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A SURVEY ON ROUTING PROTOCOLS FOR UNDERWATER SENSOR WIRELESS NETWORKS

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Abstract: *Underwater communication in recent times has gained great importance owing to reasons varying from predicting natural disasters to formulating strategic defence systems. Underwater communication systems face challenges ranging higher propagation delays to frequency related constraints like bandwidth limitations, Doppler spread, multipath propagation and is greatly affected by distance between nodes and link orientation. This calls for the formation of most appropriate routing protocol for UASN. This paper explores the significant advantages, disadvantages and applications of different existing routing protocols*

I. INTRODUCTION

Underwater sensor networks are being widely utilized in modern times in different areas of underwater research including industrial research, structural monitoring, micro-habitat monitoring[1] etc. The topic is still in the beginning stage compared to its terrestrial counterpart basically due to the involvement of high cost and physical challenges involved in. Even then, UASN found place in many vital physical applications in the fields like oil and gas exploration [2], sensing of chemical contamination and biological phenomena, seismic studies etc. This topic assumes great importance in modern times not only for scientific community but also for the governments; industries etc as it have found application in every underwater human activity.

To understand the basics of UASN, we can utilize many design principles and tools used in terrestrial sensor networks. But they are characteristically different in some fundamental points. Most importantly radio is unsuitable for underwater sensors due to their limited propagation ability [3]. This is when acoustic signals are being utilized for underwater communication which again poses many challenges[4] like high propagation delays, loss of connectivity in shadow zones, high rate of power absorption etc. Hence the requirement for specially designed routing protocols for UASN becomes inevitable. Thus, intense research programmes are being undertaken for designing efficient protocols considering the unique characteristics of underwater communication networks.

A. Applications of underwater acoustic sensor networks

The broad range of applications for underwater acoustic sensor networks can be categorized as under.

- Surveillance: surveillance and reconnaissance like detecting presence of submarines, underwater vehicles, mines and divers. It relatively delivers more accuracy than the conventional radar and sonar systems. For this, different types of sensors are utilized in combination.
- Assisted Navigation: Underwater Acoustic sensors are used in assisted navigation to locate and identify different underwater threats like rocks, shoals, submerged wrecks etc and bathymetric surveys.
- Ocean Sampling Networks: Underwater acoustic sensors can be used for synoptic, cooperative adaptive sampling of ocean environment. The introduction of sophisticated robotic vehicles of advanced models has improved the effectiveness of the UASN when used collectively.
- Environmental monitoring: The recent development in UASN and electronics can effectively be used in environmental monitoring in underwater surroundings.
- A large number of nodes can be deployed in vast areas to monitor the impact of urbanization and industrialization on oceanic environment. It also helps in assessment and of risk and environmental sustainability and also can assist with real time data about bioavailability and mobility.
- Preventing natural calamities: Underwater sensor networks can effectively be utilised [30] for monitoring submarine seismic activities which in turn can predict tsunami like disasters. It also helps to study the impact of underwater earthquakes.
- Mineral and oil exploration: Underwater sensors can be used for detecting the presence of minerals and oil under sea water. It can also be used for detecting chemical and oil leaks from commercial tankers carrying them and also in monitoring biological phenomena like presence of phytoplankton in large numbers.
- Water quality monitoring: Underwater sensors find place in analysing water properties in dams, rivers, lakes ,oceans and underground water reserves. It enables the creation of database of water bodies and allows the constant monitoring [28] in

locations of difficult access without physical human interference.

B. Major challenges in designing of UASN

Intense researches are presently underway in developing suitable networking solutions for Underwater acoustic sensor networks. Even though there are many recently developed protocols for wireless sensor networks, the entirely different characterists [31] of underwater communication systems poses different challenges[6] which can be summarized as follows.

- Propagation delay in underwater communication is 5 times higher than terrestrial channels and is also variable in nature.
- Underwater sensors face failure due to corrosion and fouling.
- Power supply to UWSN is a major concern as the battery power is limited and recharging is difficult. Again, it has higher power consumption requirements.
- Due to extreme characteristics [32,41] of underwater channel like shadow zones, temporary loss of connectivity is common accompanied by high bit error rates.
- Available bandwidth for UWSN is extremely limited.
- Underwater channels are severely impaired mainly due to fading and multi-path.
- High level of noise [33] from shipping activity and machinery noise are concern in UASNs.

II. UNDERWATER NETWORK ENVIRONMENT

Underwater sensor networks is a composition of a group of sensor nodes anchored to the sea bed which are connected to other underwater gateways by acoustic links. UASN consists of underwater LANs called clusters or cells. These clusters consists of sensors and sinks where sensors are connected to sinks within each cluster. This connections may be direct paths or multiple hops. The signals shared at each sink within cluster is sent to surface stations through a vertical link. The surface station with the help of acoustic transceivers handles multiple parallel communication with the sinks deployed under the water. A sample network environment is shown in the figure 1.[7,46].

