DEPTH BASED FOG ASSISTED DATA COLLECTION SCHEME FOR TIME-CRITICAL IOUT APPLICATIONS

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Depth based Fog Assisted Data Collection Scheme for Time-Critical IoUT Applications

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Candidate of **Master of Science in Computer Science (MSCS)** at the National University of Modern Languages do hereby declare that the thesis **Depth based Fog Assisted Data Collection Scheme for Time-Critical IoUT Applications** submitted by me in partial fulfillment of MSCS degree, is my original work, and has not been submitted or published earlier. I also solemnly declare that it shall not, in future, be submitted by me for obtaining any other degree from this or any other university or institution. I also understand that if evidence of plagiarism is found in my thesis/dissertation at any stage, even after the award of a degree, the work may be cancelled and the degree revoked.

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ABSTRACT

Title: Depth based Fog Assisted Data Collection Scheme for Time-Critical IoUT Applications

The Internet of Underwater Things (IoUT) has emerged as a game-changer for underwater applications, with acoustic waves as its go-to communication medium. On the surface, radio signals dominate communication between sinks and onshore control centers. The fusion of IoUT with Fog Computing offers a robust platform for dynamic applications, from pipeline management to large-scale emergency responses and underwater infrastructure monitoring. Sink node delays in IoUT are primarily due to limited processing power, especially concerning routing protocols. Furthermore, redundant packet transmission, while forwarding data, not only escalates energy use but also introduces delays. The developed scheme is called Depth-based Fog Assisted Data Collection (DFDC) scheme for time-critical Internet of Underwater Things (IoUT) applications. DFDC leverages fog computing to ease the load on sink nodes, slashing packet delays to onshore control systems. Moreover, it deploys a strategy to curb redundant transmissions, enhancing latency and energy efficiency in the data forwarding process for ordinary underwater sensor nodes. DFDC is compared with a High-Availability Data Collection Scheme based on Multi-AUVs for Underwater Sensor Networks(HAMA) and Data Gathering algorithm for Sensors (DGS). Through extensive simulations and analysis, this research demonstrates that the DFDC protocol outperforms both HAMA and DGS in terms of reducing packet delivering ratio, conserving energy, and minimizing redundant data transmission. These findings underscore the potential of DFDC as a groundbreaking solution for improving underwater communication, promising more efficient and reliable data transmission in underwater scenarios. This study contributes valuable insights that can shape the future of underwater communication protocols.

Keywords: Internet of underwater things (IoUT), Fog Computing, Data Collection, Routing protocols, Delay.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IOT	-	Internet of Things
IOUT	-	Internet of Underwater Things
TWSN	-	Terrestrial Wireless Sensor Networks
UWSN	-	Under Water Sensor Network
DFDC	-	Depth Based Fog Assisted Data Collection
DBR	-	Depth Based Routing
DBRS	-	Distance Based Routing Scheme
DCR	-	Depth Controlled Routing
DFR	-	Dynamic Flooding-based Routing
DREE	-	Distance based Reliable and Energy Efficient
DV-hop	-	Distance Vector hop
FDBR	-	Fuzzy Depth Based Routing
FLQE	-	Fuzzy Logic based Link Quality Estimator
GPS	-	Global Positioning System
H 2-DAB	-	Hop-by-hop Dynamic Addressing Based
ICRP	-	Information Carrying based Routing Protocol
ISO	-	International Standards Organization
MRP	-	Multilayer Routing Protocol
NS-3	-	Network Simulator 3
RDBF	-	Relative Distance Based Forwarding
R-ERP2R	-	Reliable and Energy Efficient Routing Protocol
HAMA	-	High Availability Data Collection Scheme based on multi-AUVs
DGS	-	Data Gathering Scheme

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DEDICATION

This thesis is a testament to the love, support, and inspiration I have received from the most important people in my life.

To my parents, your sacrifices, encouragement, and unwavering belief in me have been the driving force behind my journey. You've given me roots to ground myself and wings to soar.

To my special one, Haid, This thesis is a testament of my love for you. With all my heart, your presence has illuminated every step of my journey. You are my inspiration, my motivation, and my greatest joy.

CHAPTER 1

INTRODUCTION

1.1 Overview

The concept of the Internet of Underwater Things (IoUT) has gained significant traction recently due to its applicability in a wide array of underwater applications, including monitoring, navigation, surveillance, and tracking, spanning various environmental, industrial, and military sectors. The growing interest in these applications has spurred research efforts aimed at developing routing protocols tailored for underwater environments characterized by acoustic communication. Over the years, numerous underwater routing protocols have been proposed to offer efficient mechanisms for sensing, gathering, and transmitting data to onshore control systems while keeping overhead to a minimum.

However, the unique conditions prevalent in underwater environments present a host of challenges when it comes to designing routing protocols that are both dependable and efficient. This research is driven by the need to tackle three primary issues. Firstly, it seeks to address the issue of elevated energy consumption during the information distribution phase. Secondly, it aims to mitigate the problem of prolonged end-to-end delays encountered during route planning and data forwarding phases. Lastly, it focuses on enhancing network lifetime, a factor that significantly influences network performance.

1.2. Motivation

Humanity has long been attracted by the aquatic environment, which also provided an important source of food, a means of transportation, and a storehouse for a variety of natural resources (such as coal mines, salt, and natural gases) [1]. Water is necessary for human living, thus despite the advancement of science and technology, it wasn't until the 20th century that genuine exploration of the previously unexplored underwater world started. It has been researched to understand the causes of natural occurrences like hurricanes, sea storms, tsunamis, etc. as over 10% of the earth's surface is covered by water [2]. Understanding the part that oceans play in climate change over inhabited land is vital. However, the hostile maritime environment (including high water pressure and extreme temperatures) and other unforeseen circumstances make unmanned exploration with the capacity for self-configuration and communication necessary [3] Unmanned exploration has led to the use of automated underwater sensor network technology and IoUT communication protocols.

The IoT (Internet of Things) has been used more and more in recent years in a variety of industries, including smart manufacturing, smart cities, intelligent transportation, environmental monitoring, and security systems [4-6], The Internet of Things (IoT) is made up of wireless and network edge device technologies [7, 8]. Mobile devices and mobile apps are becoming more and more essential to daily life as a result of the swift advancements in wireless technologies and mobile devices [9, 10]. They also provide tremendous possibilities for the future of Mobile Edge Computing (MEC) [10]. As a result, MEC can offer quicker service responses and lessen IoT network congestion [11]. Similarly, the underwater wireless sensor networks (UWSNs) are currently undergoing a robust development process due to the quick advancements in edge devices and wireless technologies[12].The conventional multi-hop data gathering techniques have some drawbacks in UWSNs, including excessive power consumption, severe power unbalance, and others.[13] In order to address issues with energy consumption imbalance, mobile edge elements—such as an autonomous underwater vehicle, or AUV—are now frequently deployed in underwater data collection[14].UWSNs are frequently utilized in supplemental navigation, the discovery of ocean resources, and the monitoring of the underwater environment. These applications are in great demand, but for them to perform well and gather data properly, this technology must be upgraded [10].

In the UWSNs, data collection is a crucial area of study. The acquired data is prone to loss when being transmitted over long distances by wireless signal in UWSNs. Sensor nodes need to transfer the data they have collected to the receiving node, which requires multi-hop routing, which uses a lot of energy [15]. Additionally, it is challenging to recharge the underwater movable edge components' battery. Therefore, the issue of how to lower nodes' energy usage has become critical.

Multiple sinks are utilized to reduce energy use while transferring data to the sink. There is no need for numerous hops because there are many sinks, which minimizes the distance from the node to the sink. By reducing the amount of distance the detected data must travel, many sinks significantly minimize energy consumption [16], but it has its own deployment drawbacks.

Data gathering and processing take a long time because it is difficult to operate computing equipment underwater and most aquatic locations lack high-speed connectivity capabilities. As a result, the scope and sophistication of IOT applications that can use these data are constrained [17]. To help address these concerns, intermediate data centers, also referred to as fog computing, are developed and implemented, between the end user (EU) and the cloud data center (DC) [18]. One of the most promising technologies for underwater sensor networks is fog computing. The purpose of this fog layer is to bring the processing operation closer to the edge of the network and to reduce response time for the EU. To address the concerns of latency and response time, by relocating networking, storage, and compute to the network's edge, where data is generated, a dispersed computing architecture known as "fog computing" is possible [19]. Fog computing technology offers numerous benefits for bolstering Internet of Underwater Things (IoUT) applications [20]. These advantages encompass enhanced support for low latency, mobility, location awareness, scalability, and seamless integration with other systems, notably cloud computing [21].

1.3 Underwater Scenario Environment

The Internet of Underwater Things (IoUT) has recently gained significant attention due to its versatility in enabling various underwater applications, including monitoring, navigation, surveillance, and tracking, across diverse environmental, industrial, and military domains. This heightened interest in IoUT applications has spurred research endeavors focused on the development of underwater routing protocols designed for acoustic communication mediums. Over the years, numerous underwater routing protocols have been proposed, featuring streamlined mechanisms for sensing, data collection, and transmission to onshore control systems, all while striving to minimize overhead.

Nonetheless, the inherent conditions of the underwater environment pose formidable challenges in the quest for the design of dependable and efficient routing protocols. The impetus driving this research lies in the necessity to confront several pressing issues. Primarily, it seeks to address the quandary of excessive energy consumption during the information distribution phase. Secondly, it endeavors to alleviate the problem of protracted end-to-end delays encountered in both route planning and data forwarding phases. Lastly, it is dedicated to enhancing network longevity, a pivotal factor significantly influencing network performance.

Numerous designs and strategies for the deployment of underwater sensor networks have been proposed in the literature, as evidenced by references [22], [23], [24], [25]. The deployment techniques can be categorized into two primary classes. There are two main classifications for wireless sensor nodes. The first classification is based on their motion characteristics, which can be categorized as either mobile or stationary nodes, or a combination of both known as hybrid nodes. The second classification is based on the coverage space of the nodes, which can be either two-dimensional (2D) or three-dimensional (3D) in nature [26]. The diagram presented in Figure 1.1[27] depicts the deployment of several sensor nodes in order to establish underwater acoustic wireless sensor networks. Anchor nodes refer to nodes that are affixed to a cable at the seabed through the use of anchors, while retaining the ability to move vertically within the cable's length.

The acquisition of data from specific sites through the utilization of anchor nodes and autonomous underwater vehicles (AUVs) offers notable advantages in terms of localization or establishing a point of reference for the nodes. In many instances, ordinary sensor nodes are deployed in submerged environments and possess the ability to freely navigate in accordance with the water currents. In contrast, alternative underwater routing protocols, such as the Information Carrying Based Routing Protocol (ICRP) [28], similarly rely on stationary sensor nodes. The primary purpose of these common nodes is to employ acoustic modems for the purpose of detecting, collecting, and transmitting the acquired data towards the sink. Although sink nodes are commonly stationary and positioned on the water's surface, it should be noted that this is not universally true [29].

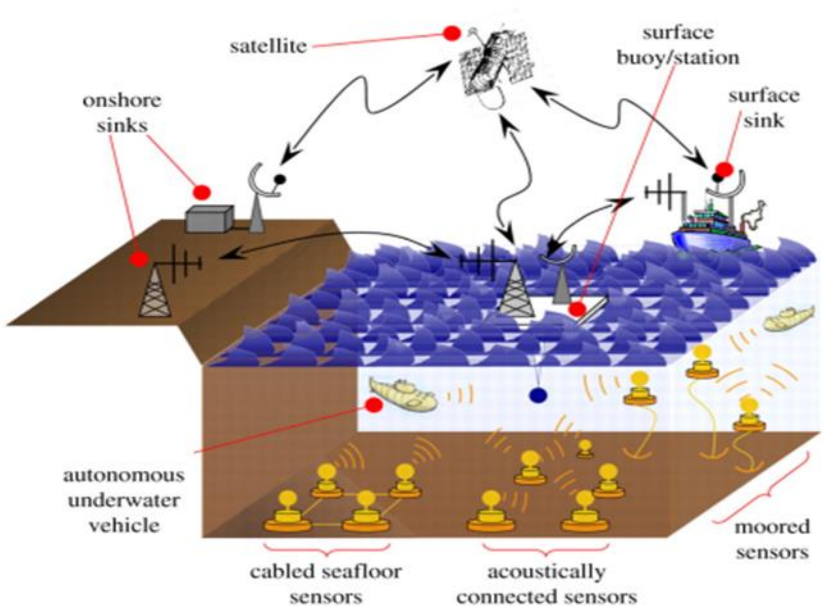


Figure 1.1: Different types of node deployment in UW-ASN [27]

Most sink nodes are equipped with both radio and acoustic modems. Acoustic modems are employed for the purpose of engaging ordinary underwater nodes, whilst radio modems facilitate inter-sink communication and enable interaction with onshore control centres. In order to transmit supplementary gathered data to a remote data centre for the purpose of data processing, on-site data collection centres employ either terrestrial or satellite connectivity.

1.4 Applications of IoUT

The Internet of Underwater Things (IoUT) is seen as a hopeful solution for dealing with the tough underwater conditions, where many sensor nodes need to work together. These applications are designed to tackle the difficulties of the underwater world. Some of these applications include underwater exploration for finding resources like oil or minerals, monitoring and controlling underwater pipelines, and setting up networks of optical cables for fast data transfer. Presented here is a concise overview of few of these applications:

1.4.1 Disaster Prevention

The integration of the Internet of Things (IoT) into disaster prevention holds immense promise for coastal regions facing seismic threats like earthquakes. IoT applications have the potential to provide continuous monitoring of critical environmental factors like soil stability, temperature variations, and atmospheric conditions. These applications, equipped with strategically placed sensors, could rapidly detect impending disasters and trigger immediate alerts. Coastal areas, which are often susceptible to seismic events and ensuing tsunamis, stand to benefit significantly from such systems. These timely warnings empower both individuals and authorities to take swift and informed actions, including initiating evacuation plans, alerting emergency services, and safeguarding critical infrastructure.

