Energy Efficient Sea Shallow Based Protocol for Improving Packet Delivery in Underwater Communication

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ABSTRACT

The communication in the underwater wireless sensor networks (UWSN) faces many challenges, and it consumes much more energy while the packet delivery ratio is low. However, studies have shown that the routing protocols for the wireless sensor networks (WSN) are not suitable for the UWSN, and the design of routing protocols for the UWSN faces many difficulties. The Global Positioning System (GPS) which uses radio signals cannot be applied in the water. For the UWSN, the positioning of the underwater acoustic sensor nodes (underwater nodes) is difficult and inaccurate without GPS.Another issue to be considered is energy. The power required by underwater acoustic communication is high while the bandwidth is low, which leads to more energy consumption for the UWSN to transmit the same quantity of data compared with radio communication. A routing protocol to be designed to overcome the disadvantage of flooding protocol traditionally used in underwater communication.

Keywords-**Underwater communication, depth analysis, Energy-aware, Routing protocol and higher data rate.**

I. INTRODUCTION

The concept of underwater communication that has immense depth in its applications and wide use for marine archaeology and oceanography. The first telephone that was made for underwater has a frequency range of 2 to 25 KHz. The prime means of communication through underwater are acoustic waves, EM waves and optical signals. The acoustic waves can the travel long distance, while the optical means are limited to shorter distance. As the temperature increases the sound increases in the acoustic medium. It even applies with the proportionality increase of depth leading to increasing in sound speed. The EM waves have random attenuation in water, while the optic signals have overcome this factor. The bandwidth is limited by a factor in acoustic waves, and optical signals carry more information nut get absorbed in water. The radio frequency waves that function in a frequency band of 30-300 GHz are electromagnetic waves that have a frequency which proliferates in the electromagnetic field as disturbed due to oscillation of electric charges. The dissolves salt in the water will make the water a slight conducting, which causes it to be functional for attenuation. Conductivity and frequency play a key role to increase the attenuation. The fact of refraction loss caused due to change of medium from air to water at the transmitter and receiver majorly affects the RF communication. SeaText was the first underwater modem made which gave a data rate of 100bps for 10 meters.

Table 1: RF Underwater communication characteristics

Range	<1m	<10Km
RF (Data rate)	100Mbps	1bps
Application	Underwater Vehicle docking	Underwater telemetry

The optical wave travels at with speed of light but leads to having short wavelength due to scattering and absorption in underwater communication. These waves have a wavelength of range 390nm to 700nm. The organic and inorganic matter accords major scattering factor in underwater communication. The optical modems are now combined with the acoustic to give better characteristics. The hybrid approach uses a laser beam in underwater communication.

Table 2: Comparison of Different Communication Models for Underwater Communication

Communication Models	Range	Channel Dependency Factors
EM	<20m	Conductivity, Multipath attenuation
Acoustic	~km	Doppler effect, Multipath propagation, Temperature, Fading losses
Optical	10-100m	Light scattering, Line of sight communication

A sound wave is a combination of compressions and rarefactions that is detected with the help of a device called hydrophone. Generally, the frequency range in underwater communication is between 10 Hz to 1 MHz However; the problem arrives with an increase in frequency, which leads to absorbing of the signal. The commonly used means that is the acoustic waves have high propagation delay and low data rate caused by multipath fading and Doppler effects due to variation in temperature and salinity in water.

Inferable from the saline nature of the water medium, the high-frequency EM waves are influenced by extreme attenuation. Along these lines, these high-frequency waves are not reasonable for underwater environments. Then again, low-frequency waves extending from 30-300 Hz can spread over long spaces in such a powerfully evolving condition. Nonetheless, for transmission of such low-frequency signals, an extensive measured radio wire with high transmission capacity is required, which is unreasonable. Conversely, optical waves do not experience the ill effects of the issue of attenuation; they require a high accuracy pointing bars which for the most part are

$r_b = 2 B \log_2(L)$

$C = B \log_2(1+SNR)$

Influenced by scattering. Then again, for underwater medium; acoustic waves are less lossy and support long-range signal transmission. In this way, acoustic signals are significantly utilised in underwater communication. In any case, underwater acoustic waves are likewise restricted by multipath propagation, Doppler Effect, and low data rates [3], [4].

