OPTIMIZING ROUTING PROTOCOLS FOR ENERGY CONSERVATION IN UWSN

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ABOUT THE AUTHOR

Dr. R. M. Gomathi is a distinguished academician and researcher with a robust background in engineering and technology. She completed her Bachelor of Engineering (B.E.) at Thiagarajar College of Engineering in Madurai, a prestigious institution known for its rigorous academic standards and strong emphasis on research and development. Following her undergraduate studies, Dr. Gomathi pursued a Master of Technology (M.Tech.) at SRM University in Chennai, where she further honed her technical skills and theoretical knowledge. Her dedication to advanced studies and research led her to earn a PhD from Sathyabama Institute of Science and Technology, focusing on the critical area of Routing in Underwater Wireless Sensor Networks. This specialization underscores her expertise in addressing communication and data transmission challenges in underwater environments.

With over 16 years of teaching experience, Dr. Gomathi has made significant contributions to academia, shaping the minds of countless students and fostering a deep understanding of complex engineering concepts. Her prolific research output matches her commitment to education; she has published nearly 50 papers in various esteemed national and international journals and conferences. She has also published two books with ISBN and DOI. Her work is well-recognized, with many of her publications indexed in Scopus and some in the Web of Science, reflecting her research's high impact and quality.

Dr. Gomathi's innovative approach and research excellence have been acknowledged through grants for various patents, highlighting her contributions to technological advancements and practical applications in her field. Her broad research interests encompass Sensor Networks, Artificial Intelligence, Machine Learning, and Data Analytics. These fields are at the forefront of technological innovation, and her work in these areas contributes to developing new methodologies and solutions with wide-ranging applications. Her dedication to teaching marks Dr. R. M. Gomathi's career, her substantial research achievements, and her continuous pursuit of innovation in engineering and technology. Her contributions significantly impact the academic community and the broader technology field.

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PREFACE

The ever-evolving landscape of technology continually pushes the boundaries of what is possible, and Underwater Wireless Sensor Networks (UWSN) represent a significant leap in exploring and understanding our underwater environments. The monograph, titled "Optimizing Routing Protocols for Energy Conservation in UWSN," delves into one of the most critical challenges faced by UWSNs: energy efficiency.

UWSNs have the potential to revolutionize various applications, including aquatic life management, pollution monitoring, and coastal surveillance. However, these applications are often hindered by high energy consumption for underwater communication and data collection. This monograph addresses these challenges by proposing innovative routing protocols aimed at conserving energy, extending the network's operational lifetime, and enhancing its reliability.

The research presented here is the culmination of extensive study and experimentation. It explores UWSN architecture, acoustic propagation, and routing protocols designed specifically for underwater environments. The proposed energy-efficient strategies are thoroughly analyzed and validated, providing valuable insights and practical solutions for researchers and practitioners in the field.

I extend my heartfelt gratitude to all those who contributed to this work, including colleagues, reviewers, and the academic community. This monograph is a step towards sustainable and efficient underwater sensor networks that can significantly impact environmental monitoring and management.

I hope this monograph serves as a valuable resource for researchers, students, and professionals, inspiring further innovations in UWSN.

Dr. R. M. Gomathi
July 2024

ABSTRACT

The monograph "Optimizing Routing Protocols for Energy Conservation in UWSN" explores advanced strategies to address the critical issue of energy efficiency in Underwater Wireless Sensor Networks (UWSNs). These networks have significant potential in various applications, such as aquatic life management, pollution monitoring, and coastal surveillance, but are often limited by high energy consumption. This work proposes innovative routing protocols that aim to conserve energy, extend the operational lifetime of the network, and enhance its reliability. The research encompasses a detailed study of UWSN architecture, acoustic propagation, and specialized routing protocols. The proposed energy-efficient strategies are thoroughly analyzed and validated through extensive experimentation, providing practical solutions and valuable insights for researchers and practitioners. The findings of this monograph contribute to the advancement of sustainable and efficient UWSNs, offering a robust framework for future developments in this field.

Keywords: UWSN, energy efficiency, routing protocols, underwater communication, acoustic propagation, network lifetime, environmental monitoring, sustainable networks

Contents

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION TO UWSN

UWSN is based on WSN, which attempts to explore the world of underwater. The UWSN consists of a group of underwater sensors that are geographically scattered to sense underwater environmental conditions, as cited by Ian Akyildiz et al. (2005). The sensed underwater data benefit numerous real-time applications such as aquatic life management, pollution management, coastal area monitoring, etc. The deployed sensor nodes sense the environmental data and communicate it among themselves.

