An Energy Efficient Sector-Based Routing Protocol for Reliable Data Transmission Through Reducing the Hop- Count and Balanced Energy Consumption in UWSNs

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Abstract. The one of the main objectives of any energy efficient routing mechanism of Underwater Wireless Sensor Networks (UWSNs) is to extend the network lifespan. The characteristics of underwater environs and acoustic communications make to prolonging network lifetime is a challenging task. To achieve the same, topology control and optimize energy consumption is needed, which can be achieved through clustering. In this paper, we proposed a sector-based forwarding scheme through dividing 3D network in sectors of same size and dimensions. Forwarding takes place in a sector-by-sector in a single hop manner via some nominated nodes called sector-heads and gateway nodes. The sector-heads of each sector elected on the basis of residual energy of the nodes, and dynamically changed after reaching energy threshold decided to forward data packets. The gateway nodes are some boundary nodes utilize when sector-head does not have sufficient energy to forward data packets towards other sector- heads. However, the proposal utilizes the depth information to forward data packets. Hence, all the communication is done towards vertical direction in, each sector-head adaptively based on the depth of a particular node. The proposal is evaluated and analyzed against some existing energy efficient routing mechanism, and the simulation outcomes reveal significant improvement in energy consumption, network lifetime, and packet reception rate of the network and reduces the overall network overhead.

Keywords: Sector-based routing, Energy-efficient routing, energy balanced routing, underwater sensor networks

1 Introduction

Underwater Wireless Sensor Networks (UWSNs) is a very promising research area these days due to variety of applications such as under water parameters assessment for water quality monitoring [1], tactical surveillance [2], oil and mineral drilling in deep ocean [3], early warning systems for underwater disaster detection and prevention [1], and military surveillances [4]. For the same, UWSNs consist of number of sensor nodes deployed all over the application area to detect and sense the activities in underwater environment. The sensor nodes collectively sensed the underwater information and send this information to the sink nodes positioned at the water surface. Information gathered by sensor nodes is sending to the sink in the form of acoustic signals through acoustic channels. Acoustic channels are most appropriate mode of communication in underwater environment [5].

However, UWSNs face several challenges due to underwater environment such as low bandwidth and high propagation delay due to the use of acoustic signals in place of radio signals for data communication. The speed of acoustic signals is very low in underwater environment, approximately five times of magnitude slower than the speed of radio signals [6]. Despite of these challenges, UWSNs are facing highly dynamic surroundings due to the water currents and submissive movements of sensor nodes, which origins added challenges. In addition to these, UWSNs also suffer due to multi- path and fading effects [7, 8, 9]. Underwater nodes are furnished with batteries of limited energy, which are almost impossible to be replaced or re-energized.

Several researchers proposed solutions to address diverse issues in UWSNs like node's sensor node deployment, mobility of nodes, channel issues, efficient routing strategy, and localization scheme. This paper is limited to network layer and address the energy- efficient routing issue to prolonging the network lifetime through reducing the overall energy consumption of sensor nodes. Multi-hop routing approach is most preferable in such scenario due to the longer distance between sensor nodes and surface sink. The objective of efficient multi-hop routing maybe to maximize the throughput of network, lower the energy consumption and shorter delay. Although, these protocols face some issues such as high energy depletion in dense networks, and lower throughput in sparse networks with longer end-to-end delay. In this paper, we proposed an Energy Efficient Sector-Based Routing (EESR) protocol for UWSNs to resolve the above-mentioned routing challenges, and to accomplish prolonging network lifetime through high energy-conservation, higher throughput of the network in terms of greater packet delivery ratio, and lower average end-to-end delay and high packet delivery ratio under dense as well as sparse network.

The leading contributions of the proposal are précised as follows.

- An energy efficient sector-based routing for UWSNs, called EESR, is proposed.
- EESR utilize the depth information to divide the whole network in sectors.
- Some specific nodes called sector-head and some boundary nodes called gateway node only able to forward data packets in sector-by-sector manner.
- The proposal classifies the neighboring sectors to optimize the forwarding process and reduce the hop-count in data transmission.
- The proposed protocol uses the classification of neighboring sectors to reduce hop-count through forwarding packets through neighboring sector-heads in horizontal directions to reduce the average delay of transmission.
- The aim of proposal is to enhance the energy consumption at node by reducing the hop-count while transmit data packets towards sink node.

The rest of the paper is structured as follows: section 2 discusses the state-of-art energy efficient routing protocols proposed for UWSNs. A conversation on the proposed EESR is discussed in section 3. The evaluation outcomes as simulation results is defined in section 4, and finally, the proposal concluded in section 5.

