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Survey on Network Architecture with Hierarchical Routing Protocols for UWSN

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Abstract: Recently Underwater Wireless Sensor Network (UWSN) is a most interesting area for the researchers due to its well interesting applications. The sensor node is responsible for extract the valuable information from the bottom of the sea and explores that information with different applications like: mine reconnaissance, offshore exploration, disaster prevention assisted navigation and tactical surveillance. This study presents the several key aspects like generalized network model which focuses on the deployment of the sensor nodes, acoustic channel characteristics and underwater network metrics. This study also presents the methodologies used in hierarchical routing protocols based on architecture for underwater wireless sensor network. This research study also focuses the major issues with the hierarchical routing protocols. The well-defined evolution methods of this research study will help the researchers do further research in the field of routing protocols for underwater wireless sensor network.

Key words: Mobility, hierarchical, clustered, deployment, sink node

INTRODUCTION

The surface of earth is covered with 70% water and the valuable application based information is placed in underwater environment (Ansari *et al*., 2015; Ilyas *et al*., 2015; Javaid *et al*., 2015). The underwater applications based information has attracted the research community to further research in the field of Underwater Wireless Sensor Network (UWSN) (Ansari *et al*., 2015; Ali *et al*., 2015; Jain *et al*., 2015). Now the research community is involved to enhance the research on Medium Access Control (MAC) layer and network layer (Kiran *et al*., 2015; Shen *et al*., 2015). Majority of the researchers are well interested to enhance the research on network layer because the valuable information can be extract by the sensor nodes with deployment and route discovery is really one kind of the challenging issue (Javaid *et al*., 2015). The research community have introduced the majority number of the routing protocols; some are vector based routing protocols, some are directional flooding, some are hop-by-hop based, some are clustered based, some are geographic and some are hierarchical based routing protocols (Jain *et al*., 2015; Umar *et al*., 2015; Wahid *et al*., 2014a, b; Ibrahim *et al*., 2014; Climent *et al*., 2014). This survey study focuses the general overview of the networks architecture for underwater, network metrics, acoustic channel limitations and architectural issues of hierarchical routing protocols. This study will guide to the research community to explore the network problems for underwater environment and to do further research in the hierarchical based routing protocols.

Underwater Wireless Sensor Network (UWSN) applications: Underwater sensor nodes are responsible to extract the valuable and application based information from the bottom of the ocean and that information can be transferred to the onshore data centers through some routing methodologies. The different application based information for underwater environment is described.

Mine reconnaissance: The sensor nodes or Acoustic Underwater Vehicles (AUVs) are able to assess the environment of underwater and extract the mine-like objects.

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Distributed tactical surveillance: Acoustic Underwater Vehicles and static sensor nodes can jointly observe areas for intrusion detection system, reconnaissance and surveillance (Akyildiz *et al*., 2005).

Disaster prevention: Underwater sensor nodes can locate the environmental conditions of the water and can predict for the marine earthquakes on coastal areas.

Assisted navigation: Sensor nodes can traverse the position of underwater rocks, mooring and submerged wrecks (Benson *et al*., 2010; Lee *et al*., 2010; Kredo and Mohapatra, 2010; Zhou *et al*., 2010).

Undersea exploration: Underwater sensor nodes can detect the underwater oilfields or minerals (Teymorian *et al*., 2009; Xie *et al*., 2009; Cheng *et al*., 2009).

Environmental monitoring: The sensor nodes can also extract the information of the underwater wild life, chemical reactions in water, biological and nuclear changes (Headrick and Freitag, 2009; Cheng *et al*., 2008; Mirza and Schurgers, 2008).

Ocean sampling: UWSN can perform the 3D coastal ocean environment and can also perform synoptic means AUVs can predict the characteristics of ocean environment.

MATERIALS AND METHODS

Underwater communication architecture: The general model of the underwater communication architecture is given in Fig. 1; the ordinary sensor nodes are deployed on the bottom of the sea floor and are connected with the one or more underwater gateways through acoustic signaling (Melodia *et al*., 2013). The sea floor sensor nodes can relays the data through multi-hop to the surface stations. The underwater gateway is equipped with the horizontal and vertical transceivers; the horizontal transceiver is used for the sea floor sensor nodes to collect the required information from the bottom and vertical transceiver is used to transfer the data to the water surface. In deep water the vertical transceivers are long-range. The surface station is equipped with RF and acoustic signaling because in deep underwater environment the acoustic signaling is used and communication with satellite the RF signaling is uses as given in Fig. 1.

