Energy efficient Routing Protocols for Underwater Acoustic Wireless Sensor Network

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LIST OF ABBREVIATIONS

ACE	Adaptive cooperation in EEDBR
ACUN	Adaptive clustering routing algorithm for underwater
AEERP	AUV aided energy efficient routing protocol
AEO (Qos)	Adaptive energy aware quality of service
AODV	Action on demand distance vector
AODV-SUARP	A-hoc on-demand distance vector sparse underwater acoustic routing protocol
BEAR	Balanced energy adaptive routing protocol.
BEEC	Balanced energy efficient circular routing protocol
BEER	Balanced energy efficient rectangular
BOA	Buffalo optimisation algorithm
CBEEC	Cluster-based energy-efficient communication
CBLS	Cluster based localization scheme.
CCRU	Clustering combined with bio inspired routing in underwater.
CDBR	Clustering depth-based routing
Co-EEORS	Cooperative energy efficient optimal relay selection
EAVARP	Energy aware and void-avoidable routing protocol
EBAP	Energy balanced based on AODV protocol.
EBDCR	Energy-balanced and depth-controlled routing protocol
EBECRP	Energy efficient and balanced energy consumption cluster-based routing protocol
EBER2	Energy balanced efficient and Reliable routing
EBLE	Energy balanced and lifetime extended.
EBLOAD-EG	Energy balanced load distribution through energy gradation

EBOR	Evidence theory based opportunistic routing.
E-CBCCP	Energy efficient chain-based routing protocol
EEC-VBF	Evenly energy consumed vector-based forwarding
EEDBR	Energy efficient depth-based routing
EEHC	Energy efficient hybrid clustering
EEIRA	Energy efficient interference and route aware
EER	Energy efficient routing
EERU-CA	Energy efficient routing - clustering approach
EGRC	Energy efficient reliable data transmission Scheme
EKEER	Enhanced K-means cluster based and energy efficient routing.
ES-VBF	Energy saving vector-based forwarding.
EVAGR	Energy-efficient void avoidance geographic routing.
E-VAR	Enhanced void avoidance routing
FLCOR	Fuzzy logic-based cooperative opportunistic routing.
IEBR	Improved energy balancing routing
IICC	Intra and inter cluster communication.
KEER	K-means cluster based and energy efficient routing.
LDBR	Light weight depth-based routing
LEACH	Low energy adaptive clustering hierarchy
LEACH-DUARP	Low energy adaptive clustering hierarchy dense underwater acoustic routing protocol
LEER	Layer-based and energy-efficient routing
MAODV	Modified action on demand distance vector.
MLCEE	Multi-layer cluster-based energy efficient
PBR	Pressure based routing.

PSBR	Pressure sensor based reliable routing.
QLACO	Q-learning aided ant colony
RECRP	Reliable energy-efficient cross-layer routing protocol
RE-PBR	Reliable energy-efficient pressure-based routing
RVHP	Routing void handling protocol
SEEC	Sparsity-aware energy efficient clustering
SFV	Stability function value
SH-WDFAD-DBR	Single hop selection
UAWSN	Underwater acoustic wireless sensor network
UMOD-LEACH	Underwater modified low energy adaptive clustering hierarchy
UWSN	underwater wireless sensor network.

DECLARATION

I declare that this research is solely my own work and has not been submitted anywhere in support for any application for award of higher degree. In view of this, I take ownership of the entire research. The contribution of other research being published and unpublished used in this research has been duly acknowledge with appropriate credit.

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[1] Saleh, M. H., Takruri, H., & Linge, N. (2022, July). Energy aware routing protocol for sparse underwater acoustic wireless sensor network. In *2022 13th International Symposium on Communication Systems, Networks and Digital Signal Processing (CSNDSP)* (pp. 750-755). IEEE.

[2] Saleh, M. H., Takruri, H., & Linge, N (2022). "Enhanced Vector Based-Forwarding Routing Protocol (ENH-VBF) for Underwater Communications". Salford Postgraduate Annual Research Conference (SPARC). University of Salford, Manchester. June 2022.

[3] Hassanu, M., Linge, N., & Takruri, H. Underwater Acoustic Wireless Sensor Networks: A Survey of Energy Efficient Routing Protocols. *Available at SSRN 4409459*. Under review, Journal of Network and Computer applications, Elsevier.

[4] Hassanu, M, Takruri, H, & Linge, N. ''Sparse underwater acoustic sensor network energy conscious routing protocol''. IET Networks journal. Under review.

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ABSTRACT

Technological advancement regarding oceanic world discovery and monitoring has led to autonomous communication, which results in the emergence of the Internet of underwater things (IoUT). Underwater acoustic wireless sensor networks have become one of the most recently researched within the IoUT. An underwater acoustic wireless sensor network consists of sensor nodes, autonomous vehicles, and remotely operated vehicles which are normally deployed to carry out a collaborative task within an underwater region. Underwater acoustic wireless sensor networks have become one of the most recently researched area which supports long transmission range. However, acoustic signals experience deformation due to factors which consist of noise, propagation delay, and low bandwidth. Sensor nodes are battery dependent which mean they are difficult to recharge or replace once deployed. Routing protocols play important role in the communication process between these sensor nodes. As a result, this research aims to develop an energy efficient routing protocol that can bring about optimal policies for energy consumption in the process of data aggregation and transmission. The developed routing protocol focused on sparse and dense network architectures by examining the popular ad-hoc routing protocol action on demand distance vector routing protocol (AODV) for sparse networks and low energy adaptive clustering hierarchy (LEACH) for dense network. For a sparse architecture this research identifies current energy and overhead challenges facing AODV which in turn modifies the protocol by creating a new energy aware and overhead friendly routing protocol called action on demand distance vector sparse underwater acoustic routing protocol (AODV-SUARP) for underwater communication. AODV-SUARP introduces the mechanism of route stability function (RSF) by colour mode to select the most energy efficient route to forwards packets. For dense architecture this research identifies the energy challenge facing the conventional LEACH routing protocol which in turn leads to its modification by creating a new energy aware routing protocol called low energy adaptive clustering hierarchy dense underwater acoustic routing protocol (LEACH-DUARP). Furthermore, for the optimal selection of eligible cluster head in a subsequent round LEACH-DUARP introduces a concept called the stability function value (SFV). The developed routing protocols (AODV-SUARP and LEACH-DUARP) were implemented in NS-3 and validated using mathematical modelling. Results obtained indicated both AODV-SUARP and LEACH-DUARP achieves a considerable result compared to other routing protocols in terms of residual energy, packet delivery ratio, and number of dead nodes.

CHAPTER ONE
GENERAL INTRODUCTION

1.1 BACKGROUND TO THE STUDY

Almost 71% of the world is naturally covered with water, which plays a vital role in human life. Water discovery has been carried out for many years, but despite discoveries, some parts of the oceanic world remain undiscovered. Water is categorised into shallow and deep water. Shallow water ranges from 0m to 305m and deep-water ranges from 305m and above in depth (Lavis, 2018)(E. S. Ali, Saeed, Eltahir, & Khalifa, 2023). Water possesses a different environmental condition that needs to be taken into consideration in the process of discovering aquatic life, water phenomena, and the natural resources that it contains. Communication in an underwater environment has become a challenging issue that has led to unmanned underwater communication that gave rise to the Internet of underwater things (IoUT) (Jouhari, Ibrahimi, Tembine, & Ben-Othman, 2019). IoUT consists of connecting underwater devices which effectively communicate between themselves in the water (Qiu, Zhao, Zhang, Chen, & Chen, 2019). To communicate effectively between such devices an Underwater wireless sensor network needs to be place and include sensor nodes and an autonomous underwater vehicle (AUV) that are interconnected with a wireless link and used to relay data from the bottom to the surface of water (Karpagam &.Prabha, 2019)(M. A. Ali, Mohideen, & Vedachalam, 2022). Sensor nodes are usually deployed in water to perform a collaborative task efficiently.

To establish a stable underwater wireless sensor network, the network needs to be reliable to effectively transmit packets of data successfully. Underwater wireless sensor networks are used in applications such as disaster forecast monitoring, for example tsunami, military surveillance, environmental water monitoring, ocean mapping and offshore oil exploration (Mohsan, Li, Sadiq, Liang, & Khan, 2023), (Felemban, Shaikh, Qureshi, Sheikh, & Qaisar, 2015). An underwater wireless sensor network communicates by employing radio, acoustic, optical and magneto inductive technologies. A radio frequency used by a terrestrial network can be applied in underwater communication, but it only covers a short range in communication with a high rate of data. Magneto inductive technology is mostly applicable in real time underwater communication but requires a high data rate, a change in channel condition and large size antenna (Modi & Gupta, 2018). Optical technology is used in underwater but with rapid signal attenuation and requires high power in its process of communication (Saeed, Celik, Al-Naffouri, & Alouini, 2019). Acoustic technology is considered the most widely used underwater technology which covers a long communication range but suffers from signal deformation and transmission loss (Song, Cho, Kang, Hodgkiss, & Preston, 2011).

Routing plays a major role in the process of communication between these underwater sensor nodes. To achieve reliable underwater communication, the routing protocol employed needs to be energy efficient to effectively prolong the network lifetime of the sensor nodes. Due to water current, a sensor nodes mobility makes the underwater wireless sensor network adapt to certain topological changes with respect to the sensor node location. Unlike the terrestrial network, underwater wireless sensor networks consider the node's location vital (Sun, Zheng, Han, Ge, & Yin, 2023), (Erol-Kantarci, Mouftah, & Oktug, 2010).

1.2 RESEARCH MOTIVATION

Water is one of the most important elements of the world for humans, possessing natural resources and offering a means of transportation. Water possesses a different environment to land. The discovery of natural resources, the early detection of underwater natural disasters and managing the recovery from unexpected disaster like the spilling of oil from wrecked tanker, and damage to ship needs underwater wireless sensor network technology with reliable protocols to communicate between the sensor nodes involved in the communication process (Kaveripaka Sathish, Ravikumar, Rajesh, & Pau, 2022), (Han, Yin, Tian, & Sheng, 2019). Underwater acoustic wireless sensor networks deal with sensor nodes which are battery dependant and result in link breakages and an unnecessary wastage of bandwidth. Therefore, this research proposes routing protocol that can select path between sensor nodes in the process of communication. Therefore, the research focus on developing routing protocols based on two underwater routing techniques a source routing technique for the sparse and a clustering routing technique for the dense part of the proposed routing protocol.

1.3 RESEARCH PROBLEM

Communication between devices in an underwater acoustic wireless sensor network has become a crucial factor when it comes to data gathering and transmission in underwater. Data gathering among sensor nodes and other self-driven devices in underwater has become an important issue. Mobile sensor nodes in this network tend to experience failure due to energy exhaustion which causes a lack of data delivery when trying to communicate with each other. Network scale plays a role in energy conservation among sensors by considering the amount of communication to base station (Fattah, Gani, Ahmedy, Idris, & Targio Hashem, 2020), (Awan et al., 2019), (Tarannum, 2010). As a result, this research focuses on sparse and dense network to effectively minimize energy consumption among sensor nodes, AODV was adopted for the sparse and LEACH for the dense network. However, the AODV and LEACH routing protocols face communication challenges in terms of the energy consumption of sensor nodes. These challenges are as follows:

AODV faces communication challenge in terms of power consumption among sensor nodes. This results in a fresh route discovery process which causes routing overhead and a lack of data delivery with excess bandwidth usage (Mohsin, 2022), (Goyal, Rishiwal, & Negi, 2023).

The LEACH routing protocol experiences energy failure among sensor nodes within a cluster while trying to aggregate and transmit data to the base station (Meena & Agarwal, 2022), (Afify, Tawfik, & Darweesh, 2022). As a result, sensor nodes find it difficult to select the most eligible sensor node to act as cluster head in subsequent rounds while trying to aggregate and transmit data effectively.

This research investigates and proposes approaches for use in underwater acoustic wireless sensor for sparse and dense networks. These approaches were developed to lower energy consumption among sensor nodes in both AODV and LEACH routing protocols.

1.4 RESEARCH AIM AND OBJECTIVES

The following outline the aim and objectives of the research

1.4.1 RESEARCH AIM

To develop routing protocols for underwater acoustic wireless sensor network that can achieve data aggregation and transmission with less energy consumption among underwater sensor nodes.

1.4.2 RESEARCH OBJECTIVES

The objectives of the research are as follows.

1. To thoroughly study underwater acoustic wireless sensor network and their structures.
2. To analyse existing underwater ad-hoc acoustic wireless sensor routing protocols.
3. To develop routing protocols with unique techniques that maximize the network lifetime to ensure adequate network performance in terms of sensor nodes energy consumption.
4. To validate the developed routing protocol by using analytical modelling.
5. To acquire test results and critically compare them to other works in terms of efficiency and reliability.

1.5 RESEARCH CONTRIBUTION

This research focuses on sparse and dense underwater sensor networks by adopting and implementing changes in AODV routing protocol for the sparse networks and LEACH routing protocol for the dense networks. The contribution of this research is to address communication challenges, i.e the reduction of energy consumption among sensor nodes to achieve better performances. This aims to ensure data delivery and reduce failures in the process of communication among sensor nodes. The main contributions of the research are as follows.

For the sparse underwater networks, the following contributions were achieved.

- Modification of the RREQ message header by introducing the sensor nodes energy status which helps to identify the most eligible sensor nodes for selection in terms of the energy status for each route to act as packet forwarders.
- Modification of the route reply message (RREP) by introducing a route stability function (RSF) to determine the most eligible route for selection to forward packets based on the energy status of the sensor nodes. This aims to avoid routing overhead by initialising a fresh route discovery the conventional AODV when sensor node experience energy failure.
- Development of mathematical modelling for the sparse underwater sensor network using RREQ and RREP AODV messages by applying performance metrics to determine efficiency.

For the dense underwater networks, the following contributions were achieved.

- Design of a mechanism called a stability function value (SFV) to select most eligible cluster head based on the energy status of sensor nodes in a cluster or average number of packets received by the cluster head within a round. This aim to avoid the total energy failure of the sensor nodes.
- Development of mathematical modelling for the dense underwater sensor network using LEACH routing protocol by applying concept of grey wolf algorithm using performance metrics to determine efficiency.

The implemented modification resulted in 30% energy reduction in AODV and 40% residual energy in LEACH.

1.6 RESEARCH METHODOLOGY

A scientific research methodology has been adopted for this research as it utilises simulation and mathematical models based on experiments. Although, the methodology may be updated as the need arise to offer a better process to solve the research problem. The main process for the research methodology is illustrated in Figure 1.1.

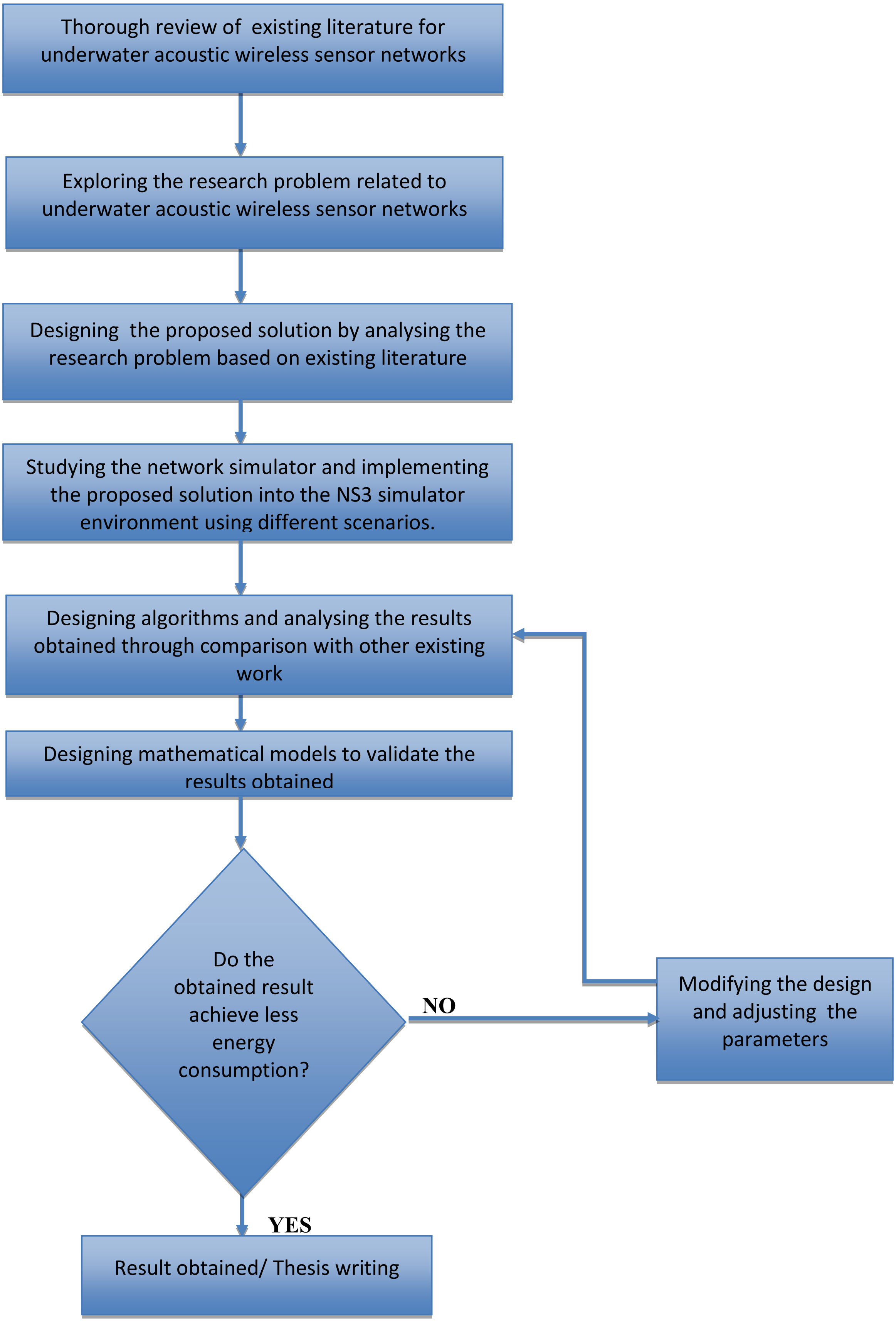


Figure 1.1: Research methodology flow diagram

1.7 ORGANIZATION OF THE THESIS

Chapter 2: Presents an overview of underwater acoustic wireless sensor networks, the architecture of underwater acoustic wireless sensor networks, areas of application of underwater wireless sensor networks and highlight the communication challenges involved in underwater acoustic wireless sensor network. Furthermore, the chapter discusses on ad-hoc routing protocols which consist of reactive, proactive and hybrid routing protocols. More also, underwater routing protocol taxonomy which consists of localization-based and localization-free underwater routing protocols, an underwater routing strategy, and the differences outlined between terrestrial and underwater routing were also discussed.

Chapter 3: Presents the literature review on developed energy localization-based underwater routing protocols as well as developed energy localization-free underwater routing protocols. The chapter also presents a summary table of the reviewed underwater routing protocols.

Chapter 4: Presents the research requirement specifications which consist of simulation modelling and discusses the categories of underwater simulators and their features. The chapter also discusses a selected simulator, Aqua-sim-NG for NS-3, and the justification for choosing it. The chapter finally presents an underwater propagation model for underwater channel modelling as well as the energy consumption model.

Chapter 5: Presents the proposed routing protocol for sparse underwater networks, an AODV routing protocol, the message type defined by AODV routing protocols (which consist of route request message, route reply message and route error messages), algorithm, and an AODV flow chart. The chapter further discussed the proposed AODV-SUARP routing protocol, the modification of and AODV route request message for AODV-SUARP, as well as its algorithm and flow chart. The chapter also discussed the proposed dense routing protocol, the LEACH routing protocol and its algorithm and flow chart. Furthermore, the proposed LEACH-DUARP combination was presented together with its phases i.e the establishment phase consisting of the selection of eligible cluster head nodes using stability function value in subsequent rounds. The data transmission phase of LEACH-DUARP was presented as well as the algorithm and flow chart of the proposed LEACH-DUARP routing protocol.

Chapter 6: Presents the implementation of the proposed AODV-SUARP and LEACH-DUARP routing protocols in an NS-3 simulation environment, explaining the models, and the network animator. Simulation scenarios for both were presented.

Chapter 7: Discussed the performance evaluation and validation using mathematical modelling. Sparse network modelling was presented using AODV-SUARP routing protocol by different performance metrics which consist of energy consumption, packet delivery ratio and delay. Furthermore, dense network modelling was presented using LEACH-DUARP routing protocol were packet delivery ratio, residual energy and number of dead nodes were used as performance metrics.

Chapter 8: Presents the conclusion of this research and recommendation for future work.

CHAPTER TWO

BACKGROUND STUDY TO UNDERWATER ACOUSTIC SENSOR NETWORK AND ROUTING PROTOCOLS

2.1 OVERVIEW OF UNDERWATER ACOUSTIC WIRELESS SENSOR NETWORK

Underwater acoustic sensor networks are one of the most widely researched areas regarding underwater communication for the Internet of underwater things (IoUT) (Lal, Petroccia, Conti, & Alves, 2016). Underwater acoustic technology covers a long communication range of more than 10km depending on the operating frequency band of the sensor node's acoustic modem using an acoustic signal as the transmission medium (Milica Stojanovic & Beaujean, 2016). Acoustic communication is faced with certain challenges which consists of low bandwidth, low transmission speeds of 1500m/s, noise, a high bit error rate, multi path fading and high propagation delays (Agajo, Joseph, Emeshili, Erhemwanahue, & Idama, 2017). Sensor nodes used in acoustic communication are battery driven which makes them difficult to charge or replace and subsequently becomes a challenging when considering the mobility of sensor nodes in underwater environmental conditions. Sensor nodes need to utilize their energy consumption to effectively prolong the network lifetime (Nayyar, Puri, & Le, 2019).

Underwater acoustic wireless sensor networks are applicable to many areas including military surveillance, oil exploration, marine environmental monitoring, and disaster detection (such as tsunamis, earthquakes) however, such applications need more enhanced techniques to allow a proper way of aggregating and transmitting the required data (Sprea et al., 2019). In recent years the design of efficient routing protocols for acoustic communication has been developed with different mechanism to transmit packets of data from underwater to surface of the water (Sharif-Yazd, Khosravi, & Moghimi, 2017). The importance of routing protocols in guiding the sensor nodes to sense, send, and receive packets of data makes it vital to develop a reliable underwater routing protocol. However, the dependency of the sensor nodes on batteries makes underwater acoustic communication more challenging when the delivering the successful transmission of data from underwater to surface water (Diamant & Lampe, 2018). Furthermore, the mobility of underwater sensor nodes results in dynamic and unpredictable topology due to water currents.

Underwater sensor nodes consume more energy compared to terrestrial sensor nodes; therefore, an energy efficient routing will effectively decrease delays, result in less energy consumption, and prolong the network lifetime. Underwater acoustic sensor networks use two transmission modes to send packets of data which consist of a single hop and multi hops to successfully deliver packets of data from the bottom to surface of the water (Dhongdi, Anupama, Sant, & Gudino, 2016). The deployment of an underwater acoustic sensor network consists of ordinary underwater sensor nodes which are deployed to sensed data and move effectively underwater by using water currents, while anchor nodes are tied at the ocean bottom using wire which allows them to adjust their length. An autonomous underwater vehicle (AUV) is used which moves in underwater to gather information among sensor nodes in specified underwater region and helps locate information on the underwater sensor nodes (Katti & Lobiyal, 2016). Sensor nodes underwater are equipped with an acoustic modem to allow them to communicate with the sink node at the surface of the water. Meanwhile the sink node is equipped with both acoustic modems to communicate with the underwater sensor nodes while the radio modem to communicates with the onshore or offshore station (Khan, Ahmed, Jembre, & Kim, 2019).

All underwater sensor nodes and autonomous vehicles are deployed underwater with a specified goal of collaborating by forming an organized network to achieve a given objective.

2.2 ARCHITECTURE OF AN UNDERWATER ACOUSTIC SENSOR NETWORK

Reliable communication depends upon a network's functionality and efficiency. The architecture of a network plays a major role in its functionality (Liou, Kao, Chang, Lin, & Huang, 2018). Underwater sensor nodes are normally deployed to perform co-operative tasks by monitoring, sensing, and transmitting the required data to the sink node. Sensor nodes involved in an underwater acoustic sensor network uses an acoustic signal as the transmission medium exchange packets of data. Underwater acoustic sensor networks use an acoustic link between sensor nodes to deliver a packet of data using an acoustic signal between the sensor nodes. The following are the network architecture of underwater acoustic wireless sensor networks.

2.2.1 TWO-DIMENSIONAL (2D) UNDERWATER ACOUSTIC SENSOR NETWORK

The underwater acoustic sensor network 2D architecture comprises underwater sensor nodes that are anchored at the bottom of the ocean and connected through an acoustic link. In 2D architecture, clusters are formed with an underwater gate way node/cluster head node as the head of the cluster. Horizontal and vertical mode of communication are used to effectively communicate among the underwater sensor nodes. The anchored underwater gate way node/cluster head is equipped with two acoustic transceivers which include the vertical acoustic transceiver and the horizontal acoustic transceiver. The horizontal acoustic transceiver was used by the underwater gate way node/cluster head node to receive data within the cluster, while the vertical acoustic transceiver was used to relay the collected data from the cluster and deliver it to the surface station. The surface station is equipped with an acoustic transceiver to receive information from an underwater gate way node/cluster head node and a radio transmitter for sending the received data to the onshore or offshore station (Akyildiz, Pompili, & Melodia, 2005).

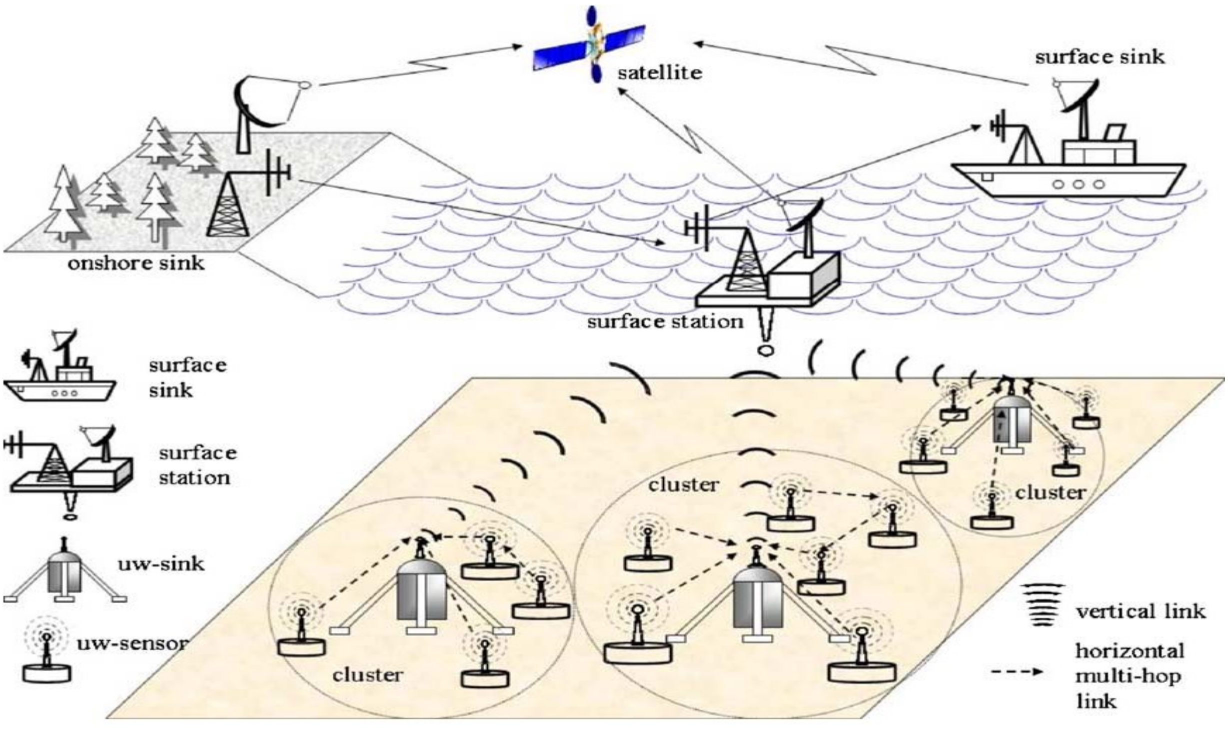


Figure 2.1: 2D Architecture for Underwater Acoustic wireless sensor network adapted from Akyilidiz, pompili and medlodia (2005)

2.2.2 THREE-DIMENSIONAL (3D) ARCHITECTURE FOR UNDERWATER ACOUSTIC SENSOR NETWORK

The three dimensional (3D) underwater acoustic wireless sensor network consist of underwater sensor nodes which are deployed in the water to sensed, monitor, and send the required data to the surface station. Sensor nodes involve in this 3D architecture are equipped with a floating buoy using wire to adjust their length by means of an electronic controlled engine in the sensor node. The underwater nodes communicate with each other using acoustic link and a multi hop mode of transmission to deliver data successfully to the surface station. The surface station is equipped with an acoustic transceiver to receive data from underwater nodes and a radio transmitter to send data using radio signals to the onshore or offshore station (Akyildiz, Pompili, & Melodia, 2006).

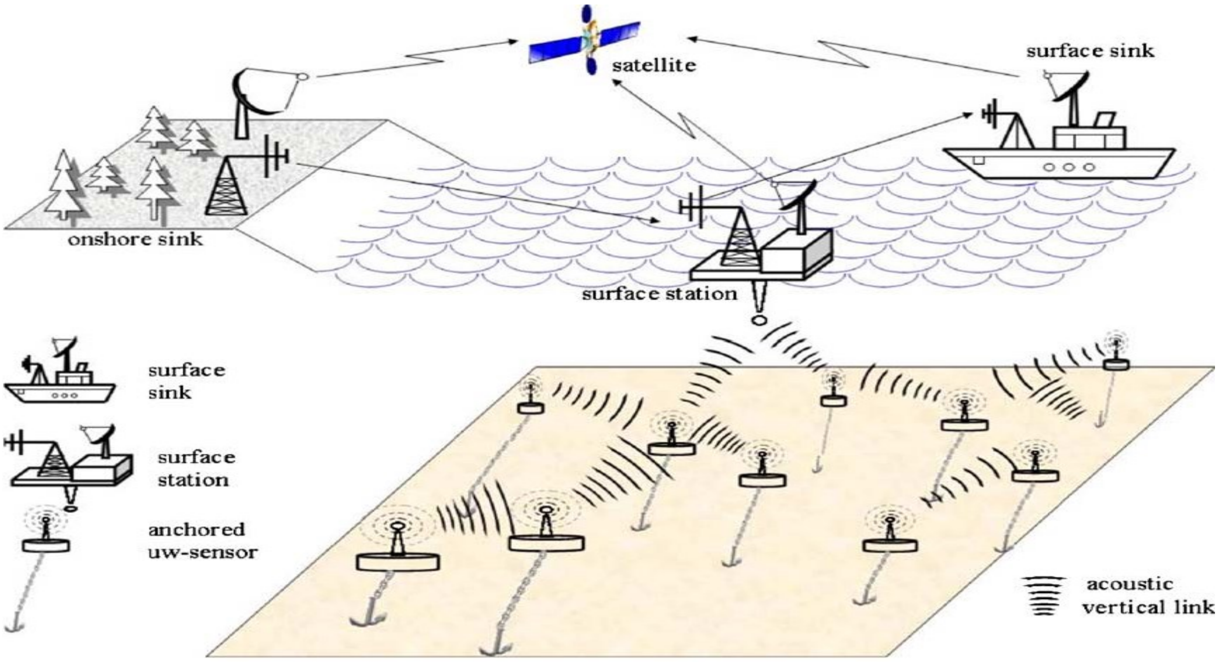


Figure 2.2: 3D Architecture of an underwater acoustic sensor network adapted from Akyilidiz, Pompilid and Melodia (2005)

2.3 AREAS OF UNDERWATER WIRELESS SENSOR NETWORK

Underwater acoustic wireless sensor networks are applicable to many areas. Sensor nodes are used collaboratively to monitor and gather required information (Khajuria & Kaur, 2018). The following are some of the application areas of underwater acoustic wireless sensor networks

- Disaster forecasting (tsunami, hurricane etc)
- Assisted Navigation.
- Offshore oil exploration
- Deep sea archaeology
- Pollution monitoring
- Military surveillance

- Marine habitat monitoring

2.4 COMMUNICATION CHALLENGES OF UNDERWATER ACOUSTIC WIRELESS SENSOR NETWORKS

Underwater acoustic wireless sensor networks experience some challenges which are outlined below:

Noise: Affects signal strength in underwater acoustic communication. Two categories of noise affect such communication namely human being and ambient (Atanackovic, Zhang, Lampe, & Diamant, 2019). Human being noise results from certain human activities, which consist of fishing activities, shipping activities, and the utilization of machines, while ambient noise consists of wind, thermal, shipping and turbulence. All these noises greatly affect the efficient exchange of packets using an acoustic signal (Milica Stojanovic & Preisig, 2009).

Attenuation: Underwater acoustic wireless sensor networks suffer from signal attenuation which affects data transmission when using an acoustic signal. A reduction of signal occurs due to absorption loss and spreading loss. Moreover, it is difficult to extract the desired data from the received signal at the destination (Heidemann, Stojanovic, & Zorzi, 2012).

Propagation delay: Underwater acoustic sensor networks experience a low transmission speed of 1500m/s which varies due to salinity, temperature, and the depth of the water. The acoustic speed variation affects the delivery of data especially for time critical applications (Ismail, Hussein, & Ariffin, 2010).

Bandwidth: The bandwidth used in underwater acoustic communication is limited. This occurs due to a convergence (transmission range) that is inversely proportional to the bandwidth. Routing protocols must take account of the transmission range for the frequencies to deliver the required data to the destination (Qiao, Babar, Ma, Liu, & Wu, 2017). In acoustic underwater communication a very long range of 100km results in a bandwidth of less than 1KH, a long range of 10-100KM result in 2-5KH of bandwidth, a medium range of 1-10KM results in a maximum 10KH bandwidth, while a short range communication of 0.1-1KM result in a maximum of 20-50KH (Khan et al., 2018).

Energy consumption: The energy consumption of the sensor node is one of the major constraints that limit the transmission of data among underwater sensor nodes (Muhammed, Anisi, Zareei, Vargas-Rosales, & Khan, 2018). Once the power level of the sensor node is depleted sensor nodes experience delays and transmission loss, which results in a general overall network failure (Qu, Zhang, Cui, Wang, & Mastorakis, 2019). The need for an efficient mechanism that can prolong the lifetime of underwater sensor nodes in the data transmission process has become vital.

2.5 ROUTING PROTOCOLS

Routing protocols play a vital role in transmitting packets from source to destination. When ensure link stability and consistency in the network, there is no difference between wired and wireless network routing protocols in terms of their working principles. However, the dynamic nature of a wireless environment is high, which leads to the poor performance of traditional routing protocols when applied (Li et al., 2020). Several routing protocols are under designe to serve a particular purpose depending upon the area of application. In an ad-hoc environment scenario, several routing protocols are being developed to serve a purpose under terrestrial wireless networks, although some of can only be applied in underwater environments only by undergoing certain modifications and enhancement for stability and overall network performance (Singh, Singh, & Singh, 2010).

2.6 AD-HOC ROUTING PROTOCOLS

Various ad-hoc routing protocols have been designed for a larger number of inconsistent network topologies. These routing protocols suffers from certain restrictions which consist of dynamic topological changes, low bandwidth, and high energy consumption. These routing protocols have been tailored towards the delivery of packets from source to destination. Ad-doc routing protocols have been classified into three categories namely proactive (table driven), reactive (on demand), and hybrid routing protocols. Proactive routing protocols are ad-hoc routing protocols and deals with table information by keeping up to date information about routing (Boulaiche, 2020). Routes are readily available in proactive routing when a node wants to exchange packets of data. Proactive routing protocols handles mobility in a periodic update, but route latency is always available.s Reactive routing protocols also known as on demand discovers routing path when the need arises. Source nodes look for available routes by disseminating a route request to successfully establish connection with the destination node (Alfawaer & Riyaz, 2017). Hybrid routing protocols are ad-hoc routing protocols that combine both proactive and reactive routing protocols characteristics. Ad-hoc routing protocols in ad-hoc are expected to avoid high communication overhead by reducing the route setup messages and route maintenance messages to enable effective communication (Mishra, Singh, & Tripathi, 2019). The decentralisation of the ad-hoc network makes routing protocols distributive and adaptive to convergence in route selection before the route becomes invalid due to network changes. The ad-hoc routing protocol taxonomy is illustrated in Figure 2.3:

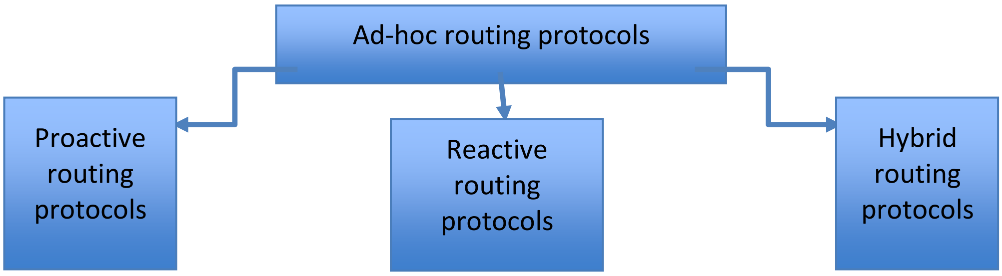


Figure 2.3: Ad-hoc routing protocol taxonomy

Based on the taxonomy of ad-hoc routing protocols in Figure 2.3, Several routing protocols are developed for ad-hoc networks which are based on the discovery and maintenance of routes. Although the taxonomy of routing protocols differentiates the working principles of the routing protocols. Table 2:1 provides a comparison based on the attributes of each routing classification.

Table 2.1: Difference and attributes of hybrid, reactive and proactive routing protocols

Routing Attributes	Proactive routing (Table driven)	Reactive routing (On-demand)	Hybrid routing
Routing overhead	Incurs high routing overheads	Incurs low routing overheads	Incurs medium routing overheads
Organization of the network	Hierarchical/Flat	Flat	Hierarchical
Handling of mobility	Through periodic updates	Through maintaining routes	Both
Latency for route	Always exist	Route latency exists when needed	Both
Dissemination of topology	Periodic dissemination	On demand dissemination	Both
Route discovery	Periodic	On demand when needed	Both
Bandwidth usage	High	Low	Medium
Energy consumption	High consumption of energy due to the existence of routes all the time.	Low energy consumption due to the existence of routes on demand	Moderate

2.6.1 PROACTIVE ROUTING PROTOCOLS

Proactive routing protocols also known as table driven are ad-hoc routing protocols that require each node to be aware and keep routing information up to date using a routing table. The use of routing tables allows nodes to periodically exchange information when changes in the network topology occur (Verma & Soni, 2017). In proactive routing, routes are always available whenever node is willing to send a packet. Maintaining up-to-date routing information by using proactive routing protocols requires a regular exchange of topological information by the nodes which leads to high overheads in the network. In comparison, in proactive routing protocols, routes are available when needed (Xie, Wang, Guo, & Wu, 2018). However, proactive routing protocols incur certain draw backs which consist of restructuring failures which occur in a slow timely manner and a requires high amount of data for maintenance. Moreover, there is an increase in bandwidth and power consumption due to table information exchange for nodes topology changes even without data transmission across the network (Mustafa, Al-Heeti, Hamdi, & Shantaf, 2020). Examples of proactive routing protocols include optimized link state routing (OLSR), Destination sequence distance vector (DSDV), and wireless routing protocol (WRP).

2.6.2 REACTIVE ROUTING PROTOCOLS

Reactive routing protocols are among the classification of ad-hoc routing protocols also known as on-demand routing protocols. The classification of routing protocols formed routes from sources to the destination when needed. The routing protocols utilise route discovery, which is triggered when a source node is willing to send data to the destination node (Meshram & Dorge, 2017). The nodes involved in a search for routes disseminate a message by broadcasting it to neighbouring nodes up to the stage where a connection will be established between the source and destination for a packet exchange. In this procedure involving route establishment through reactive routing protocols, routes are sustained until they are no longer needed or when all routes to the destination are not accessible (Bendale, Jain, & Patil, 2018). Reactive routing protocols possess less routing overhead compared with proactive routing protocols and use fewer resources due to the lack of routing table per node. Due to heavy traffic, reactive routing protocols suffer high latency especially in route set up. Furthermore, reactive routing protocols can suffer from network clogging because the network is flooded with route discovery messages when it fails to deliver packets to the destination node (Ali & Kulkarni, 2017). Examples of protocols for reactive routing include an ad-hoc on-demand distance vector routing protocol (AODV), dynamic source routing (DSR), and a temporally ordered routing algorithm (TORA).

2.6.3 HYBRID ROUTING PROTOCOLS

Hybrid ad-hoc routing protocols incorporate both the pros of on-demand (reactive) routing protocols and table driven (proactive) routing protocols. Examples of hybrid routing protocols are zone routing protocol (ZRP), and core extraction distributed ad-hoc routing protocol (Govindasamy & Punniakody, 2018).

2.7 UNDERWATER ROUTING PROTOCOL TAXONOMY

Routing is vital in terms of sending packets from source to destination. Underwater routing protocols are divided into two namely localization-based routing protocols and Localization free routing protocols (Khan et al., 2018).

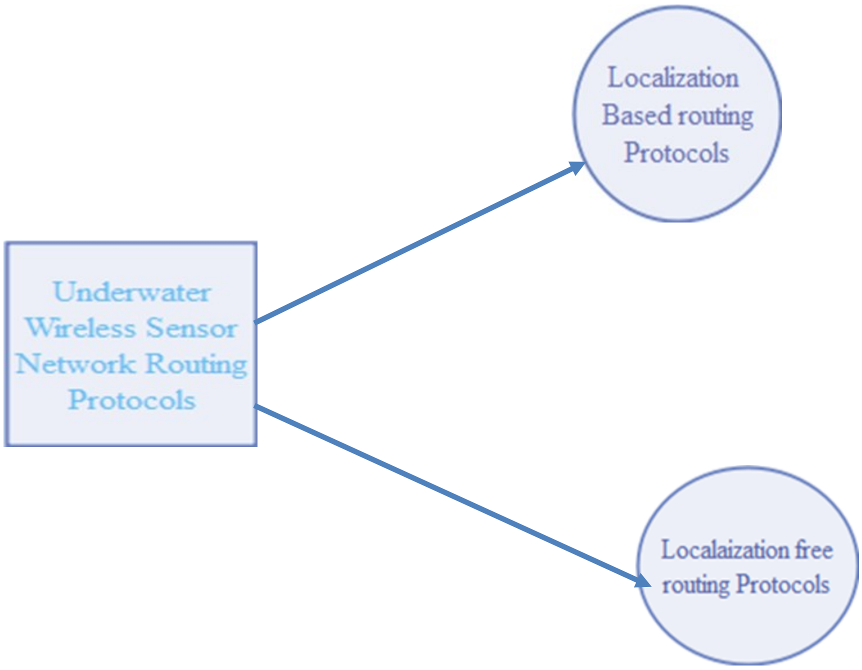


Figure 2.4: Underwater routing protocol taxonomy

2.7.1 LOCALIZATION BASED ROUTING PROTOCOLS

Localization based routing protocols need to know a two- or three-dimensional co-ordinate's information about the sensor nodes. They require a complete and full location about the network to know the actual routes to transmit packets from the bottom to the surface of the water (Ahmed, Salleh, & Channa, 2018). One example of localization based underwater routing protocol is vector based forwarding routing protocol (VBF).

2.7.1.1 VECTOR BASED FORWARDING ROUTING PROTOCOL (VBF)

The VBF routing protocol makes use of a virtual routing pipe by allowing the sensor nodes to realize their position information to effectively transmit packets from source to destination. VBF routing protocol makes the sensor nodes aware of their position information as well as the packet forwarders and destination node (sink). The sensor nodes, which happen to be within the virtual routing pipe are potential sensor nodes that can take part in the packet exchange (Fazeli & Basharzad, 2017). VBF allows the eligible sensor nodes within the virtual routing pipe to act as packet forwarders which subsequently decreases the network traffic. An increase in the number of forwarding sensor nodes in the routing pipe enables a higher packet delivery by the VBF but latency arises due to increase in the number of hops (Padmaja & Rajendran, 2018). However, a VBF routing protocol cannot recover the occurrence of a void due to the absence of nodes from the virtual routing pipe. Furthermore, VBF experiences high energy consumption due to the repeated use of nodes within the routing pipe.

2.7.2 LOCALIZATION FREE ROUTING PROTOCOLS

Localization free routing protocols do not need to know two- or three-dimensional co-ordinates of the sensor nodes as only water pressure is used to measure the depth of the sensor nodes and make routing path. Localization free routing protocols do not require complete information about the network but clearly discover routes based on depth and node-to-node searches up to the sink node (Khan, Hassan, & Jung, 2020). One renowned example of localization free underwater routing protocols is depth-based routing protocols (DBR)

2.7.2.1 DEPTH BASED ROUTING PROTOCOL (DBR)

A DBR routing protocol is one of the localization-free routing protocols which allows the sensor nodes to know their depth to effectively transmit packets of data from the bottom to the surface of the water. Sensor nodes compare the depth in the header by checking the most recent depth of the sensor nodes in order to effectively realize the eligible packet forwarding nodes (Kumar & Sinha, 2020). In DBR, sensor nodes have high depth exchange packets to sensor nodes which have less depth. DBR employ the use of holding time to do away with the occurrence of redundant packet transmission (Mahmood et al., 2020). However, DBR suffers from energy depletion in the relay sensor nodes closer to the sink. This is due to the loads they experience when transmitting packets from sensor nodes with a greater depth to the sink node.

2.8 UNDERWATER ROUTING STRATEGIES

Underwater routing protocols consist of different routing strategies in the process of packet transmissions. Such strategies include Clustering routing strategy, source routing strategy, opportunistic routing strategy, cross layering routing strategy, hop-by-hop routing strategy, reinforcement learning based routing strategy and geographical routing strategy (Gomathi, Manickam, & Sivasangari, 2016).

2.8.1 CLUSTERING ROUTING STRATEGY

A clustering routing strategy is used to group the underwater sensor nodes into several groups by taking care of the cluster head node with the position of the sensor nodes. The clustering routing strategy uses a cluster head node to takes care of the cluster when receiving packets of data from cluster member nodes. The efficiency of the cluster depends upon the co-ordination of the sensor nodes in the cluster-by-cluster head node, which requires sufficient energy and control. A clustering routing strategy achieves less data redundancy (Zhao, Qu, Liu, Qiu, & Guang, 2019).

2.8.2 SOURCE ROUTING STRATEGY

A source routing strategy considers the route specified by the sender of the packet in the network. The source node discovers the route through the route determination phase by disseminating a route request packet through the network. The source node determines the path by discovering the relay nodes in the path. In source routing, the destination node receives the route request sent by the source node and actively replies by sending back a route reply message to the source node. Route maintenance in source routing is vital as it prolong the network lifetime and overall efficiency of the network. Source routing support scalability and asymmetric channel but suffers from routing overhead (Ashraf & Ahmed, 2020).

2.8.3 HOP-BY-HOP ROUTING STRATEGY

A hop-by-hop routing strategy depends upon the individual selection of the next hop in the packet transmission by the relay nodes. The local view of the network by the relay nodes allows them to select the next hop node in the packet transmission process. A hop-by-hop routing strategy can support scalability in the network but lacks an optimal path in the packet transmission (Gomathi et al., 2016).

2.8.4 OPPORTUNISTIC ROUTING STRATEGY

An opportunistic routing strategy considers selects a dependable set of sensor nodes with the ability to act as packet forwarders. Opportunities associated with the effective transmission of packets determine the next hop but only the highly prioritized sensor nodes in the set are considered in the transmission of packets of data across the network. An opportunistic routing strategy improves the efficient transmission of packets through the characteristics of the channel (Menon & Prathap, 2016).

2.8.5 CROSS-LAYERING ROUTING STRATEGY

A cross layering routing strategy considers the functionalities of layers and information very vital. The protocol stack is stable, simple, and easy, but the interlayer exchange of information is hard and not beneficial to the performance of the network. Cross-layering interaction can be achieved through collision control and the control of power by extending the network performance and decreasing the energy cost (Bansal, Maheshwari, & Awwal, 2018).

2.8.6 REINFORCEMENT LEARNING BASED ROUTING STRATEGY

The topology adaptation result uses a Q-learning algorithm in a reinforcement learning based routing strategy to effectively determine an appropriate route in the packet transmission (Guo, Yan, & Lu, 2019). In a reinforcement learning based routing strategy, the use of function in the routing process takes account of the sensor nodes energy by selecting the most stable sensor node to act in the packet forwarding process. The network extension is achieved in a reinforcement learning routing strategy by effectively utilizing the reinforcement function (Chang, Feng, & Duan, 2019).

2.8.7 GEOGRAPHIC BASED ROUTING STRATEGY

In a geographical routing strategy, a route is determined through the position information of the sensor nodes. The coordinates positions are discovered through GPS and signal strength. However, GPS does not work well underwater, and the signal strength is also affected by noise. In geo-based routing strategy, the sensor nodes positions must be known and each individual sensor node must also know its position. Location information is used to determine where to forward packets of data by sensor nodes in the network (Coutinho, Boukerche, Vieira, & Loureiro, 2017).

2.9 TERRESTRIAL Vs UNDERWATER ROUTING

Underwater wireless sensor network routing protocols are like terrestrial wireless sensor routing protocols, but the working environment differentiate them. Underwater communication tends to be quite challenging unlike its terrestrial counter parts, as it uses the acoustic signal as a medium of communication due to the imperfect radio signals propagated in underwater (Haque, Kabir et al. 2020). An acoustic signal used by the underwater communication possess a lower bandwidth with long propagation delays unlike the terrestrial routing protocols that uses a radio frequency to communicate between devices. Underwater routing protocols experience a topology change in the process of communication due to the unique environmental characteristics of water currents. However, routing protocols used in underwater communication needs to tackle the occurrence of void by assuming for the full location of the sensor nodes through a localization process. Furthermore, both underwater and terrestrial routing protocols deal with devices that consume energy and battery dependent. However, due to the unique characteristics of the underwater environment it become difficult to recharge or replace a sensor nodes battery once deployed. Therefore, underwater routing protocols must maximize energy consumption in the communication process to prolong the network lifetime (Li, Martínez et al. 2016). The following are challenges faced by underwater routing protocols in the communication process due to its unique characteristics.