2 Related Work

This section provides the state-of-art proposed by researchers in the field of energy- efficient grid-based routing in UWSNs. Many researchers introduced various routing schemes for UWSNs, based on different nodes and network-based criteria. Based on these criteria routing protocols categorize in three types; location aware flooding-based routing protocols, depth-aware routing protocols, and grid/cluster derived routing protocol. The aim of location aware routing is to control flooding of data packets to reduce the congestion in the network through forwarding packets based on location of desired sensor nodes.

The traditional flooding-based protocol named VBF [10] uses the routing pipe through which data packets are forwarded. Each node in the network form a routing pipe or vector by computing its relative distance and angle of arrival to route data packets. Nodes which are nearer to the routing pipe are eligible to forward data packets. The radius of the routing pipe plays an important role to optimize the flooding and reduce the chances of collision. Another extension of VBF called HH-VBF [11], proposed the modifications in VBF approach by defining per node virtual routing vector to forward data packets. Each node has ability to take decision on the routing pipe direction based on its current location. VVBF [12] proposes the void handling mechanism for VBF by introducing two technique vector-shift and back-pressure. In LE-VBF [13], author proposal aims to reduce the energy intake of nodes in dense network. It allows each node to adjust its forwarding mechanism through estimation of node density at neighborhood environment. Another flooding-based routing proposed as DFR [14]. In DFR, each sensor node knows its location, its one hop neighbor location and the location of sink node. Forwarding is done in a scoped flooding to achieve the greater reliability in communication. The flooding zone is decided based on the angle between forwarder and source, and the forwarder and sink.

All flooding-based location aware routing protocols aims to reduce the number of forwarders to enhance the energy efficiency of data communication. But fails in dense network due to multiple forwarder selection, which increase the throughput of the network in the cost of more energy consumption.

Depth-based routing protocols to be work mainly on depth info, easily attained through depth sensors built-in with under water sensor nodes. The first depth-based routing protocol DBR [15], needs only the depth info to forward data packets. DBR takes forwarding decision on the basis of depth of the candidate forwarder, and forwards the data packets from higher to lower depth sensor nodes. An improvement of DBR protocol EEDBR [16] was proposed, in which residual energy of node also considers with depth of the node to select the forwarder node. It also utilizes the direct communication mechanism, in case of no forwarder with sufficient energy is selected for transmission towards surface sink. CDBR and CEEDBR [17] suggest the extension of DBR and EEDBR respectively to promote improvement in the energy consumption of routing thru the depth threshold by limiting the count of relay nodes. Another depth aware approach EEF [18], which is developing to accomplish energy efficiency in routing. The protocol calculates the fitness value to determine the best possible forwarder node based on the depth information and residual energy of the node. In [19, 20], Kumar et al. utilizes the concept of energy balancing in the depth based through computing holding time based on remaining energy and depth of the sensor node to balance the energy consumption of forwarder node.

Depth based routing is better option for energy efficient data transmission, but most of the depth-based approaches face void regions in highly sparse networks and also unadorned collisions in dense networks.

Grid-based routing protocols MGGR [21] and EMGGR [22] was introduced to reduce the number of hops in communication to enhance the energy consumption of the network. They are constructing disjoin paths to forward data packets in cell-by-cell manner in single hop communication via cell heads. Due to the use of grid view to construct routes at the time of transmission, there is no need to route maintenance, which also optimize the energy consumption of the network. But longer routes increase the average delay in packet transmission and probability of packet drops.

One another proposal named EGRC [23] for energy efficient routing was introduced, in which cell or cluster head is nominated based on the remaining energy and distance from surface. The data is aggregated at cluster-head and then route for transmission is established on the basis of residual energy and the location. EGRC achieve high energy efficiency, but due to frequent cluster head selection, network overheads are increased. GBPR [24] propose improvement in EMGGR, by classifying neighboring cell based on their priority to forward data packets. The priority level of the cell is decided on the basis of distance of cell from the sink node. The packet forwarded through higher priority cell only which reduce the hop-count of communication and reduce the energy consumption. Due to high priority of cell which is nearer to the surface being nominated frequently as forwarder, drain more energy and die earlier, which might be result in shorter network span, and also increase the chances of congestion.

ERGR-EHMC [25] introduce the enhancement of GBPR through minimizing the number of hops in transmission. During the forwarding process, source nodes can stipulate the hop-count that the packet is not supposed to surpass. It also handles void problem through the use of negative acknowledgement and retransmission policy. Which may be incurred more energy and increasing overhead due to duplicate transmission.

The state-of-art work discussed here might be provide energy-efficient routing in UWSN, but face some common issues such as;

- Increasing energy depletion specially in dense networks due to the overhead gained by broadcasting a substantial number of packets,
- Lower network throughput in terms of PDR in sparse networks,
- Longer average network delay, and
- Performance degradation due to node mobility and topology change.

In the next section of this article, we proposed a routing protocol EESR to address and resolve these issues and provide a sector-based energy efficient data transmission scheme for UWSNs.

