PERFORMANCE OF MULTI-RIS-AIDED UPLINK WIRELESS SYSTEMS WITH SHORT-PACKET COMMUNICATIONS

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Abstract: Reconfigurable Intelligent Surfaces (RISs) have been recently recognized as a revolutionary technology for optimizing wireless propagation environments, offering significant enhancements in throughput, latency, and reliability. Simultaneously, short-packet communications have become increasingly vital for enabling low-latency, mission-critical applications. This study investigates the performance characteristics of multi-RIS-aided uplink transmission model with short-packet communication over Rayleigh fading channels. Two base station (BS) combination schemes, including maximum-ratio combining and selection combining, to determine the optimal RIS of the given distributed set, are analyzed. To evaluate system performance, both explicit and analytical expressions are derived in two RIS phase-shift scenarios that are random phase-shift (RPS) and optimal phase-shift (OPS) for throughput, latency, and reliability. Our numerical analysis demonstrates that increasing the quantity of distributed RISs, along with additional non-active component, effectively mitigates numerous limitations of both RPS and OPS structure. Subsequently, the BS can maintain the target block error rate (BLER) while reducing the antenna count. Finally, the theoretical analysis is validated through Monte Carlo simulations, demonstrating consistent results across throughput, latency, and reliability metrics.

Keywords: Wireless communication, reconfigurable intelligence surface, short-packet communications, block error rate.

I. INTRODUCTION

In 6G and beyond, ultra-reliable low-latency communication (URLLC) that demand high reliability (99.99%) and low latency ($\leq$ 1 ms) is essential for supporting high-QoS implementation such as automation, transportation [1, 2]. The progression of 5G URLLC, essential for industrial applications, toward 6G URLLC by 2030, with Low Earth Orbit (LEO) satellite mesh networks expected to reduce long-distance latency and enhance global coverage and performance is highlighted in [3]. The work discusses key technical challenges for URLLC in beyond 5G (B5G) and 6G networks, with experimental results showing that URLLC requirements are adequately met in indoor environments [4, 5]. It is also emphasized that while modern network models and technologies offer optimization opportunities, they also face significant interference issues, necessitating comprehensive mitigation strategies. A defining feature of URLLC messages is their ultra-short packet length, primarily due to their function of conveying critical control information. To address this unique challenge, short-packet communication has surfaced as a vital technique enabling technology [6, 7]. This approach is specifically tailored to efficiently handle the transmission of compact data packets while maintaining the extreme reliability and low latency demands inherent to URLLC systems.

On the other hand, reconfigurable intelligent surfaces (RISs) have emerged as a promising technology to enhance spectral efficiency, energy use, and coverage by dynamically shaping the wireless environment [8, 9]. RISs consist of programmable reflective elements that can adjust phase and amplitude responses, with real-time adaptability made possible by advances in meta-materials [10, 11]. By controlling phase shifts, RISs improve signal strength and reduce interference, making them ideal for URLLC systems. Short-packet transmission using finite block length (FBL) codes has been proposed to meet these stringent requirements [12, 13].

Recent studies on Reconfigurable Intelligent Surface (RIS)-aided systems have explored various applications, including optimization of unmanned aerial vehicle (UAV) positioning, user-RIS association for information and power transfer, and performance analysis in multiple-input single-output (MISO) systems [14-16]. Researchers have also investigated the combination of RIS with URLLC, focusing on device-to-device networks, multi-user systems, and

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short packet communication (SPC) scenarios [17-19]. Despite these advancements, there is a notable gap in research regarding performance analysis and optimization of uplink RIS-aided systems [20]. Furthermore, the potential benefits of adding the number of implemented RISs on overall system performance remain an open question that warrants further investigation.

With this article, we investigate short packet communications in multi-RIS-aided uplink wireless systems that utilize maximum-ratio combining (MRC) and selection-combining (SC) approaches at the base station while considering two RIS phase-shift scenarios including random phase-shift (RPS) and optimal phase-shift (OPS), with a central concentration on analyzing and assessing performance over Rayleigh fading channels. To quantitatively assess the system's performance for each scenario, we derive closed-form and asymptotic expressions for key performance metrics, including throughput, latency, reliability, and Block Error Rate (BLER). The theoretical analysis is complemented by numerical simulations to validate the system's performance. The congruence between the simulation results and the theoretical analysis underscores the accuracy and reliability of our analytical approach. The acquired results demonstrate: (1) the considered system always achieves the fastest speed to maximize it throughput in the MRC-OPS scenario, (2) MRC provide a superior latency when compared to SC regardless of number of bits (3) With higher information bits we can obtain lower latency, especially with MRC-OPS.

