Multi Beacon Mobile Sink (MBMS): An Energy Efficient Routing Protocol for Underwater-Internet of Things (U-IoT)

by

Asif Sazzad (170021029)
Maisha Mahbub Rimi (170021046)
Nazifa Nawer (170021148)

BACHELOR OF SCIENCE
IN
ELECTRICAL AND ELECTRONIC ENGINEERING

Department of Electrical and Electronic Engineering
Islamic University of Technology (IUT)
Board Bazar, Gazipur-1704, Bangladesh.
May, 2022.

CERTIFICATE OF APPROVAL

The thesis titled,"**Multi Beacon Mobile Sink (MBMS): An Energy Efficient Routing Protocol for Underwater-Internet of Things (U-IoT)**" submitted by Asif Sazzad, Maisha Mahbub Rimi, Nazifa Nawer, St. No. 170021029, 170021046, 170021148 of Academic Year 2018-22 accepted as partial fulfillment of the requirement for the Degree BACHELOR OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING OF Islamic University of Technology (IUT)

Approved by:

____

Dr. Khondokar Habibul Kabir (Supervisor)
Professor, Electrical and Electronic Engineering Department,
Islamic University of Technology (IUT), Gazipur.

This thesis needs to be re-submit.

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Declaration of Candidate

It is hereby declared that this thesis report is only submitted to The Electrical and Electronic Engineering Department any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

Asif Sazzad
Student ID: 170021029
Date: 18-05-22

Maisha Mahbub Rimi
Student ID: 170021046
Date: 18-05-22

Nazifa Nawer
Student ID: 170021148
Date: 18-05-22

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Dedicated to my family, friends and supervisor

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List of Abbreviations

U-IoT	Underwater-Internet of Things
UWSN	Underwater Wireless Sensor Network
RF	Radio Frequency
AUV	Autonomous Underwater Vehicle
AURP	AUV-Aided Underwater Routing Protocol
DO	Dissolved Oxygen
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
BOD	Biological Oxygen Demand
SPB	Search Phase Beacon
TPB	Transfer Phase Beacon

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All praise and gratitude be to Allah, the most beneficent, the most merciful.

Abstract

Marine life and environmental monitoring of deep sea have become a major field of interest for quite a long time because of the immeasurable region of the area of the ocean that comes with its own dynamics and vulnerabilities. Creating the Underwater-Internet of Things (U-IoT) network model in Underwater Wireless Sensor Network (UWSN) provides the scope of ensuring proper marine life monitoring which supports the aspects of 4th Industrial Revolution. The U-IoT network model is designed for an automated, efficient, smart process of data transfer for both underwater and overwater communication through acoustic waves and Radio Frequency (RF) data transfer techniques respectively. The proposed U-IoT network model is created with an optimum number of autonomous underwater vehicles (AUVs) and surface sinks in order to address Bangladesh's overfishing problem. The network model is evaluated by comparing different AUV and surface sink scenarios taking the South Patch region of Bay of Bengal as the target area.

Chapter 1

Introduction and Background

1.1 Introduction

Marine life environment greatly impacts aquaculture, ecosystem which is source of biodiversity, food and life. For sustainable food security, healthy ecosystem many studies on marine life monitoring are conducted throughout the world. In order to collect and deliver marine life data, an Underwater Wireless Sensor Network (UWSN) is essential which can collect marine life data as quick as possible. Insufficient research work for underwater wireless routing protocols leads to lack of energy efficient U-IoT network with optimized data transfer rate.

1.1.1 Problem Statement

A healthy marine environment is critical for the fishing industry to thrive which is one of the most influential industries in the global economy as fish is a highly reliable source of animal protein for many people around the world and billions of people worldwide depend on oceans as a source of income and food.

However, due to uncontrolled population growth, climate change, over-fishing, coastal pollution, eutrophication, and land erosion, oceans are suffering, jeopardizing future food and economic security. This necessitates marine life monitoring in order to preserve a healthy ecosystem, as well as sustainable economic growth and food production.

Numerous studies on marine life monitoring have been conducted using radioactivity monitoring [1], biodiversity measurement [2], underwater noise measurement [3], contaminant and effect measurement [4], and coastal and oceanic observation [5]. In order to collect and deliver marine life data, an underwater sensor network must be built to measure these parameters.

1.1.2 Research Gap

Many unauthorized activities revolving ocean can be prevented by having comprehensive idea about marine life which can be attained by marine life monitoring. This can be done very quickly and effectively through a proper technological network for marine data collection. But unfortunately there is almost no technological research for marine life data collection in Bangladesh.

Developed countries have many underwater wireless network researches carried out in small scale area which is not feasible in large scale area. Even if some support large regions they can not propose any efficient structure of mobile and stationary IoT devices used in the network. Routing paths of AUVS are optimized in many researches but they don't suggest any efficient number of AUVs used. Research works are often carried out for efficient node deployment or localization but at which depth the nodes should be placed or how uniformly they should be placed these factors have a lot of scope for research.

There are many energy efficient routing protocols implemented in terrestrial network but in case of underwater wireless networks there is huge lacking in there implementation.

1.1.3 Problem Identification

Bangladesh despite of being a riverine country it can not utilize it's water resources efficiently for their maintenance. It often faces problem like i) lack of marine life environment information ,ii) unauthorized fishing during ban period. Even if many countries collect marine life information through underwater wireless network there are many deficiency in their designed model such as: i) lack of efficient structure in underwater networks, ii) slow data transfer rate ,iii) lack of efficient energy consumption saving routing protocol for U-IoT networks.