1.4.2 Environmental oceanic monitoring

The monitoring of the, fluctuations in the maritime environment, and the provision of weather forecasts. The UW-ASN system is widely regarded as a potentially effective approach for the surveillance of chemical, biological, and nuclear contaminants, as well as for the monitoring and research of aquatic fauna. The safety and detection of leaks in oil and gas pipelines are considered to be crucial applications in contemporary society. The increase in pipe length is positively correlated with heightened security risks and the requirement for enhanced monitoring. The security risk and monitoring significance are heightened by the considerable length of an undersea pipeline, which sometimes spans several miles [31].

1.4.3 Underwater exploration

The adoption of underwater exploration techniques, specifically harnessing the capabilities of IoUT (Internet of Underwater Things), represents a promising avenue for identifying and evaluating subterranean reserves of oil, gas, and valuable minerals. Additionally, these advanced underwater devices can serve a pivotal role in overseeing and managing complex oil and gas pipelines, ensuring their optimal operation and maintenance. Furthermore, the IoUT technology can be instrumental in deploying extensive optical cable networks for high-speed digital data transmission across aquatic environments, opening up new possibilities for efficient and secure data connectivity in underwater domains.

1.4.4 Tactical Surveillance and Targeting

Oceanic sampling in the Internet of Underwater Things (IoUT) can be effectively conducted through the utilization of Autonomous Underwater Vehicles (AUVs). This enables the comprehensive and collaborative collection of samples from the three-dimensional oceanic environment. The IoUT is capable of performing tactical surveillance, targeting, and incursion detection inside a three-dimensional underwater environment through the utilization of Autonomous Underwater Vehicles (AUVs). In underwater surveillance exhibits superior performance compared to traditional terrestrial radar systems when it comes to detecting low signature targets [13].

1.4.5 Assisted Navigation

Leveraging the power of the Internet of Underwater Things (IoUT) facilitates precise and efficient navigation, detection, and support for submarines and ships. This technology enhances maritime operations by providing advanced navigation assistance, enabling submarines to navigate safely and effectively through complex underwater environments. Additionally, IoUT aids in the detection of potential hazards and obstacles, further enhancing maritime safety. Overall, IoUT plays a crucial role in modernizing and streamlining underwater navigation processes, contributing to the effectiveness and security of submarine and ship operations.

1.5 Constraints in UW-ASN

In recent years, interest in underwater sensor networks as a developing field has grown quickly [32], [33]. On the one hand, underwater sensor networks enable a variety of aquatic applications, including the gathering of oceanographic data, the monitoring of pollutants, offshore exploration, and tactical surveillance applications. On the other hand, the unfavorable underwater circumstances present significant obstacles to effective networking and communication. Due to its rapid attenuation in water, radio does not function effectively in underwater conditions. Acoustic channels are therefore frequently used. Acoustic signals travel through water at a speed of around $1.5*10^3$ m/s, which is five orders of magnitude slower than radio waves at $3*10^8$ m/s. In addition, a variety of variables, including path loss, noise, multipath fading, and Doppler spread, have an impact on underwater acoustic channels. All of these increase the likelihood of errors in acoustic channels. In summary, underwater acoustic channels have a high error probability and a long propagation latency. It is exceedingly difficult to offer energy-efficient, dependable data transport for time-critical applications (such pollution monitoring and submarine detection) in such demanding network settings [17].

First, it is challenging to satisfy the latency requirements with traditional retransmission-upon-failure techniques. Simple example: If two nodes are 500 m apart, the propagation delay will be around 500/1500=1/3s. For some time-sensitive applications, even a single retransmission after a failure will impose an additional delay of at least 1/3 * 2= 2/3s. Thus, fewer or no retransmissions are preferred to achieve specific latency requirements. Conversely, when retransmission is reduced or eliminated, it often necessitates boosting the transmission power of each node to achieve a desired level of communication reliability by reducing the end-to-end packet error rate [17]. This, however, frequently results in increased energy consumption, which lowers the network's energy efficiency. Since underwater nodes are often powered by batteries, whose replacement or recharging is highly difficult, if not impossible, in hostile underwater settings, underwater sensor networks are considerably more energy-constrained than their terrestrial counterparts [33]. Therefore, one of the most crucial design factors for underwater networks is reducing overall energy usage.

Therefore, when developing routing protocols for incorporating them, it is crucial to consider the limitations of the auditory medium. The conversion of radio channels to acoustic channels has a negative impact on the performance of standard wired and wireless routing algorithms. New routing protocols and algorithms are therefore required that can support real-time applications and the harsh underwater environment while still allowing for efficient communication. In conclusion, a new transmission method that has a low latency and good energy efficiency is ideal for underwater sensor networks where time-critical applications are required.

1.6 Problem Background

Ensuring reliable data transmission for time-sensitive applications while conserving energy poses a noteworthy challenge due to the prolonged propagation delay and increased error rates characteristic of acoustic channels. A non-manned solution, like routing protocols, is required for efficient data collection and monitoring for real-time applications used in large-scale environments. A network where nodes may effectively connect with one another using acoustic wireless networks while also being capable of data relaying and communication with an offshore control system. This means that the communication overhead must be limited by a minimum threshold in order to increase network lifetime in terms of energy and prevent additional delay in the slower acoustic medium.

A balanced energy usage should be taken into account when designing a data gathering and forwarding method in order to increase the network lifespan [30]. Multiple studies have provided evidence that the utilization of routing protocols involving autonomous underwater vehicles (AUVs) for data collection is an effective strategy to achieve lower and more evenly distributed energy consumption [27]. In this approach, AUVs, either singly or in multiples (multi-AUVs), traverse the network to collect data from the sensor nodes [34]. Importantly, the nodes do not rely on long-distance and multi-hop communication to transmit data to a sink. This strategy aims to achieve reduced and balanced energy consumption, consequently extending the network's lifespan, they send data using AUVs based on short-range communication. When creating a routing system for AUVs, two crucial factors need to be taken into account. These include the AUVs' mobility model and the nodes' method of data transfer [32]. Although AUV applications have advanced UWSNs, employing them for data collection presents a number of difficulties. For instance, the network is disrupted when an AUV fails to provide data collecting service, which affects the accuracy and causes delay of the timing for nodes to gather data. AUVs are also unable to function correctly due to the complex and dynamic underwater environment. In order to overcome these difficulties, a multi-AUV-based high-availability data gathering strategy (HAMA) for UWSNs was developed [35]. The average delay is greater for HAMA, though.

One of the most significant challenges in these networks is successfully utilizing this energy because underwater network nodes have limited battery capacity. The delivery of routing services while using less energy during operations like message transmission and reception, interference reduction, error reduction, and error rate reduction is what is meant by energy efficiency in routing protocols [36]. There are few protocols which spend too much work creating the distribution path for information [37], examples include: H2 -DAB and R-ERP2R.The backup pathways that former protocol never utilizes are kept [38]. On the other hand, it uses uncontrolled flooding, in which every new item of information received at a node, such as a distance, is disseminated throughout the network. Underwater network protocols include a considerable propagation phase that creates a conduit for data delivery. These protocols overload networks with unnecessary traffic that either isn't needed for data transfer or isn't required to establish up a data channel [37].

1.7 Problem Statement

In the realm of underwater communication, the deployment of Internet of Underwater Things (IoUT) nodes presents a unique set of challenges due to the inherent limitations of these nodes. IoUT nodes are equipped with constrained resources, including limited battery power, storage capacity, and computational capabilities. These constraints stem from the harsh and resource-scarce underwater environment in which they operate.

One of the central challenges faced by IoUT networks is the scarcity of sink nodes. Sink nodes play a pivotal role in collecting data from distributed sensor nodes and relaying it to on-shore control systems. In underwater environments, the mobility of sensor nodes introduces complexities in acoustic communication. When intermediate nodes are required to relay data over extended distances, it can lead to significant delays in data forwarding, which can be detrimental to real-time applications and decision-making processes.

Ensuring reliable data transmission in underwater environments requires nodes to expend additional energy, primarily due to challenges associated with acoustic communication and the need for data to traverse varying depths and distances. However, underwater nodes operate within stringent energy constraints, and recharging or replacing their batteries is a complex and costly endeavor. As a result, developing energy-efficient routing protocols tailored explicitly for underwater scenarios is of paramount importance.

Traditional routing protocols, which are well-suited for land-based wireless sensor networks, are ill-suited for underwater sensor networks. The underwater environment introduces factors such as long propagation delays, high mobility of nodes, restricted bandwidth, multipath propagation, and the Doppler Effect, all of which have a profound impact on communication and routing. These factors necessitate the creation of routing strategies that are adapted to the underwater context.

Furthermore, underwater nodes often engage in re-transmissions of data packets due to communication challenges, which exacerbates energy consumption. This underscores the need for a data gathering strategy that not only optimizes energy usage but also minimizes transmission delays. In essence, the unique characteristics of underwater environments, including limited resources, communication challenges, and the need for energy efficiency, call for tailored solutions that can fully harness the potential of IoUT applications in underwater domains. Developing and implementing such solutions is vital for advancing the capabilities and effectiveness of underwater sensor networks.

1.8 Research Questions

The main research questions pertaining to this study, based on the enumerated research objectives, are as follows:

- What measure should be taken to avoid higher delay caused by low processing capabilities of sink and energy consumed by intermediate sink nodes in re-transmission attempts?

- How can redundant packet forwarding by ordinary underwater nodes be reduced and energy consumption be improved?

1.9 Aim of Research

The development of effective data gathering schemes in the context of Underwater Acoustic Sensor Networks (UASNs) is beset by numerous intricate challenges. These challenges stem from the unique characteristics of underwater environments, including prolonged signal propagation times, the inherent mobility of underwater nodes, bandwidth limitations, the existence of multiple transmission paths, and the impact of the Doppler Effect on signal frequency. In light of these challenges, this research endeavors to introduce an innovative underwater sensor cloud system underpinned by fog computing technology, with a particular emphasis on addressing the demands of time-sensitive underwater (IOUT) applications.

Fog Computing, as an expansion of the conventional Cloud Computing model, offers the potential to bring computing and processing of data capabilities nearer to the network's periphery. This paradigm shift paves the way for an entirely new generation of applications and services [10]. Fog Computing is characterized by several defining features, including minimal latency and location awareness, extensive geographical coverage, support for mobility, a high number of network nodes, a strong emphasis on wireless connectivity, a prevalence of streaming and real-time applications, and a heterogeneous network environment. This architecture departs from the conventional setup of underwater sensor networks, which typically involve either a single central sink node or multiple such sinks. The proposed approach seeks to establish a mechanism wherein vehicles can collaboratively change their pseudonyms, particularly when they share estimated locations.

Within this architectural framework, fog nodes play a pivotal role. These nodes are equipped with substantial computational and storage capabilities, enabling them to execute critical tasks such as data processing, dimension reduction, and redundancy elimination. They perform these operations on data collected from ordinary sensor nodes, which may have limited computational resources. Once the data is processed and compressed, fog nodes facilitate its transmission to a central surface sink node [39]. This central sink node, acting as an intermediary, is responsible for relaying the data to the cloud computing center. Moreover, this research project aims to devise a depth-based fog-assisted data collection protocol tailored explicitly to the needs of time-sensitive IOUT applications.

In essence, this research represents a significant stride toward enhancing the efficiency and effectiveness of underwater sensor network protocols. By leveraging the capabilities of fog computing and addressing the unique challenges posed by underwater environments, this approach has the potential to revolutionize data collection and processing in the realm of UASNs, ultimately benefiting a wide array of applications in underwater monitoring, exploration, and surveillance.

1.10 Research Objectives

- To design and develop a scheme that improves delay occurred at sink node when forwarding packets to onshore control systems.
- To design and develop a scheme to reduce redundant packet transmission by ordinary underwater nodes to improve energy consumption

1.11 Thesis organization

This thesis' remaining sections are organized as follows: Chapter 2 gives background information on the subject and goes on to examine related problems with underwater networks. The existing underwater routing protocols are categorized, and their advantages and disadvantages are discussed. Additionally, a detailed operational working comparison of the various protocols for underwater networks is provided.

The research gaps that were used to create and develop the fog-based routing protocol are finally covered in Chapter 2. In Chapter 3, the design of the depth-based, fog-assisted, reliable, and energy-efficient routing protocol is covered in detail along with the technique used to create it. It outlines the issues with the benchmark routing protocols and gives fixes for them. In Chapter 3, the methodological plan's objectives are clearly explained. Details on the simulation framework, the channel model, and node energy are provided .

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

In this section, we delve into the background of Internet of Underwater Things (IoUT) vehicles, shedding light on their core concepts and the primary challenges they encounter. We proceed by conducting a comprehensive review of existing studies in this domain, encompassing the latest research developments and insights. Subsequently, we draw distinctions between different categories within IoUT vehicles, accompanied by a detailed discussion of their respective operational frameworks.

Building on this, we engage in a comparative analysis of past techniques and methodologies, considering their strengths and limitations. This critical evaluation provides valuable insights into the evolution of IoUT vehicles and their practical applications. Furthermore, we pinpoint research gaps that persist in the current body of knowledge, highlighting areas where further investigation is warranted.

Ultimately, this section culminates in a comprehensive conclusion that synthesizes the key findings and contributions of the entire chapter. Through this structured approach, we aim to provide a clear and cohesive understanding of the landscape surrounding IoUT vehicles, from their foundational principles to the latest advancements and the potential avenues for future research.

