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A Performance Comparison of DS-UWB Rake Receivers for different environments

Abstract. *This paper focuses on the performance comparison RAKE receivers used in the Ultra wide-Band system. The simulations are based on implementation of the complete system using direct sequence spread spectrum approach. The results are obtained for the three types of RAKE receiver models, namely, All(A) RAKE, Selective (S) RAKE and Practical(P) RAKE. The driven results are based on the four cases presented in IEEE P802.15 propagation channel model.*

Streszczenie. *W artkule przedstawiono porównanie odbiorników RAKE używanych w systemach komunikacji ultra szerokopasmowej. Zbadano trzy różne odbiorniki RAKE. Badania bazowały na normie IEEE P802.15.* (***Porównanie odbiorników szerokopasmowych RAKE w różnych warunkach pracy***)

Keywords: DS-UWB, RAKE Receivers, Channel modeling
Słowa kluczowe: komunikacja szerokopasmowa, RAKE

Introduction

UWB has slowly developed over the past hundred years. It took years to develop such techniques that can transmit and receive data using short impulse signals between transmitter and receiver. In 1950, it was examined for military applications like radars. By late 1960s and early 1970s, the wide band non sinusoidal communications were explored for the public as well as for private sector. In 1980s research work published in [1] was about the practical implementation of low power short impulse radio using time-modulated schemes while in 1998 spread spectrum techniques for the practical implementation were presented in [2]. The concept behind the spread spectrum is that the transmitted message signal follows a random sequence and appears to be noise for an irrelevant re-ceiver. This new form of radio which uses short duration im-pulses unlike sparks and gaps can be referred as UWB [3].

The research work presented in this paper provides insight into practical implementation of UWB system. The System is composed of UWB transmitter, IEEE P802.15 propagation channel model and receiver. The System includes:

- Five fingers for each SRAKE and PRAKE receivers.
- The numbers of bits transmitted are 100 at a sampling frequency of 50 GHz.
- Pulse Amplitude Modulation (PAM) is used at transmitter.
- Results are exposed for BER in all categories.

The work presented in this paper is organized as: Section 1 describes IEEE propagation channel model, whereas the RAKE receiver model is explained in section 3. Simulation results for various scenarios like variable propagation path length are discussed in section 4. Section 5 concludes the work.

Ultra wide band Channel modeling

1. Multi path Mode

In case of multi-path channels clustering of multi-path components is observed [4]. Saleh-Vanzeula (S-V) model provides the solution to this effect of clustering of multipath components. The IEEE P802.15 Working Group for Wireless Personal Area Networks (WPANs), proposed an enhanced model which seems to handle this problem in a better way. It is a slightly modified S-V model.

The group recommended that instead of using Rayleigh distribution for the multipath gain magnitude, lognormal distribution provides better results. It is also recommended that a separated fading is assigned to each cluster and also to each path signal in the cluster.

The group formulates the channel impulse response $h_i(t)$ in following equation [1]:

$$h_i(t) = X_i \sum_{l=0}^{L} \sum_{k=0}^{K} \alpha^i_{k,l} \delta(t - T^i_l - \tau^i_{k,l}) \tag{1}$$

where: $\alpha^i_{k,l}$: are the multipath gain coefficients, T^i_l : is the delay of the l^{th} cluster, $\tau^i_{k,l}$:is the delay of the k^{th} multipath component relative to the l^{th} cluster arrival time, T^i_l , X_i represents the log-normal shadowing, and *i* refers to the i^{th} realization.

The group gives the following definitions of the parameters: T_l = The arrival time of the first path of the *l*-th cluster; $\tau_{k,l}$= The delay of the *k*-the path within the *l*-th cluster relative to the first path arrival time, T_l;

2. Channel Realizations

Following are the key parameters that define the model [4]:

Λ = cluster arrival rate;

λ = ray arrival rate, i.e., the arrival rate of path within each cluster;

Γ = cluster decay factor;

γ = ray decay factor;

σ_1= standard deviation of cluster lognormal fading term (dB).

σ_2 = standard deviation of ray lognormal fading term (dB).

σ_x = standard deviation of lognormal shadowing term for total multipath realization (dB).

These parameters are originated by trying to match important characteristics of the channel. There are many characteristics of the channel, the main characteristics chosen for simulation are:

- Mean excess delay
- RMS delay spread
- Number of multipath components (defined as the number of multipath arrivals that are within 10 dB of the peak multipath arrival).
- Power decay profile

The table shows some measurement results considering above mentioned parameters and channel characteristics. Depending upon different propagation distances and path profiles (LOS or NLOS) four channel models are taken.