1.1.4 Research Motivation

1.Lack of marine life environment information.

2.Unauthorized fishing during ban period.

3.Lack of efficient structure in underwater networks.

4.Slow data transfer rate in existing wireless networks built in underwater environment.

5.Lack of efficient energy consumption saving routing protocol for U-IoT networks.

1.1.5 Research Scopes

This research work suggests feasible and optimum solutions for the problems stated above. Many countries already have underwater research works but the optimized number of IoT devices with their placements for faster data transfer rate are not suggested anywhere. Though the U-IoT network is designed considering a small region of Bay of Bengal it can be implemented anywhere in the world with appropriate parameters. Energy consumption of nodes in underwater network is saved using optimization algorithms but a routing protocol for energy consumption saving is more efficient.

1.2 Research Objectives

The objective of our research are:
1.To monitor marine life environment with underwater wireless acoustic network.

2.To design an efficient underwater wireless network architecture constructed with IoT devices for faster data transfer rate from seabed to shore.

3.To design a routing protocol optimizing energy consumption with maximum data transfer rate for U-IoT network.

1.3 Research Outcome

1.Detection of marine objects and their movements.

2.Layered localization with optimum number of boats and AUVs for faster data collection.

3.A routing protocol with optimized node energy consumption.

1.4 Novelty of The Research

This thesis newly builds a wireless network in underwater environment and provides following advanced features:

1.Marine life data collection from ocean through any wireless network is never done in Bangladesh. The underwater wireless network architecture is designed considering real life parameters from the South Patch region of Bay of Bengal. So this network can be readily implemented in Bangladesh for marine data collection which will be first ever done in this country.

2.The designed U-IoT network optimizes number and layers of mobile AUVs and boats which combinedly collect data from node and send to stationary sinks. Without this optimized number of mobile carriers data transfer rate will drop and faster data collection is not possible.

3.Multi beacon routing protocols are usually implemented for terrestrial network. This protocol is carried out in underwater environment where communication is done through acoustic wave whereas in terrestrial network communication is done with RF wave.

4.Node energy consumption saving is done through implementing optimized duty cycle of nodes. This optimized duty cycle value is derived from multi scenario comparison.

1.5 Overview of Methodology

To build an Underwater Wireless Sensor Network (UWSN), U-IoT is seen to be the most effective and sophisticated method of network technology as it enables continuous collection, send and aggregation of data [6] on physical parameters of the marine life environment and transfer it for further processing to make work decisions based on network data using embedded systems such as sensors and communication hardware [7]. Deployment of U-IoT tremendously impacts the aspects of Fourth Industrial Revolution to create a smart network. It aids in the development of varied datasets using machine learning and artificial intelligence in order to extract usable information for use in the Underwater Marine Life Monitoring system [8]. This paper proposes an efficient U-IoT architecture to monitor marine life environment with sensor nodes, AUVs, surface sinks, and offshore sinks that optimizes data transfer time delay. Here sensor nodes are installed at the seafloor and data transferred to AUVs above them, which are then transferred to surface sinks and then to off-shore sinks as shown in Fig. 1.1.

In the proposed model, acoustic waves are used for transmission between sensor nodes and surface sinks. On the other hand, from the surface sink to the off-shore sink, the standard terrestrial mode of communication, radio frequency, is used.

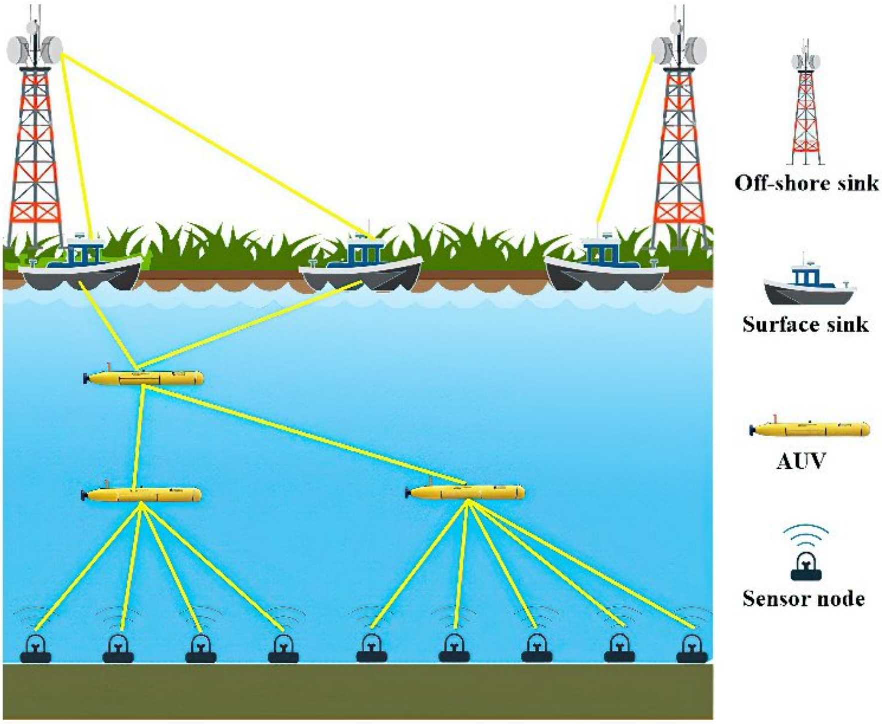

Figure 1.1: Overview of U-IoT in monitoring marine life environment using acoustic wave for underwater and RF for overwater communication.

