An energy efficient and balanced energy consumption cluster based routing protocol for underwater wireless sensor networks

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***Abstract*—In Underwater Wireless Sensor Networks (UWSNs) nodes are equipped with limited battery power and battery replacement is expensive due to underwater harsh environment. Therefore, we propose EBECRP an energy Efficient and Balanced Energy consumption Cluster based Routing Protocol for UWSNs. In depth base routing protocols nodes near the sink (low depth nodes) die in no time because of high load. We avoid depth base routing in our proposed scheme and use mobile sinks to balance load on all nodes. We also use the concept of clustering to reduce multi hoping which results in more energy consumption. The selected Cluster Heads (CHs) collect data from one hope neighbor nodes to reduce global communication into locally compressed communication. Simulation results show that EBECRP achieves maximum stability period and network life time.**

***Index Terms*—Underwater wireless sensor networks, Energy consumption, Cluster head, Sink mobility.**

I. Introduction

From the last few years UWSNs have gained popularity in research area because of their applications like environmental monitoring for scientific exploration, pollution monitoring, military surveillance, disaster prevention, resource investigation, oil extraction etc [1]. The UWSNs consist of sink(s) and acoustic sensor nodes. Acoustic sensor nodes collect data of interest from the environment and follow routing path to forward that data to the sink. The acoustic sensor nodes have limited battery power where no energy constraint on sink [2].

Many routing protocols are proposed for terrestrial Wireless Sensor Networks (WSNs). These existing routing protocols may not be suitable for underwater environment [3]. WSNs use radio waves for communication where UWSNs use acoustic channels for communication. Radio signals do not work well in water because of rapid attenuation. The acoustic signals have unique characteristics: long propagation delay, high signal to noise ratio, low bandwidth etc. Due to these characteristics developing efficient and scalable routing protocol for UWSNs is very challenging [4].

Underwater sensor nodes have limited resources: battery power, memory capacity, processing capability, bandwidth etc. Battery replacement in aquatic environment is difficult [5]. Aquatic environment needs an energy efficient routing protocol. Efficient energy consumption is defined as, we achieve more work load with less energy consumption [10]. Efficient energy consumption is in direct relation with network life time. In addition network life time is improved with balanced energy consumption of nodes in the network by dividing equally load on nodes.

In [4–9], involve static sink(s) which are deployed on water surface. However, in static sink(s) the sensor nodes which are closed to the sink die earlier because low depth nodes have unbalanced load and forward more packets than high depth nodes. This unbalanced load on sensor nodes creates routing holes in the network, result in hotspot problem. Hence, it is better to use mobile sinks for collecting information from sensor nodes [2] [11]. Therefore, we propose EBECRP which avoids depth base routing and performs cluster based routing with sinks mobility. In depth based routing low depth nodes die in no time because of unbalanced load on the nodes near the sink(s). In order to tackle this we use mobile sinks in EBECRP, which change their position frequently. To reduce the number of transmissions we use the concept of clustering. In clustering each node is responsible to communicate with its respective CH. Each CH collects data from the nodes in its vicinity and forwards collected data to sink. Thus, cluster formation saves energy by performing data compression at CH and reduces global communication to locally compressed communication [12]. By using sink mobility and clustering the balanced energy consumption is achieved in the network, result in improved stability period and network life time.

The rest of the paper is organized as follows. Related work is discussed in section II. Section III deals with motivation and the detail work of our proposed scheme EBECRP is shown in section IV. In section V we present the performance of EBECRP. Conclusion is given in section VI and finally references are given at the end of paper.

II. Related work

LEACH [13] is the first cluster based routing protocol for terrestrial WSNs. The main purpose of LEACH is to reduce global communication into locally compressed communication by using the concept of clustering. Cluster formation is based on the minimum distance and received signal strength. In each cluster there is one CH; responsible for collection of data from nodes and forward to Base Station (BS). In LEACH CH selection is randomly rotated over time to balance load on the nodes in term of energy consumption. For CH selection each node generates a random number and compare with Threshold value; Th(i), given in [13] as:

$$Th(i) = \begin{cases} \frac{p}{1-p(mod(r,1/p))}, & if i \in G \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

Where i is the current node and p is its probability to be selected as CH which is defined initially, G shows the set of nodes which are eligible for CHs selection, R shows the round number and mod$(r, 1/p)$ return modulus after division of r by $1/p$. Node is selected as CH when threshold value is greater than the random number. In LEACH, clusters are of different sizes and this phenomena leads to unbalanced energy consumption of CHs.

In [14], authors proposed energy balanced routing algorithm for WSNs based on virtual MIMO technique. The proposed algorithm has three improvements over the conventional LEACH routing algorithm in term of better cluster head selection, energy consumption and mitigates the different size cluster head distributions. For cluster head selection, the algorithm considers the residual and most recent energy expenditure of the nodes and the whole network, in order to balance the energy consumption among different sensors nodes. The propose algorithm shows better performance over the conventional LEACH algorithm in term of energy consumption and network life time.

