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A novel minimal set decode-amplify-forward (MS-DAF) relaying scheme for MIMO-NOMA

Muhammad Zeeshan[1,2] · Mahnoor Ajmal[2] · Muhammad Umar Farooq[2] · Tabinda Ashraf[2]

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Abstract

In non-orthogonal multiple access (NOMA) scheme, the strong users, located near to base station, demodulate their data by considering the information of other users as interference. One of the crucial challenges in NOMA is the design of sophisticated interference cancellation techniques to improve performance. An alternate approach is to exploit cooperative communication with more straightforward interference cancellation techniques to enhance performance without increasing computational complexity. In this paper, we propose a novel hybrid minimal set decode-amplify-forward (MS-DAF) relaying scheme with maximal ratio combining and space–time block coding for MIMO-NOMA to enhance the performance of weak users located away from the base station and/or having poor channel conditions. The proposed MS-DAF approach reduces the number of relayed links through an intelligent selection of relaying users. The aim is to minimize the re-transmission overhead without compromising the performance. Furthermore, the proposed MS-DAF approach switches between amplify-and-forward and decode-and-forward based on the channel conditions. Simulation results for both SISO- and MIMO- NOMA are presented to show the superiority of the proposed hybrid scheme over existing individual schemes. The proposed technique can be used to improve the performance of edge users in a cellular network with minimal relayed links.

Keywords NOMA · Cooperative communication · Routing · MIMO-NOMA

1 Introduction

The fifth-generation technology has revolutionized the cellular concept of communication by connecting multiple users, ensuring low latency, high data rates, and reducing costs compared to existing networks [1,2]. Traditionally, frequency division multiple access (FDMA), time division multiple access (TDMA), and Code division multiple access (CDMA) are being. These schemes have their advantages, but they can not handle the increasing service requirements and the increasing number of users due to orthogonality constraints. Therefore, the research focus has been moved towards non-orthogonal multiple access (NOMA). NOMA provides improved user fairness and spectral efficiency compared to the conventional orthogonal multiple access (OMA) techniques [3]. Also, OMA techniques cannot accommodate applications with fast communication speed, high data rates, low latency, and a growing number of users.

Power domain NOMA assigns different power levels to users so that they communicate simultaneously at the same time and frequency [1,4]. This concept of transmitting information on different power levels gives better throughput and saves energy resources, specially bandwidth resources [2]. By introducing successive interference cancellation (SIC) on the receiver side, all these NOMA users can decode their messages [1]. Each user separates its message from the superposed signal by considering the data of other users as interference.

In NOMA, user fairness is guaranteed by allocating power levels to users according to their distance from the base station. The more the distance, the more power is allocated, and vice versa [4]. Considerable performance degradation is expected if the distance of a user from the base station is very large. Specifically, path loss, diffraction, absorption, multipath effects, and diverse terrain affect the signal quality and results in signal quality degradation. This degradation can

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✉ Muhammad Zeeshan
muhammad.zeeshan@wit.ie

[1] Waterford Institute for Information and Communication Systems Science, Waterford Institute of Technology, Waterford X91 P20H, Ireland

[2] College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Islamabad 44000, Pakistan

not be undone; however, researchers have proposed numerous techniques such as user clustering [5] or by using visible light communication [6] to partially regenerate the original message being transmitted.

Cooperative communication [7] is used to access the users which are out of range from the base station, or reliable communication is not possible due to the larger distance or poor channel conditions. During the SIC process in power domain NOMA, each user subtracts the data of other users which are located relatively far from the base station. This unwanted data can be transmitted through cooperative communication to respective user(s) to improve the performance. Recent research efforts have focused on integrating either amplify-and-forward (AF) [8] or decode-and-forward (DF) [9] with MIMO-NOMA. However, hybrid decode-amplify-forward (DAF) has only been integrated with NOMA without space-time block coding (STBC) [10,11], as per our knowledge. Furthermore, the hybrid DAF scheme in combination with some relay node selection schemes is least explored in literature. Hence, there is a need to integrate hybrid DAF with MIMO-NOMA while minimizing re-transmission overhead through intelligent relay set selection. In this paper, we propose a novel minimal set decode-amplify-forward (MS-DAF) relaying scheme for MIMO-NOMA. The proposed algorithm initially identifies the users requiring cooperative support, then intelligently selects the minimal relay set from a set of potential relaying users. The aim of the proposed scheme is to retain the bit error rate performance through novel usage of the hybrid DAF approach based on channel state of the user from the base station. The goal is to reduce multiple access interference (MAI) and thus improve signal quality [3,7,12]. Another contribution of this work is the integration of the proposed MS-DAF scheme with MIMO-NOMA based on STBC. To the best of our knowledge, this is the first work that attempts to integrate hybrid MS-DAF and MIMO-NOMA in a single strategy for a better BER performance and reduced re-transmission overhead.

1.1 Research contribution

The main contributions of this paper are as follows:

1. We analyze the performance of AF and DF cooperative relaying techniques in beyond 2-user NOMA scheme for the selection of appropriate scheme under various channel conditions
2. We propose novel usage of hybrid DAF scheme with MIMO-NOMA, based on channel state and distance from the base station. As per our knowledge, either AF or DF schemes have been used for MIMO-NOMA. The hybrid scheme uses maximal ratio combining (MRC) for signal combining and quality improvement.

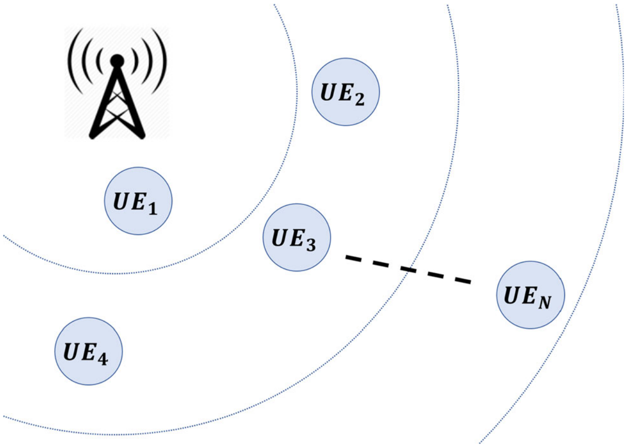

Fig. 1 Downlink NOMA system consisting of N users

3. We propose a novel MS-DAF scheme for intelligent selection of relay users to minimize re-transmission overhead without compromising the BER performance. To the best of our knowledge, this work is the first attempt to integrate minimal set relay selection with hybrid DAF scheme for MIMO-NOMA.

