Wireless under Water Sensor Network: Applications, Challenges, Characteristics and Routing Protocols

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Abstract- Nowadays, Underwater Sensor Networks (UWSN), in which data is collected through underwater sensors, have drawn lots of concern. Generally, wireless sensor network (WSNs) have important applications such as remote environmental monitoring and target tracking. Underwater acoustic sensor networks (UASNs) are often used for environmental and industrial sensing in undersea/ocean space, therefore, these networks are also named underwater wireless sensor networks. This possibility is enabled by the available smaller and cheaper sensors. These sensors are equipped with wireless interfaces which they form a network. However, there are various problems specified to underwater environments, including the communication medium. Designs of these types of networks significantly depend on their application, and factors such as environment, design objectives of the application, cost, hardware and system constraints. Underwater sensor networks are different from other sensor networks due to the acoustic channel used in their physical layer, thus we should discuss about the specific features of these underwater networks such as acoustic channel modelling and protocol design for different layers of open system interconnection (OSI) model. Each node of these networks as a sensor needs to exchange data with other nodes; however, complexity of the acoustic channel makes some challenges in practice, especially when we are designing the network protocols. MAC protocols suitable for sensor networks can be broadly classified into two categories : (i) scheduled protocols, (ii) Contention based protocols have good scalability and adaptively to changes in the number of nodes. Their energy efficiency can be improved by enabling low-duty-cycle operations on nodes. The goal of this work is to review the literature on various aspects of UWSNs, and present an overview of several new applications and their challenges. Wireless under water sensor network are reviewed to show the statistics of published works in several aspects of the WSNs.

***Keywords-* -** UWSNs , environmental and design objectives, OSI model and Routing Protocols (MAC, TDMA and CSMA).

I. INTRODUCTION

Underwater sensor network (UWSN) is emerging as an enabling technology for underwater explorations. UWSN is a fusion of wireless technology with extremely small micromechanical sensor technology having smart sensing, intelligent computing, and communication capabilities. UWSN is a network of autonomous sensor nodes [1] which are spatially distributed underwater to sense the water-related properties such as quality, temperature, and pressure. The sensed data can be utilized by variety of applications that can be used for the benefit of humans. The sensor nodes, stationary or mobile, are connected wirelessly via communication modules to transfer various events of interest [2]. Underwater communication is mainly done with a set of nodes transmitting their data to buoyant gateway nodes that relay the data to nearest coastal monitoring and control station also called remote station [3]. Generally, in UWSN acoustic transceivers are used for communication. The acoustic waves are low frequency waves which offer small bandwidth but have long wavelengths. Thus, acoustic waves can travel long distances and are used for relaying information over kilometres.

Nowadays, Underwater Sensor Networks (UWSN) is of high concern in a variety of fields such as industry, science, military, and so on. Today, majority of underwater communication systems works with acoustic technology. Factors that influence acoustic communications are path loss, noise, multi-path, delay, dropper spread. Typically, some sensors in UWSNs send their observed data to sink by multi-hop communication, but since building this type of network is in the water, therefore applying the terrestrial network protocol is difficult [4],[5].

For example, in terrestrial network, they used radio or optical waves for wireless communication. But in UWSN, it is hard to use these medium, hence they used acoustic waves. It is essential for acoustic communication to consider long delay problems that are mainly caused by the long propagation delay. Bandwidth limitation and high bit error rate, power limitation, sensor failures are the challenging problems for UWSN due to its challenging environment. Under Water Sensor Networks has two-dimensional and three dimensional architecture [6]. UWSNs are utilized for a wide range of applications such as monitoring the marine environment for scientific exploration to commercial exploitation and coastline protection to underwater pollution monitoring, from water-based disaster preventions to water-based sports facilitation. UWSN offers a promising solution to ever demanding applications.

