Underwater Wireless Sensor Network based on acoustic communication Using VBF

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Abstract—Recently, sensor networks have emerged as a very powerful technique for many applications, including monitoring, measurement, surveillance and control. The idea of applying sensor networks in underwater environments (i.e., forming underwater sensor networks (UWSNs)) has been advocated by many researchers. Investigations in hydrologic sciences are bounded because most of existing water surveillance methods are manual. Such systems are incapable to gather information at spatial and temporal level due to location constraints. In this paper, we present a novel routing protocol, called vector-based forwarding (VBF), to address the routing problem in UWSNs. VBF is robust, scalable and energy efficient, a new communication for Underwater Wireless Sensor Network (UWSN) based on acoustic communication. However, unique challenges offered by underwater environment are main hindrance in deployment of UWSN in real life applications. So, we discuss various communication methodologies to figure out which one suits best to the requirements of UWSN. Our simulation results illustrate change in data transmission rate, energy consumption and transmission time w.r.t transmission range and number of nodes in network. Results prove that multi-hop communication offer high transmission rate, large bandwidth. Moreover, multi-hop communication is much more energy and time efficient than direct communication.

Keywords:— Underwater sensor networking, autonomous vehicles. Underwater acoustic communication, wireless sensor network.

INTRODUCTION

Water is essential to fulfill all type of demands of mankind so it became imperative to develop water quality surveillance system that monitors and reports quality of water continuously in real time. In last several years, underwater sensor network (UWSN) has found an increasing use in a wide range of applications, such as coastal surveillance systems, environmental research, autonomous underwater vehicle (AUV) operation, intravenous blood infusion to name a few. UWSN is new type of sensor network that offers novel opportunity to design and implement various new applications in water. Compared to earlier proposed methods (sampling, remote monitoring, satellite and cellular communication), UWSN provides relatively inexpensive, coordinated, scalable and intelligent networks for water quality surveillance. UWSNs are able to measure different parameters in water such as pH, turbidity, dissolved oxygen and temperature using different sensors installed on a single node. Each node comprises a data acquisition board that is used to gather signal sent by sensors with the help of transducers. This type of system leads to generation of micro-dimensional analytical instruments that can effortlessly deployed even in remote geographical locations and operated autonomously without human intervention over a larger span of time. Unique characteristics of underwater communication channel and harsh condition of dynamic underwater environment limits their frequent deployment in real life scenarios. Various applications for UWSN, drawbacks with traditional approach and design challenges faced by UWSN for sensors, real-time and delay tolerant monitoring are discussed [1]. Further, authors present various communication architectures for 2-dimensional and 3-dimensional network along-with their communication details and various types of autonomous underwater vehicles to support unmanned monitoring and enhance capabilities of UWSN. Unique characteristics and critical design challenges faced by mobile UWSN in layerwise manner were also identified [2]. Authors further presented two different architectures for long-term non-time critical aquatic monitoring applications and short-term time-critical aquatic monitoring applications. Choice of architecture depends upon requirement of applications.
While UASN is a promising new field and may help in the exploration of what’s hidden in the amazingly unfathomed world that lies underwater, there are a few challenges as well. For setting up underwater applications, not all the techniques and algorithms for UASNs can derive from the already seasoned land based WSNs as some of the phenomena are primarily different [3]. Radio frequency (RF) communications was never a choice for underwater communication due to the swift decrease in the transmission range and hence lower data rates of the RF modules as we go deep down the ocean. Acoustic communication has been the technology of choice for decades when it comes to transmitting signals underwater, but with their hefty price tags and heavy power usage, underwater acoustic modems are not at all feasible for UASNs with applications as itsy-bitsy as measuring the amount of pollution from a fishing farm at the sea bed [4]. Moreover, turning from speed of light to speed of sound changes the physics of communications incurring propagation delay and effects time synchronization. The sensors available are susceptible to routine underwater challenges e.g. algae collection on camera lens [5], salt accumulation; decreasing the affectivity of sensors etc. Finally, the energy requirements of UASNs will be different as compared to terrestrial WSNs for the fact that available underwater sensors have a larger foot print consuming higher power and regular battery replenishing techniques are quite costly. Very little work has been done in the field of underwater acoustic network deployments leaving the window wide open for upcoming research and opportunities.

The remainder of this paper is organized as follows. Section II provides the overview of the related work in the field. In Section III, we present the details of the proposed Communication methodology and provides the discussion on the services provided by the proposed methodology. Formal modeling and verification of Under Water sensor network explains the experimental results, and Section IV concludes this paper.

