the need to sort the multipath components by the magnitude of their instantaneous path gains, which would require instantaneous and highly accurate channel estimation. The P-Rake only needs to find the position of the first arriving path, leading to a substantial complexity reduction" .

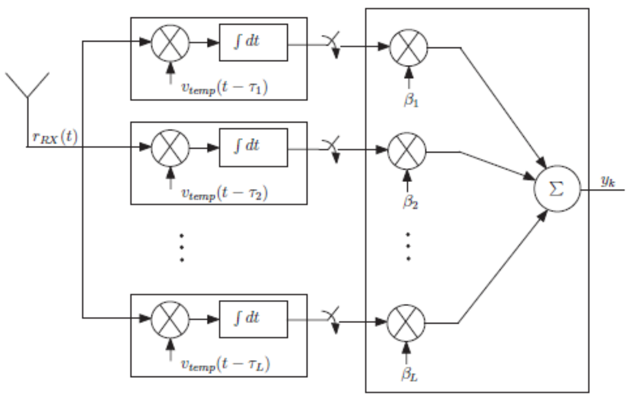

Figure 4.1 A RAKE receiver structure for TH-IR UWB system.

Subset of total resolved multipath components is used in the RAKE receivers [22]. The RAKE types based on the number of multipath components used are given as follows [24], All RAKE (A-*Rake*): The RAKE receiver which combines all the *K* resolved multipath components is called all RAKES (A-*Rake*).

Selective RAKE (*S-Rake*): The S-Rake receiver searches for the *M best paths* out of *K* resolved MPCs to use them as RAKE fingers. Partial RAKE (*P-Rake*): The P-Rake receiver uses the *M first arriving* paths out of *K* resolvable multipath components.

4.3 Common Diversity Techniques used in RAKE Receivers:

For the combination of different shifted, delayed and attenuated received signal sat the RAKE's fingers and for the determination of the desired signal, different diversity techniques are used. The most commonly used of them are:

i. Maximal ratio combining (MRC)

ii. Equal gain combining (EGC)

iii. Minimum mean square error (MMSE)

Analysis of RAKE Receiver

In this section, it is assumed that we have perfect knowledge of the channel and *A-Rake* receiver is used to receive the IR-UWB signal discussed in this Chapter. Considering the *i*th symbol, the output of the *k*th finger of the receiver can be written as

$$y_{i,k}=\int r_i(t)v_{temp}(t-\tau_k)dt$$

k=0,1,….,K— 1 for each i

Where $v_{temp}(t)$ is assumed to be normalized tamplate signal matched to the whole pulse sequence of one information symbol ,i.e

$$v_{temp}(t) = \frac{1}{\sqrt{N_f}}\sum_{j=0}^{N_f-1} d_j b_i g(t-jT_f-c_jT_c). \quad (4.12.1)$$

$0\leq t \leq N_f T_f$

and $r_i(t)$ is the received signal for ith bit, which is given by

$$r_i(t)= \frac{1}{\sqrt{N_f}}\sum_{j=0}^{N_f-1} d_j b_i g(t-jT_f-c_jT_c)+n(t).$$

The analysis of RAKE receiver is further discussed based on the assumptions of resolvable and no resolvable paths.

Resolvable Paths

It is assumed that all paths are resolvable, that is, the minimum time between any two paths is larger than the pulse width. Let us define the cross-Correlation function between *g*(*t*) and *p*(*t*) as

$$\alpha(\tau)=\int g(t)p(t-\tau),$$

Where $\alpha(\tau)=0$ if $\tau\leq -T_n$ or $\tau\geq T_n$. If there is a perfect match of the received signal with the reference signal,zero inter-frame and inter-symbol interference ,thern the output of *k*th finger after summation of N_f frames of *i*th symbol can be written in discrete time as

$$y_{i,k}=\sqrt{E_b}\, b_i \alpha_k+n_{i,k} \qquad K=0,1\ldots,k—1 \text{ for each } i$$

