# Matlab- Based Interference Mitigation in WPAN IR-UWB

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## Abstract

Impulse Radio - Ultra Wideband (IR-UWB) is a wireless technology system that offers a high data rate within a short range. Therefore, IR-UWB system is regarded as an excellent physical layer solution to the multi-piconet Wireless Personal Area Network (WPAN) applications. In spite of all the advantages of IR-UWB, there are several fundamental and practical challenges that need to be carefully addressed. The big and most important one among these challenges is the interference. Two types of Rake receivers are designed and simulated to highly mitigate the MUI these are (PRake receiver) and (SRake receiver).

**Key wards: WPAN, Recievers, Filters, MatlabToolbox.**

## استخدام حقيبة (Matlab) لتخفيف التداخل لمنظومة (WPAN IR-UWV)

**الخلاصة:**

تعتبر منظومة (WPAN IR-UWV) من المنظومات اللاسلكية التي توفر سرعة بيانات عالية لنطاق قصير. لذا فهي تمثل حلاً منسباً لتطبيقات (WPAN)، وبالرغم من تلك الميزات فأن هذه المنظومة تواجه من عدة تحديات بحاجة الى دراسة، لعل أبرزها التداخل . تم في هذا البحث تصميم وتمثيل نوعين من المستقبلات لتخفيف التداخل وهما الآخذتين (PRake receiver) و(SRake receiver).

# 1. Introduction:

It is difficult to imagine what modern living would be like without ready access to reliable, economical, and efficient means of communications. Wireless technology has become capable of reaching every location on the surface of the earth. Hundreds of millions of people exchange information every day using laptops, cellular phones, and other wireless communication devices.

As wireless communication systems are making the transition from wireless telephony to interactive Internet data and multimedia types of applications, the desire for higher data rate transmission is increasing tremendously. Ultra-Wide band (UWB) offers attractive solutions for many wireless communication areas, including Wireless Personal Area Networks (WPANs), wireless telemedicine, and UWB wireless mouse, keyboard, and speakers [1].

## 1.1. General Background

With its wide bandwidth, UWB has the potential to offer much higher capacity than the current narrowband systems. From Shannon's formula for the capacity *C* in b/s in Additive White Gaussian Noise (AWGN) the noise is said to be white if it has a flat spectrum at all frequency components like the white light. The capacity of the UWB system occupying bandwidth *BW*, as a function of the Signal to Noise Ratio (SNR) at a distance *d* between the transmitter and receiver is given by [2]:

$$C(d) = BW \quad \log_2(1 + SNR(d)) \qquad (1.1)$$

The function *C* (*d*) represents the effect of path losses on the transmitted signal. It can be seen that UWB systems offer their greatest promise for very high data rates for high *BW*. The UWB system was often referred to as base-band, carrier-free or short impulse. A UWB signal is any signal whose fractional bandwidth $BW_f$ is greater than 0.2 or occupies 500 MHz or more of the spectrum. The $BW_f$ is given by [4]:

$$BW_f = \frac{BW}{f_c} = 2\frac{(f_H - f_L)}{(f_H + f_L)} \qquad (1.2)$$

where $f_H$ and $f_L$ are defined as the highest and lowest frequencies of the transmission band respectively and $f_c$ is the center frequency.

UWB radio has gained popularity worldwide thanks to its promise of providing very high data rates at low cost. The interest in UWB to the creation of the IEEE 802.15.3a Study Group, with the aim of defining a standard for WPANs based on a UWB physical layer capable of higher data rates [3].

The high temporal resolution inherent to UWB provides robustness against multipath fading. Since the signal energy is spread very thinly over the entire bandwidth, the energy density is very low. This helps in reducing the probability of detection and interception.

Another important property of UWB signal is the high immunity to multipath fading. Multipath fading is a phenomenon observed in continuous wave signals. It occurs due to the reflection of signals off objects resulting in destructive cancellation and constructive addition. Since UWB is not a continuous wave technology, it is not affected since the reflections can be resolved in time .as a matter of fact, the narrow pulses in UWB transmission allow and hence can be used to effectively detect the transmitted simply in a multipath environment Hence, the pulses reaching a receiver from reflections can be easily distinguished from those arriving through line sight (LOS) as shown in Figure (1)) [2].

Most people would see UWB as a “new” technology, in the sense that it provides the means to do what has not been possible before, be that high data rates, smaller, lower powered devices or, indeed, some other new applications [1].

