IET Research Journals

Submission Template for IET Research Journal Papers

E^2MR: Energy Efficient Multipath Routing Protocol for Underwater Wireless Sensor Networks

ISSN 1751-8644
doi: 0000000000
www.ietdl.org

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Abstract: Underwater Wireless Sensor Networks (UWSN) is an emerging branch of wireless sensor networks. In UWSN, tiny sized sensors nodes are deployed in the ocean for various monitoring operations. These sensors have limited energy, memory and lower bandwidth. Exploration of underwater resources, oceanographic data collection, tactical surveillance, and natural disaster prevention are some of the areas of UWSN applications. UWSN is different from traditional wireless sensor network. The later uses radio waves for communication between sensors while the former uses acoustic wave for data transmission. Communication in UWSN is more challenging because of many challenges, which are associated with acoustic channels such as low bandwidth, high transmission delay, usual path loss, and intermittent connectivity. Keeping in view the aforementioned challenging issues, energy efficient and reliable data transmission in UWSN becomes hot research area. In the area of UWSN, some algorithms were introduced to enhance networks lifetime, by using a smaller battery and other for critical data transmission. However, data packets flooding, path loss and low network lifetime are few challenges with immediate attention. This article proposes a novel routing scheme referred to as Energy Efficient Multipath Routing (E^2MR) for UWSN, which is basically designed for long-term monitoring with higher energy efficiency and delivery ratio. The E^2MR establishes a priority table, the forwarder nodes are selected based on that priority table. Different experiments are carried out by simulating E^2MR and compared against other state-of-the-art location-free routing protocols including DBR, EEDBR, and H2-DAB with respect to number of alive nodes, end-to-end delay, packet delivery ratio and total energy consumption. Our results show that E^2MR outperforms when compared with other routing protocols in UWSN.

1 Introduction

Ocean covers around more than seventy percent of total earth surface [1]. It is considered to be a major source of nourishment, natural resources, defense, business transportation and adventurous purposes [2]. Ocean plays a vital role in human life, however, we have very little knowledge about the ocean and underneath resources of ocean [3]. According to existing surveys, almost ten percent of ocean has been explored, while almost ninety percent of ocean area is still unexplored [4]. Ocean plays very important roles in human lives, that is why the unexplored area of underwater resources has got a lot of importance [5]. If we see, on one side the traditional approaches for ocean monitoring have got several demerits while on the other hand human presence is not considered to be feasible for underwater environment [6].

UWSN is new technology which provides very efficient and promising methods for exploration of underwater for many areas, such as military defense, emergency, and business throughout the whole world [7]. Sensors equipped autonomous and unmanned vehicles are specifically designed for underwater monitoring [8]. Autonomous unmanned vehicles are used for exploration of underneath underwater natural resources [9]. Sensors equipped unmanned vehicles sense data and send back to sinks. Sinks forward data to the base station for processing, base station process that data and took necessary action [10]. Although WSN is based on radio waves, that can not be used in deep sea communication. That is the reason that underwater sensor nodes rely on acoustic waves for communication [11–13]. Here, when sensor nodes send data to sink then sink forwards sense data to another sink through radio waves [14].

UWSN is different from traditional terrestrial networks in several aspects. Ambiguities like high propagation delays, lower bandwidth does not usually found in terrestrial networks, however, we usually see these issues in UWSN [15, 16]. There are several issues in underwater communication such that dense salty water, high attenuation (due to high attenuation signal cannot travel a long distance in underwater), absorption effect, electromagnetic and optical signal does not work well in underwater environment [17]. Hence to tackle the aforementioned issues, researchers proposed acoustic waves for underwater data communication instead of radio waves [18], and this enhanced data transfer rate [19].

Although acoustic channel solved some problems, however it creates some issues. The speed of acoustic wave is 1500 m/sec [20] which is much less than the speed of light. Due to this slow speed, it will increase propagation delay and packets delivery time [21]. As mentioned earlier in this article, that bandwidth of acoustic channel is very limited, e.g., almost less than 100 kHz [21, 22]. Sensor nodes are considered to be static in underwater environment however, the topology of underwater sensor nodes dynamically changes, because sensor nodes move (1 to 3 meter per seconds) due to the flow of water [23]. Sensor nodes are battery operated in ocean, that is why it is very difficult to replace its battery [24, 25]. In underwater multihop and multipath network, the network topology are essential as data is forwarded through multiple nodes towards sink nodes [26]. When data is successfully delivered to one sink node, then sink node forward that data to intended receiver through radio waves [27].