Propagation delay: Routing protocols used in underwater communication uses acoustic signal between devices for the communication process. This is due to the inability of radio signals to propagate effectively in underwater. Underwater routing protocols using acoustic signals experience propagation delays in the communication between sensor nodes, this is due to its low acoustic propagation transmission speeds of 1,500m/s.

Node mobility: Underwater routing protocols tends to experience a topology change due to water currents which result in a dynamic topology and subsequently result in the occurrence of void holes for the sensor nodes unable to find their next neighbour nodes in the packet transmission process.

Energy consumption: Routing protocols used in underwater communication experience energy consumption among sensor nodes. Energy consumption among underwater sensor node is one of the major constraints that limit the transmission of data among sensor nodes underwater. Once the power level of the sensor node is depleted sensor nodes can no longer be recharged no replaced which tends to mean delays and transmission loss resulting in a general overall network failure. A reliable energy efficient routing protocol has become vital, which favours sensor nodes in the packet transmission and overall network lifetime extension (Ashraf, Ahmad et al. 2020).

2.10 CHAPTER SUMMARY

This chapter discuss an overview of underwater acoustic wireless sensor networks, the architecture of underwater wireless sensor networks, and different areas of application of such network. Furthermore, the chapter also presented the communication challenges associated with underwater acoustic wireless sensor networks which bring about disruption in the process of communication among underwater sensor nodes. Furthermore, the chapter also present a discussion about routing, routing in ad-hoc wireless networks, the classification of ad-hoc routing protocols, characteristics, and attributes for the classification of ad-hoc routing protocols. The chapter further discussed underwater routing protocols taxonomy, an underwater routing strategy and differences between terrestrial and underwater routing. The next chapter provides a literature review of the developed energy underwater routing protocols.

CHAPTER THREE
LITERATURE REVIEW

3.1 INTRODUCTION

Literature reviews play a pivotal role in research. An underwater wireless acoustic sensor network requires reliable routing for efficient data transmission. Sensor nodes collaborate with each other using an acoustic transmission medium to find a reliable transmission path. Sensor nodes depends on the battery for their functionalities in order to collaborate between themselves and achieve a common task. Hence, an energy efficient routing protocol is needed to successfully deliver packets of data from underwater to the surface of the water. This chapter presents underwater routing protocol taxonomy, underwater routing strategies and a review of related literatures on underwater routing protocols with energy considerations.

3.2 AODV ROUTING PROTOCOL FOR UNDERWATER WIRELESS SENSOR NETWORKS

AODV (Ad Hoc On-Demand Distance Vector) is well-suited for sparse networks due to its on-demand routing approach and efficient handling of intermittent communication patterns. In sparse networks, where direct communication links between nodes are infrequent, AODV's on-demand route discovery mechanism proves advantageous. Instead of maintaining a constant set of routes, AODV establishes routes only when communication is needed, reducing unnecessary overhead. This adaptive nature aligns with the sparse network environment, ensuring that routing resources are allocated dynamically, conserving bandwidth, and minimizing the maintenance of inactive routes.

Furthermore, AODV's ability to quickly adapt to changing topologies makes it particularly suitable for sparse networks where nodes may join or leave the network sporadically. The protocol employs sequence numbers to establish loop-free routes, addressing the challenge of rapidly changing topologies in sparse environments. This adaptability and loop prevention mechanism contribute to the protocol's effectiveness in maintaining reliable and efficient communication paths, even in scenarios where direct links between nodes are scarce. Overall, AODV's on-demand nature, reduced overhead, adaptability, and loop prevention mechanisms collectively make it a well-suited choice for routing in sparse ad hoc networks.

Routing techniques intended for terrestrial networks cannot be directly adapted to underwater environments without undergoing modifications due to its unique characteristics. Several routing methods designed specifically for underwater acoustic sensor network have evolved in recent years. Some of these routing protocols based on AODV are as follows.

(Shi & Liu, 2017) Design a routing protocol for energy balancing based on AODV (EBAP). EBAP routing protocol uses two phases which consist of Route discovery and Route maintenance phase. The Route discovery phase uses same method for finding route in classical AODV, while for the Route maintenance phase EBAP does not set a lifetime to a certain route, routes are established when needed, message defined by the routing protocol include the Route request RREQ which is set several times at a random interval to effectively transmit the packets of data between nodes. In the balancing of energy, nodes are chosen based on remaining energy. EBAP achieves less energy consumption of 1400joules as the sensor nodes increases to 100 against AODV with 1600joules. EBAP also achieves a network lifetime of 6000ms for a 100 number of sensor nodes against AODV with 400ms. But EBAP incur a deficiency in mechanism to overcome routing overhead and void hole.

(Liu, Zhao, & Zhang, 2016) Modified the conventional AODV routing protocol for underwater acoustic networks. The MAODV modified the route discovery phase of the classical AODV routing protocol to avoid unnecessary waste of data packets and link breakages using a mechanism of double flooding. MAODV uses double flooding mechanism to reduce the effect of routing faced by underwater acoustic channel mostly by multipath propagation. In view of this a retransmission of Route request RREQ was proposed for the classical AODV routing protocol. MAODV achieves a packet delivery ratio of 95% as the simulation time increases to 2000s against AODV with 75%. But MAODV lacks efficient mechanism to tackle sensor nodes energy consumption and void hole occurrence.

(Kaveripaka Sathish et al., 2022) Works on performance analysis of different routing protocols including AODV routing protocol for underwater wireless sensor network. Due to underwater condition, Qualnet 7.1 was used as the simulation modeler. Different performance metrics were used which consists of average transmission delay, average jitter, percentage of utilization and power used in transmit and receive. Different number of sensor nodes were used. Results obtained indicates source tree adaptive routing least overhead routing (STAR-LORA) achieves lower jitter of 85% when compared to AODV and other routing protocols. Furthermore, AODV outperforms other routing protocols with 76.4% in terms of energy consumed in received mode. Fisheye routing protocol performs better with 91.4% when compared to other routing protocols for percentage utilization. However, all the routing protocols tested do not undergo further enhancement in terms of energy optimization for effective packet transmission in underwater.

(Rakesh & Astya, 2022) Study the performance analysis and evaluation of AODV and DSR reactive routing protocols for underwater communication. The study focused on different number of nodes and nodes depth at a constant speed of 1m/s. OPNET V 14.5 was used as the simulation modeler. Different performance metrics were used which consists of throughput, network load, and end to end delay. Results obtained indicates AODV achieves higher throughput as the number of the nodes increases to 100. Furthermore, as the simulation time reaches 12 minutes, AODV performs better than DSR in terms of delay as the number of the nodes increases to 100. However, both AODV and DSR did not undergo and enhancements in terms of energy consumption for effective underwater communication.

(K Sathish, Ravikumar, Srinivasulu, & Gupta, 2022) Performed an analysis to evaluate the performance of AODV, OLSR, DSR, DYMO, STAR-LORA, ZRP, Fisheye and bellman ford algorithms for underwater wireless sensor network communication. The authors make use of constant bit rate CBR, variable bit rate VBR, and file transfer protocol (FTP) applications to evaluate the routing protocols. Qualnet 7.1 was used as the simulation modeler. Certain performance metrics were used which consist of average transmission delay, average jitter, average pathloss and energy consumption. Results obtain indicates AODV achieves least total energy when compared with other routing protocols. In terms of percentage utilization, Fisheye routing protocol achieves 92% compared to other routing protocols. DSR achieves 0.3% in terms of average path loss compared to other routing protocols. STAR-LORA achieves 86.4% for average jitter when compared with other routing protocols. However, all these routing protocols are conventional without any further enhancement in terms of energy consumption for effective packet transmission in underwater.

(Jiang et al., 2023) Developed an underwater routing protocol named as opportunistic hybrid routing protocol for acoustic radio co-operative networks. The routing protocol composed of a hybrid routing strategy and neighbour discovery mechanism. In the route establishment phase, the routing protocol effectively combine the on demand and opportunistic routing to improve the success rate of data forwarding. The radio acoustic opportunistic hybrid routing was implemented in NS-3 simulator. ROAH routing protocol was compared against AODV, OLSR, and VBF routing protocols. Result obtain indicates ROAH routing protocol performed better in terms of throughput, end to end delay and energy efficiency. However, AODV routing protocol was not enhanced to further compare its performance in terms of energy consumption for effective data transmission in underwater.

(Reddy & Vijayalakshmi, 2022) Works on comparing the performance of novel crow optimization algorithm and AODV based on energy consumption in underwater packet transmission. The work focused on grouping the two routing protocols to effectively take a sample of the result based on energy consumption. NS-2 was used as the simulation modeler with performance metrics which consists of average energy consumption, delay, and normalised routing overhead. Results obtain indicates crow algorithm performs better than AODV based on the performance metrics used. However, the work has not considered enhancing AODV algorithm to effectively use for underwater acoustic sensor network with energy consideration.

(Qadri & Shah, 2010) carried out a performance evaluation analysis for ad-hoc routing protocols which consist of AODV, DSDV, DSR and OLSR for underwater acoustic communication. Certain performance metrics were used for the selected routing protocols performance. These performance metrics consist of packet delivery ratio, average end to end delay, energy consumption, and routing overhead. NS-2 simulator was used as the simulation tool for the analysis. Result obtains indicates AODV acquires stable PDR having a standard deviation of 2.27 against DSR, DSDV, and OLSR with 5.95, 6.43 and 13.08 respectively. Moreover, as the number of sensor nodes increases DSR acquires end to end delay 7 times higher than OLSR, 6 times higher than DSDV and 5 times higher than AODV. Furthermore, as the number of sensor nodes increases OLSR acquires routing overhead 5 times higher than AODV, 3 times higher than DSDV and 2.5 times higher than DSR. Similarly, as the number of sensor nodes increases to 25, AODV acquires average energy consumption of 50% against DSR, DSDV and OLSR having 30%, 10% and 10% respectively. However, AODV and DSDV performed better than DSR and OLSR with less routing overhead which also helps in decrease in energy consumption. Although, with enhance techniques the routing protocols will realise a significant performance as the number of traffic and sensor nodes increases.

(Saxena & Sharma, 2017) performed an analysis using simulation based on AODV and DSDV routing protocols in underwater wireless sensor network. The authors used the classical AODV and DSDV routing protocols to acquire the simulation result using Aquasim network simulator for NS-2. Certain performance metrics were used which consist of packet delivery ratio, energy consumption and end to end delay. Results obtain indicates both AODV and DSDV routing protocols achieved a packet delivery ratio above 50% for a total simulation of 125 seconds. Moreover, AODV acquire end to end delay of 245.53ms against

DSDV with 79.28ms. Furthermore, both AODV and DSDV acquire 94% of energy consumption. However, both conventional AODV and DSDV lack sufficient mechanism to favour the sensor nodes to achieve significant less energy consumption in the process of packet transmission.

(Khandelwal, Mahajan, & Bagai, 2018) Study the performance analysis of AODV routing protocol using optical underwater technology. Considering the nature of the sensor nodes in terms of exchanging data in underwater sensor network. The authors used Qualnet 5.0 as the simulation modeler. Different number of performance metrics were used which include average jitter and, Average end to end delay. Random way point model was used as the network model in the simulation due to random movement of the sensor nodes. AODV routing protocol was tested for a different number of propagation distance 20m, 50m, 100m, 150m and 200m. Different data rates were used ranging from 100kbps, 10mbps, and 2mbps. The result obtains shows that as the propagation distance increases to 200m with data rate of 10mbps, AODV acquire the average jitter of 0.0221 and average end to end delay of 0.13. However, higher data rates should be employed for shorter communication ranges and lower data rates for longer communication ranges to achieve an optimum network and efficient system. Because higher data rates, measured in megabits per second (Mbps), imply faster information transfer, short-range optical communication can be used when large amounts of data must be exchanged.

(Rahman, Benson, & Frater, 2012) developed a routing protocol for underwater ad-hoc networks. The authors proposed the routing protocol to be generic in nature. The routing protocol works with two phases namely Route discovery and Route maintenance phase, three messages are defined by the routing protocol which consist of Route request RREQ, Route reply RREP, and Route alive. The RREQ was used in broadcast packets of data upon receiving the RREQ message the destination node will reply using RREP packets using forward pointer. The route maintenance phase uses a timer in the network layer to detect the route break using the route alive message. Qualnet was used as the simulation modeler and two performance metrics were used which include packet delivery ratio PDR, and control overhead. Result obtains shows that the proposed routing protocol outperforms AODV and DSR routing protocols as the number of the sensor nodes increases to 50 having 1 against AODV and DSDV with 0.98 and 0.97 respectively. Moreover, as the number of sensor nodes increases to 50 the proposed routing protocol acquires control overhead of 9% against AODV and DSR with 120% and 15% respectively. Although, the proposed routing protocol lack sufficient mechanism to tackle energy consumption among sensor nodes which result in routing overhead due to frequent route discovery.

(Vithiya, Sharmila, & Karthika, 2018) works on enhancing the routing performance of AODV routing protocol for underwater acoustic sensor network. The authors modify the conventional AODV by coming up with a protocol that will reduce routing overhead named as low overhead Ad-hoc routing (LOARP). LOARP have three messages namely Route request, Route reply and Route alive. The routing protocol (LOARP) uses route request and route reply in the route discovery while route alive message was used for the route recovery process. The routing protocol was tested together with the conventional AODV and DSR routing protocol. NS-2 was used as the simulation modeler, different number of performance metrics were used which consist of latency, packet delivery ratio and throughput. The routing protocols were tested using different number of sensor nodes ranging from 10, 20, 30, 40,50, 60 and 100. Result obtains shows that as the number of sensor nodes increases to 100 LOARP achieves 400bps against AODV and DSR with 100bps and 200bps respectively. Moreover, LOARP achieves packet delivery ratio of 40% against AODV and DSR with 15% and 22% respectively. Furthermore, as the number of sensor nodes increases to 100 LOARP achieves average delay of 0.14sec against AODV and DSR with 0.1 and 0.16 respectively. However, LOARP achieves a considerable performance but lacks sufficient mechanism to tackle sensor nodes energy consumption.

3.3 LEACH ROUTING PROTOCOL FOR UNDERWATER WIRELESS SENSOR NETWORK

LEACH (Low Energy Adaptive Clustering Hierarchy) is specifically designed for wireless sensor networks and exhibits suitability for dense networks due to its energy-efficient clustering mechanism. In dense networks, where many sensors are deployed in close proximity, energy efficiency becomes a critical concern to prolong the network's overall lifetime. LEACH addresses this challenge by organizing nodes into clusters, with each cluster having a rotating cluster head. This clustering approach reduces the overall energy consumption by enabling data aggregation at the cluster head, minimizing long-distance transmissions, and promoting localized communication. In dense environments, where nodes may be closely spaced, LEACH's clustering helps distribute the energy consumption more evenly, preventing premature energy depletion in specific regions and enhancing the network's overall stability.

LEACH's adaptive clustering mechanism further contributes to its suitability for dense networks. The rotation of cluster heads distributes the energy-intensive task of data aggregation and transmission across different nodes over time, preventing a few nodes from becoming overwhelmed with energy-demanding responsibilities. This adaptability is crucial in dense networks where the load on individual nodes can vary significantly. LEACH's ability to dynamically adjust to changing network conditions and distribute energy-intensive tasks makes it well-suited for dense wireless sensor networks, promoting efficient energy utilization and extending the network's operational lifetime.

(Zhang, Sun, & Yu, 2015) proposed a routing protocol to be used in underwater as clustered routing protocol based on improved K-means algorithm for underwater wireless sensor network (CBKU). The routing protocol uses a clustering routing strategy based on LEACH using K-means algorithm. CBKU uses the concept of K-means to select the nodes that can participate in packet transmission. Concept of primary cluster head and assistant cluster head was introduced. Primary cluster head collects data within a cluster and transfer it to assistant cluster head while the assistant cluster head forward the received data from primary cluster head to base station in multi hop way. Both primary and assistant cluster head are selected based on distance and energy status. CBKU was tested based on simulation using MATLAB against LEACH and LEACH-L routing protocols for 150 number of nodes. Certain performance metrics were used which consist of energy consumption of the network, number of alive nodes, and number of packets received. Result obtain indicates that CBKU outperforms LEACH and LEACH-L by acquiring low energy consumption, high number of live nodes and significant packet received as the number of the rounds increases to 500. Although, CBKU lacks reliable mechanism for data aggregation and transmission as the entire aggregated data from each cluster depends on assistant cluster head to transmit it to the base station which may die due to load.

(Y. Li, Wang, Ju, & He, 2014) posit an underwater routing protocol to reduce collision and improved energy efficiency named as energy efficient cluster formation protocols in clustered underwater acoustic sensor network. The routing protocols works based on the concept of clustering routing strategy for conventional LEACH routing protocol. Two clustered routing protocols were proposed namely S-LEACH, and C-LEACH. The S-LEACH routing protocol was organised to divide the sensor nodes into clusters by allowing the cluster head to broadcast and advance packets (ADV) in a control manner rather than randomly like LEACH. S-LEACH acquired a wasted slot during set up phase due to smaller number of cluster head which makes other node to keep listening to channel to receive ADV packets. This causes an additional energy consumption with much delay and leads to introduction of C-LEACH. C-LEACH uses a concept of control node to serve a function of avoiding collision between ADV packets and broadcasting ADV packets as well on behalf of cluster heads. C-LEACH chooses a time for elected cluster heads to send ICH packets by taking acre of transmission time and receiving time of ICH packets. Control nodes are transferred to act as ordinary nodes when collision of ICH packets occurs. The performance of S-LEACH and C-LEACH were tested on NS-2 simulator over 100 number of nodes. Certain performance metrics were used which consist of number of alive nodes and remaining energy. Result obtain indicates both S-LEACH and C-LEACH outperforms LEACH on the number of alive nodes as the simulation round increases to 25 rounds. Moreover, S-LEACH and C-LEACH outperforms conventional LEACH in terms of remaining energy as the number of simulation rounds increases to 25 rounds. Although, with the additional concept of control node in the cluster, a greater number of dead nodes will increase with in efficiency in energy balancing due to transfer of control node to act as ordinary node in a cluster when collision occur.

(Ahmed, Wahid, & Kim, 2014) proposed a routing protocol called energy efficient nested clustering for underwater acoustic sensor networks (EENC). The EENC routing protocol was based on clustering routing technique by grouping sensor nodes to ensure energy balancing by residual energies. EENC employ cluster inside cluster and select cluster head based on maximum residual energies to transmit packets to the sink. EENC routing protocol was simulated against LEACH and LEACH-L routing protocols. Certain performance metrics were used which consists of packet transmission ratio, network lifetime and throughput for a varying number of 25, 50, 75 and 100 nodes. Result indicates EENC acquire 80% network lifetime against LEACH and LEACH-L with increase in sensor nodes to 100. Moreover, EENC achieves a less redundant packets up to 90% compared to LEACH and LEACH-L. However, EENC routing protocol acquires less throughput with 60% against LEACH-L with 75% and LEACH with 90%. EENC routing protocol suffers from efficiency due to mechanism to tackle cluster head selection in subsequent rounds and overall energy consumption of the individual nodes.

(Abrar, Abdellatif, and Fahd, (2018) posit a technique that broadens the clustering approach employed by the low energy adaptive clustering hierarchy LEACH. The routing proposed an approach that used of time division multiple access (TDMA) and the concept of localization. Sensor nodes involved underwater modified the low energy algorithm clustering hierarchy UMOD-LEACH uses a clustering technique in the exchange of data. clusters are made based on location and transmit data in a single hop to the sink node. The use of clustering approach in UMOD-LEACH achieves a 30% decrease in energy consumption against the conventional LEACH at 70%. Nevertheless UMOD-LEACH suffers from an inefficient mechanism in the subsequent selection of cluster head.

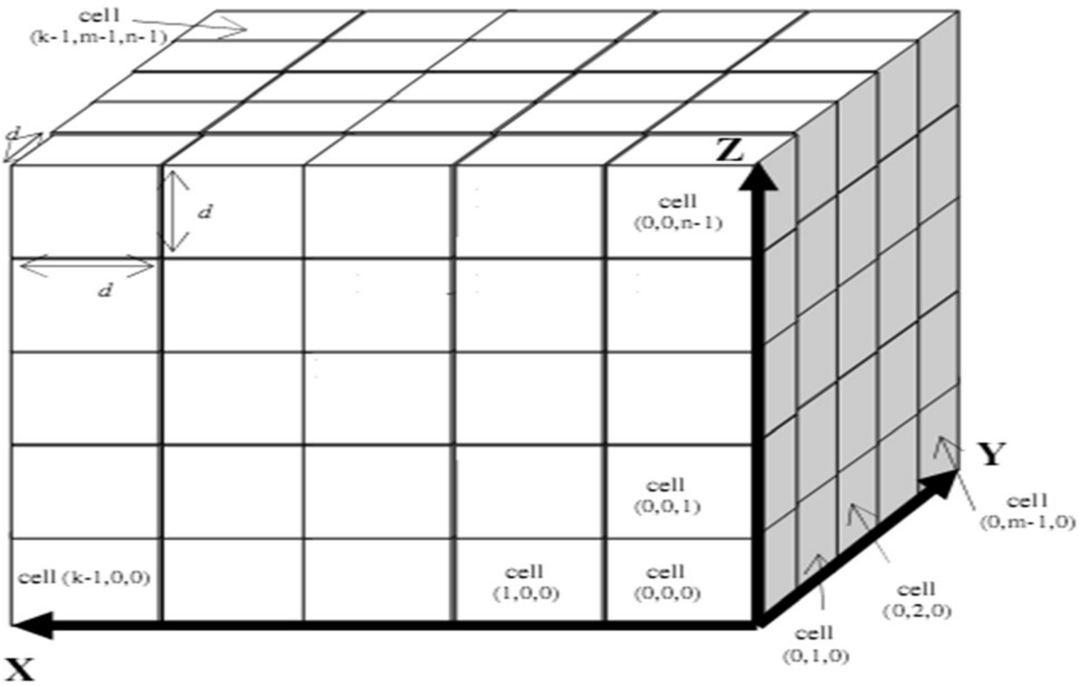
(Sujatha & Baskar, 2020) posit a routing protocol called an efficient multi-hop improved energy LEACH for underwater wireless sensor network (MH-EKMC). The MH-EKMC routing protocol effectively uses K-means clustering technique to allocate clusters. Cluster heads are selected randomly according to distance to effectively transmit packets to the sink. MH-EKMC was simulated against LEACH and direct transmission using performance metrics namely dead nodes and first dead nodes against number of rounds. Results obtain shows MH-EKMC achieves 52 dead nodes at 200 rounds compared to direct transmission with 95. For MH-EKMC its first node dies at 53 rounds while direct transmission first node dies at 53 rounds. However, MH-EKMC lacks efficient mechanism to address individual sensor nodes energy consumption with effective selection of cluster head node to prolong the network lifetime.

(G. Yang, Xiao, Cheng, & Zhang, 2010) proposed a routing protocol named as cluster head selection scheme for underwater acoustic sensor networks. The proposed routing protocol uses clustering technique to transmit packets of data. Selection of cluster head through residual energies of the sensor nodes and distance to the sink was considered. The proposed routing protocol was simulated against LEACH routing protocol using 100 nodes against 400 rounds of simulation. Number of alive nodes was used as the performance metric to compare the efficiency of the two routing protocols. Result obtains showed at 350 round LEACH nodes dies all, while the proposed routing protocol acquired 10 number of alive nodes to the end of simulation round of 400. However, the proposed routing protocol suffered from efficient mechanism to tackle absolute selection of cluster head node with energy consideration for individual nodes within cluster.

(Y. Yang, Wu, Yuan, Khishe, & Mohammadi, 2022) Developed a clustering underwater routing protocol using chimp optimization (ChOA) and hunger games search (HGS) algorithms for underwater communication. The routing protocol uses the technique of chimp optimization to select cluster head where HGS was used to determine the network pathways. Simulation was carried out based on performance metrics which includes network lifetime and energy consumption. Different scenarios were used in which the result obtain indicates ChOA-HGS outperforms LEACH routing protocols in terms of energy consumption and network lifetime. However, LEACH routing protocol was not further enhanced to effectively perform better in terms of energy consumption for underwater communication.

3.4 LOCALIZATION BASED UNDERWATER ROUTING PROTOCOLS

The following are some of the reviewed underwater localization-based routing protocols with energy consideration together with a summary table.
(Noorbakhsh & Soltanaghaei, 2022) Posit an underwater routing protocol known as energy efficient grid-based routing protocol for underwater wireless sensor network (EEGBRP). EEGBRP routing protocol uses s routing technique by applying a dimensional cell grid



division by multi hop to transmit packets among sensor nodes.

Figure 3.1: Network Model for EEGBRP (Source: Noorbakhsh & Soltanaghaei, 2022)

NS-2 was used as a simulation modeler using packet delivery, energy consumption, and end to end delay. From the results obtain EEGBRP was compared to other routing protocols where it achieves 10.65% for successful packet delivery, 8.8% for end-to-end delay and 9% for energy consumption. However, EEGBRP suffers from effective technique that can prolong the gateway nodes energy level, hence an effective technique is needed to consider sparse and dense network architecture for effective data transmission among sensor nodes.

(X. Li, Xu, Zhao, Han, & Yan, 2022) Proposed an underwater routing protocol named as an adaptive multi zone geographic routing protocol for underwater acoustic sensor network (AMGR). The AMGR was used to adjust the neighbour information acquisition according to the topology change speed.

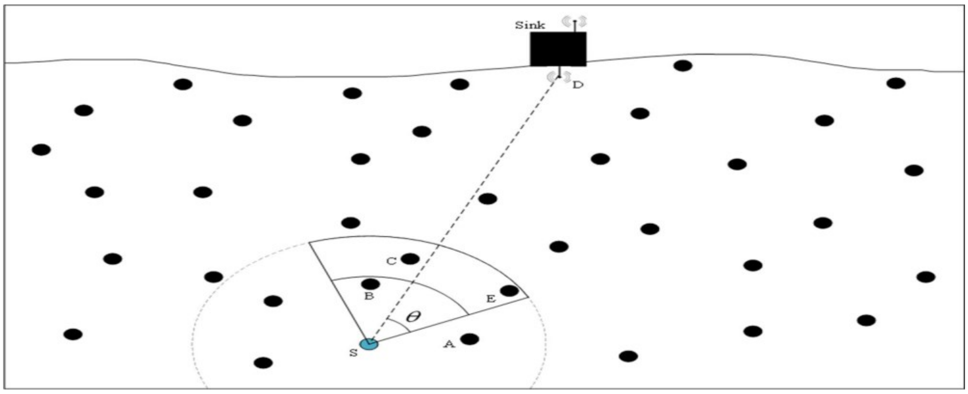


Figure 3.2: Network model for AMGR routing protocol (Source: X. Li, Xu, Zhao, Han, & Yan, 2022)

AMGR routing protocol was simulated using packet delivery ration, end to end delay and energy tax as performance metrics. Result obtained indicated AMGR achieves 90% when compared with PCR with 85%, and AHH-VBF 82%. AMGR achieves an end-to-end delay of 50% against PCR with 65% and AHH-VBF with 85%. However, AMGR lacks mechanism that considers network scale for both sparse and dense network scenarios to prolong the energy level of the senor nodes.

(Manzoor, Latif, Haq, & Jhanjhi, 2022) Developed an underwater routing protocol named as energy efficient routing protocol via angle-based flooding zone in underwater wireless sensor networks. The developed routing protocol uses a position-based routing approach to allow sensor nodes forward packets of data.

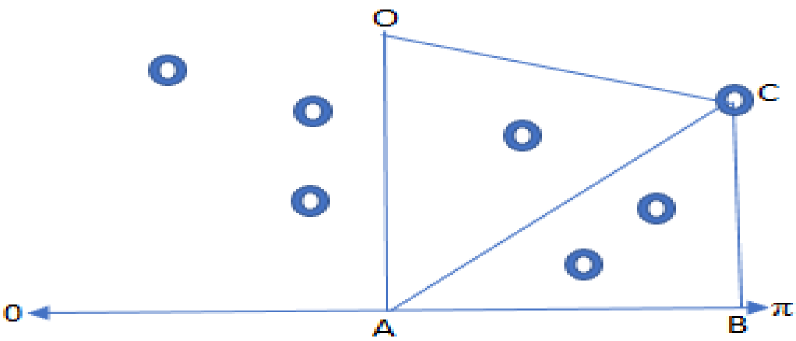


Figure 3.3: Network model showing flooding zone (Source: Manzoor, Latif, Haq, & Jhanjhi, 2022)

Simulation was carried out using Aqua-sim where packet delivery ratio, energy consumption, end to end delay were used as performance metrics. Results obtain indicates ABFZ achieves 60% packet delivery ratio against DVRP with 55% and DBR with 50%. ABFZ achieves 35% end to end delay against DVRP with 40% and DBR by 45%. More also, ABFZ achieves 80% energy consumption against DVRP with 85% and DBR with 90%. However, ABFZ lacks efficient technique to prolong the use of sensor nodes with the flooding zone repetitively by prolonging their energy level in the process of communication.

(Hameed et al., 2016) proposed a balanced energy efficient circular routing protocol for use in underwater wireless sensor networks. The BEEC routing protocol uses a division routing strategy by taking the network field in a circular form and dividing it into regions with each region divided in to eight sectors. The use of mobile sinks named MS1 and MS2, denotes the required region in the network. The first mobile sink (MS1) covered the first five region of the network while the second (MS2) covered the remaining region. Each mobile sink had the ability to moving into sectors in a clockwise direction. The movement of the mobile sink's nodes involved the direct transmission of data packets to the mobile sink node when needed this occurred in a single hop mode whenever a mobile sink came within its transmission range.

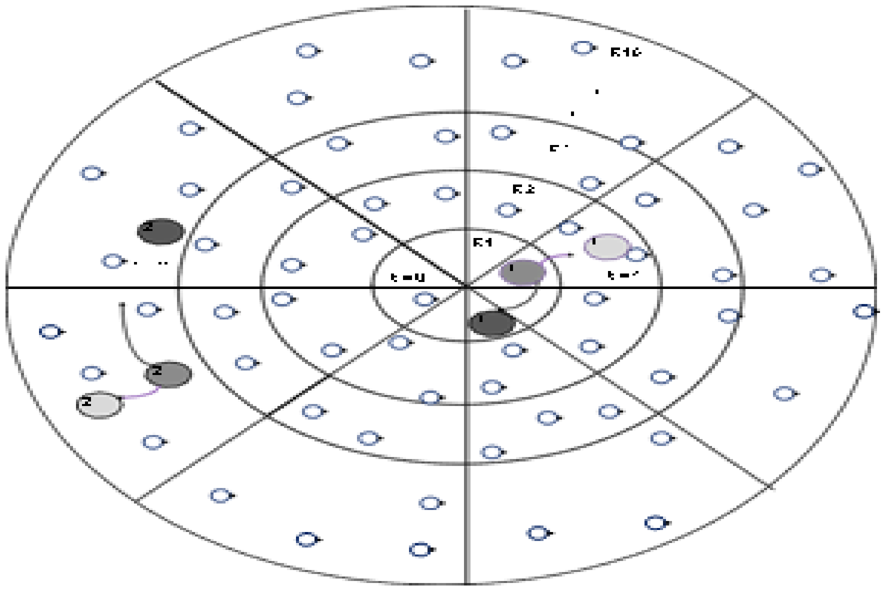


Figure 3.4: Network model for BEEC (Source: Ahmad Raza et al, 2016)

BEEC achieves throughput and energy consumption between the sensor nodes but results in packet loss due to the in ability of the sink node to collect data from sensor nodes with data to send. This resulted in a poor performance especially in sparse networks.

(Sahana and Singh, 2020) Posited a localization-based routing protocol with a clustering routing strategy for the transmission of data for underwater wireless sensor networks. The algorithm selects a cluster head in a cluster based on two parameters namely based station distance (BSD) and density function (Df). Cluster and cluster heads are formed in a random time by considering the sensor nodes energy level to actively select another reliable sensor node as cluster head node. For each cluster, a cluster head node selects a backup node for the reliable transmission of data to the sink node.

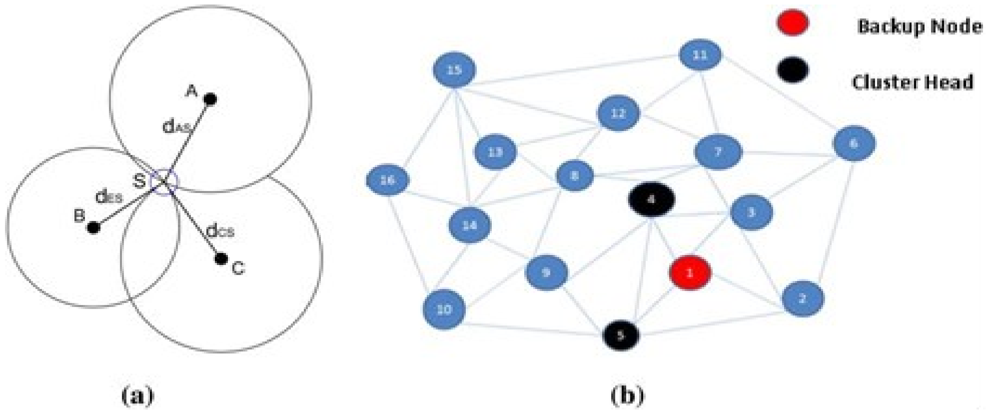


Figure 3.5: (a) The backup node position and (b) The selection of the back-up node (Source: Subrata and Singh 2020)

The algorithm actively locates the sensor nodes and speed ups in the packet transmission by using back up nodes. However, it lacks a proper mechanism in the selection of cluster head nodes in subsequent rounds with energy consideration.

(Jyoti and Rakesh, 2018) proposed a strategy for energy efficiency by using 2-D architecture with sensor nodes anchored underwater. The strategy effectively selects a head node in each cluster, as each cluster head node gathers data in its cluster and subsequently forward the data to the sink node. The distance covered between the cluster head node when forwarding packets of data to the underwater sink was calculated using Euclidean distance. Thus, it ensures that the head node select the best shortest path to send data in a multi-hop way. The effective selection of the cluster head node depends on the throughput and reliability with respect to the energy efficiency of the node. The strategy helps in efficient communication, but the mobility sensor nodes represent another challenge with respect to proper communication underwater.

(Khan et al., 2018) proposed underwater co-operative routing called co-operative energy efficient optimal relay selection routing protocol (Co-EEOR). The source node selects both the relay and destination node, in which the destination node acknowledges the successful reception of the data packets.

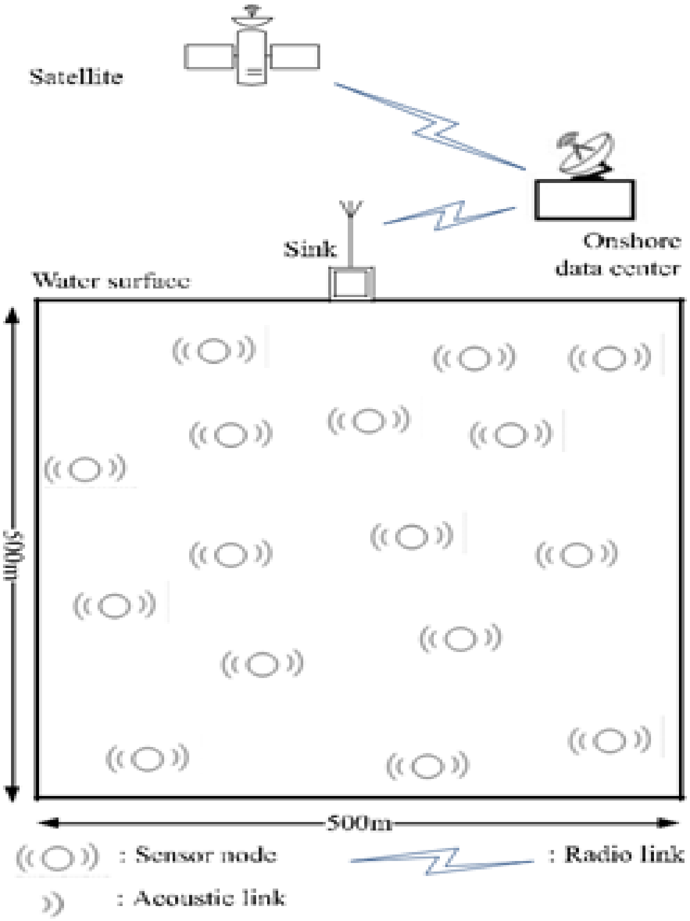


Figure 3.6: Proposed model for CO-EEORS routing protocol (Source: Anwar khan et al (2018)

The source node considers the location and depth of the sensor nodes when selecting the destination node. The Co-EEORS routing protocol delivers packets in co-operative way by considering the transmission distance among the sensor nodes. However, it lacks a dependable mechanism to consider the energy consumption of the sensor nodes over the network.

(Khalid et al., 2019) posited a routing protocol for energy efficiency multipath for underwater wireless sensor network. The routing protocol operates using a routing strategy by priority table. Data packets are disseminated based on the depth and residual energy of the participating nodes. Nodes whose entry in the priority table have depths lower than that of the sink node are regarded as nodes closer to the sink. While the entries of sensor nodes whose node depth are greater than that of the sender node are considered far nodes and will not be included in the priority table. Transmitted data is considered successful when it arrives at any of the mobile sink. The routing protocol achieves a packet delivery ratio by using the priority table but is deficient due to end-to-end delays issues with sensor nodes.

(Wang et al., 2018) proffer an energy aware and void avoidable routing protocol (EAVARP). The routing protocol employs the use of an opportunistic directional forwarding scheme (ODFS) to identify a strategy to find a reliable path to send packets from the source node to the sink node.

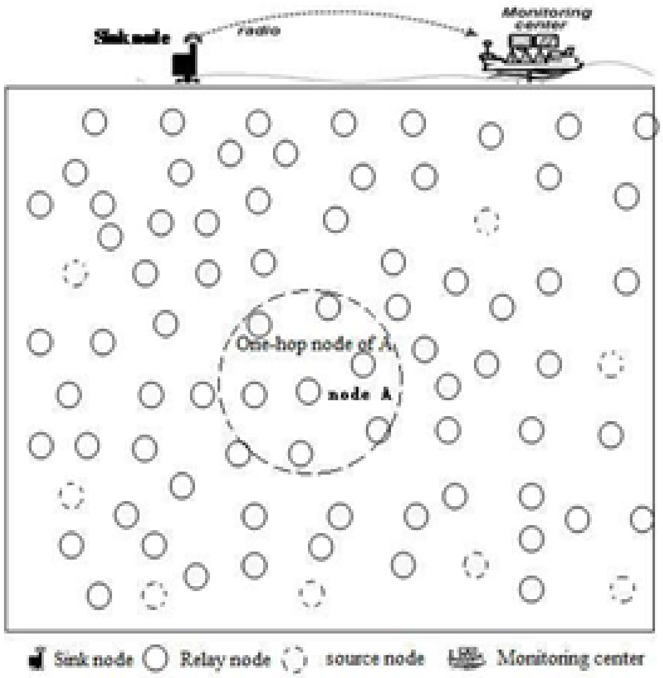


*Figure 3.7: Network architecture for the EAVARP routing protocol (Source: Zhuo*wang et al, 2018)

EAVARP using ODFS comprises two phases namely layering and data collection. The layering phase deals with concentric shell that are formed close to a sink node with sensor nodes available on different shells. The data collection phase transfers packets of data based on the concentric shells through ODFS which takes care of the remaining energy of the nodes. EAVARP exhibits energy utilization using a routing table, however an end to end delay was incurred in the selection of relay node with routing overhead due to excess use of probe packets.

(Cheema, Javaid, Sheikh, Khan, and Qasim, 2016) developed a routing protocol known as a balanced energy adaptive routing protocol (BEAR). The BEAR routing protocol uses half of a sphere as the network with sectors of equal radii. Sensor nodes closer to the sink suffer from load and energy exhaustion.

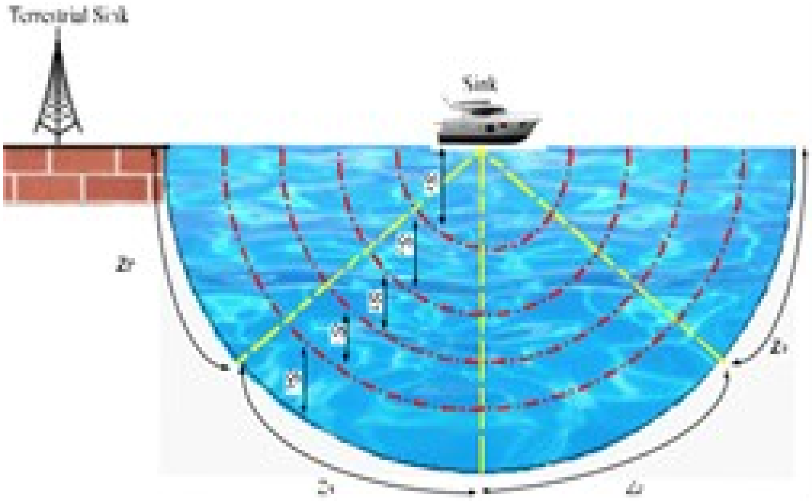


Figure 3.8: BEAR routing protocol architecture (Source: Cheema, Javid, Sheikh & Qasim, 2016)

In Figure 3.8 showing the BEAR routing protocol, data is forwarded in each sector between the senor nodes by forwarding the node to effectively reach the sink node. Energy consumption is balance in BEAR but suffers from interference near the sink node due to the deployment of more sensor nodes near the sink.

(Kun, Hui, Xiaoling, Jinfang, and Dong, (2016) developed an energy efficient grid routing protocol based on 3D cubes for underwater acoustic sensor networks. The routing protocol assumes the network to be a 3D cube with a small number of cubes seen as clusters. The strategy of finding efficient packets transmission by the routing protocol adopts a novel approach by selecting a small cube (cluster head) with the highest remaining energy and shortest distance as responsible for forwarding packets of data to the base station (BS). From the result obtained EGRC achieves energy efficiency when compared with VBF and L2-ABF routing protocols but with increase in the speed of the nodes (from 1m/s to 6m/s) EGRC achieves less end-to-end delay at 54ms, while VBF achieves 76ms and L2-ABF 66ms. However, the performance of the network degrades with the death of the cluster head nodes, hence an efficient mechanism for selecting cluster head is needed.

(Sihem, Mourad, and Mohammed, (2015) posit energy aware routing protocols for mobile underwater wireless sensor networks. The two routing protocols, KEER and EKEER, adhere to a k-clustering technique to construct clusters that are efficient in finding a reliable path for the exchange and relay of packets of data to the sink node. The routing strategy initially follows the selection of the cluster head node in terms of its near position to the centre of the cluster and the node with the highest residual energy. KEER and EKEER are measured in terms of performance metrics which consist of total energy consumption and alive nodes.

Result obtain shows efficient performance by KEER and EKEER with an increase in the number of rounds for network lifetime (alive nodes) to 112 rounds EKEER achieves 8.19% efficiency compared with KEER at 34.42%. Furthermore, an improvement is needed in terms of finding the shortest distance from the cluster head nodes to the surface node (base station).

(Nitin, Mayank, and Anil Kumar, (2016) proposed an intra and inter cluster underwater communication protocol that uses a clustering strategy for the transmission of data to save the energy of the sensor nodes when selecting a cluster head node. A fuzzy logic technique was used in the selection of a cluster head with some certain determinant factors that consisted of residual energy, distance, and node density in the appropriate selection of the cluster head node. The data gathered by the cluster head node from the cluster members is sent directly to the underwater sink node or sent through neighbouring cluster head nodes in a multi-hop way until it reaches the underwater sink node. The IICC routing protocol achieves efficiency with 67% less energy consumption than MARPC at 33%, IICC's average packet delivery ratio is 67% against MARPC at 36%. However, IICC suffer from lack of a proper mechanism for the selection of cluster head node.

(Revathi et al., (2019) proposed an algorithm for adaptive energy aware quality of services for reliable transfer in underwater acoustic sensor networks (AEA) (Qos). The algorithm uses the discrete time stochastic control process (DTSCP) and deep learning techniques (DLT) to overcome the issues of greater end-to-end delays, less reliability and high energy consumption due to its high transfer reachability.

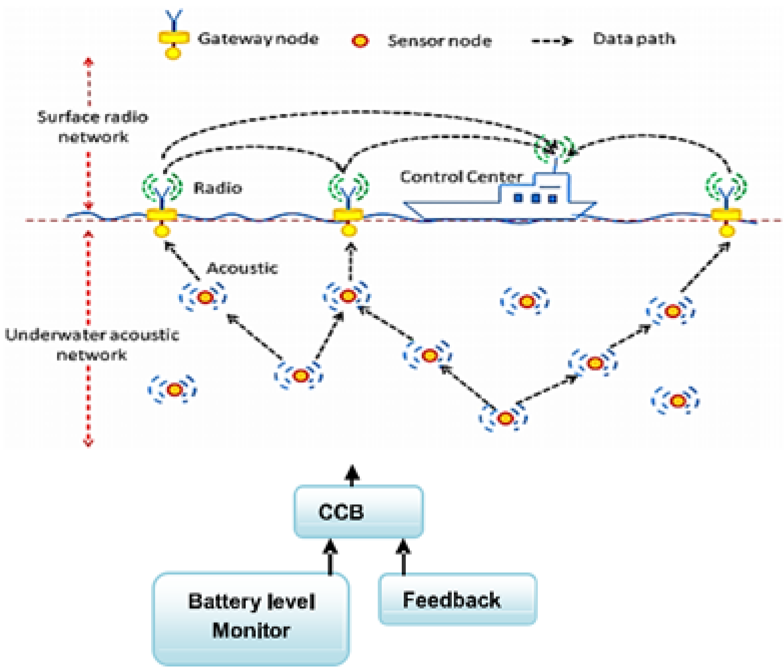


Figure 3.9: Underwater Network Architecture (Source: Ravathi et al, 2019)

The AEA (Qos) algorithm uses DTSCP and DLT to transmit data using sensor nodes that are based on the reliability of the link and the reachability of the sensor nodes which, mean less energy consumption during the transfer of data. A packet delivery ratio is achieved as the data holds time employed by the discrete time stochastic control.

(Gulista, Kamal Kumar, and Wajid, 2015) proffer a routing algorithm based on a clustering approach called energy efficient routing for underwater wireless sensor network (EERU-CA). EERU-CA consists of two phases, set up phase and data forwarding phase. EERU-CA uses special nodes, which acts as cluster heads for clustering technique. Nodes willing to send a packet of data need to find a special node within its cluster. In The absence of special nodes in the cluster, nodes use a neighbouring node method to send packets of data to the surface node. The neighbouring nodes with the short distance and maximum energy are selected. Special nodes, which are placed at a lower depth, are assumed to send data in a single hop transmission mode to the receiving unit. EERU-CA achieves a network lifetime of 3100seconds for 100 nodes opposed to DBR with 2900 seconds and MRP with 1000seconds. EERU-CA consumes less energy at 8joules for 100 nodes against DBR with 40joules and MRP with 18joules. However, EERU-CA lacks an efficient mechanism in the selection of cluster head node in the network.

(Abrar, Abdellatif, and Fahd, (2018) posit a technique that broadens the clustering approach employed by the low energy adaptive clustering hierarchy LEACH. The routing proposed an approach that used of time division multiple access (TDMA) and the concept of localization. Sensor nodes involved underwater modified the low energy algorithm clustering hierarchy UMOD-LEACH uses a clustering technique in the exchange of data. Clusters are made based on location and transmit data in a single hop to the sink node. The use of clustering approach in UMOD-LEACH achieves a 30% decrease in energy consumption against the conventional LEACH at 70%. Nevertheless UMOD-LEACH suffers from an inefficient mechanism in the subsequent selection of cluster head.

(Tongtong and Ning, (2015) proposed a reliable and even energy Consumed Routing Protocol for underwater Acoustics. The EEC-VBF routing protocol takes the energy and number of participating nodes into consideration. Two packets are used by the EEC-VBF which consist of query and data packet. Sensor nodes participate by data forwarding in a cycle time with residual energy taken into consideration.

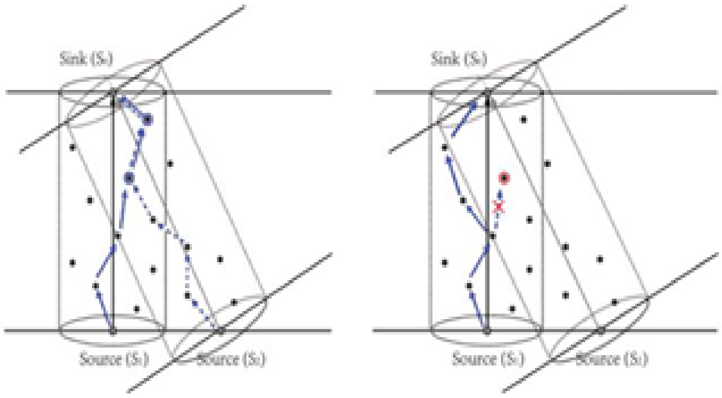


Figure 3.10: Network architecture for VBF and EEC-VBF routing protocols (Tongtong & Ning, 2015)

The first figure indicates VBF without retransmission and the second indicated VBF with retransmission. However, EEC-VBF possesses a reliable and efficient data packet transfer across the network receiving 75% of the packet as the number of retransmissions in comparison VBF received 55% and HH-VBF 67%. However, EEC-VBF lacks efficiency in receiving packets in smaller numbers of retransmissions and lack proper mechanism to tackle voids in the transmission process.

