Received: 3 June 2019 | Revised: 17 March 2020 | Accepted: 26 March 2020
DOI: 10.1002/dac.4419

RESEARCH ARTICLE

WILEY

Network-coded MIMO-NOMA systems with FEC codes in two-way relay networks

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Funding information
Center for Research and Innovation (PPPI); Faculty of Engineering, Universiti Malaysia Sabah (UMS)

Summary

This paper assumes two users and a two-way relay network with the combination of 2 × 2 multi-input multi-output (MIMO) and nonorthogonal multiple access (NOMA). To achieve network reliability without sacrificing network throughput, network-coded MIMO-NOMA schemes with convolutional, Reed-Solomon (RS), and turbo codes are applied. Messages from two users at the relay node are network-coded and combined in NOMA scheme. Interleaved differential encoding with redundancy (R-RIDE) scheme is proposed together with MIMO-NOMA system. Quadrature phase-shift keying (QPSK) modulation technique is used. Bit error rate (BER) versus signal-to-noise ratio (SNR) (dB) and average mutual information (AMI) (bps/Hz) versus SNR (dB) in NOMA and MIMO-NOMA schemes are evaluated and presented. From the simulated results, the combination of MIMO-NOMA system with the proposed R-RIDE-Turbo network-coded scheme in two-way relay networks has better BER and higher AMI performance than conventional coded NOMA system. Furthermore, R-RIDE-Turbo scheme in MIMO-NOMA system outperforms the other coded schemes in both MIMO-NOMA and NOMA systems.

KEYWORDS

interleaved differential encoding, MIMO, nonorthogonal multiple access scheme (NOMA), network coding, Reed-Solomon codes

1 | INTRODUCTION

Nonorthogonal multiple access (NOMA) is a multiple access scheme proposed for future radio access (FRA). NOMA provides multiple users with various powers, with the same spectrum resources (i.e., time, frequency, code, and space), but with minimal interuser interference. It can give better capacity gain and spectral efficiency than the conventional orthogonal frequency division multiplexing (OFDM). Thus, it is a candidate technology for fifth-generation (5G) cellular networks. Each generation of cellular technology is usually characterized by specific multiple access scheme. In NOMA, the multiple users are multiplexed in the power domain, either in downlink or the uplink. In Islam et al,[1] the base station (BS) transmits two signals with different powers in the same frequency band simultaneously as shown in Figure 1.

In Figure 1, one message will be for a user equipment (UE) which is located near the BS called UE1 while the other will be intended for a UE2 located a fair distance away. The UE1 near the base station will be allotted less power, while the UE2 far away from the base station will be allotted more power. The UE2 first decodes the message intended for the other receiver. This message is then subtracted from the received signal, and we are left with the interference-free signal that the UE1 is supposed to decode. This approach requires a successive interference cancellation (SIC) receiver. The nonorthogonality improves resource utilization and is found to increase the user throughput by about 38%. [1]

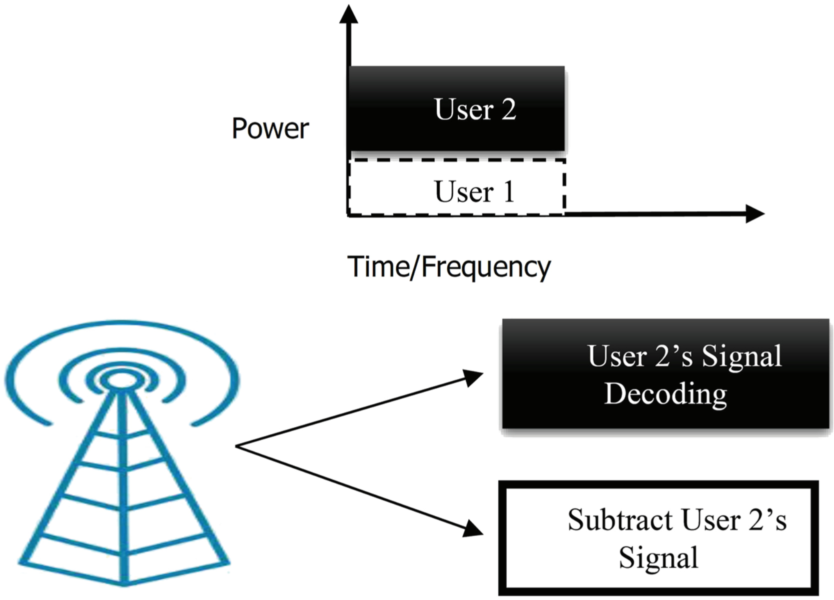

FIGURE 1 Downlink NOMA in a single cell with one BS and two users[1]

In NOMA, the signals from the users are combined at transmitter end(s) by exploiting the users' respective channel gains. The channel gains of UE1 and UE2 are h_1 and h_2 in which $h_1 > h_2$. The power allocation factor α_1 and α_2 for UE1 and user UE2 in the order $\alpha_1 < \alpha_2$ and $\alpha_1 + \alpha_2$ is less than or equal the total transmitted power (P) from BS. SIC is then applied at the receiver(s) for multiuser detection and decoding. NOMA can increase the number of simultaneously served users, and, thus, it can support massive connectivity.

NOMA system has the nature of simultaneous transmission, thus a user does not have to schedule for the transmission time slots to transmit the messages. Therefore, it has lower latency. Moreover, fairness of the user and diverse quality of service (QoS) can be maintained by applying power control between the users. By allocating more power to weak user than strong user, the data throughput of the cell-edge (weak user) can be higher. Thus, NOMA has the enhancement of cell-edge user experience property.

In Ding et al,[2] NOMA's performance is examined with randomly distributed users in a cellular downlink scenario. It shows that NOMA can give higher performance in terms of ergodic sum rates, but NOMA's outage performance relies critically on the users' targeted data rates and allocated power choices. The effect of user pairing on the efficiency of two NOMA systems is characterized with a fixed-power (F-NOMA) and cognitive-radio-inspired NOMA (CR-NOMA) in Ding et al.[3] The numerical results show that the sum rate of F-NOMA is larger than orthogonal multiple access (OMA). Through choosing users with more distinctive channel conditions, the output gain of F-NOMA over traditional MA can further be extended.

In MIMO system, multiusers beam-forming technique is a promising technology to obtain significant gains for network throughput. In downlink multiusers MIMO system, based on the number of transmit and receive antennas, each user can utilize one or many beams in the cell. To remove inter-beam interference completely, the number of antennas at transmitter must be greater or equal to the number of antennas at receiver, under the uncorrelated radio channels. Nowadays, applications of Tactile Internet have become interesting research topic[4] and they need improvement in ultra-reliable and low-latency communications (URLLC), instead of focusing on higher data throughput in the system especially for the security purpose.[5]

In addition, superior spectral efficiency is essential to manage multiple users with limited spectral resources. Thus, URLLC is also essential for future wireless communications without the need of an extra spectrum. MIMO-NOMA scheme with low-rate channel coding technique can be an assuring method for the requirement of Tactile Internet (URLLC). In multiuser MIMO-NOMA system, the antennas at the receiver side with different channel gains are organized into MIMO-NOMA clusters.

The Gaussian capacity of the MIMO system can be obtained by using iterative linear minimum mean square error (LMMSE) detection[6] and applying the coding design of LMMSE method.[7] In Liu et al,[8] the constrained capacity of MIMO systems using modulation techniques such as phase-shift keyings (PSK) and quadrature amplitude modulations (QAMs) can be obtained with approximate message passing (AMP) at the receiver. In Liu et al,[9] the low-complexity

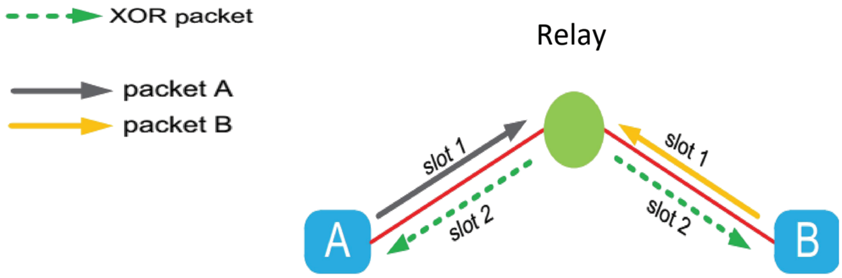

FIGURE 2 Two-way relay network[19]

Gaussian message passing is used to further decrease the problem of iterative receiver and achieve the result of capacity-approaching.

