Seas of Change: Integrating RIS for Effective Ship-to-Ship Communication

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1. Abstract.

The dynamic and unpredictable sea environment poses a major challenge for ship-to-ship communication. Reconfigurable Intelligent Surfaces (RIS) can enhance communication by more intelligently reflecting the signals and optimizing signal transmission paths pointed towards the receiver. While traditional relay stations mainly serve to step up a fading channel, RIS reduces the impacts of such fading channels, thus providing better signal strength and stability.
This work involves the placement of RIS on the lighthouse along the shore in an effort to assist in ship-to-ship communication. A 4×4 MIMO channel in Rayleigh and Weibull fading is assumed, as line-of-sight (LOS) is not always available in sea situations and the signal undergoes multipath fading. Subsequently, the performances are analyzed with and without RIS with respect to the important parameters such as BER versus SNR, channel power, channel capacity, and RSSI.

Keywords. Marine communication, Reconfigurable Intelligent Surfaces (RIS), MIMO, Rayleigh fading channel, Weibull fading channel.

2. Introduction

Earth is covered with oceans and seas for approximately 71% of the earth's surface. Hence, sea is a very crucial aspect for humans, either socially, economically or environmentally. Hence, communication in the sea environment is a necessity in all aspects to be fast, reliable, and effective. By introducing Reconfigurable Intelligent Surfaces (RIS), we improve oceanic communication significantly. By modifying the phase shifts and amplitudes of numerous passive reflecting elements, RIS has become a crucial enabling technology for intelligently reconfiguring the radio propagation environment for wireless communications beyond the fifth or sixth generation (B5G/6G). This allows for real-time control of signal reflection [1]. A RIS is a 2D material structure that has macroscopic physical properties that may be programmed. The ability to adjust a RIS's EM

wave response is its most crucial feature. RIS-aided networks allow for the control of the channels between the transmitters and the receivers. As a result, the terminal devices can increase the desired received signal's strength [2]. Maritime communications confront substantial hurdles compared to terrestrial networks, including severe latency, low bandwidth, and unreliable channels, which impair real-time collision avoidance and decision-making. Resource exploration and environmental monitoring are made more difficult by slow computation speeds and low data backhaul rates. Incompatible interfaces and data formats also make it difficult to integrate multidisciplinary technologies like satellites, FSO, and wireless radio. Adaptive-communication systems are difficult to implement due to the deteriorating oceanic environment, which is made worse by unpredictable weather [3][4].

To overcome these difficulties a MIMO system is introduced, specifically a 4×4 system. By sending multiple data streams at once, these systems increase data throughput and reliability, which is an important feature in difficult ocean settings and long distance communications. By making use of spatial variety they also improve signal robustness by reducing the effects of interference and fading. Also, MIMO systems are more suited for high-capacity communication requirements in maritime applications because of their improved spectral efficiency[5]. The Weibull fading channel is considered while simulating the results and compared with the results obtained with Rayleigh fading channel. Because it indicates the intricate and dynamic fading features of maritime environments, and is taken into consideration in marine communication. It is a strong option for assessing and creating dependable communication systems across the ocean due to its adaptability, capacity to record heavy-tailed behavior, and suitability for NLoS and ducting scenarios. At the receiver end, we have used ML detection to minimize the probability of error in estimating the transmitted symbols.

3. System and Channel Modelling

For this paper, we have considered 2 system models, with Rayleigh and Weibull fading channels. We have considered a MIMO channel with 4×4 antennas, that is for transmitter (Tx) $N_t = 4$ and receiver (Rx) $N_r = 4$. Also, we have considered RIS with 64 elements, that is $N_{ris} = 64$. The goal is to compare the behaviour of the system with and without the RIS. The transmitter is set on one ship, which is trying to communicate with another ship, it sends BPSK-modulated symbols. The transmitted symbol vector $X \in \mathbb{C}^{N_t \times 1}$ is constructed by mapping binary bits to BPSK symbols. The total number of bits sent per symbol is $N_t \times \log_2(M)$ where $M = 2$ for BPSK. The receiver is set on another ship, which observes a noisy version of the transmitted signal sent by the first ship. The received signal $Y \in \mathbb{C}^{N_r \times 1}$ is given by:

$$Y = H \cdot X + N$$

where H is the channel matrix given by $H \in \mathbb{C}^{N_t \times N_r}$ the noise added here is the AWGN which is given $by\ N \in \mathbb{C}^{N_r \times 1}$ .The RIS is placed on a light house on the shore, which is a planar array of $N_{ris} = 64$ passive elements. Each RIS element applies a phase shift to the incident signal. The phase shifts are represented by a diagonal matrix $\phi \in \mathbb{C}^{N_{ris} \times N_{ris}}$:

$$\phi = diag(e^{j\phi_1}, e^{j\phi_2}, \ldots., e^{j\phi_{N_{ris}}})$$

where ϕ_i is the phase-shift applied by the i^{th} RIS element. During communication, we have considered direct ship-to-ship communication without RIS, where the channel matrix is H_{direct}. In the RIS-assisted communication, the effective channel matrix H_{ris} is given by:

$$H_{ris} = H_2 \cdot \phi \cdot H_1$$

where $H_1 \in \mathbb{C}^{N_{ris} \times N_t}$ is the channel from the T_x to the RIS, and $H_2 \in \mathbb{C}^{N_r \times N_{ris}}$ is the channel from the RIS to the receiver. The path loss is given by:

$$d\, PL(d) = (-\alpha) d_0$$

Where d is the distance between the T_x and R_x, $d_0 = 1$ km is the reference distance, $\alpha =$
2.2 is the path loss exponent. Also, for distance for RIS-assisted communication we have considered $d_{ris} = 2$ km, and for direct communication we have considered $d_{direct} = 4$ km. For the direct channel matrix, it is modeled as:

$$H_{direct} = \sqrt{PL(d_{direct})} \cdot (H_{LOS} + H_{NLOS})$$

where H_{LOS} is the line-of-sight component and H_{NLOS} is the non-line-of-sight component. For the RIS-assisted channels (H_1 and H_2), they are modeled as:

$$H_1 = \sqrt{PL(d_{ris})} \cdot (H_{LOS,1} + H_{NLOS,1})$$

$$H_2 = \sqrt{PL(d_{ris})} \cdot (H_{LOS,2} + H_{NLOS,2})$$

The R_x signals with direct and RIS-assisted communication is given by:

$$Y_{direct} = H_{direct} \cdot X + N$$

$$Y_{ris} = H_2 \cdot \phi \cdot H_1 \cdot X + N$$

Then the BER is calculated, as the ratio of incorrectly R_x bits to the total number of T_x bits. Channel capacity is calculated using Shannon's formula:

$$C = \log_2 (1 + SNR \cdot ||H||^2)$$

where $||H||$ is the average channel power. While using the Weibull fading channel, we consider the shape ($\kappa = 2$) and scale parameter ($\lambda = 1$). The magnitude of the channel coefficients follows a Weibull distribution:

$$f(x; k, \lambda) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-(x/\lambda)^k}, \; x \geq 0$$

The phase of the channel coefficients is uniformly distributed in $[0,2\pi)$. Also we have calculated RSSI using the log-distance path loss model:

$$RSSI(d) = RSSI_0 - 10 \cdot \alpha \cdot \log_{10} \left(\frac{d}{d_0}\right)$$

where, $RSSI_0 = -45$ dBm is the reference RSSI at distance d_0. The optimized RIS adds a gain of 10 dB and random RIS adds a gain of 5 dB.

4. Simulated Results

The performance analysis of the ship-to-ship communication with phase-optimized RIS, unoptimized RIS, and direct communication is done, using Rayleigh and Weibull fading channels. We have considered a 4×4 MIMO system in which the transmitter and receiver both have 4 antennas. The RIS has 64 elements, which are used to optimize the phase of the transmitted signal. Figure 3.1 compares the BER vs SNR performance in 3 different conditions for both channels. Clearly, the optimized RIS system has the lowest BER, as the RIS is configured to maximize the signal strength at the receiver. The optimized RIS curve in Figure 3.2 has the highest channel capacity. As SNR increases, channel capacity increases for all scenarios. This is expected because higher SNR allows for higher data rates. Figure 3.3 gives the channel power comparisons in both fading channels. This graph shows that the optimized RIS has the highest average channel power, as the RIS phase shifts are optimized to maximize the signal strength at the receiver. Figure 3.4 shows the comparison of RSSI versus distance, which indicates that the optimized RIS shows the highest RSSI values across all distances, as signal strength at the receiver is maximized by aligning the phase shifts of its elements.

