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Shared Hybrid ARQ With Incremental Redundancy (SHARQ IR) in Overloaded MIMO Systems to Support Energy-Efficient Transmissions

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ABSTRACT Multiple Input and Multiple Output is a technology through which data are transmitted over the channel through multiple antennas. However, during its deployment and implementation, some pragmatic issues arise such as interference, multipath fading and noise leading to potential packet losses and consume substantial energy. To address such issues, Hybrid ARQ transmissions provide effective means for error correction, especially in a noisy wireless channel. More often few bits in packets are found to be in error and it is unnecessary to use the entire MIMO channel for retransmission to correct these errors. Hence, this paper proposes a novel approach, i.e., Shared Hybrid ARQ (SHARQ IR) using the piggyback technique in an overloaded MIMO system where the transmitting antennas are more than the receiving antennas. Additionally, the concept of a simple retransmission method is used to transform an overloaded MIMO system into either the critically loaded or under loaded MIMO systems. Simulation results outperform the contemporary approaches through reduced BER and 20% throughput gain. Such improvements have the potential to support energy-efficient transmissions for encouraging green IoT applications.

INDEX TERMS Multiuser detection, MIMO, SHARQ, BER, incremental redundancy, the Internet of Things (IoT).

I. INTRODUCTION

Enabling Ultra-Low Latency is crucial for industry 4.0 Smart Cities Applications within the domain of the Internet of Things (IoT). Due to limited energy and resources of IoT devices, such applications demand high data rates, excessive bandwidth and near real-time connections and most importantly energy-efficient transmissions [1]–[3]. To fulfill these requirements, fifth-generation (5G) technologies have been launched. The road to 5G runs through 4G wireless infrastructure and improvements to 4G technologies such as massive multiple input and multiple output (MIMO) [4] and beam-forming are promising technologies that will achieve high data rates as required in 5G. MIMO system, due to its substantial capacity and diversity gain, is a key technology practically implemented in wireless standards such as IEEE 802.11n WLAN [5], IEEE 802.16 WiMAX [6] and Long-Term Evolution (LTE) [7]. In recent years, researchers have addressed several MIMO challenges especially in the massive overloaded system along with the standard implementations [8]–[11]. However, there are some issues related to MIMO systems such as performance and complexity, especially in the overloaded scenario, i.e., $N_t > N_r$.

Generally, two techniques are used in MIMO detection: Linear detection and Non-linear detection. Zero forcing (ZF) and Minimum Mean Square Error (MMSE) comes under the category of linear detection techniques. In [12] efficiency improvement method for the implementation of ZF and MMSE has been discussed in MIMO but their performance severely degrades in overloaded systems. On the other hand, non-linear MIMO detection relies on Maximum likelihood detection ML. ZF and MMSE performance degrade much in

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an overloaded MIMO system [13] while ML is an optimal detection scheme that performs well [14]. However, during its implementation, increasing the users results in more computational power for data processing. Moreover, in an overloaded MIMO system, Multi-Users Detection (MUD) is yet another challenging task that requires a trade-off between performance and complexity. Furthermore, the existence of Co-channel interference (CCI) due to the presence of multi-users greatly debase the performance of MUD algorithms especially in overloaded scenarios [15]. To cater to such issues, especially in overloaded conditions, several other sub-optimal detection techniques [14], [16]–[18] have been proposed. Unfortunately, a large size MIMO system deployed with hundreds of antennas contributes to increased complexity exponentially. Hence, they are not viable for deployment in real-time scenarios.

To increase the reliability of communication and reduce the computational complexity, various Hybrid Automatic Repeat Request (HARQ) schemes have been used in numerous wireless standards such as LTE. Different versions of HARQ schemes are available such as HARQ chase combining (HARQ CC) and HARQ incremental redundancy (HARQ IR). With HARQ CC [19], the same versions of packets are transmitted during retransmission and at the receiving end; the receiver then combines all the packets. In HARQ IR scheme [20], for each retransmission, the transmitter incrementally sends only redundant bits for successful decoding. This increases reliability as incremental bits are transmitted only on a requirement basis. Moreover, most of the time few bits in a packet are found to be erroneous, hence, simply retransmitting the redundant bits results in bandwidth efficiency. Further to improve the bandwidth efficiency of the MIMO channel, Shared ARQ transmission (SHARQ) is used. Here, failed data packets are combined with new data packets during retransmission using MIMO diversity. Similarly, Zahid *et al.* [21] have considered an overloaded MIMO system ($N_t > N_r$) and have used two different schemes to convert this system to either critically loaded ($N_t = N_r$) or to underloaded ($N_t < N_r$) MIMO systems by combining all retransmitted packets using HARQ CC [19].

Zahid *et al.* [21] have used the concept of HARQ CC on received stacked vector and considered it as a virtual receiver antenna [22]. In this paper, a different approach has been proposed by implementing SHARQ IR in an overloaded MIMO system and extended this concept to fully utilize the channel resources. Here, the fail data packet is combined with a new data packet and shares the same MIMO diversity channel over the physical layer. This gives an added advantage of achieving better BER and throughput compared to the already implemented scheme using HARQ CC (as underlined by the simulation). Secondly, the proposed approach has an added advantage of improved performance in poor channel conditions, where in addition to redundant bits' retransmission, new data packets are transmitted as well; that makes it a strong candidate for LTE and 5G communication standards.