For underwater sensor network, acoustic waves are used as means of data transfer instead of traditional terrestrial methods of communication, such as Radio Frequency (RF) because RF reduces the transmission range rapidly and highly attenuates the transferred data [9], resulting in a lower data rate [10]. Whereas, acoustic waves have a low rate of absorption that enables long range communication and thus is a reliable data transfer medium [11].

1.6 Organization of the Thesis

This designed network with deployment of U-IoT tremendously impacts the aspects of Fourth Industrial Revolution to create a smart network. It supports the analysis using machine learning and artificial intelligence in order to extract viable information for utilization in the Underwater Marine Life Monitoring system.

This thesis focuses on the following goals to achieve the outcomes:

This thesis achieves the following outcomes: 1.Detection of marine objects and their movements

2.Layered localization with optimum number of boats and AUVs for faster data collection.

3. A routing protocol with optimized node energy consumption.

This architecture of underwater and overwater IoT is explained in detail in the sections beyond. The proposed paradigm is briefly compared to recent work on UWSN and U-IoT technology in Section 1.3. In section 3, the U-IoT network model is described using a reference region. Further in section 4 and

5, detailed simulation model is illustrated with appropriate reasoning. Lastly, the conclusion and the proposed model's future scopes are discussed in section 6.

Chapter 2

Literature Review

2.1 Literature Review

Measuring different parameters of water to monitor marine environments has been a lucrative field of research since past decades such as water quality measurement with IoT based smart technology [12] where turbidity sensors are used to measure water quality like temperature, pressure, oxygen saturation, salinity, pH, Ammonia [13]. However, these water characteristics and quality measurement models are used on a limited scale, such as in a small aquarium system or a fish pond, whereas the proposed approach in this work allows for large-scale water quality monitoring in real-life environment.

In addition to measurement of physical and chemical parameters of water for marine life monitoring, effective node deployment in the underwater seafloor has been the subject of numerous studies. A hierarchical underwater network design using edge computing where Ant-Colony-Based Efficient Topology Optimization is utilized to optimize deployment costs while maximizing network life and selecting the best node position in marine monitoring network [14]. Many other optimization algorithm is explored for this purpose such as Swarm optimization is used for finding sensor node deployment positions and efficient node sensor range [15]. An adaptive triangular node deployment that allows for an efficient spacing pattern of nodes to be determined by modifying communication performance in an underwater environment [16]. Outperforming these techniques, an effective model for node battery life is proposed using Linear Regression Technique and Deep Neural Network modeling [17]. For overcoming long multipath delay, underwater noise, restricted bandwidth, and battery life, numerous studies have been conducted [18]. The above mentioned articles mostly focus on finding node deployment positions with different optimization algorithms or modeling techniques optimizing node sensor energy, deployment cost and maximizing network life. However, the methodology presented in this paper provides an efficient cluster head node deployment in a clustered sensor node based UWSN network.

Besides efficient node deployment, AUV localization and routing path is also very important to build a network with higher data transfer rate. In large-scale UWSNs, research on autonomous underwater vehicles (AUVs) has been done, with a cluster-based AUV-aided data gathering method proposed to make a trade-off between energy savings and data transfer latency [19]. To solve this problem of trade-off a multi-hop realistic underwater sensor network model using acoustic wave is proposed [20] where various AUVs' movement patterns are simulated that shows AUV-aided underwater routing protocol(AURP) is more efficient in terms of improving data delivery ratio, energy efficiency and data transmission reliability. All of the aforementioned studies focus on AUV movement paths or AUV clusterization, but none of them assist in establishing the number of layers or AUVs required for a specific undersea region monitoring, as this paper can easily demonstrate.

Different parameters are compared to decide profitable routing algorithms. For UWSN, a number of energy-efficient and reliable MAC networks have been proposed [21]. Based on a comparison of energy, propagation delay, and throughput, a fuzzy depth based energy efficient routing algorithm provides an enhanced lifetime [22]. A simulation for the U-IoT results in a high data packet transfer rate with low energy consumption and low latency [23]. Different technologies for improved energy efficiency and data transfer rate have been studied previously, but in this study an efficient model is simulated that proposes an architecture with the least amount of data transfer latency.

None of the studies cited above propose an optimal amount of surface sinks for reducing data transfer time. As a result, this paper is driven by the idea of creating an underwater sensor network that proposes node cluster head orientation, the number of layers and movable ocean vehicles required, and the number of surface sinks that maximize data transfer time from node to off-shore sinks.

Chapter 3

Network model

The network model of U-IoT is obtained by deploying different underwater target devices such as nodes, AUVs, surface sinks and off-shore sinks. Firstly, the overall description of data transfer between these objects is explained. Later, a reference region is chosen in accordance with its importance of monitoring marine life with U-IoT.

3.1 Description of UWSN data transfer model for Marine Life Monitoring

For marine life monitoring the U-IoT is developed using nodes, AUVs, surface and offshore sinks (see Fig. 3.1). In the proposed model scenario, data is transferred from nodes to the AUV that are in range; otherwise, the data is stored. Afterwards, data is transferred from the surface sink to the off-shore sink, where it is collected and transmitted to the nearest terrestrial network. As an example, Cox's bazar and Teknaf region of Bangladesh is used as reference to build the UWSN to create U-IoT.