(Awais, Abdul, and Dongkyun, (2013) proffer an autonomous aided energy efficient routing protocol for an underwater acoustic sensor network (AEERP). The AEERP protocol uses an autonomous underwater vehicle (AUV) to collect data from the underwater gateway nodes and transmits them to the surface node. In AEERP, the network is divided into two regions, a region for gateway nodes and for member nodes. AUV in AEERP periodically broadcast an RSSI packet to the nodes to actively select a reliable gateway node among the sensor nodes. In the communication process when a gateway node exhausts its energy, the member node with the highest energy will be chosen as the gateway node. AEERP was compared with the travelling sale problem algorithm. AEERP achieves less energy consumption at 1400joules as the number of sensor nodes increases to 66 compared with TSP at 1450joules. Furthermore, AEERP achieves less delay at 550seconds as the number of sensor nodes increases to 66 against TSP with 650seconds delay. However, AEERP lacks efficiency in its packet delivery for sparse network by showing a reduction of 80% in packet delivery for 20 nodes as against TSP at 96%.

(Ding et al., (2019) developed a void avoidance mechanism by using an autonomous underwater vehicle (AUV). The technique effectively detects a trap node by using a time-based strategy that makes each sensor node to set its own timer for detecting void occurrence. In routing the void handling protocol (RVHP) an autonomous underwater vehicle dives in the water to gather data from void nodes and effectively transfers the collected data to the surface node using acoustics as a transmission medium. The effective use of an autonomous underwater vehicle in routing void handling protocol greatly reduces the energy consumption as the number of sensor nodes increases RVHP with 70joules against GEDAR with 80joules and VAPR with 90joules. Moreover, RVHP achieves a lower average end-to-end delay of 600(ms) as the number of the sensor nodes increases to 500 against GEDAR at 700 (ms) and VAPR at 650 (ms). However, the RVHP routing protocol suffers from an inefficiency in terms of its performance especially for end-to-end delay and the energy consumption for less number of sensor nodes.

(Zhiping, Shaojiang, Weichuan, and Zhiming, (2019) propose an algorithm for effective energy utilization called an energy efficient multi-level adaptive clustering algorithm for underwater wireless sensor network. The routing technique employed by ACUN adopts cluster head per each cluster to effectively transmit packet of data to sink node using multi-level hierarchical network structure. The ACUN algorithm selects a cluster head node with the highest residual energy in the cluster to effectively optimize the consumption of energy in the network. The algorithm adopts a single hop and multi hop mode of packet transmission depending on the energy strength of the cluster head node. The ACUN algorithm was efficiently tested for overall network efficiency in terms of its message complexity, and it belonged to O (N). ACUN shows the effective energy saving of the entire network at 1640joules for a maximum number of 200 sensor nodes against AFP with 1620joules and DEBCR with 1640joules. ACUN also achieves 195 number of alive nodes in the network against AFP with 180 and DEBCR with 190. Although ACUN lacks an efficient mechanism to transmit aggregated data by the cluster head node to the sink node.

(Sihem, Mourad, and Mohammed, (2015) proposed a routing protocol that combined clustering and a chain-based strategy using an ant colony for efficient data transmission (KCC ant). The K-means technique was used by the routing protocol to segment the clusters, while transmission of data packets to the sink node was adopted using chain-based mechanism with respect to ant colony algorithm. The combination of the clustering and chain techniques using the ant colony makes the KCC ant consume 80.4% less energy compared with PEGASIS at 60%. KCC ant achieves 53.77% of the network lifetime (number of alive nodes) as the number of rounds increased to 600, as opposed to PEGASIS with 40%. However, KCC ant is deficient in transmitting aggregated data to the sink node which causes delay and packet collision.

(Ghanzafar et al., 2018) posit energy balancing based on gradation with respect to underwater wireless sensor networks (EBLOAD). The technique effectively employs the use of two underwater transmission mode i.e single hop and multi hop transmission. The E-BLOAD routing technique make use of different coronas with each corona capable of transmitting data in a different transmission range based on energy gradation. The transmission of packets depends upon gradation where the gradation number of the node is higher, packets are transmitted in a multi hop mode while a sensor node with smaller energy grade transmits packets in a single hop to the sink node.

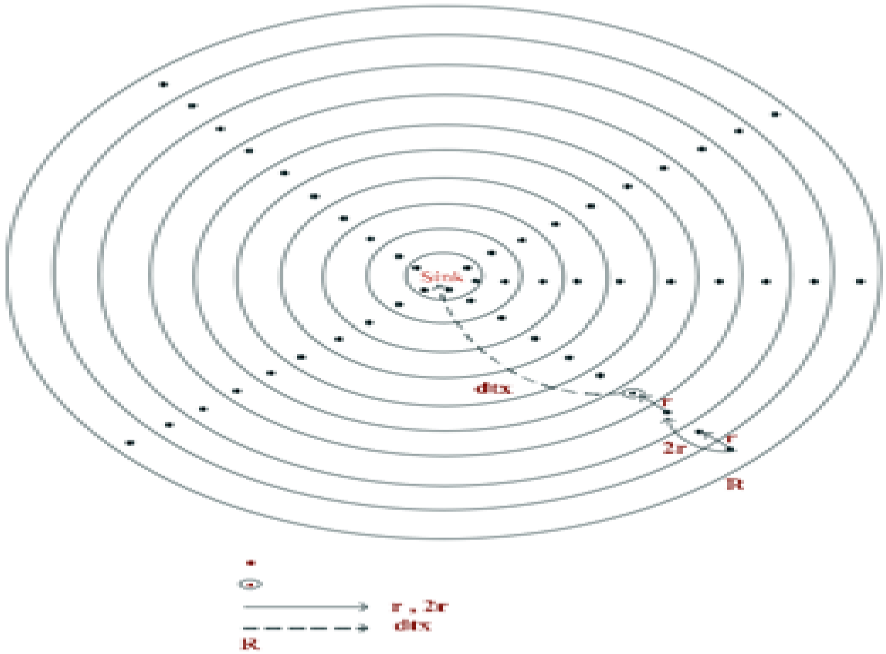


Figure 3.11: Network architecture for EBLOAD routing protocol (Source: Ghanzafar et al 2018)

At 70% EBLOAD-EG effectively consumes less energy with an increase of the number of coronas to (10 against BLOAD with 50%). Furthermore, the EBLOAD routing protocol achieves 35% (number of dead nodes) and 100% (number of alive nodes) against BLOAD with 5% (number of dead nodes) and 15% (number of alive nodes). However, EBLOAD lacks a packet delivery mechanism based on the transmission ranges for different loads in packet transmission.

(Shi and Liu, 2017) designed a routing protocol for energy balancing based on AODV (EBAP). EBAP routing protocol uses two phases which consist of route discovery and Route maintenance phase. The route discovery phase uses the same method to find route in classical AODV, while the route maintenance phase EBAP does not set a lifetime to a certain route, route are established when needed, and the message defined by the routing protocol includes the route request RREQ which is set several times at a random interval in order to effectively transmit packets of data between the nodes. In the balancing of energy, nodes are chosen based on remaining energy. EBAP consumes less energy at 1400joules as the sensor nodes increases to 100 against AODV with 1600joules. EBAP also achieves a network lifetime of 6000ms for 100 sensor nodes against AODV at 400ms. But EBAP lacks a mechanism to overcome routing overheads and void holes.

(Liu, Zhao, and Zhang, (2016) modified the conventional AODV routing protocol for underwater acoustic networks. MAODV modified the route discovery phase of the classical AODV routing protocol to avoid the unnecessary waste of data packets and link breakages this was achieved by using a double flooding. MAODV uses double flooding mechanism to reduce the effect of routing faced by underwater acoustic channel mostly by multipath propagation. In view of this, the retransmission of a route request (RREQ) was proposed for the classical AODV routing protocol. MAODV achieves a packet delivery ratio of 95% as the simulation time increases to 2000s against AODV at 75%. But MAODV lacks an efficient mechanism to tackle the energy consumption and the occurrence void hole.

(Hao, Shilian, Eryang, and Luxi, 2018) proposed an energy balanced and lifetime extended routing protocol (EBLE). Two phases were used by EBLE which consist of candidate forwarding set selection phase and data transmission phase. In the candidate forwarding selection phase cost function was used and nodes stored the position and residual energy of their neighbour nodes. In the data forwarding phase sensor nodes with the highest residual energies were selected as the nodes to forward data. Forwarding sensor nodes with lower energy level are replaced with the sensor nodes having higher energy level to balance the consumption of the energy. EBLE consumed less energy at 0.4joules as the node distribution increased to 10 against BEAR with 0.59joules, BTM with 0.42joules and direct transmission with 1.39joules. However, EBLE incur delay at the cost of energy balancing and lacks a proper mechanism to tackle void hole in the process of packet transmission.

(Bo, Yong-mei, Zhigang, Jie, & Yishan, 2013) Proffer a routing protocol to save the energy of nodes known as an energy saving vector based forwarding routing protocol (ES-VBF). The ES-VBF routing protocol unlike the VBF routing protocol, uses sensor nodes within a routing pipe and takes energy of the forwarding nodes into consideration. ES-VBF introduced a parameter to determine the energy of the nodes and their location within the routing pipe. The condition is set by ES-VBF and based on the forwarding range of the sensor nodes, moreover, using their energy status using is a desirable factor. ES-VBF achieves an average remaining energy for a static network of 149joules as the simulation time increases to 10000s as against VBF at 148joules. Also, ES-VBF achieves an average remaining energy for a dynamic network of 148joules as the simulation time increases to 10000s against VBF with 147joules. Moreover ES-VBF achieves a packet reception ratio of 0.55 against VBF with 0.54. However, ES-VBF incurs delay in the waiting time for the desirable factor and lacks a mechanism to avoid energy hole problems associated with relay nodes closer to the sink.

(Mostafa, Esmaiel, and Omer, (2020) posit an underwater routing protocol as a hybrid routing protocol that consist of acoustic and optical technologies to transmit packets of data. HEERP routing uses a source routing strategy to effectively discover routes by the sink node. A control user (C/U) plane was used to determine the maximum capacity of the data transmission for a particular coverage. A HEERP uses an acoustic signal to transmit packets of data with low data rate but high transmission range, while an optical signal was used to gather information with short communication range in multi hop way. HEERP routing protocol was compare against DBR, EECOR and HH-VBF using a MATLAB simulator. HEERP achieves a packet delivery ratio of 95% as the network size increases to 1000m against EECOR 88%, DBR 79%, HH-VBF 70%. HEERP consume less energy 45% as the network size increases to 100m against EECO9R 69%, HH-VBF 75%, and DBR 90%. Moreover, HEERP achieves a throughput of 80% against EECOR 50%, HH-VBF 45% and DBR 40%. However, HEERP lacks an efficient technique to tackle void occurrence with delay despite propagation delay incurring by underwater communication using acoustic signals.

(Suzel, Islam, Rocky, Sarkar, and Hossain, (2021) proposed an energy optimized routing protocol for underwater acoustic sensor network (EORP). The routing protocol employ the use of clustering routing technique based on LEACH to transmit packets among sensor nodes. EORP uses a random number to effectively select a reliable cluster head in each cluster. A threshold value was use in the selection of appropriate cluster head sensor node by residual energy. An EORP routing protocol was simulated using matlabR2015a to determine its performance efficiency against the conventional LEACH routing protocol. Two performance parameters were used which consisted of a dead node and residual energy. As the simulation reaches 200 rounds with 100 number of nodes, EORP achieves a smaller number of dead nodes at 50% compared to LEACH which has a higher number of dead nodes at 95%. Furthermore, as the simulation increases to 200 rounds, LEACH 'energy drops to 90% and EORP's to 60%. The results indicate an increase in performance for EORP against LEACH. However, EORP lacks a mechanism to tackle sensor nodes mobility and relay node closer to the sink which decreases the network lifetime.

Table 3.1 outlines some of the reviewed underwater localization-based routing protocols with their energy consideration together with a summary table

Table 3.1: Localization based routing protocols with energy consideration.

Authors name	Protocol	Year	Technology	Routing Strategy	Problem Address	Simulation Tool And Performance Parameters	Benefits	Draw Back
Noorbakhsh & Soltanaghaei	EEGBRP	2022	Acoustic	Geographic based	Energy consumption	NS-2, Packet delivery ratio, energy consumption, and end to end delay	Achieves packet delivery ratio and energy consumption	Deficiency in mechanism that can prolong sensor nodes energy consumption in sparse and dense network
X. Li, Xu, Zhao, Han, & Yan	AMGR	2022	Acoustic	Geographic based	Energy consumption	Energy consumption, delivery and delivery ratio	Achieves packet delivery	lacks mechanism that considers network scale for both sparse and dense network scenarios to prolong the energy level of the senor nodes.
Manzoor, Latif, Haq, & Jhanjhi	ABFZ	2022	Acoustic	Geographic based	Energy saving	Aqua-sim simulator, Energy consumption, throughput, delay, packet delivery	Attain packet delivery ratio and less delay	lacks efficient technique to prolong the use of sensor nodes with the flooding zone repetitively by prolonging their energy level in the process of communication.
Raza *et al*	BEEC	2018	Acoustic	Geographical	Node’s	NS2	Achieves	Efficiency in collecting data

				based routing strategy	mobility, Hole problem	network lifetime, stability and instability, residual energy, and throughput.	throughput and energy consumption.	by the sink node from sensor nodes with packets to send, which result in packets loss and in efficiency in sparse networks.
Subrata Sahana & Singh	CBLS	2020	Acoustic	Clustering based routing strategy	Sensor node energy efficiency.	NS2, Energy consumption	Network lifetime achieved with speed in the packet transmission using back up node.	Deficiencies in energy saving and selection mechanisms for cluster heads.
Jyoti & Rakesh	CBEEC	2018	Acoustic	Clustering based routing strategy	Sensor nodes energy consumption	Energy, throughput, reliability	Achieves throughput in transmitting packets to the sink	Instability in the energy consumption of sensor nodes
Anwar Khan *et al*	Co-EEORS	2018	Acoustic	Co-operative based routing strategy	Sensor nodes location in addition to	MATLAB End to end delay, packet delivery ratio, dead node,	Less redundant transmission	Location and depth are considered but lacks proper mechanism for energy consumption, which increases

					depth of the sensor nodes	alive node		end-to-end delay.
Muhammad Khalid *et al*	E2MER2	2019	Acoustic	Opportunistic routing strategy	Avoids flooding and energy consumption	MATLAB End to end delay, packet delivery ratio, energy consumption	A achieves packet delivery ratio using priority table	Incur end to end delay with a shortfall on nodes mobility.
Zhuo Wang *et al*	EAVARP	2018	Acoustic	Opportunistic routing strategy	Energy Void hole problem	NS3 Total energy consumption, packet delivery ration, average end to end delay	Energy utilization using a routing table	End to end delay in the selection of relay nodes with routing overhead due excess use of probe packets.
Cheema, Javaid, Sheikh, khan & Qasim	BEAR	2016	Acoustic	Geo based routing strategy	Energy balancing	Network lifetime, and energy consumption	Energy consumption balancing with network lifetime elongation	Packet transmission not controlled by the holding time and thus interference occurs near the sink due to the deployment of more nodes near the sink
Kun, Hui, Xialong, Jifang	EGRC	2016	Acoustic	Clustering routing	Energy consumption	Aqua sim End to end delay,	Energy efficiency, Throughput	Lacks the continuous efficient optimal selection of a cluster

& Dong				strategy	and channel efficiency.	Average residual energy.		head
Souiki *et al*	KEER & EKEER	2015	Acoustic	Clustering routing strategy	Energy consumption	MATLAB Total energy consumption, Alive nodes	Energy efficient packet transmission.	Deficiency in terms of finding shortest distance from cluster head to base station.
Nitin, Mayank, & Anil	IICC	2016	Acoustic	Clustering routing strategy	Energy consumption and reliable transmission path selection	NS2 Average end to end delay, packet delivery ratio, Average energy consumption.	Improved energy efficiency.	Lacks a proper mechanism for the selection of a cluster head node
Revathi *et al*	AEO (Qos)	2019	Acoustic	Reinforcement learning strategy	Improved quality of service in packet transmission.	Network simulator Simulink / Energy consumption, average delay, network traffic	Achieves throughput in the packet delivery ratio.	Incurs a significant delay in the packet transmission.
Gulista, Kamal,	EERU-	2015	Acoustic	Clustering	Energy	NS2	Consume less	In efficiency in selection of

Kumar & Wajid	CA			routing strategy	Consumption among sensor nodes.	Network lifetime, energy consumption.	energy	cluster head node.
Abrar, Abdellatif & Fahad	UMOD-LEACH	2018	Acoustic	Clustering routing strategy	Energy efficiency	MATLAB Energy consumption	Decreased energy consumption	Deficiency in subsequent selection of a cluster head node.
Tong tong & Ning	EEC-VBF	2015	Acoustic	Geo-based routing strategy	Energy consumption efficiency	Java SE Packet received, network lifetime (alive nodes)	Achieves packet received as the number of retransmissions increase due to consideration of residual energies of the nodes	Lacks efficiency in a smaller number of retransmissions
Abdul & kyun	AEERP	2013	Acoustic	Geo-based routing strategy	Energy balancing and consumption	NS-2 Energy consumption, end to end delay and successful delivery ratio	Increase in the packet delivery ratio as the number of sensor nodes increase with less energy	Lacks efficient packet delivery ratio in smaller number of sensor nodes.

							consumption by using gateway nodes	
Ding *et al*	RVHP	2019	Acoustic	Geo-based routing strategy	Void occurrence	NS-3 Average end to end delay, average energy consumption, packet transmission rate.	Increase in packet transmission rate and less energy consumption for using AUV.	Deficiency in end to end delay and sensor node energy consumption in a small number of sensor nodes.
Zhipping, Shaojiang, Weichuan & Zhiming	ACUN	2018	Acoustic	Clustering based routing strategy	Energy consumption	NS-2 Residual energy, number of alive nodes.	decreased in energy consumption	Deficiency in the proper mechanism for data transfer among cluster heads.
S.sihem, Mourad & Muhammed	CCRU	2015	Acoustic	Clustering based routing strategy	Energy conservation	MATLAB Energy consumption, number of alive nodes.	Consume less energy	Packet collision and delays in transmitting aggregated data.
Ghanzafar *et al*	E-BLOAD	2018	Acoustic	Source routing	Balanced in energy	Energy	Energy balancing is achieved based	Lacks a proper mechanism for packet delivery based on

				strategy	consumption	consumption, dead nodes, alive nodes.	on energy gradation.	transmission ranges on different load for data transmission
Shi & Liu	EBAP	2017	Acoustic	Source routing strategy	Energy balancing	NS-2 Energy cost comparison, network lifetime comparison.	Consume less energy consumption	Deficiency in mechanism to tackle routing overhead and void hole in packet transmission.
Liu Zhao & Zhang	MAODV	2016	Acoustic	Source routing strategy	Packet transmission and advancement	OMNET++ Packet delivery ratio, end to end delay.	Achieves a packet delivery	Lacks an efficient mechanism to tackle sensor nodes energy consumption and void hole.
Hao & Luxi	EBLE	2018	Acoustic	Source routing strategy	Energy balancing in packet transmission	NS3 Energy consumption,	Achieves energy balancing in choosing packet transmission path	Absence of mechanism to tackle void hole in the process of packet transmission.
Bo, Yong-mei, Zhigang, Jie & Yishan	ES-VBF	2013	Acoustic	Geographical based routing protocol.	Energy consumption of the sensor nodes.	Aqua sim, Average remaining energy, mean square error	Decreased in energy consumption	Incur delay in the waiting time for the desirable factor and lacks mechanism to avoid energy hole problem of the

						of nodes remaining energy, packet reception ratio		relay node closer to the sink node.
Mona, Hamada & Osama	HEERP	2020	Acoustic and optical	Source routing strategy	Energy consumption and packet transmission	MATLAB, packet delivery ratio, energy consumption, and throughput	Achieves packet delivery at 95% against EECOR 88%, DBR 79%, HH-VBF 70%. HEERP consume less energy consumption at 45%, against EECOR 69%, HH-VBF 75%, DBR 90%. HEERP achieves throughput of 80% against EECOR 50%, HH-VBF 45%,	Lacks an efficient mechanism to tackle void occurrence and delays despite propagation delays incurred by using the acoustic signal.

							DBR 40%	
Suzel *et al*	EORP	2021	Acoustic	Clustering	Energy consumption	MATLAB, Dead node, and residual energy	Achieves 50% a less dead nodes against LEACH at 90%. Also achieves 60% residual energy against LEACH with 10% residual energy.	Lacks a mechanism to tackle nodes mobility and the energy consumption for relay nodes closer to the sink.

3.5 LOCALIZATION FREE ROUTING PROTOCOLS

The following are some of the reviewed underwater localization free routing protocols with energy consideration together with the summary table.

(Ahmad et al., 2022) Developed a routing protocol as co-operative energy efficient routing protocol for underwater wireless sensor network (CEER). CEER uses co-operative routing technique to exchange packets among sensor nodes. Sink nodes were deployed in different sections to reduce energy consumption.

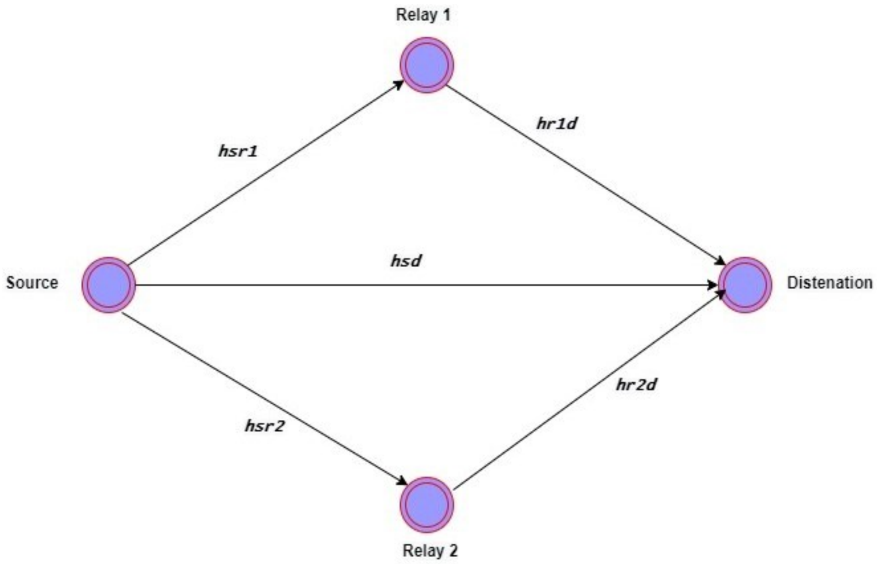


Figure 3.12: Network model of co-operation for CEER routing protocol (Source: Ahmad et al., 2022)

Results obtain indicates CEER achieves PDR by 20% approximately compared to EEDORVA, and more than 25% compared to EELRP. More also, CEER achieves lifetime of 15% compared to EEDORVA, and more than 20% compared to EELRP. However, CEER incur high delays and lacks efficient technique that can avoid sensor nodes from consuming more energy.

(Nazareth & Chandavarkar, 2022) Posit a localization free routing protocol named as localization free void avoidance routing protocol for underwater acoustic sensor network (LFVAR). The routing protocol was designed to tackle void occurrence in the process of packet transmission among sensor nodes. LFVAR select void recovery path for nodes within the void region to forward packets effectively.

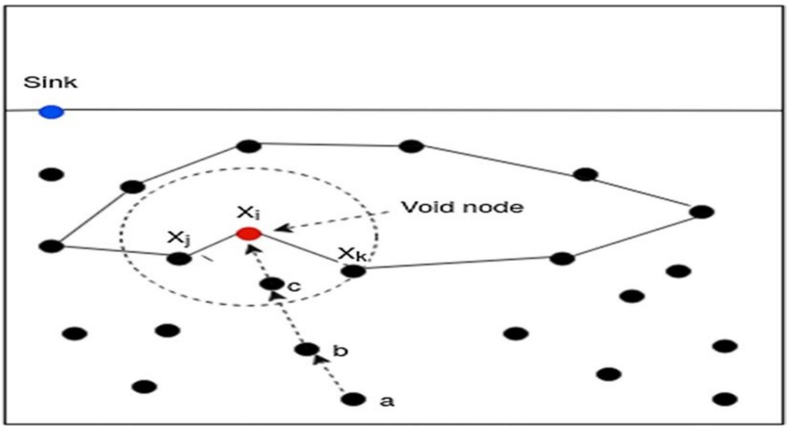


Figure 3.13: Network model for void and trap nodes (Source: Nazareth & Chandavarkar, 2022)

Unet stack was used as simulation modeler. Results obtain indicated LFVAR achieves 32.32% for transmitting packets to sink and achieves 20.54% for energy with 9.8% PDR compared to Intar routing protocol. However, LFVAR lacks effective technique to help sensor nodes achieve less energy consumption especially within the void region.

(Nandyala, Kim, & Cho, 2023) Proposed an underwater routing protocol called Q-learning based topology aware routing protocol (Q-TAR). Q-TAR routing protocol uses network topology to determine the next forwarder node candidate along the routing path. The routing protocol uses Q-learning in making decision for selecting the next forwarder.

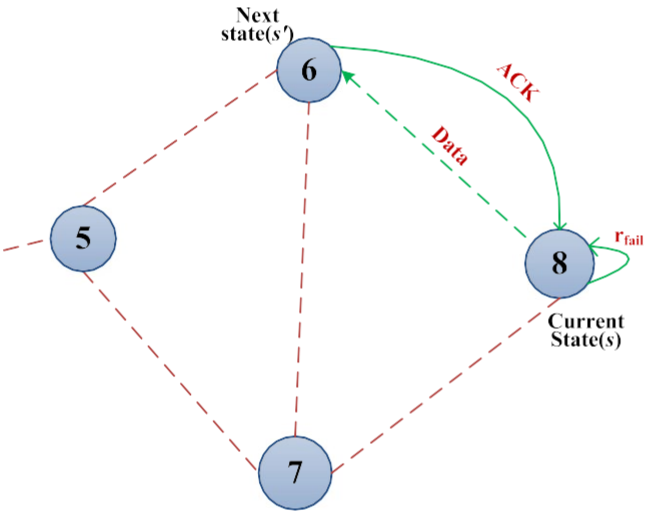


Figure 3.14: Proposed Q-learning framework for Q-TAR routing protocol (Source: Nandyala, Kim, & Cho, 2023)

Q-TAR was simulated against other routing protocols. Results obtain indicates Q-TAR achieves 70.12% for energy consumption, 37.8% latency, and 75% network lifetime when compared with QELAR, EEDBR and QDAR routing protocols. However, Q-TAR suffers from reliable technique to avoid energy consumption among sensor n odes in the process of packet transmission

(Shabbir et al., (2018) developed a routing protocol for energy balancing for use in underwater wireless sensor network. The routing protocol goal was to maximize the network lifetime through balanced energy efficient routing using sink mobility. The BEER routing protocol uses of (3) phases for a successful packet transmission which consists of the initialization phase, comparison phase and transmission phase. Sensor nodes exchanged a Hello packet to find a sink node within its transmission range. The energy of the sensor nodes are compared for reliability before exchanging packets of data. Sink mobility was divided into different region for a successful transmission coverage and reachability. However, BEER creates imbalance among sensor nodes that are not in the transmission range of the mobile sink which result in energy consumption and packet drops.

(Zahid et al., (2019) extends the network efficiency by proposing an energy balanced efficient and reliable routing protocol for underwater wireless sensor network. Hop by hop routing strategy that balances energy among sensor nodes with respect to forwarding nodes was put in place. EBER2 considered the selection of potential forwarding nodes based on residual energies when broadcast message was disseminated. Sink nodes are deployed on the surface with each packet delivered successful upon arrival to the sink node.

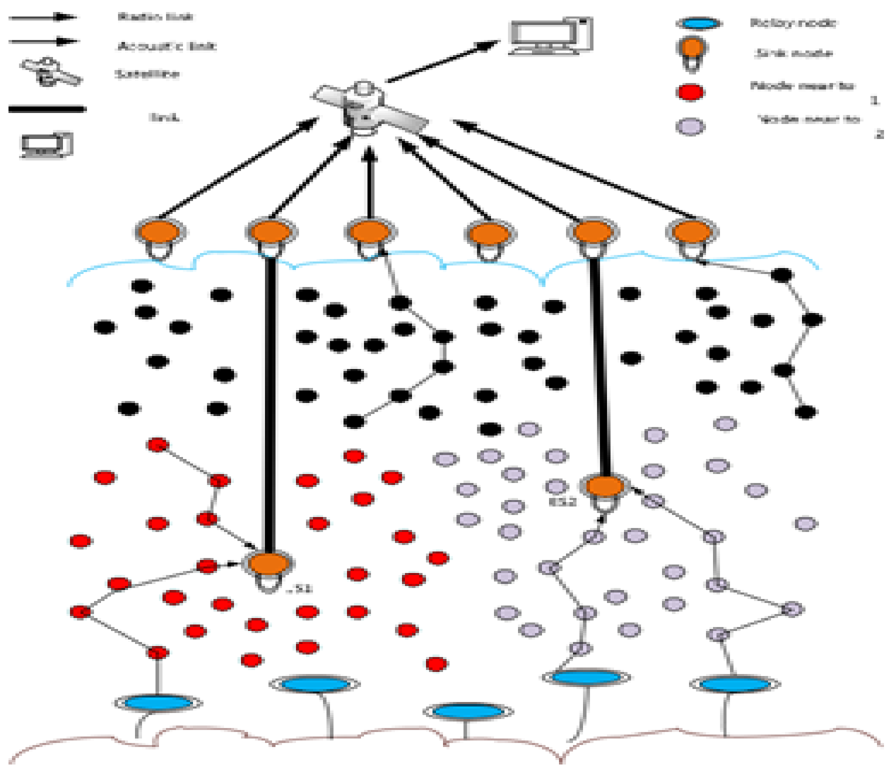


Figure 3.15: Network architecture for EBER2 (Source: Zahid et al 2019).

Two sinks are deployed underwater namely E1 and E2 to reduce end to end delays and increase high delivery ratio. EBER2 avoids void holes by considering the potential forwarding nodes with a 40% increase in network lifetime due to residual energy. However, it suffers from packet duplication and end-to-end delays due to the prioritization of potential forwarding nodes.

(Abrarahmed and Vinodkumar, (2018) posits an energy efficient path finding protocol for underwater acoustic sensor network. An opportunistic routing technique with fuzzy logic was adopted for the relay of data. It is based on the fuzzy logic sensor nodes that are willing to participate in the transmission of data are gathered in form of groups where the forwarding sensor nodes are selected by the source node based on fitness regarding maximum energy and packet delivery ratio. The packet delivery ratio was achieved with a rate of 0.62 as the number of sensor nodes increased to 100, as against DBR at routing protocol with 0.59 and EECOR with 0.58. Delay was also decrease to 8seconds for the routing protocol when the sensor nodes increase to 100 against DBR with 11.3seconds and EECOR at 9.3seconds. However, the protocol lacks the efficiency that cause routing overhead due to holding time use by the forwarding node in the packet transmission.

(Irfan et al., (2016) proposed a sparsity search algorithm (SSA) and density search algorithm (DSA) for a sparsity aware energy efficient clustering routing protocol for underwater wireless sensor network. The SEEC protocol purposely segment the network in to ten sub regions to achieve efficiency by finding a sparse and dense region using the SSA and DSA algorithms. In the case of the sparse region two mobile sinks were deployed at the network field that changed position from time to time to deal with the sparse region of the network. Meanwhile a clustering technique was employed by creating a cluster to deal with the dense part of the network in the data transmission. The SEEC routing protocol achieves 500 joules of residual energy as the number of rounds increases to 2000, as compared to DBR with 450joules and EEDBR with 480joules. Also, SEEC achieves a network lifetime (alive nodes) of 100 nodes as the round increases to 2000, compared to DBR with 90, and EEDBR at 96. However, SEEC lacks an optimal mechanism in the selection of cluster and cluster head with deficiency in the network performance when the mobile sink node dies.

(Jun, Meiming, Xingwang, Yuanyuan, & Xiaohui, 2018) proposed a reliable energy efficient cross layering routing protocol (RECRP). The routing protocol RECRP use the max-min Model to ensure the efficient delivery of data packets and energy balancing. In the next hop, the dynamically controlled transmission of power is forwarded together with the frequency of the channel with the help of physical layer. The RECRP protocol uses two phases which consist of a routing table update phase and a data forwarding phase. In the routing table update phase RECRP uses surface to bottom method to establish and update a routing table to take care of the void issue in communication. The forwarding phase make use of max-min model which gives the frequency, power, and maximum number of packets to be forwarded. RECRP achieves a packet delivery ratio of 1.0 with a maximum increase of 600 sensor nodes against DBR at 0.47 and HH-VBF at 0.63. RECRP also consumes less energy per node per message at 80joules with over 600 number of nodes, as compared with DBR at 120joules and HH-VBF at 160joules. However, RECRP is deficient in selecting relay nodes closer to the sink as it suffers from load and energy depletion.

(Khan, (2019) proposed an underwater routing protocol known as multi-layer cluster-based energy efficient routing scheme for underwater sensor networks. The routing protocol maximizes the efficiency of the network by adopting a clustering technique. Layers are formed together with clusters on each layer. Cluster head nodes are selected for each cluster per layer. Cluster head nodes transmit aggregated data to the next upper layer cluster head in a multi hop mode to the sink node. MLCEE routing protocol balanced energy consumption regarding Hotspot issue of energy depletion for sensor nodes closer to sink nodes. The MLCEE consider residual energy using Bayesian spam filtering when selecting of cluster heads (CH) to transmit of data packets. MLCEE achieves packet delivery in a high-density node at 29% compared to DBR at 15% and EEDBR at 19%. Furthermore, MLCEE consumed less energy at 70% compared to DBR at 40% and EEDBR at 55%. But MLCEE suffered less throughput due to the inefficiency in transferring aggregated data by the cluster head to the sink node.

(Zhigang, Zhihua, and Yishan, (2018) designed an opportunistic routing protocol called an evidence theory- based opportunistic routing protocol for underwater wireless acoustic sensor network. The EBOR routing protocol adopts a routing scheme by calculating the level of sensor nodes trust that occurs in the relay of data packets to sink node using Dempster Shafer theory (DST). The relay of sensor nodes involve are utilize in the packet forwarding process and based on trust about energy status. While the sensor node's location and residual energy needs to be known by the source node at the initial stage. Energy and packet delivery probability are taken into consideration for a reliable next hop selection. EBOR consumes less energy among all the sensor nodes at 5000joules as the number of sensor nodes increases to 300, as compared with GEDAR at 6000joules, VBF at 6300joules, HH-VBF at 8000joules and EECOR at 7000joules. EBOR achieves a packet delivery ratio of 90% as the number of the sensor nodes increases to 300 against GEDAR with 85%, HH-VBF with 78%, EECOR 74% and VBF with 60%. However, EBOR lacks a mechanism to tackle void occurrence by selecting an appropriate forwarding node in the transmission process.

(Nazareth and Chandavarkar, 2019) proposed an underwater routing protocol to effectively tackle communication void and was called enhanced void avoidance routing (E-VAR). The E-VAR routing protocol adopts a routing policy by using void awareness between the sensor nodes. The sensor nodes were identified as normal or void nodes. Unstable nodes are excluded in the routing process through awareness among the neighbouring nodes. The selected Potential forwarding neighbouring nodes are selected as positive forwarders based on stability status. E-VAR routing protocol was compared against interference aware routing and back tracking. The result shows that E-VAR performs better in terms of the distance to the sink at 80% the lowest hop count at 70% and awareness of 40% and back tracking at 30%. But E-VAR deficient in taking the energy of the selected forwarding sensor nodes into consideration.

(Zhengru et al., 2020) posited an efficient routing protocol for underwater communication named the Q-learning aided ant colony routing protocol for underwater acoustic sensor network (QLACO). The QLACO routing protocol adopts an ant colony scheme as routing procedure with reward mechanism and artificial ant to effectively determine the best route selection. QLACO was compared with QELAR and DBR routing protocols. The result indicates that the QLACO routing protocol decreases energy by 85%. While the nodes increase to 450 compared with DBR at 78%, and QLEAR at 98%. Furthermore, QLACO achieves a packet delivery of 98% against QELAR with 75% and DBR with 56%. However, QLACO tackles void avoidance for energy holes without considering the mobility of the forwarding nodes in relation to the void hole.

(Ahmad, Muhammad Shafie Bin, Omprakash, & and Hassan, (2018) proposed a location free routing protocol (RE-PBR), which is a reliable energy efficient pressure-based routing protocol for underwater wireless sensor networks. RE-PBR uses two phases namely data acquisition phase and data forwarding phase. The depth, residual energy and link quality were considered when using a multi metric data forwarding algorithm in RE-PBR. The integration of residual energy, link quality and depth information mean RE-PBR to achieve a decreases energy by 40j as the number of the sensor nodes increases to 400, as compared with EEDBR at 50j and DBR at 150j. Also, RE-PBR achieves a packet delivery ratio of 90% with 400 sensor nodes as compared with EEDBR at 78% and DBR at 60%. However, RE-PBR suffers from less throughput due to the re-transmission of packets for the forwarding nodes if the packet ID does not match.

(Tanveer et al., (2016) proposes a routing protocol based on depth-based routing (DBR) known as a clustering depth-based routing protocol (CDBR). CDBR adopts a routing strategy of clustering formation by electing a cluster head node with highest residual energy through random number technique using a threshold value. Depth is regarded as an important factor in CDBR for transmitting data. Cluster head nodes at less depth and closer to sink node are regarded as packet forwarders to the sink node. CDBR transmits packets in a multi-hop way by the cluster head, while cluster heads that are closer to sink node transmit packets directly to the sink node in a single hop.

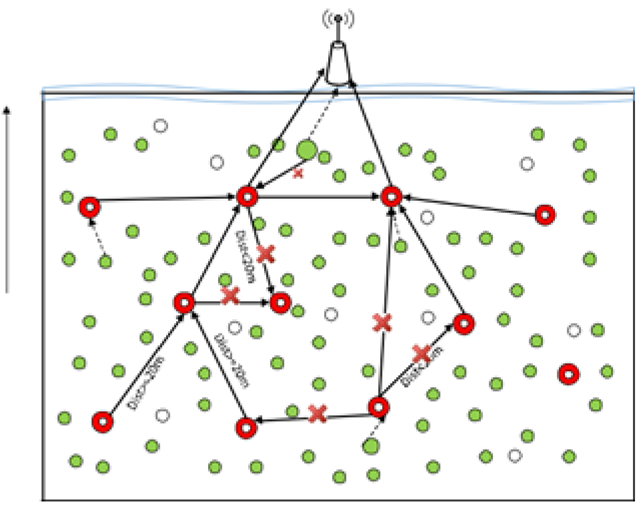


Figure 3.16: Architecture for CDBR routing protocol (Source: Tanveer et al 2016)

CDBR achieves a total network residual energy of 2000joules as the number of rounds increases to 700 compared with DBR at 1800joules and EEDBR at 1900joules. Also, CDBR achieves a smaller number of dead nodes at 110 sensor nodes as the number of rounds increases to 700 as compared to DBR at 120 and EEDBR at 140. However, CDBR lacks an efficiency to send aggregated data by the cluster head node to the sink node.

(Jianlian, Xiujuan, Duoliang, Lijuan, and Meiju, (2019) proposed a routing protocol called a layer based and energy efficient routing protocol. LEER adopted an approach to discovering a route without considering the full location of the sensor nodes. The void hole issue was addressed in LEER by using a Hello message technique to determine each forwarding node layer and thus tackle a void hole in packet transmission. The sink node in LEER calculates the time it waits for the forwarding node, this is based on the remaining and energy using a multi hop mode of packet transmission. When the network phase is set each node will have a neighbour forwarding node on the layer above it that forwards packets to the sink node to avoid a void hole. LEER achieves a packet delivery ratio at 80% as the number of the sensor nodes increases to 70 as compared with DBR at 43%. Furthermore, LEER achieves lower end to end delay of 31s for 70 nodes as compared with DBR at 4.8s. However, LEER suffers from routing overhead and lacks efficiency in sparse network due to the sensor nodes mobility.

(Shreema, Radhika, and Manohara, 2018) purposely focus on underwater sensor nodes mobility with respect to the packet transmission process by proposing a priority-based routing called energy efficient message priority-based routing (PBR). The PBR routing protocol adopts a routing policy through packet prioritization with respect to emergency and regular packets. It achieves this by considering the residual energy and, link quality when selecting the appropriate path based on priority. The shortest delay with least congested path is selected during critical communication situations in aquaculture by selecting emergency packets in the packet transmission process to effectively transmit sensory data packets. PBR was evaluated using an NS2 simulator result and indicates an increase in residual energy for the PBR at 1228joules as the simulation time increases as compared with L2-ABF at 1180joules. Moreover, PBR also achieves 125 alive nodes as the nodes increases to 150 compared with L2-ABF with 123 nodes. However, PBR lacks an energy efficient mechanism for the relay of nodes closer to the sink which suffers from packet loads.

(A. Khan, Javaid, Mahmood, Khan, and Qasim, (2016) proposed a routing approach to select an efficient route through effective energy utilization, this was called the energy Efficient Interference and Route Aware Protocol for Underwater wireless sensor network. The routing protocol adopts a routing strategy of transmitting packets of data through relay nodes. The source nodes transmit data to the relay nodes, while the relay nodes check for a sink node within its range for transmission, otherwise the relay node will transmit packets to the best relay node for transmission to the sink node. The best relay nodes are chosen based on the shortest path with fewest neighbours.

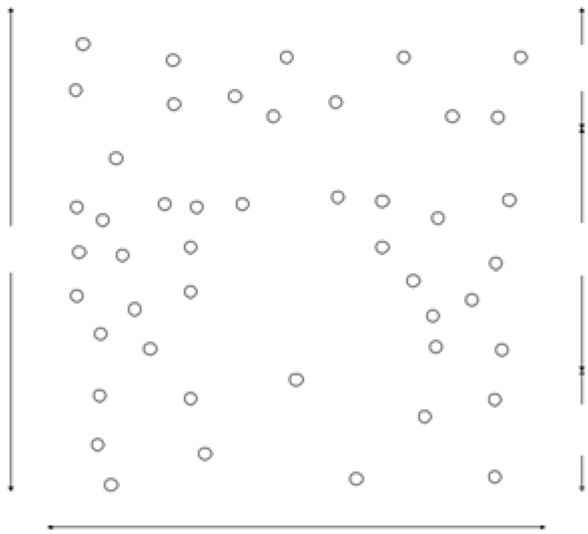


Figure 3.17: Nodes distribution for EEIRA routing protocol (Source: khan, Javid, Mahmood, khan and Qasim 2016).

The EEIRA routing protocol consumes less energy consumption at 1300joules as the number of simulation rounds increase to 1000 as compared with DBR at 1500joules. Also, EEIRA attains 80% dead nodes as the number of simulations increase to 1000 as compared with DBR at 98%. However, as the number of the simulation round increases to 1000, EEIRA incurs delay of 1400s as compared with DBR at 500s. EEIRA lacks a proper mechanism to tackle rely nodes in void region that forwards packets to the sink node.

(Mudassir et al., (2016) posited a routing protocol for a reliable packet transmission between underwater sensor nodes called an energy efficient hybrid clustering routing protocol for underwater wireless sensor network (EEHC). The EEHC routing protocol adopts a clustering technique to transmit packets of data to the sink node. Clusters are formed with cluster heads at a lower depth to sensing nodes in the cluster. Cluster heads are periodically selected based on their residual energy and switches their mode of transmission from a single to a multi hop this is based on their energy status for efficient energy consumption. EEHC consume less energy at 80% as the number of round increases to 100 compared with DB-EBH at 94%. EEHC achieves a packet received of 95% at 100 rounds compared with DB-EHC with 50%. However, EEHC lacks efficiency in transmitting aggregated data by the cluster head to the sink node.

(Abdul, Sungwon, Hong-Jong, and Dongkyun, 2011) propose an underwater routing protocol called adaptive co-operation in EEDBR. The ACE routing protocol adopts a co-operative routing through relaying nodes to successfully re-transmit of packets. The ACE routing protocol consist of three phases Depth exchange phase, path establishment phase and data transmission phase. Co-operative relay nodes are selected based on low depth and high residual energy. The ACE routing protocol achieves a throughput of 83% for a double retransmission compared with EEDBR at 80%. However, ACE consumes a high amount of energy at 10% compared with EEDBR with 7% for a double retransmission. However, the ACE routing protocol incurs routing overheads due to the frequent exchange of control packets with excess energy consumption.

(Majid et al., 2016) proffer energy efficient routing for packet transmission among underwater sensor nodes, this is called an energy efficient and balanced energy consumption cluster-based routing protocol for underwater wireless sensor network (EBECRP). The EBECRP routing protocol uses a technique of clustering when transmitting packets of data among the clustered member nodes through cluster head to the sink node. This aim to save energy through locally compressed communication. The use of sink mobility was employed to balance loads on the sensor nodes through frequent changes in their position. EBECRP achieves 180dead nodes which is a smaller number, as the round increases to 1000s with 200 nodes against DBR having 198 and EEDBR with 199. Also, EBECRP consume less energy of 97% compared with DBR at 80% and EEDBR at 85%. But EBECRP suffers from less throughput when transferring aggregated data through the cluster heads nodes to sink node.

(Hamed, Vahid, and Abolfazl, (2020) Worked on energy void avoidance by proposing a geographic routing called an energy efficient void avoidance geographic routing for underwater sensor networks (EVAGR). The EVAGR routing protocol uses a mechanism of weight function to select forwarding nodes based on energy consumption and the depth of the neighbouring nodes. EVAGR effectively avoids the void region by efficiently selecting the forwarding nodes by weight function and advancement towards the sonobuoy. The EVAGR routing protocol consume less energy at 100joules as the data generated increases to 40kbps compared with GEDAR at 600joules, also EVAGR achieves less routing overhead of 15% compared with GEDAR at 90%. But EVAGR incurs delay which leads to high average end to end delay of 80% compared with GEDAR at 25% as the data generated increases to 40kbps.

(Ayyadurai & Raja, 2020) posited a routing algorithm that adopted the behaviour of the African buffalo in underwater packet transmission among sensor nodes. The buffalo optimisation algorithm (BOA) uses a fitness function regarding maa and waa modes. When congestion level is minimal and nodes energy is above the threshold value the fitness function tends to be positive, otherwise the fitness function is negative with creation of waa mode. BOA updates the changes in the look up table whenever an acknowledgement is passed. BOA consume less energy of 155joules as the simulation time increases to 14s compared with DRP at 180joules, CAR at 220joules, VDF at 230joules. BOA also achieves a normalised routing overhead of 60% as the packet size increases to 300bytes compared with CAR at 70%, DRP at 90% and VDF at 85%. However, BOA lacks a mechanism to tackle energy holes for relay nodes closer to the sink that suffer from loads.

(Zaheer et al., 2017) proposed a routing protocol with the strategy of void occurrence for packet forwarding this was called the single hop selection SHS-WDFAD-DBR. The routing decision regarding packet forwarding depends upon the selection of two potential nodes with minimum residual energy. Potential forwarding nodes possess a minimum of two forwarding nodes in the communication range to avoid void occurrence and backward transmission. WFAD-DBR achieves packet delivery ratio of 95% as the number of the sensor nodes increases to 500 against WDFAD-DBR with 80% and Intar at 90%. SHS-WDFAD-DBR consume less energy of 30% for 500 nodes compared with WDFAD-DBR at 60% and Intar at 70%. However, SHS-WDFAD-DBR incurs delay and lacks efficiency in the packet delivery ratio in sparse networks.

(Tariq, Abd Latiff, Ayaz, Coulibaly, and Wahid, (2016) posited a routing protocol for underwater acoustic sensor networks called the pressure sensor based reliable routing protocol for underwater acoustic sensor network. The PSBR routing protocol was designed to extend the link quality by using a fuzzy logic quality estimator. The protocol uses a single path as the transmission mode for the next hop node to forward a packet of data. The PSBR protocol uses hello packets to calculate the quality of the link among the neighbour nodes. The initial phase of the routing protocol exchanges depth and residual information based on the hello packets. A link quality estimator used an equation based on fuzzy logic for the hello packets, different fields were used including the source ID, next hop ID, sequence number, destination ID. NS-2 was used as the simulation modeler with increase in the number of sensor nodes to 400 PSBR-FLQE consume less energy at 40joules compared with EEDBR at 75joules, DBR at 190joules and PSBR-ETX at 49joules. Also, PSBR-FLQE achieves a packet delivery ratio of 98% as the sensor nodes increases to 400 compared with EEDBR at 80%, DBR at 84% and PSBR-ETX at 90%. However, PSBR-FLQE lacks efficiency especially for sparse networks due to re-transmission that leads to routing overhead.

(Md Arifur, YoungDoo, and Insoo, (2018) proposed an opportunistic routing protocol called fuzzy Logic-based Cooperative opportunistic routing for underwater acoustic sensor networks (FLCOR). The FLCOR protocol was designed to enhance the reliability of transmission using a fuzzy logic system to select the best relay node to forward packet of data to the sink. MATLAB was used as the simulation modeler with a simulation of 700 rounds. FLCOR attained 220 alive nodes as the simulation rounds increased to 700 rounds compared with DBR at 218, also FLCOR achieves 130 dead nodes compared with DBR at 120. However, FLCOR lacks an efficient mechanism to tackle void holes when selecting potential relay nodes.

(Shalli, Syed Hassan, Jyoteesh, & Rajneesh, 2019) proposed an efficient chain-based routing protocol for underwater wireless sensor network (E-CBCCP). The E-CBCCP routing protocol employs the use of a bell hop tracer model to depict the network model. This is based on the transmission of data from ocean seafloor to surface per cluster in each region via hop-to-hop count. The sensor nodes, which consist of source node, neighbour node, cluster head node and a cluster co-ordinator node takes part in the packet transmission process from each region. E-CBCCP uses two phases which consist of a network set up phase and transmission phase. Relay nodes are selected based on optimal link quality, and residual energy. A two-packet format is used by E-CBCCP skp (a control packet to formed data from the node) and rpk (a control packet to notify the source node of the reception of the data). As the data packets increases to 4000 packets E-CBCCP consume less energy consumption of 80% compared with CARP at 98%. Also, E-CBCCP improved to 1.34 times over CARP when the data payload increases to 4000bytes. However, E-CBCCP lacks a proper mechanism to select the cluster head within a cluster for a subsequent round of selection.

