CHAPTER 1

INTRODUCTION

1.1 Background

Covering 70% of the earth surface, many murky depths of sea throughout the ages, remain largely unexplored due to limited technology. Existing scientific research and monitoring operations have been relying more on divers, ships, wire-lined instruments and weather conditions. These factors are often costly and unreliable. This calls for an emergence of wireless sensor networks deployed under the sea to collect information over the wireless channel. Such a network usually consists of numerous highly sophisticated sensor nodes capable of sensing events and monitoring physical variables such as water temperature, pressure, turbidity, salinity and pollutants at any water depth. These underwater sensor nodes have been widely applied in oil exploration, icebergs detection, seafloor imaging, naval missions, monitoring marine ecosystems and even species classification.

Underwater acoustic (UWA) communication entails the employment of acoustic waves to send and receive underwater information. What was once primarily researched for military purposes potentially could be applied in off-shore oil industry, naval mission and environmental domains – a credit to the novel studies of underwater acoustic networks, communications and routing protocols. Acoustic signals are used in the network where radio waves do not propagate well and where optical waves are affected by severe scattering.

The UWA communications and underwater acoustic networking (UWAN) have been active area of research for decades because of their important roles in applications for oceanographic data collection, environment impact application (pollution monitoring, chemical changes, and so on), offshore explorations, disaster prevention (tsunami, earthquake, and sea floor activities), navigation, military tactical surveillance applications, unmanned underwater vehicle such as UUV and AUV, etc. Considering these significant roles, the UWA communication research communities have been always searching for ways and approaches to maximize or improve the concepts, the performance, and the benefit of UWA networking and communications for their various potential applications. Figure 1.1 shows a typical topology of an underwater wireless sensor network where wireless acoustic communications can be deployed to transmit various data between the many sensor nodes and sink nodes.

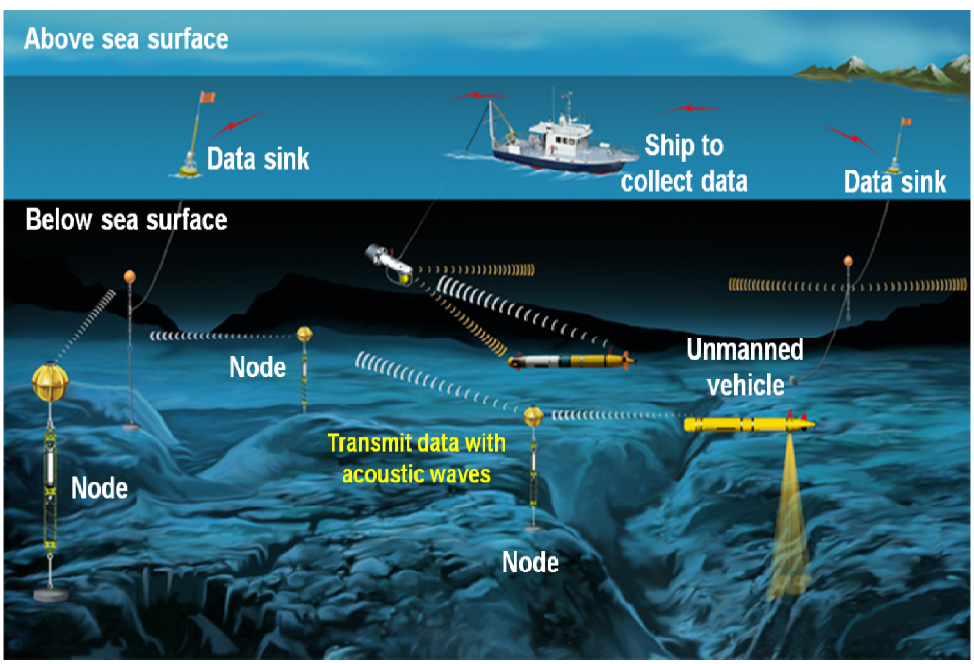

Figure 1.1: Typical topology of an underwater wireless sensor network [1]

In underwater wireless communications and particularly in UWAN deployment many challenges have been identified by researchers in the relevant research communities. Typical challenges involved are the following:

- *Cost*. It is always a top challenge to deploy such network because the hardware and the technology involved are often very costly. The limitation of electromagnetic waves communication systems and the high rate of absorption of electromagnetic signals in sea water/fresh water required a specially designed equipment and unique system deployment.

