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Review on Non-cross-layer Mobility and Time Delaying Routing Protocols for Underwater Wireless Sensor Network

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Abstract

Objectives: To study the analysis of non-cross-layer and time-delaying routing protocols for underwater wireless sensor networks which help the researchers for further research in field of proposed routing protocols. **Methods/Analysis**: This review article focuses the advantages and limitations, analytical and numerical simulation methods for non-cross-layer mobility-based and non-cross-layer time delaying routing protocols. **Findings**: The non-cross-layer mobility-based routing protocols focus the movement of the node in underwater 3D environment where as time delaying routing protocols focuses the routing link quality. The novelty in this review article is based on its unique classification; analytical method of analysis and unique numerical simulation method based on theoretical perspective. The outcome of this review may lead to a better approach as compared to existing reviews. **Applications/Improvements**: Through proposed routing protocols we can extract valuable information from the bottom of the sea like information for minerals such as nickel, copper, gold, silver etc.

Keywords: Mobility, Non-cross-layer, Routing Protocols, Time-delaying, Underwater

1. Introduction

Recently underwater wireless sensor network plays a vital role in the field of research due to its enormous applications[1]. Enormous applications like renewable energy harvesting from the sea bottom. Furthermore, minerals such as cobalt, nickel, copper, rare earths, silver, and gold will be mined from the seafloor[2]. Ocean underwater environmental research is not so easy because of the underwater pressure, underwater environmental conditions, and water current[3–5]. Research community which is involved in the field of wireless sensor network is taking an interest in the researchof underwater wireless sensor network. From research point of view the design of routing protocol is well interesting area, majority of the routing protocols for underwater environment has been introduced; some are clustering routing protocols, some are multipath based routing protocols, some are depth based, and some are location based[6–8]. This review article focuses the non-cross-layer routing protocols for underwater environment. Non-cross-layer routing protocols are further divided into mobility based routing protocols and time delaying routing protocols as mentioned in Figure 1. The major contribution in this review article is as follow:

i. Precise description of Mobility-Based and Time Delaying routing protocols.
ii. Proposed routing protocols' advantages and limitations.
iii. Performance analysis through analytical method for proposed routing protocols.
iv. Performance analysis through numerical simulation method for proposed routing protocols

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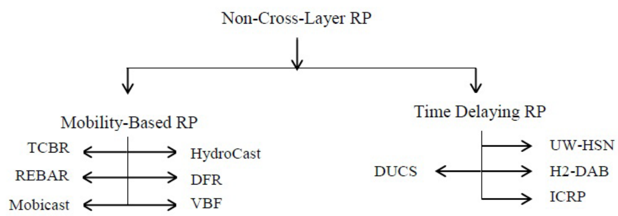

Figure 1. Classification of non-cross-layer routing protocols for UWSN.

In this section we are discussing the principles of routing protocols' design which is based on non-cross-layer mobility-based routing protocols and non-cross-layer time delaying routing protocols.

1.1 Mobility-Based (MB) Routing Protocols

Node mobility is the major issue in underwater environment because due to the water current and water pressure the node can change its position from one place to other place[9–11]. Due to the node movement the routing path can be broken and link quality may be affected[12–14]. To overcome the node movement, the efficient routing algorithm is needed[15]. The following are the mobility-based routing protocols which focuses the controlling of node mobility in underwater environment.

1.1.1 Temporary Cluster Based Routing (TCBR) Protocol

In[16] the Temporary Cluster Based Routing (TCBR) protocol is proposed. TCBR is based on multi-hop depth based routing which consists on ordinary nodes, courier nodes, and sink nodes. Courier and ordinary nodes are deployed in underwater depths whereas sink nodes are deployed on the water surface. Courier nodes are the powerful nodes and have ability to move vertically with embedded mechanical module. Courier nodes make the temporary clusters with ordinary sensor nodes and are responsible to collect the data from ordinary sensor nodes and will forward the data towards sink nodes through the power of mechanical module. TCBR sets the communication range between 300 to 500 meters for the better usage of battery power for sensor nodes. The correspondence between courier and ordinary nodes is based on *hello packet*; which shows the presence of courier nodes for ordinary nodes.