The rate of transmission of data r (Data rate) is an important characteristic of a channel, though it varies from that medium to another. It majorly depends on channel bandwidth (B), channel SNR (Signal to Noise ratio) and the number of levels in a transmitted signal. The Nyquist bit rate for an (L) level signal is given as:

The capacity of information transmitted in a channel varies with bandwidth and signal to noise ratio of the signal, which is called Shannon's Channel Capacity:

Where C = channel capacity, B = Bandwidth of the channel,S = Average received signal power, N = Average noise power, S/N = signal to noise ratio.

We can see that more interference leads to a decrease in signal power in comparison to noise power, which proportionally leads to a decrease in channel capacity.

II. CHALLENGES IN UNDERWATER COMMUNICATION

The major challenges associated with underwater applications are as follows:

- The propagation delay is quite high in the underwater medium in comparison with the terrestrial environment.
- The dynamic nature of the channel due to multipath fading problem.
- Temporary losses of connectivity and high error in bit rates can be experienced in the channel characteristics.
- The power factor of the batteries is a major drawback due to its high-power requirement.
- Pollution and corrosion have played a key role to cause failure for underwater sensors [1], [2].

III. FACTORS AFFECTING UNDERWATER COMMUNICATION

The main factors that alter underwater communication are: Ambient noise It is a background source level in each point, which is used to study invasive sound source. It varies with the effect of turbulence that is seen at low-frequency points where it is less than 10 Hz. The motion of the waves causes surface motion that leads to a frequency ranging from 100 Hz to 100 kHz. The high-frequency factor is the thermal noise which effects at a frequency greater than 100 kHz

Doppler effect an effect which is considered to have a key role in affecting underwater communication. As the Doppler frequencies are greater than the carrier frequency and the speed of the sound is low, it leads to playing that key role. The motion between the transmitter and receiver due to movement of the sea surface the Doppler shift completely distorts the frequency of the transmitted signal.

c) Multipath channel the propagation speed of the acoustic network is around one kilometre per second, which is quite low compared to other modems. The water medium is comprised of many scattering parameters and the reflection caused from the surface adds up to the occurrence of multipath in the underwater acoustic channel. From the Rayleigh fading model, we can see that,

$$R(t) = M(t) * S(t) + N(t)$$

Where, R (t) = Received Signal, M (t) = Message Signal, S (t) = Modulated Signal, N (t) = Additive white Gaussian noise. It is a major factor to cause inters symbol interference (ISI); inter-channel interference (ICI) and fading of the signal. The signal flow gets majorly disrupted through these factors, which leads to time and frequency spreading causing high attenuation in a signal.

IV. DEPTH BASED FORWARDING PROTOCOL

Underwater Wireless Sensor Networks consist of a variable number of sensors and vehicles that are implemented to perform collaborative monitoring tasks over a given area. However, designing energy-efficient routing protocols for this type of networks is essential and challenging because the sensor nodes are powered by batteries, underwater environment is harsh, and propagation delay is long. Most of the existing routing protocols used for underwater wireless sensor networks use a greedy approach to deliver data packets to the destination sink nodes at the water surface. Further, routing protocols do not require full-dimensional location information of sensor nodes. Instead, it needs only local information, which can be easily obtained with an inexpensive sensor that can be equipped in every underwater sensor node. To overcome these limitations Depth Based Routing protocol uses depth information along with the location-aware model as the metric for choosing a router node in the communication path. This decision reduces the high energy consumption and long end to end delay which will degrade network performance.

Algorithm:
ForwardPacket(p)
Get previous depth dp from p
Get node's current depth dc
Compute d = (dp – dc)
IF** d < Depth Threshold dth **THEN
IF** p is in Q1 **THEN
Remove p from Q1
ENDIF
Drop p
return
ENDIF
IF** p is in Q2 **THEN
Drop p
return
ENDIF
Update p with current depth dc
Compute holding time HT
Compute sending time ST
IF** p is in Q1 **THEN
Get previous sending time of p STp
Update p's sending time with min(ST, STp)
ELSE
Add the item <p, ST> into Q1
ENDIF