2 Related work

Several techniques are present in the literature to integrate cooperative communication in NOMA [13–21]. In [13], authors discuss the AF relaying scheme for cognitive radio networks based on NOMA under imperfect SIC. The primary network shares its licensed spectrum with a secondary network through NOMA working principle. Another cooperative relaying scheme based on the amplify-and-forward principle for NOMA is proposed in [14]. Authors have shown that the outage probability and performance of NOMA with AF relaying is better than that of DF relaying scheme. Integration of device-to-device (D2D) communication with cooperative NOMA is investigated in [22]. The closed-form expressions of sum-rate are derived, and an appropriate power assignment strategy is proposed to maximize the resulting sum-rate. Performance analysis of cooperative communication in NOMA is carried out [23] under cascaded Rician fading channels. Authors have shown that the capacity is reduced as the cascading degree increases.

A threshold-based cooperative NOMA scheme is proposed in [24] to increase the data reliability. The main idea is to transmit symbols to the cell-edge user if the signal-to-interference plus noise ratio (SINR) is greater than a pre-defined value. The paper also provides optimal threshold value to minimize bit error probability. A dual-hop cooperative relaying network for NOMA is proposed in [25] to select the best relay as an active user. The authors assume that both

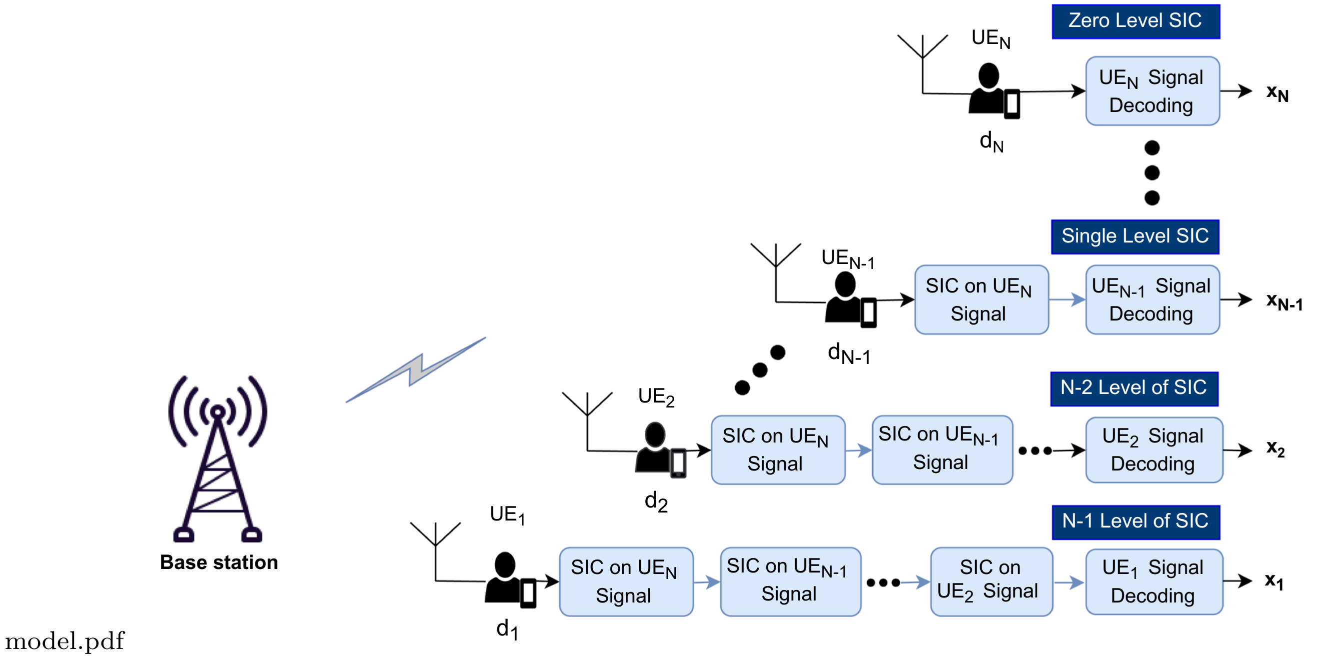

Fig. 2 Downlink SISO-NOMA model having N users with SIC

AF and DF relays are applied to the selected relay. The proposed scheme is not a hybrid scheme; rather it analyzes both AF and DF schemes individually for the dual-hop cooperative network and shows that DF relaying performs better than AF relaying in NOMA. A successive user relaying for cooperative NOMA is proposed in [26] to enhance reliability. Authors propose an algorithm to optimize the power split factor to improve user fairness and outage probability for cooperative NOMA scheme.

In [27], the performance analysis of cooperative NOMA in the presence of imperfect SIC is carried out. For cooperative NOMA, closed-form analytical expressions for outage probability are derived from near and far users. A two-stage relaying selection strategy for two user power domain NOMA is proposed in [28]. The algorithm selects AF or DF relaying scheme based on the required quality-of-service of each user. The outage probabilities of two user NOMA for the two-stage AF and DF scheme are also derived. A UAV-enabled relaying scheme for downlink NOMA is proposed in [29] which is based on providing relay connection through circularly moving UAV via the decode-and-forward relaying scheme. The aim is to provide reliable communication links in emergency situations. A concept of relay-aided cognitive radio-based NOMA is proposed in [20]. The concept is to use the opportunistic spectrum access capability of secondary users (SU) to act as a relay to provide reliable communication to other users in the network. A two-way relaying mechanism for NOMA through multiple antennas is proposed in [30]. Two cooperative strategies, namely multiple access broadcast NOMA and time division broadcast NOMA are proposed and analyzed.

Recently, research efforts have also been made to investigate the potential of applying hybrid AF/DF relaying in wireless communication networks. In [31,32], authors have proposed a thresholding mechanism based on the channel state between the source and relay for the selection of either AF or DF relaying. It is shown that the hybrid scheme achieves 7 dB better performance as compared to the traditional relaying. The concept of hybrid AF/DF relaying is first applied to NOMA in [10] for better performance. The comparison with traditional relaying is made in terms of channel capacity and average throughput. The hybrid AF/DF approach is further extended for NOMA with application to D2D networks in [11]. The proposed scheme selects either AF or DF relaying by using a similar thresholding mechanism given in [31]. As stated earlier, hybrid relaying scheme has not yet been integrated with MIMO-NOMA, as per our knowledge. However, AF relaying with both fixed gain and variable gain is applied to MIMO-NOMA [8]. It is shown that AF with variable gain achieves better performance compared to other schemes. In [9], a DF relaying scheme is integrated with MIMO-NOMA with the availability of statistical channel state information at the transmitter. It is shown that the relay position is very vital for the performance of the network.