Ashfaq *et al.* proposed cluster based routing scheme [10] to maximize lifetime and throughput of WSNs. The CHs selection is similar to that of LEACH where each node generates a random number and compares with threshold value. Node is elected as CH if the generated random number is less than the threshold value and is not selected for the last 1/p rounds. After election, natural selection mechanism is used to choose optimal number and distant CHs in the network. If the selected CHs is less than the optimal number of CHs (ten percent of the total nodes in network) the Away Cluster Heads (ACH)^{2}carried out re-election. If the selected CHs are greater than the optimal number, CHs are minimized in number. Otherwise scheme operation is carried out. In this way (ACH)^2 has clustered of almost same size which results in uniform load on CHs. (ACH)^2 avoids back transmission; where node associates with the CH which increases over all distance of the node from BS.

Authors discuss localization free Depth Based Routing protocol (DBR) In [4] for UWSNs. DBR uses the depth of the sensor node as forwarding metric for sending data to the BS. The data from source to destination is forwarded in multi hop fashion. Sender node includes its depth information in the data packet and broadcast to the nodes in its threshold range. The receiver node compares its depth with the depth of the forwarder node. If the depth of the receiver node is greater than the forwarder node the receiver node just discard the packet. Otherwise, holds the data packet for certain time. The node with smaller depth has less holding time and is selected as next eligible forwarder for data packet. Thus, the nodes having smaller depth always involve in data forwarding due to which their energy deplete very quickly and create hotspot problem in network. In DBR the nodes with low depth have more loads as compared to high depth nodes, due to this unbalanced load the low depth nodes die very quickly.

For efficient energy cunsumption, an Energy Efficient Depth Based Routing protocol (EEDBR) [5] is presented for UWSNs. EEDBR is a localization free depth based routing protocol for UWSNs. It uses depth as well as residual energy of the sensor node as forwarding metric for sending data to sink. The sender node selects the node with high residual energy in its neighbor as next forwarder and data is forwarded from source to sink in multi hop fashion. In EEDBR nodes which are near to sink have more load than those nodes which are far away from the sink. Due to this unbalanced load nodes near the sink die earlier and create hotspot problem in network.

Ayaz *et al*. proposed H^2-DAB (Hop-by-hop Dynamic Addressing Based) [6] routing protocol for UWSNs. In H^2-DAB each sensor node is assigned a unique HopID based on the hop count from the sink. The procedure for assigning HopID to each sensor node is as follows. Sink broadcast hello packet to one hop away sensor nodes. The nodes which receive hello packet is assigned HopID. The receiver nodes increment the HopID and re-broadcast the hello packet to their one hop neighbor nodes with updated HopID. The HopID is updated hop by hop. Therefore, nodes near the sink are assigned a smaller HopID than the nodes which are far away from sink. During data forwarding nodes with smaller HopID are always selected for data forwarding, similar to that of DBR. Due to frequent data transferring the nodes with smaller HopID die earlier than the other nodes in network. During data forwarding H^2-DBR also uses request and replay inquiry packet which is not suitable in resource-constrained environment as UWSNs [5].

To maximize the network lifetime, an Adaptive mobility of Courier nodes in Threshold-optimized Depth based routing (AMCTD) [9] is proposed for UWSNs. AMCTD uses the weight function not only to balance load on the nodes in network but also gives optimal holding time for the neighbors of source node. On the basis of weight function source node selects the next best possible forwarder of data packet in its threshold-based neighbors. Furthermore, adaptive movement of courier nodes in sparse condition uphold the network throughput.

In [7], authors proposed localization-free and flooding based routing protocol; Improved Adaptive Mobility of Courier nodes in Threshold-optimized depth-based-routing (IAMCTD) for UWSNs. IAMCTD uses Forwarding-Function (FF); to cal-

TABLE I
COMPARISON OF DIFFERENT ROUTING PROTOCOLS.