V. VECTOR-BASED FORWARDING PROTOCOL

Vector-Based Forwarding (VBF) protocol addresses the node mobility issue in a scalable and energy-efficient way. In VBF, each packet carries the positions of the sender, the target and the forwarder (i.e., the node which forwards this packet). The forwarding path is specified by the routing vector from the sender to the target. Upon receiving a packet, a node computes its relative position to the forwarder by measuring its distance to the forwarder and the angle of arrival (AOA) of the signal1. Recursively, all the nodes receiving the packet compute their positions. If a node determines that it is close to the routing vector enough (e.g., less than a predefined distance threshold), it puts its computed position in the packet and continues forwarding the packet; otherwise, it simply discards the packet. Therefore, the forwarding path is virtually a routing "pipe" from the source to the target: the sensor nodes inside this pipe are eligible for packet forwarding, and those outside the pipe do not forward.
In VBF, each packet carries positions of the sender, the target and the forwarder in three fields, represented by SP, TP and FP respectively. To handle node mobility, each packet contains a RANGE field. When a packet reaches the area specified by its TP, this packet is flooded in an area controlled by the RANGE field. The routing pipe is defined by the vector from the sender (with position SP) to the target (with position TP), and the radius of the pipe is defined in the RADIUS field. Routing in VBF is initiated by query packets. VBF routes different queries in different ways:
(1) Sink Initiated Query. There are two types of such queries: one is location dependent query in which the sink is interested in some specific area and knows the location of the area; another is the location-independent query in which the sink wants to know some specific type of data regardless of its location. For a location-dependent query, the sink issues an INTEREST query packet, which carries the coordinates of the sink and the target in the sink-based coordinate system, i.e., it has the information of SP and TP. This query is then directed to the targeted area following the pipe defined by SP and TP. For a location independent query, the TP field of the INTEREST packet is invalid, and this query will be flooded to the target nodes. Upon receiving such query, the intended nodes can compute their locations in the sink-based coordinate system and then direct the subsequent data packets to the sink.
(2) Source Initiated Query. If a source initiates a transmission, it first sets up a coordinate system originated at itself and flooded DATA READY packet into the network. Therefore, each node (including sink) can compute its location in the source-based coordinate system. The sink transforms the position of the source into its coordinate system and sends a location-dependent INTEREST packet to the source to allow the source to compute its position in the sink-based coordinate system for the subsequent communication.
Both vector based routing algorithm and depth and energy based router node selection strategy increase the packet delivery ratio by avoiding the generation of void routs in the communication channel. The wireless network was implemented in the NS2 environment, and the performance of the network is measured in terms of performance metrices like throughput, packet delivery ratio, packet loss ratio, the end to end delay and residual energy.

VI. RESULTS AND DISCUSSIONS

The throughput is the measure of data rate between the sender and receiver nodes and also referred to as the measure of bandwidth consumption of the network nodes. Increase in throughput increases the performance of the network.
Throughput:
current_time_instance = nxt_time_instance;
nxt_time_instance += interval;
throughput = bytes_recvd / current_time_instance;
throughput = current_time_instance (throughput/1024);

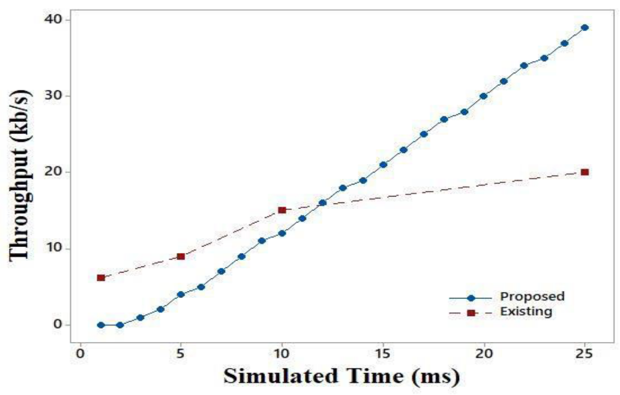

Figure 1: Throughput

The packet delivery ratio is the measure of successfully transmitted data packets between the sender and receiver nodes. Increase in packet delivery ratio increases the throughput of the network. The increase in throughput and packet delivery ratio will differ based on the conditions. In the first condition, the data packets from sender to receiver was successfully transmitted only at second trial due to congestion. In the second condition, the packets were successfully transmitted only at the fifth trial the throughput will be same in both the situations but the packet delivery ratio of both the situations vary about 0.5%.

