

Reconfigurable Intelligent Surface-Assisted Uplink Sparse Code Multiple Access

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Abstract—Reconfigurable intelligent surface-empowered communication (RIS) and sparse code multiple access (SCMA) are promising candidates for future generations of wireless networks. The former enhances the transmission environments, whereas the latter provides a high spectral efficiency transmission. This letter proposes, for the first time, a low-cost design for RIS-assisted uplink SCMA (SCMA-RIS) scheme to improve the conventional SCMA spectrum efficiency. The message passing algorithm (MPA) is utilized and modified to decode the SCMA-RIS transmitted signals. Moreover, a low-complexity decoder for the SCMA-RIS scheme is proposed to significantly reduce the MPA decoding complexity and improve the bit error rate performance of the conventional SCMA. Monte Carlo simulations and complexity analysis are presented, which support the findings.

Index Terms—Sparse code multiple access (SCMA), reconfigurable intelligent surface (RIS), message passing algorithm (MPA), low-complexity decoder.

I. INTRODUCTION

SPARSE code multiple access (SCMA) is a code-domain non-orthogonal multiple access (C-NOMA) approach; it represents a promising candidate for beyond 5G wireless networks that can provide a high spectral efficiency transmission [1]–[4]. In the SCMA scheme, a unique multi-carrier sparse code is assigned to each user to share the wireless medium [5], [6]. The message passing algorithm (MPA) can be utilized to decode the SCMA transmitted signals due to the sparsity property of the codes. The MPA is an iterative algorithm that provides a near maximum likelihood (ML) bit error rate (BER) performance with a relatively lower decoding complexity [7].

Reconfigurable intelligent surface (RIS)-empowered communication is another promising technology for beyond 5G wireless networks, which enhances the transmission environment for wireless communication schemes [8], [9]. Without a need for coding or encoding, an RIS adjusts the incident signals' phases using low-cost passive reflecting elements to enhance the quality of the received signal [10]. Recently, RIS and power-domain NOMA have been jointly explored in [11]–[14]. In [11] and [12], the system performance of a

downlink NOMA-aided RIS system is enhanced for single and multiple antenna systems, respectively. The energy efficiency is maximized in [13] using machine learning for the NOMA-RIS system. The authors in [14] investigated the performance of cell-edge users for the downlink NOMA-aided RIS system.

It is worth noting that power-domain NOMA and C-NOMA are completely different medium access schemes, which share the users' data using powers and codes, respectively. To the best of the authors' knowledge, C-NOMA, especially SCMA, has not been investigated yet under the RIS scenario.

For the first time, this letter explores the uplink SCMA scheme assisted by an RIS (SCMA-RIS), to improve the spectral efficiency and reduce the decoding complexity of the conventional SCMA scheme. A low-cost design of the RIS is proposed to suite the SCMA and to improve the propagation environment based on the selection of the geometric median of the users' phases. At the receiver side, the conventional ML and MPA decoders are adapted to decode the proposed SCMA-RIS transmitted signals. Furthermore, a novel non-iterative low-complexity (LC) decoder for the SCMA-RIS, referred to as SCMA-RIS-LC, is proposed to overcome the high decoding complexity of the iterative MPA. The proposed LC decoder provides a trade-off between the BER performance and decoding complexity, as a function of number of RIS reflecting elements. Compared to the SCMA-MPA, SCMA-RIS-MPA provides significantly enhanced BER performance with slight increase in the decoding complexity, while the SCMA-RIS-LC shows its superiority in both BER performance and decoding complexity. Monte Carlo simulations and complexity analysis are provided to evaluate our findings.

The rest of the letter is organized as follows: Sections II and III introduce the system model and detection algorithms for the uplink SCMA-RIS, respectively. In Section IV, simulation results are presented, whereas Section V concludes the letter.

II. UPLINK SCMA-RIS SYSTEM MODEL

Consider U users which deliver their data to the base station using the SCMA scheme, through an RIS with N reflecting elements, as illustrated in Fig. 1. Each user accesses the medium by employing a unique sparse codebook, $\mathbf{C}_u \in \mathbb{C}^{R \times M}$, $u = 1, \dots, U$, which is spread over R orthogonal resource elements (OREs). It is worth noting that each user's codebook contains M codewords, $\mathbf{c}_{u,m} \in \mathbb{C}^{R \times 1}$, $m = 1, \dots, M$, which have d_v non-zero codeword elements. The U users are overloaded over OREs such that the number of users that share each ORE, d_f , is fixed. The base station and users are equipped with a single antenna.