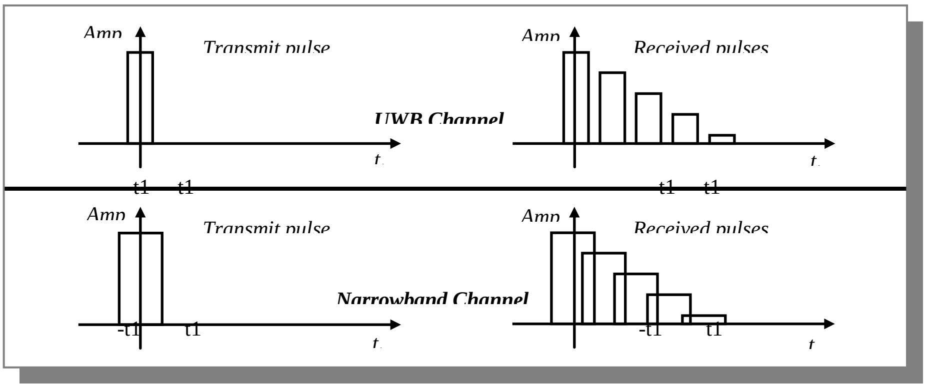



**Fig. (1) illustration of multipath resolution with broader and narrow pulses.**

## 1.2 UWB Spectrum:

UWB systems cover a large spectrum and interfere with existing users and narrow band services. In order to keep this interference as minimum as possible, a spectral mask was specified for different applications which show the allowed power output for specific frequencies. In Fig.(2), the spectral mask for in door UWB systems is shown. A large contiguous bandwidth of 7.5 GHz is available between 3.1 GHz and 10.6 GHz at a maximum power output of −41.3 dBm/MHz [5].

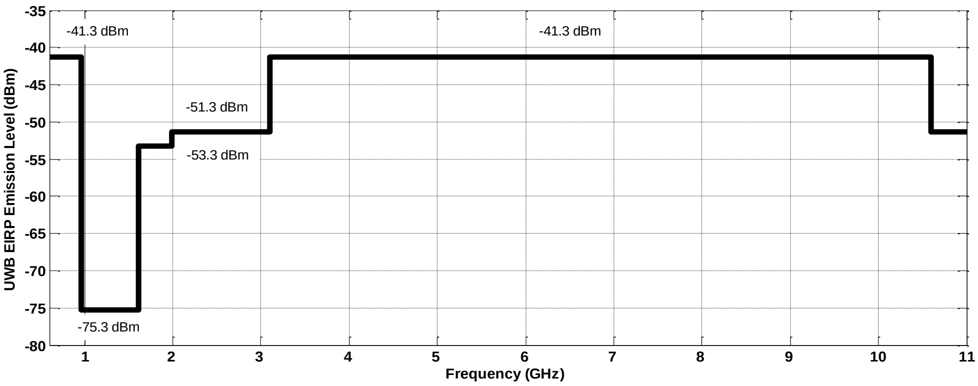



**Fig. (2) The spectral mask for indoor UWB systems.**

### 1.3 Impulse Radio – UWB:

A possible technique for implementing UWB is the Impulse Radio (IR), which is based on transmitting extremely short (in the order of nanoseconds) and low power pulses. These very short pulses in transmission result in a UWB spectrum [6] The most popular approach for realizing UWB communications is TH-IR. It allows a very simple transmitter structure that consists of only a baseband pulse generator, completely obviating the need for passband components like mixers, local oscillators, etc. However, the implementation of the receiver can be considerably more complex in a multipath environment [7].

### 1.4 UWB Advantages:

UWB has a number of advantages. In particular, UWB systems:

a. Have potentially low complexity and low cost;
b. Have very high data rates;
c. Has no carrier, results in simple Radio Frequency (RF) circuits.

The low complexity and low cost of UWB systems arises from the essentially baseband nature of the signal transmission. Unlike conventional radio systems, the UWB transmitter produces a very short time domain pulse, which is able to propagate without the need for an additional RF mixing stage. The RF mixing stage takes a baseband signal and 'injects' a carrier frequency to it [2].

### 1.5 UWB Challenges:

Multi User Interference (MUI) cancellation, removing the Inter Pulse Interference (IPI) and Inter Frame Interference (IFI), accurate modeling of UWB channels, estimation of multipath channel parameters, waveform coding, and coefficients are some of the issues that still require a great deal of investigation.

Besides, the synchronization of the receiver to extremely narrow pulses and the very high sampling rate [2].

## 2. IR-UWB Receivers Architectures in Multipath Channel (MPC):

High-capacity, high-data rate, simple, power-efficient, low-cost, and small IR-UWB receivers design is a challenging task. There are several receivers proposed for IR-UWB communication. A fully coherent receiver like optimal attached filtering, which is employed by Rake reception, performs well but at the expense of extremely high computational and hardware complexity. In general, a coherent receiver requires several parameters concerned with the received signal, radio channel, and interference characteristics. Multipath delays, channel coefficients for each delayed MPCs, and distortion of the pulse shape need to be estimated for optimal coherent reception. Note that, in UWB channel, the number of multipath components is very large (can be a few hundred). Also, the transmitted power and the power in each of these MPCs will be very low. Therefore, estimating the delays and coefficients from the received MPCs is an extremely challenging task [8].

## 2.1 IR-UWB Rake-Based Scheme:

The Rake receiver is promising candidate to reduce the required SNR. The robustness of UWB signals to multipath fading is due to their fine delay resolution, which - in combination with a Rake receiver - leads to a high multipath diversity gain. MPCs having delays of the order of nanoseconds (approximately equal to the inverse of the spreading bandwidth) are resolved by the Rake. However, in order to fully take advantage of this high delay resolution, the Rake receiver must be able to capture most of the energy carried by a very large number of different multipath signals [8].

### (a) Types of Rake Receivers:

Depending on the number of MPCs that can be captured by Rake receiver, there are three types of Rake receivers. These are: all Rake (ARake), selective Rake (SRake), and partial Rake (PRake) receivers [8].