II. SYSTEM MODEL

A. System Detailing

As illustrated in Figure 1, we investigate a multi-RIS-aided uplink wireless system where a single antenna user (U) communicates with a source station (B) equipped with T antennas, utilizing a carefully chosen RIS (R) from a set of M RISs, each with K reflective elements. Considering high distance conditions, the signals transmitted via primary and indirect links may arrive at the receiver at different times due to varying distances between the direct and non-direct paths. Note that the receiver is assumed to have perfect channel state information (CSI).

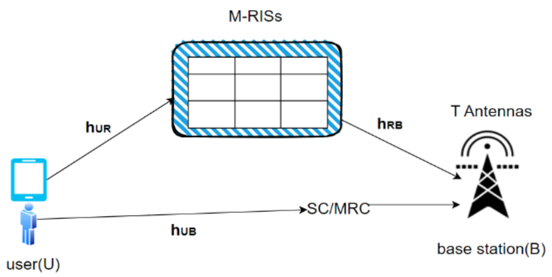


Figure 1. Short-packet communications-enable multi-RIS-aided uplink wireless system.

We denote the channel matrices: $h_{UB} = [h^1_{UB}, \dots, h^T_{UB}]$, $h_{UR} = [h^1_{UR}, \dots, h^K_{UR}]$, and $[H^m_{RB} = h^{1,1}_{RB}, \dots, h^{T,1}_{RB}; \dots; h^{1,K}_{RB}, \dots, h^{T,K}_{RB}]$, $m \in \{1, \dots, M\}$ for the links of $U \to B, U \to R$, and $R \to B$ in the same order. Each element of h_{UB}, h_{UR}, and H_{RB} is modeled as Rayleigh block-fading with a mean of zero and the appropriate variances of Ω_{UB}, Ω_{UR}, and Ω_{RB} separately.

B. Information Transmission

In order to achieve the finest SNR at B, the RIS augmentation scheme is taken into account with the MRC technique is applied at B, which can be represented as

$$m^* = arg \max_{i=1,\dots,M} \|h_{UB} + h^i_{UR} H^i_{RB} \Phi^i\|^2 \quad (1)$$

and when B utilizes SC technique, the selection strategies of RISs and antennas can be represented as

$$(m^*, n^*) = arg \max_{i=1,\dots,M, j=1,\dots,T} \|h^j_{UB} + h^{i,j}_{UR} H^{i,j}_{RB} \Phi^{i,j}\|^2 (2)$$

Following the R evaluation method, the signals acquired at B can be represented as

$$y^m = \sqrt{P}(h_{UB} + h^m_{UR} H^m_{RB} \Phi^m)x + \eta \quad (3)$$

where x is the symbol of the signal, P is U transmitted power, $\Phi^m = diag\big(exp\ (j\phi_1), \dots, exp\ (j\phi_K)\big)$ is the diagonal phase-shift matrix at the m-th RISs, $\phi_k \in (0,2\pi]$ with $k \in \{1, \dots, K\}, E[|x|^2] = 1$, and η is the additive white Gaussian, with $\eta \sim CN(0, \sigma^2 I)$ and an $1 \times T$ identity vector I.

In the case where B utilizes the MRC method, the signal-to-noise ratio (SNR) at B for analyzing x can be formulated as

$$\gamma_{MRC} = \frac{P}{\sigma^2} \|h_{UB} + h_{UR} H^m_{RB} \Phi^m\|^2 \quad (4)$$

According to [23] for the optimal phase shift scenario, the targeted pattern of the phaseshift at the R is as $arg\ (h_{UB}) - arg\ (h_{UR}) - arg\ (h_{RB})$ [24, 25]. Hence, the SNR for MRC in OPS configuration can be represented as

$$\gamma_{MRC} = \frac{P}{\sigma^2} \left|\sum_{n=1}^{T} \left[|h^n_{UB}| + \sum_{k=1}^{K} |h^{n,m}_{UR,k}||h^{n,m}_{RB,k}|\right]\right|^2 \quad (5)$$