2.2 Underwater sensor network

This chapter undertakes a critical review of the relevant literature to provide the necessary background information and establish a solid foundation for the research and material discussed in subsequent chapters. The demand for underwater applications, Examples of these applications include oil and gas exploration, disaster prevention, ship navigation support, and intrusion detection, necessitates the maturity of technology to effectively collect data from underwater sources. The rapid advancements in IoT (Internet of Things) and wireless technologies have led to the vigorous development of underwater wireless sensor networks (UWSNs). However, UWSNs face challenges due to their acoustic channels with limited available bandwidth, variable delay, and harsh underwater environment. Additionally, the emergence of new applications further necessitates a comprehensive review and attention to UW-ASN [40].

2.3 Data Collection Schemes for Underwater Sensor Networks

. Underwater Wireless Sensor Networks (UWSNs) form a comprehensive monitoring system, comprising numerous sensor nodes endowed with communication, data collection, and computing capabilities. Data collection stands as a pivotal domain within UWSNs and can be likened to a mobile edge application [44]. Modern underwater applications generate vast datasets, including high-definition video, audio, and images. However, when transmitting this data over long distances through wireless signals in UWSNs, there's a considerable risk of data loss. Sensor nodes collect data that must be sent to a receiving node, often necessitating multi-hop routing, which consumes substantial energy [18]. Moreover, recharging the batteries of underwater mobile elements presents a formidable challenge. Consequently, the imperative issue at hand is how to curtail node energy consumption. Considering the presence of mobile elements specialized in gathering of data within the network, routing protocols for Underwater Wireless Sensor Networks (UWSNs) can be classified into two categories: those that do not involve mobile elements and those that incorporate mobile elements [35].

2.3.1 Routing Protocols without Mobile Elements

Without mobile elements, all sensor nodes in underwater sensor networks (UWSNs) are immobile and unable to move or navigate in the underwater environment. Without mobile elements, routing protocols transfer data from nodes to neighboring nodes first, then the receiver continues the process until the data is sent to a sink.

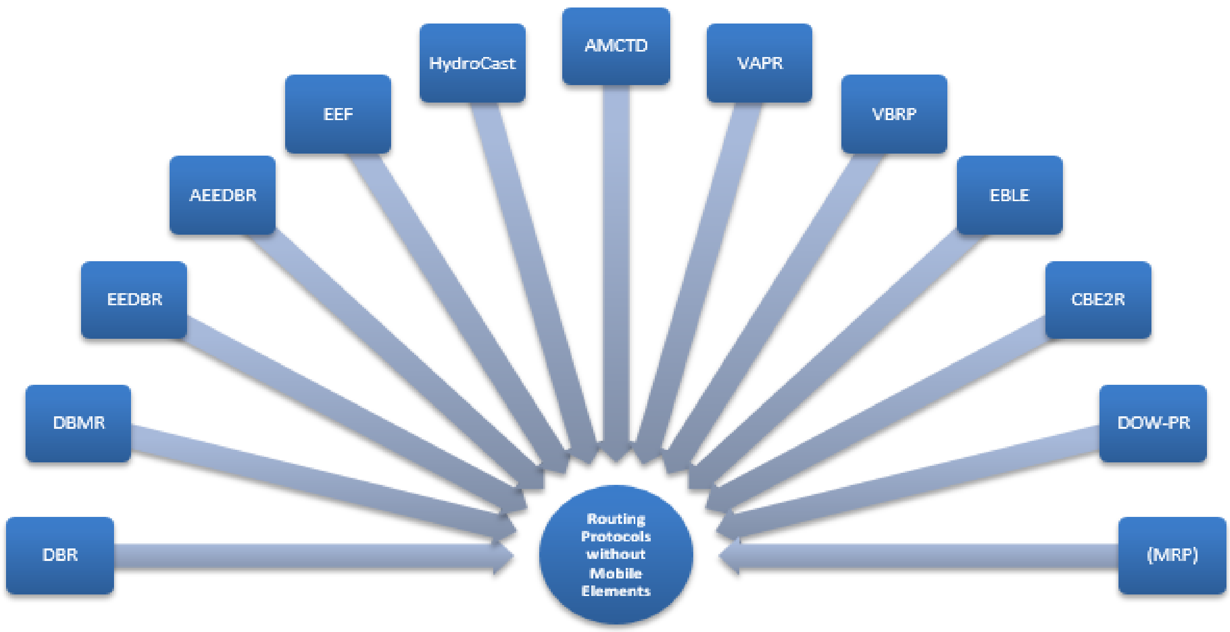


Figure 2.1: Routing Protocols without Mobile Elements

In the described approach, data is relayed hop by hop, passing from one node to another due to the limited transmission distance of these nodes. To improve network performance, it's crucial to implement an efficient routing protocol [35].

In a pressure-based routing protocol [45], the protocol operates without the need for location information of the nodes. Its primary objectives are to ensure communication which is reliable and reduce the usage of energy of the nodes. During the development of this protocol, several factors, including link quality, depth, and residual energy, were taken into account. The protocol calculates routing costs based on two main factors: the residual energy of nodes and the overall network quality. Data transmission decisions are influenced by both the routing cost and the depth of the source node. This protocol shows promise in improving both network longevity and the successful delivery rate of packets. However, while it effectively reduces end-to-end delays, it does not adequately address the issue of excessive computational load on sink nodes, which can result in higher delays for time-sensitive applications.

The authors proposed a modified version of the Vector-Based Forwarding Protocol (VBF), referred to as the Vector-Based Routing Protocol (VBRP) [46]. In the context of the VBF protocol, data transmission between nodes relies on the use of a routing pipe for forwarding information. Altering the radius of this routing pipe can impact the number of forwarding nodes and subsequently affect energy consumption. A smaller radius reduces both the number of forwarding nodes and can significantly influence the packet delivery ratio. To address these challenges, the Vector-Based Routing Protocol (VBRP) is introduced. In VBRP, the radius of the "pipe" depends on the underwater network's dimensions and node count. This protocol effectively manages energy usage among nodes and enhances packet delivery, although it does not fully address network lifetime and the computational load on sink nodes.

In their study, Wang et al. introduced a protocol referred to as the energy balanced and lifetime extended routing protocol (EBLE). The primary objective of this protocol is to achieve a balance in energy consumption while simultaneously prolonging the overall lifespan of the network [47]. The protocol employs a load balancing mechanism that takes into account the remaining energy of the nodes, while also streamlining data transmissions through cost-effective routes. In this system, nodes share information about their positions and remaining energy levels. It maintains a list of potential forwarding nodes and calculates the cost associated with currently available nodes. Data is then directed along paths characterized by high remaining energy and low cost. This protocol successfully reduces energy usage and extends the network's overall lifespan; nevertheless, it does not specifically address the packet delivery ratio and computational burden on sink node.

Ahmed proposed a Clustered-Based Energy Efficient Routing Protocol (CBE2R) for underwater wireless sensor networks [48]. The primary goal of this protocol is to maximize the battery life of nodes by employing a clustered approach. The network is divided into seven distinct layers, and it strategically places stationary courier nodes across these layers, consisting of two node types: source nodes and ordinary nodes. Source nodes are positioned at the deeper layers of the underwater environment, while ordinary nodes are dynamically deployed in the lower layer. The courier nodes are strategically located in the lower level to efficiently collect data from ordinary nodes. Data gathered by intermediary nodes is then relayed to a central receiver on the surface via these intermediary nodes. This protocol significantly improves network performance, extends its overall lifespan, and reduces node energy usage. However, it should be noted that implementing this network comes with increased costs due to the inclusion of courier nodes.

In reference [49], Wadud introduced a routing system known as DOW-PR, which stands for DOlphin and Whale Pods Routing system for Underwater Wireless Sensor Networks (UWSNs). The researchers considered the number of hops from potential forwarding nodes to a sink, specifically focusing on the first and second hops. The network utilized three distinct types of nodes, namely sink nodes, relay nodes, and anchoring nodes. The sink nodes are situated at the surface of the sea, in contrast, the anchored nodes, responsible for gathering data from the surroundings, are securely positioned at the bottom. Relay nodes, employed for the purpose of data forwarding, are strategically positioned at various levels within the network. The process of selecting a route is determined by the disparity in depth between the initial and subsequent hops of the prospective forwarding pathway. The study reveals that there is an improvement in the packet delivery ratio and a decrease in the end-to-end delay. Nevertheless, it is important to note that the expenses related to deploying of heterogeneous networks are comparatively more.

Gomathi and her team introduced a multi-layered routing protocol (MRP) in their study, aiming to optimize routing for minimizing communication delay and maximizing network lifespan [50]. This protocol creates a relay pathway for forwarding requests from one node to another until they reach their destination. The routing path, which accumulates the highest energy usage, is accountable for data forwarding. Implementing this protocol results in reduced energy consumption among the nodes, decreased communication delay, and potential enhancements in the overall network lifespan. However, it's important to acknowledge that this protocol also presents challenges related to network lifespan and an increased computational burden on the sink node.

In [51], the authors introduced a routing system that employs fuzzy logic and vector-based data-forwarding. This protocol considers both location and energy information when establishing routing paths. It takes into account various parameters, including energy levels and distances, resulting in favorable performance in terms of energy efficiency, communication delay reduction, and ensuring communication reliability.

2.3.2 Routing Protocols with Mobile Elements

Mobile elements in underwater sensor networks (UWSNs) refer to devices that can move on their own or under control in the water. Mobile elements can change positions and move through the water, in contrast to immobile fixed sensor nodes. In routing protocols employing mobile elements, data transmission from nodes occurs either via single-hop or multi-hop methods to reach the mobile element(s), which subsequently relay the data to a sink or onshore control station [35].

The implementation of this routing system, specifically in the context of mobile data collection, has been observed to result in a notable reduction in energy consumption among the nodes involved. Additionally, it has been found to enhance the packet delivery ratio. Consequently, the implementation of this routing system, specifically in the context of mobile data collection, has been observed to result in a notable reduction in energy consumption among the nodes involved. Additionally, it has been found to enhance the packet delivery ratio. Consequently, a growing body of scholars has directed their attention towards the collecting of mobile data, resulting in significant advancements in this field [35].

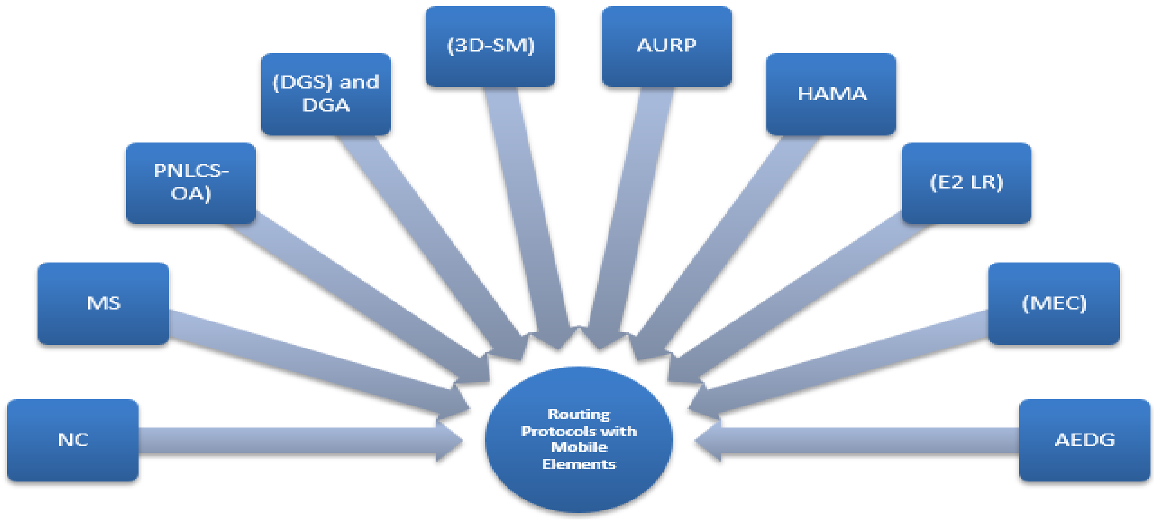


Figure 2.2: Routing Protocols with Mobile Elements

The authors introduced a mobile data collection protocol designed to optimize energy usage. In this protocol, a mobile surface node is employed to collect data from underwater nodes [52]. The undersea environment is divided into several sub-zones, and data collection is facilitated by a mobile surface node through a practical node cooperation protocol. In this collaboration protocol, a source node broadcasts packets, which are then received by all nearby nodes. If the destination node does not receive the data successfully, the neighboring node that initially received the packet from the source node will transmit it to the intended destination. While this protocol demonstrates relatively low energy consumption, it does impose computational burdens on sink nodes. The nodes use multi-hop transmissions to facilitate data exchange. Additionally, in the event of a failure of the surface mobile node, timely delivery of data to a sink is not possible.

In a prior investigation [53], a data collection method was introduced that takes into account the energy limitations of nodes, aiming to optimize the network's longevity. This proposed system is compatible with networks that can handle delays. The network is divided into several sections based on spatial proximity to the data collection stations. The mobile sink travels across various locations, pausing at each to collect data from the nodes. This approach involves modeling the movement and duration of travel of the mobile sink as an optimization challenge. While the protocol effectively extends the network's lifespan, it does exhibit shortcomings in case of a mobile sink failure.

The probabilistic neighborhood-based data gathering approach was proposed [54]. The technique employs a probabilistic underwater acoustic communication model known as PNLCS-OA, together with the parameter of data collection distance. The data collection distance is adaptively adjusted depending on the demand probability. In this approach, an Autonomous Underwater Vehicle (AUV) is utilized to collect data by the nodes. while computing the probability of neighborhood coverage, there's no need for the AUV to visit all nodes for data collection. This method successfully reduces and balances the energy usage of the nodes. Furthermore, if an AUV failure occurs, the nodes are unable to transmit the sensed data to a sink, rendering the algorithm non-functional.