- *Limited battery powered energy source*. Since the network is to be deployed in underwater environment, the node's battery life-time comes to be very crucial. The operation in changing the battery is very hard and costly. The solar power on the other hand cannot always be deployed to recharge the equipment.

- *Channel Impairment*. The underwater channel is very often severely impaired, especially due to its unique multi-path and fading phenomena.

- *Performance*. Data accuracy is always being well concerned. To achieve reliable accuracy of specially designed topology, protocol and so on, there is always a need to be put in place a mechanism for obtaining high level data quality. This is especially so for real-time systems. The performance of the network may also have a significant influence on the equipment battery requirements.

Communications in underwater do not rely solely on acoustic waves. The trade-offs in using acoustic, radio or optical waves were examined in [1]. Electromagnetic signals are well known to be readily absorbed by sea water consequently limiting its usage in underwater wireless communications. Optical wave has some disadvantages of being sensitive to the scattering effect, refraction, and reflection in underwater environment leading it to be an ineffective medium for relaying wireless signals. From decades of research, the outlook of acoustic signaling has proven to be relatively favorable to electro-magnetic waves or optical waves. This recognition has elevated acoustic waves to be a primary form of underwater wireless communications [2].

Since acoustic waves instead of electromagnetic waves are used for data transmission, underwater acoustic (UWA) communication systems always face the unique challenges aroused from the distinct characteristics of acoustic wave propagations. UWA communication is often affected by sound absorption in water, energy spreading, and waveguide nature of the underwater wireless link [3]. These factors induce spreading and absorption losses, extensive time-varying multipath, propagation delays, reverberation, and Doppler spread effect [1],[2].

For medium range communication channel in very shallow warm water, such as the coastal regions of South-East Asian countries, acoustic multi-path propagation frequently occurs as both sea-surface and sea-floor act as acoustic wave reflectors [4]. As acoustic propagation in water is relatively slow due to refraction and reflection, it poses a limitation in data transmission rates, bringing about some low effective data rates [5] in data transmission. All these factors have somehow hindered the full benefits of UWA applications. For many researchers, a research on UWA communications has always been a challenge that include severe fading, limited bandwidth, frequency-dependent attenuation, rapid time-variation, extended multi-path interferences, refractive properties of the media, and large Doppler shift.

Many publications on the recent advances and challenges in UWA communications and networking exist [6-11]. It is well known that UWA environment is so different from its terrestrial counterpart that many researchers have investigated the performance of UWA communications under different performance metrics with reference to the more matured wireless terrestrial/radio frequency communications. It is observed that many of the UWA researches were focused on the communication protocols or the routing protocols with an aim to improve/enhance UWA channel performance and efficiency. From the author's rigorous findings, there seemed to be very few published works on data packet size optimization for UWA communications in comparison to the similar works accomplished in the terrestrial wireless communications and wireless sensor networking (WSN) [12-15].

In the past one decade, research in designing new UWA routing protocol and UWA MAC protocols have spurred up a great interest in the UWA community. However, again, it is found that there are only a handful of publications on UWA channel parameters optimization, notably in analysis of data packet size optimization in the context of energy efficiency that is always to be an issue in UWA data transmission. It is especially so in UWA sensor networking applications where the sensors are operated by non-rechargeable power sources. This then is to be the reason motivating the author of this thesis to embark on a research to develop an effective mechanism/algorithm to determine or compute optimal data packet size for UWA data transmission based on a given set of performance metrics as the optimal size qualifiers. The performance metrics (qualifiers) may include transmission range, data bit rate, error probability, bit error rate, types of protocol, energy per useful bit, modulation used, etc.

