Low complexity RAKE receiver for TH-based multiuser UWB system with realistic UWB indoor channel

Himanshu B. Soni*, U.B. Desai and S.N. Merchant

SPANN Lab, EE Department, 
Indian Institute of Technology-Bombay, 
Mumbai-400076, India
E-mail: sony_himanshu@iitb.ac.in
E-mail: ubdesai@ee.iitb.ac.in
E-mail: merchant@ee.iitb.ac.in
*Corresponding author

Abstract: We have considered multiuser communication scenario with ultra wideband (UWB) communication. UWB device is transmitting the data by time hopping (TH)-based system, TH-PPM, TH-PAM and DS-UWB. The UWB device is transmitting data over multipath rich channel model recommended by IEEE 802.15.3a working group. This channel model is based on Saleh-Valenzuela model. For better performance at receiver side, adaptive equaliser is required; this increases the complexity of receiver. Here we have considered the RAKE receiver for TH-based UWB system. This RAKE receiver structure is not a conventional RAKE, but it is pre-RAKE structure. In this case, we have evaluated performance of system by considering the RAKE receiver at the transmitter side. Here we have assumed the condition that channel sounding is available before transmission for quasi static UWB channel. Based on this knowledge RAKE fingers are selected for pre-RAKE. UWB channel is multipath rich channel so full RAKE adds more complexity in receiver and hence put limitation on effective data rate. Here we have considered low branch RAKE receiver. Performance of the system model is evaluated with realistic UWB channel model.

Keywords: ultra wideband; UWB; RAKE receiver; SV model.


Biographical notes: Himanshu Soni received his BE from Birla Viswakarma Mahavidyalaya College in 1997, his Master of Engineering degree from Birla Institute of Technology and Science (BITS), Pilani in 2004 and his PhD from the Indian Institute of Technology, Bombay (IIT-B), India in 2009. Presently, he is working as a Professor and Head of the Electronics and Communication Engineering Department of G.H. Patel College of Engineering and Technology. His areas of interest are statistical signal processing, adaptive signal processing, wireless and mobile communication and UWB communication. He has attended various training programmes in area of communication engineering from India and abroad.

Uday Desai received his BTech from IIT Kanpur, India in 1974, his MS from the State University of New York in 1976 and his PhD from The Johns Hopkins University. From 1979 to 1984, he was an Assistant Professor in the EE Department at Washington State University and an Associate Professor at the same place from 1984 to 1987. Since 1987, he has been a Professor in the EE Department at the IITB, India. Currently, he is working as the Director of IITH. He has held visiting positions at Arizona State University, Purdue University, Stanford University and EPFL, Lausanne.

S.N. Merchant is a Professor in the Department of EE, IIT Bombay. He received his B.Tech, M.Tech and PhD from the Department of EE, IIT-Bombay. He has made significant contributions in the field of signal processing. His noteworthy contributions have been in solving state of the art signal and image processing problems faced by Indian defence. He has served as a consultant to both private industries and defence organisations. He is a recipient of the 10th IETE Prof. S.V.C. Aiya Memorial Award for his contribution in the field of detection and tracking.
1 Introduction

Ultra wideband (UWB) radio is widely accepted for short range, high speed wireless personal area network (WPAN) applications (Jin and Kim, 2003; Zhang et al., 2002). For providing access in UWB difference, multiple access techniques were suggested by the literature Win and Scholtz (2000), Vojcic and Pickholtz (2003) and Batra et al. (2003). These literatures suggest mainly two type of access technique – time hopping (TH)-based (Win and Scholtz, 2000; Vojcic and Pickholtz, 2003) and multi-band orthogonal frequency division multiplexing (OFDM)-based (Batra et al., 2003). Here we have considered the TH-based system for UWB communication.

TH-based technique is combined with pulse position modulation (PPM) or pulse amplitude modulation (PAM) schemes. Depending upon modulation scheme TH UWB signal is known as TH-PAM UWB (Gabreilla et al., 2003) or TH-PPM UWB (Gabreilla et al., 2003; Hu and Beaulieu, 2004). Also direct sequence ultra wideband (DS-UWB) approach proposed in Vojcic and Pickholtz (2003) which is same as TH-PAM UWB except minor difference.