In wireless communication system, it can be beneficial if network coding is applied in physical layer.[10] Zhang et al[11] introduced the network coding in physical layer to exchange the messages between two nodes by using a relay in two-way relay networks. To exchange the messages from different users, there will be two phases. A relay node will receive the information from two source nodes simultaneously in phase 1. In phase 2, the relay node will process the network coding which is the encoding of messages from two source nodes. In Hu and Qian,[12] a higher spectrum efficiency can be obtained by applying two-way relay network. The concept of physical-layer network coding (PNC) was clarified in Zhang et al[13] and it is explained that how exclusive-OR (XOR) network coding can be done in PNC. Superimposed XOR is studied in Liu et al.[14]

In Koike-Akino et al,[15] a flexible scheme is proposed in which there is no channel coding and only suitable constellation technique is applied. PNC is designed at the message level, and decoding technique is remodelled to decode XOR messages in Zhang et al.[16] Convolutional encoding and Viterbi decoding are performed in PNC in Yang et al.[17]

Viterbi decoding is done with maximum likelihood (ML) method in Lu et al.[18] Due to the lossy wireless channels and the architectures of the hardware, wireless network has disadvantages, which are lower network throughput, lower data rate, higher latency, less network security, and limited power. Therefore, it is very important to develop the stronger performance of the wireless network, and we can improve it by applying network coding. The process of two-way relay network is demonstrated in Figure 2.

In Figure 2, the packets are combined with XOR method at the relay $a \oplus b$. Finally, "A" decodes XOR-coded packets with the already sent packet, that is, $a \oplus b$ and thus recovers the original packet "b." Similarly, "B" decodes $a \oplus b$ and recovers "a." Here, only two transmissions were needed. The intermediate nodes will combine these packets rather than moving them forward. This is known as network coding (NC) technique. The PNC using compute and forward (CF) method has been designed in the two-way relay network and MIMO channels.[20] To the best of our knowledge, PNC has not been designed in NOMA or MIMO-NOMA systems with two-way relay networks.

In Xu et al,[19] the network-coded multiple-access (NCMA) scheme has been simulated for the two users. The performance of PNC has been analysed in rectangular and hexagonal networks in Yang et al.[15] The combination of PNC with MIMO was investigated in Yang et al.[21] The two-way relay network is designed to get maximum transmission rate in Li et al[22] in order to obtain the modulation-coded (MC) scheme which is implemented in Chattopadhyay et al.[23] The PNC with QPSK using the AWGN channel, Rayleigh multipath flat fading channel, and Rician fading channel are studied to evaluate the BER performance in Sachin et al.[24] To analyse the symbol error rate in PNC, the higher-order modulation techniques has been proposed in Fang et al.[25]

Differential-chaos-shift-keying (DCSK) system with network-coding is investigated in Rayleigh fading channels in a two-relay in Cai et al.[26] By implementing a decode-and-forward protocol, when the two relays first decode the orthogonal signals sent by the two users, and then return their XORed version to the users. This proposed method has proved that it could be a successful candidate for wireless sensor networks.

Fang et al reviewed the low-density parity check (LDPC) codes, known as root protograph (RP) LDPC codes. In addition to encoding linear complexity and high-speed decoding using the quasi-cyclic (QC) structure, RP codes give near-outage efficiency in specific block fading (BF) scenarios.[27] Furthermore, distributed rate-compatible (RCRP) codes are modelled to obtain full diversity in multirelay CC-based networks and the outage performance.[28]

In data transmission, the error can occur randomly or in bursts. To correct these types of errors, the error-correcting codes have been designed. To correct burst errors, RS codes can be used while binary cyclic codes are used to correct multiple random errors. Random error-correcting code can be applied in correcting of burst errors when interleaved encoding and decoding technique is used. Thus, interleaving is advantageous because of its ability to correct burst errors.

It can be implemented using either block or convolutional codes, and it is one of the techniques used for improving error correction code (ECC).

For interleaving techniques, random, helical, tree-based, and prime interleavers are investigated in terms of BER and needed memory in Sharma et al.[29] It has shown that BER performance of random interleaver is almost similar with tree-based and helical interleavers. In this paper, random interleaver is considered because of less complexity.

Drawbacks for MIMO-NOMA system is having interferences and power control which can lead to bandwidth expansion and BER performance degradation. The bandwidth expansion can make the loss in the data rate. Global wireless communication needs higher rate of data transmission. As a result, it requires spectrally efficient modulation technique and power efficient forward-error correction (FEC) schemes.

As a potential multiple access technique for the 5G mobile communication systems, NOMA has received tremendous interests from the communication research society. Although NOMA demonstrates a significant enhancement of spectral efficiency gain without requiring any additional resources, there is still interuser interference which is the main problem for NOMA. And, most of the researches focus on user clustering and power allocation to reduce the interuser interference. Combination of NOMA with MIMO can reduce the interuser interference. Therefore, the necessity for interuser interference of NOMA systems toward the upcoming 5G standard is one of the motivations of this paper.

In this paper, system model of network-coded MIMO-NOMA is demonstrated with relevant block diagram and equations in Section 2. Channel coding and decoding is explained in Section 3 followed by convolutional encoding and Viterbi decoding in Section 3.1, Galois field theory, and RS encoding and decoding in Section 3.2 and turbo encoding and decoding techniques in Section 3.3, respectively. Results and discussions are described in Section 4, and conclusion is given in Section 5.

2 | THE PROPOSED SCHEME MODEL

This section describes the proposed system model for the MIMO-NOMA network-coded system in two-way relay networks. Messages are generated randomly from two users and encoded with FEC codes using the encoding process such as convolutional, RS, and turbo codes. The encoded messages are interleaved and processed with a differential technique of encoding followed by NC method. Then, QPSK modulation method is applied to modulate network-coded messages. Then, these messages are superimposed for the NOMA and space time block (STB) coded through the MIMO channel. After that, such messages will be transmitted through Rayleigh and Rician channels. Finally, the resulting messages will be XOR-coded. The diagram of the proposed scheme is shown in Figure 3.

On the receiver side, log likelihood ratio (LLR) detection approach is used to detect XOR-ed messages. Then, SIC will be done for decoding of NOMA and STD for MIMO-NOMA system. After this, deinterleaving, differential decoding, and demodulation techniques are performed. The messages decoded are interpreted and processes are replicated as expressed in Figure 3.

The scheme is proposed for two user data streams, x_1 and x_2, and 2×2 MIMO-NOMA scheme. The length of interleaver is equal to the messages length. Such two source nodes are encoded with a half rate encoding. Random interleaving and differential encoding methods are applied. Such FEC coded with randomly interleaved differential messages are transmitted through XOR to obtain redundant data streams. The output of XOR-coded messages will apply for redundancy at the transmission level. All these data streams are modulated by QPSK modulation.

