CHAPTER 4

SYSTEM SETTINGS AND IMPLEMENTATIONS

4.1 Introduction

The simulation models of both the IEEE802.15.3a and IEEE802.15.4a standards, the parameters and the channel models are all discussed in this chapter. The link budget analysis explains the parameters that are measured on the receiver side and how BER is calculated.

OMNET is used to determine the application setup in a real-time environment. The parameter sets used in OMNET-MIXIM for IEEE802.15.4a and MATLAB Simulink for IEEE802.15.3a are also compared. The simulation is used as a flexible platform for designing and developing numerous wireless solutions instead of a single solution. A wireless sensor network comprises various simulators, including NS2, OMNET++ and OPNET. In the comparison of these simulators, OMNET++ emerges as the best given its achievement of the capabilities of UWB technologies over WSN. Therefore, MIXIM-UWB is simulated under OMNET++ only after confirming the UWB parameters. The UWB is evaluated by considering certain characteristics, such as bandwidth, frequency channel, data rate, mean pulse repetition frequency and centre frequency. The BER and throughput are analysed in evaluating the performance of the channel.

4.2 Simulation Environment

The proposed TH-PPM UWB system that has been described mathematically in the previous chapter is translated into a simulated system at different levels, including point-to-point static simulation in MATLAB, point-to-point real-time simulated scenarios in Simulink and real-time multi-nodes in MAXIM. The simulation translates the whole table of the link budget, including all associated settings of transmission, signal propagations in different AWGNs, multipath fading channel models of IEEE 802.15.3a and IEEE 802.15.4a and the receiver structure. All these settings are required to meet the application requirements for BER and data rate in various distance scenarios.

4.3 MATLAB Simulation

Table 4.1 presents the UWB template link design parameters of the communication system with AWGN and IEEE802.15.3a that is to be implemented in MATLAB point-to-point and Simulink real-time simulated scenarios.

4.3.1 Link Budget of the Proposed Communication System

The performance analysis evaluates the IR-UWB wireless link in terms of its BER in various distance and data rate scenarios by using data transmissions, channel models and propagation environments as the dependent parameters. The trade-off flexibility amongst these variables can be translated as a template design for all the variable parameters with the sample of their possible values that can be tuned in for certain performance requirements. The proposed tunable IR-UWB is verified by conducting a BER simulation at the design level across various distance and data rate scenarios. BER is predicted during the simulation (the collected simulation data are shown in Appendix A) and verified on the basis of the theoretical results. Table 4.1 shows the link parameters and their fixed and possible setting values for the simulation.

Table 4.1: IR-UWB Template Link Budget Design Parameters of The Communication System

Simulation	Link Parameter	Possible Values
PHY Parameters	POW: Average transmitted power (dBm)	–30, –35 and –40 db
	Spreading spectrum technique	TH (TM)
	FC: Sampling frequency	50e-9
	Numbits: Number of bits generated by the source	1000, 3000, 6000 and 9000
	TS: Frame time (i.e. average pulse repetition)	1e-9, 3e-9, 4e-9 and 8e-9
	NS: Number of pulses per bit	1000, 3000, 6000 and 9000
	Data rates	333, 500, 666 and 833 Mbps
	TC: Chip time (s)	1e-9, 5e-9, 10e-9 and 30e-9
	NH: Cardinality of the TH code	3
	NP: Periodicity of the TH code	5
	TM: Pulse duration (s)	0.65e-9, 0.9e-9, 0.2e-9, 0.5e-9 and 0.8e-9
	TAU: Shaping factor of the pulse (s)	0.2e-9, 0.5e-9, 0.65e-9 and 0.8e-9
	M: Modulation techniques	PPM and PAM
Channel Models	Two-channel models	AWGN and IEEE 802.15.3a multipath fading channel model
Receiver Structure	Rake	Different fingers (L) contributing to the multipath fading environment
Evaluation Criteria	BER	Not exceeding 1/100
Link Evaluation Criteria	Predicted E_b/N_o	8.2 dB for 9.6 Mbps, 14.2 dB for 2.4 Mbps and 20.2 dB for 600 Kbps (MATLAB and Simulink)
	Predicted BER	$1.2 * 10^{-3}$ for 9.6 Mbps, $<1.0 * 10^{-2}$ for 2.4 Mbps and $<1.0 * 10^{-2}$ for 600 Kbps