Protocol name	**Features**	**Flaws/Deficiency**	**Advantages achieved**
LEACH [13]	Cluster based routing.	CHs are randomly selected; result in different size cluster and imbalanced energy consumption. Election probabilities are the same for all eligible nodes.	Reduce global communication into locally compressed communication
Energy balance routing algorithm [14].	Cluster based routing algorithm based on Virtual MIMO.	Computational overhead involved. Not consider end to end delay.	Increased network life time and reduced energy consumption.
$(ACH)^2$ [10]	Cluster based routing with optimal CHs selection mechanism.	Computation overhead involved.	Optimal number of cluster with same size. Removed back transmission
DBR [4]	Localization free depth based routing. Receiver based approach where, next forwarder of data is selected on the basis of depth.	Imbalanced energy consumption. In efficient for sparse and dense network. Least depth nodes die earlier.	High data delivery and low end to end delay.
EEDBR [5]	Localization free depth based routing. Sender based approach where, sender node decides next forwarder of data on the basis of depth and residual energy.	Imbalanced energy consumption and inefficient for dense network. Nodes with medium depth die earlier.	Efficient energy consumption and decreased end to end delay. High data delivery
H^2-DAB [6]	Localization free depth based routing protocol with multiple sink structural design.	Imbalanced energy consumption. Nodes with smaller hop ID deplete energy earlier. Request and replay inquiry act as overhead.	Does not require full- dimension information High data delivery
IAMCTD [7]	Localization free depth based routing for time critical applications along with courier nodes. Courier nodes collect data from sensors node.	Overhead involved in term of control packet exchange.	Improved network life time and minimized end to end delay.
AMCTD [9]	Localization free depth based routing with courier nodes. Courier nodes collect data from sensors node.	Not suitable for data-sensitive applications. High transmission loss.	Improved network life time.
CoDBR [8]	Localization free depth based routing along with cooperation.	High energy consumption and increased end to end delay.	Increased reliability and throughput efficiency. Reduced packet drop and increased packet acceptance ratio.
R-ERP2R [15]	Localization free routing based on physical distance and residual energy. Forwarder node is selected on the basis of distance, link quality and residual energy.	Computational overhead in term of multiple metrics.	Reduced energy consumption and end-to-end delay. Increased network lifetime and delivery ratio.
AURP [16]	Multiple AUSs collect data from sensor nodes through gateway nodes.	Increased delay.	Minimized energy expenditure and maximized packet delivery ratio.
Delay-sensitive routing schemes [21]	Localization free depth based routing. Courier nodes collect data from sensor nodes and forward to sink.	Reduced throughput.	Minimized total energy expenditure, transmission loss and average end to end delay.
SPARCO [24]	Cluster based routing protocol.	More forwarding nodes and energy consumption.	Enhanced stability period, network life time, packet delivery ratio.
Mobicast [17]	The AUV travels on user defined route and collects data from a series of 3-D ZORs. Mechanism to wake up sensor nodes for next 3-D ZOR. Able to cover the drift distance of node.	Increased energy consumption and result in message overhead.	Improved throughput and packets delivery ratio, minimized end to end delay.
AEDG [18]	AUV follows elliptical path for data collection from sensor nodes through gateway nodes. Mechanism to balanced load on gateway nodes.	High packets delivery ratio, reduced energy consumption and transmission loss.	Increased end to end delay.
DEADs [2]	Single and multiple relay cooperative routing along with sinks mobility (elliptical, linear).	High energy expenditure and short stability period. Control and processing overhead.	Increased throughput efficiency and reduced packet drop.
Chain based [19]	Application oriented routing protocol for finding local optimum and global optimum solution for data collection in cylindrical networks.	High routing overhead.	Increased network lifetime and packet sending rate. Decreased end-to-end delay, path loss, and transmission loss.
Co-UWSN [20]	Cooperative communication. Beneficial for delay-sensitive and time-critical applications	Increased end to end delay and more forwarding nodes.	Improved stability period, network life time and packet delivery ratio.
Link expiration [23]	Link expiration time, handles node mobility and probability technique selects next forwarder.	Acknowledgment packet acts as overhead. Increased end to end delay.	Improved network life time and data delivery ratio.
LAFR [22]	Link-State Based Adaptive Feedback Routing with asymmetric link.	Computational overhead in term of Asymmetric link.	Minimized energy consumption and average end to end delay. Increased packet delivery ratio.

culate optimal holding time by using routing metrics (LSNR, SQI, ECF and DDF), which tackle flooding, path loss, and propagation latency. Furthermore, optimized mobility pattern of courier nodes reduces end to end delay in later rounds. In IAMCTD nodes near the surface deplete energy earlier, which results in hotspot problem. Furthermore, their depth threshold change according to network density, which require exchange of control packet on regular basis. This exchange of control packet acts as overhead and waste network resources [2].

For reliable data delivery authors propose Cooperative Depth Based Routing (CoDBR) [8] for UWSNs. Cooperation is performed at network layer, in order to increase reliability and throughput efficiency of the network. Source node selects two relay nodes on the basis of depth information. Source node forwards its data to relay nodes and destination. The relay nodes then forward that data to the destination node by using Amplify and Forward (AF) technique. The three received copies of data at the destination are combined using diversity combining technique.

Authors propose R-ERP2R (Reliable Energy-efficient Routing Protocol based on physical distance and residual energy) [15] for UWSNs. R-ERP2R employs multiple routing metrics into account, that is, physical distances, link quality and residual energy to selects forwarder node. It exercises to accomplish higher throughput on the basis of physical distance as a routing metric. It also provides efficient energy solution with better link quality for data forwarding. furthermore, There is no holding time in R-ERP2R, which results in short end to end delay.

In [21], authors proposed three routing protocols as an improvement to localization-free depth based routing protocols: DBR, EEDBR, and AMCTD. Delay-Sensitive Depth-Based Routing (DSDBR) is an improved version of DBR which performs routing on basis of depth information, holding time and depth threshold. DSDBR uses *Fi* and *WF* for better forwarder selection and minimizes end-to-end delay, in order to make DBR adaptable for time-critical applications. The improved version of EEDBR that is, DSEEDBR (Delay-Sensitive Energy Efficient Depth-Based Routing) uses depth threshold (dth) variation for sensor nodes and provide an analysis to estimate DSHT (Delay-Sensitive Holding time). DSHT removes the inadequacy of multiple retransmissions in the low-depth, in order to tackle high propagation delays. The improved version of AMCTD that is, DSAMCTD (Delay-Sensitive Adaptive Mobility of Courier nodes in Threshold-optimized Depth-based routing) uses PF formulae for selecting a sensor node with higher neighbors as an optimal forwarder for data packets. It provides minimal end-to-end delay with adaptive mobility of courier nodes allowing a slight decrease in network throughput.

AEDG ((AUV)-Aided Efficient Data-Gathering) [18], presents an Autonomous Underwater Vehicle (AUV) based routing protocol for efficient data-gathering and reliable data delivery in UWSNs. AUV collects data from gateway nodes. Sensor nodes use a shortest path tree (SPT) algorithm for association with gateway node. The AEDG protocol limits the number of nodes associate with gateway node and rotate it with the passage of time to minimize the network energy consumption and prevent it from overloading. Furthermore, AEDG improves network throughput with elliptical trajectory of AUV by using a connected dominating set (CDS).

