A Review of Underwater Wireless Sensor Network Routing Protocols and Challenges

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Abstract The underwater wireless sensor networks is a rapidly growing area of research as it monitors and collects data for environmental studies of seismic monitoring, flocks of underwater robots, equipment monitoring and control, pollution monitoring applications. The main purpose is to create a new set of routing protocols optimized various factors from the major differences in the underwater wireless sensor network and terrestrial network. Energy efficiency plays an important role in underwater wireless communication as underwater sensor nodes are powered by batteries which are difficult to replace or charge once the node is deployed. This paper surveys various routing techniques. Modern research trends focus to improve the performance on various issues like propagation delay, mobility, limited link capacity and limited battery power on the sea ground and sea surface.

Keywords UWSN · Routing protocols · Energy efficiency · Underwater communication

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1 Introduction

Underwater wireless sensor networks (UWSNs) consist of a variable number of sensor node and autonomous vehicles that are deployed to perform collaborative task for various applications. To achieve this objective, sensors and autonomous vehicles are placed in an autonomous network which can acquire to the characteristics of the ocean environment [1].

Wireless communication in underwater is one of the enabling technologies for the development of future ocean-observation systems and monitoring. Applications of underwater sensing range from military purposes to pollution monitoring and include environment monitoring, pollution control, climate status and prediction of natural disasters. It improves the search and survey missions, and study of marine life.

Routing in underwater wireless sensor networks plays important role due to the difference between the characteristics of the acoustic communication to that of the radio-magnetic waves. Various protocols have been designed to satisfy the different requirements of the acoustic communications such as delay efficiency, bandwidth efficiency, reliability, cost efficiency, delivery ratio. But the major requirement that has been highlighted is energy efficiency. Energy efficiency depends on many metrics which should be considered while designing the protocol. We focus basically at helping the protocol designers in providing an overview of the existing protocols and propose an optimized routing scheme to improve performance.

Nowadays, people have proposed and developed some routing protocols. Underwater wireless sensor networks can be divided into deep water and shallow water. Underwater wireless sensor networks routing protocols further can be classified based on communication as acoustic communication, radio wave communication and optical communication. In underwater acoustic sensor networks, there are number of corresponding protocols, for example, VBF [2], MURAO [3], DDD algorithm [4], Void-Aware Pressure Routing [5], GPS-free Routing Protocol [6] and DBMR [7].

2 Related Work

Several researchers worked on routing of underwater wireless sensor networks. Studies have continued significantly to find protocols to support the development in underwater. However, most of the protocols are not implemented so far. The major constraints are speed, propagation delay, limited bandwidth and energy. The purpose to provide a suitable routing protocol can improve a wide communication such as terrestrial network. Routing protocols are classified based on location, path, energy efficient, multi-level and GPS-free. Major work in energy as battery life is a major challenge [1, 8] in underwater networks.

3 Characteristics of Channels

Acoustic channels [9] are well in deep waters and can propagate a long distance. The communication speed is slow and it works in very low frequency. The speed of the sound in water varies on temperature and pressure of water.

Electromagnetic medium [9] requires higher frequencies. It works on large bandwidths ($\sim$MHz). EM works in very short range. The speed of EM is faster than acoustic channels. It reduces propagation delay significantly. EM is quite free from tidal noise and noise from surface area.

Light medium [9] works properly in clear and still water. Optical waves signal is absorbed when depth of water increases as pressure increases. Highly cost-effective and it can send large data bits as well. It works for short range and performance significant in shallow water (Table 1).

4 Differences in Underwater Sensor Network and Terrestrial Networks

Underwater sensor network is very challenging issue over terrestrial networks. We have identified some crucial parameters mentioned in Table 2. These parameters are very essential while designing routing protocols for both the network scenarios.

Table 1 Comparative study of various acoustic mediums

Parameters	Acoustic	Electromagnetic	Light
Speed	Low	High	High
Depth	Deep water	Deep and shallow water	Shallow water
Bandwidth	Less	>Acoustic	>Electromagnetic
Distance	Long distance	Short distance	Very short distance
Frequency	Less	>Acoustic	>Electromagnetic

Table 2 Differences in underwater communication and terrestrial networks

Parameters	Terrestrial sensor networks	Underwater sensor network
Cost	Terrestrial sensor networks will be cheaper and cheaper with the time	UWSNs are expensive
Deployment	Terrestrial SNs are densely deployed	UWSNs are generally more sparse
Power	Not a major issue in terrestrial	UWSNs are higher
Memory	Terrestrial sensors have less capacity	Sensors require large memory capacity
Bandwidth	More bandwidth available	Poor available bandwidth
Path loss	Not frequent, easy path discover	Attenuation provoked by absorption due to conversion of acoustic energy into heat
Noise	Not affected as EM has less impact	Man-made noise, ambient noise
Delay	Less	5 $\times$ radio frequency (RF) ground

With respect to terrestrial networks, underwater sensor network required significant attentions in all the parameters while designing a routing protocol. Researchers working in this domain required to consider these parameters for better design and implement of a routing protocol.

