UNDERWATER WIRELESS SENSOR NETWORKS:A SURVEY

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***Abstract*--Underwater Sensor Networks are typically distributed in nature and the nodes communicate using acoustic waves over a wireless medium. Such networks are characterized by long and variable propagation delays, intermittent connectivity, limited Bandwidth and low bit rates. Due to the wireless mode of communication between the sensor nodes, a Medium Access Control (MAC) protocol is required to coordinate access to the shared channel and enable efficient data communication. However, conventional terrestrial wireless network protocols that are based on RF technologies cannot be used underwater. More than 70% of the earth's surface is covered with water. As more research is being done on underwater systems, data collection and environment monitoring become major components. These raise the need for an effective way to collect data and monitor the environment.**

Keywords-Underwater sensor networks; MAC protocol; Communication signals; multi hop routing

I. INTRODUCTION

Ocean bottom sensor nodes are deemed to enable applications for oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Multiple Unmanned or Autonomous Underwater Vehicles (UUVs, AUVs), equipped with underwater sensors, will also find application in exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. To make these applications viable, there is a need to enable underwater communications among underwater devices. Underwater sensor nodes and vehicles must possess self-configuration capabilities, i.e., they must be able to coordinate their operation by exchanging configuration, location and movement information, and to relay monitored data to an onshore station. Wireless underwater acoustic networking is the enabling technology for these applications. Underwater Acoustic Sensor Networks (UW-ASN) consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. To achieve this objective, sensors and vehicles self-organize in an autonomous network which can adapt to the characteristics of the ocean environment. Underwater networking is a rather unexplored area althoughunderwater communications have been experimented since World War II, when, in 1945, an underwater telephone was developed in the United States to communicate with submarines.

Acoustic communications are the typical physical layer technology in underwater networks. In fact, radio waves propagate at longdistances through conductive sea water only at extra low frequencies (30-300 Hz), which require large antennae and high transmission power. Optical wave do not suffer from such high attenuation but are affected by scattering. Moreover, transmission of optical signals requires high precision in pointing the narrow laser beams. Thus, links in underwater networks are based on acousticwireless communications.

This can be obtained by connecting underwater instruments by means of wireless links basedon acoustic communication.Many researchers are currently engaged in developing networking solutions for terrestrial wireless ad hoc and sensor networks. Although there exist many recently developed network protocols for wireless sensor networks, the unique characteristics of the underwater acoustic communication channel, such as limited bandwidth capacity and variable delays, require for very efficient and reliable new data communication protocols.

A. *Major challenges in the design of underwater acoustic networks are:*

- Battery power is limited and usually batteries cannot be recharged because solarenergy cannot be exploited.
- The available bandwidth is severely limited.
- The channel suffers from long and variable propagation delays, multi-path andfading problems.
- Bit error rates are typically very high.
- Underwater sensors are prone to frequent failures because of fouling, corrosion

B. *The depth of water is a serious factor impacting UWSN*

The factor that influent the underwater communication as follows:

- **Transmission loss:** Attenuation and geometric spreading are the main concern of the transmission loss. The attenuation mainly refers to the energy absorption or conversion into heat. Attenuation of radio waves in water increases both with increase in conductivity and increase in frequency. The geometric spreading can also spread the energy of signal because of the expansion of wave fronts.
- **Multipath:** The propagation in multipath can severely degrade the signal. The link configuration such as horizontal channels characterization determines the geometry of multipath.
- **Noise:** Environment noises include man-made noise and ambient noise. Man-made noise mainly refers to machinery noise like pumps while natural noise refers to seismic and biological phenomena can cause ambient noise.
- **Propagation delay and delay variance:** Large propagation delay and high delay variance can be reduced the throughput of the system.

II. NETWORK MODEL IN UWSN

A network model between two nodes in UWSN environment is shown in Figure 1. The network is composed of underwater sensor nodes, underwater sink node andSurface sink node. The underwater sensor nodes are deployed to the bottom of the monitored environment such as ocean and river. While underwater sink nodes take charge of collecting data of underwater sensor deployed on the ocean bottom and then send to the surface sink node. Lastly, surface sink node is attached on a floating buoy with satellite, radio frequency (RF) orCell phone technology to transmit data to shore in real time.