Some relay selection schemes without hybrid DAF for NOMA are presented by some researchers. In [33], a relay selection scheme is proposed which uses the relay nodes to establish communication of the base station with the far user via relaying through underlay environment. The scheme itself supports only two users with DF relaying scheme. Another joint relay selection scheme for device-to-device NOMA networks is proposed in [34] by using multiple DF relay nodes to communicate with the far user. The closed-form expressions for the outage probabilities are derived and validated through simulations. In [35], a similar cooperation scheme for two user NOMA is proposed in which the base station communicates with the far user either through near user or through multiple non-NOMA relay nodes. It also uses either AF or DF relaying for cooperation. Hence, the minimal relay selection scheme with hybrid DAF relaying proposed in our paper is a significant contribution towards the cooperative MIMO-NOMA, to the best of our knowledge.

3 System model and problem forumulation

A typical downlink SISO-NOMA model with a base station (BS) having a single antenna and carrier frequency, consisting of N users, is shown in Fig. 1. The BS transmits the data of all user equipments (UEs), denoted by UE_1 to UE_N, at the same time, using the same frequency, but with user-specific unique power levels. This is achieved by transmitting a composite signal $x(t)$ obtained through superposition coding applied to all the users' data. Unique power levels are assigned by the base station to all the users depending upon the relative distance of BS and users and channel conditions. Distant users and/or users experiencing poor channel conditions get higher power factors, while the near users get low power factor values. Larger differences in power and maximum possible phase shifts result in better BER performance [1].

After superposition coding, the transmitted signal is

$$x(t) = \sum_{i=1}^{N} x_i(t), \tag{1}$$

where

$$x_i(t) = \sqrt{p_i}\, s_i(t), \tag{2}$$

for $i = 1, 2, \ldots, N$. Here $x_i(t)$ denotes users signal after power multiplexing, p_i denotes power factors and $s_i(t)$ denotes the modulated signal for ith user. After passing through channel, signal received at ith UE will be

$$y_i(t) = h_i x(t) + n_i(t), \tag{3}$$

where, h_i is the channel gain between transmitter and receiver, and n_i is the Additive White Gaussian Noise (AWGN), both corresponding to ith user. The overall block diagram of N-user NOMA receiver is shown in Fig. 2. Using Eqs. (1)–(3), the composite signal received at by ith user is given by

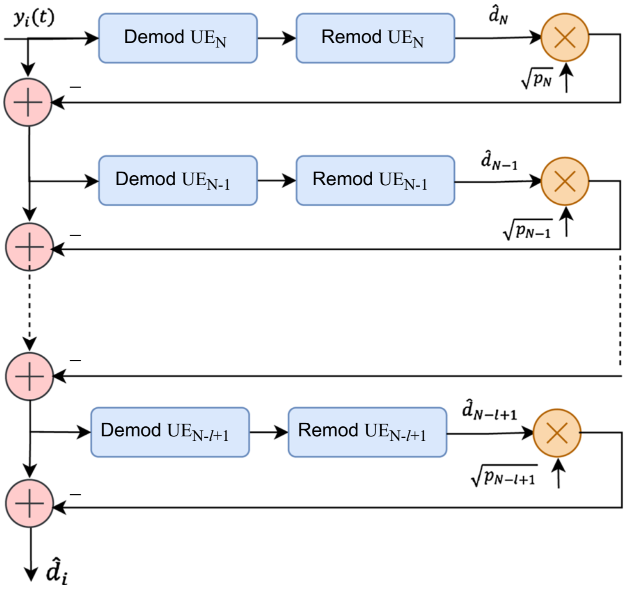

Fig. 3 Multi-level SIC for interference cancellation in NOMA

$$y_i(t) = h_i \sum_{i=1}^{N} \sqrt{p_i}\, s_i(t) + n_i(t) \tag{4}$$

At each receiver, the signal is decoded by performing l-level successive interference cancellation (SIC) to cancel the interference from other users. The decoding order of SIC is set from stronger to weaker users to realize better interference cancellation [36]. The number of levels l is related with the power factor of any UE. If a UE has the power factor p_i in N user NOMA system, then it will perform $l = N - i$ level SIC. The generalized architecture of l-level SIC is shown in Fig. 3. Let $y_i(t)$ be the received signal at ith receiver, then the final data prior to demodulation, after $l-$level SIC, is given by

$$\hat{d}_i = y_i(t) - \sum_{j=1}^{N-i} \sqrt{p_{N-j+1}}\, \hat{d}_{N-j+1} \tag{5}$$

One of the major challenges in the power domain NOMA is to serve the users either located far from the base station (also called edge users) and/or having poor channel conditions. In both these cases, the performance degrades badly due to severe interference from other users. A promising solution to this problem is to exploit a cooperative communication strategy. Since each NOMA user has partial or complete knowledge of the other users' data due to the essential SIC process, therefore relaying can be efficiently implemented to improve the performance of edge or weak users.

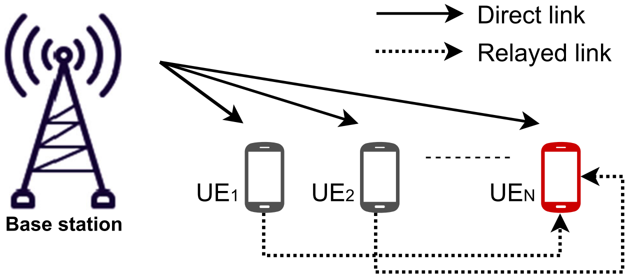

Fig. 4 Typical relaying scenario for N-user NOMA

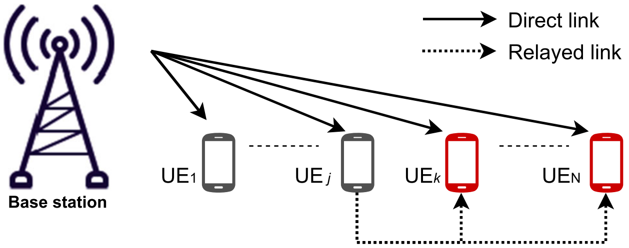

Fig. 5 Hybrid DAF relaying through MRC followed by minimal relay set formulation

Traditionally, amplify-and-forward (AF) and delay-and-forward (DF) are used as relaying schemes. The performance of DF relaying is better than AF relaying in poor channel conditions. The cost is the higher computational complexity of DF as compared to AF. A typical relaying scenario for N-user NOMA is shown in Fig. 4, where UE$_N$ (shown in red) experiences degraded performance. In the absence of a proper relay selection mechanism, all other users start acting as a relay to provide re-enforced link to UE$_N$, resulting in $N-1$ additional re-transmissions. Hence, the integration of relaying mechanism in power domain NOMA poses two major challenges; (1) re-transmission overhead increases drastically if relaying users are not selected appropriately, and (2) a single relaying scheme is not feasible due to performance and complexity constraints. This paper addresses these challenges by developing an approach to select the bare minimum set of relay users through a simple and efficient mechanism by not compromising the bit error rate performance. Furthermore, a novel usage of hybrid decode-amplify-forward (DAF) relaying is proposed for both SISO- and MIMO-NOMA based on channel conditions.