3.2 Proposed Scenario of Marine Life Monitoring: Case study of Over-Fishing Problem of Hilsa in Bangladesh

The preservation of Hilsa fisheries resources in the sea has been one of Bangladesh's most essential and critical issues. Overfishing during the breeding season has put fishing stocks of Bangladesh in jeopardy, as the fish breed is on the verge of extinction and fishing stocks are rapidly declining [24]. In order to address Bangladesh's overfishing problem, many new inventive ideas have been developed by issuing a banning period where fishing is kept to halt. The majority of them included resolving the issue at the community level, such as providing appropriate food supplies to fishermen's families during the ban period.

Despite government legislation, illicit and unauthorized fishing occurs during the ban period, as Hilsa fishing is easy to carry out because Bangladesh is a riverine country. However, existing techniques of controlling overfishing do not completely alleviate the problem because it is unable to check or monitor abnormalities during the dark hours. In order to be able to solve the predicament and provide an infallible solution, an UWSN using U-IoT is built considering the south patches region of Bay of Bengal shown in Fig. 3.2

Bay of Bengal is taken into account as it is one of the favorable oceans with huge occurrence and variety of marine species with four fishing grounds which are i) South patches ii) South of south patches

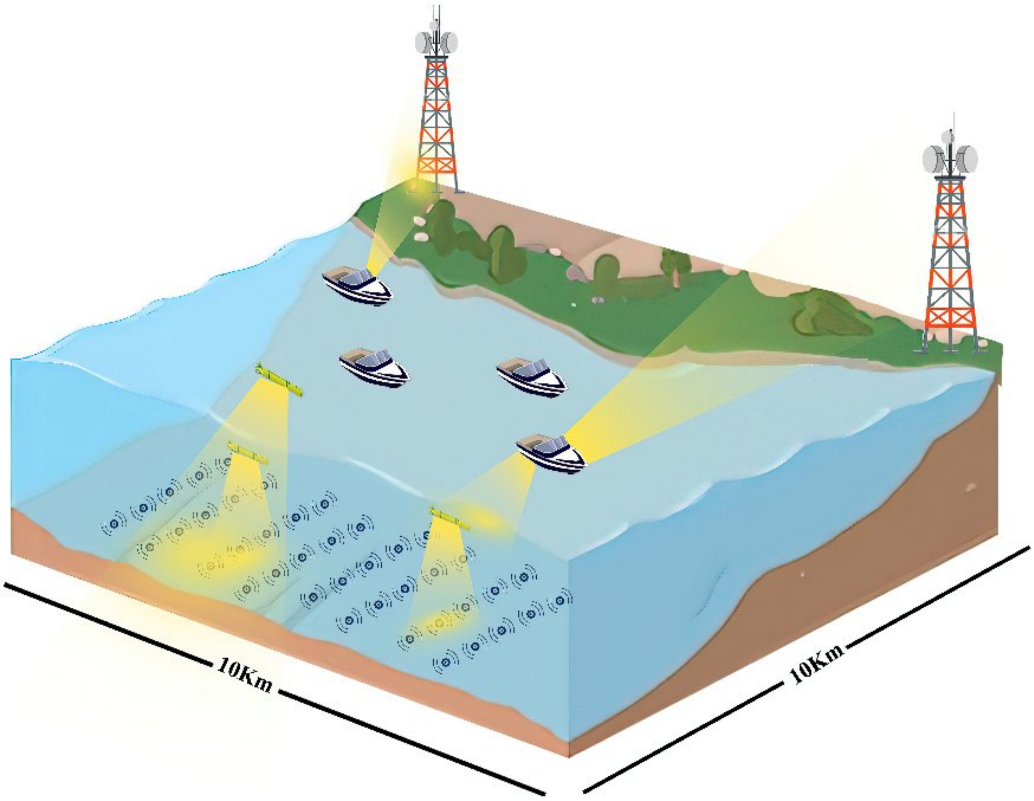

Figure 3.1: 3D View of U-IoT Simulation Model.

iii) Middle ground iv) Swatch of no ground [25]. The UWSN proposed in this paper for marine life monitoring system is conducted in the region of South patches which covers an area of 3662 sq km and falls under Cox's Bazar region of Bangladesh [25] that can be utilized to monitor the undersea environment even at night, ensuring 24-hour monitoring and better supervision and control of the overfishing situation.

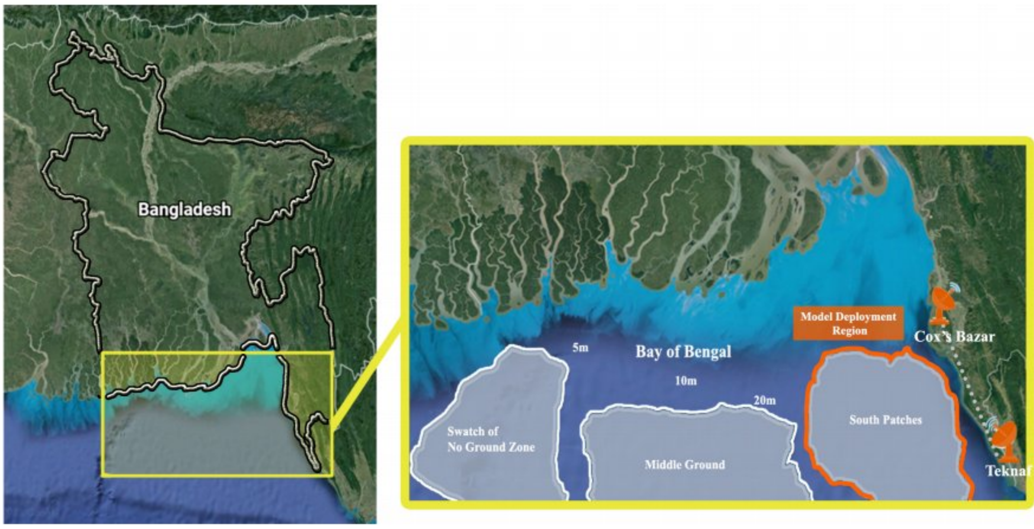

Figure 3.2: Target Region (Bay of Bengal-South Patch) for Monitoring Marine Life Environment.

