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Energy Efficient Routing Protocols for UWSN: A Review

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Abstract

The Underwater Sensor Network (UWSN) is main interesting area due to its most valuable applications like: disaster preventions, distributed tactical surveillance, undersea exploration, seismic monitoring, environmental monitoring and many more. The design of energy efficient routing protocol however is a challenging issue because in underwater environment the batteries of the sensor nodes cannot be recharged easily. Majority of the researchers have adapted the terrestrial WSN methodologies to overcome this problem but in underwater environment the terrestrial WSN approach is not feasible due to the acoustic signaling and water current. This research paper focuses the key limitation of the current energy efficient routing protocols. The simulation results with comparative analysis for energy efficient routing protocols are also presented in this research article; which helps the researchers to find the further research gap in the field of energy efficient routing protocols.

Keywords*: deployment, sink node, onshore data center, data forwarding, localization*

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1. Introduction

In last few years the underwater wireless sensor networks (UWSNs) have gained a lot of interest in the field of research due to its well interesting and versatile applications likes: seismic monitoring, environmental monitoring, and distributed tactical surveillance, under sea exploration, assisted navigation, and scientific exploration and disaster preventions. The underwater equipments such as underwater sensor nodes, Acoustic Underwater Vehicles (AUVs) and underwater modems with acoustic channel, have made communication possible in the underwater environment. Underwater sensor nodes are able to transmit the important data with their sensing capabilities within the short distance [1-3]. The underwater sensor nodes are composed of sensing unit, acoustic modem, processing unit, communication unit and power unit. The sensing unit measures the physical conditions like temperature and the pressure Acoustic modem is responsible to convert the RF signal into acoustic signaling while processing unit is responsible to process the data and converting it into the required signaling form [4]. The communication unit will transfer the data to the acoustic modem. All the discussed units have need for power and the power unit is responsible to supply the required energy to all these units to perform the task in underwater environment. The environment may consist hundreds or thousands sensor nodes that have the ability to communicate either each other or directly to the base station or sink nodes that are deployed on the surface of the water [5]. Majority of the researchers have given feasible algorithms, deployment methodologies, different architectural structures as well as data forwarding mechanisms to save the energy level of the sensor nodes; but due to the underwater environmental conditions and some delay factors, the underwater sensor nodes cannot maintain their power levels and the the power supply deplete earlier [6]. This research paper focuses the deployment mechanism, data forwarding mechanism and route mechanism, route maintenance mechanism and energy efficient mechanism of the different energy efficient routing protocols for underwater environment. The critical view of the issues present in the energy efficient routing protocols for underwater wireless sensor networks will guide researchers for further research study. The comparative analysis of the research may also guide researchers to find the gap in the designing of the energy efficient routing protocols for underwater sensor network.

This research paper is consists of: background and literature review with limitations, results and analysis, and conclusion.

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2. Background and Literature Review

There are several energy efficient routing protocols for underwater wireless sensor networks. This review focuses on the current protocol as depicted in Figure 1.

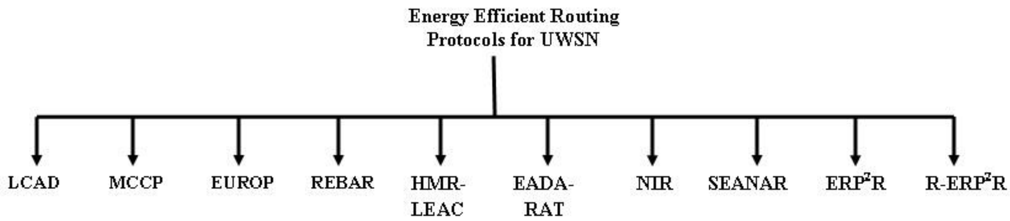

Figure 1. Classification of Energy Efficient Routing Protocols for UWSN

2.1. Location-Based Clustering Algorithm for Data Gathering (LCAD)

2.1.1. Protocol Operation

The authors of this research paper have suggested that a 3D girds network structure for LCAD routing protocol [7]. The size of each gird has been adapted in 3D form measured in meters as 30×40×50. Authors have suggested communication structure in terms of three phases: (i) transmission, (ii) data gathering, and (iii) setting up. In transmission phase, the data is collected through clustered head and can be delivered with the help of Autonomous Underwater Vehicles (AUVs) to the base stations. In data gathering phase the data are transferred with the help of the sensor nodes to the clustered heads. Setting up phase will select the proper cluster.