In addition, the lower bandwidth is a major issue in acoustic communication. That is why routing protocols of terrestrial networks (which required high bandwidth) are not suitable in acoustic communication, due to its high energy consumption and an end to end delays. Also in underwater networks, the topology does not remain the same because sensor nodes are dynamic due to flow of water [28]. Routing protocols of TCP/IP, Delay Tolerant Networks (DTNs)

[29], Mobile Ad-hoc Networks (MANETs), Vehicular Ad-hoc Networks (VANETs) [22] and WSNs cannot be directly applied to underwater networks. Routing protocols that are used in other networks cannot be directly applied to underwater networks. Till date many protocols have been proposed for underwater sensor networks. These are mainly divided into two types which are localization based and localization free protocols [30]. Localization free protocols do not require any prior geographic or network information. Most of these protocols are used in underwater networks [31].

Researchers proposed various routing protocols for UWSN. These protocols are mainly divided into two categories, which are localization-based and localization-free routing protocols [32]. In localization protocols, geographic information (that is location of every node) and networks information (topological information of networks) is required in advance. Unlike localization based, localization free routing protocols do not require location and network information in advance [33]. Most of the researchers proposed localization free routing protocols for UWSN [31], due to its less energy consumption and suitability in underwater networks scenarios [34], [35], [36].

Summarized Contribution of Proposed algorithm: The goal of the proposed algorithm, namely E^2MR, is to avoid flooding type routing and enhanced energy consumption of every node. Following are some of the major contribution of this article.

- Energy Efficiency: E^2MR can reduce energy consumption (which will be proved in simulation section of this article).
- Avoidance of Multiple Message Copies: E^2MR avoids all those types of routing which leads towards a large number of messages in the networks, which obviously enhances network lifetime. The algorithm avoids multiple copies for both sensing nodes and sinks.
- Avoid Flooding: E^2MR avoids flood strategies in which one node forwards received packet to all nodes in the networks.
- Packet Holding Time: E^2MR enhances holding time of packets because holding time depends on residual energy. This algorithm enhanced holding time.

The rest of the article is organized as follows. In section 2, the architecture of UWSN has been discussed. Section 3 discusses literature review of existing routing protocols. Section 4 is related to our design. Section 5 implements comparison between our design with literature works falling into localization free routing protocol. Finally, section 6 concludes our work.

2 Architecture of Underwater Wireless Sensor Network

This section will briefly introduce the architecture of UWSN. Fig. 1 shows general architecture of UWSN. There are generically five different components in the architecture of UWSN, which are data sensing unit, energy management unit, processing unit, data communication unit, and depth measuring unit [37].

Data Sensing Unit: Data Sensing Unit is responsible for sensing of any sort of data in UWSN. Various kinds of sensor nodes (used for Flooding, underwater resources and movement etc) are used for various purposes. In particular, the data sensing unit sense data even nodes in a sleep mode.

Processing Unit: Processing Unit is one of the most important components of UWSN. It is responsible for any sort of processing.

Data Communication Unit: Data communication unit is responsible for data transfer between various sensing nodes. It sends data from sensing nodes to sink nodes, and also exchanges data between sink nodes and base station.

Depth Measuring Unit: Depth measuring unit is used for measuring depth of every node. It plays a vital role because position layer of node is very important for routing in UWSN. Here, the position layer refers to which depth of ocean a node is located.

Energy Management Unit: UWSN is operated on battery, and is almost impossible to replace the battery. Therefore, the operation of UWSN depends on availability of energy. In case of energy exhaustion, the node will be shut down, and this influences network service. Energy Management Unit is responsible for two tasks, it manages remaining energy of nodes (need to maintain energy to last network lifetime) and also manages consumption of node in run time (to consume less energy in run time).

