Intelligent NOMA-Based Wireless Backhauling for IoT Applications without End-Device CSI

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Abstract—The article introduces an innovative wireless backhauling approach employing non-orthogonal multiple access (NOMA) and automatic repeat request (ARQ) mechanisms. In this novel scheme, power allocation follows a round-robin (RR) method, ensuring equitable performance among paired users. To address the potential packet loss after ARQ, an intelligent packet repair technique is incorporated to recover the dropped packets. A key feature involves storing dropped data packets for subsequent processing before forwarding to their respective IoT devices (IoDs). The proposed methodology hinges on recognizing that interference within a dropped packet may correspond to a packet retrievable in a forthcoming transmission, facilitating recovery through iterative successive interference cancellation (SIC). Significantly, the scheme enhances data reliability without necessitating an increase in the ARQ retransmission limit, which makes it particularly suited for certain Internet of things (IoT) applications. Empirical results confirm a substantial success rate in recovering dropped packets. Notably, the iterative interference cancellation (IIC) technique demonstrated a noteworthy reduction in the packet drop rate (PDR) from $10^{-1}$ to $10^{-5}$, representing a 100-fold improvement. This implies the successful recovery of 99% of the packets initially dropped in specific scenarios, showcasing the efficacy of the proposed approach.

Index Terms—Backhauling, non-orthogonal multiple access (NOMA), automatic repeat request (ARQ), throughput, packet drop, Internet of things (IoT), 5th generation (5G), 6th generation (6G).

I. INTRODUCTION

The global data traffic increase is currently experiencing unprecedented rates. For example, the total mobile data traffic reached 84 exabyte per month at the end of 2021 [1]. The main drivers for the increase in traffic volumes are the continuous increase in the number of smart phones used and Internet of things (IoT) deployed devices, and the tendency of most applications towards multimedia communications, which currently correspond to the major portion of the traffic of wireless networks. For example, mobile video traffic represented 59% of the total mobile data traffic in 2017, and was expected to reach 79% in 2022 according to Cisco report [2]. For multimedia communications, especially video, reliability, spectral utilization, power consumption, and high data rate transmission requirements have emerged as key challenges. In particular scenarios, multimedia transmission might require ultra reliable low latency communications (URLLC) services [3], [4]. Therefore, extensive research efforts are being devoted to enable beyond 5G (B5G) and 6th generation (6G) cellular networks to handle such challenging requirements. An extensive list of 5th generation (5G) and 6G technologies is given in [5]. It is worth noting that the spectrum scarcity challenge is more prominent in wireless sensor network (WSN) and IoT architectures, because the spectral requirements are generally doubled due to the need for two-hop wireless transmission [6]. The first hop is between the IoT device (IoD) and the IoT gateway (IoG), and the second is between the IoG and the base station (BS) to backhaul the IoDs data to the BS.

In the literature, several solutions are proposed to improve the reliability of data over wireless backhaul links, however automatic repeat request (ARQ) is widely used because it can provide closed-loop error correction through a handshake process between the transmitter and the receiver [7], [8]. Nevertheless, ARQ is mainly based on repetitive transmission of packets that could not be detected successfully at the receiver. Consequently, ARQ can degrade the power and spectral efficiency of the system and increase the delay [7]. In addition, to avoid severe delays, time jitter, power consumption, and throughput deterioration, the number of transmissions per packet is usually limited. Therefore, packets that are not successfully detected after a certain number of retransmissions will be dropped.

To mitigate the spectrum scarcity problem, the design of spectral-efficient multiple access schemes and signal designs is currently attracting substantial attention. In terms of multiple access, non-orthogonal multiple access (NOMA) is considered a key technology and a potential solution to the spectrum scarcity problem [9]–[22]. Besides its advantages in multiuser communications, NOMA can improve the spectral efficiency of point-to-point wireless communications, including wireless backhauling [23]–[30]. NOMA generally requires ARQ to provide quality of service (QoS) provision [31]–[33], while the non-orthogonal multiplexing (NOM) in [23] and [24] is designed particularly for systems that incorporate ARQ because some packets are opportunistically transmitted using...
the residual power that remains after allocating sufficient power to the primary packets. Therefore, such packets may not be received correctly due to their low power. Consequently, the use of ARQ is crucial to guarantee that such packets will eventually be received correctly. To the best of the authors’ knowledge, NOMA packet recovery after reaching the ARQ limit transmission has never been considered in the literature, except for [34]. However, the developed recovery algorithm is applicable to the multi-user scenario, and it also requires data exchange between the users.

A. Related Work

The integrated NOMA-ARQ model for multiuser communications has attracted significant attention from the research community. For example, Choi [35], shows that NOMA-assisted hybrid-ARQ (HARQ) outperforms orthogonal multiple access (OMA)-HARQ in terms of outage probability. A trade-off between the allocated power levels and the number of transmissions in NOMA-HARQ with Chase combining (CC) is presented in [31], where it is shown that HARQ-CC with NOMA can provide a substantial gain in terms of outage probability. The performance of a cooperative network with NOMA-ARQ/HARQ error control methods is studied in [36]. A notable throughput gain is reported compared to conventional OMA transmission. Because larger packets adversely affect reliability, the concept of short-packet communications has been considered. For example, the authors in [37] proposed a NOMA assisted ARQ system for short-packet communications to ensure ultra-reliability and increase throughput. An efficient power allocation strategy for a HARQ-CC enabled NOMA system is proposed in [32]. An effective NOMA-assisted HARQ system for ultra-reliable communications is introduced in [38] where the retransmitted and new packets share the channel and the received packets are combined to improve the effective signal to noise ratio (SNR). The performance of the HARQ-CC and HARQ with incremental redundancy (IR) aided NOMA systems is studied in [39] where the performance is evaluated in terms of outage probability. A dynamic power allocation scheme is presented in a NOMA-HARQ based transmission scheme in [40], leading to a reduced number of retransmissions. The performance of two users on the downlink NOMA using HARQ-CC is studied in [41]. The authors in [42] proposed a dynamic retransmission strategy for the two-user uplink NOMA scenario with HARQ and multiple allowed retransmissions. The simulation results demonstrate that the proposed dynamic approach significantly improves the packet error rate (PER) of the low-power user at the expense of a negligible increase in the PER of the high-power user. Finally, the performance of NOMA with HARQ for short packet communications in massive IoT networks is studied in [43].