In a previous study [55], a data gathering algorithm utilizing a probabilistic neighborhood-based approach was introduced. This algorithm incorporates a probabilistic underwater acoustic communication model. An autonomous underwater vehicle (AUV) navigates within the network and acquires data from the various nodes. In order to minimize network latency, the autonomous underwater vehicle (AUV) selectively avoids traversing certain nodes. The network is partitioned into multiple sub-regions, wherein the Autonomous Underwater Vehicle (AUV) navigates to the central location of each sub-region in order to gather data from the individual nodes. The method successfully achieves a reduction in energy consumption. However, it fails to address the processing mechanism in the event of an Autonomous Underwater Vehicle (AUV) failure.

Cheng et al. presented a data gathering protocol for sensors (DGS) along with a data gathering algorithm (DGA) that takes into account the data's significance [56]. An Autonomous Underwater Vehicle (AUV) traverses the network and collects data from different nodes. The collected dataset is classified into two categories: significant data and regular data. Regular data is directly received by the AUVs, while crucial data is relayed to a sink using multi-hop transmission. This protocol demonstrates an improvement in the successful packet delivery ratio.

Simultaneously, the nodes in close proximity to an Autonomous Underwater Vehicle (AUV) have higher energy consumption rates and exhibit premature failure. Furthermore, the network's functionality is compromised in the event of an Autonomous Underwater Vehicle (AUV) failure.

In their publication [57], the authors introduced a data gathering system named 3D-SM. This system utilizes a mobile sink and three cluster heads for data collection purposes. Both the mobile sink and cluster heads have mobility within the network. Sensor nodes transmit the data they collect to the mobile sink and cluster heads based on the spatial distribution of the source nodes. Eventually, the data gathered from the cluster heads is relayed to the mobile sink. This protocol has the potential to extend the network's lifespan. However, if the mobile sink or cluster heads encounter malfunctions or failures, the network becomes non-operational.

The authors, Naveed et al., introduced a routing protocol called AEDG, which utilizes an Autonomous Underwater Vehicle (AUV) [58]. An autonomous underwater vehicle (AUV) navigates within the network. Nodes in proximity to the trajectory of an Autonomous Underwater Vehicle (AUV) are referred to as gateway nodes, while the remaining nodes are denoted as member nodes. The gateway nodes take the lead in transmitting control packets, with member nodes sending data to the gateways using the received signal strength indication (RSSI). Subsequently, data originating from the gateway nodes is relayed to an Autonomous Underwater Vehicle (AUV). This approach demonstrates a significantly improved delivery of packet and reduced energy usage. Nevertheless, issue of the overburden computation on the sink nodes arises, wherein the nodes in close proximity to the trajectory have a greater forwarding burden for the Autonomous Underwater Vehicle (AUV). In the event of an autonomous underwater vehicle (AUV) malfunction, the entirety of the collected data will be irretrievably destroyed.

Seokhoon and colleagues introduced an innovative underwater routing protocol (AURP) designed to enhance the performance of underwater wireless sensor networks (UWSNs) by employing autonomous underwater vehicles (AUVs) [59]. The protocol utilized by AUVs entails gathering data from the nodes closest to them, which, in turn, collect data from other nodes to minimize energy consumption. To achieve this, nodes and AUVs utilize long-distance, low-rate communication for control packet transmission, capitalizing on its small size. Data transmission between nodes employs midrange communication, striking a balance between speed and accuracy. For proximity between AUVs and the sink, communication protocols prioritize short-range, high-speed transmissions. While the protocol demonstrates a high delivery of packet ratio, the presence of numerous control packets in the network results in increased power consumption. Additionally, the methodology does not account for malfunctioning AUVs.

Guangjie Han proposed a data gathering strategy with high availability to mitigate the likelihood of failure in Autonomous Underwater Vehicles (AUVs) and the issue of an excessive amount of control packets. The utilization of many autonomous underwater vehicles (AUVs) inside the network results in a decrease in energy consumption by the individual nodes. The reduction in the quantity of control packets within the network can be attributed to the utilization of predetermined trajectories for Autonomous Underwater Vehicles (AUVs) and the implementation of a reliable communication time mechanism, which guarantees dependable transmissions [35]. The method for detecting and rectifying malfunctions ensures the data collection scheme maintains a high level of availability in the event that an Autonomous Underwater Vehicle (AUV) fails to gather data.

2.4 Comparison of Routing Protocols without Mobile Elements

Table 2.1: Summary of Schemes

Protocols	Factors	Packet Delivery Ratio	Energy Consumption	End-to-End Delay	Advantages	Disadvantages
Routing Protocols without Mobile Elements						
DBR	Only Depth	Medium	high	high	• Reduce cost (didn't use full location information). • Use multisink (reduce battery drain and high traffic)	Use only one parameter (depth information). • Decrease network lifetime (using the same node many time as a next forwarder node). • High energy consumption (redundant packet transmission). • High end-to-end delay. •Communication void.
DBMR	Depth Node ID Residual energy	Medium	medium	high	Reduce energy consumption (using single best path).	Communication voids (high packet loss). • Didn't use link quality. • Reduce throughput.
EEDBR	Depth Residual energy Priority value	high	low	low	Provide energy balancing (use residual energy with depth information) • High	Communication void. • Delay (adding list of forwarding along the packets). • Didn't use link quality

					delivery ratio	
AEEDBR	Depth Residual energy	Medium	medium	medium	Provide energy balancing (employ residual energy).	Communication void. • Delay (adding list of forwarding along the packets). • Didn't use link quality
EEF	Depth Residual energy Fitness value	Medium	low	medium	Less energy consumption. • Reduce end-to-end delay	Communication void. • Didn't use link quality. • Transmission of same packets (didn't update history of sent packets)
HydroCast	Depth Link quality	high	medium	medium	Reduce end-to-end delay. • High delivery ratio. • Void handling (using recovery path).	High energy consumption (repeating the process of finding detour path). • High overhead (using two hop neighboring nodes).
AMCTD	Depth Courier node Residual energy	high	medium	low	Reduce communication void (courier nodes). • High throughput.	High energy consumption (extra use of hello packets). • High end-to-end delay (increase the waiting time).
VAPR	Depth Hop count Sequence number Link quality	high	high	high	Reduce end-to-end delay. • Void handling (directional opportunistic data forwarding algorithm). • Use multisink (reduce	High energy consumption (enhance beaconing).

					battery drain and high traffic).	
VBRP	based on the routing pipe	high	low	high	Minimizes node energy consumption and enhances packet delivery efficiency	The issues concerning network longevity and coverage gaps remain unresolved.
EBLE	Determined by the remaining energy of the nodes.	Low	low	medium	It equalizes the traffic distribution by considering the remaining energy of the nodes and optimizes data transfers.	The issue of the packet delivery ratio remains unaddressed.
CBE2R	based on a cluster	medium	low	low	Enhances network throughput, extends network longevity, and decreases energy consumption	deployment cost of the network is high
DOW-PR	Based on the hops count	medium	low	low	high Packet Delivery Ratio (PDR), low energy tax, Increased the network lifetime.	The deployment expenses for the heterogeneous network are comparatively elevated.
(MRP)	Based on multilayered routing	high	medium	medium	high Packet Delivery Ratio (PDR),	dependable data transfer

2.5 Comparison of Routing Protocols with Mobile Elements

Protocols	Factors	Packet Delivery Ratio	Energy Consumption	End-to-End Delay	Advantages	Disadvantages
Routing Protocols with Mobile Elements						
(NC)	Based on multiple sub-zones	Medium	low	high	• this protocol exhibits relatively low energy consumption	it has a small coverage ratio. • In the event of a surface mobile node failure, data cannot be delivered to a sink in a timely manner.
MS	determined by the geographical distance to the data collection points.	low	high	high	Improve network lifetime within the specified area. suitable for delay tolerant networks	high packet delivery latency • routing complexity increases with degree of multi-hopping.
(PNLCS-OA)	likelihood of the neighborhood coverage set	high	medium	high	decreases and equalizes the nodes' energy usage based on the likelihood of demand	Data transmission voids occur when communication is lost. In the event of an AUV failure, the nodes are unable to transmit their sensed data to a sink, rendering the algorithm non-

						operational.
(DGS) and DGA)	Sensors and AUV BASED	HIGH	HIGH	HIGH	The protocol enhances the packet delivery ratio.	Nodes in close proximity to an AUV experience higher energy consumption and shorter lifespans. The network's functionality is compromised in the event of an AUV failure.
(3D-SM)	Utilizing a mobile sink and three cluster heads as its foundation	Medium	low	medium	The operational lifetime of the network can be significantly prolonged through the implementation of this protocol.	In the event of a malfunction or failure of the mobile sink or the cluster heads, the network becomes non-functional.
AEDG	Based on AUV	high	high	medium	Reduce end-to-end delay. • High delivery ratio.	Nodes located near the trajectory of the AUV bear a heavier data forwarding load from the AUV. If the AUV experiences a failure, all data may be lost.

AURP	Based on AUV	high	high	medium	This protocol achieves a high packet delivery ratio.	Elevated energy consumption due to a large number of control packets in the network. The protocol does not account for malfunctioning AUVs.
HAMA	Based on Multi-AUVs	high	low	medium	Reduced end-to-end delay and increased reliability due to predefined AUVs and reliable transmissions. The protocol incorporates a malfunction detection and repair mechanism, ensuring high availability even if an AUV fails in data collection.	Multi AUVs are used to collect data. Deployment cost is high
(E2 LR)	based on the routing pipe	high	low	high	controls unnecessary flooding of hello packets to reduce energy consumption regularly updates the energy status	it may not provide a significant reduction in end-to-end delay, which can be a limitation in time-sensitive applications.
(MEC)	In accordance with the nodes' remaining	Low	low	medium	Equalizes the data traffic distribution	The protocol does not focus on improving the packet

	energy levels				by considering the nodes' remaining energy and optimizes data transmission	delivery ratio

2.6 Research Gap and Directions

The examination of the existing body of literature pertaining to underwater sensor protocols has revealed several significant shortcomings that merit thorough consideration. These primary deficiencies are elucidated as follows:

2.6.1 Routing Protocols without Mobile Elements

A central challenge that plagues routing protocols lacking of mobile elements lies in the uneven distribution of energy consumption among nodes. This issue becomes particularly evident when a relay node finds itself in close proximity to the receiving node. In such cases, the node near the end of the data transmission chain consumes a disproportionately high amount of energy compared to others in the network. This disparity in energy consumption poses a significant predicament within underwater sensor networks and necessitates the development of routing strategies that mitigate these imbalances while concurrently boosting packet delivery rates.

To elaborate further, consider an underwater sensor network deployed in a large and complex underwater environment. The network's objective is to collect data from various sensors distributed across the environment and transmit it to a central receiving node or sink. Routing protocols are responsible for determining the most efficient path for data transmission. In scenarios where a relay node is situated close to the receiving node, it becomes the primary data carrier, leading to intensive energy utilization. This localized energy drain not only jeopardizes the longevity of the relay node but also creates a bottleneck in data transmission, potentially causing delays and packet losses.

Hence, the crux of the matter lies in designing routing paths that can effectively distribute the energy burden more equitably among the nodes. This distribution aims to prevent certain nodes from becoming overburdened, thus promoting balanced energy consumption and ensuring the network's reliability and longevity. Ultimately, the challenge emphasizes the need for innovative routing strategies that strike a harmonious balance between energy efficiency and optimal packet delivery, a critical endeavor in the context of underwater sensor networks.

2.6.2 Routing Protocols with Mobile Elements

Routing protocols that incorporate elements which are mobile confront a substantial challenge related to the delay in data collection. This delay primarily arises from the necessity for Autonomous Underwater Vehicles (AUVs) to traverse all nodes and gather data during each operational cycle. Moreover, the movement speed of AUVs tends to be comparatively sluggish, particularly when engaged in the data-forwarding phase, where they transport information from source nodes to mobile elements. Additionally, the mechanical aspects of mobile element(s) movement introduce further complexities into this process.

To elaborate further, in an underwater sensor network, mobile elements like AUVs play a crucial role in data collection and dissemination. These AUVs are tasked with visiting individual sensor nodes distributed throughout the underwater environment to retrieve their collected data. However, this process of data retrieval is not instantaneous; it entails the AUVs navigating through the underwater space to reach each sensor node, collect data, and move on to the next. This sequential data collection process inherently introduces delays, especially when dealing with a large number of nodes.

Furthermore, during the data-forwarding phase, where the AUVs transfer the collected data to the designated destination or sink node, their movement speed is often constrained, potentially resulting in additional delays. Factors like water flow, water pressure, and obstacles in the underwater environment can affect the velocity and navigation of AUVs, making their progress less predictable.

In conclusion, routing protocols that involve mobile elements, while valuable for data collection in underwater sensor networks, grapple with inherent challenges related to data collection delays, often attributed to the sequential nature of node visitation, slow AUV movement during data forwarding, and the dynamic underwater environment. Addressing these challenges is crucial for optimizing the efficiency and performance of such routing protocols in underwater scenarios.

2.6.3 Assumption of Constant AUV Velocity

Several AUV-assisted data collection methods commonly rely on the assumption of a consistent velocity for the AUV. Nonetheless, in the underwater environment, the velocity of an AUV can be subject to diverse influences, including factors like water flow, water pressure, and the presence of obstacles. Moreover, the AUV's movement encompasses ascending, descending, and maneuvering as it navigates to different target nodes, resulting in fluctuations in its velocity. Consequently, adhering strictly to a fixed velocity assumption can lead to situations where AUVs fail to reach specific target nodes within the expected timeframe.