4 Proposed MS-DAF relaying scheme

This section presents the proposed minimal-set decode-amplify-forward (MS-DAF) relaying scheme for multiuser downlink power domain NOMA. The proposed scheme provides a reliable link to the weak users through the hybrid use of AF and DF scheme by using a minimal set of relay users to reduce re-transmission overhead.

4.1 Minimal relay set selection

The first stage of the proposed scheme is the selection of a minimal set of relay users. The proposed selection mechanism is depicted in procedures I and II of the algorithm I. Let N be the total number of NOMA users. First of all, a set C of users requiring cooperative support is formulated. All users having signal-to-noise ratio (SNR) less than a pre-defined value γ are placed in set C. Let P be the set of potential relay users containing users not placed in C. In procedure I, an accessibility map (AM) is populated. This map indicates users, selected from P, that can serve as relay users for each member of set C. This selection is made on the basis of distance. A jth user is selected as a relay if its distance from UE$_i$, taken from set C, is less than d_{max}, which is the maximum distance within which relaying is possible. Therefore, a list S_i, containing all potential relay users for UE$_i \in C$, is populated as part of the complete accessibility map.

For minimal relaying set formulation, the first step is to search for any list S_i containing only one element, i.e., $|S_i| = 1$. If found, the only UE$_j$ is moved to set R, which is the set of minimal relaying users. Also, UE$_j$ is removed from all the listings of AM. For the remaining map listings, a search is carried out to find the list containing the minimum number of elements. Let x be a set containing all UEs in that particular list. The proposed algorithm selects UE$_k$ having the highest membership in AM, places it in set R, and removes all AM listings containing UE$_k$. The process is repeated until all the listings of the accessibility map become empty. The set R contains the minimal set of users that can be used as a relay for all the users in set C requiring cooperative support. The process is further elaborated with the help of a working example presented in Sect. 4.4.

4.2 Hybrid DAF relaying

Once the minimal set of relay users is selected, the next step is to perform relaying through the novel usage of the hybrid DAF approach. A typical scenario of $N-$user NOMA is shown in Fig. 5, where $R = \{j\}$, and $C = \{k, N\}$. Each user has a direct link, shown by the solid line, from the base station. The relayed link is established only from the users included in set R. As shown in Fig. 5, UE$_j$ is acting as a relay, and the signal received at UE$_j$ is given by

$$y_j(t) = h_j x(t) + n_j(t). \tag{6}$$

UE$_j$ acts as a relay to transmit $\hat{x}_k(t)$, and $\hat{x}_N(t)$ (re-modulated signals of UE$_k$ and UE$_N$) using either AF or DF scheme. The selection of AF or DF scheme depends on the relative distance between the two users and/or channel condition.