Chapter 4

Simulation model

The underwater sensors are positioned in a 10x10 km region in the proposed model to make the calculation easier and a maximum depth of 100m for the South patch region is taken into account which is shown in Fig. 3.1, where 46 nodes are placed on the seabed since the delivery rate and energy usage are both optimal [26]. The node sensor range is set at 35 meters ensuring short-range acoustic communication [26]. Moreover, nodes are deployed in clusters where each cluster has a cluster head, and all other nodes in that cluster send their data to that cluster's cluster head, which communicates with AUV within its range and provides data with data generation rate of 1 kbps [15]. The nodes are placed at seabed both uniformly and randomly that will be further discussed in the next section.

To reduce packet loss, AUVs are deployed in the middle layer between the surface sink and nodes and through graphical analysis efficiency of the double layer deployment of AUVs are found that is further examined in Section 5.

For optimal data transfer to the surface sinks, the AUV sensor range employed in the simulation is set at 1700 meters [27]. When the target items fall into the sensor range of each sender, they interact with one another. When the upper-level target device within at a radius of 1700 meters data is transferred from the lower level to the upper-level target device [27]. AUVs transport data to surface sinks and from surface sinks to off-shore sinks stationed in the study area in a similar manner. Also, it is assumed that the data collected from the AUVs will be sent from the boat through Sigfox. As a result, 40 kilometers is considered as the sensor range for terrestrial communication from the surface sink to offshore sink [28].

Finally, two sinks are positioned at Teknaf and Cox's Bazar which will receive data from the surface sink (considered boat in the proposed model) and will process it further.

The UWSN deploying U-IoT to monitor marine life is modeled using specific object parameters and their values which are tabulated in Table 4.1.

Table 4.1: Parameters for marine life monitoring for Bangladesh's Hilsa Scenario.

Oceanic Parameters	Value
No. of nodes	46
Node sensor range	35 m
Data generation rate	1 kbps
AUV sensor range	1700 m
Depth of lower level AUV (from sea bed)	30m
Depth of upper level AUV (from sea bed)	70m
Speed of AUV	1.0 m/s
Boat sensor range	40 km (Sigfox)

In the next section, the above-mentioned parameters are further explained using the Netlogo model environment in order to draw the appropriate conclusions from the simulation results.

Chapter 5

Discussion of Simulation and Result Analysis

In this section, firstly the optimum node positioning at sea bed is discussed along its graphical outcome. Secondly, the AUV deployment scenario involving layering of different number of AUVs is analyzed and the result generating optimum use of the devices is concluded accordingly. In the similar manner, the number of surface sink usage is also carried out. Finally using the optimal node, AUV and surface sink deployment a comparison analysis is given in the following subsections.

5.1 Uniform and Random Node Deployment in seabed

Simulation is carried out using uniform and random node positioning in the U-IoT network model as shown in Fig. 5.1

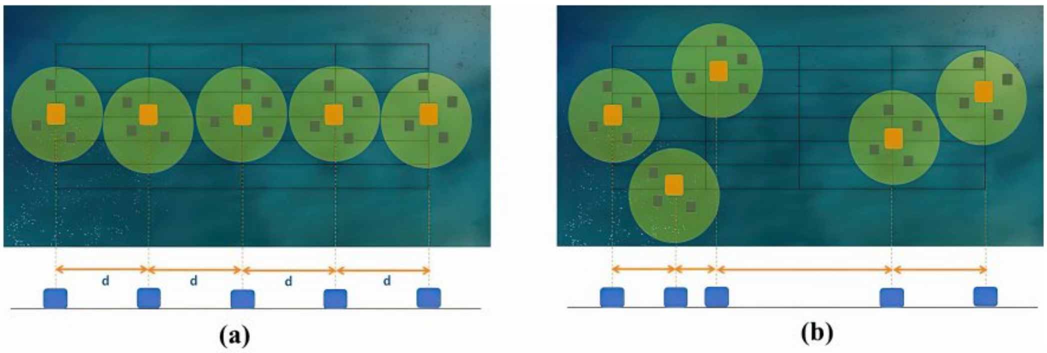

Figure 5.1: Orientation of Sensor Cluster with (a) Uniform cluster-heads (b) Random cluster-heads.

In case of uniform node deployment, greater rate of data transfer occurs at any time instance as a constant number of node is linked to the AUV for data transfer. On the contrary, in case of random node distribution the data transfer rate is non-uniform as the number of nodes connected to AUVs at each time instance keeps changing. Sometimes, a few nodes are connected and sometimes none, causing this fluctuation of data rate transfer. Thus, from the simulation output as shown in Fig. 5.2. it can be deduced that data generated by the uniformly spaced node is received at the sink faster compared to when the network is randomly deployed.

As a result, the uniform distance within the node cluster head is taken into account because it depicts a closer relation to the ideal case scenario.