4.4 Tuneable IR-UWB Link Model and Settings in Simulink

The proposed design is implemented as a simulation model with complete settings of radio link parameters for signal shaping, modulation and timing structure to optimise the design according to the link requirements. These settings control the transmission rates at the PHY level. The system BER is evaluated via a real-time digital signal processing (DSP) simulation as shown in Figure 4.1. The S-Function-developed blocks (by MATLAB coding) in Simulink includes the M-ary data source block, pilot source block, PM template generator block and integrate and demodulator block. These blocks control the data transmission by tuning the signal shaping, coding and modulations by using the parameter values for the desired transmission rates for the modulated transmitted data and demodulated received data. The acquisition of the received signal is implemented by using the developed S-Function (MATLAB coded) for the pilot template generator and the UWB signal detection blocks to determine the threshold level that considers the lost signal in order to restart the reacquisition processes. The error rate block calculates the error as the received signal detected from the transmitted signal at a certain sampling rate.

The configuration of the pulse shapes and modulation options are shown in the Simulink block (MATLAB S-Function) settings shown in Figure 4.1. The parameter settings in the developed S-Function blocks determine the data transmission rates by choosing the modulation type of the pulses and the pulse shaping type. The S-function block also takes the input parameter values of the pulse modulation binary order, pulse width (Tau), the pulse generated power, pulse TH unit and time-shifting introduced by PPM modulation.Also, another pulse modulation techiques as Pulse Amplitude Modulation (PAM) is considered as pulse where the amplitude of the pule can be utilized to carry the 0 or 1 binary information. The transmitted data is evaluated in terms of BER after the simulated propagation in the IEEE 802.15.3a channel model.

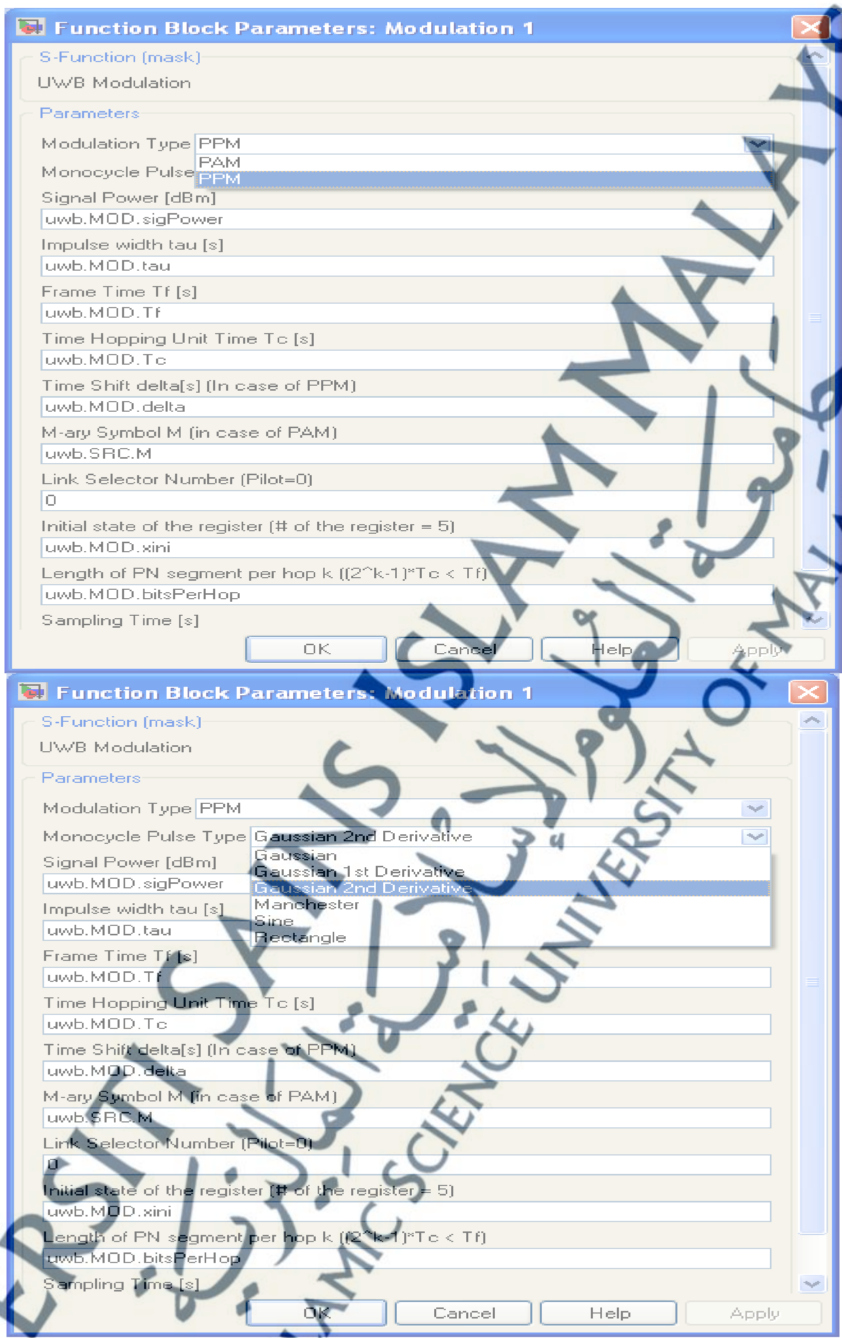
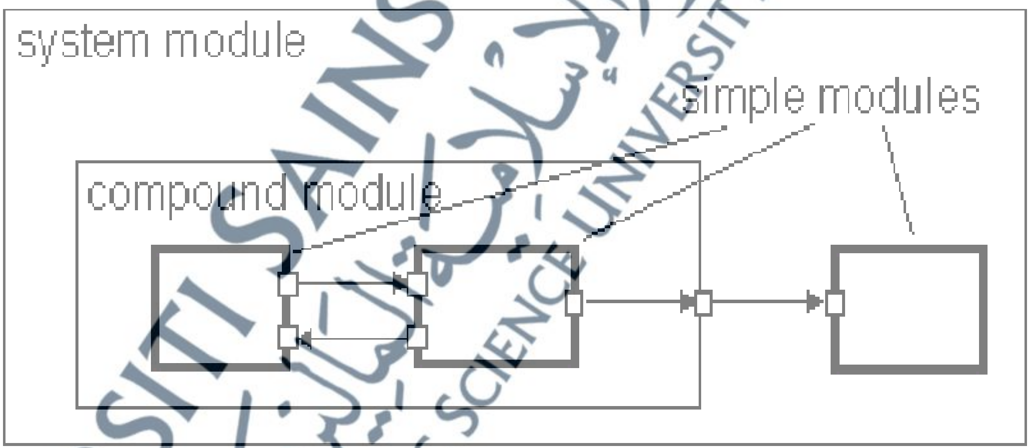