This proposed approach is an extension of our approach proposed in [23]. In [23], correctly decodable users remain idle during the next retransmission. However, to further improve wireless channel utility and improve BER and throughput, SHARQ IR is implemented by retransmitting the redundant bits along with the transmission of new bits for correctly decodable users. The proposed scheme is compared with conventional HARQ using simulation and 20% improvement in throughput is observed with reduced BER.

The rest of the paper is structured as follows. In Section II, an allied study that is carried out in the field of MIMO has been reviewed, followed by the system model in Section III. Section IV furnishes the proposed technique and Section V presents the simulation results by considering various parameters for BER and throughput analyses. Section VI concludes the work while highlighting potential research directions.

II. RELATED STUDY

The foremost algorithms proposed for the detection of multi-users in MIMO systems have been the Diagonal Bell laboratories layered space-time (D-BLAST) and V-BLAST but D-BLAST algorithm is more intricate as compared to V-BLAST. V-BLAST provides optimum performance for multiple users but during detection, it leads to performance degradation by not considering the channel estimation error. Secondly, V–BLAST algorithm [24], due to its singularity nature [16], fails in an overloaded MIMO system and results in more errors during the detection process. Numerous optimum and sub-optimum techniques have also been proposed for MIMO detection. The optimal techniques like ZF and MMSE, due to their low complexity and simplicity for implementation, make them strong candidates for MIMO detection. However, the performance of these schemes degrades drastically in overloaded MIMO systems [13]. Furthermore, the implementation of such schemes in overloaded MIMO systems results in more computational complexity ultimately resulting in increased errors at high Signal to Noise Ratio (SNR). The ultimate focus of this paper is to transform an overloaded MIMO system to a critically loaded or under loaded MIMO system through simple retransmission and used a novel scheme Share Hybrid ARQ schemes in conjunction with MIMO system to enhance the throughput and spectral efficiency.

Hybrid ARQ transmission schemes are proposed in MIMO systems for enhancement in throughput [25]. This approach uses the Forward-Error Correction (FEC) technique [26] for error detection and correction. It is observed that HARQ IR protocol is more active for error correction compared to simple HARQ, and chase combining HARQ CC [19]. In [27], a linear precoder has been considered and joint HARQ detection has been carried out by combining all the stacked received vectors. However, only critically loaded conditions have been used in [27].

Although MIMO systems offer high spectral efficiency and diversity gain, they are more immune to channel noise and interference. While encountering channel distortion and

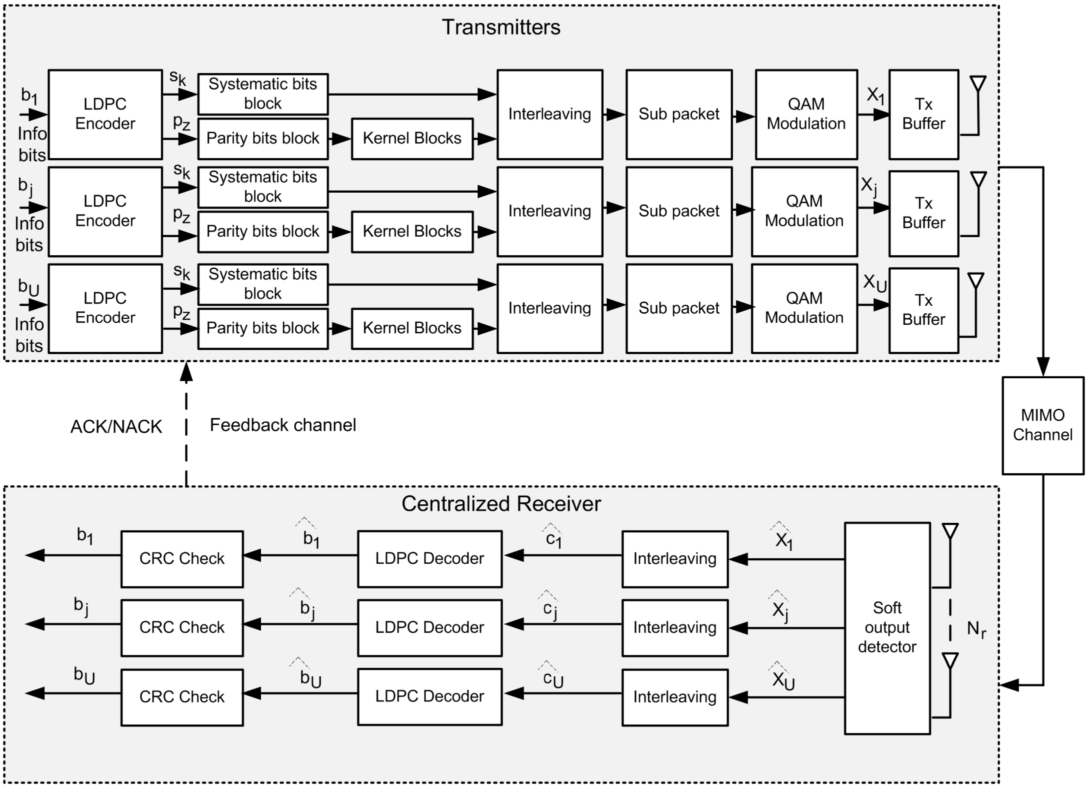

FIGURE 1. **SHARQ IR MIMO architecture.**

fading, MIMO transmission often leads to packet loss. Moreover, most of the techniques focus on the retransmission keeping in view to fully utilizing the MIMO channel. However, only a few bits may be erroneous in the whole packet. Hence, it is not efficient to reuse the entire MIMO channel for the same packet retransmission. It is therefore of great motivation to investigate how to fully utilize channel efficiency by employing SHARQ IR in an overloaded MIMO system.