In order to construct a NOMA, the superposition coding and SIC are applied at the transmitter and receiver for users with the same spectrum. By taking a cell as a circular form with a BS in the middle and two UEs, UE1 is closer to the BS than UE2. The channel gains of UE1 and UE2 are h_1 and h_2 in which $h_1 > h_2$. The power allocation factor α_1 and α_2 for UE1 and UE2 in the order of $\alpha_1 < \alpha_2$ and $\alpha_1 + \alpha_2$ is less than or equal the total transmitted power (P) from BS. At the transmitter, the addition of every single signal is shown in equation (1).

$$S_{S_mR_n} = \sqrt{\alpha_1 P}x_1 + \sqrt{\alpha_2 P}x_2. \tag{1}$$

In equation (1), x_1 and x_2 are the signals modulated of UE1 and UE2 and P is the overall power transferred. At the receiver, the obtained signal with k^{th} user since $k = \{1, 2\}$ is described in equation (2).

$$Y_{S_mR_n}[k] = h_{S_mR_n}[k]X_{S_m}[K] + N[k]. \tag{2}$$

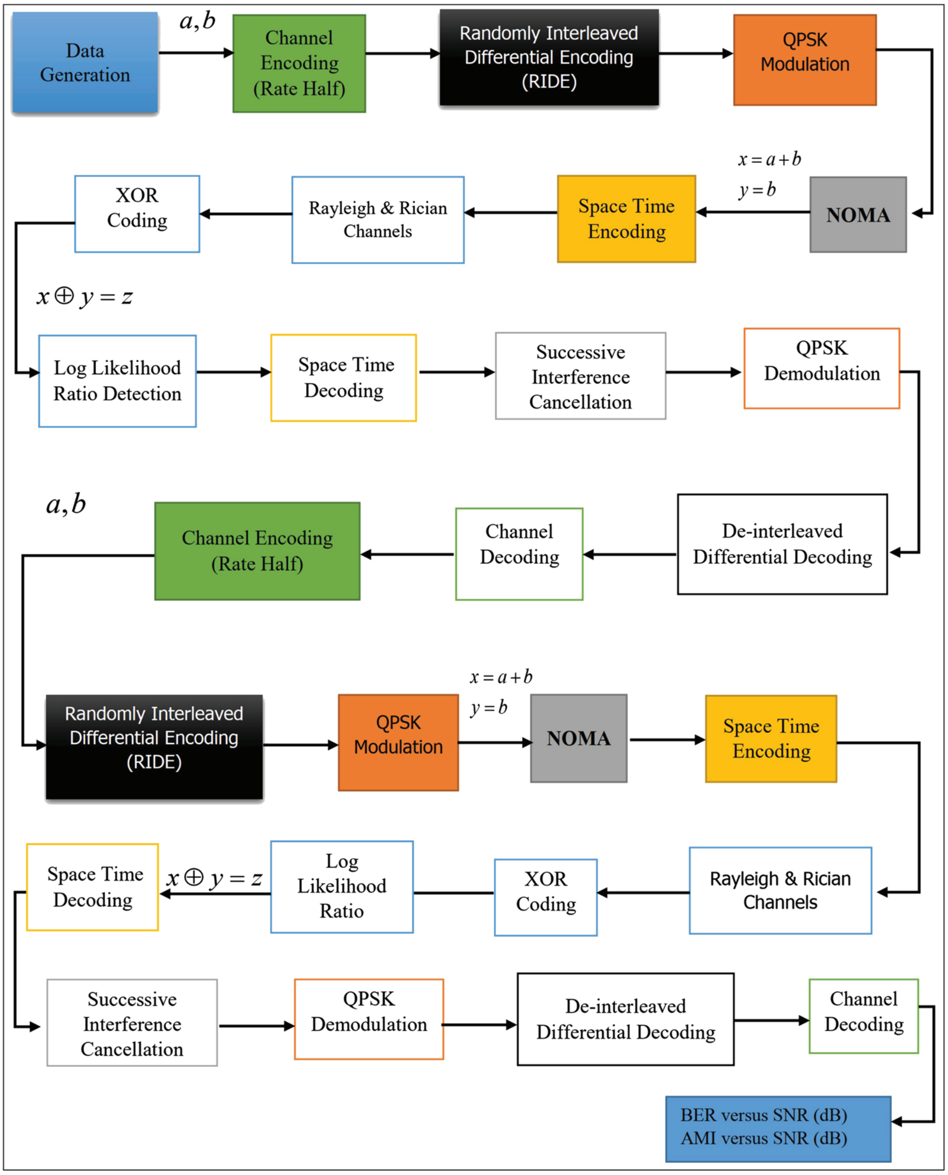

FIGURE 3 Network-coded MIMO-NOMA system in TWR networks

In equation (2), $h_{S_m R_n}$ is the channel gain of source to relay and $n(k)$ is the AWGN noise at the k^{th} user. Since the allotted power for UE2 is higher, UE1 must be decoded first and the interference of UE2 must be cancelled with SIC. SIC does not have to run on the UE2 because the UE1 has less power, which does not interfere with UE2. Thus, the far user will assume the signal of the near user as noise. At the receiver, SIC can be represented in equation (3) by detecting a signal for UE1.

$$\widehat{s_1} = \left(\frac{y_{S_1 R_1}[k_1] - \sqrt{\alpha_2} S_{S_1 R_1}}{\sqrt{\alpha_1}} \right). \tag{3}$$

Likewise, the estimated UE2 can be described as equation (4).

$$\widehat{s_2} = \left(\frac{y_{S_2 R_2}[k_2]}{\sqrt{\alpha_2}} \right). \tag{4}$$

Then, after decoding, demodulation will take place followed by detecting the relay using soft decision method. And, at the relay node, the decoding will be done. With the aid of XOR coding, the decoded messages can be retrieved from source nodes in the two-way relay network.

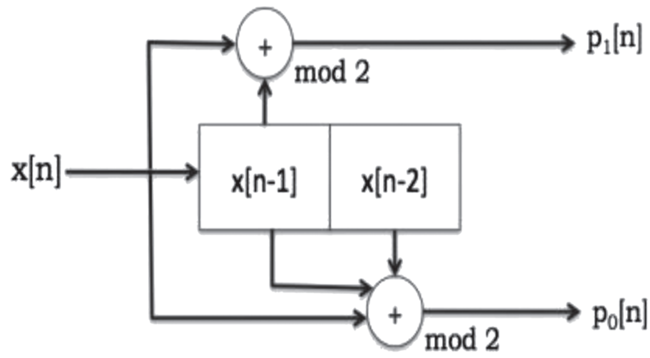

FIGURE 4 Block diagram of convolutional coding with shift registers

Assume all sources to relay and relay to sources are time-invariant channels throughout the transmission of a single phase. In the subsequent phases, $h_{S_mR_n}[k]$ is the channel gain of $S_m \rightarrow R_n$ and $h_{R_nS_m}[k]$ is the channel gain of relay to sources $R_n \rightarrow S_m$. During phase 1, on the number of subcarriers, the received signal at the relay node can be expressed as equation (5).

$$y_{S_mR_n}[k] = \sqrt{P}h_{S_mR_n}[k]X_{S_m}[k] + n_{S_mR_n}[k]. \tag{5}$$

In phase 1, $X_{S_m}[k]$ is the transmitted symbol by source nodes on the k number of subcarriers where $k = 1, \dots K$, P is the average transmitted power of each source node and $n_{S_mR_n}[k]$ is the zero mean additive Gaussian noise, with variance $\sigma^2_{S_mR_n}$. The simulation with MATLAB will be done with QPSK modulation and frequency selective Rayleigh fading channel and Rician channels of unity power throughout the simulations. LLR detection rule will be employed for the coded information bits from sources to relay. LLR symbol detection involves the soft decisions on the code information bits. They are decoded by soft Viterbi algorithm (SOVA). Then, each relay node takes the steps like source node to generate the relay signal which is broadcast to both the sources.

In link $R_n \rightarrow S_m$, in phase 2, the transmitted signal can be modelled as equation (6).

$$y_{R_nS_m}[k] = \sqrt{P}h_{R_nS_m}[k]X_{R_n}[k] + n_{R_nS_m}[k]. \tag{6}$$

3 | CHANNEL CODING AND DECODING

In communication system, forward error correction (FEC) is a technique applied to correct the errors in data transmission over unreliable or noisy communication channels.[30] The messages will be encoded with redundant scheme by using FEC codes. In this paper, three main types of FEC codes are used. They are convolutional, RS, and turbo codes.

3.1 | Convolutional encoding and Viterbi decoding

In 1995, Elias introduced the convolutional codes. An (n, k, m) convolutional code consists of an k input, n output linear sequential circuit with input memory m. Then, n and k are small integers with $k < n$, but the memory order m should be greater to obtain the less error. If $k = 1$, the arrangement of the messages can be done continuously not instead of dividing into blocks.