I. EXPERIMENTAL STUDY

In this Survey relative mechanisms and the methods which are employed earlier to attain Underwater sensors possess large memory for data caching due to intermittent connections. Since water quality surveillance is a long term, non-real time monitoring application. And also the advantages and disadvantages of each technique are discussed. According to the survey of the earlier mechanism, it finds that the current system implemented has more advantages.

A. Literature Survey:

A Survey of Practical Issues in Underwater Networks
Jim Partan, Jim Kurose ,Brian Neil Levine

Underwater sensor networks are attracting increasing interest from researchers in terrestrial radio-based sensor networks. There are important physical, technological, and economic differences between terrestrial and underwater sensor networks. Previous surveys have provided thorough background material in underwater communications, and an introduction to underwater networks. This has included detail on the physical characteristics of the channel, on underwater acoustic communications and surveys of underwater acoustic networks. In this survey, we highlight a number of important practical issues that are not emphasized in the recent surveys of underwater networks, with an intended audience of researchers who are moving from radio-based terrestrial networks into underwater networks.


Underwater sensor nodes will find applications in oceanographic data collection, pollution monitoring, offshore exploration, disaster prevention, assisted navigation and tactical surveillance applications. Moreover, unmanned or autonomous underwater vehicles (UUVs, AUVs), equipped with sensors, will enable the exploration of natural undersea resources and gathering of scientific data in collaborative monitoring missions. Underwater acoustic networking is the enabling technology for these applications. Underwater networks consist of a variable number of sensors and vehicles that are deployed to perform collaborative monitoring tasks over a given area. In this paper, several fundamental key aspects of underwater acoustic communications are investigated. Different architectures for two-dimensional and three-dimensional underwater sensor networks are discussed, and the characteristics of the underwater channel are detailed. The main challenges for the development of efficient networking solutions posed by the underwater environment are detailed and a cross-layer approach to the integration of all communication functionalities is suggested. Furthermore, open research issues are discussed and possible solution approaches are outlined.


“The large-scale mobile underwater wireless sensor network (UWSN) is a novel networking paradigm to explore aqueous environments. However, the characteristics of mobile UWSNs, such as low communication bandwidth, large propagation delay, floating node mobility, and high error probability, are significantly different from ground-based wireless sensor networks. The novel networking paradigm poses interdisciplinary challenges that will require new
technological solutions. In particular, in this article we adopt a top-down approach to explore the research challenges in mobile UWSN design. Along the layered protocol stack, we proceed roughly from the top application layer to the bottom physical layer. At each layer, a set of new design intricacies is studied. The conclusion is that building scalable mobile UWSNs is a challenge that must be answered by interdisciplinary efforts of acoustic communications, signal processing, and mobile acoustic network protocol design.

Liu, L., Zhou, S., and Cui, J. H , “Prospects and problems of wireless communication for underwater sensor networks” This paper reviews the physical fundamentals and engineering implementations for efficient information exchange via wireless communication using physical waves as the carrier among nodes in an underwater sensor network (UWSN). The physical waves under discussion include sound, radio, and light. We first present the fundamental physics of different waves; then we discuss and compare the pros and cons for adopting different communication carriers (acoustic, radio, and optical) based on the fundamental first principles of physics and engineering practice. The discussions are mainly targeted at underwater sensor networks (UWSNs) with densely deployed nodes. Based on the comparison study, we make recommendations for the selection of communication carriers for UWSNs with engineering countermeasures that can possibly enhance the communication efficiency in specified underwater environments.