The authors further classified the network with two key elements that are C_NODE and C_HEAD (Cluster Node and Cluster Head). The C_NODE has extra energy power and memory; which is the qualifier of C_HEAD, and is placed at the center level of each gird. The ordinary sensor nodes are around the C_NODE makes clusters.

AUVs will collect the data from C_HEADS instead of ordinary sensor nodes. The authors have set the acoustic link around 500m only. The authors have also adapted the number of tiers approach on highest and lowest level. They settled the highest level tiers approach for dense deployment and lowest for the sparse deployment; through this approach the authors claimed that that they are getting the overall best results.

The proposed technique resolves the two issues: (i) energy dissipation during transmission versus distance between sender and receiver and (ii) energy drain due to multi-hop approach from source to sink node.

2.1.2. Limitations of LCAD

1. The results of the LCAD are measured in terms of terrestrial deployment of sensor nodes; in real scenario this kind of simulation is not suitable for underwater environment and no any kind of proper energy methodology has been defined.
2. The behavior of node movement according to the deployment regions; focuses that node can drop the packets frequently and will lose the battery life immediately.

2.2. Minimum-Cost Clustering Protocol (MCCP)

Minimum-Cost Clustering Protocol (MCCP) is a technique which focuses on node clustering problem in underwater environment [8]. The authors of this research paper claimed that MCCP is competence to improve the energy efficiency and prolong the network life time. The MCCP technique focuses the solution of three major parameters that are: (i) total energy consumed by cluster members for sending data to cluster head, (ii) residual energy of cluster member and cluster head, and (iii) relative location between cluster head and sink node. The authors have focused firstly, the minimum-cost clustering algorithm (MCCA) and secondly, the minimum-cost clustering protocol (MCCP) to solve the problems. The authors claimed that they have considered the node clustering problem as cluster-centric cost-based optimization problem [8].

MCCP distributed approach works according to following steps:
1. All the nodes are cluster-head candidates and cluster member candidates.
2. Cluster-head candidate with neighbor nodes forms a cluster.
3. Cost of formed cluster can be calculated through cost metric parameters.
4. Computed cluster with its cost metric and cluster-head node broadcast two hop neighbors.

2.2.1. Limitations of MCCP
1. The authors have used the energy model as described in [9] is not suitable for this kind of architecture.
2. The time period of re-clustering will affect the battery life of ordinary sensor nodes.

2.3. Energy-Efficient Routing Protocol (EUROP)
EUROP used pressure factor as a substantial indicator for sensor nodes to sense the depth of water according to multiple layers. The authors claimed that the designing of EUROP reduces the broadcast *hello messages* and hence decreases the total energy consumption [10]. The EUROP simulation efficiency has been compared with the terrestrial AODV routing protocol.

The authors have focused the hop-by-hop approach for data forwarding in 3D water environment. Nodes are deployed at the bottom level of depth water and every node is equipped with the electronic module that can be bloated by a pump, this electronic module can push the node towards surface level of water and can back again to its original position. The nodes which are deployed at the bottom level of the water are eligible to make the different layers according to the depth of water. The nodes used *REQ* and *REPL* packets pattern for communication purpose. The different layers are recognized by the sensor nodes with hop count and pressure indicator.

2.3.1. Limitations of EUROP
1. In depth finding mechanism the majority number of packets can be dropped and automatically will affect the network resources and will drop the energy level of the ordinary sensor node.

2. Designing of electronic module will increase the cost of sensor node and extra burden will reduce the life of the sensor node.

2.4. Reliable and Energy Balanced Routing Algorithm (REBAR)
In this research paper the authors have analyzed the energy consumption through sphere energy depletion model and extended energy depletion model (for node mobility).

2.4.1. REBAR Energy models
The REBAR has used the two energy models; (i) sphere energy depletion model, and (ii) extended energy depletion model; which show the distance between sink to ordinary nodes in different tiers.

In REBAR the sink node is fixed at the center of surface and every node knows its location and sink will assign a unique ID number. Every node will transfer the packets to sink through hop-by-hop routing. The transmission range of nodes is fixed to *R*. The size of the broadcast is the serious concern. The nodes broadcast mechanism may cause the high energy consumption. The broadcast issue relates with the size of the broadcast. If the broadcast size is high, it requires more energy and if the broadcast size is low, then less energy consumption is required. The REBAR has solved this issue to keep the broadcast size on balanced level.

