LoRa Based Underwater Wireless Network System

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***Abstract*—To apply the Internet of Things (IoT) underwater, a robust protocol is needed to connect devices. LoRa, known for its long-range and low-power characteristics, is a widely used protocol in IoT. Its significance in underwater environments lies in enabling reliable data transmission between sensors and Autonomous Underwater Vehicles (AUVs), forming an IoT network. However, implementing LoRa underwater is challenging due to high attenuation at its typical operating frequency of 433 MHz. This paper contributes by testing the performance of underwater communication systems at a frequency of 40 MHz using a planar hexagonal loop antenna, which experiences lower attenuation. Our method involves transmitting text underwater via the LoRa protocol using microcontroller and LoRa module, employing Down Conversion and Up Conversion techniques to shift the frequency from 433 MHz to 40 MHz and vice versa, using Software Defined Radio (SDR). The results demonstrate successful reception and display of the transmitted text, indicating the potential of the proposed system for effective underwater communication.**

***Index Terms*—internet of things (IoT), radio communication, underwater communication, lora, and wireless network system.**

I. Introduction

The integration of Internet of Things (IoT) technology into underwater environments holds immense promise for advancing our understanding of the world's oceans and facilitating various underwater activities such as offshore surveys, underwater navigation, and defense and security [1]. These activities build an underwater network system that includes data transmission from sensor to sensor, Autonomous Underwater Vehicle (AUV) to AUV, and from AUV to sensor. Recent advancements in underwater IoT have been driven by a company named ”WSense”, which has developed an underwater IoT network designed for data transmission between sensors and AUVs. This local network transmits data to a gateway, enabling connectivity between the underwater IoT system and the cloud [2]. However, realizing the full potential of underwater IoT requires a robust and reliable communication infrastructure capable of efficiently transmitting data in the challenging underwater environment.

There are three types of transmissions in underwater communication systems: acoustic, optical, and radio. Acoustic signal transmission offers the advantage of long-distance coverage but suffers from relatively low speed and susceptibility to Doppler effects. Optical signal transmission provides high data rates but requires a line of sight between transmitter and receiver devices. Radio signal transmission excels in fast, short-range communication but is affected by mild Doppler effects [3], [4], [5], [6]. Among these three types of transmission, there is growing interest in leveraging emerging wireless technologies using radio transmission, such as Long-Range (LoRa) communication, for underwater IoT applications.

In terrestrial IoT environments, LoRa technology, known for its long-range capabilities, low-power operation, easy deployment, and low operation costs, offers a promising solution [7]. It builds a wireless network system that interconnects sensors and devices. Recent studies have explored the application of LoRa in various environments, including urban [8], forest [9], and inside buildings [10]. The research aim to investigate the application of LoRa technology in underwater environments to establish a wireless network beneath the surface.

This paper discusses the performance of underwater communication systems using LoRa, which is suitable for underwater radio transmission. The paper will be organized as follows: Section II discusses the system model, Section III presents the implementation design and experimental results, and Section IV concludes the paper.

II. System Model

Our proposed system is designed to utilize LoRa technology for underwater communication. The primary challenge associated with using LoRa communication underwater is its high operating frequency of 433 MHz, which experiences significant attenuation underwater [11]. To reduce attenuation underwater, a lower frequency signal is required.

The proposed system is depicted in Figure 1. It comprises two main components: the transmitter and the receiver. In the transmitter, message transmission is programmed by a microcontroller, which then converts the message into a radio signal transmitted through the LoRa module underwater. The LoRa module employs the Chirp Spread Spectrum (CSS) modulation technique, which is robust against channel noise due to the utilization of the entire bandwidth that is used to send data [12]. The standard frequencies specified in the LoRa protocol are 433 MHz for Asia, 868 MHz for Europe, and 915