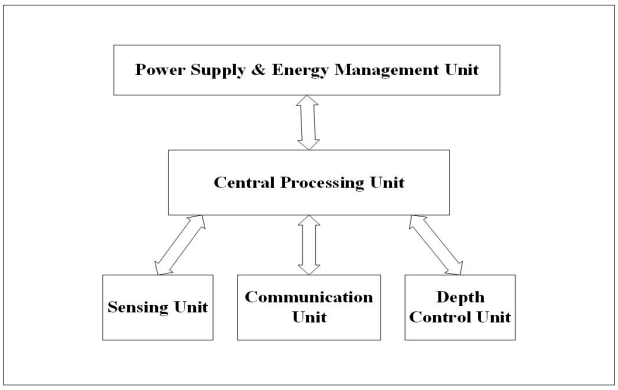

Fig. 1: Node Architecture

3 Background on Routing in UWSN

In the Last decade a lot of research have been conducted and achieved certain results to minimize energy consumption in UWSN. Dario Pompili et al [38] proposed a multimedia cross-layer protocol. The contents of the protocol are as follows: (i) Study of the interaction of key components of the underwater communication system, such as forward error correction, modulation, Media Access Control (MAC) and routing. (ii The design of a distributed cross-layer communication method, sensor nodes can share the network bandwidth efficiently. The protocol confirms improving energy efficiency and network throughput through experimental results. Sarath Gopi et al propose energy optimization path unconscious hierarchical routing protocol called E-PULRP. The E-PULRP consists of a layered and communication phase, proposing a layered structure, utilizes a gathering node as the centre and other nodes located on concentric circles [39]. By considering the width of each layer and node transmission loss, the success probability of nodes to send data and to avoid node transmission loss is improved. In the communications phase, an alternative energy optimal relay node algorithm transmits data to the sink node. Experiments to comparing analysis with other algorithms display the validity of the E-PULRP protocol for energy efficiency. Junfeng The proposed network of underwater acoustic communication fading channel de-multiplexing asymmetric communication protocol called AMDC. The protocol takes into account the uneven distribution of underwater noise and the actual underwater propagation environment with noise is attenuated [5]. The underwater communication space is divided to build a tree-based multi-path transmission channel to improve the network energy efficiency and reliability of data transmission.

Routing protocols can be divided into two categories [40], i.e. Location Based Routing (LBR) and location Free Routing (LFR). LFR protocols do not relay on any pre-network geographical information. These type of routing protocols perform their operations without having any location information of other nodes in the network [39]. Most of the LFR protocols uses flooding phenomenon for faster packet delivery ratio. While in LBR, the geographic information of the network must be known to every node in the network [38]. In LBR protocols, paths calculation and node's geographic information are pre-requisite for network, in a results a high end-to-end delay and energy consumption.

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3.1 *Location Based Routing*

Vector based forwarding (VBF) is a LBR scheme and maintain its routing path frequently. VBF is primarily a position based scheme, where a very small number of nodes are involved in data forwarding process. As a specified number of nodes are involved in sending data packets so it usually sends packet in a single direction towards sink. In VBF every node knows the location of other nodes and their respective information. The sending node knows the final location of the data packet that is being sent by node. VBF uses the idea of developing virtual pipe in routing process. In virtual pipe a few number are involved in routing procedure that combination develops a routing pipe. The data packets are forwarded with the help of node lies in the area of virtual pipe. The enhanced version of VBF is presented as Hop-by-Hop Vector Based Forwarding HH-VBF. HH-VBF focuses on robustness, energy efficiency, path loss and higher delivery of data packets. VBF used a single virtual pipe for packet forwarding while HH-VBF proposed the use of multiple virtual pipes for data forwarding. In HH-VBF involves a larger number of nodes in data forwarding process and it develops multiple virtual pipes, through which packet can be delivered to its final destination.

3.2 *Location Free Routing*

3.2.1 Depth Based Routing: Depth Based Routing (DBR) is a LFR scheme and does not need any pre-network node location information. The DBR primarily takes sensor depth into consideration while forwarding a data packet. In data packet forwarding, a node compares its depth with that of proposed receiver node. It only forwards data when depth of receiver node is lower than sender itself. Sometimes it is unable to find a node with defined parameters, in a result it simply drops the packet or send it back to a higher depth node. It starts sending data to all nodes whose depth are lower than the sender node. On one hand it is beneficial for decreasing end to end delay but on the other hand it generates a sort of flooding which produce a higher energy consumption. This flooding process in DBR continues until packet is received by any of the sinks installed onshore. Most of the time this process produces multiple copies at sinks level. DBR analyse only depth information while performing data forwarding operations. DBR leads towards a few drawbacks like, short network life of network, flooding and higher energy consumption. It mostly sends data to the multiple node of same depth level. DBR has no proper mechanism defined for path selection, protocol generates a random path for every data packet generated.

3.2.2 Energy Efficient Depth Based Routing: Energy Efficient Depth Based Routing (EE-DBR) is an enhanced form of DBR. It has more capabilities as compared to DBR. A node in EE-DBR forwards a data packet, it takes the depth of the receiving node, residual energy and distance from sink. In the first step it compares the depth just like DBR. While in second step, it checks for residual energy and compare it with the set threshold. Node with higher residual energy than threshold and lower depth then sender node are selected as data forwarders. Every node in the network usually has information on depth and residual energy about their neighbours nodes. The drawback of EE-DBR, it is not flexible for long term and in few cases it flood the data packets as well. Sometimes a node might forward packet to another node, which is far away from sender node. Similarly, no mechanism is defined for analysing shortest and efficient path selection.

3.2.3 Hop-by-hop Dynamic Addressing Based Scheme: Hop by Hop-Dynamic Addressing Based routing (H2-DAB), is a location free routing scheme. The scheme dynamically assigns addresses to nodes. The address "0" is assigned to sink as it is on the uppermost portion. This address is lower for the nodes near to sink while higher for nodes having a longer distance with the sink. In this scheme, every node is allotted two kinds of addresses, called Node-ID and Hop-ID. Node-ID is the physical address of node which stays the same throughout the network lifetime whereas Hop-ID changes when node moves from one place to another. Hop-ID starts from top level or sink. It moves downwards in an increasing manner. Similarly the node with higher depth has the highest Hop-ID. H2-DAB supports multi-sink architecture. The scheme assign the same "0" ID to all sinks. Being having same hop-ID, data packet received to any sink is considered as received. After receiving at sink, it is easy to forward it to other sinks. Sometimes due to the random movement of nodes it is not possible to find out a node with suitable hop-ID. In this situation either a sender node have to wait for an appropriate next hop-ID or send the data packet backward.