2.4.2. Limitations of REBAR
1. REBAR focuses the data delivery ratio increases with respect to node movement but in real scenario the enhancement of data delivery ratio is not possible because the nodes behavior in underwater environment is not controllable.

2. Horizontal and vertical node movement methodology is not clearly defined; so obviously packets drop ratio increases and results into the reduction of the overall network throughput.

3. Removal of void regions are just hypothesis and this may also reduce the data delivery ratio.

2.5. Hierarchical Multipath Routing-LEACH (HMR-LEACH)

HMR-LEACH proposed by [11] is the advancement in terrestrial LEACH protocol. The authors have employed HMR-LEACH algorithm to save energy level of the sensor nodes during the path transmission mechanism. Authors claimed that HMR-LEACH algorithm reduces the single path to energy depletion phenomena, and thus extends the network life time.

HMR-LEACH use 2D deployment of sensor nodes with covering area of 100m×100m with dynamic deployment of the sensor nodes. The authors have considered the same energy level of the all the sensor nodes with unique ID number and also considered the nodes coordinate system according to the position calculation with respects to the node movement. HMR-LEACH considered the static base station with unlimited battery power. It also considered the adjustment of the node transmission power according to the bi-directional connectivity and communication distance. HMR-LEACH also considered the multi-hop mechanism for those nodes which are far from the base station; through this mechanism the energy level of the far nodes are maintained.

As for routing algorithms, the authors proposed HMR-LEACH for the construction of the nodes cluster mechanism. The authors have divided the HMR-LEACH algorithm into two phases: (i) Multipath establishment process, and (ii) path selection process. The authors have used the color-coded communication model for the transmission of controlled packets from sink node to the base stations by formation adjacent clusters and non-adjacent clusters.

2.5.1. Limitations of HRM-LEACH

1. HRM-LEACH formation of clusters is just hypothesis in real scenario this kind of formation is not valid for underwater environment because the sensor nodes continuously changes their positions.
2. Simulation results are based on terrestrial networks and terrestrial network parameters are not valid for underwater environment.
3. No any localization based algorithm has been considered by authors; even the methodology purely focused the localization procedures.
4. Energy efficient model is also defined for authors which is only suitable for terrestrial network.

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

EADA-RAT proposed by [12] has been designed to overcome the problems: (i) acoustic signal behavior in underwater environment reduced the network throughput due the latency in transmission with low propagation speed, and (ii) the batteries of the sensor nodes cannot be easily charged in underwater environment; so energy consumption of sensor nodes must be under consideration.

The EADA-RAT protocol designing mechanism is based on the tree structure with the performance of the data aggregations. The data aggregation tree uses the dynamic pruning and grafting functions with the changing of routing paths by computing the aggregation count and minimum residual energy of the sensor nodes [12]. The technique adapted by authors is that each sensor node(s) knows the location of the parent and child nodes with the assigning of the unique ID to each sensor node(s). The authors have divided the operation of the EDA-RAT into four phases. First phase focuses the interest propagation of the sensor nodes; second phase is for the selection of the decision node; third phase is for the reconfiguration of the aggregation tree and the last phase is for data transmission phase with time expire factor. For selection of the decision node the authors have developed the DN-Algorithm and for reconfiguration aggregation tree they have used the RAT-Algorithm.

2.6.1. Limitations of EADA-RAT

1. Node selection mechanism through tree structure is complicated and is not suitable for underwater environment because in underwater environment the nodes can change their position within 2 to 3 seconds.

2. DN-Algorithm's calculation mechanism is not as easy as described by authors because the underwater environmental parameters cannot support such kind of calculation mechanism.

3. Tree aggregation mechanism cannot remove the void regions and in resultant the majority number of packets can be dropped and overall data delivery ratio may be reduced.

2.7. Node Information Routing (NIR)

NIR routing protocol as described in [13]; used the hierarchical network model with assumptions that include: sensor nodes are randomly deployed in underwater domed area, sink nodes are deployed from surface to middle of the water in fixed way, sensor node(s) knows the coordinates of the sink nodes, the sensor nodes sends the data packets to the sink nodes with multi-hop technique, every node can knows their coordinates via GPS system, nodes are isomorphic, every node has their own unique ID and every node keeps the fixed range (*R*).