III. SYSTEM MODEL

We have considered 'U' users for an overloaded MIMO communication system, 'N_t' as transmit antennas and 'N_r' receive antennas. The correlation between the transmitted signal and receive signal vector for 'N' transmission is given by:

$$\boldsymbol{y}_i = \boldsymbol{H}_i + \boldsymbol{x}_i + \boldsymbol{n}_i, \tag{1}$$

where $i = 1, 2, \ldots\ldots N$.

Here, $\boldsymbol{y}_i$ is the $N_r \ x \ 1$ received signal vector, $\boldsymbol{H}_i$ is the $N_r \ x \ N_t$ channel matrix and $\boldsymbol{n}_i$ is the $N_r \ x \ 1$ AWGN noise at time i respectively. The wireless channel unveils quasi-static, frequency-flat Rayleigh fading. The architecture of SHARQ IR employed in this paper is shown in Fig. 1.

The system model uses some information 'K' bits, which comprises of the data bits and CRC bits for error detection. Low-Density Parity Check (LDPC) encodes the data bits at the rate of $R_c = K/N$. The rate at which the transmitted bits are encoded is referred to as *mother code* and generate a code packet. This is further classified into systematic S and parity P blocks. There are classified kernel blocks in the systematic and parity blocks, which have changed priorities to each other. The kernel blocks are classified in relation to the order in which the data bits are transmitted. There is a block-wise generation for systematic bits and parity bits. Encoded packet C is described as follow:

$$\boldsymbol{C} = \{\boldsymbol{S}; \boldsymbol{P}\} = \{\boldsymbol{s_0}, \boldsymbol{s_1}, \boldsymbol{s_2}, \ldots, \boldsymbol{s_k}; \boldsymbol{p_0}, \boldsymbol{p_1}, \boldsymbol{p_2}, \ldots \boldsymbol{p_z}\}, \tag{2}$$

where $s_0, s_1, s_2, \ldots s_k$ are systematic bits of k^{th} order and $p_0, p_1, p_2, \ldots p_z$ are parity bits of z^{th} order.

Parity bit blocks are included in k^{th} kernel block set Ψk, $(k = 1, 2 \ldots 5)$ are given as follows:

1st kernel blocks $= \Psi 1 = \{P\ B1\}$; $P\ B1$ is the parity bits in Block 1

2nd kernel blocks $= \Psi 2 = \{P\ B2\}$; $P\ B2$ is the parity bits in Block 2

3rd kernel blocks $= \Psi 3 = \{P\ B3\}$; $P\ B3$ is the parity bits in Block 3

4th kernel blocks: $= \Psi 4 = \{P\ B4\}$; $P\ B4$ is the parity bits in Block 4

5th kernel blocks: $= \Psi 5 = \{P\ B5\}$; $P\ B5$ is the parity bits in Block 5

There is a shuffling of parity bits in each block. If the receiver detects that a packet contains an error, a negative ACK will be sent to the transmitter requesting for the 1^{st} kernel block. If the packet is still in error, the second negative ACK will be sent to the sender asking for sending of 2^{nd} kernel block and this procedure will be endured till the retransmission of the last 5^{th} kernel block. After the last kernel block, i.e., 5th kernel block, the packet is now considered as a dropped packet.

The shuffled coded bits and parity bits are then forwarded to the inter-leaver to generate a sub-packet. Here, both the *shuffled coded bits* and *priority bits* are concatenated to form coded bits. The coded bits are then modulated by QAM modulation. The wireless channel after adding noise or interference will forward it to the receiver. The receiver employs two different schemes for detection purposes. One is Joint Maximum Likelihood (JML) and the second one is Suboptimal MMSE detection.

Joint Maximum Likelihood detection is a technique used in the MIMO system to minimize the probability of error at the receiver end and is given by:

$$L\left(c_p^u\right) = log\left(\frac{(P[c_p^u = 1|\boldsymbol{y}, \boldsymbol{H}])}{P[c_p^u = 0|\boldsymbol{y}, \boldsymbol{H}]}\right), \tag{3}$$

where $u = 1, 2, 3, \ldots\ldots. U$,

$$L\left(c_p^u\right) = log\left(\frac{\sum_{x\in X_p^1} \exp\left(-\frac{1}{\sigma_v^2}||\boldsymbol{y} - \boldsymbol{Hx}||^2\right)}{\sum_{x\in X_p^0} \exp\left(-\frac{1}{\sigma_v^2}||\boldsymbol{y} - \boldsymbol{Hx}||^2\right)}\right), \tag{4}$$

Applying log approximation [25] to the above equation results in:

$$L\left(c_p^u\right) = \frac{1}{\sigma_v^2}\left(min_{x\in X_p^0}||\boldsymbol{y} - \boldsymbol{Hx}||^2 - min_{\boldsymbol{x}\in X_p^1}||\boldsymbol{y} - \boldsymbol{Hx}||^2\right), \tag{5}$$

However, equation (5) is difficult to implement due to its complexity.