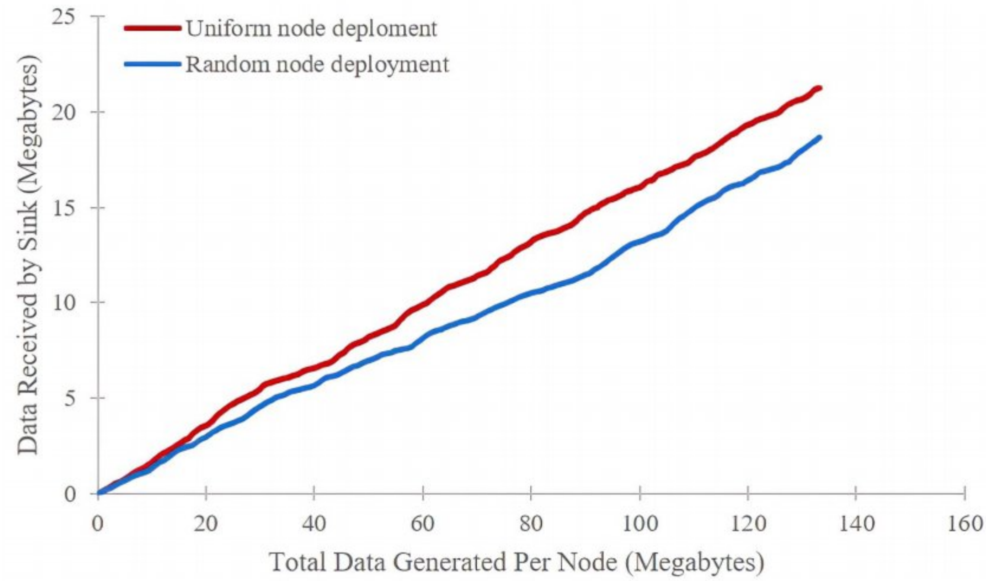

Figure 5.2: Effect of Uniform and Random Node deployment on Network Performance.

5.2 Optimal deployment of underwater AUV and surface sinks in UWSN

In the middle layer, data transmission is done to the AUVs and from AUVs to the boats by implementing various scenarios as shown in Fig. 5.3.

In Fig. 5.4 and Fig. 5.5 analysis of different number of boat classifications used in both scenarios are shown respectively.

The data sent by the AUV is limited to the maximum data packet of 5 kbps that can be transferred to the target devices causing data received by the upper level AUV to get limited as well. Thereby, after installation of two boats, no matter how many surface sinks are introduced the rate of data transfer between AUVs and boats does not increase. Now, it can be seen from the simulation that using two boats results in faster transfer of data, regardless of the number of AUVs employed in the two layers.

The main objective of this paper is to increase the rate of data transfer. So, when 3 AUVs are used, more data is received by the upper level AUV from the lower level AUV as an extra AUV is present in the bottom layer. Thus, from Fig. 5.6, among the two scenarios it can be concluded that the scenario with 3 AUVs gives the best flow of data to the surface sink.

Finally, the above-mentioned research proves that the scenario with three AUVs localized in two layers communicating with two boats provides the best possible data transmission in the U-IoT network model.

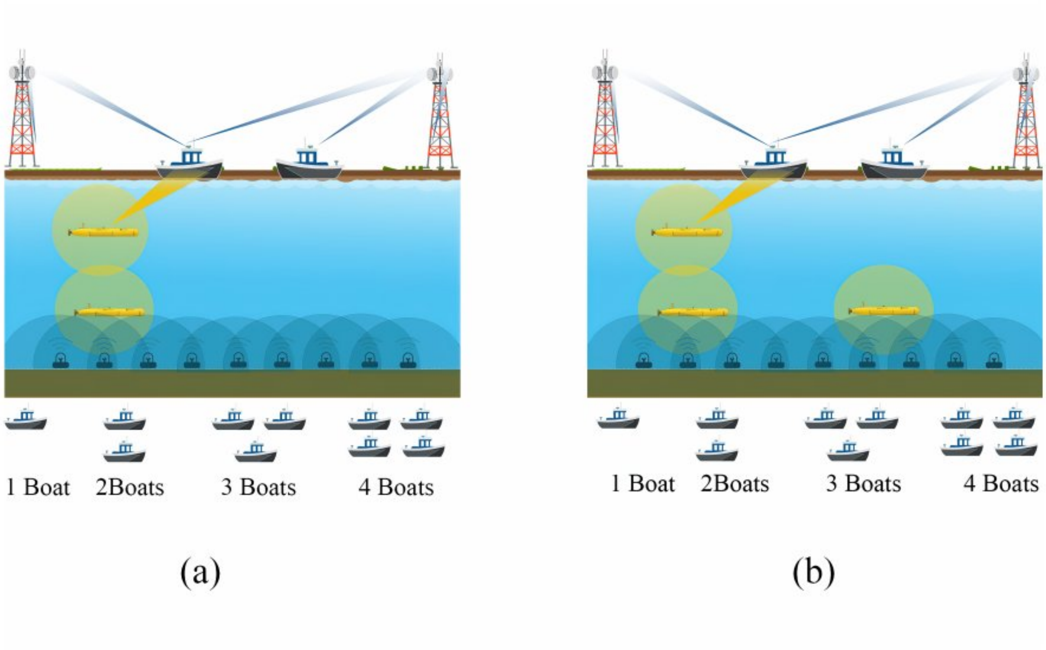

Figure 5.3: Scenario 1: AUV localization in U-IoT with 2 AUVs in double layer with respect to (a) 1 boat (b) 2 boats (c) 3 boats (d) 4 boats.