The authors of the NIR have used the sphere energy consumption model like a REBAR. The NIR has used the single path Greedy Forwarding (GF) for saving the energy level of the sensor nodes. The GF algorithm is based on the weight of the neighbor node; if neighbor node has a highest weight than node can transfer the packets to that neighbor node. The highest weight calculation means the node nearer to the sink node keeps the highest weight.

2.7.1. Limitations of NIR

1. The weight calculation mechanism is not based on removal of void regions because if the void regions are created; the sensor nodes will continuously drop the packets and resultant these nodes will die earlier and data delivery ratio will be reduced.

2. The sphere energy consumption model is not fully described by authors for their selected energy parameters.

3. The network architecture defined by authors will create a localization problem with respect to the deployment of the sensor nodes.

2.8. Energy-Efficient and Topology-Aware Routing Protocol (SEANAR)

SENAR is energy-efficient and topology-aware routing protocol for underwater wireless sensor network [14]. The authors of this routing protocol have adapted the greedy approach like NIR routing protocol. SENAR is based on topology information and degree information of neighboring nodes for making the routing decisions. The network model of SENAR is based on sensor nodes sparsely deployed in the fixed area of the underwater with 3D manner. SENAR has considered the 2D horizontal freely movement of the homogenous nodes and slightly movement of the nodes towards vertical direction. Also it considered the stationary and fixed sink nodes at the center of the surface. Each sensor node sends the packets to the sink node by using the multi-hop techniques. The transmission range of sensor nodes is fixed (R).

In SENAR, the selection of the neighbor nodes for packets sending is based on higher weight calculation as described by [13]. SENAR also adapted the same energy model like REBAR and NIR. SENAR divided the neighbor nodes accordingly to the layered energy model as: inner neighbor nodes, aside neighbor nodes and farther away neighbor nodes. The position of these neighbor nodes is based on the layer position towards sink node. The neighbor node can send the data packets to other nodes on arrival of hello message with layer position and calculation of higher weight neighbor position with multi-hop pattern towards the sink node.

2.8.1. Limitations of SENAR

1. The higher node weight calculation mechanism defined by SENAR is not feasible in underwater water environment because the underwater parameters are not taken in calculation mechanism.

2. Layered energy model with different classification of neighbor nodes creates a problem; because if the maximum number of nodes are farther the sink node due to water movement; means these nodes cannot able to transfer the packets and in resultant they will drop the packets continuously and automatically will lose their energy levels and die earlier.

2.9. Energy-Efficient Routing Protocol based on Physical Distance and Residual Energy (ERP^2R)

The authors of ERP^2R [15] have explained the novel idea of utilizing the physical distance of the sensor nodes towards sink node. The network model of ERP^2R is based on the sink nodes; which are deployed on the water surface and ordinary sensor nodes which are deployed from surface to underwater region. The authors have proposed the Time of Arrival (ToA) approach to calculate the physical distance from sensor to neighbor nodes. The mechanism of ERP^2R is based on two phases: (i) cost estimation phase with knowledge of acquisition of residual energy, and (ii) data forwarding phase [15].

The first phase is based on *Hello* message with field: SensorID, Sequence number, Residual energy and cost. When sink node broadcast the *Hell*o message, then each neighbor node will receive this message format and will calculate the distance; the link will be developed with those neighbor nodes which have less distance and also the residual energy of less distance nodes' are taken in account.

In second phase; when the path link developed between sensor, neighbor and sink nodes by physical less cost calculation mechanism with residual energy; then the data packets will be transferred from source to sink nodes.

2.9.1. Limitations of ERP^2R

1. In ERP^2R physical path calculation mechanism is not clearly defined.
2. When nodes enter in sparse area than data forwarding mechanism defined by authors is purely failure because proper data forwarding methodology is not defined.
3. It is greater chance that in such kind of path calculation mechanism the majority number of same sensor nodes involved in less physical distance path mechanism; so ultimately they will reduce their energy level and will die earlier, may be for further transmission mechanism these nodes will not involve and will drop their packets. In this case the data delivery ratio will be affected.