III. DIFFERENCE BETWEEN TERRESTRIAL AND UASN

Due to the major difference in the operational environments, there exists many basic differences[8] between terrestrial sensor networks and their underwater counterparts. They can be summarized as follows:

- Difference in deployment: Since terrestrial sensor networks are deployed densely, the underwater deployment of sensors are sparse due to the involvement of high cost factor and difficulty in deployment itself.
- Cost: Due to more complex design and hardware protection requirements, the underwater sensors are much more costlier than terrestrial sensors.
- Power requirement: Underwater sensor networks require more power consumption [34] due to higher distance and usage of complex signal processing methods at the receivers to balance the impairments of the channel.
- Storage: Underwater sensor need to have more data storage capability as the channel may be intermittent.
- Performance: Performance [40] of ground based wireless sensor networks are better than underwater acoustic protocols.
- Mobility: Terrestrial networks use fixed sensor and underwater sensors are mobile [39,47].

IV. NETWORK LAYER CHALLENGES

The main objective [38] of the network layer is to allow end system, connected to different networks, to exchange data through intermediate systems called router. It find the path from source to the destination while taking into consideration of the characteristics of the channel.

This includes energy of nodes, propagation delays etc. Routing protocols for underwater sensor networks face a number of difficulties due to the peculiar underwater environment. Routing protocols are divided in to three categories namely proactive, reactive and geographical[9,44] .Due to memory, energy and scalability issues, proactive routing protocols are generally avoided. High latency and asymmetrical links and topology of reactive protocols make them unsuitable for underwater sensor networks. Geographical routing protocols [36] are promising for their scalability and localized signaling. But strict synchronization requirement of geographical routing protocols are difficult to obtain in underwater networks due to variable propagation delays. GPS used in terrestrial networks to estimate the geographical location cannot be used in underwater environment as the GPS radio receivers doesn't work [48] under water. Scope for further research is immense in this area.

Open research issues at the network layer [10] are,

- Mechanisms have to be developed for delay-tolerant
- applications to manage loss of connectivity without provoking immediate retransmissions.
- Development of healthy routing algorithms is required with respect to the intermittent connectivity of acoustic channels. Due to fading and multipath, the quality of acoustic links is highly unpredictable.
- The delay variance of acoustic signals to propagate from one node to another heavily depends on the distance between two nodes. The delay variation in horizontal acoustic links are generally larger than in vertical links which is due to multipaths [37]. This necessitates the development of algorithms to provide strict or loose latency bounds for time critical applications [11].
- Credible simulation models and tools are required to be developed for accurate modeling to understand dynamics of data transmission at network layers.
- Protocols and algorithms are required to be developed to address connection failures, unforeseen mobility of nodes and battery depletion.
- Suitable algorithms for local route optimization needs to be designed [12] to address the consistent variations in the metrics describing the energy efficiency for the underwater channel.
- In case of geographical routing protocols development of efficient underwater location discovery techniques [42] are to be developed.
- Necessary integration mechanisms are to be developed to integrate AUVs in underwater to communicate between sensors and AUVs.

V. ROUTING PROTOCOLS FOR UASN

Designing an optimum routing protocol is the basic issue involved with any network. Formulating an efficient routing algorithm is an important issue related to network layer. Till recent times, most of the research works involving underwater sensor networks were limited to physical layers. But a substantial shift of interest towards research on network layers is taking place in recent times. Still the field of underwater sensor networking and routing protocols are in the incipient stage of research.

The major routing protocols proposed for UASN are discussed below:

A. Vector based forwarding (VBF)

In vector Based Forwarding [13], data packets are forwarded along redundant and interleaved paths from the source to sink. This helps in handling the problems of packet losses and node failures. Forwarding path is nominated by the routing vector from sender to target. All the nodes receiving the packet computes their positions by measuring its distance to the forwarder. It is assumed that every node already knows its location and each packet carries the location of all nodes involved. The forwarding path is virtually a routing pipe and the nodes inside this pipe are eligible for packet forwarding.

B. Hop-by-hop Vector based forwarding (HH-VBF)

In HH-VBF [14], virtual routing pipe concept is used. Each forwarder is defined by per hop virtual pipe. Based on its current location, every intermediate node makes decision about the pipe direction. The advantage is, HH-VB can find delivery path even if the number of nodes available in the forwarding path is very limited in number. Simulation results show that it has good packet delivery ratio and more signaling overhead in sparse areas than VBF. Simultaneously, it faces the problem of routing pipe radius threshold, affecting its performance.

