Link Quality Energy Efficient Routing Protocols for Underwater Wireless Sensor Network: A Review

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Summary
Routing in underwater is one of the complicated tasks, the majority of the researchers have designed the many routing protocols for particular applications. This research article classified the novel classification pattern with single-sink underwater routing protocols and multi-sink underwater routing protocols. The operation of routing protocols with merits and limitations is defined in its relevant classification. The performance analysis has been analyzed through novel contribution of parametric and simulation based. From performance analysis it is observed that mult-sink routing protocols performs well as compare to single-sink routing protocols.

Key words:
Single-sink; multi-sink; link-quality; water-depth

1. Introduction

Ocean research is more difficult as compare to terrestrial network because in underwater environment the deployment of the sensor nodes to extract the valuable information from seabed is the complicated task [1-3]. The majority number of issues for designing of routing protocols still needs improvement, some of these issues listed below:

i. Sound speed is 1500 m/sec, so acoustic signal creates the propagation delay. RF signaling is speedy but we cannot use RF signaling in underwater environment.
ii. Multipath fading affects the acoustic signaling, so for designing of routing protocol we have to take care of multipath fading.
iii. Acoustic signaling can also create the noise, so to remove noise from the acoustic signaling is also the challenging task.
iv. Underwater obstacles create the problems for data forwarding and nodes may become the void nodes, due to such kind of obstacles.
v. In underwater environment the devices like sensor nodes or AUVs may be damaged because of corrosion and fouling.
vi. Batteries of nodes have a limited power, so it is hard to recharge the battery in underwater harsh environment.

This research article focuses the link quality and energy efficient routing protocols for underwater wireless sensor network (UWSN). To maintain the link quality between nodes in underwater harsh environment is also one of the complicated task, because environmental conditions of water cannot maintain efficient link between nodes [4-7]. However another major issue is to prolong the battery power of the nodes in underwater environment, because the batteries of sensor nodes cannot easily be recharged in underwater environment due to unavailability of any electric power or ultraviolet light [8-10]. We classified the routing protocol for underwater as shown in Fig. 1.

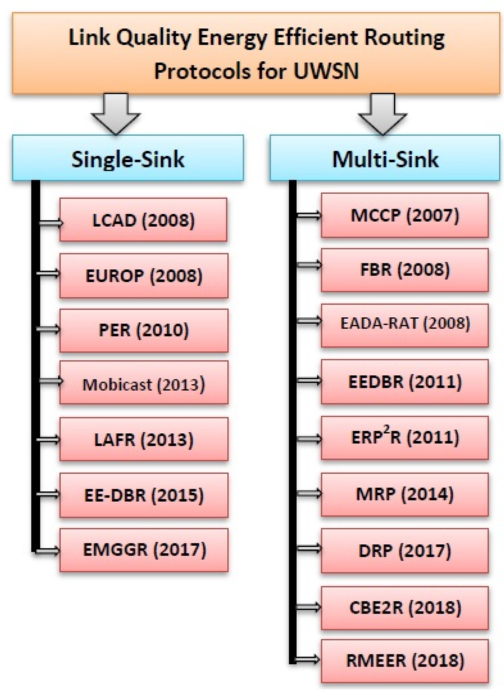

Fig. 1 Classification of UW- LQ-EE Routing Protocols

The main contribution of this review article is mentioned below:

i. Novel classification according to architecture.
ii. Protocol operations with merits and limitations.
iii. Parametric performance analysis.

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iv. Simulation based performance analysis.

The rest of the contents are: section 2 refers the related work, section 3 refers the parametric performance analysis, section 4 refers the numerical simulation performance analysis, and section 5 refers the conclusion.

2. Related Work

2.1 Single-Sink Routing Protocols

Single-Sink routing protocols focuses the deployment of sink (destination node) on the water surface. The operation of single-sink routing protocols is defined as following.

Location-Based Clustering Algorithm for Data Gathering (LCAD)

When data is transmitted between source and sink nodes the major concern is to prolong the battery life of the nodes, if distance increases the energy of the nodes dissipates more, to resolve this issue the LCAD has been proposed which is mentioned in [11]. In LCAD the nodes are deployed in 3D manner with fixed relative depth in the interest area in underwater. The cluster formation through selection of the cluster head node has been adapted for LCAD. For packets forwarding mechanism the horizontal acoustic link is used. To prolong the battery power of the nodes the 500m interest area is used. LCAD process is based on three phases: In setup phase the cluster head node is selected by LCAD, in data gathering phase data is sent to the cluster head node, and in data transmission phase data from cluster head node to AUVs to base station node which is deployed on the water surface. The grid formation structure is mentioned in LCAD and every cluster head node is placed in the center of grid. From the performance analysis of the LCAD it is observed that node mobility and water pressure parameters are not considered by authors which affects the overall performance for average energy consumption because the cluster head node may move due to water pressure and can drop the packets. It is also observed that the grid formation mechanism is also affected due to underwater pressure.

