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Radius-based Multipath Courier Node Routing Protocol for Acoustic Communications

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Abstract: Underwater Wireless Sensor Networks (UWSNs) use acoustic waves to communicate in underwater environment. Acoustic channels have various limitations that can be low bandwidth, a higher end to end delay and path loss at certain nodes. Considering the limitations of UWSNs, energy efficient communication and reliability of network UWSNs has become an inevitable research area. The current research interests are to operate sensors for a longer time. Currently investigated research area towards efficient communication have various challenges, like flooding, multiple copies creation path loss and low network life time. Different from previous work which solve these challenges by measuring the depth, residual energy and assigning hop-ID's to node. This article has proposed a novel scheme called Radius-based Courier Node (RMCN) routing. RMCN uses radius-based architecture in combination with cost function, track-id, residual energy, and depth to forward data packets. The RMCN is specifically designed for long term monitoring with higher energy efficiency and packet delivery ratio. The purpose of RMCN is to facilitate network for longer periods in risky areas. The proposed routing scheme has been compared with DBR and EMGGR in respect of alive nodes left, end to end delay, delivery ratio and energy consumption.

1 Introduction

Underwater Wireless Sensor Networks are newly emerged wireless networks, by providing the most promising mechanism for discovering underwater environment very efficiently. UWSNs could be used for many applications such as, military surveillance, Underwater animals monitoring, flood monitoring and commercial applications as well [1]. Autonomous Underwater Vehicles (AUVs) and Unmanned Vehicles (UVs) are usually equipped with sensors. They are designed for underwater communication and it moves around autonomously [2]. Most of the time, AUVs are used in such areas where exploration of natural resources is required, and these places cannot be accessed through human resources. These AUVs and UVs gather data and send the collected data to off-shore sinks, which is forwarded to base station for respective purpose and processing. As radio waves cannot travel in UWSNs, therefore only acoustic channels are developed to be used in UWSNs [1, 3]. A data packet is sent to sink through acoustic channels and from sink it can be forwarded through radio waves to base station [3]. UWSNs environment carries various challenges like higher propagation delay and lower bandwidth. A terrestrial Wireless Sensor Networks (WSNs) is much different when compared to UWSNs. Usually these challenges are faced by UWSNs due to dense salty water, high attenuation, and higher absorption effect. Therefore, signals are not able to travel long distance. To overcome the above problems researchers are working to improve the performance of acoustic channels and to provide better transfer rate in UWSNs.

UWSNs environment is much different from that of terrestrial Wireless Sensor Networks (WSNs). In WSNs, ambiguities like high propagation delay and lower bandwidth do not exists [4]. Normally the challenges in UWSNs communication are due to non-applicability of electromagnetic and optical signals [5]. Acoustic channels can overcome the challenges in underwater communication and provides a considerable transfer rate [6]. In acoustic channels, propagation speed get down from the speed of light the speed of sound, that is 1500m/sec. Lower speed usually results in longer propagation delays [7]. Bandwidth is an important issues for every communication and in acoustic channel, bandwidth is very limited and almost less than 100KHz [8]. In UWSN scenarios, sensor nodes are usually considered as static but in real situation it may move from 1 to 3 meter/second due to flow of water [9]. All sensor node used in UWSNs are battery operated and battery replacement is impossible [10]. In underwater network, a scenario with multiple paths going through different nodes and reaching sink is required. The data packets are forwarded to sink by using different nodes and different paths every time. Which probably results in lower energy consumption when taken as a whole [11] [12]. In UWSN, multiple sinks are installed for efficiency purpose. The data packet can be received at any of the sink. Once it is received, it is relocated to the concern sink [13] [14].

Clustering in routing means that there are multiple clusters in the network; each cluster acts as a tree structure consisting of a plurality of cluster head and cluster members. The data collected by the cluster members are sent to cluster head for data fusion through other multi-hop cluster heads or sent directly to the base station. The result of the clustering routing algorithm in every round to cluster head election is advantageous to network node energy load balancing. The data collected by cluster member nodes are forwarded by the cluster head after fusion to reduce the network energy consumption. For data transmission and to avoid each cluster member node forwarding data separately, cluster head is used. Cluster routing algorithms for WSNs are widely used; the classic clustering routing algorithms are LEACH [15], HEED [16] and others. These clustering routing algorithms do not apply to UWSN. LEACH protocol does not consider the node residual energy situation in the election of the cluster head. The probability of a high residual energy node becoming a cluster head in HEED. The agreement is higher but does not fully consider the energy consumption of the propagation distance. ItâĂŹs because in the process of propagation, underwater energy loss is higher.