As shown in Fig. 1, each user transmits a codeword, $\mathbf{c}_{u,m}$, which corresponds to $\log_2(M)$ bits through N passive

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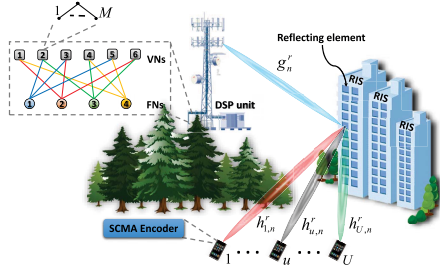


Fig. 1. Uplink SCMA-RIS scheme.

reflecting elements. The task of the RIS elements is to adjust the phase of the incident signal to improve the signal quality at the receiver side. The noisy signal at the receiver side for each ORE, y^r , is

$$y^r = \sum_{u \in \Lambda_r} \left(\sum_{n=1}^N h_{u,n}^r e^{j\phi_n^r} g_n^r \right) c_{u,m}^r + w^r, \quad (1)$$

where $h_{u,n}^r$ and g_n^r represent the Rayleigh fading channel coefficient for the r -th ORE from the u -th user to the n -th reflecting element and from the n -th reflecting element to the receiver, respectively. Here, Λ_r represents the set of users' indices that share the r -th ORE, ϕ_n^r denotes the adjustable phase produced by the n -th reflecting element at the r -th ORE, and $w^r \sim \mathcal{N}(0, \sigma^2)$ is the additive white Gaussian noise at the r -th ORE with zero-mean and variance of σ^2 . It is worth noting that the OREs for SCMA can be orthogonal time or frequency elements. However, time OREs are suitable for our design to adjust the RIS phases for each ORE in a range of micro-seconds in practice.

The channel coefficients, $h_{u,n}^r$ and g_n^r , can be written in the polar form, respectively as

$$h_{u,n}^r = \alpha_{u,n}^r e^{-j(\theta_{u,n}^r)}, \quad g_n^r = \beta_n^r e^{-j(\vartheta_n^r)}, \quad (2)$$

Hence, by plugging (2) into (1), the received signal, y^r , can be expressed as

$$y^r = \sum_{u \in \Lambda_r} \left(\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)} \right) c_{u,m}^r + w^r, \quad (3)$$

where $\Theta_{u,n}^r = \phi_n^r - (\theta_{u,n}^r + \vartheta_n^r)$ represents the resulted phase after the adjustment of the n -th reflecting RIS element for the u -th user at the r -th ORE. To improve the instantaneous signal-to-noise ratio (SNR) as a sub-optimal solution of the RIS phases at the r -th ORE in (3), ϕ_n^r can be obtained as

$$\phi_n^r = \arg \min_{\phi_n^r \in [-\pi, \pi]} \sum_{u \in \Lambda_r} |\phi_n^r - (\theta_{u,n}^r + \vartheta_n^r)|^2. \quad (4)$$

The optimum solution for (4) is the *geometric median* of the users' phases, which share that ORE, i.e., $\phi_n^r = \text{med}(\theta_{u,n}^r + \vartheta_n^r)$ for all $u \in \Lambda_r$, with $\text{med}(\cdot)$ denoting the geometric median. Consequently, the values of $\theta_{u,n}^r$ and ϑ_n^r should be known at RIS to optimize ϕ_n^r . It is worth noting that (4) is designed to improve the BER performance of the SCMA-RIS scheme with low complexity, and reformulation of (4) can be considered as a new optimization problem in future work.