### (b) The All Rake (ARake):

The ideal Rake receiver structure captures all of the received signal power by having a number of fingers equal to the number of MPCs. To achieve this, it requires

$L_r = T_{mds}/T_c$ taps.

where $L_r$ is and $T_c$ is

The problem with this approach is the need for an infinite number of Rake branches, which also means an infinite number of correlators as shown in Fig. (3) [9].

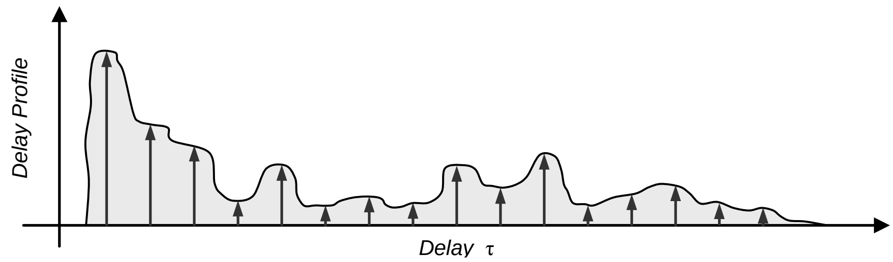



**Fig. (3) The principle of ARake receiver.**

### (c) The Selective Rake (SRake):

In practice, non-perfect Rake receivers are considered. Non-perfect Rake receivers do not receive all MPCs and the number of fingers is less than the number of arrived components. Two main non-perfect Rake receiver structures proposed for UWB systems are the Selective Rake (SRake) and Partial Rake (PRake) receivers [9].

The SRake only uses the $L_r$ strongest propagation paths. Information on the channel impulse response is required in order to use the SRake. Channel estimation algorithms must be used to obtain this a priori information. The SNR is maximized when the strongest paths are detected. Fig.(4) shows the MPCs used by the SRake. The channel profile equals to the one presented in Fig.(3) [9].

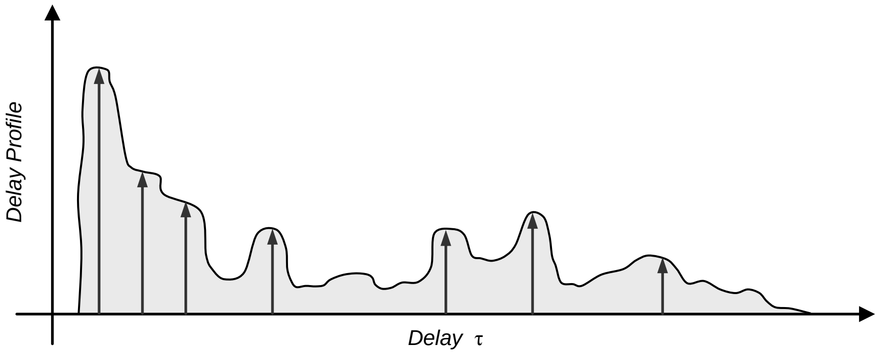



**Fig.(4) The principle of SRake receiver.**

**(d) The Partial Rake (PRake)**

The PRake receiver is a simplified approximation to the SRake. The PRake involves combining the $L_r$ first propagation paths.

The disadvantage of PRake is that the MPCs for the PRake receiver combines are not necessarily the strongest MPCs, so optimum performance will not be achieved. Fig.(5) shows the PRake for $L_r$ = 7 branches using the same channel profile as earlier examples [9].

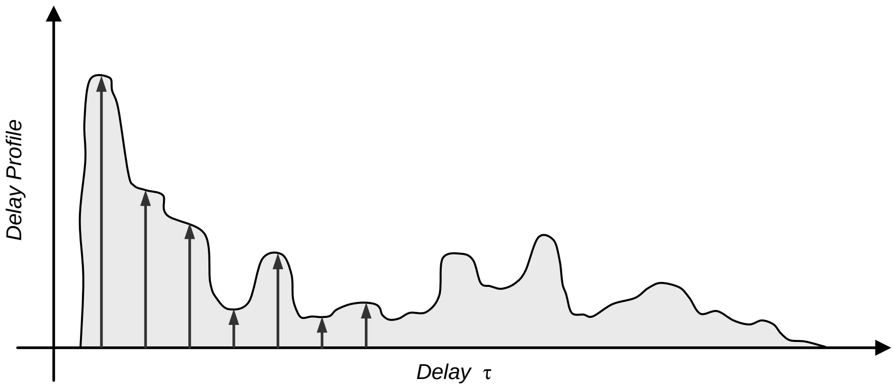



**Fig.(5) The principle of PRake receiver.**

## 2.2 Rake Construction:

The basic version of the conventional Rake receiver - Fig.(6) - consists of $L_r$ correlators (fingers) where each of the fingers can detect/extract the signal from one of the MPCs provided by the channel. The outputs of the fingers are appropriately weighted and combined to reap the benefits of multipath diversity [10].