3 The Proposed Routing Protocol

The proposed routing protocol is a depth –based routing protocol that advances the routing packets, hop-by-hop, towards the surface sink in multi-hop manner. The network is viewing as a 3D logical grid of sectors, forwarding takes place in sector-by- sector manner. Data forwarding takes place between a set of specific nodes called sector-heads only. The target forwarder is selected based on the depth difference towards the surface sink and the residual energy of the node. Nodes deployed with sufficient intensity that, each node having one forwarder node within the communication range to avoid void regions. Due to the limited number of forwarders, the proposed routing protocol achieved high packet delivery ratio, low energy consumption and lower average end-to-end delay in routing.

3.1 Network Model

3.1.1 Assumptions

The sensor nodes are deployed in 3-dimentional area of underwater wireless sensor network to perform collaborative task of gathering data from underwater environment and transmit it to the surface sink positioned at surface level. The following assumptions are taken for underwater wireless network architecture:

- A finite number of sensor nodes deployed uniformly in random fashion in in the application area of UWSNs. All sensor nodes have equal acoustic communication range R. They are assumed to have similar capabilities in terms of storage, communication range, and initial energy.
- Sensed data packets are transmitted to one of multiple sinks positioned at water surface and presumed to be motionless. All the sink nodes are equipped with both type of modem, acoustic modem to communicate to underwater nodes in the form of acoustic signal and radio links to connect with surface stations.
- All sensor nodes are supposed to have been equipped with a depth sensor to measure the depth of the nodes from the surface sink.

3.1.2 Sector Formation

The network is alienated into a 3-dimensional grid of sectors of same width and breadth as shown in Figure 1. The width of the sector is 2/3 of the communication range R of a sensor node and breadth is equal to the range R.

Sectors belongs to an axis donated as Ni (i is denoted one dimension of the network from three dimensions x, y, z), can be different from another axis. The neighborhood of sectors represented through the difference of dimensions. The difference between the three dimensions is -1, 0, or +1 only acceptable for neighborhood. In other words, two sectors are the neighbor of each other if the difference between the three dimensions of the both sectors lies in -1, 0, or +1. If the difference between these dimensions is zero, means local sector and no neighborhood detected.

Suppose (x1, y1, z1) and (x2, y2, z2) are the coordinates of two adjacent sectors S1 and S2, respectively. Let $\delta x = | x1 - x2 |$, $\delta y = | y1 - y2 |$ and $\delta z = | z1 - z2 |$. S1 and S2 are neighbor sectors if following condition must be fulfilled:

$$(\delta x \leq 1) \text{ and } (\delta y \leq 1) \text{ and } (\delta z \leq 1) \text{ and } (\delta x \neq 0 \text{ and } \delta y \neq 0 \text{ and } \delta z \neq 0)$$

Algorithm 1 is used to check the above-mentioned condition and derived the neighborhood between two sectors.

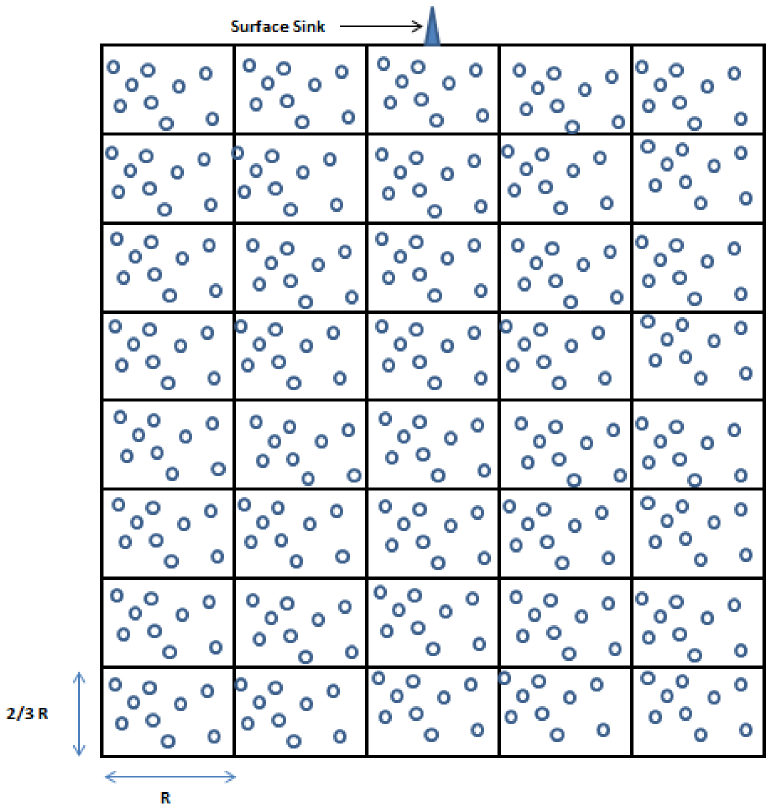

Figure 1. 3-dimensional grid view of the sectors

Algorithm 1: isNeighbor (x_1, y_1, z_1, x_2, y_2, z_2)
// For finding neighborhood between sectors (x_1, y_1, z_1) & (x_2, y_2, z_2)