Table 1. The parameters of the sensor

Target Channel Characteristics[5]	CM 1[1]	CM 2[2]	CM 3[3]	CM 4[4]
Mean excess delay (nsec) (τ_m)	5.05	10.38	14.18	
RMS delay (nsec) (τ_{rms})	5.28	8.03	14.28	25
NP_{10dB}			35	
NP (85%)	24	36.1	61.54	
Model Parameters				
Λ (1/nsec)	0.0233	0.4	0.0667	0.0667
λ (1/nsec)	2.5	0.5	2.1	2.1
Γ	7.1	5.5	14.00	24.00
γ	4.3	6.7	7.9	12
σ_1 (dB)	3.3941	3.3941	3.3941	3.3941
σ_2 (dB)	3.3941	3.3941	3.3941	3.3941
σ_x (dB)	3	3	3	3
Model Characteristics[5]				
Mean excess delay (nsec) (τ_m)	5.0	9.9	15.9	30.1
RMS delay (nsec) (τ_{rms})	5	8	15	25
NP_{10dB}	12.5	15.3	24.9	41.2
NP (85%)	20.8	33.9	64.7	123.3
Channel energy mean (dB)	-0.4	-0.5	0.0	0.3
Channel energy std (dB)	2.9	3.1	3.1	2.7

[1] This model is based on LOS (0-4m) channel measurements reported in [5].
[2] This model is based on NLOS (0-4m) channel measurements reported in [5].
[3] This model is based on NLOS (4-10m) channel measurements reported in [5], and NLOS measurements reported in [6].
[4] This model was generated to fit a 25 nsec RMS delay spread to represent an extreme NLOS multipath channel.
[5] These characteristics are based upon a 167 psec sampling time.

Ultra Wide Band Receiver model

Any signal propagating through a channel gets modulated by the channel impairments. These impairments could be in the form of noise, attenuation due to its scattering and multipath effect. At receiver end an estimated signal is received which is based on the prior knowledge about the signal. This knowledge could be about its envelope shape, time of arrival or modulation scheme used. Based on this knowledge receiver already has a pattern and receiver work is to correlate the received energy with this already known pattern [7]. In other words at the receiver end, correlation is performed to recover the original signal. Block diagram of RAKE receiver is depicted in figure 1. RAKE Receiver normally used to mitigate the effect of multipath interference which is caused by reflected signals from obstacles in the propagation path as well as from ground [8].

In order to make signal less susceptible to noise many techniques are used. Spread spectrum techniques (direct sequence and frequency hopping) are very common in them. In this work direct sequence spread spectrum technique is used in which the message signal is modulated with coded signal which makes the message noisy for the irrelevant receiver. Thus noise effects are minimized. A detailed literature on spread spectrum is given in [9].

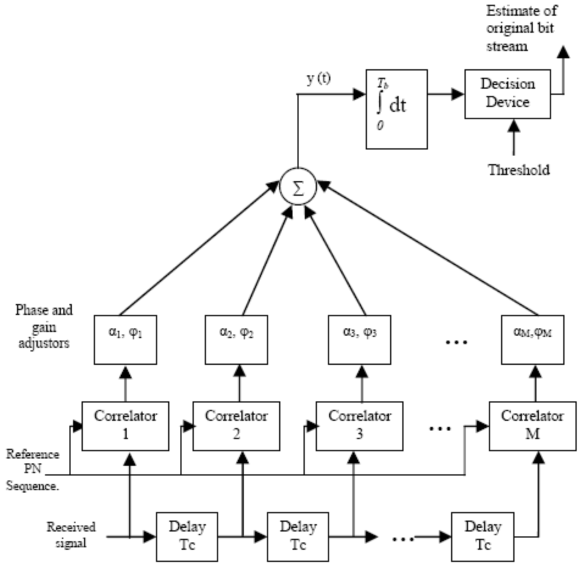

Fig. 1. Block Diagram of RAKE receiver [8]

1. RAKE Receiver Architecture:

RAKE receivers are used in any kind of spread spectrum system to get the cumulative signal energy of each multi-path component of the transmitted signal [10]. Correlation is used to cancel out the diversity effect [11].