Convolutional encoding can be done with using a shift register which applies modulo-two addition. A shift register is the sequence of flip-flops where the output of n^{th} flip-flop is connected to the input of the flip-flop. Block diagram of convolutional encoding is shown in Figure 4. In convolutional encoding, each register has 1 bit input and starts with 0 values.

The convolution of generator polynomials and sequence of messages are denoted in equation (7).

$$p_i[n] = \sum_{j=0}^{k-1} g_i[j]\,x[n-j]. \tag{7}$$

The length of the messages will be converted to a single code-word which has memory. Memory registers have 1 input bit starting on a value of 0 to encode the message. There are two modulo-2 adders and generator polynomials. The left-most register holds an input bit of $x[n]$. The encoder outputs bits using generator polynomials and current values in the remaining registers. Then, the register will be shifted to the right ($x[n]$, moves to $x[n-1]$, $x[n-1]$ to $x[n-2]$), and waits for the next input bit. If the input bits are done with encoding, the encoder continues output until all registers come back in zero.

Although, there are many algorithms to decode convolutional codes such as trellis decoders, sequential (Fano) decoders, and stack decoders, the optimal decoder is Viterbi algorithm which can deduce the probability of error. The Viterbi algorithm is a maximum likelihood (ML) decoder in which ML decoders maximize. Usually, the LLR function is used and expressed in equation (8).

$$logp\left(r|y'\right) = \sum_{i=0}^{L+k-1}\left[\sum_{j=0}^{n-1}p\left(r_i^j|y_i'^j\right)\right]. \tag{8}$$

L is the number of transmitted sequences. Log probabilities are known as bit matrices, and they usually converted into small integers.

3.2 | Galois field theory, Reed-Solomon encoding and decoding

Reed-Solomon code is based on the arithmetic of the galois field GF which consists of an element produced from a primitive element and referred to α .

For a given primitive element, α field elements takes values: $\left(0, \alpha^0, \alpha^1, \alpha^2, \ldots\ \alpha^{N-1}\right)$ where $N = 2^{m-1}$. GF elements can be represented as polynomial expression in equation (3), where $\alpha_{m-1}, \ldots, \alpha_0$ take the values 0 or 1.

$$f(x) = \left(\alpha_{m-1}x^{m-1} + \ldots + \alpha_2x^2 + \alpha_1x^1 + \alpha_0x^0\right) = \sum_{i=0}^{m}\alpha_ix^i. \tag{9}$$

The GF generator polynomial is a polynomial $P(x)$ of degree m with no factors. In this paper, 9-bit symbols ($m = 9$) and $GF\left(2^9\right)$ are used. The parity symbols are added to the original messages, and it is shown in equation (10).

$$N = K + 2t, \tag{10}$$

where N = Transmitted Symbols, K= the original messages, and $2t$ = the parity symbols. For RS encoder and decoder, a generator polynomial $g(x)$ which contains $2t$ factors is constructed in equation (11).

$$g(x) = \prod_{i=0}^{2t-1}\left(x + \alpha^i\right). \tag{11}$$

Detection up to $2t$ symbols and correction up to t error symbols can be done by RS decoder at the receiver. If the locations of error are not known, correction can be done by RS decoder to half the number of parity symbols added. But, errors with known locations are called erasures which can be corrected up to $2t$ by RS decoder. A combination of errors and erasures may be corrected as long as the sum of these corrections is lesser than the number of parity symbols added in equation (12).

$$R(X) = T(X) + E(X), \tag{12}$$

where $R(x)$ is the received messages, $T(x)$ is transmitted messages, and $E(x)$ is the error messages. The RS decoder will identify the error messages as shown in equation (13).

$$T(X) = R(X) + E(X). \tag{13}$$

In equation (13), the minus sign is omitted because addition and subtraction are equivalent in GF arithmetic. In RS encoding, $T(X)$ is divisible by if there are no errors for some (i) in $(0, \ldots, 2t-1)$, so dividing by $g(X)$ will give the zero value. But, if there are errors for some or all terms of (i), then dividing by $g(X)$ will give a nonzero value. This value is called syndrome. The equation for syndrome is written in equation (14).

$$S_i = R\left(\alpha^i\right) = T\left(\alpha^i\right) + E\left(\alpha^i\right) = E\left(\alpha^i\right). \tag{14}$$

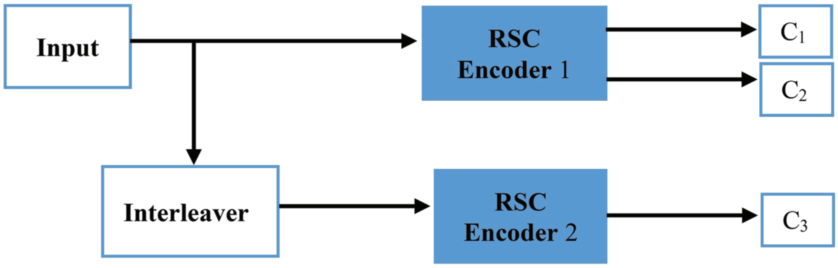

FIGURE 5 Block diagram of turbo encoder

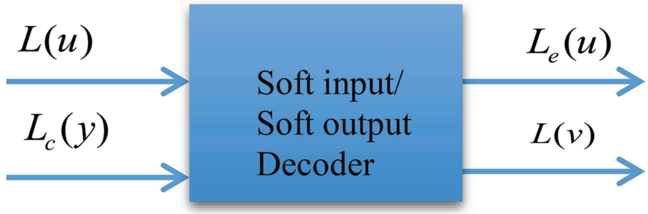

FIGURE 6 Block diagram of turbo decoding

Since $T\left(\alpha^i\right)$ is 0 as $x+\alpha^i$, a factor of $g(X)$ which is also a factor of $T(X)$. S_i can be written in the form of equation (15).

$$S_i = Y_1\alpha^{ie_1} + Y_2\alpha^{ie_2} + \ldots + Y_v\alpha^{ie_v}. \tag{15}$$

By substituting $X_j = \alpha^{e_j}$ in equation (15), we can obtain equation (16).

$$S_i = Y_1X_1^i + Y_2X_2^i + \ldots + Y_vX_v^i, \tag{16}$$

where $e_1, e_2, , \ldots, e_v$ are the locations of errors and $Y_1, Y_2, , \ldots, Y_v$ are the coefficients of errors.

3.3 | Turbo encoding and decoding techniques

In the turbo encoding scheme, there are two equal recursive systematic convolutional (RSC) codes with parallel concatenation. One of the inputs is connected with an interleaver than sent to the RSC 2 encoder and another input is connected directly with RSC 1 encoder as shown in Figure 5.

By considering a rate half RSC convolutional code with memory size M and generator sequences $g_1 = g_{10}, g_{11}, g_{12}, , \ldots, g_{1v}$, d is the input sequence, S and P represent the two output sequences which are shown in equation (17) and (18).

$$S_k = \sum_{i=0}^{v} g_{1i}d_{k-i}, \tag{17}$$

$$Y_k = \sum_{i=0}^{v} g_{2i}d_{k-i}. \tag{18}$$

The coded messages are again decoded. In decoding the Bahl, Cocke, Jelinek, and Raviv (BCJR) algorithm, the maximum a posterior (MAP) algorithm is applied to retrieve the original message bits. In MAP algorithm, there are a pair of decoders which operate simultaneously to clarify and improve the estimate of original messages. The decoded message is looping until the soft decisions converge on a stable set of values. The code works by an iterative operation to estimate a message.

At the beginning of the decoding process, the signals are used by the decoder with bit probability equal to half and calculates the probability of message by applying MAP algorithm. It is repeated until it obtains the precise probability. The most critical part is that calculated probability of the last iteration will be used as the initial probability. After demodulating the signal, soft decisions information will be produced. If the outputs of decoded messages are bits, it is called soft-decision decoder. In turbo codes, two or more component codes are used, therefore the output of a decoder is the input of other decoder. Hence, the decoder in turbo decoder is called soft-input/soft-output decoder as shown in Figure 6.