3.2.4 Energy Efficient Dynamic Addressing Based Routing: Energy Efficient Dynamic Address Based routing (EE-DAB) does not require any network related information for data forwarding. In this routing scheme, every node is provided with two kind of basic id's. The first id type is called s-id. This id remains fixed for a node throughout network lifetime while the other type is call c-id. The second type of id is also known as next-hop id. Both of these two id consist of two digits.

3.2.5 Mobile Delay Tolerant Routing: As acoustic communication uses more energy than radio communication. As wireless sensor nodes are battery operated and higher energy consumption which lead towards a serious problem. Thus energy efficiency has become a major problem in underwater wireless sensor networks. In a delay tolerant protocol is proposed which is called delay-tolerant data dolphin scheme. This proposed scheme is designed for delay tolerant systems and applications. In this protocol all the sensing nodes stay static and data sensed by static nodes are passed on to data dolphin which acts a courier node. In this methodology high energy consumed hop by hop communication is avoided. Data dolphins which act courier nodes are provided with continuous energy. In the architecture all the static nodes are deployed in the sea bed. These static sensors go into sleep mode if there is no data to sense and it periodically wakes up when it sense some data. After sensing some kind of desired data it simply forward this data to courier nodes which are also called data dolphins. These data dolphins take this data and deliver it to base station or sink. The number of dolphin nodes depends upon the kind of network and its application and the number of nodes deployed in the network.

3.2.6 Energy-efficient-Multipath Grid-based Geographic Routing: Energy-efficient Multipath Grid-based Geographic Routing (EMGGR) protocol divides the whole network area into 3D grids. Where XYZ coordinates are used to identify each grid. In EMGGR, nodes are deployed randomly in network area. Certain nodes are used as gateways for forwarding data packets. Gateways are selected through an appropriate election procedure and at most one gateway is elected in each cell. The election is carried out on multiple parameters like distance from other node, sink and residual energy.

4 Proposed Scheme

This section discusses the proposed routing model for UWSN in detail;

4.1 *Node Architecture*

A general architecture of underwater wireless sensor node is composied of five main elements. Which are energy management unit, data sensing unit, depth measuring unit, communication unit and central processing unit [6]. Processing unit is responsible for all kind of data processing while energy management unit has the responsibility to manage the remaining energy of node. Data sensing unit is used for sensing data in forward relevant data to the node ahead. Data sensing unit is always in active mode even when node itself is in sleep mode. Communication unit is responsible for overall data communication whereas depth measuring unit is used for measuring depth of water when deployed in sea.

4.2 Network Architecture

The proposed protocol will be able to avoid data flooding phenomenon and creation of multiple copies. It will be able to take advantage of having underwater sensor network architecture with multiple sinks. This kind of network will have multiple equipped sinks both with acoustic and radio-frequency modems. These sinks are deployed at surface of water. The static sensor nodes are deployed in desired underwater area. These nodes are capable of collecting data and forwarding it to sink in multi-hop fashion or to courier node, if any. Courier node are provided with continuous power and they are only capable of receiving data from static sink and forwarding it to sinks. A sink can easily communicate with each another sink through radio channels. We can easily validate this assumption by this fact that sound propagates almost at the speed of approximately 1.510^3 meter/seconds in water, five of orders of magnitude slow than that of radio waves which is having a propagation of 310^8 meter/second in air. In our scenario, we have assumed that a when packet reaches its destination as soon as it is successfully delivered to any of the sinks.

4.3 Energy Efficient Multipath Routing Protocol for Underwater Wireless Sensor Network

The main problems of already proposed routing protocols are high energy consumption, fewer nodes and smaller lifetime. Most of the existing routing protocols in UWSN is based on flooding phenomenon. It forwards multiple messages to nodes. This type of routing strategy is not efficient in any kind of network and especially in UWSN where residual energy is very much limited. Because it forwards multiple copies without any pre-defined efficient manner. This type of strategy leads to high energy consumption of both forwarder and receiver nodes. Also, this type of routing scheme degrades overall network performance.

This article proposes "Energy Efficient Multipath Routing Protocol (E^2MR) for UWSN. The main goal of this routing algorithm is energy efficiency, higher packet delivery ratio and longer network lifetime. The proposed scheme has enhanced energy consumption and improved network lifetime. It avoids to send multiple packets to next node in the network. The proposed routing algorithm of this article take advantages of UWSN architecture of multiple sink [20]. In this type of UWSN architecture, multiple sinks are deployed in the desired environment. Multiple sink operates both on acoustic frequency modem and radio frequency. In this type of architecture, underwater sensors nodes are randomly deployed into a specific location. Sink node communicates with another sink node through radio frequency channel. The proposed routing algorithm of this article assumed when sensors nodes forward packets to multiple sink nodes. If the packet successfully delivered to any of the sink among multiple sink, it will be considered successful delivery. This article also assumes that every node knows depth information of all network nodes, which is also called vertical distance. Depth information of nodes is easily calculated through depth sensor.

