Acoustic system for under water communication

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ABSTRACT

The expanding use of underwater acoustic communications (UWAC) in industrial and military contexts underscores the need for robust communication security. Underwater acoustic networks (UWANs), which often operate autonomously over extended periods, pose a unique challenge due to the lack of encryption in UWAC packets caused by physical limitations. This exposes UWANs to threats like fraudulent messages. To address this, a novel algorithm for message authentication in UWANs is introduced. The algorithm capitalizes on the distinct spatial dependence of underwater acoustic channels, where attackers can imitate the channel associated with a legitimate transmitter for a limited set of receivers. Trusted nodes in the network collaborate with a central sink node to enhance authentication. The sink node combines evaluations from trusted nodes upon receiving each packet, based on estimated statistical channel attributes sensitive to transmitter-receiver placement shifts. The algorithm's effectiveness is supported by comprehensive simulation results, showcasing its accuracy in detecting malicious packets from potential attackers. Additionally, empirical evidence from a sea experiment validates the practicality and efficacy of the proposed approach in confirming message authenticity within underwater acoustic networks.

Keywords— Underwater acoustic communication, Underwater acoustic communication networks, channel-based security, cooperative security, authentication, UWAC, sea experiment, MAT LAB.

I. INTRODUCTION

The concept of wireless undersea communications, although seemingly distant, has been actively researched for over a decade. This research aims to develop methods for transmitting information underwater wirelessly, gathering crucial data from remote undersea locations. Achieving high data rates underwater is challenging due to factors like electromagnetic signal propagation limitations, acoustic signal attenuation, and lack of accurate mathematical models for underwater acoustic channels. Wired connections also suffer from dispersion and low data rates due to underwater pressure. This has spurred interest in wireless underwater communications, which, when combined with sensor and vehicular technology, enables applications like environmental monitoring, oceanographic data collection, marine archaeology, search and rescue missions, and more.

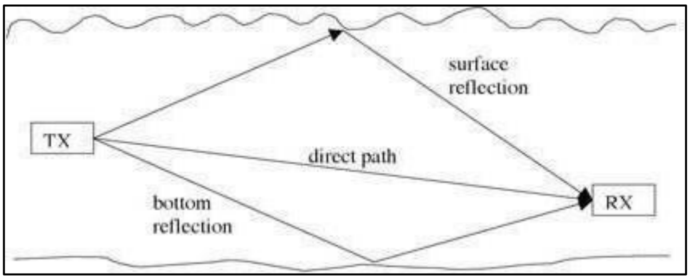

Figure 1: Basic underwater communication system

The central focus of this project is to enhance the performance of underwater communication systems by investigating various algorithms. Addressing the primary limitation of low data rates in underwater communication systems is the key objective. To achieve this, novel algorithms tailored for underwater systems will be explored, optimizing modulation schemes and communication parameters specific to underwater channels. Existing underwater channel models from published literature will inform simulations, enabling the exploration of strategies to improve system performance.

A. Limitation of the current work

The current work focuses on the challenges of underwater wireless communication, especially concerning channel models, attenuation, transmission distance, power consumption, SNR ratio, bit error, inter-symbol interference, error coding, modulation strategies, instrumentation, and underwater interferences. Interferences arise from signal carrier characteristics (electromagnetic, optical, acoustic), propagation medium properties (water type, pressure, impurities), and instrumentation system design.

B. Problem Definition

The project's problem definition centers on designing modulation and demodulation for broadband signals using PSK for underwater communication.

Applications include communication between vehicles, pollution monitoring, environmental data harvesting, seismic monitoring, ocean current monitoring, acoustic navigation for AUVs, etc.

C. Objectives

The objectives involve achieving accurate communication using acoustic waves, optimizing SNR, and reducing noise to enhance accuracy.

D. Methodology

The methodology entails characterizing the underwater channel using established mathematical models, surveying communication schemes, studying modulation techniques, and implementing and optimizing these schemes for underwater channels, with a focus on PSK modulation.

Phase Shift Keying (PSK) is chosen for modulation, which changes the phase of a carrier signal to convey data. MATLAB is the primary software tool for simulations and analysis due to its versatile numerical and symbolic computation capabilities, along with the Simulink package for dynamic system simulation and design.