The use of NOMA for point-to-point multiuser communications, i.e. backhauling, has been considered in the literature, but at a small scale [25]–[30]. For instance, Nguyen et. al. [25] investigate the utilization of unmanned aerial vehicle (UAV)-based small cell BSs for downlink (DL) transmissions in wireless backhaul networks, with a particular focus on NOMA. This work demonstrates the advantages of the proposed NOMA and wireless backhauling technique by defining an optimization problem to maximize user rates and solving it with a convex approximation-based low-complexity algorithm. A DL NOMA in heterogeneous small cell networks with wireless backhaul is discussed in [26] to maximize energy efficiency (EE) while addressing practical constraints. The optimization problem is split into subproblems and an iterative approach is employed for power optimization as well as a closed-form solution for bandwidth allocation. A novel cooperative transmission scheme that utilizes NOMA in two-tier heterogeneous networks with wireless backhaul is presented in [27]. The work discusses the decoding order of NOMA and presents two optimization problems related to maximizing the total achievable rate and user satisfaction. The backhaul challenge that arises in 5G heterogeneous ultra-dense networks is investigated in [28]. Comparing the EEs of cooperative OMA and cooperative NOMA schemes, it presents a two-layer hierarchical model for cooperative wireless backhaul. Greedy algorithms are used to maximize EE.

A cellular UAV system is presented in [29], where several UAVs cooperate to transmit sensory data to a central BS using two communication modes: UAV-to-network and UAV-to-UAV. This work aims at improving the allocation of communication resources for UAVs to enhance the backhaul efficiency. A dynamic wireless backhaul scheme for two-layer heterogeneous networks is presented in [44]. This scheme switches between OMA, NOMA and cooperative NOMA modes depending on the channel quality. By examining the backhaul capacity and outage performance of these modes, this work devises power allocation strategies for NOMA and cooperative NOMA for improvements over the traditional modes. Ref. [45] proposes an approach for improving spectrum efficiency in NOMA-enhanced ultra dense networks for both wireless backhaul and user access links. As demonstrated in [46], [47], the use of NOMA improves spectrum efficiency for both DL and uplink (UL) transmissions in the wireless backhaul networks. The work in [48] focuses on the use of small BSs as intermediate relays in cooperative communications to combat multi-path fading, enhance energy efficiency, and improve network reliability and capacity through relay selection in a NOMA-based cooperative wireless backhaul network model. An opportunistic NOMA scheme for unreliable wireless backhaul and uncertain fronthaul channels is introduced in [49]. The proposed scheme offers two transmitter selection approaches based on receiver proximity, addressing challenges posed by unreliable backhauls and fading in the fronthaul. The work in [50] addresses wireless backhaul in a multi-tier heterogeneous cellular network coordinated by a cloud-based central station by employing NOMA to enhance spectral efficiency in the wireless DL. The authors develop power allocation strategies for different cell types, considering practical power consumption and wireless backhaul. In [51], a DL NOMA transmission in UAV-enabled wireless backhaul networks with NOMA is proposed to improve connectivity and spectral efficiency. Bushra et. al. in [52] explore EE resource allocation in UL multi-carrier NOMA networks with wireless backhaul. The focus is on optimizing subchannel allocation.
and power allocation to maximize system EE while ensuring user fairness and adhering to QoS constraints.

B. Motivation

Although the synergy of NOMA and ARQ is considered an effective solution to provide reliable and spectrally efficient wireless links, the full potential of this configuration has not been entirely exploited due to the conflicting nature of the two technologies. Although NOMA can improve the spectral efficiency, it can deteriorate reliability. On the contrary, ARQ can improve reliability at the expense of spectral efficiency. Therefore, the number of transmissions allowed for ARQ is typically limited to a few transmissions. Packets not received correctly after ARQ are discarded at the transmitter and dropped at the receiver [7]. Therefore, this work aims to propose a new NOMA-ARQ protocol for point-to-point and backhaul wireless links.

The main contributions of the work can be summarized as follows:

1) Proposes a new low complexity round-robin (RR) power allocation for NOMA users.
2) A novel iterative interference cancellation (IIC) is proposed to repair and recover the dropped packets at the receiver and thus improve the packet drop rate (PDR).
3) The proposed scheme is carried out by exploiting the correlation between the packets received due to the nonorthogonal transmission and ARQ.
4) The proposed protocol does not require additional interaction with the transmitter to repair dropped packets, beyond conventional ARQ. Thus, it does not affect the system throughput, spectrum efficiency, or power efficiency. However, it incurs additional storage and computational power requirements at the receiver.
5) The performance of the proposed scheme is evaluated in terms of packet drop rate and buffering requirements.
6) The results obtained demonstrate that the proposed scheme can significantly reduce the number of packets dropped. In certain scenarios, the packet drop rate improvement exceeds a 100 fold, equivalent to a 12 dB gain.

C. Paper Organization

Sec. II introduces the ARQ system model. Sec. III describes the proposed NOMA-based backhauling with RR and IIC. Sec. IV presents the performance evaluation of the system and Sec. V discusses the results. and Sec. VI draws the conclusions, Appendix I presents the error probability of secondary packet when the primary packet fails the cyclic redundancy check (CRC), Appendix II presents the list of Acronyms, and Appendix III shows the list of symbols.

II. ARQ System Model

The ARQ system considered in this work consists of a transmitter that needs to transmit $M$ packets to the receiver through a wireless link, where each packet consists of $B$ bits that are mapped to $K$ modulated symbols. If binary phase shift keying (BPSK) is adopted, then $K = B$. The transmitter and receiver communicate using a truncated ARQ with the stop-and-wait (SW) flow control protocol with a maximum number of transmissions of $L$, including the initial transmission [7]. A packet that fails the error check following its $L$ transmissions is dropped. The channel between the BS and IoD is modeled as a block fading channel, i.e., the channel remains constant during a single transmission session but varies randomly over consecutive transmission sessions. Therefore, the sequence received during the $i$th transmission session of packet $i$ can be written as

$$y_i^{(l)} = h_i^{(l)} \sqrt{p_i^{(l)}} x_i^{(l)} + w_i^{(l)}$$

where $p$ is the transmission power, the channel frequency responses (CFRs) $h_i^{(l)} \forall \{i, l\}$ are independent and identically distributed (i.i.d.), $h_i^{(l)} \sim CN(0, \sigma_h^2)$, $w$ is the additive white Gaussian noise (AWGN) vector, $w = [w_1, w_2, \ldots, w_K]$, $w_i^{(l)} \sim CN(0, \sigma_w^2)$ are i.i.d. $\forall \{i, l\}$. The transmitted data packet is defined as $x_i = [x_{i,1}, x_{i,2}, \ldots, x_{i,K}]$, where the data symbols $x_{i,j}$ are selected from a particular constellation such as phase shift keying (PSK) or quadrature amplitude modulation (QAM).