The MMSE linear detector has low intricacy and shows acceptable performance. The received signal is given by:

$$\hat{X}_{MMSE} = (\boldsymbol{H}^{\boldsymbol{H}}\boldsymbol{H} + \sigma_v^2\boldsymbol{I})^{-1}\boldsymbol{H}^{\boldsymbol{H}}\boldsymbol{y}, \tag{6}$$

where $\boldsymbol{I}$ is the identity matrix. The MMSE based detector [24], output is given by:

$$L\left(c_p^u, j\right) = \frac{1}{\sigma_{j,u}^2}\left(min_{x\in X_p^0}\left|\left|x_{j^u} - x\right|\right|^2 - min_{x\in X_p^1}\left|\left|x_{j^u} - x\right|\right|^2\right), \tag{7}$$

where $j = 1, 2, 3 \ldots\ldots. N_t^u$.

The resulting soft detector is passed to bit de-interleavers and then to the channel decoders for each user. CRC mechanism is considered at the receiver end for error detection. The feedback channel is anticipated to be acting like free of errors for sending positive ACK and negative ACK to the transmitter in case of any packet success or failure, respectively.

IV. PROPOSED TECHNIQUE

In the proposed technique, SHARQ IR protocol has been used in an overloaded MIMO system with LDPC encoder using multiple retransmission techniques. Here, a user is encoded by LDPC mother code at the transmitter end. Initially, few encoded bits are transmitted over the channel and decoding is attempted at the receiver end. When packet errors occur, negative ACK is conveyed to the transmitter through the feedback channel. During re-transmission, there is no need to use the entire wireless channel; only additional redundant information bits are transmitted incrementally to correct the erroneous bits in the erroneous data packet along with the transmission of a new data packet. It implies that new data and failed data packets are now combined over the MIMO channel for the effective utilization of bandwidth.

At the receiver, after JML detection or MMSE detection, LDPC performs the decoding of received packets. For simplicity at the receiver combining side, we keep the same modulation and the same coding scheme for each re-transmission.

Using equation (1), the received signal vector at the g^{th} (re)transmission is given by equation (8) as:

$$\boldsymbol{y}(g) = \boldsymbol{H}(g)\,\boldsymbol{x}(g) + \boldsymbol{v}(g), \tag{8}$$

where g is the retransmission counter and ranges from $1, 2, \ldots G$ and G the total retransmission number.

Similarly, the combined received vectors [27] after G (re)transmissions can be written as:

$$= \begin{bmatrix} \boldsymbol{y}(1) \\ \boldsymbol{y}(2) \\ . \\ . \\ \boldsymbol{y}(G) \end{bmatrix} = \begin{bmatrix} \boldsymbol{H}(1) \\ \boldsymbol{H}(2) \\ . \\ . \\ \boldsymbol{H}(G) \end{bmatrix} \boldsymbol{x} + \begin{bmatrix} \boldsymbol{v}(1) \\ \boldsymbol{v}(2) \\ . \\ . \\ \boldsymbol{v}(G) \end{bmatrix}. \tag{9}$$

The pseudo-code of the proposed procedure is given in algorithm 1 and is explained as follows:

At time $t = 1$, all users will transmit their data. Here, after checking CRC in the first transmission, all those columns in $\boldsymbol{H}$ matrix representing the correctly decoded users are set to zeros. The received signal using the modified $\boldsymbol{H}$ matrix is given by:

$$\tilde{\boldsymbol{y}}(1) = \tilde{\boldsymbol{H}}(1)\,\boldsymbol{x}(1) + \boldsymbol{v}(1). \tag{10}$$

Secondly, the interval parity bits of erroneous users are retransmitted along with a new message. It means that they contain both new and retransmitted information. At the receiver end, both the signal vectors are stacked, as shown by equation (11):

$$r = \begin{bmatrix} \tilde{y}(1) \\ y(2) \end{bmatrix} \tag{11}$$

This process continues until the correction of all data bits or the maximum number of G (retransmission) is received. The packet is treated as lost if decoding fails and the maximum G is reached.