Typically a Rake Receiver [8, 12] used in UWB system consists of a set of correlators which are connected in parallel and have synchronization between them. Each correlator has two inputs:

i. A delayed version of the received signal.

ii. A reference PN sequence which is already used at the transmitter.

Each correlator receives multi-path component individually at different interval of times. This creates phase misalignment in the received signal. A delay is introduced for aligning the phase of different multipath components. Certain gain is assigned to the output of each correlator. The strong multipath component has larger value of gain which allows it to contribute more and suppress those multipath components which have lower gains. Finally the outputs from the correlators are added algebraically to get the decision variables. On the bases of these decision variables, detector decides the signal waveform that was actually transmitted. The final output has no multi-path effects and it act like as if there is a single propagation path from transmitter to receiver.

2. RAKE Receivers Test Platforms:

Three different types of RAKE receiver architectures are used for BER performance comparison. These are briefly discussed below:

A. Ideal or All RAKE (I-RAKE or A-RAKE):

It is an ideal model of the RAKE receiver. In this approach, number of correlators which performs matching is equal to the number of multi-path components received at the receiver.

As an ideal case it makes the receiver capable of receiving all signal power. As there is infinitely large number of multi-path components, thus infinitely large numbers of correlators are required for receiving the signal. Thus its implementation is not possible and its just and ideal model.

B. Selective RAKE (S-RAKE):

This approach is actually a compromise on I-RAKE. In this approach, all multi-path components are collected but only specific components are selected for further processing. The emphasis is on the signals with larger amount of power i.e., the stronger ones. Since only selected signals are accepted, thus limited correlators are required. It is less complex and a practical approach than A-RAKE.

C. Practical RAKE (P-RAKE):

A more simplified model is P-RAKE. This approach works on the same principle as S-RAKE i.e., accepts selective multi-path components but it accepts earlier ones and ignores other. The order of the receiver decides how many components it can accept but these must be the first arriving components. This approach is based on the assumption that early received components could contain more power than the later one. It could be a disadvantage because some times later signals have more power so in this case it could not provide good performance.

Simulation Results

The RAKE receiver simulations are performed for different scenarios according to the cases given in IEEE P802.15. These scenarios are enlisted in Table II.

Table II: Test scenarios for BER Comparison.

Case	Fingers	Distance d (m)	Receiver Type	Environment
A	L=5 S=5	2	PRAKE SRAKE	LOS
B	L=5 S=5	8	PRAKE SRAKE	NLOS
C	L=5 S=5	2	PRAKE SRAKE	NLOS
D	L=5 S=5	8	PRAKE SRAKE	Extreme NLOS.

* For all cases A-RAKE branches are unlimited

S represents the S-RAKE branches and L represents PRAKE branches. 'd' represents the distance between transmitter and receiver in meters.

Following simulation results shows the system performance for each case given in the IEEE standard. The objective is to observe the system behavior in all four cases which includes both LOS and NLOS environment.

The results are shown as:

CASE A (Channel Model 1),
CASE B (Channel Model 2),
CASE C (Channel Model 3),
CASE D (Channel Model 4).

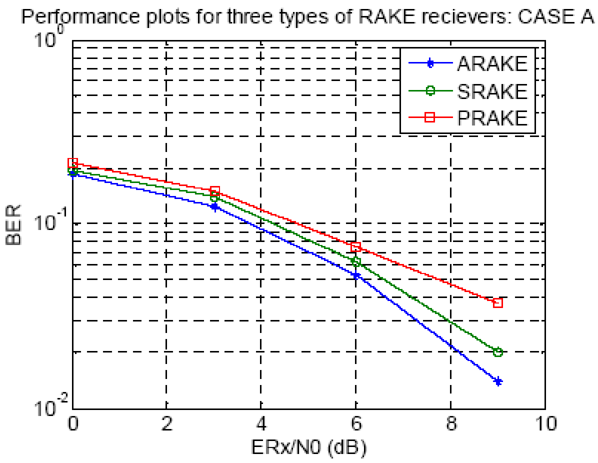

Fig 2. L=5, S=5, d=2, environment = LOS.