II. BASIC PRINCIPLES

Acoustic communication networks involve the use of sound waves to determine the position of equipment. These networks are commonly applied in underwater settings and can be tailored to various scales. The underlying concept in all acoustic communication networks is straightforward: Distance equals the product of speed and travel time. If we know the travel time and speed of the sound signal, we can calculate the distance between the source and receiver. In most cases, the speed of the acoustic signal is assumed at a fixed value, either derived from measurements between two known points or calculated using specific equipment based on environmental conditions.

Underwater Acoustic Communication:

Underwater acoustics delves into the propagation of sound in water and how mechanical waves interact with water and its boundaries. This field applies to oceans, lakes, and tanks, with frequencies typically ranging between 10 Hz and 1 MHz Propagating sound at frequencies below 10 Hz requires penetrating deep into the seabed, while frequencies above 1 MHz are seldom used due to rapid absorption. Underwater acoustic communication, involving the transmission and reception of messages underwater, often employs hydrophones. Challenges arise due to factors such as multipath propagation, channel variations over time, limited bandwidth, and significant signal attenuation, especially over long distances. Unlike terrestrial communication, underwater communication relies on acoustic waves rather than electromagnetic waves.

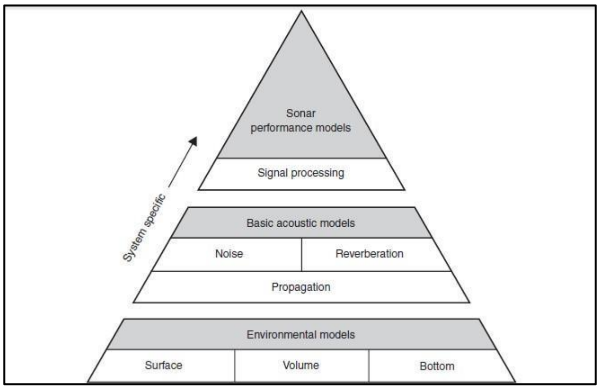

Figure 2: Interconnected environmental, acoustic, and sonar performance models

Historically, ships communicated underwater using bells, and later innovations like the Fessenden oscillator enabled communication with submarines. Underwater acoustic channels pose considerable communication challenges, operating at low frequencies with limited bandwidth. Despite low data rates, underwater acoustic systems exhibit unique signal distortion due to delay spreading, Doppler effects from motion, and other underwater conditions.

Modeling And Simulation:

Modeling involves organizing knowledge gained from observation or underlying principles, while simulation implements models over time. In underwater acoustics, modeling and simulation convert our understanding of underwater sound into mathematical models that simulate complex acoustic systems in the undersea environment.

Sound Propagation in Water:

Underwater sound propagation is influenced by numerous factors. The direction of sound propagation is shaped by gradients in sound speed in the water. As sound travels in water, it encounters various phenomena, including shadow zones and caustics, caused by sound speed profiles and refractive properties of the medium. Certain phenomena, like the Deep Sound Channel and Convergence Zones, enable guided sound propagation over long distances. Factors such as surface ducts and turbulence affect propagation and introduce scattering and attenuation of sound signals.

Underwater Noise Sources:

Underwater noise stems from diverse sources, each contributing differently to the overall noise environment.

- **Attenuation**: Sound signals undergo attenuation as they propagate due to intrinsic limitations and natural effects.
- **Shipping Noise**: Varies with ship speed, traffic density, and sea state, dominating in busy areas like the English Channel.
- Wave Noise: Generated by wave movements impacting sound signals, with greater impact during intense wave activity.
- **Thermal Noise**: Imposed by molecular agitation, providing a lower limit to detecting weak signals.
- **Ambient Noise**: Prevailing background sound at a location and time, interfering with communication signals.
- **Wind & Rain Noise**: Wind and rain influence underwater acoustics, dampening signals and causing disturbances.
- **Seismo-Acoustic Noise**: Arises from Earth's interior and oceans due to geological processes.
- **Arctic Ambient Noise**: Distinct noise environment in the polar region with minimal contamination and unique ice properties.
- **Bioacoustic Noise**: Generated by marine animals communicating, interfering with transmitted signals.
- **Beam Noise**: Introduced by narrow beams used in passive sonar systems, varying based on array configuration and orientation.
- **Volume and Sea Surface Reverberation**: Caused by scattering and reflection from volume, sea surface, and seafloor.
- **Turbulence**: Induced by ship movements and tidal energy, leading to water disturbances.
- **Self-Noise**: Generated by transceivers emitting and receiving acoustic waves, contributing to overall noise.
- **Flow Noise and Strumming Noise**: Caused by water flow around transceivers and vibrating structures.
- **Blade Rate and Propeller Noise**: Emitted from rotating blades on ships and boats, varying with speed.
- **Resonance Noise and Machinery Noise**: Generated by mechanical vibrations and moving parts of ships.
- **Facet Scattering and Air Bubble Scattering**: Arises from surface facets and air bubbles near the ocean surface.
- **Under Ice Reverberation**: Caused by ice chunks impacting sound waves and generating reverberation.
- **Sea Floor Reverberation**: Reflects and scatters sound signals from the ocean floor.
- **Turbulence**: Resulting from ship speed and tidal energy, creating disturbances in water.