Energy-efficient Routing Protocol (EUROP)

In [12] the EUROP is proposed, this routing protocol is based on pressure factor for measuring the water depth through multiple layers. The authors of the EUROP have avoided the use of hello message due to the overburden on the nodes. EUROP works like AODV. The 3D deployment mechanism is adapted and data forwarding mechanism is based on hop-by-hop. The authors used the electronic module with pressure pump for the nodes, which move the node up and down in underwater. The RREQ and RREP are used between nodes for communication purpose. In EUROP nodes have ability to find the layers with hop count and pressure indicator. The major limitation for EUROP is that it follows the working functionality of the AODV which is purely the terrestrial based protocol. No energy aware based mechanism is adapted by EUROP to prolong the battery power of the node. The designing of electronic module is just imaginary.

Power Efficient Routing (PER)

PER is mentioned in [13] and is based on forwarder nodes selector and tree trimming mechanisms. The use of fuzzy logic and decision tree selects the forwarder node. In PER authors have not used the proper mechanism for energy saving of the nodes and it is also observed that the authors have not taken care of the underwater parameters like water pressure, water current and node mobility which are the major concerns in underwater environment.

Energy Efficient Mobicast

3D Mobiscast is described in [14], in this routing protocol the apple peel mechanism is used to avoid the 3D holes during the data forwarding mechanism. Autonomous Underwater Vehicle (AUV) is used for data forwarding with 3D Zone Of Reference (3D-ZOR). The 3D Zone Of Relevance (3D ZOR3) and 3D Zone of Forwarding (3D ZOF) mechanisms through AUV is used to sense the packets forwarding node. The authors claimed that Mobicast uses the fully distributed algorithm which reduces the power consumption of the nodes. Mobicast has used the AUV based nodes which are much more costly and overall cost of the entire network increases. Mobicast has not used any proper algorithm which saves the energy consumption of the entire network.

Link-state Adaptive Feedback Routing (LAFR)

LAFR protocol is mentioned in [15], this routing protocol refers the adaptive routing feedback and link detection mechanisms for efficient data forwarding from source to sink node. This routing protocol deploys the 3D nodes in underwater environment. The credit-based dynamic routing update mechanism for LAFR reduces the overall energy consumption of the entire network. However this routing protocol performs well in vertical data forwarding but when network becomes sparse then this routing protocol cannot maintain the link between nodes and in resultant the forwarder node will drop the packets which enhance the overall energy consumption.

Energy Efficient Depth Based Routing (EE-DBR)

EE-DBR is mentioned in [16], this routing protocol reduces the multiple redundancy to prolong the battery power of the node. The distance between nodes is measured through geometrical model with directional angle mechanism with Time of Arrival (ToA) mechanism. In EE-DBR there is no any link quality maintained mechanism is used between nodes, even forwarder node may be affected due to water pressure and can drop the packets.

Energy-efficient Multipath Grid-based Geographic Routing (EMGGR)

EMGGR is described in [17], is the position based routing protocol which makes the 3D grid based network in underwater environment which shown in Fig 2. In grid structure every cell comprises its relevant addressing mechanism. In EMGGR the Multipath route selection mechanism is used in between source and virtual cell. The data forwarding functionality of EMGGR is based on four phases: In first phase the virtual cell is selected. In second phase the multipath route is developed between source and virtual cell. In fourth phase the packets are forwarded vertically from source to virtual cell node to sink node and in final phase packets are received by destination. The authors have used the term gateway elected node for source node. EMGGR refers the complicated 3D grid formation mechanism; even due to water pressure EMGGR cannot maintain its link quality.