To notice the improvement in the BER performance after optimizing ϕ_n^r , we consider a blind scenario in which the

reflector elements of RIS are reflecting the incident signals without any adjustment to the phases (i.e., $\phi_n^r = 0$ for $\forall n$). The two scenarios of the ϕ_n^r can be summarized as

$$\phi_n^r = \begin{cases} \text{med}(\theta_{u,n}^r + \vartheta_n^r) & \forall u \in \Lambda_r \text{ optimized} \\ 0 & \text{blind.} \end{cases} \quad (5)$$

The vector of received signals, \mathbf{y} , for the SCMA-RIS scheme for all OREs is

$$\mathbf{y} = \sum_{u=1}^U (\text{diag}(\mathbf{H}_u) \mathbf{c}_{u,m}) + \mathbf{w}, \quad (6)$$

where $\mathbf{y} \in \mathbb{C}^{R \times 1} = [y^1, \dots, y^R]^T$, $\mathbf{w} \in \mathbb{C}^{R \times 1} = [w^1, \dots, w^R]^T$, and $\mathbf{H}_u \in \mathbb{C}^{R \times 1}$ is

$$\mathbf{H}_u = \left[\left(\sum_{n=1}^N \alpha_{u,n}^1 \beta_n^1 e^{j(\Theta_{u,n}^1)} \right), \dots, \left(\sum_{n=1}^N \alpha_{u,n}^R \beta_n^R e^{j(\Theta_{u,n}^R)} \right) \right]^T, \quad (7)$$

where $\text{diag}(\mathbf{H}_u) \in \mathbb{C}^{R \times R}$ represents a diagonal matrix whose r -th diagonal element is $\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)}$.

III. UPLINK SCMA-RIS SIGNAL DETECTION

In this section, we present three decoders for the proposed uplink SCMA-RIS scheme, which are ML, MPA and LC decoders. The complexity analysis is also provided.

A. SCMA-RIS-ML Decoder

In SCMA-RIS, the ML decoder provides theoretical the optimum BER performance by performing an exhaustive search for all $(M)^U$ users' codeword combinations. The estimated transmitted codewords for all users, $\hat{\mathbf{C}}_{\text{ML}} \in \mathbb{C}^{R \times U} = [\hat{\mathbf{c}}_{1,m} \dots \hat{\mathbf{c}}_{U,m}]$, using the ML decoder can be expressed as

$$\hat{\mathbf{C}}_{\text{ML}} = \arg \min_{j \in M^U} \left\| \mathbf{y} - \sum_{u=1}^U (\text{diag}(\mathbf{H}_u) \mathbf{c}_{u,m(j)}) \right\|^2, \quad (8)$$

where $m(j)$ is the value of $m \in \{1, \dots, M\}$ at the $(M)^U$ codeword combination. However, the SCMA-RIS-ML is not used due to its impractical implementation.

B. SCMA-RIS-MPA Decoder

The MPA is an iterative decoder that provides a near ML BER performance at an implementable decoding complexity for the SCMA-RIS scheme. The SCMA-RIS-MPA uses a factor graph method as depicted in Fig. 1. The MPA iteratively updates the probability of the messages between the function nodes (FNs) representing the OREs and variable nodes (VNs) that represent the served users. The MPA stops after K iterations to detect the users' codewords that correspond to the maximum joint message probability. It is worth noting that the conventional SCMA-MPA is modified to estimate the SCMA-RIS transmitted codewords.

To formulate the MPA, consider that $\mathcal{P}_{v_u \rightarrow f_r}^{(t)}(c_m^{r,u})$ and $\mathcal{P}_{f_r \rightarrow v_u}^{(t)}(c_m^{r,u})$ represent the probability of passing the message from the u -th VN to the r -th FN and from the r -th FN to

the u -th VN, respectively, at the k -th iteration, $k = 1, \dots, K$. At the first iteration, all messages sent from VNs to FNs are assumed equiprobable; i.e.,

$$\mathcal{P}_{v_u \rightarrow f_r}^{(0)}(c_m^{r,u}) = \frac{1}{M}, \quad \forall u, \forall r, \forall m. \quad (9)$$

