CHAPTER 1

INTRODUCTION

1.1 Overview and Research Motivations

The communication technologies have come more sophisticated and rather complex, which requires considerable rising of several networks in the domain of what's so-called wireless sensor network (WSN) topologies. Numerous interferences may increase the intensity in future wireless environments because of the high density of wireless communications. Signal collisions may also occur due to the multipath fading amongst WSNs. Numerous interferences may result in an equal collision. As WSNs gradually penetrate different fields, many WSN applications have also been developed Yetgin et al. (2017). These applications require different data rates, coverage ranges and quality of service (QoS) and may include indoor wireless communications that are known for their short to medium distances and low to moderate data rates. WSNs have attracted usage in a wide range of disciplines and in the physical world. In our regular schedule, the WSN has established a significant element during wireless communications dependent on disseminated sensing abilities. The essential component of WSNs that must be taken into account is the channel through which the data must be transmitted.

The demand for high-quality data transfer and the bandwidth requirements have both increased along with the continuous emergence of modern communication technologies. This trend is most obvious in some new applications, such as remote sensing, radar communication and industrial wireless sensing monitoring networks H Taki et al. (2017). To satisfy these requirements, ultra-wideband (UWB) can be used to transmit signals over a short coverage area with high bandwidth and low radiated power.

UWB transmission has recently received much attention from academic and industrial practitioners due to its potential use in wireless communication applications Van den Brande et al. (2018). Specifically, UWB has many benefits, including its high data rate (HDR), low-cost transceivers, low transmit power and low interference, Vauche et al. (2016). UWB also operates with emission levels that are commensurate with those of common digital devices, such as laptops, palm pilots and pocket calculators. In 2002, the US Federal Communications Commission (FCC) approved the use of UWB and set an unlicensed frequency band of 3.1 GHz to 10.6 GHz (7.5 GHz) for indoor UWB wireless communication systems. Industry standards, such as IEEE 802.15.3a (HDR) and IEEE 802.15.4a (very low data rate or LDR), have also been introduced on the basis of UWB Mahbub et al. (2017).

The main advantage of UWB lies in its transmission of ultra-short pulses in a very wide bandwidth, which can enhance the performance of systems that require high resolution in the real-time detection and tracking of movable objects, H Taki et al. (2017). The quality of the received signal in impulse UWB can be maintained either as high-data-rate transmission over short-distance ranges (few metres) or as low-to-medium data-rate transmission over medium-coverage ranges (up to a few hundreds of metres). IEEE802.15.4a is an industry-standard that describes impulse-based UWB technology for low-to-medium data transmission over medium-coverage ranges. This technology has lower complexity and power consumption compared with discreet communication technologies, which emit trains of short pulses over bandwidths with frequencies of above 500 MHz. Compared with other communication systems, IEEE

802.15.4a has advantages in accuracy and performance, especially in indoor-tracking applications, given its high detection resolution.

High transmission rate, reliability, energy efficiency and long lifetime are some of the predictors of major problems in a wireless network given that these factors are not independent of one another. Moreover, it is very difficult to bring those improvements into a single aspect. In this study, a cross-layer design is applied to optimise system reliability and energy efficiency for delay and jitter, X. Chen et al. (2017). According to Saadon et al. (2013), IEEE802.15.4a UWB is used for long-range communications in wireless sensor applications.

1.2 Problem Statement

The problem of this research is formulated from the characteristics of UWB.

UWB wireless communication can be used for different data rate requirement and application scenarios, including tracking applications that require LDRs (Kbps) and wireless medical sensor networks that transmit medical images at HDRs (Mbps) Zhou & Chiang (2016). UWB is highly preferred due to its flexible wireless communication design, reliability and low complexity. Given these merits, UWB can satisfy different data rate requirements across various distance scenarios. This feature raises the question of how to combine different UWB pulse solutions that are utilised for different wireless short ranges into a single solution. Impulse-based UWB can be used to fulfil such objective with its high and low data rates, which can be achieved by tuning the discrete pulses generated by different modulation techniques H. Liu et al. (2016). Impulse-based UWB is a highly adaptive technology in both wireless communication and radar applications given its flexibility in generating pulses by using different coding, modulation and shaping techniques, thereby allowing for an excellent tuning of data rates and improving the quality of the received signal across various distance scenarios J. Chen et al. (2017). However, which UWB pulse architecture can be tuned to serve short/medium wireless ranges? One of the most interesting aspects of impulse-based UWB is that this technology has low complexity in terms of the hardware used for generating the pulses.

Moreover, impulse-based UWB is highly resilient to interferences as the generated pulses are very small over a huge bandwidth. Mahbub et al. (2017). In future wireless scenarios, wireless nodes are expected to be used in dense methods to depict it to the spectrum overlapping and interferences, in high multipath fading. Given that short-range wireless applications are increasingly being deployed for different services, each node should communicate in a secure manner with high interference and multipath fading and should respond vigorously towards its environment. Moreover, the changes in QoS result from the energetic tuning of IR-UWB signal parameters in real-time at the PHY-MAC level. Given these considerations, the performance of an optimised UWB single solution that supports different application requirements must be examined across various channels and interference scenarios. The performance of this solution also needs to be validated at different levels of verifications, including the point-to-point network, multi-point network and real-time running simulated levels. All these aspects highlight the importance of dynamically tuning UWB physical link parameters to achieve performance improvements.