Underwater acoustic channel: The acoustic channel can be temporally and spatially varied due to the transmission medium and underwater environmental physical properties. The signal speed of acoustic channel is 1.5×10^3 m sec^{-1} which is five orders in magnitude is lower than radio frequency signaling. The bandwidth of the acoustic channel is limited and depends on transmission range and frequency. Almost in underwater environment the acoustic channel can operate the frequencies as given in Table 1 for different ranges.

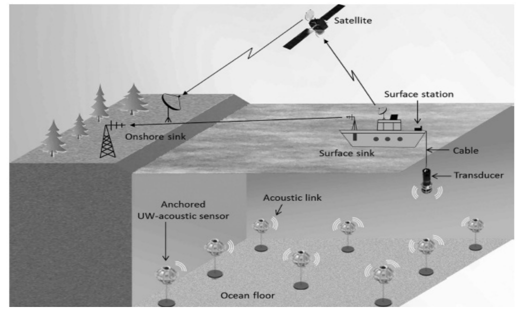

Fig. 1: Architecture of underwater wireless sensor network

Table 1: Acoustic channel bandwidth for different ranges

Range scale	Distance (km)	Bandwidth (kHz)
Very short	<0.1	>100
Short	0.1-1	20-50
Medium	1-10	10
Long	10-100	2-5
Very long	1000	< 1

Acoustic channel can be affected with many factors like: path loss doppler spread noise and multipath, due to these factors the cause of high bit error rate and delay variance occurs. We can determine the bandwidth through communication range and frequency of acoustic signal. If the communication range is larger than frequency will be lower.

Network evolution metrics: The network evolution metrics covers the major objectives like: benefits of UWSN, network deployment in underwater environment and the intended usage of the network. Underwater wireless sensor networks evolution metrics are: lifetime coverage cost and ease of deployment response time and temporal accuracy.

Lifetime: In underwater wireless sensor network the lifetime means the network's initial deployment to the first loss of coverage; means that the time until the first node dies (Vlajic and Stevanovic, 2009). The easiest to capture indicator of this metric is the maximum per-node load, where a node's load corresponds to the number of packets sent from or routed through the given node. Clearly, the network setup that minimizes the maximum node load is the one that will ensure the maximum network lifetime (Vlajic and Stevanovic, 2009).

Coverage: Coverage is basically the deployment of sensor nodes in large underwater sparse or dense area. Maximizing the coverage and minimize the deployment cost in underwater environment is one of the challenging issues (Chen and Lin, 2013; Wu *et al*., 2012; Zhang *et al*., 2013; Namazi and Faez, 2013; Wang *et al*., 2013). If the deployment strategies are well enough; then we will accomplish the affective approach for energy conversion in UWSN. Majority of the researches have focused the deployment coverage either static or dynamic. Many simulation results focus the optimal deployment strategy with respect to the less number of nodes (Xu *et al*., 2011; Bayrakdar *et al*., 2011; Zhou *et al*., 2011). Coverage metric is actually not relates with the communication links. Majority of the researchers are using the multi-hop techniques for the deployment of the sensor nodes in underwater environment which is actually not feasible because multi-hop extends the network range indefinitely and ultimately it will increases the power consumption of the nodes and in resultant it will decrease the network lifetime and will increase the deployment cost (Wahid and Kim, 2012; Wahid *et al*., 2014; Yoon *et al*., 2012; Casari and Zorzi, 2011).

Cost and ease of deployment: Ease of deployment means deployment of the sensor nodes with some mechanism that the network should be able to reconfigure automatically on demand in order to tolerate the occurrences. In the network lifecycle the initial deployment and configuration is the first step. The deployment of sensor nodes must be secure and robust because the maintenance cost is too much high. The hardware and software must be carefully tested before the deployment; the sensor system must be designed with careful deployment so that can perform continual self-maintenance.

