# Enhancing the Performance of 433 MHz Underwater WSN Using Handover Mechanisms

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***Abstract***—Wireless technology has taken part of our daily life which paved the way to underwater wireless communication to flourish as a research area. This research field is important for exploration of the seabed as oceanographers stated that there are still unexplored ocean perceptions. Latency and distance are considered to be the main factors that confronts this particular field and degrades the overall performance. This paper investigates the performance of RF signals in varying water depths. A point to point system was first considered with 2 nodes, the results of this experiment along with our previous work aroused the idea of Star topology. Another experiment was done testing the proposed topology within a particular distance before the data is completely lost. Moreover, a relaying technique using amplify and forward, was introduced to the system at high depth where the data is lost; changing the topology from star to line topology. The system performance was measured in terms of end to end delay and calculating the throughput of the whole system.

***Index Terms***—Underwater Communications (UWC), UWSN, RF, WSN.

## I. Introduction

Water, in the shape of rivers, seas and oceans, covers most of the planet earth. The Deep Ocean is considered to be a place full of mysteries that need to be explored. Each day, many more secrets are being discovered from theer. For this reason and many more, underwater communication is being developed so that the process of exploring and monitoring this frontier could be done. Moreover, the development of more stable communication protocols will help in easing the existence of underwater applications.

Underwater communications (UWC) differ from terrestrial communications in many ways. One of these differences is the limitation imposed by the restricted behavior of communication signals in underwater environments which makes underwater communications highly bounded. Generally speaking, UWC depends on increasing the transmission power in order to overcome the severe degradation that is caused by the communication distances [1]. Lately, research has opened the field for new approaches that were created to improve the capability of underwater communications over long distances. Transmission under water is normally done by one of three ways; acoustic signals, optical signals, or Radio Frequency (RF) signals.

Communication using acoustic signals was found to support long distances that can reach large distances up to 20 km. However, this comes with large latency and it can only achieve low data rates in order of kbps [2]. On the other hand, optical communication systems were found to be able to provide both low latency and ultra-high data rates reaching in the order of Gbps. However, this could only be done over relatively short distances in terms of meters. Another limitation of optical communications is also that they are faced with the difficulty of crossing water/air boundary, not to mention the importance of line-of-sight (LoS) between the transmitted and the receiver, which is not always achievable. Finally, research has shown that RF communication is capable of providing reasonable Mbps transmission rates as well as they have no problem when crossing through water/air boundary in short distances.

In this paper, RF transceivers are chosen based on the facts that they are able to cross the water/Air boundary and provide reasonable data rates. Furthermore, since the operating frequency is an important factor that affects the propagation distance in the network, choosing the best frequency for the application is an important factor in the success of the work. The experiments implemented in this paper is an extension to the work done in [3], where two frequencies were tested. And so, the operating frequency that had the best performance in the previous paper was used.

The rest of the paper is organized as follows. Section II illustrates the related work to our paper. Section III gives a description on the case study. Section IV is about the experimental results and the discussion about them. Finally, Section V is the paper's conclusion.

## II. Related Work

Researchers have been working hard to explore extensively the three communication technologies mentioned in the introduction section. The consensus is that both acoustic and optical technologies based on several implementation strategies providing low data rates over large distances and high data rates on relatively short distances. Chowdhury, et al. in [4] proposed a node

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estimation technique for underwater communication networks that is based on cross-correlation using three sensors due to the characteristics of underwater propagation. This has been shown to improve the performance of the system but with the cost of complexity.

Sarker, *et al*. in [5] used spread spectrum (SS); four Sensors in Square locations bearing in mind the propagation in both direct way and multipath. It was considered to be an enhanced node estimation statistical approach for UWCNs that provided more accuracy.

Chen, *et al*. in [6] and Kebkal, et al. in [7], explored the high data loss that UACNs are exposed to because of the interference. Chen, *et al*. developed several MAC protocol forms in order to overcome the high loss of data. While, Kebkal, *et al*. managed to reduce the high data loss by implementing a coding algorithm which helped in increasing the throughput.

Li, *et al*. in [8], developed an underwater wireless optical communication system with relatively high speed reaching 100 Mbps.

Anguita, *et al*. in [9], studied the light propagation and distribution in water contributing to simulate a model of an optical underwater network.

Vavoulas *et al*. in [10], overcame the scattering in optical communications as well as the high absorption using a novel transmission method.

Additionally, Yin *et al*. in [11], integrated underwater acoustic waves, optical fiber and wireless light to propose a novel underwater sparse cellular network. On the other hand, only few research articles aimed to use RF communications having their capability in water/air boundary crossing.