And SNR for MRC in RPS can be:

$$\gamma_{MRC} = \frac{P}{\sigma^2} \|h_{UB} + h_{UR} H^m_{RB}\|^2 \quad (6)$$

In another scenario where B employs SC scheme, the SNR at B, using the n-th selected antenna for clarifying the signal x, can be represented as

$$\gamma_{SC} = \frac{P}{\sigma^2} \left||h^n_{UB}| + \sum_{k=1}^{K} \left|h^m_{UR,k} h^{n,m}_{RB,k} exp\ (j\phi_k)\right|\right|^2 \quad (7)$$

Similarly, SNR for SC technique in OPS configuration can be expressed as

$$\gamma_{SC} = \frac{P}{\sigma^2} \left||h^n_{UB}| + \sum_{k=1}^{K} |h^{n,m}_{UR,k}||h^{n,m}_{RB,k}|\right|^2 \quad (8)$$

and SNR for SC in RPS is given by

$$\gamma_{SC} = \frac{P}{\sigma^2} \left|h^n_{UB} + \sum_{k=1}^{K} |h^{n,k}_{UR} h^{n,k}_{RB}|\right|^2. \quad (9)$$

III. PERFORMANCE ANALYSIS

This segment presents a comprehensive performance evaluation of the investigated uplink wireless system optimized with multiple RIS, with a particular emphasis on the block error rate (BLER) and its asymptotic characteristics under finite block transmission conditions. Our analytical approach builds upon and extends the systematic structure established in previous publications [13], adapting it to the specific context of our multi-RIS system configuration.

The estimated analytical expression for infinite block lengths is given by,

$$\omega = \int_0^{\infty} \Xi(\gamma) f_\gamma(x)\,dx = \chi \int_{p_l}^{p_h} F_\gamma(x)dx \qquad (10)$$

where $F_\gamma(.)$ and $f_\gamma(.)$ are CDF and PDF of γ respectively,

$$\Xi(\gamma) = \{1, \gamma \le p_l, 1/2 - \chi(\gamma - \tau), p_l < \gamma_i < p_h, 0, \gamma \ge p_h\} \quad (11)$$

in which $\chi = [2\pi(2^{2r} - 1)/l]^{-1/2}, \tau = 2^r - 1, p_h = \tau - 1/(2\chi)$, $p_l = \tau + 1/(2\chi)$, and $r = N/L$ with the number of information bits, N, and the block-length of L.

A. Optimal Phase Shift Configuration

The CDF of γ_{MRC} and γ_{SC} for the design of OPS can be expressed as

$$F_{\gamma Z}^{o} = \left[1 - \frac{\Gamma\left(\alpha_0, \sqrt{\frac{x}{\alpha_0^2 \rho}}\right)}{\Gamma(\beta_0)}\right]^{M\tau} \qquad (12)$$

Where $\tau = 1, \tau_1 = T, Z = MRC$ for the case of MRC and $\tau = T, \tau_1 = 1, Z = SC$ for that of SC, while $\rho = P/\sigma^2, \Gamma(n) = \int_0^{\infty} t^{n-1} exp\,(-t)dt$ represents the Gamma function [21], and $\Gamma(n, a) = \int_a^{\infty} t^{n-1} exp\,(-t)dt$ denotes the upper incomplete Gamma function [21].

According to [23], BLER of MRC and SC with OPS configuration can be express as

$$\omega_Z = \sum_{k=0}^{D} \frac{2C_k}{\rho \beta_o \tau M} [\Theta_Z(p_h) - \Theta_Z(p_l)] \qquad (13)$$

where $D \to \infty, C_k = \chi\left(k, \tau, M, \beta_o, \sqrt{\rho}\alpha_o\right)$ is a recursive function [21, Eq. (0.314)] and

$$\Theta_Z(y) = {}_1F_1\left(k + \tau M\beta_o + 2; k + \tau M\beta_o + 3; \frac{\tau M\sqrt{y}}{\rho}\right) \times B(1, k + \tau M\beta_o + 2)\sqrt{y}^{k+\tau M\beta_o+2} \quad (14)$$

