Wireless Pers Commun (2017) 94:2417–2440
DOI 10.1007/s11277-016-3495-2

# Balanced and Multi-objective Optimized Opportunistic Routing for Underwater Sensor Networks

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Published online: 14 July 2016


**Abstract** Underwater sensor communication medium has been motivated in the recent years, to explore probing targets in the area of interest within the ocean. The main challenge in acoustic sensor networks is to maintain the energy level balance among the nodes, throughout the entire lifetime of the network. Hence, a Balanced Multi-objective Optimized Opportunistic Routing (BMOOR) is proposed to forward the packet through multi-hop from downstream node to upstream node, so as to reach the sink at the surface. The proposed method refashions the nodes based on the dynamic estimations with respect to energy and the selection of optimal forwarders along the depth in a three dimensional network. In contrast to the existing techniques, the proposed protocol does not require spatial location, which is very expensive in UWSN. This in turn overcomes the fear of the single node getting trapped during greedy forwarding. The proposed method is further optimized using meta-heuristic, generation based bio-inspired algorithm (Bat) for delay minimization and delivery ratio maximization. Bat algorithm optimizes the opportunistic path by random fly with respect to fitness till it converges to an optimal pareto front, thereby the network lifetime is enhanced. Extensive simulation study using NS2 with an underwater simulation package proved that BMOOR contributes significant performance improvements over other representative UASN routing protocols.

**Keywords** Underwater acoustic sensor networks · Opportunistic routing · Energy efficiency · Optimization · Bat algorithm

## 1 Introduction

Recent development in the field of underwater communication has been fueled by the demand for real time monitoring of areas of interest within the ocean. Monitoring underwater environments presents certain unique challenges such as poor visibility

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tracking, the propagation speed of sound, added with highly dynamic physical characteristic of sea water such as temperature, pressure and salinity [1] makes it versatile. Hence it becomes essential to monitor such challenging environment by using multiple sensors with a low bandwidth acoustic modem. The time sensitive applications to be monitored include oil spill detection [2], monitoring under water pipelines [3], habitat monitoring [4], mine detection, sensing military and naval activities etc.

Since the ocean area is vast and occupies [5] three fourth of the earth's surface it is obligatory to deploy multiple sensors to monitor the area of interest. The intention of deployment becomes meaningful, only when the sensed data is routed to the common sink at the superior surface of the ocean. Henceforth an efficient routing protocol becomes mandatory to complete the course of action. The problem of forwarding the sensed data becomes multifaceted if it does not choose multi-hop [6]. Multi-hop routing would be an ideal method to minimize the energy usage of the battery which is an essential measure in underwater environment. Proposed method utilizes this to forward packets through a node at lower depth with an optimum hop distance.

Traditional terrestrial reactive protocols such as AODV [7], DSR [8] perform flooding frequently in a systematic order. Route maintenances and subsequent operations performed in the conventional methods are very expensive to carry out in an underwater environment. The main objective of this paper is to devise a routing protocol that performs routing opportunistically with multiple objectives like minimizing delay and maximizing delivery ratio to achieve the required Quality of service (QoS). In general opportunistic routing protocols like EXOR [9], MORE [10], LCOR [11] and SOAR [12] mostly depend on the global topology of the network, but do not rely on geographic information. Underwater environment is prone to dynamic changes like variations in temperature, salinity, water currents etc. Proposed routing protocol employs opportunistic routing which forwards the sensed packet from a deep node to a shallow depth node in a greedy fashion by using geographical information.

Even opportunistic routing achieved through several hops would provide ideal benefit, only if it satisfies the application specific requirements. However several protocols suffer from severe overhead, especially while selecting, prioritizing and maintaining its node's path at each stage. Hence the proposed method incorporates multi-objective optimization methodology. Multi-objective optimization [13] while suggesting opportunistic path promises robust routing. The multi-objective optimization ensures Quality of Service (QoS) [14] by minimizing delay, and maximizing delivery ratio.

The proposed new framework is called as Balanced and Multi-objective Optimized Opportunistic Routing (BMOOR). BMOOR operates in four phases: Initial Beaconing, Dynamic Lifetime Estimation based Acceptance and Confirmation, Route Estimation (Initial Population) and Bat based route optimization. BMOOR invites its one-hop neighbors by broadcasting the invitation request message and receives its reply. Based on the received acceptance messages from the immediate forwarders, the optimal forwarder is selected considering the energy, geographical or spatial information. In this way the sensed information from underwater environment is routed to the common sink. The opportunistic path obtained during initial population is further prioritized and optimized using meta-heuristic iteration based Bat algorithm [37]. This assures balanced traffic with minimum energy and delay and maximizes the delivery ratio. The objective is to overcome the challenging issues in routing for underwater environment and to provide an optimal solution. The highlights of BMOOR routing are listed as follows:

- The forwarding node's participation is limited through Effective Neighbor Selection list ENS ( $\mathfrak{N}_i$).
- The routing approach is enhanced with Dynamic Lifetime Estimation based Acceptance (DLEA) by calculating Dynamic Lifetime of every individual node and thereby limiting its adaptability.
- The opportunistic routing is exploited with multi-objective optimization to overcome the existing issues like the need of spatial requirements; receiver based approach, unbalanced energy consumption and makes it reliable for underwater environment.
- Fulfilling the above guarantees successful route for data transfer, thereby achieving the required QoS.

The rest of the paper is organized as follows. Section 2 elaborates the related work. Section 3 presents the proposed methodology. Section 4 describes performance evaluation. Finally Sect. 5 concludes the paper.

## 2 Related Work

In this section some protocols available to route information in underwater sensor networks are presented. They are classified into two namely: Spatial routing protocols and Non-spatial routing protocols. The former is localization dependent while the latter is localization independent.

### 2.1 Spatial Routing Protocols

This section presents a quantity of routing protocols that depend on spatial information. Xie et al. [16]. have proposed a position based protocol known as Vector-Based Forwarding (VBF). To make the best decision the spatial information is coded along the packet and forwarded through the virtual pipe. The disadvantage is that only the packets, forwarded by the nodes that are close to vector reach the destination. The reception ratio is directly proportional to the radius of the pipe or vector; it further decreases the overall delivery ratio. One more enhancement made to the existing VBF called as Hop-by-Hop VBF (HH-VBF) [17] has improved its performance by making the next hop neighbors as decision makers and forwards its messages. HH-VBF has improved the delivery ratio but the problem with the radius of the vector pipe remains the same. Focused Beam Routing (FBR) protocol [18] operates by assuming spatial information about source and destination. It operates on exchanging RTS/CTS packets that contain the necessary spatial information. The key feature of this protocol is that several power levels can be adopted and can be increased to reach the next hop neighbor so as to reach the destination. The limitation is that exchanging request messages may cause energy consumption and delay. Node movement away the cone angle due to water currents influence the protocol's performance. Reliable and Energy Balanced Routing (REBAR) [19] algorithm overcomes the water current problem by shifting the position of the node in the network so as to avoid the void but induces more End-to-end delay. To reduce overhead and to achieve reliable data sharing Hwang et al. [20] have introduced routing algorithm known as Directional Flooding-based Routing (DFR) that limits the figure of nodes participating in the process for a specific data packet based on the quality of link.