The proposed scheme is called Energy Efficient Multipath routing protocol for Underwater Wireless Sensor Networks (E^2MR). The goal of this routing protocol to provide energy efficient communication and it will run a node for a longer lifetime. The proposed protocol will also contribute towards lifetime of the network. It will avoid flooding by forwarding data packet to a pre-selected node. It will also lead to avoid generating multiple copies. E^2MR protocol is designed to provide energy efficient communication, high network lifetime and, higher packet delivery ratio. E^2MR protocol will be able to take advantage of having underwater sensor network architecture with multiple sinks [20]. This kind of network will have multiple equipped sinks both with acoustic and radio-frequency modems. These sinks are deployed at surface of water. Underwater sensor nodes are deployed inside water in the desired area of interest. These nodes are able to collect data, also able to help forward data to sinks. A sink can easily communicate with other sink through radio channels. In our scenario, we have assumed that when a packet reaches its destination as soon as it successfully received to any of the sinks deployed on the water surface.

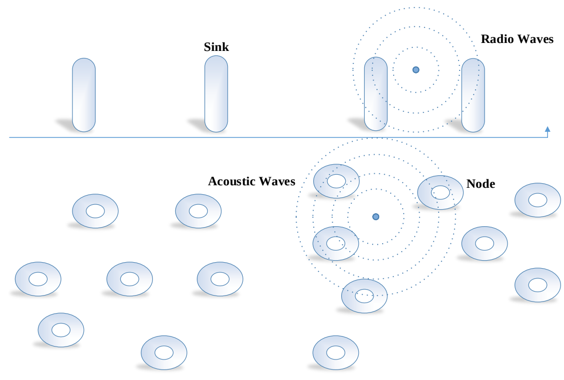

Fig. 2: Network Architecture

In E^2MR algorithm a small table is created at every node. This article calls this table, priority table. The proposed priority table calculate a priority value of all eligible nodes in the networks. During the initial set-up phase, the proposed algorithm broadcasts hello packet to every surrounding node in the networks. The proposed algorithm forward request packet to every surrounding node for basic information. The request packet includes residual energy, depth information, node ID and distance from sender node. When nodes receive hello packet they will send back required information with a REPLY-HELLO packet. Which will include all the requested information. After receiving replying packet, all those nodes are dropped who are having higher depth than that of sender node. The nodes having lower depth are entered into a small priority table after calculating their values with the formula discussed in later section. Nodes getting the higher values will be placed higher in table. It will be used as forwarding nodes for sending out data when received. Fig. 2 shows network architecture of E^2MR.

E^2MR protocol basically focuses on energy efficiency and will avoid all those phenomena which lead towards more energy consumption like, avoidance of flooding mechanism. Where a node sends a received packet to all node which lies in its range of communication, avoiding creation of multiple copies where multiple copies of the same data packet are received by the sink and holding time in which a node holds a packet for a certain amount of time depending on their residual energy.

Protocol Design In protocol design, this article briefly the working condition, network set-up phase and communication phase of E^2MR.

4.4 Set-up Phase

In Set-Up phase, all nodes are randomly deployed in the ocean. In step one nodes initially broadcast some control message, this article calls this control message a hello packet. There are two different scenarios for communication of nodes in UWSN, that is soft communication and hard communication. Nodes forwards hello packet to those nodes which lies in 25-meter range, which is known by name soft communication. In hard communication, range nodes can directly communicate with sink nodes. When receiver nodes receive control message (hello packet) from sender it will reply with response hello packets. Receiver node reply with those parameters which sender inquired (which is already mentioned in previous topic of this article). The distance of sender node will be calculated through Received Signal Strength Indication (RSSI).

underwater environment, all nodes broadcast a hello packet to all other nodes which lie in their soft communication range which is set to 25 meters while in hard communication range a node can directly communicate with sink. Upon receiving Hello packet, all nodes will reply to sender node with the parameters enquired through Hello packet. Likewise residual energy, depth of node and distance from sender node which will be measured through Received Signal Strength Indication (RSSI).

When sender node receives a reply of hello packet, the first thing they do is to compare depth of itself with the nodes from whom it has received a reply of hello packet. Only then an entry is added to priority table when its depth is lower than that of sender node which obviously means that it will be more nearer to sink. All entries of those nodes whose depth are higher than sender node will not be added to the table.