Where $\tau = 1, \tau_1 = T, Z = MRC$ for the case of MRC and $\tau = T, \tau_1 = 1, Z = SC$ for that of SC. A Meanwhile, α_0 and β_0 represent the scale and shape parameters, respectively, as

$$\alpha_o = \frac{(16-4\pi)\Omega_{UB} + \Omega_{UR}\Omega_{RB}(16-\pi^2)}{(4K\pi\sqrt{\Omega_{UR}\Omega_{RB}} + 8\pi\sqrt{\Omega_{UB}}/\sqrt{\tau_1}} \qquad (15)$$

$$\beta_o = \frac{\tau_1\left(K\pi\sqrt{\Omega_{UR}\Omega_{RB}} + 2\pi\sqrt{\Omega_{UB}}\right)^2}{(16-4\pi)\Omega_{UB} + \Omega_{UR}\Omega_{RB}(16-\pi^2)}. \qquad (16)$$

B. Random Phase Shift Configuration

The CDF of γ_{MRC} and γ_{SC} for RPS can be formulated as

$$F_{\gamma Z}^{r} = \left[1 - \frac{\Gamma\left(\beta_r, \frac{x}{\rho\alpha_r}\right)}{\Gamma(\beta_r)}\right]^{M\tau} \qquad (17)$$

Where $\tau = 1, Z = MRC$ for the case of MRC and $\tau = T, Z = SC$ with the case of SC respectively.

Similarly, as given in [22], BLER of MRC or SC with RPS configuration can be express as

$$\omega_Z = \sum_{k=0}^{D} \frac{C_k}{\rho \beta_r \tau M} [\Theta(p_h) - \Theta(p_l)] \qquad (18)$$

where $D \to \infty, C_k = \chi(k, \tau, M, \beta_r, \rho\alpha_r)$, and

$$\Theta_Z(y) = {}_1F_1\left(k + \tau M\beta_r + 1; k + \tau M\beta_r + 2; \frac{\tau M y}{\rho}\right) \times B(1, k + \tau M\beta_r + 1) y^{k+\tau M\beta_r+1} \qquad (19)$$

where $\tau = 1, Z = MRC$ in case of MRC and $\tau = T, Z = SC$ with the case of SC respectively. Herein, ${}_pF_q$ denotes Generalized hypergeometric function. Meanwhile, α_0 and β_0 represent the scale and shape parameters, respectively, as

$$\alpha_r = \frac{\Omega_{UB}^2 + 2K\Omega_{UB}\Omega_{UR}\Omega_{RB} + (K^2 + 2K)\Omega_{UR}^2\Omega_{RB}^2}{\Omega_{UB} + K\Omega_{UR}\Omega_{RB}} \qquad (20)$$

$$\beta_r = \frac{\tau_1(\Omega_{UB} + K\Omega_{UR}\Omega_{RB})^2}{\Omega_{UB}^2 + 2K\Omega_{UB}\Omega_{UR}\Omega_{RB} + (K^2 + 2K)\Omega_{UR}^2\Omega_{RB}^2}. \qquad (21)$$

C. Throughput, Latency, and Reliability

Based on calculated BLERs in the latency-restricted communication mode, the structure throughput of the investigated wireless uplink structure at a static data transfer rate with *i* ∈ {SC, MRC} and *j* ∈ {OPS, RPS} can be represented as

$$T_{i,j} = (1 - \omega_{i,j})r. \qquad (22)$$

As stated in [23], given pre-determined throughput *T*, the latency *Łi,j* and reliability *Ri,j* of the studied system can be represented respectively as follows.

$$Ł_{i,j} = \frac{LT}{1 - \omega_{i,j}} \qquad (23)$$

and,

$$R_{i,j} = \left(1 - \omega_{i,j}\right) \times 100\%. \qquad (24)$$

IV. EXPERIMENTAL RESULTS

Numerical simulations are carried out in this section to validate the accuracy of the closed-form expressions outlined in Section III. We present an analysis of throughput, latency, and reliability for both RPS and OPS configurations, with each evaluated using SC and MRC techniques. Table I presents the essential parameters and their respective values utilized for the simulation and analysis. This provides a comprehensive performance assessment across different system configurations and combining methods. The obtained analysis, simulation, random phase shift and optimal phase shift results are respectively labelled as "*Ana*", "*Sim*", "*rand*" and "*opt*".

TABLE I. SIMULATION VALUES AND PARAMETERS.