Response time: Response time is defined as the time required by any node in the network when the packets arrives in its buffer to the time the node about to transmit the packet (Xu *et al*., 2011; Khan and Ali, 2012). Best thing for the response time is that when the intrusion is detected by node than node will alarm immediately. Despite low power operation, nodes must be capable of having immediate, high-priority messages communicated across the network as quickly as possible (Xu *et al*., 2011). In underwater environment the response time is too much critical due void regions and other obstacles (Climent *et al*., 2014; Wahid *et al*., 2014a, b).

Temporal accuracy: The network in underwater environment must be designed in such a manner that every node must response to other nodes with in the time period. Time synchronization must be joined between the nodes. The frequency for temporal accuracy between the nodes is based on time clock.

Hierarchical routing protocols based on network architecture: Hierarchical routing protocols based on network architecture. This study covers the basic architecture of the hierarchical routing protocols with data forwarding mechanism, route discovery and route maintenance. The issues with every hierarchical routing protocol are also mentioned in this study.

- LCAD
- DUCS
- MCCP
- HydroCast
- TCBR
- Multi-sink
- Multi-path VS

Location-based Clustering Algorithm for Data gathering (LCAD): LCAD is location based 3D grid network routing protocol (Anupama *et al*., 2008) LCAD routing protocol has resolved the two issues: energy drain due to multi-hop approach from source to sink and energy dissipation during transmission distance between sender and receiver nodes. LCAD each gird size is composed of $30\times40\times50$ m. The cluster formation is based on cluster node and cluster head (c-node and c-head). The c-nodes have extra power and memory and are the qualifier of c-head and both are placed at the center level of each gird, ordinary sensor nodes are around the c-node which makes a cluster with acoustic link of 500 m. The operation of LCAD is consists of three phases:

Transmission phase: In this phase the c-head collects the data form Autonomous Underwater Vehicles (AUVs) and transfers to the base station.

Data gathering phase: This phase refers the data collection by AUV through ordinary sensor nodes.

Setting up phase: This phase selects the proper cluster for data transmission mechanism. The researcher 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 for good network throughput.

Issues with LCAD: The researchers have adapted the terrestrial network approach in simulation scenarios which is not feasible for underwater wireless sensor network environment.

- Network life time is based on node movement but researchers have not clearly defined the node movement
- Overall network performance is not reasonable

Distributed Underwater Clustering Scheme (DUCS) DUCS is the scalable and energy efficient routing protocol and has been introduced by Domingo and Prior (2007). DUCS is non-time critical application protocol but is based on node mobility for long term. This self organising routing protocol divides the entire network into multiple clusters with the help of distributed algorithm. The wireless sensor ordinary nodes are divided into cluster-heads and non-cluster-heads. One cluster head node makes the cluster of the multiple non cluster-heads. The non-cluster-head nodes are also called the member nodes which are able to transfer the data packets to the respective cluster-head nodes with single hop mechanism. The cluster-head nodes collect the data from non-cluster-head nodes and will transfer the data by using the aggregation function to the other cluster-heads through multi-hop mechanism and the nearby cluster-head node will transfer the data packets to the sink node which is deployed on the water surface. The DUCS scheme is composed of two phases. One is the setup phase and other is the operation phase, setup phase is responsible to make the clusters whereas the operation phase is responsible to transfer the data packets in form of frames towards the sink node. The coordination between cluster-head nodes and non cluster-head nodes is called the intra-cluster coordination and coordination between one cluster-head nodes with another cluster-head node is called inter-cluster coordination.

Issues with DUCS: The continuous node movement will affect the life of the cluster and in resultant the data delivery ratio will be reduced. Overall network throughput may be affected due the member node movement; if member node moves away from the cluster-head nodes.

Minimum-Cost Clustering Protocol (MCCP): Minimum-Cost Clustering Protocol has been introduced by Wang *et al*. (2007). The architecture of MCCP is composed of onshore control center, surface station, UW-Sink nodes and ocean bottom sensor nodes. The ocean bottom sensor nodes are divided into cluster-member nodes and cluster-head nodes which makes the cluster around the UW-Sink nodes. The cluster-member nodes transfer the data packets to the cluster-head nodes and cluster-head nodes transfer the data packets to the UW Sink nodes through hop-by-hop mechanism. The UW Sink node transfers the data packets directly to the surface station through acoustic channel and surface station transfers the data packets to the onshore control center through RF signaling. The researchers claimed that they have improved the energy efficiency and network lifetime through MCCP routing protocol. MCCP routing protocol is based on Minimum-Cost Clustering Algorithm (MCCA) to control the node movement in underwater environment.