Based on the statement of the problem in this research can be defined as:

In sum, this study aims to address the need for an adapted PHY-MAC architecture design of impulse-based UWB systems that can achieve data rate requirements and an acceptable level of received signal quality across different distance scenarios. Previous studies have merely focused on two time-hopping pulsemodulated techniques in two IEEE protocols of UWB, namely, IEEE 802.15.3a and IEEE 802.15.4a. Different UWB time-hopping technologies can be combined into a single solution that supports the qualities of the received signal and the data rate requirements across various distance scenarios and channel models.

1.3 Research Objectives (RO)

This research aims to assess different UWB pulse technologies in terms of their flexibility, complexity and reliability. The objectives of this research are enumerated as follows:

RO1. To investigate a cross-layer architecture design that provides the best data transmission rates for UWB systems.

RO2. To examine the physical-based parameters of the generated UWB pulses to reach an acceptable quality of the received signal in terms of bit error rate (BER), data rates and network throughput.

RO3. To implement link budget models with physical parameters of the generated signal and channels models as simulated static and real-time simulations scenarios.

RO4. To evaluate the performance of the received signal in term of BER Vs SNR under different conditions of distance, data rates and pre-defined quality of services. Also, in different channel models propagation scenarios (LOS and NLOS channels models).

1.4 Research Questions (RQ)

The following research questions are raised to address the aforementioned research problem:

RQ1. How to utilise cross-layer architecture of impulse-based UWB technology to serve different applications of short-range communications?

RQ2. Which UWB pulses architecture can be adapted as a solution in different impulse-based UWB communication scenarios?

RQ3. How the different simulations verifications of the communication link budget template under-study can be proof-of-concept of the proposed tunable impulse-based UWB solution?

RQ4. What are the physical-based parameters that can effectively guarantee an acceptable quality of the generated signal in terms of bit error rate (BER), data rates and network throughput under different channels models?

1.5 Significance of the Study

The study contributes authentic practical information on impulse-based UWB in two ways.

Firstly, this research proposes a new design that sets the impulse-based UWB parameters according to the proposed mathematical model of the UWB communication system and then transforms this model into a communication link for the entire system with a special focus on those settings that can improve the quality of the received signal.

Secondly, by tuning the impact of the UWB communication system at the PHY level according to its cost function, the proposed cross-layer architectural design can be considered a significant advancement towards achieving a dynamic and optimal impulse-based UWB communication. This design can also be combined with different transmission rates into a single solution.

1.6 Research Contributions

This research contributes to the impulse-based UWB design literature in the following aspects:

- The generated UWB pulses are clearly defined on the basis of different physical parameter settings at the physical layer, thereby allowing direct control over the generation of UWB pulses for satisfying certain short-range wireless application requirements.
- The cross-layer design architecture of the PHY–MAC interaction is defined in such a way that allows the MAC layer to define the PHY layer parameters according to some criteria to achieve the desired BER and throughput.
- The template communication link defines all parameters in the physical and MAC layers and the settings of the channel model to simulate different scenarios. The pre-defined performance setting requirements are also determined. With the settings of fixed and varying parameters, the capabilities of designing impulse-based UWB can be tuned to serve different applications and requirements in wireless scenarios.

1.7 Overall Methodology Of The Proposed Time-Hopped Pulse Position UWB Solution

The overall methodology has been followed for the proposed solution, can be divided to main three modules of implementation in MATLAB, SIMULINK and OMNET++ simulator, than can be verified for the proposed architecture of cross-layer design of the tunable TH-PPM system.

Figure 1.1 summarises the research flow, starting from the definition of the research problem up to the presentation of the conclusions and recommendations for future work.