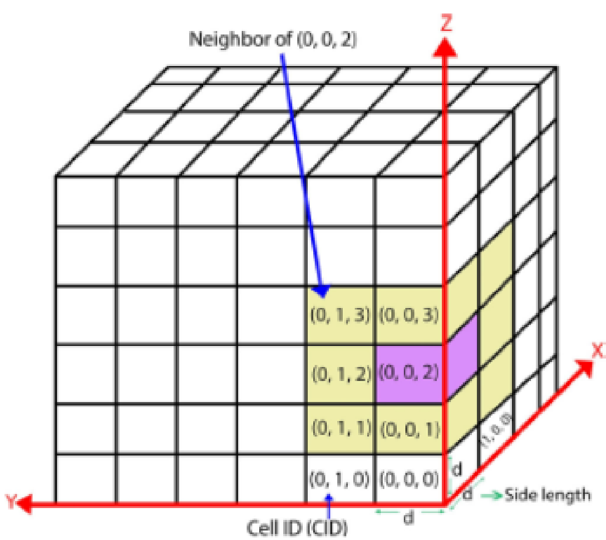

Fig. 2 3D Grid view of EMGGR [7]

2.2. Multi-Sink Routing Protocols

In Multi-Sink routing protocols, the multiple sink nodes (destination nodes) are deployed on the water surface. The operation of multi-sink routing protocols is given below:

Minimum Cost Clustering Protocol (MCCP)

MCCP is described in [18] resolves the problems of node clustering with cluster-centric cost-based optimization. MCCP prolongs the battery power of the nodes with distributed minimum cost clustering mechanism. MCCP balanced the load between cluster head node and cluster member node during formation of the clusters through periodic re-clustering mechanism. MCCP working functionality is based on initialization stage and execution stage. In initialization stage all the nodes including neighbor nodes are set as candidate nodes. In execution stage the 2-hop mechanism with cost centric mechanism is adopted and a node which keeps the minimum cost will become as a cluster head node and all the cluster head nodes collects the data and forward to the uw-sink node, and underwater sink node forward that data to the onshore data center. The functionality of MCCP is good for small area network, if network becomes expanded the MCCP is unable to maintain the link quality between nodes and unable to prolong the battery life of the nodes.

Focused Beam Routing (FBR)

Location based FBR is mentioned in [19]. For data forwarding the multi-hop technique is used. The distributed algorithm is used for packets forwarding with transmission radius through limited number of energy levels. The confine flooding mechanism is used to reduce the energy of the FBR. For link development the Request To Send (RTS) and Clear To Send Signals are used. For packets forwarding between source and destination the cone with angle mechanism is used with power levels to control the energy of the nodes. FBR is based on limited cone development mechanism in underwater environment, however underwater depth and distance is larger than interest area defined by FBR, so in real scenario the FBR cannot maintain its link quality when network is spread according to real scenario. Even FBR cannot prolong the energy level of nodes in real scenario.

Energy Aware Data Aggregation via Reconfiguration of Aggregation Tree (EADA-RAT)

EADA-RAT is mentioned in [20] uses the tree structure based algorithm to connect the underwater sensor and underwater sink nodes. The functionality of the EADA-RAT is based on four steps: In steps one the nodes are propagated in the interest area, in second step, selection of decision node with aggregate function has been selected, third step focuses the reconfiguration of the aggregation tree between nodes and sink, in step four, the data transmission through selected path with assigned time is takes place. EADA-RAT resolves the problem of acoustic signal behavior and energy depletions of the batteries. However the performance of the EADA-RAT is good but underwater environment cannot support the tree structure mechanism, because it is observed that node moves due to water pressure in every two to three seconds, so EADA-RAT in this situation is unable to maintain the link quality between nodes.

Energy Efficient Depth Based Routing (EEDBR)

EEDBR as mentioned in [21] resolves the problem of underwater depth and prolong the battery life of the sensor nodes. EEDBR consists of two phase: phase one refers the knowledge acquisition, under which the hello message is forwarded to the underwater nodes with depth Id and residual energy parameters, if any node which has smaller depth-ID and larger residual energy are used for path selection. Second phase focuses the data forwarding phase, when route is selected in the first phase the data is forwarded from source node to sink nodes. The Depth calculation with depth-ID is the complicated and time consuming which puts the extra burden on node and node will drain its energy very soon.

Energy-efficient Routing Protocol based on Physical Distance and Residual energy (ERP^2R)

ERP^2R is described in [22] is based on Time of Arrival (ToA) technique to calculate the distance from sensor nodes to neighbor nodes. This protocol covers the two phases, in phase one which is knowledge acquisition with residual energy, Hello packet format with fields: Sensor_ID, Sequence number, residual energy, and cost is broadcast by sink node which is deployed on the water surface to all the underwater nodes. When all the nodes will receive this hello packet then every node will calculate its distance and residual energy, the less calculated distance between nodes with high residual energy and least cost will make the route for packets forwarding. In second phase which is the data forwarding phase the packets will be forwarded from source to sink node through developed route as mentioned in phased one. It is observed from the performance analysis for ERP2R, that when network becomes sparse the proposed protocol cannot maintain its link quality and energy efficiency.