C. Focused beam routing (FBR)

FBR protocol [15] for acoustic sensor networks are intended to avoid unnecessary flooding of broadcast queries. Overall expected throughput can significantly be reduced by overburdened networks due to uncertain location information of nodes. In FBR, every node in the network is expected to be aware of its location and every source node is aware of its destination. Locations of intermediate nodes are insignificant here and routes are established vivaciously during data transfer.

The concept of FBR is not free from drawbacks. Due to water movements, nodes can become sparse resulting in a situation that none of the node lie within the forwarding cone of angle. Secondly if some nodes are positioned outside the forwarding area, it is forced to retransmit the RTS eventually resulting in the increase in communication overhead. It will subsequently affect the data delivery in the sparse areas. Lower flexibility of network is also a drawback of FBR concept.

D. Reliable and energy balanced routing algorithm (REBAR)

It is a location based routing protocol [16]. An adaptive scheme is formulated by defining data propagation range to balance the energy consumption of the network. Geographic information is used by the nodes between the source and sink to transfer the data. Each node is assigned a unique ID and fixed range. REBAR is based on the following assumptions.

a) Every node knows its location and of the sink through multihop routing.
b) Sensed data i are sent to the sink at a specific rate.

The major disadvantage of REBAR is that the available simulation results focus only on delivery ratios and energy consumption with different node speeds. But end to end delays, variable according to different node movements, are not taken in to consideration.

E. Sector-based routing with destination location prediction (SBR-DLP)

It has been designed for routing a data packet in mobile UASN where both intermediate and destination nodes are mobile. It is assumed that each node knows its own location and pre planned movement of destination nodes. Forwarding of data packets are done in a hop by hop manner to avoid flooding. SBR-DLP [17] tries to achieve destination mobility by assuming that all pre planned movements are known to all nodes before the deployment. But the limitation of this concept is that, post launch position changes are impossible. Moreover, scheduled movements of destination nodes can be affected by underwater currents.

F. Directional flooding-based routing (DFR)

Reliability, packet loss and dynamic conditions are the major challenges in UASN which results in retransmissions. This protocol enhances reliability by packet flooding technique[18]. The assumption is that all nodes knows about its own location, location of one hop neighbours and that of the final destination. Link quality is the foundation for deciding the forwarding nodes. This protocol rectifies the void problem by the selection of at least one node to transmit the data packet towards the sink. But void problem can still exist if the sending node cannot find a next hop closer to the sink as reverse transmission of data packet is impossible.

G. Location aware source routing (LASR)

In LASR [19], two techniques are adopted for handling high latency of acoustic channels, namely link quality metric and location awareness. Link quality metric assures better routes through the networks. All the network information including routes and topology information are passed on in the protocol header. Resultantly header size increases as the hop count between source and sink increases. This leads to overhead for acoustic communication with a narrow bandwidth.

H. Depth based routing (DBR)

Unlike the location based routing protocols, the DBR [20] requires only the depth information of sensor node. Depth sensors are used for this purpose. When a node wants to send a data packet, it senses own relative current position from the surface and place its value in the header and then broadcasts. The receiving node calculates its own depth position and compares this value with the value embedded in the packet. If it is smaller, the packet is forwarded. Otherwise the packet will be discarded. The process is repeated until the packet reaches the destination. The main disadvantage of this protocol is that in sparse and high density areas, the performance is affected by packet loss and inefficient memory usage.

I. Pressure routing (HydroCast)

In order to overcome the limitations of geographic routing, Hydrocast [21]is proposed as an alternative as it doesn't require distributed localization. Like DBR, data packets are greedily forwarded towards a node with lowest pressure level of the surrounding nodes. Hydrocast is not affected by the problem of void regions.

High delivery ratios are also ensured in Hydrocast by the use of simultaneous reception among the neighbour nodes. But the problems like energy usage of pressure sensors and delivery of multiple copies of the same data due to opportunistic routing are still to be addressed.

J. Adaptive routing

In UWSN, unavailability of persistent route from source to destination is a common problem arising out of sparse deployment and node mobility. Hence, UWSNs are called intermittently Connected networks (ICN) or Delay Tolerant Network (DTN) [22,43] and usual routing techniques are unsuitable for them. Adaptive routing [23] is technique is introduced where it is assumed that all nodes know their 3rd position. Here routing decisions are dependent on the characteristics of each packets. Main disadvantage of this method is that, due to the complex nature of the protocol, energy consumption and end to end delays are common.