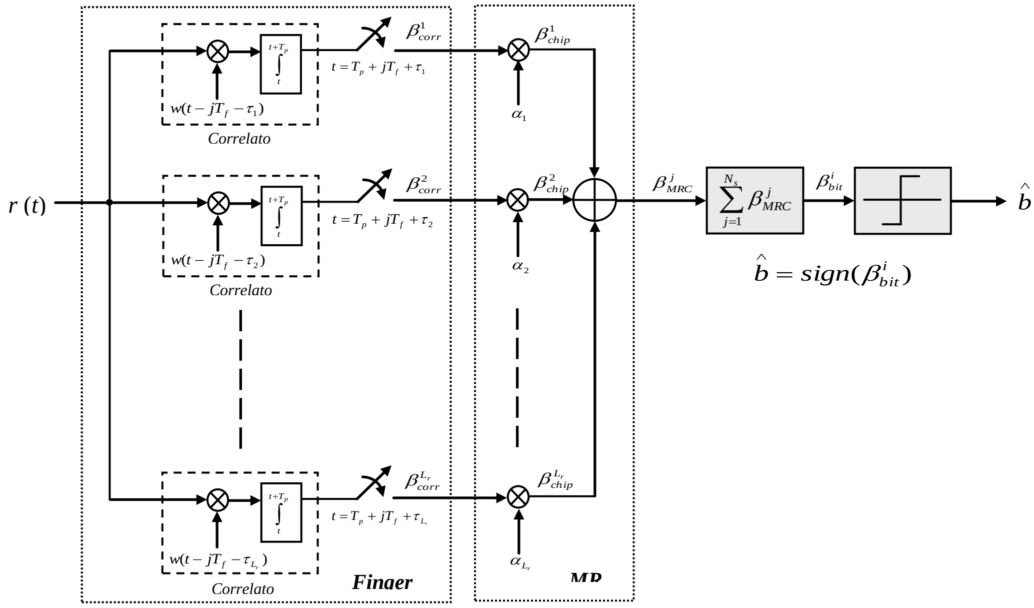



**Fig.(6) The conventional Rake receiver.**

## 2.7 Signal Model for Rake Receiver:

A BPSK TH IR-UWB system is considered with $N_u$ users, in which the transmitted signal $S_{tx}^{(v)}(t)$ from user *v* is represented by:

$$S_{tx}^{(v)}(t) = \sqrt{E_p^{(v)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(v)} \quad w_{tx}(t - jT_f - c_j^{(v)}T_c - \tau_o^{(v)}) \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

Where $w_{tx}(t)$ is the transmitted UWB pulse, $E_p^{(v)}$ is the pulse energy of user *v*, $b_i^{(v)} = \{+1,-1\}$ is the binary information symbol transmitted by user *v*, $\lfloor j/N_s \rfloor$ denotes the integer part of $j/N_s$ and $\tau_o^{(v)}$ represents $v^{th}$ user's reference delay relative to the first user caused by asynchronous transmission where, $0 \le \tau_o^{(v)} \le T_f$. In order to allow the channel to be shared by many users and avoid catastrophic collisions, a TH sequence $\{c_j^{(v)}\}$, where $c_j^{(v)} \in \{1,2,....,N_c\}$, is assigned to each user, and $N_c$ is the number of frame's chips.

The $S_{tx}^{(v)}(t)$ is transmitted through the IEEE 802.15.3a standard of WPAN indoor multipath channel. This channel is modeled as a linear, time-varying filter which is time-invariant over a $T_f$ duration with impulse response for user *v*, $h^{(v)}(t)$ and has a certain $T_{mds}$ value. The IEEE 802.15.3a standard for multipath model for user *v* consists of the following discrete time impulse response:[11]

$$h^{(v)}(t) = \sum_{l=1}^{L} \alpha_l^{(v)} \delta(t - \tau_l) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots... \quad (2.2)$$

Where $h^{(v)}(t)$ is the $v^{th}$ user's channel impulse response and $\tau_l = lT_c$.

At the receiver side, the receiver is assumed to be completely synchronous with the transmitter, i.e., all the path delays $\tau_l$ for $1 \le l \le L$ are known to the receiver.

However, the number of branches (fingers) of the Rake receiver is assumed to be limited to $L_r \leq L$. The received signal is:

$$r(t) = \sum_{v=1}^{N_u} h^{(v)}(t) \otimes S_{tx}^{(v)}(t) + n(t) \quad \text{.......................................} \quad (2.3)$$

Where $n(t)$ is the AWGN with spectral density $N_o$. The received signal can be expressed as:

$$r(t) = \sum_{v=1}^{N_u} \sqrt{E_p^{(v)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(v)} \sum_{l=1}^{L} \alpha_l^{(v)} w_{rx}\left(t - jT_f - c_i^{(v)} T_c - lT_c - \tau_o^{(v)}\right) + n(t) \quad . \quad (2.4)$$

Where $w_{rx}(t)$ is the received unit-energy UWB pulse, which is usually modeled as the derivative of $w_{tx}(t)$ due to the effects of the receiving antenna. For simplicity, $r(t)$ can be expressed in the following form:

$$r(t) = \sum_{v=1}^{N_u} \sqrt{E_p^{(v)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(v)} \; g_{rx}^{(v)}\left(t - jT_f - c_j^{(v)} T_c - \tau_o^{(v)}\right) + n(t) \quad \text{.......} \quad \text{...}(2.5)$$

Where $g_{rx}^{(v)}(t) = w(t)_{tx} \otimes h^{(v)}(t)$ and $\otimes$ denotes convolution.