The receiver detects the received sequence $y_i^{(l)}$ and checks its transmission counter $l$, if $l = 1$, then $y_i^{(l)}$ is detected to obtain the estimated version of $x_i$, denoted as $\hat{x}_i$. The packet detection process is denoted as $\hat{x}_i = D_1 \{y_i^{(l)}\}$, and it is performed by using maximum likelihood detection (MLD) for each symbol in the received sequence,

$$\hat{x}_{i,k} = \arg \min_{x_{i,k} \in \mathbb{X}} \left| y_{i,k}^{(1)} - h_{i,k}^{(1)} x_{i,k} \right|^2 \triangleq D_1 \{y_{i,k}^{(1)}\}, k = [1, 2, \ldots, K]$$

where $\mathbb{X}$ is the set of all trial values of $x_{i,k}$. The receiver then verifies if $x_i = \hat{x}_i$, using certain error detection schemes such as CRC. If the CRC indicates that $x_i = \hat{x}_i$, then an acknowledgment (ACK) is sent to instruct the transmitter to send packet $x_{i+1}$. Otherwise, a negative acknowledgment (NACK) is sent to instruct the transmitter to resend $x_i$. However, if $l > 1$, CC is used to combine $y_i^{(1)}, y_i^{(2)}, \ldots, y_i^{(l)}$, and then the combined sequence is detected and remaining processes are similar to the case where $l = 1$. The CC process

\[Fig. 1: Wireless backhauling using NOMA.\]
in this case is similar to the maximum ratio combining (MRC). In this work, we consider Type-I ARQ, which implies that the same packet can be transmitted up to \( L \) times [7].

### III. Proposed Backhauling Protocol

In this work, we define wireless backhauling as the use of wireless connection for the core network connectivity, for which fiber cables are traditionally used. For IoT networks, IoDs and IoG can be deployed in rural areas without wired connectivity to the core network. Consequently, wireless backhauling is indispensable. In some IoT applications, the IoG can be deployed on a UAV, hence wireless backhauling is the only solution [25]. It should also be noted that wireless backhaul means wireless connectivity in both downlink and uplink connections [30].

#### A. NOMA Backhauling With RR Power Allocation

The considered system model is shown in Fig. 1 where a master server (MS) communicates with a number of IoDs via a BS and IoG. In downlink, the IoG receives the NOMA packets from the BS, demultiplexes the packets of all users, and finally forwards each packet to the corresponding user. The demultiplexing process is realized by applying successive interference cancellation (SIC). Due to the inter-user-interference inherent in NOMA, which becomes significant for a large number of users, and in order to reduce the receiver complexity, this work considers the case where the number of users \( N = 2 \). Without loss of generality, we consider that packets \( x_1, x_3, \ldots, x_{M/2-1} \) are received correctly, and assume that \( i \) is odd. For notational simplicity, we consider that odd packets, \( x_1, x_3, \ldots, x_{M/2-1} \), belong to the first user \( U_1 \), while even packets, \( x_2, x_4, \ldots, x_{M/2} \), belong to the second user \( U_2 \). Because both users in point-to-point backhauling will experience the same channel, the power allocation is performed in a RR manner. In this allocation, the first packet of \( U_1 \) is assigned a higher power than the corresponding packet of \( U_2 \), until it is received correctly or dropped. Then, a packet of \( U_2 \) is assigned a higher power until it is received correctly or dropped. Thus, a packet with higher power in a given transmission will be denoted as the primary packet, while the one with the lower power will be denoted as the secondary packet.

It is worth noting that varying the power assignment at the BS requires knowledge of the channel state information (CSI) between the IoG and IoDs, which might be prohibitively expensive due to the high signaling overhead [6, 53], and therefore CSI is considered to be unavailable at the BS. Therefore, with this approach, users will experience a degree of fairness in terms of resource allocation. However, different power allocations for each user can still be applied in the last hop, i.e., IoG-IoD.

Based on the system model considered, the transmitted ith NOMA packet can be expressed as

\[
s_i = \sqrt{\alpha_{i,l}^{(1)} x_{i,l}^{(1)}} + \sqrt{\alpha_{i+1,l}^{(1)} x_{i+1,l}^{(1)}}
\]

where \( \alpha_{i,l}^{(1)} \) and \( \alpha_{i+1,l}^{(1)} \) are the powers allocated for the primary and secondary packets, respectively, such that \( \alpha_{i,l}^{(1)} + \alpha_{i+1,l}^{(1)} = 1 \), \( 1 \leq l \leq 2L \). In the representation of the transmitted packet \( x_{i,l}^{(1)} \), the first subscript \( a \) indicates the packet sequence number, and the second subscript \( b \) represents the total number of transmissions of the packet when transmitted as primary or secondary. The superscript \( c \) indicates the transmission counter of the packet when transmitted as primary, which specifies when a packet should be dropped. For example, \( x_{i,3}^{(1)} \) implies that the current primary packet is \( x_4 \), which belongs to \( U_2 \). The superscript indicates that it has been transmitted once as a primary packet and the second subscript, i.e., 3, indicates that it is transmitted three times in total, including both primary and secondary transmissions, i.e., once as a primary packet and twice as a secondary packet. The received composite NOMA packet can be expressed as

\[
y_{i,l}^{(1)} = h_i^{(1)} s_i + w_{i,l}^{(1)}
\]

where \( w \) is the AWGN vector whose elements are i.i.d., \( w \sim \mathcal{C}\mathcal{N}(0, \sigma_i^2) \), where \( I \) is a \( K \times K \) identity matrix.

Due to ARQ, the detection process for \( y_{i,l}^{(1)} \) depends on the value of \( l \), and generally follows the conventional SIC detection used in NOMA systems where the packet with the highest power is detected first while considering lower power packets as unknown additive noise. For \( \ell = 1 \), the primary packet is transmitted only once and is directly detected as \( \hat{x}_i = D_1 \{ y_{i,l}^{(1)} \} \). The secondary packet \( x_{i+1} \) is detected by applying SIC and then MLD to the resulting sequence, which can be written as

\[
\hat{y}_{i,l}^{(1)} = y_{i,l}^{(1)} - h_i^{(1)} \sqrt{\alpha_{i,l}^{(1)}} \hat{x}_i
\]

then,

\[
\hat{x}_{i+1} = D_2 \{ \hat{y}_{i,l}^{(1)} \}.
\]

For notational simplicity, the three operations required to detect \( x_i \) and \( x_{i+1} \), i.e., MLD of \( x_i \), SIC, and MLD of \( x_{i+1} \) will be denoted as

\[
\{x_i, \hat{x}_{i+1}\} = D_2 \{ y_{i,l}^{(1)} \}.
\]