1.1.2 A Reliable and Energy Balanced Routing Algorithm (REBAR)

In[17] the Reliable and Energy Balanced Routing Algorithm (REBAR) is proposed. REBAR refers the two models one is sphere energy depletion model and second is extended energy depletion model;which shows the distance between sink node toordinary nodes in different tiers. REBAR is location based routing protocol where every node knows its location. The sink node is fixed at center of the water surface and sink node is also responsible to assign the unique ID to every node.After assigning the unique ID to every node the nodes will forward the data packets to the sink node through hop-by-hop mechanism. REBAR also refers the broadcast size with high and low values; if broadcast size is high the node will consume the high energy and if the broadcast size is low the node will consume the less energy. REBAR resolves this issue through the balancing of the broadcast size. In REBAR the source node has ability to calculate the routing direction towards sink node through vector mechanism. REBAR removes the void regions through *boundary set* and *non-boundary set* mechanism.

1.1.3 Mobicast Routing Protocol

In[18] Mobicast routing protocol is proposed for underwater wireless sensor network which refers the node mobility. Mobicast resolves the problem of 3D holes through *apple peel* mechanism. The architecture of Mobicast is based on underwater sensor nodes which are deployed randomly in *3D* area of water around the Autonomous Underwater Vehicles (AUV) in form of *3Dzone of reference* or ***3D ZOR.*** The AUV travels along the user defined path and collects the information from the sensor nodes within different time intervals of ***3D ZORs.***The sleep and active nodes are used to resolve the problem of unpredictable holes. Active nodes are responsible to forward the sensed data to the AUV.The Mobicast uses the geographic *3D* Zone of Relevance (***3D ZOR***^{3}) and *3D* Zone of Forwarding (***3D ZOF***) which are created by AUV at time *t* to indicate which sensor node should forward the sensed data to the AUV.

1.1.4 HydroCast Routing Protocol

In[19] the pressure routing protocol named HydroCast is proposed. HydroCast is the geographic distributed localization mobile routing protocol. HydroCast is the extension version of DBR which resolves the problem of void regions. HydroCast protocol utilizes the depth information of the sensor nodes with their clusters on basis of pressure levels. This protocol forms the clusters without hidden information of terminal nodes. In this 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 better priority. The maximum progress node has shortest time-out time for transmission. In this 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; this 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.

1.1.5 Directional Flooding-based Routing (DFR) Protocol

In[20] the Directional Flooding-Based Routing (DFR) is proposed. DFR is composed of two famous protocols one is VBF and other is HH-VBF. DFR focuses the two major techniques one is the involvement of maximum number of nodes in data forwarding mechanism and other is to maintain the link quality between nodes. DFR also refers the *packets forwarding decision* algorithm and packets flooding method for forwarding the data packets from source to destination which assures the good reliability. The data forwarding in DFR refers the calculation of Base Angle (BA) and flooding scope.

1.1.6 Vector-Based Forwarding (VBF) Routing Protocol

In[21] the Vector-Based Forwarding (VBF) routing protocol is proposed. Node mobility based VBF refers the routing pipe and radius pipe mechanism for data forwarding. Routing pipe mechanism controls the sender position and Target position for data forwarding from source to destination; whereas radius pipe controls the radius of the pipe which is involved in data forwarding mechanism. VBF also refers the two types of queries for data forwarding one is *sink-initiated query* and other is *source-initiated query*which controls the data forwarding within the radius pipe from source to destination with data forwarder nodes.

1.2. Time Delaying (TD) Routing Protocols

Time delaying routing protocols is affected due to the propagation delay. Low propagation delay and high attenuation ratio is really a serious problem in underwater environment. Small propagation delay is cause of good energy consumption performance. The time delaying routing protocols' design is mentioned in the following routing protocols.

1.2.1 Distributed Clustering Scheme for Underwater (DUCS) Routing Protocol

In[22] the Distributed Clustering Scheme for Underwater (DUCS) is proposed. DUCS refers the distributed routing algorithm to divide the entire network into multiple clusters. The underwater sensor nodes are divided into cluster head nodes and non-cluster head nodes. Every cluster head node will make the cluster with non-cluster head nodes. The non-cluster head nodes will collect the data and forward to the relevant cluster head nodes through single hop mechanism. Cluster head nodes will forward the data packets by using the data aggregation function to other cluster head nodes through multi-hop mechanism; in this way the data will be received by the nearby cluster head node to sink node. DUCS refers the setup phase for formation of clusters and operation phase for data forwarding.