V. SIMULATION RESULTS

Simulation results are evaluated by considering 2 and 4 uplinks in the MIMO architecture. It means that to properly evaluate the performance of our simulations, we have considered two scenarios with 2 and 4 transmitters respectively. Performance evaluation has been carried out with different receiver combinations. The packet is considered to contain 576 bits encoded at a rate of 1/2 LDPC code using

Algorithm 1 SHARQ IR

```
1.  Initialize: $g = 1$, $¥ = 0$ and $€ = 0$
      g = no of iterations of retransmission, ¥ = set of users
      whose data packets are decoded correctly and
      € = set of users whose data packets are decoded
      with error
2.  Generate H submatrix and perform detection on
      matrix received $\mathbf{y}$ (1).
3.  Calculation of CRC for each data packet
4.  Update g, ¥, € and $\Psi$ where $\Psi$ is a set of parity
      bits in kernel block
5.  Repeat the process till last kernel block, i.e., $\Psi 5$
      is transmitted
6.  Each user belonging to set € will retransmit its packet
      whereas those users belonging to set ¥ will
      transmit a new data packet in the next time interval
7.  If $€ \neq 0$ then update $g = g + 1$ and transmit the
      first kernel block $\Psi 1$
8.  Received signal matrix $\mathbf{y}$ are then stacked with the
      previously received matrices
9.  Perform MUD on the resulting matrix to obtain LLR
      and calculate CRC for each decoded packet
10. Update ¥ and €
11. If $g = G$ and $¥ \neq \emptyset$ then consider that packet as
      a dropped packet
12. All users will transmit a new packet
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16-QAM modulations. G is 4, i.e., the maximum number of retransmission after which packet is considered as dropped packet. The performance of SHARQ IR is evaluated in comparison with simple HARQ CC using BER and throughput as performance parameters using JML and MMSE detection techniques.

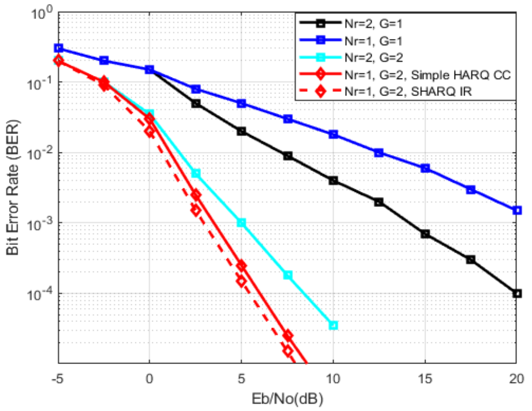

FIGURE 2. BER comparison of SHARQ IR and HARQ CC using JML detection with $N_t = 2$.

As shown in Fig. 2 and 3, a simple critically loaded MIMO system 2×2 ($N_t = 2$, $N_r = 2$) and 2×1 overloaded MIMO system ($N_t = 2$, $N_r = 1$) MIMO system with optimal JML detection and MMSE detection is evaluated in terms of BER and SNR (Eb/No(dB)).

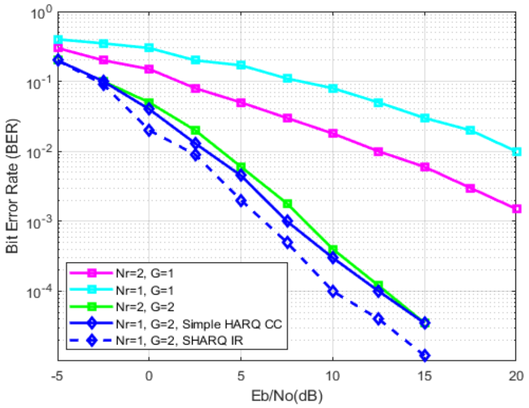

FIGURE 3. BER comparison of SHARQ IR and HARQ CC using MMSE detection with $N_t = 2$.

As shown in Fig. 2, the critically loaded system (2×2) with $G = 1$, performs better than overloaded system (2×1) with same number of retransmission, i.e., $G = 1$. This improved performance is due to the fact that in-spite of same number of retransmission, the critically loaded system has the higher diversity order as compared to overloaded system. Moreover, as the number of retransmission increases with $G = 2$, BER improves with an increase in Eb/No (dB). Similarly, significant improvement in the performance is observed when compared SHARQ IR with that of simple HARQ CC. This performance is evaluated by considering 2×1 overloaded MIMO system with the same number of retransmission, $G = 2$. Similarly, by deploying MMSE detection as shown in Fig. 3, SHARQ IR performs better in contrast to HARQ CC for the same configuration. SHARQ IR outperforms because bits are retransmitted incrementally along with the transmission of new data until the packet is decoded correctly by the receiver.

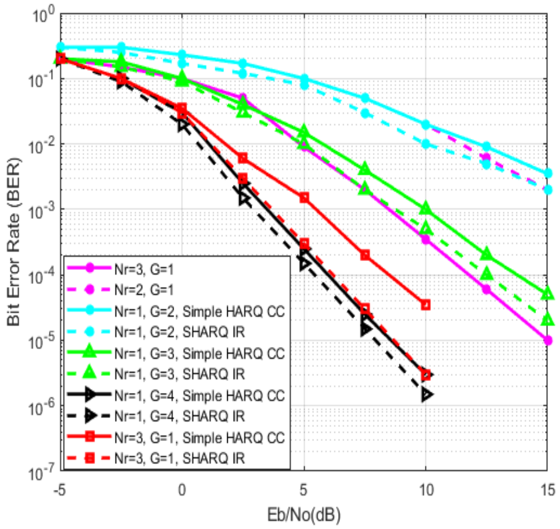

FIGURE 4. BER comparison of SHARQ IR and HARQ CC using JML detection with $N_t = 4$.