Figure 4.1: Simulink S-Function Block Settings For The Signal Parameters

The IR-TH PPM system is designed for specific data transmissions of predefined BER requirements. The propagating scenarios take place over four IEEE 802.15.3a channel models (with different simulated LOS and NLOS and distances ranging up to 10 m). The characteristics of the four simulated LOS or NLOS multipath-fading-affected scenarios for the IEEE.802.15.3a channel model are shown in Section 3.4.2.2.

4.5 OMNET++ Simulation for EEE 802.15.4A UWB PHY

The OMNET++ network simulator model has a general component architecture, which elements do not have a fixed representation, unlike other simulator network models. The model components of OMNET++ include network devices, protocols, wireless channels and modules. These modules are used to pass information either directly or through a predetermined connection. Based on the domain model the information (i.e., message) may be of commands, packets or other objects. Figure 4.2 shows the OMNET++ model structure and its hierarchically nested modules Varga & Hornig (2008).



Source: Varga & Hornig (2008)

Figure 4.2: OMNET++ Model Structure

The simulation components are generated by using the C++ kernel and class library, and the components are organised by using the NED language. The integrated development environment (IDE) is used to design, execute and examine the simulations. OMNET++ also provides extension interfaces for real-time environments, parallel distributed environments and database connectivity. The event handling process, including sending and receiving messages and scheduling events, is performed by using the simulation library. The most important part of the simulation is the eclipse-based IDE simulation, which, similar to Java IDE, is used for many developer-oriented applications. The MIXIM and INET frameworks are applied to reuse the model. OMNET++ is an object-oriented modular discrete occasion renovation condition that is designed for simulating communication systems. However, OMNET++ is used in this study to mimic any discrete occasion framework. OMNeT++ gives a segment based engineering to models. An OMNET++ model comprises modules that are programmed in C++. By using an abnormal state dialect called network description (NED), these modules are progressively amassed into larger compound modules and models. OMNET++ also has a solid Graphical User Interface (GUI) bolster and an embeddable recreation portion. The modules communicate by sending each other messages that may contain complex data structures. They have their own parameters to customise their behaviour. Straightforward modules that are actualised in C++ and embody the conduct are located at the lowest level of the module chain of importance Dhobale et al. (2014). OMNET++ is a segment-based, secluded and open-design reproduction condition with a solid GUI bolster and an embeddable re-enactment piece. The test system is used for display, correspondence conventions, PC systems, movement demonstrations, multi-processors and circulated frameworks. The features considered whilst choosing the OMNET++ to be used for this project are discussed in the following sections.

4.5.1 The Language Of Network Description (NED)

To describe the component model, OMNET++ has its own domain-specific language called NED. Extensible Markup Language (XML) is considered too verbose and is usually inappropriate for human consumption.

Simple module declarations, compound module definitions and network definitions are typical components of NED. Simple module statements define the module interface, gates and parameters. Defining the compound module involves declaring the external interface of the module (gates and parameters) and defining and interconnecting the submodules. Network definitions are composite modules that can be considered self-contained models of simulation. Limited programming constructs (loop, conditional) enable the use of parametric topologies, such as routers with an unbound amount of ports or a parametric hexagonal mesh. A sample code (mostly self-explanatory) that defines a compound module is presented below.

```
/
// This file is part of an OMNeT++/OMNEST simulation example.
//
// Copyright (C) 2003-2008 Andras Varga
//
// This file is distributed WITHOUT ANY WARRANTY. See the file
// `license' for details on this and other legal matters.
//
simple Tic9
{
38
parameters:
@display("i=block/routing");
gates:
```

```
input in;
output out;
}
simple Toc9
{
parameters:
@display("i=block/process");
gates:
input in;
output out;
}
//
// Same as Tictoc8.
//
network Tictoc9
{
submodules:
tic: Tic9 {
parameters:
@display("i=,cyan");
}
toc: Toc9 {
parameters:
@display("i=,gold");
}
connections:
tic.out --> { delay = 100ms; } --> toc.in;
tic.in <-- { delay = 100ms; } <-- toc.out;
}
```

Simulation modules are often installed as system module offspring, but the simulation library also supports dynamic instantiation. Simple and compound modules can be created during runtime. Compound modules are automatically constructed up to their internal structures (e.g. submodules and connections), especially in cases where dynamic instantiation can be helpful, such as when loading the network topology at runtime and when the network is dynamically evolving (e.g. mobile devices that arrive or leave the playground or network connections that are being cut or added).

4.5.2 MIXIM-UWB Simulation Model

Both OMNET++ and the MIXIM framework are very easy to install, can operate on Windows and Linux and have proper documentation backed up by an online community. They produce the same results when the same set of random generator seeds adopted in the original experiment runs are used. The MIXIM framework models the physical layer up to the signal level to obtain the most accurate results.

The MIXIM-UWB framework for OMNET++ is used for the simulation. Various frameworks used for wireless and mobile simulation with OMNET++ are combined to form the MIXIM framework, which provides a protocol library and infrastructure that allows an accurate modelling of the environment, mobility, connectivity, reception, obstacles and collision JV et al. (2014).

MIXIM offers a node structure and a means of communication. Figure 4.3 presents a basic simulation of MIXIM. This framework comprises several nodes, a connection manager, a world utility module and a playground where the area nodes can be placed. The world utility module stores worldwide simulation data, such as playground size. The connection manager should set up communication between nodes.