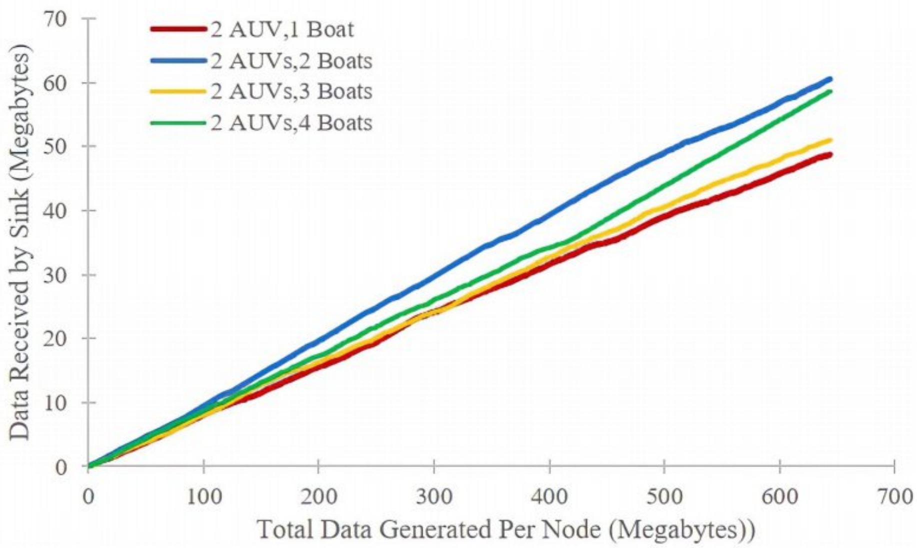

Figure 5.4: Effect of Scenario 1 on network performance.

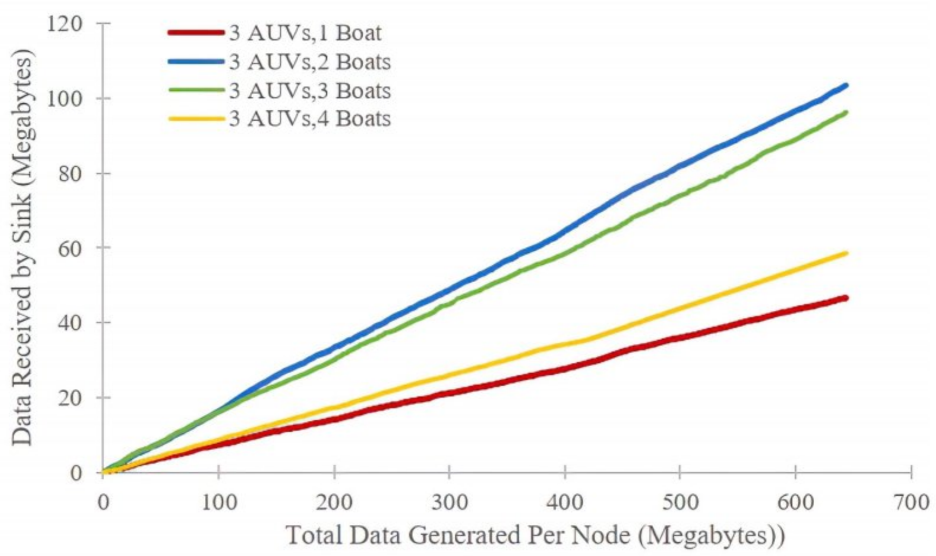

Figure 5.5: Effect of Scenario 2 on network performance.

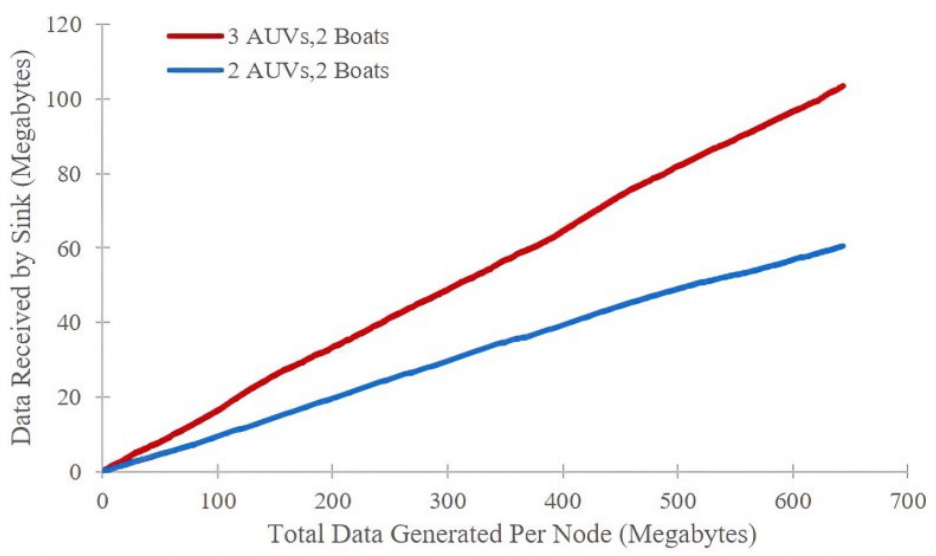

Figure 5.6: Comparison analysis of data packet delivery between different AUV combination.