2.10. Reliable Energy-Efficient Routing Protocol based on Physical Distance and Residual Energy (R-ERP^2R)

R-ERP^2R proposed by [16]. The authors of R-ERP^2R have considered the physical distance calculation parameter to calculate the distance between the sensor nodes and sink nodes and a balanced energy level of the sensor nodes. The architecture of R-ERP^2R is based on sink nodes which are deployed on the water surface and are connected through RF signaling with the onshore data center; the sensor nodes are deployed in the deployment region of the water and are connected with the acoustic signaling with each other and with sink nodes. The protocol operation is based on three phases: in phase one initialization phase the sensor nodes have responsibility to calculate the physical distance and the Expected Transmission Count (ETX) with respect to share the residual energy information among the neighbor nodes. Second refers the data forwarding phase with cost calculation among the source and sinks nodes. Third phase refers the cost updating and maintenance phase; this phase updates periodically the ETX, residual energy information and physical distance. The authors have considered the calculation of ETX parameter based on the forward delivery ration and reverse delivery ratio between the two linked nodes. Every node has a responsibility to calculate the ETX, physical distance and residual energy information. Physical distance calculation based on the Hello message and Time of Arrival (ToA) mechanism. When every node knows the ETX, physical distance and residual energy; then they will forward their data packets towards the sink nodes.

2.10.1. Limitations of R-ERP^2R

1. Physical path calculation mechanism is not clearly defined.
2. The authors are forwarding the data through hop-by-hop mechanism but they have not mentioned in in their research paper.
3. Majority number of packets may be dropped when sensor nodes come in the void region areas because removal of void regions are not considers by authors.

3. Results and Analysis

The performance analysis is based on analytical method and numerical simulation method. Table 1 focuses the analytical method of energy efficient routing protocols under which we analysed the different characteristics parameters based on architecture like: single or multiple sink nodes, hop-by-hop or end-to-end, single or multiple copies, cross or non-cross layer, hello or control message, and localization needed. The characteristic parameters we have derived from the protocol operations. Numerical simulation method focuses the comparison of protocols through energy consumption parameter measured in joules. Table 2 focuses the simulation parameters used by NS2.30 with AquaSim simulator. Figure 2 focuses the number of nodes versus energy consumption of the proposed routing protocols. From the analysis ERPPR and R-ERPPR consumes the less energy as compare to other proposed routing protocols as shown in Figure 2

Table 1. Analysis of Energy Efficient Routing Protocols Through Characteristic Parameters

Protocol	Single or Multi-Sink	Hop-by-Hop/End-to-End	Single or Multiple Copies	Cross-layer/ Non-Cross layer	Hello Message	Localization Needed
LCAD	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	×
MCCP	Multi-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	√
EUROP	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	√
REBAR	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	×	√
HMR-LEACH	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	√
EADA-RAT	Single-Sink	End-to-End	Single	Non-Cross-Layer	√	×
NIR	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	√
SEANAR	Single-Sink	Hop-by-Hop	Single	Non-Cross-Layer	√	√
ERP^2R	Multi-Sink	Hop-by-Hop	Multiple	Non-Cross-Layer	√	×
$R\text{-}ERP^2R$	Multi-Sink	Hop-by-Hop	Multiple	Non-Cross-Layer	√	×

Table 2. Simulation Parameters used by NS2.30

N/W Size (meters)	240x240x120
Communication range	30 meters
Node speed	0-2 m/s
Node Velocity	0-2√2 m/s
Sink node fixed at meters	120x120x120
Node Broadcast period	25 sec
Initial Clock	30 sec
Initial Energy of node	1000 J
Sending Energy cost	60 µJ/bit
Receiving energy cost	3 µJ/bit
Length of data packets	100 bits