When \( \ell > 1 \), all the earlier copies of the received sequence with the same primary packet index are first combined using CC. Given that the index of the current primary packet is \( i \), and that it has been retransmitted \( \ell \) times as a primary packet, then CC is given by

\[
C \{ y_{i,1}^{(1)}, \ldots, y_{i,\ell}^{(1)} \} \cong d_i = \frac{\sum_{n=1}^{\ell} | h_i^{(n)} y_{i,1}^{(n)} |^2 }{\sum_{n=1}^{\ell} | h_i^{(n)} |^2 }, \ell \leq L
\]

where the \( \dagger \) indicates that the total transmission index is ignored and \( | \cdot |^* \) denotes the complex conjugate operator. As can be seen in (8), CC is similar to MRC except that it is applied to packets instead of individual symbols. Channel coefficients \( h_i^{(n)} \) \( \forall \{i, n\} \) can be obtained using various blind- or pilot-aided channel estimation schemes [54]. The MLD in such cases can be written as

\[
\hat{x}_{i,j} = \arg \max_{x_{i,j} \in \mathbb{X}} | d_{i,j} - x_{i,j} |^2 , \ i \in \{ 1, \ldots, M \}, \ j \in \{ 1, 2, \ldots, K \}.
\]
from $y_{1,1}$; however, both fail the CRC process, and therefore, both packets are retransmitted. The receiver again attempts to recover $x_1$ and $x_2$ from $y_{2,1}$, but the CRCs for both $x_1$ and $x_2$ fail for the second time. Consequently, $x_3$ is dropped because $L = 2$ with respect to $x_1$. After dropping $x_1$, the transmitter designates $x_2(U_2)$ as the primary packet. Consequently, it is multiplexed with $x_3(U_1)$, which becomes the secondary packet. The combined packets are then transmitted, resulting in the received sequence $y_{2,3}$. As can be seen in Fig. 2, $y_{1,2}$ and $y_{2,3}$ are partially correlated because they have one packet in common, which is $x_2$. The same argument applies to $\{y_{2,3}, y_{2,4}\}$, which are fully correlated, while $\{y_{2,4}, y_{3,3}\}$ are partially correlated. In the figure, $x_3$ and $x_4$ are considered correctly detected and have passed the CRC processes.

As shown in Fig. 2, packets $x_3$ and $x_4$ are successfully detected in the 5th transmission slot, whereas packets $x_1$ and $x_2$ are dropped due to exceeding the maximum number of transmissions allowed. However, as observed in the figure, $y_{3,3}$ is partially correlated with both $y_{2,3}$ and $y_{2,4}$ with $x_3$ being the common packet between these two received sequences. Therefore, the interference caused by $x_3$ on $y_{2,3}$ and $y_{2,4}$ can be eliminated using a second SIC iteration. It is worth noting that the SIC in this case differs from conventional SIC used in NOMA, as it eliminates weak interference rather than strong interference. Once the interference is removed, the sequences $y_{2,3}$ and $y_{2,4}$ will become interference-free and can be combined and detected, significantly increasing the probability of successful detection compared to initial detection process with interference. Given that $x_2$ is successfully recovered, the same process can be applied to cancel its interference from $y_{1,1}$ and $y_{1,2}$. Subsequently, an attempt can be made to re-detect $x_1$.

The detailed process of the IIC algorithm for the example in Fig. 2 is depicted in Table I. The processing performed in each transmission session is as follows:

**TS 1**: The BS sends $s_1$, which is received as $y_{1,1}$, as defined in (4). If the primary packet $x_1$ is detected erroneously, as indicated by the CRC process, then the detection process for packet $x_2$ is not initiated. Instead, a retransmission is requested using a NACK $\{0, 0\}$.

**TS 2**: The BS resend $s_1$ for the second time. The received sequence, in this case, is denoted as $y_{1,2}$. Since the received sequences $y_{1,1}$ and $y_{1,2}$ are fully correlated, CC can be utilized to combine them. The combining process can be described as,

$$\mathcal{C}\{y_{1,1}, y_{1,2}\} \triangleq d_1 = \frac{[h_1^{(1)}]^{*} y_{1,1} + [h_1^{(2)}]^{*} y_{1,2}}{|h_1^{(1)}|^2 + |h_1^{(2)}|^2}. \quad (11)$$

The sequence $d_1$ is then passed to the detector to recover packet $x_1$, resulting in the detected packet $\hat{x}_1$. If $x_1 \neq x_1$, the receiver sends a NACK to the transmitter. The transmitter eventually drops $x_1$ since it has reached the maximum number of transmissions allowed. Moreover, the receiver discards $\hat{x}_1$ and stores the associated received sequences $y_{1,1}$ and $y_{1,2}$ along with the corresponding channel coefficients $h_1^{(1)}$ and $h_1^{(2)}$, in the drop buffer $A$. It is worth noting that (11) is
TABLE I: Example of IIC for $L = 2$ and $M = 4$.

<table>
<thead>
<tr>
<th>Process</th>
<th>Output</th>
<th>CRC</th>
<th>Drop buffer ($A$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TS 1: $y_{1,1}^{(1)}$</td>
<td>$\hat{x}_1, \hat{x}_2$</td>
<td>0, 0</td>
<td>$h_{1,1}^{(1)}$</td>
</tr>
<tr>
<td>TS 2: $y_{1,2}^{(1)}$</td>
<td>$\hat{x}_1, \hat{x}_2$</td>
<td>0, 0</td>
<td>$h_{1,1}^{(2)}, h_{1,2}^{(1)}$</td>
</tr>
<tr>
<td>TS 3: $y_{2,3}^{(1)}$</td>
<td>$\hat{x}_2, \hat{x}_3$</td>
<td>0, 0</td>
<td>$h_{1,2}^{(2)}, h_{2,1}^{(1)}, h_{2,1}^{(2)}, h_{2,2}^{(1)}$</td>
</tr>
<tr>
<td>TS 4: $y_{2,4}^{(1)}$</td>
<td>$\hat{x}_2, \hat{x}_3$</td>
<td>0, 0</td>
<td>$h_{1,2}^{(2)}, h_{2,1}^{(1)}, h_{2,1}^{(2)}, h_{2,2}^{(1)}$</td>
</tr>
<tr>
<td>TS 5: $y_{3,3}^{(1)}$</td>
<td>$\hat{x}_2, \hat{x}_3$</td>
<td>0, 0</td>
<td>$h_{1,2}^{(2)}, h_{2,1}^{(1)}, h_{2,1}^{(2)}, h_{2,2}^{(1)}$</td>
</tr>
</tbody>
</table>

Algorithm 1: Iterative Interference Cancellation (IIC) Routine

1. $X = \emptyset$; received sequence & channel
2. $d_1 = C\{y_{i,j}^{(1)}, \ldots, y_{i,j}^{(L)}\}$
3. $\{\hat{x}_i, \hat{x}_{i+1}\} = D_2\{d_1\}$
4. If $\hat{x}_i$ fails CRC then
   5. put $y_{i,j}^{(1)}, h_{1,1}^{(1)}$ in buffer $A$
   6. return
   7. If $\hat{x}_{i+1}$ fails CRC then
   8. $X = X \cup \{\hat{x}_i\}$
   9. else
   10. $X = X \cup \{\hat{x}_i, \hat{x}_{i+1}\}$
11. while drop buffer $A$ is not empty do
   12. extract and remove the $L$ received sequences from the drop buffer $y_{i-1,j-L-1}^{(1)}, \ldots, y_{i-1,j}^{(L)}$ for some $j$
   13. use IIC to estimate $\hat{y}_{i-1,j-L-1}^{(1)}, \ldots, \hat{y}_{i-1,j}^{(L)}$ as in (12) and (13)
   14. $d_2 = C\{\hat{y}_{i-1,j-L-1}^{(1)}, \ldots, \hat{y}_{i-1,j}^{(L)}\}$
   15. $\hat{x}_{i-1} = D_1\{d_2\}$
   16. If $\hat{x}_{i-1}$ fails CRC then
   17. empty the drop buffer $A$
   18. return
   19. else
   20. $X = X \cup \{\hat{x}_{i-1}\}$
   21. $i = i - 1$

3) At this stage, the receiver might have managed to repair and recover only $x_3$, both $x_1$ and $x_2$, or neither. In any cases, the drop buffer will be cleared because the next transmitted packets will be independent of the buffered sequences. The detailed IIC process is described in Algorithm 1.