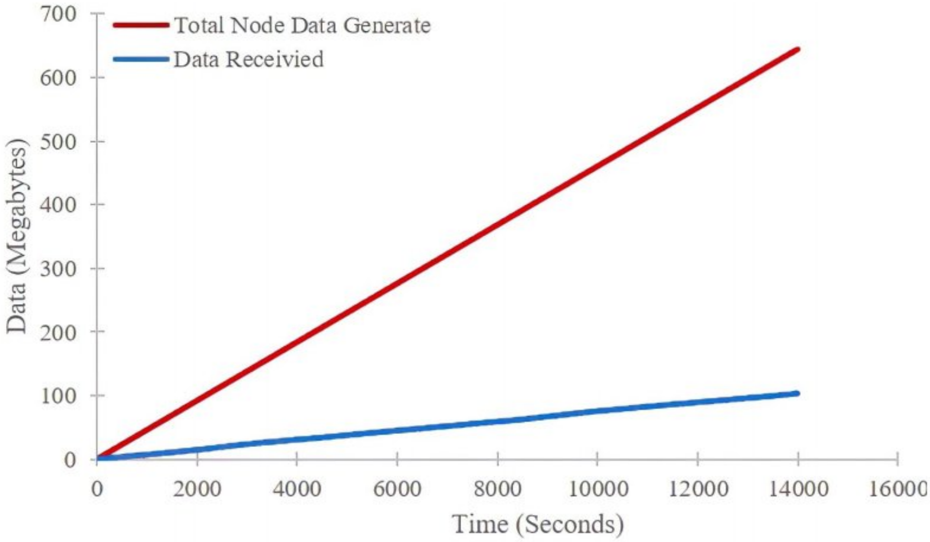

Figure 5.7: Co-relation of data packet sent from the Underwater Sensor Node and the received data volume at the Overwater Sink.

Chapter 6

Routing Protocol

In order to make an energy efficient Underwater sensor network model, it is necessary to choose a protocol that provides the best possible result. The target in this research is to make a routing protocol that not only provides energy efficient outcome but also an optimized rate of data transfer. Trade-off between these two parameters will provide the optimized result. The routing protocol worked with in this research is the Multi-beacon Mobile sink routing protocol. In this protocol, two phases are considered, one is the search phase and the other is the transfer phase. In the search phase, beacon signals are sent from the mobile sink to the sink node which indicates, if received the range in which the mobile sink is currently at. Similarly, in the transfer phase, beacons are also sent, which when received starts the transfer of data from the sink node towards the mobile sink. Moreover, whenever beacon signals are received in these two regions the duty cycle in increased to ensure higher percentage of data transfer. Otherwise, the duty cycle is maintained low to ensure low energy consumption.

6.1 State Diagram

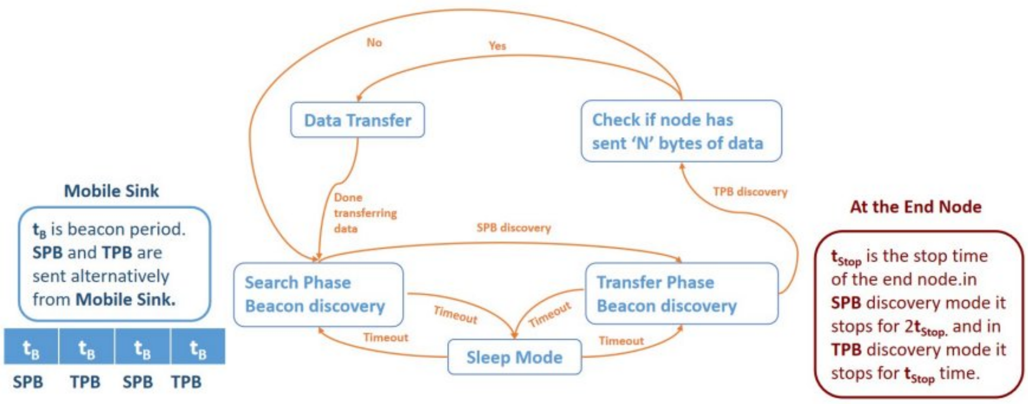

Figure 6.1: Multi-Beacon State Diagram

6.2 Pseudo Code

```
Calculate distance between mobile sink
and node
if distance > range
      send beacon signal;
      print spb_sent-count ++;

elseif distance < range
      send beacon signal;
      print tpb_sent-count ++;
      if data packet received
         print data_receive_count ++;
               send ack message;
         print ack_sent_count ++;
      end if
end if
```

Figure 6.2: Mobile Sink Pseudo Code

```
if spb beacon received
         if node is awake
         print spb_receive_count ++;
         convert to high duty cycle;
         else
         packet dropped;
end if
else if tpb beacon received
         if node is awake
         print tpb_receive_count ++;
         convert to high duty cycle;
if node_storage > "N" bytes
         send data packet;
         print data_sent_count ++;
          if ack message received
           print ack_receive_count ++;
          else
           print ack lost;
         end if
end if
else
         packet dropped;
         end if
end if
```

Figure 6.3: Sink Node Pseudo Code

Chapter 7

Conclusion and Future Scopes

In this research, it is demonstrated that the UWSN architecture can implement the U-IoT network model efficiently, which can be used to monitor marine environmental conditions and collect specialized data. The results discussed above also provide proper evidence for the usage of optimal carrier deployment both underwater and overwater. This ensures an efficient, automated and reliable rate of data transfer through the U-IoT device positioning. Moreover, the U-IoT network model that is created in this paper also allows 24/7 surveillance of marine life. Thus, the overfishing problem in Bangladesh can be mitigated, as a very detailed monitoring outcome is generated through the U-IoT network model.

Furthermore, this architecture model ensures proper marine life monitoring in any part of the world, resulting in long-term ecosystem preservation. It is also evident that underwater sensor networking is an area with a lot of room for advancement in the future. Further variables in IoT devices, like energy efficiency,storage capacity, carrier band limitation and other data routing protocols can help to improve the model even more.

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