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Ultra Wideband Channel Model for IEEE 802.15.4a and Performance Comparison of DBPSK/OQPSK Systems

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Abstract

Ultra Wideband (UWB) is a radio technology that can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of the radio spectrum. Ultra Wideband (UWB) systems transmit signals across a much wider frequency than conventional systems and are usually very difficult to detect. The focus of this research is to model the Ultra wideband (UWB) channel for IEEE 802.15.4a. It provides different models for the following frequency ranges and environments. The operating frequency range from 2 GHz to 10 GHz, it covers indoor residential, indoor office, industrial, outdoor and open outdoor environments (Line of sight and Non line of sight properties). For the frequency range from 100 MHz to 900 MHz, it gives a model for indoor office type environments. IEEE 802.15.4a channel model is simulated in MATLAB 7. Under the IEEE802.15.4a channel model, performance of Differential binary phase shift keying (DBPSK) and Offset qudrature phase shift keying (OQPSK) modulations using rake receiver are compared in terms of bit error rates (BERs).

Keywords: UWB, Line of sight, Offset qudrature

1. Introduction

Ultra Wideband (UWB) is a radio technology that can be used at very low energy levels for short-range high-bandwidth communications by using a large portion of the radio spectrum. Ultra Wideband (UWB) systems transmit signals across a much wider frequency than conventional systems and are usually very difficult to detect. The amount of spectrum occupied by a UWB signal, i.e. the bandwidth of the UWB signal is at least 25% of the center frequency. Thus, a UWB signal centered at 2 GHz would have a minimum bandwidth of 500 MHz and the minimum bandwidth of a UWB signal centered at 4 GHz would be 1 GHz. The most common technique for generating a UWB signal is to transmit pulses with durations less than 1 nanosecond. Most recent applications target sensor data collection, precision locating and tracking applications. Objective of this paper is to model the Ultra wideband (UWB) channel for IEEE 802.15.4a. and this model provides different models for the following frequency ranges. Those are given by 1) The operating frequency range from 2GHz to 20GHz, It covers residential, indoor, outdoor, industrial and open outdoor environments. 2) The operating frequency range from 100MHz to 900MHz, It covers indoor office environment.

Several modulation techniques are proposed for Ultra wideband (UWB) signals such as Differential binary phase shift keying (DBPSK) and Offset qudrature phase shift keying (OQPSK) modulation techniques are implemented in the UWB channel model IEEE 802.15.4a.

2. Problem Statements

Compared to the conventional (Narrow band) channels, Ultra wideband channels behave differently. The difference can be due to large absolute and relative bandwidth of UWB signals [2]. The absolute performance of a given system depends on the channel it is operating. Path gain and power delay profile gives the propagation effect that determines whether the system can perform satisfactorily [3]. In any case, just design and implement a system and try it out is more accurate than measuring and modeling propagation channels and simulating system performance based on the models.

A constant cycle of redesign field testing is an exceedingly expensive way of building communications systems. Especially for standardized systems such an approach is almost impossible. Even when test results show that a system does not work well in a given environment (propagation channel), this does not immediately explain why the problems happen [5]. A detailed understanding of the channel and its interaction with the system is required to design suitable UWB systems. Hence UWB channel propagation characteristic parameters, power delay profile cluster arrival behavior are studied thoroughly for both indoor and outdoor environments. Using this channel model, the system performance is studied for different modulation schemes.

2.1 Ultra Wide Band

Ultra wideband (UWB) technology offers a promising solution to the RF spectrum allowing new services to coexist with current radio systems with minimum interference. This coexistence brings the advantage of avoiding the expensive spectrum licensing fees. Traditional narrow band communication system modulates the continuous radio frequency (RF) wave with a high frequency carrier to transmit and receive information. Ultra wideband (UWB) devices require low transmit power to transmit information. The availability of large bandwidths, the wide scope of the data rate/range trade off and the potential for very low cost, these properties gives a unique opportunity for UWB to the people interact with communication systems.

The power limitation effectively relegates UWB to indoor, short range communications for high data rates, or very low data rates for longer link distances. Applications such as wireless USB and personal area networks have been proposed offering hundreds of Mbps to several Gbps with distances of 1 to 4 meters. For ranges of 20 meters or more, the achievable data rates are very low compared to existing wireless local area network (WLAN) systems.