First time multiple AUVs are used in AURP [16]; An AUV-Aided Underwater Routing Protocol for underwater Acoustic Sensor Networks. AUVs act as relay nodes, which collect data from sensor nodes through gateway nodes and forward to sink. Moreover, controlled mobility of AUVs make it possible to achieve high data delivery ratio and low energy consumption.

Authors propose mobicast [17], also called a mobile geocast, routing protocol to minimize energy consumption while maximizing the data collection for three dimensional UWSNs. Sensor nodes near the AUV form 3-D ZOR. The AUV travels on user defined route and collects data from a series of 3-D ZORs. As sensor nodes are usually in sleep mode. Therefore, the routing protocol operates in two phases: in first phase AUV collects data from sensor noses within 3-D ZOR and in second phase those sensor nodes are waked up for the next 3-D ZOR.

Amara *et al*. [2], propose DEADs (Depth and Energy Aware Dominating Set based algorithm) to improve reliability and efficiency by using dominating set based cooperative routing with sink mobility. They discuss two mobility pattern of mobile sink: elliptical mobility pattern and linear mobility pattern. The linear mobility pattern performs better than the elliptical mobility pattern. DEADs works in three phases: neighbor selection, DS and CC set formation, and threshold based data sensing and routing. In neighbor selection phase each node finds its one hop neighbor nodes and stores their depth and residual energy information. On the basis of this information, source node selects its respective DS and CC nodes for cooperative routing. In last phase source nodes sense data on the basis of pre-defined threshold and perform cooperative routing.

Authors proposed SPARCO (Stochastic Performance Analysis with Reliability and COoperation) [24], cooperative based routing protocol for UWSNs. SPARCO uses cooperation and signal to noise ratio to enhance the stability period, network life time, packet delivery ratio and reduces the energy consumption; particularly in sparse condition. It considers optimal weight calculation, features of multi-hop and single-hop communication to lower path loss and provides load balancing in the network. Furthermore it also takes relay selection into account for reliable data delivery.

Co-UWSN [20] increases the network lifetime and reduces the energy consumption of UWSNs by using cooperative strategy and signal-to-noise ratio. Relay selection is based on link conditions and distance among neighboring nodes to successfully relay packets to destination. Furthermore, variation in depth threshold increase the number of eligible neighbors which results in minimal data loss. Thus Co-UWSN is useful for delay-sensitive and time-critical applications.

For application oriented networks specifically for cylindrical networks authors propose chain-based routing schemes [19] and formulate mathematical models for finding global optimum path. In 4-chain based routing scheme, network is divided into four groups of sensor nodes. These four interconnected chains of sensor nodes in cylindrical network are used for data routing. Where, first of all chain is created and then interconnected to achieve global optimum paths from the local optimum paths for data routing. In 2-chain based routing scheme, network is divided into two groups of sensor nodes. Data routing is performed by using two interconnected chains of sensor nodes to achieve a global optimum solution for data transmission. In Single-Chain Based Routing scheme, data routing is performed by using a single chain of sensor nodes in a cylindrical network. The performance of 4-chain-based scheme is better than the other two chain-based schemes because it selects optimal number of neighbors and balances load on sensor nodes.

Zhang *et al.* [22], propose Link-state based Adaptive Feedback Routing protocol (LAFR) for UWSNs. LAFR tackles the impact of the beam width and three-dimensional direction of UWSNs. It makes smooth routing feedback in UWSNs with high proportion of asymmetric links. Furthermore, it uses a credit-based dynamic routing update mechanism to reduce energy consumption of regularly update routing table.

Authors [23], propose Link Expiration Time-Aware Routing Protocol for UWSNs. This protocol uses link expiration time to handle node mobility and probability technique to select forwarder node. Furthermore, it uses Acknowledgment packet for reliable data delivery to forwarder node.

The comparison of the protocols discuss in related work are listed in table I.

III. Motivation

DBR is a localization free depth based routing protocol for UWSNs. In which route selection is based on selecting the neighbor with least depth. Source node selects the neighbor with least depth as next forwarder to transfers data to the sink. The data from source to BS is forwarded in multi hope fashion. Due to this multi hop fashion and selecting the neighbor with least depth, the nodes near the sink die in no time. In depth based routing nodes near the sink die very quickly. To reduce the load on the nodes near the sink is become our motivation to propose EBECRP. Which avoid depth based routing and solves the problem with sink mobility. Furthermore, we also use clustering to reduce global communication into locally compressed communication in UWSNs.