In order to separate the received signal for user 1, $r(t)$ is rewritten as:

$$r(t) = \sqrt{E_p^{(1)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(1)} \; g_{rx}^{(1)}\left(t - jT_f - c_i^{(1)} T_c - \tau_o^{(1)}\right) + \sum_{v=2}^{N_u} \sqrt{E_p^{(v)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(v)} \; g_{rx}^{(v)}\left(t - jT_f - c_i^{(v)} T_c - \tau_o^{(v)}\right) + n(t) \quad \text{.....} \quad (2.6)$$

If the transmission of the intended user is assumed at time $\tau_o^{(1)} = 0$ without loss of generality, then:

$$r(t) = \sqrt{E_p^{(1)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(1)} \; g_{rx}^{(1)}\left(t - jT_f - c_i^{(1)} T_c\right) + \sum_{v=2}^{N_u} \sqrt{E_p^{(v)}} \sum_{j=-\infty}^{\infty} b_{\lfloor j/N_s \rfloor}^{(v)} \; g_{rx}^{(v)}\left(t - jT_f - c_i^{(v)} T_c - \tau_o^{(v)}\right) + n(t) \quad \text{...} \quad (2.7)$$

Where the first term in the right side is the desired signal of the intended user [11].

## 2.8 Output of the BPSK Matched Filters:

The received MPCs are considered to arrive in successive bins. Each bin has duration of $T_c$. Therefore $\tau_{l2} - \tau_{l1} = (l_2 - l_1)T_c$.

Since there are $L_r$ matched filter outputs, so, $L_r$ template waveforms there be matched on the signal from the first (desired) transmitter.

The template signals for the incoming signal can be expressed as:

$$S_{temp}^{(1)}(t) = \sum_{l=1}^{L_r} w_{rx}\left(t - jT_f - c_i^{(1)} T_c - lT_c\right) \quad \text{.......................................} \quad (2.8)$$

The template signal for the $l^{\text{th}}$ finger is given by:

$$S_{temp,l}^{(1)}(t) = w_{rx}\left(t - jT_f - c_i^{(1)} T_c - lT_c\right) \quad \text{.......................................} \quad (2.9)$$

For the $i^{th}$ information symbol of user 1, the output of $l^{th}$ Rake finger $\beta_{corr}^{l}$ is:

$$\beta_{corr}^{l} = \int_{o}^{T_p} r(t) \, . \, S_{temp,l}^{(1)}(t) \quad dt \quad \text{.......................................} \quad (2.10)$$

The quantity before the MRC $\beta_{chip}^{l}$ is expressed as:

$$\beta_{chip}^{l} = \alpha_{l}^{(1)} \, . \, \beta_{corr}^{l} \quad \text{.......................................} \quad (2.11)$$

For the conventional BD Rake receiver, the quantity after the MRC $\beta_{MRC}^{j}$ of the first $L_r$ paths is expressed as:

$$\beta_{MRC}^{j} = \sum_{l=1}^{L_r} \beta_{chip}^{l} \quad \text{.......................................} \quad (2.12)$$

Then, the decision statistic $\beta_{bit}^{i}$ for $i^{th}$ bit for $N_s$ frames is expressed as:

$$\beta_{bit}^{i} = \sum_{j=1}^{N_s} \beta_{MRC}^{j} \quad \text{.......................................} \quad (2.13)$$

And finally, the estimated bit $\hat{b}$ is given by $sign(\beta_{bit}^{i})$ . [16]

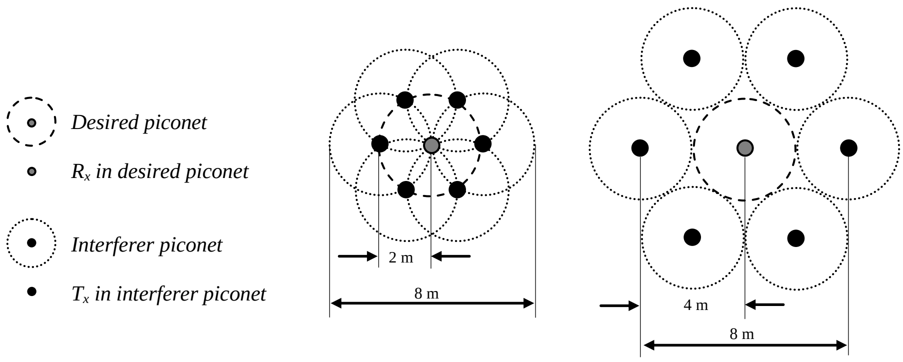
# 3. Results and discussions:

## 3.1 Suggested Multi-piconet WPAN Scenarios:

Three different multi-user multi-piconet WPAN scenarios are suggested in this paper that satisfies the restrictions of the IEEE 802.15.3a standard in these scenarios, the interferer piconets of the transmitter and the receivers are omitted.

In scenario (1), six interferers' piconets form a circle and are overlapped around/with the desired piconet which is in the WPAN center shown in Fig.(7-a) with $d_{int}$ is set to 2 m.