2.2 Ultra Wideband (UWB) Signals

Ultra wideband usually refers to impulse based waveforms that can be used with different modulations. The transmitted signal consists of train pulses order of nanoseconds. Each transmitted pulse is referred to as monocycle. The information can be carried by the position or amplitude of the pulses. In general, narrower pulses in the time domain correspond to electromagnetic radiation of wider spectrum in the frequency domain [6]. Thus, the baseband train of nanosecond impulses can have a frequency spectrum spanning from zero to several GHz, resulting in the so called UWB transmission. Short duration pulses are used in Ultra wideband technology offers several advantages over narrow band communication systems.

2.3 Challenges

Ultra wideband technology has many challenges involved in using very short duration (nano second) pulses for communication. Some of main challenges are given,

2.3.1 Pulse shape distortion

Radiation characteristics of UWB pulses are more complicated than those of continuous narrowband sinusoids. A narrowband signal remains sinusoidal throughout the transmission channel. However, the weak and low-powered UWB pulses can be distorted significantly by the transmission link.

According to Friis transmission formula

$$P_r = P_t G_t G_r \left({}^{C}\!/_{4\pi df} \right)^2 \qquad \text{\_\_\_\_\_\_\_\_} (1)$$

Where Pt and Pr are the transmitted and received signal powers, Gt and Gr are the transmitter and receiver gains, c is the speed of light, d is the distance between the transmitter and receiver and f is the signal frequency.

2.3.2 Channel estimation

Because it is not possible to measure every wireless channel in the field, it is important to use training sequences to estimate channel parameters, such as attenuations and delays of the propagation path. Given that most UWB receivers correlate the received signal with a predefined template signal, prior knowledge of the wireless channel parameters is necessary to predict the shape of the template signal that matches the received signal. However, as a result of the wide bandwidth and reduced signal energy, UWB pulses undergo severe pulse distortion; thus, channel estimation in UWB communications systems becomes very complicated.

2.3.3 High frequency synchronization

Time synchronization is a major challenge in Ultra wideband (UWB) communications systems. As with any other wireless communications system, time synchronization between the receiver and the transmitter is a must for UWB transmitter and receiver pairs. However, sampling and synchronizing nanosecond pulses place a major limitation on the design of UWB systems. In order to sample these narrow pulses, very fast (on the order of gigahertz) analog-to-digital converters (ADCs) are required [7]. Moreover, the strict power limitations and short pulse duration make the performance of UWB systems highly sensitive to timing errors such as jitter and drift. This can become a major issue in the success of pulse-position-modulation (PPM) receivers, which rely on detecting the exact position of the received signal.

3. Ultra Wideband Channel Model for IEEE 802.15.4a

There are two common methods for characterization of UWB channels. In the first method, an environment with materials of known electromagnetic characteristics is considered, and it is assumed that complete geometric information of the environment is available. Then, one can generate the propagation characteristics of the environment by using an electromagnetic simulation tool with ray tracing techniques. This approach is called deterministic modeling. The major drawback of the deterministic modeling is that it is site-specific. Furthermore, gathering accurate site-related information might be quite cumbersome. If the site geometry changes, the corresponding model might easily become obsolete. Results from various deterministic modeling-based propagation characterizations are reported in detail in .Common way for channel modeling is to derive statistical models from actual channel measurements. This is so called statistical modeling approach is less complex than deterministic modeling. The key channel parameters that need accurate modeling are path loss, shadowing, power delay profile, and small-scale fading.

3.1 Path Loss Model

Path loss (PL) is defined as the ratio of the received signal power P_{rx} to the transmitted Signal power P_{tx}, and Path loss (PL) component is a frequency dependent parameter for UWB systems.

For narrowband systems Path loss (PL) at a distance d can defined as

$$\mathrm{PL}(d) = \frac{E\{P_{rx}(d, f_c)\}}{P_{tx}} \qquad (2)$$

where fc is center frequency and E is expectation over the large area to average out a shadowing and small scale fading . For Ultra wideband systems, a frequency dependent Path loss (PL) can be defined as

$$\mathrm{PL}(d,f) = E\left\{\int_{f-0.5\Delta f}^{f+0.5\Delta f} |H(d,f)|^2 df\right\} \qquad (3)$$

where H (d, f) is a transfer function Δf is a small band of frequency over which material properties are constant and integration gives over all Path loss (PL) over a frequency range.