In Figure 6, $L(u)$ means a priori values for all information bits, $L_c(y)$ means channel values for all information bits, $L_e(u)$ means extrinsic values for all information bits, and $L(v)$ means a posteriori values for all information bits. The soft

TABLE 1 Parameters for the proposed R-RIDE-C scheme

Parameter	Value
Channel	Rayleigh & rician Channels
Number of subcarriers	512
Modulation method	QPSK
SNR	0-20 dB
Constraint length	3
Type of encoding	Convolutional encoding,
-	differential encoding
Rate of coding	Half
Type of decision	Soft decisions
Type of decoding	Viterbi decoding,
-	differential decoding
Operation mode	Continuous
Trace-back depth or length	64
Type of interleaving	Random

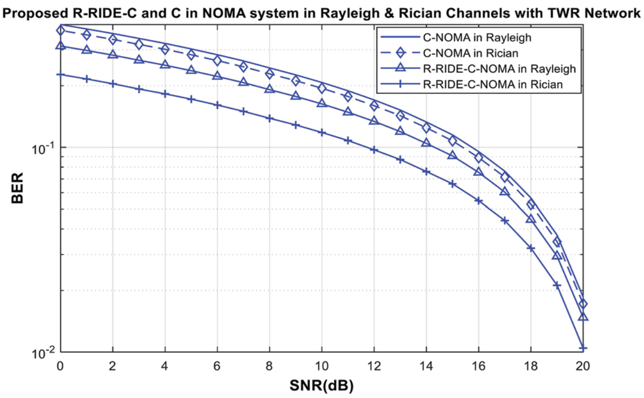

FIGURE 7 BER versus SNR (dB) of the proposed and conventional NOMA schemes in TWR network

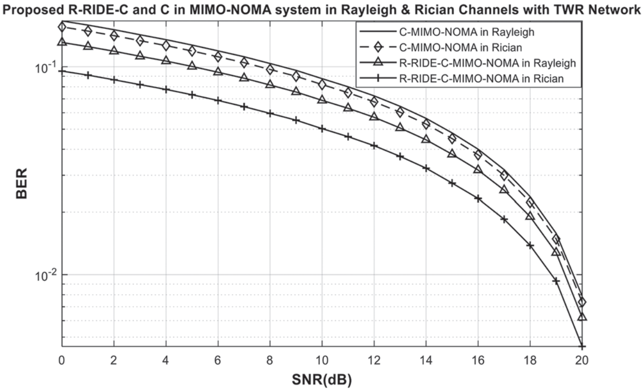

FIGURE 8 BER versus SNR (dB) of the proposed and conventional MIMO-NOMA schemes in TWR network

TABLE 2 BER versus SNR (dB) in the proposed and conventional NOMA and MIMO-NOMA systems

System	Channel	Method	SNR(dB)		
-	-	-	*5*	*10*	*20*
NOMA	Rayleigh	C	1.34E-01	2.25E-01	1.86E-02
-	-	R-RIDE-C	1.05E-01	1.76E-01	1.43E-02
-	Rician	C	1.26E-01	2.12E-01	1.75E-02
-	-	R-RIDE-C	7.66E-02	1.29E-01	1.05E-02
MIMO-	Rayleigh	C	5.63E-02	9.60E-02	7.89E-03
NOMA	-	R-RIDE-C	4.44E-02	7.55E-02	6.21E-03
-	Rician	C	5.28E-02	8.99E-02	7.37E-03
-	-	R-RIDE-C	3.24E-02	5.52E-02	4.51E-03

output for an information bit u can be expressed in equation (19).

$$L(u) = L(u|y) = log\frac{P(u=+1|y)}{P(u=-1|y)}. \tag{19}$$

Let $x = (x_{11}, x_{12},, \dots, x_{1n}, \dots, x_{L1}, \dots, x_{Ln},)$ be a codeword of L branches where $x_{i1} = u_i$ and $x_{i2}, \dots, x_{in}$ are parity bits.

Let $y = (y_{11}, y_{12},, \dots, y_{1n}, \dots, y_{L1}, \dots, y_{Ln},)$ be the receiver vector. Then, we can write the following equations (14), (15), and (16):

$$L(u_i) = L(u_i|y) = log \frac{P(u_i = +1|y)}{P(u_i = -1|y)}, \tag{20}$$

$$= L_c y_{i1} + log \frac{P(y - \{y_{i1}\} u_i = +1)}{P(y - \{y_{i1}\} u_i = -1)} + L(u_i,) \tag{21}$$

$$= L_c y_{i1} + L_e(u_i) + L(u_i). \tag{22}$$

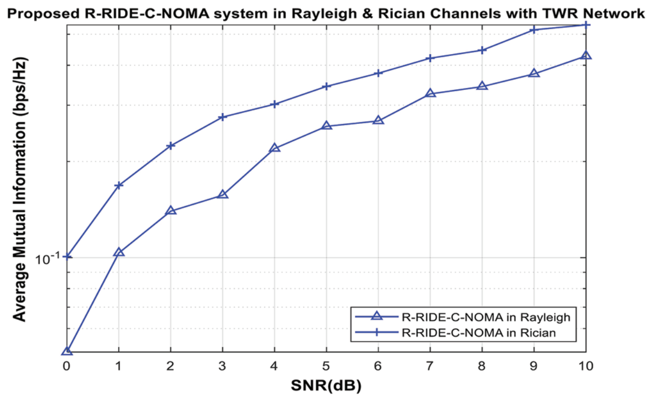

FIGURE 9 AMI (bps/Hz) versus SNR (dB) of the proposed and conventional NOMA schemes in TWR network

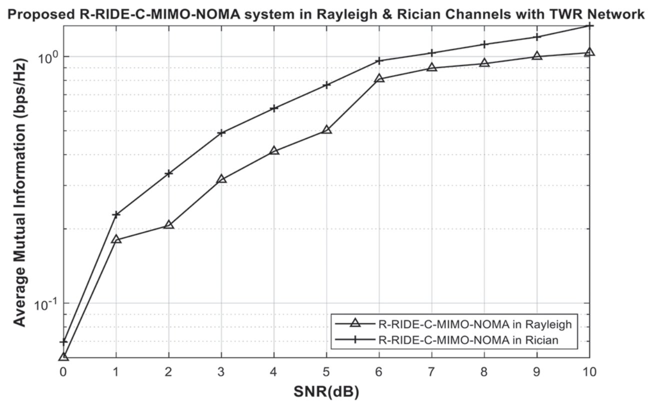

FIGURE 10 AMI (bps/Hz) versus SNR (dB) of the proposed and conventional MIMO-NOMA schemes in TWR network

TABLE 3 AMI (bps/Hz) versus SNR (dB) in the proposed and conventional schemes in NOMA and MIMO-NOMA systems

System	Channel	Method	SNR(dB)		
-	-	-	*1*	*3*	*10*
NOMA	Rayleigh	R-RIDE-C	0.0506	0.1397	0.3757
-	Rician	R-RIDE-C	0.1007	0.2239	0.5163
MIMO-	Rayleigh	R-RIDE-C	0.0600	0.2062	0.9988
NOMA	Rician	R-RIDE-C	0.0694	0.3353	1.1993

TABLE 4 Parameters for the proposed R-RIDE-RS scheme

Parameter	Value
Channel	Rayleigh & Rician fading channel
Number of bits	512 (9-Bit Symbol)
Modulation method	QPSK
SNR	0-20 dB
Type of encoding	RS encoding,
-	differential encoding
Rate of coding	Half
Type of decoding	RS decoding,
-	differential decoding
Type of interleaving	Random

4 | RESULTS AND DISCUSSIONS

In this section, the simulation results of the proposed network-coded MIMO-NOMA with two users transmitting to the BS in the same time-frequency slot with the full-duplex two-way relay networks are given. The relay will operate network coding in which the user will transmit messages to its own designated destination via a relay node shared by both users. In order to increase the network reliability without reducing network throughput, we have proposed network-coded schemes in which the information of the two users are superposed by applying superposition coding in NOMA. Then, information from the original generated messages from the same user are mixed by applying PNC in two-way relay network. The different FEC codes which are convolutional, RS and Turbo codes, are applied in NOMA and MIMO-NOMA system. The proposed R-RIDE is implemented to get better error performance in the network.