Another six interferer piconets are also shown in Fig. (7-b) in scenario (2) all of them are attached with the boundary of the desired piconet. The interferers' piconets also form a circle around the desired piconet which is in the WPAN center with $d_{int}$ is set to 4 m.




*a. Scenario (1)* *b. Scenario (2)*

**Fig. (7) The suggested multi-piconet WPAN scenarios**

## 3.2 Performances of the Rake Receivers:

The SRake only uses the $L_r$ strongest propagation paths. Information on the channel impulse response is required in order to use the SRake, while The PRake receiver is a simplified approximation to the SRake. The PRake involves combining the $L_r$ first propagation paths, so that, S/N ratio of SRake is stronger compered to PRcke, this leads to SRack receiver is better BER with S/N than PRacke receiver as shown in fig. (8).

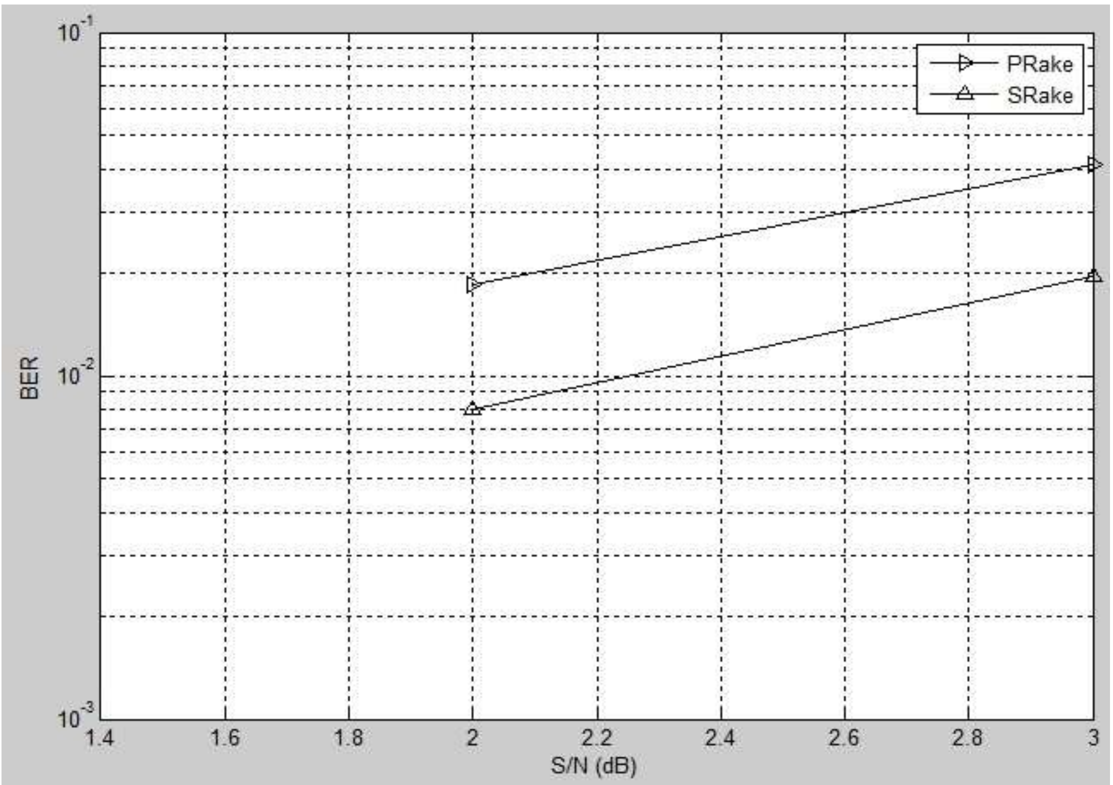



**Fig. (8) Average BER achieved as a function of S/N(dB).**

It's the time now to discuss the performance of the Rake receivers with various scenarios.

### 3-2-1 System performance with Scenario (1):

The average BER achieved for *Power spectral density* $PT_1$ = -100 dBm/Hz is illustrated in Fig. (9). In the case of $N_u$ = 1, only background noise degrades BER performance and all receivers have 0 BER except the PRAKE which has about 0.5 BER.When $N_u$ is increased, system performance quickly degrades for all receivers