## 2.2 Non-spatial Routing Protocols

This section presents some routing protocols based on Non-spatial information. The novel routing proposed by Liang et al. [21] called as Information-Carrying Routing Protocol (ICRP) couples the control and data information in a single packet and initiates it during routing. It broadcasts the route request message only if no route exists.

This maintenance helps to obtain a reverse path for the destination and to send acknowledgement for the previous request. The larger the threshold, the route remains open, if the time to live being too large raises the protocol overhead. Depth Based Routing protocol (DBR) [22] is a geographic routing protocol which takes “depth” as a key measure to decide the next forwarding node. The receiving node compares its depth at the current position with respect to the depth of the previous one to select a qualified forwarder. In light of the fact that it considers only depth as decision parameter it exhibits redundancy to some extent and more delay and is less energy efficient. The layered routing protocol designed by Gopi et al. [23] termed Path Unaware Layered Routing Protocol (PULRP) for 3D underwater acoustic networks works in two phases. The layering phase divides the area of interest into different concentric circles to reach the sink. The communication phase is decided on the fly to select the successful next hop to forward the information to the destination. Above would have been competent, if it has considered the energy measure that is essential for under water environment. H2DAB [24] called as a Hop-by-Hop Dynamic Addressing Based protocol assigns dynamic address to each node from bottom to top. The nodes at the bottom will have larger addresses than the nodes at the top. Hence first it assigns address and forwards data later increasing the hop id. Due to multi-hop the node with small address is most frequently attempted for routing which in turn leads to energy draining.

QELAR [25] a Machine-Learning-Based Adaptive Routing implements Q-learning to update the dynamic changes of the routing environment. To achieve this it satisfies Markov decision process to stabilize the network load among the acoustic sensors. QELAR checks the eligibility of a node to be the next hop by exchanging metadata. This type of dynamic learning improves data delivery ratio and minimizes the energy. The Energy optimized routing is introduced by Gopi et al. [26] E-PURLP strongly presents the layering structure of nodes and differs from the traditional method. Here the nodes are layered in different concentric circles with the one that has a similar hop count. Unlike PURLP this protocol calculates transmission energy of the node by fixing boundary conditions. Further this idea prevents the traffic getting overloaded in a particular layer.

The Energy Efficient Depth-Based Routing Protocol (EEDBR) [27] initially broadcasts energy and depth information to select the successful next neighbor node. The sensed data is forwarded to nodes at shallow depth that have high energy level than the current node. To avoid collision EEDBR calculates holding time to forward the successive packet from the same node. This protocol would have been more efficient, if it has performed load balancing for the entire network. The Multi-layered Routing Protocol (MRP) [40] eliminates the need of spatial information with the help of super nodes which are responsible to forward packets through different layers. The failure of a single super node may degrade the performance of the protocol. Multi population Firefly Algorithm (MFA) [28] routing performs optimization process by restricting energy and bandwidth. Apart from the traditional view of routing, firefly algorithm uses intensity and attractiveness of the node that corresponds to the location and distance for optimization. This improves the convergence speed and efficiency of the network.

A Low Overhead Routing protocol (LOARP) introduced by Rahman et al. [29] reduces the overhead of the entire network by performing route discovery and maintenance in a reactive manner. In addition to the above, the traffic is also reduced by detecting the failure nodes and recovering them intelligently. Link- State based adaptive Feedback routing incorporates upstream and downstream table to exploit symmetric link to verify the link stability of the particular link. The feedback mechanism introduced by Zhang et al. [30] alters the route if it congregates a void. Pressure based routing by Lee et al. [31] includes a sea swarm structure monitored by buoys to perform efficient routing. The basic operating principle is based on hydraulic pressure available along different depths in the sea. Opportunistic routing is performed to prioritize the forwarders and maximize the greedy process.

### 2.3 Opportunistic Routing Schemes

Most often the Opportunistic routing protocols like EXOR [9], MORE [10], LCOR [11] and SOAR [12] perform any path routing based on global topology of the network. Especially in Underwater Sensor Network (USN) the nodes tend to be mobile which requires dynamic opportunistic path to be laid out based on spatial or non spatial information. The dynamic opportunistic path could also be obtained non- geographically either by beaconing or by sensing depth information. The pressure based routing [31] uses only depth information based on Expected Packet Advance (EPA) metric for assuring link quality between nodes for its opportunistic path. This protocol also considers Void metric to avoid the hole in its [32] communication.

Wahid et al. have proposed an ERP2R protocol which is a receiver initiated protocol where the sink sends out beacon packets that includes essential information. Hello packet information assists the node to find out Time Of Arrival (TOA) and analyzes the cost to finalize the optimal forwarder in the opportunistic path to reach the receiver. Further calculation of holding time assigns priority to every node to ease the process. The void metric is not considered in this paper. Void Aware Pressure Routing (VAPR) by Noh et al. [33] has provided solution for communication void problem in a greedy way. The depth information obtained from hello messages helps the local maximum node to find its neighbor either in the upward or downward direction based on its location either shallower or deeper.

### 2.4 Optimization Schemes

Optimization in routing plays an important role, when the sensing area is relatively large and tightly constrained sensor nodes function in an intermittently changing topology. In addition optimization plays a successful role when the chance of failure is high due to the consideration of uncertainty in UWSN. The uncertainty refers to non synchronized communication between acoustic sensors. A solution can be pareto efficient only after applying proper optimization techniques. The optimization is generally based on two main divisions namely Deterministic which utilizes a fixed path and stochastic algorithms which depend on randomness. There exists a number of bio-inspired optimization algorithms namely ACO (Ant Colony Optimization) [34], GA (Genetic Algorithm) [35], PSO (Particle Swarm Optimization) [36] etc. For instance ACO solutions are based on pheromone deposition of ants, GA inhibits chromosome behavior and PSO resembles swarming behavior. Bat Algorithm [37] which is stochastic in nature inhibits the bio-sonar behavior of bat. Bat algorithm has several unique features like echolocation and frequency tuning which can be varied for several iterations to generate the optimal best solution. Multi-Objective Bat Algorithm (MOBA) [38] expands for itself in a wider view of solving complex Multi-objective design problems.

## 3 Proposed Methodology

The proposed routing algorithm forwards packet in an opportunistic or greedy approach in underwater environment from source to destination. During routing process the depth of the optimal forwarders decreases while approaching the sink. BMOOR considers depth along with energy based on DLE while choosing the next optimal forwarder. The existing routing protocols consider energy or depth or both in an unbalanced way which degrades the performance of the routing process. The key idea of BMOOR is that, it exhibits sender approach in choosing the next optimal forwarder based on energy and depth in a balanced way. The proposed work is explained in the following steps (1) Network architecture overview, (2) BMOOR overview, (3) Bat based Route Optimization.