The distance and frequency dependent path loss can be treated as independent, Path loss (PL) can be expressed as

$$''\quad PL''(''d,f'')'' = PL''(''d'')''\,PL''(''f'')'' \qquad (4)$$

where PL (f) frequency dependent path loss, given by

$$\mathrm{PL}(f) \propto f^{-2k} \qquad (5)$$

where k is frequency decaying factor

And PL (d) distance dependent path loss, given by

$$\mathrm{PL}(d) \propto d^{-n} \qquad (6)$$

where n is path loss exponent. The distance dependent path loss can be expressed in dB as (Power law)

$$\mathrm{PL}(d) = \mathrm{PL\_0} + 10n\,\mathrm{log\_10}\ (d\,/d\_0\,) \qquad (7)$$

where d_0 is a reference distance (1 meter) and PL_0 is the Path loss at reference distance, both path loss exponent and frequency decaying factors are dependent on environment.

3.2path Loss Channel Model

Path loss (PL) is defined as the ratio of received power at the receiver antenna and transmitted antenna, depending on the operating frequency range, and also depending on their specific applications [17].

The transmitted power spectrum can be defined as the product of the output spectrum of the transmit amplifier and frequency dependent antenna efficiency.

$$P_t(f) = P_{Tx-amp}(f)\,\eta_{Tx-amp}(f) \qquad (8)$$

Frequency dependent power density at a distance

$$P(d,f) = K_0 \frac{P_t(f)}{4\pi d_0^2}\left(\frac{d}{d_0}\right)^{-n}\left(\frac{f}{f_c}\right)^{-2k} \qquad (9)$$

Where K_0 is the normalization constant

The received frequency dependent power at receiver given by the multiplying the power density at the receiver location with antenna area (A_{rx}) given by

$$A_{rx}(f) = \frac{\lambda^2}{4\pi} G_{rx}(f) \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad (10)$$

3.3 Channel Parameters

Here we can define auxiliary parameters related to power delay profile given by

3.3.1 Time of first arrival (τ_a):

Time of first arrival (τ_A) corresponds to the arrival of first signal component. Accurate estimation of Time of first arrival is important in the range estimation. In this case first received signal component is not a strongest arrival, the range estimation error greatly increases.

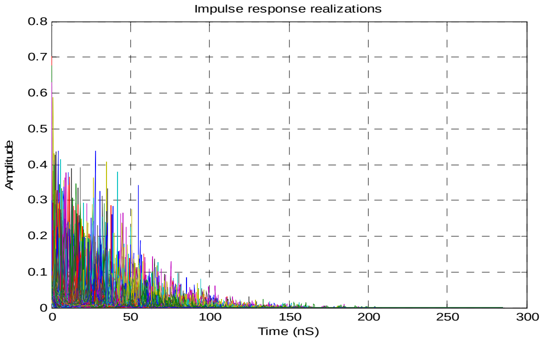
3.3.2 Mean excess delay and root mean square (rms) delay spread:

Mean excess delay defined as the first moment of the power delay profile given by

$$\tau_E \frac{\int \tau P(\tau)\, d\tau}{\int P(\tau)\, d\tau} \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad (11)$$

And RMS delay spread defined as the square root of the second central moment of the power delay profile given by

4.1 Simulations for Residential Line-of-sight (LOS) environments (CM1)



$$\tau_{rms} = \left[\frac{\int (\tau - \tau_i)^2 P(\tau)\, d\tau}{\int P(\tau)\, d\tau}\right] \quad \text{\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_} \quad (12)$$

RMS delay spread gives the information about multipath spread within a given channel and also time dispersion characteristics of the channel.

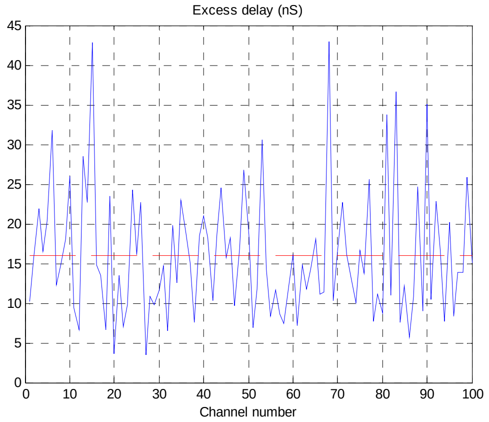
3.4 A 2 GHz to 10 GHz band

This band is defined for residential, indoor, outdoor and industrial environments as given below