It is worth noting that acoustic channel does not support higher bandwidth. The routing protocols used in terrestrial sensor network may not perform well in UWSNs. There are multiple which may include higher delays and more energy consumption. Another difficulty in UWSNs is its non-static topology which changes with every second with the flow of water. The basic architecture of UWSNs is depicted in fig. 1.

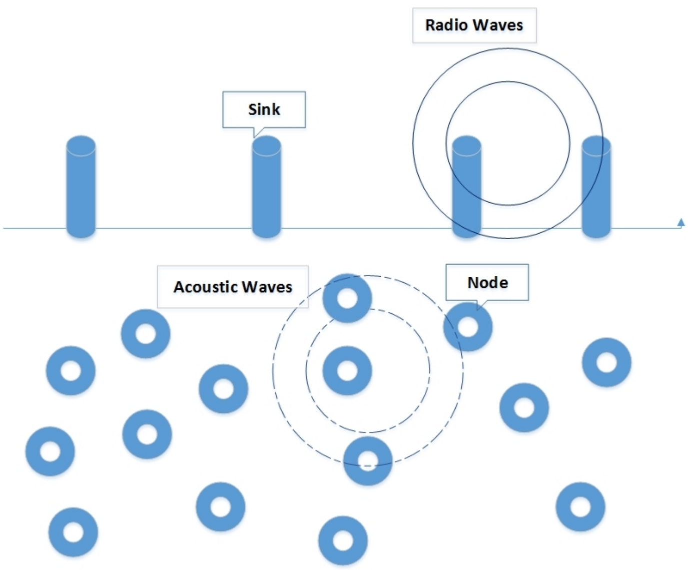

Fig. 1: Underwater Wireless Sensor Network Architecture

Keeping in view the main challenges in current routing protocols, which are high energy consumption, higher delay, and shorter lifetime. The main contributions of this article are as follows;

- RMCN divides the network area into sink and node area depending on the radius of network area.
- It forwards data packet comparing track-id, analysing cost function and depth of the node.
- Node coordinates with courier as well as other static nodes for efficient delivery of data packets.

The article is structured as follows;

In section 2, routing protocols in UWSNs has been discussed. Section 3 elaborates on the proposed routing scheme. Section 4 includes comparison of designed scheme with the state of the art routing schemes and finally conclusion has been drawn in section 5.

2 Background on Routing in UWSNs

There are many scholars who have conducted research and achieved certain results for the UWSN energy consumption minimization problem. Dario Pompili et al [17] 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) Through the design of a distributed cross-layer communication method, sensor nodes can share the network bandwidth efficiently. The protocol confirms the effectiveness of the algorithm in improving energy efficiency and network throughput by experimental results. Sarath Gopi et al [18] 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 that uses a gathering node as the centre and other nodes located on concentric circles. 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 comparing analysis with other algorithms display the validity of the E-PULRP protocol for energy efficiency. Junfeng Xu [19] proposed a 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. 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 mainly be divided into two categories [12], i.e. Location Based Routing (LBR) and location Free Routing (LFR). LFR protocols do not require any pre-network geographical information. These type of routing protocols perform their operations without having any location information of other nodes in the network [20]. 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 [21]. In LBR protocols, paths calculation and node's geographic information are pre-requisite for network, which results in high end-to-end delay and energy consumption.

2.1 *Location Based Routing*

Vector based forwarding (VBF) [22] is an 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 knows also know 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 combinedly develops a routing pipe. The data packet is forwarded with the help of node lies around virtual pipe. The enhanced version of VBF is presented as Hop-by-Hop Vector Based Forwarding HH-VBF [23]. 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. So 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 destination.

2.2 *Location Free Routing*

2.2.1 Depth Based Routing: Depth Based Routing (DBR) is an LFR scheme and does not require any pre-network node location information [24]. The DBR primarily takes sensor depth into consideration when forwarding a data packet. When a node is going to forward a data packet, it compares its depth with that of proposed receiver node. It only forwards data when depth of receiver node is lower than sender itself. Sometimes when it is unable to find a node with defined parameters, 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 results in higher energy consumption. This flooding process in DBR continues until packet is received by any of the sinks installed on-shore. Most of the time this process produces multiple copies at sink level. DBR analyse only depth information while performing data forwarding operations. Which 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. There is no proper mechanism defined for path selection, protocol generates a random path for every data packet generated.