TS 6: At this stage, the BS should send two new packets: $x_5, x_6$.

IV. PERFORMANCE EVALUATION

Consider that the BS wants to transmit $M$ packets, which are denoted as $x_1, \ldots, x_M$. A dropped packet is represented as $\hat{x}_i$, a correctly detected packet is denoted as $\hat{x}_i$, and a packet

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equivalent to an MRC process at the packet level, making its extension to an arbitrary number of users straightforward.

**TS 3:** The BS drops $x_1$ and generates $s_2$ by multiplexing packets $x_2$ and $x_3$. In this case, the received sequence is denoted as $y_{2,3}^{(1)}$. Because $y_{2,3}^{(1)}$ is only partially correlated with $y_{1,1}^{(1)}$ and $y_{2,2}^{(1)}$, CC cannot be applied. Therefore, $y_{2,3}^{(1)}$ will be directly processed by the detector to generate $\hat{x}_2$. If $x_2 \neq \hat{x}_2$, the receiver sends a NACK to the transmitter, requesting the retransmission of $s_2$.

**TS 4:** The BS sends $s_2$ for the second time, which is received as $y_{2,4}^{(2)}$. Consequently, $y_{2,3}^{(1)}$ and $y_{2,4}^{(2)}$ are fully correlated and can be combined as described in (11), to produce $d_2$. Given that the detector fails to correctly detect $x_2$, the receiver sends a NACK to the transmitter, which eventually drops $x_2$. Moreover, the sequences $y_{3,3}^{(1)}$ and $y_{2,4}^{(2)}$ along with their corresponding channels information are stored in the drop buffer $A$.

**TS 5:** The BS sends $s_3$ which is received as $y_{3,3}^{(1)}$. Since $y_{3,3}^{(1)}$ is only partially correlated with all buffered sequences, it cannot be combined with any other sequence. Therefore, it is applied directly to the detector. Given that packets $x_3$ is detected correctly, SIC can be applied to extract $x_4$. In such scenarios, the partial correlation between $y_{2,3}^{(1)}, y_{2,4}^{(2)}$ and $x_3$ can be exploited to apply the IIC process, which can be described as follows:

1) Because $x_3$ is considered as interference with respect to $y_{2,3}^{(1)}$ and $y_{2,4}^{(2)}$, its detrimental effect can be eliminated as:

$$\hat{y}_{2,3}^{(1)} = y_{2,3}^{(1)} - \sqrt{\alpha_{2,3}^{(1)} h_{1,2}^{(1)}} \hat{x}_3$$

$$\hat{y}_{2,4}^{(2)} = y_{2,4}^{(2)} - \sqrt{\alpha_{2,4}^{(2)} h_{1,2}^{(2)}} \hat{x}_3.$$  (12)

The interference cancellation (IC) in this case is denoted as IIC because the cancellation is performed between symbols from different transmission slots. The signal to interference plus noise ratios (SINRs) of $\hat{y}_{2,3}^{(1)}$ and $\hat{y}_{2,4}^{(2)}$ are expected to be better than $y_{2,3}^{(1)}$ and $y_{2,4}^{(2)}$ due to the IC.

2) Compute $d_2 = C\{y_{2,3}^{(1)}, y_{2,4}^{(2)}\}$ as described in (11). Then apply $d_2$ to the detector to generate $\hat{x}_2$. If $\hat{x}_2 = x_2$, repeat the process by applying the IIC to eliminate the effect of $x_2$ from $y_{1,1}^{(1)}$ and $y_{1,2}^{(1)}$, and then detect $x_1$. If $\hat{x}_2 \neq x_2$, terminate the IIC, drop $x_1$ and $x_2$ permanently, and clear the drop buffer.

3) At this stage, the receiver might have managed to repair and recover only $x_3$, both $x_1$ and $x_2$, or neither. In any cases, the drop buffer will be cleared because the next transmitted packets will be independent of the buffered sequences. The detailed IIC process is described in Algorithm 1.

**TS 6:** At this stage, the BS should send two new packets: $x_5, x_6$. 

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that is incorrectly detected is denoted as $\hat{x}_i$. Therefore, the average packet drop probability can be expressed as

$$P_D = \frac{1}{M} \sum_{i=1}^{M} Pr(\hat{x}_i). \quad (14)$$

### A. Packet Drop Probability without IIC

During the first transmission, packets $x_1$ and $x_2$ are combined and sent as a single NOMA packet. The same two packets can be transmitted for a maximum of $L$ times, with CC applied at the receiver side after each transmission of the same packets. Consequently, the CC applied after the second transmission can be represented as $C\{y_{1,1}, y_{1,2}\}$, while the CC after the third transmission is denoted as $C\{y_{1,1}, y_{1,2}, y_{2,3}\}$, and so on for subsequent transmissions. Therefore,

$$Pr(\hat{x}_1) = Pr\left(\hat{x}_{1,1}^{(1)}\right) Pr\left(\hat{x}_{1,2}^{(2)}\right) \times \cdots \times Pr\left(\hat{x}_{1,L}^{(L)}\right)$$

$$= \prod_{l=1}^{L} \left[1 - \left(1 - P_{B_1}^{(l)}\right)^{B}\right] \quad (15)$$

where

$$P_{B_1}^{(l)} = \frac{1}{2} Q\left(A_1 \sqrt{\sum_{k=1}^{l} \gamma_{1_k}^{(k)}}\right) + \frac{1}{2} Q\left(A_2 \sqrt{\sum_{k=1}^{l} \gamma_{1_k}^{(k)}}\right) \quad (16)$$

where $P_{B_1}$ is the error probability of the bits in the $i$th primary packet and the instantaneous SNR $\gamma_{1_k}^{(k)} = \frac{|h_{1_k}|^2}{\sigma_n^2}$, $A_1 = \sqrt{\alpha} - \sqrt{1 - \alpha}$ and $A_2 = \sqrt{\alpha} + \sqrt{1 - \alpha}$.