3.4.1. Channel models (cm) in ieee 802.15.4a are classified as follows:

- CM-1: Residential Lion of sight (LOS)
- CM-2: Residential Non lion of sight (NLOS)
- CM-3: Indoor Office LOS
- CM-4: Indoor Office NLOS
- CM-5: Outdoor LOS
- CM-6: Outdoor NLOS
- CM-7: Industrial LOS
- CM-8: Industrial NLOS
- CM-9:Open outdoor environment NLOS

4 Simulation results and Discussion



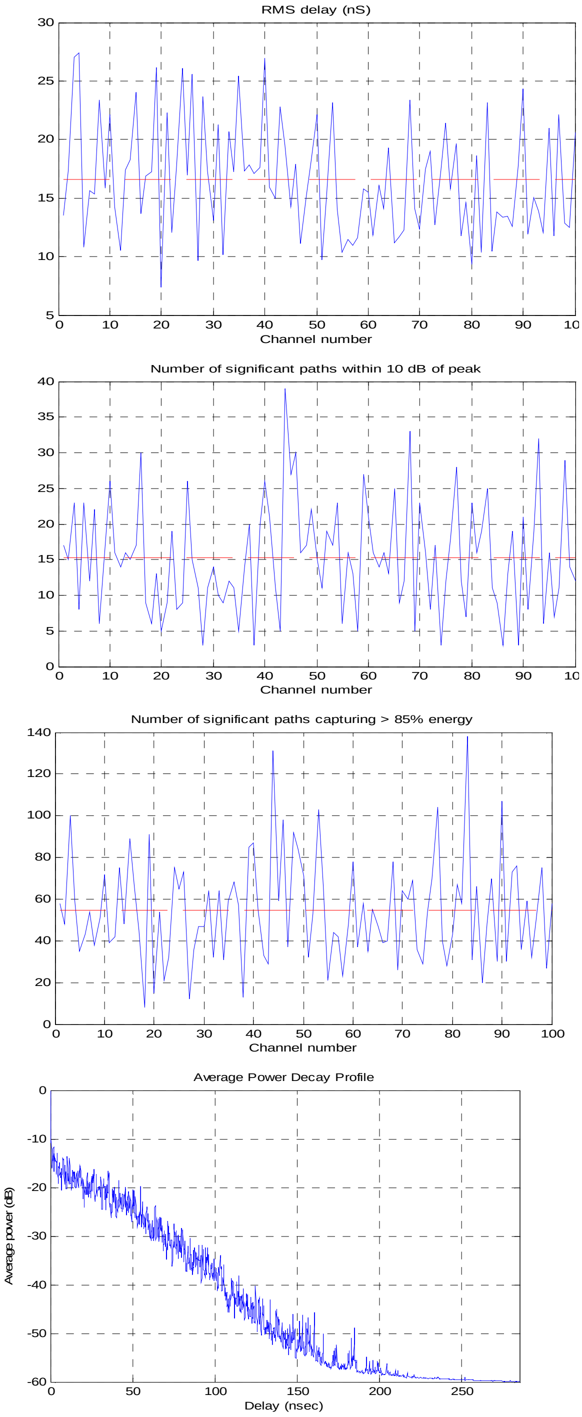


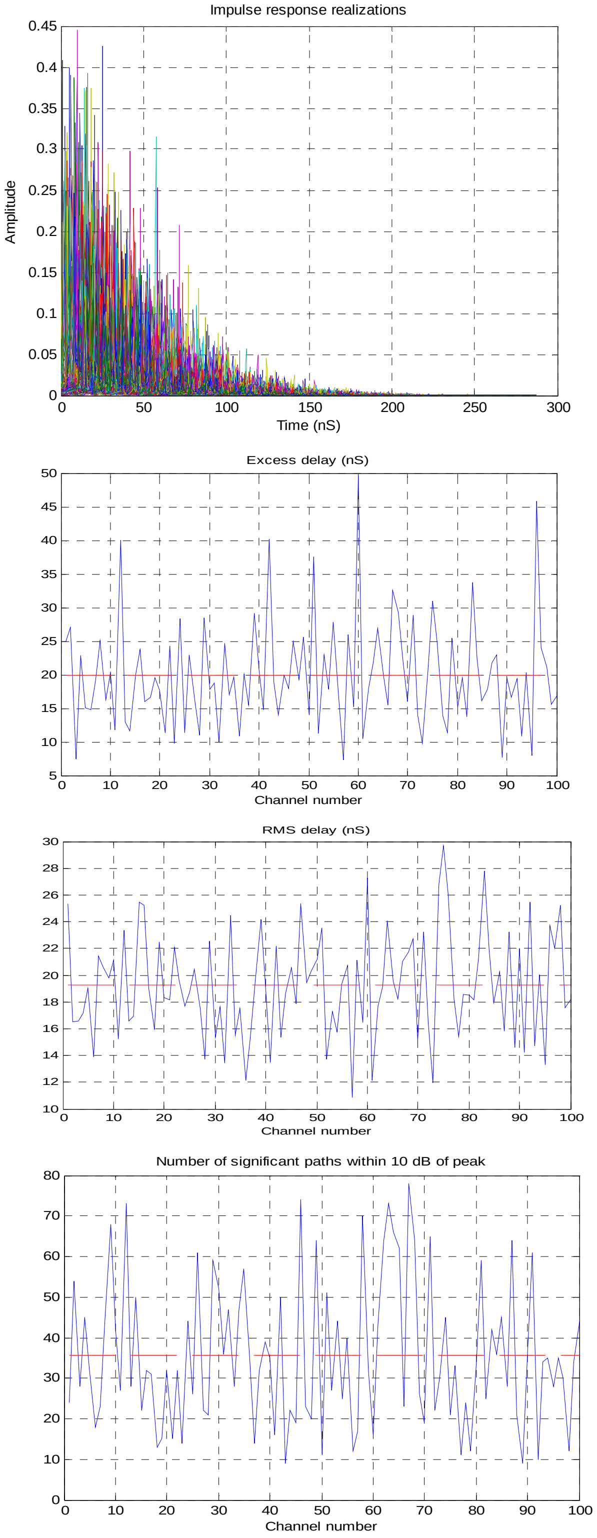