2.2.2 Energy Efficient Depth Based Routing: Energy Efficient Depth Based Routing (EE-DBR) [25] is an enhanced form of DBR. It has more capabilities when compared to DBR. When 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 have information on depth and residual energy about their neighbourâĂŹs nodes. The drawback of EE-DBR is that it is not flexible for long term and in few cases, it floods 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.

2.2.3 Hop-by-hop Dynamic Addressing Based Scheme: Hop by Hop-Dynamic Addressing Based routing (H2-DAB) [26], is a location free routing scheme. This scheme dynamically assigns addresses to node. 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, very 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 start 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. This scheme assigns 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 must wait for an appropriate next hop-ID or send the data packet backward.

2.2.4 Energy Efficient Dynamic Addressing Based Routing: Energy Efficient Dynamic Address Based routing (EE-DAB) [27] does not require any network related information for data forwarding. In this routing scheme, every node is provided with two kinds 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 IDâĂŹs consist of two digits.

2.2.5 Mobile Delay Tolerant Routing: As acoustic communication uses more energy than that of radio communication. As wireless sensor nodes are battery operated and higher energy consumption lead towards a serious problem. Thus, energy efficiency has become a major problem in underwater wireless sensor networks. In [28], 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 node stay static and data sensed by static nodes are passed on to data dolphin which acts a courier node. So, in this methodology high energy consumed hop by hop communication is avoided. Data dolphins which acts a courier node are provided with continuous energy. In the architecture all the static nodes are deployed in the sea bed. These static sensor goes into sleep mode if there is no data to sense and it periodically wakes up when it senses some data. After sensing some kind of desired data, it simply forwards 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 depend upon the kind of network and its application and the number of nodes deployed in the network.

2.2.6 Energy-efficient-Multipath Grid-based Geographic Routing: Energy-efficient Multipath Grid-based Geographic Routing (EMGGR) [29] 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.

2.2.7 GEDAR: GEographic and opportunistic routing with Depth Adjustment-based topology control for communication Recovery over void regions (GEDAR)[30], is an opportunistic any cast routing protocol used in UWSN. GEDAR en-routes data packets from senor nodes to sink placed on surface of sea water. GEDAR divides the network region into two parts i.e. void region & un-void region. Data sending operations are performed normally in un void region while recovery mode is used when data packet moves in voif region of the netwrok. GEDAR performs multiple path maintenance & optimization operation in void region.

2.2.8 Diagonal & Vertical Routing: Diagnol & Vertical Routing Protocol (DVRP) [19] uses flooding angle. The flooding zone angle is used by all sender nodes towards the sinks installed on the surface of water. In DVRP, flooding zone angle plays vital role in transmitting data packets. It make a local decision based of residual energy and distance to attain an optimized path.

3 Radius-based Courier Node Routing Scheme

3.1 Node Architecture

A general architecture of underwater wireless sensor node is composed of five main elements. Which are energy management unit, data sensing unit, depth measuring unit, communication unit and central processing unit [3]. Processing unit is responsible for all kind of data processing which energy management unit has the responsibility to manage the remaining energy of node and consumption of energy in runtime as well. Data sensing unit is used to sense data. It is always in active mode even when node itself is in sleep mode. Communication unit is responsible for all kind of data communication whereas depth measuring unit is used for measuring depth of water when it is deployed in sea.

3.2 Network Architecture

In this article a novel routing scheme has been proposed called as Radius-based Multipath Courier Node (RMCN) routing protocol. RMCN Routing protocol is designed to provide energy efficient communication, longer network lifetime and high packet delivery ratio. The proposed protocol will be able to avoid data flooding phenomenon and creation of multiple copies. RMCN Routing protocol will be able to take advantage of having underwater sensor network architecture with multiple sinks and mobile nodes. 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 courier and static sensor nodes are deployed in desired underwater area. These nodes can collect data and forwarding it to sink in multi-hop fashion or to courier node. Courier node are provided with continuous power and they are only capable of receiving data from static sink and forwarding it to sinks. As sinks have Radio Frequency modems. Sinks can easily communicate with each other through radio channels. We can easily validate this assumption by this fact that sound propagates almost at the speed of approximately 1.5×10^3 meter/second in water, five of orders of magnitude slow than that of radio waves which is having a propagation of 3×10^8 meter/second in air. In our scenario, we have assumed that a when packet reaches its destination as soon as it is successfully reaches to any of the sinks. So, if a data packet is delivered to any of the sink is considered as delivered.