B. Related Study:

Some recent papers propose network layer protocols specifically tailored to underwater acoustic networks. In [6], a routing protocol is proposed that autonomously establishes the underwater network topology, controls network resources and establishes network flows. The protocol relies on a centralized network manager running on the surface station. The manager implements network management and routing agents that periodically probe the nodes to estimate the channel characteristics. This information is exploited by the manager to establish efficient data delivery paths in a centralized fashion, which allows avoiding congestion and providing forms of quality of service guarantee. The performance evaluation of the proposed mechanisms has not been thoroughly carried out yet. In [7], a framework is provided for 3D position based routing in ad hoc networks. It is assumed that each node knows its 3D position and the position of the destination node, and a cell structure is leveraged in order to aggregate the topological information at each node. Although it is claimed that the mechanism can be applied to ocean sensor networks, all the experiments performed assume radio frequency communications among terrestrial mobile devices. In [8], it is shown with simple acoustic propagation models [9] that multi-hop routing saves energy in underwater networks with respect to single hop communications, especially with distances in the order of some kilometers. Based on this, a simple ad hoc underwater network is designed and simulated, where routes are established by a central manager based on neighborhood information gathered by all nodes by means of poll packets. In general, while most developed protocols for terrestrial ad hoc networks, mostly due to scalability and mobility concerns, are based on packet switching, i.e., the routing function is performed separately for each single packet and paths are dynamically established, virtual circuit routing techniques can be considered in UW-ASNs. In these techniques, paths are established a priori between each source and sink, and each packet follows the same path. This may require some form of centralized coordination, and implies a less flexible architecture, but allows exploiting powerful optimization tools on a centralized manager (e.g., the surface station) to achieve optimal performance at the network layer (e.g., minimum delay paths, energy efficient paths), with minimum communication signaling overhead. Furthermore, routing schemes that account for the 3D underwater environment need to be devised. Especially, in the 3D case the effect of currents should be taken into account, since the intensity and the direction of currents are dependent on the depth of the sensor node. Thus, underwater currents can modify the relative position of sensor devices and also cause connectivity holes, especially when ocean-column monitoring is performed in deep waters.

C. COMMUNICATION METHOLOGIES:

For wireless communication, we can use different communication technologies (radio, optical and acoustic). Propagation medium largely influences characteristics of communication technologies. Communication models used for terrestrial networks cannot be used in underwater environment because new sort of challenges are offered by underwater environment. In this section, we will discuss different ways of wireless communication and possible challenges faced by them in water.

- Radio Waves

Radio wave is a form of electromagnetic frequency that ranges from 3KHz to 300GHz and travels from 100Km to 1mm respectively [10]. It is so called because it contains energy in electric and magnetic fields. Radio waves travel with speed of light (3*108m/s) in vacuum and slow down when travel through a medium according to medium properties. Doppler Effect (change in duration and shift in frequency during propagation of signal from transmitter to receiver in a mobile environment) is negligible in radio waves because high speed of radio wave leads to small duration of transmission. However, wavelength of signal is inversely proportional to frequency so high frequency radio waves travel very short distances and they became useless for transmission over long distances. Conductive nature of sea water further decreases wavelength. Pure water acts as
an insulator but heterogeneities present in water (such as salinity and temperature) make it partial conductor. Very low radio frequencies (3-30KHz) penetrate up to depth of 20 meters [11]. Low penetration level of radio waves and very short propagation distance restrict their use in water. Attenuation is directly proportional to square root of frequency and conduction of medium. So, high frequency radio waves lose their strength very rapidly and infeasible for underwater communication. Absorption losses are directly dependent on frequency, distance and chemical properties of propagating medium so radio waves are quickly absorbed (while transmission wave energy is converted in other forms depending upon propagating medium elasticity and objects in path) by water due to their high frequency band. Absorption loss has adverse effect on signal and results in huge loss of signal intensity, effects transmission range and controls quality of received signal. Moreover, radio waves are able to across boundary from water to air and crossing boundary further reduces strength of signal. Multipath effect (multiple arrival of same signal) is less in radio waves due to high attenuation and small amount of reflection from sea surface and sea bed as shown in Fig 1.1. Although radio waves offer some great advantages in terms of high frequencies, large propagation speed and small duration but high frequency radio waves are infeasible for communication in water due to heavy absorption loss and attenuation. They can only be used at low frequencies but low frequencies suffer from their own drawbacks like limited bandwidth and extremely short propagation length. Also, limited bandwidth restricts data transmission rate and supports very low traffic capacity.

To achieve communication over longer distances, one possible way in case of radio wave is to transmit data from water to air at sender’s side and from air to water at receiver side. It enables transmission over longer distances but involves water to air refraction loss and limits depth of sender as well as receiver.