Fig 4.1: Simulation result for Residential (LOS) environments

Channel model parameters:

Mean delays: excess (tau_m) = 16.0 ns, RMS (tau_rms) = 17 ns,

No of paths: NP_10dB = 15.3, NP_85% = 54.6.

ons for Residential Non-line-of-sight (NLOS) environments (CM2)



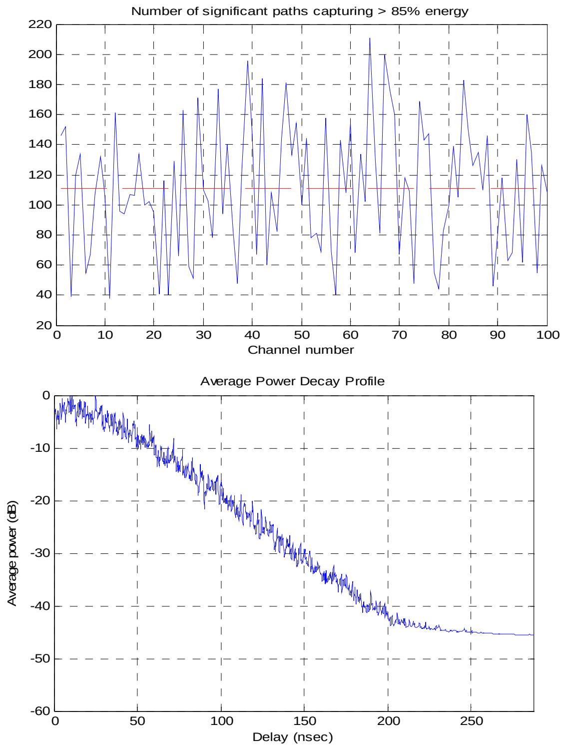
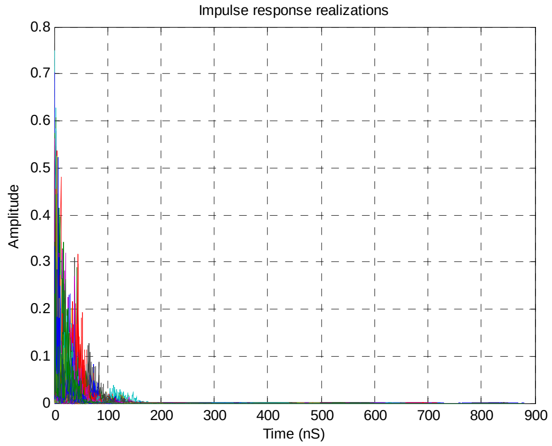
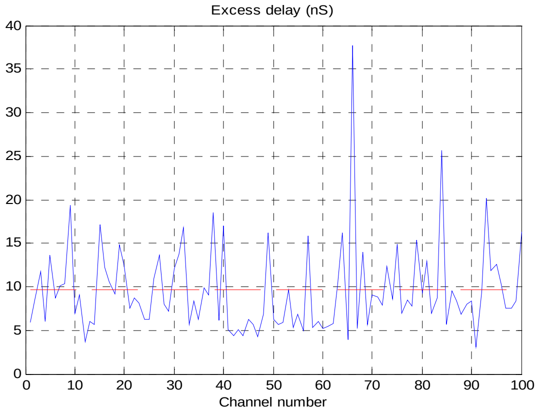
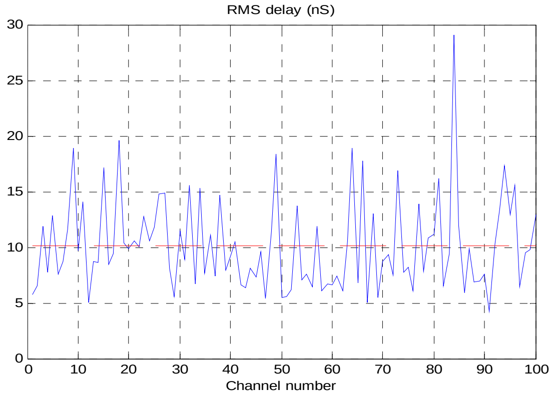