3.3 Design of RMCN

In the proposed protocol, the network area is considered as circle area, as depicted in Fig.2. The area is broadly divided into two parts, (i) The sink area (ii) The Node's area. The one fourth of total area is designated for sink while the remaining area is assigned for nodes deployment. The Nodes area is further divided into two equal regions for static and courier nodes. The area is divided in such way that more static nodes are deployed towards higher depth. It helps the network to perform for higher time. As the structure of network show, sink area has been surrounded by static and courier nodes. The circle architecture is proposed in such a way that sink can be accessed through any path by a node. The Nodes area is divided into equal segments called triangles. The node area is divided equally between static and courier nodes.

Each triangle in the nodes area is divided into tracks. Each track in a triangle is assigned with a number called Track-ID (T-ID). The more away the track is from the sink, the higher will be its T-ID. The static nodes are assigned a physical address called Static-ID (S-ID) while courier nodes are assigned with Courier-ID (C-ID). T-ID of a node changes with its movement while S-ID remains the same throughout the network lifetime. As depicted in Fig.2.

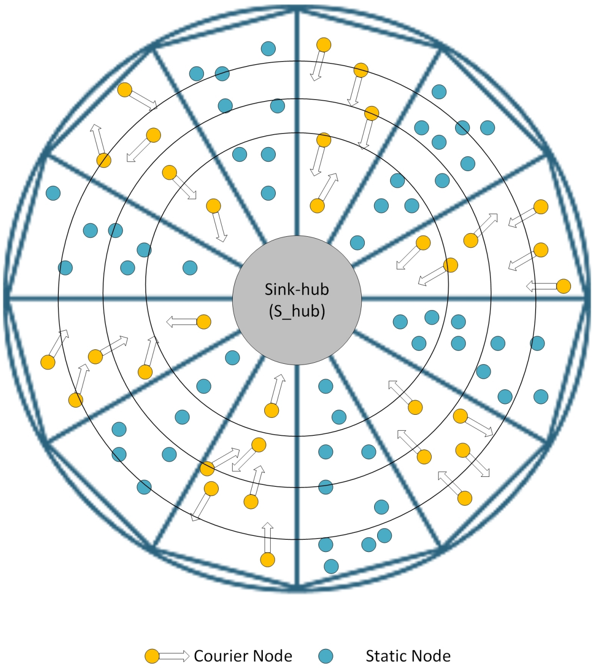

Fig. 2: RMCN Network Architecture

RMCN Routing protocol basically focuses on energy efficiency and will avoid all those phenomenon, which leads towards more energy consumption like, avoidance of flooding mechanism, multiple copies of a same packet and retransmission etc. Where a node sends a received packet to all nodes which lie in its range of communication, avoiding creation of multiple copies where the sink receives multiple copies of a same data packet. In RMCN Routing protocol a table will be created at every node, initially all nodes broadcast a hello packet to their surrounding nodes. Which includes their residual energy, depth information, node-ID and sector-ID. Network architecture of RMCN Routing is defined in 2. A hello packet is send to all other nodes which lies in node's soft communication range. The soft communication range is a phenomenon where a node comparatively less energy and is set to 100 meters while in hard communication range a node can directly communicate with sink. Upon receiving Hello packet, all nodes will reply to every sender node with the parameters enquired in Hello packet. Likewise, residual energy, depth of node and distance from sender node, node-ID and sector-ID.

Once a static sensor node sense data or receive data packet from another node, then it takes decision to forward it to another node near the sink. In the first step, it compares the distance from itself to other nodes in its region as depicted in 3. The distance is illustrated by d1 and d2. In the following steps, the node analyses the other parameter as discussed in 5.