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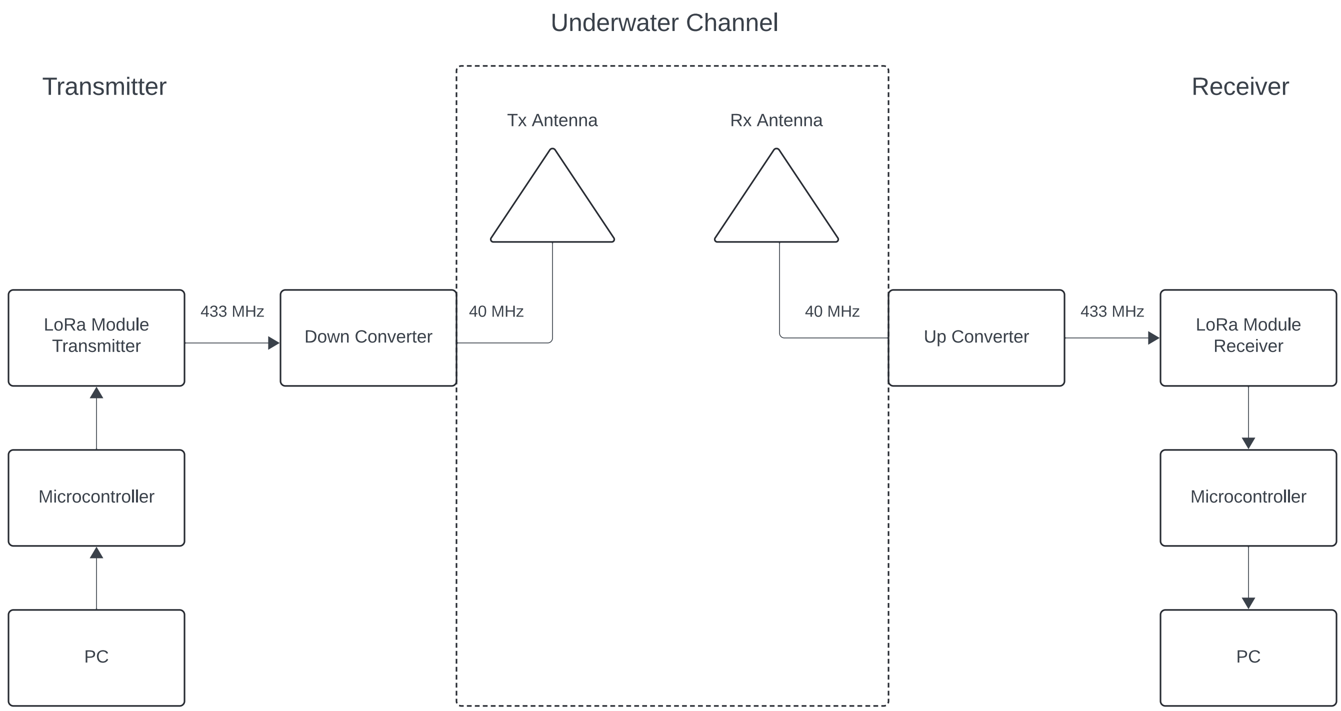

Fig. 1: Proposed system block diagram.

MHz for North America [13]. For this design, a frequency of 433 MHz is employed since the future deployment of the system will take place in the Asian region. However, the use of a 433 MHz frequency poses a challenge due to significant attenuation underwater, resulting in inadequate data transmission.

The antenna used is a planar hexagonal loop antenna that operates at a low band VHF of 40 MHz with a gain of -2 dBi [14]. This frequency disparity necessitates the use of components to down-convert the frequency from 433 MHz to 40 MHz using a Down Converter. Subsequently, LoRa transmission can take place underwater. At the receiver, LoRa signals at 40 MHz are received, and the frequency is up-converted from 40 MHz to 433 MHz using an Up Converter. Both Up Converter and Down Converter are implemented using Software Defined Radio (SDR). The frequency-converted signals can then be received by the LoRa module, which subsequently demodulates them to retrieve the transmitted message. LoRa demodulation uses the dechirping method that converts LoRa chirp symbols to constant frequency symbols and they will be decoded using FFT [15]. LoRa uses a simple binary Hamming code for the Forward Error Correction (FEC) algorithm [16]. This message is then displayed on the serial monitor via the microcontroller.