These various noise sources impact underwater communication, and understanding their effects is crucial for effective signal transmission and reception.

III. IMPLEMENTATION PROCESS

Our implementation involves coding within three distinct models: the Ainslie-McColm model, Fisher-Simmons model, and Thorp model. Within each model, we manipulate parameters such as range, shipping factor, and wind factor. Our approach unfolds as follows:

Model Selection:

1. We will execute the code separately for the Ainslie-McColm model, Fisher-Simmons model, and Thorp model.

Parameter Variation: Wind Factor

2. For each model, we start by varying the wind factor while maintaining a constant shipping factor. This process is carried out for three distinct ranges: 1Km, 5Km, and 10Km. We analyze the results for each model individually (Ainslie-McColm, Fisher-Simmons, and Thorp).

Parameter Variation: Shipping Factor

3. Next, we shift our focus to varying the shipping factor while keeping the wind factor constant. Similar to the previous step, this is done for the three ranges (1Km, 5Km, and 10Km) within each model.

Result Tabulation and Comparison

4. We compile the results from all variations and tabulate them. These results are evaluated based on transmitted signal strength, received signal strength, and Signal-to-Noise Ratio (SNR) profiles.

Outcome Analysis

5. By meticulously comparing the outcomes, we are able to determine the efficacy of each model (Ainslie-McColm, Fisher-Simmons, and Thorp) for varying maximum ranges.

Software Algorithm (Version 4.1)

1. Input Provision:
   Enter the necessary parameters: power, range, and margin.

2. Transmitter Properties Definition:

   Define transmitter characteristics such as transmitter symbol rate (dependent on frequency), receiver symbol rate, number of tones, and frame duration.

3. Frequency Assignment:
   Assign distinct frequency values to each individual tone.

4. QPSK Bit Pattern Generation:
   Generate a QPSK bit pattern using 16 randomly generated tones (equivalent to 32 bits).

5. Frequency Domain Conversion:
   Transform the generated bit pattern into the frequency domain using the Inverse Fast Fourier Transform (IFFT) approach.

6. Transmitted Signal Display:
   Display the transmitted signal.

7. Noise Estimation and Attenuation Calculation:
   Estimate the noise and calculate attenuation.

8. Channel Effect Calculation:
   Compute the impact of the channel on the signal at the receiver end.

9. Received Signal Plotting:
   Plot the received signal.

10. SNR and C/B Ratio Calculation:
    Calculate the Signal-to-Noise Ratio (SNR) and Carrier-to-Noise Ratio (C/B ratio).

11. C/B Ratio Rounding:
    Round the calculated C/B ratio value using a rounding algorithm.

12. SNR and C/B Ratio Plotting:
    Plot the SNR and C/B ratio values before and after applying the rounding algorithm.

By adhering to this outlined approach and software algorithm, we aim to successfully implement and assess the three models, ultimately comparing their performance across varying conditions and ranges.

IV. OUTCOMES AND ANNOUNCEMENT

A. Experimental Outcomes

1. Wind Factor: 15, Shipping Factor: 2

The subsequent outcomes showcase the transmitted signal, received signal, SNR profile, probability profile, and probability profile following round-off. These observations are derived with a wind factor of 15 and a shipping factor of 2, spanning various ranges and models.