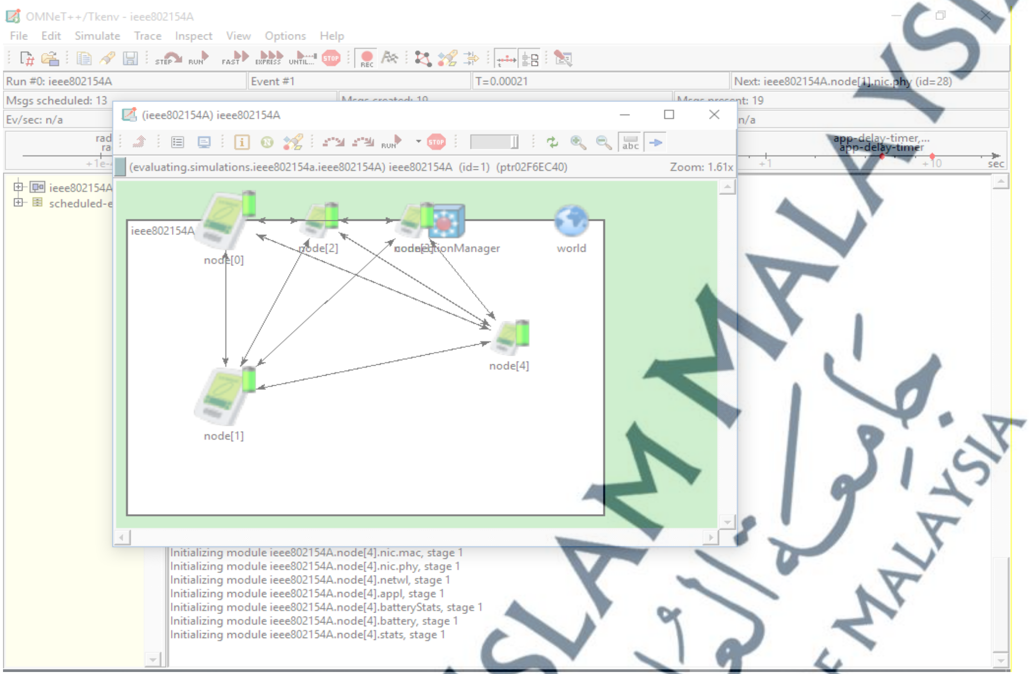


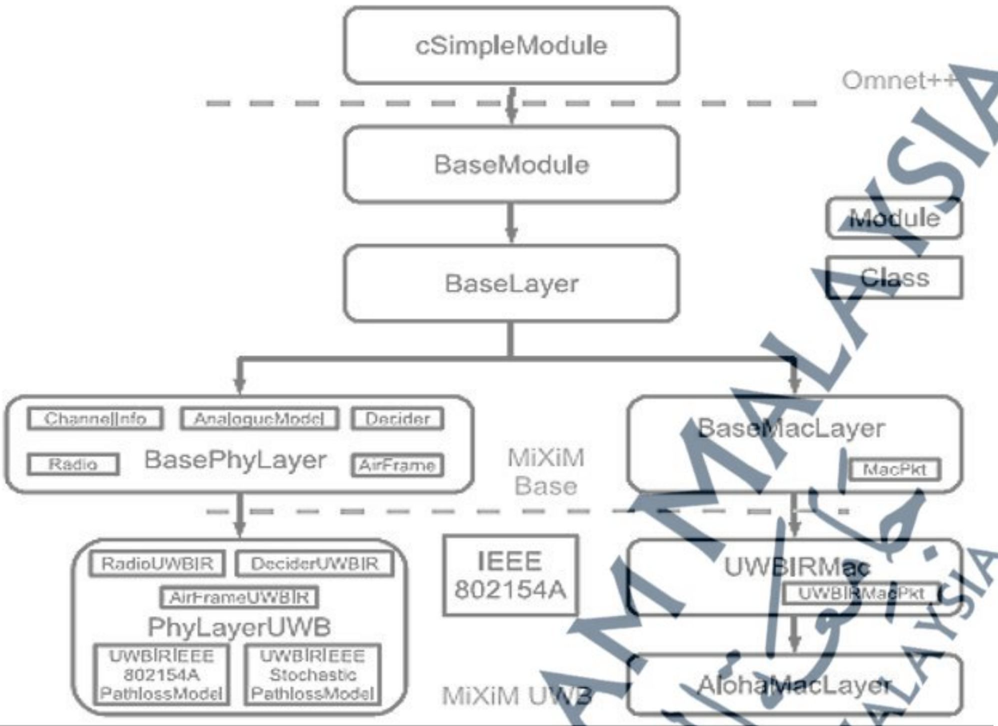
Figure 4.3: Simulation Of Basic MIXIM

Figure 4.4 displays the node structure of MIXIM. Each node comprises modules that represent networking layers and other node-like mobility functionalities. Each node has an application module, networking layer and NIC, which comprises two modules, namely, the MAC layer and the physics layer.