In all TH-UWB method single bit duration ($T_b$) is divided into $N_f$ number of frames, each with equal duration of ($T_f$) such that, $T_b = N_f T_f$. Further, each frame duration ($T_f$) is divided into $N_c$ number of chips of duration ($T_c$). During each chip period ($T_c$), UWB radio signal is transmitted. This UWB pulse is Gaussian pulse or its derivative, transmitted depending upon TH code. UWB radio signal comprised of a sequence of subnanosecond second duration pulses. In TH-PAM, antipodal signal is used for representing data bit '1' and '0'. In TH-PPM, UWB pulse will take additional delay of $\delta$ at the beginning of chip duration when data bit '1' is transmitted.

For UWB applications, IEEE 802.15.3a working group (Batra et al., 2003) has recommended power level with power spectral density (PSD) of $-41.3$ dBm/MHz. Here, signal is PSD limited rather than bandwidth limited. This nature of signal leads to higher multipath resolvability under fading channel.

For improving SNR in wideband communication, we need to equalise channel by considering large number of multipath components. RAKE structure with large numbers of fingers is required to compensate channel. RAKE receiver combines the multipath components which are time shifted versions of the original signal. Combining is done in order to improve the SNR at receiver side. RAKE receiver tries to collect the time shifted versions of the original signal by providing separate correlation for each multipath component. It is possible as all multipath components are statistically uncorrelated with each other when the delay in transmission is more than chip/frame delay.

In case of UWB, the working group has proposed channel model which is highly multipath. Due to nature of channel the full RAKE increases the complexity of receiver and reduces the effective data rates. For less complexity we have consider different RAKE fingers depending up on the channel model case. To reduce the complexity of receiver we have consider pre-RAKE at UWB device which is transmitting data over downlink channel. Here channel sounding is done before transmitting data over channel. Here we have considered the indoor communication so channel is more static rather than dynamic as in outdoor propagation.

The paper is organised as follows: in Section 2, we have discussed the general scenario for downlink communication with multimedia transmission under multiuser environment. In this section, we have described the TH-based systems, THPPM, TH-PAM and DS-UWB. In Section 3, UWB channel model is described in detail with power delay profile for each case. In Section 4, the receiver configuration with pre-RAKE receiver is discussed. Section 5 shows the simulation results with different UWB channel model. Finally in Section 6, we conclude our work.

2 TH-based UWB system

Figure 1 shows multimedia transmission scenario with UWB, where different users (or multimedia devices) data is transmitted by UWB device. In this system model, we have considered that the UWB device is collecting the data from different sources. After combining the data, device is transmitting the information with TH-based UWB signal over multipath rich UWB channel. To reduce the complexity of receiver design we have considered that, UWB device has per-information of channel so RAKE type structure is available at transmitter side. For comparison purpose, we have considered conventional RAKE. In our case, the UWB device itself is adding the multiuser data, hence multiuser interference (MUI) is added by device itself.

![Multimedia transmission scenario for UWB communication](image)

2.1 TH-PPM UWB signal model

In the literature Win and Scholtz (2000), Hu and Beaulieu (2004) and Durisi and Benedetto (2003), TH-PPM UWB system is proposed for UWB communication. In this, single
bit duration $T_b$ is divided into $N_f$ frames each with equal duration $T_f$, so $T_b = N_f T_f$. Further, each frame is divided in to $N_c$ chips with chip duration of $T_c$ such that $N_c T_c \leq T_f$. During each frame, UWB pulse is transmitted which is Gaussian monocycle or Scholtz monocycle. UWB pulse is transmitted during chip duration depending up on TH code $c_j$ which takes value such that $0 \leq c_j \leq N_c - 1$.

During each bit duration $N_f$, UWB pulses are transmitted by TH-PPM transmitter. Additional delay of $\delta$ is provided to UWB pulse at the beginning of chip duration when data bit ‘1’ is transmitted. Here, TH-PPM signal is represented as:

$$S^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} w\left(t - j T_f - c_j T_c - d^{(k)}_i \delta\right)$$

where $S^{(k)}(t)$ is $k$th user signal, $d^{(k)}_i$ is $k$th user data, $N_f$ is number of frames per bit, $w(.)$ is UWB pulse.