El Bouanani *et al*. in [12], statistically derived end-to-end signal-to-noise ratio (SNR) of the overall wiretap channel as well as key system parameters on the secrecy performance.

Lloret, *et al*., in [13], used the ISM band to examine RF underwater communication which helped in maximizing the overall distances between communicating nodes.

Che, *et al*. in [14], proposed an RF communication using static multi hop topology under specific circumstances of shallow water which allowed some nodes to sleep on schedule while not transmitting.

Finally, Maher, et al. in [3], proposed RF under water communication between two nodes with a relatively low cost nodes based on point to point behavior. The proposed system's performance was explored through multiple parameters such as number of corrupted packets, end-to-end delay and throughput. The experiments were conducted on two different RF modules using two different operating frequencies which concluded that RF module operating at 433MHZ was better in Air-to-Water providing lower end to end-to-end delay and higher throughput for long distances. In this paper, we are building on that work by developing a multi hop RF underwater communication system that is able to provide the same characteristics of an RF UWC but for much longer distances and on different scales.

## III. Case Study

In this section we present the case study used to test the proposed system.

### A. *Node Setup*

In this work, we consider a wireless sensor network consisting of two main nodes. One acts as the server collecting and processing data and it is placed above water, while the other one acts as the terminal node that only sends data from its allocated position underwater. The Server node is made up of an Arduino Uno and a 433MHz receiver. While the terminal node contains an Arduino Uno, a 433MHz transmitter, and a DS18B20 temperature sensor sealed in a waterproof container. Moreover, the antenna and the temperature sensor probe are attached to the container externally in order to be in direct contact with the water. The operating frequency of the 433MHz module is 434 MHz with Amplitude Shift Keying (ASK) as the modulation scheme, it has a range up to 200m in air. The selection of the operating frequency was made after studying the work done in [3]. The transmitter is set to transmit data at 2 Kbps. Whereas the DS18B20 is a water proof temperature sensor providing useful water monitoring data to be sent and processed by the server. The nodes are supplied with a 9V battery providing 8000mA. In Fig. 1, the server and terminal node are presented.

Fig. 1. Hardware setup of the node.

### B. *System Performance Measurements*

The transmitter and receiver are operating with a reliable datagram running through packet switching network. In order to make this process work efficiently, an independent algorithm was written for the server and terminal nodes. The algorithms describe the server and terminal procedure in details.

**Algorithm 1 At Terminal node**

*1: Extract length of message*
*2: Buffer is cleared*
*3: Message placed on buffer*
*4: Compare (message length, maximum capacity of transmitter)*
*5:* ***If*** *(message length allowed)* ***then***
*6: Encode message into 6-bit symbols containing*
*{*
*Message length*
*CRC bits*
*Headers (include source and destination)*
*Actual message*
*}*

*7: Message Transmitted in serial*
*8: System stays idle until message is fully transmitted*
*9:* ***else***
*10: Transmission will be denied*
*11: Buffer cleared*
*12:* ***end if***
►*this condition shows the transmission algorithm and conditions that allow transmission*

**Algorithm 2 At Server node**
*1: RF Receiver waits for signal*
*2:* ***If*** *(Packet Received)* ***then***
*3: Check source and destination*
*4: Check length and FCS*
*5:* ***If*** *(source not in wireless sensor network || destination not server)*
*6:* ***then*** *Discard message*
*7:* ***else***
*8:* ***if*** *(error detected by FCS)* ***then***
*9: Server notes that signal could not be recovered*
*10:* ***else***
*11: Overheads removed*
*12: Message recovered and displayed*
*13: Server notes that signal is recovered*
*14 Clear Buffer*
*15:* ***end if***
*16:* ***end if***
►*this algorithm detects the validity of the message*

*17:* ***If*** *(1 minute passed)* ***then***
*18: Evaluate system performance*
*19:* ***end if***

The system performance is measured at the server node. The node processes data and calculate the average End-to-End delay, counts the number packets that were recovered and the number of packets that were corrupted over one minute.

The number of corrupt and successful packets are used to calculate the total number of packets sent per one minute which is referred to here as $N_T$

$$N_T = N_s + N_c \tag{1}$$

where $N_s$ is the number of successful packets recovered per minute, $N_c$ the number of packets that were received but could not be recovered per minute. The throughput of the system is determined by the server according to the received packets. It is calculated by the equation:

$$Throughput(bps) = Bandwidth \times Latency \tag{2}$$

The bandwidth in this system is considered as the total amount of data generated by the transmitter to fill the communication channel

$$Bandwidth = B \tag{3}$$

$$Latency = \frac{N_s}{60 * t} \tag{4}$$

where B is the number of useful bits per packet and t is the total transmission time in seconds. $N_s$ is calculated per second by dividing its value over 60 seconds.