MCCP major concerns for energy efficiency and node control:

- Total energy consumed by cluster-members for sending data to cluster heads
- Residual energy of cluster-member nodes and cluster-head nodes
- Relative location between cluster-head and sink node.

MCCP assumptions:

- All the nodes are cluster-head candidates and cluster member candidates
- Cluster-head candidate with neighbor nodes forms a cluster
- Cost of formed cluster can be calculated through cost metric parameters
- Computed cluster with its cost metric and cluster-head node broadcasted to the two hop neighbor

Issues with MCCP:

- The researchers have used the energy model as described in (Sozer *et al*., 2000) is not suitable for this kind of architecture
- The time period of re-clustering will affect the battery life of ordinary sensor nodes

Hydraulic pressure based any cast (HydroCast): HydroCast is geographic distributed localization routing protocol proposed by Khasawneh *et al*. (2015). According to researchers the HydroCast mobility based routing protocol has resolved the two major issues: ocean current which affects the node movement and controls the bandwidth and energy level of the sensor nodes. The researchers of the HydroCast have used the basic ideas of the Depth Based Routing (DBR) protocol. The HydroCast protocol utilizes the depth information of the sensor nodes with their relevant cluster through water pressure levels. This protocol forms the clusters without hidden information of terminal nodes. In HydroCast architecture the clusters are formed with the maximum progress of those nodes which are closer to the destination and maximum progress can be calculated with packets delivery probability. A sensor node which is the part of the cluster, the information of that node will be embedded in the packet format. In data forwarding mechanism the maximum progressive node has highest priority. The maximum progress node has shortest time-out for transmission. In HydroCast protocol the local maximum recovery method has been used which performs the limited flooding mechanism approach. In the flooding mechanism the local maximum node is called the performer node. The tetra horizontal method has also been used in the designing of this protocol. The tetra horizontal method will identify the neighbor nodes for local maximum node (surface node). The local maximum nodes will transfer the information to other local maximum nodes by using of limited hops and data packets will be forwarded to the destination nodes placed on water surface. The researchers of HydroCast protocol have also used the greedy based mechanism for removal of void regions.

Issues with HydroCast:

- Multiple copies of the same packets have been received by the sink node which will enhance the extra load on network
- Energy efficiency parameter is hidden

Temporary Clustered Based Routing (TCBR): TCBR multi-hop protocol is an energy efficient routing protocol and has been introduced by Ayaz *et al.* (2010). The ordinary, courier nodes and sink nodes are used in the architecture of the TCBR. The ordinary node collects the data from the bottom of the sea and transfers that data to the courier node. Courier node is equipped with mechanical module and courier node is responsible to relay the data packets through the usage of the mechanical module to the sink nodes which are deployed on the water surface. The researchers have settled the communication range around 300-500 m for the better power usage. The TCBR routing protocol is based on multi-sink architecture and designed for equal energy consumption. The researchers have used the hello message format in between courier and ordinary nodes and this format will alarm to the ordinary node for the presence of the courier nodes. The underwater communication between nodes is based on the acoustic signaling. From surface sink nodes onshore data center the communication is based on RF signaling.

Issues with TCBR:

- The extra usage of mechanical module in the courier node increases the cost of TCBR protocol and it is also observed the functionality of mechanical module is not appropriate in underwater environment
- For critical time based scenarios the TCBR response is not well enough

Multi-sink: Multi-sink is 2D quasi-stationary routing protocol for underwater wireless sensor network and introduced by Li (2008). The architecture of the Multi-sink is based on mesh structure with the usage of underwater sensor nodes, mesh nodes, Underwater Sink nodes (UW-Sink), surface buoys and monitoring center. The surface buoys are deployed on the sea surface and are directly linked through wire with the UW-Sink. The surface buoys are also linked through RF signaling with the monitoring center. The high power mesh nodes are collecting the data packets from the neighbored underwater sensor nodes and transfers the data packets to the UW-Sink nodes. The high power mesh nodes can be recharged by the underwater controlled vehicles. The UW-Sink nodes directly transfer the data packets to the surface buoys. The surface buoys transfers the same data packets to the monitoring center. The mesh node also uses the data aggregation function to aggregate the data.