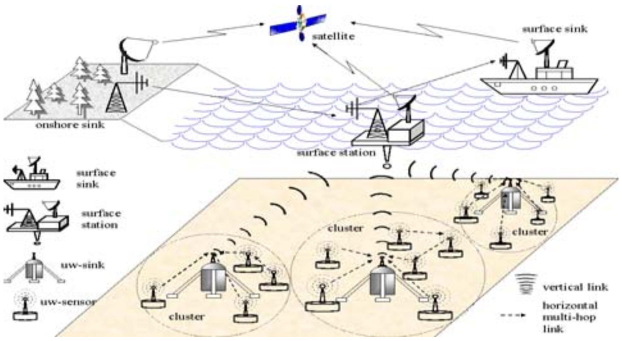

Figure 1: Underwater sensor networks

The depth of the fresh water for this research is lower than 100 m while the range between two nodes is about 6m until 20m for short range communication. The MAC protocol is very important in ensuring data reliability to the underwater sensor network. Differentapplications required different requirements on MAC protocol. In this project, the aim is to design a MAC protocol for long term applications such as water qualitymonitoring for agriculture purposes. This application is not sensitive to end-to-end delay because the communication link of UWSN is using RF electromagnetic waves that have high propagation speed which is 3×10^8 m/s. Hence, the propagation delay is very low and can be ignored. The most important goal of MAC protocol for such underwater sensor network is to solve the data packet collision efficiently in terms of energy consumption. Another goals of the designing MAC protocol in this project are to achieve guarantee high network throughput, low energy consumption and low channel access delay.

A reason why current terrestrial Radio Frequency (RF) based MAC protocol cannot be used directly in UWSN because of the harsh physical characteristics of underwaterChannel. Currently, the existing MAC protocol for UWSN is using acoustic as a link for communications. There has no existing MAC protocol that can be adapted in UWSN using RF electromagnetic link. This project will be developed a MAC protocol that can be adapt in UWSN for shallow water environment using RF electromagnetic link. A major difference between RF and acoustic propagation is the velocity of propagation. Radio waves travel at the speed of light as mentioned above. The speed of sound in water is around 1500 m/s, and it varies significantly with temperature, density and salinity, causing acoustic waves to travel on curved paths.

III. DIFFERENT TYPES OF COMMUNICATION SIGNALS

Present underwater communication systems involve the transmission of information in the form of sound, electromagnetic (EM), or optical waves. Each of these techniques has advantages and limitations.

A. Acoustic communication

Acoustic communication is the most versatile and widely used technique in underwater environments due to the low attenuation (signal reduction) of sound in water. This is especially true in thermally stable, deep water settings. On the other hand, the use of acoustic waves in shallow water can be adversely affected by temperature gradients, surface ambient noise, and multipath propagation due to reflection and refraction. The much slower speed of acoustic propagation in water, about 1500 m/s (meters per second), compared with that of electromagnetic andoptical waves is another limiting factor for efficient communication and networking. Nevertheless, the currently favorable technology for underwater communication is upon acoustics.

B. Electromagnetic (EM) waves

On the front of using electromagnetic (EM) waves in radio frequencies, conventional radio does not work well in an underwater environment due to the conducting nature of the medium, especially in the case of seawater. However, if EM could be working underwater, even in a short distance, its much faster propagating speed is definitely a great advantage for faster and efficient communication among nodes.

C. Optical Wave communication

One of the biggest sources of noise for underwater optical communications in littoral regions is the presence of sunlight. While the sun produces anywhere from 10,000-100,000 lx most LEDs, used for transmission in digital communication will be on the order of 100 lx. This means that the signal strength is substantially smaller than the noise created by ambient light. Furthermore, simply by tilting the receiver even slightly there might be a large change in incident light on the photodiode and ultimately a different current running through it. Many optical modems use a high pass filter technique to differentiate ambient level from signal. Since typically PPM is used there is a very high frequency component on the edges of each pulse whereas the ambient is changing at a very low frequency. Using a high pass filter will remove the ambient light level however it comes at a cost of imposing a frequency requirement on the signal to be transmitted.

SUMMARY OF ACOMM, EMCOMM, AND OCOMM FOR UWSN IN SEAWATER ENVIRONMENTS

	ACOMM	EMCOMM	OCOMM
Major hurdles	bandwidth-limited, interference-limited	power-limited	environment-limited
Data rate	up to 100 kbps	up to 10 Mbps	up to 1Gbps
Antenna complexity	medium	high	medium
Transmission range	~ 50m-5km	~ 1m-100m	~ 1m-100m

IV. NETWORKING CHALLENGES FOR UNDERWATER SENSOR NETWORKS

In this section, we focus on the networking challenges for underwater sensor networks. Due to the unique characteristics of underwater acoustic channels (long latency and low bandwidth) and the harsh underwater environments (resulting in high channel dynamics), technology used in terrestrial radio networks could not be applied to underwater acoustic networks.