To elaborate further, AUVs are employed in underwater sensor networks to collect data from various sensor nodes distributed across the underwater domain. During their missions, AUVs must visit these nodes to retrieve the data they have gathered. However, the AUV's travel speed is not a constant; it can vary due to environmental conditions and the AUV's own actions. For instance, when encountering water currents, the AUV's velocity may be either enhanced or impeded, impacting its ability to maintain a consistent pace.

Furthermore, the AUV's movement is not limited to straightforward horizontal motion; it also includes ascending to the surface, descending to greater depths, and making turns to navigate efficiently. Each of these maneuvers can alter the AUV's speed, making it challenging to predict its exact velocity at any given moment.

In conclusion, the assumption of a fixed AUV velocity in underwater data collection methods may not accurately reflect the real-world conditions and complexities of underwater environments. Variations in velocity due to factors like environmental conditions and AUV maneuvers should be considered to ensure the successful collection of data from all target nodes within an underwater sensor network.

2.6.4 Reliance on Cloud-Based Data Collection:

The majority of data collection algorithms are designed to operate on cloud platforms, which are often located at considerable distances from the data source nodes within an underwater sensor network. The transmission of collected data to these remote cloud resources results in a substantial increase in energy consumption for the nodes involved in the data transfer process. This heightened energy expenditure is primarily due to the extended communication distances that data packets must traverse to reach the distant cloud servers.

To delve further into this matter, when data is collected by sensor nodes within the underwater network, it must ultimately find its way to the cloud computing infrastructure, where further processing, analysis, or storage can take place. This entails the transmission of data packets over potentially long and energy-intensive communication links. As data traverses these extensive distances, it consumes significant amounts of energy, particularly when considering the power requirements for signal propagation and data packet forwarding.

Furthermore, the reliance on a centralized cloud platform for data processing and storage can introduce a vulnerability to the network. In the event of the premature failure of certain critical nodes within the network—nodes that serve as key communication intermediaries or data relays—

the entire network's functionality may be compromised. This is because the failure of these critical nodes disrupts the flow of data, potentially leading to data loss, communication breakdowns, and a loss of network connectivity.

In conclusion, the deployment of data collection algorithms that transmit data to distant cloud platforms in underwater sensor networks presents challenges related to increased energy consumption during data transmission and the network's susceptibility to critical node failures. These challenges necessitate the exploration of more energy-efficient data processing and routing strategies, as well as robust mechanisms for network resilience and fault tolerance.

2.6.5 Delay Occurs at the Sink Node

The primary source of delay within a sensor network often manifests at the sink node, particularly when forwarding packets to onshore control systems. This delay can carry profound implications for the overall performance of the network, the reliability of data transmission, and the ability to make real-time decisions based on the collected data. Consequently, the resolution of these shortcomings becomes imperative in the quest to enhance the efficiency and effectiveness of underwater sensor network protocols.

To elaborate further, the sink node within a sensor network plays a pivotal role as the central point for receiving and aggregating data from various sensor nodes deployed in the field. This collected data is typically destined for onshore control systems, where it undergoes further analysis, processing, and utilization. Nevertheless, the transfer of this collected data from the sink node to the onshore control systems may encounter significant delays.

These delays can have cascading effects on the network's performance. They can impede the timely delivery of critical data, potentially leading to missed opportunities for real-time decision-making. Moreover, extended delays can compromise the reliability of data transmission, introducing the risk of data loss or corruption during transit. These issues are particularly critical in applications where real-time monitoring, response, or control is essential, such as environmental monitoring, disaster management, or industrial processes.

In conclusion, mitigating delays associated with data forwarding from sink nodes to onshore control systems is paramount for enhancing the overall efficiency and effectiveness of underwater sensor network protocols. Addressing these challenges demands the development of optimized routing, data transmission, and communication strategies that minimize delays and ensure the timely and reliable delivery of data to its intended destination.

Based on the above findings, this research endeavor is focused on suggesting a strategic deployment of fog nodes across the network. This deployment strategy carries the promise of alleviating the computational load on sink nodes. Moreover, in comparison with conventional cloud services, the adoption of a decentralized architecture holds the potential to efficiently disperse network traffic and curtail the response time of real-time Internet of Things (IoT) devices. This framework also holds the prospect of prolonging the network's lifespan and redistributing the computational and communication responsibilities from conventional sensor nodes to the strategically placed fog nodes.

2.7 Summary

This chapter serves as the foundational cornerstone for the entire body of work, providing a crucial overview of underwater routing protocols. Its primary aim is to conduct a thorough review of the existing landscape of mobile-based routing protocols tailored for underwater environments. These protocols, designed to navigate the unique challenges of underwater communication, undergo a rigorous scrutiny of their reliability and energy efficiency mechanisms. This comprehensive analysis delves deep into the inner workings of each protocol, assessing their strengths and weaknesses with a critical eye. Undergo a rigorous scrutiny of their reliability and energy efficiency mechanisms. This comprehensive analysis delves deep into the inner workings of each protocol, assessing their strengths and weaknesses with a critical eye.

Furthermore, the chapter goes beyond merely assessing these protocols; it delves into the theoretical exploration of the advantages and disadvantages associated with each strategy. By illuminating both the merits and limitations, it offers a well-rounded perspective on the landscape of underwater routing. In closing, the chapter unveils the issues and shortcomings inherent in various routing protocols while placing a spotlight on the key considerations that should guide the development of future protocols. This comprehensive evaluation provides a solid foundation for the subsequent phases of research, laying the groundwork for the development of more effective and efficient underwater routing solutions.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter discusses the research methodology used to design and develop a Depth based Fog Assisted Data Collection Scheme for Time-Critical IoUT Applications. To improve energy consumption and latency caused by redundant packet forwarding by ordinary underwater nodes, as well as to avoid greater delay induced by poor processing capabilities of sink and energy used by intermediate sink nodes in re-transmission efforts, is the primary focus of this research.

Another goal of this research is to avoid higher delay caused by low processing capabilities of sink. In order to accomplish this goal, a Depth-based Fog-Assisted Data Collection (DFDC) Scheme for an underwater sensor network has been devised. This scheme lessens the load placed on sink nodes, which in turn shortens the amount of time it takes for packets to reach onshore control systems. This method also suggests a solution to eliminate redundant transmission as a means of improving latency and energy consumption in the process of data forwarding by ordinary underwater sensor nodes operating in a hostile underwater environment. As a result, the focus of this chapter is on research methodology as one of the preliminary steps toward producing a road map and achieving the goals that have been established.

3.2 Operational Framework

There are three main stages to this operational framework, and each is important to the creation and assessment of the DFDC protocol. Initially, we conduct a thorough investigation of the need for routing techniques in underwater sensor networks (UW-ASN). We address the difficulties presented by the underwater acoustic medium, analyses the state-of-the-art routing protocols, and carefully break down the limitations and complexities that drive us to design the need for an improved, energy-efficient routing solution.

The journey is continued in the second phase, uncovering an extensive number of challenges and insights from the comprehensive research. Equipped with this understanding, it carefully maps out the stages needed to create the DFDC protocol, making sure it successfully addresses the issues found. Here, an in-depth knowledge of the underwater communication environment serves as a guide as the DFDC design continues to take shape.

The third phase, which involves a thorough review of the DFDC technique, is the final stage of our work. Its performance was carefully evaluated against the most recent and well-established routing techniques by using important indicators including packet delivery ratio, energy consumption, network the lifespan, and end-to-end delay as benchmarks for developed study. The aforementioned phase offers the essential insights required to determine the effectiveness and applicability of DFDC, hence validating its potential as a creative and effective solution in the domain of underwater data routing.

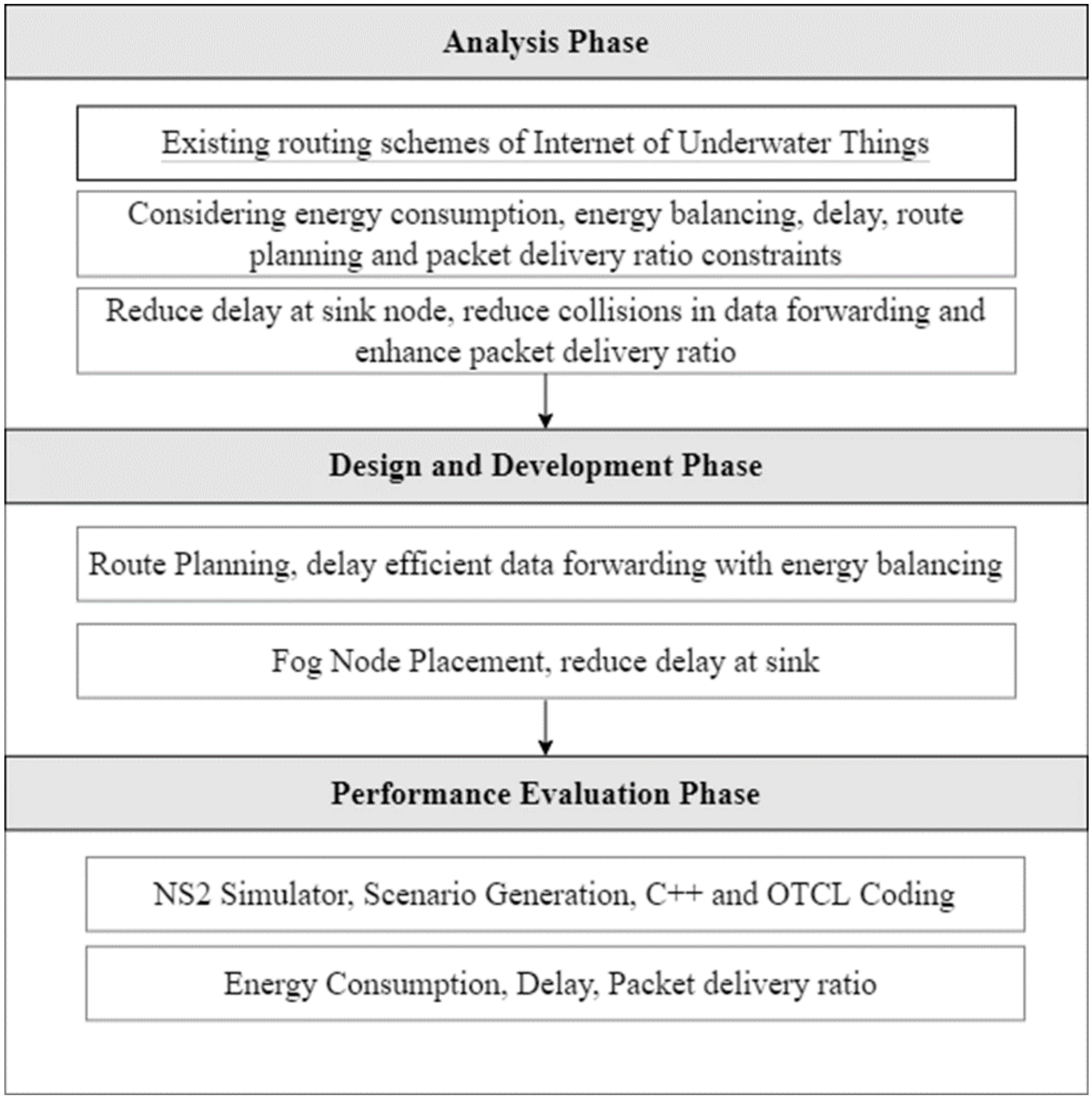


Figure 3.1: Operational Framework

3.3. Research Design and Development

We will discuss potential approaches to designing and improving the DFDC routing protocol in the next section. This project consists of three essential stages: the route planning stage, the maintenance stage, and the information distribution stage. For the purpose of providing visual clarity, these stages are graphically represented in Figure 3.2. These stages work together to create the fundamental elements that lead to the development and improvement of the DFDC protocol.

Consider it as a step-by-step procedure, where each stage contributes an important component to the overall structure of the protocol, transforming DFDC into a productive and useful instrument for controlling underwater data transmission.

3.4 Data Collection Scheme for Underwater Sensor Cloud System

In the initial phase, the fundamental architecture of the DFDC protocol is formulated, comprising four distinct layers: the physical sensor layer, fog layer, sink layer, and cloud layer. The physical layer nodes, equipped with acoustic antennas, possess constrained storage and computational capabilities. In contrast, fog nodes within the fog layer are endowed with robust computational and storage capabilities relative to the physical layer nodes. These fog nodes execute localized computations on the data received from the physical nodes.

The second step consists of developing a data collection scheme (DFDC). In the DFDC protocol, the nodes will forward the data on the bases of two things: Depth and Energy Information. The ratio of depth and energy information is calculated. Consequently, the nodes forward data if the depth& energy ratio of the current node is more than that of the previous node to reduce end-to-end delay.

In the third phase, fog nodes endowed with substantial computational and storage capabilities undertake the tasks of data computation, dimension reduction, and redundancy elimination for the information gathered from ordinary sensor nodes. Subsequently, these processed and compressed data are transmitted to the central surface sink node.

Finally, the central sink node conveys the data received from the fog nodes to the cloud computing center. The Depth-based Fog Assisted Data Collection (DFDC) routing protocol is meticulously crafted with the aim of diminishing energy consumption, reducing end-to-end delays, and augmenting the network's longevity. Furthermore, utilized simulator, simulation parameters, performance evaluation metrics and scenarios considered for protocol evaluation are included in this chapter.

3.5 Architecture of Underwater Sensor Cloud System Based on Fog Computing

An architecture for an underwater sensor cloud system based on fog computing has been designed, as illustrated in Figure 3.2.