### 3.1 Network Architecture Overview

The network architecture proposed in this work well suits applications like habitat monitoring along with superior monitoring applications like deep sea mineral exploration, ocean and sea weather forecast information, monitoring remotely generated water currents, wind waves, cyclone formation, prediction of sea surface and ocean sub surface variations etc. The hydro acoustic communication architecture consists of sensors arranged together to form a network. The ocean bottom sensors are anchored with very deep anchors. To maximize the coverage of the sensing area, the sensors are deployed at various depths and can withstand harsh weather conditions. In this three-dimensional static architecture the nodes are suspended with the surface buoys whose depth can be regulated through wires. They gather data from 3-D area and relay to the surface sinks with help of long-range vertical acoustic transceiver.

### 3.2 BMOOR Overview

BMOOR routing protocol works on single-sink architecture. As mentioned earlier, BMOOR balances the energy constraint of the network, thereby increasing the reliability and data delivery ratios. Figure 1 BMOOR operates in four phases: Initial beaconing, Dynamic lifetime estimation based acceptance and confirmation, Route Estimation (Initial Population), and BAT based Route optimization. Thus the developed protocol is helpful to prolong the network lifetime, limiting the overhead.

#### *3.2.1 Packet Structure and Message Flow in BMOOR*

The routing packet types and message formats of BMOOR are illustrated in Figs. 2, 3 and 4. The packet header of any packet consists of two fields: Sender ID, Packet Sequence number. "Sender ID" is the identifier of the Underwater Sensor node. "Packet Sequence Number" is the unique sequence number assigned by the underwater sensor node to the packet. Sender ID combined with the Packet Sequence Number helps to avoid duplication during routing process. Routing information includes energy and depth. "Energy" is the

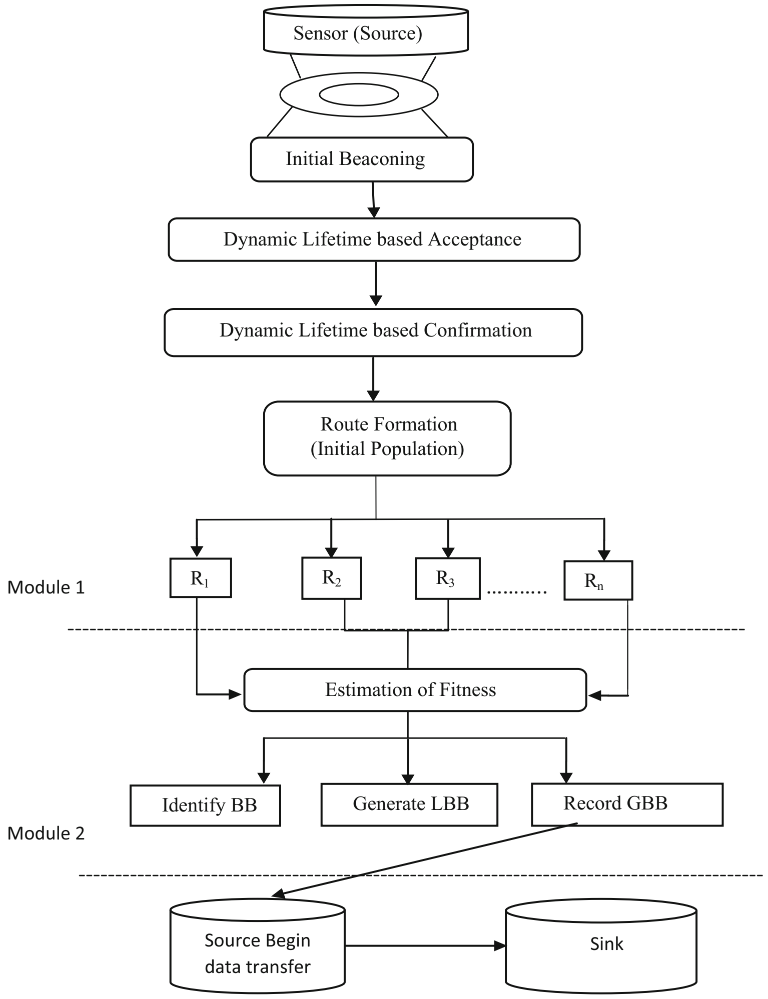


**Fig. 1** Architecture of BMOOR proposed approach

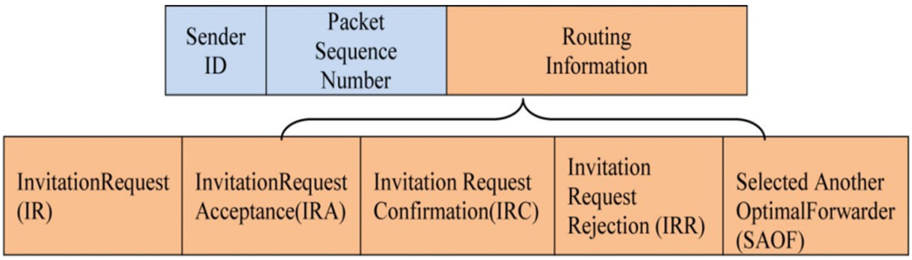


**Fig. 2** BMOOR routing packet types

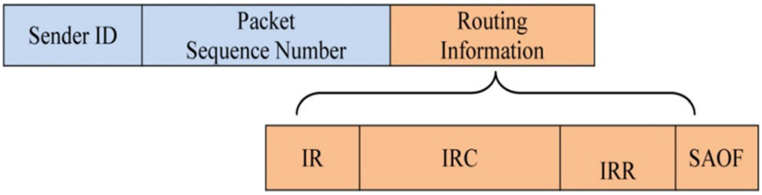


**Fig. 3** BMOOR IR, IRC, IRR and SAOF message format

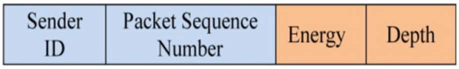


**Fig. 4** BMOOR invitation request acceptance message frmat

residual energy of the beaconing node. "Depth" is the depth information of the current forwarder that automatically gets updated for every hop during the beaconing stage. Routing information consists of five types of request namely Invitation Request, Invitation Request Acceptance, and Invitation Request Confirmation, Invitation Request Rejection, Selected another Optimal Forwarder. "Invitation Request" (IR) is the initial beaconing message sent to eligible one hop neighbors. Upon receiving the invitation request "Invitation Request Acceptance" (IRA) is issued after Dynamic Lifetime Estimation (DLE). This helps to balance the load and lessens the burden of the same node getting trapped during greedy forwarding. "Invitation Request Confirmation" (IRC) is the final message before data transfer. "Invitation Request Rejection" (IRR) is the rejection message issued if the request exceeds the DLE. "Selected Another Optimal Forwarder" (SAOF) is the redirection message sent to all nodes that have sent IRA earlier in reference to an IR except the node that is confirmed as the optimal forwarder. The detailed explanation for routing information is discussed in the subsequent sections.

