# CHAPTER 7

# CONCLUSIONS AND FURTHER RESEARCH

## 7.1 Conclusions

This research project was initiated by considering some vital questions and issues (listed in chapter 1) on data packet size optimization in the scope of data packets transmission effectiveness and its energy efficiency in underwater acoustic or wireless communications. Rigorous related facts probing and literature review had led the author to look into shallow water UWSN for solutions to those vital questions/issues. The deep water UWSN scope was discarded by the author based on the fact that it is a matured technology whereby numerous information on it are readily available from deep water research communities.

The outcomes of this project fulfill all the objectives stated in Section 1.4. A new data packet size optimization algorithm, literally called "2Q Optimization Algorithm" has been proposed and developed by the author. This algorithm uses two crucial underwater channel/link performance metrics: throughput efficiency and energy efficiency as qualifiers (thus 2Q) to determine an optimal data packet size for underwater data transmission. The algorithm does take into consideration the link quality (the BER) between a source-sink pair of nodes. Other tacit qualifiers include the rate of data bit transmission and the distance between the source-sink pair of nodes. In this work the 2Q algorithm has been developed for a one-hop data transmission. Multi-hop is left as a topic for further research.

Simulation of the algorithm via ns-2 simulator packages running on Ubuntu operating system has served as a platform for the modeling and setting up of a single-cluster static 3D UWSN environment with nodes arranged in a centralized star topology. This platform was also used to determine how data packet sizes could be qualified with various performance metrics and eventually allow the author to consolidate sets of data forming databases that can be used as tacit knowledge for the 2Q algorithm for computing optimal data packet size.

MatLab was also used as a supplement tools in the course of simulation and also for some data analysis and plotting of graphs. The consolidated data sets from ns-2 were exported to MicroSoft Excel software for more in depth data analysis.

The outcomes of the simulation were critically analyzed and studied to verify the viability and applicability of the 2Q algorithm in the context of energy efficiency. In view of energy conservation as one of the main factors in UWSN for enhancing the network life span it has been chosen as the basis for the various simulation results analyses and comparative studies. The analyses showed that the 2Q algorithm with two qualifiers was able to compute an optimal packet size with good energy efficiency in comparison with the algorithm using just one or two performance metrics. For information, algorithm with single or two performance metrics are in fact the variants of the proposed algorithm. However there are situations where using two performance metrics can be better than using 2Qs.

It should be mentioned here that the analyses were based on the outcomes of the simulation results. The algorithm is yet to be implemented in the real acoustic modem for open field testing. However a small scale laboratory fish tank testbed using two micro acoustic modems was set up to verify the simulated results. Although it was a small scale and a controlled environment, the laboratory outcomes seemed to match the simulation results. The practicality of 2Q algorithm in the open field would be left as the next course of research when a research grant is secured by the author to purchase the relevant underwater acoustic systems and the essential underwater communication apparatus/equipment.

## 7.2 Further Research

The long propagation delay coupled with high error rate of acoustic channels always poses special challenges to the underwater acoustic channel for providing reliable data packet transmission, particularly in the context of energy efficiency. It was found that many of the traditional retransmission-upon-failure control approaches are not promising enough for time-critical services. Therefore it is of this author's opinion that by incorporating the 2Q data packet size optimization algorithm (together with its energy efficient capability) into time-critical applications may provide a direction for further research. Considering the importance of "time critical" factor in real-time services/applications, research in exploring a practically feasible strategy to have multi-path and multi-hop data transfer instead of one-hop single route transfer is a hopeful way forward for ad-hoc time-critical UWSN data transmission. Interested readers may refer to a related work in [81] where the authors have presented a scheme to combine power control with multipath routing, and data packets combining at the destination node.

Since the optimization algorithm proposed in this thesis has been verified only based on the Aloha protocol, therefore the author is of the opinion that there exist a direction for further research for readers who may be interested in exploring how the proposed 2Q algorithm may perform in data packets transmission based on CSMA protocol at the MAC layer.

Battery power capacity requirements in the sensor/sink nodes and the high cost of acoustic modems are currently causing some UWSNs economically infeasible for large scale long-term underwater applications. Consequently this situation has created a compelling need to develop low-cost and low-power acoustic modems to support long-lived, dense, and economically feasible UWSNs. Exploring to create better techniques in producing new generation modem with capability to support the 2Q algorithm for the benefit of dense sensing and reliable underwater communications is another promising research direction.

The author has assumed a static transmitter and receiver for a one-hop data transmission in his research work. However, in real situation, there are applications that demand a mobile platform in which the transmitters and receivers are moving with respect to each others, such as underwater environment data collections using underwater automated unmanned vehicles (AUVs). A mobile platform is certainly to impose different complications than those in static platform. For instance, if the relative speed is large enough, Doppler compensation will be needed for reliable data packet transmission between source-sink pair. In this perspective, the author foresees the 2Q data packet optimization approach presented in this dissertation would have to be technically revised and reviewed thoroughly and critically in response to the more stringent demands from a mobile platform. Further promising solutions to enhance the 2Q approach are needed by considering its application in mobile platform in shallow waters where acoustic wave propagations are always complicated by strong interactions with both the water surface and the bottom surface leading to more complex multipath factors. The strategic positioning of the surface gateways in response to the movement of mobile sensor nodes in a particular cluster would be an issue in mobile platform. Consequently this would be another direction worth an effort for further investigation.

For the past decade advances in underwater acoustics technology have occurred in many areas and domains. Is happening that design paradigm shifts from military oriented applications to commercial viable based applications. Interested readers may find many exceptional sources of information from the Ocean Conference (OC) proceedings and from IEEE Journal of Oceanic Engineering (JOE). The current and more immediate advances are documented in OC while JOE provides prominent archived publications. Some research works published in OC proceedings do in due course reached the JOE archives.

In years to come many innovations and improvements are undoubtedly expected for the UWASN technology to provide a better, a more effective, and practically feasible applications such as real-time marine species recognition, transmission of marine video/voice, acoustic image processing, in-situ data processing/manipulations, etc for the betterment of underwater wireless sensor network communications.