This chapter presents the basic idea of UWSN. Initially, section 1.2 discusses the basics of acoustic propagation. The architecture of UWSN is presented in section 1.3. The internal structure and the protocol stack of underwater sensors are presented in sections 1.4 and 1.5, respectively. Sections 1.6 and 1.7 summarise the applications and challenges involved in UWSN. The research motivation, core objectives and contributions are outlined in sections 1.8, 1.9 and 1.10, respectively. Finally, the organisation of the thesis is presented in section 1.11.

The sensor nodes can be either static or mobile. Usually, the sensor nodes forward the sensed data to the BS or Remote Station (RS), as cited by Felemban (2013). Data communication is possible underwater using an acoustic transceiver. The acoustic transceiver generates low-frequency acoustic waves with shorter bandwidth and longer wavelengths, as Tariq Ali et al (2013) claimed. Despite numerous benefits, UWSN still suffers from several crucial challenges, such as energy efficiency, unstable weather conditions, network lifetime, etc. This chapter intends to discuss the basic concepts of UWSN, including the applications and challenges involved. The following section presents the basics of acoustic propagation.

1.2 BASICS OF ACOUSTIC PROPAGATION

Subwater sensors deployed at different ocean depths in harsh environments develop an underwater acoustic network. The data can be transmitted through the acoustic connection between these sensor nodes, as shown in Figure 1.1.

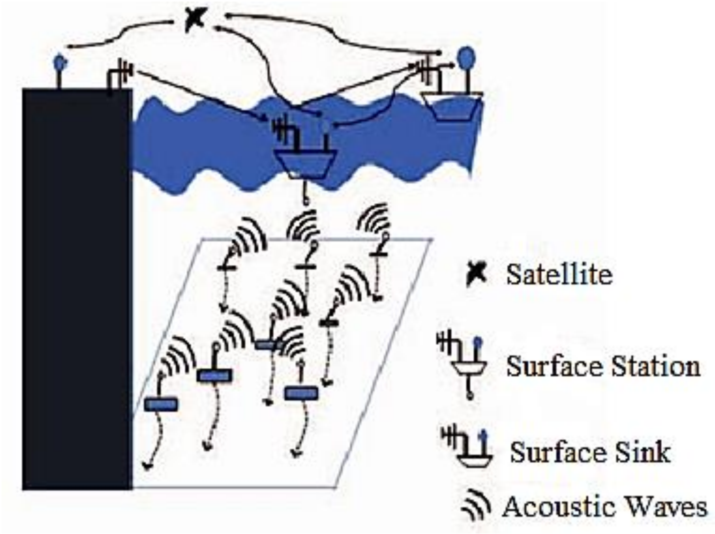

Figure 1.1 Sample 3D UWSN

Most of all, route split, shout blaring, multi-path, physicist unfolding, and high and unpredictable delays in communication impact acoustic communications. All these attributes check acoustic communication's spatial and temporal variance and establish the usable transmitting potential of underwater acoustic communication, restricted and dramatically affected by each radius. Long-distance signals transmitted over several hundreds of kilometres could have only a few kilohertz (KHz) transmission power. In contrast, a signal with a shortrange working over several tens of meters could have a transmission strength of around 100 KHz.

These attributes are ahead in each system with low bit rates. Therefore, the contact area is drastically reduced compared to terrestrial radio frequency. AUVs are usually fitted with advanced communication equipment with more facilities, such as processing space and relays for communication. An AUV is an unmanned vehicle that gathers sensed information from sensor nodes of 3D underwater environments, as shown in Figure 1.2.