### *3.2.2 Initial Beaconing*

During the initial beaconing the acoustic sensor nodes validate and contribute their depth information among the nodes that lie within the transmission range ($\mathfrak{R}_i$). [ENS ($\mathfrak{R}_i$)] inserts the effective neighbors towards the sink whose depth is less than that of the node that has initiated invitation. i.e., $j_{disttosink} < i_{disttosink}$.

The depth measurement becomes mandatory since the packet has to travel upward to the sink that resides on the surface level. Whenever a sensor initiates a data packet to be forwarded to the destination, it can select some optimal forwarders within its Effective Neighbor Selection list [ENS ($\mathfrak{R}_i$)]. The list [ENS ($\mathfrak{R}_i$)] generated during initial beaconing prevents the sensor nodes from unnecessarily broadcasting the invitation request to all neighbor nodes. The initial beaconing procedure is as follows: A sensor node at a deeper depth broadcast the Invitation Request (IR) to the nodes at shallow depth listed in [ENS ($\mathfrak{R}_i$)]. Invitation beaconing is initiated on regular intervals to update the acoustic nodes about their available neighbors (Table 1).

**Table 1** Terminology

| Terms | Definitions |
|---|---|
| $\mathfrak{R}$ | Neighboring nodes within the transmission range |
| ENS | Effective Neighbor Selection |
| Dist to sink | Distance to Sink |
| S | Set of nodes $\{s_1, s_2,\ldots, s_n\}$ |
| IR | Invitation request |

**Algorithm 1** Invitation beaconing phase

1: **procedure (*Invitation Beaconing)***
2: Let $\mathfrak{R}_i \epsilon\, S \longleftarrow$ //nodes around the communication range of node i //
3: **ENS ($\mathfrak{R}_i$)** = {empty set}
4: ***For each j*** $\epsilon\, \mathfrak{R}_i$
5: **If** $j_{disttosink} < i_{disttosink}$
6: Insert node **j** to the list of **ENS ($\mathfrak{R}_i$)**
7: **end if**
8: E**nd for**
9: Broadcast **IR** to each **ENS ($\mathfrak{R}_i$)**

### 3.2.3 Dynamic Lifetime Estimation (DLE)

Dynamic Lifetime Estimation helps the sensor node to ascertain itself how many packets it could successfully transfer with its available energy. Adding to that it also helps to pick up the optimal forwarders. It is obvious that the nodes having high residual energy will have higher lifetime. Assume that the sensors denoted by $S = \{s_1, s_2, \ldots s_n\}$ are homogeneous and every sensor node has the ability to choose the optimal forwarder from the set of forwarders based on its local information like Energy, Depth. As shown in Eq. (1) a node can declare itself as an optimal forwarder only if its residual energy is above the $\mathcal{E}ng(\tau_{th})$. $\mathcal{E}ng(\tau_{th})$ is defined as the minimum energy required to transmit a k-bit message over a distance t.

$$\mathcal{E}ng(\tau_{th})_{(k,t)} = \min_{t' \geq t} \mathcal{E}ng(\mathrm{T}\chi(\mathrm{t}', \mathrm{k})). \tag{1}$$

After subsequent time, the nodes that have participated in data transfer perform an individual scan to recognize its significant energy usage. The residual energy remaining in the node is estimated by deducting the energy dissipated by the individual node as given in Eq. (2). During the initial stage of communication the residual energy of every node will be approximately equal to the initial energy.

$$\mathcal{E}ng_{residual} = \mathcal{E}ng_{initial} - \mathcal{E}\mathrm{ng}_{dissipated} \tag{2}$$

The nodes may dissipate energy after subsequent transmission or reception of packets in course of time. Energy dissipated by every node is given by Eq. (3)

$$\mathcal{E}\text{ng}_{dissipated} = \mathcal{E}\text{ng}_{\text{Transmit}} + \mathcal{E}\text{ng}_{\text{Receive}} \tag{3}$$

Hence all the nodes in the network estimate its DLE as shown in Eq. (4)

$$Dynamic\,Lifetime\,Estimation(DLE) = \frac{\mathcal{E}ng_{residual}}{\mathcal{E}ng_{(\tau th)}} \tag{4}$$

1. Dynamic Lifetime Estimation based Acceptance (DLEA)
   In this stage, Fig. 5 the nodes take an initial decision as to involve in the data transfer as an optimal forwarder by issuing an acceptance. The decision may be confirmed by the node lying beneath it. Otherwise the node initiated withdraws itself. Also the node lying behind may reject its acceptance if it has found an even better forwarder which is explained in the following sub sections.
   In this section, the Dynamic Lifetime Estimation based Acceptance (DLEA) of sensors in the Network is discussed.DLEA ascertains whether the particular request (IR) can be processed or not based on the previously estimated DLE in Eq. (4). DLEA

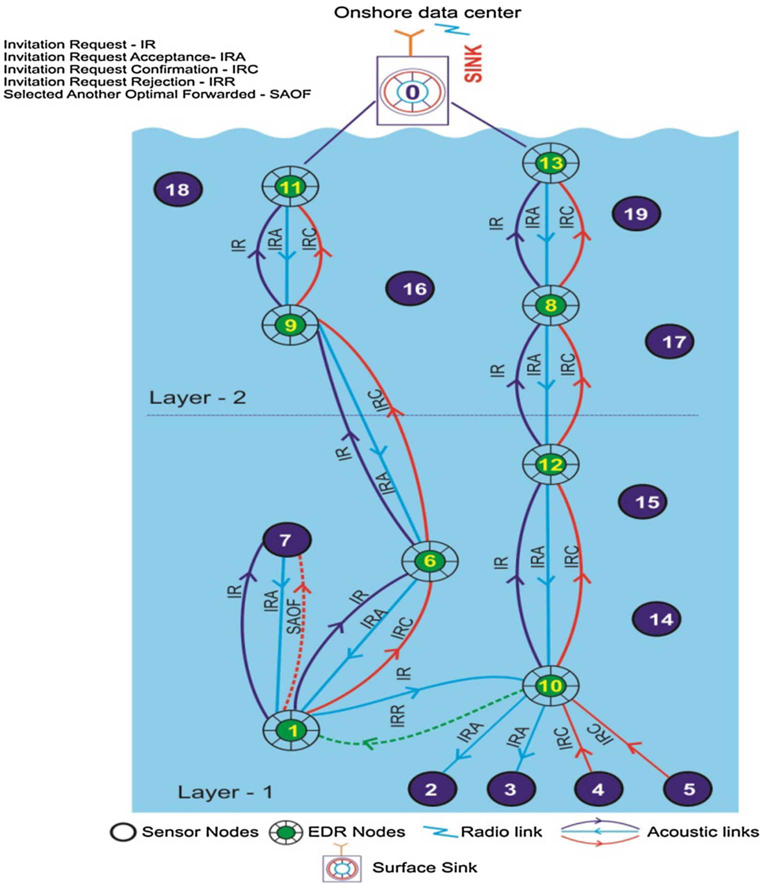


**Fig. 5** Dynamic lifetime estimation based acknowledgements

functions by issuing either IRA or IRR token based on the individual node's DLE. The shallow depth node which receives the IR and issues IRA acts as parent node, while the one at a deeper depth which confirms the IRA by transmitting IRC serves as the child. All the nodes in the network maintain a table called List Of Acceptances (LOA) that contains the IRA's issued while the node acts as a parent and IRC's issued by the particular node as a child are maintained in the table called List Of Confirmations (LOC). At this juncture, on receiving the IR the parent node figures whether the particular request towards transmission bounds within the parent node's capacity based on its estimated DLE. This is processed by summing the count of $(LOA_m)$., $(LOC_m)$. and current request which should be less than DLE of the particular node. If the condition in Eq. (5) is satisfied it issues IRA token and adds an entry in the $(LOA_m)$. Otherwise it issues an IRR token.