IV. EBECRP: Proposed scheme

Network model :In underwater environments sensor nodes collect data of interest from their surrounding and forward to BS. In our propose scheme EBECRP, nodes are of four types: CHs (Type C), non CHs (Type S, Type N) and BS (Sink1, Sink2). Type S nodes are those nodes which are near the sink and transmit directly data to sink. Type N nodes are far away from the sink and transfer data to sink through CHs. Type C nodes are selected as CHs, these nodes collect data from normal nodes (Type N) and transfer locally gather and compressed data to nearest sink. In our propose scheme BS

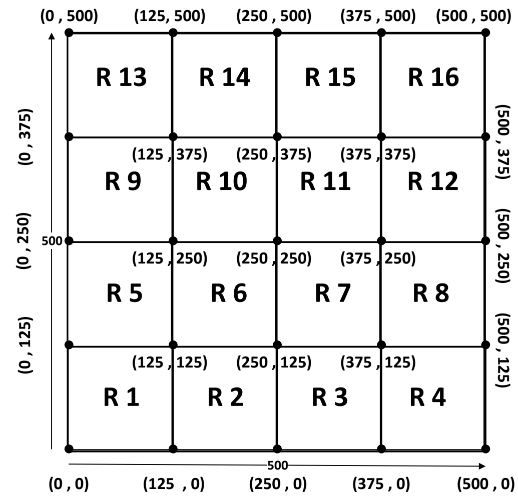

Fig. 1. Regions formation in our propose EBECRP

are two mobile sink, which change their position frequently in order to balanced load on nodes in network. We describe our propose scheme in detail by dividing them into four sections.

A. Sink mobility

B. Network initialization and configuration

C. CH formation

D. Data transmission

The first section (*A*), deals with region formation and sink mobility. Node deployment, network initialization and configuration are discussed in section two (*B*). Section three (*C*) describes the procedure for optimal number of CHs selection and last section (*D*) describes node association and data transferring to the sink.

A. Sink mobility and region formation

In our proposed scheme EBECRP we implement two mobile sinks (sink1,sink2), in such a way that we divide the whole network into sixteen regions of equal size (as shown in fig. 1) and check the density of nodes in each region. Mobile sink1 covers the most nine dense regions while mobile sink2 covers the remaining seven sparse regions. We assume that sinks are aware of sparse and dense regions. Mobility of sink1 is managed in such way that it moves from most dense region to less dense region and so on. Whenever, sink1 visit all the nine dense regions it returns to the most dense region again from where it starts. This process is continued till the end of network. While sink2 moves from the sparse region to less sparse region and so on. The rest of the process of sink2 is similar to sink1. When sink remain in certain region the nodes in that region send data directly to sink, while nodes in other region send data to the nearest sink through clustering. When all the nodes in certain region die both the mobile sinks stop visit that region and it only covers those region where nodes are alive. As in sparse region nodes die earlier than dense region. When all the nodes of sparse regions die. The mobile

Algorithm 1 Sparse regions search algorithm

procedure SPARSE REGIONS
  for $Each\ region\ r \in R$ **do**
    $i \leftarrow 1$
    for $Each\ node\ n \in N$ **do**
      if $n \in r$ **then**
        $r(i) \leftarrow n$
        Increment i
      end if
    end for
    $R(r) \leftarrow r$
  end for
  $R \leftarrow$ Ascending sort(R)
  $Sparse\ regions \leftarrow \{r \mid r \in R \wedge r < R/2\}$
end procedure

Algorithm 2 Dense regions search algorithm

procedure DENSE REGIONS
  for $Each\ region\ r \in R$ **do**
    $i \leftarrow 1$
    for $Each\ node\ n \in N$ **do**
      if $n \in r$ **then**
        $r(i) \leftarrow n$
        Increment i
      end if
    end for
    $R(r) \leftarrow r$
  end for
  $R \leftarrow$ Ascending sort(R)
  $Dense\ regions \leftarrow \{r \mid r \in R \wedge r >= R/2\}$
end procedure

Algorithm 3 CH selection algorithm

procedure CH–SELECTION
  $E - avg \leftarrow$ Average energy of network
  $E - r \leftarrow$ Residual energy
  $K - opt \leftarrow$ Optimal distance between CH
  $Flag \leftarrow$ True
  for $Each\ node\ i \in N$ **do**
    $Rand \leftarrow$ Generate random number
    if $Rand \leq Th$ **then**
      if $Epoc\ condition$ **then**
        if $E - r \leq E - avg$ **then**
          if $Cluster\ exist$ **then**
            for $Each\ node\ j \in CH$ **do**
              $Min - dist \leftarrow$ Find CH with minmum distance
              if $Min - dist < K - opt$ **then**
                $Flag \leftarrow$ False
              end if
            end for
            if $Flag == True$ **then**
              Broadcast hello message to its neighbor
            end if
          end if
        end if
      end if
    end if
  end for
end procedure

sink2 stars covering the dense regions where nodes are alive, which improves the network life time and packet delivery ratio of our propose scheme in later rounds. We also assume that both the sink does not visit the same region at the same time. The whole scenario is shown in fig. 2.