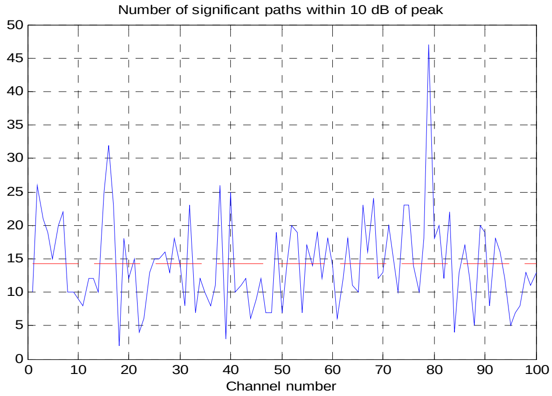
Fig 4.2: Simulation result for Residential (NLOS) environments
Channel model parameters:
Mean delays: excess (tau_m) = 19.9 ns, RMS (tau_rms) = 19 ns,
No of paths: NP_10dB = 35.6, NP_85% = 110.7.

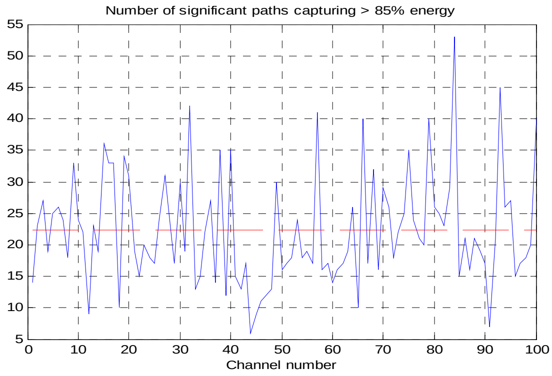
4.3 Simulations for indoor Line-of-sight (LOS) environments (CM3)











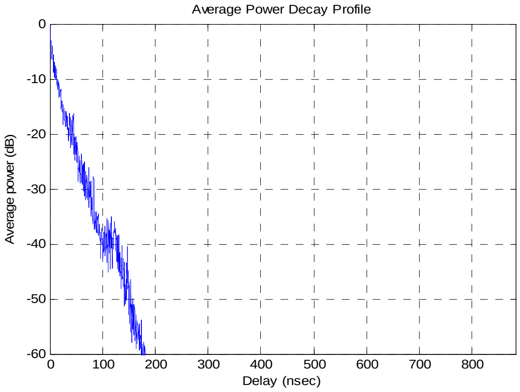
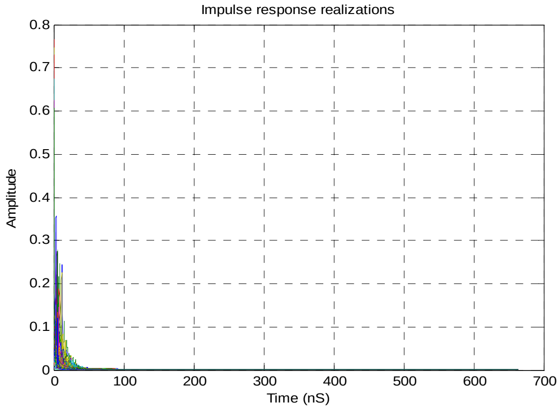
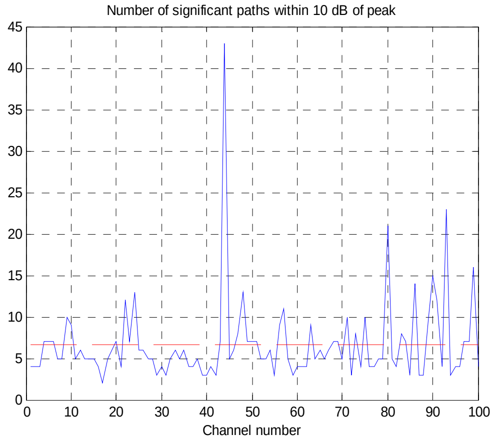