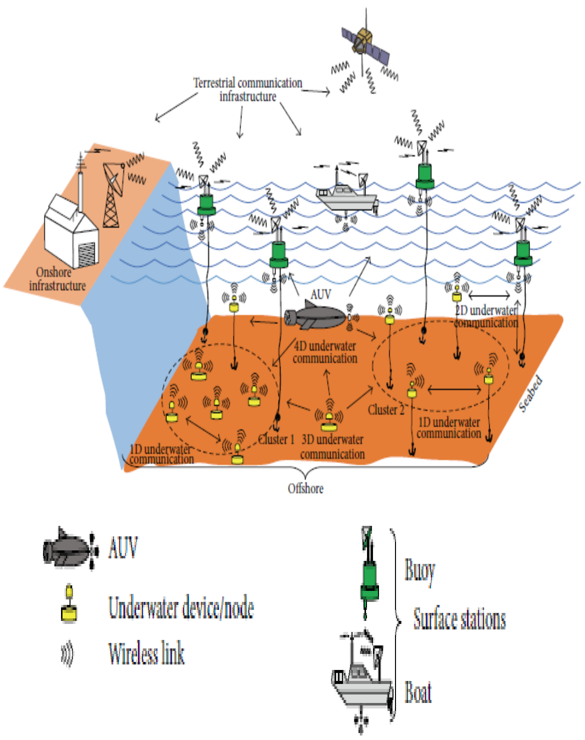

Fig.1: Underwater sensor network architecture [6]

However, UWSN applications are exciting but challenging at the same time. The reason lies in unpredictable conditions of water environment which creates serious constraints in the design and deployment of such networks. The focus of this paper is to survey the available UWSN application. The paper further focuses on classifying these applications and presenting a summary for each class.

II. LITERATURE SURVEY

Sensing and subsequent transmission of radio frequency waves in sub-sea environment and deep sea exploration requires a particular approach for medium in communicating. Noticing the fact that a huge amount of unexploited resources lies in the 70% of the earth covered by oceans this technology is mode more apparently critical to the new world. Yet, the aquatic world has mainly been unaffected by the recent advances in the area of wireless sensor networks and their pervasive penetration in modern day research and industrial development. However, majority of underwater deployments rely on acoustics for enabling communication combined with special sensors having the capacity to take on harsh environments of the oceans. A recently published survey paper presented by Murad et al. [7] particularly focuses on gathering most recent developments and experimentation related to key underwater sensor network applications and acoustic-type underwater sensor networks deployments for monitoring and controlling of underwater domains.

Felemban et al. [8] has presented a survey paper focusing on gathering most recent developments in underwater sensor networks applications and their deployments. In that paper, the authors have classified the underwater applications into five main classes as monitoring, disaster, military, navigation, and sports, to cover the large spectrum of these sensor networks. These applications are further divided into relevant subclasses. They have also shown the challenges and opportunities faced by recent deployments of underwater sensor networks.

The location information of sensor nodes is important and they should be accompanied with data collected through sensors. Thus, localization for underwater acoustic sensor network has becomes a very interesting topic of research in the last decade. However, several limitations of acoustic channel like low bandwidth, high bit error rate etc. along with long propagation delay of the sound wave and limited battery power of the sensor nodes within the water make the localization of underwater nodes very challenging. Regarding these challenges, an event-driven time-synchronization free distributed localization scheme for large scale three dimensional underwater acoustic sensor networks is presented in the work of Kundu and Sadhukhan [9]. Their scheme employs a recursive localization process in which successfully localized nodes can act as reference node to aid for localization of the other ordinary sensor nodes and two ways for distance measurement in order to avoid the requirement of time synchronization.

In general, battery-powered sensors in a sensor network operates while they can. In this context, it has two competing objectives; the first one is to maximized performance based on upper bound probability of successful search for false alarms, and second one is to maximized network operational time. As both sensing and communication of data use battery energy thus accurate amount of energy is needed to improve the operational lifetime of the sensor network. In a recently published paper, Jha et al. [10] presents an optimal energy allocator for nodes to manage energy consumption adaptable according to that sensing and communication node to maximize the network performance subject to specified constraints. Fixed total amount of energy allocation for specific time reduce the problem to synthesis an optimal network topology that maximizes successful search probability in a surveillance region.