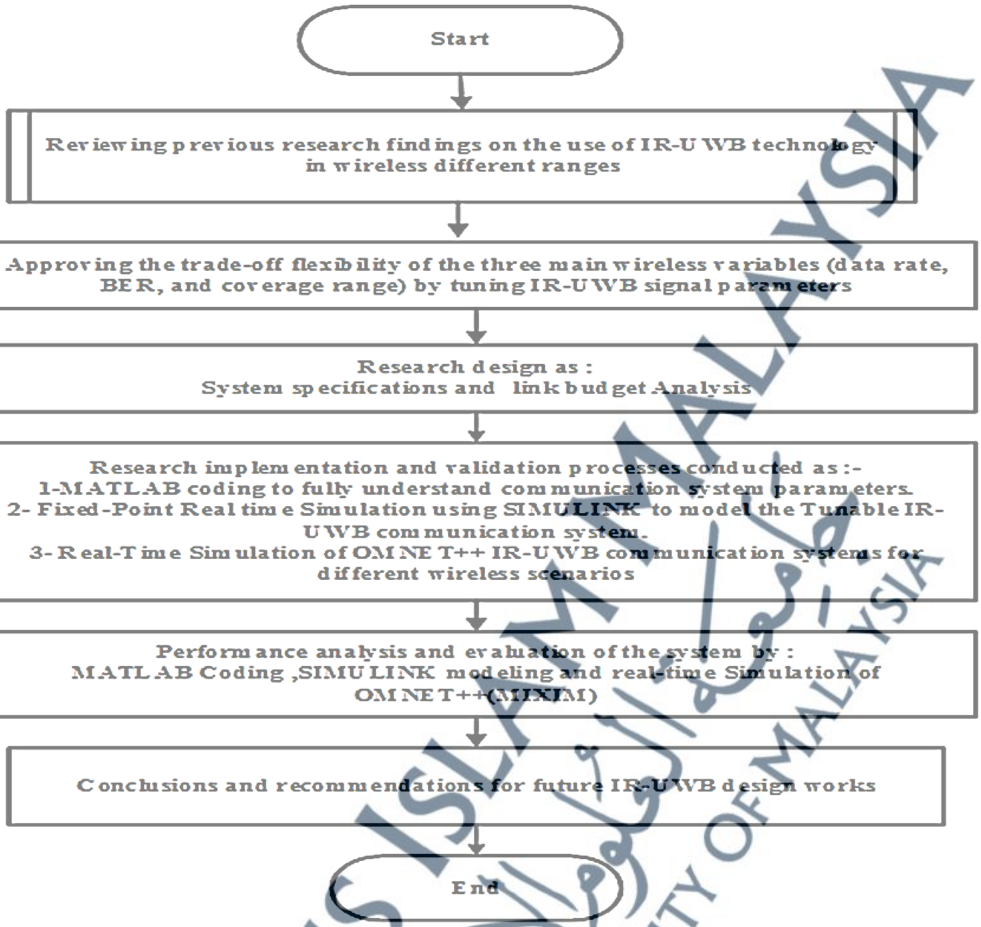

Figure 1.1: Research flow

1.8 Scope of the study

The scope of this research and the verification and validation implementations are summarised as follows:

- This research examines the impact of impulse-based UWB on different aspects via simulation and evaluation processes to validate the applicability of the proposed impulse-based UWB platform for satisfying various requirements.
- This research presents a point-to-point proof of concept of the adaptive IR-UWB solution. The parameters of interest for tuning in the adaptive solution include the physical parameters of generated pulse shapes, modulation types, an order of modulations and coding.

- The proposed solution will be validated by using a mathematical model, and the effect of each parameter, including BER and SNR, will be simulated in MATLAB. Simulink will be used to model the IR-UWB communication link given its ability to control the physical generated parameters. The received IR-UWB signal quality will be analysed on the basis of the achieved throughput across different data rate and distance scenarios in indoor and outdoor propagation environments. The QoS is maintained at a suitable level.

Diverse multipath channel model's ultra-wideband pulse simulation utilizing OMNET++ programming with IEEE802.15.4a (which incorporates up to 16 distinctive LOS and non-LOS (NLOS) for indoor and open-air channel model situations) and a MATLAB library and SIMULINK for recommending a UWB WSN communication link design with IEEE802.15.3a (simulation 4 different LOS and NLOS indoor and outside various situations).

1.9 Thesis Outline

This thesis is divided into six chapters. Chapter 1 presents the research problem, objectives, contributions, questions, scope and limitations.

Chapter 2 reviews the previous literature on IEEE 802.15.3a, IEEE802.15.4a and UWB technologies and the recent and ongoing studies on IR-UWB systems, specifically their physical uniqueness compared with other narrowband systems, their recent advances and future trends, their application in WSNs and the recent proposals for their use in integrating different short-range wireless technologies. The limitations of such proposals are also highlighted and compared with the proposed IR-UWB platform to verify the contributions of this study.

Chapter 3 investigates the IR-UWB system design and parameters, signal processing, signal generation, propagation and receiver activities. The methodologies displayed in this chapter incorporate mathematical and design analysis of tunable IR-UWB solution designed as a template budget-link interface executed as baseband (BB) in MATLAB coding and fixed-point simulation created by means of Simulink additionally, real-time simulation of OMNET++. The latter can control the signal transmission parameters in PHY. The experimental design and settings are also described along with the propagation environment. A link budget design of the IR-UWB and the proposed cross-layer architecture are also presented.

Chapter 4 discusses the system settings and implementations, the implementation and simulation environments, the settings at the Base Band (BB) implementation level and the real-time testing across different scenarios. These settings plainly characterise the scope of qualities for the signal parameters to be created mainly in the various situation of data rates for pre-requirements of sign prerequisites in differed separations situations. The validation results agree well across different levels of BBs and real-time implementations. The improvements achieved by tuning certain signal generation parameters also agree well with the reference generated signal.

Chapter 5 analyses the results obtained at different levels. The reference IR-UWB signal is initially generated with certain physical parameters and is then examined by using certain parameter values to generate a signal with high data transmission and to maintain its quality. The simulation settings and outputs are presented along with the results of the indoor/outdoor environment simulations.

Chapter 6 concludes the paper by presenting proof of the proposed solution. Some directions for future work are also presented to achieve a fully optimised IR-UWB solution.