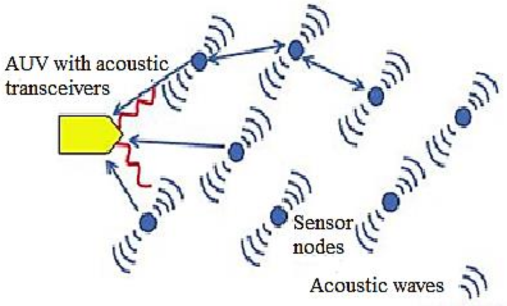

Figure 1.2 Data collection by AUV using an acoustic transceiver

Onshore acoustic communication waves can be uniformly arranged and differ as long, overlong, moderate, short, or highly abbreviated links. The acoustic channels are often divided roughly vertically and horizontally, keeping with the sound ray method. The propagation characteristics are systematically different, especially regarding time delay, multi-path extends, and variance delay. The problems solved within the onshore network are as follows. Accessible transmission ability is severely restricted, and the underwater acoustic links may be compromised due to fading and multi-path. Underwater communication delay is five magnitude orders beyond the radio frequency channels and parameters. High prices characterise underwater sensors since additional protective sheaths allow for sensors to be measured squarely, and suppliers offer a relatively small variety of square measurements. Battery power is banned, and batteries are often not rechargeable, so substitute power cannot be used. In addition, underwater sensors are vulnerable to failures due to fouling and corrosion. In the following section, the system model of the proposed work is presented.

1.3 BASIC ARCHITECTURE OF UWSN

Felemban et al. (2015) presented a detailed architectural plan for UWSN. There are three kinds of sensors in UWSN: surface buoys, anchors, and regular nodes. The surface buoy nodes float on the water surface and are usually loaded with a Global Positioning System (GPS) to obtain the location information of the nodes. Anchor nodes are intermediary nodes directly communicating with the surface buoys and regular nodes. The regular nodes are the normal nodes that cannot communicate directly with the surface buoys but can communicate with the anchor nodes. The architectural plans of UWSN are presented in four dimensions: 1D, 2D, 3D, and 4D. The basic architectures are presented in the following subsections.

1.3.1 Architecture of 1D UWSN

The architecture of one-dimensional UWSN relies on a network of self-governing underwater sensor nodes. All the sensor nodes involved may perform various operations, such as local data processing, sensing and data forwarding, as claimed by Khalid Mahmood Awan et al. (2019). Usually, an underwater sensor node in 1D architecture may be distributed as a surface buoy node or an underwater node. The underwater information is collected when the underwater sensor node is deployed as a surface buoy node. On the other hand, when the sensor node acts as an underwater node, it collects the underwater details and shares them with the remote station. Similarly, the sensor node may act as an AUV that can descend underwater to collect information and share it with the remote station.

1.3.2 Architecture of 2D UWSN

In the 2D architecture, the sensor nodes are deployed in groups called clusters underwater, as stated by Guang Yang et al. (2019). Every cluster of sensor nodes possesses a CH node, which can also be called the anchor node. The sensor nodes communicate with the anchor node for data transmission to the remote station. The sensor nodes are interlinked to the anchor nodes through wireless acoustic channels. The anchor nodes are responsible for transmitting messages to the remote station, which is achieved by means of acoustic transceivers. There are two kinds of acoustic transceivers: horizontal and vertical transceivers. The 2D architectural diagram is depicted in Figure 1.3. The horizontal transceiver is meant to transmit messages to the underwater sensor nodes and accumulate the data collected by the sensors.

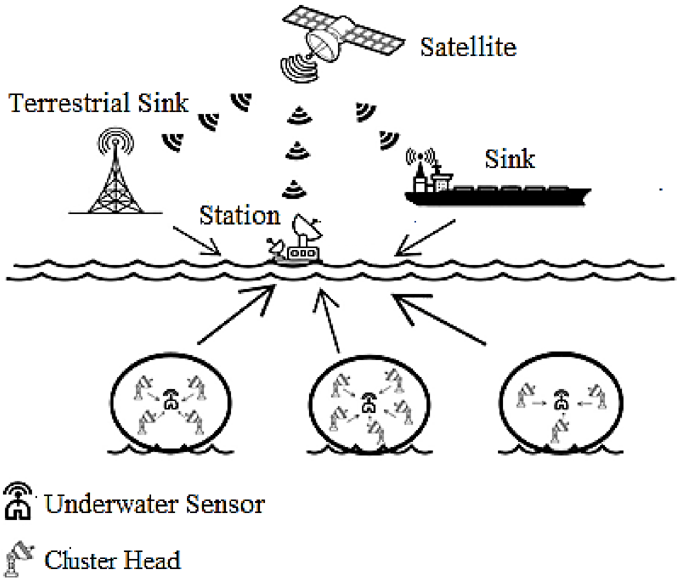

Figure 1.3 Two-Dimensional Architecture of UWSN

The anchor nodes use the vertical transceiver to relay messages to the remote station. The remote station is provided with an acoustic transceiver, which can handle simultaneous communication with several anchor nodes at a time. In this architecture, the sensor nodes may be linked to the anchor nodes either directly or indirectly. An indirect link connects the corresponding sensors to the anchor node via some intermediary sensors.