Moreover in Fig. 4, the BER vs SNR (Eb/No (dB)) performance for an overloaded MIMO system ($N_t = 4$, i.e., four transmitters) and multiple combinations of receivers using JML detection is shown. The result clearly shows that SHARQ IR outperforms HARQ CC when G, i.e., the number of retransmission increases. BER for the SHARQ IR is still better even when new bits are retransmitting in the next time slot. For example, at $G = 2$ and SNR of 10 dB, BER of SHARQ IR is 0.01 whereas BER of simple HARQ CC is 0.015, which means BER of SHARQ IR is better than simple HARQ CC by a factor of 0.005 using JML detection. Similarly, further increasing the number of retransmission, i.e., at $G = 4$ and SNR of 10 dB, SHARQ IR results in BER of 1.25 whereas simple HARQ CC results in 1.99, i.e., further improvement by a factor of 0.74 is observed. Here, it is important to reiterate that cumulating G means increasing sending the new packets with the erroneous data. Similarly, by comparing it with different combinations of receivers, i.e., $N_r = 3$ with $G = 1$ using the SHARQ IR technique, it performs better than $N_r = 1$ using $G = 2$. As the product of $N_r\ x\ G$ for 3×1 MIMO system using $G = 1$ provides higher diversity as compared to $N_r = 1$ with $G = 2$ using the same number of transmitters which is equal to 4. Also by comparing 4×3 MIMO system using $G = 1$ with 4×1 system that uses $G = 4$, the factor of $N_r\ x\ G$ is better than 4×3 system due to which substantial performance gain is observed as shown in Fig. 3.

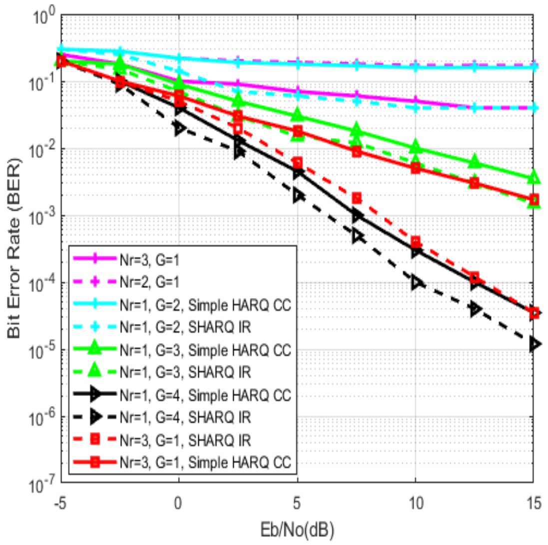

FIGURE 5. **BER comparison of SHARQ IR and HARQ CC using MMSE detection with $N_t = 4$.**

In Fig. 5, SHARQ IR is evaluated and BER vs SNR (Eb/No (dB)) performance for an overloaded MIMO system ($N_t = 4$), i.e., four transmitters and a different arrangement of receivers using MMSE detection are presented. In this scenario, SHARQ IR performs better than simple HARQ CC for each transmission. As illustrated at SNR of 10 dB and $G = 2$, BER of SHARQ IR is 0.010 while that for simple HARQ CC BER is 0.015. It is important to highlight that in this overloaded MIMO system, the proposed scheme's performance increases with the increase of G, i.e., the number of retransmission. This is because the scheme allows transforming the overloaded system to either critically loaded or under loaded MIMO system using a sufficient number of retransmissions. However, throughput gain is affected by increasing the number of retransmissions. Similarly, a higher value of G means more number of retransmissions and more cancellation of correctly decoded packets. This results in increasing SINR and permitting to apply MMSE during overloaded conditions. Also by evaluating the different combinations of receivers, e.g., 4×1 overloaded MIMO system with $G = 4$ performs better than 4×3 with $G = 1$ system as an increase in the number of G means more cancellation of correctly decoded users and increase in the number of the retransmitted packet with the erroneous data.

The vital role of this paper is to improve throughput under the channel condition when it is noisy. It is given by equation (12) as:

$$\delta = \frac{\log_2 \omega R(1 - P_{rate})}{N_{avg}} \mathrm{B/s/Hz}, \tag{12}$$

where N_{avg} is the maximum number of retransmission, P_{rate} is drop packet rate and R is the code rate.

In the simulation, it is evaluated that SHARQ IR throughput is high as compared to simple HARQ CC, as shown in Fig. 6 and Fig. 7.

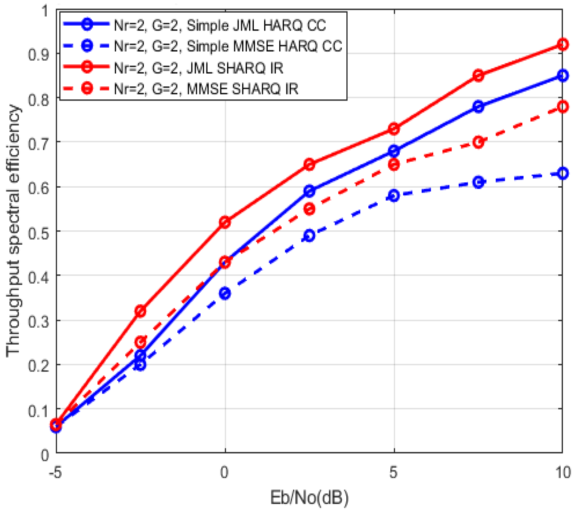

FIGURE 6. **Throughput comparison of SHARQ IR and HARQ CC when $N_r = 2$ and $G = 2$.**