At receiver side multiuser signal received which is contaminated by multipath fading and AWGN which is given as:

$$r(t) = \int_{0}^{\infty} h(\tau, t) s(t - \tau) d\tau + n(t)$$

where $h(\tau, t)$ is channel response, $n(t)$ is AWGN and $s(t)$ is:

$$s(t) = \sum_{k=1}^{N} \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f - c_j T_c - d^{(k)}_i \delta\right)$$

$N$ is total number of users in the system.

2.2 TH-PAM UWB signal model

In the literature Bai and Sup (2005), TH-PAM UWB system is considered for UWB communication. In TH-PAM, first the user data is converted into antipodal data then UWB pulse will take particular slot of frame. As in TH-PAM UWB single bit duration $(T_b)$ is divided into $N_f$ number of frames each with equal duration $T_f$, so $T_b = N_f T_f$.

Further, each frame is divided into $N_c$ chips with chip duration of $T_c$ such that $N_c T_c \leq T_f$. During each frame, UWB pulse is transmitted which is Gaussian monocycle or Scholtz monocycle. UWB pulse occupy one chip slot depending on TH code $c_j$ which take value such that $0 \leq c_j \leq N_c - 1$. During each bit duration $N_f$, UWB pulses are transmitted by TH-PAM transmitter. For modulation, antipodal pulses are used. TH-PAM UWB signal is represented as:

$$s^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f - c_j T_c\right)$$

where $S^{(k)}(t)$ is $k$th user signal, $d^{(k)}_i$ is $k$th user bipolar data, $N_f$ is number of frames per bit and $w(.)$ is UWB pulse.

In TH-PAM system transmitted signal is represented as:

$$S^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f\right)$$

where $S^{(k)}(t)$ is $k$th user signal, $d^{(k)}_i$ is $k$th user bipolar data, $N_f$ is number of frames per bit and $w(.)$ is UWB pulse.

At receiver side multiuser signal received which is contaminated by multipath fading and AWGN which is given as:

$$r(t) = \int_{0}^{\infty} h(\tau, t) s(t - \tau) d\tau + n(t)$$

where $h(\tau, t)$ is channel response, $n(t)$ is AWGN and $s(t)$ is:

$$s(t) = \sum_{k=1}^{N} \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f - c_j T_c\right)$$

2.3 DS-UWB signal model

UWB signals generated using DS-UWB (Vojcic and Pickholtz, 2003) are just like direct spread spectrum signals. The concept is the same, a raw data is spread by a maximum length sequence PN code ,creating a spreading of the data by a factor of N, where $N = 2^m - 1$ and $m$ is the number of shift registers used to generate the PN code. The difference between the DS-CDMA and DS-UWB is that DS-UWB transmits signals in form of pulses. A DS-UWB signal has a duty cycle of 100%.

The drawback of DS-UWB is that the transmitted signal suffers from inter symbol interferences and inter-channel interferences due to the lack of silent periods between pulses.

In DS-UWB system transmitted signal is represented as:

$$S^{(k)}(t) = \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f\right)$$

where $S^{(k)}(t)$ is $k$th user signal, $d^{(k)}_i$ is $k$th user bipolar spreaded data, $N_f$ is number of frames per bit, $w(.)$ is UWB pulse.

Received signal is contaminated by multipath fading and AWGN which is given as:

$$r(t) = \int_{0}^{\infty} h(\tau, t) s(t - \tau) d\tau + n(t)$$

where $h(\tau, t)$ is channel response, $n(t)$ is AWGN and $s(t)$ is:

$$s(t) = \sum_{k=1}^{N} \sum_{i=-\infty}^{\infty} \sum_{j=0}^{N_f-1} d^{(k)}_i w\left(t - j T_f\right)$$

$N$ is total number of users in the system.
3 UWB channel model

In wireless channel multipath fading (Lee, 1997) will take place due to scattering, reflection and refraction. This fading can be slow fading or fast fading, which will change parameter of received signal envelope and phase. This fading problem is more critical in indoor channel due to presence of many scatterers. So perfect channel modelling is required for improving performance of receiver.

By considering the assumption of static scatter the channel impulse response (CIR) for time-invariant channel is given as:

$$ h(t) = \sum_{n=0}^{N} \alpha_n \delta(t - \tau_n) $$

(10)

Here $N$ is number of multipath components, $\alpha_n$ is attenuation for $n$th path and $\tau_n$ is delay for $n$th path. In UWB the channel model is based on Saleh-Valenzuela model (Saleh and Valenzuela, 1987).