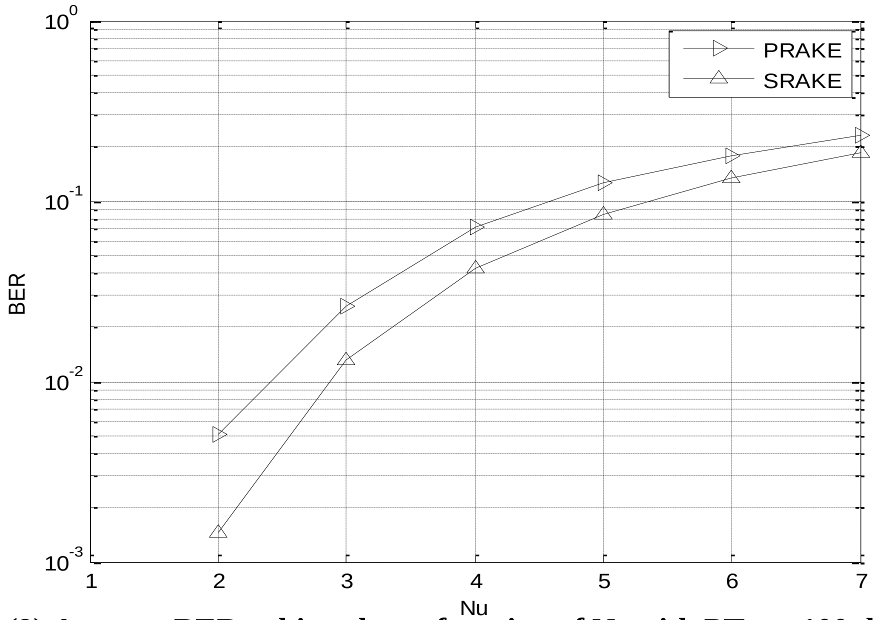



**Fig. (9) Average BER achieved as a function of $N_u$ with $PT_1$ = -100 dBm/Hz.**

Next at $PT_1$ = -110 dBm/Hz, the S/N is decreased, i.e., the performances of the receivers in terms of BER is degraded as shown in Fig.(10) for both types of Rakes. This is due to the dominant of noise on the signal at the receiver input. On the other hand, the change in the performance of the Rake especially for the Prake is clear.

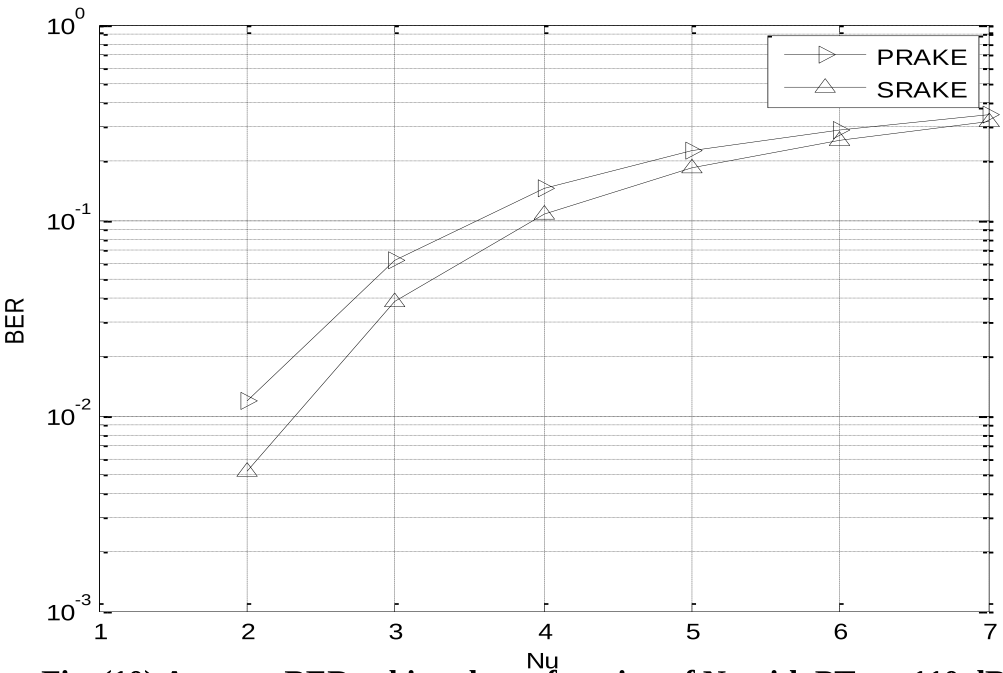



**Fig. (10) Average BER achieved as a function of $N_u$ with $PT_1$ = -110 dBm/Hz.**

### 3-2-2 Performance with Scenario (2):

Scenario (1) has a random topology. It seems like the real situation in which the interferer piconets can be represented with slow movements relative to the desired piconet. In other words, in each transmitted bit for all piconets, the interferer piconet has a different location, and so, has a different relative $d_{int}$, which results in different free space losses. Therefore, the piconets' interferer powers can be received by the desired piconet with also at different values.

Again, two cases will be studied and simulated in this scenario corresponding to four different $PT_1$ values.

It's clear from Fig.(11) that receivers achieved 0 BER in single piconet system which represents only the AWGN channel. The SRake has the best performance.