Entry will only be added to the table if the following condition satisfies,

$$D_r < D_s \tag{1}$$

D is known as calculated depth, Receiver node depth is presented by symbol DR, while symbol DS represent sender node depth. Table. 1 shows the format of hello packet in our proposed routing algorithm. This article proposed specific format packet for hello packet which contains Sender Id (SI), Receiver Id (RI), Residual Energy (RE), depth and distance from receiver to sender node. SI and RI uniquely identify sender and receiver respectively. Residual energy is the remaining energy of the node. The last entry in table measure distance between receiver and sender.

Table 1 E^2MR Hello Packet Format

SenderID	ReceiverID	Residual Energy	Depth	Distance from Sender-node to sender-node

Proposed algorithm uses specific packet format which we call E^2MR data packet. Data Packet of E^2MR protocol is illustrated in Table 2. It clearly shows the elements of Data Packet. In this table sender ID is assigned to the sender of every packet, receiver ID is assign to receiver of every packet, unique number is assign to every data packet which is known as packet sequence number.

Table 2 E^2MR Data Packet Format

SenderID	ReceiverID	Packet sequence number	Data

4.5 Priority Table creation:

After receiving replies from node, the sender node compares its depth with that of other node through equation (2)

$$D_r < D_s \tag{2}$$

Where D is knows as calculated depth, D_r is depth of receiver node while D_s is depth of Sender node, when this condition gets true then that packet will be picked up for further processing. As depth of the receiver node is less than sender so it means that receiver node is supposed to be nearer to sink. Other nodes whose depth is higher than sender node will be dropped. Now lets Suppose

$$V_p \alpha E_r \tag{3}$$

$$V_p \propto \frac{1}{D_{s \longrightarrow r}} \tag{4}$$

Now by combining (3) and (4), we get

$$V_p \propto \frac{E_r}{D_{s \longrightarrow r}} \tag{5}$$

The packets which are selected for further processing has to pass through equation (5). Where V_P is known as priority value, E_r for residual energy, depth is that how deep a sensor node has been deployed while $D_{s \longrightarrow r}$ is distance from sender to receiver node. The value of residual energy will be taken in joules while depth and distance between nodes will be counted in meters. After calculation, the value will be put into the priority table. Getting a higher value of V_p means that it will have a higher priority to be selected a forwarding node while a lower value leads towards minimum selection chances. Development of priority table is demonstrated in Fig. 3 and Fig. 4.

Table 3 Priority Table of Node: 1

Id	R.E	Distance	Vp
2	77	2	38.5
3	87	4	21.75
4	55	7	7.8

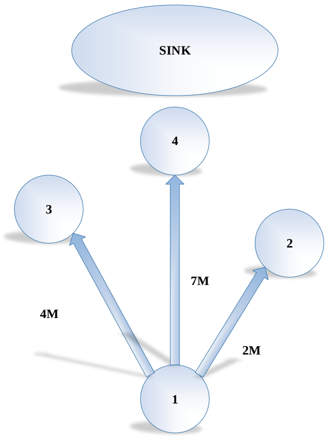

Fig. 3: Priority Table Creation

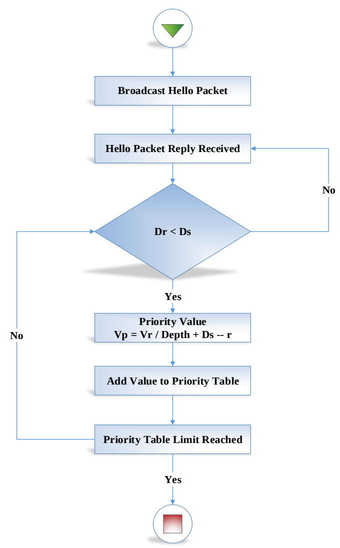

Fig. 4: Priority Table Creation Flow Chart

4.6 Priority Table Update:

Once priority table is created then every node is set to forward data packets. Every node will select a node having highest priority value from their priority table. After some time the residual energy of forwarding nodes will start decreasing and if any alternate path is not chosen then node will obviously run out of residual energy. This protocol is designed to update the priority table of every node after a fixed interval of time. When a threshold is reached, every node will automatically broadcast a hello packet to its surrounding nodes and the whole process of creating priority table will be repeated.

4.7 Sleep Mode:

In this protocol, if data is not being sensed for a specified period of time, the node will go into sleep mode and will woke up upon sensing some data or any movement movement. In the mean time, the node will not process any data but the data sensing unit will stay active in case if any data is sensed.

4.8 Sink Architecture:

In this protocol a data packet reached sea level or shore level will be considered as delivered to sink. As in [41], all sinks are connected with each other through wireless means and nodes are connected through acoustic communication. Therefore packet received at any sink will be considered as delivered. When received, packet will be recognized by its sequence number and will be placed at its desired location.