(a) Basic node. (b) Basic NIC.

Figure 4.4: Basic MIXIM Node and NIC Modules

These modules mainly interact by passing messages to portray the network stack functionality. The base functionality is given in each module that handles the passing of messages. Other modules can use the blackboard to interact with one another, thereby preventing these modules from being tightly linked (i.e. calling module a within module b). A global blackboard can also be used to read or write global values. A module can read items that are of interest from the blackboard and write new information. Figure 4.5 shows the many base classes of MIXIM and how they are connected to one another. All these classes are ultimately inherited from the simple module of OMNET++. In most cases, a programmer can simply inherit from the base modules of MIXIM and add their specific functionalities.



Source: Rousselot & Decotignie (2009)

Figure 4.5: UML Inheritance Diagram Representing The Relationships Amongst OMNET++, MIXIM and MIXIM UWB classes

4.6 Configurable Channels of IEEE802.15.4A

The MIXIM-UWB framework only implements the mandatory channel of frequency band 1 (i.e. channel number 3 from the 15 channel's models that can be simulated in IEEE802.15.4A). The OMNETT++ simulation setup requires some parameters that are tabulated in Table 4.2. A new class called IEEE802154A_Config is added to the model to allow the real-time selection of a different channel number and/or bit rate. Table 4.2 shows the channel parameters to be configured for each node in the wireless network.

Table 4.2: Configurable channel parameters and permissible values

Parameter Name	Description	Permissible Values
channelNum	Channel number (Optional – Default = 1)	0 to 15
complexChannelNum	Complex channel number that denotes the index to	1 = First preamble code specified for the channel 2 = Second preamble code

	the length 31 preamble code to use.	specified for the channel
meanPRF	Mean pulse repetition frequency (PRF)	1 = 3.90 MHz 2 = 15.60 MHz 3 = 62.40 MHz
dataRate	Data rate	0 = (non-UWB PHY) 1 = 110 kbps 2 = 850 kbps 3 = 1.70 Mbps (for PRF of 3.90 MHz) else = 6.81 Mbps 4 = 6.81 Mbps (for PRF of 3.90 MHz) else = 29.24 Mbps
nbPreambleSyncSymbols	The number of repetitions of the preamble symbol used in SHR.	8 or 64

The physical layer of each node maintains a pointer to the IEEE802154A_Config instance configured for that node. The arguments supplied to the channel change function are the same parameters listed in Table 4.2. Therefore, a new channel and/or a new bit rate is configured through this call.

4.7 Summary of Parameter Setting

4.7.1 Frequency Band and Channel Parameters

The MIXIM-UWB framework only implements the mandatory channel of the frequency band. In this research, the factors that affect the performance of UWB are analysed. These factors include the effect of the channel model, data rate, bandwidth and different PRFs.

To achieve the above objectives, the suitable frequency band and channel parameters for each factor must be determined. The parameters that are considered under the frequency band and channels include the centre frequency, bandwidth size, mean PRF and data rate. The frequency band and channel parameters are summarised in Tables 4.3 to 4.5.

Acquiring, synchronising and performing channel estimation are necessary before the receiver performs data detection. The parameters evaluated under this category, all of which are essential for simulation, include the symbol duration (Tdsym), burst duration (Tburst), number of chips per burst (Ncpb), preamble symbol duration (Tpsym), SHR preamble duration (Tpre), length of the ternary code and SFD length. These parameters are explained in detail in the IEEE 802.15.4a UWB PHY standard.

4.7.2 Simulated Environmental Setting

The settings of the OMNET++ nodes for the signal transmission in simulated scenarios under analysis in this thesis are chosen as the following table 4.3 showed.

Table 4.3: Signal Transmission Sittings of the Simulated TH-PPM Nodes of the Network in OMNET++

Centre Frequency (MHz)	**4492.8**
Bandwidth (MHz)	499.2
Total Packets Sent	150
PHY Payload (bytes)	8
Transmitted Bits	36000
Data Rate (Mbps)	0.11
Mean PRF (MHz)	15.60
Pulse Duration (ns)	2
Symbol Duration (ns)	8205.13
Burst Duration (ns)	256.41
Number of Chips per Burst	128
Preamble Symbol Duration (ns)	993.6
Duration of SHR Preamble	71.5
Length of the Ternary Code	31
SFD Length (symbols)	64

4.7.3 Parameter Setting of Data Rate Effects

Table 4.4: Different Data Rate Settings Of The Generated TH-UWB Signal

Data Rate (Mbps)	**0.11**	**0.85**	**6.81**
Bandwidth (MHz)	499.2	499.2	499.2
Mean PRF (MHz)	15.60	15.60	15.60
Symbol Duration (ns)	8205.13	1025.64	128.21
Burst Duration (ns)	256.41	32.05	4.01
Number of Chips per Burst	128	16	2
SFD Length (symbols)	64	8	8

4.7.4 Parameter Settings of Bandwidth Effects

The parameters settings for different bandwidths are shown in Table 4.5.