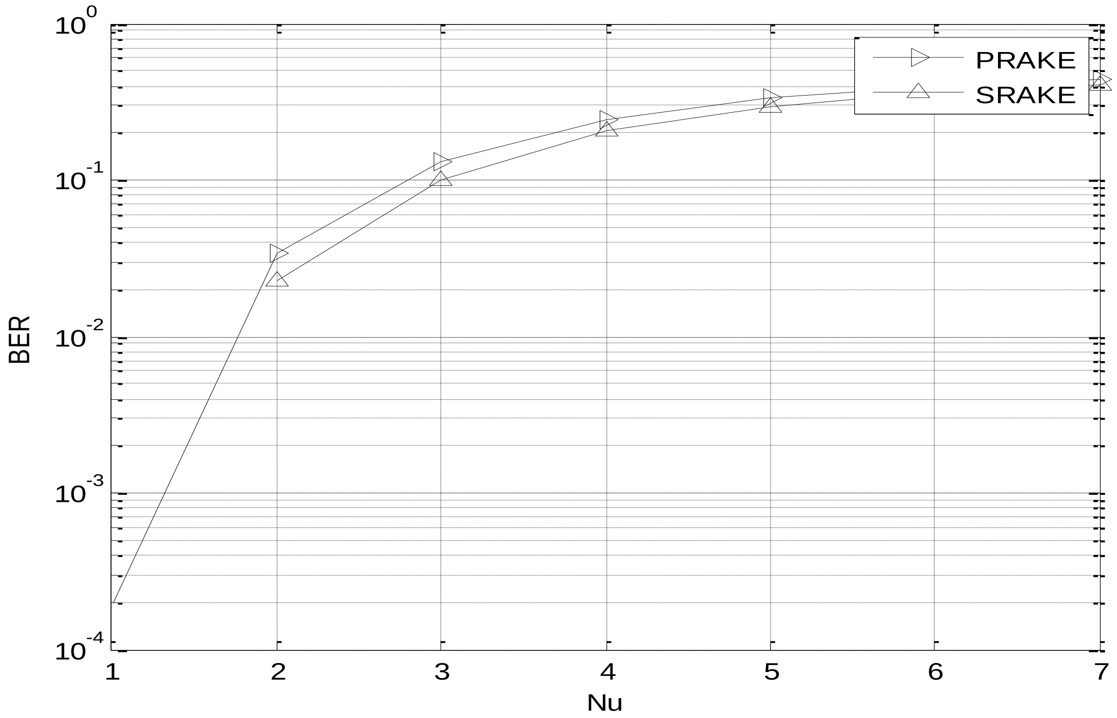



**Fig. (11) Average BER achieved as a function of $N_u$ with $PT_1$ = -100 dBm/Hz.**

Again, the change in the performance of Rake receivers when $PT_1$ is decreased to -110 dBm/Hz especially for PRake is clearly shown in Fig.(12). But still has a BER value in the AWGN channel ($N_u$ = 1).

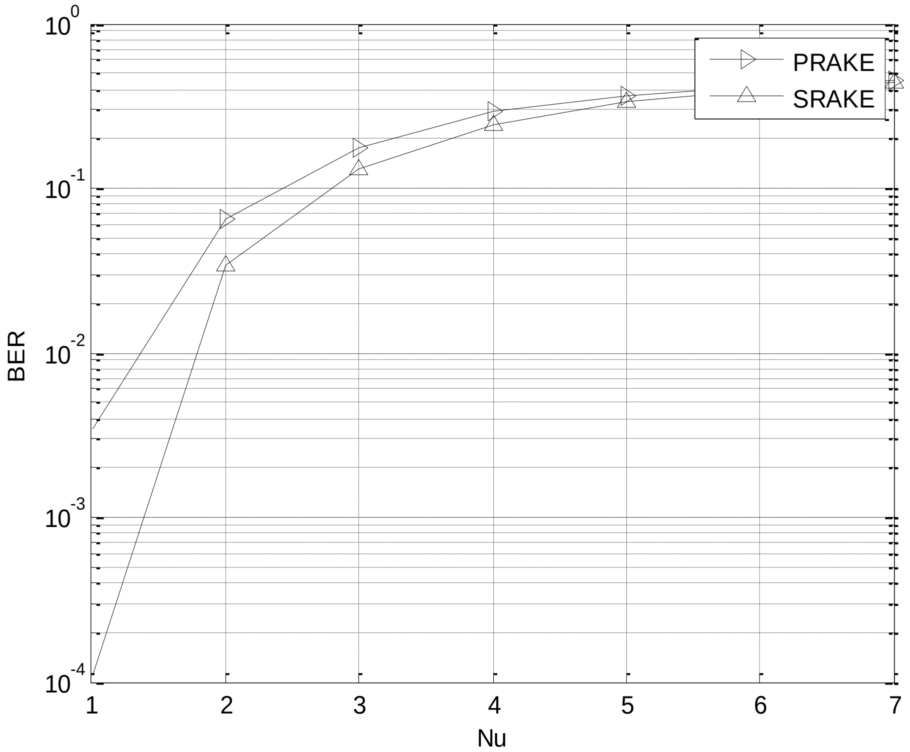



**Fig. (12) Average BER achieved as a function of $N_u$ with $PT_1$ = -110 dBm/Hz**

It's clear from Fig.(12) that receivers achieved 0 BER in single piconet system which represents only the AWGN channel. The SRake has the best performance due to its adaptive threshold as previously stated. The SRake and PRake receivers have nearly similar achievements and the same BER values for both types of Rakes.

## 4. Conclusions:

The objectives of this project are to semi-analyze and investigate the performance of multi-piconet WPAN IR-UWB Rake receivers. The performance was evaluated in the presence of MUI indoor dense multipath IEEE 802.15.3a, and AWGN.

a. In dense MUI, it can be concluded that the SRake outperforms the PRAKE because of the maximum bins in SRake.

b. The number of Rake fingers is much related to the performance. There is a gap between the BER performance of the PRake and SRake, i.e., all the results using SRake are better than PRake. But, nevertheless, all the Rake receivers can be implemented simply by using the PRake. PRake is less complex than the SRake, because it does not have selection diversity. Also, full channel estimation is not necessary for PRake**.**

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