$\delta x = | x_1 - x_2 |$ $\delta y = | y_1 - y_2 |$ δz
$= | z_1 - z_2 |$
if ($\delta x = 0$ and $\delta y = 0$ and $\delta z = 0$)
return false; //local sector
else if ($\delta x \leq 1$) and ($\delta y \leq 1$) and ($\delta z \leq 1$) and ($\delta x \neq 0$ and $\delta y \neq 0$ and $\delta z \neq 0$)
return true; //neighbour sector
else
return false; // neither local nor neighbour

Each sector has a sector id denoted Si, which is also known to the nodes belonging to a sector. Sector head (SH) is selected among all the nodes within a sector based on energy grading.

Each Sector contain three types of Nodes as shown in Figure 2:

- Sensor Node - sense data and forward towards sector head (SH)
- Sector Head (SH) - forward data packets received through sensor nodes towards the surface sink.
- Gateway Node - Some boundary nodes utilize when the depth difference between two SH is greater than the communication range of the forwarder SH.

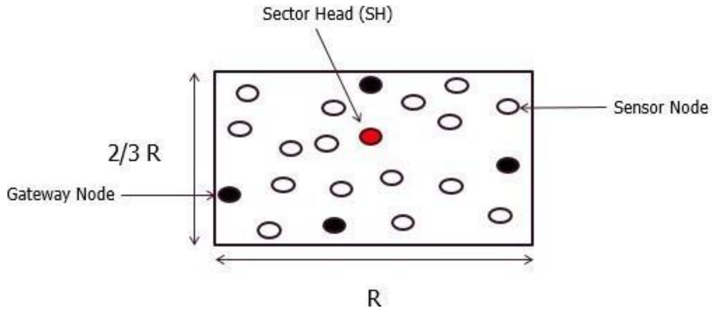

Figure 2. An inner view of one sector

3.2 Energy Grade Estimation

A sensor node consumes energy to transmit l bit packet over distance d.

$$ETx\ (l, d) = lPodkvdt \qquad (1)$$

where t is the transmission duration measured in seconds, P0 is the initial power level of the sensor node and v is the absorption coefficient.

The initial transmission energy ETx of each sensor node is distributed into energy grades and the values of Unit residual energy grades REL is calculated as:

$$RE_L = \frac{E_{Tx}}{L} \qquad (2)$$

where L is the optimum power levels requisite to transmit data bits in a given transmission range of a sensor node.

Same as the transmission energy, energy consumed to receive a data packet at the sensor node as follows,

$$E_{Rx}(l) = lP_r t \qquad (3)$$

where Pr is a constant term represent power consumed at receiver end and depends on Receiver node.

The energy consumption for single data packet at a node comprises sensing energy E_{sen}, receiving energy ERx and the transmit energy ETx and calculated as per following equation.

$$E_T(t) = E_{sen}(l) + E_{Rx}(l) + E_{Tx}\ (l, d) \qquad (4)$$

At starting, the initial energy E0 is same for all sensor nodes belong to each slice of network. And based on Equation (2), the Initial Energy E0 is divided in same Residual Energy Grades REL.

3.3 Neighboring Sectors Classification Groups

A sensor node belongs to a sector has multiple neighboring sectors, from which some sectors are closest to the surface sink in terms of depth and some are farther distance from the sink node in comparison to the sector of source node. Therefore, we have classified the neighboring sectors in two groups Active Group (G1) and NonActive Group (G2) based on their distance in terms of depth from the surface sink compare to the forwarder sector.

Let us assume that the source sector src, its nearest neighboring sector n, the nearest sink to be skc, have the coordinates (xsrc, ysrc, zsrc), (xn, yn, zn), and (xskc, yskc, zskc) respectively. Then narrative used to represent two neighboring groups as follows:

Forwarder Group (G1): Forwarding group represent the set of neighbor sectors, which are closer to the sink in terms of depth than the source src and is represented as:

$$G1 = \{n | d_{min}^{skc-n} < d_{min}^{skc-src}\} \quad (5)$$

Where,

d_{min}^{skc-n} represent the depth of neighbouring sector from sink, and

d_{min}^{skc-n} represent the depth of source sector from sink

This group contain the neighboring sectors, which are capable to forward data packets towards surface sink.