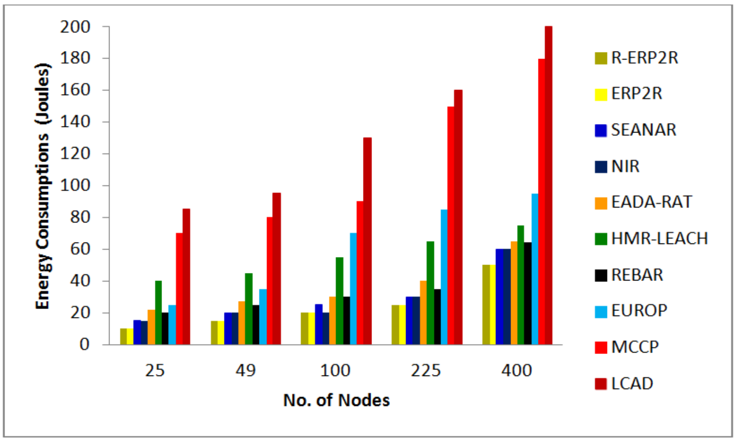

Figure 2. Number of Nodes Versus Energy Consumption

4. Conclusion

This research article focuses the energy efficient routing protocols for underwater wireless sensor network. The main purpose of this article is to elaborate the protocols operations with its designed architecture, route discovery, route maintenance, data forwarding, and energy consumed by sensor nodes. The limitation of proposed protocols will guide the researchers to further research in the field of routing protocols. This research article further focuses the analytical analysis method and numerical simulation analysis method. In numerical simulation method we observed that the ERP^2R and $R\text{-}ERP^2R$ consumes the less energy as compare to rest of the proposed routing protocols which shows that these protocols have used the reliable methodology for energy efficiency.

References

[1] M Ahmed, M Salleh. Localization schemes in Underwater Sensor Network (UWSN): A Survey. *TELKOMNIKA Indonesian Journal of Electrical Engineering.* 2015; 17.

[2] MZ Abbas, KA Bakar, MA Arshad, M Tayyab, MH Mohamed. Scalable Nodes Deployment Algorithm for the Monitoring of Underwater Pipeline. *TELKOMNIKA (Telecommunication Computing Electronics and Control).* 2016; 14: 1183-1191.

[3] N Bahrami, NHH Khamis, A Baharom, A Yahya. Underwater Channel Characterization to Design Wireless Sensor Network by Bellhop. *TELKOMNIKA (Telecommunication Computing Electronics and Control).* 2016; 14: 110-118.

[4] M Ahmed, M Salleh, MI Channa. Critical Analysis of Data Forwarding Routing Protocols Based on Single path for UWSN. *International Journal of Electrical and Computer Engineering (IJECE).* 2016; 6.

[5] G Han, J Jiang, N Bao, L Wan, M Guizani. Routing protocols for underwater wireless sensor networks. *Communications Magazine, IEEE.* 2015; 53: 72-78.

[6] N. Li, JF Martínez, JM Meneses Chaus, M Eckert. A Survey on Underwater Acoustic Sensor Network Routing Protocols. *Sensors.* 2016; 16: 414.

[7] K Anupama, A Sasidharan, S Vadlamani. *A location-based clustering algorithm for data gathering in 3D underwater wireless sensor networks.* In Telecommunications, 2008. IST 2008. International Symposium on. 2008: 343-348.

[8] P Wang, C Li, J Zheng. *Distributed minimum-cost clustering protocol for underwater sensor networks (UWSNs).* In Communications, 2007. ICC'07. IEEE International Conference on. 2007: 3510-3515.

[9] EM Sozer, M Stojanovic, JG Proakis. Underwater acoustic networks. *Oceanic Engineering, IEEE Journal.* 2000; 25: 72-83.

[10] CH Yang, KF Ssu. *An Energy-Efficient Routing Protocol in Underwater Sensor Networks.* Proceedings of the Third International Conference on Sensing Technology. 2008: 114-118.

[11] G Liu, C Wei. *A new multi-path routing protocol based on cluster for underwater acoustic sensor networks.* In Multimedia Technology (ICMT), 2011 International Conference on. 2011: 91-94.

[12] H Nam, S An. *Energy-efficient routing protocol in underwater acoustic sensor networks.* in Embedded and Ubiquitous Computing, 2008. EUC'08. IEEE/IFIP International Conference on. 2008: 663-669.

[13] J Yifeng, S Lin. *NIR: UWSN Routing Protocol Based on Node Neighbor Information.* In Future Information Technology and Management Engineering (FITME), 2010 International Conference on. 2010: 219-222.

[14] X Wu, G Chen, J Chen. *Energy-efficient and topology-aware routing for underwater sensor networks.* in Computer Communications and Networks (ICCCN), 2010 Proceedings of 19th International Conference on. 2010: 1-6.

[15] A Wahid, S Lee, D Kim. *An energy-efficient routing protocol for UWSNs using physical distance and residual energy.* In OCEANS, 2011 IEEE-Spain. 2011: 1-6.

[16] A Wahid, S Lee, D Kim. A reliable and energy-efficient routing protocol for underwater wireless sensor networks. *International Journal of Communication Systems.* 2014; 27: 2048-2062.