Thus, $\mathcal{P}_{f_r \rightarrow v_u}^{(k+1)}(c_m^{r,u})$ can be written as

$$\begin{aligned} & \mathcal{P}_{f_r \rightarrow v_u}^{(k+1)}(c_m^{r,u}) \\ &= \sum_{\psi(i), i \in \Lambda_r \setminus u} \left\{ \mathcal{P}(\mathbf{y} | \psi(i), \psi(u) = c_m^{r,u}) \right. \\ & \quad \left. \times \prod_{i \in \Lambda_r \setminus u} \mathcal{P}_{v_i \rightarrow f_r}^{(k)}(\psi(i)) \right\}, \quad \forall m, \forall r, u \in \Lambda_r, \quad (10) \end{aligned}$$

where $\Lambda_r \setminus u$ represents Λ_r except the u -th user, $\psi^r = \{\psi(1), \dots, \psi(i), \dots\}$ denotes the possible codewords of all users that share the r -th ORE, and

$$\begin{aligned} & \mathcal{P}(\mathbf{y} | \psi^r) \\ &= \frac{1}{\sqrt{2\pi\sigma}} \\ & \quad \times \exp\left(-\frac{\left|y^r - \sum_{u \in \Lambda_r} \left(\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)}\right) c_m^{r,u}\right|^2}{2\sigma^2}\right). \quad (11) \end{aligned}$$

It should be noted that the effect of RIS obviously appears in (11). Now, $\mathcal{P}_{v_u \rightarrow f_r}^{(k+1)}(c_m^{r,u})$ can be updated as

$$\begin{aligned} & \mathcal{P}_{v_u \rightarrow f_r}^{(k+1)}(c_m^{r,u}) = \gamma_{u,r}^{(k+1)} \\ & \quad \times \prod_{j \in \Omega_u \setminus r} \mathcal{P}_{f_j \rightarrow v_u}^{(k+1)}(c_m^{r,u}), \quad \forall m, \forall u, r \in \Omega_u, \quad (12) \end{aligned}$$

where Ω_u represents the OREs' indices that correspond to d_v non-zero positions of the u -th user, $\Omega_u \setminus r$ denotes Ω_u except the r -th ORE, and $\gamma_{u,r}^{(k+1)}$ is

$$\gamma_{u,r}^{(k+1)} = \left(\sum_{m=1}^M \mathcal{P}_{v_u \rightarrow f_r}^{(k)}(c_m^{r,u}) \right)^{-1}. \quad (13)$$

After K iterations, the estimated transmitted codeword of the u -th user can be given by

$$\{\hat{c}_m^u\}^{(K)} = \arg \max_{m=1, \dots, M} \prod_{j \in \Omega_u} \mathcal{P}_{f_j \rightarrow v_u}^{(K)}(c_m^{r,u}), \quad \forall u. \quad (14)$$

The set of all estimated transmitted users' codewords using the SCMA-RIS-MPA decoder, $\hat{\mathbf{C}}_{\text{MPA}}$, is

$$\hat{\mathbf{C}}_{\text{MPA}} = \left\{ \{\hat{c}_m^1\}^{(K)}, \dots, \{\hat{c}_m^U\}^{(K)} \right\}. \quad (15)$$

C. SCMA-RIS-LC Decoder

In this subsection, an LC algorithm for the SCMA-RIS scheme is proposed and analyzed. Thanks to the RIS, the SCMA-RIS-LC algorithm provides a non-iterative decoder that significantly reduces the decoding complexity to overcome

the high complexity of the MPA. The proposed SCMA-RIS-LC decoder performs two stages to decode the transmitted users' codewords. The first stage is a preparation stage that initiates the values to the second stage. The second stage plays the decoder's main role, and decodes the transmitted signals based on the initial values provided by the first stage. A detailed explanation of the two stages is as follows:

Stage 1: In this stage, the SCMA-RIS-LC decoder detects the transmitted users' codewords using a single ORE by trying all possible combinations between the users' codewords, which share that ORE. The detected users' codewords are employed to sequentially detect the rest of the users' codewords for the other OREs. This stage stops when all users' codewords are detected. Thus, this stage may not use all OREs. It should be noted that the detected users' codewords from this stage represent the initial values for the next stage. The detected users' codewords from Stage 1, $\hat{\mathbf{C}}_{\text{LC}}$, is

$$\hat{\mathbf{C}}_{\text{LC}} = \arg \min_{j=1, \dots, M^{\dot{U}^r}} \left| y^r - \Psi_1 - \Psi_2(j) \right|^2, \quad 1 \leq r \leq R, \quad (16)$$

where Ψ_1 and Ψ_2 respectively represent the users' signals that have already been detected and that need to be detected at the r -th ORE, given as

$$\Psi_1 = \sum_{u \in \hat{\Lambda}_r} \left(\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)} \right) \hat{c}_{u,m}^r \mid \hat{c}_{u,m}^r \in \hat{\mathbf{C}}_{\text{LC}}, \quad (17)$$

$$\Psi_2(j) = \sum_{u \in \Lambda_r \setminus \hat{\Lambda}_r} \left(\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)} \right) c_{u,m(j)}^r. \quad (18)$$