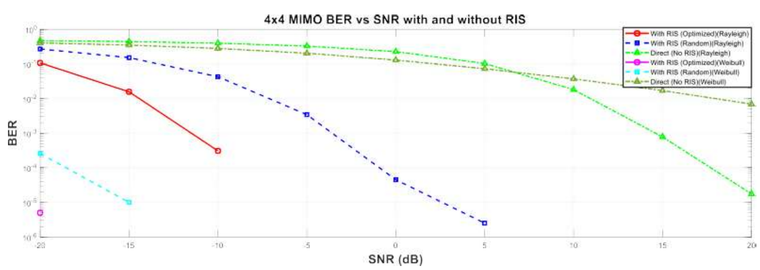

Figure 3.1. BER vs SNR Comparison

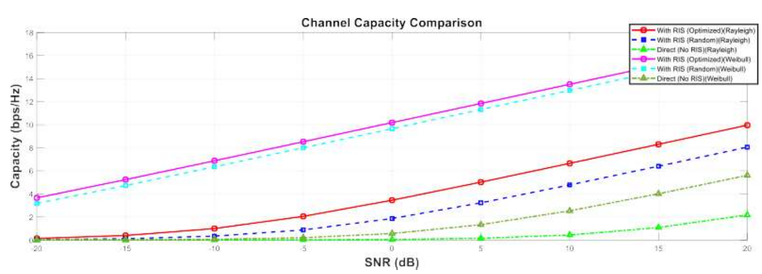

Figure 3.2. Channel Capacity Comparison

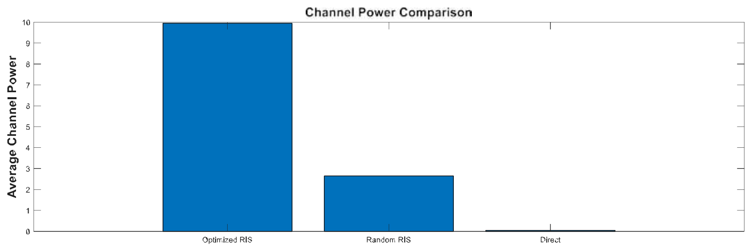

Figure 3.3. Channel Power Comparison

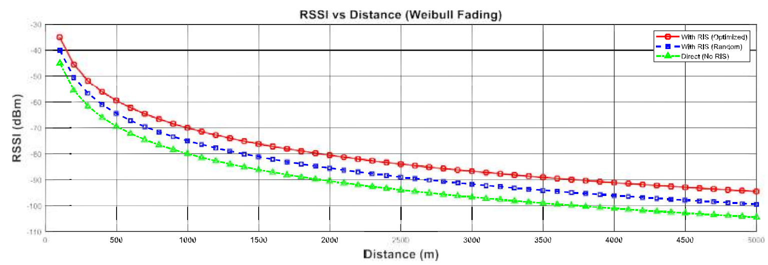

Figure 3.4. RSSI vs Distance Comparison for Weibull Fading Channel

5. Conclusion and Future Work

In this study, the performance of ship-to-ship communication systems enhanced by Reconfigurable Intelligent Surfaces (RIS) was analyzed. The BER versus SNR comparison showed that the RIS-integrated system surpasses the conventional non-RIS system, offering a promising solution for enhancing maritime wireless communication. The BER analysis results revealed that placing RIS strategically, such as on a lighthouse, improves the system reliability and improved capacity, making it an attractive solution to enhance data transmission efficiency.

Also, RSSI performance showed great improvement for RIS-aided communication in comparison to non-RIS systems, thus demonstrating the efficiency of RIS in counteracting signal degradation with an accompanied distance. Therefore, incorporating RIS into ship- to-ship communication serves as an efficient means of mitigating challenging maritime channel conditions and enhancing signal reliability and overall system behaviour.

In Future, the research work may focus on the dynamic configuration of RIS, adaptive beamforming, and the role of environmental factors in RIS-assisted communication optimization.

6. References

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7. Biographies

Vedashree G.L received the bachelor's degree in electronics and communication engineering(ECE) from VTU University in 2023, and pursuing master's degree in digital electronics and communication engineering from Manipal Institute of Technology (MIT), Manipal.