3.1 UWB channel model recommendation by IEEE 802.15.3a working group

IEEE 802.15.3a working group has suggested channel model for indoor UWB communication. This model should be used for evaluating the performance of different physical layer proposal. This proposed model is based of input given by Saleh and Valenzuela (1987), Ghassemzadeh and Tarokh (2003), Pendergrass and Beelar (2002), Foerster and Li (2002), Hovinen et al. (2002), Kunisch and Pamp (2002), Ghassemzadeh and Tarokh (2002), Molisch et al. (2002) and Cramer et al. (2002). UWB channel model is cluster-based model. In this model (SV model) the same pulses multipath components are grouped in to cluster. This cluster arrival is modelled as a Possion process with arrival rate of $\lambda$ as:

$$ P(T_n | T_{n-1}) = \lambda e^{-\lambda(T_n - T_{n-1})} $$

(11)

Here, $T_n$ is time of arrival for $n$th cluster and $T_{n-1}$ is time arrival of $(n-1)$th cluster. In each cluster, the multipath components of same pulse is also model as a Possion process with arrival rate of $\Delta$ as:

$$ P(\tau_{ni} | \tau_{(n-1)i}) = \Delta e^{-\Delta(\tau_{ni} - \tau_{(n-1)i})} $$

(12)

Here, $\tau_{ni}$ is time of arrival of the $n$th pulse in the $i$th cluster and $\tau_{(n-1)i}$ is time of arrival of the $(n-1)$th pulse in the $i$th cluster. The gain of the $n$th pulse in $i$th cluster is complex random variable as:

$$ A_{ni} \angle \Theta_{ni} $$

(13)

with,

$$ p(A_{ni}) = \frac{2\gamma A_{ni}^2}{E[|A_{ni}|^2] e^{-\frac{A_{ni}^2}{E[|A_{ni}|^2]}}} $$

(14)

and

$$ p(\Theta_{ni}) = \frac{1}{2\pi} \text{ with } 0 \leq \Theta_{ni} \leq 2\pi $$

(15)

Here,

$$ E[|A_{ni}|^2] = E[|A_{00}|^2] e^{-\frac{T_e}{T} e^{-\gamma}} $$

(16)

$A_{00}$ is the energy of the first path of the first cluster, $\Gamma$ and $\gamma$ power decay profile for cluster and components within cluster respectively. IEEE working group has suggested some variation in this SV model to make it more realistic channel model for UWB as, multipath gain amplitudes are considers as log-normal distributed. The UWB channel model is described as:

$$ h(t) = X \sum_{n=1}^{N} \sum_{k=1}^{K(n)} \alpha_{nk} \delta(t - T_n - \tau_{nk}) $$

(17)

$X$ is log-normal distributed which represent the gain of channel. $N$ is number of clusters, $K(n)$ is the number of multipath components of same UWB pulse within the $N$th cluster. $\alpha_{nk}$ is magnitude of component in $N$th cluster. $\tau_{nk}$ is delay of component in $N$th cluster. The channel coefficient $\alpha_{nk} = \pm(1)^n \beta_{nk}$, where $\beta_{nk}$ is the log-normal distributed channel coefficient of multipath components $k$ for cluster $n$. $\beta_{nk}$ is defined as $\beta_{nk} = 10^{\frac{2\gamma}{20}}$, where $x_{nk}$ is
assumed to be a Gaussian random variable with $\mu_{nk}$ mean and $\sigma^2_{nk}$ variance. The random variable $x_{nk}$ is further decomposed as:

$$x_{nk} = \mu_{nk} + \xi_n + \zeta_{nk}$$  \hspace{1cm} (18)

where $\xi_n$ and $\zeta_{nk}$ are two Gaussian random variables which represent the variation of the channel coefficient on each cluster and in each path within cluster respectively.

Finally channel model of UWB channel is described by:

$$h(t) = X \sum_{n=1}^{N} \sum_{k=1}^{K(n)} \alpha_{nk} \delta(t-T_n - \tau_{nk})$$  \hspace{1cm} (19)

with the following parameters,

- the cluster arrival rate of $\lambda$
- UWB pulse arrival rate with in cluster is $\Delta$
- power decay profile of cluster and pulse with cluster is $\Gamma$ and $\gamma$
- the variance of $\sigma^2_{\xi}$ and $\sigma^2_{\zeta}$ for variation of fluctuations of channel coefficient for cluster and pulse within cluster respectively.