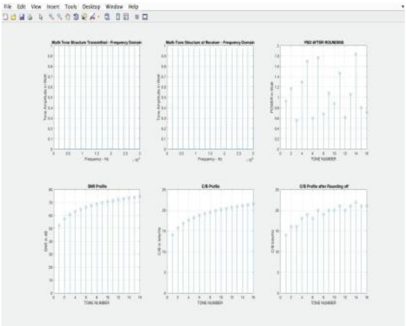

Figure 3: Ainslie Model for Range-1Km

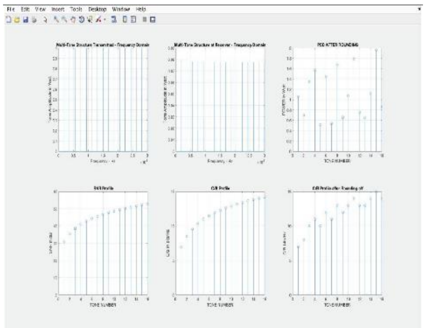

Figure 4: Ainslie Model for Range-5Km

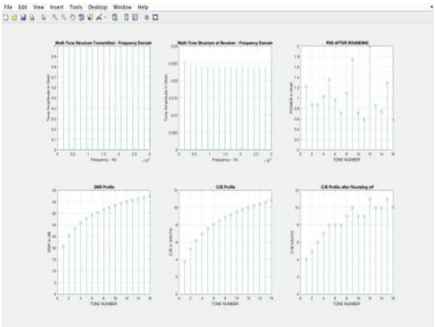

Figure 5: Ainslie Model for Range-10Km

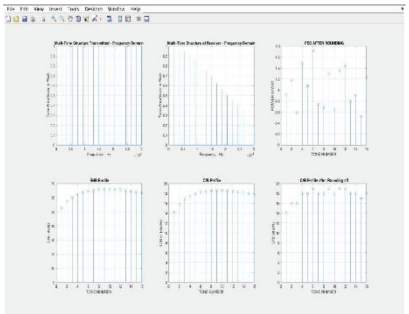

Figure 6: Fisher Simmons for Range-1Km

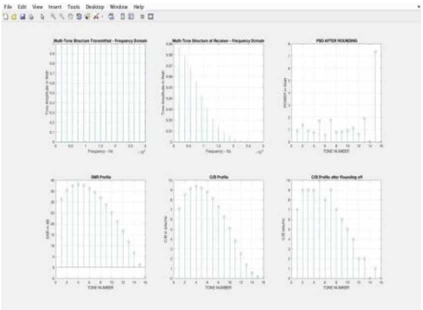

Figure 7: Fisher Simmons for Range-5Km

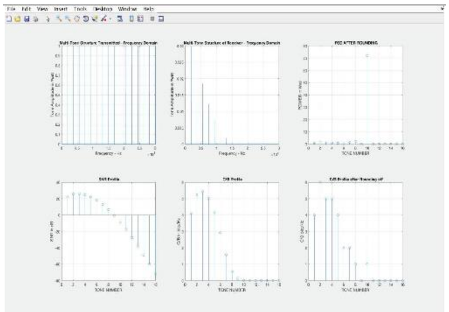

Figure 8: Fisher Simmons for Range-10Km

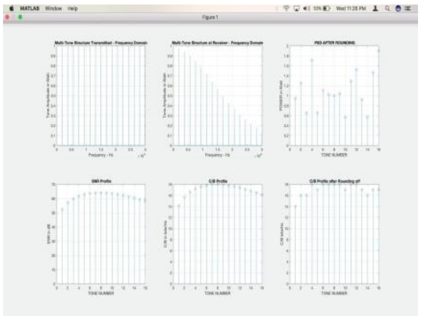

Figure 9: Thorp for Range-1Km

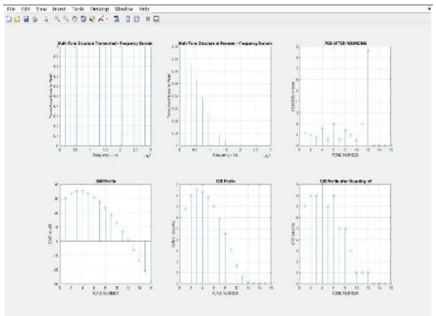

Figure 10: Thorp for Range-5Km

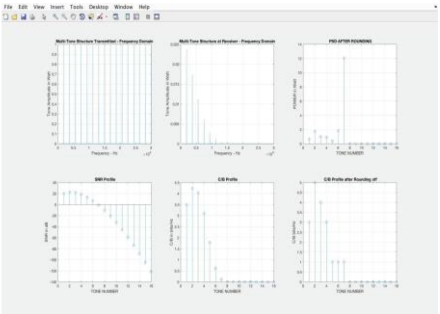

Figure 11: Thorp for Range-10Km

2. WIND FACTOR: 25, SHIPPING FACTOR: 2

The ensuing findings illustrate the transmitted signal, received signal, SNR profile, probability profile, and probability profile after rounding off. These observations are obtained with a wind factor of 25 and a shipping factor of 2, across various ranges and models.