A. Physical Layer

Outside water, the electromagnetic spectrum dominates communication, since radio or optical methods provide long-distance communication (meters to hundreds of kilometers) with high bandwidths (kHz to tens of MHz), even at low power. In contrast, water absorbs and disperses almost all electro-magnetic frequencies, making acoustic waves a preferred choice for underwater communication beyond tens of meters. Propagation of acoustic waves in the frequency range of interest for communication can be described in several stages. Fundamental attenuation describes the power loss that a tone at frequency f experiences as it travels from one location to another. The first, basic stage, takes into account this fundamental loss that occurs over a transmission distance d.

The second stage takes into account the site specific loss due to surface-bottom reflections and refraction that occurs as sound speed changes with depth, and provides a more detailed prediction of the acoustic field around a given transmitter. The third stage addresses the apparently random changes in the large-scale received power which are caused by slow variations in the propagation medium.

The same network protocol may perform differently under a different frequency allocationmoving to a higher frequency region will cause more attenuation to the desired signal, but the interference will attenuate more as well, possibly boosting the overall performance. Also, propagation delay and the packet duration matter, since a channel that is sensed to be free may nonetheless contain interfering packets; their length will affect the probability of collisions and the efficiency of re-transmission. Finally, power control, coupled with intelligent routing, can greatly help to limit interference.

B. Medium Access Control and Resource Sharing

Multi-user systems need an effective means to share the communications resources among the participating nodes. In wireless networks, the frequency spectrum is inherently shared and interference needs to be properly managed. Several techniques have been developed to provide rules to allow different stations to effectively share the resource and separate the signals that coexist in a common medium. In designing resource sharing schemes for underwater networks, one needs to keep in mind the peculiar characteristics of the acoustic channel. Most relevant in this context are long delays, frequency-dependent attenuation, and the relatively long reach of acoustic signals. In addition, the bandwidth constraints of acoustic hardware must also be considered.Signals can be deterministically separated in time (Time Division Multiple Access, TDMA) or frequency (FDMA). In the first case, users take turns accessing the medium, so that signals do no overlap in time and therefore interference is avoided. TDMA can be more flexible, but requires synchronization among all users to make sure they access disjoint time slots. Many schemes and protocols are based on such an un delaying time-division structure, which however needs some coordination and some guard times to compensate for inconsistencies in dealing with propagation delays.

CDMA-based medium access protocols with power control have been proposed for underwater networks, and have the advantages of not requiring slot synchronization and being robust to multipath fading. While these deterministic techniques can be used directly in multi-user systems, data communication nodes typically use contention-based protocols that prescribe the rules by which nodes decide when to transmit on a shared channel. In the simplest protocol, ALOHA, nodes just transmit whenever they need to (random access), and end-terminals recover from errors due to overlapping signals (called collisions) with retransmission.

More advanced schemes implement carrier-sense multiple access (CSMA), a listen-before-transmit approach, with or without collision avoidance (CA) mechanisms, with the goal of avoiding transmission on an already occupied channel. While CSMA/CA has been very successful in radio networks, the latencies encountered underwater (up to several seconds) make it very inefficient underwater. In fact, while ALOHA is rarely considered in radio systems due to its poor throughput. T-Lohi exploits collision avoidance tones, whereby nodes that want to transmit signal their intention by sending narrowband signals, and proceed with data transmission if they do not hear tones sent by other nodes, providing lightweight signaling at the cost of greater sensitivity to the hidden-terminal problem. CSMA-based protocol that uses synchronization is to reduce the probability of collision, but is also subject to longer delays due to guard times.

C. Reliable Data Transfer

Reliable data transfer is important in UWSNs, especially for those aquatic exploration applications requiring reliable information. There are typically two approaches to reliable data transfer: end-to-end and hop-by-hop. The most common end-to-end solution TCP (Transmission Control Protocol). In

UWSNs, due to the high and dynamic channel error rates and the long propagation delay, TCP's performance will be problematic. There are a number of techniques that can be used to render TCP's performance more efficient. However, the performance of these TCP variants in UWSNs is yet to be investigated. Another type of approach for reliable data transfer is hop-by-hop. The hop-to-hop approach is favored in wireless and error-prone networks, and is believed to be more suitable for sensor networks. One possible direction to solve the reliable data transfer problem in UWSNs is to investigate coding schemes, including erasure coding and network coding, which, though introducing additional computational and packet overhead, can avoid retransmission delay and significantly enhance the network robustness. In a network coding scheme is proposed for underwater sensor networks. This scheme carefully couples network coding and multi-path routing for efficient error recovery.