Main parameters	***Variable name***	***Value***
Base station location	S	(0,0)
RIS location	R	(27,10)
The user position	U	(5,50)
The RIS number	M	3 to 5
The reflective elements number per RIS	K	20
Number of base station antennas	T	2 to 3
Block length	L	300 to 2000
Number of information bits	N	200 to 300
Monte-Carlo		10^6

A. BLER Analysis of MRC and SC Techniques under Different OPS and RPS Configuration

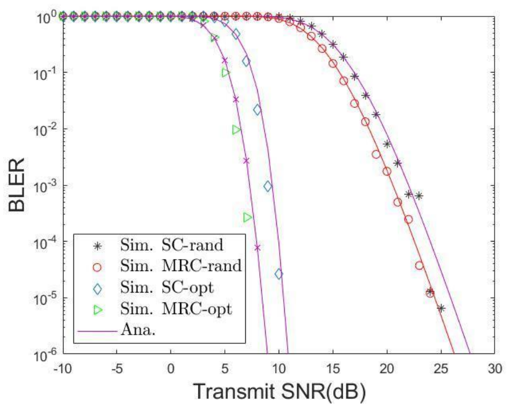


Figure 2. Obtained BLER of different configuration with T = 2, $M = 3$.

In Figure 2, we show the analysis of the average block error rate of B with MRC and SC technique in the cases of optimal and random phase shift configuration. As observed, the Hypothetical assessment aligns closely with the simulation findings, confirming the clarity of equations (13), (18). On top of that, at BLER $= 10^{-6}$, Figure 2 highlights several notable conclusions: (1) For both the MRC and SC techniques, the BLER of OPS outperforms that of RPS by approximately 11 dB; and (2) B utilizing MRC consistently delivers superior BLER performance compared to SC, whether OPS or RPS is applied. This is because MRC leverages all T antennas to help B achieve a higher SNR, whereas SC relies solely on the single strongest antenna.

B. Throughput

Figure 3 illustrates the system throughput with respects to the varied transmit SNR. The obtained outcomes suggest that an increase in SNR leads to the system throughput curves experience a sharp improvement before ultimately converging to a maximum value. Specifically, in the RPS scenario, both the selection combining (SC) and maximum-ratio combining (MRC) techniques require up to a 17 dB gain to maximize the efficiency of the system (from 0 to 0.84). In contrast, in the optimal phase-shift configuration (OPS), the SC technique requires only a 7 dB gain to reach its peak throughput. The throughput curves for both scenarios exhibit a sharp initial increase and then gradually converge towards the maximum throughput, given by the expression $r = N/L$. Furthermore, the curves corresponding to OPS consistently show a 10 dB advantage compared to those of RPS, indicating superior performance. Additionally, in both MRC and SC simulations, RPS consistently exhibits a slower convergence to the maximum throughput of 0.83 compared to OPS. Another notable observation is that the MRC technique demonstrates a faster convergence to the maximum throughput with lower transmit power dB in both OPS and RPS scenarios.

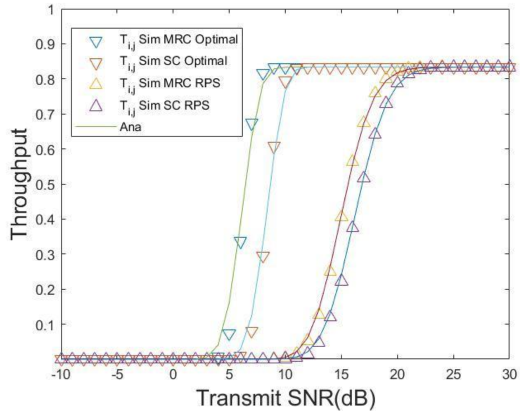


Figure 3. Throughput of SC and MRC when $T = 2$ and $M = 3$.

C. Latency

Figure 4 presents the Block Error Rate (BLER) performance of various configurations involving OPS and RPS under both SC and MRC techniques. It is evident that MRC consistently outperforms SC in terms of BLER in both OPS and RPS configurations. The results imply some key insights when applying MRC and SC along with OPS or RPS: 1) MRC consistently delivers superior BLER performance compared to SC, as the BLER of MRC decreases more rapidly than that of SC in all scenarios, 2) The BLER reduction is steeper when using MRC and SC techniques for OPS, whereas RPS design provides a more gradual decline in BLER. For instance, beyond 2000 users, neither technique achieves the desired BLER threshold of 10^{-6}. The performance gap between OPS and RPS becomes increasingly pronounced as the number of users rises, particularly in the case of MRC. As user density increases, the reliability, and error resilience offered by the MRC technique stand out, making it a preferred choice for minimizing BLER under high-traffic conditions.