The link budget formula for the proposed system can be summarized as follows:

- Transmit antenna gain (G_{Tx}): -2 dBi
- Receive antenna gain (G_{Rx}): -2 dBi
- Path loss (L_{Fs}): 7.57 dB (estimated for 40 MHz underwater at 90 cm distance)
- Underwater Radio loss (L_{Ch}): 8.154 dB (estimated for 90 cm distance)
- Cable loss (L_c): 1 dB (estimated for cable at 40 MHz)
- Receiver sensitivity (S_{Rx}): -120 dBm (typical for LoRa at weak signal)

Using the link budget formula:

$$P_{Tx} = S_{Rx} - G_{Tx} - G_{Rx} + L_{Fs} + L_{Ch} + Lc \qquad (1)$$

From the calculation, the minimum transmitted power is -99.28 dBm.

III. Implementation Design and Experimental Results

In this section, we present the implementation design and experimental results of the proposed LoRa-based underwater communication system as described in the previous section. The experimental setup consists of a hardware setup and an antenna configuration underwater, depicted in Figure 2. The experiment was conducted in a container with dimensions of 1048×728×559 mm, as shown in Figure 2b. The planar hexagonal loop antenna used has a return loss of -12 dB at the operating frequency of 40 MHz. The transmitter and receiver were positioned within the container at distances of around 90 cm from each other due to container limitations. The setup consisted of two primary components: the transmitter and the receiver. Each component was equipped with essential hardware elements, including a Laptop/PC, microcontrollers, LoRa modules, antennas, an Up Converter, and a Down Converter, as shown in Figure 2a. The transmitter encoded

(a) Hardware configuration.

(b) Antenna configuration.

Fig. 2: Experiment setup.

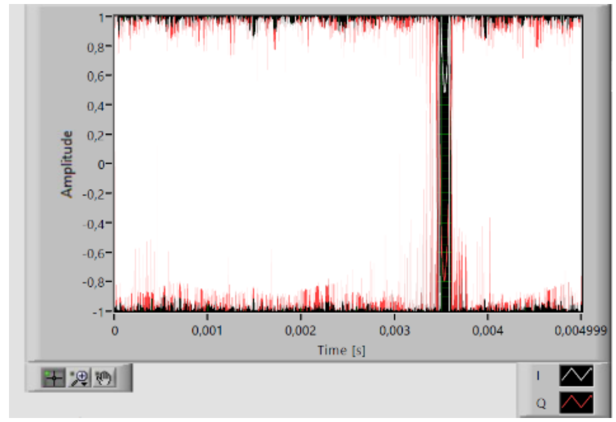

Fig. 4: LoRa transmitted waveform.

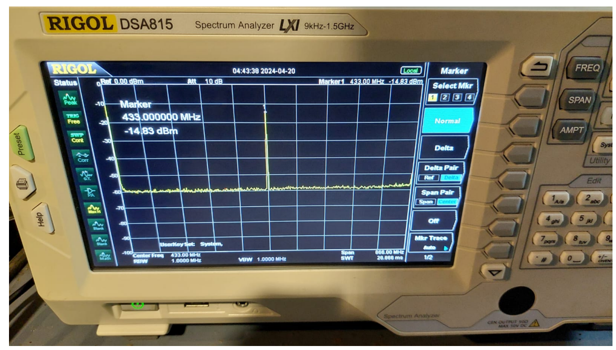

Fig. 5: Transmitted 433 MHz signal spectrum.