D. Multi-hop Routing

Forwarding data from source nodes to command/control stations efficiently is very challenging in UWSNs, especially in mobile UWSNs for long-term applications. In such networks, saving energy is a major concern. At the same time, routing should be able to handle node mobility. This requirement makes most existing energyefficient routing protocols unsuitable for UWSNs. Various routing protocols are,

- Vector based forwarding (VBF)
- Focused beam routing (FBR)
- Reliable and Energy Balanced Routing Algorithm (REBAR)
- Information-Carrying Routing Protocol (ICRP)
- Directional Flooding-Based Routing (DFR)
- Distributed Underwater Clustering Scheme (DUCS)
- Depth Based Routing (DBR)
- Hop-by-Hop Dynamic Addressing Based Routing (H2-DAB)

E. Localization

Localization of mobile sensor nodes is indispensable for UWSNs. Some applications such as aquatic monitoringdemands high-precision localization, while other applications such as surveillance network requires a localizationsolution that can scale to a large number of nodes. However, underwater acoustic propagation characteristics andsensor mobility pose great challenges on high-precision and scalable localization solutions in that:

- Underwateracoustic channels are highly dispersive, and time delay of arrival (TDOA) estimation is hampered by dense multipath.
- Acoustic signal does not travel on a straight path due to the stratification effect;
- Underwater acoustic channelshave extremely low bandwidth that renders any approach based on frequent message exchange not appealing;
- Large scale sensor deployment prevents centralized solutions; and
- Sensor mobility entails dynamic networktopology change.

V. DIFFERENCES WITH TERRESTRIAL SENSOR NETWORKS

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

- **Cost:** While terrestrial sensor nodes are expected to become increasingly inexpensive, underwater sensors are expensive devices. This is especially due to the more complex underwater transceivers and to the hardware protection needed in the extreme underwater environment.

- **Deployment:** While terrestrial sensor networks are densely deployed, in underwater the deployment is deemed to be more sparse, due to the cost involved and to the challenges associated to the deployment itself in the underwater environment.
- **Power:** The power needed for underwater communications is higher than in terrestrial radio communications due to higher distances and to more complex signal processing at the receivers.
- **Memory:** While terrestrial sensor nodes have very limited storage capacity, uw-sensors may need to be able to do some data caching as the underwater channel may be intermittent.
- **Spatial Correlation:** While the readings from terrestrial sensors are often correlated, this is more unlikely to happen in underwater networks due to the higher distance among sensors.

VI. APPLICATION SCENARIOS

The above described features enable a broad range of applications for underwater acoustic sensor networks:

- **Ocean Sampling Networks:** Networks of sensors and AUVs, such as the Odyssey-class AUVs, can perform synoptic, cooperative adaptive sampling of the 3D coastal ocean environment Experiments such as the Monterey Bay field experiment in August 2003 demonstrated the advantages of bringing together sophisticated new robotic vehicles with advanced ocean models to improve our ability to observe and predict the characteristics of the oceanic environment.
- **Environmental Monitoring:** such as pollution monitoring (chemical, biological, etc.), monitoring of ocean currents and winds, improved weather forecast, detecting climate change, understanding and predicting the effect of human activities on marine ecosystems, etc.
- **Assisted Navigation:** Sensors can be used to locate dangerous rocks or shoals in shallow waters, mooring positions, submerged wrecks, etc.
- **Distributed Tactical Surveillance:** AUVs and fixed underwater sensors can collaboratively monitor areas for surveillance, reconnaissance, targeting and intrusion detection systems.
- **Mine Reconnaissance:** The simultaneous operation of multiple AUVs with acoustic and optical sensors can be used to perform rapid environmental assessment and detect mine like objects.

VII. CONCLUSION

UWSN data reliability of a sensor node is described as a probability of data packet being delivered from sensor node to the sink. Therefore, this MAC protocol design is needed to improve the reliability data delivery for efficient underwater communication and to enhance water monitoring, mine reconnaissance, distributed tactical surveillance, environmental monitoring assisted and navigationapplications. To achieve that, MAC protocol should provide collision avoidance and energy efficiency for managing and controlling communication channels which are shared by many nodes to avoid collisions and maintain reliable transmission conditions. On the other hand, transport protocol will be provided end-to-end reliability, congestion control and also energy efficiency and various protocols using in UWSN to improve the various characteristics.

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