Non-Forwarder Group (G2): Non-Forwarding group represent those sector that are away from the sink node in terms of depth than the source sector src and is represented as:

$$G2 = \{n | d_{min}^{skc-n} \geq d_{min}^{skc-src}\} \quad (6)$$

Where,

d_{min}^{skc-n} represents the depth of neighboring sector from sink, and

d_{min}^{skc-n} represents the depth of source sector from sink

This group contain the neighboring sectors, which are not capable to forward data packets towards surface sink due to the higher depth than the source sector src.

Every sensor node in a sector maintain some information regarding neighbour sectors. For the same every node maintains two tables: Forwarder Group Table (FGT) and Non- Forwarder Group Table (NGT) to store information regarding neighboring sector belongs to group G1 and G2. As shown in Figure 3, the table contains the id of neighboring sector, the sensor node id, which nominated as sector-head for neighboring sector, the depth of the sector-head from the surface sink, and the status of the sector- head. The status is active means 1 if the node is free to forward data packets, otherwise busy or 0 in case node already process and forward data packets.

Neighboring Sector Id	Sector Head Id	Depth	Status
S1	N1	d1	1
S2	N2	d2	0
Sn	Nn	dn	1

Figure 3. Structure of Neighboring Group Tables FGT and NGT

3.4 Sector-head Selection Procedure

To minimize the number of hop-count in routing, we adopted sector-by-sector forwarding scheme to transmit data from source to surface sink. A single node called sector head (SH) will be responsible to forward data packets to the neighboring sectors only. The selection of SH is carried out through election process which consider node residual energy and depth to elect a node as sector head (SH). Each node belongs to sector record the sector-head (SH) in neighboring group tables FGT and NGT. The election process is carried out in two phases: Initialization Phase, and Maintenance Phase.

3.4.1 Initialization Phase for selecting Sector-head (SH)

At the initialization phase, each deployed sensor node needs to gather the neighborhood information to forward data packets. In first step after deploying in interest area, each sensor node determines its sector and store the sector id of own sector as Sid in its neighboring tables. After that, any one node having energy grade REL is greater than the energy threshold, adjust a timer to initialize a sector-head election process. On initiation of the SH selection process, each node participating in SH selection will wait for a timer (Tw) to get fired before declaring itself as SH through broadcast of a message.

$$T_w = Max\ Delay / RE_L \qquad (7)$$

In equation (7) Max Delay is a network define timer and REL is the residual energy grades of the sensor node. Sensor nodes having more energy grades get a priority in election process due to short timer. Hence, the probability of elected as sector head SH is higher for the node, which have more residual energy.

After the timer of the node terminates, sensor node advertise itself as sector-head (SH) through broadcast of a beacon message among all nodes belonging to a sector. On receiving a SH declaration message, each node will cancel its timer and will register the sender of this message as the corresponding SH. The node also records itself as the sector-head SH of that sector in its neighbouring tables. The format of the advertised beacon packet is shown in Figure 4.

Type	S_{id}	N_{id}	d_{SH}	RE_L

Figure 4. Beacon Packet Format

Where,

- Type- designates the packet type (advertise or withdraw)
- Sid is the ID of the sector, SH belongs to
- N_{id} is the ID of the *SH*
- d_{SH} indicate depth of the *SH* towards surface,
- RE_L is the residual energy grade levels of *SH*

Each sector-head SH of neighboring sectors, after receiving advertise beacon from new elected SH, determine the group of that sector among Forwarder group G1 and Non-Forwarder G2 based on the information provided in beacon packet. After identify the group each neighboring SH record the information stored in beacon packet in appropriate group table FGT or NGT. Sensor nodes belong to same sector also record the entry of SH in their table.

3.4.2 Maintenance Phase

Sector Head (SH) withdraw itself as SH by sending beacon packet with packet type withdraw to all nodes belonging a sector in following two conditions:

- Residual Energy Grade REL of SH is lower or equal to the threshold value of Energy, or
- SH was forced to communicate data packets consecutively seven times to a single hop node because of Residual Energy Grade.

After receiving withdraw message all nodes initialize their timer and elect a new node as Sector Head (SH).

To minimize the frequent sector-head election process, the proposal only elect new node as sector-head SH, when the residual energy grade of existing SH is lower or equal to the energy threshold. By reducing the control packet transmission protocol achieve high energy efficiency as well as lower the chances of collision and optimize average delay of the network.

3.5 Forwarding Data Packets

In the proposed protocol EESR, selection of forwarder depends on depth difference of the node from surface. EESR is a depth-aware routing, which utilizes the energy and depth information to select the candidate forwarder to route the packets towards sink node to balance the energy consumption and extend the lifetime of the sensor network.