All experiments were done in a swimming pool in order to ensure that the signal is transmitted through only water and that the terminal node can reach a depth where signal is no longer received by the server.

## IV. Experimental Results and Discussion

In this paper, two experimental setups are considered for underwater RF communications. The two experiments are shown in Fig. 2.

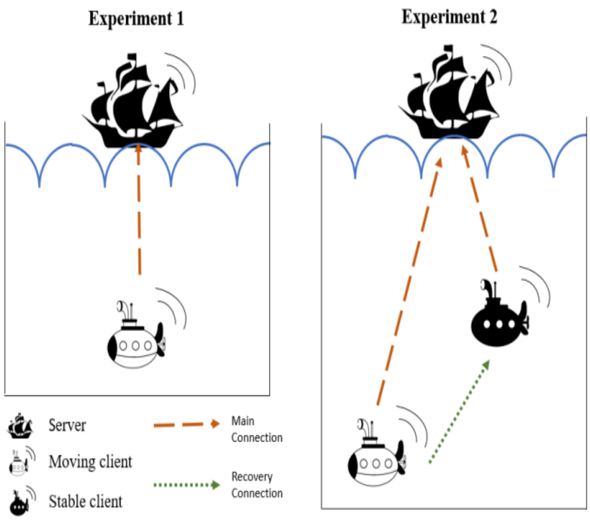


Fig. 2. Experiment Methodology.

The performance of the RF signal is considered in different water depths. The performance is measured in terms of throughput and end to end delay of the system. Moreover, star topology is investigated while enabling a recovery technique in case a node was unable to communicate with the star node.

### *A. Experiment 1: Investigation of Water Depth on the RF Signal*

In this scenario, a node was placed above water acting as a server, processing data whereas the terminal node is placed at a varying depth from the server. We started by a distance of 50 cm and incremented the distance gradually by 50 cm increments. A time of 20 seconds was given to the terminal node/server to establish a stable connection before starting to note down the readings of the system. At each of the depths in consideration, the server and terminal nodes were kept at a line of sight situation in order to achieve the maximum throughput at this depth.

Fig. 3 shows the end to end delay of the proposed system. It was found that the system experienced a similar delay up to 250 cm depth. After 250 cm, the delay increased sharply over 100 cm till it reached 350 cm where the server could not recover any data from the terminal node's message. This is expected as the distance increases, the path loss with also increase. And so, after a certain depth, the receiver will not be able to received the transmitted signal from the first transmission and will require additional retransmission. This will cause the end-to-end delay to increase exponentially.

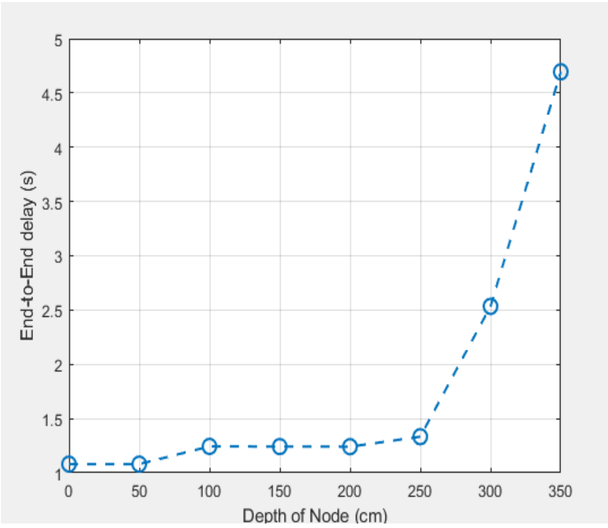


Fig. 3. End to end delay vs depth (Experiment 1).