In order to have efficient routing protocols for data packet delivery in underwater sensor networks (UWSNs) and deal with roughness of acoustic channel network, coding has become vital. This technique is promising technique for efficient data packet delivery because of acoustic channels broadcast nature and their sensor nodes high computation capabilities. In this work, Hao et al. [11] introduced GPNC which is a geographic routing protocol for underwater sensor networks that works cooperatively with partial network coding to encode data packets and forward data to sink node. They have mentioned that GPNC has effectively reduced delays and retransmission which caused additional energy uses.

III. APPLICATIONS AND CHALLENGES IN UWSNs

The described features in the literature enable a broad range of applications for underwater sensor networks as:

- Environmental Monitoring: Environmental monitoring is one of the most important applications of underwater sensor networks. Such as Monitoring of chemical and biological pollutions, ocean currents and winds, weather forecasting and detecting climate changes [12].
- Assisted Navigation: Exploring and locating rocks, shoals, mooring positions, submerged wrecks and any other critical position of interest are another important application of underwater sensor networks.
- Distributed Tactical Surveillance: Using underwater sensor networks one can monitor an area for surveillance, reconnaissance, targeting and intrusion detection systems [13].
- Seismic Monitoring of Underwater Fields: Seismic monitoring of underwater fields is another important application of underwater sensor networks. Studies of variation in the oil reservoir over time which can be used for assessment of field performance and necessary interventions refer to the topic of “4-D seismic monitoring”.
- Disaster prevention: measuring remote location seismic activity from remote locations can help to detect oceans disaster such as tsunami.

In the previous section, we understood the specific features of an acoustic communication channel. These features create challenging issues in underwater sensor networks. In sub-sections of the current section, we review corresponding issues of different layers of UASNs from the PHY layer to application layer.

- Physical Layer (Phy) and
- MAC Protocol

Table 1. shows available bandwidth for different ranges in underwater acoustic channels, in fact, the features of underwater acoustic channel have caused these outputs in practical studies. Note that this table is independent from any signalling scheme (communication modulation, coding and etc.) and also transmission power, and in fact only shows available bandwidth in Hz. Explicitly, bandwidth is depended to distance from wave source that it is known as communication range in Km. Therefore, the bandwidth limitation is a major problem in the acoustic channels.

Table 1. Available bandwidth for different ranges in underwater acoustic channels [12]

Coverage	Range (Km)	Bandwidth (KHz)
Very long	1000	< 1
Long	10-100	2-5
Medium	1-10	10

Table 2. Progress in digital modulation techniques for acoustic channels; notation (s) shows shallow waters and (d) shows deep waters. [13]

Type	Year	Rate (Kbps)	Bandwidth (KHz)
FSK	**1984**	**1.2**	**5**
DPSK	**1997**	**20**	**10**
8-PSK	**2010**	**120**	**80**

Medium access control (MAC) is an important part of data link layer (the second layer in the OSI model). Main duty of MAC is channel allocation or in the other words, bandwidth multiplexing based on multiple access techniques in networks. Hereby, MAC protocols in addition to modulation and channel coding techniques which are used in PHY layer, can be known a way for enhancing the network signaling. Of course, there are some appearances of signaling in the application layer, i.e ., control of the network performance based on application layer tools and efficient signal processing techniques.

This table 3 also shows reasons of each challenge briefly. Some of them are main reasons of lower bandwidth of the acoustic links and the rest of them are main reasons for low data rate (Kbps) directly.

Table 3. A brief list of the challenges in PHY layer based on the acoustic channel. [13

Challenges	Reason(s)
Path loss	**Geometric spreading/Energy loss**
Noisy channel	**Human made noise/Ambient noise/Other noises**
Hard channel fading	**Multipath**

IV. CHARACTERISTICS IN UWSNs AND DIFFERENCES (TERRESTRIAL and UWSNs)

UWSN has its own characteristic, for example, underwater acoustic channels are unique. Over all, terrestrial networks specification could not be used in underwater acoustic ones.

- Physical Implementation Limitations
- Medium Access Control
- Resource Sharing
- Data Transfer in Reliable State
- Multi-hop Routing
- Localization.

The main differences between terrestrial and underwater sensor networks are as follows [14]:

- Cost: Due to complexity and hardware protection challenges underwater sensors unlike terrestrial sensor nodes are expensive.

