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Research Article

UNDERWATER WIRELESS SENSOR NETWORKS: APPLICATIONS AND CHALLENGES IN OFFSHORE OPERATIONS

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A B S T R A C T

Underwater Wireless Sensor Networks (UWSNs) comprise numerous components such as vehicles and sensors deployed in a specific acoustic area to perform collaborative monitoring and data gathering tasks. Presently, UWSNs face issues and challenges regarding limited bandwidth, high propagation delay, 3D topology, media access control, routing, resource utilization, and power constraints. Research on alternate methodologies to overcome these issues and challenges is underway. However, some of issues remain open for research due to variable characteristics of underwater environment. This paper is a survey of UWSN issues and challenges, in particular, regarding underwater communication, environmental factors, localization, routing protocols, and effect of range and packet size on underwater communication. The paper further proposes solutions to mitigating some of these issues and challenges in real time underwater monitoring using UWSNs.

INTRODUCTION

Three quarters of the earth is covered with water bodies such as streams, rivers, dams, lakes, seas, and oceans. There is need to explore and monitor various resources underwater through technology. Technological advances are making it possible to utilise various sensors at different levels. Accordingly, Underwater Wireless Sensor Network (UWSN) is emerging as an enabling technology for underwater exploration and monitoring applications. 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 distributed underwater to sense various water-related properties such as quality, temperature, and pressure.

The sensed data is collected and processed by a variety of applications that results in a number of benefits. The sensor nodes maybe be stationary or mobile, and are connected wirelessly via communication modules to transfer various events of interest [1]. Underwater communication comprises a set of nodes transmitting their data to buoyant gateway nodes that relay the data to nearest coastal monitoring and control stations called remote stations [2].

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Generally, acoustic transceivers are used in UWSN communications. The acoustic waves are low frequency waves, which offer small bandwidth but have long wavelengths. Thus, acoustic waves can travel long distances facilitating relaying of information over long distances of up to kilometres away[3].

Applications of UWSNs include 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.

However, UWSN applications are promising but drawbacks due to a number of issues and challenges hinder their rapid development and implementation. The main reason is the unpredictable conditions of water environments, which create serious constraints in the design and deployment of this type of sensor networks. This paper is a survey of current UWSN applications. The paper further focuses on issues and challenges on design, development and implementation of these sensor networks. In the end, concludes the survey and offers future research directions.

Underwater Wireless Sensor Network Architecture

In this section, we discuss the common UWSN architectures, illustrated in Figure 1. These are the basis for designing

UWSN applications. Underwater network's physical layer utilizes acoustic technology for communication. The technology is characterised by limited bandwidth, capacity, and variable delays. Therefore, new data communication techniques and efficient protocols are required, for underwater acoustic networks. The network topology requires significant planning from design stages since underwater network performance is generally dependent upon topology design. Energy consumption of the network topology is another important factor to consider. Design of topology for underwater sensor network is an open area for research. Various architectures for Underwater Wireless Sensor Networks are in Figure 1.

One Dimensional Underwater Wireless Sensor Network Architecture

In One-dimensional (1D) UWSN architecture, deployment of sensor nodes occurs autonomously. Individual sensor nodes represent a stand-alone network, responsible for sensing, processing, and transmitting the information to the remote station [4]. A typical example of a node in this architecture can be a floating buoy sensing underwater properties or deployed underwater for a particular period to sense information and then float towards the surface for transmission of gathered information to the remote station. This may also be an Autonomous Underwater Vehicle (AUV) deep inside the water to sense or gather required underwater properties, and communicate the information to the remote station. In 1D, communicating nodes can UWSN utilise acoustic, Radio Frequency (RF), or optical communication. Moreover, the topological nature of 1D UWSN is star where the transmission across the sensor node and the remote station is over a single hop.