$$\text{DLEA} = \begin{cases} IRA & if \quad (LOA_m) < DLE_m \\ IRR, & otherwise. \end{cases} \tag{5}$$

2. Dynamic Lifetime Estimation based Confirmation (DLEC)
   In this section, the Dynamic Lifetime Estimation based Confirmation (DLEC) of sensors in the Network is discussed. DLEA ascertains whether the received IRA can be confirmed or not. In this phase the child node gets an opportunity to confirm, one of the best parent's based on the Energy Depth Range (EDR) information. The IRA ten issued by the parent node at a shallow depth. The acoustic child node that has detected the event, after receiving the IRA token, confirms the best optimal forwarder node at a shallow depth. The polling is based on EDR information maintained for that node in a table. If a child receives more than one IRA token it gets a chance to confirm one of the best node's at the upper layer towards the sink without compromising the EDR as given in Eq. (6).

**Table 2** Terminology

| Terms | Definitions |
|---|---|
| S | Set of nodes $\{s_1, s_2, \ldots, s_n\}$ |
| CR | Current request |
| *DLE* | Dynamic lifetime estimation |
| *IR* | Invitation request |
| *EDR* | Energy depth range information |
| *IRA* | Invitation request acceptance |
| *IRC* | Invitation request confirmation |
| *IRR* | Invitation request rejection |
| *SAOF* | Selected another optimal forwarder |
| Msg | Message |
| m and n | Parent node and child respectively based on the *'**msg**'* type |
| $(LOA_m)$ | List of nodes which are accepted |
| $(LOC_m)$ | List of nodes which are confirmed |

$$EDR = Max\{E_m \;\; D_m\}; \quad m = 1, 2\ldots n \tag{6}$$

where $E_m$ and $D_m$ are the Energy and Depth differences from the sink to the nodes in $(LOA_m)$.

Once the downstream node confirms by issuing IRC based on the condition in (6) its entry in the acceptance column is removed, after placing a corresponding entry in confirmation (IRC). This updating is done periodically. Hence confirmation state information is to express the link or connectivity between the child and parent which is necessary for Route Estimation (Initial population). The child in turn sends a notification message Selected Another Optimal Forwarder (SAOF) to the immediate upstream nodes (except the one confirmed) who sent their IRA earlier. The upstream nodes, that have received the 'SAOF' message, remove the acceptance entry from $(LOA_m)$ and update their DLE (Table 2).

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**Algorithm 2** *DLEA & DLEC:*

**procedure** Message Handling
**switch case ('msg')**
**case 'msg' eq IR ('m' receiving IR from 'n')**
  **begin**
    ***if the count of [*** $(LOA_m) + (LOC_m) + \mathrm{CR}] \le DLE_m$
      *Send reply message* ***'msg'*** as **IRA**
      *Add n to* $(LOA_m)$
    ***else***
      *Send reply message* ***'msg' as IRR***
    ***end***
  ***end***
**case 'msg' eq IRA ('n' receiving IRA from 'm')**
  **begin**
    ***if*** *m posses the max EDR*
      *Send* ***'msg'*** *as* ***IRC***
      *Add m as the optimal forwarder for n*
    then
      *Send* ***'msg'*** *as SAOF to all other nodes in* $(LOA_m)$
    **end**
  **end**
**case 'msg' eq IRC ('m' receiving IRC from 'n' )**
  **begin**
    *Remove n from* $(LOA_m)$ *and Add m to* $(LOC_n)$
  **end**
**case 'msg' eq SAOF ('m' receiving SAOF from 'n' )**
  **begin**
    *Remove n* from$(LOA_m)$
  **end**

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3. Initial Population
   Once the connectivity is established between a child and parent, they are ready for data transfer. Likewise a path is established from source to destination by connecting a child and parent at every layer. During the initial stage ‘n’ the node at a lower depth issues IRC to ‘m’ at a shallow depth. Now the node ‘n’ which has initiated the transmission is added to the path. Further the confirmed nodes in the upper layers are added to the path till ‘m’ equals sink. BMOOR exploits opportunistic routing by exploring the broadcast nature of the underwater wireless medium by connecting multiple one-hop neighbors. This increases the packet forwarding reliability, thus improving the throughput and energy efficiency. Initial population size may vary depending upon the size of the network (Table 3).

**Algorithm 3** Initial Population

*Input: Node pair who are confirmed; Output: Path connecting Source and Destination*

1: **procedure (*Initial Population*)**
2: *Let ‘n’ be the source*
3: ***begin***
4: *Add n to the path*
5: *Let the node in its ($LOC_n$) table be ‘m’*
6: *Set n=m*
7: *Repeat step 4 until m equals sink*
8: ***end***

## 3.3 Bat Based Route Optimization

A new Meta heuristic search algorithm developed by Xin-She Yang is called Bat Algorithm [37]. Micro bats use echolocation to detect their prey, obstacles and locate their roosting crevices in the dark. To accomplish them exactly they estimate the time difference between emission and reverberation of the same signal. The emitted pulses last only for a few thousandths of a second i.e. (about 8–10 ms). The frequency ranges between 25 and 150 kHz. The rate of pulse emission may vary depending upon the fly near or farther the prey. Normally it is around 200 pulses per second when it is close to the prey. This work focuses on redesigning echolocation model of bats targeting their food/prey to that of the packets advancing towards the best fitness node along its path to reach the sink.