- Optical Waves

Optical signal ranges from 400THz to 900THz [12]. Similar to radio frequencies, higher frequencies of optical waves achieve high transmission rate and low power consumption but suffers from the drawback of short propagation distance. They can only travel from single meters to tens of meters that too with high transmission power. Speed of optical waves in water is ¾ of speed of light in vacuum due to absorption and reemission. Optical waves can transmit data over quite large distance than radio signals and they have very high transmission speed. This advantage is especially important in applications that involve frequent exchange of message over small distance in short time span. With high speed of optical waves, Doppler effect is negligible because transmission duration is small so chances of frequency shift became very less. Like radio waves, optical waves also suffered from huge absorption loss in water due to their high range frequency band so it is one of the major factors that avoids propagation of optical waves in water. High frequency optical waves also lead to high level of attenuation. For optical frequencies, attenuation is a very major problem due to their high frequency range. Scattering is another major reason for failure of optical waves in underwater. Scattering leads to energy loss of original signal because during scattering high amount of energy is reflected. This process is known as backscattering and it can be reason of noise. Heterogeneities in water (dust particles, marine life, various dissolved salts and mineral particles in suspension or navigation of ships etc) scatter the wave from straight trajectory especially in case of high frequencies. In addition to absorption and noise, energy loss is directly proportional to turbidity. Moreover, no specific optical modems are available for underwater communication. Optical waves also demand line of sight and clear visibility for communication between sender and receiver to reduce effect of scattering and increase transmission range. Acoustic Waves Sound (acoustic) waves are considered as primary carrier for transmission of information in underwater primarily because of low frequency band (20Hz-20KHz). Acoustic waves propagate very fast in fluids than air. In air, speed of sound is 343.2meter/second whereas in case of fluid propagation speed of acoustic wave is 1480 meter/second i.e. acoustic waves propagate 4.3 times faster in water when compared to air. Further, speed of acoustic increases with depth of water. Low frequencies result in less attenuation. In case of acoustic wave, attenuation losses are very small. Low frequency band of acoustic wave helps to transmit data up to few kilometers. However, acoustic waves are again constrained with limited bandwidth. So, utilizing bandwidth effectively is a major concern for underwater channels. Multipath effect is more in acoustic waves due to high amount of reflection from sea surface and seabed and inability to across air to water boundary. Refraction (change in direction of signal) distorts propagation path of acoustic waves due to their slow speed. Slow propagation speed of acoustic in water and multipath phenomenon increase overall propagation time for data transmission. Reflection of acoustic wave from surface and bottom of water further increases duration of transmission. With acoustic waves, propagation speed is very low so duration is high. Doppler effect in acoustic is considerable. Absorption is most important factor that limits us to use low frequencies in water. Absorption loss influences attenuation of signal. Low frequency acoustic waves have minimum absorption loss. Noise is one of the major concerns in long distance communication in respect of quality of received signal. Whether a particular acoustic signal is important or not is decided by level of noise. This is often referred as signal-to-noise ratio (SNR). It is clear from the above discussion that acoustic waves are best suited in underwater environment due to low attenuation, absorption and high range of data transmission. All aforementioned challenges make it challenging to receive an identifiable signal without errors. These challenges motivate us to find a comprehensive solution.
II. EXPERIMENTAL RESULTS

Based on spatial coverage, UWSN communication architecture can be deployed in 2D (2-dimensional) and 3D (3-dimensional) manner. In 2D architecture, depth is not taken into consideration. For example, all nodes are deployed at bottom of sea. In static 2D architecture [13] sensors nodes communicate with the help of transceiver. Node senses data and forwards it to BS (Base Station) with the help of underwater sinks. 3D architecture takes depth into consideration, deploys nodes at different depth levels to observe environment more accurately. In this section, we propose a 3D architecture for UWSN because static 2D architecture is not able to adequately monitor quality of water because contamination may vary at different depth levels. Static 3D architecture (nodes are deployed at various depth and their location will remain fixed) doesn’t ensure optimal coverage due to obstruction by various biological activities, marine life, ship navigations etc. Dynamic 3D architecture along-with Autonomous Underwater Vehicles (AUVs) goes well with requirements of water quality application. In dynamic 3D architecture, sensor nodes are deployed at different vertical and horizontal levels at different instances of time. Value of water quality parameters can vary at different horizontal and vertical levels. Sensors nodes equipped with AUVs can change their position and became more immune to several types of obstructions, by various biological activities, marine life, ship navigations etc. Dynamic 3D architecture along-with Autonomous Underwater Vehicles (AUVs) goes well with requirements of water quality application. In dynamic 3D architecture, sensor nodes are deployed at different vertical and horizontal levels at different instances of time. Value of water quality parameters can vary at different horizontal and vertical levels. Sensors nodes equipped with AUVs can change their position and became more immune to several types of obstructions as shown fig 1.1. Major concern with dynamic 3D architecture is that sensors must possess self configuration property to regulate their location in order to provide optimal (complete) coverage of monitored region. Proposed architecture focuses on this issue and suggests an approach to regulate location of sensors in an optimal way. We use acoustic communication model for our architecture because it is clear from the above discussion that they work best in underwater environment compared to their counterparts. Proposed architecture comprises of four component.