Algorithm 1: Proposed MS-DAF relaying algorithm

```
Notations:
$N$: Total number of users
$R$: Minimal set of relaying users
$\gamma$: SNR threshold
$d_{max}$: Maximum distance within which relaying is possible
$d_{th}$: Threshold distance for switching of relaying schemes
$C$: Set of users requiring cooperative support, $\text{UE}_i \in C$, if
    $\text{SNR}_i < \gamma$
$d_{ij}$: Distance between $\text{UE}_i$ and $\text{UE}_j$
$AM$: Accessibility map, defining mapping of each $\text{UE}_i \in C$
    to the selected potential relay users
$P$: Set of potential relay users containing all $\text{UE}_i \notin C$
$S_i$: $i$th list of $AM$ corresponding to $\text{UE}_i \in C$

Procedure I: Population of accessibility map
for ($i = 1 : N$) do
    if ($\text{UE}_i \in C$) then
        for ($j = 1 : i - 1$) do
            if ($d_{ij} < d_{max}$) && ($\text{UE}_i \notin C$) then
                Append $j$ in $S_j$ ;
            end if
        end for
    end if
end for

Procedure II: Minimal relaying set formulation
for (Each $i$th list in $AM$) do
    if ($|S_i| == 1$) then
        Select the only $\text{UE}_j$ from $S_i$;
        R $\leftarrow \text{UE}_j$ ;
        Remove all $AM$ listings having $\text{UE}_j \in S_i$ ;
    end if
end for
while ($AM$ is not empty) do
    $x = \arg\min |S_i| \quad \forall \ i$ ;
    for (Each UE$\in S_i$) do
        Select $\text{UE}_k$ having highest membership in $AM$ ;
        $R \leftarrow \text{UE}_k$ ;
        Remove all $AM$ listings having $\text{UE}_k \in S_i$
    end for
end while

Procedure III: Hybrid DAF relaying
for (Each $\text{UE}_i \in C$) do
    if ($d_{th} < d_{ij} < d_{max}$ || SNR$< \gamma_0$) then
        Apply AF relaying ;
    else if ($d_{ij} > d_{th}$ || SNR$> \gamma_0$) then
        Apply DF relaying;
    end if
end for
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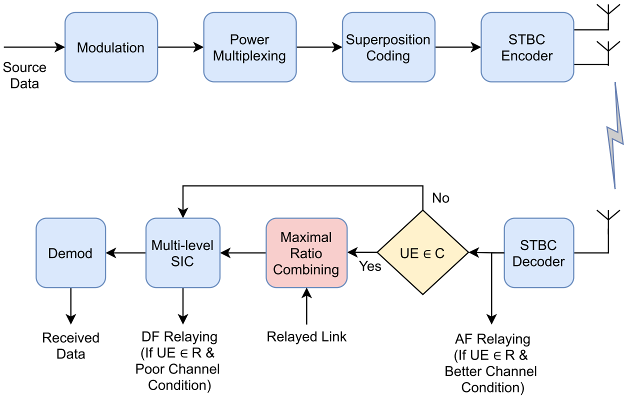


Fig. 6 Proposed MS-DAF scheme with MIMO-NOMA

The hybrid DAF relaying scheme is illustrated as procedure III in algorithm I. Let $d_{th} < d_{max}$ and γ_0 be the threshold distance and SNR for switching of relaying schemes. If the relative distance is less than d_{th} or SNR is greater than γ_0, then DF scheme is applied. On the other hand, if the relative distance is greater than or equal to d_{th} or SNR is less than or equal to γ_0, then AF scheme is applied. At each receiver of the member of set C, maximal ratio combining (MRC) is used to combine the two signals received through the direct and relayed link. MRC is one of the best combining methods with low computational power. It multiplies all the received signals with the conjugate of their respective channel gains and adds all the resulting signals. Therefore, the outputs of MRC at UE_k and UE_N are given, respectively, by

$$y'_k(t) = y_k(t) + h^*_{j,k}\hat{x}_k(t) + n'_k(t) \tag{7}$$

and

$$y'_N(t) = y_N(t) + h^*_{j,N}\hat{x}_N(t) + n'_N(t) \tag{8}$$

where $h^*_{j,k}$ and $h^*_{j,N}$ are the conjugate of channel gains of UE_k and UE_N relative to relay user UE_j, and $n'_k(t)$ and $n'_k(t)$ are the respective AWGN for UE_k and UE_N. The signals $y'_k(t)$ and $y'_N(t)$ are then passed through the respective multi-level SIC process, depending upon the distance from the base station.

4.3 Proposed MS-DAF scheme with MIMO-NOMA

Another major contribution of this paper is the novel usage of the proposed MS-DAF scheme with MIMO-NOMA. As per the authors' knowledge, the hybrid DAF scheme has not been integrated into MIMO-NOMA with minimal relay set selection. The integration of the proposed MS-DAF scheme into MIMO-NOMA system brings diversity and thus improves the BER performance. In particular, we use the Alamouti scheme based on space-time block coding (STBC) in the existing model. It improves the BER performance of the system through space diversity. We assume two antennas on the base station and a single antenna on each user equipment. Therefore, the base station to user link becomes 2 × 1 system. In this way, two copies of the signal are transmitted from the base station to provide diversity through STBC. The proposed MIMO-NOMA transceiver with MS-DAF scheme is shown in Fig. 6.

Table 1 Alamouti STBC encoder rule

	Antenna 1	Antenna 2
Time slot 1	s_1	s_2
Time slot 2	$-s_2^*$	s_1^*

After passing through power multiplexing and superposition coding stages, the modulated data is encoded through STBC and is transmitted in two different time slots via 2 antenna elements. As per the Alamouti scheme, the symbols s_1 and s_2 are transmitted, one from each antenna in the first time slot. In the second time slot, the sequence of the same symbols is reversed, and the conjugate symbols are transmitted. The complete structure is shown in Table 1.