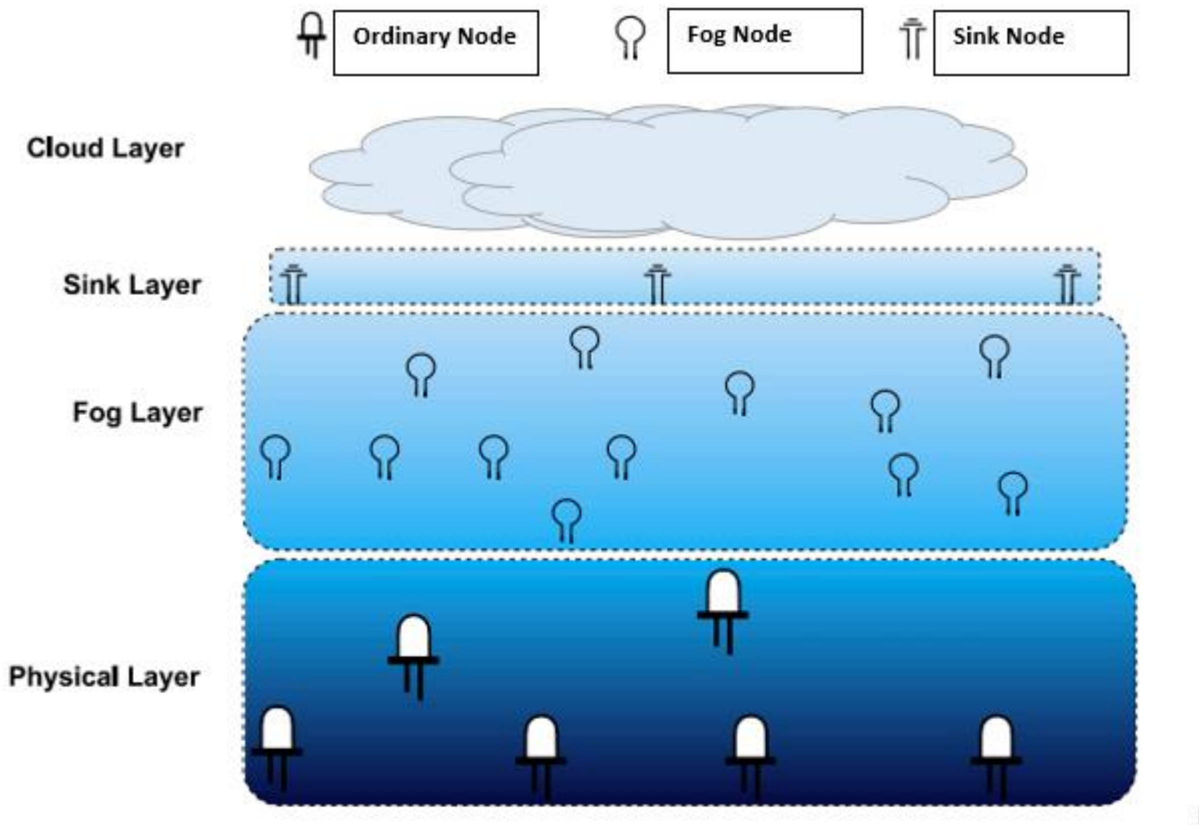


Figure 3.2: Architecture of Underwater Sensor Cloud System

The architecture consists of four layers:

- **Physical layer**
- **Fog layer**
- **Sink layer**
- **And cloud layer**

The communication process within this architecture functions as follows: Within the underwater sensor network, the physical layer encompasses nodes equipped with acoustic antennas. These nodes possess limited storage and computational capabilities [18]. These nodes are typically stationary, anchored to the ocean floor or floating at specific depths using buoys. They primarily gather data from the underwater environment and use acoustic links to transmit this information to the corresponding fog nodes, following specific routing policies.

Moving up to the fog layer, we encounter fog nodes that possess robust computational and storage capacities, often taking the form of Autonomous Underwater Vehicles (AUVs) or other mobile nodes [18]. These fog nodes are distributed throughout the underwater sensor network and are responsible for local data processing within designated areas, emphasizing proximity-based principles. These fog nodes carry out local computations on the data received from physical nodes, performing tasks like filtering out irrelevant information, reducing dimensionality, or extracting critical insights. Based on the outcomes of these computations, fog nodes determine the appropriate mode for delivering data, depending on the urgency of the data. For data that can tolerate some delay (delay-insensitive data), mobile fog nodes transport the computed results to the surface. Once the fog nodes reach the water's surface, they transfer the data to surface sink nodes located in the sink layer. In contrast, for data with stringent delay requirements (delay-sensitive data), the data computed by fog nodes is transmitted to the surface sink nodes through a multi-hop process facilitated by higher-level fog nodes.

To illustrate this, let's take the example of detecting an environmental pollution event through data analysis. This scenario underscores the challenge of meeting delay requirements due to the movement speed of AUVs. AUVs and other mobile nodes are equipped with both acoustic and radio antennas. Acoustic antennas are responsible for underwater communication with physical nodes or other fog nodes, while radio antennas handle communication with surface sink nodes on land. Nodes in the sink layer receive the processed data from the fog nodes. Following data fusion operations, the sink nodes transmit the fused data to a cloud computing center using radio signals.

In traditional underwater sensor network architectures, surface sink nodes are burdened with receiving both raw data and transmitting it to a control center. This scenario may lead to packet loss because sink nodes struggle to handle simultaneous data receptions, causing reception delays. However, in the proposed sensor cloud system architecture based on fog computing, surface sink nodes exclusively receive processed data from AUVs or mobile nodes, relieving them of the raw data reception burden. Furthermore, fog nodes can collaborate to schedule data transmissions efficiently. The cloud computing center in the cloud layer is responsible for data storage and complex data computations [43].

3.6 Route Planning and Data Forwarding Phase with DFDC

Underwater routing protocols show a different behavior as compared to terrestrial networks. For example, it is almost impossible to find and then maintain an end-to-end path with continuous mobility of the node. Consequently, maintaining end-to-end path will result in constant drain of limited available battery resources and shorten the network lifetime. Therefore, transmitting data on hop-by-hop basis is a preferred choice, where it is more likely to find a next hop neighbor.

The proposed routing scheme is based on location unaware depth based fog assisted data collection (DFDC) routing protocols for time-critical IoUT applications. In the DFDC protocol, the nodes will forward the data on the bases of two things: Depth and Energy Information.

For depth information, the nodes will be keeping the information of their own depth and the depth information of fog nodes. The sensor nodes will also be keeping the Energy information of its own. The ratio of depth and energy information is calculated and on the basis of that calculation a timer will run. Sensor nodes detect data and broadcast it to their neighboring nodes along with information about their own depth (i.e. how close or far away they are from a central "Fog" node). When a neighboring node receives the packet, it compares its own depth with the depth included in the packet. If the depth difference is negative, it means that the receiving node is closer to the Fog node and is eligible to forward the packet. This means that multiple nodes may be recipients of the same packet and eligible to forward it. To prevent redundant packet forwarding, all eligible forwarder nodes start a timer based on their residual energy (ER) and their distance to the sink. Nodes with higher residual energy and shorter distance to the sink will have shorter timers, which can be calculated using the energy to distance ratio. Once the timer for any eligible forwarder node expires, it will broadcast the packet. Other nodes in the network will refrain from forwarding the same packet when they hear it from their neighbors in order to reduce redundant transmissions.

3.7 Mathematical Illustration of Proposed DFDC scheme

Now we define the holding time based on the criteria. It is assumed that any node A know their coordinates A(XA, YA, zA) and coordinates of the sink node S(xS , yS , zS) and therefore know the distance between these nodes $d(A, S)$ can be calculated by the Euclidean distance

$$d(A,S) = \sqrt{(x_A - x_S)^2 + (y_A - y_S)^2 + (z_A - z_S)^2}$$

The packet is forwarded to those nodes that are at a lesser depth, that is, when a sensor node detects the data; it will broadcast the packet to its neighbors containing its depth information. Any node that receives the packet will compare its own depth with the depth received in the packet and measure the depth difference (dd) by measuring, dd = zA − zB. If the depth difference is in negative value, it means that receiving node is closer the Fog node and eligible to forward the packet.

In this way multiple nodes may be recipient of the packets and eligible to forward the received packet. To eliminate redundant packet forwarding. All eligible forwarders nodes (xF, yF, zF) start the timer based on their residual energy ER and their distance to the sink. A node having higher residual energy and shorter distance will have shorter timer that can be calculated by energy to distance ratio

$$T_{\text{hold}} = \frac{E_{\text{energy}}}{\text{distance}} \equiv \frac{E_R}{d(F,s)}$$

where $E_R = KE_{\max} + (1-K)E_{\min}$ and $E_{\max}$ are the minimum and maximum energy of the node and k is the arbitrary parameters

$$0 < k < 1$$

Once the timer for any eligible forwarder expires, it will broadcast the packet. Neighbors on hearing the similar packet they possess from their neighbor will refrain from forwarding that packet to reduce redundant transmission.

3.8 Management Area of Fog Node

The "Management Area of Fog Node" elaborates on the organizational structure and responsibilities of the fog nodes within an underwater sensor network deployment. Here's a detailed breakdown of the provided information:

3.9 Fog nodes and their distribution

In the underwater sensor network, each fog node has distinct roles: data collection, local computation, and local storage.

The deployment area of the network is represented as a three-dimensional space with dimensions L×L×L[60].

The number of fog nodes in the network is denoted as N. These fog nodes are distributed across the deployment area.

3.10 Dividing Deployment Area:

To manage the underwater network effectively, the deployment area is divided into M sub-areas, each managed by a specific fog node [60].

The ith sub-area is managed by the ith fog node, denoted as FNi, and is referred to as Area i.

The scope of the ith sub-area is confined within a specific range.

3.11 Range of fog nodes‘ Area

The range of the ith sub-area is confined to:

$$[0,0,(i-1)\times L/N]\,)\times[L,L,i\times L/N]$$

In more explicit terms, the range of the ith sub-area is confined within the following spatial coordinates:

For the x-coordinate: [0, 0]

For the y-coordinate: [(i - 1) × L/N, L]

For the z-coordinate: [0, i × L/N]

This essentially signifies that the x-coordinates are constrained within the range of [0, 0], indicating that the sub-area is positioned along a single vertical plane. The y-coordinates span from (i - 1) × L/N to L, signifying the vertical extent of the sub-area. Additionally, the z-coordinates are confined within the range of [0, i × L/N], encapsulating the depth-wise scope of the sub-area [60].

The result of this spatial confinement is that each fog node, designated to manage its respective sub-area, operates within these specified coordinates. This arrangement ensures that data collection, computation, and storage activities are concentrated within a well-defined region, optimizing the efficiency of the fog node's operations while enabling effective coordination with the sensor nodes positioned within this confined sub-area.

3.12 Fog Node Movements and Trajectories

Each fog node moves along a circular trajectory within its designated sub-area. The fog node follows a circular path, making designated stops for a certain duration at specific locations within the sub-area to collect data from sensor nodes [60]. The circular trajectory ensures that the fog node can cover its designated sub-area effectively.

3.13 Equation of Circle Trajectory

The equation that defines the circular trajectory of the fog node in the ith sub-area is provided [60]:

$$(\mathrm{x} - L/2)^2 + (y - L/2)^2 = (\sqrt{2}L/2)^2$$
$$Z = L * 2/N + (i - 1) * L/N$$

3.14 Partitioning for Efficient Data Transmission:

The partition mode ensures that the trajectory curve of the fog node is divided equally in both horizontal and vertical directions. This partitioning strategy optimizes data transmission efficiency by minimizing the number of hops required for sensor nodes within each sub-area to communicate with the corresponding fog node. overall the "Management Area of Fog Node" section outlines how fog nodes are strategically distributed, each managing a designated sub-area within the underwater sensor network. These fog nodes move along circular trajectories, collecting data from nodes in their respective sub-areas. The equation of the circular trajectory is provided, and the partitioning strategy ensures efficient data transmission through optimal path division. This arrangement enhances the overall data collection, computation, and storage capabilities of the underwater sensor network.

3.15 Forwarding Priority of packets in DFDC

When a sensor node detects data that needs to be transmitted, it initiates a process by broadcasting the data packet to its neighboring nodes. This broadcast includes not only the data itself but also the depth information of the sender node. This depth information corresponds to the distance of the sender node from the water's surface or some reference point. As a result, the packet is directed towards nodes that are positioned at shallower depths within the underwater environment.

Upon receiving the broadcasted packet, any recipient node performs a comparison between its own depth and the depth information contained in the received packet. This comparison serves as a basis for determining the depth difference between the two nodes, often represented as "dd." The depth difference is calculated using a straightforward formula: depth difference (dd) = zA - zB, where zA is the depth of the receiving node and zB is the depth information acquired from the packet.

An important interpretation of the depth difference arises from this calculation. If the resulting value of the depth difference is less than zero, it signifies a crucial piece of information: the receiving node is actually physically closer to the Fog node compared to the other node that was initially responsible for broadcasting the packet. This proximity-based evaluation establishes a qualification criterion for the receiving node to be designated as suitable for the task of forwarding the packet.

In essence, this depth-driven mechanism ensures that the packet's forwarding is guided by the underwater nodes' relative positions and their distances from the Fog node. Nodes that are closer to the central point of data processing are chosen to perform the forwarding, enhancing the efficiency of data transmission by leveraging the spatial arrangement of nodes in the underwater network. This strategy optimizes the routing of packets, resulting in more effective data dissemination in the underwater environment.

3.16 Eliminate redundant packet forwarding in DFDC

In order to eliminate the occurrence of redundant packet forwarding within the network, a systematic approach is introduced. This involves identifying and engaging all qualified forwarder nodes (denoted as (xF, yF, zF)) that are capable of forwarding packets. These forwarder nodes initiate a timer mechanism, which is determined by considering their residual energy (E_R) as well as their respective distances from the sink node.