Design of hello packet and data packet in RMCN routing protocol have been illustrated in 4, which contains of sender and receiver-ID, residual energy, depth and distance from sender node to receiver node. Where Sender-ID's and receiver-ID's are known as identification of sender and receiver node respectively. Residual energy is

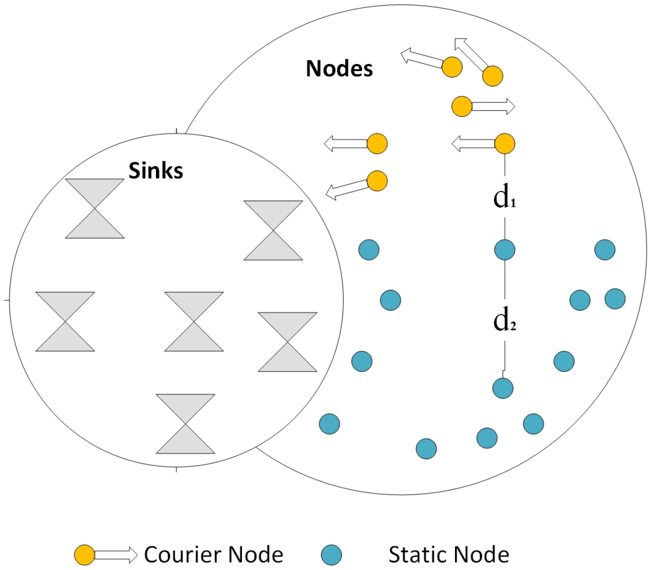

Fig. 3: Selection Between Courier & Static Node

the remaining energy of the node and last element is used for measuring distance between sender and receiver node. The data packet contains sender ID, receiver ID, sector ID, packet sequence number and data. Where packet sequence number is unique number which is assigned by sender node to data packet. When static nodes sense data, they first search for in-range courier node. If they found any courier node, packet is forwarded to courier node. Once courier node receives data packet, it is directly forwarded to sink as courier node are supported with external power. Similarly, if there is no courier node in range then packet is forwarded to another in-range static node after complying with certain parameters as depicted in Fig.5.

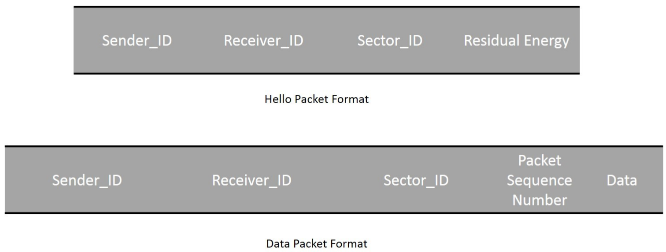

Fig. 4: Packet Format

âĂć In network deployment phase, static nodes as well as courier nodes are deployed in the designated network area. There are a few scenarios where nodes are randomly deployed. In RMCN nodes are distributed according to a set criterion.

âĂć In the second phase, ID's are assigned to nodes. An ID assigned to a static node can be identified as S-ID while ID assigned to courier node may be recognized as C-ID.

âĂć The next step is the Hello packet exchange. Node exchange their information with their surrounding nodes and start the process of sensing and sending data.

âĂć When a node sense data, it checks the next-hop value towards sink. If this value is greater than 0 then search for courier node is initiated. If courier node in-range is founded, packet is forwarded to it. This packet is then delivered to sink by courier node. In other case if there is no courier node in-range, then static nodes with considerable residual energy are selected for further steps.