Multi-layer Routing Protocol (MRP)

MRP is given in [23] is based on the use of super nodes and layer formation mechanisms around the super nodes mechanisms. The super nodes are the powerful nodes which prolongs the battery power of the ordinary nodes. The super nodes are deployed in upper and lower depth of the water. Layers are formed with layer_Id mechanism around the super nodes. The higher depth super nodes collect the data packets from the source nodes. Source node will forward the data packet with its own layer_Id, the receiving node compare its layer_Id with sender layer_ID, if receiving node layer_ID is higher than sender layer_ID, it simply drop the packets. Otherwise the receiving node will compute the holding time with residual energy. The higher depth nodes will receive the packets and will forward the packets to lower depth super node and lower depth super node will further forward these packets to the sink nodes. The authors have used the 2D deployment with static super nodes. The performance of the MRP is good but when node calculated the holding time, so this complicated calculation mechanism puts the extra burden on the node and in resultant the node will die earlier.

Energy-efficient Distance Routing Protocol (DRP)

DRP is described in [24] s based on the distance collision probability mechanism for route selection. DRP avoids the collision between nodes issue. Sink nodes which are deployed on the water surface forward the HELLO packet periodically with residual energy for suitable route selection. The multipath route selection mechanism has been adapted between source to sink nodes for packets forwarding. The energy efficient route selection mechanism is adapted by DRP for packets forwarding. The performance analysis of DRP is based on limited nodes, if nodes are increase the performance in terms of link quality and energy efficiency will be affected.

Clustered-based Energy Efficient Routing (CBE2R)

CBE2R as mentioned in [25] is based on layer formation and cluster development mechanisms. The layer formation mechanism controls the water depth whereas the use of courier nodes reduces the average energy consumption of the entire network. The static courier nodes are deployed in seven layers and ordinary nodes are deployed at the seabed level (in layer seven to seabed), source nodes are deployed at seabed level, the seven layer courier nodes forms the cluster of neighbor nodes with weight value mechanism and route is developed between source to courier nodes through low weight value mechanism. Layer seven courier nodes collects the data packets through cluster formation with low weight value from source to ordinary nodes and forward them to the sink nodes by using the maximum power levels through layered courier nodes. It is observed that the performance of the CBE2R is not reasonable when network becomes sparse.

Reliable Multipath Energy Efficient Routing (RMEER)

RMEER is mentioned in [26], it is observed that the functionality of RMEER resemble with the CBE2R, only the modification is that, RMEER develops the multipath route development at layer seven courier nodes to seabed source nodes. The optimal energy efficient route selection mechanism is adapted for packets forwarding from source to courier nodes and from courier to sink nodes which are deployed at sea surface. The performance of RMEER is not reasonable when network becomes sparse.

3. Analysis through parameters

Analysis through parameters is mentioned in Table 1, and Table 2. The parameters are selected through protocol operations.

Table 1: Single-Sink routing protocols parametric performance

Routing Protocol	Year	Single/Multiple copies	Hop-by-hop/end-to-end	Multipath	Hello/Control Packet	Requirement and Assumptions
LCAD	2008	Single-copy	Hop-by-hop	×	yes	Network with special H/W
EUROP	2008	Single-copy	Hop-by-hop	×	yes	Network with special setup
PER	2010	Single-copy	Hop-by-hop	v	yes	Geo, location information
Mobicast	2013	Multiple-copies	Hop-by-hop	v	no	Depth information
LAFR	2013	Single-copy	End-to-end	v	no	n/a
EE-DBR	2015	Single-copy	Hop-by-hop	v	no	Depth directional information
REEP	2015	Single-copy	End-to-end	×	yes	Depth information
EMGGR	2016	Single-copy	Hop-by-hop	v	no	Depth information