When a sensor node sensed any event and sense data to forward to the sink, the node simply forwards the data packet to the sector-head SH of the own sector. The SH then after receiving sensed data from sensor node set the source sector id, source node id and sequence number of the data packet. To forward data packets through SH in sector- by-sector have two scenarios of data transmission:

- First if SH belongs to the sector which also contain Sink Node, then SH simply set the next forward node id to the sink node and send data packet directly to the sink node. Otherwise,
- SH checks the neighbor table FGT of Forwarder Group G1 to find the forwarder node in neighboring sectors. FGT table is already sorted on the basis of depth difference from sink. SH select the top entry from the FGT table and set the next forwarder node id to this sector head and forward the data packet to that SH of neighbor sector.

At intermediate node after receiving data packet in the format shown in Figure 5, to forward, the SH of that sector first check that packet belongs to the node having entry in NGT table. The forwarder SH only forward packets, which are received from the sectors belongs to Non-Forwarder Group G2. If so, SH follow the same process as previous hop, first check the table FGT to find the next forwarder SH, and update the next forwarder node id to finally transmit data packet to that node. Forwarding process continue in same manner till the packet delivered to the destination.

Sometimes, when no forwarder node selected, nodes at boundary of the sector known as gateway node utilize to forward data packets toward the sector-head of appropriate neighbor sector. Gateway nodes and sector-head both type of nodes is only used to forward data packets, not used to sense application area.

$srcS_{id}$	***$srcN_{id}$***	***seqNum***	***$nextN_{id}$***	***payload***

Figure 5. Data Packet Format

Where,

- The *$srcS_{id}$* indicate the Sector ID of host sector.
- The *$srcN_{id}$* represent the ID of sector-head of host sector.
- *seqNum* denoted the unique sequence number of data packet.
- The *$nextN_{id}$* represent the next forwarder node ID, which is an entry field of G1- neighbourtable having minimum distance from sink as well as maximum residual energy grade.
- *payload* contains the data which is delivered to the sink node. The detail

algorithm for forwarding data packets is discussed below:

Algorithm: Forward_DataPacket(Pkt)

If the source node:
Generate a data packet Pkt Send to Sector Head SH
Else If the Sector Head: *Pkt.srcS$_{id}$ = S$_{id}$*
Pkt.srcN$_{id}$ = N$_{id}$
Pkt.seqNum = getSeqNum Pkt.payload = sensed data

If *(sink_feild==1)*
Forward Pkt to the sink Pkt.nextN$_{id}$ = sink$_{id}$
Else
Select a forwarder with $d_{nextNid} \leq d_{Nid}$ Pkt.nextN$_{id}$ = selected forwarder
Forward the packet to the selected forwarder
End if

Else if an intermediate forwarder
Select a forwarder with $d_{nextNid} \leq d_{Nid}$ *Pkt.next*N_{id} *= selected forwarder*
Forward the packet to the selected forwarder
Else
Do nothing
End if

4 Experimental Results

4.1 Simulation Settings

This section evaluates the performance of the proposal Energy Efficient Sector-based Routing (EESR) Protocol against VBF and ERGR-EMHC routing protocols. Considering 3-dimensional network range of (5×5×5) km3. Sensor nodes are deployed uniformly throughout the network randomly in sufficient intensity that, each node has a at least one forwarder within the communication range. Stationary sink nodes are placed at surface level. For the purpose of contention resolution broadcast Mac [26] is used in overall simulation scenario. Before sending data packets, sensor node listens the channel. If the channel is idle, send the packet immediately, otherwise, wait for a time called back off time. The back off limit used in all scenario is four. After the back off limit, packet is automatically dropped. There is no need to send the acknowledgement by the receiver after receiving any data packet. The initial transmission range of sensor node R is set to be 1 km. Initial power levels for packet transmission, packet reception, and for idle situation set to be 6.0 W, 0.60 W and 0.006 W, respectively. The transmission frequency is fixed to 35.695 kHz. The bitrate of transmission is set to17.80. Table 2 summarize the other simulation parameters in detail;

Table 2: Additional Simulation Parameters

Parameter	Value
Number of Sensor Nodes	100, 200, 300, 400, 500
Initial Energy of each Sensor Node	300 J
Data Packet Size	200 byte
Energy Threshold at each Node	20 J

The performance evaluation of the proposal is carried out on the basis of the following performance metrics [27, 28]:

Packet Delivery Ratio (PDR): Ratio between the successful packet transmission over all packets generated in the system.

Average End-To-End Delay: Delay between packet generated and received at the destination

Energy Consumption: Overall energy consumption by sensor nodes in whole network

The above stated metrics are considered under different node density as (100, 200, 300, 400, and 500) nodes in a given network range with traffic instillation rate of 0.07 packets/s.