On the receiving side, STBC decoder is used. It combines input signals received from all the receiving antennas and the channel estimate signal to extract the soft information of symbols. Now, if the receiver UE is a member of C, it needs to perform MRC by combining the direct and relayed links. Otherwise, there is no need for MRC, and the output of the STBC decoder is fed directly to multi-level SIC and demodulation blocks. Furthermore, if the receiving UE is a member of R, then it will regenerate the signal(s) for all the respective members of C through AF or DF relaying, depending upon the channel condition and relative distance.

4.4 Working example

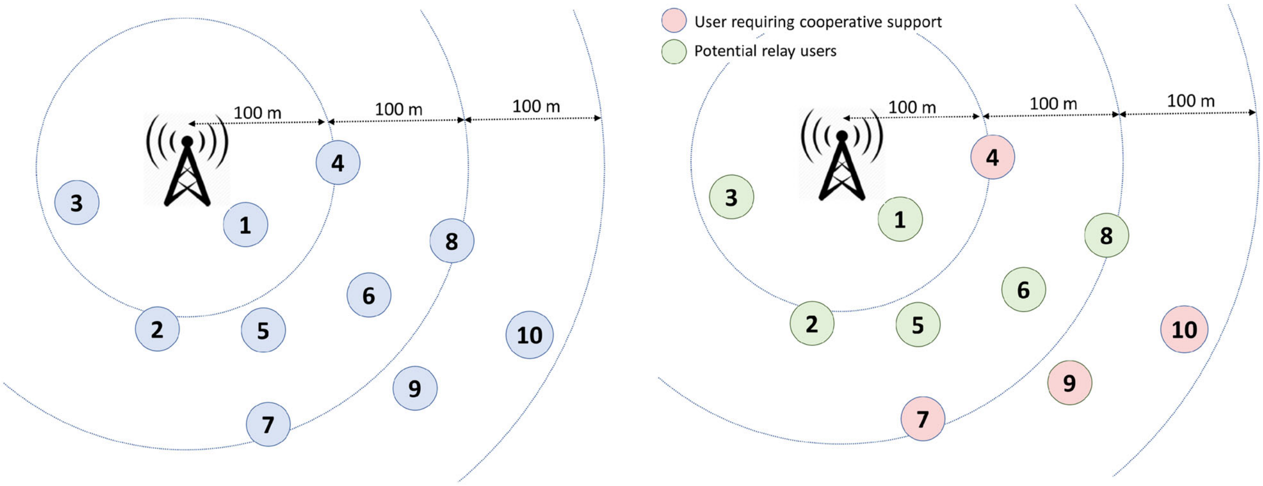
Now, we thoroughly explain the complete working of the proposed MS-DAF scheme with the help of a comprehensive example. Consider a downlink NOMA system consisting of $N = 10$ users, as shown in Fig. 7. First of all, the selection of potential relay users and the users requiring cooperative support is accomplished. For $d_{max} = 125m$, the cooperative support set is given by $C = \{4, 7, 9, 10\}$. Therefore, the set P will contain all the remaining users, i.e. $P = \{1, 2, 3, 5, 6, 8\}$. In the absence of minimal set selection, all the potential relay users will act as relays to regenerate signals for the respective members of C. The complete paths for users 4,7,9, and 10 will be BS → 1 → 4, BS → 2,5,6 → 7, BS → 5,6,8 → 9, and BS → 6,8 → 10. Therefore, a total of nine relayed links will be in use. This information is used to populate the accessibility map (AM), shown in Table 2. The first column contains the members of set C. For ith member of C, the subsequent list S_i contains the potential users capable of acting as a relay.

For minimal relaying set formulation, the first step is to search for any list S_i containing only one element, i.e., $|S_i| = 1$. In this example, the first list contains only one element (UE_1); therefore, it is moved to the minimal relay set $R = \{1\}$. After removing UE_1 from the listings, the AM will be updated as shown in Table 3. Upon searching the remaining map listings, it is found that the last list contains minimum (2) members, i.e., UE_6 and UE_8, so $x = \{6, 8\}$. The membership of UE_6, and UE_8 is three and two, respectively. Therefore, we select UE_6 as the relay and place it in set R, which now becomes $R = \{1, 6\}$. After removing all listings containing UE_6, it is found that AM becomes empty, indicating the completion of the process. The minimal set found through the proposed scheme is $R = \{1, 6\}$. It means that all the four users requiring cooperative support can be provided with the relayed links only through UE_1 and UE_6, as indicated in Fig. 7. The number of required relayed links is reduced from nine to four, resulting in 55.6% reduction in the re-transmission overhead. Once the users are identified as members of set R, the subsequent selection of AF or DF scheme depends on the distance and/or channel condition and is explained in the earlier section.

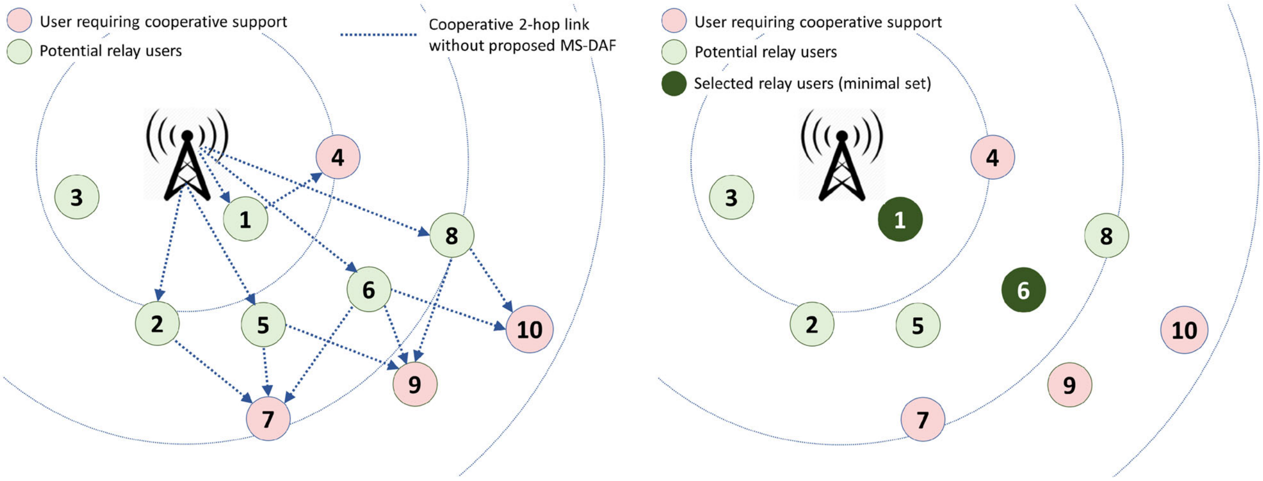
5 Simulation results

In this section, we present the simulation results of the proposed MS-DAF scheme for the MIMO-NOMA system. The simulation parameters are summarized in Table 4. As mentioned earlier, if the decoding is perfect (i.e. BER approaches to zero), DF relay is selected, otherwise AF relay is selected. Since the modulation scheme for all users is set to BPSK, γ_0 = 10 dB is selected as the threshold SNR because the BER of BPSK becomes approximately zero at this SNR. To ensure near-zero outage, the cell radius in 5G is approximately between 100 and 150 m [37]. Therefore, the maximum distance is taken as the average of these two distances, resulting in the outage probability of 10^{-2} at SNR of 10 dB. The threshold distance is taken as almost midway between the base station and the cell edge. Consider a downlink SISO-NOMA system consisting of four users, as shown in Fig. 8. For SNR threshold (γ), UE_3 and UE_4 are placed in cooperative support set $C = \{3, 4\}$. It can be seen that three relayed links are used in the absence of minimal relay selection. Based on the proposed minimal relay set selection method, UE_2 is selected as the only element in the set $R = \{2\}$. Hence, the number of relayed links is reduced to two, resulting in a percentage reduction of 33% in the number of re-transmissions. The proposed algorithm reduces the re-transmission overhead by not much compromising the BER performance. This is shown by comparing the BER performance of UE_3 and UE_4, with and without the proposed MS-DAF scheme. The comparison is shown in Fig. 9. It can be seen that the performance of both the users is almost the same with and without minimal relay set selection.