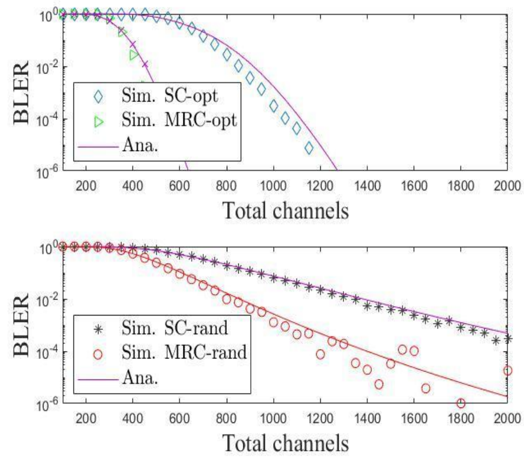
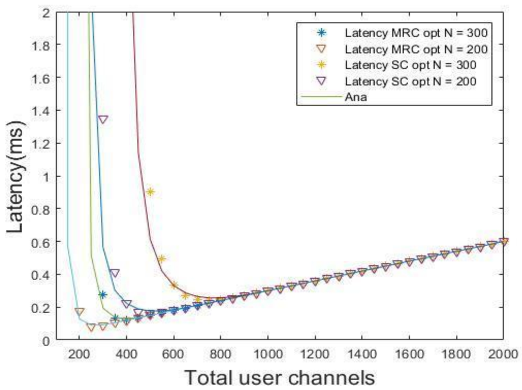
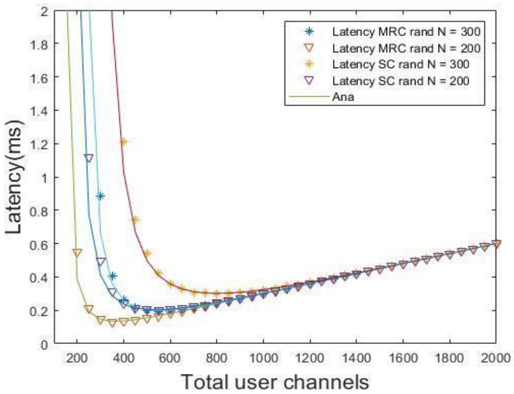


Figure 4. BLER of B with different configuration OPS and RPS for SC and MRC.

The system's latency performance under the impact of the number of information bits N is evaluated in Figures 5 (a) and (b). The curves across all scenarios indicate a sharp initial decrease in latency, followed by a gradual increase. It is apparent that latency decreases as the number of information bits increases, irrespective of the system configuration. As we can infer from the obtained graphs of Figure 5, the latency of the SC techniques demonstrates a higher latency comparing to MRC. The use of MRC offers less latency than that of SC thanks to its better performance, in terms of BLER, no matter which configuration applied. The OPS configuration achieves a slightly lower latency when compared to RPS configuration with both MRC technique and SC technique. With MRC technique in OPS design the latency decline to 0.15 ms with 200 bits compared to RPS configuration, the latency acquires it minimum at approximately 0.2 ms at 250 users. Notably, for N = 300 in both OPS and RPS configuration, the SPC attains a latency Ł of 0.19 ms with about 400 channel users with the MRC technique. While for SC technique, to achieve Ł = 0.2 ms require up to 550 users and only low number of bits = 200. In Figure 5 (b) with RPS configuration, the latency increases significantly for SC technique to reach Ł = 0.35 ms. For both configurations, the latency reduces as the information bit number, N, is decreased. These results further highlight. The effectiveness of the suggested system in achieving minimal latency across diverse communication configurations.



(a) Optimal phase shift configuration



(b) Random phase shift configuration

Figure 5. Effect of number of information bits N on the latency of SC and MRC when $T = 3$ and $M = 5$.

D. Reliability

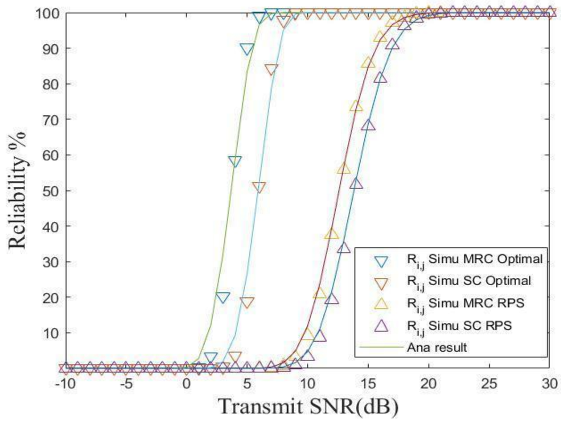


Figure 6. Reliability of SC and MRC scenarios when $T = 2$ and $M = 3$.