4.2 Simulation Results

The impact of node density in network on Packet Delivery Ratio:

The outcome of the changing node density on the Packet Delivery Ratio (PDR) is inspected and shown in Figure 6. It is clearly depicted from the figure that, the PDR is improved, while growing in the node density of deployed sensor nodes in a given range of network. Packet delivery ratio for all simulated proposals has increased with the increasing node density ranging from 100 nodes to 500 nodes. This is due to the higher probability to discover the next candidate forwarder in case of large number nodes in a given range. Overall PDR is increased for all proposals due to greater possibility to finding the forwarder while increasing the number of sensor node. However, the proposed protocol outpaces the other proposals due to the depth aware forwarding approach employed through the proposal, which hand out the load between the nodes of neighboring sectors. While increasing the node density, specifically at 500 nodes, the proposed EESR is perform better than counterpart techniques by approx. 2.0% and 8.5%, for ERGR-EMHC and VBF respectively in terms of PDR.

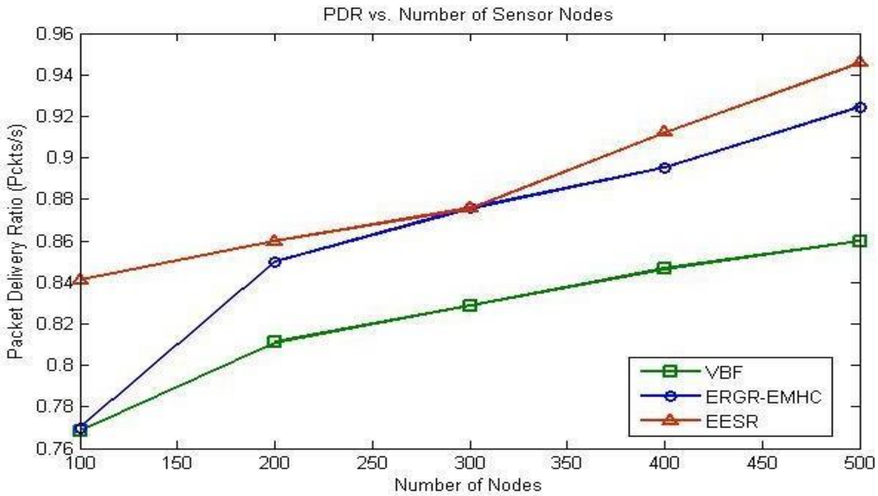

Figure 6. Impact of node density on packet delivery ratio

As in VBF, the packet delivery ratio is slightly increasing, as the number of sensor nodes increases in comparison to other two proposals. This is because off the additional nodes are positioned in routing pipe of VBF, which intern increase the possibility of collision and decrease the chance of successfully delivery of packets towards destination. In other hand, ERGR-EMHC performs better than VBF, due to void handling technique and also due to the forwarding mechanism used to share loads among other neighbouring cells which overall increase the number of forwarders and increase the successful transmission of packets.

The impact of node density in network on Average End-to-end Delay:

Figure 7 depict the influence of node density of network on network delay. Clearly shown in figure that the VBF protocol reveals a different inclination on average delay than other two proposals. As a packet is forwarder through routing pipe in case of VBF, while increasing the node density, the chances of more forwarder is increased in routing pipe, which intern increase the chance of collision. This origin the probability of congestion, and sensor nodes have to wait in getting access to channel, and increased the delay in packet forwarding. While in case of ERGR-EHMC, average end-to-end delay is reduced with the growing node density, since the possibility of forwarder is increased, and chances to selection of cell heads is also increased. Therefore, packet can be reached destination with less number of hops. By reducing number of hops in transmission, the overall delay of network is decreased. On the other side, the delay in proposed EESR is slightly increase due to almost fix number of hops in transmission. As the node density is enlarged the hop count in data forwarding is also slightly increase in case of EESR, which results in increasing overall delay of the network. Despite of increase in delay, the proposed EESR almost outperform other technique in terms of end-to end delay. The delay in EESR is almost 70% lessor than the

VBF for 500 nodes and approximately same as ERGR-EHMC. The delay is lower in EESR and ERGR_EHMC due to less probability of link breakage and less chance of packet drops.