This timer mechanism plays a vital role in regulating packet forwarding activities and avoiding unnecessary duplications. Nodes with higher remaining energy and shorter distances to the sink are assigned shorter timers. The calculation of these timers is based on the energy-to-distance ratio, aptly denoted as T_"hold " and is defined as:

$$T_{\text{hold}} = \frac{E_{\text{energy}}}{\text{distance}} \equiv \frac{E_R}{d(F,s)}$$

3.17 Compute Holding Time of packet in DFDC

We establish the foundation for determining the holding time using a specific criterion. We assume that each node in the network, denoted as node A with coordinates A(XA, YA, zA), possesses knowledge of its own position and that of the sink node, represented as S(xS , yS , zS). This knowledge empowers nodes to compute the distance between themselves and the sink, represented as (A, S). This distance calculation is performed using the Euclidean distance formula, which is an established mathematical method [60].

The Euclidean distance between node A and the sink node S can be calculated using the following formula:

$$d(A,S) = \sqrt{(x_A - x_S)^2 + (y_A - y_S)^2 + (z_A - z_S)^2}$$

Here, the individual coordinates (x, y, z) represent the positions of node A (XA, YA, zA) and the sink node S (x , yS , zS). The Euclidean distance formula computes the three-dimensional geometric distance between these two nodes.

This distance measurement serves as a key component for determining the holding time, a critical factor in the packet forwarding process. As we established earlier, the holding time influences the timing of packet forwarding by nodes based on their residual energy and proximity to the sink. The Euclidean distance calculation aids in assessing how far a node is from the sink, which, when combined with other parameters, contributes to setting an appropriate holding time.

In essence, by leveraging the Euclidean distance calculation, nodes are equipped with the information needed to understand their spatial relationship to the sink node. This information is pivotal in constructing a more precise and context-aware strategy for forwarding packets within the network, enhancing both efficiency and performance.

3.18 Work Flow of the System from Physical Layer to Fog Layer

START

1. For each Node in physical Layer and Fog Layer

2. d (Ord, Fog) ← sqrt $((X_{ord} - X_{fog})^2 + (Y_{ord} - Y_{fog})^2 + (Z_{ord} - Z_{fog})^2)$

3. When the Data is Detected then

4. Broadcast that Packet to its neighbors

5. for each Node N that Receives a packet

6. $dd = Z_N - Z_P$

7. if dd<0 then

8. Add N in EligibleToForward Vector

9. end if

10. end for

11. for each Node E in EligibleToForward Vector

12. R_{EDR}←COMPUTE_EDR (R_E, $R_{d(Ord, Fog)}$)

13. StartTimer(R_{EDR})

14. if Timer for R expires

15. Forward Packet

16. end if

17. end for

END

3.19 Work Flow of the System from Fog Layer to Sink Layer

START

1. For each Node in Fog Layer and Sink Layer

2. d (Fog, Sink) ← sqrt $((X_{fog} - X_{sink})^2 + (Y_{fog} - Y_{sink})^2 + (Z_{fog} - Z_{sink})^2)$

3. When the Frame is Received then

Broadcast that Packet to its neighbors

for each Node N that Receives a packet

if Packet Already Received then

Broad Cast Packet Already Received

Discard Packet

else

$dd = Z_N - Z_F$

if $dd < 0$ then

Add N in EligibleToForward Vector

end if

end if

end for

for each Node E in EligibleToForward Vector

$R_{EDR} \leftarrow$ COMPUTE_EDR (R_E , $R_{d(Ord,Fog)}$)

StartTimer(R_{EDR})

if Timer for R expires

Forward Packet

end if

end for

END

COMPUTE_EDR (N_E , $N_{d(Ord,Fog)}$)

Return $N_E / N_{d(Ord,Fog)}$

3.20 Simulation Setup

The simulation setup plays a pivotal role in this study as it enables a comprehensive evaluation of the proposed data gathering scheme, particularly the DFDC routing protocol. This assessment occurs within the framework of the underwater sensor cloud system, driven by the innovative fog computing architecture. To facilitate this evaluation, we utilize the NS-2 simulation tool, a highly regarded discrete event simulator known for its precision and adaptability.

3.21 NS-2 Simulation Tool:

NS-2 is a robust platform that lets us imitate real-world scenarios and analyses how this proposed DFDC routing protocol responds to a variety of environmental factors. This has made possible by the fact that NS-2 serves as a model of the real world. By making use of this technology, we are provided with insightful information regarding the responsiveness, efficiency, and efficacy of the architecture that we have developed.

3.22 Evaluation of DFDC Routing Protocol:

Through the NS-2 simulation tool, we can rigorously evaluate the DFDC routing protocol's performance within the underwater sensor cloud system. This involves emulating scenarios where data collection, local computation, and storage activities interact, reflecting real-world conditions. By subjecting the DFDC protocol to diverse scenarios and varying conditions, we aim to uncover its strengths, weaknesses, and the extent to which it aligns with the overarching goals of optimizing data gathering efficiency, energy utilization, and delay management.

In essence, the simulation setup is a pivotal phase of this research methodology, enabling it to objectively and comprehensively assess the practicality and effectiveness of this proposed DFDC routing protocol. By employing NS-2 and carefully configuring the parameters, it can draw meaningful conclusions about the protocol's performance and make informed decisions for its potential implementation in real-world underwater sensor cloud systems.

3.23 Main Parameters Setup:

Establishing a basic parameter set that will serve as a guide for the simulations allows it to keep things organized and makes conducting experiments much simpler. The evaluation will continue to be consistent and under control as long as these parameters are used because they include crucial characteristics of the simulated environment. Table 1 gives a condensed summary of these parameters and their associated settings.

Table 3.1: Parameter setup

Parameter	**Value**
Sending energy	50 W, default in NS-2
Receiving energy or idle state	158 mW, default in NS-2
R	2 km
Frequency	1.5 MHZ
Data rate	16 kbps
Node number	200-500, randomly generate network topology
Deployment region	3D area of $(10\ \text{km})^3$
Fog node number	5
Movement model	Random Walk 2D Mobility Model
Source node	Randomly deploy at the depth of 10 km
Sink location	At the center of the surface
Packet generation model	1 packet per 5 s, Poisson distribution,

3.24 Assumptions and Limitations

In the process of evaluating the DFDC protocol, the following assumptions are taken into consideration throughout the simulation:

i. The simulation makes the assumption that communication between nodes is perfect and error-free, but it does not take into account issues that could occur in the real world, such as signal attenuation, interference, or underwater obstacles.

ii. It assumes that every node is capable of making an accurate determination of its depth in relation to either the water's surface or a reference point.

iii. For the sake of correctly calculating time differences, it is assumed that all nodes have clocks that are synchronized with one another.

iv. The simulation works under the presumption that data aggregation at fog nodes is completely effective, without taking into account any potential delays or overhead.

v. All of the nodes communicate with one another across a wireless channel that is shared.

3.25 Summary

This chapter lays the foundation for developed research by offering a comprehensive overview of the methodology, tools, and processes employed throughout the development, modeling, and evaluation of the proposed Depth-based Fog Assisted Data Collection (DFDC) protocol. While subsequent chapters will delve into the specifics of these methods, here we provide a high-level view of the framework that underpins the evaluation of developed protocol.

This framework encompasses a range of crucial components, including the formulation of algorithms, the intricate design of simulations, the fine-tuning of parameters, the establishment of critical assumptions, and the imposition of necessary constraints. These elements collectively form the scaffolding upon which the evaluation of developed protocol is constructed. Think of this chapter as the blueprint that guides this research journey, ensuring that each phase is conducted rigorously and systematically. Ultimately, it is through these carefully crafted methods and processes that we aim to validate the effectiveness and reliability of the DFDC protocol in the context of underwater data collection and management.

CHAPTER 4

RESULT AND ANALYSIS

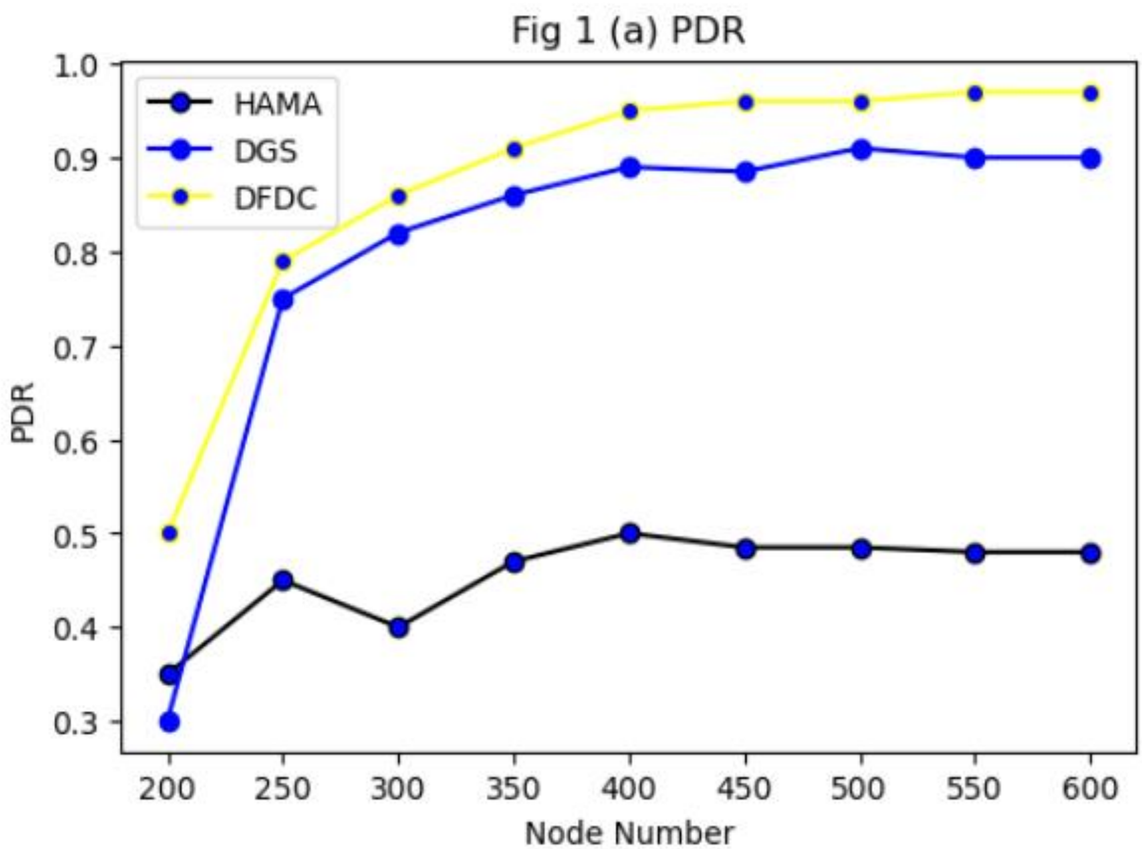
4.1 Simulation

In this section, the effectiveness of DFDC will be analyzed as well as the performance of any additional data collection methods. No other research that we are aware of has been reported on the depth-based data collection scheme that is based on fog computing (DFDC), to the best of our knowledge.

In the simulation, we analyze the performance of the suggested data gather method, namely the DFDC routing protocol in the architecture of an underwater sensor cloud system that is based on fog computing. This is done with the help of the NS-2simulation tool, which is a discrete event simulator. As a result, the simulation was developed to evaluate HAMA [35] and DGS [56] side-by-side. For The packet delivery ratio (PDR), the end-to-end delay, and the amount of energy consumed are all examples of performance measures.

4.2 Packet Delivery Ratio(PDR) Comparison

The comparison of Packet Delivery Ratio (PDR) is illustrated in Figure 3(a).



Within the framework of the proposed fog computing-based underwater sensor cloud system architecture, the PDR metric exhibits superior performance in contrast to other routing protocols. This achievement is attributed to a series of compelling reasons, which are elucidated as follows:

First and foremost, the strategic integration of fog nodes into the architecture plays a pivotal role. The data harnessed by these fog nodes undergoes localized processing, effectively curtailing the volume of transmissions required to reach the surface sink node. This local processing not only mitigates the data's transmission load but also empowers the sink node at the surface to avoid being inundated with excessive incoming data. Unlike the conventional protocols, wherein the sink node is potentially overwhelmed by multiple incoming packets, the proposed architecture capitalizes on the role of fog nodes to alleviate this concern.

During the simulation process, a significant revelation surfaces: while other protocols occasionally lead to packet loss at the sink node due to its constrained processing capacity, the proposed architecture consistently circumvents this issue. The architecture ensures that, in a majority of instances, the ultimate delivery of packets to the surface sink node is facilitated by the concerted efforts of fog nodes. This approach remarkably reduces the incidence of packet loss and augments the overall efficacy of the protocol.

Furthermore, the distinct characteristics of the Depth-based Fog Assisted Data Collection (DFDC) routing algorithm contribute to the observed improvement in Packet Delivery Ratio when compared to the two other routing protocols under scrutiny. This enhancement is attributed to two primary facets, each of which plays a strategic role:

On one hand, the DFDC routing algorithm boasts the capacity to assign distinct forwarding priorities to nodes sharing the same distance to the destination. In scenarios marked by dense network configurations, the algorithm effectively trims down the number of forwarding nodes in comparison to the alternative protocols. As a direct consequence, the redundancy in packet forwarding at receivers is appreciably reduced.