(Pan et al., (2019) proposed an improved energy balanced routing algorithm (IEBR). IEBR uses a routing strategy that establishes routes by depth transmission distance with threshold values among the relay nodes. IEBR adopts a ring sector with sensor nodes available in each sector to transmit data. Energy conservation with respect to data transmission was used by the energy level of the successor node if it is lower it finds another reliable relay node to balance energy. As the network radius increases to 5km, IEBR achieves a throughput of 9000p compared with EBR at 2100p, BTM at 1700p, and UDAR at 1100p. Also, IEBR achieves a 25% increase in network lifetime as the number of sensor nodes increases to 160 over a 5km network radius. However, IEBR lacks deficiency in the mechanism for void hole occurrence for packet transmission in sparse network.

(Abdul et al., 2015) posited a routing protocol with regards to energy efficiency known as energy efficient depth-based routing protocol (EEDBR). EEDBR uses a routing strategy by transmitting packets of data based on sensor nodes depth and residual energy. The forwarding nodes that take part in the transmission process must be lower in depth than the source node. EEDBR balances energy based on the holding time between the sensor nodes and using residual energy. During the packet transmission sensor nodes with a low residual energy hold back their transmission by allowing the sensor nodes with high residual energy to forward the packets of data. EEDBR achieves an end-to-end delay of 15% as the sensor nodes increase to 225 compared with DBR at 90%. Furthermore, as the number of the sensor nodes increases to 225 EEDBR consume less energy at 40% compared with DBR at 85%. However, EEDBR lacks a proper mechanism to tackle the energy consumption of relay nodes closer to the sink that suffer from loads.

(Safia, Sana, and Imran Ali, 2018) focus on a light weight-based routing protocol for underwater wireless sensor network. The LDBR routing protocol is an enhancement of depth-based routing where all nodes are considered based on their depth thus nodes with less depth are taken as forwarding nodes. The LDBR routing protocol follows a routing strategy by incorporating energy consumption within the forwarding nodes in the packet transmission process unlike DBR that considers the depth of the nodes. Forwarding nodes compare their current depth and level of their energy to forward packet to the sink node. As the simulation time increases to 330s, LDBR consumed 80joules of energy compared with DBR at 100joules. In addition, as the simulation time increases to 400 LDBR achieved 50% in throughput of receiving packets compared with DBR at 80%. However, LDBR incurs delays due to the hold time used by forwarding nodes in the packet transmission. Moreover, it's a lacks in efficient mechanism to avoid energy depletion amongst the relay nodes closer to the sink node.

(Qin, Zhang, Wang, and Cai, (2017) developed an underwater routing protocol called an energy balanced and depth control routing protocol (EBDCR). The EBDCR routing protocol adopts a hop-by-hop routing strategy by greedy forwarding that selects the next hop node through energy efficiency and by node adjustment. Sensor nodes near the sink at a low depth suffer from load and energy depletion are replaced with the nodes far from the sink node having higher energy status. As the number of sensor nodes increases, EBDCR achieves an extended network lifetime of 20% compared with the DCR and EEDBR routing protocols. However increases in the number of sensor nodes means that s EBDCR to incur end to end delay by 2% energy consumption as a result of node adjustment.

(Mhemed, Comeau, Phillips, and Aslam, (2021) proposed an underwater routing protocol called an energy efficient depth based opportunistic routing protocol for underwater wireless sensor network (EEDOR). EEDOR employs the use of an opportunistic routing strategy to effectively transmits packets of data from underwater to the surface of the water. A greedy approach was used that selects the most appropriate forwarding nodes in the packet's transmission by the holding time factor. EEDOR makes use of rank with nodes having less holding time to effectively determine the eligible forwarding nodes despite having equal depth. EEDOR was tested against DBR and EEDBR using the MATLAB simulator and different parameters were used which consist of total energy consumption, packet delivery ratio and network lifetime. EEDOR consume less total energy at 30% as the number of sensor nodes increase to 800 compared with EEDBR at 50% and DBR at 90%. EEDOR achieves 90% packet delivery compared with DBR at 80%, and EEDBR at 70%. Moreover, for 200 number of nodes EEDOR achieves a network lifetime of 90% with EEDBR at 89%, and DBR at 80%. However, EEDOR lacks a mechanism to tackle void occurrence which subsequently results in greater energy consumption and delays in the packet transmission process.

(Chen et al., (2020) developed a combined routing protocol based on an ant colony optimization algorithm (ACOA), artificial fish swarm algorithm (AFSA), and a dynamic coded strategy (DCC) to effectively achieve a stability in the packet transmission among underwater sensor nodes. The routing protocol employs the use of hop-by-hop routing strategy to deliver packets of data. ACOA-AFSA-DCC consider the distance between two nodes to effectively allow the co-operative node to participate in the packet transmission process through decoding. ACOA-AFSA-DCC was simulated using MATLAB against four artificial intelligence routing protocols with a varying number of sensor nodes 10, 50 and 100. Energy consumption was used as the performance parameter to compare their efficiency. As the number of sensor nodes increases to 100 ACOA-AFSA-DCC consume less energy compared with 40% compared with ASA at 60%, ACOA at 69%, and ACOATS at 78%. However, ACOA-AFSA-DCC lacks efficiency in the selection of the next hop node which causes delay in the packet transmission process.

(Qadir et al., 2020) Posited an underwater routing protocol called as energy aware and reliability-based localization free co-operative routing protocol for underwater acoustic wireless sensor network. The routing protocol adopts the use of hop-by-hop co-operative routing strategy to deliver packets by using two routing schemes namely energy path and channel aware (EPACA) and, co-operative energy path channel aware (co-EPACA). The EPACA technique effectively consider certain factors in the selection of appropriate forwarding nodes which consist of residual energy, distance, and packet history. While co-EPACA effectively consider the delivery of data with reliability to the sink. EPACA and co-EPACA were simulated using MATLAB to effectively determine their efficiency in packet transmission compared with co-DBR. Certain performance parameters were used which consists of total energy consumption, packet delivery ratio, end to end delay, dead nodes, and alive nodes. Result shows that as the number of rounds reached 4500, EPACA consumed less total energy consumption of 1000j compared with co-EPACA at 1190j, and co-DBR at 1250j. co-EPACA achieves a high packet delivery ratio of 90% compared with co-DBR at 89|%, and EPACA at 50%. As the number of the simulation round reaches 4500, EPACA achieves less end-to-end delay at 0.8s compared with aco-EPACA at 1.9s, and co-DBR at 1.2s. EPACA achieves a smaller number of dead nodes at 70% against co-DBR at 82%, and co-EPACA at 89%|. Moreover, EPACA achieves a higher number of alive nodes at 85% compared with co-EPACA at 80% and co-DBR at 75%. However, the routing protocol lacks an appropriate mechanism to tackle void occurrence in the packet transmission process which subsequently result in delay and greater energy consumption.

(Saeed, Khalil, Ahmed, Ahmad, and Khattak, (2020) proposed an underwater routing protocol called a secure energy efficient and co-operative routing protocol (SEECR). The SEECR routing protocol employed the use of a hop-by-hop routing strategy with security measure to deliver packets of data. The scheme used by SEECR tries to detect an active routing attack between relay nodes in the packet transmission process by eliminating the attacker node and dropping the packet. Relay nodes are selected based on their residual energy and weight value. SEECR was simulated against the AMCTD routing protocol for a certain performance parameter which consist of the number of alive nodes, transmission loss, throughput, energy tax, and end to end delay. Result indicates that as the nodes increases to 225, SEECR with attack achieves 111 of alive nodes compared with SEECR without attack at 112, AMCTD with attack 68, and AMCTD without attack 82. SEECR with attack achieves 43.7% for the overall transmission loss as compared with SEECR without attack at 43.1%, AMCTD with attack at 100%, and AMCTD without attack at 98.8%. Moreover, SEECR without attack achieves a better throughput of 42.6% compared with SEECR with attack at 42.4%, AMCTD without attack at 37.6%, and AMCTD with attack at 32.9%. SEECR without attack achieves an overall energy tax of 76.1% compared with SEECR with attack at 77.3%, AMCTD without attack at 88.3% and AMCTD with attack at 100%. Furthermore, SEECR with and without attack achieves same end to end delays at 70.2%, compared with AMCTD with attack at 95.5%, and AMCTD without attack ata 100%. However, SEECR lacks a mechanism to tackle the energy depletion of the relay nodes closer to sink which causes the overall network failure.

(Kumar, Bhardwaj, and Mishra, 2020) posit an underwater routing approach as energy balanced, depth aware data transmission to effectively prolong the network lifetime of the underwater sensor nodes. The proposed routing protocol (EBH-DBR) adopts the use of hop-by-hop routing strategy among underwater sensor nodes in the process of communication by enhancing conventional depth-based routing (DBR). The EBH-DBR routing protocol employ the use of holding time which consist of depth and residual energy to determine the next relay node to forward data to the sink. EBH-DBR was tested using MATLAB simulator together with performance metrics which consists of network lifetime, average energy per node, and throughput. Results shows that as the number of sensor nodes increases to 800, EBH-DBR achieves a network lifetime of 75% compared with DBR at 50%, and EEDBR at 55%. EBH-DBR achieves an average residual energy per node of 80% compared with DBR at 40%, and EEDBR at 60%. Furthermore, EBH-DBR achieves a throughput of 87% compared with EEDBR at 60% and DBR at a40%. However, EBH-DBR lacks an efficient technique to solve the void hole problem which subsequently results in greater energy consumption and overall end to end delays.

(Guan, Ji, Liu, Yu, and Chen, 2(019) posit an underwater routing protocol called the distance vector based on the opportunistic routing for underwater acoustics sensor networks (DVOR). DVOR employs the use of an opportunistic routing strategy to exchange packets among underwater sensor nodes. The routing protocol addresses the issue of void region and long detour. DVOR effectively uses relay nodes based on priority with the lowest number of hop counts selected as the forwarding node to the sink. DVOR was simulated using NS-2 against DBR and DUOR. Three performance metrics were used packet delivery ratio, average hop count of delivered packets, and average end to end delay. Results indicated that as the number of nodes increases to 500, DVOR achieves a higher packet delivery ratio of 90% compared with DUOR at 80% and DBR at 55%. Moreover, as the number of nodes increases to 500, DVOR achieves a lowest average hop count for delivered packets at 50% compared with DUOR at 62% and DBR at 80%. Furthermore, DVOR achieves a lower average end to end delay of 30% compared with DUOR at 70% and DBR at 90%. Although, DVOR lacks an efficient mechanism to tackle the energy consumption of relay nodes closer to the sink.

Table 3.2: Summary of the localization free routing protocols with energy consideration.

Authors name	**Protocol**	**Year**	**Technology**	**Routing Strategy**	**Problem Addressed**	**Simulation Tools / Performance Parameters**	**Benefits**	**Draw backs**
Ahmad *et al*	CEER	2022	Acoustic	Co-operative routing strategy	Energy consumption to increase network lifetime	Delay, energy consumption, packet delivery ratio, transmission loss	Achieves packet delivery ratio with less transmission loss	incur high delays and lacks efficient technique that can avoid sensor nodes from consuming more energy
Nazareth & Chandavarkar	LFVAR	2022	Acoustic	Opportunistic routing startegy	Void hole avoidance and energy consumption	Unet stack simulator, Packet delivery and energy consumption	Achieves packet delivery.	Lacks efficient mechanism to help sensor nodes achieve less energy consumption especially within the void or trap region.
Nandyala, Kim, & Cho	Q-TAR	2023	Acoustic	Opportunistic routing strategy		MATLAB (r2021b),	Less latency, and network lifetime	Suffers from technique to avoid energy consumption among sensor nodes in the process of packet

								transmission.
Junaid *et al*	BEER	2018	Acoustic	Opportunistic routing strategy	Sink nodes mobility and hole problem	MATLAB Packet received and energy consumption.	Throughput is achieved using sink mobility in packet transmission	Increase in energy consumption and packet drop among sensor nodes that are out of the transmission range of the mobile sink node.
Zahid *et al*	EBER2	2019	Acoustic	Opportunistic routing strategy	Void hole avoidance and energy consumption	MATLAB Average energy consumption, packet delivery ratio, average end to end delay	Void hole is avoided with improvements in packet delivery ratio and energy efficiency.	Packets duplication and end to end delays due to potential forwarding node (PFN) prioritization
Abrahamed & Vinodkumar	EER	2018	Acoustic	Opportunistic routing strategy	Energy consumption	Aqua sim, Average packet delivery ratio, average end to end delay, average energy consumption	Lower energy consumption with decrease in end-to-end delay.	Lacks efficiency cause by routing overhead due to hold time use by the forwarding nodes
Irfan *et al*	SEEC	2017	Acoustic	Clustering	Balanced		Low energy	Less throughput

				routing strategy	energy consumption	Network lifetime, network residual energy, packet sent & packet received, stability and instability of the network	consumption	
Jun, Meiming, xingwang, Yuanyuan & Xiaohui	RECRP	2018	Acoustic	Cross-layering routing strategy	Channel and energy efficiency	Packet delivery ratio, Energy consumption, end to end delay.	Achieves an increase in delivering packets with less energy consumption.	Deficiency in selecting reliable relay nodes that suffers from load and energy depletion.
Wahab khan	MLCEE	2019	Acoustic	Clustering routing strategy	Energy consumption	MATLAB Throughput, packet delivery ratio, end to end delay, Network lifetime	Lower energy consumption.	Less throughput because of inefficiency in transferring aggregated data by the cluster head nodes to the sink node.
Zhigang, Zhihua & Yishan	EBOR	2018	Acoustic	Opportunistic routing strategy	Energy efficiency	MATLAB Energy consumption, end to end delay,	Lower energy consumption and packet delivery ratio	Lacks a mechanism to tackle void occurrence for the forwarding nodes in the transmission

						packet delivery ratio.		process.
Nazareth & Chandavarkar	E-VAR	2015	Acoustic	Hop-by-hop routing strategy	Void avoidance	MATLAB Hop count, distance	Achieves packet delivery through minimal number of hop count by avoiding loops	Deficient in taking energy of the selected forwarding sensor nodes into consideration.
Zhengru *et al*	QLACO	2020	Acoustic	Reinforcement learning routing strategy	Energy efficiency	Energy consumption, packet delivery, latency	Decrease in energy consumption.	Deficiency in tackling void due to mobility of the forwarding nodes.
Ahmad, Muhammad, Omprakash & Hassan	RE-PBR	2017	Acoustic	Hop-by-hop routing strategy	Energy balancing and consumption.	Aqua sim End to end delay, packet delivery ratio, network lifetime.	Achieves less energy consumption with increase in packet delivery	Decreased in throughput due to the re-transmission of packets.
Tanveer *et al*	CDBR	2016	Acoustic	Clustering routing strategy	Energy consumption	Packet sent, packet drop, residual energy, dead nodes, alive nodes.	Attain Higher sensor nodes residual energy	Lacks efficient mechanism in sending data by the cluster head node to the sink node with processing

								overhead.
Jianlian, Xiujuan, Duoliang, Lijuan & Meiju	LEER	2019	Acoustic	Hop-by-hop routing strategy	Void avoidance	NS-3 End to end delay, packet delivery ratio	Achieves packet delivery ratio as the number of the Sensor node increases	Inefficiency in tackling sensor nodes void hole due to the forwarding nodes mobility.
Shreema, Radhika & Manohara	PBR	2018	Acoustic	Opportunistic routing strategy	Energy consumption	DESERT, Packet delivery ratio, residual energy, network lifetime	Achieves packet delivery ratio	Lacks mechanism to tackle relay nodes energy consumption which suffers from packet loads
A.khan, Javaid, Mahmood.khan & Qasim	EEIRA	2016	Acoustic	Hop-by-hop routing strategy	Energy efficiency in packet transmission	MATLAB Number of dead nodes, network total energy consumption, network total end to end delay, total packet received.	Attain less energy consumption.	Lacks proper mechanism to tackle relay nodes in void region. And incur delay due to selection of relay nodes
Mudassir *et al*	EEHC	2016	Acoustic	Clustering routing	Energy balancing	Energy consumption,	Decreased energy consumption	In efficiency in transmitting aggregated

				strategy	and consumption.	number of dead nodes, packet received		data by the cluster head node to the sink node.
Abdul, Sungwon, Hong-jong & Dongkyun	ACE	2014	Acoustic	Hop-by-hop co-operative routing strategy	Enhancing throughput through re-Transmission	MATLAB Throughput, total energy consumption, packet acceptance ratio, packet drop	Achieves throughput in packet transmission	Incurs routing overhead due to frequent exchange of control packets with excess energy consumption
Majid *et al*	EBECRP	2016	Acoustic	Clustering based routing strategy	Energy consumption among sensor nodes	Throughput, residual energy, packet drop, dead nodes, alive nodes,	Attain less energy consumption and packet drop	Less throughput through transferring aggregated data by the cluster heads nodes to the sink node.
Hamid, Vahid & Abolfazl	EVAGR	2020	Acoustic	Opportunistic routing strategy	Void avoidance through energy consumption.	Aqua sim, Average energy consumption, routing overhead, average end to end delay	Decrease in energy consumption and routing overhead.	Incurs delay and lacks a mechanism to tackle void nodes due to mobility.
Ayyadurai &	BOA	2020	Acoustic	Hop-by-hop	Energy	NS-2,	Lower energy	Unavailability of

Raja				routing strategy	consumption and data collision	Energy consumption, routing overhead, delay, packet loss ratio.	consumption with less routing overhead.	mechanism to tackle relay nodes energy consumption closer to the sink.
Zaheer *et al*	SHS-WDFAD-DBR	2018	Acoustic	Hop-by-hop routing strategy	Void hole	Packet delivery ratio, energy consumption.	Attain a decrease in energy consumption in dense network	Delay and Lacks efficiency in packet delivery in sparse network
Tariq, Abdullatif, Ayaz, Coulibaly & Wahid	PSBR	2016	Acoustic	Hop-by-hop routing strategy	Energy consumption through link quality estimation.	NS-2 Energy consumption, packet delivery ratio, end to end delay, network lifetime.	Achieve a decrease in energy consumption and attain a packet delivery ratio	Lacks efficiency due to ret-transmission of packets that leads to routing overhead in sparse network.
Md Arifur, Youngdoo & Insoo	FLCOR	2018	Acoustic	Opportunistic routing strategy	Packet advancement towards sink	MATLAB Number of dead nodes, number of alive nodes.	Attains network stability of alive nodes	Absence of efficient mechanism to tackle void hole by selecting potential relay nodes.

Shalli, SyedHassan, Jyotesh & Rajneesh	E-CBCCP	2019	Acoustic	Clustering routing strategy	Energy consumption	MATLAB Energy consumption	Lower energy consumption among sensor nodes.	Lacks efficient mechanism to select a cluster head in a subsequent round of selection.
Pan *et al*	IEBR	2019	Acoustic	Hop-by-hop routing strategy	Energy balancing	Throughput, network lifetime	Achieves energy balancing and throughput among sensor nodes	Deficiency in mechanism for void hole in Packet transmission.
Abdul *et al*	EEDBR	2015	Acoustic	Opportunistic routing strategy.	Sensor nodes energy consumption.	NS-2, Energy consumption, end to end delay, delivery ratio, delivery ratio	Achieves energy consumption among sensor nodes	Lacks an efficient mechanism to tackle the energy consumption of relay nodes closer to the sink.
Safia, Sana & Imran	LDBR		Acoustic	Opportunistic routing strategy	Energy consumption of the sensor nodes	Throughput, energy consumption	Decrease in energy consumption of the forwarding nodes	Incurs delays due to hold time use in packet transmission.

Qin, Zhang, Wang & Cai	EBDCR	2017	Acoustic	Hop-by-hop routing strategy using greedy forwarding	In efficiency in Sensor nodes energy consumption through depth adjustment.	Aqua sim Network lifetime, average end to end delay, average energy consumption.	Increase in Network lifetime as the number of sensor nodes increase.	End to end delay because of node adjustment which affects the delivery of data.
Mhemed, Comeau, Phillips, & Aslam	EEDOR	2020	Acoustic	Opportunistic routing strategy	Energy consumption	MATLAB/ total energy consumption, packet delivery and network lifetime.	consume less total energy consumption at 30%, compared with EEDBR at 50%, DBR 90%. EEDOR achieves a packet delivery of 90% compared with DBR 80%, EEDBR 70%.	Lacks mechanism to address void occurrence which subsequently result in delay in the packet transmission process.

Chen *et al*	ACOA-AFSA DCC	2020	Acoustic	Hop by hop routing strategy	Energy consumption	MATLAB/ energy consumption	ACOA-AFSA consumes less energy 40% as the number of the sensor nodes increases to 100 against AFSA 60%, ACOA 69%, ACOATS 80%.	In efficiency in the selection of appropriate next hop nodes which causes delays in the transmission of data packets.
Qadir *et al*	EPACA and Co-EPACA.	2020	Acoustic	Hop by hop co-operative routing strategy	Energy consumption and packet delivery.	MATLAB/ total energy consumption, packet delivery ratio, end to end delay, dead node, and alive nodes.	EPACA routing scheme achieves a lower total energy consumption of 1000j as the number of the round increases to 4500 compared with co-EPACA 1190J, and co-DBR 1250j. co-EPACA achieves a packet delivery ratio of 90% compared	Lacks an appropriate mechanism to tackle void occurrence in the packet transmission which causes delay and more energy consumption.

							with co-DBR at 89%, and EPACA 50%. EPACA achieves less end-to-end delay of 0.8s compared with co-EPACA 1.9s, and Co-DBR 1.2s. EPACA achieves fewer dead nodes with 70% compared with co-DBR 82%, and co-EPACA 89%. EPACA achieves high number of alive nodes with 85% compared with co-EPACA at 80%, and co-DBR at 75%.	

Saeed, Khalil, Ahmed, Ahmad, & Khattak, 2020	SEECR	2020	Acoustic	Hop by hop routing strategy	Energy efficiency and security	Transmission loss, throughput, energy tax, end to end delay.	SEECR with attack achieves 111 alive nodes compared with SEECR without attack 112, AMCTD with attacks at 68, AMCTD without attacks at 82. SEECR with attack achieves a transmission loss of 43.7%, SEECR without attacks at 43.1%, AMCTD with attack at 100%, AMCTD without attack 98.8%. SEECR without attack achieves a better throughput of 42.6% compared	Lacks a mechanism to tackle the energy depletion of relay nodes closer to sink which suffers from packet load.

							with SEECR with attack having 42.4%, AMCTD without attack 37.6%, AMCTD at attack 32.9%. SEECR without attack achieves an overall energy tax of 76.1% against SEECR at attack having 77.3%, AMCTD without attack 88.3% and AMCTD with attack 100%. SEECR with and without attack achieves same end to end delay of 70.2% compared with AMCTD with attack at 95.5%, and	

							AMCTD without attack at 100%.	
R. Kumar, Bhardwaj, & Mishra	EBH-DBR	2020	Acoustic	Hop by hop	Energy consumption	MATLAB/ network lifetime, average residual energy per node, throughput.	EBH-DBR achieves a network lifetime of 75% compared with DBR with 50%, EEDBR at 55%. EBH-DBR achieves an average residual energy per node of 80% compared with DBR 40%, EEBDR at 60%. Furthermore EEBH-DBR achieves a throughput of 87% compared with EEDBR at 60% and DBR at 40%.	EBH-DBR lacks an efficient technique to address void hole problem which result in greater energy consumption and overall end to end delay.

Guan, Ji, Liu, Yu, & Chen	DVOR	2019	Acoustic	Opportunistic	Void avoidance	NS-2, packet delivery ratio, average end to end delays, and a average lowest hop count for delivered packets.	Achieves a packet delivery among the sensor nodes in the packet transmission process	Lacks an efficient mechanism to tackle relay nodes energy consumption closer to the sink.

Most of the literatures reviewed based on localization based and localization free routing protocols are focused based on different design perspective with emphasis on different underwater routing strategies. However, most of the literatures been reviewed had not consider a separate design for sparse and dense network (scalability) which plays a significant role in determining the amount of communication between sensor nodes from underwater to the base station. The literatures which have been reviewed proposes some energy consumption techniques to minimize energy consumption among underwater sensor nodes without considering a detail design architecture for both sparse and dense network. Each of the literatures reviewed uses one routing strategy to support network scale for the sensor nodes in the process of communication. However, these underwater routing strategies differs based on their working principles in supporting sensor nodes for effective communication in underwater. As a result, this research focus on separate design perspective to support both sparse and dense underwater architecture by considering different routing strategies. These design perspectives support the sensor nodes in the process of communication in underwater. Furthermore, for this research, different techniques were developed for both source and clustering routing strategies to minimize energy consumption for the proposed sparse and dense network architectures.

3.6 CHAPTER SUMMARY

This chapter presented the literature review for developed energy localization based underwater routing protocols and developed energy localization free underwater routing protocols, while their advantages and draw backs were also presented in summary table. Each of the literatures reviewed focus on one routing strategy without considering a separate design to support scalability in the process of minimizing energy consumption among underwater sensor nodes. As a result, this research focus on developing a routing protocol with separate design to support both sparse and dense network to minimise energy consumption among sensor nodes in underwater. The next chapter present the research requirement specification.

CHAPTER FOUR
RESEARCH REQUIREMENT SPECIFICATION

4.1 SIMULATION MODELLING

Underwater wireless sensor networks possess a different environment unlike their terrestrial counterparts. The relevance and significance of underwater communication increases day by day. An underwater acoustic sensor network incurs high cost in practical deployment for real life testing. Hence there is a need for an actual simulation environment that can evaluate the performance of a routing protocol for underwater scenario. Some of the existing terrestrial wired and wireless simulators cannot be directly applied to validate a routing protocol or algorithm without undergoing certain modifications due to the unique characteristics of the underwater environment. To effectively model an underwater acoustic channel with 3D deployment and sensor node mobility, an efficient simulator is needed to simulate and validate the specific characteristics of the underwater environment. The following are classifications of underwater simulators, while some are used for terrestrial application, they can be further configured for use underwater and some are purposely developed to simulate an underwater environmental scenario.

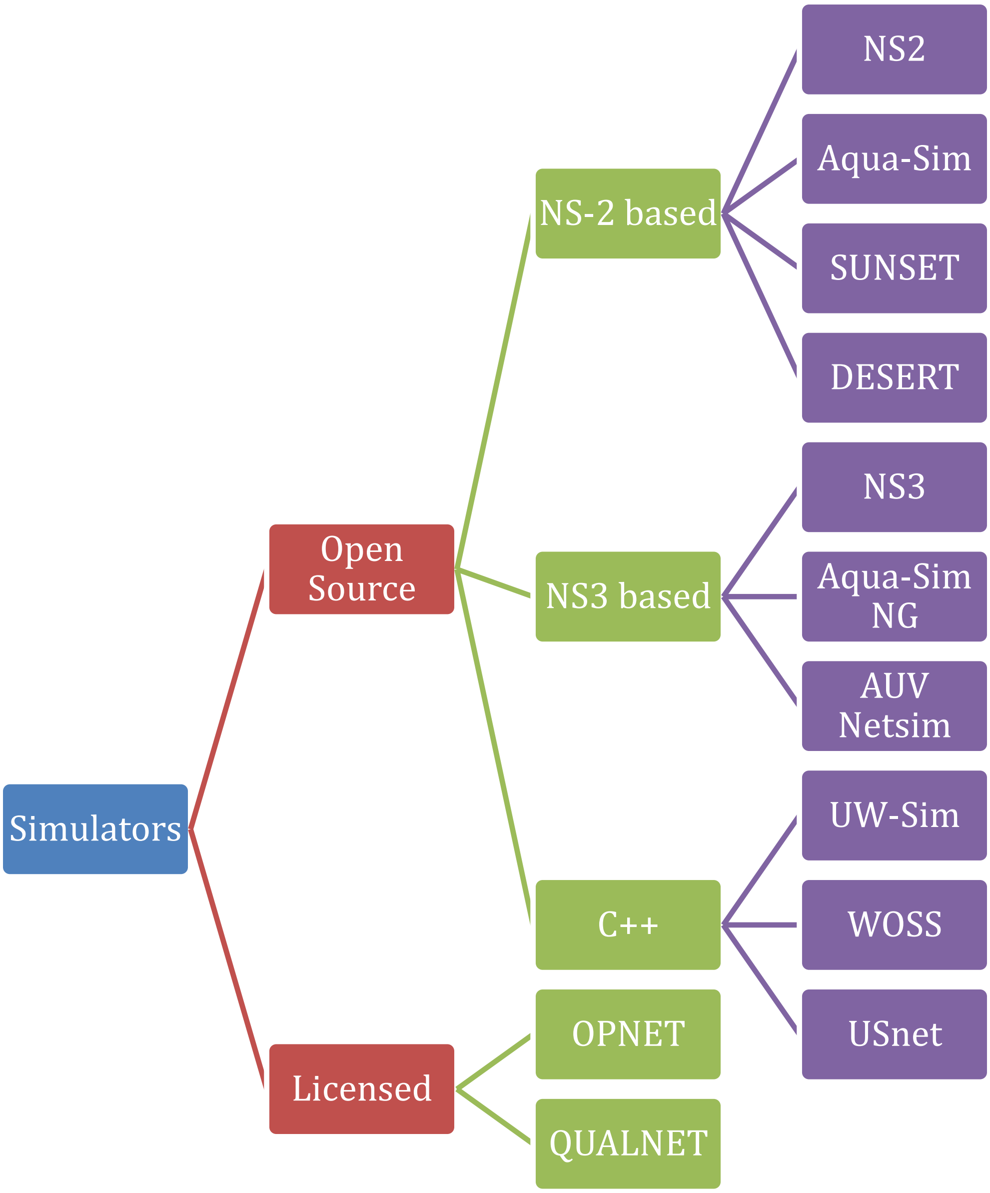


Figure 4.1: *Diagram showing the categories for underwater simulators.*

Figure 4.1 shows the categories of underwater simulators which consist of open source and licensed network simulators. The open-source simulators consist of AquaSim which is a discrete event simulator based on NS-2 with C++ as core and oTCL as the scripting language that simulates an underwater environment (Jouhari, Ibrahimi, & Benattou, 2017). Aqua sim handled the propagation model, acoustic signal attenuation and packet collision (Nayyar & Balas, 2019). SUNSET is also an NS-2 based simulator that uses different channel models in acoustic communication for simulation and emulation (Cardia et al., 2019). Desert simulator support simulation and emulation for underwater routing protocols provides an enabling environment for 2D and 3D network scenarios using different modules (Coccolo, Campagnaro, Signori, Favaro, & Zorzi, 2018). NS-3 an open-source network simulator that is used to model underwater scenario. NS-3 was developed using python and C++ with the support of an underwater acoustic channel and propagation model (Adel, Abdallah, Moussa, & Thomas, 2017). AquaSim-NG is an enhanced version of an AquaSim simulator that simulates an underwater environment with underwater channel features, physical model support and improved memory management support (Martin, Rajasekaran, & Peng, 2017). AquaSim-NG is the latest version of AquaSim simulator it possesses an enhanced real-world feature that supports layer protocols with strong packet header handling. AUVnetsim is an underwater network simulator that supports parameters as packages with a physical layer based on the thorp model. However, AUVnetsim lacks the modelling in different underwater conditions (Schneider & Schmidt, 2018). UWsim an underwater simulator that support dynamic motion with robots and sensor nodes and it was developed using C++ (Centelles, Soriano, Martí, Marin, & Sanz, 2019). The world ocean simulator is a simulator based on C++ that support different underwater features with acoustic propagation model. However, world ocean simulator is limited to a smaller network scenario (Luo et al., 2017). USnet is an underwater network simulator that supports 3D deployment but lacks simulating routing protocols based on clustering routing strategy (Anjana & Sabu, 2016). Qualnet is a licensed network simulator with GUI and used to simulate an underwater scenario with platform for testing network behaviour (Mukhtar, Emad, Shamala, Adil, & Saad, 2017). However, Qualnet restrict only the use of a random way point mobility model for nodes mobility.

Open-source simulators, such as ns-3 and OMNeT++, offer advantages for underwater sensor network research due to their flexibility, transparency, and collaborative nature. Researchers can modify the source code to tailor simulations to specific underwater scenarios and experiment with novel protocols and algorithms. Additionally, the community-driven development fosters knowledge sharing and continuous improvement. However, open-source simulators may lack user-friendly interfaces and comprehensive documentation, demanding a steeper learning curve. On the other hand, licensed simulators like MATLAB/Simulink provide a more user-friendly environment and extensive support, but they come with a cost, limiting accessibility for some researchers. Furthermore, proprietary simulators may have restrictions on customization, hindering the exploration of highly specialized underwater sensor network scenarios. Researchers must weigh these factors based on their specific needs and resources when choosing between open-source and licensed simulators for underwater sensor network research.

4.2 AQUA SIM NEXT GENERATION (AQUA SIM-NG) FOR NS-3

AquaSim-NG an NS-3 based underwater network simulator replaced the former version of Aqua sim network simulator based on NS-2. The replacement came as result of impediment which consisted of inadequate memory performances, unsatisfactory architecture arrangement and, real system module restriction with a steep learning curve for users. AquaSim-NG was developed to overcome the previous challenges associated with aqua sim by offering improved memory management, improved real world features, additional modules for development by user's and overall simplicity (Jafri, Balsamo, Marin, & Martin, 2018). AquaSim-NG was developed along with new features which consist of channel support that entails noise generators, multiple channel support, a range-based propagation model and trace driven support. AquaSim-NG consists of an expanded physical support that shows how packets of data are handled based on propagation model where sensor nodes received packets for a transmission delay based on signal attenuation. Furthermore, Aqua sim employs the use of a signal cache and SINR checker for the received packets, which are based on decoding on the physical layer. Another distinguishing feature is the nodes localization that consists of the Euclidean distance for 2D and 3D, the location list management of the sensor nodes, and a busy terminal queue in the base class of the MAC layer's busy modem. This effectively monitors the transition of packets, where packets will remain in a queue until the sensor nodes modem is idle, which permits the transmission of other packets in the queue transmitted. Another distinguishing feature of AquaSim-NG is the attack module that deals with routing attacks. These consist of denial of service, sink hole and sybil attacks with attributes that include the creation of packets for the denial of service, the adjustment packet drop frequency and location spoofing (Hendrik, Ruki, Mohammad, Riri, & Aisha, 2019).

AquaSim-NG as a discrete event simulator was selected as the network simulator for use in the research due to the upgraded features and modules that supported 3 dimensional networks, enhanced underwater acoustic channels and localization support.

4.3 MATHEMATICAL MODELLING

The following are the mathematical modelling used in this research.

4.3.1 UNDERWATER PROPOAGATION MODEL

The underwater acoustic channel is affected by environmental conditions, such as noise, when using an acoustic signal as the transmission medium to send packets of data between underwater sensor nodes. The need for an underwater acoustic channel model has become vital for the effective transmission of the desired data to the destination. The empirical formula depends on the frequency domain, where the transmission range of an acoustic application is inversely proportional to the bandwidth. The higher the transmission range the lower the bandwidth. Underwater propagation models help to determine the frequency domain for the communication range when transmitting packets of data among the underwater sensor nodes using an acoustic signal (Stojanovic, 2007). Thorps model was chosen as the propagation model for the underwater acoustic channel because of its frequency domain range of (100HZ to 3KH) that covers a long transmission range (Al-Aboosi, Ahmed, Shah, & Khamis, 2017).

Thorps model is one of the propagation models used to Modell the underwater acoustic channel. An underwater acoustic model can be used, assess, and quantify the fundamental bandwidth and channel capacity as functions of distance over a transmission range between sensor nodes. Sound propagation theory, developed by Urick (1982), describes a normal molecular movement that propagates to neighbouring particles in an elastic material. A sound wave can be regarded as the mechanical energy transmitted from particle to particle by the source at the speed of the sound through the ocean. Thorp's empirical formula is described as the decrease in sound intensity through the path between the source and destination nodes. The absorption coefficient factor α depends on the sound frequency f. The proposed acoustic attenuation expression is described as follows

$$A\,(d,\,f) = d^k\ \alpha(f)^d \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (1)$$

where d: distance, k: Geometry (k = 1: Cylindrical, k = 2: Spherical).

4.3.2 ENERGY CONSUMPTION MODEL

Underwater sensor nodes are battery dependent, which results in a challenge issue when replacing or recharging them once deployed. Energy saving plays a pivotal role in prolonging the lifetime of the underwater sensor nodes. Underwater sensor nodes perform collaborative monitoring where each task result in energy consumption, hence, the need to minimize the energy consumption and maximize the lifetime of the underwater sensor nodes has become very vital. A linear regression model was chosen because it is used to model the relationship between two or more variables by fitting a linear equation to observed data (Arregi & Garay, 2017). The model takes the following form.

$$Y = \beta 0 + \beta 1 x 1 + \beta 2 x 2 + \ \ldots\ldots . + \beta n x n \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where Y is the independent variable

Xn (n= 1,2…….) are the independent variables

βn (n= 1,2………) are the regression co-efficients

Underwater sensor nodes undergo a sleep and awake mechanism in the packet transmission process to effectively save energy. The mechanism to exchange modes from sleep to awake results in the sensor nodes consuming energy. While other energy consumption actions performed by the sensor nodes in the awake mode include the energy consumed in sensing the data, sending packets of data, moving packets of data and receiving packets of data. The overall actions performed by the sensor nodes in the mechanism will be adopted as the total energy consumption of the sensor node.

4.4 CHAPTER SUMMARY

The chapter presented the research requirement specifications, the simulation modelling needed for the research, different categories of underwater simulators, Aqua-sim-NG for the NS3 simulator and the justification for its selection. The chapter also presents the mathematical models needed for the research for validation purposes. The next chapter presents the proposed routing protocol for the research.

CHAPTER FIVE
PROPOSED ROUTING PROTOCOL

5.1 INTRODUCTION

The proposed routing protocol focused on sparse and dense network with an emphasis on effectively bringing about stable techniques to decrease energy consumption among sensor nodes involved in the data transmission. The proposed sparse routing protocol (AODV-SUARP) was derived from the working principle of an ad-hoc on-demand vector routing protocol (AODV) which focused on enhancing the conventional AODV by developing a mechanism that to help the sensor nodes to effectively communicate in underwater. AODV-SUARP addressed the challenges faced by AODV which consist of the energy consumption among sensor nodes and the routing overhead. The proposed dense routing protocol (LEACH-DUARP) was derived from the working principle of a low energy adaptive hierarchy routing protocol (LEACH). LEACH-DUARP focused on enhancing the working of the conventional LEACH to effectively allow the sensor nodes to aggregate and transmit data effectively. LEACH-DUARP addressed the challenges face by the conventional LEACH by organising clusters through the optimal selection of eligible cluster head in subsequent rounds.

5.2 PROPOSED ROUTING PROTOCOL FOR SPARSE UNDERWATER NETWORKS

The proposed routing protocol AODV-SUARP was derived from the conventional AODV routing protocol with an enhanced mechanism. The primary focus of the proposed routing protocol was to minimize energy consumption among sensor nodes by selecting reliable routes in the packet transmission. The selection of alternative routes allow the data to be transmitted successfully to the sink without much interruption or failure.

5.2.1 AD-HOC ON DEMAND DISTANCE VECTOR PROTOCOL (AODV)

An ad-hoc on-demand distance vector (AODV) is an ad-hoc reactive routing protocol that determined routes to the destination based on demand. The AODV algorithm allows selfstarting, and dynamic and multi-hop routing among nodes which need to initiate and maintain an ad-hoc network (Sheng Liu, Yang, & Wang, 2013), (rfc, 3561). The working of AODV routing protocol permit nodes to sustain routes quickly for new destination, although AODV does not allow nodes to sustain routes to destination that are not in active communication. The working of AODV is loop free and provide a quick convergence when the ad-hoc network topology changes this is achieved by avoiding the ‘’bellman-ford’’ counting to infinity problem that typically occurs when a node moves in the network (Patel, Patel, Kothadiya, Jethwa, & Jhaveri, 2014). When a link breaks in the network, AODV allows the affected nodes to be aware so they are able to make the affected routes invalid by using the lost link. One of the distinguishing characteristics of AODV is the use of a destination sequence number for each route entry. The destination sequence number in AODV is formed for inclusion in the route information which is send to the requesting node. AODV is simple to program and assures loop freedom by using destination sequence. In AODV when a requesting node has a choice between two routes to a destination, it must choose the one with the highest sequence number (Sharma, 2015).

5.2.1.1 MESSAGE TYPE DEFINED BY AODV

The AODV routing protocol work on two phases route discovery and route maintenance. The route discovery phase of AODV allows nodes to discover routes to the destination to transmit packets of data, while the route maintenance phase allow routes to be maintained and notifies the affected node when a link breaks in the affected route (rfc, 3561). AODV works with a message that allows nodes to effectively communicate and exchange packets when needed, these messages consist of a route request (RREQ), route reply (RREP), and route error (RERR). AODV has no effect if the endpoints of a communication connection have proper routes to each other (Perkins, Belding-Royer, & Das, 2003).

5.2.1.1.1 ROUTE REQUEST MESSAGE (RREQ)

In AODV, the node disseminates a RREQ when it determines that it needs a route to a destination and does not have one available. RREQ is disseminated to the nearby nodes closer to the source node in search of routes to the destination. When RREQ reaches either the destination or an intermediate node with a fresh enough route to the destination, a route can be determined. A fresh enough route is a valid route entry for the destination whose associated sequence number is at least as great as that included in the RREQ this is considered fresh enough. The destination sequence number field in the RREQ message is the last known destination sequence number for this destination and is copied from the destination sequence number field in the routing table. The originator sequence number in the RREQ message is the nodes own sequence number which is incremented prior to insertion in the RREQ. The RREQ ID field is incremented by one from the previous RREQID used by the node. In AODV each node maintains only one RRE ID. The hop count is set to zero (Perkins, Belding-Royer, & Das, 2003), (rfc, 3561).

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |J|R|G|D|U|   Reserved          |   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            RREQ ID                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination IP Address                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Originator IP Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Originator Sequence Number                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.1: AODV RREQ message format

Type: 1

J: join flag, reserved for multicast

R: Repair flag, reserved for multicast

G: Gratuitous RREP flag, which indicates if a gratuitous RREP should be unicast to the node specified in the destination address

D: Destination only flag, indicate a destination may respond to this RREQ

U: Unknown sequence number, indicates the destination sequence number is unknown

Reserved Sent as 0, ignored on reception

Hop count: The number of hops from the originator IP address to the node handling the request

RREQ ID: A sequence number uniquely identifying the RREQ when taken in conjunction with the originating nodes IP address

Destination IP address: The IP address of the destination for which a route is desired

Destination sequence number: The latest sequence number received in the past by the originator for any route towards the destination.

Originator sequence number: The current sequence number for use in the route entry pointing towards the originator of route request.

5.2.1.1.2 ROUTE REPLY MESSAGE (RREP)

AODV makes use of a route reply message to respond to the source node by notifying the node that a connection has been established. If the generating node for the route reply is the destination itself, it must increment its own sequence number by one if the sequence number in the RREQ packet is equal to that incremented value. Otherwise, the destination node does not need to change its sequence number by incrementing it before sending a route reply RREP message. The destination node put the newly incremented sequence number into the destination sequence number in the field of the RREP and put value zero in the hop count field of the RREP. When generating the RREP message, node copies the destination IP address and originator sequence number from the RREQ message into the corresponding field s in the RREP message. Processing is slightly different, depending on whether the node is the requested destination, or an intermediate node with a fresh enough route to the destination. Once created, RREP is unicast to the intermediate node towards the originator of the RREQ. As the RREP is forwarded back towards the originator node for the RREQ, the hop count field is incremented by one at each hop. Thus, when the RREP reaches the originator, the hop count represents the distance, (in hops) of the destination from the originator (Perkins, Belding-Royer, & Das, 2003), (rfc, 3561).

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |R|A|    Reserved     |Prefix Sz|   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Destination IP address                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Originator IP address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                           Lifetime                            |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.2: AODV RREP message format

The format for the route reply message is indicated in the above diagram. The following are the field contain the RREP message (rfc, 3561).

Type 2

R Repair flag, used for multicast

A Acknowledgement required.

Reserved Sent as 0, ignored on reception.

Prefix Size if non-zero, the 5-bit prefix size specifies that the indicated next hop may be used for any node with the same routing prefix (as defined by the prefix size as the requested destination

Hop count: The number of hops from the originator IP address to the destination IP address. The multicast route request indicates the number of hops to the multicast tree member sending the RREP

Destination IP address: The IP address of the destination for which a route is supplied.

Destination sequence number: The destination number associated with the route.

Originator IP address: The IP address of the node which originate the RREQ for which the route is supplied.

Lifetime: The time considered for the route to be valid.

5.2.1.1.3 ROUTE ERROR MESSAGE (RERR)

In AODV, the route error message is utilised when a link breakage occurs between two nodes thereby causing one or more of the destinations to be unreachable from some of the node's neighbours. Certain factors contribute to link breakage which consist of energy depletion and the nodes mobility there by effecting in the network. The route error message is sent to the neighbouring nodes to notify the source node about the link breakage which give rise to the discovery of another route (rfc, 3561). The route error message format of AODV is follows. (see Figure 5.3):

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |N|          Reserved           |   DestCount   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|            Unreachable Destination IP Address (1)             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|         Unreachable Destination Sequence Number (1)           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-|
| Additional Unreachable Destination IP Addresses (if needed)  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|Additional Unreachable Destination Sequence Numbers (if needed)|
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.3: AODV Route error message format

The format for the route error message is indicated in Figure 6.3 and contains the following fields.

Type 3

N No delete flag, set when a node has performed a local repair of a link, and upstream nodes should not delete the route.

Reserved Sent as 0, ignored on reception.

Dest Count The number of unreachable destinations included in the message, must be at least 1

Unreachable destination sequence number: The sequence number in the route table entry for the destination listed in the previous unreachable destination's IP address field.