This parameters are defined for different four cases of UWB communication as mentioned in Table 1.

**Table 1**  Parameters for UBW channel model

<table>
<thead>
<tr>
<th>Case</th>
<th>$\Lambda$</th>
<th>$\lambda$</th>
<th>$\Gamma$</th>
<th>$\gamma$</th>
<th>$\sigma_{\xi}$</th>
<th>$\sigma_{\zeta}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case A</td>
<td>0.0233</td>
<td>2.5</td>
<td>7.1</td>
<td>4.3</td>
<td>3.3941</td>
<td>3.3941</td>
</tr>
<tr>
<td>Case B</td>
<td>0.4</td>
<td>0.5</td>
<td>5.5</td>
<td>6.7</td>
<td>3.3941</td>
<td>3.3941</td>
</tr>
<tr>
<td>Case C</td>
<td>0.0667</td>
<td>2.1</td>
<td>14</td>
<td>7.9</td>
<td>3.3941</td>
<td>3.3941</td>
</tr>
<tr>
<td>Case D</td>
<td>0.0667</td>
<td>2.1</td>
<td>24</td>
<td>12</td>
<td>3.3941</td>
<td>3.3941</td>
</tr>
</tbody>
</table>

Here Case A is line of sight (LOS) communication between transmitter and receiver with maximum separation between them is 2 metres, Case B is non-line of sight (NLOS) communication between transmitter and receiver with maximum separation between them is 2 metres, Case C is NLOS with 8 metres of maximum TR separation. Case D is Extreme NLOS multipath channel with maximum TR separation of 8 metres. Based on IEEE 802.15.3a channel model recommendation, Figures 3, 4, 5 and 6 illustrate the four typical power delay profile (PDP) of UWB channel model. From this PDP, it is clear that in channel model case A the first received component has highest energy compared to subsequent component. So in this case if we use partial RAKE with lower fingers then we can expect good result. From Figure 4 it can be seen that near to several strongest peak smaller peaks are surrounded. This indicates that channel response is combinations of the several overlapping clusters. Also the strongest peak is not first one but is can occur at any position in sequence due to reflections from scatterer. So here partial RAKE will not give expected result but we have to select the strongest component in cluster hence SRAKE is required to use. From channel model C Figure 5, it can be seen that here channel is more time dispersive. Components are available up to around 70 nsec, while in case A and B it is available up to around 40 nsec. This indicate that here we have to use selective RAKE to achieve desired result. From Figure 6, it can be seen that channel in this case is more time dispersive and components are available till 150 nsec. So here the effective data rate goes down to achieve the ISI free communication. In this case more fingers required to consider for achieving good SNR at receiver.
Figure 5  PDP for channel model C, NLOS (4 to 8mt) (see online version for colours)

Figure 6  PDP for channel model D, extreme NLOS (up to 8 mt) (see online version for colours)

4 Transmitter and receiver configuration

Here we have considered alternative of RAKE receiver for equalising the signal at receiver as in Esmailzadeh and Nakagawa (1993). For reducing the complexity of receiving nodes, we have considered the RAKE type construction at the transmitter side. Here we are assuming that, the perfect channel information is available at transmitter side. This information is available easily as in UWB the forward link and reverse link operates with similar parameters. When the channel characteristics are changing very slowly, the use of pre-RAKE type structure for diversity combining will give effective results. IEEE 802.15.3a working group has proposed the UWB channel model as discussed in Section 3 is also slowly time varying model. In this case we have used the pre-RAKE structure after combining the all user data. Transmitted signal is scaled and delayed according to the delay and attenuation of multipath channel response. This structure operates on signal, which is modulated by the TH or DS-based UWB system. Figure 7 shows the system model for pre-RAKE structure. Here we have considered the partial RAKE and selective RAKE type at the transmitter side. This structure will operate data with inverse channel operation before transmission. In partial pre-RAKE structure, we have considered first N number of paths reaching at the receiver side. Channel model C and D for UWB is more dispersive. Under this channel model, if we select the partial RAKE structure then we need to consider large number of fingers for pre-RAKE structure. This increases the complexity of system. So under this two channel model we have considered the Selective RAKE structure. This selective RAKE structure will select the strongest $L$ components out of $M$ received signal components. For comparison purpose we have also considered the partial RAKE structure in this channel model.