Where the last term $n_{i,k}=\int_{-\infty}^{\infty} n(t)\, v_{temn}(t-\tau_k)dt$ is the noise at the output of the correlator which has zero mean and variance σ_n^2. All the fingers the Rake use a delayed version of the tamplate signal $v_{temn}(t)$, with the delay chosen from the vector $\boldsymbol{\tau}=[\tau_0, \ldots \ldots .\tau_{K-1}]^T$,to match it

To the specific multipath component .The output of all the fingers (correlators) for the *i*th symboy can be written together in vector notation as

$y_i=\sqrt{E_b} b_i \alpha + n_i$,

Where $y_i=|y_i 0,\ldots..,y_i k-1|^*$, $\alpha=[\alpha_0,\ldots..,\alpha_{K-1}]^T$and $n_i=|n_i 0,\ldots..,n_i k-1|^*$. (4.13.2)

Furthere,the diversity combining using the weight vector β yields the decision for *i*th bit as

$z_i=\beta^T y(i)$

$=\sqrt{E_b} b_i \sum_{k=0}^{k-1} \beta_k \alpha_k + \sum_{k=0}^{k-1} \beta_k n_{i,k}$ (4.14)

To determine the bit error probability (BEP) at the output of the RAKE, the approximate mean and variance of the decision statistic at the output of RAKE from the evaluated as

$E[z_i]=\sqrt{E_b} \sum_{l=0}^{k-1} \beta_k^2$, $\mathrm{Var}(z_i)=\sigma_n^2 \sum_{k=0}^{k-1} \beta_k^2$.

In case of binary antipodal modualtion ,the approximate expression of BEP condition on a particular channel realization is given by

$p_e|(\alpha,\tau) = Q\left(\sqrt{\frac{[illegible]}{[illegible]}}\right)$

$=Q\left(\sqrt{\frac{[illegible]}{2\sum_{k=0}^{k-1}\beta^2 [illegible]}}\right)$, (4.16.1)

$=Q\left(\sqrt{\frac{2E_b}{N}\sum_{k=0}^{k-1}\beta_k^2}\right)$ (4.16.2)

Here Q( ) is the standard function

Q(x)= [illegible] dt

Assuming that the two paths may be less than a pulse width apart ,the autocorrelation function of the wave is now eident .The output of *k*th finger for *i*th symbol can be written as

$y_{i,k}=\sqrt{E_b} b_i \alpha_k + \sqrt{E_b} b_i \sum_{i=0,i\neq k}^{k-1} \alpha_i R(\tau_i-\tau_k) + \widetilde{n_{i,k}}$dt, (4.17)

K=0,1,……..,K— 1 for each i

Where $R(\tau)$ is the aoutocorrelation of the pulse $p(t)$,defined as

$R(\tau)=\int_{-\infty}^{\infty} P(t)p(t-\tau)dt$,

And $\widetilde{n_{i,k}}$ is the noise with zero mean and variance $\sigma_n^2 \sum_{i=0}^{k-1} \alpha_i R(\tau_i-\tau_k)$.The output of all the fingers can be written in vector form as $y_i = |y_{i,0},\ldots\ldots\ldots\ldots\ldots,y_{i,k-1}|^*$,then the decision statistic is formed using diversity

$z_i = \beta^T \, y(i)$ (4.18)

$= \sqrt{E_b} b_i \sum_{k=0}^{k-1} \beta_k \alpha_k + \sqrt{E_b} b_i \sum_{k=0}^{k-1} \sum_{i=0, i \pm k}^{k-1} \beta_k \alpha_k R(\tau_i - \tau_k) + \sum_{k=0}^{k-1} \beta_k \widetilde{n_{i,k}}$

As the A- Rake receiver with MRC combining,β=α, thus

$z_i = \sqrt{E_b} b_i \left| \sum_{k=0}^{k-1} \beta_k^2 + \sum_{k=0}^{k-1} \sum_{i=0, i \pm k}^{k-1} \beta_k \beta_i R(\tau_i - \tau_k) \right| + \sum_{k=0}^{k-1} \beta_k \widetilde{n_{i,k}}$