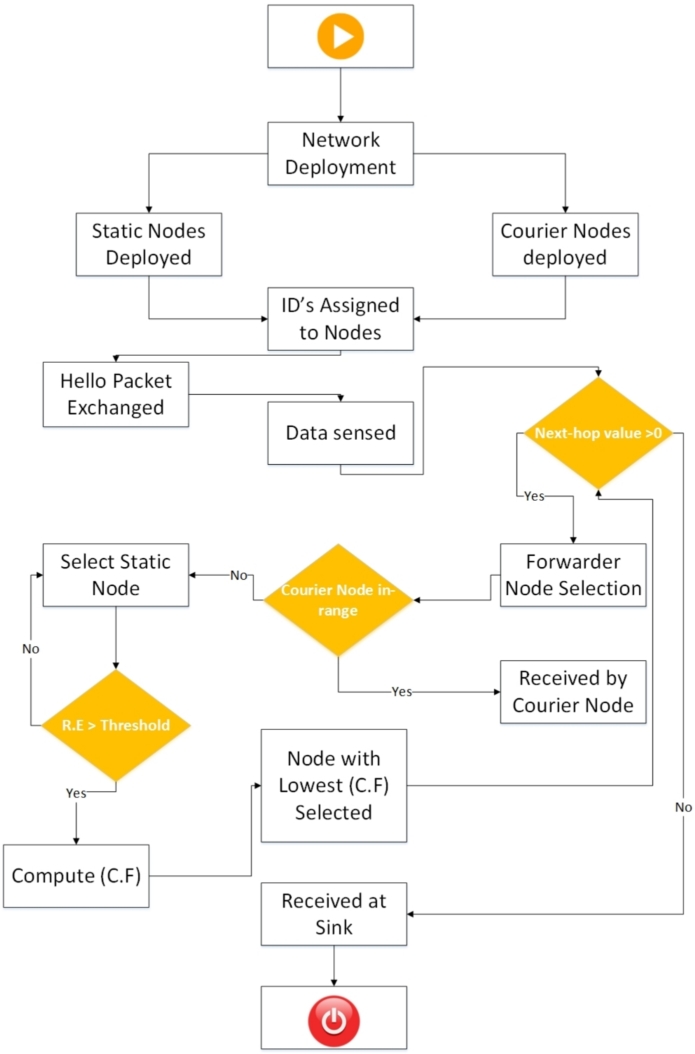

Fig. 5: Data Flow Diagram

âĂć After selecting nodes having about threshold energy, their cost functions are calculated. The cost function values of these node are compared and node with the lowest value is selected as forwarding node. Similarly, this process continues until packet is received by the sink.

3.4 *Energy Consumption Model*

According to the energy consumption model [31]and Signal-to-Noise Ratio (SNR) through the passive sonar equation can be calculated as follows:

$$SNR = S_L - T_L - N_L + D_I \geq D_T \tag{1}$$

Where S_L can be defined as source level, T_L as transmission loss, N_L as noise loss, D_I as directive index and D_T as detection threshold.

While T_L using Thorp model [32] is as follows:

$$T_L = 10log(d) + \alpha d \times 10^{-3} \tag{2}$$

Where d is supposed to be the distance between sender and receiver node whereas, α as the absorption coefficient. The N_L is composed of four components which can be computed by the following equation, where f is the frequency of signal.

$$10log_n(N_t f) = 18 - 30log(f) \tag{3}$$

$$10log_n(N_s f) = 40 + 20(s - 0.55) + 26log(f) - 60log(f + 0.033) \tag{4}$$

In the equation below, w is wind constant while s is shipping constant,

$$10log_n(N_w f) = 50 + 7.5w^{\frac{1}{2}} + 20log(f) - 40log(f + 0.4) \tag{5}$$

Noise produced by turbulence, wind, thermal and shipping activities are denoted by Nt , Nw , Nth and Ns respectively. SL can also be calculated by passive sonar equation.

$$SL = SNR + TL + NL - DI \tag{6}$$

While signal intensity can be calculated by I_T

$$I_T = 10\frac{SL}{10} \times 0.067 \times 10^{-18} \tag{7}$$

and the source transmitted power can be calculated by

$$P_T(d) = 2\pi \times 1m \times H \times I_T \tag{8}$$

Whereas energy consumption of sending k bytes over distance d can be given by:

$$E_{TX}(k, d) = P_T(d) \times T_{TX} \tag{9}$$

Here, delay can be calculated by using end-to-end delay model [33],

$$T_P = \frac{s}{v} \tag{10}$$

Where s is distance between sender and receiver and v is speed of acoustic signal and can be calculated as follows;

$$\begin{aligned} v = 1449.05 + 45.7t - 5.21t^2 + 0.23t^3 + \\ (1.333 - 0.0126t + 0.009t^2)(S - 3S) + 16.3z + 0.18z^2 \end{aligned} \tag{11}$$

$$t = \frac{T}{10} \tag{12}$$

3.5 *Mathematical Model for RMCN*

According to the above scenario the area of network (N) can be derived by N, As area is mainly divided into two circles as depicted in 2. The inner circle also called Sink-hub (S-hub) and outer circle is called as Operational-hub (O-hub).

$$N = \pi r^2_{(1)} + \pi r^2_{(2)} \tag{13}$$

Basically the network area is divided in such a way the Sink-hub should $r\frac{1}{4}$ and Operation-hub as $r\frac{3}{4}$, where r is the radius.