1.2.2 Underwater Wireless Hybrid Networks (UW-HSN) Routing Protocol

In[23] the Underwater Wireless Hybrid Networks (UW-HSN) is proposed. UW-HSN time delaying routing protocol uses the mechanical module for sensor nodes which forces the sensor node to swim on surface and dive back to the different levels of water. UW-HSN refers the TurtleNet hybrid concept for negative and positive vertical movements of the node through piston to reach on surface and dive back to the bottom depth levels of water. The Trutle Distance Vector (TDV) algorithm determines the communication channel in order to minimize average event delay. Term event delay means successful reception time duration between source nodes and base station.

1.2.3 Hop-by-Hop Dynamic Address-Based (H2-DAB) Routing Protocol

In[24] the Hop-by-Hop Dynamic Address-Based (H2-DAB) routing protocol is proposed. The time delaying H2-DAB refers the dynamic addressing scheme till water depth. The water depth is divided in different water levels from top to bottom. The dynamic addressing scheme is divided from lower depth to higher depth. Sink node which is deployed on water surface will generate the dynamic addressing from top to bottom levels with *hello* message. If any node will receive the *hello* message than will forward the data packets to the upper level through greedy algorithm. From bottom to top levels the packets will be forwarded to the sink node through dynamic addressing mechanism.

1.2.4 Information-Carrying Routing Protocol (ICRP)

In[25] the Information-Carrying Routing Protocol (ICRP) for underwater acoustic sensor networkis proposed. ICRP is the time delaying routing protocolin which the source node is responsible for route discovery through route discovery message.On arrival of route discovery message the intermediate or neighbor nodes will establish the reverse route for acknowledgement. When the route is established the source node will forward the packets and will wait for acknowledgment through reverse route.The established routes refer the TIMEOUT function, if the threshold time exceeds the TIMEOUT than route become invalid. When the data packets received through the established route to the destination the delivery refers the successful packets delivery.

1. 3 Advantages and Limitations of Mobility-based and Time Delaying Routing Protocols

Table 1focuses the advantages and limitations of non-cross-layer mobility-based and time delaying routing protocols.

2. Performance Analysis and Evaluation Methods

We have divided the performance analysis and evaluation methods in two ways; one is analytical method and other is numerical simulation method. The following subsequent sections focus the both of the performance analysis and evaluation methods.

2.1 Analytical Method

In analytical evaluation method we have deeply viewed the different characteristics of the proposed routing protocols like: either protocols' are hop-by-hop or end-to-end, what kind of assumptions the proposed protocols' have taken, protocols are either clustered based or single entity and protocols either keeps the hello or control message.Table 2 focuses the different characteristics of the proposed routing protocols.

Table 3 shows the performance metrics of the non-cross-layer mobility-based and time delaying routing protocols. We have evaluated the performance metrics like: performance of proposed routing protocols, cost efficiency, data delivery, energy efficiency, bandwidth efficiency, and reliability.

2.2 Numerical Simulation Method

In numerical simulation method we compare the performance of the proposed routing protocols through data delivery ratio. The performance is based on NS2.30 with AquaSim network simulator. We have considered the generalized parameters for simulation purpose. Table 4 shows the simulator parameters used by NS2.30. We have considered the sensor nodes from 100 to 600 with 3D deployment size of 1500x1500x1500 m with communication range of 500m and measured the data delivery ratio of non-cross-layer mobility based and time delaying routing protocols.

2.2.1 Mobility based Routing Protocols

Figure 2 shows the packets delivery ratio of mobility-based routing protocols. In Figure 2 the packets delivery ratio of TCBR and HydroCast is higher than VBF, DFR, Mobicast and REBAR because in TCBR and HydroCast the node mobility methodology is controllable.

2.2.2 Time Delaying Routing Protocols

Figure 3 shows the packets delivery ratio of time delaying routing protocols. In Figure 3 the packets delivery ratio of H2-DAB is higher than ICRP, UW-HSN and DUCS because H2-DAB routing protocol considered the energy saving mechanism.