4.1 | Results for convolutional coded schemes

The convolutional code with R-RIDE-C is proposed in both NOMA and MIMO-NOMA systems with TWR network. Viterbi decoding algorithm is used to decode the information bits. Redundancy is applied in both sources and relay. The simulation results are described in terms of BER versus SNR (dB) and AMI (bps/Hz) versus SNR (dB). The needed parameters for simulation of proposed schemes are presented in Table 1.

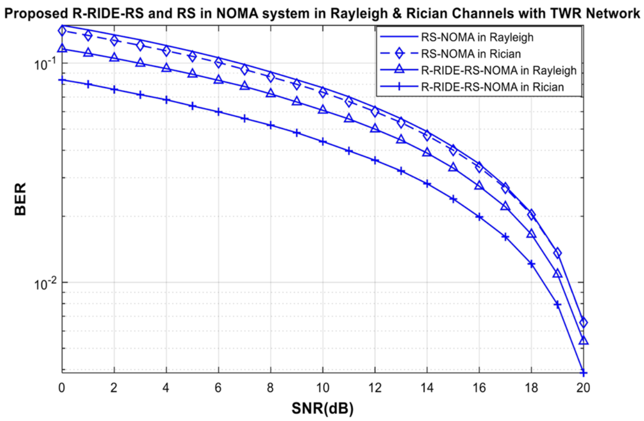

FIGURE 11 BER versus SNR (dB) of the proposed and conventional schemes in TWR network

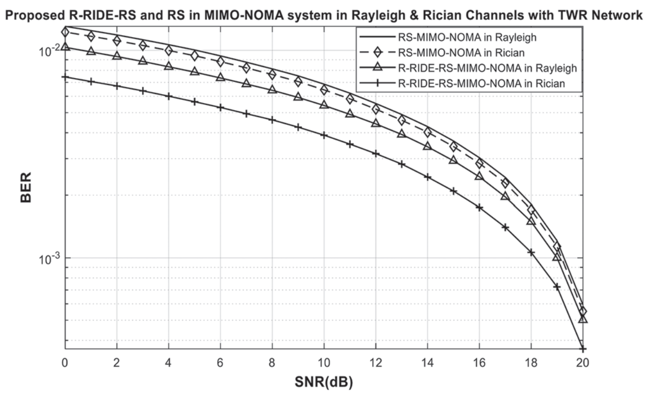

FIGURE 12 BER versus SNR (dB) of the proposed and conventional schemes in TWR network

TABLE 5 BER versus SNR (dB) in the proposed R-RIDE-RS and RS in NOMA and MIMO-NOMA systems

System	Channel	Method	SNR(dB)		
-	-	-	*5*	*10*	*20*
NOMA	Rayleigh	RS	1.20E-01	8.39E-02	6.58E-03
-	-	R-RIDE-RS	9.43E-02	6.64E-02	5.38E-03
-	Rician	RS	1.13E-01	7.99E-02	6.55E-03
-	-	R-RIDE-RS	6.80E-02	4.81E-02	3.86E-03
MIMO-	Rayleigh	RS	1.06E-02	7.52E-03	5.94E-04
NOMA	-	R-RIDE-RS	8.32E-03	5.92E-03	5.02E-04
-	Rician	RS	9.97E-03	7.06E-03	5.52E-04
-	-	R-RIDE-RS	6.00E-03	4.25E-03	3.64E-04

The proposed scheme is compared with convolutional coded scheme without adopting interleaved with differential encoding scheme which is called C-NOMA and C-MIMO-NOMA. In Figure 7, the simulation result of BER versus SNR (dB) for the proposed convolutional coded (R-RIDE-C-NOMA) and conventionally coded NOMA in Rayleigh and Rician fading channels are shown. The performance of the simulation on the proposed R-RIDE-C-NOMA obtained a better performance compared to the conventionally coded scheme as shown in Figure 7.

In Figure 8, the simulation result of BER versus SNR (dB) for the proposed convolutional coded (R-RIDE-C-MIMO-NOMA) and conventionally coded MIMO-NOMA in Rayleigh and Rician fading channels are shown.

The simulated results of both Rician and Rayleigh channels are expressed in the Table 2. As can be seen from the Table 2, the BER of the proposed scheme in the Rician channel in MIMO-NOMA outperforms almost 77% than the proposed scheme with the Rician channel in NOMA system.

Simulation of the AMI of the proposed schemes in NOMA and MIMO-NOMA systems are presented in Figures 9 and 10, and the numerical results are listed in Table 3.

In Figure 9, the Rician channel's proposed scheme has a nearly 38% higher AMI value than the Rayleigh channel's proposed scheme in NOMA system.

In Figure 10, the Rician channel's proposed scheme has nearly 90% higher AMI value than the Rayleigh channel's proposed scheme in MIMO-NOMA system. Therefore, the Rician channel's proposed scheme in MIMO-NOMA system outperforms the other coded schemes. The simulated results are shown in Table 3.

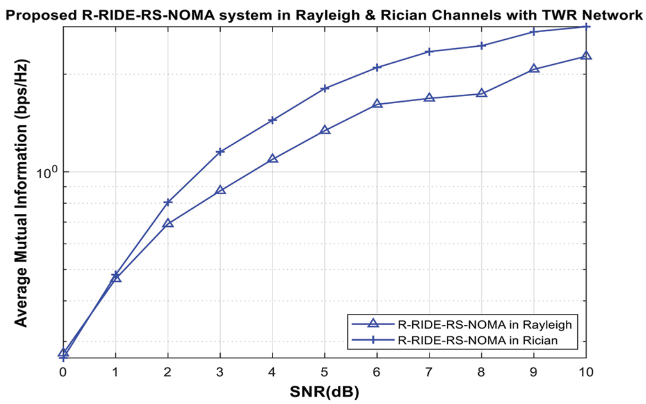

FIGURE 13 AMI (bps/Hz) versus SNR (dB) of the proposed R-RIDE-RS-NOMA and RS-NOMA schemes in two-way relay network

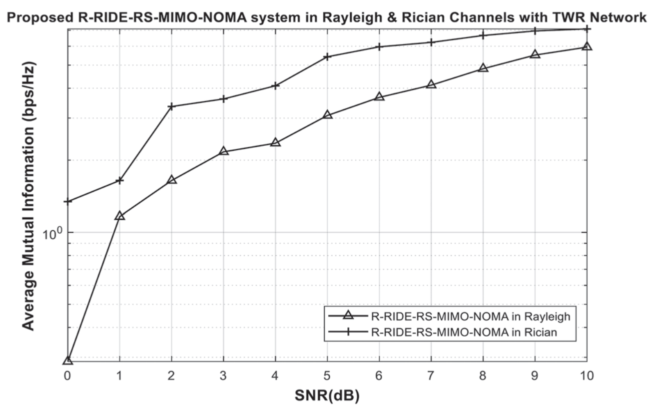

FIGURE 14 AMI (bps/Hz) versus SNR (dB) of the proposed R-RIDE-RS-MIMO-NOMA and RS-MIMO-NOMA schemes in two-way relay network

TABLE 6 AMI (bps/Hz) on SNR (dB) in the proposed R-RIDE-RS and RS in NOMA and MIMO-NOMA systems

System	Channel	Method	SNR(dB)		
-	-	-	*1*	*3*	*10*
NOMA	Rayleigh	R-RIDE-RS	0.2757	0.6909	2.0708
-	Rician	R-RIDE-RS	0.2667	0.8055	2.7031
MIMO-	Rayleigh	R-RIDE-RS	0.2880	1.6434	5.5084
NOMA	Rician	R-RIDE-RS	1.3417	3.3549	6.9514

4.2 | Results for Reed-Solomon coded schemes

In second, the Reed-Solomon code with random interleaved differential encoded with redundancy scheme (R-RIDE-RS) is applied in NOMA and MIMO-NOMA systems. This scheme is compared with Reed-Solomon coded without interleaving and differential encoding scheme. The needed parameters for simulation of the proposed R-RIDE-RS and RS schemes in NOMA and MIMO-NOMA systems are presented in Table 4.