Table 4.5: Parameter settings for different bandwidths

Channel Number	**3**	**7**	**11**	**15**
Centre Frequency (MHz)	4492.8	6489.6	7987.2	9484.8
Bandwidth (MHz)	499.2	1081.6	1331.2	1354.97
Pulse Duration (ns)	2	0.92	0.75	0.74

4.7.5 Parameter Settings of PRF Effects

Table 4.6 shows different PRF settings and highlights the relationship amongst different PRFs for certain data rates, bandwidths, burst durations, numbers of chips per pulse, SFDs, mean PRFs and symbol durations.

Table 4.6: Different settings for PRF

Data Rate (Mbps)	**0.11**	**0.11**	**0.11**
Bandwidth (MHz)	499.2	499.2	499.2
Mean PRF (MHz)	3.90	15.60	62.40
Symbol Duration (ns)	32820.51	8205.12	2051.28

Burst Duration (ns)	256.41	256.41	256.41
Number of Chips per Burst	128	128	128
SFD Length (symbols)	64	64	64

4.8 Summary

In this chapter, the radio link of the proposed IR-UWB architecture from the signal transmission to signal propagation is investigated along with the activities at the receiver. The parameter settings for signal transmission that tune the data transmission rates for predetermined BER requirements across various distance scenarios can be designed in the PHY–MAC aware architecture for the proposed dynamic tunable IR-UWB solution. The template design of the radio link is used to verify the proposed model at the BB simulation level in MATLAB and Simulink. This chapter describes the simulation and channel models used for IEEE802.15.4a and the IEEE802.15.3a. The simulation set up uses MATLAB and Simulink for IEEE802.15.3a and OMNET and MIXIM for IEEE802.15.4a. The link budget model is used to define the losses and gains at the transceiver side. The transmitted and received data parameters and their corresponding settings are analysed in the following chapter.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Introduction

The performance of the proposed tunable impulse-based UWB system is evaluated by using BER criteria for different pulse shapes, coding and timing structures. The physical parameters of the pulses are tuned to achieve different transmission rate requirements in various distance scenarios. The channel conditions of AWGN, IEEE802.15.4a and IEEE 802.15.3a multipath fading channel models are considered in the simulation and the real-time simulation in indoor/outdoor environments. System performance can be simplified as predetermined BER versus different data rate requirements in various distance scenarios.

Impulse-based UWB technology is highly tunable at the PHY level. Pulses with different transmission rates can be generated depending on the Pulse Repetition Interval (PRI), pulse modulation (M) and a number of generated bits (N). Therefore, the relationship between system design and evaluation can be defined as BER versus PRI, M, N and D in different channel conditions.

The purpose of the real-time simulation setup and implementation is to statistically analyse and evaluate the captured packets in terms of their BER and data rates across various distances in indoor/outdoor channels. The channel model discussion is entirely based on MATLAB, Simulink and OMNET-MIXIM, which have been fully described in Chapter 4.

5.2 Simulation Signal Design and Generation

5.2.1 Signal Parameter Settings and Generation of IR-UWB

An IR-UWB signal can be designed according to certain pulses, shapes and modulations. This tunable capability of an IR-UWB signal is crucial for implementing a Pulse Generator (PG) to satisfy different transmission rate requirements, for improving system performance in severe wireless environments with high interference and multipath fading effects and for enhancing object detection in the tracking system. All these improvements can be achieved by tuning the shape of the IR-UWB signal for the best tracking resolutions. The parameters of the IR-UWB reference signal are listed in Table 5.1 and compared with those of other signals for the performance evaluation.