### *3.3.1 Need for Bat Algorithm*

Optimization plays a vital role when dissimilar objectives conflict and the chance of failure are high due to the consideration of uncertainty e.g. (UWSN). Adding to that it is difficult

**Table 3** Terminology

| Terms | Definitions |
|---|---|
| *n* | Node issuing confirmation from lower depth or source |
| *m* | confirmed at shallow depth |

**Table 4** Terminology

| Terms | Definitions |
|---|---|
| *1…n* | Initially populated path ($p_i$) or Bat |
| *Xi and* $e_i$ | Position or depth and energy of the nodes |
| *LBB* | Local best bat |
| *BB* | Best bat |
| $f\varphi$ | Fitness based on weights |
| $mo_1, mo_2$ | Objectives |

to obtain a single solution which could be optimum with respect to all objectives. Optimization is an essential process to obtain the best result irrespective of the circumstances. Multi-Objective Bat Algorithm (MOBA) [38] expands for itself in a wider view solving complex Multi-objective design problems. It helps to achieve global optimization for highly non-linear problem either single or multi-objective. Bat algorithm possesses the rewarding properties of Swarm intelligence. Bat algorithm attains quick convergence rate [37] at the earlier stages of iteration. It mimics the echolocation property of bat into reality through frequency variations. The motivation beyond Bat Algorithm provides an option to choose the best path from among the set of possible paths to the sink (Table 4).

### *3.3.2 Optimization Through Bat*

**Algorithm 4** Bat Algorithm

*Initialize the path (bat population) with Xi* $_{and}$ $e_i$ *based on DLE for i = 1…n*
***For*** *m = 1 to N (points on Pareto fronts)*
    *Produce K weights* $w_k \geq 0$ *such that* $\sum_{k=1}^{K} W_K = 1$
    *Fitness for multi objective* $f\varphi = \sum w_k^{mo_1}, w_k^{mo_2}$
    ***While*** *(t < Tmax) // number of iterations*
        *Rank the* $f\varphi$ *for the obtained paths*
        *Obtain BB*
        *Generate LBB around the obtained BB*
        *Generate new solutions by random fly*
            ***If*** $( fit_{LBB} < fit_{BB})$
                *Update LBB as BB*
            ***end if***
        *Rank BB as Global best bat*
    ***end while***
    *Record Global best path as a non-dominated solution*
***End for***

The bat algorithm illustrated in Algorithm 4 captures the bat behavior into fitness function. The goal is to establish an optimized path with minimum delay and maximum delivery ratio. Opportunistic paths are populated during initial population from source to destination by varying the *Xi* $_{\text{and}}$ $e_i$ based on DLE. In UWSN network, effective communication can be achieved with minimum delay and maximum delivery ratio. To endow with Pareto optimal solutions the weighted parameters are estimated to obtain the fitness of the Bat or path. The fitness ($f\varphi$) with normalized multi objective weights such as delivery ratio $(mo_1)$. and delay $(mo_2)$ are obtained using equation

$$f\varphi = \mathrm{W}^{mo1} + \mathrm{W}^{mo2} \tag{7}$$

where $\mathrm{W}^{mo1} = 1 - mo_1$ and $\mathrm{W}^{mo2} = mo_2$.

Fitness based on weights is calculated for the initially populated paths and are ranked. Based on the rank the path with minimum fitness is named as Best Bat (BB) as shown in Eq. (8).

$$BestBat(BB) = min[f\varphi(p_i)] \tag{8}$$

$$BB = P; \quad P \in p_i \tag{9}$$

where $p_i$ is the initially populated path (Bat) and P is the bt path (Bat) among the initially populated path.

Further LBB is obtained by randomly varying the better individual with the best individual based on BB. After random fly if the fitness of LBB is less than BB, update the fitness of LBB as BB. Now the converged fitness bat (BB) is recorded as Global best bat. The path corresponding to Global best bat that has been obtained is chosen for data transfer.

# 4 Performance Evaluation

In this section, the performance of the proposed routing protocol, BMOOR is compared to existing routing protocols in UWSN like DBR [22], EEDBR [27] and MRP [40]. The reason for choosing the above protocols for comparison is that they belong to the Non-spatial routing category similar to the proposed algorithm.

## 4.1 Simulation Settings

The performance of the proposed work is simulated by using NS2 with an underwater simulation package called Aqua-sim [39]. The simulation parameters are listed in Table 5. The Experiments are repeated for 30 trials with different sets (i.e. 25, 50, 75 and so on till 225) nodes for random topology. The nodes are assumed to be stationary once deployed. The sink is deployed at the center of the water surface. The source node initiates routing

**Table 5** Simulation parameters

| Parameter | Value |
|---|---|
| # of sensor nodes | 25, 50, 75, 100 125, 150, 175,200,225 |
| Area size | 300 m × 300 m × 300 m |
| Data packet size | 64 bytes |
| MAC protocol | IEEE 802.11 |
| Initial energy | 70 J |
| Queue size | 50 |
| Topology | Random |
| Compared routing protocols | DBR, EEDBR, MRP |
| Transmission range | 100 m |
| Population size for Bat | 50 |

from the bottom of the deployment area. The amount of energy consumption for transmitting, receiving and idle listening is set to 2, 0.75 W and 8 mW respectively. The source generates data packet once in every 30 s. The control and request packet size are 4 bytes and 16 bytes respectively.

### 4.2 Performance Metrics

The following metrics are used to evaluate the performance of the proposed BMOOR protocol.

*Network Lifetime* Network life-time is the time when the first node expires in the network (i.e.) when the energy of that node is completely exhausted.

$$Network\ Lifetime = T_s - T(\mathcal{E}ng_{n1}) = 0. \tag{10}$$

$T_s$ is the start time of data transfer in the network.

$T(\mathcal{E}ng_{n1})$ is the time when the energy of first node that get exhausted.

*Energy Consumption* Energy consumption is the total energy dissipated by all nodes in the network for their communication (transmitting, receiving and idle energy) to promise successful delivery of packets from source to sink.

$$\mathcal{E}ng_{consumption} = K\left\{\sum_{i=1}^{n}\left[2 \times \mathcal{E}ng_{dissipated} + \mathcal{E}ng_{amp}(d_i)^{\alpha}\right]\right\} \tag{11}$$

$\mathcal{E}ng_{dissipated}$ is the total energy dissipated by all nodes in the network, K is the message length, $\mathcal{E}ng_{amp}$ is the amplification, $(d_i)$ is the distance between the transmitter/receiver and $\alpha$ is the attenuation factor.

*End-to-End Delay* The end-to-end delay is the average time taken by a packet to travel from a source node to a destination/sink node at the surface.

$$End - to - EndDelay = AVG_t(P_s \sim P_D) \tag{12}$$

$AVG_t$ is the average time, $(P_s \sim P_D)$ is the difference of time for a packet to reach from source to destination.