5 Routing Protocols

5.1 Vector-Based Forwarding (VBF)

Vector-based forwarding [2] is a routing protocol which needs location information rather than state information. It reduces the energy consumption as interleaved paths are used for routing. It is based on self-adaptive algorithm dropped low benefit packets. It calculates the path based on relative position and the angle of arrival.

5.2 Distributed Minimum-Cost Clustering Protocol (DDD)

In this protocol [4], collector nodes are defined as underwater vehicles. Underwater vehicles admit its presence by sending beacon messages. Underwater vehicles collect the data when it reaches to the sink and reduce the cost of the networks. Number of underwater vehicles can be reduced but it increases collision and overhead.

5.3 Energy Optimized Path Unaware Layered Routing Protocol (E-PULRP)

E-PULRP [4] does not require location information. It is based on formation of sphere around sink. Here, packets are transmitted through multiple hops and energy can be reduced if number of layer is increased up to a significant level. Energy consumption depends on transmission and sphere formation.

5.4 A Mobile Delay-Tolerant Approach (MCCP)

A distributed minimum-cost clustering protocol (MCCP) [10] is proposed cluster head formation based on the assumption. So, energy requirements are comparatively less in cluster head selection. Total energy requirement = residual energy of the cluster head + total energy consumption of the cluster + cluster members and the distance of the cluster head to the sink. It requires more energy efficiency in comparison with ad hoc networks.

5.5 DBMR Protocol

Depth-based multi-hop routing [7] can work in both multicast and unicast mode. This protocol gives better performance in sparse area. The performance of DBMR is quite impressive in terms of packet delivery and delay. Communication cost is also reduced in this protocol. This protocol is working on neighbour-group and distant node selection. Here, energy is a major issue but compared to DBR, it gives better performance [11]. In this protocol, each and every node is omni-directional. Nodes are deployed randomly and then update the routing table accordingly.

5.6 GPS-Free Routing Protocol

Distributed Underwater Clustering Scheme (DUCS) [6] is based on self-organizing protocol. It follows distributed algorithm. In this protocol, cluster head formation takes place in set up phase. Non-cluster nodes send packet to their heads in a single hop. Cluster head sends packets via multi-hop to the other cluster heads. Cluster head is randomly changed after a certain time to optimize energy consumption. Network operation is performed in steady state. This protocol gives satisfactory results in deep water. It increases very high packet delivery ratio as well as throughput for UWSNs.

5.7 Void-Aware Pressure Routing

Void-aware pressure routing [5] is a simple and robust based on subset of forwarders. It follows two strategies: efficient greedy forwarding and dead-end recovery methods. In these protocols, nodes send packets towards next-hop direction towards the surface. This protocol is very robust to network dynamics such as node mobility and failure. VAPR does not require any recovery path maintenance during recovery. VAPR is composed of two major components, namely enhanced beaconing and opportunistic directional data forwarding.

5.8 Multi-level Routing Protocol

The experiment results show that MURAO [3] achieves much higher delivery rates and delay is very less. It based on multi-level distributed Q-learning scheme. It can

Table 3 Comparative study of various routing protocols [12–14]

Routing protocols	Advantages	Disadvantages
VBF	Energy efficient, data delivery high	Packet delivery low, more delay
E-PULRP	Location based, energy efficient	More delay
DDD	Energy efficient, bandwidth fair	Packet delivery low, cost high Overall performance low
MCCP	Robustness, energy consumption	Packet delivery low, more delay
DBMR	Packet delivery ratio high	Not energy efficient
GPS-free	Packet delivery high, scalable	Deliver ratio less, not reliable
VAPR	Simple and robust, excellent performance, delivery ratio high, delay efficient	Not energy efficient More cost
MURAO	Higher delivery rates Delay is very less	Data delivery rate low, more delay

be deployed in long range in acoustic communication. This protocol consists of cluster formation and update, inter-cluster routing, intra-cluster routing and inter-layer interaction. MURAO adopted dynamic change in networks (Table 3).

6 Conclusions

In this paper, we have explained various routing protocols depicted in underwater wireless sensor networks theoretically. Basic purpose of various routing protocols is to face challenges in UWSN. The protocols are designed to minimize energy as battery life of sensor node is limited. On the other side, keep in mind various application domains for improving delivery speed with minimum packet loss. We have shown two different scenarios: deep and shallow water. Routing protocols depend on various communication medium as bandwidth is a major issue in underwater wireless sensor networks. We have discussed comparative study on various communication mediums. It will be helpful to the researchers for limitations in various application domains. Further, we have given detailed major challenges in underwater wireless sensor networks compared with terrestrial networks.

7 Future Scope

Clustering techniques improve throughput and reliability while minimizing power consumption. Energy harvesting can enhance routing in underwater wireless sensor networks. For long distance, energy harvesting will give a secure and reliable solution towards variety of application such as disaster and pollution control. Optimized path selection towards destination can maximize battery life and speed up communication.

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