Table 2: Multi-Sink routing protocols parametric performance

Routing Protocol	Year	Single/Multiple copies	Hop-by-hop/end-to-end	Multipath	Hello/Control Packet	Requirement and Assumptions
MMCP	2007	Single-copy	Hop-by-hop	v	yes	n/a
FBR	2008	Single-copy	Hop-by-hop	×	yes	Geo, location is available
EADA-RAT	2008	Multiple-copies	Hop-by-hop	v	no	Geo, location is available
EEDBR	2011	Multiple-copies	Hop-by-hop	v	yes	Depth information
ERP²R	2011	Multiple-copies	Hop-by-hop	v	yes	n/a
MRP	2014	Multiple-copies	Hop-by-hop	v	yes	Depth information
DRP	2017	Single-copy	Hop-by-hop	v	yes	Depth information
CBE2R	2018	Multiple-copies	Hop-by-hop	×	No	Depth information
RMEER	2018	Multiple-Copies	Hop-by-hop	v	Yes	Depth information

4. Analysis through simulation

The analysis through simulation is considered by use of NS2.30 with AquaSim simulator. The simulation parameters are set in Table 3.

Table 3: NS2.30 Simulation parameters

Parameters	Values
Network Size	1500m x 1500m x 1500 m
No. of Nodes	350
Surface to bottom layer distance	250m
Data Packet size	64 byte
Initial Energy	70 J
MAC Protocol (Shin & Kim, 2008)	802.11-DYNAV
Energy consumption for transmitting	2w
Energy consumption for receiving	0.75w
Energy consumption for idle listening	8mw
Transmission range	100 m to 150 m
Surface sink distance difference	100 m
Number of layers	7
Number of courier nodes	49
Simulation time	1000 sec

In simulation results we have only simulated the average energy consumption of the nodes for single-Sink and multi-Sink routing protocols.

Average Energy Consumption of Single-Sink Routing Protocols.

Average energy consumption for single sink routing protocols are shown in Fig. 3.

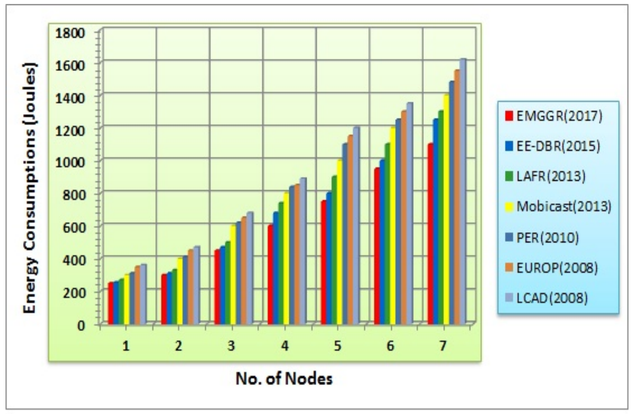

Fig. 3 Energy consumption of single-sink routing protocols

In Fig.3, the energy consumption of the EMGGR is lower than other protocols because EMGGR is based on 3D grid formation mechanism with multipath route development through grid cells_ids. The battery power of the nodes consumes less energy due to small interest area.

Average Energy Consumption of Multi-Sink Routing Protocols.

The energy consumption of the multi-sink routing protocols is shown in Fig. 4.

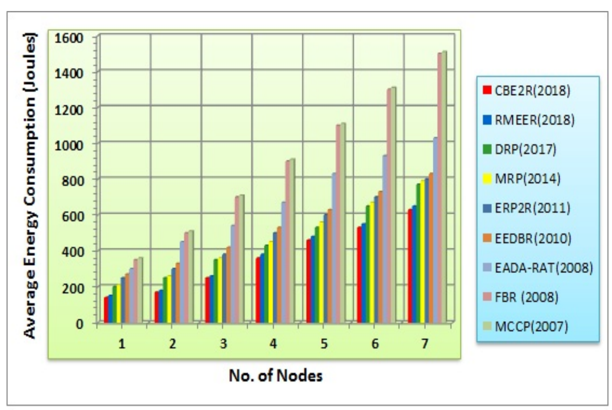

Fig. 4 Energy consumptions of multi-sink routing protocols

In Fig. 4, the energy consumption of CBE2R is lower than other proposed multi-sink routing protocols because the use of courier nodes and depth controlling through layers mechanism reduces the energy consumption of CBE2R. The weight value mechanism of CBE2R also maintains the link quality.

5. Conclusion

This review article focuses the operation of the single-sink and multi-sink routing protocols. In single-sink routing protocols the operation of each protocol is defined with its merits and limitations. In same way the operation with merits and limitations are also described for multi-sink routing protocols. The parametric performance analysis through unique parameters is also shown in this paper. The simulation performance analysis considered the NS2.30 simulator to show the average energy consumption of single-sink and multi-sink routing protocols. It observed from the simulation responses that multi-sink routing protocols perform well as compare to single-sink routing protocol.

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