Packet delivery ratio = received packets / generated packets *100

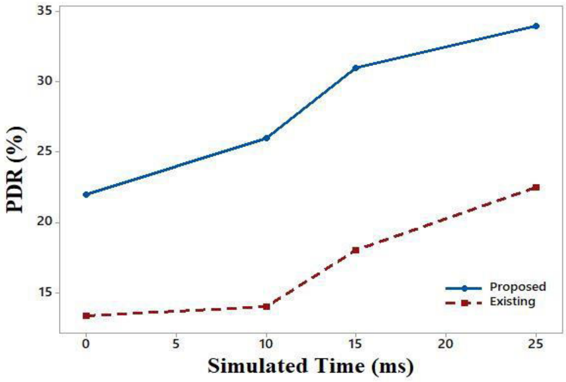

Figure 2: Packet Delivery Ratio

Packet loss is the measure of the failure of one or more packets during the transmission of data between the sender and receiver nodes. The ratio of packet loss ratio increases will affect the rate of packet delivery ratio. The packet loss occurs due to multiple factors in the transmission medium. The major factor is multipath fading. In the underwater wireless sensor network, multipath fading is most common due to the water and aquatic creatures like plants, fishes and uneven underwater land surface.

Packet loss = Generated packet - received packet

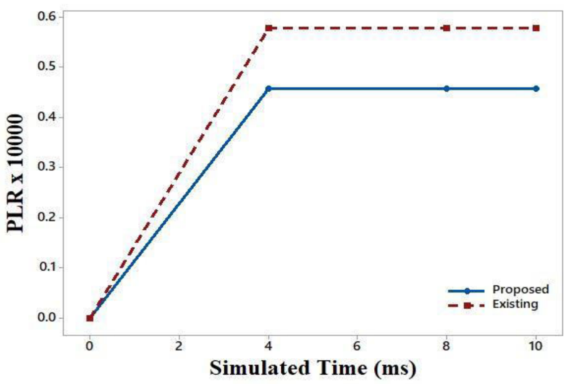

Figure 3: Packet Loss Ratio

End to End delay is the time taken by the packet to transfer between the sender node to the destination node. The time taken for uni-direction flooding is measured which is different from the round trip time measured in the network. The end to end delay was affected based on the amount of time taken by the sender node to identify the location of the destination node in the network. The end to end delay increases more when the source and destination nodes are mobile nodes

i = packet sequence number

count = Total packet count

Delay[i] = received time[i] – sent time[i]

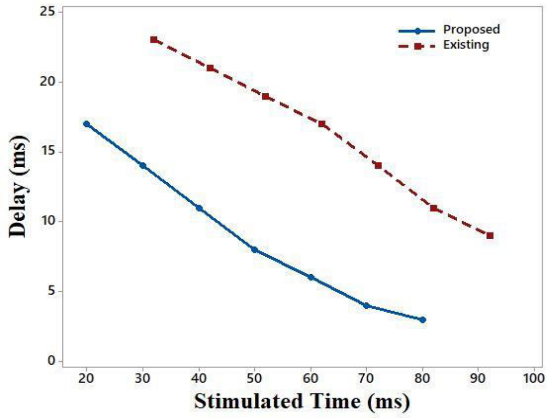

Figure 4: End to end delay

All the nodes placed in underwater wireless sensor network were powered by a battery source. The lifetime of the network is more concentrated to avoid the occurrence of early dead nodes in the network. An energy model is set to define the energy levels of the nodes in the network. The energy model defines the average energy possessed by the node at the initial state of the network. The initial energy of the network is assigned as 100J, and the energy of the node will be decreased for every iteration of transmission and reception of packets in the simulated time. The rate of decrease in the residual energy represents the lifetime of the network.

Residual energy = initial energy – (number of packets * (ideal power + Tx power + Rx power))

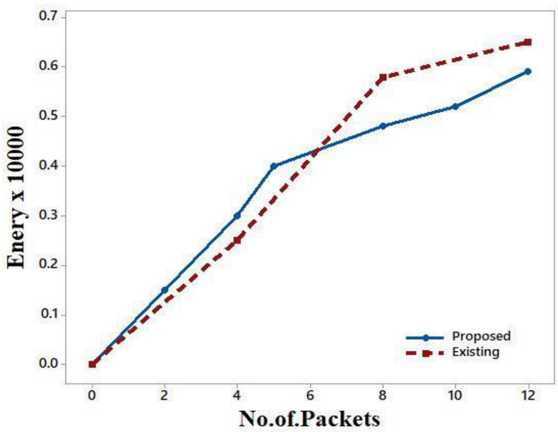

Figure 5: Residual Energy

VII. CONCLUSION

Based on our results, we conclude that although ambient noise in shallow water is higher than in deep water, the vector-based forwarding routing protocol combined with the depth and energy based routing protocol performs better in shallow water. This is due to the attenuation of the signal that is much higher in deep water than in shallow water. Also, the pressure is higher in deep water than shallow water, and this causes a rapid decrease in signal strength in deep water as compared to shallow water.

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