1.3.3 Architecture of 3D UWSN

In the 3D architecture, clustered underwater sensors are deployed at varying depths, presenting a communication scenario that extends beyond two dimensions. However, floating nodes at different depths is a challenging task. The 3D architecture of UWSN, depicted in Figure 1.4, is a testament to the innovative solutions required to overcome these challenges.

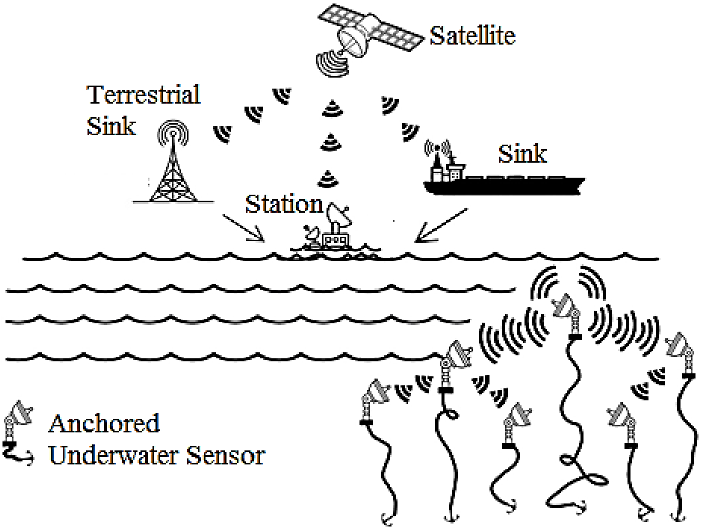

Figure 1.4 3D architecture of UWSN

One of the simplest solutions is to connect the sensor node with a surface buoy node with the help of adjustable wires, as claimed by Cayirci et al (2006). Yet, this solution involves several security threats and inconveniences. Hence, the underwater sensor nodes are anchored to the Ocean's underside and packed with a buoy and a pump. With this equipment, the buoy can drive the sensor to different depths. The performance of 3D UWSN is discussed in Ravalomanana's work (2004). However, the major issue being faced is coverage.

The proposed work collects the sensor node data via AUV by the side of a user-specified path. To get the sensed information from the sensor nodes, the AUV moves from one ZOR to another ZOR. All 3D ZOR sensor nodes will be awakened and held in active mode when AUV arrives in the ZOR field. If the 3D ZOR sensor nodes are in sleep mode, the AUV cannot acquire the sensed information effectively. The proposed method decreases the underwater network's energy consumption by having a static node in each area more efficiently. This stationary node remains in a fixed location, intended to accumulate data from all sensor nodes in its area, as depicted in Figure 3.2.

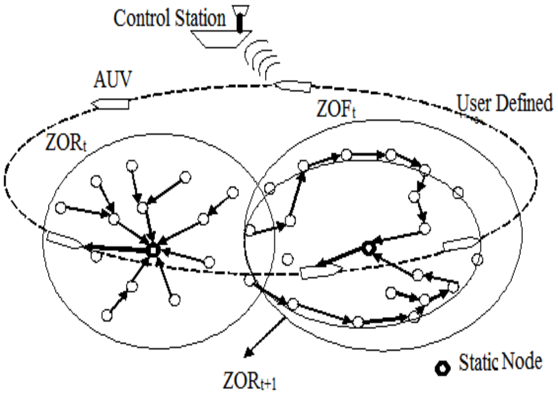

Figure 3.2 Proposed model of modified mobicast routing protocol with static node in ZOR region

AUV drives between two zones to capture packets from these static nodes and delivers the collected information to the control station. The scenario of the ZOF region is represented in Figure 3.3. Due to the limited storage and battery capacity of the sensor nodes, excessive loss of information must be prevented. Once AUV reaches the ZOR field, all sensor nodes become active and more energy is consumed.