*Delivery Ratio* Delivery ratio for the node $n_i$ is defined as the ratio of the number of distinct packets [*DP*] received successfully by the sink node at the surface $N\left[DP^i_{\Gamma}\right]$ to the number of distinct packets [*DP*] generated from the source node $N\left[DP^i_{\hat{g}}\right]$.

$$Delivery\ Ratio = \frac{N\left[DP^i_{\Gamma}\right]}{N\left[DP^i_{\hat{g}}\right]} \tag{13}$$

### 4.3 Results and Discussion

#### 4.3.1 *Network Lifetime*

The Network Lifetime of BMOOR in random topology is compared against DBR, EEDBR, and MRP as shown in Fig. 6. In BMOOR the optimization due to bat algorithm evidences tremendous improvement over the existing routing protocols. Bat algorithm dynamically optimizes the path obtained through initial population by randomly varying optimal

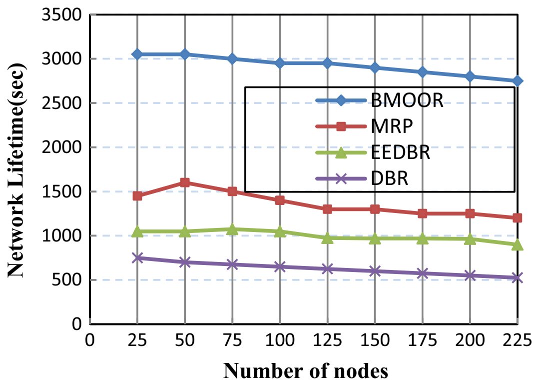



**Fig. 6** Network lifetime of against DBR, EEDBR and MRP

forwarders with reference to best path. This prolongs the Lifetime of the network limiting the same node getting trapped during data forwarding. Besides in BMOOR, when an acoustic node receives a packet only the node with high residual energy and depth closer to the sink forwards the packet. In the next session when the data packet arrives to the same layer it selects other better optimal forwarder to advance the packet. Hence the energy balancing in BMOOR helps the node to stay alive for a long period.

In contrast DBR [22] performs routing by forwarding packets to the node at smaller depths. Since the same node is frequently involved the energy of the node gets exhausted rapidly.DBR also exhibits redundancy. In EEDBR the depth along with energy is estimated while choosing the forwarder. Since there is no limitation or balancing the frequency of the node acting as forwarder the energy of the node drains quickly. This issue is resolved in BMOOR where the eligible nodes acting as optimal forwarder are limited by their DLE. In MRP the super nodes dominate the entire network with their abundant energy. But there is minimum consideration about the nodes in the intermediate layers. Therefore BMOOR with its limited adaptability and optimized forwarders enhances the Network Lifetime.

### *4.3.2 Energy Consumption*

Figure 7 shows the comparison of energy consumption of BMOOR against DBR, EEDBR and MRP. BMOOR filters the forwarding node's participation using ENS ($\mathfrak{N}_i$) list. The implementation of DLEA and DLEC approach limits the node from draining its energy quickly. This balanced way of picking the reliable forwarders reduces the superfluous energy expenditure. Moreover the DLE function in BMOOR dynamically estimates the node's lifetime and also restricts the nodes issuing their acceptance beyond its own DLE also saves energy. Additionally the quick convergence rate of Bat algorithm identifying the Global best path for data transfer also restricts the energy burning up. As shown in Fig. 8 the energy rapidly increases with the increase in network density. This is due to raised number of nodes participating during Routing or initial population.

In DBR, depth is the only deciding parameter to direct the packet to upper layers. The sensor nodes in same depth having similar holding time forwards the same packet concurrently causing redundancy and excessive energy consumption. Even though EEDBR considers energy and depth as eligible parameters for forwarding, there is a steep increase in energy usage since the nodes having high residual energy is more recurrently used. In

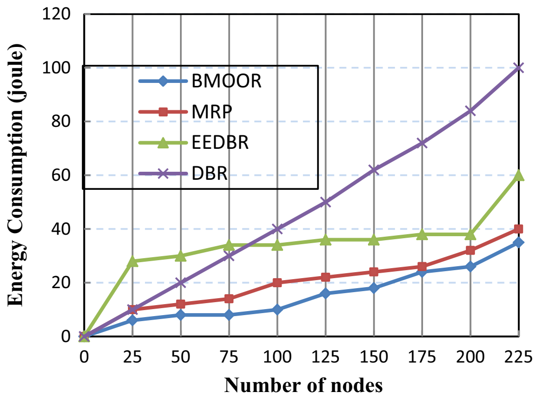



**Fig. 7** Energy consumption against DBR, EEDBR and MRP

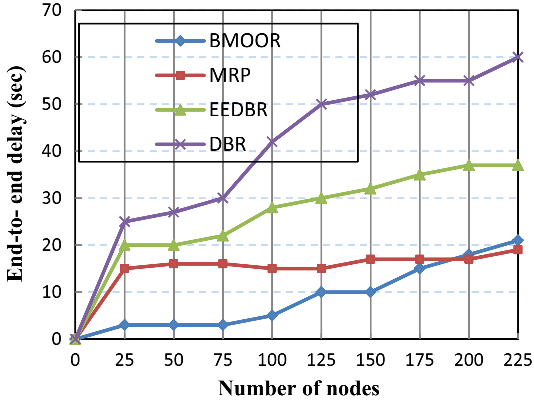



**Fig. 8** End-to-end delay against DBR, EEDBR and MRP

MRP the super nodes spend more energy in broadcasting probe packets during layering phase and also in handling Layer IDs.

### *4.3.3 End- to-End Delay*

Figure 8 shows the association of end to end delay of BMOOR with respect to DBR, EEDBR and MRP. In DBR every sensor holds the data packet based on the depth difference from the node to sink. The holding time is proportional to the depth difference. Hence if the hop count increases in pushing the packet from the source to sink, the holding time in turn increases. This results in increase end to end delay. Even though EBDR eliminates the redundancy compared to DBR, the holding time to assign the priority induces considerable delay with increase in network density.MRP protocol also causes delay in two ways. First the nodes in different layers hold the data till the highest energy node forwards it. Next the super node causes some delay by forwarding it to another super node to reach the sink.

In contrast BMOOR doesn't calculate holding time to avoid collision. The proposed protocol checks the reliability of the node while issuing acceptance and confirms the best node at the upper layer based on EDR. Bat algorithm in BMOOR optimizes the route established by randomly replacing the optimal node with reference to fitness of the Best

Bat. Hence the data is forwarded to the sink in an opportunistic path which reduces substantial delay. The energy harmonizing between the sensor nodes in BMOOR ensures that the data reaches the sink in an optimal path without delay. Even Though little delay is induced due to inquiry of request packets, it is less than the existing protocols, and it considerably increases the delivery ratio.

#### *4.3.4 Delivery Ratio*

Figure 9 shows delivery ratio of all protocols. In DBR the forwarders are chosen based on the depth. Hence the packet reaches the sink in different routes. Even a packet through a particular link fails; the same packet reaches the sink through other routes. Hence the delivery ratio of DBR is better when compared to EEDBR. In EEDBR the packet lost at any hop cannot reach the sink in any other route, since recovery mechanism is not employed. In MRP the super node mechanism improves the delivery ratio than DBR and EEDBR. In BMOOR the delivery ratio is ensured in various ways. The initial beaconing avoids the unnecessary nodes participation through ENS ($\mathfrak{N}_i$). Next the estimation of DLE ensures the reliability of the node based on energy. DLEA decides whether the node can act as an optimal forwarder or not. Further data transfer comes into action after DLEC. The delivery ratio in BMOOR is ensured in the above ways. Additionally in BMOOR the optimization algorithm identifies the global best path dynamically which is also responsible for improved delivery ratio.