5.2.1.1.4 ROUTE REPLY ACKNOWLEDGEMENT (RREP-ACK)

The route reply acknowledgement (RREP-ACK) message format of AODV is a message format that is sent to acknowledge the reception of a RREP message. This message is typically done when there is a danger of unidirectional links preventing the completion of route discovery phase (Perkins, Belding-Royer, & Das, 2003).

```
 0                   1
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |   Reserved    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.4: RREP -ACK message format for AODV

Type 4

Reserved Sent as 0, ignored on reception.

5.3 JUSTIFICATION FOR CHOOSING AODV ROUTING PROTOCOL

The following are the justification for selecting an AODV routing protocol.

AODV offers an efficient reactive routing protocol support for a low number of nodes to enable scalability in the data transmission.

The energy consumption of nodes using AODV (as a reactive routing protocol) is low, because AODV utilises routes based on demand.

The bandwidth usage is relatively low as routes are utilised based on demand which helps in bandwidth control.

5.4 ALGOITHM FOR AODV ROUTING PROTOCOL

An AODV routing protocol discover route based on route discovery. A source node check for route availability if it exists otherwise the source node will initiate a route request message by broadcasting it to the intermediate nodes for delivery to the destination node. When the route request message reaches the destination, the destination node will select the path with the minimum hop count and send a route reply message back to the source node to establish a connection between the source and destination node (rfc, 3561). The algorithm for the AODV routing protocol is as follows.

Node X check **if** (available valid route exists to destination) **else**

Initialise a RREQ message

If the (destination is known to node x or a valid route to destination expire or marked invalid) **then**

(Destination Sequence number_RREQ = Destination Sequence number_Route table) **else**

Set unknown sequence number flag

End if

Increment RREQID_rrq > RREQID_table

Node x sends RREQ message with (RREQID, Destination IP address, Source IP address, Originator sequence number)

If (node receives a RREQ message with RREQID = Previous RREQID, and Originator IP address = Previous Originator IP address) **then**

Discard the newly received RREQ **else**

Update the route by incrementing Hop_count value in the RREQ

End if

The destination node (d) received RREQ message, create a reverse route by sending route reply to check

If (Destination sequence number_table entry ≥ Destination sequence number_rrq) **else**

Destination sequence number_table entry++1

End if

Destination node (d) send a RREP message to the source node (x) on reverse path with

RREP (Destination IP address, originator IP address, Destination sequence number, hop count)

Node (x) receives a RREP message back from destination node (d)

Node (x) will start sending data packets to the destination node (d) through intermediate nodes

5.5 AODV ROUTING PROTOCOL FLOW CHART

Figure 5.5 is the flow chart for the AODV routing protocol.

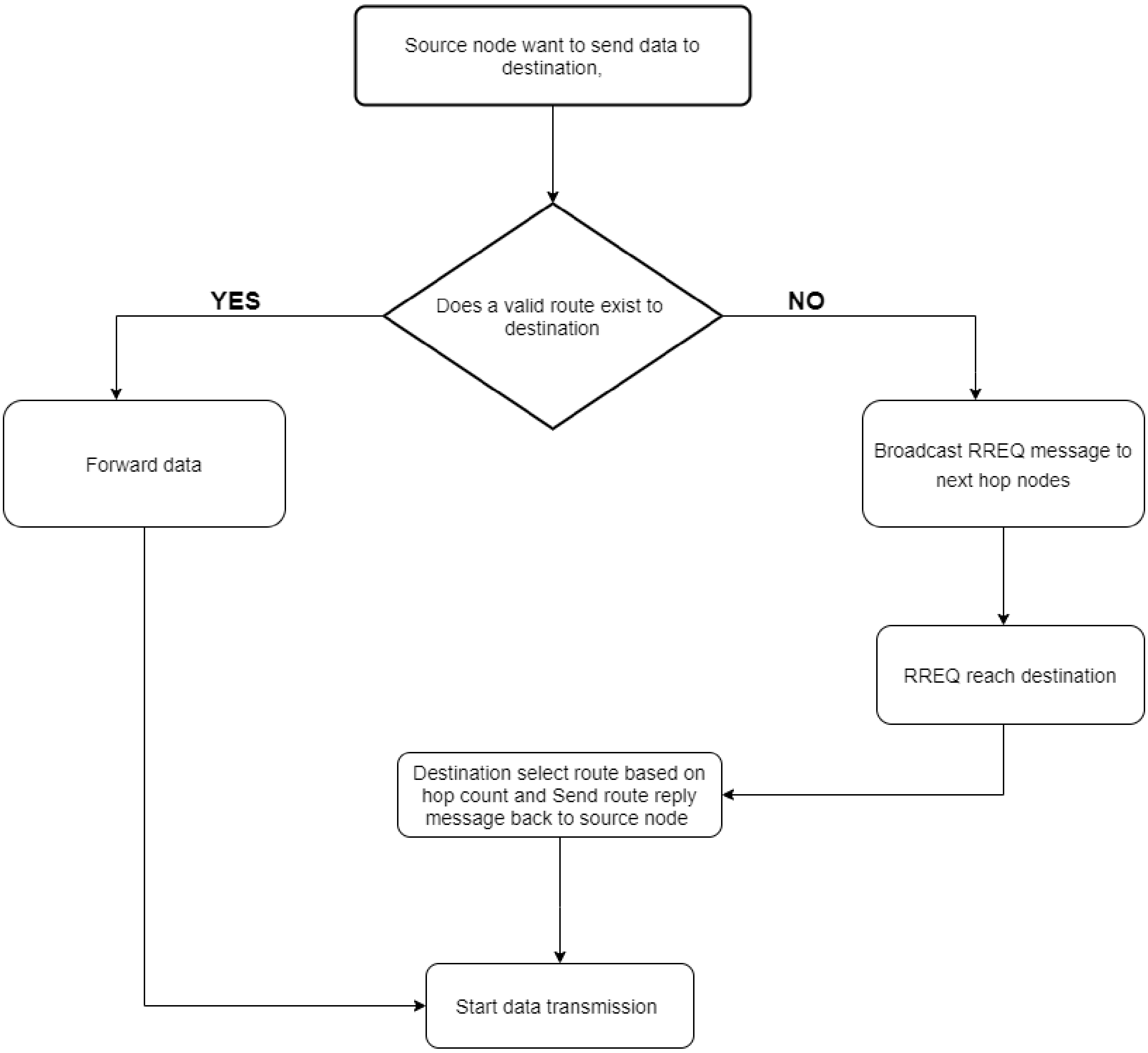


Figure 5.5: AODV flow chart (rfc 3561)

5.6 PROPOSED AODV-SPARSE UNDERWATER ACOUSTIC ROUTING PROTOCOL (AODV-SUARP)

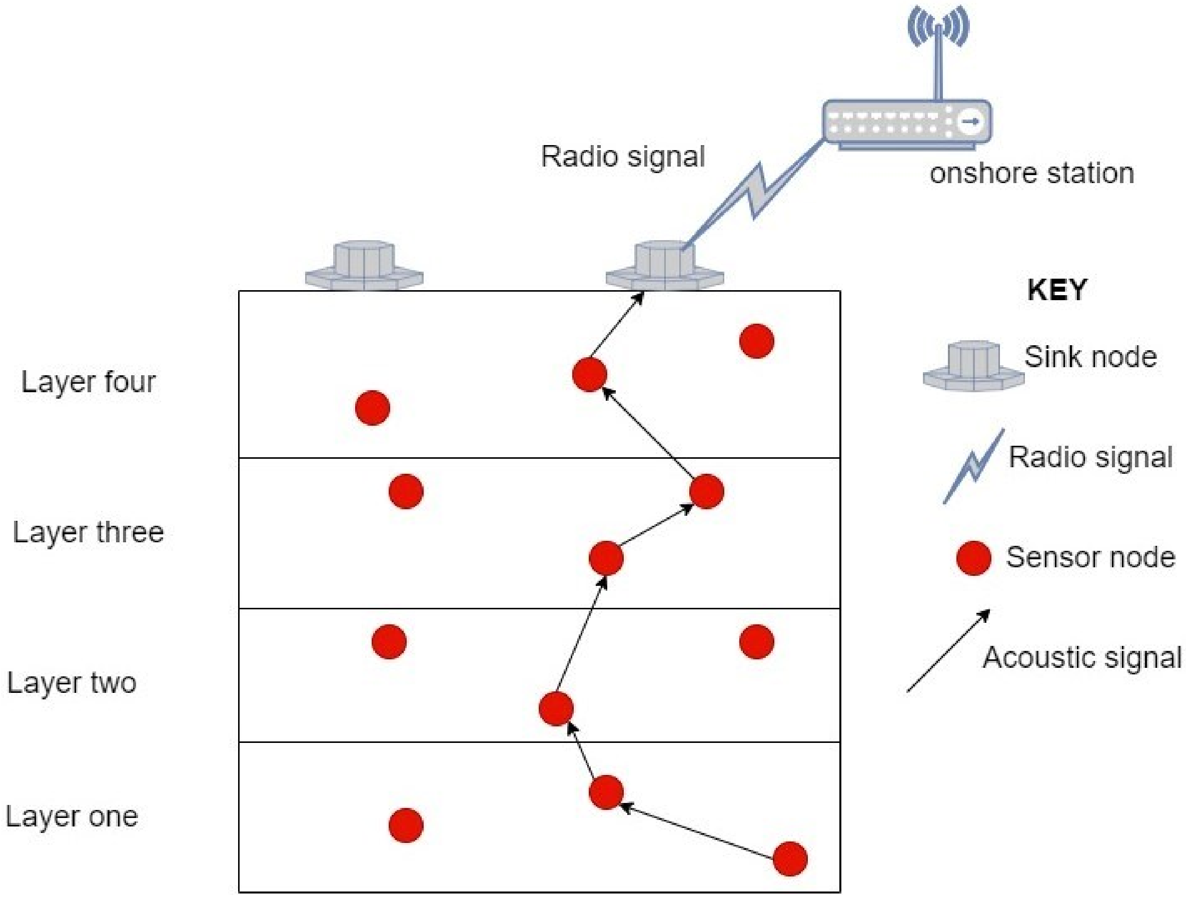


Figure 5.6: Diagram showing the proposed sparse network architecture.

In figure 5.6, the proposed network adopts a 3D underwater network with a dimension of 4000m x 4000m x4000m that consists of randomly deployed sensor nodes divided into four layers and each layer has a depth difference of 1000m between them. Each layer of the network consists of underwater mobile sensor nodes namely the source node that normally sense and forwards the data in the monitored area to the forwarding nodes which are present at the first, second, third and fourth layers for successful transmission of data packets to the sink node at the surface of the water. All underwater sensor nodes transmit data packets using the acoustic signal to the sink node which is equipped with both radio and acoustic modems. The acoustic modem is responsible for communication with the underwater sensor nodes using acoustic signal due to the imperfection of radio signals underwater (Sendra, Lloret, Jimenez, & Parra, 2015), while the radio modem of the sink node is responsible for communicating and forwarding packets of data to the onshore station using radio signals. All sensor nodes involve are equipped with lithium battery with a higher energy life and power densities (Ovaliadis, Savage, & Kanakaris, 2010).

The proposed sparse routing protocol AODV-SUARP is proposed to work based on two phases which consist of route-finding phase and path maintenance phase

Phases of the proposed routing protocol are as follows,

1. Route finding and data forwarding phase

- Route requisition message
- Route response message

2. Route Maintenance phase: consist of a function called ‘’route stability function’’(RSF) with respect to the light reliability mode which consists of the following.

- Route monitoring through the detection of unreliable sensor nodes with respect to individual nodes energy status using an energy stability parameter by the threshold value

5.6.1 ROUTE FINDING AND DATA FORWARDING PHASE

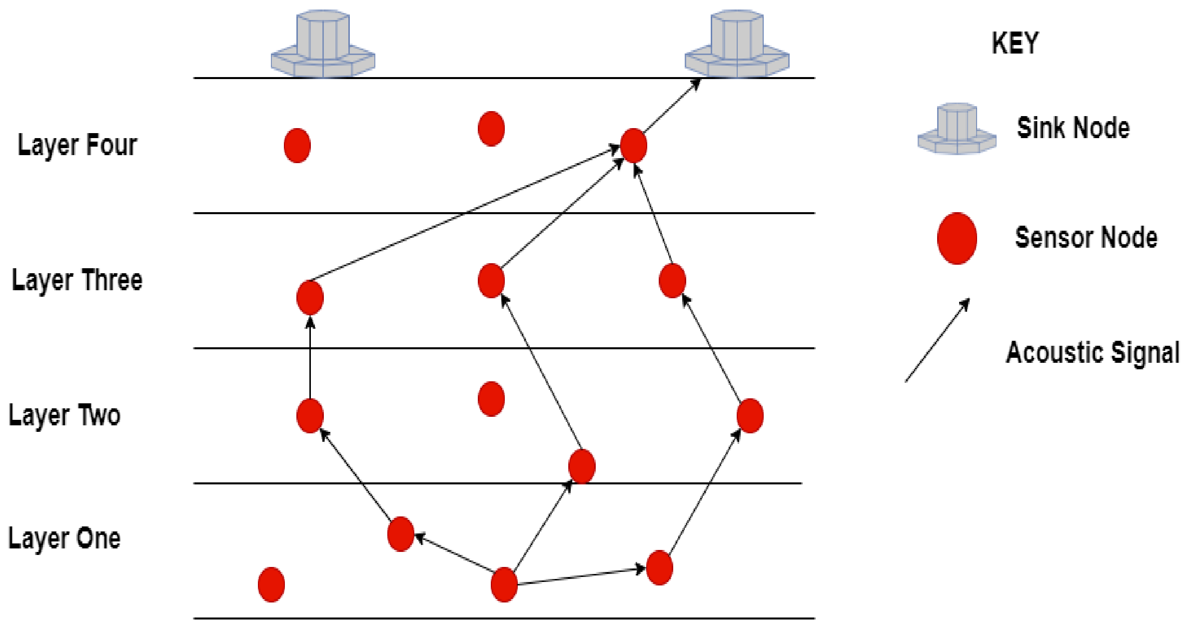


Figure 5.7: Diagram showing the route finding for AODV-SUARP

Route requisition message

With the randomly deployed underwater sensor nodes, when a sensor node senses information and is willing to send the data, the sensor node checks for an available active route to send the data through the forwarding nodes involved in the transmission process, otherwise if there is no available route the source node will initiate a route requisition message. The broadcast message is called the ‘’ Route requisition message’’(RRQ) will contain the following fields in the packet header RRQ ID, destination sequence number, source ID, originator sequence number, sensor node energy level and hop count. The RRQ message will be broadcasted to the nearby neighbouring forwarding nodes for transmission to the destination or sink node. The sink node receives the RRQ message by the sink node through intermediate node from different path. The Sink node will start checking the first received RRQ message by checking the path for reliability using the ‘’route stability function’’ by checking the stability of the path with respect to the link between the sensor nodes based on two factors: the energy status of the individual sensor nodes and the transmission range between the forwarding nodes for each link using the hop count. A sink node will employ energy stability parameter by using a threshold value to determine the eligible nodes for each route that can take part in the packet transmission. The ‘’Route stability function’’ comprises the sensor node’s energy stability as well as its location and distance over a transmission range through the hop count. The sink node categorises the route stability function based on a colour mode with respect to the reliability of the routes and based on energy status of the nodes. The route stability function based on a colour mode comprises green, orange, and red route modes. The green mode stands for the ‘’strongest path’’, orange mode stands for a ‘’ stronger path’’, red stand for ‘’strong path’’, and purple for weak path. After the sink node receives the RRQ message, it will check the reliability of the routes based on the route stability function which helps to select the best three paths. This is based on reliability mode with respect to route stability function. The best path for selection by the sink node will be the ‘’strongest path’’ namely the green mode. The second best will be the ‘’stronger path’’ (the orange mode), and third best is the ‘’strong path’’ (the red mode). Both the source and sink nodes will keep information on the ‘’ stronger path’’ and ‘’strong path’’ in the buffer.

After the sink node successfully selects the bests three paths based on the route stability function, the sink node will send a route response (RRP) message back through the strongest path. It will contain the following fields in the packet header source node ID, sink node ID, sensor nodes energy status, hop count, and route stability function in a single path to the source node to establish a connection between the two sensor nodes and will start communicating by transmitting packets of data.

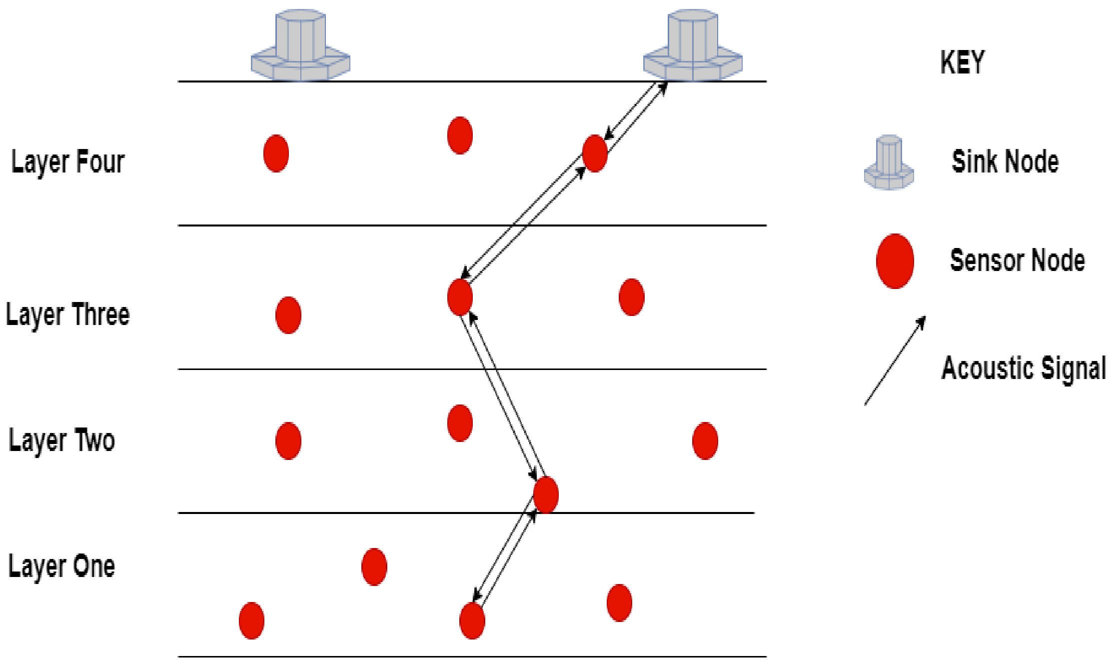


Figure 5.8: Diagram showing the route selection for data forwarding for AODV-SUARP.

5.6.2 MODIFICATION OF AODV ROUTE REQUEST AND ROUTE REPLY MESSAGE FOR AODV-SUARP

The route request and route reply messages are the message types defined by AODV, which play a vital role in establishing a connection between the source and destination node. The RREQ message is broadcasted by a source node to the intermediate node in search of a route to the destination. The RREP message is unicast by the destination node on a reverse path to the source node as a response to establish a connection. The modifications of route request and route reply to messages for the AODV-SUARP message format are detailed in the following sections.

5.6.3 ROUTE REQUEST MESSAGE MODIFICATION AS ROUTE REQUISITION MESSAGE PACKET FORMAT IN AODV-SUARP

The route request message plays a significant role in route discovery, which helps to determine the nodes that take part in the packet transmission for each route. A route request message is modified in AODV-SUARP as a route requisition message by including the sensor node energy level in the message header. This allows AODV-SUARP to be aware of the energy status of each node before a route can be selected for use in the data packet transmission. The modified route request message is shown in Figure 5.9.

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |J|R|G|D|U|   Reserved          |   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                            RRQ ID                             |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Destination IP Address                     |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                  |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                    Originator IP Address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Originator Sequence Number                   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  sensor nodes energy level                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.9: Route requisition message format for AOD-SUARP

The sensor nodes energy level for each node represents an important field, as it determines the selection of eligible sensor nodes for each route that can participate in the data transmission. The selection of an eligible sensor node was proposed by using an energy stability parameter. The energy stability parameter is such that $1 \leq \alpha \leq 100$. The parameter α is used to determine the sensor nodes energy level for each path. Thus, any sensor node with an energy level below the range of α, 1 to 100 will not be able to take part in the packet transmission, which will make the route unstable based on energy level of the nodes. The selection of an eligible sensor node based on the energy level allows the network lifetime to be extended by avoiding unreliable nodes in the data packet transmission based on their energy level which plays a vital role in the packet transmission.

5.6.4 ROUTE REPLY MESSAGE MODIFICATION AS ROUTE RESPOND MESSAGE PACKET FORMAT IN AODV-SUARP

The route reply message is unicast by the destination node in response to the route request and made by the source node in search of a route. The route reply message is modified as route respond message in AODV-SUARP by including the route stability function to effectively select the most eligible path for the data transmission. The route stability function is added to the route respond message header to be sent back to source node with the eligible route. The modified route reply message shown in Figure 5.10.