Here, $\hat{\Lambda}_r$ denotes the users' indices that share the r -th ORE and their codewords are already detected, $\Lambda_r \setminus \hat{\Lambda}_r$ represents Λ_r except $\hat{\Lambda}_r$ (i.e., the user's indices whose codewords need to be detected), and $\dot{U}^r = \text{card}\{\Lambda_r \setminus \hat{\Lambda}_r\} \leq d_f$ with $\text{card}\{\cdot\}$ as the number of set elements.

Stage 2: In this stage, all OREs are utilized to detect users' information by detecting a single user's codeword at a time using his d_v non-zero OREs that carry its codeword. Also, all other users' codewords that share the d_v non-zero OREs of the desired user are considered to be known from Stage 1 (or from Stage 2 if they have been detected already). The detected user's codeword, \hat{c}_m^u , is

$$\hat{c}_m^u = \arg \min_{j=1, \dots, M} \sum_{r \in \Omega_u} \left| y^r - \Psi_3 - \Psi_4(j) \right|^2, \quad u=1, \dots, U, \quad (19)$$

where

$$\Psi_3 = \sum_{\hat{u} \in \Lambda_r \setminus u} \left(\sum_{n=1}^N \alpha_{\hat{u},n}^r \beta_n^r e^{j(\Theta_{\hat{u},n}^r)} \right) \hat{c}_{\hat{u},m}^r \mid \hat{c}_{\hat{u},m}^r \in \hat{\mathbf{C}}_{\text{LC}}, \quad (20)$$

$$\Psi_4(j) = \left(\sum_{n=1}^N \alpha_{u,n}^r \beta_n^r e^{j(\Theta_{u,n}^r)} \right) c_{u,m(j)}^r. \quad (21)$$

TABLE I
THE DECODING COMPLEXITY OF THE SCMA-RIS DECODERS

	Real Additions (RA)	Real Multiplications (RM)
SCMA-MPA	$Rd_f M^{d_f} (4d_f + K + 1) - KRd_f$	$Rd_f M^{d_f} (4d_f + Kd_f + 3) + M(d_v - 1)(KRd_f + U)$
SCMA-RIS-MPA	$Rd_f M^{d_f} (4d_f + K + 1) + Rd_f(N - K) + 1$	$Rd_f M^{d_f} (4d_f + Kd_f + 3) + M(d_v - 1)(KRd_f + U) + Rd_f N$
SCMA-RIS-LC	$R(2d_f - 1) + (4d_f + 1) \left(UM + \sum_{r=1}^R 1^M \dot{U}^r \right) + Rd_f N + 1$ $\dot{U}^r \neq 0$	$2Rd_f + (4d_f + 2) \left(UM + \sum_{r=1}^R M \dot{U}^r \right) + Rd_f N$ $\dot{U}^r \neq 0$