Fig 4.3: Simulation result for Indoor (LOS) environments
Channel model parameters:
Mean delays: excess (tau_m) = 9.6 ns, RMS (tau_rms) = 10 ns,
No of paths: NP_10dB = 14.3, NP_85% = 22.3.

4.4. Simulations for industrial line-of-sight (los) environments (cm7)





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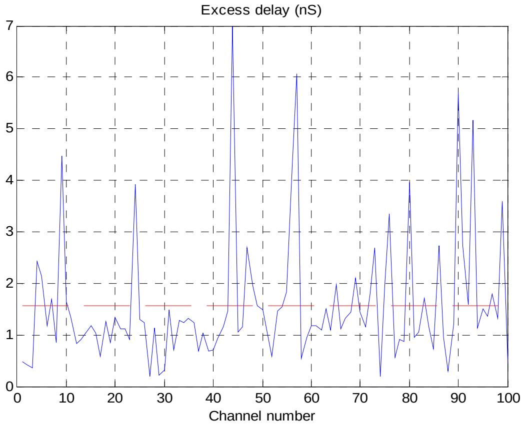

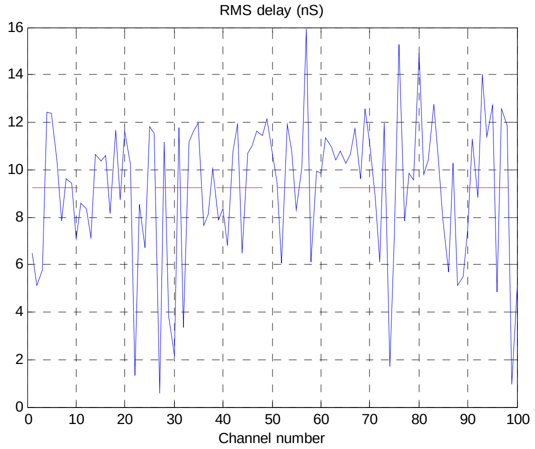

Fig 4.4: Simulation result for Industrial (LOS) environments
Channel model parameters:
Mean delays: excess (tau_m) = 1.6 ns, RMS (tau_rms) = 9 ns,
No of paths: NP_10dB = 6.7, NP_85% = 8.7

5. Modulation techniques for IEEE 802.15.4a

5.1. Differential binary phase shift keying (DBPSK) Modulation

In Differential BPSK (DBPSK), the bits are modulated using the following formula

$$E_n = R_n \otimes E_{n-1}$$

E_n is the n_{th} DBPSK encode bit, R_n is the n_{th} data bit, initially E_0 taken as '0'.

5.2. Offset qudrature phase-shift keying (OQPSK)

The phase of the carrier wave can be changed in one of four ways to represent the symbols 00, 01, 10, and 11. The advantage of QPSK is that two bits can be represented per symbol unlike BPSK, which can only represent one bit per symbol. However, QPSK is more susceptible to noise than BPSK. Compared to a BPSK system, noise can cause a particular phase value to appear as the other phase values with a higher probability as the phase shift values are closer to each other in an OQPSK system. QPSK works because the sine wave and the cosine wave are orthogonal with respect to each other.