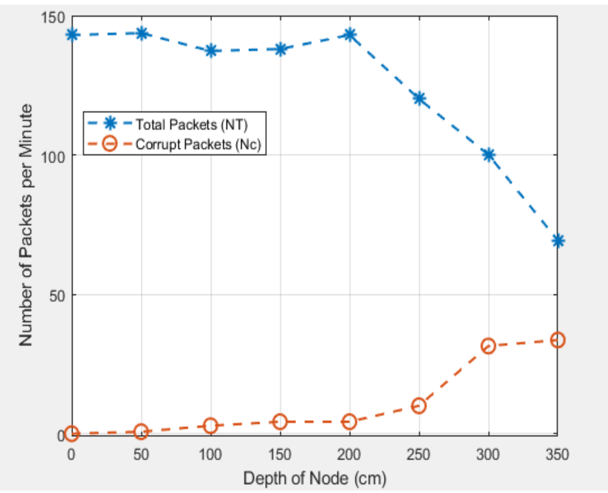


Fig. 4. Packets count over depth (Experiment 1)

Fig. 4 analyzed the packet loss behaviour over the various depths. It was observed the system experienced slight change in $N_T$ averaged at 140 packets per minute until 200 cm. However, the trend changed and there was a significant decrease after 200 cm depth. It decreased from 140 packets per minute at 200 cm to 51 packets per minute at 350 cm. More than half of the expected total packets were lost at 350 cm. Moreover, $N_c$ experienced a very slight increase every 50cm until reaching 250 cm where there was a noticeable change in the pattern. This graph shows that although the packet loss rate started to increase after 200 cm, the system was still reliable and operated well till 250 cm where $N_s$ is still more than $N_c$. This coincides with the end-to-end delay experiment. As the packet loss increase as the delay increases.

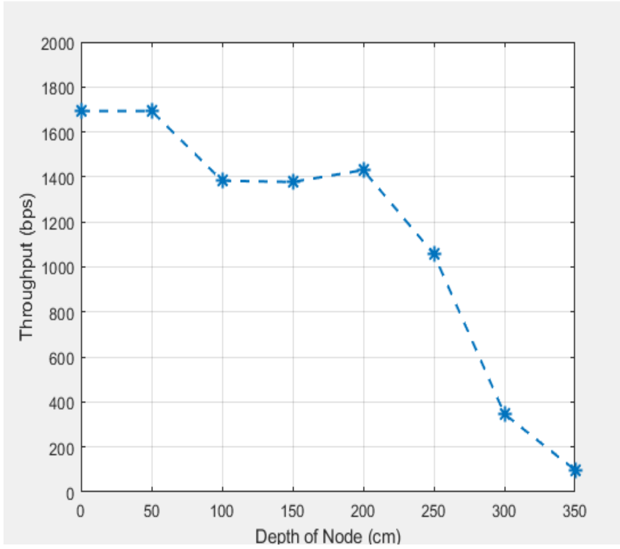


Fig. 5. Throughput analysis (Experiment 1).

Fig. 5. shows the throughput calculated at each depth up to 350 cm. The throughput was found to be constant at 2 different intervals before decreasing almost linearly after 200 cm. The first interval takes place from 0 cm to 50 cm where the throughput was maintained at 1700 bps. It decreased in the next interval that was between 100 cm to 200 cm to have a steady rate of 1400 bps. After 200 cm the decrease is almost linear with a slope of – 6 bps/cm. The system achieved a throughput of 100 bps before the signal was completely lost. This happens because as the loss increase, the number of useful packet decrease, which causes the overall throughput to decrease.

## *B. Experiment 2*

A similar setup to that of experiment 1 was re-implemented. A new terminal node was added to the system at a depth of 300 cm that sends the monitoring observation at its surroundings to the server. The system typically works as star topology when the moving terminal node is at a distance between 0 cm to 300 cm. After, exceeding the 300 cm the moving terminal node almost loses its connection with the server according to experiment 1; therefore, the information gathered by the moving node will be relayed through the stable terminal node. The relaying technique of this experiment is to amplify and forward. This relaying technique is preferred to detect and forward in the underwater environment as the signal already experiences high attenuation and is slightly corrupted before reaching the stable node; if it was forwarded without amplification, it would have been more likely to be completely lost. The main aim of this system is to receive data in water at greater depth as this can practically be used to explore the seabed. This experiment recorded the analysis of the data coming from the moving terminal node only. The star topology idea was introduced due to the work that was done in [3]. Moreover, our findings in experiment 1 helped in shaping the multi-hop technique. A reliable datagram was initiated and tested through the three nodes.