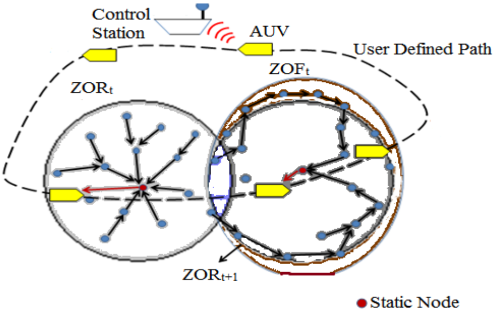

Figure 3.3 Scenario of ZOF in modified mobicast routing protocol

Using a static node at each ZOR can even reduce this energy consumption. Sensor nodes pass on the data to their region's static sensor node every time they have data to send; if not, it will be in sleep mode. The results of the suggested solution will be discussed in the following section.

3.4 RESULTS AND DISCUSSIONS

This chapter presents a modified mobicast routing protocol for UWSN that consumes less energy. The proposed approach is simulated with simulator NS2. The proposed scheme with the inclusion of static node is compared with the existing mobicast routing protocol without a static node. Figure 3.4 displays the test simulation area. All sensor nodes are distributed on an irregular basis in the underwater environment. As the sensor nodes float, they are allocated irregularly in each ZOR field. When the simulation is started, the sensor nodes move away from the area because of the onshore current impact and can make a hole. AUV moves in the pathway specified by the user. Each region is placed with a static node close to the user-defined path. Before AUV arrives, this static node gathers data from every sensor node. Using the NS2 simulator, the proposed protocol is implemented.

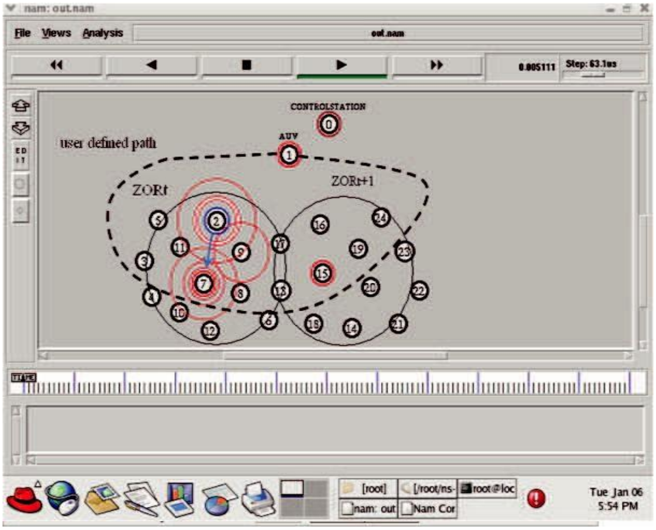

Figure 3.4 Sample simulation screen of EP-MMRP

21 sensor nodes are distributed randomly in Figure 3.4, which includes static nodes, and two ZOFs are introduced, ZOR at time t and ZOR at time t+1. The ZOR_t's and ZOR_{t+1}'s static nodes are nodes 7 and 15, correspondingly. Such static nodes are located near the given path of the AUV. Until AUV arrives in that area, these stationary nodes collect information from every sensor node. Node2 sends data, for example, to node 7, as depicted in Figure 3.4. AUV progresses in the path the user identifies and collects all the data from the static node. Static node 7 remains active when AUV moves

through the small zone, while the remaining nodes are in sleep state for minimal energy consumption. This transfers to the ZOR_{t+1} zone after AUV collects data from the ZOR_t zone. Here, the static node 15 shows that leftovers are in active mode. In terms of packet delivery ratio, energy consumption and end-to-end delay, the performance of the proposed modified mobicast routing protocol is evaluated.

The results are shown in the following Figures 3.5-3.7. In the presence of static nodes, the energy consumption has gradually reduced by 15 percent in EP-MMRP, as shown in Figure 3.5. The average energy consumption is the relation between the total energy utilised for receiving the whole data packets and the total amount of energy the nodes use for data transfer. In addition, the proposed approach shows a 10 percent increase in PDR compared to the current method, which is represented in Figure 3.6.