Issues with multi-sink: Multi-sink mechanism of data forwarding is totally depended on mesh node; if mesh will die due to some underwater obstacles the overall network performance will be degraded. Underwater environment cannot support the static UW-Sink nodes due to continuous movement of water. The mechanism focuses the duplication of packets which causes to increase the number of hops and ultimately the data delivery ratio will be affected.

Multi-path VS: The Multi-path Virtual Sink (VS) has been introduced by Seah and Tan (2007). The architecture of Multi-path VS is based on three components: sensor nodes, local sink and aggregator. This clustered based routing protocol divides the clusters into aggregator points. The aggregator points make the mesh structure and are linked through RF signaling with local sink. The aggregator point is the source to develop the multiple paths between local sink and sensor nodes. The authors have used the multiple paths to enhance the data delivery ratio. The path between sensor node and local sink node will be developed through hop-count message. When multiple paths established between source nodes to local sink nodes the packets transmission mechanism will be performed. The local sink nodes will further transfer the data packets to the onshore data center.

Issues with multi-path VS:

- Multipath data transmission mechanism is not suitable for underwater environment
- According to multipath mechanism; if any path terminates than the overall network throughput will be affected
- The mechanism defined by the researchers in the methodology is without the consideration of the void regions so if void region occurs on any path than packets delivery ratio will be affected

Table 2: Comparison of hierarchical routing protocols based on architecture through performance metrics

Protocol	Performance	Cost efficiency	Data delivery	Delay efficiency	Energy efficiency	Bandwidth efficiency	Reliability
LCAD	Low	Low	Fair	Low	Fair	Fair	Low
DUCS	Low	Good	Fair	Low	Fair	Fair	Low
MCCP	Fair	High	Low	Low	High	Fair	Fair
HydroCast	High	Fair	High	High	Fair	Fair	Fair
TCBR	Low	Low	Fair	Low	Fair	Fair	Fair
Multi-sink	Low	N/A	High	Low	Fair	Fair	Fair
Multi-path VS	Fair	Low	Fair	Fair	Low	Fair	High

Table 3: Comparison of hierarchical routing protocols based on architecture through characteristics

Protocol	Single/multiple Coppies	Hop-by-hop/ End-to-end	Flooding address based	Pathbased	Distributed clustering	Clustering source based	Single/multi-sink	Helo Msg	Localization needed
LCAD	Single	Hop-by-Hop	NO	NO	NO	YES	Single-sink	YES	YES
DUCS	Single	Hop-by-Hop	NO	NO	YES	NO	Single-sink	YES	NO
MCCP	Single	Hop-by-Hop	NO	NO	YES	NO	Multi-sink	YES	YES
HydroCast	Multiple	Hop-by-Hop	NO	NO	NO	YES	Multi-sink	NO	NO
TCBR	Single	Hop-by-Hop	YES	NO	NO	NO	Multi-sink	YES	NO
Multi-sink	Multiple	Hop-by-Hop	NO	YES	NO	NO	Multi-sink	NO	NO
Multi-path VS	Multiple	Hop-by-Hop	NO	YES	NO	NO	Multi-sink	YES	NO

Performance methods: The most common evolution methods are used for underwater sensor networks are: analytical method, real deployment method and numerical simulations as described by Ayaz *et al*. (2011).

Analytical method: This performance metric is very complicated. Analytics looks the past and the present data with powerful insights, optimization and predictions. Data can be collected from the different research articles which are present on the current research especially in underwater wireless sensor network which can be worked on, analyzed to find data which is transformational and equally high value. Table 2 and 3 focuses the analytical method for hierarchical routing protocols based on architecture for underwater wireless sensor network. In Table 2 we have used the measurement ratings like: low, fair and high and based on the metrics like: performance, cost efficiency, data delivery, delay efficiency, energy efficiency, bandwidth efficiency and reliability of the hierarchical routing protocols based on network architecture. Table 3 focuses the architectural characteristics of the hierarchical routing protocols and evolution parameters are: single or multiple copies send by protocols, either protocols transfers the packets through hop-by-hop or end-to-end basis, protocols are path based or not, protocols are either distributed clustering or clustering source based, protocols have single sink or multi-sink, protocols sends hello message or not and protocols have need of localization or not.