Figure 7  Pre-rake-based structure for TH-UWB and DS UWB

In each path, the correlator detects the time shifted version of the original signal and correlates the signal by at least one chip/frame time. $M$ correlators are used to capture the $M$ strongest path. The gain adjuster is providing the weighting coefficient. This weighting network is used to provide a linear combination of the correlator output for bit decision. The output of correlator is weighted by the weighting factor $(GA)_k$ to $(GA)_m$, these coefficients are based on SNR from each correlator output.

This gain adjustment factors are normalised such that they sum to unity.

In general case, without pre-RAKE structure the transmitted signal is given as,

- in TH-PPM case:
  \[ P(t) = \sum_{k=1}^{N} \sum_{m=0}^{x} \sum_{j=0}^{N-1} w(t - jT_f - c_j^{(k)}T_c - d_j^{(k)}) \]  \hspace{1cm} (20)

- in TH-PAM case:
  \[ P(t) = \sum_{k=1}^{N} \sum_{m=0}^{x} \sum_{j=0}^{N-1} d_j^{(k)} w(t - jT_f - c_j^{(k)}T_c) \]  \hspace{1cm} (21)

- in DS-UWB case:
In RAKE receiver signal is seen as sum of multipath signals, where the received signal from each path was scaled by factor according to path characteristic. This is equivalent to the multiplication of the received signal by time reverse channel response. In our case this is carried out at the transmitter side in down link so transmitted signal is given as,

\[ P(t) = \sum_{k=1}^{N} \sum_{n=1}^{N_k} \sum_{j=0}^{N_k-1} d_{ij} \alpha_{nk}^* P(t - jT_f) \]  

(22)

which keeps the instantaneous transmitter power constant regardless of the number of cluster N and paths within cluster \( k(n) \) for UWB channel mode. So it keeps constant power regardless of \( N_kk(n) \) paths.

The received signal is convolution of channel response with signal \( s(t) \). At receiver side this produces the strong peak, which is equivalent to the conventional RAKE diversity combining. Because of this the receiving UWB device do not required to equalise the channel. Here pre-RAKE structure puts the maximum power in the desired component. At receiver side, signal is expressed as:

\[ s(t) = \frac{X}{\sqrt{P}} \sum_{n=1}^{N} \sum_{k=1}^{K(n)} \alpha_{nk}^* P(t - T_n - \tau_{nk}) \]  

(23)

\[ s(t) = \frac{X}{\sqrt{A}} \sum_{n=1}^{N} \sum_{k=1}^{K(n)} \alpha_{nk}^* P(t - (T_n - \tau_{nk})) \]  

\[ \sqrt{A} \] is normalising factor given by:

\[ \sqrt{A} = \frac{\sqrt{P}}{X} \]  

(24)

5 Simulation parameters and results

We have carried out extensive Monte Carlo simulations for many sample paths for different UWB channel model. Bit error rate (BER) is used as a performance comparison criterion and evaluated the performance of pre-RAKE structure under various user conditions. For comparison purpose we have also consider the conventional RAKE structure at receiver side and ensure the performance. Simulation parameters for TH-based system are shown in Table 2. Here we have used second derivative of Gaussian pulse known as Scholtzs monocycle as a UWB pulse \( p(t) \):

\[ p(t) = \left(1 - \frac{4\pi^2 (t/T)^2}{\pi^2} \right) e^{-2\pi^2 (t/T)^2} \]  

(28)

For analysing the performance of system we have consider the UWB channel model for LOS distance and NLOS distance. From Figure 3, PDP of channel model A, it is seen that components are decaying gradually so selection of partial RAKE and selective RAKE for limited number of component will give almost same result. In channel model B, Figure 4, it is observed that largest component is