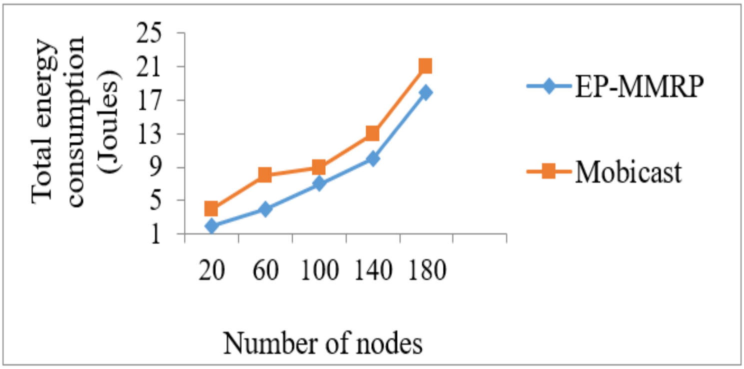

Figure 3.5 Energy consumption of EP-MMRP and Mobicast routing protocol under varying number of nodes

The PDR is computed by the count of data packets successfully procured at the BS concerning the total count of data packets communicated. The proposed approach also proves minimal packet end-to-end delay, and the outcomes are available in Figure 3.7. The end-to-end delay is the average time the information packet needs to move from the source sensor node to the sink node in seconds. This metric is computed by the following equation.

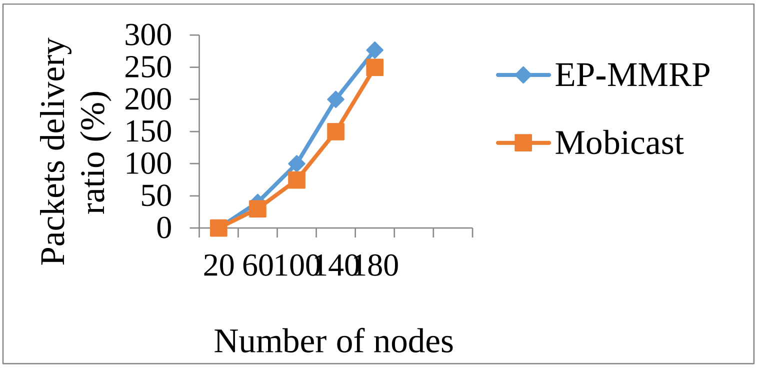

Figure 3.6 Packet delivery ratio of EP-MMRP and Mobicast routing protocol under varying number of nodes

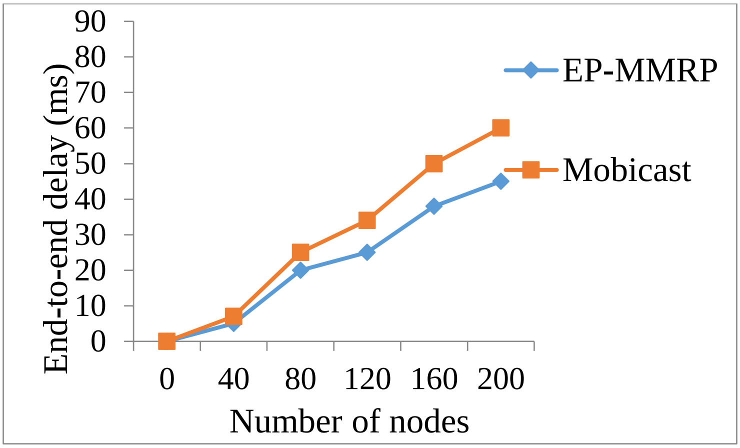

Figure 3.7 End-to-end delay of EP-MMRP and Mobicast routing protocol under varying number of nodes

The experimental outcomes prove that the proposed modified mobicast routing protocol with static node results in less energy consumption and minimal end-to-end delay while proving higher PDR. The summary of this section is presented in the next section.

3.5 CHAPTER SUMMARY

This chapter introduces a modified mobicast routing protocol with static node for UWSN and compares the performance of the proposed protocol to the existing static node-free mobicast routing protocol. The existing mobicast routing protocol establishes the ZOR to manage a collection of sensor nodes and collect information using AUV from nodes. This AUV sends information to the surface station at the bottom. When AUV reaches the ZOR region, every sensor node in that region is in active mode, which consumes more energy.

The proposed modified mobicast routing protocol uses a static node in each zone, and when AUV reaches that area, this fixed node remains active. Compared with the existing system, this concept consumes minimal energy. The simulation outcomes are finally described with respect to efficient transmission speed, energy consumption and packet delay.