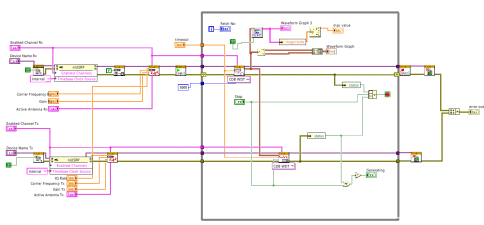

Fig. 3: Up converter and down converter block diagram.

and transmitted messages, while the receiver received and decoded the transmitted signals. The Up Converter and Down Converter were all programmed by SDR. The programming block diagram is depicted in Figure 3.

Prior to conducting experiments, both the transmitter and receiver were calibrated to optimize their performance parameters, including transmission power and antenna orientation, to ensure accurate and reliable communication. Careful attention was paid to antenna placement and component orientation during the positioning of the transmitter and receiver, aiming to maximize the received power.

Continuous transmission tests, lasting 5 minutes each, were conducted to assess the system's ability to maintain connectivity and transmit data accurately underwater. These tests involved monitoring parameters such as the transmission power and reception of the LoRa module, Up Converter, and Down Converter, providing insights into the robustness and resilience of the LoRa-based underwater communication system.

In the transmitter setup, the microcontroller was programmed to transmit a message every 10 seconds in a data string containing the text ”23223018_Naufal Zaidan Nabhan,” via the LoRa module to prevent message overload and alleviate the memory burden on the receiving microcontroller. The transmitted signal operated at a frequency of 433 MHz using Chirp Spread Spectrum (CSS) modulation, as depicted in Figure 4. The output power of the LoRa module, measured by a spectrum analyzer, was -14.83 dBm at a frequency of 433 MHz above the minimum transmitted power level of -99.28 dBm, as shown in Figure 5. This output was then down-converted to 40 MHz using a Down Converter and amplified using internal SDR amplifier of 15 dB gain, with power measured at -53.68 dBm, illustrating intermodulation frequency due to power saturation of the SDR, as shown in Figure 6. The signal was then propagated through a water medium using a transmitter antenna.

At the receiver, the microcontroller was programmed to receive LoRa signals every 5 seconds. The received signal of 40 MHz, measured at the antenna receiver, displayed a power of -70.77 dBm, indicating weakening and distortion due to underwater channel effects, as shown in Figure 7. The frequency of the signal was subsequently up-converted

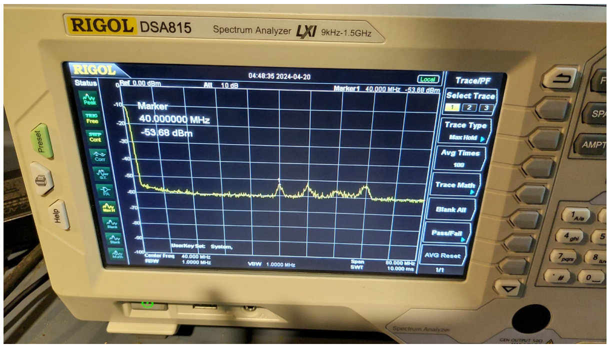

Fig. 6: Transmitted 40 MHz signal spectrum.

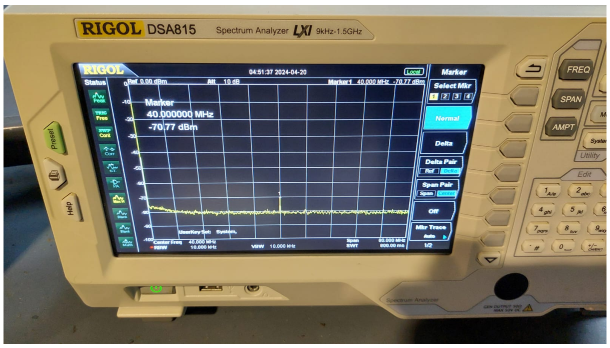

Fig. 7: Received 40 MHz signal spectrum.

back to 433 MHz and amplified with a gain of 15 dB to increase the signal power for reception by the LoRa module. The resultant signal power was measured at -58.94 dBm, as depicted in Figure 8. This signal power remained above the receiver sensitivity threshold of -120 dBm.