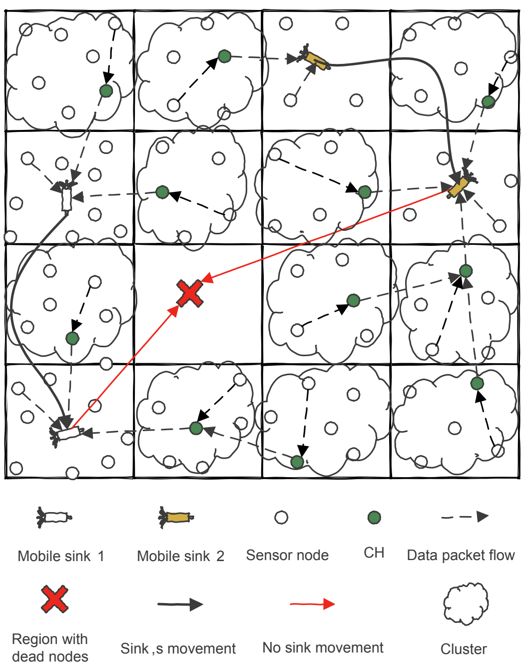

Fig. 2. System model of our proposed scheme

B. Network initialization and configuration

After deployment nodes are unaware of reliable infrastructure for communication, so information sharing is impossible for UWSNs. Network initialization starts with sink moment. Whenever, sink moves into certain region network initialization starts with basic aim to upgrade the UWSNs. When nodes are aware of one hop neighbors and position of sink the chance of successful communication increase. For this purpose we use hello packet (as shown in fig. 3) consists of node id, Coordinate of other nodes and coordinate of sink1 and sink2. In the EBECRP hello packet exchanges only when sink change its position and moves from one region to other region. The node which receives hello packet, identifies the position of both the sinks in network and associates with the nearest one; node transfers data to the nearest sink with them. Whenever, node receives a hello packet it looks for the position of sinks, which the node already stores. If the position of any sink is changed, node stores the update information otherwise, it discard the hello packet. When node stores the update information it share this information with one hop neighbor nodes.

C. CHs formation

As we divide the whole network into sixteen regions. Sink1 covers dense regions while sink2 covers sparse regions. When sink visits certain region nodes in that region send data directly to sink while other regions nodes send data to sink through clustering. For CHs selection each node generate a random number and compare with Th value. There are two possible cases:

Case 1: When the value of random number is greater than Th value, the node is selected as normal and marked as type N.
Case 2: When the value of random number is less than or equal to Th value and node is not selected as CH for the last (1/p) rounds. The node nominates for CHs selection.

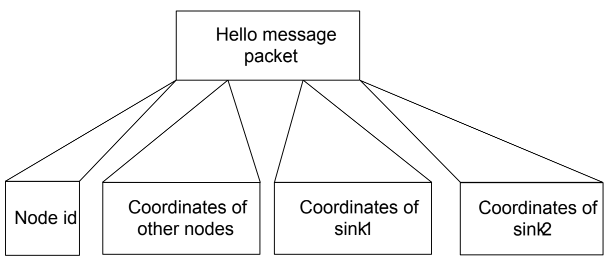

Fig. 3. Hello message packet

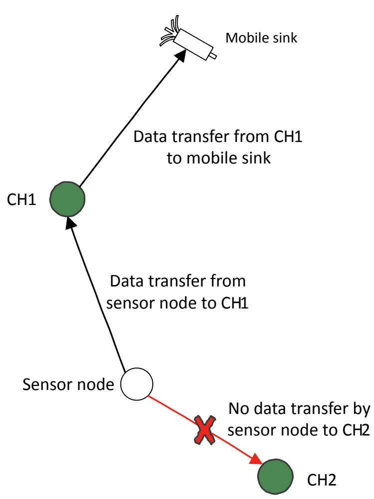

Fig. 4. Association of a node with CH.

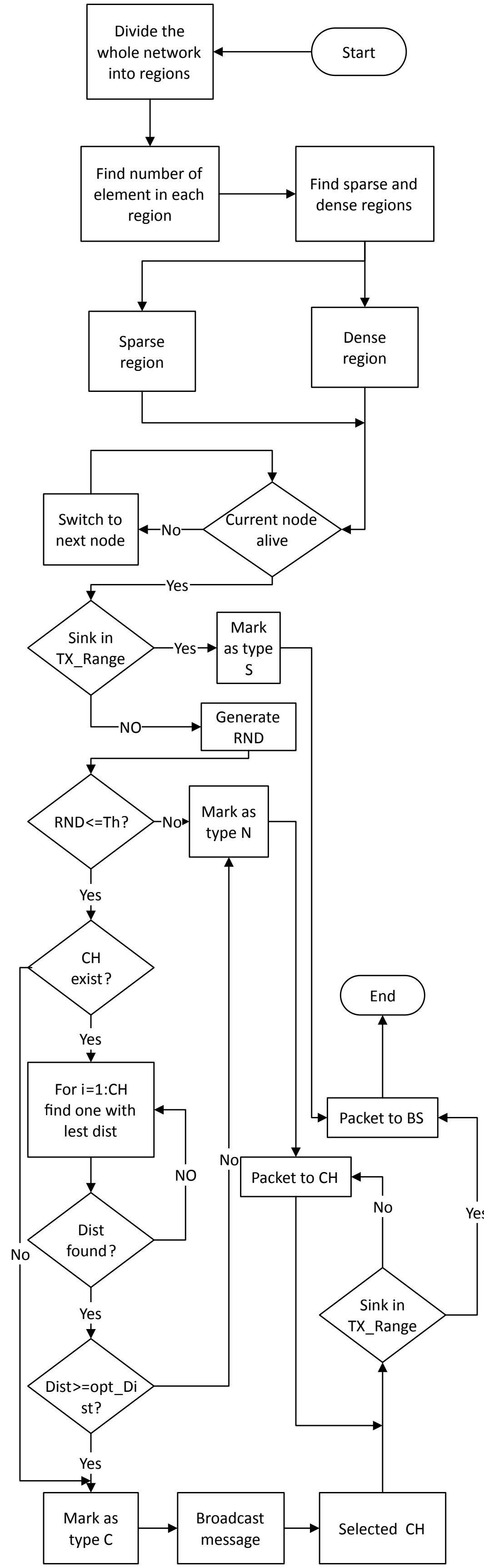

Fig. 5. Flow chart

After nomination node compares its energy with average energy of the network. Now again there are two possible cases:

Case 1: When the energy of nominated node is less than the average energy of network. the nominated node is marked as type N.
Case 2: otherwise it remain as nominated node.