In Figures 11 and 12, the proposed schemes are compared with conventionally Reed-Solomon coded schemes without adopting interleaved with differential encoding scheme which is called RS-NOMA and RS-MIMO-NOMA. The two types of fading channels which are Rayleigh and Rician are used in these schemes.

In Figure 11, the proposed scheme always outperforms the conventional scheme and Rician channel's proposed scheme has almost 28% better BER performance than the Rayleigh channel's proposed scheme.

Moreover, Rician's proposed scheme in MIMO-NOMA has almost 91% better BER performance than that of NOMA system which is shown in Figure 12. The results of the proposed and conventional schemes are tabulated in the Table 5.

The average mutual information of the proposed schemes for NOMA and MIMO-NOMA systems are simulated and shown in Figures 13 and 14.

TABLE 7 Parameters for the proposed R-RIDE-T scheme

Parameter	Value
Channel	Rayleigh & Rician fading channel
Number of bits	512
Modulation method	QPSK
SNR	0-20 dB
Type of encoding	Turbo encoding,
-	differential encoding
Type of decision	Soft decision
Rate of doding	Half
Type of decoding	Turbo decoding,
-	differential decoding
Type of interleaving	Random

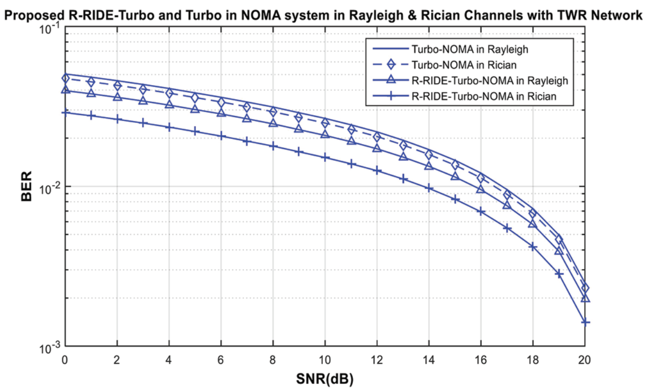

FIGURE 15 BER versus SNR (dB) of the proposed and conventional schemes in TWR network

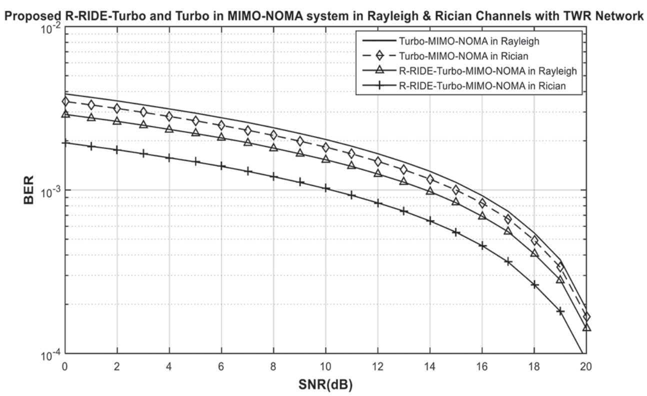

FIGURE 16 BER versus SNR (dB) of the proposed and conventional schemes in TWR network

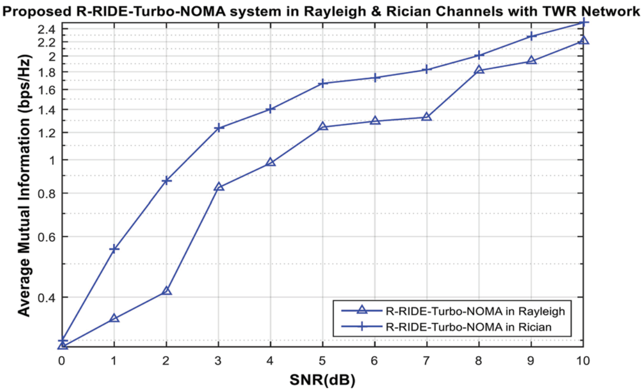

FIGURE 17 AMI (bps/Hz) versus SNR (dB) of the proposed and conventional schemes in TWR network

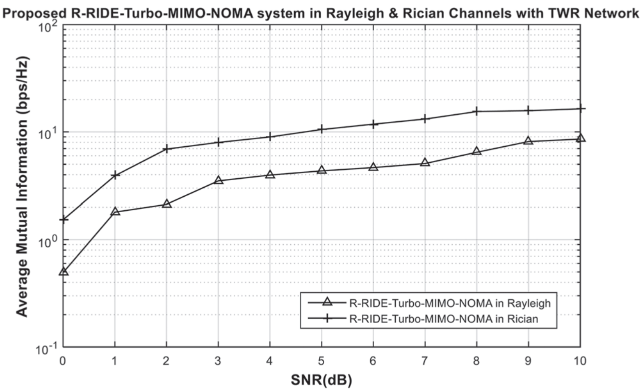

FIGURE 18 AMI (bps/Hz) versus SNR (dB) of the proposed and conventional schemes in TWR network

In Rician, the proposed AMI value is almost 31% higher than that of a Rayleigh at 10 dB in Figure 13. And, the proposed AMI value is almost 26% higher than that of a Rayleigh at 10 dB in Figure 14. The results of AMI are shown in Table 6.

Consequently, applying MIMO-NOMA in the Rician channel's proposed scheme has a 60% higher AMI value than that of NOMA system alone.

4.3 | Results for turbo-coded schemes

Turbo code is investigated and applied in the proposed interleaved differential turbo coded in both NOMA (R-RIDE-Turbo-NOMA) and MIMO-NOMA (R-RIDE-Turbo-MIMO-NOMA) systems. The needed parameters for simulation of proposed R-RIDE-Turbo and turbo schemes in NOMA and MIMO-NOMA systems are presented in Table 7.

The simulation results of BER versus SNR (dB) for the proposed and conventional scheme in Rician and Rayleigh channels can be observed in Figure 15 for NOMA system and in Figure 16 for MIMO-NOMA system.

The results of the simulation for selected values of SNR (dB) among the proposed and conventional schemes are tabulated in the Table 8.

As results shown in Table 8, the Rician's proposed scheme in MIMO-NOMA system has almost 94% better BER performance than in NOMA system.

TABLE 8 BER versus SNR (dB) in the proposed R-RIDE-Turbo and turbo in NOMA and MIMO-NOMA systems

System	Channel	Method	SNR(dB)		
-	-	-	*5*	*10*	*20*
NOMA	Rayleigh	Turbo	4.05E-02	2.84E-02	2.35E-03
-	-	R-RIDE-Turbo	3.73E-02	2.21E-02	1.86E-03
-	Rician	Turbo	3.80E-02	2.66E-02	2.20E-03
-	-	R-RIDE-Turbo	2.31E-02	1.60E-02	1.38E-03
MIMO-	Rayleigh	Turbo	3.13E-03	2.21E-03	1.870E-04
NOMA	-	R-RIDE-Turbo	2.34E-03	1.66E-03	1.42E-04
-	Rician	Turbo	2.81E-03	1.99E-03	1.69E-04
-	-	R-RIDE-Turbo	1.57E-03	1.11E-03	9.00E-05

System	Channel	Method	SNR(dB)		
-	-	-	*1*	*3*	*10*
NOMA	Rayleigh	R-RIDE-Turbo	0.1797	0.5972	1.3866
-	Rician	R-RIDE-Turbo	0.6165	0.8902	3.1987
MIMO-	Rayleigh	R-RIDE-Turbo	0.4935	2.1239	8.1349
NOMA	Rician	R-RIDE-Turbo	1.5315	6.9229	15.7800

TABLE 9 AMI (bps/Hz) on SNR (dB) in the proposed R-RIDE-Turbo and turbo in NOMA and MIMO-NOMA systems

Simulation of the AMI of the proposed schemes in NOMA and MIMO-NOMA systems are presented in Figures 17 and 18, and the numerical results are listed in Table 9.