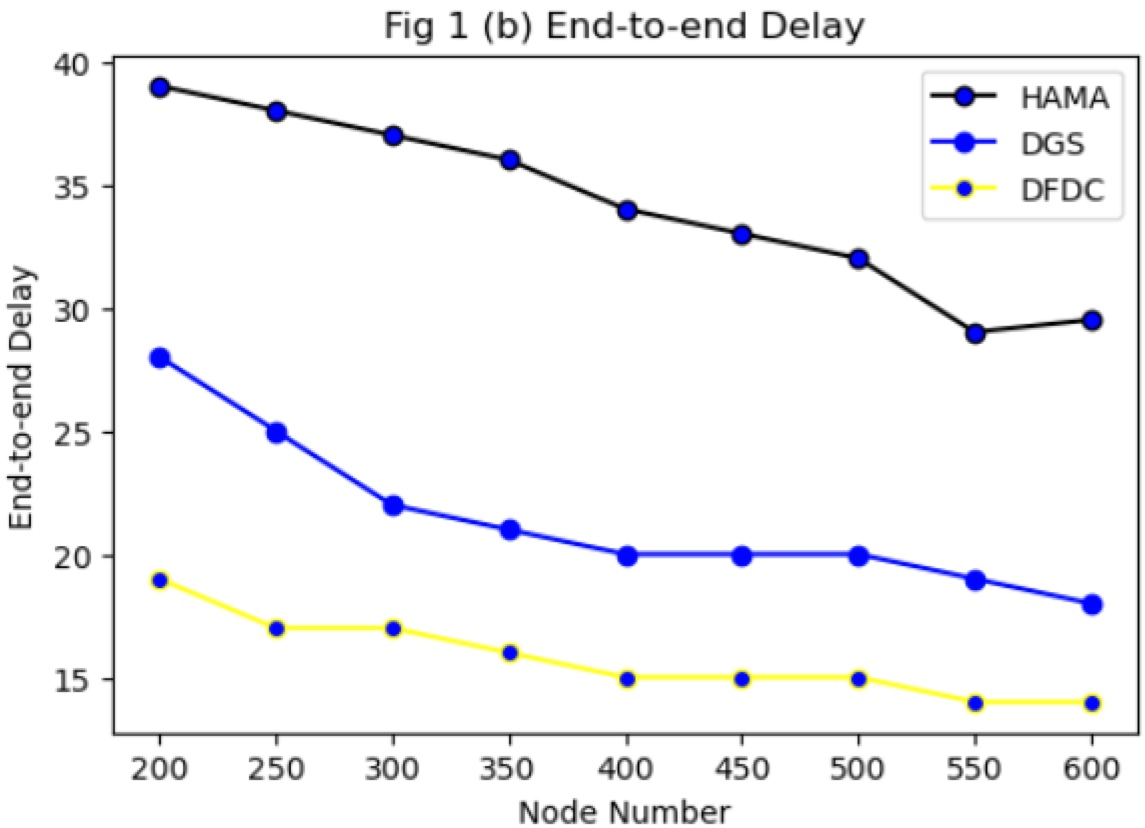
On the other hand, the algorithm leverages the concept of Energy Ratio (ER) to fine-tune its forwarding strategies. The higher the ER value, the more probable it is for a node to become the next hop forwarder. This is attributed to the larger valid forwarding area of the next hop node, a direct result of its heightened ER. Within the DFDC forwarding policy, a neighboring node's eligibility to forward a packet hinges on a comparison between its own depth and the depth included within the packet. This approach creates a situation wherein multiple nodes might potentially qualify as recipients for the same packet, all eligible to forward it.

To address the potential issue of redundant packet forwarding, the architecture introduces an innovative timer-based mechanism. This mechanism mandates that all qualified forwarder nodes initiate timers that are determined by their residual energy (ER) and their distance to the sink node. Nodes endowed with superior residual energy and closer proximity to the sink node are bestowed with shorter timers, as calculated by the energy-to-distance ratio. Once the timer expires for any eligible forwarder node, it takes the initiative to broadcast the packet. This minimizes the chances of redundant transmissions by compelling other nodes in the network to abstain from forwarding the same packet upon hearing it from their neighboring nodes. The decline in the packet delivery ratio can be attributed to the expanding size of the deploying area.

This phenomenon occurs because the size of the deploying area impacts the number of neighboring nodes; the greater the area, the fewer neighbors there will be. Since HAMA had two AUVs, it resulted in a low packet delivery ratio, and the same pattern was observed for DGS, as depicted in the graph. In essence, the proposed architecture's adept utilization of fog nodes, coupled with the sophisticated mechanisms embedded within the DFDC routing algorithm, collectively elevate the Packet Delivery Ratio (PDR) and confer substantial advantages over traditional protocols. The architecture's proficiency in mitigating packet loss, reducing redundant forwarding, and optimizing data distribution underscores its efficacy within the underwater sensor cloud system context.

4.3 End-to-End Delay Comparison

The graph in Figure 3(b) illustrates a comparison of end-to-end delays.



In the proposed network architecture, the collected data undergoes processes like computation and removal of redundant information. As a result, the volume of data decreases, leading to a reduction in end-to-end delays. Additionally, the architecture optimizes data transmission by directly relaying processed data with delay requirements from lower to upper areas using AUVs. This approach bypasses the need for intermediate relay nodes or alternative modes of AUV carriage. Consequently, the delays associated with holding packets and AUV movements to reach the surface are minimized, contributing to overall delay reduction.

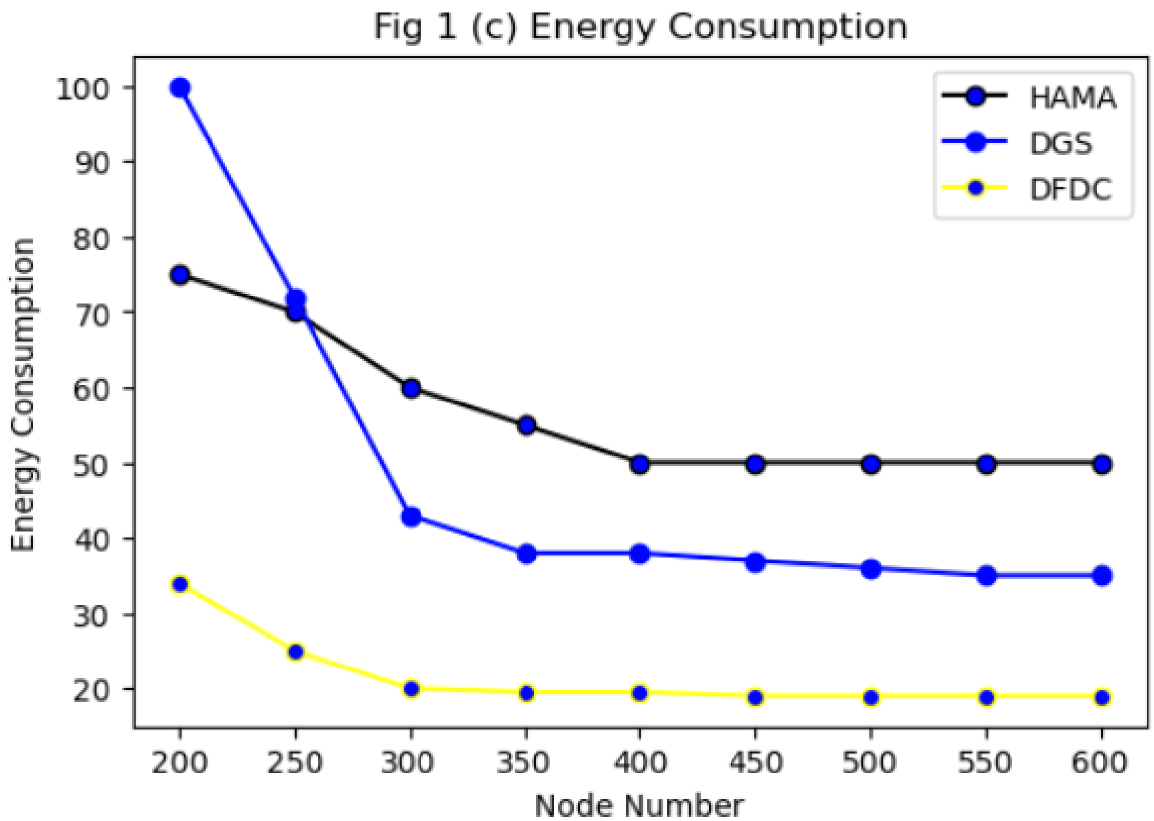
Moreover, the unique attributes of the Depth-based Fog Assisted Data Collection (DFDC) routing algorithm further enhance delay performance compared to the other two routing protocols studied. Specifically, eligible forwarder nodes initiate timers based on their residual energy (ER) and distance to the sink. Nodes with higher energy and shorter distances have shorter timers, calculated using an energy-to-distance ratio.

Additionally, the average delay, influenced by factors such as acoustic signal speed, transmission distance, AUV speed, and trajectory length, reveals noteworthy insights. HAMA exhibits larger average delay due to the slower AUV speed and extended trajectory. Both HAMA and DGS experience larger delays since gateway nodes wait for AUVs to approach, leading to prolonged delays. The simulation results underscore HAMA's suitability for delay-tolerant networks, while DGS demonstrates relatively higher end-to-end delays.

In conclusion, the end-to-end delay comparison highlights how the proposed architecture's data processing, optimized transmission strategies, and the characteristics of the DFDC routing algorithm collectively contribute to mitigating delays. The specific dynamics of each protocol's operation, including AUV speeds and trajectory lengths, further influence delay performance across different scenarios.

4.4 Energy Consumption Comparison

The comparison of energy consumption, presented in Figure 3(c):



This study provides valuable insights into the efficiency of various network architectures. In the proposed architecture, each fog node within a designated sub-area takes on the responsibility of locally storing and processing the collected data in its vicinity. For data that is sensitive to delays, the processed information is transmitted to the surface sink node through multi-hop routes. Conversely, data that is less time-sensitive is transported by mobile fog nodes to the surface and then forwarded to the sink node. Leveraging local processing significantly reduces the volume of data, thereby leading to a reduction in corresponding energy consumption.

Furthermore, the inherent characteristics of the Depth-based Fog Assisted Data Collection (DFDC) routing algorithm also contribute to enhancing energy efficiency in comparison to the other two routing protocols studied. These enhancements are the result of well-orchestrated mechanisms that ensure optimized energy usage in various scenarios:

Notably, the network lifetime of the HAMA protocol emerges as the longest among the other protocols examined. This outcome is attributed to the unique design of HAMA, featuring only two Autonomous Underwater Vehicles (AUVs), which incur relatively high energy consumption. Nodes with lower energy levels have reduced selection weight, making them less likely to be chosen for data transmission tasks. As a result, the energy load on these nodes remains light, promoting a balanced distribution of energy consumption. This balance in energy usage ensures the network lifetime remains stable even with an increase in the number of nodes, a characteristic that sets HAMA apart.

On the other hand, the network lifetime of the Data Gathering Scheme (DGS) protocol is comparatively shorter. This is primarily due to nodes located in close proximity to the trajectory of mobile elements (such as AUVs), which deplete their energy resources faster. Additionally, the fixed trajectory of these mobile elements contributes to a non-uniform energy consumption distribution, impacting the overall network lifetime.

In essence, the energy consumption comparison provides a comprehensive view of how the proposed architecture's data processing strategies, routing algorithms, and the distinct attributes of each protocol contribute to energy efficiency. The results underscore the advantages of local data processing, optimized routing, and well-balanced energy consumption in extending the network's operational lifetime and ensuring efficient energy utilization.

4.5 Summary

The "Performance and Evaluation" chapter assesses the proposed architecture and routing protocols through various metrics. Packet Delivery Ratio (PDR) analysis showcases the architecture's effectiveness in reducing losses, aided by fog nodes. End-to-end delay comparisons highlight lower delays through data processing and AUV optimization. Energy consumption evaluation reveals efficient local processing and routing, enhancing overall energy efficiency. These insights collectively underscore the architecture's prowess in improving data delivery, minimizing delays, and optimizing energy usage.

CHAPTER 5

CONCLUSION AND FUTURE WORK

5.1 Overview

The research outcomes suggest a novel architecture for fog-based computing that is founded on underwater sensor cloud systems. The challenges of latency in communication and power consumption are to be addressed head-on with the implementation of this design. The proposed architecture enhances the performance of the network by reducing the amount of communication overhead and reducing the burden placed on surface sink nodes, both of which contribute to the network's overall performance. The utilization of fog nodes and the improvement of data processing efficiency both contribute to the achievement of this goal.

5.2 Summary of Research work

In summary, this research has presented an innovative architecture and routing scheme aimed at tackling significant issues within underwater sensor networks. The novel underwater sensor cloud system architecture, based on fog computing, successfully eases the burden on surface sink nodes, resulting in reduced communication delays and energy consumption. Through the utilization of fog nodes for local data processing and optimized data relay, this architecture has exhibited significant enhancements in packet delivery, end-to-end delay, and energy efficiency.

Furthermore, the Depth-based Fog Assisted Data Collection (DFDC) routing protocol presented in this study introduces a refined approach to routing decisions in underwater networks. This leads to reduced energy consumption, lower end-to-end delays, and enhanced data reliability.

The findings of this research showcase the potential of fog computing and well-designed routing protocols in elevating the performance of underwater sensor networks. By addressing the challenges of data delivery, energy consumption, and delay, the proposed architecture and DFDC protocol contribute to a more efficient, reliable, and sustainable underwater network ecosystem. As technology advances and underwater applications diversify, the insights presented in this study hold significant promise for shaping the future of underwater communication and data processing. The outcomes demonstrate that the proposed approach outperforms comparable methods in terms of average energy usage, network lifetime, and packet delivery ratio.

5.3 Future Work

In the future, there's potential to enhance the way data moves from fog nodes to sink nodes. Fog nodes could work together to better organize how they send data. When AUVs come up to the surface, they could discuss and agree on a plan for how data should be sent using radio communication. The specific details of this plan are beyond what's covered in this paper. This kind of coordination could help prevent data from getting lost and make the process more efficient.

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