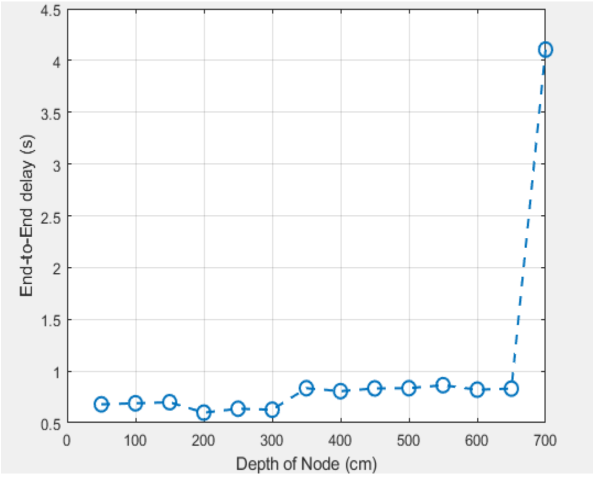


Fig. 6. End to end delay vs depth (Experiment 2).

Fig. 6 shows the end-to-end delay of the moving node mode. As expected, the moving terminal node could reach double of the stable terminal node's depth with acceptable performance. The server could still recover signals from the terminal node at 700 cm but with extremely slow rate. The data took a steady shape of delay wherever the moving terminal node was placed between 350 cm to 650 cm. This steady end to end delay is due the delay of the stable terminal node's data to the server.

Fig. 7 expressed the trend taken by the calculated throughput of the system at every experimental depth. The throughput was found to take a similar trend to that of experiment 1 but with lower throughput, the decreased throughput of the system is due to the induction on the new end node to the system that introduces more processing time at the server's end. The throughput remained constant with almost 1400 bps when the moving end node was between the server and the stable end note. This was expected as the lost data was relayed through the stable end node causing hardly any packet loss in the system. Moreover, after 300 cm the system turned to line topology, where the data at the moving client is always relayed through the stable node as it could not reach the server directly. The throughput decreased because at this point the packet could be lost due to either of the two paths; between moving and stable end nodes, between stable node and server. But Although the message may be reached at a faster rate to the stable node the system throughput was determined by the delay introduced due to the presence of the node at 300 cm. The throughput between the interval 300 cm to 650 cm was averaged to be 1100 bps. At 700 cm the system could still detect the signal but with a very slow unreliable rate of 100 bps after which the signal is completely lost.

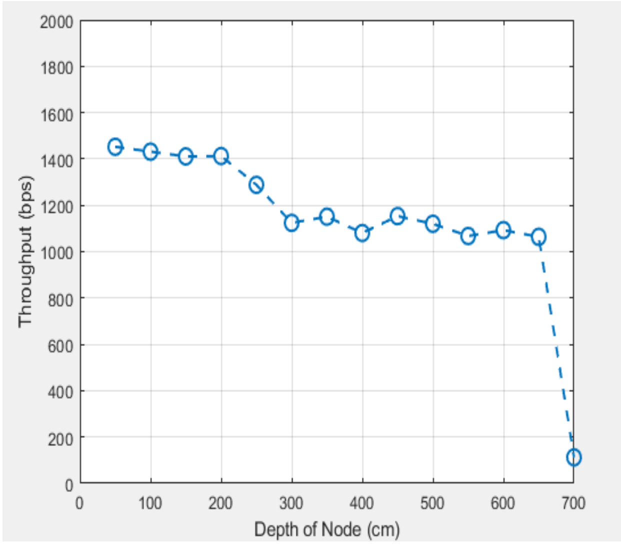


Fig. 7. Throughput analysis (Experiment 2).

According to the measurements, it is clear that the system was able to adapt to the changing environment. This could open the door to implementing more network topologies underwater that could have different performance measures than that typically experienced in air.

## V. Conclusion

This paper introduced a hardware implementation of an underwater wireless sensor network with operating frequency of 433 MHz at rate 2 Kbps. The system included a single server operating with 2 terminal nodes. In the first experiment, 1 terminal node was put to sleep mode and the system performance was measured with one functional terminal node. The system was reliable up to 250 cm with a throughput of 1200 bps Whereas in the second experiment the 2 terminal nodes were operating. The system had a star topology before a distance of 300 cm, after that the far signal is relayed using amplify and forward algorithm. This multi-hop technique could maintain a throughput up to 1100 bps in 650 cm. This work is intended to be a building block to a much larger and complex network to be used in underwater applications such as underwater monitoring.

Future work will include the multi-hop scenario with changing the depth of the stable terminal node or increasing the transmission power. Different network topologies could also be tested.

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## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Ms. Salma and Mr. Ziad have created the prototype, performed the experiments, and gathered the data. The work was done under the supervision of Dr. Sameh and Dr. Mohammad who have analyzed the data and presented the results. All authors have helped in the writing of the paper and all the authors approved the final version.

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