Intelligent reflected surfaces assisted code domain non-orthogonal multiple access scheme

Aasheesh Shukla¹

The propagation medium plays a crucial role in any wireless communication networks, the channel between the transmitter and the receiver, deteriorate the quality of the received signal due to the uncontrollable interactions such as scattering, reflection, and refraction in the channel with the surrounding objects. To overcome this challenge, the recent advent of reconfigurable intelligent surfaces can be helpful, in which the network operators can control the radio waves, *eg*, the phase, amplitude, frequency, and even polarization, of the impinging signals without the need of complex decoding, encoding, and radio frequency processing operations. On the other hand, few research papers reported an efficient code domain non-orthogonal multiple access (NOMA) such as Interleave division multiple access (IDMA) system for wireless information transfer. Persuaded by the capability of this arising RIS technology, the present article is aimed to provide the modified framework of IDMA (code-domain NOMA) communication system based on RIS technology. Simulation results demonstrate that the proposed system achieves better SNR performance than the conventional IDMA framework.

Keywords: SCMA, IDMA, NOMA, code domain NOMA, power domain NOMA

1 Introduction

Non-orthogonal multiple access (NOMA) has just been considered as an expected possibility for (5G) and future communication network [1], [2]. Further, numerous NOMA methods, such as, power-domain NOMA (PDNOMA) [3], code domain NOMA (CDNOMA) [4], pattern division multiple access (PDMA) and low density spreading (LDS) have already been suggested in the literature. These numerous NOMA strategies used the assets to resources to maintain the non-orthogonality amongst the users in a controlled way to assist massive accessibility.

Usually in NOMA literature, the code-domain NOMA *eg* interleave division multiple access (IDMA) [5-6], have been considered separately to enhance the spectral efficiency of the wireless systems. The authors in [5] proposed the IDMA based communication system, which was improved version of conventional CDMA (code division multiple access) system and considered as an efficient multiple access scheme up to 5G wireless networks and even beyond wireless networks. In the literature, it has been already established that the IDMA transmitter and receiver are capable to deal with the effect of fading and hence IDMA based communication system can be more effective in deep fading propagation environment.

Further, to meet the requirements of 6G communication networks, which are generally the extension of 5G standards, the existing IDMA communication network need to join hands with recent trends for being suitable for 6G wireless networks [7-9].

Recently, another innovation has been drawn the consideration of the remote examination network named as reconfigurable intelligent surfaces (RISs). The RISs are man-made surfaces of electromagnetic (EM) material that are electronically controlled with coordinated gadgets and have interesting remote correspondence capacities. The RISs have offered ascend to the arising idea of "smart radio conditions" [10-11]. As opposed to current remote communication network where the climate is not in the control of media transmission administrators, a smart radio climate is a remote environment where the climate is transformed into a keen reconfigurable space that assumes a functioning part in moving and handling data. Smart radio conditions to a great extent expand the idea of software networks. Future communication standards, specifically, are quickly developing towards a software based and reconfigurable stage, where all aspects of the network will be equipped for adjusting to the adjustments in the environment [12-14].

We have elaborated, a code-domain NOMA. After presenting the RIS scheme we present the proposed RIS-IDMA system and compare the IDMA and RIS assisted NOMA schemes.

2 Code domain NOMA

As discussed, the plethora of NOMA has subdivided in two categories. PD-NOMA is already discussed in previous section. The other multiplexing domain can be based on signature code, which is named as code domain NOMA. This scheme can support large number of users

¹ Department of Electronics and Communication, GLA University, Mathura, India-281406, aasheesh.shukla@gla.ac.in

transmission in same time/frequency resource block by assigning different signature codes to different users.

An interesting feature is associated with code-domain NOMA is that it can perform better in power balanced scenarios, when all the signature sequences are unique. However, the code domain NOMA has received less attention of the researchers in comparison to PD-NOMA because the detection algorithms used in CD-NOMA are complex and nonlinear in nature such as; message passing algorithm (MPA), maximum likelihood (ML) and a maximum posteriori (MAP) detection. In this section we explore different available code-domain NOMA schemes [8-9]. Existing code domain NOMA solutions include low density spreading CDMA (LDS-CDMA), LDS-OFDM, sparse code multiple access (SCMA) and interleave division multiple access (IDMA)

3 IDMA

Interleave division multiple access (IDMA) is recently considered as a potential candidate in the field of code domain NOMA. It can be considered as a special case of direct sequence- code division multiple access (DS-CDMA). Unlike CDMA system, the user specific spreading sequences are not used in IDMA to distinguish the users. Instead, the whole bandwidth is devoted to forward error correction code (FEC) that results a very low-rate code as compared to CDMA system. Further, as a unique feature, user specific interleavers are used to separate users in IDMA. Originally IDMA was proposed with the help of sparse graph scheme [5-6].