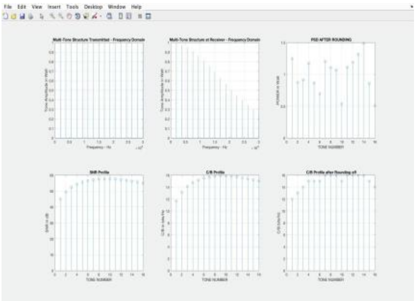

Figure 12: Fisher Simmons for Range-1Km

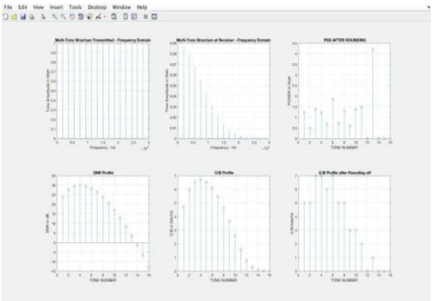

Figure 13: Fisher Simmons for Range-5 Km

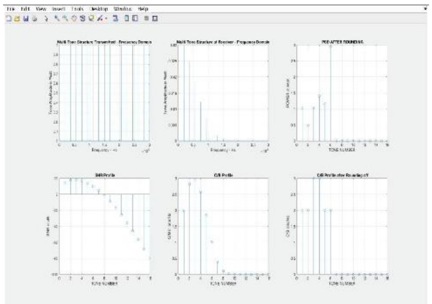

Figure 14: Fisher Simmons for Range-10 Km

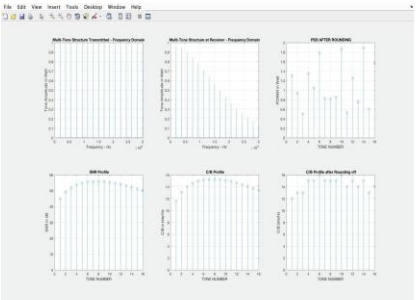

Figure 15: Thorp Model for Range-1Km

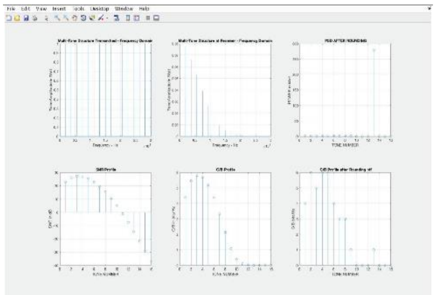

Figure 16: Thorp Model for Range-5Km

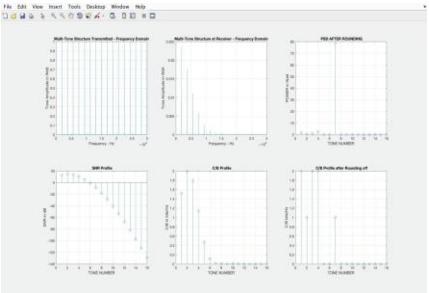

Figure 17: Thorp Model for Range-10Km

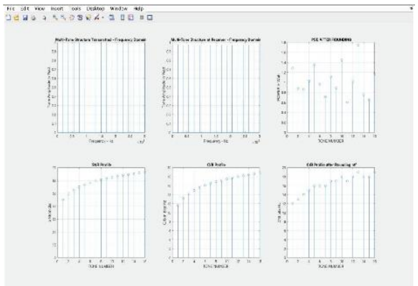

Figure 18: Ainslie Model for Range-1Km

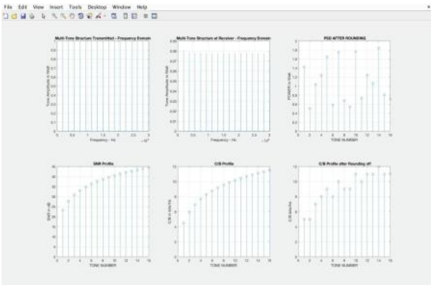

Figure 19: Ainslie Model for Range5 Km

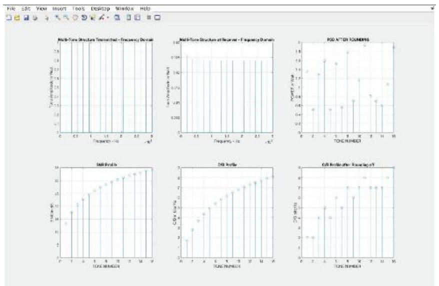

Figure 20: Ainslie Model for Range-10 Km

3. SHIPPING FACTOR: 1, WIND FACTOR: 25

The ensuing outcomes display the transmitted signal, received signal, SNR profile, probability profile, and probability profile after rounding off. These results are presented for a wind factor of 25 and a shipping factor of 1, across diverse ranges and models.