The approximate mean and variance of the decision statistic at the output of RAKE are avaluated as

$E[z_i] = \sqrt{E_b} \left| \sum_{k=0}^{k-1} \beta_k^2 + \sum_{k=0}^{k-1} \sum_{i=0, i \pm k}^{k-1} \beta_k \beta_i R(\tau_i - \tau_k) \right|,$

$\mathrm{Var}(z_i) = \sigma_n^2 \sum_{k=0}^{k-1} \sum_{i=0}^{k-1} \beta_k \beta_i R(\tau_i - \tau_k)$

The approximate expression of BEP conditioned on a particular channel realization is given by

$$P_B\left((\alpha, \tau)\right) = Q\left(\frac{[illegible]}{[illegible]}\right)$$

Where $\sum_{k=0}^{k-1} \sum_{i=0, i \pm k}^{k-1} \beta_k \beta_i R(\tau_i - \tau_k)$represents the additional term due to path correlations. Because the delays and amplitudes of the RAKE fingers will be shifted when path correlations are nonzero, the development of is a simplified analysis

Result

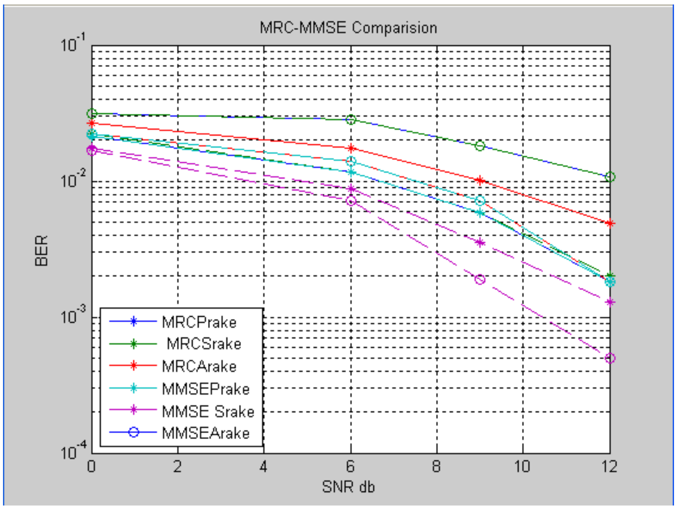

Figure: 1 Evaluate the performance of combining techniques employed when the channel of simulation is taken with interference .MMSE outperforms MRC .High BER is achieved in S-R in MMSE at 10 d B, $10^{-1.8}$ BER . A-Rake in MMSE has the lowest BER as compared to MRC at 10 d B. Optimum combining is achieved when MMSE is used one of optimization technique simulate the TH-UWBRake

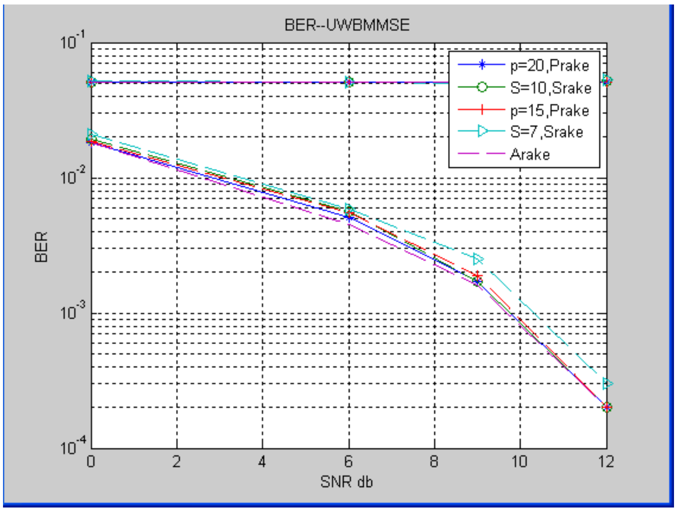

Figure:2 Performance on effect of increasing shaping factor of pulse when the transmitting power is taken at -40d B, and sampling frequency at 4GHz. N_s=2, N_m=2, N_h=10.S =7 achieves the high BER of $10^{-2.7}$ at 8 d B while the A Rake has the lowest BER of $10^{-2.85}$.channel model is CM2