Table 2 Simulation parameters

<table>
<thead>
<tr>
<th>TH-PAM UWB parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frames ( N_f )</td>
<td>6</td>
</tr>
<tr>
<td>Frame duration ( T_f )</td>
<td>3 nsec</td>
</tr>
<tr>
<td>Number of chips ( N_c )</td>
<td>3</td>
</tr>
<tr>
<td>Chip duration ( T_c )</td>
<td>1 nsec</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>2nd derivative of Gaussian</td>
</tr>
<tr>
<td>Pulse shape factor ( \tau )</td>
<td>0.25 nsec</td>
</tr>
<tr>
<td>UWB pulse duration ( T_p )</td>
<td>0.15 nsec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TH-PPM UWB parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frames ( N_f )</td>
<td>6</td>
</tr>
<tr>
<td>Frame duration ( T_f )</td>
<td>3 nsec</td>
</tr>
<tr>
<td>Number of chips ( N_c )</td>
<td>3</td>
</tr>
<tr>
<td>Chip duration ( T_c )</td>
<td>1 nsec</td>
</tr>
<tr>
<td>PPM Shift ( \delta )</td>
<td>0.5 nsec</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>2nd derivative of Gaussian</td>
</tr>
<tr>
<td>UWB pulse duration ( T_p )</td>
<td>0.15 nsec</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DS-UWB parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of frames ( N_f )</td>
<td>6</td>
</tr>
<tr>
<td>Frame duration ( T_f )</td>
<td>3 nsec</td>
</tr>
<tr>
<td>Pulse shape</td>
<td>2nd derivative of Gaussian</td>
</tr>
<tr>
<td>UWB pulse duration ( T_p )</td>
<td>0.15 nsec</td>
</tr>
</tbody>
</table>
not always the first component reaching to receiver. So here partial RAKE will not give satisfactory result. Because of this reason we have also considered the selective RAKE. Same behaviour is seen in case of channel model C and D in Figures 5 and 6, respectively, except the difference that in this two cases channel is more time dispersive. So this indicates that in selective RAKE we have to consider more components for selecting the strongest path.

In simulation we have considered the selective diversity combining with RAKE and pre-RAKE structure. In this case we have considered the different fingers as 1, 5, 20. In S-RAKE, the strongest \( L \) paths are selected from first received \( M \) paths. Also we have considered the partial RAKE in which the first \( L \) paths are selected from received \( M \) paths. In channel model case A use of partial RAKE will give satisfactory result but in other channel model this gives poor result.

**Figure 8** BER Performance with UWB channel model A (three users) with TH-PAM (see online version for colours)

In simulation we have considered the first 60 components reaching at the receiver side. From this we are selecting strongest \( L \) components for selective RAKE and first \( L \) components in case partial RAKE. Figure 8 shows the BER performance of pre-RAKE system with TH-PAM under the UWB channel model A. Here we have evaluated the performance with different number of RAKE fingers. In simulation we have considered the partial RAKE and selective RAKE. All user signal is transmitted with non-orthogonal code. From PDP of UWB channel model case A, Figure 3, it is observed that the channel is less time dispersive. From Figure 8, we can see that the performance gap between partial RAKE with 20 fingers and selective RAKE with 20 fingers is approximately 1 dB. Selective RAKE out perform the partial RAKE as it selects the strongest \( L \) components from received \( M \) components. Also, Figure 8 shows the performance of selective RAKE with five and one finger. Figure 9 shows the performance under seven user case with TH-PAM under channel model A. Almost same condition is observed in this case with selective and partial RAKE with 20 fingers. Compared to three user case performance is degraded by 1 dB. UWB channel model A, is less time dispersive and first reaching components have larger magnitude compared to the rest of components coming at receiver. Because of this reason the performance gap is small between selective RAKE and partial RAKE with 20 fingers.

**Figure 9** Performance with UWB channel model A (seven users) with TH-PAM (see online version for colours)

Figures 10 and 11 shows the performance of TH-PAM pre-RAKE system with three and seven users, respectively, with channel model case B. In this condition, the performance gap between partial and selective RAKE with 20 fingers is of 2 dB. As channel model B is more time dispersive compared to channel model A, we need to consider more fingers to achieve performance as channel mode A. Same performance gap is observed in case of seven users. The performance of selective RAKE with five fingers is poor, while in case of channel model A performance is acceptable with five fingers. Reason for performance degradation in case of seven users is MUI. If we consider orthogonal code for simulation same result as three users can be achieved in case of the seven-user condition.