5.3. Simulation results

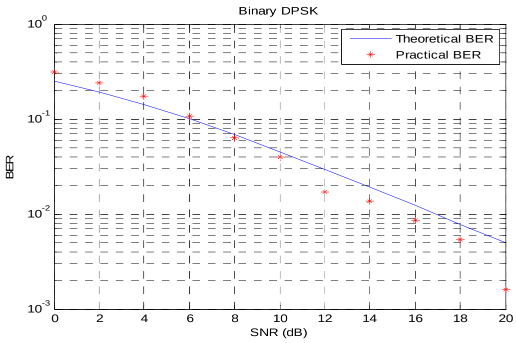

Fig 5.1(a): comparison of BERs of DBPSK and OQPSK systems

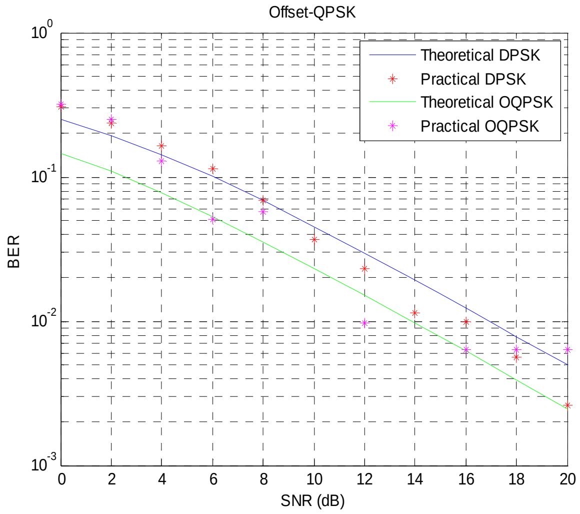

Fig 5.1(b): comparison of BERs of DBPSK and OQPSK systems

5.5. Comparisons of dpsk and oqpsk in terms of bit error rates (bers)

SNR (dB)	DPSK Bit error rate	OQPSK Bit error rate
0	$10^{-0.7}$	$10^{-0.7}$
2	$10^{-0.76}$	$10^{-0.75}$
4	$10^{-0.93}$	$10^{-0.95}$
6	$10^{-0.98}$	$10^{-1.6}$
8	$10^{-1.3}$	$10^{-1.5}$

Table 4.b: Comparison of DBPSK and OQPSK systems

5.6 Comparisons of channel model parameters

	Residential		Indoor		Outdoor		Industrial		Open outdoor
	LOS	NLOS	LOS	NLOS	LOS	NLOS	LOS	NLOS	NLOS
tau_m (ns)	16	19.9	9.6	18.4	26.8	72.8	1.61	23.9	17.2
tau_rms (ns)	17	19	10	13	30	74	9	20	22
NP_10dB	15.3	35.6	14.3	30.4	17.9	24.7	6.7	128.5	5.4
NP_85%	54.6	110.7	22.3	45.4	35.9	65	8.7	186.6	6.5

Table 4.a: Comparison of channel model parameters

6. Conclusion and future work

The channel model IEEE802.15.4a is based on a large number of measurement and simulation campaigns and includes the most important propagation effects in UWB channels, including the frequency selectivity of the path loss, stochastic interarrival times of the MPCs. in some NLOS situations. The model allows to test a wide variety of UWB transceivers in a unified and reproducible way. We have also discussed the limits of applicability and possibilities for future improvement and generalization .For residential environment the maximum excess delay (excess delay for which power level fallows below the threshold, 10dB) is more in NLOS environment (19.9 ns) than LOS environments (16 ns), the number multipath components required to capture the 85% of total transmitted power is more in NLOS environment (110.7 components) than LOS environments (54.6 components), the rms delay (difference between times of arrival of first multipath component to last multipath component) is more in NLOS environment (19 ns) than LOS environment (17 ns). Similarly for any channel environments of the IEEE 802.15.4a, maximum excess delay is more in NLOS than LOS environment, the rms delay is also more in NLOS than LOS environment, the number of multipath components required to capture the 85% of total energy is more in NLOS than LOS environments, for such a sparse impulse response, a relatively small number of Rake fingers can collect most of the received energy.

The channel impulse response is a sum of delayed, attenuated, and distorted MPCs and impulse response can become sparse (not every resolvable delay bin contains significant MPCs).Compare the bit error rate performances through the application of impulse radio signal, of DBPSK and OQPSK systems with rake receiver at the IEEE 802.15.4a channel environment. From simulation result DBPSK shows better performance than that of OQPSK system for medium and larger SNRs.

Nomenclature

IR-UWB : Impulse Radio Ultra Wideband
FCC : Federal Communications Commission
NLOS : Non Line-of-Sight
DBPSK : Differential Binary Phase Shift Keying
OQPSK : Offset Qudrature Phase Shift Keying
P L0 : Path loss at 1m distance
N : Path loss exponent
Σs : Shadowing standard deviation
A ant : Antenna loss

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