For balanced energy consumption the CHs in network must be optimal in number. When node is nominated it lookes in its vicinity for already selected node. If found it calculates the distance with them, and compares with the optimal distance which is initially defined. Now if the calculated distance is greater than or equal to the optimal distance. The node is selected as CHs and is marked as type C, otherwise it is marked as type N. The selected node broadcast a hello message to its one hop neighbor nodes about their selection. In this way we have optimal nouber of CHs in our propose scheme.

D. Data transmission

Soon after CHs selection data transferring phase starts. As nodes knows the position of sink and coordinates of one hop neighbor nodes. Each N type node sends data to CH in such way that no back transmission occurre; which increases the over all distance of the node from the sink (as shwon in fig. 4). The type C nodes collect data from associated normal nodes and perform data aggregation. CH Transfers data directly to sink if sink in his transmission range or through multi hoping (CH transfers data to other CH which is in its transmission range and is near to sink) to the nearest sink. The nodes which are marked as type S transfer data directly to sink. The working flow of our proposed scheme is shown in fig. 5.

V. Simulation and Results

We validate our propose scheme via simulations by comparing with DBR and EEDBR. For the sake of fair comparison, we use the same number of nodes in our propose scheme as that of DBR and EEDBR that is, 200 nodes. The 200 sensor nodes are randomly deployed in a 500m X 500m X 500m 3-D area. Each sensor node is equipped with initial energy of 5 joules. Transmission range of each sensor node is 100m (in all direction). Size of data packet and hello message packet is 200 byte and 8 byte respectively. The LinkQuest UWM1000 [25] acoustic modem(s) are used, having a bit rate of $10k$ bps. Power consumption of node in sending and receiving of data is 2W and 0.1W respectively. Simulation parameters are given in table II.

A. Performance parameters: Definition

We use the following parameters for the performance evaluation.

1) Stability period: Stability period is the duration till the first node dies in a network.

2) Instability period: Instability period is the duration after the death of first node till the death of all nodes in a network.

TABLE II
Parameters used in the simulation.

Parameters	Values
Network size	500m X 500m X 500m
Number of nodes	200
Initial energy of nodes	5 joule
Data packet size	200 byte
Hello packet size	8 byte
Transmission range of the sensor node	100 meter
Number of sink	2

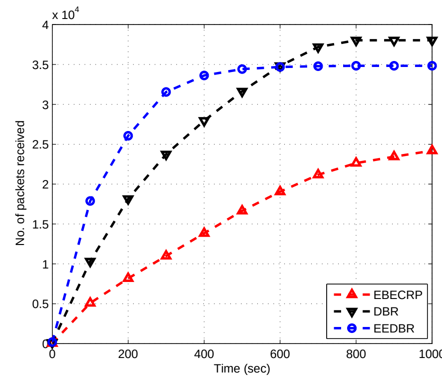

Fig. 6. Number of packet received at the sink

3) Network lifetime: Network lifetime is the duration till all the nodes in a network run out of their energy. Dead nodes represent the number of node which have run out their energy where alive nodes represent the number of nodes which have enough energy for data transmission.

4) Throughput: Shows the number of successful packets receive at the mobile sink(s).

5) Packet drop: It shows the number of packets which is not received at the mobile sink(s).

6) Packet acceptance ratio (PAR): It is define as the ratio of successful packets receive at the mobile sink to the number of packets sent to the mobile sink(s) at regular time interval.

7) Residual energy: It is the total amount of energy possessed by all the sensor node in network per time instant.

B. Performance parameters: Discussions

1) Throughput: In fig. 6 number of packets received at sink is shown. DBR and EEDBR receive more packets and show high throughput as compare to EBECRP. In EBECRP we use clustering for data collection. CHs collect data from nodes in their vicinity and send that data as one composite packet to sink. We consider that one composite packet as one packet received at the sink. Thats why the throughput of EBECRP is less than DBR and EEDBR.

2) Packet drop: In fig. 7 number of packet drop of DBR, EEDBR and EBECRP is shown. DBR has more packet drop than EEDBR and EBECRP. Packet drop in DBR is high due to flooding. In our proposed scheme we avoid flooding by using clustering which reduces packet drop as compare to DBR. At

TABLE III
PERFORMANCE TRADE-OFFS MADE BY THE ROUTING PROTOCOLS.

Protocol	Mechanism	Advantages achieved	Price paid/at the cost of
DBR	No mechanism to balanced energy consumption. Node with least depth die earlier.	High throughput (fig. 6).	Low stability period and network life time (fig. 9)and (fig. 8). High energy consumption (fig. 10). High packet drop (fig. 7).
EEDBR	Efficient energy consumption Mechanism. Nodes near the sink die earlier.	High throughput (fig. 6). Less packet drop (Fig. 7).	Low stability period and network life time (fig. 9)and (fig. 8). High energy consumption (fig. 10).
EBECRP	Mechanism to balanced energy consumption and load on the nodes near the sink.	Improved stability period and network life time (fig. 9)and (fig. 8). Less packet drop (fig. 7). Less energy consumption (fig. 10).	Less throughput (fig. 6).