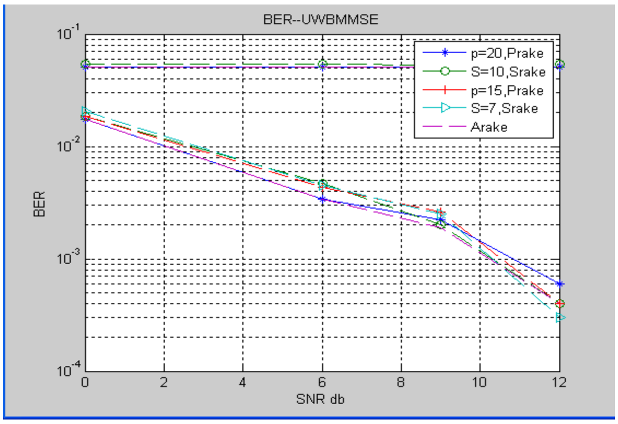

Figure: 3 Performance of increasing frame time by 2.4681×10^{-3} and simulated in channel CM4 at 4GHz. N_s=2, N_v=2, N_h=10. S-Rake =7 achieves low BER at 12 d B $10^{-3.8}$ where by P=20 has the highest BER of $10^{-3.5}$.At 4 d B P=20 and ALL-Rake have the same BER of $10^{-2.6}$

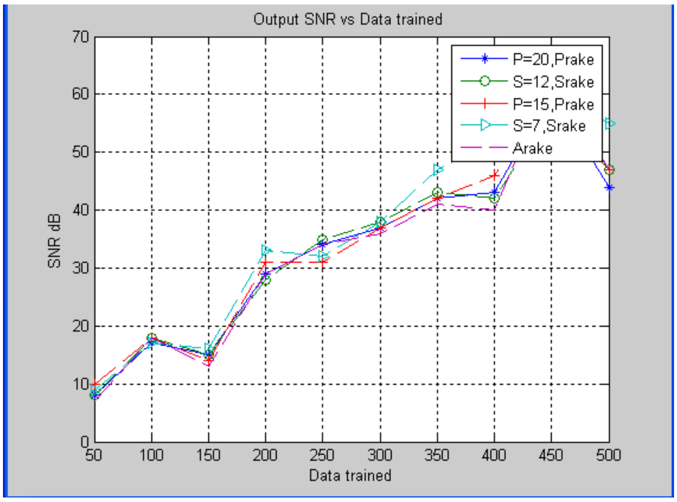

Figure :4 Performance on Data trained vs SNR in d B is evaluated with different Rakes types .S=7 achieves high SNR in d B. At 200 bits SNR achieved is 33d B as compared to other types of Rake, implies that to achieve high SNR with respect to Data of bits trained S=7 outperforms others .Then the optimization is achieved when S-Rake with less multipath component is selected. The channel model used is CM 4 when simulated in 5GHz. $N_s = 2, N_v = 2, N_h = 5$ While Time shift introduced by PPM 6.17×10^{-5}

Conclusions

Optimization has been achieved in the entire simulation where by various types of Rakes have been taken into account .That is: A rake, P rake , and S rake .MMSE UWB has been used as the proposed candidate in combining techniques together with PPM in achieving optimization with low BER as compared to MRC when all multipath components were applied. A rake in the entire project has been the vital candidate in achieving low BER when various parameter have been applied .Channel model CM2,CM4,and CM8 at different frequency 4GHz, 5GHz are been the vital when simulation was carried on using Mat lab software as the flat form for simulation .Effect on pulse position, time chip and frame time as well as time shift in pulse position modulation had a great effect on performance of all typed of rakes. Training of data with respect to SNR All rake has outperformed other for achieving highest SNR when comparison is drawn from the graphs.

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