1.2 Scope of Studies

This research is purposively focused on the medium range (50m to 2km) data packet transmissions in the tropical shallow water (50m to 200m deep) environment. The main reason for zooming into shallow waters is that there have already been many attempts at adapting various communication techniques in deep water channels and various mature technologies at the moment are readily available [3]. However the various valuable mature technologies and concepts in deep water communications shall be used as references in the course of the author's research.

1.3 Issues and Questions

1.3.1 Issues

A series of published papers on data packet size or packet length optimization for terrestrial WSN can be readily obtained from various WSN research communities. Numerous full text papers can be easily downloaded from IEEE Communications Society under the WCNC (Wireless Communications & Networking Conference) proceedings. In contrast, there are relatively much fewer such papers from the UWA research communities. This is a clear indication that there are still many of the similar works that can be done by the UWA researchers to investigate other ways, techniques or new concepts to improve the communication performance in UWA channels/links.

From the related works discussed in the later chapters of this thesis and from other non-cited similar literatures reviewed, the authors observe that the mechanism for data packet size optimization in UWA communications can be obtained from the various solutions proposed in the terrestrial WSN counterparts. The main issue here is, of course, what could be the best choice among many proposed solutions in WSN communications that can be adopted into the UWA environment for effective and efficient underwater wireless data transmission.

1.3.2 Questions

The most straightforward question for this research is:

> How could the various data packet optimization solutions proposed in the terrestrial WSN communications be modified, calibrated, fine tuned, etc so that they can be effectively imposed onto the UWA channels for boosting the UWA data transmission performance, if not to its optimal level, then it should be at least to some noticeable extents, at par to its terrestrial counterpart?

The next question of interest is:

> What are the correlations between the data packet size and the various UWA channel performance metrics/parameters such as, BER, data rate, types of protocol, throughput, latency, energy efficiency, etc?

The related questions are:

> How could the correlations be defined? Should it be defined on one-to-one or one-to-many basis? That is, should the correlations be defined based on

data packet size with each of the channel parameters or should it be defined based on packet size and the hybrid or combinations of parameters?

Other fundamental questions related to this research are:

What could be the real practical impact factors for data packet size optimization in UWA communications in shallow water?

What could be the best means to consolidate the outcomes of data packet optimization so that it can effectively be implemented in UWA systems i.e. the inclusion of the optimization mechanism into the hardware/firmware of UWA modem for good performances in underwater wireless data transmission?

1.4 Research Objectives

1.4.1 General Objective

The general objective of this research is to seek several effective solutions for data packet size optimization in the UWA communications in the context of shallow tropical waters (depth of 50m to 200m) with a transmission range from 50m to 2km. It is quite obvious that the research works shall involve the data link and the physical layer of the OSI model. The aim is to develop an optimization mechanism or algorithm that may be integrated into UWA modem for improving UWA channel performance in the context of energy efficiency. The readers should be reminded that energy conservation always becomes an important issue in underwater communication systems.

1.4.2 Specific Objectives

The specific objectives for this research include the followings:

1. To design and implement a new data packet size optimization or algorithm for UWA communications by considering the various unique characteristics of the UWA channel in the context of shallow tropical waters.

2. To investigate the correlations between data packet size and the various unique parameters of UWA channel accordingly enabling for identification of high impact factors to improve UWA channel data packet transmissions.
3. To model the shallow tropical water UWA channel with references to the WSN counterparts and to use this model for relevant simulation works to verify the feasibility of implementing the proposed algorithm.
4. To perform critical analysis on the research outcomes against other similar works accomplished by the UWA communities.

1.5 Research Outcomes and Contributions

The primary outcome of this research shall be a data packet size optimization look-up table or a look-up graph based on various databases constructed by considering some of the important UWA performance metrics such as throughput efficiency, energy efficiency, and bit error rate (BER), energy per useful bit (EPUB), etc. Figure 1.2 illustrates conceptually the outcome of this research.