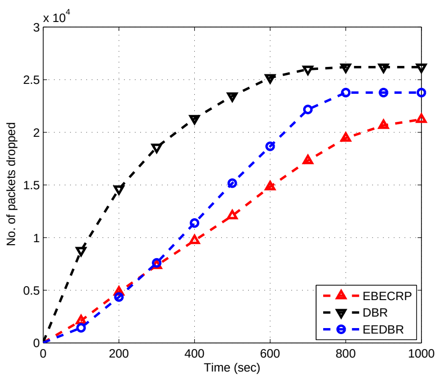

Fig. 7. Number of packet dropped

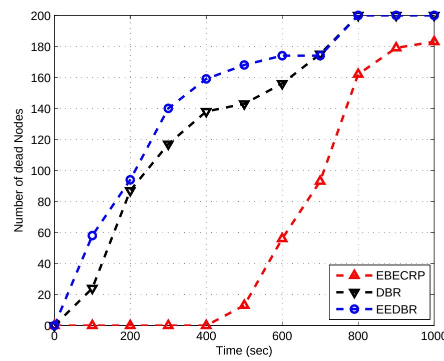

Fig. 8. Number of dead nodes

the start EEDBR and EBECRP have same packet drop. In EEDBR sensor nodes die very quickly which creates routing holes in network thus in later rounds its packet drop increases.

3) Network lifetime: Stability period of EBECRP is more than DBR and EEDBR (as shown in fig. 8). DBR and EEDBR perform multi hoping and depth base routing due to which load on sensor nodes with least depth or near the sink is high. These snsor nodes die earlier than other sensor nodes of the network. By using mobile sinks and clustering the network life time of our proposed scheme is improved as compare to DBR and EEDBR as shown in fig. 9.

4) Network residual energy: Network residual energy of EBECRP is much better than the DBR and EEDBR. We use mobile sinks and clustering in EBECRP to balance load on all the nodes in network which results in balanced energy consumption as shwon in fig. 10. In DBR and EEDBR multi hoping and flooding are involved which result in high energy consumption of network.

C. Performance trade-offs

In this section, we validate and evaluate the performance of our proposed protocol with DBR and EEDBR in terms of achievements and drawbacks. The performance trad offs of our proposed protocol with DBR and EEDBR are listed in table III. In DBR flooding is involved which results in high throughput and high packet drop. DBR uses depth based

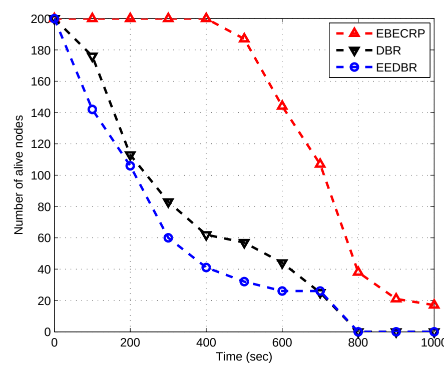

Fig. 9. Number of alive nodes

routing and multi hoping to transfer data to sink, which results in high load on low depth nodes. Thus low depth nodes die very quickly result in sharp stability period (fig. 8) and low network life time (fig. 9). DBR shows unbalanced energy consumption mechanism (fig. 10), which results in high throughput (fig. 6) at the cost of high packet drop (fig. 7), sharp stability period (fig. 8) and low network life time (fig. 9). EEDBR is depth based routing protocol and perform multi hoping for data transmission to sink, which results in high load on nodes near the sink. These nodes die very quickly showing sharp stability period and low network life time as shown in

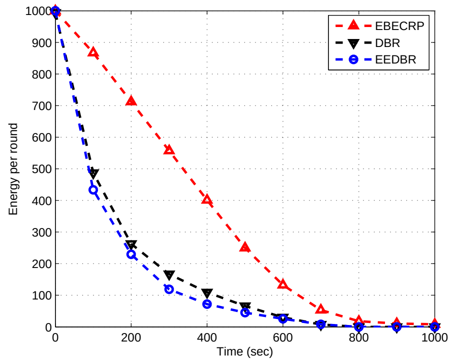

Fig. 10. Energy consumption per round

fig. 8 and fig. 9. EEDBR shows efficient energy consumption mechanism which results in high throughput (fig. 6) and less packet drop (fig. 7) at the cost of sharp stability period and low network life time. In EBECRP we avoid depth based routing in order to balance loads on nodes, which results in improve stability period and network life time as shown in fig. 8 and fig. 9. EBECRP shows efficient and balanced energy consumption (fig. 10) which results in low packet drop (fig. 7), high stability period (fig. 8) and improved network life time (fig. 9) at the cost of less throughput (fig. 6).

VI. Conclusion

In this paper, we presented a routing protocol EBECRP, to improve the stability period and network life time of UWSNs. The beauty of our proposed protocol is that it reduced load on the nodes near the mobile sink to achieve balanced energy consumption. As nodes consume more energy in transmitting than in receiving (in case of multi hoping) to reduce the number of transmissions we used the concept of clustering where CHs collect data from their one hop neighbor nodes and forward compressed data to the sink. Simulation results shown improved performance of EBECRP compared with DBR and EEDBR in terms of balanced energy consumption and network life time.

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