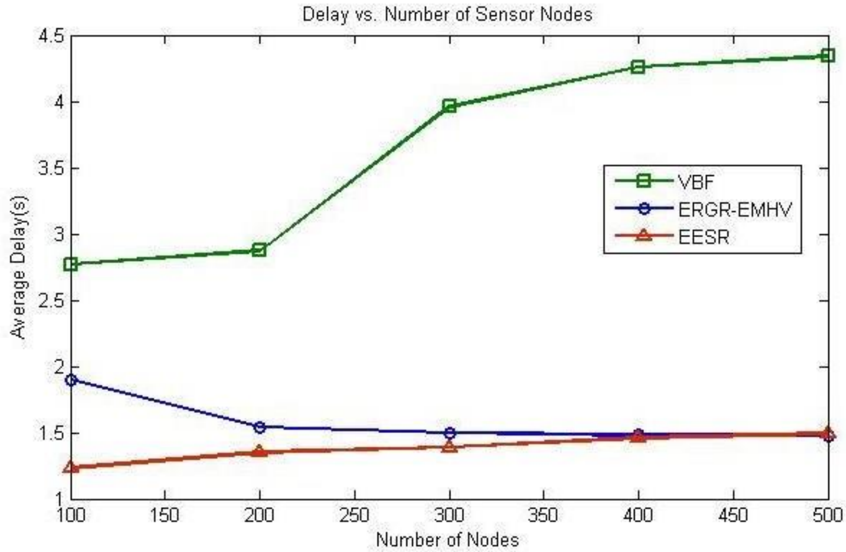

Figure 7. Impact node density on average end-to-end delay

The impact of node density in network on Energy Consumption:

The impact of node density on overall energy consumption of network is illustrated in Figure 8. As revealed in figure, all the simulated protocol exposed increasing energy depletion as the node density of the network increased. However, the proposed protocol EESR leave behind other two protocols VBF and ERGR-EHMC in terms of energy intake. Lower energy consumption is shown in EESR, due to the almost fix number of hops to forward the data packets. EESR use the depth information for selecting forwarder in place of location information, which also reduce the energy consumption of nodes for maintaining location information. The node density cannot affect the energy utilization of network in EESR, due to the fact that the forwarding data packets depends on the depth difference which is almost static. Hence, working efficiently in dense as well as sparse network in terms of energy depletion. The energy consumption in EESR is amplified while increasing the node density, due to the control packet transmission to select the sector-head frequently. At the highest node density of 500 nodes, EESR saves energy on average 35% and 78% as related to ERGR-EHMC and VBF, respectively.

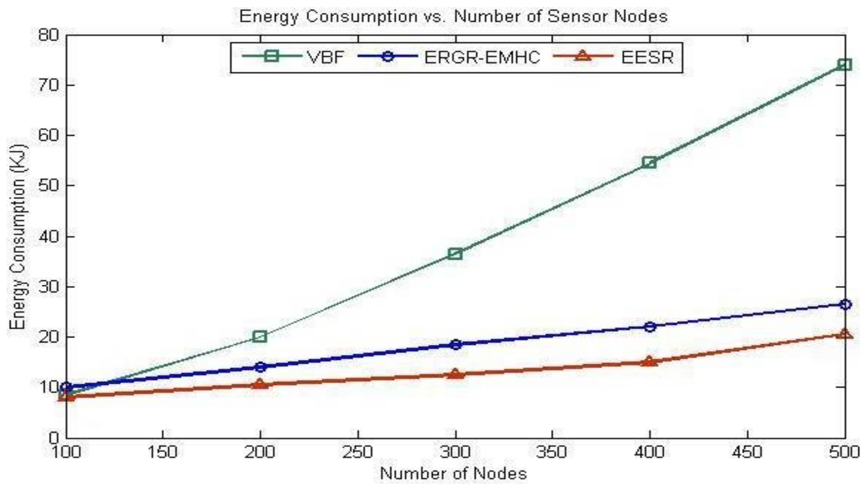

Figure 8. Impact of node density on energy consumption

From all three simulated protocols, the VBF shows highest level of energy ingestion. The energy depletion rises hugely with the increase in node density. The VBF entails the propagation of duplicate packet transmission with increase in node density, which results in more candidate forwarder in routing pipe that leads the more energy consumption at nodes and increase the overall energy depletion of the network. On the other hand, cell-by-cell data packets transmission carried over cell heads in ERGR-EMHC. Though, same as EESR, frequent cell-head election process in ERGR-EHMC consume more energy and increase the overheads. The ERGR-EMHC, also selects forwarder with the help of two parameters Hmin and Hpkt, and should process one packet at a time, which reduce the chances of link break and reduce the energy consumption.

5 Conclusion

In this article, we have proposed an energy efficient depth aware routing protocol Energy Efficient Sector-based Routing (EESR) protocol for UWSNs. The protocol is considering the network as a 3-dimesional grid of sectors, in which data packet transmission is achieved in a sector-by-sector manner through sector-heads only. The proposal intelligently utilizes the depth information to forward data packets towards the surface sink. The number of hops to forward data packets to the density is depends on the depth of source node and almost fixed. For forwarding data packets sector-head maintain the neighborhood in form of active and passive group of sectors. Data packets forwards only through sector-head of active group only. The performance of the proposal evaluated against two known routing protocols named ERGR-EHMC and VBF. The simulated results clearly indicate that, the proposed EESR outpace the others two in terms of energy depletion, average end-to-end delay and packet delivery ratio. EESR also incurred less network overhead due to a smaller number of control packet transmission in comparison to other two protocols. Still some further improvement is required to reduce the network overhead through reducing the frequency of election process.

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