Fig. 6 shows the throughput comparison of SHARQ IR with simple HARQ CC when $G = 2$ and $N_r = 2$. As shown, SHARQ IR throughput is enhanced in comparison to simple HARQ CC. For example, at SNR of 10 dB, the throughput of SHARQ IR is 0.92 whereas throughput of simple HARQ CC is 0.85 using JML detection. Similarly, for MMSE detection, at SNR of 10 dB, the throughput of 0.78 is achieved for SHARQ IR as compared to the throughput of simple HARQ CC, which is 0.62.

Throughput is also evaluated for $G = 4$ and $N_r = 1$ as shown in Fig. 7. As illustrated, during JML detection at SNR of 10 dB, the throughput of SHARQ IR is 0.68 whereas throughput of simple HARQ CC is 0.48. Moreover, for

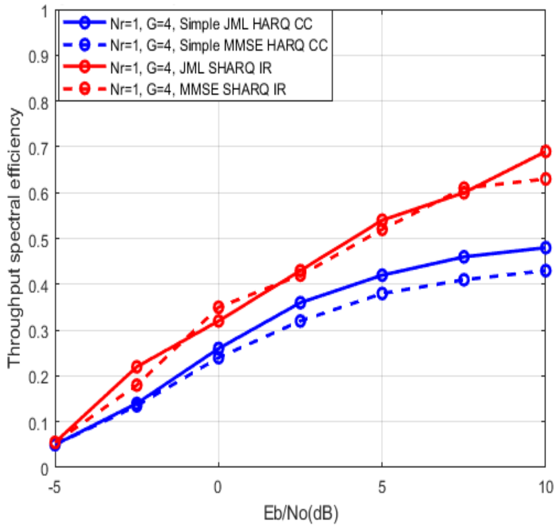

FIGURE 7. **Throughput comparison of SHARQ IR and HARQ CC when $N_r = 1$ and $G = 4$.**

MMSE at SNR of 10 dB, the throughput of 0.64 is achieved for SHARQ IR as compared to simple HARQ CC, which is 0.44. It means an increase of 20% in throughput is achieved when we increase the number of retransmissions. This enhanced performance of SHARQ IR than contemporary to simple HARQ CC is due to its capability to adapt itself to error correction under the varying channel conditions. SHARQ IR is sending the parity bits incrementally along with the new data bits during each (re)transmission.

VI. CONCLUSION

In this paper, a scheme named as SHARQ IR is proposed that utilises piggyback technique in overloaded MIMO systems using the concept of simple retransmission method and multi-users detection to transform an overloaded MIMO system into critically loaded or under loaded MIMO system.

Improved results both in terms of BER and throughput are achieved with the proposed scheme without adding complexity to the overall system. Moreover, this approach conserves bandwidth by combining both data and parity bits along the wireless channel which envisaged to support energy-efficient transmissions for green IoT applications.

A thorough analysis to understand the pros and cons of the proposed scheme and its implementation in the IoT model is a part of our ongoing research.

REFERENCES

[1] M. Saadi, M. T. Noor, A. Imran, W. T. Toor, S. Mumtaz, and L. Wuttisittikulkij, "IoT enabled quality of experience measurement for next generation networks in smart cities," *Sustain. Cities Soc.*, vol. 60, Sep. 2020, Art. no. 102266.

[2] M. A. da Cruz, J. J. Rodrigues, G. F. Gomes, P. Almeida, R. A. Rabelo, N. Kumar, and S. Mumtaz, "An IoT-Based Solution for Smart Parking," in *Proc. 1st Int. Conf. Comput., Commun. Cyber-Sec. (IC S)*. Singapore: Springer, 2019, pp. 213–224.

[3] T. Taleb, S. Dutta, A. Ksentini, M. Iqbal, and H. Flinck, "Mobile edge computing potential in making cities smarter," *IEEE Commun. Mag.*, vol. 55, no. 3, pp. 38–43, Mar. 2017.

[4] E. G. Larsson and L. Van der Perre, "Massive MIMO for 5G," *IEEE 5G Tech Focus*, vol. 1, no. 1, pp. 1–4, Mar. 2017.

[5] M. Uthansakul and P. Uthansakul, "Experiments with a low-profile beamforming MIMO system for WLAN applications," *IEEE Antennas Propag. Mag.*, vol. 53, no. 6, pp. 56–69, Dec. 2011.

[6] T. S. Siadari, S.-Y. Shin, and F. P. Rezha, "Applied MIMO based on Hadamard transform in IEEE 802.16 WiMAX system," in *Proc. IET Int. Conf. Inf. Commun. Technol. (IETICT)*, Apr. 2013, pp. 582–586.

[7] B. Badic, R. Balraj, T. Scholand, Z. Bai, and S. Iwelski, "Impact of feedback and user pairing schemes on receiver performance in MU-MIMO LTE systems," in *Proc. IEEE Wireless Commun. Netw. Conf. (WCNC)*, Apr. 2012, pp. 399–403.

[8] S. Takabe, M. Imanishi, T. Wadayama, R. Hayakawa, and K. Hayashi, "Trainable projected gradient detector for massive overloaded MIMO channels: Data-driven tuning approach," *IEEE Access*, vol. 7, pp. 93326–93338, 2019.

[9] R. Hayakawa and K. Hayashi, "Convex optimization-based signal detection for massive overloaded MIMO systems," *IEEE Trans. Wireless Commun.*, vol. 16, no. 11, pp. 7080–7091, Nov. 2017.