As results shown in Table 9, the proposed scheme of MIMO-NOMA system has better error performance than NOMA system because it has two transmitting and receiving information streams compared with NOMA system alone.

5 | CONCLUSION

To build the strong and reliable communication system, the strength, duration, and speed of the signal are important elements to be considered. These elements work to obtain the highest quality of data transmission with the best speed. But, the control of quality of data transmission depends on the bit error probability at the receiver. Network coding for the two-way relay network model with R-RIDE is proposed and applied with different channel encoding techniques in NOMA and MIMO-NOMA systems. To prevent the data from burst noise, the information messages need to be encoded with channel encoding techniques. According to the conducted studies, the simulated results show that the R-RIDE-Turbo network coded in the MIMO-NOMA system is better than the other coded schemes as regards BER and AMI. In addition, the MIMO-NOMA system combination always surpasses the NOMA system alone. Therefore, we are able to conclude that the proposed MIMO-NOMA R-RIDE-Turbo system has excellent results for BER and AMI analysis in wireless communication network.

ACKNOWLEDGEMENTS

This research is supported by the Center for Research and Innovation (PPPI) and Faculty of Engineering, Universiti Malaysia Sabah (UMS).

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REFERENCES

1. Islam S, Zeng M, Dobre OA. Noma in 5G systems: exciting possibilities for enhancing spectral efficiency. arXiv preprint arXiv:170608215; 2017.
2. Ding Z, Yang Z, Fan P, Poor HV. On the performance of non-orthogonal multiple access in 5G systems with randomly deployed users. *IEEE Sig Process Lett*. 2014;21(12):1501-1505.
3. Ding Z, Fan P, Poor HV. Impact of user pairing on 5G nonorthogonal multiple-access downlink transmissions. *IEEE Trans Vehic Technol*. 2015;65(8):6010-6023.
4. Simsek M, Aijaz A, Dohler M, Sachs J, Fettweis G. 5G-enabled tactile internet. *IEEE J Sel Areas Commun*. 2016;34(3):460-473.
5. Popovski P. Ultra-reliable communication in 5G wireless systems. In: 1st International Conference on 5G for Ubiquitous Connectivity IEEE; Akaslompolo, Finland; 2014:146-151.
6. Liu L, Chi Y, Yuen C, Guan YL, Li Y. Capacity-achieving mimo-noma: iterative lmmse detection. *IEEE Trans Sig Process*. 2019;67(7):1758-1773.
7. Chi Y, Liu L, Song G, Yuen C, Guan YL, Li Y. Practical mimo-noma: low complexity and capacity-approaching solution. *IEEE Trans Wirel Commun*. 2018;17(9):6251-6264.
8. Liu L, Liang C, Ma J, Ping L. Capacity optimality of amp in coded systems. arXiv preprint arXiv:190109559; 2019.
9. Liu L, Yuen C, Guan YL, Li Y, Huang C. Gaussian message passing for overloaded massive MIMO-NOMA. *IEEE Trans Wirel Commun*. 2018;18(1):210-226.
10. Farzamnia A, Hlaing NW, Mariappan M, Fan LC. Network coding schemes with MIMO-NOMA for two-way relay networks. In: 2018 IEEE International Conference on Artificial Intelligence in Engineering and Technology (IICAIET). Kota Kinabalu, Malaysia: IEEE; 2018:1-5.
11. Zhang S, Liew SC, Lam PP. Hot topic: physical-layer network coding. In: Proceedings of the 12th Annual International Conference on Mobile Computing and Networking; Los Angeles, USA; 2006:358-365.

12. Hu RQ, Qian Y. An energy efficient and spectrum efficient wireless heterogeneous network framework for 5G systems. *IEEE Commun Mag*. 2014;52(5):94-101.
13. Zhang S, Liew SC, Lu L. Physical layer network coding schemes over finite and infinite fields. In: IEEE GLOBECOM 2008-2008 IEEE Global Telecommunications Conference IEEE; New Orleans, USA; 2008:1-6.
14. Liu J, Tao M, Xu Y, Wang X. Superimposed XOR: a new physical layer network coding scheme for two-way relay channels. In: GLOBECOM 2009-2009 IEEE Global Telecommunications Conference IEEE; Honolulu, USA; 2009:1-6.
15. Koike-Akino T, Popovski P, Tarokh V. Optimized constellations for two-way wireless relaying with physical network coding. *IEEE J Sel Areas Commun*. 2009;27(5):773-787.
16. Zhang S, Liew S-C. Channel coding and decoding in a relay system operated with physical-layer network coding. *IEEE J Sel Areas Commun*. 2009;27(5):788-796.
17. Yang T, Yuan X, Ping L, Collings IB, Yuan J. A new physical-layer network coding scheme with eigen-direction alignment precoding for MIMO two-way relaying. *IEEE Trans Commun*. 2013;61(3):973-986.
18. Lu L, You L, Liew SC. Network-coded multiple access. *IEEE Trans Mobile Comput*. 2014;13(12):2853-2869.
19. Gao H, Lv T, Zhang S, Yuen C, Yang S. Zero-forcing based MIMO two-way relay with relay antenna selection: transmission scheme and diversity analysis. *IEEE Trans Wirel Commun*. 2012;11(12):4426-4437.
20. Xu L, Pan P, Wang X, Wu W. Physical-layer network coding and connected dominating set based routing protocol in wireless multi-hop network. In: 2012 Fourth International Conference on Intelligent Networking and Collaborative Systems IEEE; Bucharest, Romania; 2012:259-263.
21. Yang L, Yang T, Yuan J, An J. Achieving the near-capacity of two-way relay channels with modulation-coded physical-layer network coding. *IEEE Trans Wirel Commun*. 2015;14(9):5225-5239.
22. Li D, Xiong K, Zhang Y, Qiu Z. SER analysis of physical layer network coding at high SNR over awgn channels. 2011.
23. Chattopadhyay A, Sharma K, Chandra A. Error performance of RS coded binary FSK in PLC channels with Nakagami and impulsive noise. In: 18th IEEE International Symposium on Power Line Communications and Its Applications IEEE; Glasgow, UK; 2014:184-189.
24. Sachin K, Nikhil S, Nisarga C, Apeksha S, Usha S. A review of hybrid arq in 4G LTE. *Int J Adv Res Innov Ideas Educ*. 2015;1(3):160-165.
25. Fang Y, Han G, Chen P, Lau FC, Chen G, Wang L. A survey on DCSK-based communication systems and their application to UWB scenarios. *IEEE Commun Surv Tutor*. 2016;18(3):1804-1837.
26. Cai G, Fang Y, Han G, Xu J, Chen G. Design and analysis of relay-selection strategies for two-way relay network-coded DCSK systems. *IEEE Trans Vehic Technol*. 2017;67(2):1258-1271.
27. Fang Y, Chen P, Cai G, Lau FC, Liew SC, Han G. Outage-limit-approaching channel coding for future wireless communications: root-protograph low-density parity-check codes. *IEEE Vehic Technol Mag*. 2019;14(2):85-93.
28. Fang Y, Liew SC, Wang T. Design of distributed protograph LDPC codes for multi-relay coded-cooperative networks. *IEEE Trans Wirel Commun*. 2017;16(11):7235-7251.
29. Sharma S, Sau PC, Shukla A. Performance survey of IDMA with different interleavers. In: 2014 International Conference on Signal Processing and Integrated Networks (SPIN) IEEE; Noida, India; 2014:344-348.
30. Rashed M, Kabir MH, Reza M, et al. Transmission of voice signal: BER performance analysis of different FEC schemes based OFDM system over various channels. arXiv preprint arXiv:12073875; 2012.

How to cite this article: War Hlaing N, Farzamnia A, Mariappan M, Kumar Haldar M. Network-coded MIMO-NOMA systems with FEC codes in two-way relay networks. *Int J Commun Syst*. 2020;e4419. https://doi.org/10.1002/dac.4419