Real deployment method: Real deployment method for underwater environment is much more expensive due to the unavailability of hardware and it needs the high class laboratories for real experiments. If we collect the hardware but it is difficult to do experiment in deep water.

Table 4: Simulation parameters for multiple protocols

Parameters	Rating
No. of nodes	350
Deployment size (3D)	1000×1000×1000 m
Node speed	1-3 m sec^{-1}
Communication range	100-400 m
Packet size	512 bytes
Data sending rate	1 packet/sec
MAC standard	IEEE 802.11
Propagation loss (Sph.)	20 log(R/R_{1m})
Distance of adjacent nodes	1 km
Transmission power	105 dB

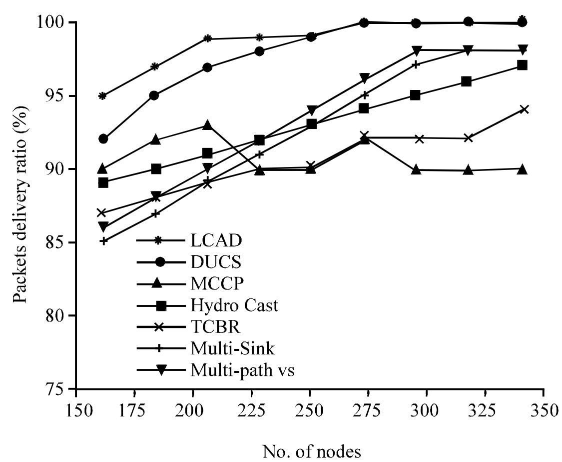

Fig. 2: Nodes versus packets delivery ratio (%) for hierarchical protocols

Numerical simulation method: Most of the researchers prefer simulation based methods for underwater wireless sensor network or terrestrial wireless sensor network. This kind of method is also complicated but now days the user friendly software and simulators made it possible to simulate the results which almost resemble the real scenarios (Fig. 2 and Table 4). Most famous software we can use like structured C, C++, VC++ and Java and most common simulators are used like NS2, AquaSim with NS2, riverbed, OPNET, Qualnet and AUVNetsim. We also have used the NS2 with AquaSim to simulate the packets delivery ratio of the hierarchical routing protocols based on architecture for underwater wireless sensor network. focuses the simulation parameters and focuses the simulation scenario. In this simulation scenario we have analyzed that the TCBR and HydroCast routing protocols shows the best performance in comparison of other hierarchical routing protocols.

Future challenges: The future challenges for underwater wireless sensor networks are listed:

- The mechanism is needed for the proper deployment of the sensor nodes in deep underwater environment which can reduce the acoustic signaling overheads and can enhance the data delivery ratio
- Local route optimization algorithms are needed to react to consistent variations in the metrics describing the energy efficiency of the underwater channel (Akyildiz *et al*., 2005)
- Algorithm is needed which can show the node or route failure causes
- For data transmission in underwater environment the credible simulation tools are needed which can measure the performance of the routing protocols in underwater deep environment
- Robust algorithms are needed which can focus the connectivity of the acoustic channel because the quality of the acoustic channel is very poor and the design of multi-path and fading model is also complicated
- For delay-tolerant application the special mechanism is needed which can handle the loss of connectivity without provoking the immediate re-transmissions (Akyildiz *et al*., 2005)
- The best-fit localization algorithm is needed which can focus the proper deployment of the sensor nodes
- The algorithm is need for the removal of void regions
- Proper mechanism is needed to recharge the battery of the sensor nodes in underwater environment

CONCLUSION

In this research study, we presented an overview of different applications for underwater wireless sensor network; we also presented the general communication model of the underwater wireless sensor network which focuses the deployment of sensor nodes and the transmission mechanism from bottom of sea to the onshore data center. In this research study, we also presented the characteristics of the acoustic channel and network metrics. The major purpose of this article is based on the deployment of sensor nodes, data forwarding mechanism, route maintenance mechanism and issue with the hierarchical routing protocols based on architecture. We also presented the three basic evolution methods and in these methods we presented the analytical method of the hierarchical routing protocols. The numerical simulation method focuses the simulation results for packets delivery ratio of the hierarchical routing protocols. The last section of this research paper is based on future challenges which guide the researchers to further research in the field of underwater wireless sensor network.

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