4.9 Data forwarding node selection:

Once the priority table is created then we will be a having a mechanism for selection of node to which data can be forwarded. It will mainly rely on VP which is known as priority value and can be calculated through the already defined equation. The higher the priority value of a node, the greater will be its chances of selection as forwarding node. When a priority node is first selected for data forwarding, its status will be checked through Ready To Send, Clear To Send mechanism, if found available then data will be forwarded otherwise another node in the queue will be selected and the same process will be carried out. In network set-up phase, when all the network nodes are deployed, every node starts broadcasting a hello packet to its surrounding nodes. When reply received by the sender node, it includes Sender ID, receiver ID, depth of receiver node which is denoted by D_r, Residual energy of receiver node denoted by Er and distance from sender towards receiver node which is denoted by $s- > r$. when hello packet is received by Sender node, it compares the depth of itself with that of the receiving node. If depth of sender node is higher then that of receiver node then its priority value is calculated by using the formula $V_p \propto \frac{E_r}{D_{s \longrightarrow r}}$. The higher the priority value, the higher will be its chances of selection as forwarding node. The priority value is updated after a selected interval of time. Algorithm for network set-up phase is demonstrated in Algorithm 1.

Algorithm 1 Algorithm for Network Set-up Phase

Setup Phase (S) :

1: Broadcast Hello packet by sender node H_s
2: Reply by receiver node h_R
3: Calculate D_s
4: Calculate D_r
5: Compare D_s, D_r
6: **if** $D_s > D_r$ **then**
7: Compute Priority V_p.
8: $V_p \propto \frac{E_r}{D_{s \longrightarrow r}}$
9: Add V_p to Priority Table
10: **else**
11: Repeat Step: 2
12: **end if**=0

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5 Evaluation Results

The proposed routing algorithm E^2MR has been evaluated with the help of MATLAB simulation. This proposed routing protocol has been compared with the existing protocols i.e. DBR, EEDBR and H2-DAB. The comparison is based on various parameters, which are packet delivery ratio, network path loss, network lifetime, number of alive nodes left and, total energy consumption. Table 4 shows the values of simulation set-up parameters that are taken into account while performing the simulation.

Table 4 Simulation Parameters

PARAMETERS	VALUES
Network size	500m X 500m
Total Nodes	3 225
Initial Energy	25J
Minimum Packet Size	1000bits
Frequency	30Hz
No. of Sinks	4
Transmission Range	100m
Rounds	9000

5.1 Evaluation Parameters

Following are the evaluation parameter with a brief description;

1. End to End Delay: It is the amount of time required to successfully deliver packet from forwarder node to the receiver node. A smaller end to end delay is required for time-critical situation while an end to end delay will be a little relaxed for the situation where long term monitoring is required.
2. Number of Alive Nodes: Nodes which are in operation and have enough energy to forwards packets is known as alive nodes. It is obvious that a node which is mostly busy in communication will run out of battery before a node which does not take part in unnecessary communication.
3. Packet Delivery Ratio: Packet delivery ratio is number of total delivered packets out all created packets. Packet delivery ratio is very important for all kind of networks.
4. Total Energy Consumption: Total Energy Consumption is the total amount of energy consumed in network (energy consumption of all nodes are included in this process) after some certain defined time. Energy consumption is very important parameter for UWSN because if nodes totally consumed its energy so defiantly it will die, which leads to whole network down. Replacement of battery in UWSN is almost impossible that is why energy consumption is measure issue in UWSN.

Fig. 5 has compared the End to End delay of the above defined four protocols. The figure shows that H2-DABâĂŹs end to end delay is higher of all because it involves the process of assigning dynamic addresses to all the nodes in the network and while performing data forwarding operations, dynamic addresses, as well as some other parameter like residual energy, are compared with each other. Which cause end to end delay. Similarly when nodes are displaced by water movement and other environmental factors. It also causes delay. The above figure shows that end to end delay of E^2MR protocol is higher than other two protocol i.e. DBR and EEDBR. As DBR and EEDBR work on the phenomenon of flooding so their end to end delay will obviously be low. As far as E^2MR is concern, it is basically designed