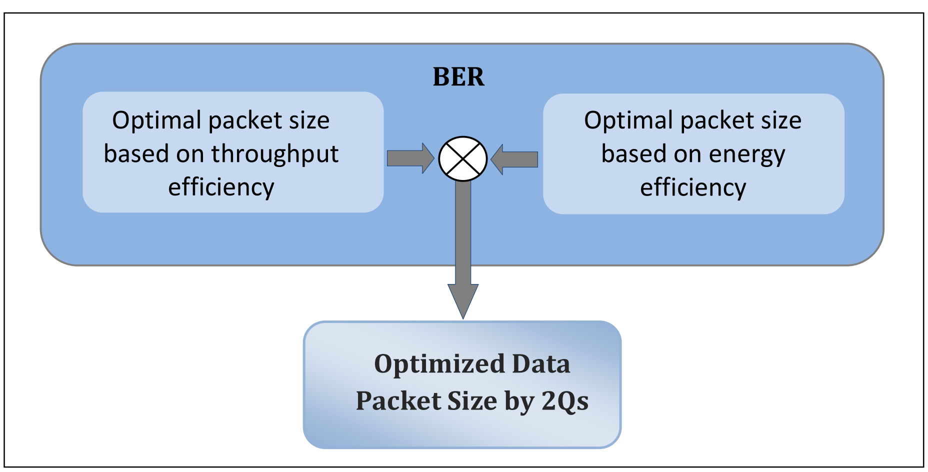

Figure 1.2: Conceptual outcome of the research work

On application perspective, the proposed data packet size optimizing algorithm together with its databases may be download or installed into a UWA modem for a dynamic controlling of optimal data packet size during a data transmission. This is to be the main contribution of this research. The proposed algorithm shall be a new data packet optimization mechanism for UWA communications to improve UWA wireless data transmission efficiency and performances in the environment of shallow tropical waters for a medium transmission range.

The other related outcomes of this research is the possibility in contributing to the existing UWA technical and scientific knowledge by laying down some fundamental bases for the development of data packet size optimization for a more effective UWA communication technique. By leveraging the underwater communications and perhaps its networking efficiency:- better underwater applications for monitoring, sensing, and exploring could be a reality.

1.6 Thesis Organization

Chapter 2 begins by presenting the literature review and the related works on data packet size optimization in wireless communications i.e. data packet size optimization in underwater wireless communications and in terrestrial radio waves wireless communi-cations. This chapter summarizes a comparison of both types of wireless communications.

Chapter 3 proposes an optimization model based on the analysis of optimal data packets size in the context of throughput efficiency and energy efficiency based on various bit-error-rate (BER). Energy efficiency is analyzed with energy per useful bit (EPUB) as an implicit metric.

Chapter 4 describes the simulation works conducted using the ns2 simulator tool. It also highlights a general scenario deployed in the simulation and the relevant simulation parameters setting. Consequently the results obtained from the simulations are discussed in details. The proposed data packet optimization algorithm is presented at the end of his chapter along with example screenshots of its prototype. The reader is hereby reminded that acoustic frequency range (20 – 20 kHz) is used throughout the simulation works in Chapter 4.

Chapter 5 presents a critical analysis on the outputs of the proposed algorithm. These analyses should not be taken as a benchmarking against other existing approaches since most of the methods/techniques in the reviewed literature are the direct outcomes of some fundamental research works. These methods/concepts are merely at the proposal states i.e. they are not a de facto standard for UWA data packet optimization. So benchmarking should not arise.

Chapter 6 presents a case study to show the feasibility of deploying the proposed algorithm in an underwater environment where a UWSN network is being proposed for collecting data/signal in a long-term non-time critical water pollution monitoring application.

Chapter 7 concludes the whole research work and opens up some issues which may interest the readers to embark on further research in the scope of the new algorithm for data packet size optimization in UWA communications.

1.7 Chapter Conclusions

This chapter highlighted the issues on the lack of data packet optimization in UWA communications and emphasized the reasons for embarking on a research to find new optimization algorithm for UWA data transmission aimed to improve data packet transmissions and energy efficiency.

This chapter also describes the possible outcomes and contributions which are deemed beneficial to the UWA research communities. The ultimate objective of this research project is to design, develop and thus to formulate and enact a fundamental basis for the development of a new data packet optimization algorithm for UWA communications based on two important performance metrics of throughput efficiency and energy efficiency qualified under different BERs.