### 4.4 Simulation Results Varying the Number of Layers

This Section presents the results of BMOOR for various numbers of layers. The number of layers is taken into account since the performance characteristics get deviated with the increase in layers.

#### *4.4.1 Network Lifetime and Energy Consumption*

Figures 10 and 11 shows the Network lifetime and Energy consumption of BMOOR for various layers.The topology of the network is varied for different number of nodes (25,50,100,150) and layers. When Network lifetime and Energy consumption is considered

**Fig. 9** Delivery ratio against DBR, EEDBR and MRP

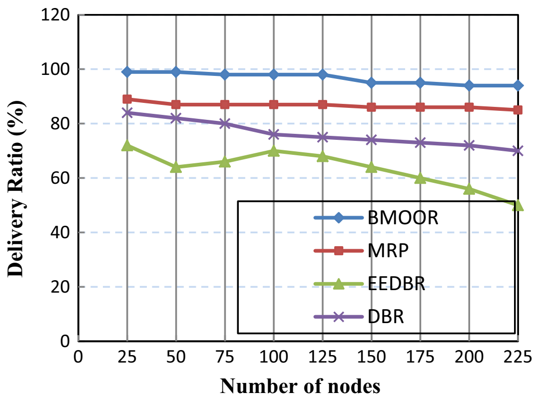


**Fig. 10** Network lifetime for different number of layers

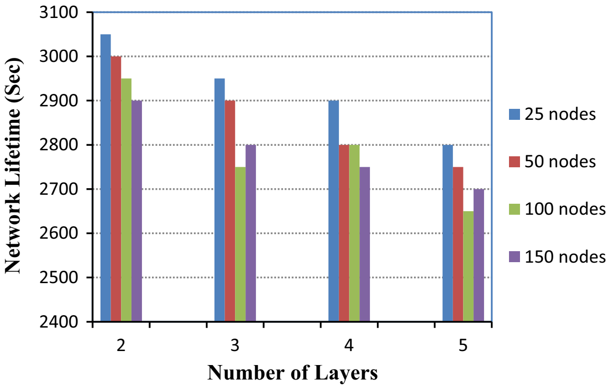
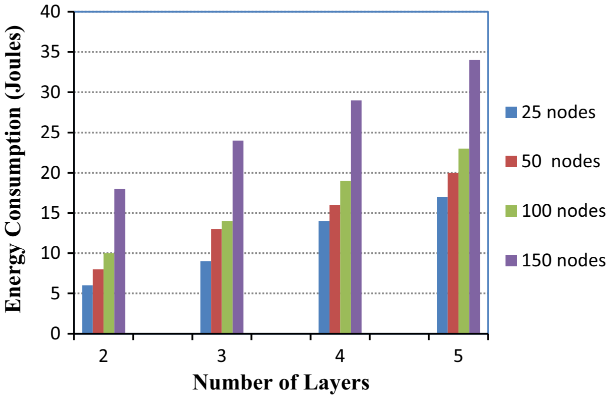



**Fig. 11** Energy consumption for different number of layers




it apparently decreases when the packets raises up to higher layers. The reason is that the nodes consume more energy due to the varied load in the higher layers. Moreover the hop count also keeps increasing while approaching towards the sink.

### *4.4.2 End- to-End Delay and Delivery Ratio*

Figures 12 and 13 shows the End- to-end delay and Delivery ratio of BMOOR for various layers. The topology of the network is varied for various numbers of nodes (25,50,100,150) and layers. In End- to-end delay, it rather increases in upper layers than lower one. But when we discuss about Delivery ratio it outperforms all since the energy of the nodes is balanced through DLE and due to the availability of nodes in the higher layers it guarantees the Delivery ratio. At the same time packet collision is also reduced by opportunistically forwarding the packet through multi-hop.

## 5 Conclusions

In this paper, the proposed protocol BMOOR which belongs to the non spatial routing category chooses the optimal forwarders to forward data to the sink. The forwarders to the sink are inserted into ENS ($\mathfrak{R}_i$). From the inserted list life time estimation is done through

**Fig. 12** End-to-end delay for different number of layers

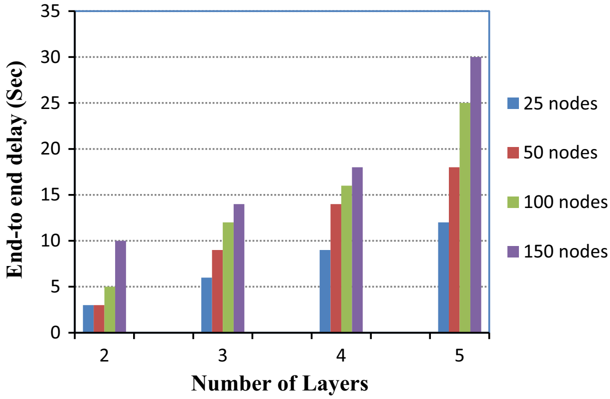
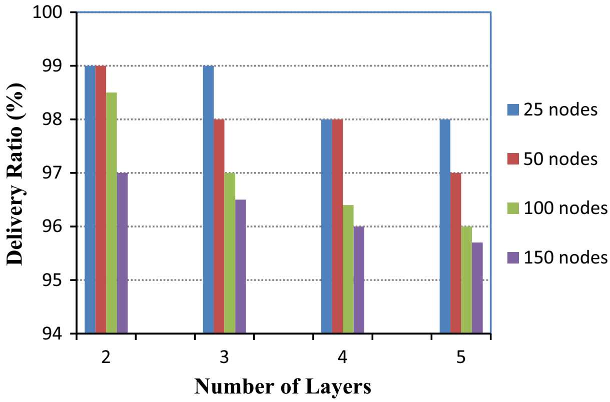



**Fig. 13** Delivery ratio for different number of layers




DLE. Based on the individual node's DLE, DLEA tokens are issued to eligible nodes to act as optimal forwarders. Finally the optimal forwarder is confirmed by DLEC message. With the set of optimal forwarders, possible paths are constructed from source to destination during initial population. The initially populated routes are dynamically optimized using Bat algorithm. The bat algorithm finds the fitness of the initially populated paths and picks the best fitness path. The converged path with excellent fitness is indicated as the best bat. The best bat is iterated with other populated path (bat) till the converged global best path is obtained for data transfer. The results through simulations prove that the proposed method improves the delivery ratio with minimum delay and minimum energy consumption. Simulation results of BMOOR are compared against other representative protocols in UWSN like DBR [22], EEDBR [27] and MRP [40]. The proposed method has shown improved performance in terms of network lifetime, energy consumption, end-to-end delay and delivery ratio. Additionally, in future, enhanced routing for mobile acoustic networks can be considered. The impact of multi sinks with appropriate recovery mechanisms can also be investigated in the future research work.

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