K. Distributed underwater clustering scheme (DUCS)

Main concern related to UWSNs is effective utilization of energy because continuous power supply is dependent on batteries having limited capacity [45]. This emphasized the requirement of an energy efficient routing protocol. DUCS [24] is designed as an adaptive self-organizing protocol and the network is divided into clusters of nodes having a cluster head. All other nodes except cluster head transmit data packet to cluster head node. Cluster heads process the signals and transmit it to the sink. This ensures high packet delivery ratio and reduces the network overhead. Major problem faced by DUCS is that the cluster structure can be affected by underwater currents which reduces the cluster life. Another serious drawback is that communication is possible only between cluster heads.

L. Distributed minimum-cost clustering protocol (MCCP)

In this routing technique, clusters are formed by computing three major parameters, ie, total energy requirement, residual energy of cluster head and members and relative location of the cluster head and underwater sink. In MCCP [25], clusters are selected using a centralized approach. In this, all the sensor nodes are candidates for cluster head and cluster member. Each node constructs its neighbour set and uncovers neighbour set in order to form a cluster. Average cost of particular cluster is calculated and broadcasted among the all nodes within its two –hop range with its cluster head ID. The node with minimum cost becomes the cluster head and other nodes become members. This approach avoids formation of hot spots and balances the traffic load periodically. Major disadvantage of this

M. Temporary cluster based routing (TCBR)

In many of the existing routing protocols for UWSN, a general problem faced by the network is that the nodes around the sink more prone to energy depletion and their life span is short comparative to the other nodes. TCBR [26] is proposed to address this problem where multiple sinks are deployed on the water surface \to receive data packets. This ensures higher bandwidth and reduced propagation delays. Two different types of nodes are used in this protocol namely ordinary and courier nodes. Ordinary nodes are supposed to sense event happening and collect information which is forwarded to nearer courier node. Courier nodes transmits data packets to the surface sink. Here, 2 to 4 percentage of total nodes are used as courier nodes which enables equal energy consumption throughout the network. The major disadvantage of TCBR is that it is not suitable for time critical applications.

N. Location-based clustering algorithm for data gathering (LCAD)

A cluster based architecture is proposed for three dimensional UASN which can address the problem of rapid energy drains of sensor nodes around the sink. In this architecture, sensor nodes are deployed at fixed relative depths. Sensor nodes in each tier are deployed in clusters with multiple cluster heads. According to the node position, this algorithm select cluster head at each cluster. The maximum length of horizontal acoustic link is limited to 500m which are used for intra-cluster communication. Data packet collection from the cluster heads are done by AUVs. LCAD [27] performance depends on the position of cluster head inside the grid structure. Node movements are not considered here. Therefore this structure is less applicable for UASN.

VI. CONCLUSION

Underwater communication is assuming greater importance day by day due to its ever increasing application in industrial, commercial and defense fields [50]. Unmanned underwater explorations are necessitated by the environment like inhospitable surroundings, unpredictable underwater activities, high pressure conditions [49]. In this paper we have presented an overall view of the UASNs and different routing protocols used depending on the requirements, appropriateness and availability of resources. Development of optimum routing protocol which makes it reliable and efficient is regarded as the vital part in UASNs. We have tried to compare, analyze and classify different routing techniques on the basis of their advantages, disadvantages and applications. Due to the different qualities these routing techniques possess, it becomes difficult to propose a particular one for a particular situation. Eventually, this study is to provide an overview of the topic which is growing rapidly and steadily.

VII. COMPARISON OF PROTOCOLS

Category	**Routing Protocol**	**Application**	**Advantages**	**Disadvantages**
Location Based Routing	VBF HH-VBF FBR REBAR SBR-DLP DFR LASR	Energy Efficient UWSN	a) Energy efficient b) Robustness c) High success of data delivery	a) Low bandwidth b) High latency c) Delay, efficiency, performance and reliability are low

Depth Based Routing	DBR	Dense Network Application	a) Very high packet delivery ratio b) No need of full dimensional location information of nodes	a) Not energy efficient b) Batteries are stranger to recharge
Pressure Based Routing	Hydro cast	Dense Network Application	a) Lower end-to-end delay b) Good performance and delivery ratio c) Delay efficient	a) Bandwidth and energy efficiencies are not good b) Higher cost in packet transmission
Adaptive Routing	Adaptive	Underwater delay/disruption tolerant sensor network	a) Energy and Bandwidth efficient b) Reliable c) High delivery ratio	a) Not able to use water current movement b) Delivery efficiency is not good
Cluster Based Routing	DUCS MCCP TCBR LCAD	Energy Efficient UWSN	a) High scalability and robustness b) Less load and energy consumption	a) Processing overhead is complex

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