Unlike $Pr(\hat{x}_1)$, $Pr(\hat{x}_2)$ depends on the detection process of $x_1$ where

$$Pr(\hat{x}_2) = Pr(\hat{x}_2|x_1) Pr(\hat{x}_1) + Pr(\hat{x}_2|x_1) Pr(\hat{x}_1) \quad (17)$$

here, $Pr(\hat{x}_2|x_1)$ denotes the probability of $x_2$ being dropped, given that $x_1$ has already been dropped. This probability can be computed using both (15) and (16), as the individual bit error probabilities of $x_1$ and $x_2$ in this case are identical because $x_1$ will be initially the primary, and when it is dropped, $x_2$ becomes the primary. On the other hand, $Pr(\hat{x}_2|x_1)$ represents the probability of $x_2$ being dropped given that $x_1$ is correctly detected. This scenario is distinct because $x_2$ is received over multiple transmissions as both a primary and a secondary packet. Therefore,

$$Pr(\hat{x}_2|x_1) = \prod_{i=1}^{l} \int \int \int \Pr(\hat{x}_i) Pr(\beta_{i,k}) d\beta_{i,k}$$

The number of times $x_2$ is transmitted as a secondary packet is random. For example, it is transmitted once as a secondary packet if $x_1$ is correctly detected during its first transmission as a primary packet. Conversely, $x_2$ can be transmitted $L$ times as a secondary packet if $x_1$ undergoes $L$ transmissions before being successfully detected. On the other hand, $x_2$ must undergo $L$ transmissions when transmitted as a primary packet before it is considered as dropped. The probability that $x_2$ is received incorrectly after being transmitted as a secondary packet for $\ell$ times is given by

$$Pr(\hat{x}_{2,\ell}^{(0)}) = \prod_{i=1}^{l} Pr\left(\hat{x}_{2,\ell}^{(0)}\right)$$

$$= \prod_{i=1}^{l} \left[1 - \left(1 - P_{B_2}^{(l)}\right)^{B}\right]. \quad (19)$$

where $P_{B_2}$ is the bit error probability in the $j$th secondary packet. With a correct SIC, $P_{B_2}^{(l)}$ can be written as $[55]$.

$$P_{B_2}^{(l)} = \left[Q\left(\sqrt{(1 - \alpha) \sum_{k=1}^{l} \gamma_{2_k}^{(k)}}\right)\right]. \quad (20)$$

If $x_2$ is not detected correctly while being transmitted as a secondary packet, it will be retransmitted as a primary packet. It will only be dropped if all detection attempts fail across $L$ transmissions. Therefore, to increase the likelihood of correct detection, the receiver must combine the secondary and primary versions of $x_2$,

$$C\{y_{1,1}, y_{1,2}, \ldots, y_{1,\ell}, y_{2,\ell+1}, y_{2,\ell+2}, \ldots, y_{2,L+\ell}\}, \quad 1 \leq \ell \leq L. \quad (21)$$

However, $\gamma$ corresponds to an OMA signal, where $x_1$ is correctly detected after its $\ell$th transmission. This is then subtracted from the received NOMA signals $y_{1,1}, \ldots, y_{1,\ell}$ to obtain OMA signals $\tilde{y}_{1,1,1}, \ldots, \tilde{y}_{1,1,\ell}$. On the other hand, $y_{2,\ell+1}, y_{2,\ell+2}, \ldots, y_{2,L+\ell}$ corresponds to a NOMA signal. Hence, computing the exact probability of packet error becomes intractable. Therefore, to simplify the analysis, we consider combining only the transmissions where $x_2$ appears as a primary packet, i.e., we combine the signals

$$C\{y_{1,1}, y_{1,2}, \ldots, \tilde{y}_{1,\ell}, y_{2,\ell+1}, y_{2,\ell+2}, \ldots, y_{2,L+\ell}\}. \quad (22)$$

By adopting this approach, the calculated probability becomes an upper bound for the actual probability of packet error. Therefore, $Pr\left(\hat{x}_{2,\ell+k}\right)$ can be calculated using (15) and (16).

The same method can be applied to derive $Pr\left(\hat{x}_i\right)$ for $i = 3, 4, \ldots, M$. This will demonstrate that $Pr(\hat{x}_i)$ depends on the probabilities $Pr(\hat{x}_{i-1}), Pr(\hat{x}_{i-2}), \ldots, Pr(\hat{x}_1)$. By noting that all expressions are conditioned on channel gain $|h_i^{(i)}| = \beta_i^{(i)}$, we can average over the probability density functions (PDFs) of the channels’ gains,

$$\overline{P}_D = \frac{1}{M} \sum_{i=1}^{M} \sum_{p=1}^{L} \int \cdots \int Pr(\hat{x}_i) f_{\beta_{i,k}}(\beta_{i,k}) Pr(\beta_{i,k}) d\beta_{i,k} \quad (22)$$

where $\beta_{r,k}$ is the $k$th set of all channel gains associated with packet $x_r$, which is a random set that depends on the detection process and channel gains of all transmissions of packet $x_{r-1}$. For example, for $L = 2$, $\beta_{2,1} = \{\beta_1^{(1)}, \beta_2^{(1)}, \beta_2^{(2)}\}, \beta_{2,2} = \{\beta_1^{(1)}, \beta_2^{(2)}, \beta_1^{(1)}, \beta_2^{(2)}\}, \beta_{2,3} = \{\beta_2^{(1)}, \beta_2^{(2)}\}$. The PDF of the set of gains is referred to as $f_{\beta_{r,k}}$. Consequently, the analytical evaluation of (22) is intractable and thus will be evaluated using Monte Carlo simulation.
B. Packet Drop Probability with IIC Round Robin

With IIC, the analysis should start at the end and work backward due to the nature of the recovery process. For the last packet \( x_{M} \), the packet drop probability, \( \Pr (x_{M}) \), is similar to that in conventional NOMA, since the last packet cannot be repaired. The drop probability of \( x_{M-1} \) is given as,

\[
\Pr (x_{M-1}) = \Pr (x_{M-1} | x_{M}) \Pr (x_{M}) + \Pr (x_{M-1} | \bar{x}_{M}) \Pr (\bar{x}_{M})
\]

(23)

where \( \Pr (x_{M-1} | x_{M}) \) is equal to \( \Pr (x_{M-1}) \) in conventional NOMA. However, \( \Pr (x_{M-1} | \bar{x}_{M}) \) depends on the detection result of \( x_{M-2} \). Consequently, it can be expressed as

\[
\Pr (x_{M-1} | \bar{x}_{M}, \bar{x}_{M-2}) = \prod_{i=1}^{L} \Pr (x_{M-1, i}^{(i)} | x_{M-2})
\]

(24)

Similarly, \( \Pr (x_{M-1} | x_{M}, \bar{x}_{M-2}) \) is given in (25), where \( P_{B2}^{(i)} \) corresponds to the error probability where \( x_{M-1} \) is a secondary packet and \( x_{M-2} \) is detected correctly. The values \( \Pr (x_{M-1, 1}^{(0)}) \) correspond to OMA signals and can be computed similar to that in (19). As evident from (25), the assumption of separately combining primary and secondary packets is applied. Moreover, it is worth noting that \( \Pr (x_{i}) \) depends on all instances \( \Pr (x_{j}) \) for \( j \neq i \). This is a deviation from the NOMA case, where \( \Pr (x_{i}) \) is only dependent on \( \Pr (x_{j}) \) for \( j < i \).