The reliability performance of the system in OPS and RPS configurations with SC and MRC techniques is depicted in Figure 6, complementing the throughput and BLER results from previous figures. The reliability curves show that in the OPS configuration, reliability surges to 100% with MRC technique at only 3 dB, which is half the value required by the SC technique (6 dB). This demonstrates the superior performance of MRC in achieving high reliability with lower transmit power. Additionally, the RPS configuration provides lower reliability compared to OPS under the same transmit power. The MRC technique consistently shows better reliability than SC in both RPS and OPS configurations, with faster convergence to full reliability. This underscores the advantage of using MRC over SC in high-reliability communication scenarios, particularly when deploying OPS.

V. CONCLUSION

This paper examines short packet communications in multi-RIS-assisted uplink wireless systems, with a focus on performance analysis and evaluation over Rayleigh fading channels. The investigated system employs maximum-ratio combining (MRC) and selection-combining (SC) techniques at the base station, while implementing two distinct phase-shift configurations at the RIS: random phase-shift (RPS) and optimal phase-shift (OPS). For each scenario, we develop and analyze both analytical and asymptotic expressions to evaluate system performance metrics, including throughput, latency, reliability, and Block Error Rate (BLER). Our theoretical findings are validated through comprehensive numerical simulations, which demonstrate strong alignment with the analytical results. Key insights from our numerical analysis reveal that: (1) the MRC-OPS configuration achieves peak throughput most rapidly, (2) MRC consistently delivers superior latency performance compared to SC, irrespective of information bit quantity, and (3) increasing the number of information bits leads to improved latency, particularly in the MRC-OPS configuration.

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HIỆU NĂNG HỆ THỐNG ĐƯỜNG LÊN DỰA TRÊN ĐA BỀ MẶT PHẢN XẠ THÔNG MINH KHẢ CẤU HÌNH VỚI TRUYỀN THÔNG GÓI TIN NGẮN

Tóm tắt: Công nghệ bề mặt thông minh khả cấu hình (RIS) gần đây đã nổi lên như một công nghệ đột phá để tối ưu hóa môi trường truyền dẫn không dây, mang lại những cải thiện đáng kể về thông lượng, độ trễ và độ tin cậy. Đồng thời, truyền thông gói ngắn đã trở thành một yếu tố quan trọng cho các ứng dụng có độ trễ thấp và yêu cầu độ chính xác cao. Bài báo này tập trung nghiên cứu và phân tích hiệu năng của hệ thống truyền dẫn đường lên dựa trên đa bề mặt phản xạ thông minh khả cấu hình với truyền thông gói ngắn qua các kênh fading Rayleigh. Hai sơ đồ kết hợp tại trạm gốc (BS), bao gồm kết hợp tỉ số cực đại (MRC) và kết hợp lựa chọn (SC), được phân tích để xác định RIS tối ưu trong tập hợp phân tán. Để đánh giá hiệu năng hệ thống, các công thức dạng đóng và công thức thức xấp xỉ của các tham số hiệu năng được đưa ra trong hai kịch bản pha RIS: pha ngẫu nhiên (RPS) và pha tối ưu (OPS) đối với thông lượng, độ trễ và độ tin cậy. Phương pháp mô phỏng số được áp dụng để xác minh tính đúng đắn và độ chính xác của việc phân tích cũng như đánh giá hiệu năng của hệ thống theo thông lượng, độ trễ và độ tin cậy. Các kết quả đạt được cho thấy rằng việc tăng số lượng RIS phân tán, cùng với các phần tử thụ động bổ sung, có thể làm giảm một cách hiệu quả các hạn chế trong cả hai kịch bản RPS và OPS, nhờ đó, trạm gốc có thể duy trì tỷ lệ lỗi khối (BLER) mong muốn trong khi giảm số lượng ăng-ten cần thiết.

Từ khoá: Truyền thông không dây, bề mặt thông minh có thể tái cấu hình, truyền thông gói ngắn, tỷ lệ lỗi khối (BLER).

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