Two-Dimensional Underwater Wireless Sensor Networks

Two Dimensional (2D) networks utilise deep ocean anchors for connection of sensor nodes in two-dimensional underwater sensor network architecture. Anchored underwater nodes use acoustic links to communicate with each other or with underwater sinks. Underwater sinks are responsible for collecting data from deep ocean sensors and transmitting to offshore command stations using surface stations. Underwater sinks connect to horizontal and vertical acoustic transceivers. Purpose of horizontal transceivers is to communicate with sensor node, for data collection or sending commands to the nodes, as have been received by offshore command station. Vertical transceiver for transmission of data to command station. Vertical transceiver should have a longer range since oceans can be as deep as 10 km. In addition, surface sinks equipped with acoustic transceivers has the capability to manage parallel communication using multiple organized underwater sinks. Surface sinks are also equipped with long-range radio frequency transmitters, to communicate with offshore sinks.

Three-Dimensional Underwater Wireless Sensor Networks

In Three-Dimensional (3D) architecture, sensor nodes float at diverse depths monitoring a particular activity in three-dimensions. Traditionally underwater three-dimensional sensor networks utilise surface buoys that provide ease in deployment of these networks. However, there is vulnerability to weather and tampering. The 3D architecture utilises the ocean bottom to anchor sensor nodes. Wires attached to anchors control the depth of the sensor nodes. Varying conditions and properties of the ocean present major challenges to these networks [4–8].

Four-dimensional Underwater Wireless Sensor Networks

The Four-dimensional- (4D) UWSN incorporates immobile networks, such as the 3D-networks and mobile UWSNs. The mobile UWSN comprises of Remote Operative underwater Vehicles (ROVs) for data collection from the anchor nodes and relaying it to remote stations. ROVs can be autonomous submersible robots, vehicles, ships, and even submarines. Individual sensor nodes can autonomous relay collected data direct to ROVs depending on proximity to the ROV. The communication to be used is either acoustic or radio depending on the distance and data to be transmitted between the nodes. Since the transmission is direct to the ROVs, sensors having large data and are close to ROVs can utilise radio links while the sensors which have small data to transmit or are far from ROVs utilise acoustic links [9],[10].

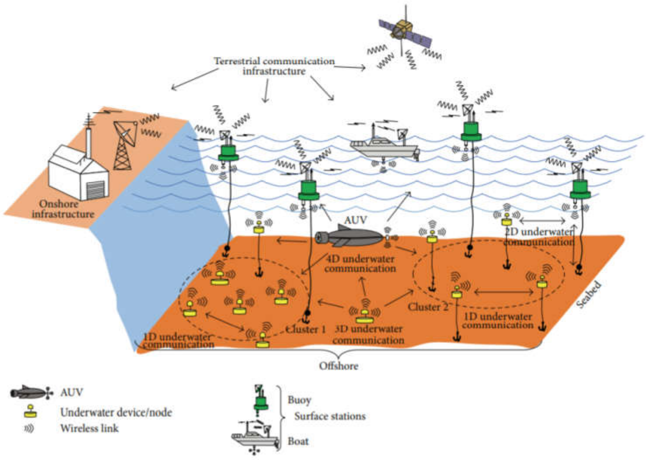

Figure 1 Underwater Wireless Sensor Network Architecture

Underwater Wireless Sensor Networks Monitoring and Control Applications

Seismic monitoring

Seismic monitoring for oil extraction from underwater fields is promising application of these UWSNs. Regular seismic monitoring is of significance in oil extraction. The 4-D seismic is a study of variation in the reservoir over a certain period; this is useful for monitoring overall field performance and motivating intervention. This allows constant monitoring of Terrestrial oil fields, permanently instrumented fields and storage facilities depending on requirements such as continuously, daily, quarterly or annually. However, this area has many existing challenges. The monitoring of underwater oil fields is complex, partly because the deployment of current seismic sensor in underwater fields is not permanent. Instead, seismic monitoring of underwater fields typically involves a ship with a towed sonar array as the sensor and air cannon as the actuator. The capital and operational costs involved for the ship and crew prohibits constant evaluation of these underwater fields. As a result, it is difficult to implement intervention strategies and asset management approaches suitable for terrestrial fields to underwater fields.