Based on (25), we can conclude that packet correlation makes the analysis intractable. This is because it necessitates considering a large number of transmission scenarios, each with its unique probability. As an example, Fig. 3 shows the transmission flow diagram for a simple case where \( L = 1 \) and \( M = 4 \). As observed from the figure, the probability of a packet being permanently dropped depends on the complete path from the start to the end. To establish a benchmark for comparison, we consider the OMA scenario, where all packets are independent, free from interference with each other, and transmitted with full power. Consequently, all packets exhibit a similar drop probability, given as

\[
\Pr (x_{i}) = \Pr (x_{1}^{(1)}) \Pr (x_{2}^{(2)}) = \prod_{\ell=1}^{L} \left[ 1 - P_{B1}^{(\ell)} \right]^{B}
\]

(26)

where \( P_{B1}^{(\ell)} \) is given in (16).

C. Complexity Analysis and Convergence of IIC Algorithm

To evaluate the system’s complexity, this subsection will focus on the worst-case time complexity and convergence of the proposed IIC algorithm. The complexity is expressed using the big \( O \) notation [56].

Because the operations \( d_{1} \) and \( d_{2} \) incur constant costs, they are not included in the global complexity analysis. The worst-case complexity corresponds to the case where only the last packet is correctly received and all dropped packets are correctly recovered. This implies that there would be \( LM - 1 \) entries in the drop buffer, with \( L \) being a constant. Furthermore, in the worst-case scenario assumed, the while loop between steps 12-21 will be executed \( M - 1 \) times. The loop encompasses the \( L \) sequence extractions and the \( d_{1} \) and \( d_{2} \) operations, all of which are fixed-cost operations. Generally, fixed-cost operations are omitted in big \( O \) complexity analysis. Therefore, the complexity of the proposed algorithm can be expressed as \( O(M - 1) \), which approximates to \( O(M) \) and indicates a linear complexity.

V. Numerical Results

This section presents the performance evaluation of the proposed IIC scheme in terms of PDR, number of recovered packets, and buffer occupancy. The results are obtained for values of SNR ranging from 0 to 35 dB, maximum allowed transmissions per packet \( L \in \{1, 2, 3\} \), and power coefficient \( \alpha \in \{0.6, 0.7, 0.8, 0.9\} \). The channel is modeled as a block Rayleigh fading and the information bits are modulated using BPSK. The Monte Carlo simulation is generated using \( 2^{16} = 65,536 \) packets each of which has 128 bits. In the proposed IIC, a packet is considered dropped if it fails the CRC after being transmitted as a primary packet for \( L \) transmissions and the IIC technique fails to recover it.

Fig. 4 to Fig. 7 compare the system PDR with and without IIC using various values of \( \alpha \) and \( L \). Moreover, the theoretical results for the NOMA and OMA are also included for comparison purposes. As can be seen from the figures, the PDR improves significantly for all values of \( \alpha \) and \( L \). For example, in Fig. 4 with \( \alpha = 0.6 \) and \( L = 3 \), PDR improves approximately 15 dB at PDR of \( 10^{-4} \). In Fig. 6, for \( \alpha = 0.8 \), which is the near-optimum power allocation to maximize throughput [23], the improvement is about 6 dB. The PDR difference between IIC and NOMA versus \( L \) is generally small, where roughly the same performance difference is observed for all the values considered of \( L \). It can also be seen that the efficiency of the proposed IIC is more significant at low values of \( \alpha \), which is due to the fact that interference from secondary packets is more severe in such scenarios. Therefore, applying IIC would cause significant SINR improvement. The upper bound derived for NOMA appears to be tight for low and moderate values of \( \alpha \) and high values of SNR. The bound becomes slightly loose for \( \alpha = 0.9 \). The performance of OMA opposes the behavior of the NOMA upper bound. For example, when \( \alpha = 0.6 \), the interference of NOMA is significant and IIC cannot recover all dropped packets. At high values of \( \alpha \), orthogonal multiplexing (OM) and IIC-RR offer approximately the same performance. Consequently, PDR of OMA can be considered as an approximate lower bound for IIC.

Fig. 8 shows the actual number of packets that were repaired and recovered after exceeding the maximum number of permitted transmissions and being dropped by the transmitter. The presented results in the figure were obtained by considering the total number of packets to be transmitted \( M = 16,384 \) packets, and the results are averaged over four realizations.
\[
\Pr (\mathbf{x}_{M-1}|\mathbf{y}_{M}, \mathbf{x}_{M-2}) = \prod_{i=1}^{\ell} \Pr (\mathbf{x}_{M-1,i}) \prod_{j=1}^{L} \Pr (\mathbf{x}_{M-1,t+j}) \\
= \prod_{i=1}^{\ell} \left[ 1 - \left( 1 - P_{B_2}^{(i)} \right)^B \right] \prod_{j=1}^{L} \left[ 1 - \left( 1 - P_{B_1}^{(j)} \right)^B \right]
\] (25)

Fig. 3: Transmission state diagram that shows all possible transmission/reception scenarios where \( L = 1 \) and \( M = 4 \). The packet in the bottom corresponds to the primary packet.

As can be noted from the figure, the proposed IIC approach can effectively repair and recover a significant portion of the dropped packets, particularly for low values of \( \alpha \) and high \( L \) values. For example, the IIC scheme managed to recover about 12,000 packets at SNR = 12 dB, \( \alpha = 0.6 \), and \( L = 3 \). Given that the PDR for the considered scenario is about 0.9, it implies that the proposed IIC scheme managed to recover about 80% of the dropped packets. Decreasing the value of \( L \) increases the probability that certain packets will be permanently dropped due to the loss of correlation at multiple positions in the buffered sequences. Increasing the value of \( \alpha \) reduces the interference caused by the secondary packets, and thus, a smaller number of packets can be recovered. For example, for \( \alpha = 0.7 \) and \( L = 3 \), the maximum number of packets that was recovered is about 7,500 at SNR of 10 dB. By considering that \( PDR = 0.7 \) at the considered SNR, then the IIC managed to recover about 65% of the dropped packet,
which is a tangible ratio. At very low SNRs, most packets will be dropped, and hence, the IIC process will not be applied, and most initially dropped packets will be permanently dropped. At high SNRs, the number of dropped packets is small, and thus, most initially dropped packets can be recovered using the IIC. Therefore, the recovery ratio may increase to 100%.

Figs. 9 and 10 show the buffering requirements of the proposed IIC for $\alpha = 0.8$ and 0.9, respectively, and for $L = [1, 2, 3]$. The figures show the maximum and average buffer occupancy. The maximum buffer occupancy can be used as an indicator for the drop buffer capacity requirements, and the average buffer occupancy can be used to indicate the IIC average delay. As can be noted from Fig. 9, the buffer occupancy at SNR = 0 dB and $L = 1$ is about 4,500 packets, which is quite large. Nevertheless, no reliable communications can be performed at such low SNRs, and we usually have $L > 1$. Therefore, the design can consider the case of SNR $\geq 2$ dB and $L = 3$, which implies that the buffer size should be about 500 packets. Unlike the maximum occupancy, the average is generally much smaller, and it can be less than 100 packets for $L = 3$. The same trends can be also observed in Fig. 10. However, the buffering requirements and delay are much smaller because the primary packet has high power, and the interference is weaker. In such cases, the receiver can either recover or permanently drop the buffered packets. Overall, although the delay is relatively high at low SNRs, practical communications systems require SNR $\gg 0$ dB to offer reliable performance. Moreover, the proposed IIC is proposed for delay-tolerant applications. Therefore, the system should be able to tolerate such delays.