For TH-PAM, Figure 12 indicates the performance of system with channel model C under three-user case. From Figures 11 and 12 it is observed that in case of selective RAKE with 20 fingers almost 2 dB more power is required in case of the channel model C. The reason is, channel is more time dispersive in this case compared to channel model B, Figure 5. Performance gap between partial RAKE and selective RAKE with same fingers is quite large. It is observed here that, in this case the performance of selective RAKE with lower fingers outperforms the partial RAKE with large fingers. This is due to the nature of UWB channel model C.
Figure 10 Performance with UWB channel model B (three users) with TH-PAM (see online version for colours)

Figure 11 Performance with UWB channel model B (7 users) with TH-PAM (see online version for colours)

Figure 12 Performance with UWB channel model C (three users) with TH-PAM (see online version for colours)

Figure 13 shows the performance of system model with UWB channel model D. This channel model is extreme NLOS with 8 m of maximum TR separation. So we need to select large number of fingers in case of selective RAKE. In computer simulation, we have considered the 50 fingers in selective RAKE case. This performance is near to the performance of the selective RAKE with 20 fingers in case of channel model B, Figures 10 and 13. Also the performance in this case with partial RAKE with 20 fingers is almost same as selective RAKE with five fingers.

Figure 13 Performance with UWB channel model D (3 users) with TH-PAM (see online version for colours)

Figure 14 shows the comparison with conventional RAKE and pre-RAKE structure with channel model B under three users case. It is clear that the performance of pre-RAKE and conventional is almost same under same channel characteristics.

Figure 14 Performance with conventional RAKE and Pre-RAKE with channel model B with TH-PAM (see online version for colours)
Figures 15 and 16 shows the performance of DS-UWB system with pre-RAKE structure. In simulation we have considered the UWB channel model A and D for evaluating the BER performance. Here we have evaluated the performance with different RAKE fingers by keeping the \([E_b/N_0]\) fixed.

**Figure 15** Performance of DS-UWB system with channel model A under different fingers of selective RAKE (see online version for colours)

![Ber performance with UWB channel model A under 3 user case with DS-UWB](image)

**Figure 16** Performance of DS-UWB system with channel model D under different fingers of selective RAKE (see online version for colours)

![Ber performance with UWB channel model D under 3 user case with DS-UWB](image)

Figures 17 and 18 shows pre-RAKE performance of TH-PPM system with UWB channel model A and D respectively. BER is performance measurement criterion.

As in case of TH-PAM, in DS-UWB and in TH-PPM performance of system degrade under UWB channel model D. This degradation is more when lower fingers are considered in pre-RAKE structure. From Figures 15 and 16, it can be seen that BER performance of \(10^{-2}\) can be achieved with lower fingers in channel model A compared to channel model D. For achieving \(10^{-2}\) BER almost five fingers are required in case of channel model A, while in case of channel model D almost ten fingers required (for \([E_b/N_0] = 15\) dB). For lower \([E_b/N_0]\) the requirement of fingers in UWB channel model D is more compared UWB to channel model A. This is due to more dispersive nature of UWB channel.

**Figure 17** Performance of TH PPM-UWB system with channel model A under different fingers of selective RAKE (see online version for colours)

![Ber performance with UWB channel model A under 3 user case with TH-PPM UWB](image)

**Figure 18** Performance of TH PPM-UWB system with channel model D under different fingers of selective RAKE (see online version for colours)

![Ber performance with UWB channel model D under 3 user case with TH-PPM UWB](image)

From Figures 17 and 18, it can be seen that in case of THPPM for achieving performance of \(10^{-2}\) BER under channel model D, 12 fingers are required (for \([E_b/N_0] = 15\) dB). From Figures 15, 16, 17 and 18, it is clear that DS-UWB performs better compared to TH-PPM under multipath channel.

### 6 Conclusions

In this paper, we have evaluated the performance of pre-RAKE structure with multi user TH-based system.
Performance is evaluated with all UWB channel models, as IEEE802.15.3a proposal. It is observed that in channel model A and B with lower fingers reasonably good BER performance is achieved. The performance gap in these two cases is as 2 dB in case of three users and almost 4 dB in case of seven users. Also the performance gap of 1 dB is observed in case of partial RAKE and selective RAKE with same number of fingers 20. UWB channel models C and D both are more time dispersive. Performance gap of almost 2 dB is observed in case of channel model C with selective RAKE with five fingers and 20 fingers. In channel model C, to achieve good performance of pre-RAKE structure with partial RAKE required more RAKE fingers.

References