Similarly area of operational-hub can also be derived as

$$S = \frac{\pi r^2_{(2)}}{2}, C = \frac{\pi r^2_{(2)}}{2} \tag{14}$$

$$O - hub_{area} = \frac{\pi r^2_{(2)}}{2} + \frac{\pi r^2_{(2)}}{2} \tag{15}$$

While the sink area as,

$$S - hub = \pi r^2 - (O - hub) \tag{16}$$

While the cost of transmitting data to next hope can be calculated through cost function,

$$(C.F)_n = \frac{d}{Residual_{Energy} \times P_T(d)} \tag{17}$$

Algorithm 1 Forwarding Node Selection

procedure SELECTION
  Deploy ← Nodes
  Exchanged ← Hello Packet
  Nodes ← ID Assigned
  if $Next - hop$<0 **then**
   Sink ← Packet sent return true;
  else $SearchforNextHop$
   if $Courier\ \ node\ \ in\ \ range$ **then** *Courier node* ← Packet sent return true;
   else *Find C.F of nodes in upper track*
   Lowest C.F node ← Packet sent
    Sink ← Send
    goto *top*

- r is radius of circle
- π is pre-defined value as 3.14
- $O - hub_{area}$ is the area where static sensor and courier node lies.
- $S - hub_{area}$ is the area where sinks are deployed.
- $P_T(d)$ is transmission power.
- d is distance between sender and receiver node.
- $Residual_{Energy}$ is the remaining energy of node n at time t.
- S_L shows Source Level.
- T_L represents Transmission Loss.
- N_L illustrates Noise Loss.
- D_I denotes Directive Index.
- d is distance between sender and receiver.
- I_T is signal intensity.
- P_T is the source transmitted power.
- D_T is Detection Threshold.
- α is absorption coefficient.
- w is wind constant.
- s is shipping constant.

4 Performance Evaluation

The proposed RMCN Routing protocol has been evaluated through various techniques by simulation in MATLAB. RMCN protocol is compared with the existing state of the art routing protocols i.e. DBR [24] and EMGGR [29]. They are analysed based on packet delivery ratio, end-to-end delay, total energy consumption and number of operational node left at certain rounds. 1 illustrates the parameters and their values used while performing simulation.

Table 1 Evaluation Parameters

Parameter	Value
Network size	500 m x 500 m
Number of nodes	225
Initial energy	25 J
Minimum packet size	1000 bits
Frequency	30 Hz
Number of sinks	5
Transmission range	100 m
Number of rounds	9000

4.1 Evaluation Parameters

• End-to-end delay: The time taken by a data packet from its initiation till it is received by the respective sink or destination is called end-to-end delay. Network usually have higher end-to-end delay when more intermediate nodes are involved in routing process.
• Number of operational nodes: In every network, when nodes are battery operated, some node uses their batteries very fast while other uses their battery in a more moderate way. The total number of nodes