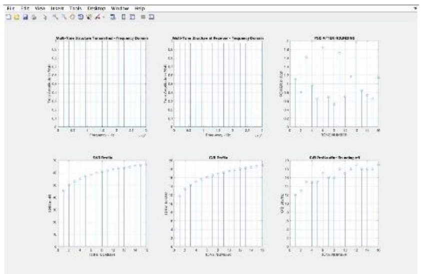

Figure 21: Ainslie Model for Range-1Km

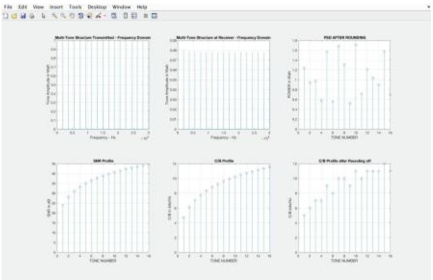

Figure 22: Ainslie Model for Range-5 Km

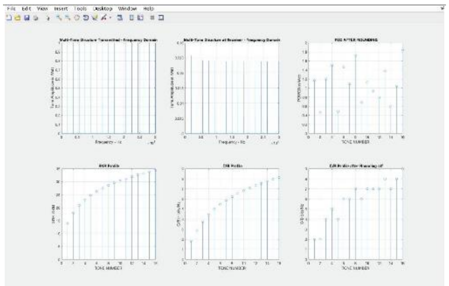

Figure 23: Ainslie Model for Range-10 Km

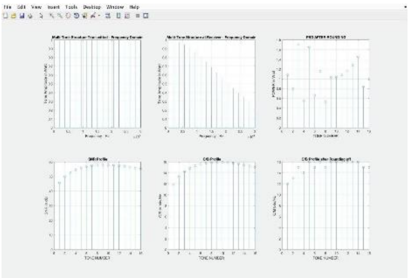

Figure 24: Fisher Simmons for Range-1Km

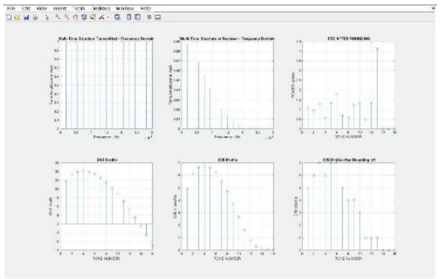

Figure 25: Fisher Simmons for Range-5 Km

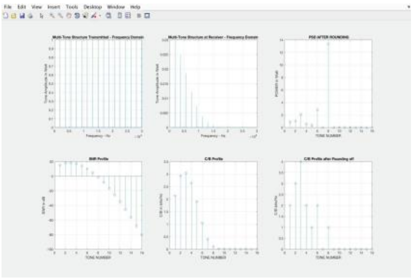

Figure 26: Fisher Simmons for Range-10Km

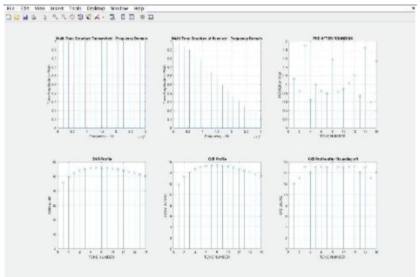

Figure 27: Thorp Model for Range-1Km

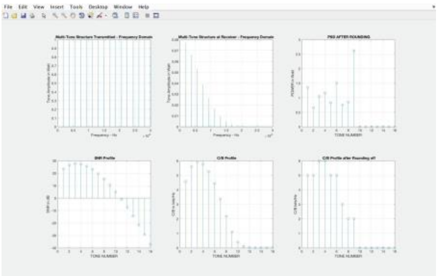

Figure 28: Thorp Model for Range-5 Km

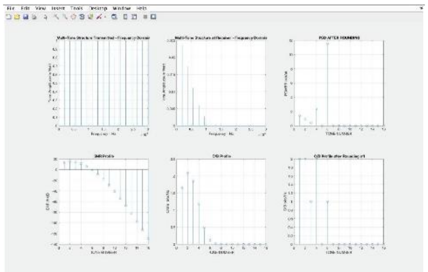

Figure 29: Thorp Model for Range-10 Km

Table 1: Comparison of all underwater models

Model Type	Range	Shipping Factor	Wind Factor	Transmitted Signal Strength	Received SNR	Signal Strength
AINSLIE	1KM	SF-1	WF-25	Good	Good	Good
FISHER- SIMMONS	1KM	SF-1	WF-25	Good	Average	Good
THORP	1KM	SF-1	WF-25	Good	Average	Good
AINSLIE	5KM	SF-1	WF-25	Good	Good	Good
FISHER- SIMMONS	5KM	SF-1	WF-25	Good	Bad	Average
THORP	5KM	SF-1	WF-25	Good	Bad	Bad
AINSLIE	10KM	SF-1	WF-25	Good	Good	Good
FISHER- SIMMONS	10KM	SF-1	WF-25	Good	Bad	Bad
THORP	10KM	SF-1	WF-25	Good	Bad	Bad
AINSLIE	1KM	SF-2	WF-15	Good	Good	Good
FISHER- SIMMONS	1KM	SF-2	WF-15	Good	Good	Good
THORP	1KM	SF-2	WF-15	Good	Average	Good
AINSLIE	5KM	SF-2	WF-15	Good	Good	Good
FISHER- SIMMONS	5KM	SF-2	WF-15	Good	Bad	Average
THORP	5KM	SF-2	WF-15	Good	Bad	Bad
AINSLIE	10KM	SF-2	WF-15	Good	Bad	Bad
FISHER-SIMMONS	10KM	SF-2	WF-15	Good	Good	Good
THORP	10KM	SF-2	WF-15	Good	Bad	Bad
Ainslie	1KM	SF-2	WF-25	Good	Good	Good
FISHER-SIMMONS	1KM	SF-2	WF-25	Good	Average	Good
THORP	1KM	SF-2	WF-25	Good	Average	Good

AINSLIE	5KM	SF-2	WF-25	Good	Good	Good
FISHER-SIMMONS	5KM	SF-2	WF-25	Good	Bad	Average
THORP	5KM	SF-2	WF-25	Good	Bad	Bad
AINSLIE	10KM	SF-2	WF-25	Good	Good	Good