IDMA system model

For simplicity, the SISO-IDMA system can be considered. Let d_k be the data and $\mathbf{c}_k = \{c_k(j)\}$ is the coded bits of k^{th} user of length j . Assume BPSK modulation *ie*, $c_k(j) \in [1, +1]$ for transmission. Hence a transmitted symbol with BPSK modulation can be expressed as, [10]

$$x_k(j) = \sqrt{p_k} c_k(j''), \quad (1)$$

where j'' is defined with by the user specific chip level interleaver, and p_k is the power control parameter. The received signal at the receiver $y(j)$ can be given as

$$y(j) = \sum_{k=1}^K h_k x_k + n(j), \quad (2)$$

where, h_k is the channel coefficient for user k and noise $n(j)$ is considered as AWGN sample. In IDMA receiver, the iterative detection scheme is used through the use of elementary signal estimator (ESE) and decoder (DEC). Both ESE and DEC are used to calculate the extrinsic log likelihood ratios (LLRs) in the process of taking decision for final outcome

$$LLR_{\text{ext}}[c_k(j'')] = \log \frac{\Pr(c_k(j'') = +1)}{\Pr(c_k(j'') = -1)} - LLR_{\text{apr}}(c_k(j'')), \quad \forall k, j'' \quad (3)$$

Here 'ext' and 'apr' stand for extracted and a priori.

Basically, IDMA receiver iterates between ESE and DEC in the following steps; (1) ESE evaluates the extrinsic LLR, without considering the coding constraints and fed to DEC as a priori LLR. (2) DEC calculate the extrinsic LLR using local decoders and fed it to ESE as a priori LLR.

Fig. 1. Iteration between ESE and DEC in IDMA receiver

The operation of decoder (DEC) is standard, however maximum likelihood (ML) detection can be used at ESE, [5]. The complexity of ML-ESE increases as the number of users K . The complexity may further increase for other modulation schemes, for example, the complexity of QPSK modulated transmitted symbols is $O(4^K)$. Further gaussian approximation (GA) can be the cost-effective solution for ESE detection. In [5] the MRC estimator with GA is suggested, which is as follows. Using the extrinsic information from DEC, the mean and variance of transmitted symbol $x_k(j)$ can be written as

$$\mu_K^x = E(x_K(j)), \quad (4)$$

$$v_K^x = \text{Var}(\text{Re}\{x_K(j)\}). \quad (5)$$

Let us assume that $\text{Re}\{x_K(j)\} = \sqrt{\frac{p_k}{2}} c_k(j'')$ for the interleaved sequence of length j'' . In traditional MRC estimator the estimated received symbol can be expressed as

$$\hat{x}_k(j) = h_k x_k(j) + \xi_k(j). \quad (6)$$

With the help of GA, the $\xi_k(j)$ can be approximated and extrinsic LLR can be described as

$$LLR_{\text{ext}}(c_k(j'')) = \frac{2h_k \sqrt{p_k/2}}{\text{Var}(\text{Re}\{\xi_k(j)\})} \text{Re}\{\hat{x}_k(j) - E(\xi_k(j))\}. \quad (7)$$

In the IDMA system model, there are some issues which may have impact on the system performance. They can be as follows; Power control- the power control parameter p_k can be optimized for better system performance. Detailed discussions can be found in [5].

Interleaver design

In IDMA, the interleaver is crucial for system performance, as the users are distinguished on the basis chip

level interleaver and interleavers also offers sparsity in IDMA so that iterative detection may be possible.

With random interleaver (RI) IDMA system performs well, however memory requirement and receiver complexity increased in the case of RI. Many interleavers design have already reported in [5]-[6]. Phase control- the phase of received signal can be controlled to reduce the interference. However, the phase control requires accurate information about channel i. e perfect CSIT, which can lead to extra cost on feedback link. Further phase typically changes faster than power. On the other hand, to compensate the phase, we need to adjust the phase shift of the channel. In MIMO system, it is usually difficult to adjust the phase shift for all the antennas. Signal shaping and spatial coupling may be other parameters to take care for the improvement of IDMA system performance.

Fig. 2. IDMA systems with EPC and SPC over AWGN channels. Rate-1/3 turbo coding followed by rate-1/2 repetition coding is used for each user with QPSK modulation, [5]

In Figure (2) the performance of SISO-IDMA is shown with QPSK signaling. It is clear that SPC performs marginally better than EPC at $K = 3$, however at $K = 6$ and 12 , the advantages of SPC are more significant for IDMA. Further the performance of ML and GA

are almost same at $K = 3$. However, the complexity of GA is much smaller than ML. the complexity order of ML $O(4^K)$ becomes almost unbearable at higher values of $4K$ such that for $K = 6$ and 12 . Similarly the impact of phase control, spatial coupling and interleaver design can also be evaluated for IDMA system

4 Reconfigurable intelligent surfaces

In the context of future communication standards wireless communication paradigms, the controlling of the refection, scattering, and refraction characteristics of electromagnetic waves are required for better QoS/ achievable rate in wireless communication. Previously, spatial scattering modulation, IM-based emerging schemes such as beam index modulation (IM) and media-based modulation use the changes in the signatures of received signals by exploiting reconfigurable antennas to transmit information bits in scattering environments.