[10] H. Matsuoka, Y. Doi, T. Yabe, and Y. Sanada, "Open-loop correlation reduction precoding in overloaded MIMO-OFDM systems," *IEICE Trans. Commun.*, vol. E99.B, no. 1, pp. 202–210, 2016.

[11] Y. Nin, H. Matsuoka, and Y. Sanada, "Performance comparison of overloaded MIMO system with and without antenna selection," *IEICE Trans. Commun.*, vol. E100.B, no. 5, pp. 762–770, 2017.

[12] N. V. Apanasenko, A. A. Burkov, and A. M. Turlikov, "Performance analysis of ZF and MMSE algorithms for MIMO systems," in *Proc. Wave Electron. Appl. Inf. Telecommun. Syst. (WECONF)*, Saint Petersburg, Russia, Nov. 2018, pp. 1–4.

[13] L. Bai and J. Choi, *Low Complexity MIMO Detection*. Springer, 2012.

[14] M. Krause, D. P. Taylor, and P. A. Martin, "List-based group-wise symbol detection for multiple signal communications," *IEEE Trans. Wireless Commun.*, vol. 10, no. 5, pp. 1636–1644, May 2011.

[15] S. Sugiura, S. Chen, and L. Hanzo, "MIMO-aided near-capacity turbo transceivers: Taxonomy and performance versus complexity," *IEEE Commun. Surveys Tuts.*, vol. 14, no. 2, pp. 421–442, 2nd Quart., 2012.

[16] B. W. Zarikoff, J. K. Cavers, and S. Bavarian, "An iterative groupwise multiuser detector for overloaded MIMO applications," *IEEE Trans. Wireless Commun.*, vol. 6, no. 2, pp. 443–447, Feb. 2007.

[17] K. T. Tasneem, P. A. Martin, and D. P. Taylor, "Iterative soft detection of cochannel signals using ant colony optimization," in *Proc. IEEE 23rd Int. Symp. Pers., Indoor Mobile Radio Commun. (PIMRC)*, Sep. 2012, pp. 1617–1621.

[18] K. Obaidullah and Y. Miyanaga, "Efficient algorithm with lognormal distributions for overloaded MIMO wireless system," in *Proc. Asia–Pacific IEEE Sig. Inf. Process. Assoc. Annu. Summit Conf. (APSIPA ASC)*, Dec. 2012, pp. 1–4.

[19] D. Chase, "Code combining–a maximum-likelihood decoding approach for combining an arbitrary number of noisy packets," *IEEE Trans. Commun.*, vol. 33, no. 5, pp. 385–393, May 1985.

[20] Y. Wu and S. Xu, "Energy-efficient multi-user resource management with IR-HARQ," in *Proc. IEEE 75th Veh. Technol. Conf. (VTC Spring)*, May 2012, pp. 1–5.

[21] Z. Rauf, P. A. Martin, and D. P. Taylor, "Multiuser detection of overloaded systems employing HARQ," in *Proc. IEEE Int. Conf. Commun. Syst. (ICCS)*, Nov. 2012, pp. 300–304.

[22] D. M. Rankin, D. P. Taylor, and P. A. Martin, "Improved information outage rate in certain MIMO systems," *IEEE Signal Process. Lett.*, vol. 13, no. 7, pp. 393–396, Jul. 2006.

[23] M. Kashif, Z. Ullah, M. Iqbal, L. Musavian, S. Sarwar, X. Wang, S. Mumtaz, Z. Ul-Qayyum, and H. M. Safyan, "Multiuser detection using hybrid ARQ with incremental redundancy in overloaded MIMO systems," in *Proc. Int. Conf. Collaborative Comput., Netw., Apps Worksharing (CollaborateCom)*. Cham, Switzerland: Springer, Aug. 2019, pp. 642–653.

[24] S. Zhang, C. Nie, L. Lu, S. Zhang, and G. Qian, "MIMO physical layer network coding based on VBLAST detection," in *Proc. Int. Conf. Wireless Commun. Signal Process. (WCSP)*, Oct. 2012, pp. 1–5.

[25] E. N. Onggosanusi, A. G. Dabak, Y. Hui, and G. Jeong, "Hybrid ARQ transmission and combining for MIMO systems," in *Proc. IEEE Int. Conf. Commun. (ICC)*, Anchorage, AK, USA, May 2003, pp. 3205–3209.

[26] S. Lin and D. J. Costello, Jr., *Error Control Coding*, 2nd ed. Upper Saddle River, NJ, USA: Prentice-Hall, 2004.

[27] X. Liang, C. Zhao, and Z. Ding, "Sequential linear MIMO precoder optimization for hybrid ARQ retransmission of QAM signals," *IEEE Commun. Lett.*, vol. 15, no. 9, pp. 913–915, Sep. 2011.

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