Data Gathering Component

Sensors nodes are deployed in field at their respective locations with acoustic modems, nodes gather data about different parameters related to water quality (such as pH) with the help of transducers. Transducers collect information from environment about desired parameters in analog form and convert it into digital form. There can be various parameters like pH, dissolved oxygen, salinity, temperature, etc and for each parameter node must be equipped with separate type of sensor. Here, we have taken an example of pH. Desired value of pH for drinking water lies between 6.5 - 8.5. For ambient pH measurement, magnetoeelastic sensors are used in sensor nodes to ensure drinking water safety. One possible way for sensors to collect information is to continuously sense the environment and gather information. However, this type of operation consumes huge amount of energy (especially in case of acoustic modem, they consume substantial amount of energy during listen mode). Energy is a very important constraint in underwater sensor nodes due to their battery operated nature and non-rechargeable location. Moreover, continuous monitoring of surveillance region is not required in water quality surveillance because value of parameters cannot go processing of bulk data. Data management and decision support subsystem performs in-depth investigation, provides concise information about each and every parameter so that necessary actions (related to prevention and remediation of water contamination) can be taken whenever necessary. To allow exchange among users, data is stored in standard storage formats. Moreover, information is well organized in such a manner that user can easily access it. Onshore surface station is connected to Ethernet or can be provided with GUI based on web technology so that users can analyze information (for generating alarms, for research purposes), exchange information, query information and automatically generate alarms when quality is below pre-defined standards. This subsystem also maintains metadata i.e. information about function of water bodies, their history, past trends of degradation, type of contamination water body is prone to, etc. This metadata along with retrieved information prove much beneficial in corrective decision making when compared to decision taken only with the help of retrieved information.

III. PERFORMANCE EVALUATION

Although the above tests verified that control of the vehicle was possible, additional sea trials were undertaken to test the potential of both tracking and communicating with the vehicle acoustically. This is an important aspect of our program. Additional sea trials were therefore undertaken in order to characterize the acoustic transmission path between the vehicle and either a ship (in our case) or another vehicle. For these generic tests, a set of 5 Vemco VR22 transmitters were utilized with frequencies from 34 kHz to 42 kHz. The transmitters’ output power level was approximate 165 dB re 1 μPa. Although these transmitters were designed to track large animals, we chose to suspend them at candidate depths
on a small mooring in order to determine their suitability for our tracking and to also investigate the features of the acoustic channel. The Vemco transmitters simply emit a “ping” at a fixed frequency (narrow band) at an inter-ping interval that is proportional to their depth. Results were inspected in order to judge both the signal level/quality and usefulness for range/angle estimates needed for localization purposes. Results indicated that the range sensing capability was highly dependent on the temperature structure of the water with the longest range of 2 km achieved in well-mixed conditions. Apparently, in other scenarios, the temperature structure of the water resulted in a downward refraction of the sound rays which decreased the receive level by a large amount compared to well mixed conditions. This limited detection in highly temperature dependant environments to ranges of 0.5 km.

Signals were also analyzed in order to judge the quality of the received sound in faithfully reproducing the transmit signal. Results indicated that the received pulses were substantially longer than transmit, presumably due to reverberation from the sea surface at these shallow depths. As such, coherent processing of the signal was limited to the initial arrival that occurred in the first millisecond. Nevertheless, phase extraction methods, for these narrow band signals were successful in yielding a good estimate for angle of arrival, as judged on a set of four receiving hydrophones. Ultimate range bearing resolution was judged to be approximately +/- 5 meters over a range of one km. Owing the relatively short range capability of the acoustics (.5 km – 2 km) and the seeming disparity between the interest of the oceanographers to study features on the scale of 5 – 10 km, we have been pursuing the idea of networking the drogues so that information can be passed from a ship or shore station to them and retrieved.

IV. CONCLUSION

In this paper, we have compared various communication methodologies (radio, optical and acoustic waves using vbf) to evaluate which one fits better in a watery environment. It is clear from the above discussion that acoustic works best in underwater environment. Further, we presented a new 3-dimensional dynamic communication architecture that uses acoustic links for communication. In this paper, UWSN is used as a special case for water quality surveillance application. We evaluated transmission rate, energy and transmission time to determine performance of multi-hop over direct communication. Simulation results depict that performance of multi-hop communication is much better than direct communication for UWSN in terms of transmission rate, transmission time and most importantly energy consumption because small amount of power is involved during transmission of signals over small distances. Also, loss in strength of signal due to absorption loss and scattering is very minute. It endorses proposed communication architecture that uses short range and multi-hop based acoustic communication.

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V. REFERENCES