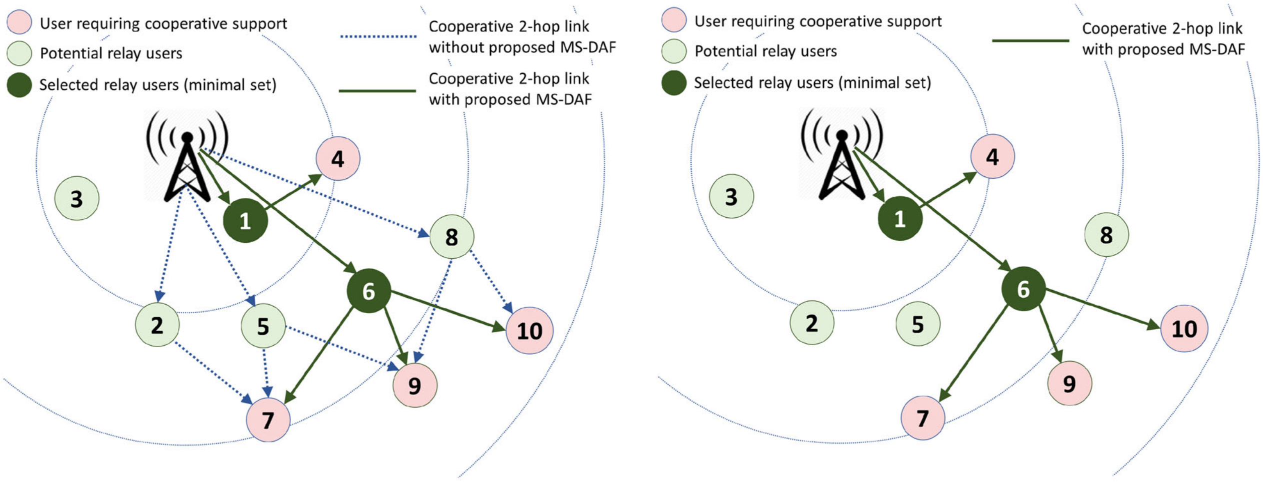
The reduction in re-transmission overhead through the proposed MS-DAF scheme becomes more significant as the number of users is increased. To prove this fact, a downlink NOMA system consisting of different number of users is simulated. For each case, the placement of users is randomized



(a) Placement of 10 NOMA users at different locations **(b)** Selection of relay and cooperative support users



(c) Cooperative 2-hop link without proposed MS-DAF **(d)** Minimal relay set formulation using proposed MS-DAF



(e) Cooperative 2-hop link with and without proposed MS-DAF **(f)** Cooperative 2-hop link with proposed MS-DAF

Fig. 7 Working of the proposed MS-DAF algorithm in a downlink network of 10 NOMA users

Table 2 Example of accessibility map for 10 NOMA users: first iteration

Users requiring cooperative support	Potential relay users
4	1
7	2,5,6
9	5,6,8
10	6,8

Table 3 Example of accessibility map for 10 NOMA users: second iteration

Users requiring cooperative support	Potential relay users
7	2,5,6
9	5,6,8
10	6,8

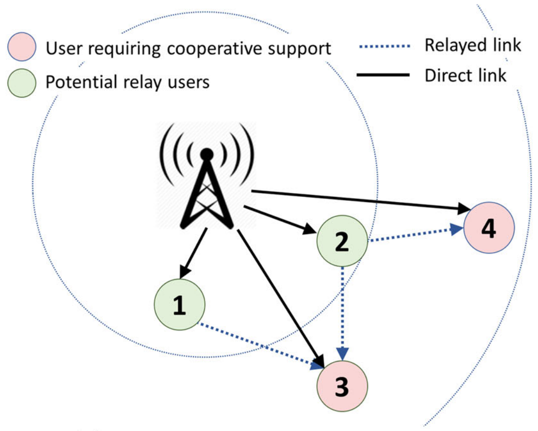
Table 4 Simulation parameters

Parameter	Value(s)
SNR threshold (γ)	5 dB
SNR threshold for AF/DF switching (γ_0)	10 dB
Maximum distance d_{max} (cell radius)	125 m
Threshold distance d_{th}	75 m
User placement	Uniform distribution
Number of simulation runs	500
Modulation scheme	BPSK
Single-tap channel	Rician

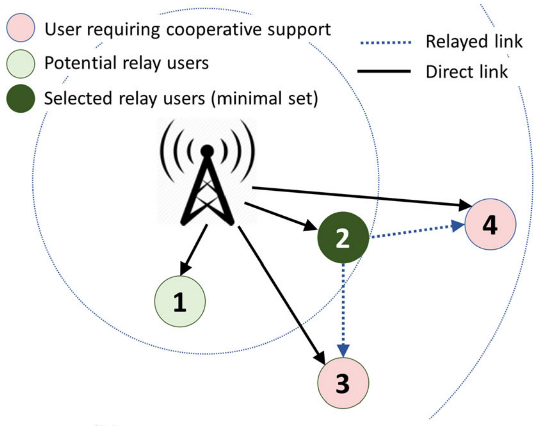
by uniform distribution, and the average percentage reduction in re-transmissions is computed by multiple simulation runs. The percentage reduction versus the number of users is shown in Fig. 10. It can be seen that the percentage reduction in re-transmissions is increased as the number of NOMA users increase. As expected, the reduction is more significant as we increase the number of users.

Now, we present the performance of four user NOMA system with the proposed MS-DAF scheme. In particular, four scenarios are considered; (1) without cooperation, (2) with AF relay cooperation, (3) with DF relay cooperation, and (4) with the proposed MS-DAF scheme. The performance comparison is shown in Fig. 11. It can be seen that the performance of the proposed MS-DAF scheme is not only better than that of without cooperation but also better than that of individual AF or DF relay cooperation for all the SNRs. The switching is made on the basis of threshold distance and SNR, whose values are indicated in the simulation parameters.

As mentioned earlier, one of the main contributions of this paper is the integration of the hybrid DAF scheme with minimal relay selection in MIMO-NOMA system with STBC. Figure 12 shows the performance analysis of four



(a) Without minimal relay set selection



(b) With minimal relay set selection

Fig. 8 Downlink SISO-NOMA system consisting of four users

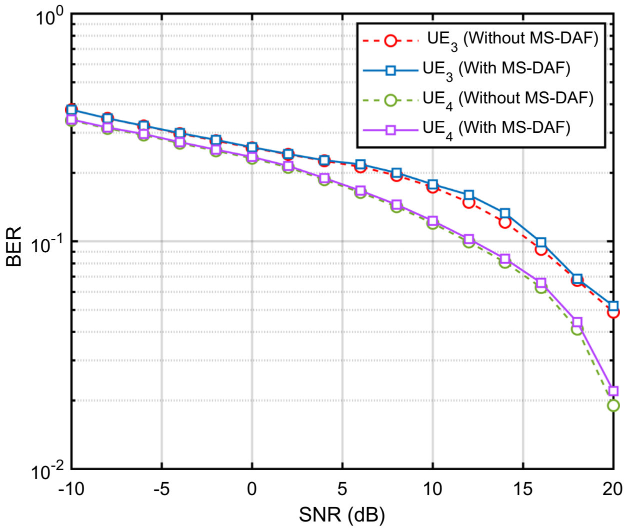


Fig. 9 BER performance comparison with and without proposed minimal relay set selection

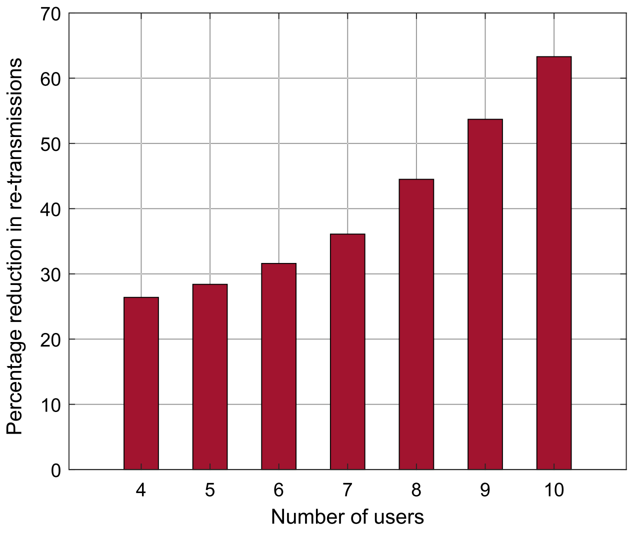


Fig. 10 Percentage reduction in re-transmission overhead

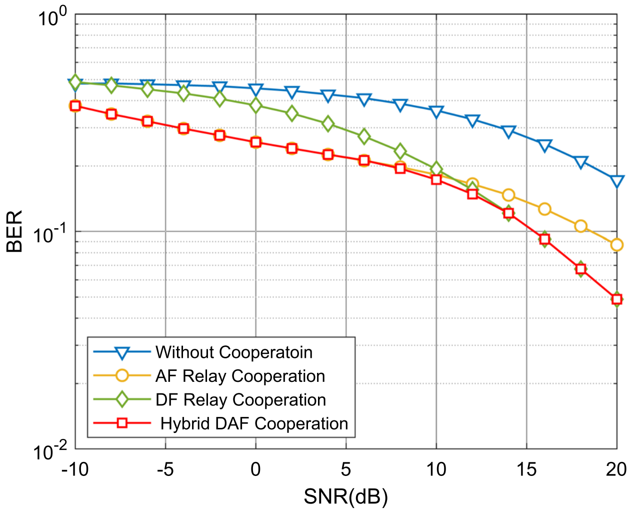


Fig. 11 BER Performance analysis of various relay cooperation schemes

user NOMA system. Due to the time and space diversity provided by STBC, MIMO-NOMA performs better as compared to SISO-NOMA, both using the proposed MS-DAF scheme. It can be seen that MIMO-NOMA with MS-DAF scheme is approximately 2 dB superior to SISO-NOMA. We also compare the performance of the proposed scheme with the relay selection scheme supported by DF method proposed in [33] with the same number of relays. It is clear that the proposed scheme is approximately 3 dB superior. These simulation results validate the effectiveness and simplicity of the proposed MS-DAF relaying scheme for both SISO- and MIMO-NOMA.

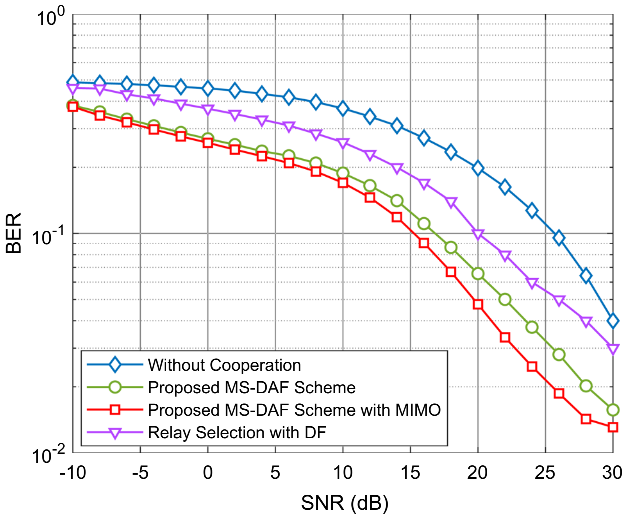


Fig. 12 BER performance of the proposed MS-DAF scheme with MIMO-NOMA system

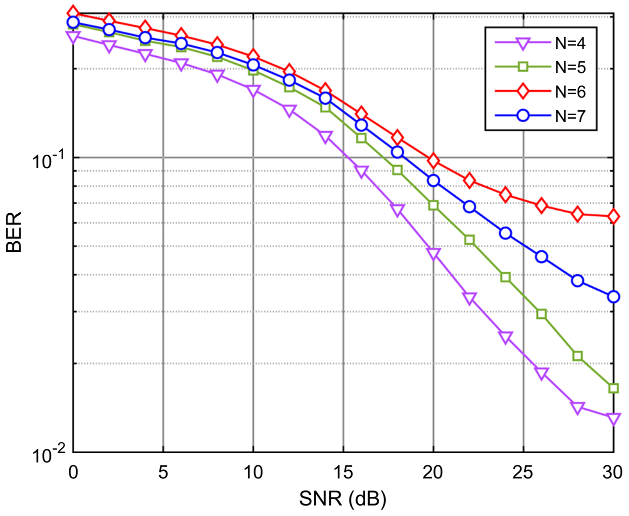


Fig. 13 BER performance of the proposed MS-DAF scheme with MIMO-NOMA system for different number of users

Figure 13 shows the impact of increasing number of users in MIMO-NOMA system with proposed MS-DAF scheme. Since the performance of NOMA heavily relies on the interference cancellation, inclusion of higher number of users degrades the BER performance, as more interference is experienced by stronger users. Despite this fact, the proposed algorithm is capable of admitting upto 7 users with BER less than 10^{-1} at SNR greater than or equal to 20 dB. Due to the performance limitation of standard NOMA scheme, ultra-density required by next generation communication systems is usually supported by the hybrid use of various multiple access schemes.