```
0                   1                   2                   3
 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|     Type      |R|A|    Reserved     |Prefix Size|   Hop Count   |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Destination IP address                      |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                  Destination Sequence Number                    |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|                     Originator IP address                       |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
|              Route stability function                           |
+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+-+
```

Figure 5.10 Route response message format for AODV-SUARP

The selection of the best path in AODV-SUARP in the process of packet transmission is (ESP) energy stability parameter is denoted as α, where α is such that $1 \le \alpha \le 100$ .considering the table below.

S/NO	α level	Routes (R)
1.	1 - 39	Weak path
2.	40 – 59	Strong path
3.	60 – 69	Stronger path
4.	70 – 100	Strongest path

The route condition denote as (RC) comprises of routes $x_{1,}x_{2,}x_{3,}x_4$ based on the energy level of the nodes in which the routes are categorized as

$x_1 : 1 \leq \alpha \leq 39$

$x_2 : 40 \leq \alpha \leq 59$

$x_3 : 60 \leq \alpha \leq 69$

$x_4 : 70 \leq \alpha \leq 100$

The route stability function represents an important filed as it used to select the most eligible routes by the destination node based on energy level of the sensor node. When the destination node receives the RRQ message from the originator node, it will use the route stability function on light mode. This is based on sensor nodes energy level and used when selecting the three most eligible paths after which they are sent back to the source node by including them in the route response packet header. The destination node assigns an ID to each route when it receives a RRQ message. By using the route stability function the destination node categorises the routes with the highest sensor node energy level ≥70 is strongest route, with the greatest node energy level ≥60 denotes stronger route, while ≥40 is a strong route, and the weak route with ≥1 is considered the lowest node energy level amongst the four routes.

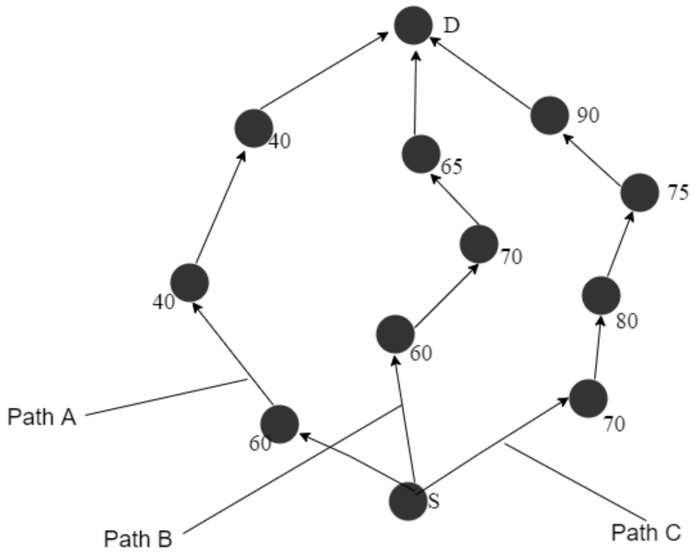


Figure 5.11: Scenario for route selection in AODV-SUARP (1)

The scenario in Figure 5.11 shows the source node (S) broadcasting a RRQ message to the destination node (D) on different paths. As the destination node receives RRQ message from different path, the destination node will use the route stability function to select the most eligible path based on the sensor nodes energy level. Path C shows sensor nodes with the energy level ≥70 which is the strongest path. This is followed by path B with the energy level ≥60 denoting the stronger path, and path A has an energy level ≥40 meaning it is a strong path.

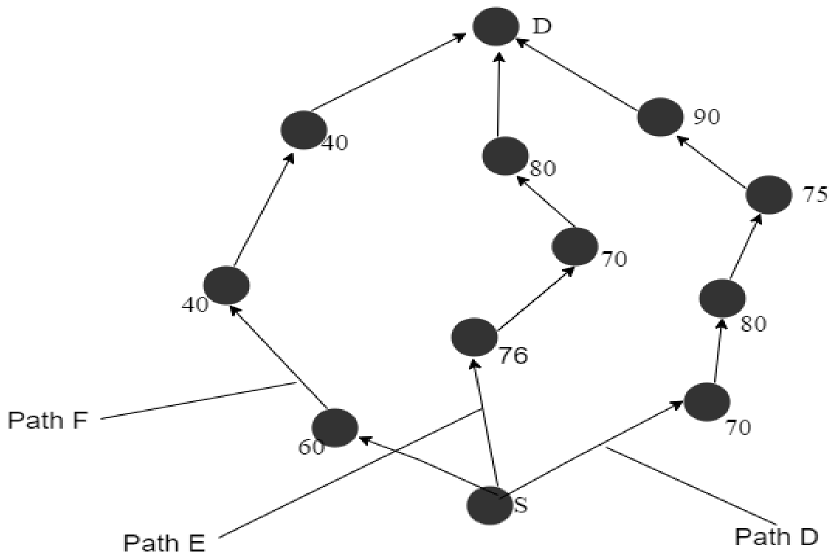


Figure 5.12: Scenario for route selection in AODV-SUARP (2)

The scenario in figure 5.12 shows the source node (S) broadcasting a RRQ message to the destination node (D) on different paths. As the destination node receives RRQ message from different path, the destination node will use the route stability function to select the most eligible path regarding the sensor nodes energy level. Path E will be selected as the strongest path having all sensor nodes energy is ≥70. Path D will be the second-best path and the stronger path as all sensor nodes energy level≥70 but with higher hop count compared to path E. The third best path has all sensor node with an energy level≥40 meaning it is the strong path.

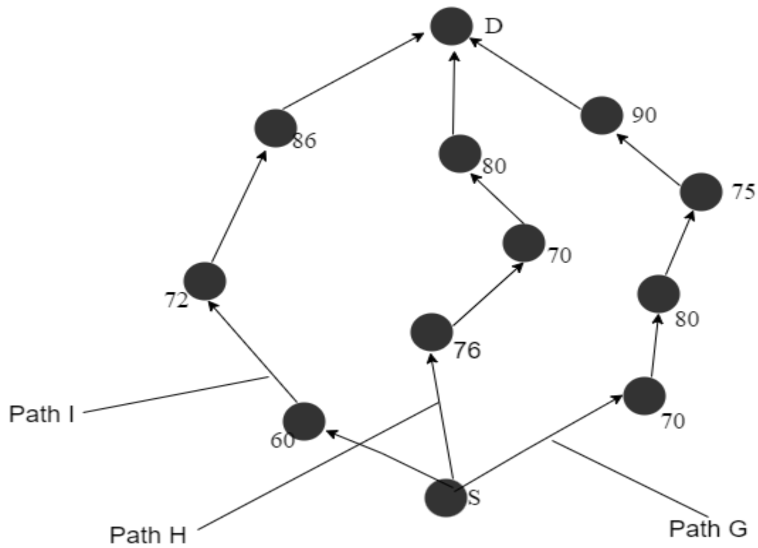


Figure 5.13: Scenario for route selection in AODV-SUARP (3)

The scenario in Figure 5.13 shows the source node (S) broadcasting a RRQ message to the destination node (D). When the destination node D receives the RRQ from a different path, the destination node will select the most eligible path. Path H will be selected as the strongest path as the sensor node energy level ≥70 despite having the same hop count with path I. Path G will be selected as the second-best (or stronger) path with the sensor nodes energy level ≥70 despite having higher hop count than path I. Thus path I will be selected as the third best path (strong) path because one of the sensor nodes energy level is ≥60

5.7 ALGORITHM FOR ADOV-SUARP ROUTING PROTOCOL

The AODV-SUARP routing protocol discover route based on route discovery. The source node checks for route availability if any of the three best routes exists. If not, the source node will initiate a route request message by broadcasting it to the intermediate nodes to be delivered to destination node. When the route request message reaches the destination, the destination node will select the three best routes based on the route stability function with respect to the energy level of the sensor nodes as well as the minimum number of hop counts. It will send a route reply message back to the source node to establish a connection between the source and destination node. The algorithm for the AODV-SUARP routing protocol is as follows.

1. Node X Check if (available valid route exist to the destination) else
2. Initialise a RREQ message
3. If (Destination is known to node x or valid route to Destination expire or marked invalid) then
4. (Destination Sequence number_RREQ = Destination Sequence number Route table) else
5. Set unknown sequence number Flag
6. End if
7. Increment RREQID_rrq > RREQID_table
8. Node x sends an RREQ message with (RREQID, destination IP address, source IP address, originator sequence number, sensor nodes energy level)
9. If (node receive RREQ message with RREQID = Previous RREQID, and Originator IP address = Previous Originator IP address) then
10. Discard the newly received RREQ else
11. Update route by incrementing hop_count value in the RREQ

12. End if
13. Destination node (d) received RREQ message, create a reverse route by sending route reply to check
14. If (destination sequence number_table entry ≥ destination sequence number_rrq) else
15. Destination sequence number_table entry++1
16. End if
17. Check the routes received
18. If (the least sensor node energy_level in a route≥70) then
19. Route= (strongest route ‘’green’’) then
20. If (the least sensor node energy_level in a route≥60) then
21. Route= (stronger route ‘’orange’’) then
22. If (the least sensor node energy_level in a route≥40) then
23. Route= (strong route ‘’red’’) then
24. If (the least sensor node energy_level in a route≥1) then
25. Route= (weak route ‘’purple’’) then
26. End if
27. End if
28. End if
29. End if
30. Destination node (d) send RREP message to the source node (x) on reverse path using the strongest path with
31. RREP (Destination IP address, originator IP address, Destination sequence number, route stability function, hop count)
32. Node (x) receive RREP message back from the destination node (d)
33. Node (x) will start sending data packets to the destination node (d) through the intermediate nodes

5.8 FLOWCHART FOR AODV-SUARP

The following represents the flow chart for the AODV-SUARP routing protocol

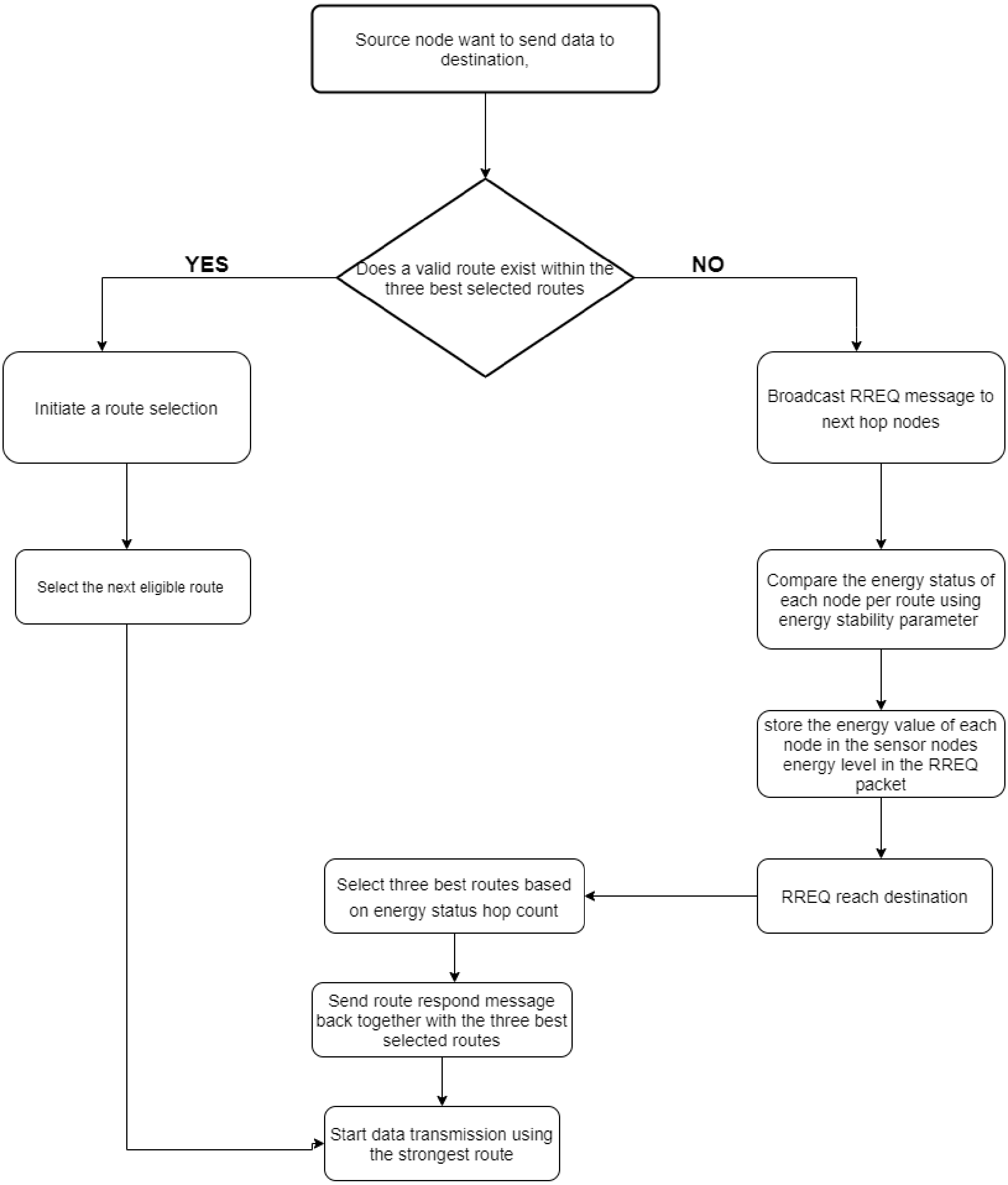


Figure 5.14: Flow chart for AODV-SUARP

5.9 PROPOSED ROUTING PROTOCOL FOR DENSE UNDERWATER NETWORK

The proposed routing protocol LEACH-DUARP was derived from the conventional low energy adaptive routing hierarchical routing protocol (LEACH) proposed with enhance mechanism for data transmission. The primary focus of the proposed routing protocol LEACH-DUARP was to minimize the energy consumption among sensor nodes by selecting reliable sensor nodes in data aggregation and transmission. The selection of alternative energy stable nodes allows the data to be transmitted successfully to the sink without much interruption and failure.

5.9.1 LOW ENERGY ADAPTIVE CLUSTERING HIERACHY ROUTING PROTOCOL

The LEACH routing protocol is one of the examples of a hierarchical clustering routing protocol which works based on clustering. Clustering is a technique that is applied for energy efficient communication among sensor nodes to deliver their sensed data to the sink (destination). Hierarchical routing protocols divide the network into clusters using clustering technique. The nodes are divided into several clusters, with each cluster consist of cluster head which is responsible for collecting data from the cluster nodes and transmit it to the sink (destination). Data collected from the cluster head is forwarded to other cluster heads in higher layer in a multi hop way delivery to the sink (destination). Clustering provides capabilities for the cluster head which plays a vital role in data transmission(Gnanambigai, J., Rengarajan, D. N., & Anbukkarasi, K. (2012).

LEACH is the earliest and most widely used energy efficient clustering routing protocol for wireless sensor network and was designed to decrease the power consumption among sensor nodes involve in data aggregation and transmission. LEACH allows cluster heads to forward data in direct communication to the based station. The LEACH routing protocol is based on an aggregation technique that integrated and aggregate data into a smaller quantity which contains relevant information for all sensor nodes within clusters. LEACH split the network into clusters which are organised using localised coordination to reduce the data sent to the sink while also making the routing and data distribution more robust and scalable. LEACH’s operation is based on rounds and divided into two phases namely: set up and data aggregation and transmission. Although LEACH clustering terminates in a finite number of iterations its does not guarantee the excellent distribution of CH and assumes a uniform energy consumption for the cluster heads. Moreover, as LEACH assist sensor nodes within a cluster to consume their energy slowly, cluster heads consumed a lot of energy due to data aggregation within the cluster member nodes and transmission.

5.10 JUSTIFICATION FOR CHOOSING THE LEACH ROUTING PROTOCOL

The following are justification for choosing the LEACH routing protocol.
LEACH routing protocol is a hierarchical routing protocol that supports a high density of sensor nodes.
The LEACH routing protocol organise sensor nodes into clusters to reduce energy consumption in data aggregation and transmission, this also helps to minimize cost between sensor nodes and their cluster heads.

5.11 ALGORITHM FOR LEACH ROUTING PROOTOCOL

The LEACH routing protocol is based on two phases namely set-up and steady state. The first which is the set-up phase deals with the organisation of sensor nodes into clusters as well as cluster head advertisement. The second is the steady state phase and deals with data aggregation and transmission (Gnanambigai, J., Rengarajan, D. N., & Anbukkarasi, K. (2012). The LEACH routing protocol works based on number of rounds. The algorithm is as follows.
Line 1: Initialise the network by deploying N number of sensor nodes.
Line 2: Select cluster heads CH within N_number of nodes.
Line 3: Divide the N_number of sensor nodes into clusters for each CH
Line 4: Compute energy status for each node
Line 5: For each N_number of nodes in each cluster
Line 5: N_number of nodes sense and transfers data to CH in the cluster with a corresponding TDMA
Line 6: End for
Line 7: For each CH
Line 8: CH receives data from N number of nodes within its cluster

Line 9: CH aggregate and transfers data to the base station

Line 10: End for.

5.12 FLOW CHART FOR THE LEACH ROUTING PROTOCOL

The following diagram represents the flow chart for the LEACH routing protocol.

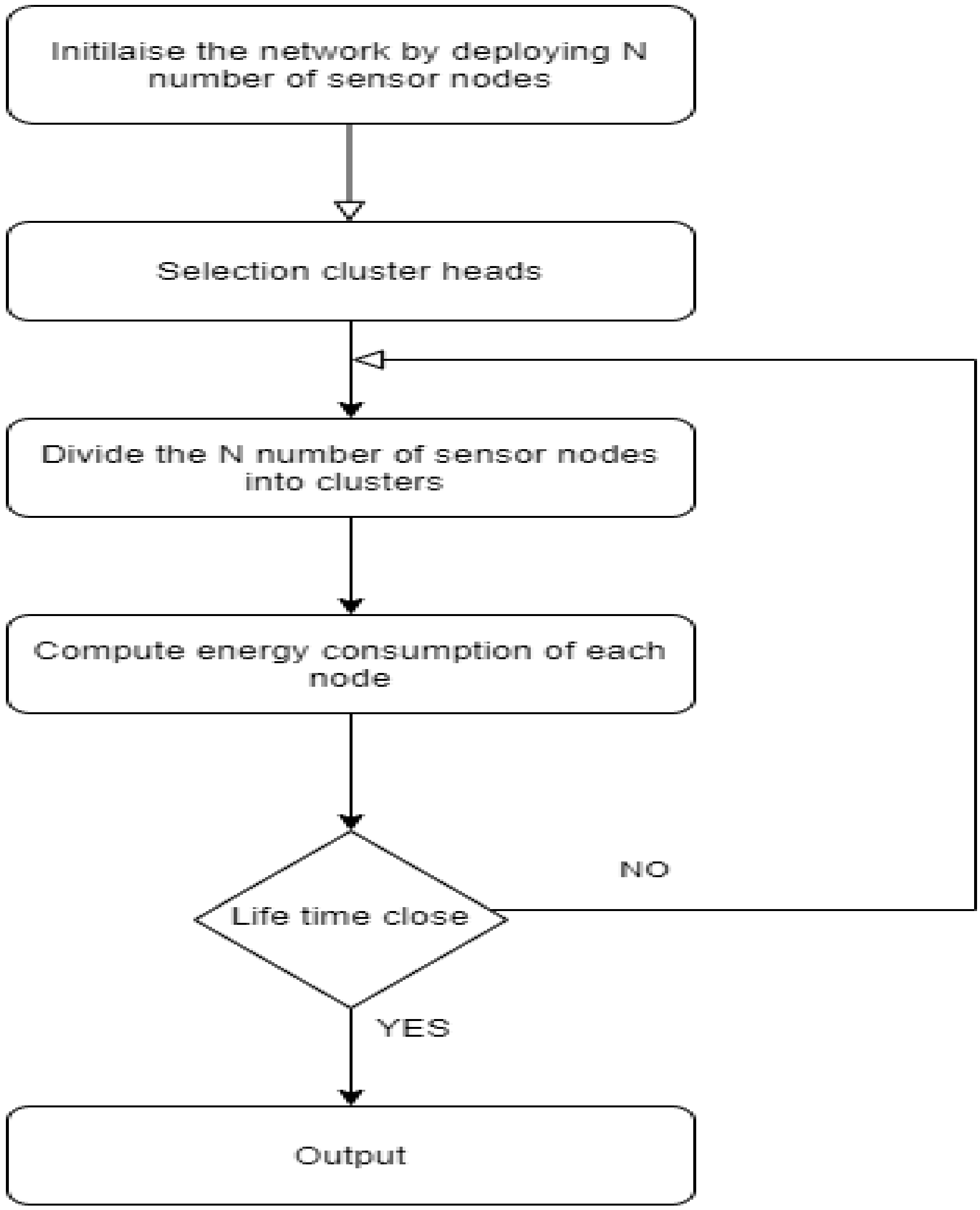


Figure 5.15: Flow chart for the LEACH routing protocol(Gnanambigai, J., Rengarajan, D. N., & Anbukkarasi, K. (2012).

5.13 PROPOSED LEACH-DENSE UNDERWATER ROUTING PROTOCOL LEACH-DUARP

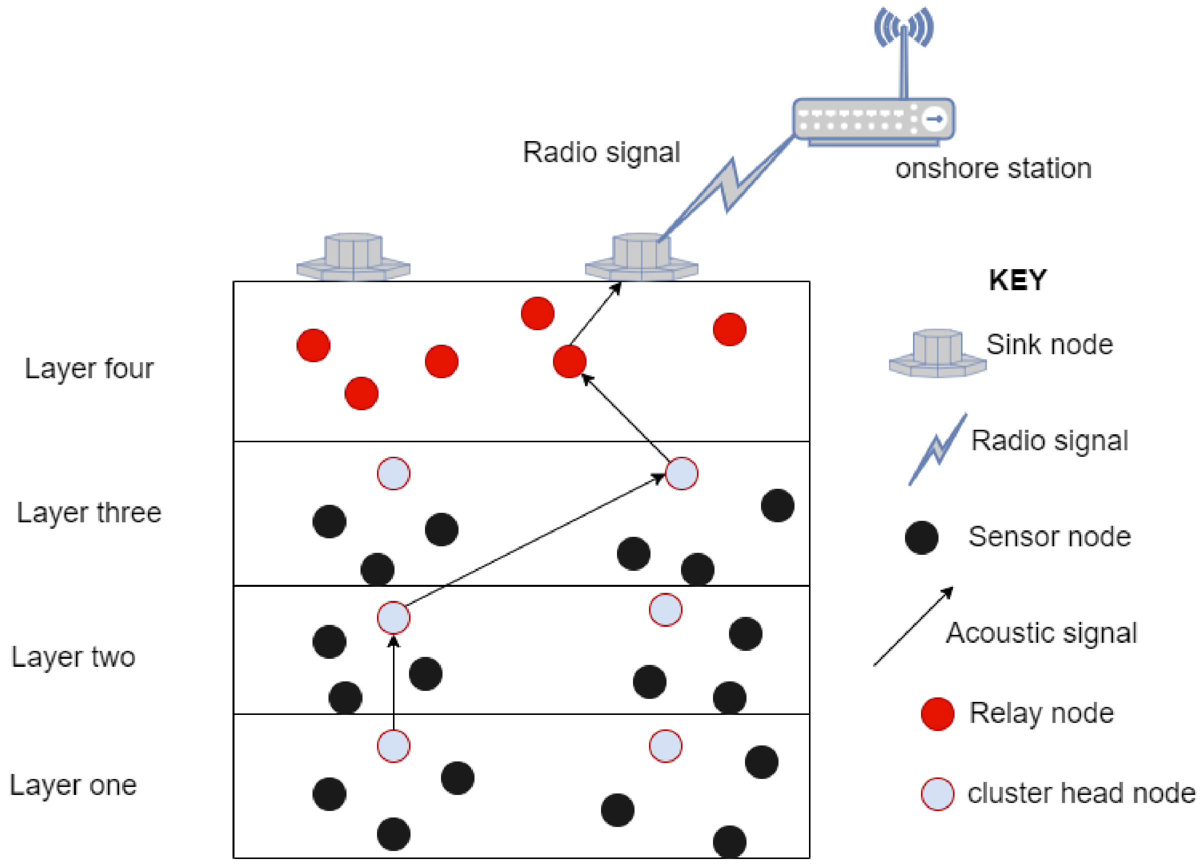


Figure 5.16: Diagram showing the architecture of the proposed dense routing protocol.

In figure 5.16, the Underwater network consists of underwater sensor nodes which are deployed and present at different layers of the water. Densely deployed underwater sensor nodes lead to the occurrence of cluster presence at each layer depth of the water. An unequal number of sensor nodes exist on each cluster for each layer. Moreover, data transmission occurs to the sink node from the cluster head nodes. Sensor nodes in each cluster are eligible to participate as a cluster head node based on certain criteria based on stable status regarding energy efficiency and transmission distance in the cluster. Sink nodes exist at the surface of the water and are equipped with an acoustic modem to receive packets from underwater cluster head nodes and a radio modem for transferring the received data to an onshore or offshore station using radio signals. The densely proposed underwater routing protocol LEACH-DUARP consists of the following three phases.

Establishment phase which consists of

Cluster formation and cluster head selection phase.

Cluster head selection for subsequent rounds.

2. Data transmission phase.

   Relay node selection

5.13.1 ESTABLISHMENT PHASE

The establishment phase of LEACH-DUARP consists of cluster formation and cluster head selection at the initial stage and cluster head selection for subsequent rounds.

Cluster formation and Cluster head selection :(Initial stage)

Energy utilization among underwater sensor nodes remain a vital constraint in the process of underwater acoustic communication. Underwater sensor nodes depend on batteries which are difficult to charge or replace once deployed underwater. Hence energy saving among underwater sensor nodes has become vital in finding a reliable and efficient way to transmit packet. Densely deployed underwater sensor nodes in this proposed routing protocol (LEACH-DUARP) use a K-means clustering technique to allocate each sensor node to its respective cluster. K-means is used in dense underwater communication for its ability to form clusters, optimize resource allocation, reduce interference, and adapt to dynamic underwater environments. Its scalability, simplicity, and efficiency make it suitable for organizing devices, minimizing interference, and improving resource utilization in underwater networks, where bandwidth and energy constraints are prevalent. Sensor nodes send their location information to the nearest sensor node at centre position with sensor nodes ID, energy level, and distance. After the sensor node in the centre position has received control packets from the sensor nodes, those in the centre position will select the closest positioned sensor nodes by sending back a cluster head ID (CH ID), cluster head energy level (CHel), and cluster head position (CHp). The number of sensor nodes present in the layer effectively determines the number of clusters formed at each layer. After the sensor nodes receive the cluster head information a cluster will be formed with each sensor node aware of its cluster and cluster head.

Sensor node ID	Sensor node energy level	Sensor node distance

Figure 5.17: Packet format for sensor nodes sending to cluster head at the initial stage

Cluster head ID	Cluster head energy level	Cluster head position

Figure 5.18: Packet format for cluster head sending to sensor node for cluster formation at the initial stage

Selection of cluster head node at subsequent rounds

After the successful formation of clusters, sensor nodes in each cluster need to select the most eligible sensor node to act as the cluster head node in subsequent rounds. LEACH-DUARP uses two conditions which give rise to the next round selection of cluster head node. The conditions are as follows.

In the process of packet transmission and aggregation, the cluster head node receives packets from an average number of cluster member sensor nodes, after which the selection of the next eligible cluster head node should take effect. This avoids total exhaustion of cluster head node energy in the packet transmission process within a cluster while trying to aggregate and transmit packets. The average number of sensor nodes participating in the packet transmission to a cluster head within a cluster is proposed as

$$\text{AnP} = \frac{X}{Q-1} * (Q-1)^1 \text{……………………. (3)}$$

Where X = number of sensor nodes in the cluster that participate by sending packets to the cluster head.

Q-1 = total number of sensor nodes in a cluster excluding the cluster head.

The equation **AnP** denotes the average number sensor nodes that transmit packets to cluster head node is

determined by the cluster head node through **α** as a comparable parameter such that

$\boldsymbol{\alpha}$ is $\mathbf{0} \leq \boldsymbol{\alpha} \leq \frac{Q-1}{2}$

When sensor nodes energy level reaches a threshold level in the process of data transmission between cluster head node and non-cluster head member nodes. The activity of a sensor node in a cluster leads to energy consumption. These actions consist of sensing, forwarding, dropping, receiving channel hearing as well as data gathering. The residual energy of the cluster head node when reaching a threshold value leads to selection of the next eligible cluster head in the cluster. The residual energy of the nodes is

$$\text{Re}(node) = V(i) - Ce(i) \text{……………………. (4).}$$

Where V(i) is denoted as the initial energy of the sensor node, and Ce(i) stands for the consumed energy of the sensor node after performing some activities in the communication process. Then the threshold value for the residual energy of a sensor node is determined through β as a comparable parameter and is such that $0 \leq \beta \leq V(i)$ where

$$\beta = \frac{V(i)}{2}$$

After the cluster head node achieves one of the above conditions, the selection of next eligible cluster head node in a cluster will take effect. LEACH-DUARP proposed the conditions to determine the selection of next eligible cluster head by prolonging the network lifetime in the process of communication. Each sensor nodes in the cluster has a sequence number and cluster head ID indicating the status ‘0’ if a sensor node has acted as a cluster head node and ‘1’ indicating that a sensor node has not acted as a cluster head before in the cluster. The stability function value was proposed to select the most eligible sensor node as a cluster head which is based on Gray wolf optimization algorithm technique. The selection of the sensor node in the cluster is determined after anyone of the conditions holds. Then the CH broadcasts a message to the sensor nodes in the cluster to notify each sensor node to compute its stability function value. The cluster head node broadcasts a message containing the cluster head node ID, and cluster head energy level. Upon receiving the broadcast message each sensor node will compute its stability function value. The stability function value is as follows

$$SFV = \mathrm{Re}(node)i \times wi + SQi \text{ ………………………….. (5)}$$

Re(node)i, is the residual energy of a sensor node, Wi is the CHID status of a sensor node, and SQi is the sequence number of the sensor node. After each sensor node compute its stability function value. Each node sends back a message to the cluster head node containing sensor node ID, sensor node CHI status, sensor node sequence number, sensor node stability function value (SFV). When the cluster head node receives the message back from the sensor node within the cluster, sensor node with the highest stability function value will be selected as the next eligible cluster head in the cluster.

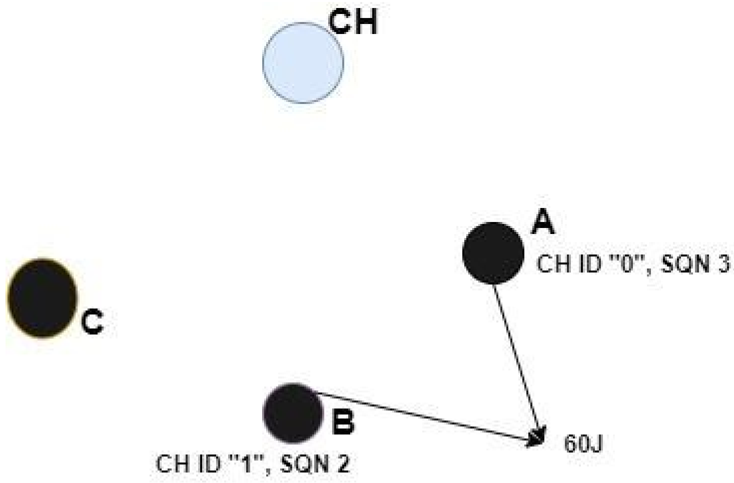


Figure 5.19: Scenario for the selection of eligible cluster head in subsequent round using SFV (1)

The above scenario in figure 5.19 illustrates a cluster when sensor node A and B have the same residual energy of 60J. And node A has a cluster head ID status of ‘0’, and a sequence number of ‘3’. While node B has a cluster head ID status od ‘1’, and a sequence number of ‘2’. To avoid conflict when selecting the next most eligible next cluster head among node A and B, the stability function value (SFV) can be applied. To determine SFV of node A we thus have

$$Node\ (A)SFV = \frac{60 * 0 + 3}{1} = 3$$

$$Node\ (B)SFV = \frac{60 * 1 + 3}{1} = 63$$

To resolve the conflict between node A and B, node B will be selected as the next eligible cluster head having the highest stability function value

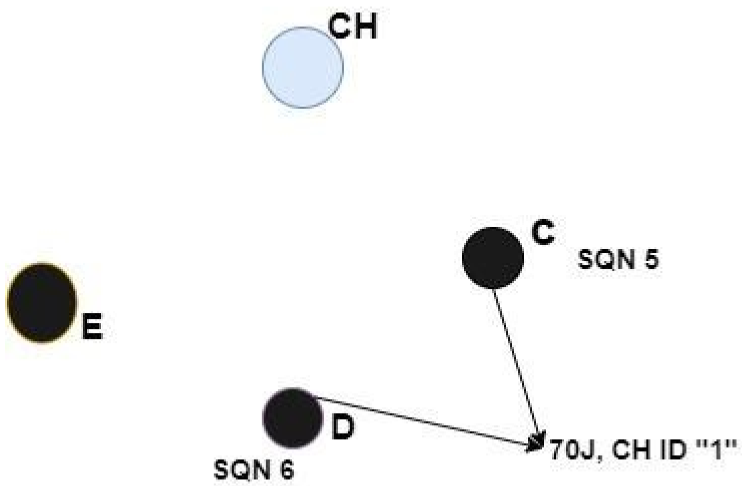


Figure 5.20: Scenario for selecting an eligible cluster head node in subsequent round using SFV (2)

Consider the above scenario in figure 5.20 where two nodes C and D, have the same residual energy of 70J and the same cluster head ID status of ‘1’. However, node C has a sequence number of ‘5’ in the cluster and node D has a sequence number of ‘6’ in the cluster. To determine the next eligible cluster head between nodes C and D, the stability function value is used, where

$$Node\ (C) SFV = \frac{70 * 1 + 5}{1} = 75$$

$$Node\ (D) SFV = \frac{70 * 1 + 6}{1} = 76$$

To resolve the conflict in selecting the next eligible cluster head in the cluster, node D will be selected having the highest stability function value.

From the above scenarios in figure 5.19 and 5.20 each sensor node is expected compute its stability function value and send back to the cluster head node, after which cluster head will select the next cluster head node based on the node with the highest stability function value. The packet format is shown in Figure 5.21.

Sensor node ID	Sensor node residual energy	Sensor node cluster head Id status	Sensor node sequence number	Sensor node stability function value.

Figure 5.21: Packet format for selecting the most eligible sensor node as the next cluster head based on SFV.

5.13.2 DATA TRANSMISSION PHASE

After the successful emergence of sensor nodes in their respective cluster heads, sensor nodes need to avoid packet collision in the channel utilisation process for packet transmission. Sensor nodes are allocated a CDMA that enable sensor node to access the channel in dependently by sending packets as the need arise. When the sensor node senses information, it forwards it to the cluster head using an independent channel that adopts the TAG mechanism. This indicates the packet transmission between the sensor node and cluster head. The TAG mechanism employs the use of ‘1’ to indicate transmission of packets by the sensor node to the cluster head. While a ‘0’ status indicates a node is not in the process of transmitting a packet to a cluster head within a cluster. The TAG mechanism helps the sensor nodes to send data to the cluster head by avoiding packet interference and collision. All sensor nodes in the cluster send their packets to a cluster head in a single hop mode. While the cluster head node aggregates and transmits to cluster head node at a shallower depth layer in the multi hop mode.

5.13.3 RELAY NODE SELECTION

Underwater sensor node mobility indicates less possibility of cluster formation for the sensor nodes closer to the sink node at the surface of the water. Sensor nodes at lower depth closer to the sink are considered relay nodes that participate in packet forwarding to the sink. The selection of a relay node depends on relay node residual energy and location to the sink. When cluster head node closer to the relay node needs to send aggregated data to the relay node, the cluster head will send a control packet containing the CH ID, and CH residual energy. The relay node that receives the control message will reply to the cluster head with the relay node ID, relay node residual energy, and relay node distance to sink. Then the cluster head node will choose the relay node with the highest residual energy and smallest distance to the sink by selecting it to participate in packet forwarding to the sink.

5.14 ALGORITHM FOR LEACH-DUARP ROUTING PROTOCOL

The algorithm for the LEACH-DUARP routing protocol is as follows.

Step 1: Start.

Step 2: (Cluster formation and cluster head selection)

Step 3: Input K number of sensor nodes.

Step 4: If (sensor_ node = = Centre _position Lj) then

Step 5: sensor node status = = Cluster_ head.

Step 6: End If

Step 7: For each sensor node find the nearest sensor node at the centre_ position Lj with average distance Ci ------- Lj .

Step 8: end For

Step 9: If (sensor_ node location = = average min distance to sensor_ node at centre_ position Lj) then.

Step 10: Send information Sensor_ node ID (SNid), Sensor _node energy level (SNel), sensor_ node distance (SNd).

Step 11: else, repeat step 5.

Step 12: end If.
Step 13: If (sensor_ node at centre _position Lj received information from sensor_ nodes with average min distance) then,
Step 14: Reply by broadcasting to the sensor_ nodes through assigning sensor nodes by forming clusters with information (cluster head _node ID (CHid), cluster head _node energy level (CHel), cluster head_ node distance (CHd)).
Step 15: end If.
Step 16: (selection of cluster head node at subsequent rounds)
Step 17: Initialise the number of sensor nodes in the cluster Pi (i= 1,2 …… r) check
Step 18: If (CH sensor node received average number of packets from sensor nodes in the cluster) then
Step 19: Initialise the selection of CH in the cluster.
Step 20: else if (CH energy k is less than or equal to threshold value β.
Step 21: initialise the selection of the next cluster head.
Step 22: Calculate the fitness of the sensor node (Fc) in the cluster using the stability function value M.
Step 23: If (the sensor nodes stability function value M where
Step 24: sensor nodes energy level is less than the threshold value β and the sensor node CH ID is not equal to 0.) then
Step 25. Update the sensor nodes fitness (Fc) in the cluster with the sensor nodes having the highest level where CH ID equals 0.
Step 26: Return the sensor node in the cluster with the highest stability function (Fc) as the CH.
Step 27: End if
Step 28: End if.

5.15 FLOW CHART OF LEACH-DUARP

Figure 5.22 shows the flow chart of LEACH-DUARP routing protocol.

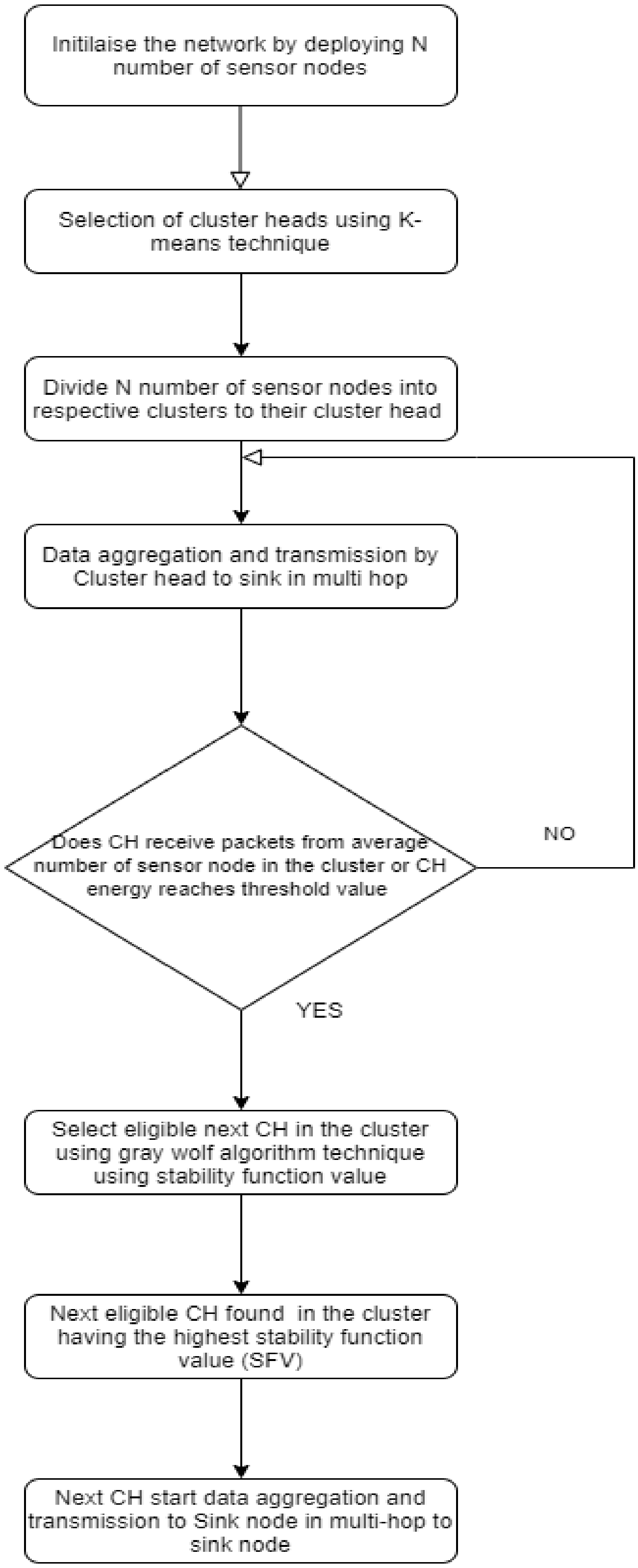


Figure 5.22: Flow chart for LEACH-DUARP routing protocol

5.16 CHAPTER SUMMARY

This chapter presented the design of the proposed routing protocol for sparse and dense network. The sparse proposed routing protocol which is based on the AODV routing protocol was discussed, and the background on AODV routing protocol and messages type defined by AODV were also presented. The proposed routing protocol for sparse networks (AODV-SUARP) was presented which was proposed to help in decreasing the energy consumption incurred by sensor nodes in the process of communication. This leads to the redesign of the AODV RREQ packet header by adding a new field name sensor node energy level. The new field was proposed to take note of the sensor nodes energy level using energy stability parameter. The RREP message of AODV was also redesigned for AODV-SUARP with the addition of a new field called the route stability function. This function that selects the three most eligible path for use in the packet transmission and is based on the energy levels of the sensor nodes. It is proposed to reduce routing overhead caused by AODV due to link breakages because of insufficient energy that gives rise to the initialization of new route discoveries. This chapter further discussed the proposed dense routing protocol based on LEACH named as LEACH-DUARP. The routing protocol was proposed to minimize energy consumption among sensor nodes and effectively select most eligible sensor node to act as a cluster head node in subsequent rounds. Adding a stability function value enhanced the steady phase of LEACH, this was based on the Gray wolf algorithm concept to selects the most eligible cluster head in subsequent rounds. The next chapter will present the implementation of the proposed routing protocol.

CHAPTER SIX

IMPLEMENTATION OF THE PROPOSED AODV-SUARP AND LEACH-DUARP IN SIMULATION ENVIRONMENT

6.1 SIMULATION

Simulation is regarded as a technique that model the working behaviour of a real system. The evaluation of a design system by simulation using a computer program tends to be less costly compared to real life testing. Simulation is used to test and implement a given system to determine its performance and efficiency. To effectively simulate an underwater scenario the selection of an appropriate simulator needs to be taken into consideration as it has to simulate an underwater scenario that is quite different from its terrestrial counterpart. This research will focus on a discrete event simulation which allows a set of events to be processed based on the simulation time. Aquasim next generation is an open-source simulator based on NS-3 version 3.29 has been chosen for this research as it provides upgraded features and modules that support 3-dimensional networks with an enhanced underwater acoustic channel and localization support. The implementation of the proposed routing protocols AODV-SUARP and LEACH-DUARP is based on the network architecture scenarios for sparse and dense. The objective of the simulations was to effectively decrease energy consumption in the communication process underwater among sensor nodes. The first simulation for AODV-SUARP which is based on the workings of the conventional AODV addresses the communication challenges of conventional AODV by minimizing energy consumption in the communication process. The scenario validates the performance of AODV-SUARP based on the energy consumption, packet delivery, packet loss and delay. The simulation was conducted for a varying number of nodes (15, 30 and 50). The second simulation for LEACH-DUARP which was based on the workings of the conventional LEACH routing protocol addresses communication challenges by decreasing the energy consumption based on rounds and the subsequent selection of eligible cluster heads in the communication process. The scenario for the proposed dense LEACH-DUARP was validated based on the residual energy per number of rounds, packet delivery ratio per number of rounds, and number of dead nodes per number of rounds. The simulation was conducted for two different node densities (200, and 300).

6.2 SIMULATION ENVIRONMENT

NS-3.29 is a discrete event simulator that has been chosen for this research for Aquasim-ng. NS-3 provides an open flexible environment for simulation by managing several events which are scheduled execution in a specific time simulation period. It was designed to execute tasks sequentially. Events in NS3 are generated based on the simulation code. The code usually determines the scheduled execution of the simulation task. NS-3 as a discrete event simulator consists of files in the source folder (src) directory which contains the aqua-sim-ng and other files that consist of AODV, DSDV, energy, the netanim, WiMAX, propagation, OLSR, point to point, DSR, traffic control, and CSMA layout. All these files contain some examples that can be tested and run by transferring them to the scratch folder.

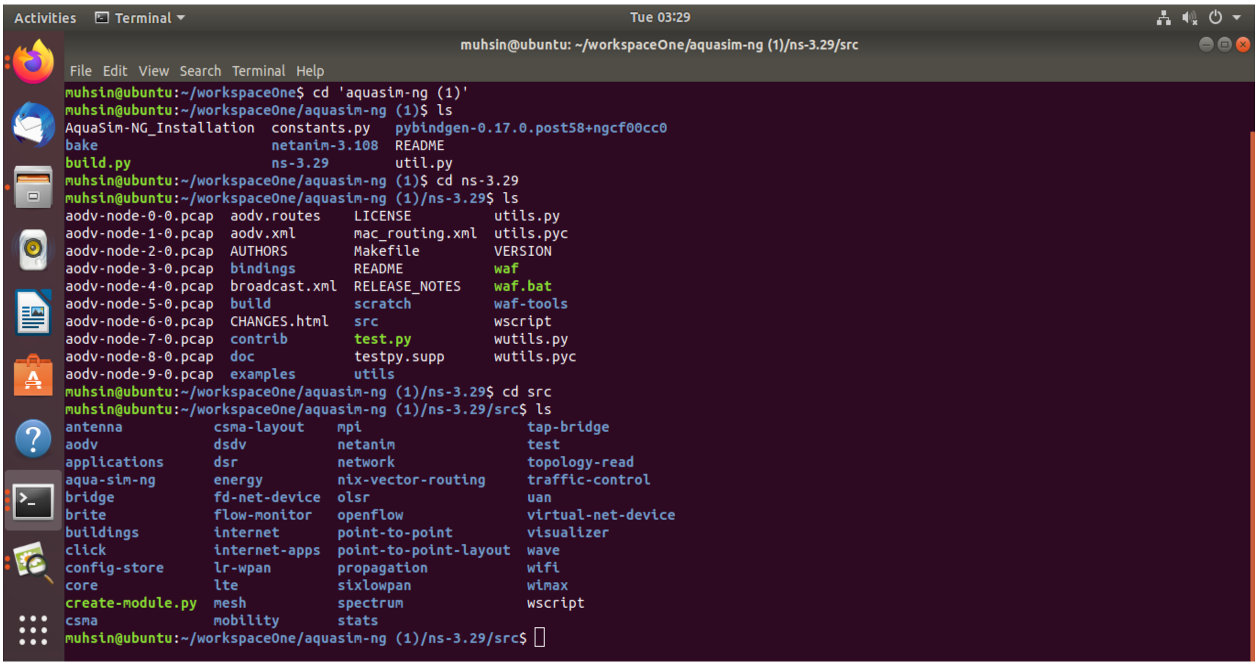


Figure 6.1: Source files for NS-3

6.3 SIMULATION MODELS

Aqua-sim-ng is based on NS-3.29 and contains some models based on underwater properties which can be used to simulate an underwater communication scenario. Such modules include: the aqua-sim-mobility model, aqua-sim-noise-generator, aqua-sim-energy model, aqua-sim-propagation, aqua-sim-sink, aqua-sim-mac-routing, aqua-sim-routing-aloha, and the aqua-sim-mobility model. The NS-3.29 using aquasim-ng provide a built-in energy model that can be used to realise the energy cost of nodes during packet transmission, sensing, sending, forwarding, receiving, channel hearing and data gathering.

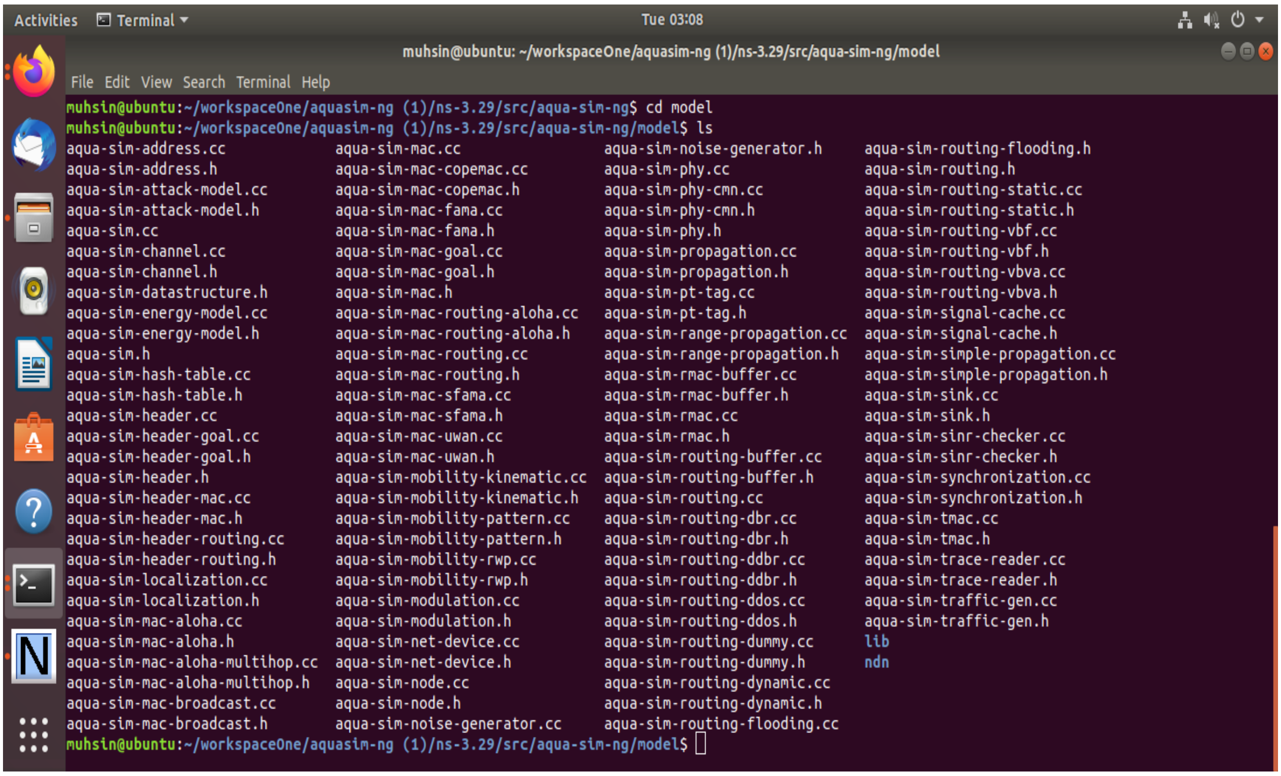


Figure 6.2: Aquasim-NG modules on NS-3

6.4 NETWORK ANIMATOR (NETANIM)

Network animation (netanim) is an animation visualizer for network simulation that shows different distributions of the sensor nodes based on the tested simulation. The latest version of netanim-3.108 was used in the simulation. Netanim generate animation XML file during simulation using **‘’ns3::AnimationInterface’’** in the ns-3 code base. Netanim generate animation trace file. After the execution of the simulation, and by integrating the netanim code in the simulation code netanim XML trace file can be loaded in the netanim window. A header file in the simulation code also needs to be included for netanim which is **#include ‘’nas3/netanim-module.h’’**

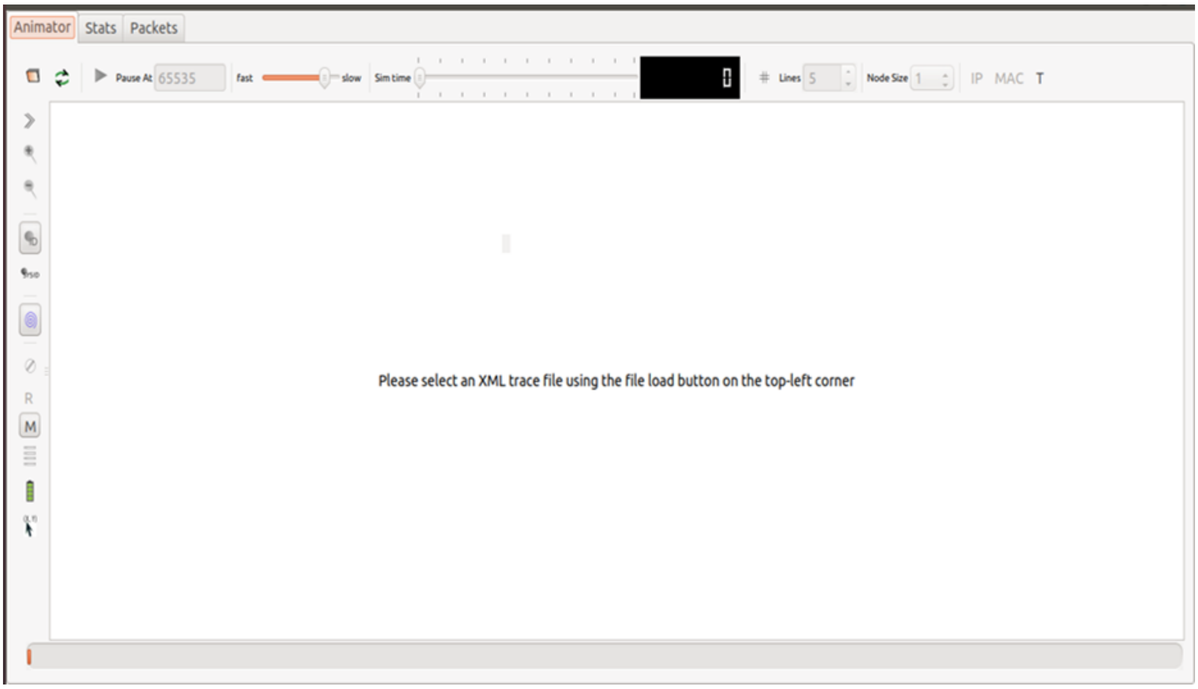


Figure 6.3: Network Animation window

6.5 SIMULATION SCENARION ENVIRONMENT FOR AODV/AODV-SUARP

The simulation scenario of the proposed sparse network architecture aimed to determine the extent of minimizing energy consumption in the process of communication by reducing the routing overhead. This process occurs when conventional AODV tries to discover the route at the route discovery phase by incurring routing overhead through RREQ message which helps in energy consumption and bandwidth utilisation among the sensor nodes. The implementation of AODV-SUARP in aquasim-ng for NS-3.29 discusses the simulation result obtain. Netanim-3.108 was used as the simulation environment for the network formation scenario. The simulation was executed for 200 seconds and compared against AODV and VBF routing protocols using a varying number of nodes (15, 30 and 50) in a 4000m X 4000m simulation environment.

6.5.1 SIMULATION FOR 15 NODES

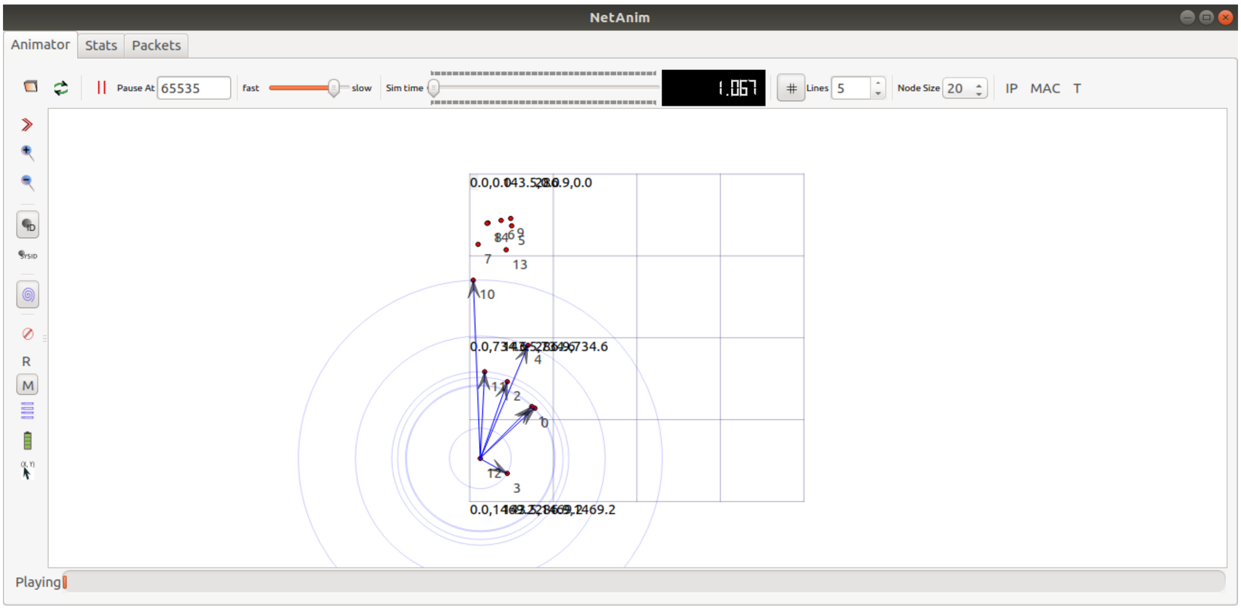


Figure 6.4: Simulation window for 15 nodes on netanim

The simulation window in Figure 6.4 shows the distribution of 15 nodes including the sink node. The simulation was tested for 200 seconds against quality-of-service parameters which included the packet received, packet loss, energy consumption and delay. Three routing protocols were used which consisted of AODV, VBF and AODV-SUARP. A data rate of 1000bps was used with a packets size of 50 bytes. The maximum nodes speed was placed at 1m/s with a transmission power of 10J for nodes at the initial stage. Thorps model was used as the propagation model, while random way point model was used as the mobility model and aquasim-ng energy model was used as the energy model. Moreover, 10khz was used as the frequency carrier for the acoustic signal and 20dB was set as the background noise. Table 7.1 shows the simulation parameters.

Table 6.1: Simulation parameters

Parameter	**Value**
Simulation Duration	200 seconds
Number of nodes	15
Data rate	1000bps
Packet size	50bytes
Number of sink node.	1
Node speed	1m/s
Acoustic channel noise	20 decibels (Db)
Transmission power	10J
Mobility model	Random way point mobility model
Propagation model	Thorps model
Frequency carrier acoustic signal	10khz
Acoustic channel noise	20 decibels (db)
Routing protocols	AODV, AODV/SUARP and VBF

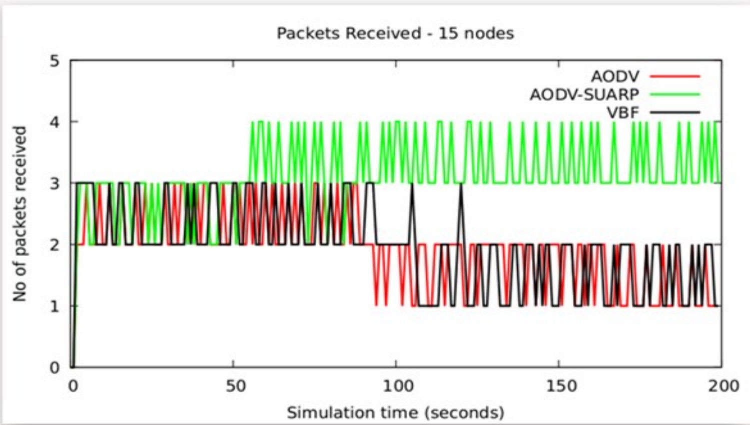


Figure 6.5: Packets received for 15 nodes.

Figure 6.5 shows the simulation results for the packet received for three routing protocols AODV-SUARP, AODV and VBF with a total number of 15 nodes including the sink node. The simulation was run for a total time of 200 (s). The results indicates that the three routing protocols from the start of the simulation to 50 (s) of simulation time received the same number of packets until 52(s) when AODV-SUARP started receiving a higher number of packets than the AODV and VBF routing protocols. This continued up to the end of the simulation time. Furthermore, as the number of the simulation increased AODV and VBF routing protocols started to receive a smaller number of packets at 95 (s) up to the end of the simulation time of 200 (s).

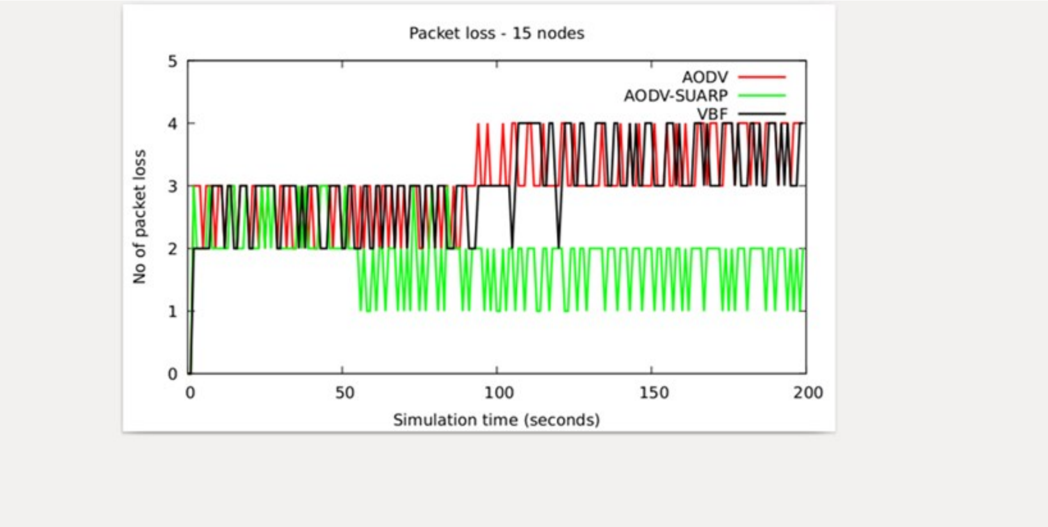


Figure 6.6: Packet loss for 15 nodes

Figure 6.6 shows the simulation results for the three routing protocols AODV-SUARP, AODV and VBF routing protocols for packet loss in the packet transmission. From the start of the simulation to 52 (s) the three routing protocols lost the same number of packets until AODV-SUARP at 52 (s) started to experience less packet loss up to the end of the simulation at 200 (s). While the performances of AODV and VBF changed by losing more packets at 95 (s) up to the end of simulation time of 200 (s).

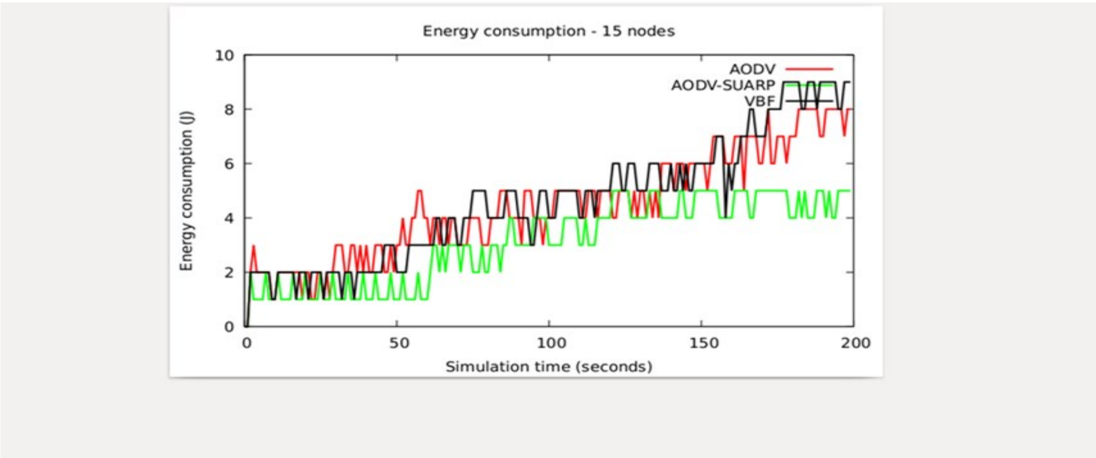


Figure 6.7: Energy consumption for 15 nodes

Figure 6.7 indicates the simulation result for the energy consumption of three routing protocols which consists of AODV-SUARP, AODV and VBF. The simulation was run for 15 of nodes (including the sink node) and with a total energy of 10 (j) for a simulation time of

200 (s). At the start of the simulation all three routing protocols consumed less energy between 2 (j) until when the simulation time increased to 30 (s) when AODV started to consume more energy than AODV-SUARP and VBF. However, the VBF routing protocol started to consume greater amount of energy at 50 (s) compared to AODV-SUARP. The energy consumption for all three routing protocols continued to increase but AODV-SUARP consistently consumed less energy up to the end of simulation time at 200s. In comparison AODV and VBF continued to consume a higher amount of energy up to the end of simulation than AODV-SUARP.

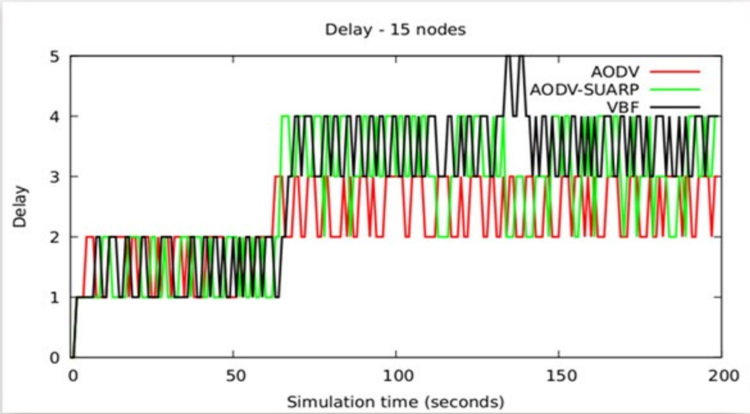


Figure 6.8: Delay for 15 nodes

Figure 6.8 shows the simulation results for the three routing protocols, AODV, AODV-SUARP and VBF for a delay against 15 of nodes (including the sink node). The simulation time was run to a total of 200 (s). The results indicate that the three routing protocols experienced the same delay at the start of the simulation up to 60 (s) of the simulation time. At 65 (s) both AODV-SUARP and VBF routing protocols experienced greater number of delays compared to the AODV routing protocol. Although, AODV-SUARP increases delays than AODV the delay continued to rise with VBF up to the end of the simulation time of 200 (s) compared with AODV that experienced a notably smaller number of delays.

6.5.2 SIMULATION FOR 30 NODES

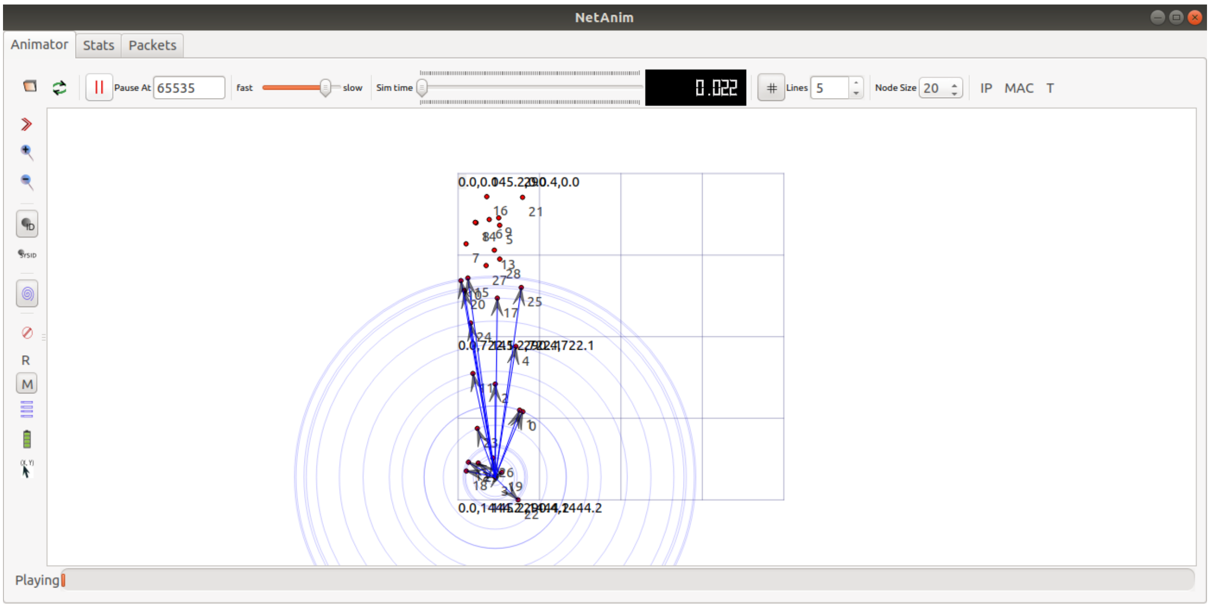


Figure 6.9: Simulation window for 30 nodes on netanim

The simulation window in Figure 6.9 shows the distribution of 30 nodes including the sink node. The simulation was tested for 200 seconds against the quality-of-service parameters which included the packet received, packet loss, energy consumption and delay. Three routing protocols were used which consist of AODV, VBF and AODV-SUARP. A data rate of 1000bps was used with a packet size of 50 bytes. A maximum node speed was implemented at 1m/s with a transmission power of 10J for nodes at the initial stage. Thorps model was used as the propagation model, random way point model was used as the mobility model and aquasim-ng energy model was used as the energy model. 10khz was used as the frequency carrier for the acoustic signal and 20 decibels was set for the acoustic channel noise. Table 6.2 shows the simulation parameters as follows.

Table 6.2: Simulation parameters

Parameter	**Value**
Simulation Duration	200 seconds
Number of nodes	30
Data rate	1000bps
Packet size	50bytes
Number of sink node.	1
Node speed	1m/s
Transmission power	10J
Mobility model	Random way point mobility model
Propagation model	Thorps model
Frequency carrier acoustic signal	10khz
Acoustic channel noise	20 decibels (db)
Routing protocols	AODV, AODV/SUARP and VBF

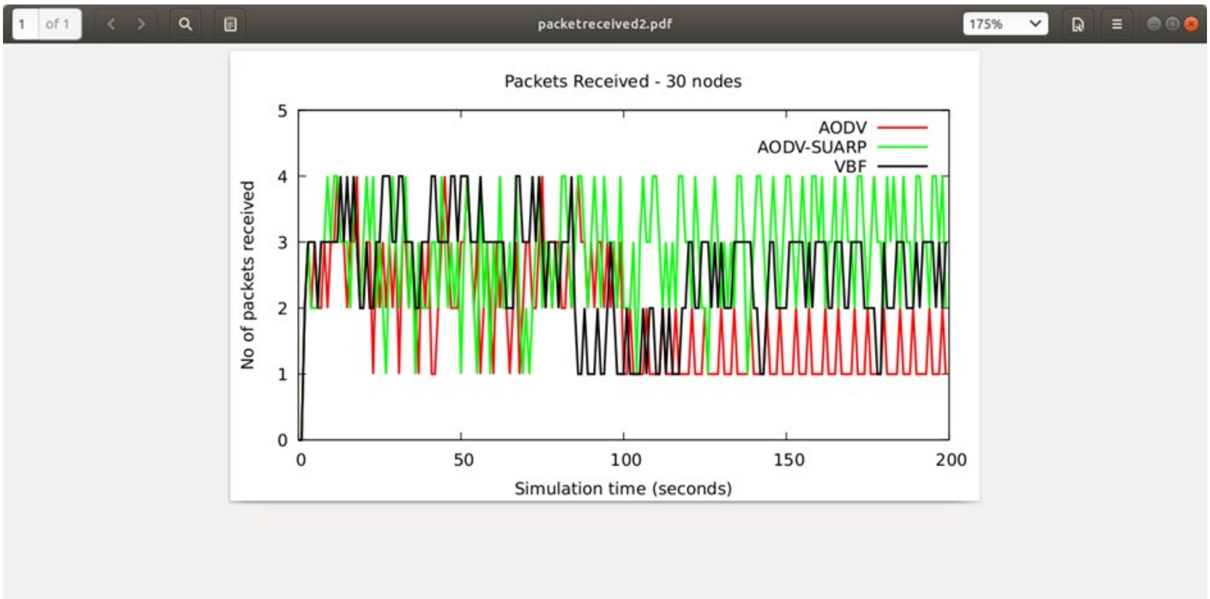


Figure 6.10: Packets received for 30 nodes.

Figure 6.10 shows the simulation result for the packets received for three routing protocols AODV, AODV-SUARP and VBF for 30 nodes (including the sink node). The simulation was run for a total time of 200 seconds. The result indicates that the VBF routing protocol received more packets at 80 seconds compared to AODV and AODV-SUARP. As the simulation time reaches 100 seconds AODV started receiving higher packets compared to

VBF and AODV. As the simulation time reached 200 seconds, AODV-SUARP received considerably more packets followed by AODV and then VBF.

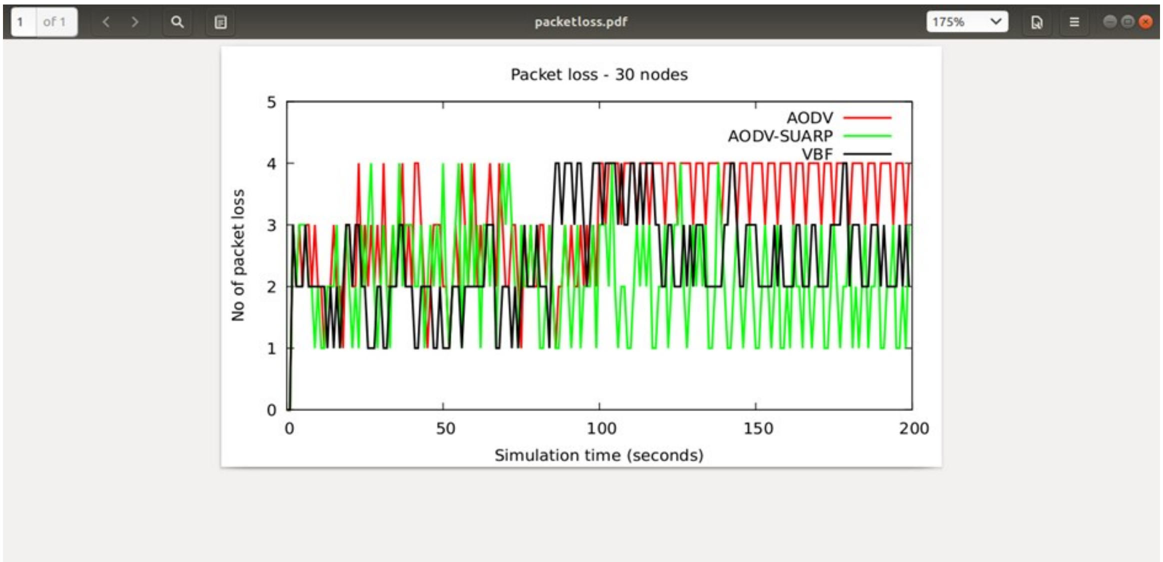


Figure 6.11: Packet loss for 30 nodes.

Figure 6.11 shows the simulation result for the packet loss for three routing protocols, AODV, AODV-SUARP and VBF for 30 nodes (including the sink node). The simulation was run for 200 seconds. The result indicates that the VBF routing protocol experienced less packet loss from the start of the simulation to 80 seconds compared with AODV and AODV-SUARP. As the simulation time reached 100 seconds AODV-SUARP started experiencing less packet loss compared to AODV and VBF routing protocols. As the simulation time reached 200 seconds AODV-SUARP, noted less packet loss followed by AODV then VBF.

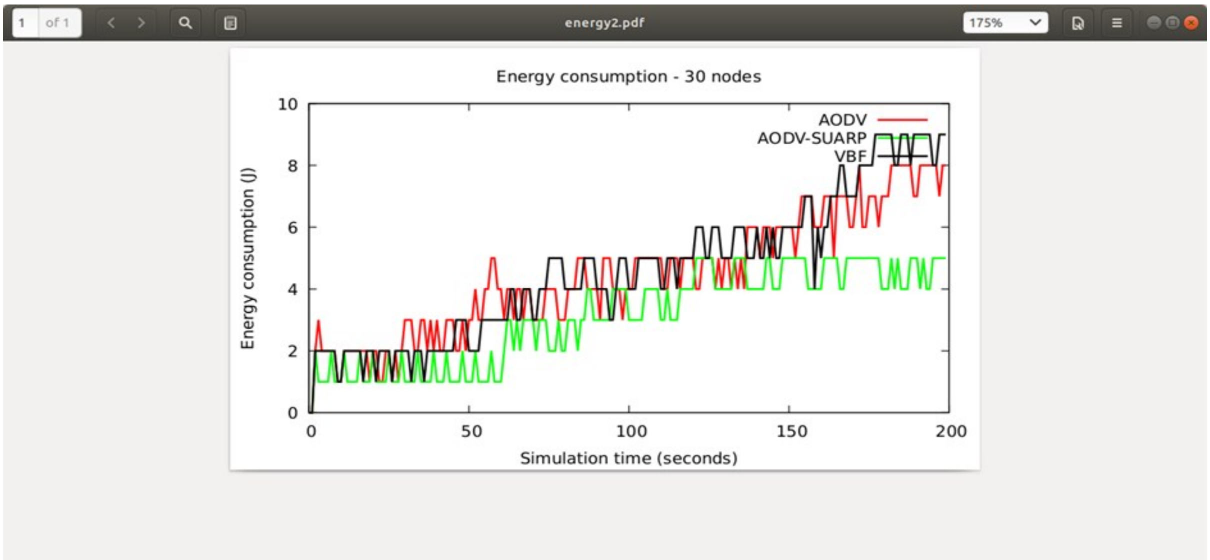


Figure 6.12: Energy consumption for 30 nodes

Figure 6.12 illustrates the simulation result for the energy consumption of the three routing protocols (AODV-SUARP, AODV and VBF). The simulation was run for 30 nodes (including the sink node) with a total energy of 10 (j) for a simulation time of 200 (s). All three routing protocols consumed less energy between 2(j) up to 25 seconds, after which AODV started to consume more energy compared to VBF and AODV-SUARP. VBF also consumes more energy compared to AODV-SUARP. As the simulation reached 200 seconds AODV-SUARP consumed less energy compared to AODV while VBF consumed more energy.