Equipment Monitoring and Control

Another application of importance is the underwater equipment monitoring. Ideally, underwater equipment includes monitoring support when deployed, possibly associated with tethered power and communications therefore less intervention is required. However, provisional monitoring would benefit from low power, wireless communication. Provisional monitoring is useful when equipment immediately after equipment deployment for confirmation of the deployment or when issues arise. Possibilities of this application include remote-operated or robotic vehicles or divers. Equipment monitoring and control shares many technical requirements of seismic monitoring, such as the need for wireless (acoustic) communication, automatic configuration of a multi-hop network, localization and hence time synchronization, and energy efficient operation. The main difference is a shift from burst type of traffic and interval-based sensing in seismic networks, to a steady and frequent sensing in equipment monitoring. Connecting underwater equipment with acoustic sensor networks enables and simplifies remote control and operation of equipment. Current remote operation relies on cables connecting to each piece of equipment. However, deployment and maintenance costs are still considerably high.

Flocks of Underwater Robots

An application area gaining prominence is the use of UWSNs in supporting groups of underwater autonomous robots. The application includes coordinating adaptive sensing of chemical leaks or biological phenomena and equipment-monitoring applications as discussed. Communication is pivotal in the operation of groups of robots on land for a coordinated action. Underwater robots today are typically either fully autonomous but largely unable to communicate and coordinate with each other during operations. They may be tethered to communicate, but with limitations on deployment depth and manoeuvrability. These communications among underwater robots should be low-rate information for telemetry, coordination, and planning. Bottlenecks still exist in Underwater Real time Monitoring, Control and Communication systems due to various constraints such as low data rates to support full-motion video and tele-operation. Existing solutions mostly support on-line delivery of commands and the ability to send back still frame images.

Field Components of Underwater Real time Monitoring, Control and Communication System

The important field components of any underwater monitoring system prerequisite for real-time monitoring and control of underwater pipelines consist of sensors and measurement and control devices. The sensors measure and monitor pipeline parameters such as pressure, vibration, flow, acoustic, level, sound, density, temperature, etc. Sensing devices such as transducers, transmitters, indicators and meters accomplish real-time monitoring and measurement. The relationship between sensors and measurement devices also called transducers in the block diagram in Fig. 2.

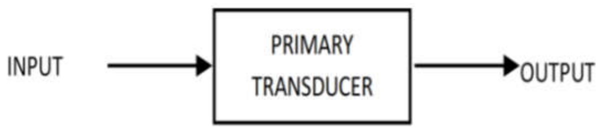

Figure 2 Block Diagram of a Sensor Node

The communication systems maybe based on wired or wireless links such as copper, fibre optics, RF wireless or hybrid networks. These Communication systems transmit data gathered from the underwater pipelines to remote control stations. Global Positioning System (GPS) is predominantly used to transmit sensed data from underwater sensors to control stations. It uses satellite communications and the Global System for Mobile Telecommunication (GSM) General Packet Radio Service (GPRS) to map location of sensed data to Google Map. This enables control devices to accomplish remote control of valves and switches from indicated remote locations.

Furthermore, this supports emergency shutdown procedures from any of the specified offsite locations. These may be control of the plant and/ or any vital equipment when onsite control is difficult. An example of a real-time underwater monitoring system shown in Fig.3. It is a multi-hop system comprising 3 sensing or relay nodes to monitor the seabed with an installed pipeline. This type of underwater monitoring system utilises temperature-based wireless sensor nodes attached to modems with a GPS receiver to sense, transfer and map the sensed data to the control station through the sink node. Google Maps is used to map the sensed datain order to locate the exact position where a phenomenon such as a pipeline burst is detected by the underwater monitoring system.