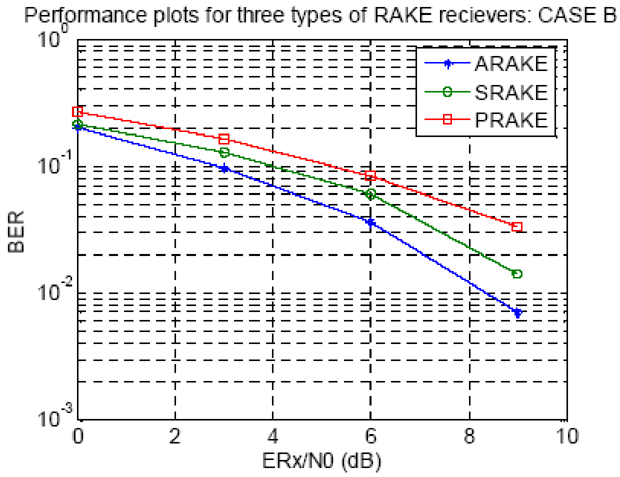

Fig.3. L=5, S=5, d=8, environment =N LOS

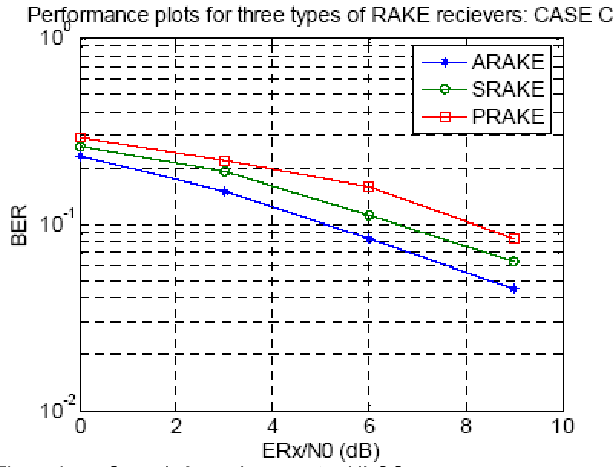

Fig. 4. L=5, S=5, d=2, environment = NLOS

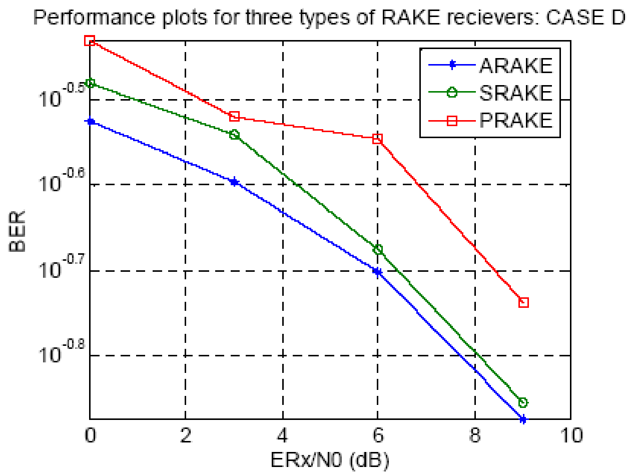

Fig. 5. L=5, S=5, d=8, environment = Extreme NLOS.

All the four graphs show the result for three types of RAKE receivers, A-RAKE, S-RAKE and P-RAKE. In all the cases S-RAKE performs better than P-RAKE and hence proves to be the best for implementation with some complexity and expense. P-RAKE is a low cost and less complex solution. However, P-RAKE could outperform S-RAKE in case if the earlier arrived paths are strongest.

P-RAKE is a low cost and less complex solution. However, P-RAKE could outperform S-RAKE in case if the earlier arrived paths are strongest. A-RAKE is only a theoretical model and it results are only achieved to compare both S-RAKE and P-RAKE with ideal conditions.

It is obvious from the graph (Case A) that when distance is minimum (d=2) and environment is Line of Sight (LOS) then system provides the best result. This is due to less scattering of signal and also the receiver receives more direct paths. The rest of the three cases, deal with Non Line of Sight (NLOS) environment. The multipath scattering of the signal is high in this case. As the distance between receiver and transmitter increases, receiver receives less direct or strong paths. Especially in case of extreme NLOS maximum distance i.e., 8m (case D), there is much scattering which results in poor performance of P-RAKE.

Conclusions

The UWB receiver is highly capable of mitigating multi-path effect. It outperforms conventional techniques using correlation and detection. The methodology was exposed for three types of RAKE receivers which are A-RAKE, S-RAKE and P-RAKE. The performance curves are obtained for each RAKE receiver and also for each of the four cases. The numbers of bits transmitted were 100, with sampling frequency of 50 GHz. The graph shows average BER by taking the readings for each case given in the standard.

The results show that RAKE performs better in LOS environment as compared to NLOS environment, because in LOS environment multi-path effect is reduced, which results in error free transmission.

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