Algorithm 1 The SCMA-RIS-LC Algorithm Pseudo-Code

- **Input** channel matrices and codebooks for all users;
- **Buffer** $\hat{C}_{LC} = \{\cdot\}$ and $\Lambda = \{\cdot\}$;
- 1: **While** $r \leq R$, **do**
- 2: **Set** $\hat{\Lambda}_r \leftarrow \{\Lambda \cap \Lambda_r\}$;
- 3: **Compute** $\bar{y}^r \leftarrow y^r - \Psi_1$, using (17);
- 4: **Solve** $\{\hat{C}^r, \hat{j}^r\} = \arg \min_{j=1, \dots, M^{\dot{U}^r}} \left| \bar{y}^r - \Psi_2(j) \right|^2$;
- 5: **Update** \hat{C}_{LC} based on \hat{C}^r and Λ based on \hat{j}^r ;
- 6: **if** $\text{card}\{\Lambda\} == U$
- 7: **Go to** Line #10;
- 8: **end if**
- 9: **Set** $r \leftarrow r + 1$;
- 10: **end While**
- 11: **For** $k = 1 : K$, **do**
- 12: **For** $u = 1 : U$, **do**
- 13: **Compute** $\bar{y}^r \leftarrow y^r - \Psi_3$, using (20);
- 14: **Solve** $\hat{c}_m^u = \arg \min_{j=1, \dots, M} \sum_{r \in \Omega_u} \left| \bar{y}^r - \Psi_4(j) \right|^2$;
- 15: **Update** \hat{C}_{LC} based on \hat{c}_m^u ;
- 16: **end For**
- 17: **end For**
- **Output** \hat{C}_{LC} .

It is worth noting that Ψ_4 represents the desired user's information that needs to be detected. Algorithm 1 summarizes the procedure of the SCMA-RIS-LC decoder.

D. Complexity Analysis

In this subsection, the decoding complexity of the proposed SCMA-RIS decoders is deduced in terms of the real additions (RA) and real multiplications (RM) that are required to decode the users' codewords. Table I presents the complexity summary for the two proposed decoders of the SCMA-RIS scheme and the conventional SCMA-MPA. Since the users' codebooks of SCMA and SCMA-RIS are sparse, MPA can be considered as the benchmark decoder. It is worth noting that the summation term in the RA and RM expressions for the SCMA-RIS-LC decoder depends on the system parameters; for $U = 6$, $R = 4$ with $d_f = 3$ it becomes $M^3 + M^2 + M$. Numerical comparisons will be given next.

IV. SIMULATION RESULTS

In this section, Monte Carlo simulations are used to assess the BER performance of the proposed SCMA-RIS schemes compared to the conventional SCMA-MPA scheme.

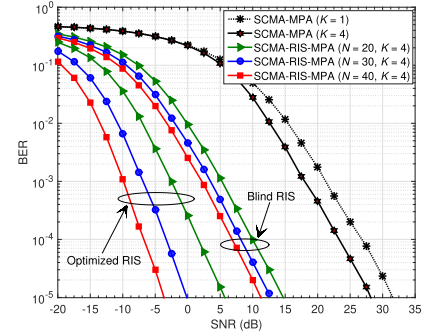


Fig. 2. BER performance comparison of the SCMA-MPA and SCMA-RIS-MPA schemes for $M = 2$.

The codebooks used for all users are designed based on the approach in [6]. It is assumed that the Rayleigh fading channels of all users are perfectly known at the receiver. In our setup, we consider $U = 6$, $R = 4$ with $d_f = 3$, $M = 4$ and 2, and $N = 20, 30$ and 40. Moreover, the assessment of the blind and optimized scenarios in (5) for the proposed SCMA-RIS schemes is presented.

The number of iterations, K , used in MPA for the proposed SCMA-RIS-MPA and conventional SCMA-MPA is 4. It is worth noting that the improvement of the BER performance for the MPA decoder is saturated at $K = 4$ (i.e., no improvement occurs when $K > 4$) for both SCMA-MPA and SCMA-RIS-MPA.

Figs. 2 and 3 depict the BER performance comparison between the proposed SCMA-RIS-MPA and conventional SCMA-MPA for $M = 2$ and 4, respectively. As seen from these figures, the two SCMA-RIS-MPA scenarios (i.e., blind and optimized) significantly improve the BER performance compared to the conventional SCMA-MPA. For instance, the blind SCMA-RIS-MPA scheme for $M = 2$ and 4 provides around 13 dB, 15 dB and 16.5 dB improvement in the BER performance for $N = 20, 30$ and 40 with $K = 4$, respectively, compared to the SCMA-MPA with $K = 4$. For the optimized SCMA-RIS-MPA scenario of $M = 2$ and 4, the improvement in the BER performance increases to 22 dB, 27 dB and 31 dB for $N = 20, 30$ and 40 with $K = 4$, respectively, compared to the SCMA-MPA with $K = 4$. Thus, the optimized scenario and an increased number of reflecting elements provide more BER improvements.