- Deployment. Due to the cost and challenges associated with the deployment of sensor nodes, compared to terrestrial sensor nodes which are compactly deployed, underwater sensor nodes deployment is sparser.
- Power. Due to long distances and more complexity of signal processing at the receivers, the power assumption for underwater sensor network communication is higher than radio communication.
- Memory. While underwater sensors carry out some data storage on the other hand, terrestrial sensor nodes have very limited storage capacity.
- Spatial Correlation. Because of farther distance between underwater sensors, readings data is different from readings in terrestrial sensors.

V. ROUTING PROTOCOLS IN UWSNS

In this section we give an overview of the concept of OR, its advantages, and different issues and parameters that should be considered for its use in different types of networks.

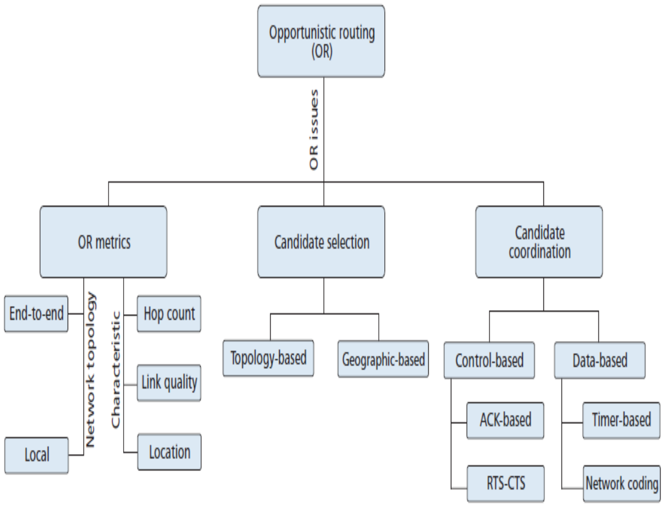

Fig.2: Routing Protocol in Various classification [14]

When a node sends a packet to a designated next-hop forwarder in a wireless environment with unreliable and lossy links, the next-hop node may not receive the packet. However, due to the broadcast nature of the wireless medium, a packet that is transmitted to the next-hop forwarder may be received by neighbouring nodes which will be unable to assume the role of designated next-hop forwarder. Therefore, using OR, each packet travels along different paths toward the destination. This property of OR makes it suitable to be used in UWSNs, which face low link delivery probability. The performance of OR protocols is affected by three main factors:- [15]

• The algorithm that selects the candidates.
• The metric used to select and prioritize the candidates.
• The method used by nodes in the CS to communicate with each other in order to do the coordination.

- **Candidate Selection ,** it places it in the data packet header and broadcasts it. The candidates that have received the packet should collaborate with each other to decide which one must continue forwarding the packet, while the others should discard the packet.
- **Geographical :** The geographic positions of nodes are used in this category of OR protocols in UWSNs to select candidates and make the decision to forward the packets. By knowing the positions or the coordinates of their neighbours, the nodes are able to forward the packets.
- **Depth based routing :** It uses the depth information of nodes as a metric to decide whether to forward the packets. It assumes that each node is equipped with a depth sensor to measure the depth of node. With the OR concept, the nodes closer to the water surface are potential candidates for receiving and forwarding the packet.

VI. CONCLUSION

UWSNs have been concerned in recent years for their applications in data collecting, by scattering sensors in water. Underwater wireless sensor networks have important applications in remote monitoring and target tracking, due to their intelligent sensors. Equipping with wireless interfaces with which they communicate raises various problems specified to underwater monitoring, including the communication medium. The design of a UWSN depends on factors such as environment, application's design objectives, and cost, hardware and etc. We reviewed the features and challenges of the underwater acoustic links in order to apply in underwater sensor networks. Generally, main idea of this survey is creation of a perception of underwater acoustic sensor networks' challenges. The discussed items contained PHY layer constraint, MAC and routing design, and new topics regarding signal processing of UASNs. We find out that all of these challenges create networking complexity; therefore, attention to these challenges is an essential condition while designing the efficient network protocols.

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