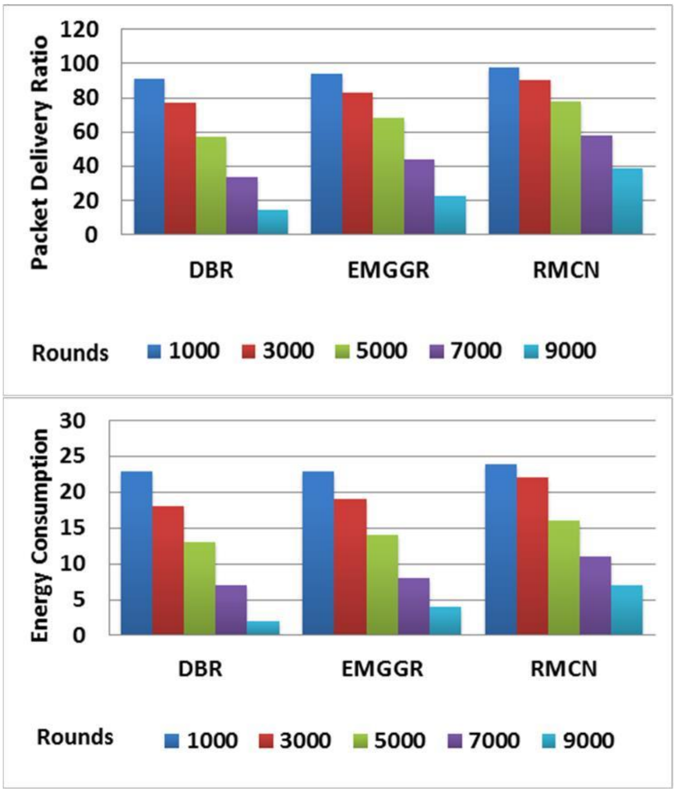

Fig. 6: Packet Delivery Ratio & Energy Consumption

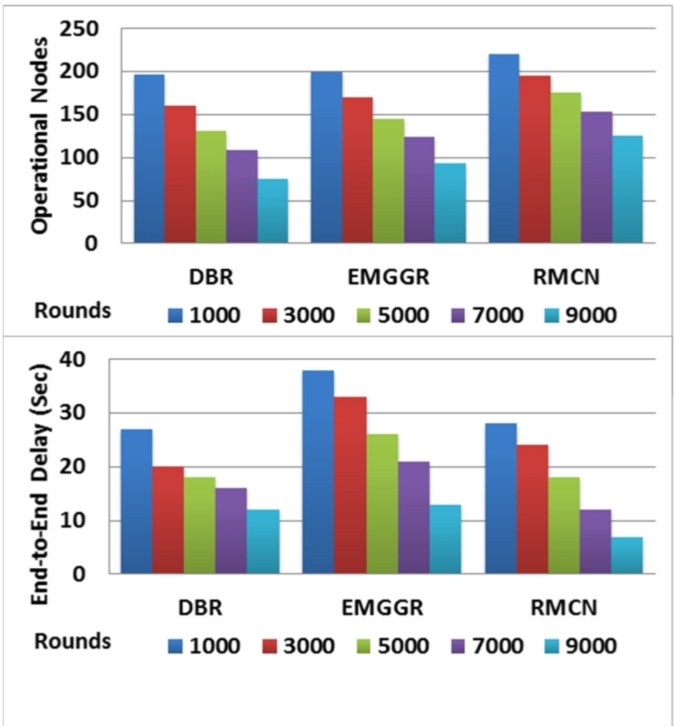

Fig. 7: Operational Nodes & End-to-End Delay

which are in working condition at a certain time t are called number of operational at time t.

- Packet delivery ratio: Its show the actual ratio between the total number of packet sent versus total number of packet delivered. The packet delivery ratio between 90-95 is considered as good.
- Total energy consumption: It is the amount of energy consumed by the network at a specific time t or after a certain number of rounds. The amount of total energy consumed by different routing scheme may be different for the same network.

Fig.6 illustrates the comparison of packet delivery ratio and energy consumption with respect to number of rounds. This comparison is carried out between three routing protocol i.e. DBR, EMGGR and RMCN. The packet delivery ratio of RMCN has remained higher and consistent throughout the network lifetime while lower in DBR and EMGGR when network reaches 9000 rounds. The packet delivery ratio of DBR in earlier rounds stays higher because it involves sort of semi-flooding concept. It compares only the depth parameter and forward same packet to all the nodes fulfilling that criteria. The proposed protocol make decision between courier and static node considering distance parameter. Similarly, RMCN consumes less energy than DBR and EMGGR. DBR uses most of its energy in producing multiple copies of same packet and these copies increases exponentially. While EMGGR involves complex calculations and complex decision making.

In Fig.7 comparison has been carried out on end-to-end delay and number of operational node left at certain time t, between DBR, EMGGR and the proposed scheme. The result shows that end-to-end delay of DBR and RMCN is almost same, although route planning is not involved in DBR which usually leads towards higher energy consumption on the other end while RMCN performs route planning as well. The end-to-end delay of EMGGR is higher than RMCN at certain rounds as depicted in Fig.7. On one hand end-to-end delay of DBR is lower but on the other hand the nodes in DBR drains out its energy earlier and cannot remain operational for a longer time. The number of operational node left at time t in RMCN is higher than DBR and EMGGR. The overall confidence interval for this simulation was recorded as 97.33%.

5 Conclusion

This paper has proposed a novel routing scheme called Radius-based Multipath Courier Node (RMCN) for UWSNs. The RMCN Protocol does not require any prior network information or any geographical information of other nodes in the network. In RMCN scheme, network area is divided into two basic parts know as sink area and node area. Sensors are divided into two categories, static & courier nodes. The proposed scheme considers depth, distance, residual energy and analyse cost function for forwarding data packets. The RMCN is primarily designed for long term monitoring. This protocol has proved to be energy efficient and have higher network life time and packet delivery ratio. Due to lower bandwidth and variable topology. Results shows that RMCN out performs DBR and EMGGR with respect to energy efficiency, packet delivery ratio, alive nodes left and end-to-end delay. To achieve better performance, fast recovery algorithm and topology handling algorithms must be developed in future. Dynamic topology management will focus more on network stability. Bandwidth will be divided into segments and allotted on priority basis.

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