On the other hand, the decoding complexity of the SCMA-RIS-MPA is slightly higher than for the conventional SCMA-MPA. For example, from Table I for $M = 2$ and $K = 4$, the increase in the number of RA and RM of the SCMA-RIS-MPA does not exceed 30.4% and 17.8% than that of the conventional SCMA-MPA, respectively. Furthermore, when $M = 4$, the increase in both RA and RM number for the SCMA-RIS-MPA does not exceed 3.4%.

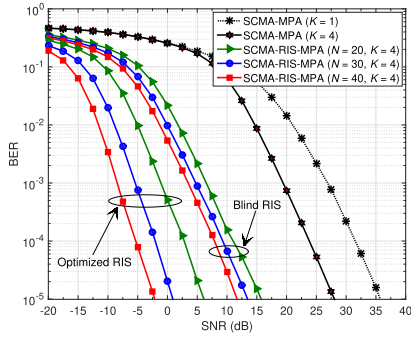


Fig. 3. BER performance comparison of the SCMA-MPA and SCMA-RIS-MPA schemes for $M = 4$.

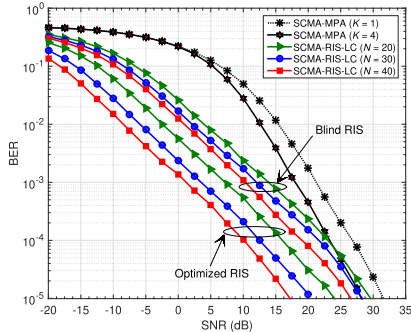


Fig. 4. BER performance comparison of the SCMA-MPA and SCMA-RIS-LC schemes for $M = 2$.

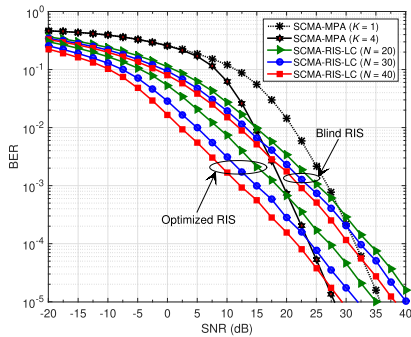


Fig. 5. BER performance comparison of the SCMA-MPA and SCMA-RIS-LC schemes for $M = 4$.

As seen from Figs. 4, 5 and Table I, the proposed SCMA-RIS-LC decoder significantly reduces the decoding complexity with a better BER performance than the SCMA-MPA, especially in low SNR. For instance, the reduction in the RA for the SCMA-RIS-LC with $M = 2$ is 47%, 54.6% and 62.2%, while it saves around 68%, 72.3% and 76.7% RM for $N = 40, 30$ and 20 , respectively, compared to SCMA-MPA with $K = 4$. For $M = 4$, the saving in the complexity of the proposed SCMA-RIS-LC decoder enhances compared to the SCMA-MPA with $K = 4$; it is around 85.4%, 86.3% and 87.2% in the RA, whereas it reaches 90.4%, 91% and 91.5% for RM when $N = 40, 30$ and 20 , respectively. Thus, as N decreases, the saving in the complexity increases, whereas the improvement of the BER performance decreases.

Finally, the proposed SCMA-RIS-MPA provides a significant improvement of the BER performance at the expense of an acceptable increase in the complexity when compared with the conventional SCMA-MPA. Further, the proposed SCMA-RIS-LC significantly reduces the complexity with a

considerable improvement in the BER performance when compared with SCMA-MPA.

V. CONCLUSION

In this letter, we have investigated the SCMA under two RIS scenarios, referred to as blind and optimized SCMA-RIS. Our RIS design for the SCMA scheme is proposed to optimize the RIS phases with a low-cost. The MPA is adapted to decode the SCMA-RIS transmitted signals. Furthermore, a low-complexity decoder is proposed and analyzed for the SCMA-RIS, i.e., SCMA-RIS-LC. It is shown that the SCMA-RIS-MPA provides up to 31 dB improvement in the BER performance with an increase in the decoding complexity that varies from 30.4% to less than 3.4%, compared to the SCMA-MPA. Furthermore, the proposed SCMA-RIS-LC reduces the decoding complexity in a range of 47% to 91.5% with a better BER performance, compared to the SCMA-MPA.

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