Table 5.1: TH-PPM Signal Parameters

Tunable IR-UWB Transmission Parameter	Description
Average transmitted power (Pow) in dBm	–30
Sampling frequency (Fc)	$50*10^{9}$
Number of bits generated by the source	1000
Average pulse repetition (Ts)	$3*10^{-9}$
Number of pulses per bit (Ns)	1
Chip time (Tc)	$1*10^{-9}$
The cardinality of the TH code (Nh)	3
Period of the TH code (Np)	2
Pulse duration (Tm)	$0.5*10^{-9}$
Shaping factor for the pulse (Tau)	$0.25*10^{-9}$
Modulation techniques	Binary-PPM
Channel models	AWGN

The parameter values listed in Table 5.1 for the signal data structure that controls the signal shapes and transmission rates are included as inputs in the Simulink model. Figure 5.1 shows the frame timing structure and the pulse M-PPM modulation tuneable values for the parameters, including frame length in time, sampling frequency in time, hopping unit in terms of time value and pulse shaping factor. These parameters are tuned to increase the data rate transmission by tuning the M-PPM modulation from 4 PPM to 8 PPM.

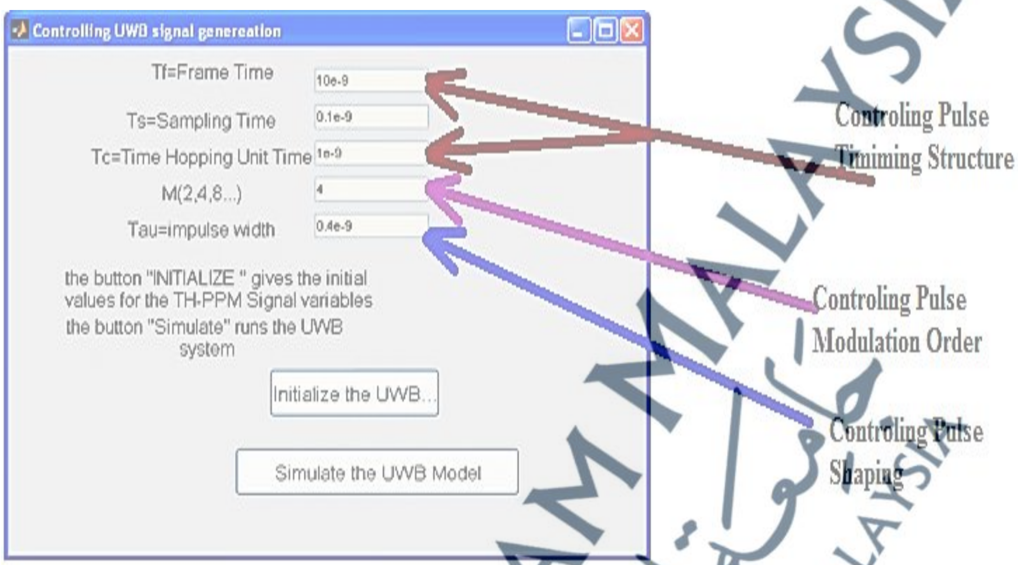


Figure 5.1: Modelling Of The Database Interface For Controlling The IR-UWB PHY Parameters

Real-Time Simulation of the generated signal with different parameter settings for signal modulation is shown in Figures 5.2 and 5.3.

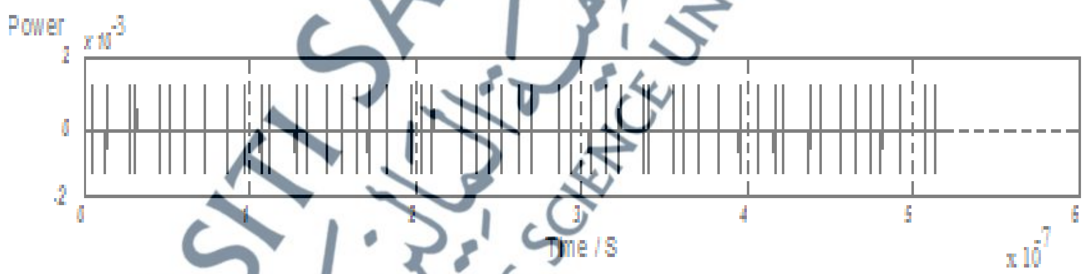


Figure 5.2: Simulink Simulation Of The Transmitted IR-UWB Signal In Real-Time DSP According To The Parameter Settings Shown In Figure 5.1