Table 1. Advantages and limitations of non-cross-layer mobility and time delaying routing protocols

Classification	Protocol	Advantages	Limitations
Protocols Based on Mobility	TCBR	Increasing the reliability, reducing the energy consumption and managing the node mobility.	Suitable for time critical applications and the cost of the mechanical module is high.
	REBAR	Reducing the energy consumption of the nodes near the sink and increasing the data delivery ratio.	Due to uncontrolled node movement the data delivery may be affected.
	Mobicast	Resolves the problem of 3D holes through *apple peel* mechanism. Enhancing the data delivery ratio.	Network performance may be reduced due to the void regions.
	HydroCast	Limiting co-channel interference and maximizing greedy progress.	Multiple copies of same packets received by sink will increase the extra burden for network.
	DFR	Removing the void problem and enhancing the data delivery ratio.	In area where the link quality is not good than forwarder node will drop the packets.
	VBF	Scalable, energy efficient and robustness for high dynamic networks.	Forwarder node forwards the packets continuously and will lose the energy of nodes. If nodes away from virtual pipe will affect the n/w performance.
Protocols Based on Time Delaying	DUCS	Reduce the interference, improves the communication quality and maintains the node mobility.	Continuous node movement reduces the life of ordinary node and cluster.
	UW-HSN	Lower the delay and improve the overall network performance.	Hardware used by UW-HSN increases the cost of overall network.
	H2-DAB	Minimize the message latency; reduce the energy consumption without any extra or specialized network equipment.	Hop count and greedy methods are not properly defined by H2-DAB; so calculation of data delivery is baseless.
	ICRP	Combine the routing discovery and the data transmission together; improve the energy efficient, scalable, and the reliability of the data paths.	Node mobility model may be affected due to the void regions and will reduce the packets delivery ratio.

Table 2. Comparison of routing protocols through characteristics

Classification	Protocol	Year	Hop-by-Hop Or End-to-End	Assumptions	Cluster/ Single Entity	Hello/Control Message
Mobility Based	TCBR	2010	Hop-by-Hop	Based on Mechanical Module	Clustered	Yes
	REBAR	2008	Hop-by-Hop	Location Information	Single entity	No
	Mobicast	2013	End-to-End	Based on AUV	Single entity	No
	HydroCast	2010	Hop-by-Hop	Pressure Information	Single entity	Yes
	DFR	2008	Hop-by-Hop	Location Information	Single entity	No
	VBF	2006	End-to-End	Location Information	Single entity	No
Time Delaying	DUCS	2007	Hop-by-Hop	Based on Mechanical Module	Clustered	Yes
	UW-HSN	2008	Hop-by-Hop	n/a	Single entity	Yes
	H2-DAB	2009	Hop-by-Hop	n/a	Single entity	Yes
	ICRP	2007	End-to-End	n/a	Single entity	No

2.2.3 Comparison between Mobility based and Time Delaying Routing Protocols

In this section we have compared the higher packets delivery ratio of mobility-based and time delaying routing protocols. Figure 4 focuses the packets delivery ratio of TCBR, HydroCast and H2-DAB routing protocols. TCBR and HydroCast are the mobility based routing protocols and H2-DAB is the time delaying routing protocol.

Table 3. Comparison of routing protocols through performance metrics

Classification	Protocol	Year	Performance	Cost Efficiency	Data Delivery	Delay Efficiency	Energy Efficiency	Bandwidth Efficiency	Reliability
Mobility Based	TCBR	2010	Low	Low	Fair	Low	Fair	Fair	Fair
	REBAR	2008	Fair	Low	Fair	Low	High	Fair	Fair
	Mobicast	2013	Low	Fair	Fair	Fair	Low	Low	Fair
	HydroCast	2010	High	Fair	High	High	Fair	Fair	Fair
	DFR	2008	Fair	Low	Fair	Fair	Low	Fair	Fair
	VBF	2006	Low	Low	Low	Low	Fair	Fair	Low
Time Delaying	DUCS	2007	Low	High	Fair	Low	Fair	Fair	Low
	UW-HSN	2008	Low	Low	Fair	High	Low	Fair	Fair
	H2-DAB	2009	Fair	High	High	Fair	Fair	Fair	Fair
	ICRP	2007	Low	High	Low	Low	Fair	Fair	Low