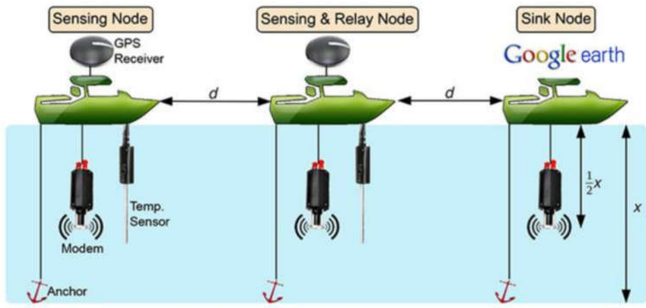

Figure 3 Real-timeunderwater wireless sensor monitoring system

Issues and Challenges

The issues and challenges presented are with respect to UWSNs application in underwater equipment monitoring and control [11], [12]. A typical example of such equipment are pipelines. Using UWSNs for monitoring and control offer new and promising research. However, there exist several issues and challenges, especially in oil pipeline monitoring and control.

The following issues and challenges are some of the key factors that may make applications or their deployments difficult in underwater oil pipeline monitoring and control:

- Volatile underwater environment
- Complex network design and deployment
- Lack of scalability
- Localisation
- Protocols for UWSNs
- Low data rates
- Physical damage to equipment
- Power Management
- Equipment Acquisition and Deployment

Volatile underwater environment

Underwater environments are exceptionally unpredictable. The high-water pressure, unpredictable underwater activities and irregular depths of the waterbed present challenges in the design and deployment UWSNs.

Complex network design and deployment

The unpredictable underwater environment makes it difficult to deploy and maintain the network of underwater sensors that work reliably and are fault tolerant. The current tethered technology allows constrained communication but incurs significant deployment costs as well as maintenance, and device recovery to cope with volatile undersea conditions.

Lack of Scalability

Traditional underwater exploration relies on either a single high-cost underwater device or a small-scale underwater network. There are limitations on existing technology for applications covering a large geographical area. The underwater sensor network technology is essential for exploring the underwater space.

Localisation

Underwater sensor nodes are in continuous motion due to the water currents, thus locating nodes underwater becomes much more difficult and challenging [13].

Protocols for UWSNs

The medium of communication in underwater networks communication is water, unlike air as in terrestrial sensor networks. Therefore, the network communication protocols for terrestrial are not applicable underwater. Mostly, underwater communication utilises acoustic signals for long distances and radios for short distance, water surface communication. Radio Frequency signals communicate long distances at extremely low frequencies thus requires large antennas and high transmission power, which can drastically diminish the overall network lifetime. However, there is high propagation delay in acoustic communication compared to RF communication resulting in many algorithms and protocols designed for terrestrial WSN directly inapplicable to UWSN [13].

Low Data Rates

Radio frequency communications are less effective in underwater communications due to the media effect on communication. RF energy absorption by water reduces the communication range. Due to its low bandwidth, acoustic communication is preferred for transmission of pulse signals and low fidelity information. Potential UWSN applications such as measuring the level of pressure variation in pipelines installed at the seabed require a considerably high bandwidth. However, utilising low frequencies requires a lot of time to send the dynamic data that in turndrastically drain the battery energy of the underwater sensors.

Physical damage to Equipment

Intentional physical damage to equipment by oil thieves and vandals on installed monitoring devices underwater or above the ground with intention to vandalize crude oil pipelines undetected [14].

Power Management

Like all sensors, the underwater sensor nodes require replacement or recharging; replacing or recharging batteries of these underwater sensor nodes can be very challenging due to the environment. Therefore, energy consumption in underwater sensor networks can be enhanced by developing efficient water communication techniques or protocols to increase network lifetime [15].

Equipment Acquisition and Deployment

Finally, the equipment requirements and cost of underwater wireless sensor networks are higher compared to that of terrestrial wireless sensor networks. Procurement and deployment of acoustic wireless sensor nodes underwater is cost prohibitive but necessary considering the fact that majority of the oil pipelines are deployed underwater and the requirements for integration with Internet of Things (IoT) [16].

CONCLUSION AND FUTURE DIRECTION

In this paper, we have presented a comprehensive literature review of UWSN applications, issues and challenges in underwater oilfields. Underwater sensor networks will give way to a number of applications for the harsh underwater environment. UWSNs has become one of the prime focuses for researchers. Design and deployment of these applications will save time and money. Although UWSNs have seen a tremendous amount of growth in the past few years, there is still a room for ample contributions particularly in the physical deployments of the systems on large scale.

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