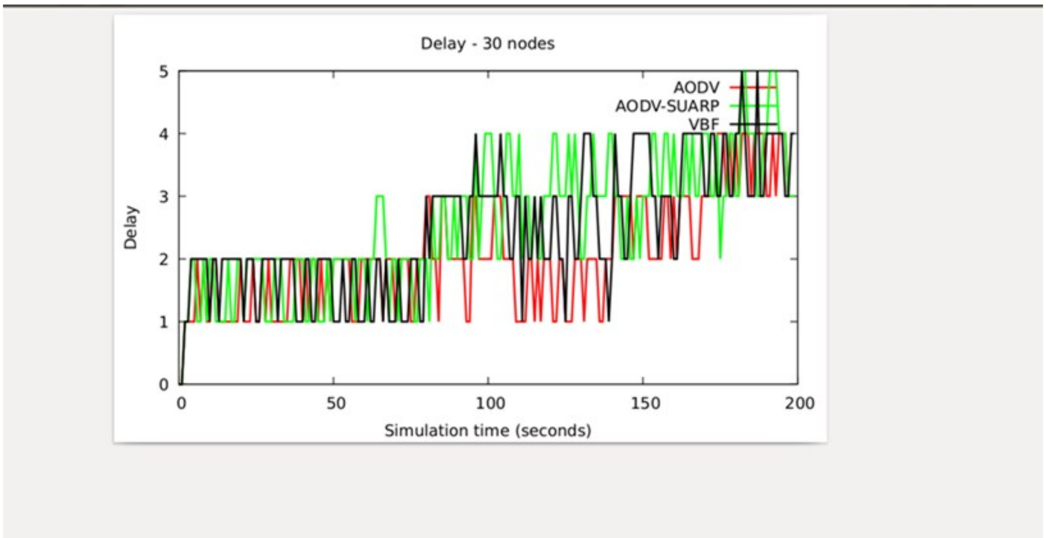


Figure 6.13: Delay for 30 nodes

Figure 6.13 above indicates the simulation result for the delays for three routing protocols (AODV-SUARP, AODV and VBF). The simulation was run for 30 of nodes including the sink node with a simulation time of 200 seconds. The results indicated that all three routing protocols acquired less delay from the start of the simulation up to 70 seconds when the AODV-SUARP delay results diverged from AODV and VBF. After 70(s), the delay decreased to the same as those by AODV and VBF and continued in this way up to 90 seconds. As the simulation reached 95 seconds AODV-SUARP started to experience greater delay due to the introduction of route stability function, then followed by VBF then AODV up to the last of the simulation time of 200 seconds.

6.5.3 SIMULATION FOR 50 NODES

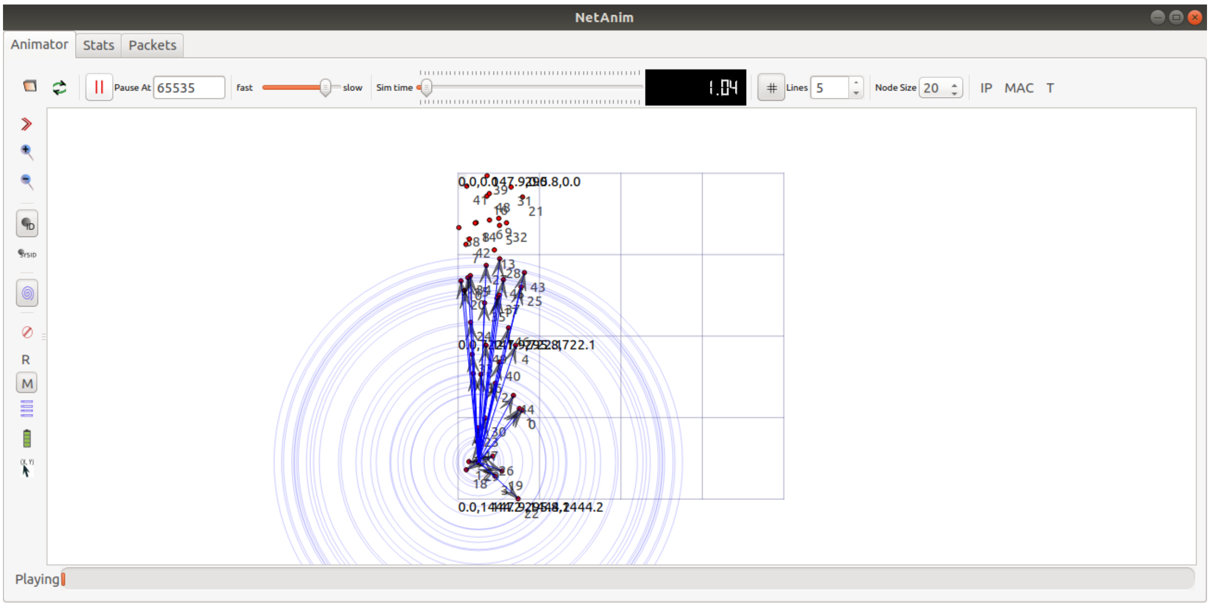


Figure 6.14: Simulation window for 50 nodes on netanim

The simulation window (shown in Figure 6.14) shows the distribution of 50 nodes including the sink node. The simulation was tested for 200 seconds against the quality-of-service parameters which include packet received, packet loss, energy consumption and delay. Three routing protocols were used which consist of AODV, VBF and AODV-SUARP. A data rate of 1000bps was used with 5a packet size of 50 bytes. A maximum nodes speed was implemented at 1m/s with a transmission power 10(J) for nodes at initial stage. Thorps model was used as the propagation model, random way point model was used as the mobility model and aquasim-ng energy model was used as the energy model. Furthermore, 10khz was used as the frequency carrier for the acoustic signal. Table 6.3 shows the simulation parameters.

Table 6.3: Simulation parameters

Parameter	**Value**
Simulation Duration	200 seconds
Number of nodes	50
Data rate	1000bps
Packet size	50bytes
Number of sink node.	1
Node speed	1m/s
Transmission power	10J
Mobility model	Random way point mobility model
Propagation model	Thorps model
Frequency carrier acoustic signal	10khz
Acoustic channel noise	20 decibels (db)
Routing protocols	AODV, AODV/SUARP and VBF

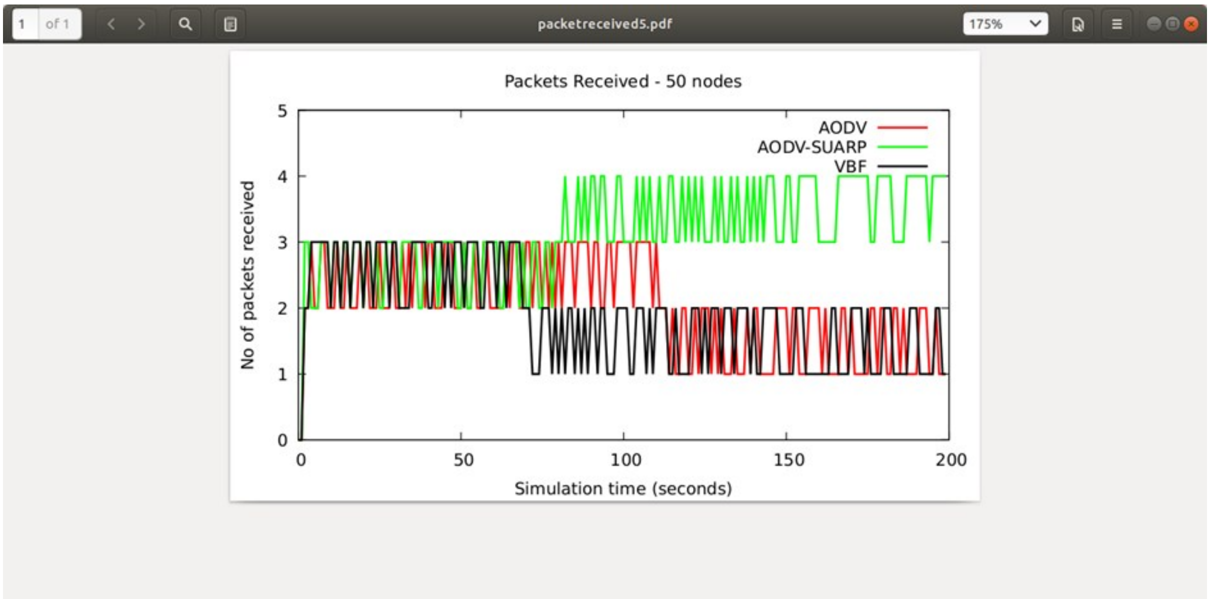


Figure 6.15: Packets received for 50 nodes

Figure 6.15 shows the simulation of three routing protocols AODV, AODV-SUARP and VBF with a total 50 nodes (including the sink node). The simulation was run for a total time of 200 (s). The results indicate that all three routing protocols received the same number of packets up to 70 seconds when AODV and AODV-SUARP started receiving more packets compared to VBF. As the simulation reached 94 seconds AODV-SUARP continued to receive more packets compared to AODV and VBF up to the last simulation time of 200 second. AODV received more packets than VBF between 94 to 110 seconds after which both AODV and VBF continued to receive the same number of packets to the end of the simulation time.

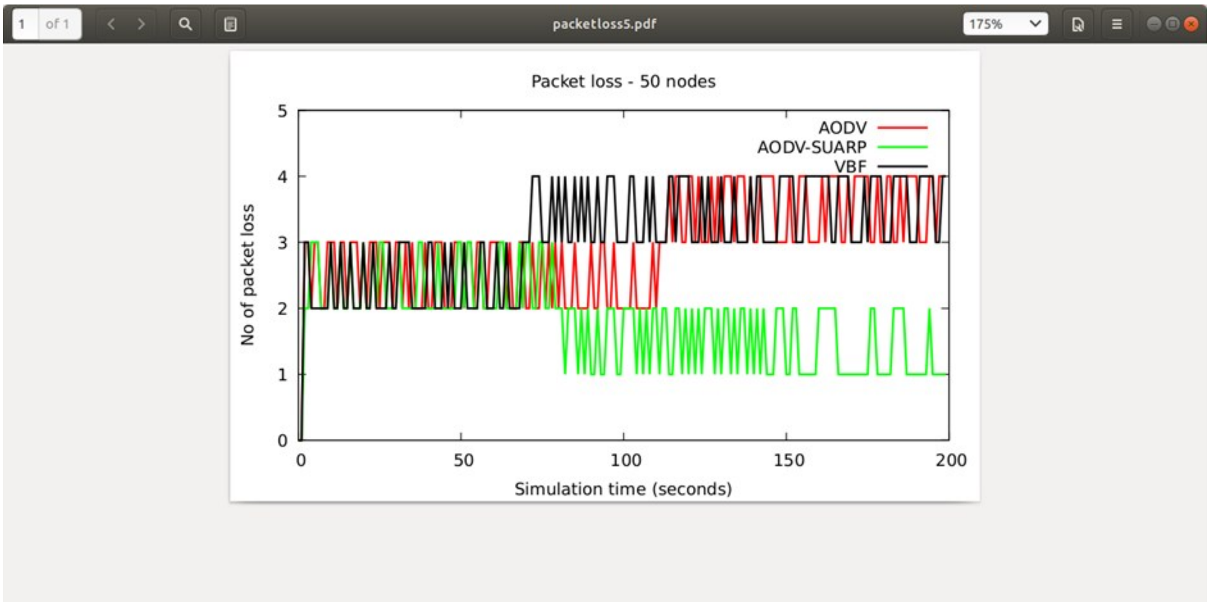


Figure 6.16: Packet loss for 50 nodes

Figure 6.16 shows the simulation results for AODV, AODV-SUARP and VBF concerning the packet loss for 50 nodes (including the sink node). The simulation was run for 200 seconds. The results indicate that all three routing protocols lost the same number of packets until the simulation time reached 70 seconds when AODV-SUARP lost fewer packets than VBF and AODV up to the end of the simulation time of 200 seconds. As the simulation time reached 94 seconds VBF lost fewer packet compared to AODV, which continued up to 110 when both AODV and VBF experienced the same packet loss up to the end of the simulation time, but more than AODV-SUARP.

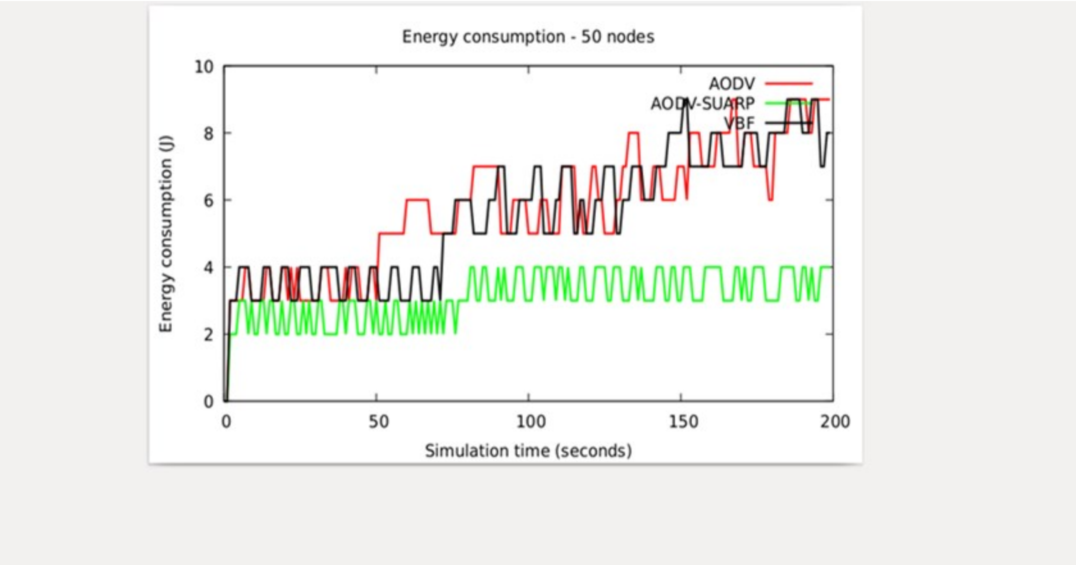


Figure 6.17: Energy consumption for 50 nodes

figure 6.17 indicates the energy consumption simulation results for three routing protocols (AODV-SUARP, AODV and VBF. The simulation was run for 30 nodes (including the sink node) together with a total energy of 10 (j) for a simulation time of 200 (s). From the start of the simulation and up to the end of the simulation time, AODV-SUARP consumed less energy compared to AODV and VBF. Both AODV and VBF consumed the same amount of energy from the start of the simulation up to 50 seconds of the simulation time after which AODV consumed more energy than VBF up to 80 seconds of the simulation time. As the simulation time reached 95 seconds, both AODV and VBF continued to consumed a amount of energy up to the end of the simulation.

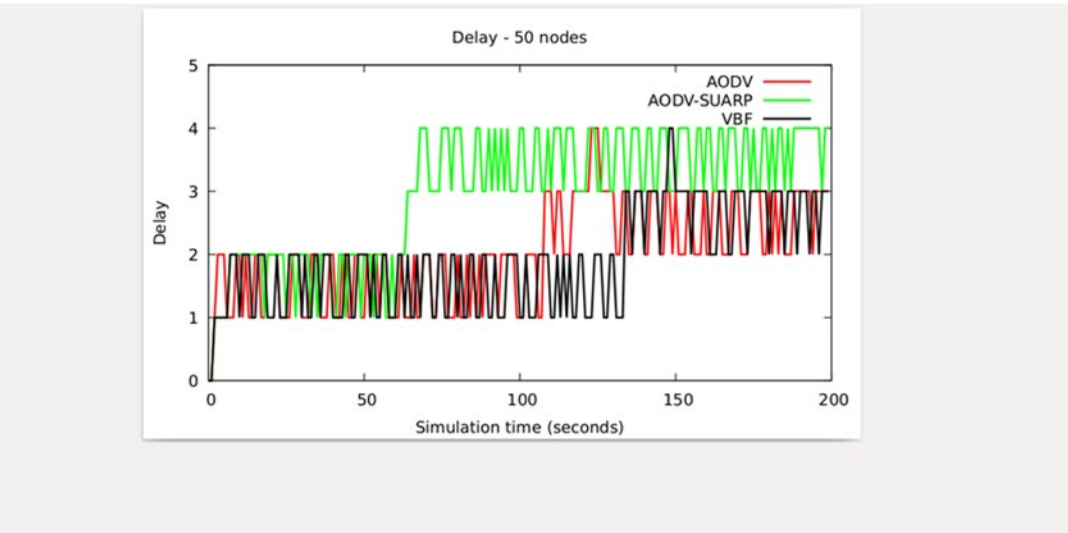


Figure 6.18: Delay for 50 nodes

Figure 6.18 shows the DELAY result for three routing protocols AODV, AODV-SUARP and VBF for 50 of nodes, the simulation was run for 200 seconds. The results in Figure 7.18 indicates that the three routing protocols acquired the same delay of up to 60 seconds of the simulation time. As the simulation reached 60 seconds, AODV-SUARP experience greater delays compared with the AODV and VBF routing protocols due to the introduction of route stability function, this continued up to the end of the simulation time. While AODV and VBF had the same delay up to 105 seconds, after this point of the AODV experienced greater delays than VBF up to 140 seconds. As the simulation time reached 141 seconds, AODV and VBF experienced the same delay up to the end of the simulation time of 200 seconds.

6.6 SIMULATION SCENARIO ENVIRONMENT FOR LEACH/LEACH-DUARP

The simulation scenario of the proposed dense network architecture aimed to determine the extent of energy consumption could be minimized in the communication process by maximizing the network lifetime. This process occurred when conventional LEACH tried to select the eligible cluster head in a subsequent round at the establishment phase. The stability function value was proposed to select the most eligible sensor node as the cluster head in subsequent rounds. The implementation of LEACH-DUARP in NS-3.29 discuss the simulation result. Netanim-3.108 was used as the simulation environment for the network formation scenario. The simulation was executed for 1000 rounds compared with LEACH and DIRECT transmission in LEACH routing protocols using 200 and 300 nodes in a 4000m X 4000m simulation environment.

6.6.1 SIMULATION FOR 200 OF NODES

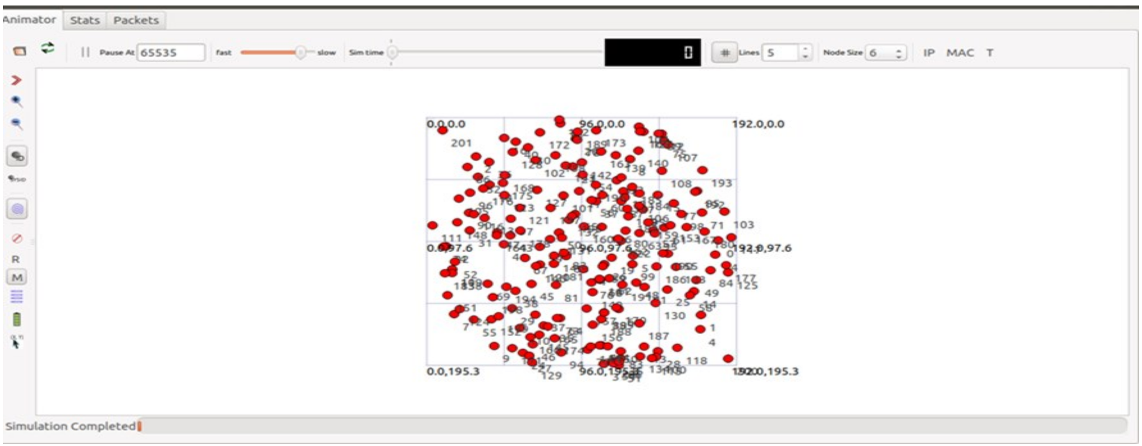


Figure 6.19: Simulation window for 200 nodes on netanim

The simulation window in Figure 6.19 shows the distribution of 200 nodes including the sink node. The simulation was tested for 1000 rounds against quality-of-service parameters which include residual energy of the nodes, packet delivery ratio, and the number of dead nodes. Three routing protocols were used, namely LEACH, DIRECT and LEACH-DUARP. A data rate of 1000bps was used with a packet size of 50 bytes. A maximum node speed was put on 1m/s with a transmission power of 10 (j) for nodes at the initial stage. Thorps model was used as the propagation model, random way point was used as the mobility model and aquasim-ng energy model was used as the energy model. In addition, 10khz was used as the frequency carrier for the acoustic signal. A maximum value of 20 decibel (db) was set as the noise for the acoustic channel to last for the duration of the total simulation time. Table 7.4 shows the parameters.

Table 6.4: Simulation parameters

Parameter	**Value**
Simulation Duration	1000 rounds
Number of nodes	200
Data rate	1000bps
Packet size	50bytes
Number of sink node.	1
Node speed	3m/s
Transmission power	10J
Mobility model	Random way point mobility model
Propagation model	Thorps model
Frequency carrier acoustic signal	10khz
Acoustic channel noise	20 decibels (dB)
Routing protocols	LEACH, DIRECT, and LEACH-DUARP

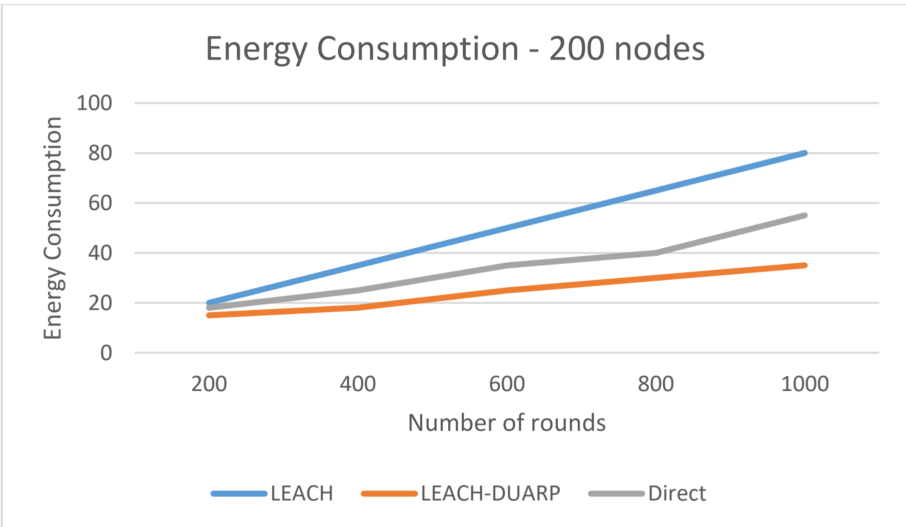


Figure 6.20: Energy consumption for 200 nodes

Figure 6.20 shows the residual energy for 1000 rounds for each routing protocol namely, LEACH, DIRECT transmission and LEACH-DUARP. The results indicate that as the number of rounds increased to 700 LEACH-DUARP possessed a less energy consumption at 35 percent compared to LEACH at 55 percent and DIRECT transmission at 30 percent. As the number of rounds reached 1000 rounds LEACH-DUARP acquired less percentage of energy consumption of the nodes at 35 percent whilst LEACH acquired 80 percent and DIRECT 55 percent.

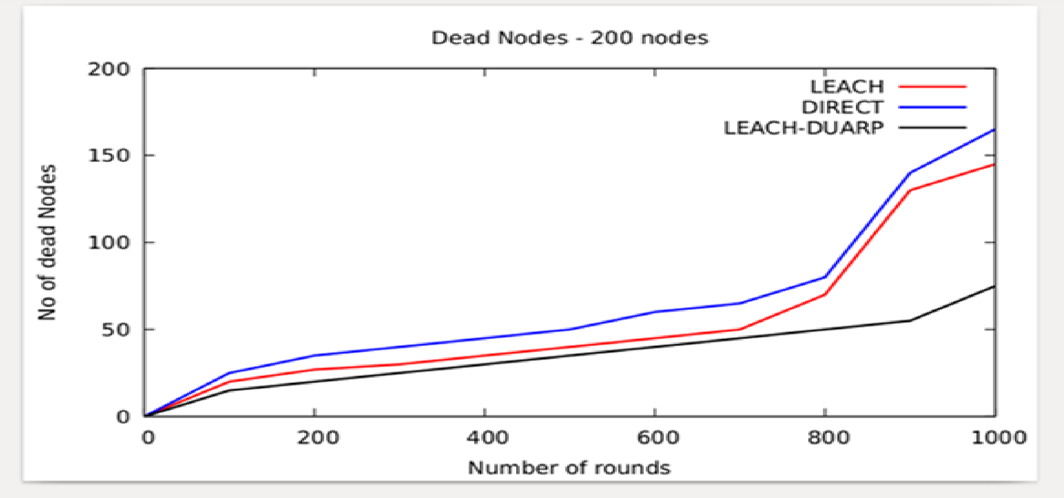


Figure 6.21: Number of Dead nodes for 200 nodes

Figure 6.21 shows the simulation of LEACH, DIRECT and LEACH -DUARP for 200 nodes. The result above indicates that LEACH-DUARP acquired the fewest dead nodes (45) as the simulation increase to 700 rounds. In comparison LEACH acquired 50 and DIRECT 65 dead nodes. As the simulation reached 1000 rounds, DIRECT acquired more dead nodes (165) than LEACH at (145) and LEACH-DUARP at 80 dead nodes.

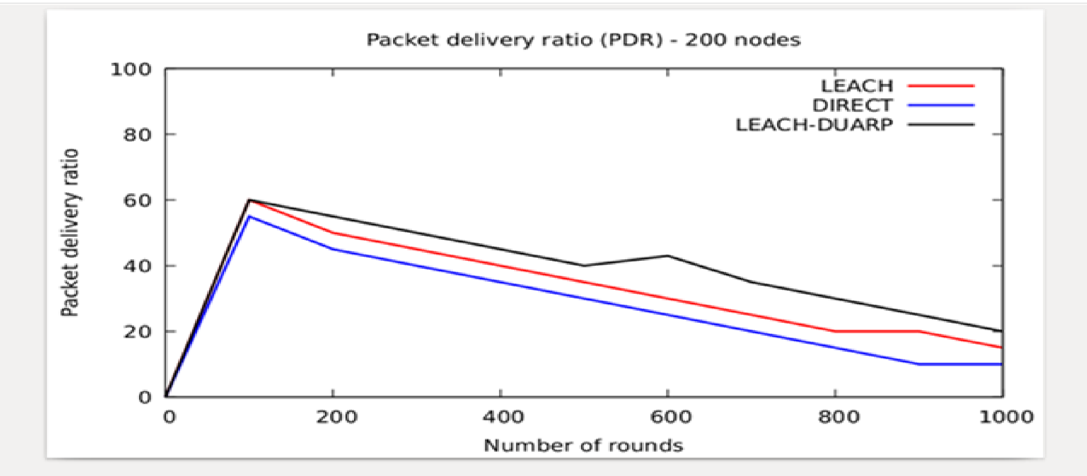


Figure 6.22: Packet delivery ratio for 200 nodes

Figure 6.22 indicates the PDR for 200 nodes for the three routing protocols LEACH, DIRECT and LEACH-DUARP. The result indicates that at the start of the simulation round to 100 rounds both LEACH and LEACH-DUARP acquired a higher packet delivery ratio compared to DIRECT. As the simulation round increased to 1000 rounds, the PDR for all the three routing protocols continued to drop, but LEACH-DUARP experienced a higher PDR at 20 percent than LEACH at 15 percent and DIRECT at 10 percent.

6.6.2 SIMULATION FOR 300 NODES

Figure 6.23: Simulation window for 300 nodes on netanim

The simulation window in Figure 6.23 shows the distribution of 200 nodes, including the sink node. The simulation was tested for 1000 rounds against the quality-of-service parameters which included the residual energy of the nodes, the packet delivery ratio, and number of dead nodes. Three routing protocols were used LEACH, DIRECT and LEACH-DUARP. A Data rate of 1000bps was used with a packet size of 50 bytes. A maximum nodes speed was put at 1m/s with a transmission power of 10 (j) for nodes at the initial stage. Thorps model was used as the propagation model, random way point model was used as the mobility model and aquasim-ng energy model was used as the energy model. Moreover, 10khz was used as the frequency carrier for the acoustic signal. Table 7.5 shows simulation parameters is as follows.

Table 6.5: Simulation parameters

Parameter	**Value**
Simulation Duration	1000 rounds
Number of nodes	300
Data rate	1000bps
Packet size	50bytes
Number of sink node.	1
Node speed	1m/s
Transmission power	10J
Mobility model	Random way point mobility model
Propagation model	Thorps model
Frequency carrier acoustic signal	10khz
Acoustic channel noise	20 decibels (Db)
Routing protocols	LEACH, DIRECT, and LEACH-DUARP

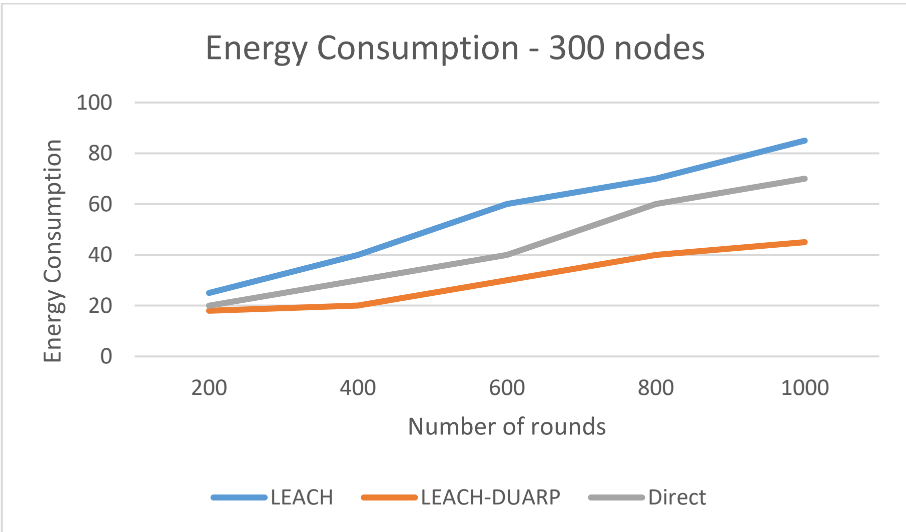


Figure 6.24: Energy consumption for 300 nodes

Figure 6.24 indicates the residual energy percentage of the nodes for 300 nodes. Three routing protocols were tested LEACH, DIRECT and LEACH-DUARP against 1000 rounds of simulation. The result indicates that as the simulation reached 800 rounds LEACH-DUARP acquired less energy consumption within the nodes at 40 percent compared to LEACH at 70 percent and DIRECT with 60 percent. As the simulation increased to 1000 rounds LEACH-DUARP acquired 45 percent less energy consumption amongst the nodes compared to LEACH at 85 percent and DIRECT at 70 percent.

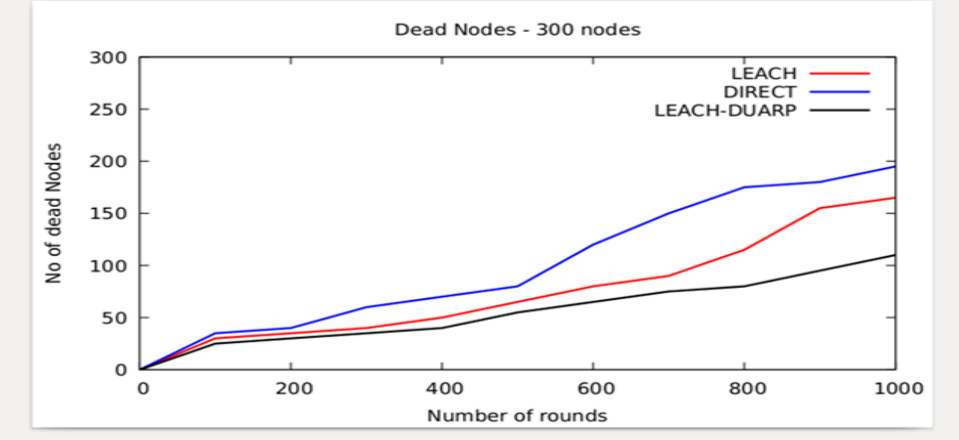


Figure 6.25: Number of Dead nodes for 300 nodes

Figure 6.25 indicates the number of dead nodes for the three-routing protocol LEACH, DIRECT and LEACH-DUARP for a total simulation of 1000 rounds. The result indicates, that as the simulation reached 700 rounds, LEACH-DUARP experienced the lowest number of dead nodes at 75 at LEACH at 90 and DIRECT at 150. As the simulation rounds reached 1000, LEACH-DUARP acquired the lowest number of dead nodes (110) compared with LEACH at 165 and DIRECT at 185.

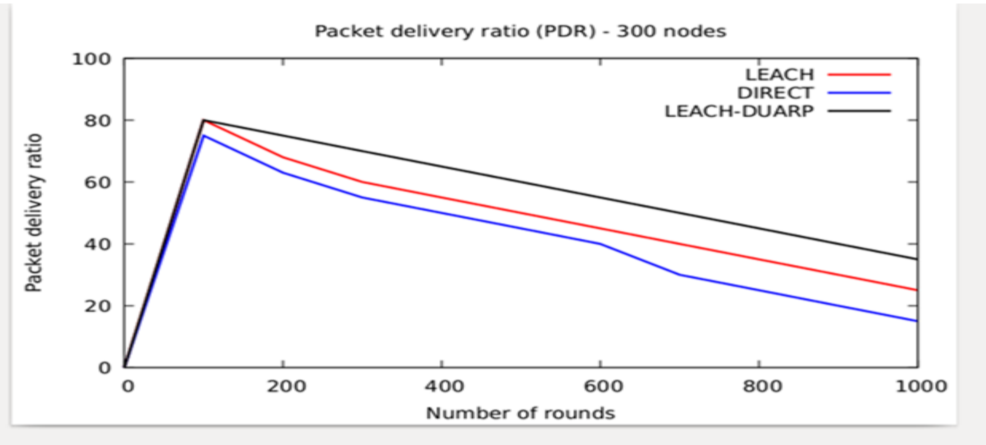


Figure 6.26: Packet delivery ratio for 300 nodes.

Figure 6.26 shows the simulation for 300 nodes for three routing protocols LEACH, DIRECT and LEACH-DUARP for a simulation of 1000 rounds. The result indicates that all three experienced higher packet delivery ratios up to 80 percent from the start of the simulation. As the simulation round increased to 1000 rounds LEACH-DUARP acquired the highest PDR at 35 percent compared with LEACH at 25 percent and DIRECT at 15 percent.

6.7 ANALYSIS OF THE SIMULATION RESULT FOR SPARSE ARCHITECTURE

The simulation for the proposed sparse network architecture was tested with a different number of nodes namely 15, 30 and 50 based on the action on demand vector routing protocol (AODV), AODV-SUARP and Vector based forwarding (VBF) as a localization-based routing protocol that deals with the location of the sensor nodes when sending packets of data across an underwater channel. Four parameters were considered which consist of packet received, packet loss, energy consumption and delay. The first simulation which consisted of 15 nodes indicated that AODV-SUARP consumed a significantly less energy among its sensor nodes, less packet loss and more packets received than the AODV and VBF routing protocols. Although, AODV-SUARP acquires a less delay at the start of the simulation but later incurred delay together with VBF routing protocol to the end of the simulation. The second simulation was tested with 30 nodes and the results indicated that AODV-SUARP received significantly more packets, less packet loss and less energy consumed compared to the simulation for 15 number of nodes using AODV and VBF routing protocols. However, AODV-SUARP like VBF incurred significantly longer delays with VBF compared with the AODV routing protocol. The third simulation for the sparse architecture was tested by increasing the number of the sensor nodes to 50, For this simulation AODV-SUARP received more packet, lost fewer packet, and consumed less energy compared with AODV and VBF at the 30 nodes simulation. However, in the later simulation using 15 and 30 nodes AODV-SUARP acquired greater delays compared with AODV and VBF. The overall simulation for the sparse network indicates that as number of the sensor nodes increase, AODV-SUARP continued to receive more packet, lose fewer packets, and consumed less energy but with greater delays due to introduction of route stability function. As a result, AODV-SUARP takes the energy of the sensor nodes into consideration by introducing the route stability function to select eligible routes based on the sensor nodes energy levels in the packet transmission. This is compared with AODV and VBF routing protocols which helps to reduce energy consumption among sensor nodes.

6.8 ANALYSIS OF THE SIMULATION RESULT FOR DENSE ARCHITECTURE

The simulation for the proposed dense network architecture was tested for different number of sensor nodes 200 and 300 against the LEACH, DIRECT and LEACH-DUARP routing protocols. Three parameters were taken into consideration namely packet delivery ratio (PDR), residual energy of the nodes, and number of dead nodes. The first simulation consisting of 200 nodes indicated that LEACH-DUARP achieved a significantly fewer dead nodes, higher residual energy and a higher packet delivery ratio compared to LEACH and DIRECT. The second simulation increased the number of senor nodes to 300, and the results indicated that LEACH-DUARP acquired a significant higher packet delivery ratio, fewer dead nodes, and higher residual energy. The overall simulation for the dense architecture indicated that as the number of sensor nodes increased LEACH-DUARP continued to experience significantly higher packet delivery ratio, fewer dead nodes and less energy consumed. As a result, LECAH-DUARP is considered to select an eligible range of reliable sensor nodes based on their stability function value and by considering residual energy of the nodes participating in the packet transmission.

6.9 CHAPTER SUMMARY

This chapter presented the implementation of the proposed routing protocol. Two scenarios were presented namely sparse and dense network. The first simulation was conducted for a sparse network, which was set up to determine the energy consumption of the sensor nodes by considering the performance metrics which consists of the packet received, packet loss, energy consumption and delays. The first simulation for the sparse network was tested for a varying number of sensor nodes namely 15, 30, and 50 nodes. The results indicated that the proposed routing protocol AODV-SUARP performed better than the AODV and VBF routing protocols as the number of the sensor nodes increased in terms of packet received, less packet loss and consumed less energy. The AODV-SUARP performance was attributed to the identification of energy levels amongst the sensor nodes by selecting three best path to use for packet transmission before initializing another route discovery process, this helped to reduce routing overhead. The second simulation (on dense routing protocols) was based on the LEACH routing protocol which works based on rounds. The simulation was conducted for 200 and 300 nodes by considering performance metrics, which include the packet delivery ratio, residual energy of the nodes and number of dead nodes. The result indicates that LEACH-DUARP performed better than LEACH and DIRECT LEACH in transmission as the number of sensor nodes increased. LEACH-DUARP acquired considerable residual energy from the nodes, high packet delivery and fewer dead nodes compared to LEACH and DIRECT. This was due to selection of an eligible cluster head node in subsequent rounds by considering the sensor node's energy levels through the stability function value. The next chapter presents the performance evaluation and validation.

CHAPTER SEVEN

PERFORMANCE EVALUATION AND VALIDATION

7.1 INTRODUCTION

The objective of this Chapter is to validate the simulation results of the proposed routing protocols for both sparse and dense network architecture using mathematical approach and evaluate their performance compared to other related work. The proposed AODV-SUARP and LEACH-DUARP routing protocols were initially implemented in Aquasim-NG for NS-3 using different simulation scenarios as presented from the previous chapter. The simulation for the proposed sparse network architecture was conducted based on AODV routing protocol to minimize the energy consumption among sensor nodes and to select the best eligible route to transmit packets across the network. To extend the lifetime of the network, sensor nodes energy level was examined together with the introduction of route stability function to select the best route based on energy level. The second simulation for the proposed dense network architecture was conducted based on LEACH routing protocol to effectively select the most eligible cluster head node with the highest energy level to participate in cluster data aggregation and transmission. However, to avoid selecting ineligible cluster head node within a cluster, the concept of stability function value was introduced to select the most eligible sensor node to act as the cluster head node for subsequent rounds. This chapter is focused on the mathematical representation of the proposed AODV-SUARP routing protocol with numerical energy consumption, packet delivery ratio and delay. Furthermore, Mathematical representation of LEACH-DUARP with numerical representation of energy consumption, packet delivery ratio and number of dead nodes are presented respectively.

7.2 ANALYTICAL VALIDATION OF THE PROPOSED AODV-SUARP ROUTING PROTOCOL

The analytical validation of the proposed AODV-SUARP routing protocol is based on the metrics in the simulation which were presented on the previous chapter consisting of energy consumption, packet delivery ratio and delay. In other words, the simulation parameters of the proposed AODV-SUARP will be used to produce the mathematical result and compare it with the simulated results.

AODV-SUARP as mentioned earlier (Saleh, Takruri, & Linge, 2022) is based on AODV routing protocol that selects routes based on sensor nodes energy level, thereby extending the life span of the sensor nodes with low energy level. AODV-SUARP routing protocol modifies the route request (RREQ) packet $\mu(p)$ format by adding the sensor nodes energy status which helps to identify the most eligible sensor nodes for each route to act as packet forwarders. The initial AODV RREQ message format $\mu(p)$ (Perkins, Belding-Royer, & Das, 2003) is mathematically presented as

$$\mu(p) = \sum_{j=1}^{6} RQi \quad \text{.......................... (8-1)}$$

The representation of RQ_1, RQ_2, RQ_3 …….. RQ_6 is presented in table 8-1

Table 7.1: Description of AODV RREQ packet header

Notation	Representation
RQ_1	Message type
RQ_2	Route request ID
RQ_3	Destination IP address
RQ_4	Destination sequence number
RQ_5	Originator IP address
RQ_6	Originator sequence number

The new packet format for AODV-SUARP as proposed is expressed as

$$\mu(p)_1 = \mu(p) + Sn_e \quad \text{.................... (8-2)}$$

Where Sn_e represent the sensor nodes energy level as an indicator of node energy level of sensor nodes participating in route request message dissemination across the route to destination node. The senor nodes energy level provides the information to help in selecting the most eligible senor nodes to act as packet forwarders for route request message in the process of establishing a route from the initiator of the route request message to destination node. AODV-SUARP (Saleh et al., 2022) proposed the new route request message as RRQ to effectively disseminate a route request with energy consideration. This message ensures sensor nodes energy level is determined in the process of establishing a route from source to destination. The conventional AODV (Perkins et al., 2003) upon receiving the RREQ message effectively respond back by route reply message (RREP) to the sensor node that initiates the route request message. The initial route reply message is expressed mathematically as

$$\mu(d) = \sum_{k=1}^{5} Rp_n \qquad \text{………………….. (8-3)}$$

The representation of the Rp_1, Rp_2, …….... Rp_5 is listed in the table 8-2 as follows.

Table 7.2: Description of AODV route reply packet header

Notation	**Representation**
Rp_1	Message type
Rp_2	Destination IP address
Rp_3	Destination sequence number
Rp_4	Originator IP address
Rp_5	Lifetime

Then the new packet format $\mu(d)_1$ for AODV-SUARP consist of the conventional AODV route reply RREP packet format $\mu(d)$ together with route stability *(RST)* which is expressed as

$$\mu(d)_1 = \mu(d) + RSF \qquad \text{……………… (8-4)}$$

Where $\mu(d)_1$ represents the newly proposed route reply message RRP for AODV-SUARP which was modified from the original RREP message for the conventional AODV routing protocol. This message consist of the initial RREP message content in which route stability function was added. For the conventional AODV routing protocol when RREQ message is received it will then disseminate the route reply message back to the source node without taking the energy of the sensor nodes into consideration. However, AODV-SUARP (Saleh et al., 2022) effectively introduces the concept of route stability function to choose the most eligible route to send the route reply message by taking the senor nodes energy into consideration for the selected routes. Route stability function RSF selects and categorise the routes based on the energy level of the sensor node for each path using energy stability parameter α to compare the energy level for each sensor nodes within the selected routes with a range $1 \leq \alpha \leq 100$. Where x_1 represent the weak route, x_2 represent the strong route, x_3 represent the stronger route, and x_4 represent the strongest route. The concept of the route stability function is mathematically expressed using step function as:

$$RSF = \begin{cases} x_1 = 1 \leq \alpha \leq 39 \\ x_2 = 40 \leq \alpha \leq 59 \\ x_3 = 60 \leq \alpha \leq 69 \\ x_4 = 70 \leq \alpha \leq 100 \end{cases} \quad \text{.. (8-5)}$$

Thus, we can say that the proposed AODV-SUARP routing protocol consists of the modified route request message and route reply message in the route discovery phase where these messages are expressed as

$$M_d = \mu(p)_1 + \mu(d)_1 \quad \text{.................................... (8-6)}$$

M_d represents the overall modified messages for AODV-SUARP at route discovery phase with energy consideration. Low energy sensor nodes experience quick power failure especially for underwater communication where they can neither replace nor recharge due to the nature of the environment. AODV-SUARP (Saleh et al., 2022) proposes the concept of route stability function to further improve the energy conservation, and effectively extend the lifespan of low powered sensor nodes in the process of communication. The analytical validation of the AODV-SUARP routing protocol is based on the following performance metrics energy consumption, packet delivery ratio and delay.

7.2.1 ENERGY CONSUMPTION

The energy consumption of a sensor node plays a vital role in the process of communication especially when the sensor nodes depend on battery as power supply. The numeric energy consumption is based on the linear regression model as highlighted in (Arregi & Garay, 2017) which defined the variables within the linear equation where it fits the sum of energy consumption of a node in sensing, transmitting, receiving and idle states. Considering the energy consumption of sensor nodes for each state

Let E_X represent default sum of the current sensor node states which can be expressed as

$$E_X = e_s + e_t + e_r + e_{idl} \quad \text{.................................. (8-7)}$$

Where e_s represent the sensor node energy in sensing, e_t represent the sensor node energy in transmitting, e_r represent the sensor node energy in receiving and e_{idl} represent the sensor node energy in idle state at default.

The transmit and receive energy are determined by power from signal transmission of the physical layer. The underwater acoustic channel is affected due to some external interference where noise was considered as a factor for acoustic signal degradation (Wang et al., 2020). This noise affects the acoustic signal, transmit and receive energy which are determined by signal transmission power from the physical layer. The power spectral density (J. Li et al., 2020) which consists of four types of noise as thermal, turbulence, shipping and wind in decibels are expressed as follows.

$$PSD = S_N + Th_N + T_N + W_N \quad \text{................................ (8-8)}$$

Moreover, the bandwidth (BW) used for the acoustic signal is limited due to the convergence (transmission range) that is inversely proportional to its bandwidth. This result to limited frequencies for routing protocols in selecting path to deliver packets from source destination. In acoustic underwater communication a very long range of over 100km requires a bandwidth of less than 1kH, a long range of 10-100kM requires 2-5kH of bandwidth, a medium range of 1-10kM requires a maximum 10kH bandwidth, while a short-range communication of 0.1-1kM requires a maximum of 20-50kH (Khan et al., 2018). The bandwidth is expressed as

$$B_d = \sum_{I=1}^{1} BW \quad \text{... (8-9)}$$

Let K_X represent the consumed sensor nodes state during sensing, transmitting, receiving and idle states. By substituting E_X with K_X respectively then, the total energy consumption by sensor nodes to transmit and receive packet. Then the total energy consumed by sensor nodes to transmit and receive packet at time t can be expressed as:

$$K_X = \frac{E_X(\sum_{i=1}^{4} e)}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(8-10)}$$

The parameters for calculation of the energy consumption are presented in the table below

Table 7.3: Parameters for calculation of energy consumption

Definition	**Symbols**	**Value(s)**
Sensor node default transmission power	E_X	10J
Maximum battery percentage of sensor nodes based on route priority for $i = 1 - 4$	e	39%, 59%, 69%, 100%

The calculated result was obtained using the total energy consumption formular from equation (8-10) based on the parameters from table 8-3. different number of sensor nodes were used.

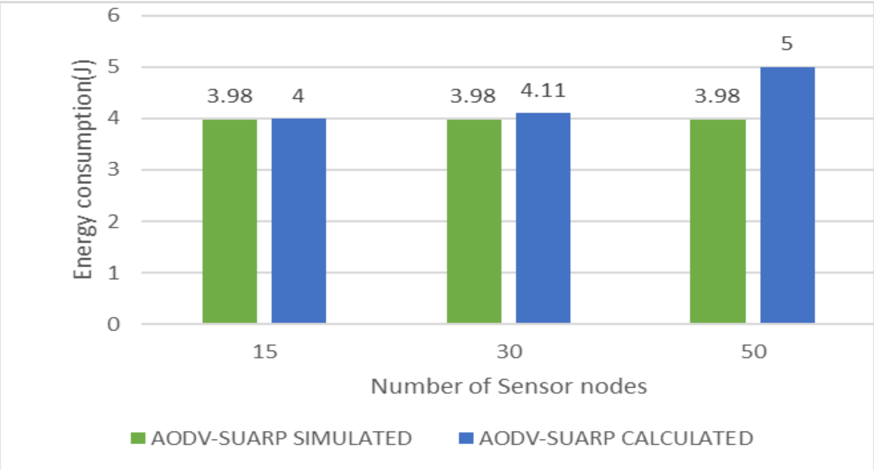


Figure 7.1: Comparison of simulated and calculated energy consumption of AODV-SUARP

The calculated results were obtained using the total energy consumption formular in equation (8-10) based on the parameters in Table (7.3). The model utilised a transmission rate of 5pct/sec over the duration of 200 seconds with the node density of 15, 30, and 50 nodes as used in the simulation. It can be seen from figure 8-1, the energy consumption used as a parameter in the simulation is a bit lower compared to the calculated mathematical model for AODV-SUARP routing protocol. This is due to the unpredictable nature of underwater environment, with the introduction of noise for the underwater acoustic channel, and the mobility model for the simulation. However, the energy consumption of the sensor nodes for both simulated and calculated AODV-SUARP is quite reasonable considering the number of nodes and the packets being transmitted successfully as compared in which AODV-SUARP achieved less energy consumption of 30% as compared to (Singh & Gupta, 2021) which achieved 38% for energy utilization among sensor nodes.

7.2.2 PACKET DELIVERY RATIO

The packet delivery ratio is one of the crucial metrics for evaluating the effectiveness of the routing protocol in any network. The packet delivery ratio is calculated by dividing the total number of packets of data that arrived at destinations divided by the total number of packets sent from source. In other words, Packet delivery ratio is the ratio of number of packets received at the destination to the number of packets sent from the source. This metric effectively expresses the transmission reliability of AODV-SUARP (Saleh et al., 2022). Packet delivery is expressed below as:

$$PD = \frac{p_t}{p_r} \qquad \text{.. (8-11)}$$

Where p_t is denoted as the number of packets successfully received, and p_r denote as the number of packets sent. Although to determine the sum of the total number of packets being received successfully over the network mathematically, a model known as Bernoulli probability distribution model (Dai, Bao, & Bao, 2013)was used. Then, the probability of the successful packet being received over the network is expressed using Bernoulli probability as

$$B_n = \sum_{j=1}^{h} v^{j-1}(1-v) = 1 - v^h \qquad \text{............................ (8-12)}$$

Where (*h*) and (*v*) denoted the number of transmissions per second and the probability of success (Dai et al., 2013). From the equation above, the probability of packet transmission when (*v*)=1 is 0. This shows that, all packets that are transmitted are successfully received. And the probability of packet transmission when (*v*)=0 is 1, which imply that the total number of packets not received that is the complete packet loss. This can be expressed as

$$z_s = \begin{cases} 1, v = 0 \\ 0, v = 1 \end{cases} \qquad \text{..................................... (8-13)}$$

To determine the total number of packet transmission, we say R_1 represent the total number of successful packets received, and R_0 represent the total packet loss. Then from equation by determining the packet transmission when *v=1* for total number of packets received based on Bernoulli distribution, we expressed it as

$$S_0 = 1 \times R_1 \quad \text{.......................................} \quad (8\text{-}14)$$

Furthermore form equation to determine the packet transmission when *v=0* , i.e when no any packet is received which is the total packet loss based on Bernoulli distribution we expressed it as

$$N_0 = 0 \times R_0 \quad \text{......................................} \quad (8\text{-}15)$$

To determine the overall packet delivery ratio from equation its then represented as

$$PDR = \frac{\sum p_t}{\sum p_r} \times 100 \quad \text{......................................} \quad (8\text{-}16)$$

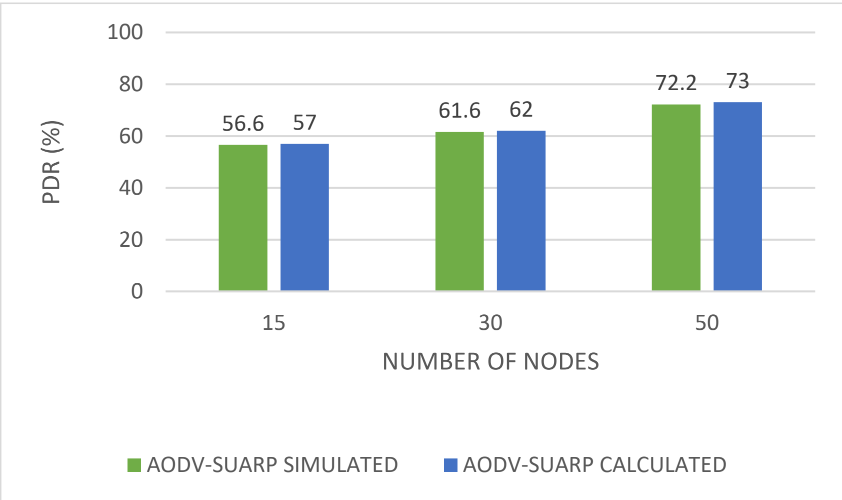


Figure 7.2: Comparison of packet delivery ratio for simulated and calculated AODV-SUARP

Figure 7.2 represent the packet delivery ratio (PDR) for simulated and calculated AODV-SUARP routing protocol. As previously stated, based on the simulation 5 packets per second was used with a total simulation time of 200 seconds. As seen from the packet delivery ratio, the difference between simulated and calculated AODV-SUARP is not much which can be attributed to other factors that affects the simulation which cannot be quantified mathematically. For the proposed routing scheme of AODV-SUARP, reasonable number of packets were delivered for both simulated and calculated PDR for 72% as compared to (Singh & Gupta, 2021) which achieved 70% for packet delivery ratio.

7.2.3 DELAY

Partitioning the packets into smaller segments is a necessary step in the transmission of a packet from one endpoint to another in a network. At the destination, the packets are packetized after being sent separately. This procedure is heavily reliant on the quantity of intermediary nodes and the distance from the source to destination (Bellalta, 2020). However, packet experiences several delays at each intermediary node, as discussed in the subsection below.

7.2.3.1 PROPAGATION DELAY

Acoustic signals are primarily constrained by propagation delay in underwater environments, which is about 2×10^5 times slower than electromagnetic propagation in terrestrial conditions. This delay indicates the amount of time needed for a packet to move in a network between source and destination nodes. It depends heavily on characteristic of the medium in place and the distance between the receiver and transmitter. Then, propagation delay is D⁄S where D is the distance between nodes and S is the propagation rate.

$$P_d = \frac{D}{K} \quad \text{………………………………………… (8-17)}$$

7.2.3.2 TRANSMISSION DELAY

The nodes can have many nodes specific delay variables such as queueing or packet processing, but all nodes involve in packet transmission are required to get the packets onto the transmission link and this is known as the Transmission Delay. The time needed to send all bits of packets with a size of M over a transmission rate of G in bps is also referred to as transmission delay. This is express as

$$T_d = \frac{M}{G} \quad \text{………………………………………… (8-18)}$$

7.2.3.3 QUEUING DELAY

The amount of time a packet spends in queue while awaiting transmission onward is represented as a queuing delay. It is highly influenced by the quantity of packets that needs to be transmitted. A queuing delay is a wait while a node prepares and transmits packets. Nodes with multiple packets handle set up a queue for processing because they can only deal with one at a time. This creates a delay until the node can clear data and start transmitting. Queueing Delay is a function of transmission delay, Td and average queue length, AV which is represented as follows.

$$Q_d = T_d * AV \quad \text{………………………………………. (8-19)}$$

7.2.3.4 PROCESSING DELAY

The time it takes a node to process a packet in a network, which is dependent on the speed of the device and congestion in the network. This delay refers to the time required by a node to analyse received packets. The analysis includes checking packets for error and destination. It completely hardware specific.

7.2.3.5 NODE TOTAL DELAY

As packet travels from one node to another along its path, the packet suffers from several types of delays at each node along the path. The most important of these delays are the processing delay, queuing delay, transmission delay, and propagation delay; together, these delays accumulate to give a total nodal delay.

$$N_d = prc_d + Q_d + T_d \quad \text{…………………………….. (8-20)}$$

7.2.3.6 END TO END DELAY

End-to-end delay is the amount of time it takes a packet to travel from source to destination across a network. This delay shows how long a packet took to travel between its source node to destination node. This value is dependent on some certain characteristics of delay which include transmission, propagation, processing and queuing, distance, and traffic load. Most of these delays are static which mean they do not change over transmission period (Bellalta, 2020). End to end delay relies on transmission characteristics which include traffic load, distance and number of hops from source to destination which can be expressed as follows

$$E2E_d = \sum_{j^i} d(m,n) \quad \text{……………………. (8-21)}$$

From the equation above it is observed that the dominant variance of end-to-end delay in constant flow packet network is queueing delay which will be the focus for analysis in this work. Given that *P(t)* is the number of packets over time, which is related to packet arrival and departure functions as ω *and* δ respectively. The transmission delay is always the same when a packet of a given size v is sent through a network at a given transmission rate q. But queueing delay or waiting time differs since it typically depends on buffer size and buffer condition (Bellalta, 2020).

Especially in network modelling, service transmission time is usually taken into consideration in which $S_{trans} = \frac{n(l)}{q}$, transmission rate ($q$), where maximum packet departure $E\delta = \frac{p}{S_{trans}}$, with traffic intensity $\beta = \frac{\omega}{\delta}$ which is measured in erlangs. Erlang notation of $M/M/S/K$ queueing system has been used for modelling network in the past, where number of servers S represents number of active simultaneous calls in a link or cell (Bellalta, 2020). For the creation of network models, the Erlang notation of M/M/S/K and M/M/1 is employed. Poisson arrival and exponential distribution service time are represented by the first and second Ms, respectively. S stands for server, while K is the size of the buffer. $M/M/1$ system assumes nodes buffer size is large or infinite ($k = \infty$). This queueing system provides accurate model and allow estimation of different expected end-to-end delay through simple expression than $M/M/1/K$ system (Bellalta, 2020). Therefore, it is considered as a complementary queueing modelling technique can be used to test performance of new system with useful results. Busy server occurs due to high service rate, where service rate depends on the state of the system. Markov chain relationship between packet departure for a service rate is illustrated below.

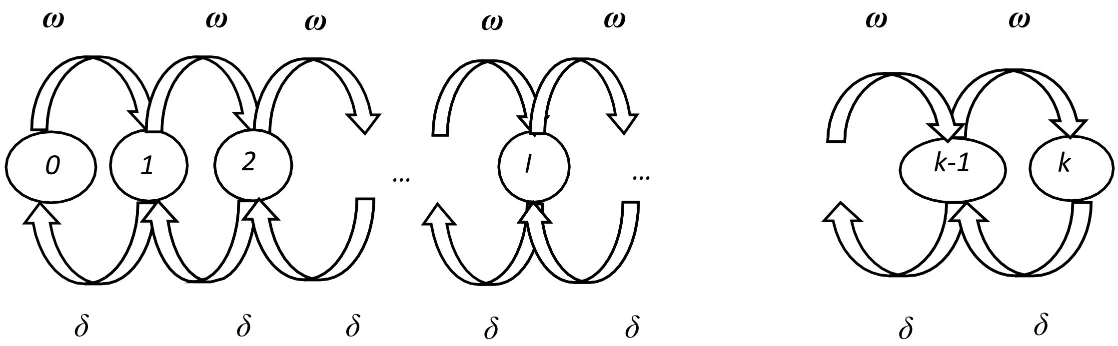


Figure 7.3: Queuing delay for Markov chain based on packet departure (bellalta,2020).

Furthermore, below are some of the explanations of parameters used in the modelling for the end-to-end delay.

Table 7.4: Description of terms used for end-to-end delay modelling.

Value	**Interpretation**
ω	Arrival rate of packet
δ	Packet departure rate
λ	Poisson arrival process
N	System utilisation
β	Traffic intensity
L	Packets length
Q	Packets in buffer (K-S)
K	Overall number of packets in a system
S	Number of servers (transmitters and processor)
P_L	Probability of packet loss
R	Transmission rate
$P = \omega_0$	Probability at any given time for nodes buffer to be empty
$P_L = \omega_k$	Packet loss probability
$\rho = 1 - \omega_0$	Time fraction in which an active system transmits packets
ω_i	Probability in which there exist I number of packets at any arbitrary time.

The explanation of M/M/1/K in case of load balancing is describe from figure 8-3 below.

$$\lambda_0 \omega = \omega_1 \delta$$
$$\lambda_1 \omega = \omega_2 \delta$$
$$\cdots$$
$$\lambda_{i-1}\delta = \lambda_i \delta \rightarrow \lambda_i = (\frac{\omega}{\delta})\lambda_{i-1} = \beta\lambda_{i-1} \rightarrow \lambda_i = \beta\lambda_0$$
$$\cdots$$
$$\lambda_{k-1}\omega = \lambda_k \delta$$

By applying normalisation condition to acquire equilibrium distribution in which the sum of probability states equals to 1, and the probability of for M/M/1/K is specified in equation below

$$\lambda_0 = \frac{1}{\sum_{n=0}^{k} \beta^n} = \frac{\frac{1}{1-\beta^{k+1}}}{1-\beta} = \frac{1-\beta}{1-\beta^{k+1}}$$
…………………….

(8-22)

Considering the equilibrium distribution model of M/M/1/K which is similar to M/M/1 systems, as $k \rightarrow \infty$ which leads to $\beta^{k+1} = 0$, Where $\beta < 1$ is expressed as follows

$$\lambda_0 = \frac{1}{\sum_{n=0}^{\infty} \beta^n} = \frac{\frac{1}{1}}{1-\beta} = 1-\beta$$
………………….. (8-23)

By acquiring the probability for the initial state (O^{th}) for M/M/1 and M/M/1/K system, therefore the i^{th} probability for both queuing systems is expressed below.

$$\lambda_i = \beta^i \lambda_0 = \frac{(1-\beta)\beta^i}{1-\beta^{k+1}}$$
………………………… (8-24)

$$\lambda_i = \beta^i \lambda_0 = (1-\beta)\beta^i$$
………..……………….. (8-25)

Moreover, to obtain the probability where the packets arriving meets a full state (K) is equivalent to the probability of a packet loss because of overflow (Bellalta, 2020), and this can be expressed below as follows.

$$P_L = \lambda_k = \frac{(1-\beta)\beta^k}{1-\beta^{k+1}} \quad \text{……………………………. (8-26)}$$

$$P_L = 0 \quad \text{……………….…………….. (8-27)}$$