Table 4. Simulation parameters used by NS2.30

Parameters	Rating
No. of Nodes	100to 600
Deployment Size (3D)	1500x1500x1500 m
Surface to bottom layer distance	250 m
Communication range	500 m
Packet size	512 bytes
N/W traffic	1 packet/sec

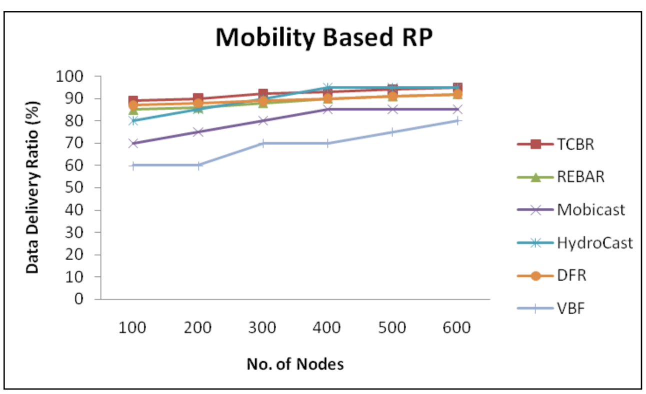

Figure 2. No. of nodes versus data delivery ratio for mobility-based RPs.

From comparison we have observed the packets delivery ratio of time delaying H2-DAB is higher than TCBR and

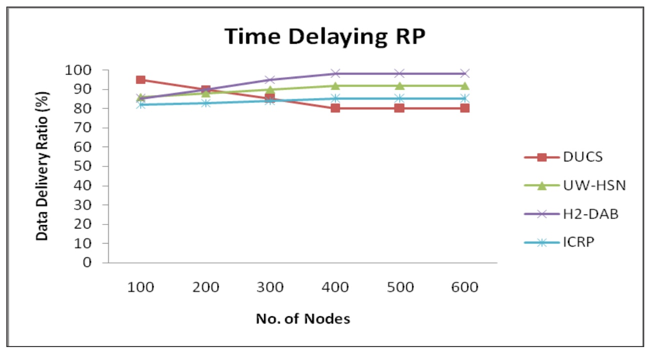

Figure 3. No. of nodes versus data delivery ratio for time delaying RPs.

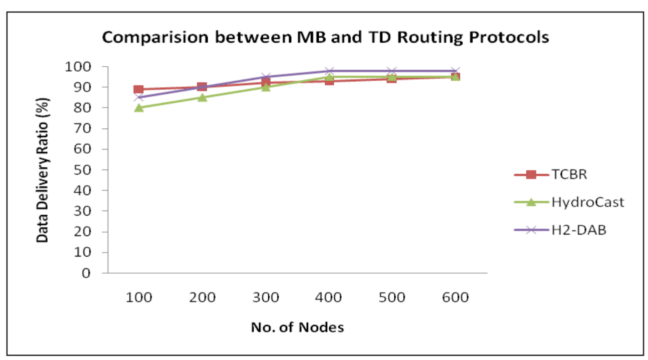

Figure 4. No. of nodes versus data delivery ratio of MB and TD RPs.

HydroCast because in mobility-based routing protocols the node can move its place and can broke the routing link which reduces the packetsdelivery ratio.

3. Conclusion

In this review article we introduced the non-cross-layer mobility-based and time delaying routing protocols for underwater wireless sensor network. In mobility-based routing protocols the routing link may be broken due to the water current and water pressure. The broken link may affect the link quality for a certain time period and may affect the data delivery ratio. Time delaying routing protocols has used the methodology to maintain link quality for enhancing the data delivery ratio. This review article also focuses the design architecture and data forwarding mechanism of non-cross-layer mobility-based and time delaying routing protocols. The advantages and limitations of mobility-based and time delaying routing protocols will guide to the researchers for further research in the field of underwater routing protocols. We also focused the analytical and numerical simulation performance and evaluation methods under which we compared the performance of proposed routing protocols and we observed that the time delaying H2-DAB routing protocol is better in performanceas compare to rest of the mobility-based routing protocols.

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