On the other hand, reconfigurable intelligent surfaces (RIS)/walls/rect-arrays/meta-surfaces are the smart devices that control the propagation environment to improve the signal quality at the receiver. So, the reconfigurable intelligent surface (RIS)-based communication, in which the large number of passive elements on an RIS are used that reflects the signal with controllable phase shift and hence achieve the dedicated beam towards users. The concept of RIS is inspired by the term software-dened radio. Here the term radio signifies that all of the physical layer functions are software dened and the interaction between the incident signal and the intelligent surface is controllable seems like software-dened, hence intelligent surfaces can also be called as software-dened surface (SDS) [12]-[14]

5 Proposed RIS-IDMA system

In this section the proposed IRS assisted code domain NOMA system has been described in Fig. 3. At the trans-

Fig. 3. RIS assisted code domain NOMA network for single user

Fig. 4. IRS assisted code domain NOMA Vs IDMA network for single user

mitter the user information is appropriately interleaved and then sent over the channel. The proposed system is SISO IDMA- RIS System. the transmitter has single antenna and it can connect to W users, each is equipped with single antenna. Further, the $N > 1$, RIS has also been installed at some appropriate location.

With the suitable change in amplitude and phase of the RIS elements, the high efficiency beam can be formed towards the user. In Fig.1, the received signal, without RIS can be written as

$$y = h_{sd}\sqrt{p} + \eta, \quad (8)$$

where p is the transmitted signal power and $\eta \approx N(0, \sigma^2)$ is the receiver noise. Further, the capacity of the SISO channel can be written as

$$R = \log_2 \left(1 + \frac{p|h_{sd}|^2}{\sigma^2} \right). \quad (9)$$

Now, in the setup of IRS assisted code domain NOMA, the channel between the transmitter and IRS element can be denoted as h_{sr} and the channel between IRS element and the destination can be described as h_{rd} . Further the IRS properties can be characterized by the diagonal matrix, $\theta = \beta \text{diag}(e^{j\theta_1} e^{j\theta_2} \dots e^{j\theta_N})$, where $\beta \in (0, 1]$ is the amplitude coefficients and $\theta_1 \theta_2 \dots \theta_N$ are the phase shift variables that can be optimized by IRS. So, the received signal at destination can be written as

$$y = (h_{sd} + h_{sr}\theta h_{rd})\sqrt{p} + \eta. \quad (10)$$

Further, in code domain NOMA (IDMA), the users in downlink communication employ Successive interference cancellation (SIC) scheme to decode signal. The SIC in IDMA also offers some more advantages, such as; in SIC based IDMA the convergence rate is faster in frequency domain analysis and ordering of users can be optimized according to SINR. Now, without the loss of generality, the SINR of decoding of k^{th} user can be shown as

$$\gamma_k = \frac{\alpha_k P |g_k^H \Theta f + v_k|^2}{\sum_{i=k+1}^K \alpha_i P |g_k^H \Theta f + v_k|^2 + \sigma^2}, \quad (11)$$

where α is power allocation vector and v_k is the k^{th} user.

Fig. 5. - RIS assisted code domain NOMA network for single user

6 Simulation results and discussions

For the simulation experiment, the transmitter -to- user channels are considered as Rayleigh fading and the large-scale pathloss is $103d^4$, where d is the distance in meter [10]. Both the Transmitter to- RIS channel and the RIS-to-user channels are also assumed to be Rayleigh fading, and their pathloss are $103d^2$ and $103d^{2.8}$, respectively. Figure 4 plots the symbol error rate (SER) vs SNR for traditional code domain NOMA (IDMA) (without IRS but with optimized power allocation at the BS) and IRS-assisted NOMA. The results are based on the data length of 10000 bits and random interleavers is used in IDMA for the purpose of scrambling.

Figure 5 plots the energy efficiency (EE) of both the NOMA network. This has been also shown in [14] that IRS can improve the EE. Figure shows the EE as a function of achievable rate (bit/s/Hz) As per the simulation result, it can be clearly analyzed that SISO system has max EE at approx. 4 bit/s/Hz, however the IRS assisted IDMA system shows the better EE performance beyond 4 bit/s/Hz. So, it can be concluded that IRS assisted IDMA can have better EE at higher achievable rates.

7 Conclusions

In this article, first the brief description of the concept of the intelligent reflecting surfaces has been discussed. To illustrate the impact of IRS, the IDMA communication (code domain NOMA) SISO network has been adopted. After the mathematical analysis, the simulation results of the proposed system have been presented and the IRS assisted code domain NOMA communication performs better in terms of SNR as well as energy efficiency.

The modified IDMA based communication wireless network along-with RIS is proposed to significantly reduce the randomness of the propagation environment and hence, to either simplify the transceiver architecture and/or to increase the quality of service (QoS). We elaborated the code-domain NOMA, and the scheme and

proposed the proposed RIS-IDMA system. The proposed NOMA framework has higher flexibility in terms of user pairing.

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Aasheesh Shukla obtained his Master degree in Electronics and Communication Engineering from HBTI, Kanpur. He is currently pursuing PhD in GLA University, Mathura. His areas of interest include Multiple Access schemes, IDMA and other latest trends in technology. He has more than 10 years of experience in teaching and research in the area of wireless communication.