To realise the expected average number of packets over the network for queue occupancy, the following parameters are utilised as follows.

Q_N Number of packets expected in a system.

Q_0 Number of packet delay expected in a system.

Q_P Packet delay expected in a buffer.

Q_R Number of packets expected in a queue.

Q_S Packet delay expected in a server.

Q_T Number of packets expected in a service.

To obtain the average number of packets in a queue when traffic intensity β is such that $\beta < 1$ for M/M/1 system and $\beta \neq 1$ for M/M/1/K queueing system is expressed below as follows.

$$Q_N = \sum_{V=0}^{k} \lambda_v V = \frac{\beta}{1-\beta} - \frac{(k+1)\beta^{k+1}}{1-\beta^{k+1}} \quad \text{………………………. (8-28)}$$

$$Q_N = \sum_{V=0}^{\infty} \lambda_V V = \frac{\beta}{1-\beta} \quad \text{……………………………… (8-29)}$$

It can be observed that when β=0 implies that no packet exists in the buffer. This research work focus on every time a packet is transferred form one node to another it meets another packet in its buffer. However, Poisson arrival distribution process was utilised for the queuing systems in which the arrival rate is multiplied by the average time a packet spent in the system which is obtain as follows.

$$Q_O = \frac{Q_N}{\omega(1-P_L)} \quad \text{(8-30)}$$

$$Q_P = \frac{Q_R}{\omega(1-P_L)} \quad \text{(8-31)}$$

$$Q_S = \frac{Q_T}{\omega(1-P_L)} \quad \text{(8-32)}$$

$$Q_R = \sum_{i=s+1}^{k} (i-s)\times\lambda_i = Q_N - Q_T \quad \text{(8-33)}$$

$$Q_T = \sum_{i=0}^{k} \min(i,s)\times\lambda_i \quad \text{(8-34)}$$

$$Q_N = \sum_{i=0}^{k} i\times\lambda_i \quad \text{(8-35)}$$

The models above utilised the queuing system of M/M/1/K using Markov chain which uses the service time distribution and Poisson arrivals. Moreover, certain conditions are needed for M/M/1 queuing system which consist of the traffic intensity to be $\beta<1$, and buffer size of the node to be large or infinite ($k=\infty$) (Bellalta, 2020). Low traffic intensity is needed for the system to effectively realised an accurate model. For M/M/1/K queuing system. As this allows end to end delay estimation. The following equations below are used to express the system occupancy for M/M/1 system.

$$Q_N = \sum_{y=0}^{\infty} \lambda_y y = \frac{\beta}{1-\beta} \quad \text{(8-36)}$$

$$Q_T = 1-\lambda_0 = \beta \quad \text{(8-37)}$$

$$Q_R = Q_N - Q_T = \frac{\beta}{1-\beta} - \alpha = \frac{\beta}{1-\beta} \quad \text{(8-38)}$$

$$Q_S = \frac{Q_T}{\omega(1-P_L)} = \frac{\beta}{\omega} = \frac{1}{\delta} \quad \text{(8-39)}$$

$$Q_O = \frac{Q_N}{\omega(1-P_L)} = \frac{\beta^2}{\omega(1-\beta)} = \frac{\beta}{\delta(1-\beta)} = \frac{\beta}{\delta-\omega} \quad \text{.................... (8-40)}$$

The assumptions as described above are based on Jackson and burkes theorems (Tsitsiashvili & Osipova, 2018) in which they prove and demonstrated that the M/M/1 queuing systems follows the Poisson distribution which enable us to describe the behaviour of the network interface independently. Then end-to-end delay over the network is represented as the time in which a packet spent between source and destination nodes which is the sum of average time spend in each node and average delay of packets in a network. This is represented below as follows.

$$E_2Ed = \sum_{\forall i}(Q_O + Q_P) \quad \text{...................................... (8-41)}$$

Where Q_O and Q_P are the expected delay and expected queuing delay. Furthermore, the end-to-end delay is substituted below as

$$E_2Ed = \sum_{\forall i}\frac{1}{\omega-\delta} + \frac{\beta}{\omega-\delta} \quad \text{... (8-42)}$$

$$E_2Ed = \sum_{\forall i}\frac{1+\beta}{\omega-\delta} \quad \text{... (8-43)}$$

Moreover, number of participating nodes *Pi*, hop count *hp*, and time *T*, and acoustic channel noise *n* were added, where the overall end to end delay is represented in the model below as follows.

$$O_{verall}d = E_2Ed \times (P_ih_pTn) \quad \text{................................ (8-44)}$$

Table 7.5: Parameters for calculating end to end delay.

Variable	**Value**	**Unit**
Ω	(200, 300, 500)	Packets/second
Packet size	50	Bytes
Acoustic channel noise(n)	20	Decibels (db)
R	1000	BPS
Pi	15, 30, 50	-
T	200	Seconds
β	0<β<1	Erlangs
δ	5	Packets/second

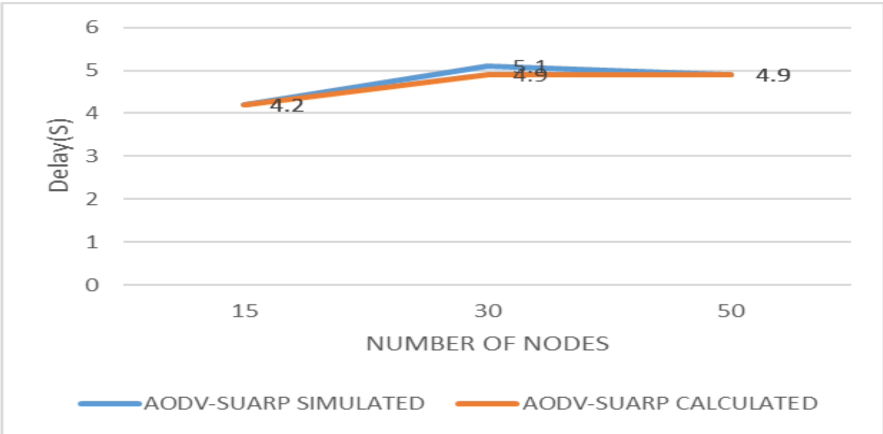


Figure 7.4: Comparison for the simulated and calculated End to End delay for AODV-SUARP

Figure 7-4 represent the computed end to end delay for AODV-SUARP routing protocol as compared to the simulated AODV-SUARP for 15, 30, and 50 nodes. The end-to-end delay for the simulated AODV-SUARP is lower compared to the calculated AODV-SUARP over the simulation time of 200 (s). This shows a significant performance in terms of acquiring less delay in the process of packet transmission for the simulate and calculated AODV-SUARP with 40% as compared to(Singh & Gupta, 2021) with 50% delay.

7.3 ANALYTICAL VALIDATION OF THE PROPOSED LEACH-DUARP ROUTING PROTOCOL

The analytical validation of the proposed LEACH-DUARP routing protocol is based on the metrics in the simulation which was presented on the previous chapter consisting of packet delivery ratio and number of dead nodes. In other words, the simulation parameters of the proposed LEACH-DUARP will be used to produce the mathematical result and compared it with the simulated result. LEACH-DUARP as mentioned earlier is based on LEACH (Gnanambigai, Rengarajan, & Anbukkarasi, 2012) routing protocol which selects the most eligible sensor node to act as a cluster head node within a cluster based on some certain factors which consist of energy level. This is proposed to prolong the life span of the senor nodes within each cluster and the overall network lifetime.

Let B be a set of space which contains a set of discrete random variables t. where each entity of t denoted as i is weight based on certain characteristics q. then to formalise the distribution of the variables within a space, a set of nodes B is such that $B = t(i.....n)$

To assign each sensor nodes closest distance between two or more points, we use Euclidean distance to find the closest points between the sensor nodes which is expressed as

$$d(p,q) = \sqrt{\sum_{i=1}^{n} (q_i - p_i)^2} \quad \text{.................................... (8-45)}$$

Where p and q are two points i.e the distance between sensor nodes. Then to determine the centroid between each cluster allocation between sensor nodes using average minimum distance, concept of K-means clustering was use by assigning each point to determine the distance between cluster head and sensor nodes in the cluster initially. K-means is expressed as

$$J = \sum_{j=1}^{k} \sum_{i=1}^{n} \left\| x_i^{(j)} - c_j \right\|^2 \quad \text{... (8-46)}$$

Where k= number of clusters, n=number of cases, cj= centroid for cluster j.

For a subsequent selection of cluster head node for upcoming rounds, concept of grey wolf algorithm is used for the selection of eligible cluster head. Gray wolf Optimization algorithm is a metaheuristic bio inspired algorithm developed by (Mirjalili, Mirjalili, & Lewis, 2014) to mimic the biological, social, hunting and leadership behaviour of the Gray wolf packs. Gray wolf typically lives in packs and the social hierarchy of the wolves are categorized into four according to their fitness. Gray wolf optimization algorithm works on fitness value regarding the wolves. Any wolf in the pack that achieve a fitness regarding a task will shift its position there by allowing other wolves in the pack to also adjust their task in the pack. The Gray wolf optimization algorithm works on three stages which consist of searching/hunting, encircling, and attacking. The first two stages which are searching, and encircling are regarded as exploration phase and the last stage which is the attacking stage is regarded as the exploitation phase.

During hunting, the location of the prey is assessed by α, β, and δ wolves, and the remaining wolves calculate the distance between themselves and the prey; then, the wolves encircle the prey. The following are the stages for the grey wolf in their hunting over a prey.

In the hunting process of the wolves over a prey, wolves in the pack update their position and distance towards the prey. The α, β, δ evaluate the position of the prey by determining their position. This is mathematically modelled as

$$\vec{D} = \vec{C} \times \vec{X}_P^t - \vec{X}^t \quad \text{……………………………… (8-47)}$$

$$\overrightarrow{X^{t+1}} = \vec{X}_p^t + \vec{A} * \vec{D} \quad \text{……………………………….. (8-48)}$$

X_p stand for the position of the prey, *t* stand for the number of iterations, $\vec{X}$ and stand for the position of the wolf. $\vec{D}$ Stand for the distance between the prey and the wolves. $\vec{A}$ and $\vec{C}$ Stand for the vectors co-efficient, where.

$$\vec{A} = 2\vec{d} * \vec{r_1} - \vec{a} \quad \text{………………………………….. (8-49)}$$

$$\vec{C} = 2\vec{d} * \vec{r_2} \quad \text{……………………………………. (8-50)}$$

$\vec{a}$ linearly decreased from 2 to 0 because of iteration, where r_1 and r_2 represent the range of vectors from (0,1).

The hunting for the prey in the pack is carried out by the wolves having much whereabout for the location of the prey. These hunting is guided by the α, β, and δ. So, the finest solution is used to update the positioning of ω wolves, which can be.

$$\overrightarrow{D_\alpha} = \overrightarrow{C_1} * \overrightarrow{X_\alpha} - \vec{X}, \quad \overrightarrow{D_\beta} = \overrightarrow{C_2} * \overrightarrow{X_\beta} - \vec{X}, \quad \overrightarrow{D_\delta} = \overrightarrow{C_3} * \overrightarrow{X_\delta} - \vec{X} \quad \text{…………………. (8-51)}$$

Where X_α, X_β, X_δ represent the position of α, β, and δ, while D_α, D_β, D_δ represent the position being updated by α, β, and δ. $\vec{X}$ stand for the current position to the solution.

To obtain the position of final solution, then

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1} * \overrightarrow{D_\alpha}, \quad \overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2} * \overrightarrow{D_\beta}, \quad \overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_3} * \overrightarrow{D_\delta} \quad \text{…………………… (8-52)}$$

Then the three best solutions will be

$$\vec{X}_{(x+1)} = \frac{X_1 + X_2 + X_3}{3} \quad \text{…………………………….. (8-53)}$$

After successful iteration, the wolves will then update their position each to determine the wolve with the best position X_α which is suited to be the optimal solution to capture the prey.

Then to determine the next round selection of cluster head in a cluster the concept of grey wolf algorithm was adopted if the current cluster head node in a cluster achieve some conditions which consist of receiving packets from average number of sensor nodes within the cluster or when the residual energy is below threshold value which is expressed mathematically as

$$C_n = \begin{cases} Anp = \dfrac{X}{Q-1} \times (Q-1) \\ \mathrm{Re}(node) \leq \beta \end{cases} \quad \text{.......................... (8-54)}$$

Where *X*= total number of the sensor nodes within the cluster including the cluster head, *Q-1*= total number of the sensor nodes within the cluster excluding the cluster head node. The cluster head node uses two comparable parameters for the two conditions to determine if any one of them is achieved. α is used for the first condition where α is such that $0 \leq \alpha \leq \frac{q-1}{2}$. And β is used for the second condition to determine the residual energy where β is such that $0 \leq \beta \leq \frac{V(i)}{2}$, $V(i)$ is the initial nodes energy level. If any one of the above conditions hold for the current cluster head node, then the selection for cluster head for the next round will take effect.

Then to determine the eligible sensor nodes within the cluster to be selected as the next cluster head, we use variable h_q to denote the next strong eligible cluster head. In which h_q depends on the stability function value X_v. This is expressed mathematically as

$$h_q = X_v \quad \text{...................... (8-55)}$$

To obtain the stability function value X_v, grey wolf algorithm solution for determining the strongest wolf X_α with the best position to capture prey is adopted. Where certain characteristics were taken into consideration which consist of sensor node residual energy V_e, sensor nodes sequence number S_v, and sensor nodes status of being cluster head before d_v. Then stability function value X_v for the node h_q with the highest stability function value which will be the next cluster head is expressed mathematically as

$$X_v = V_e \times d_v + S_v \quad \text{……………………… (8-56)}$$

7.3.1 ENERGY CONSUMPTION

Clustering is extremely helpful for extending network lifespan and reducing sensor node energy consumption. Without clustering, data transmission requires a substantial amount of energy since nodes must communicate with the sink node, which could use an excessive amount of energy. Instead of communicating with the sink node, which may be located far from the node, clustering only allows nodes to connect with the CH located closest to them. As a result, it is crucial to efficiently group sensor nodes into clusters to lower the network's overall energy consumption. The residual energy of a node plays an essential role to determine the nodes energy capability in participating in packet transmission. Residual energy of a sensor node is determined by calculating the sum of energy depleted while the node is in each state. Energy consumption of model of an electric vehicle was adopted (Abousleiman & Rawashdeh, 2015) which is the integration of power output of the battery terminals. Where the sum of forces acting on electric vehicle are dependent on resistance, rolling, air and acceleration which is expressed mathematically as

$$\sum f = f_{roll} + f_{grad} + f_{air} + f_{acc} \quad \text{…………………….. (8-57)}$$

For the sensor nodes initial energy, we expressed it as

$$E_n = Er_{init} \quad \text{…………………………………… (8-58)}$$

Then to find the energy consumption of a sensor node, the above equation was adopted where the total sum of energy of a node in sensing, transmitting, receiving and idle state for packet transmission is expressed as

$$E_{con} = En_{sens} + En_{tran} + En_{rec} + En_{idl} \quad \text{………………………… (8-59)}$$

Then the residual energy of a node is expressed as

$$\mathrm{R}_{en} = Er_{init} - E_{con} \quad \text{……………………… (8-60)}$$

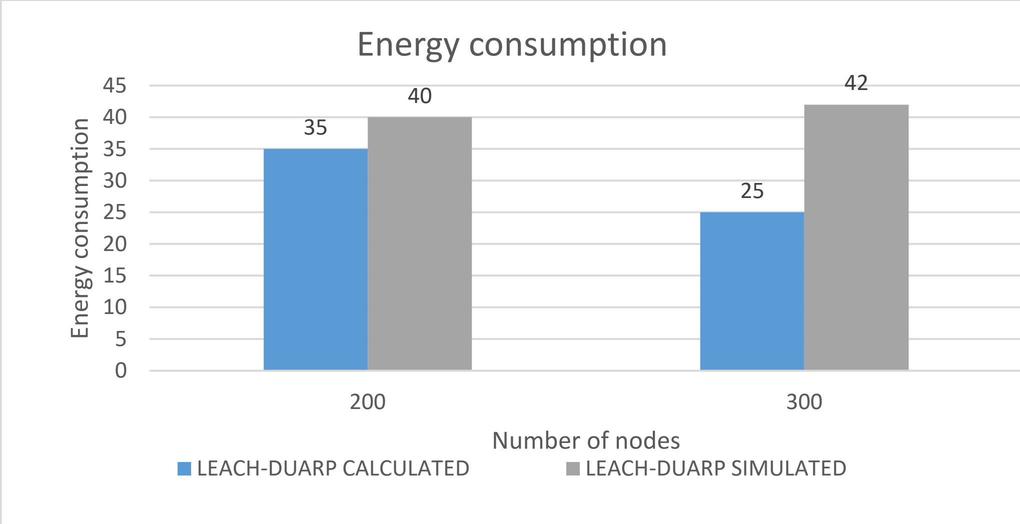


Figure 7.5: Comparison of energy consumption for LEACH-DUARP calculated and simulated.

Figure indicated the percentage for residual energy for both simulated and calculated LEACH-DUARP routing protocol. As previously stated on the simulation, 1000 number of rounds was used for LEACH-DUARP routing protocol. The result was tested over varying number of 200 and 300 nodes. LEACH-DUARP introduce a technique of stability function value to determine the eligible sensor node to act as cluster head node for a subsequent number of rounds through energy stability parameter. The increasing difference between calculated and simulated results for LEACH-DUARP with a higher number of nodes could be attributed to the stability function's sensitivity to network scale and the unpredictable nature of underwater features. The result for the simulated and calculated LEACH-DUARP over 1000 rounds indicates LEACH-DUARP simulated and calculated achieves 40% less on the sensor nodes energy consumption compared to, (Rizvi, Khan, & Enam, 2023) which achieves 30%.

7.3.2 PACKET DELIVERY RATIO

The ratio of total packets delivered to the total packets sent from source node to destination node in the network is known as the packet delivery ratio (PDR). Maximum data packets arriving at the destination is what is desired. The increase and decrease in PDR in a network determine the network performance. Packet delivery is expressed as

$$Pdelrat = \frac{packetsreceived(P_r)}{packetsent(p_s)} \quad \text{.................................... (8-61)}$$

Where (P_r) denotes the number of packets being received successfully at the destination node, and (p_s) denote the number of packets being successfully sent. Bernoulli distribution ws used to determine the successful outcomes of success or failure regarding the packets over the network where.

$$P(n) = P^n(1-p)^{1-n} \quad \text{... (8-62)}$$

Then the probability density function for either failure to occurs where n=0 as success and n=1 as failure, which equally determines the success or failure of packets over the network as adopted from Bernoulli density function where

$$P_n = \begin{cases} 1-p, for, n=0 \\ p, for, n=1 \end{cases} \quad \text{... (8-63)}$$

Then to determine the overall packet delivery ratio for the packets over the network, which is the ratio of the total packets received by the total packet sent is expressed as

$$Pdelrat = \frac{packetsreceived(P_r)}{packetsent(p_s)} \times 100 \quad \text{.................................... (8-64)}$$

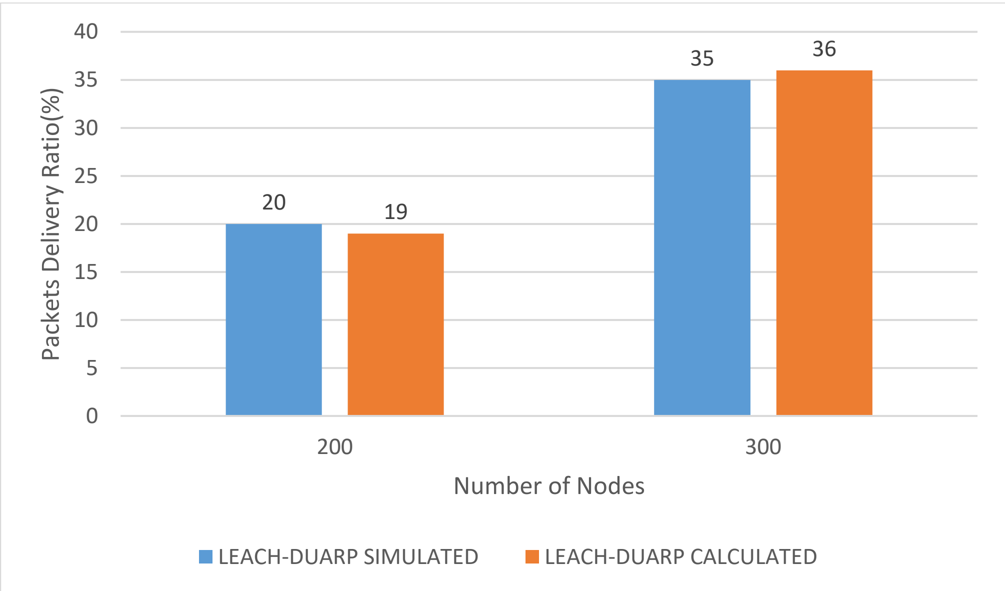


Figure 7.6: Comparison for packet delivery ratio for LEACH-DUARP

Figure 7.6 indicate the comparison between LEACH-DUARP simulated and calculated based on packet delivery ratio. Based on the simulation carried out earlier, the simulation parameters which were set on 1000 packets with a rate of 5 packets per second for a total duration of 1000 rounds. Different varying number of 200 and 300 nodes were used to test the efficiency of the LEACH-DUARP routing protocol. The compared result indicated a slide difference in terms of the simulated and calculated LEACH-DUARP. As the number of the nodes increases LEACH-DUARP achieve 66% of packet delivery as compared to (Bharany, Sharma, Alsharabi, Tag Eldin, & Ghamry, 2023) which achieves 60% of PDR.

7.3.3 NUMBER OF DEAD NODES

Number of nodes in a network plays a major role in determining the efficiency and the overall network lifetime. Especially when dealing with a network where a considerable number of nodes a needed to participate in the exchange of packets over a particular duration. Nodes which are involve in packet transmission needs to maximize their lifetime to support the network prolongation. However, due to their dependency on battery for their life, sensor nodes must find a better way to extend their residual energy to stay for the duration of packet transmission. As the number of the rounds in the simulation keeps increasing, number of nodes keeps changing due to the number of actions they carried out. LEACH-DUARP routing protocol introduces a concept of maximizing the number of sensor nodes through stability function value to select the most eligible sensor node to act as cluster head without exhausting their energy. Number of dead nodes is generated from the total number of nodes within the network which is expressed as follows:

$$K_n = \sum_{i=1}^{n} n \qquad \text{.. (8-65)}$$

Where K_n stands for the total number of nodes distributed over the network, to determine the successful nodes that remain alive after a specified duration based on energy consumption after performing some actions in the process of packet exchange, we expressed as

$$J_d = \sum_{k=1}^{f} f \qquad \text{.. (8-66)}$$

Where J_d stands for the total number of successful nodes which remain alive within the duration of packet exchange. To effectively determine the number of dead nodes over the duration of packet exchange as a result of energy depletion, sum of squared deviations for grouped data model (Ando & Bai, 2016) for different variables was adopted which is expressed as

$$ss_x = \sum_{i=1}^{k} x^2 - kx^2 \qquad \text{...} \; (8\text{-}67)$$

To find the number of dead nodes d_n for a specified duration of packet transmission across the network, the above model was adapted were,

$$d_n = \sum_{i=1}^{n} n - \sum_{k=1}^{f} f$$

Number of dead nodes d_n is obtain by excluding the number of alive nodes for the specified duration of packet transmission from the total number nodes distributed initially to participate in packet exchange.

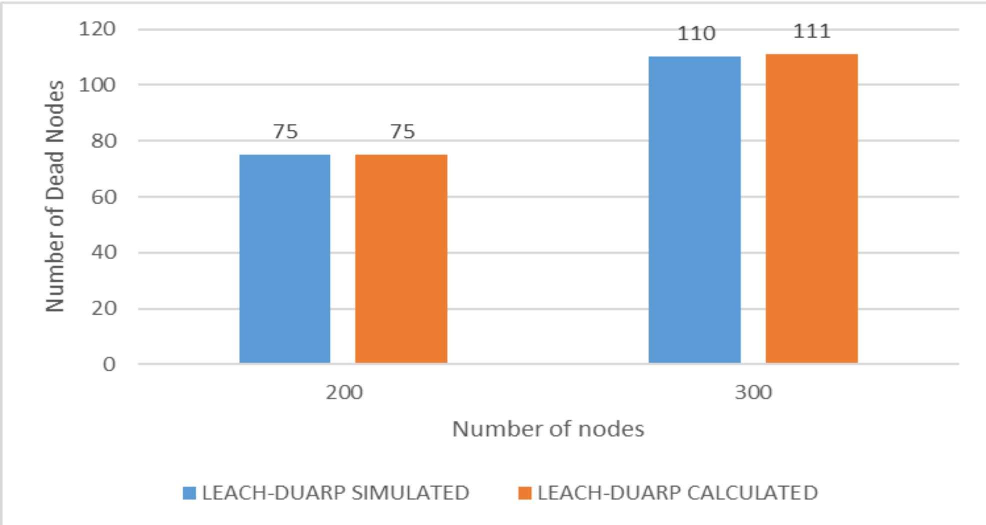


Figure 7.7: Number of dead nodes for LEACH-DUARP routing protocol.

Figure 7.7 represent number of dead nodes for both calculated and simulated LEACH-DUARP routing protocol. As mentioned earlier, the simulation was carried out for a different number of nodes which consist of 200 and 300 nodes. A total duration of 1000 round of simulation was used. To determine the efficiency of LEACH-DUARP, certain underwater parameters were used which consist of noise in the acoustic channel, and a limited packet size of 50 bytes due to unique underwater environment. After a complete round of simulation result indicates a close range between the simulated and calculated LEACH-DUARP based on the number of dead nodes. However, LEACH-DUARP introduces a concept of stability function value to minimize energy consumption among sensor nodes which result to number of dead nodes as the simulation rounds increases. Although, as the number of nodes increases a slight number of dead nodes increases without reaching an average number of the total number of nodes. LEACH-DUARP significantly performed in terms of less number of dead nodes with 36% when compared with (Rizvi et al., 2023) with 80%.

7.4 CHAPTER SUMMARY

This chapter discussed about the validations for the proposed AODV-SUARP and LEACH-DUARP routing protocols. The validations were discussed through mathematical modelling where modifications of both AODV and LEACH together with their performance metrics were discussed as used in the simulation. The proposed mathematical models for AODV-SUARP were observed and evaluated based on packet delivery ratio, energy consumption and end to end delay. While LEACH-DUARP mathematical models were evaluated based on sensor nodes residual energy, packet delivery ratio, and number of dead nodes. The calculated results were compared with the simulated result. The difference based on the simulated and calculated result can be attributed due to unpredictable nature of underwater environment and the limitation of the simulation. The result is trivial which can be compensated for error correction due to difference between the simulated and calculated results.

CHAPTER EIGHT

CONCLUSION AND FUTURE WORK

8.1 INTRODUCTION

This chapter explains the conclusion and future work for this research. This thesis proposed an efficient underwater acoustic wireless routing protocol by considering the sparse and dense underwater network architectures. An intensive review of background of underwater acoustic wireless sensor network was conducted which gives a basic understanding on how relevance underwater communication is to different areas which consist of disaster forecasting, pollution monitoring, offshore exploration, and military surveillance etc. More also, the background provides an opportunity to effectively identify suitable routing protocol to be used for underwater acoustic wireless sensor network. A comprehensive literature review was conducted on taxonomy of underwater routing protocol consisting of localization-based routing protocol and localization free routing protocols with energy consideration. Moreover, AODV and LEACH literature review with regards to underwater routing protocol with energy consideration has been conducted. The proposed design of the routing protocol for sparse and dense networks describes the formation of sensor nodes in the packet transmission process. AODV routing protocol was enhanced for the sparse network architecture where AODV-SUARP was developed. AODV-SUARP introduces the mechanism of route stability function to select the most energy efficient route to forwards packets. AODV-SUARP equally modifies the conventional AODV RREP packet header by adding a new field called the node energy status based on the sensor nodes residual energy. The introduction of the node's energy status leads to the appropriate selection of energy efficient reliable routes by extending the network lifetime. For dense architecture this thesis identifies the energy challenge facing the conventional LEACH routing protocol which in turn leads to its modification by creating a new energy aware routing protocol called low energy adaptive clustering hierarchy dense underwater acoustic routing protocol (LEACH-DUARP). LEACH-DUARP introduce the concept of selecting the most eligible sensor node as the cluster head through the average number of sensor nodes participating in packet transmission as well as the energy consumption of the nodes. Furthermore, for the optimal selection of eligible cluster head in a subsequent round LEACH-DUARP introduces a concept called the stability function value (SFV). SFV was used to effectively selects the most eligible cluster head to participate in data gathering and transmission. In order to effectively observed the performance of the proposed routing protocols in a simulation environment, an appropriate simulator known as Aqua Sim-NG was selected. Aquasim-NG was based on NS-3 acquires an enhanced features and modules that can effectively simulate and underwater scenario. The simulation examined a localization-based routing protocol known as VBF, AODV routing protocol against the proposed AODV-SUARP routing protocol when transferring packet sensor nodes. The result of the simulation is evident, and it is proposed that AODV-SUARP incurred delay for all the three simulations for each number of nodes (15, 30 and 50). However, significant performance was achieved based on other parameters namely packet received, packet energy consumption. The dense architecture simulation for conventional LEACH and the DIRECT transmission of LEACH against the proposed LEACH-DUARP considered both data aggregation and transmission. The result of the simulation showed that the proposed LEACH-DUARP routing protocol achieved a considerable performance based on the parameters tested which consist of packet delivery ratio, number of dead nodes and energy consumption. The simulation for the dense architecture was tested against two scenarios consisting of 200 and 300 nodes. The outcome indicated the efficiency of LEACH-DUARP through the introduction of a stability function value when increasing in number of sensor nodes over the LEACH and DIRECT routing protocols.

The analytical validation model for the AODV-SUARP is based on performance metrics which consists of energy consumption, packet delivery ratio and delay. The model utilised a transmission rate of 5packets/sec over duration of 200 seconds with 15, 30 and 50 number of nodes in the simulation. The simulated and calculated result are approximately the same based on the parameters used. The mathematical model proves that AODV-SUARP enhances energy by avoiding selection of routes which have sensor nodes with low energy level. More also, LEACH-DUARP analytical model is based on energy consumption, packet delivery ratio and number of nodes which are used as performance metrics. The model also utilised a transmission rate of 5 packets/sec for each round of simulation with 200 and 300 number of nodes. The simulated and calculated results are approximately the same based on the parameters. It is evident that LEACH-DUARP effectively selects the most eligible cluster head node having the highest stability function value to act as cluster head in data gathering and transmission.

8.2 FUTURE WORK

The proposed architecture for sparse and dense networks have been implemented in the simulation environment. The results obtained show the effectiveness of the proposed AODV-SUARP and LEACH-DUARP as both introduce a technique that helps to achieve a significant performance in data gathering and transmission. As previously mentioned, the research modifies the conventional AODV and conventional LEACH routing protocols to reduce the energy consumed in packet transmission and avoid routing overhead. In sparse network scenario with an increase in the number of sensor nodes, greater delay is incurred for the proposed AOD-SUARP. In future, a system with a technique is needed to address the delay incurred as this will give a better picture of the overall improvement offered by the proposed AODV-SUARP in the sparse network. However, the simulation was set to send 5 packets per second. In future more packets will be tested to observe the impact of congestion caused by high numbers of packets. For the LEACH-DUARP routing protocol more packets will need to be added to effectively determine the congestion and routing overhead within the network. More also, design of suitable link quality for reliable packet routing. Sensor nodes in underwater are constantly moving due to ocean currents. As a result, underwater topology is dynamic and therefore routing link is unstable. Therefore, future studies should focus on developing a sable link quality for reliable packet routing. In future, the security issue involves in underwater communication which consist of denial-of-service attack, routing failure, wormhole attacks, sybil attacks, eavesdropping etc. by developing a local monitoring detective approach need to be introduce that can secure the network from attacks.

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APPENDICES

LIST OF INDUCTION TRANING ATTENDED

S/NO	TITLE OF TRANINIG	ABOUT TRAINING	DATES ATTENDED
1.	Research ethics workshop	Ethics approval framework	10^{th}-02-2020
2.	Academic writing workshop on I. Writing I.A, IE II. Writing an abstract for SPARC III. Publishing writing	A research development training which addressed about ethics approval framework, discussed on knowing common mistakes on I.A, I.E, and also addressed on how to write a lay abstract on SPARC and impact on a quality of a good publishing and writing.	11^{th}-02-2020
3.	Promoting research workshop on I. Designing and presenting a poster II. Writing a lay abstract	A research development training that addressed on how to design and present a poster, and how to give a confident presentation with impact and writing a lay abstract.	12^{th}-02-2020

LIST OF TRAININGS FOR FIRST YEAR ATTENDED WITH DATES

S/NO	TITLE OF TRAINING	ABOUT TRAINING	DATES ATTENDED
1.	Methodology Challenges	How to go about challenges on research methodology	13th-03-2020
2.	Structural equation modelling	The training addressed on how to understand structural equation modelling and its application on research	24^{th}-02-2020
3.	Making most of library research	Workshop addressed on how to perfectly search for library resources	1^{st}-04-2020

4.	Preparing for assessment Viva's, IA, IE and new online formats	The training addressed on how to be prepared for each assessment for online formats which consist of IA & IE	15th-04-2020
5.	Lay abstract writing workshop	The workshop discussed on how to write a lay abstract in a preferred way.	14th-05-2020
6.	Getting started with endnote	The training teaches on how ton use endnote for managing references	15th-05-2020
7.	How to carry out digital research in the age of social distancing.	The online workshop addressed on digital research and the tools to carry out the research.	3rd-06-2020
8.	Fundamental ideas quantitative methodology	The online training addressed on how to differentiate and qualitative methodologies and appropriate application to research	17th-06-2020
9.	Managing the doctorate through social distancing	The training teaches on how to carry out doctorate research and its challenges during crisis	6th-07-2020
10	PGR inter-disciplinary research seminar series	The seminar focused on research presentation by a research student from school of science, engineering, and environment.	8th-07-2020
11.	Preparing for assessment Viva's, IA, I.E and new online formats	The training addressed on how to prepare for doctoral assessment which consist of Viva's, I.A and I.E.	21st-07-2020
12.	Writing retreat online	The training focused on excellent writing with certain techniques.	11th-08-2020

13.	Ethics Q & A	The online session addressed about ethics question and answers in a research.	9^{th}-09-2020
14.	PGR inter-disciplinary research seminar series	The seminar focused on different postgraduate research from different fields.	7^{th}-10-2020
15.	PGR return to campus induction with click and collect session.	The training discussed about the procedure for return to campus and the process to follow for collecting an item from school.	12^{th}-10-2020
16.	Introduction to analysing text	The online session discussed about how to analyse and evaluate text.	13^{th}-10-2020
17.	Open access publishing- School of science, engineering and environment.	The training discussed on the various benefits of open access.	12^{th}-11-2020
18.	PGR inter-disciplinary seminar	The seminar covers about strategies and approaches with risk analysis to support research in period of crisis.	18^{th}-11-2020
19.	IEEE Latin American conference	The conference covers on different research work on networks and communication with current trends.	18^{th}-20^{th}-11-2020
20.	Open research monthly drop-in session (library session for academic staff and PGR's)	The online training discussed about the benefits for open access.	3^{rd}-12-2020

LIST OF TRAININGS FOR SECOND YEAR

S/NO	TITLE OF TRAINING	ABOUT TRAINING	DATE ATTENDED
1.	IEEE Consumer communications & networking conference (CCNC).	The conference discussed about current research on network communication	9th-12th January-2021.
2.	IEEE UK & I. Webinar on Future of Authentication.	The webinar discussed on the different methods of authentication and their application.	1st February-2021.
3.	Researcher development Conference: How to pass the IA, IE & viva assessment	The training discussed on what is needed by the researcher to prepare for IA, IE, and Viva assessments.	11th February-2021.
4.	Researcher Development Conference: How to Write a Lay Abstract	The training discussed on how to write and understand a lay abstract properly.	11th February-2021.
5.	The cyberfort group UK. Webinar on hacking authentication and authorisation.	The webinar discussed on different methods on how hackers get access to resources and the potential ways on how to secure authentication.	19-February-2021.
6.	Performing hardware/software co-design for Xilinx RFSoc Gen 3 devices using MATLAB and Simulink	The webinar discussed about model design using Simulink and creating code using mscript code.	18-March-2021.
7.	Satellite communication in	The webinar discussed about the applicability, design, and	30-March-2021.

	MATLAB	challenges of satellite communication in MATLAB	
8.	Inferential statistics	The webinar discussed on the relevance of statistical analysis to research and the notable tools used in research.	12-April-2021.
9.	IEEE Communication society industrial talk: open radio access network (O-RAN) tech talk.	The webinar discussed about the O-RAN, its architecture, alliance, as well as RAN programmability and its relevance to machine learning and 5G.	13th-April-2021
10.	MATLAB EXPO	The expo discussed about different enhancement and features of MATLAB with wide range of how to use MATLAB in different areas.	4th-5th May-2021
11.	Open access publishing	The webinar discussed about the benefits of open access publishing, open access policies, different types of open access as well as how to choose a reputable open access.	11th-May-2021
12.	Developing your research identity (ORCID)	The webinar discussed about the importance of ORCID for researchers and the advantage of using ORCID in research community	12th-May-2021
13.	IEEE International Conference on Communications (ICC 2021)	The Conference discussed about different research on communication technology based on recent trends in communications.	14th -23rd -June-2021.
15.	Copyright for	The webinar discussed about how	23rd -june-2021.

	researchers.	to use copyright material in research and how to protect your own copyright as a researcher	
16.	IEEE International Conference on network and softwarization	The conference discussed about different research on accelerating network softwarization in the cognitive age with recent technological trends.	28th June- 2nd July 2021.
17.	Salford postgraduate Annual research conference (SPARC)	The conference discussed about different research currently undergoing by university of Salford research students.	30th June-1st July 2021.
18.	Graduate application	The webinar discussed about making applications by graduate through realizing the benefits and common mistake encountered during application.	9th-august 2021.
19.	Developing your research identity (ORCID)	The webinar discussed about building ORCID profile, connecting ORCID & fig share as well as relevance of ORCID to researchers.	8th -September 2021.
20.	IT essential skills	The webinar discussed on vital IT skills for researchers as well as making use of enrolling for professional certifications which are globally recognized.	13th-september 2021
21.	Getting ready for Viva workshop (Tips and techniques)	The webinar discussed on viva preparation, how to respond using different technique, and techniques of developing confidence.	26th-October 2021
22.	Open access publishing	The webinar discussed on	27th-October 2021

		benefits of open access publishing, how to choose reputable open access publisher, and how to comply with university and funder open access policies.	

LIST OF TRAININGS FOR THIRD YEAR

S/NO	TITLE OF TRAINING	DETAILS	DATE ATTENDED
1.	App development, proof of concept.	The webinar discussed about the development of BAME App for Salford city college by giving valuable input by PGR student from ACP.	25th-JAN-2022.
2.	Academic citizenship program (Facilitation and teaching).	The webinar discussed about differences between facilitation and teaching their goals and how an information is being transfer in the process of learning	22nd-FEB-2022.
3.	Academic citizenship program (teaching style roles).	The webinar discussed about differences between in teaching. styles and their roles in delivering teaching.	1-MARCH-2022.
4.	Academic citizenship program (Problem-based learning)	The webinar discussed about the use of student-based learning in delivering teaching	8th-MARCH-2022

		as a student-centred approach in solving an open ended problem	
5.	Academic citizenship program.	The webinar discussed about ACP projects covering the HEA. application, different method, techniques, and teaching roles need to be included in the application.	2-APRIL-2022
6.	Academic citizenship program (Community practice/prep session)	The webinar discussed about ACP. projects covering the HEA application, different method, techniques, community practice and teaching roles needed to be included in the application.	10-MAY-2022
7.	Academic citizenship program (writing retreat)	The webinar discussed about ACP writing retreat needed to be included in the HEA application.	7th-JUNE-2022
8.	Salford postgraduate annual research conference (SPARC)	The Conference focused on different. aspect of research areas within Salford PGR students.	29th-30th JUNE-2022
9.	5G smart junctions	The event focused on project show casing the	26th- JULY-2022

		project on 5G technology on junctions to extract live data and analyse it.	
10.	IT essentials	The online webinar discussed about different IT platforms together with their features and functionalities for student use	20th- SEPT-2022
11.	Qualitative research approaches.	The online webinar discussed about the relevance of qualitative method as a research approach, the use of experimental design, surveys, need assessment and non-experimental designs in research	18th- OCT-2022
12.	Cambridge wireless international conference: The hyper connected Human.	The International conference discussed about industry latest trends in technology and how connectivity is now a ubiquitous part of our lives, from wearable and smart devices to connected cars, houses, and cities.	2nd-NOV-2022
13.	AWS CIS foundation benchmark: philosophy and use case.	The lecture discussed on analytics and	15TH- DEC-2022

		applications, importance of the CIS AWS foundation benchmark, and the benefits of implementing it.	

LIST OF TRANINIGS FOR FOURTH YEAR

S/NO	TITLE OF TRANINIG	ABOUT TRAINING	DATES ATTENDED
1.	Overcoming Math anxiety	The webinar discussed about understanding math anxiety, causes and symptoms that contributes to math anxiety, and how math anxiety can affect student learning	20th JAN-2023
2.	An introduction to End note	The webinar discussed about end note as a referencing software which can be used to manage your information sources and create citations and references list automatically and correctly	23rd-FEB-2023
3.	Academic profiles & research information system (APRIS)- PGR work tribe.	The webinar discussed about using the new system of depositing thesis at the end of PhD thesis writing.	21st-MARCH-2023
4.	Making most of e-books	The workshop discussed how to find and use electronic books in the library search. It also showcases eBooks and what they can do and tips on using built in tools to help save time	21-03-2023

		on targeting users reading.	
5.	Update on current knowledge of radio frequency RF safety 2023.	The event discussed about different broad range of topics focusing on implications of RF safety for the work force and general public which include modelling and measuring RF exposure as well as new study exploring the health effect of 5G.	03-05-2023.