6 Conclusion

In this paper, we have proposed a novel hybrid minimal set decode-amplify-forward (MS-DAF) relaying scheme for a multiuser NOMA system. The aim of the proposed scheme is to reduce the number of re-transmissions through an intelligent selection of relaying users while maintaining the BER performance. A novel usage of a hybrid DAF relaying scheme is also proposed for MIMO-NOMA with maximal ratio combining (MRC) and space-time block coding (STBC). The proposed MS-DAF approach switches between amplify-and-forward (AF) and decode-and-forward (DF) based on the channel conditions. Simulation results for both SISO- and MIMO- NOMA are presented to show the superiority of the proposed hybrid scheme over existing individual schemes. The reduction in the number of re-transmissions through minimal relay set selection is also indicated through rigorous analysis under the uniformly distributed placement of multiple users in the downlink NOMA system.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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Muhammad Zeeshan received Ph.D. degree in Electrical Engineering with specialization in wireless communications, from College of Electrical and Mechanical Engineering, National University of Sciences and Technology (NUST), Pakistan in 2015. From 2010 to 2016, he was with the Center for Advanced Research in Engineering (CARE), Pakistan, first as a Senior Design Engineer, and then as a Member Technical staff, starting 2014. From 2016 to 2021, he has been working at the Department of Electrical Engineering, College of Electrical and Mechanical Engineering, NUST, Pakistan, first as an Assistant Professor, and then as an Associate Professor, starting May 2021. From September 2021 to January 2022, he was a Research Fellow at the Wearable Technologies Lab, University of Sussex, United Kingdom. Since January 2022, he has been with the Walton Institute of Information and Communication Systems Science, Waterford Institute of Technology, Ireland, where he is currently a Postdoctoral Researcher under VistaMilk project. His research interests include SDR waveform development, cooperative communication, time/frequency synchronization, non-orthogonal multiple access and digital design of wireless communication systems. He is serving as an Academic Editor of PLOS One, since 2021, and is a reviewer of the IEEE Transactions on Communications. IEEE Transactions on Industrial Informatics, and Wireless Personal Communication.

Mahnoor Ajmal received her Bachelor's degree in Electrical Engineering from Institute of Space Technology (IST), Islamabad, Pakistan, in 2018, and her Masters' degree in Electrical Engineering with specialization in Wireless Communication, from National University of Sciences and Technology, Islamabad, Pakistan. Her research interests include wireless communication, 5G networks, machine learning, signal processing and cooperative communication.

Muhammad Umar Farooq received the master's degree in computer science from Quaid-i-Azam University, Pakistan, the master's degree in software engineering from the National University of Sciences and Technology, Pakistan, and the Ph.D. degree in computer science from the University Politehnica of Bucharest, Romania. He is currently an Assistant Professor of computer and software engineering with the College of Electrical and Mechanical Engineering, National University of Sciences and Technology. He is an inventor of one awarded US patent, a reviewer of several international conferences and journals, and the author of several international publications. His research interests include routing and MAC protocols for wireless ad hoc networks, delay tolerant networks, and the Internet of Things.

Tabinda Ashraf completed her BS and MS in Electrical Engineering from National University of Sciences and Technology (NUST), Pakistan in 2016 and 2020, respectively. From July 2016 to present, she has been working as Lab Engineer at the Department of Electrical Engineering, College of Electrical and Mechanical Engineering, National University of Sciences and Technology (NUST), Pakistan. At this department, she is also member of the Cognitive Radio and Wireless Communications (CoRWiC) research group. Her areas of interest include 5th generation wireless communications, embedded systems, and signal processing.