The received signals were demodulated and decoded by the LoRa module, displaying messages on the serial monitor as seen in Figure 9. This display included the string data text ”23223018_Naufal Zaidan Nabhan,” matching the transmitted data. Over the course of a 5-minute test, the LoRa receiver module was expected to receive approximately 30 data messages. As shown in Figure 9, all 30 data messages were successfully received, indicating a 100% success transmission rate. Despite encountering underwater channel effects, the

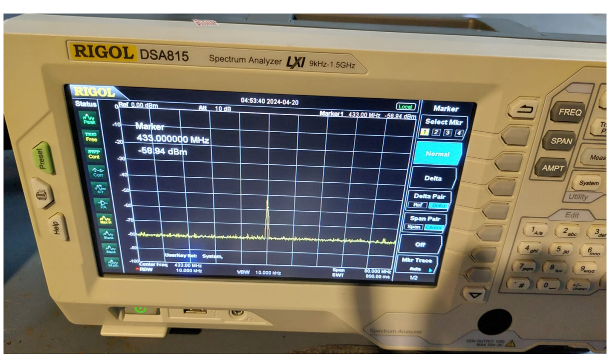

Fig. 8: Received 433 MHz signal spectrum.

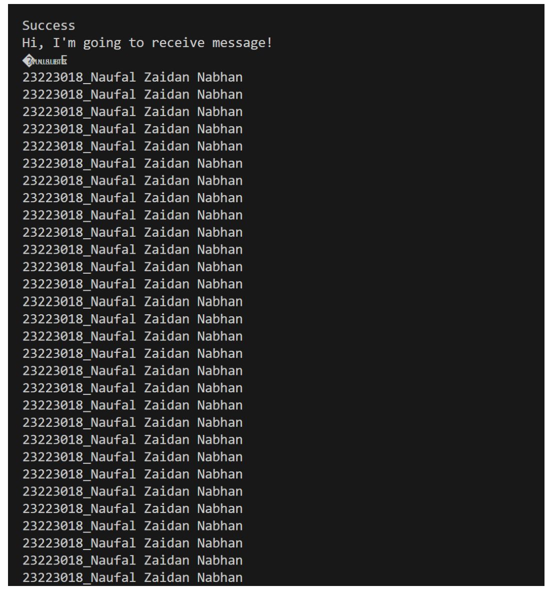

Fig. 9: Messages received in receiver.

received power level remained above the receiver sensitivity threshold, ensuring successful demodulation and decoding of the signal. This success is attributed to the LoRa demodulation and error correction algorithms within the LoRa module.

The experimental results underwent thorough analysis to evaluate the reliability of the LoRa-based underwater communication system. This reliability assessment was enhanced by the encryption and decryption capabilities of the LoRa module, which include modulation and demodulation with error correction factors, all performed within the LoRa module.

IV. Conclusions

In conclusion, this paper has explored the application of LoRa technology in underwater communication systems. The experimental results have provided valuable insights into the performance of the LoRa-based underwater communication system across various parameters such as received signal power and signal waveform. The transmitted signal power is -14.83 dBm at 433 MHz and -53.68 dBm at 40 MHz, while the received signal power is -70.77 dBm at 40 MHz and -58.94 dBm at 433 MHz. This indicates a decrease in signal power during transmission due to cable loss and underwater attenuation. Despite the challenges posed by underwater environments, our findings indicate that the received power remains above the receiver's sensitivity threshold, ensuring a 100% successful transmission rate.

Looking ahead, further research and development efforts are warranted to refine and enhance LoRa-based underwater communication systems. Future studies may explore the integration with other IoT technologies and enable data connection between underwater networks and gateways to send all the data to the Internet. This will extend the capabilities and applications of both underwater and terrestrial networks.

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