FISHER-SIMMONS	10KM	SF-2	WF-25	Good	Bad	Bad
THORP	10KM	SF-2	WF-25	Good	Bad	Bad

The preceding table provides a comprehensive juxtaposition of transmitted signal, received signal, and SNR across varying models including Ainslie, Fisher-Simmons, and Thorp, as well as different ranges achieved by manipulating shipping and wind factors. Notably, upon analysis, it becomes evident that the Ainslie model consistently outperforms the Fisher-Simmons and Thorp models, offering superior results.

V. CONCLUSION

Undoubtedly, the intricate nature of the underwater acoustic channel presents formidable obstacles when designing communication systems, particularly in scenarios involving high-speed communication within shallow-water environments. This project has been dedicated to meticulously shaping the underwater channel, as well as transmitter and receiver attributes, through the utilization of MATLAB code. Although significant advancements have been achieved in the realm of underwater wireless communication, there remains an extensive scope for further exploration, particularly in the largely uncharted domain of the ocean floor.

The overarching objective remains to transcend current limitations and establish a robust framework for the efficient transmission of broadband signals.

Building upon the outcomes obtained thus far, the future trajectory of this endeavor will encompass several pivotal endeavors, including the application of the CMA evolution strategy within the simulation framework, the realization of electronic design components, the refinement of simulations through practical tests with implemented electronics, the formulation of advanced signal processing algorithms grounded in real-world data, and the synthesis of insights from both environmental realities and simulation outcomes.

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