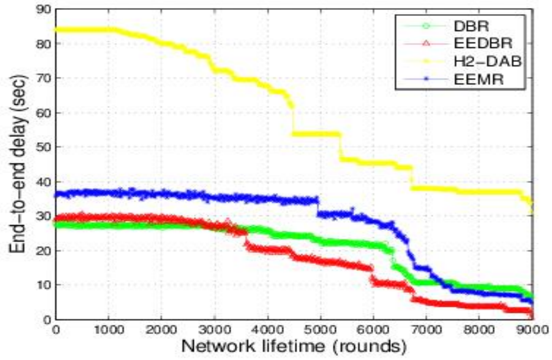

Fig. 5: End to End Delay vs Network Life Time

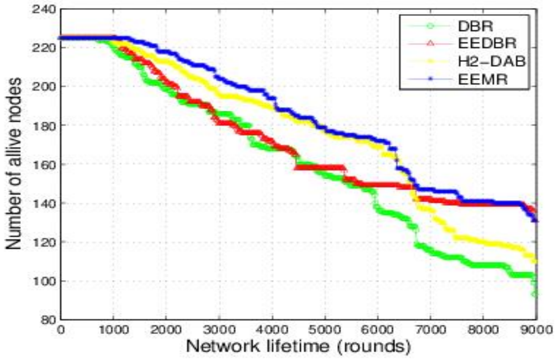

Fig. 6: Number of Alive Nodes vs Network Life Time

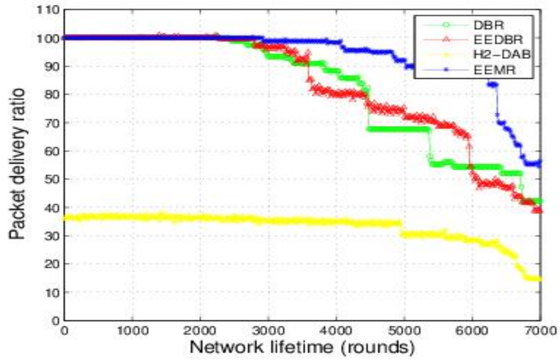

Fig. 7: Packet Delivery Ratio vs Network Life Time

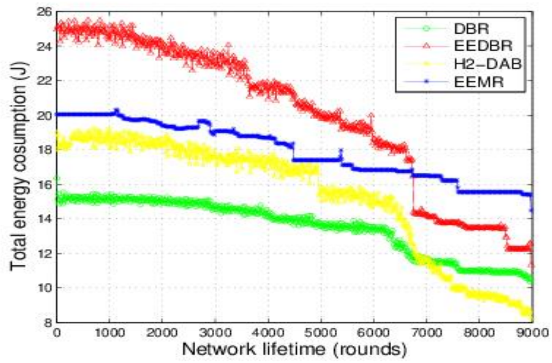

Fig. 8: Total Energy Consumption vs Network Life Time

for long term monitoring and low energy consumption. Therefore to avoid and packet duplication its end to end delay is a little high.

Fig. 6 shows number of alive nodes which comparison to increase in rounds. In the figure four protocols are compared with respect to number of alive nodes. Fig. 6 show that number of nodes left alive are higher while using E^2MR schemes in comparison to other protocols. When we study the previous three protocols, we will understand that DBR, EEDBR and H2-DAB use some nodes very frequently which ultimately leads toward death of frequently used nodes.

Fig. 7 shows the number of packet delivered during data forwarding operation and four protocol are compared with respect to packet delivery. Packet delivery ratio is measured

after specified rounds of data forwarding. Figure shows that packet delivery ratio of newly proposed E^2MR scheme is high of all other protocols compared. DBR, EEDBR and H2-DAB present low results during simulation when compared on the basis of packet delivery ratio. As these other protocols generate multiple copies of the same packet which leads towards duplication of same packet as well as some of them get dropped and some of them are dropped as same packet is already been received on the other end.

Fig. 8 shows the total amount of energy consumed of the four routing schemes during simulation. The above figure shows that battery of a node dies out earlier while using DBR protocol as it forwards data packet to all nodes whether they are far or near. H2-DAB assigns dynamic addresses to all nodes and data is forwarded only to selected nodes in each round. Similarly, EEDBR compares residual energy while forwarding data so it works for a long time then DBR and H2-DAB. As far as newly proposed scheme E^2MR is concerned, it loses more energy in its initial deployment of nodes and network set-up. Later on its routing operation remains stable and consume less amount of energy than other protocols. That is why its battery dries out last of all. As E^2MR consumes less energy and work for a longer period of time that is why this protocol is suitable where long term monitoring is required.

6 Conclusion

This paper has proposed a novel routing protocol for underwater sensor networks called Energy-Efficient Multipath Routing Protocol. E^2MR does not require any prior network information or any geographical information of other nodes. In this protocol, a unique type of table called priority table is developed. This table is created with the help of other nodes residual energy and its distance from sender node. Nodes having higher priority value are placed on the top in the table. Selection of forwarding node is made on the basis of priority value. This protocol can easily take benefit from multiple sink which is deployed offshore. E^2MR is basically designed for long term monitoring. This protocol proved to be energy efficient and having higher network lifetime and packet delivery ratio. Due to lower bandwidth and variable topology, communication in underwater wireless sensor networks is very challenging. To achieve better performance, fast recovery algorithm and topology handling algorithms must be developed. Lower bandwidth consumes more energy to retransmit the same packet again. In E^2MR, energy efficiency, long term monitoring and long network lifetime were taken into consideration. Our future work includes dynamic topology management, lower end to end delay and bandwidth management. This factor will results in more stable and long-lasting network for UWSN. Dynamic topology management will focus more on network stability. Bandwidth will be into segments and will be allotted, depending on the priority of the data.

7 Conflicts of Interest

The authors declare that there are no conflicts of interest.

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