VI. CONCLUSION AND FUTURE WORK

In conclusion, this study introduced an innovative approach for enhancing the reliability of data transmission in NOMA-based backhauling communications. The devised scheme com-
prises two key components: RR power allocation and an IIC process aimed at minimizing packet drop rates without escalating the maximum number of transmissions for the ARQ. The RR power allocation ensures equitable distribution among users, even in the absence of IoG-IoT channel information, fostering fairness in communication.

The IIC scheme was meticulously designed to harness correlations within received sequences, enabling the repair and recovery of initially discarded packets. These packets, rejected during the CRC process, were efficiently salvaged by the IIC process. Consequently, this strategy significantly bolstered the reliability of received data without necessitating additional spectrum utilization or heightened power consumption.

System performance was comprehensively evaluated using metrics such as PDR, buffer occupancy, and the number of recovered packets. The results demonstrated the effectiveness of the proposed RR-IIC scheme, achieving a remarkable 100% recovery of dropped packets and a noteworthy improvement in PDR under specific scenarios.

Looking ahead, our future endeavors will extend the applicability of the proposed IIC scheme to scenarios featuring adaptive systems with a larger number of users. This extension introduces challenges related to the varying and time-sensitive nature of multiplexed packets in each transmission. The IIC design will need to adapt to diverse correlation patterns, and careful evaluation of buffering requirements will be imperative to prevent overflow, especially as correlated received sequences are anticipated to be longer in scenarios with a larger number of users. This forward-looking perspective underscores the ongoing commitment to advancing the proposed scheme in the dynamic landscape of NOMA-based communications.

APPENDIX I: PROOF

To simplify the discussion, we consider that \( i = 1 \) in (3) and the modulation is BPSK. Moreover, since \( a = c = 1 \) in \( x_{a,b}^{(c)} \), we drop the variables \( a \) and \( c \), hence \( x_{a,b}^{(c)} \rightarrow x_a \) where \( a \in \{1, 2\} \). The same assumptions are applied to the power coefficients, and hence they are denoted as \( \alpha_1 \) and \( \alpha_2 \). Given that the primary packet \( x_1 \) failed the CRC implies that the SIC failed for at least one symbol out of the \( K \) possible symbols in \( x_1 \). By noting that all symbols in \( x_1 \) have equal probability of error, and the error events are independent, then the probability that \( x_2 \) fails the CRC depends on the number of detection errors in \( \hat{x}_1 \) rather than the actual error pattern. Therefore,

\[
\Pr(\hat{x}_2 \neq x_2 | \hat{x}_1 \neq x_1) = \sum_{k=1}^{K} \Pr(\hat{x}_2 \neq x_2 | \hat{x}_1 \neq x_1, \lambda = k) \times \Pr(\lambda = k) = 1 - Pr_{B_1}, \quad \frac{(K)}{K!} \frac{P_{B_1}}{1 - Pr_{C_1}} (28)
\]

where \( P_{C_1} = 1 - Pr_{B_1}, \quad \frac{(K)}{K!} \frac{P_{B_1}}{1 - Pr_{C_1}} \) and

\[
Pr(\hat{x}_2 \neq x_2 | \hat{x}_1 \neq x_1, \lambda = k) = 1 \left(1 - Pr_{B_2}\right)^{K-\lambda}, \quad \frac{P_{B_1}}{1 - Pr_{C_1}} \)

where \( Pr_{B_1} = Pr(\hat{x}_1, i \neq x_1, \lambda = k) \), which is given in (16). Therefore,

\[
Pr(\hat{x}_2 \neq x_2 | \hat{x}_1 \neq x_1, \lambda = k) = 1 - \left[\left(1 - Pr_{B_2}\right)^{K-\lambda}\left(1 - Pr_{B_2}\right)^{\lambda}\right], \quad 1 \leq \lambda \leq K(29)
\]

The same assumptions are applied to the \( \hat{x}_1 \) and \( \hat{x}_2 \) cases that should be considered separately. The two cases should be considered due to symmetry. The two cases are anticipated to be longer in scenarios with a larger number of users. This forward-looking perspective underscores the ongoing commitment to advancing the proposed scheme in the dynamic landscape of NOMA-based communications.

APPENDIX II: ACRONYMS
5G 5th generation.
6G 6th generation.
ACK acknowledgment.
ARQ automatic repeat request.
AWGN additive white Gaussian noise.
B5G beyond 5G.
BER bit error rate.
BPSK binary phase shift keying.
BS base station.
CC Chase combining.
CFR channel frequency response.
CRC cyclic redundancy check.
CSI channel state information.
DL downlink.
EE energy efficiency.
HARQ hybrid-ARQ.
i.i.d. independent and identically distributed.
IC interference cancellation.
ICIC iterative interference cancellation.
IoD IoT device.
IoG IoT gateway.
IoT Internet of things.
IR incremental redundancy.
MLD maximum likelihood detection.
MRC maximum ratio combining.
MS master server.
NACK negative acknowledgment.
NOMA non-orthogonal multiplexing.
OM orthogonal multiplexing.
PDF probability density function.
PDR packet drop rate.
PER packet error rate.
PSK phase shift keying.
QAM quadrature amplitude modulation.
QoS quality of service.
RR round-robin.
SIC successive interference cancellation.
SNR signal to noise ratio.
SW stop-and-wait.
UAV unmanned aerial vehicle.
UL uplink.
URLLC ultra reliable low latency communications.
WSN wireless sensor network.
\(x\) Incorrectly detected packet
\(\gamma\) Instantaneous SNR
\(\hat{x}\) Estimated version of \(x\)
\(d\) CC of the received sequences with the same primary packet
\(s\) Transmitted NOMA packet
\(w\) AWGN vector
\(x\) Transmitted data packet
\(y\) Received NOMA sequence
\(A\) Drop buffer
\(B\) Number of bits per packet
\(\check{x}\) Dropped packet
\(\tilde{y}\) Received sequence after SIC
\(h\) Channel response
\(p\) Transmission power

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APPENDIX III: LIST OF SYMBOLS

\(K\) Number of symbols per packet
\(L\) Maximum number of transmissions per packet
\(M\) Total number of transmitted packets
\(N\) Number of combined packets per transmission slot
\(P'_D\) Average packet drop probability
\(P_B\) Bit error rate (BER) of the packet
\(\check{x}\) Correctly detected packet
\(\alpha\) Power allocated for the primary packet


