A Low-Complexity Interference Cancellation Approach for NOMA

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***Abstract*— Non-orthogonal multiple access (NOMA) has been studied during the standardization of the new radio (NR), fifth generation (5G) of mobile communications systems. It has been shown that NOMA could potentially offer a robust performance in highly interfered scenarios. Despite the observed capacity gain and performance, the issue of NOMA receiver complexity may remain as a potential impediment to adoption of NOMA. The proposed advanced receivers for NOMA are more complex than regular interference cancellation receivers used in base stations. A typical advanced receiver for NOMA is composed of a core multi user detector (MUD) and a forward error correction (FEC) decoder that iteratively attempts to estimate and suppress multi-user interference. At each iteration, interference from previously decoded users are reconstructed and cancelled allowing remaining users to be successfully decoded. Among the proposed advanced receivers for NOMA, receivers using expectation propagation algorithm (EPA) has attracted much attention due its high performance. However, high complexity of such iterative decoding architectures has shadowed their performance and capability. In this paper, we investigate the performance of a simplified version of such iterative MUD receiver such as EPA receiver. According to our evaluations, the simplified receiver can maintain a similar performance as the original EPA receiver for packets with low code rates in both low and high interference environment. In case of packets with a higher code rate, the performance is only marginally degraded.**

***Index Terms*—Wireless, 5G, New Radio, Non-orthogonal multiple access, NOMA, EPA, MPA, SCMA, interference cancellation, iterative receiver.**

I. Introduction

Due to its promising merits, non-orthogonal multiple access (NOMA) transmission has received a significant level of interest recently [1-7]. NOMA is considered among the main features of the 5th generation of mobile communications systems [8]. The 3rd generation partnership project (3GPP) has been studying NOMA since the initial 5G NR R-14 study phase [9], where it was considered as a potential uplink transmission scheme [10]. The study evaluated different NOMA schemes for the uplink where multiple user equipment (UE) are multiplexed onto the same time-frequency resources. This study was concluded with some initial results captured in [11]. For 5G NR R-16, a more in-depth study item was completed [5], where thorough link-level and system-level evaluations were performed. Details on the different NOMA schemes such as transmit/receive signal processing, operational procedures and evaluation methodologies/metrics are summarized in [9].

In NR, NOMA has been studied for all three 5G use cases namely, massive machine type communication (mMTC), ultra-reliable low-latency communication (URLLC), and enhanced mobile broadband (eMBB) [8]. Each of these use cases are intended for different applications, thus each demands a set of different requirements. For example, low power consumption and high connection density are key performance indicators (KPIs) for mMTC, while URLLC applications demand low latency and high mobility. eMBB demands a range of requirements including high peak data rates, high spectrum and energy efficiency, and high area traffic capacity [5]. NOMA has shown significant potential to adapt as a solution to cater all these use cases.

Studying receiver complexity was one of the main component of 3GPP NOMA study item for NR. The aim was to identify low-complexity and low-cost receivers that harvest NOMA gains without adding excessive processing latency. By its design the NOMA air interface is not completely orthogonal. This allows more users to concurrently access the same time-frequency resources giving significant capacity gains but results in residual interference between the UEs. Therefore, NOMA receivers should be able to separate each UE's signal from the sum interference of rest of the UEs. To this end a family of turbo-like iterative multi-user interference cancellation (IC) receivers [12] have been proposed. These receivers decode users in multiple successive attempts with the help of a multi-user detector (MUD), forward error correction (FEC) [13], and IC. Minimum mean square error (MMSE), expectation propagation algorithm (EPA) [14, 15], elementary signal estimator (ESE) [16] are some of the popular MUDs. As multiple iterations are used, the overall complexity of the receiver depends on the complexity of each module as well as the number of iterations required. In general, for interference cancellation at each iteration, interference from the previously decoded user(s) are computed and cancelled. To this end, better performance can be achieved if the interference is hard cancelled. However, this typically leads to a higher complexity, and it requires additional hardware.

Among the proposed advanced receivers for NOMA, EPA has attracted much attention due its high flexibility and performance [14]. However, its highly complex architecture has somehow prevented its widespread use. Therefore, in this paper our focus is on a simplified implementation of EPA. We propose an alternative approach which enables the core MUD to perform interference estimation and cancellation at a lower complexity.

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Furthermore, since hard interference cancellation is not required, decoding latency is also improved.

The remainder of the paper is organized as follows. In Section II, different iterative interference cancellation approaches for NOMA are discussed. The proposed low complexity EPA approach is presented in Section III. In Section IV, we present link-level simulation results and highlight the capabilities of this new IC approach. Sections V concludes the paper.

II. Iterative Interference Cancellation Receiver for NOMA

In an iterative NOMA receiver, at each decoding iteration, the receiver attempts to decode at least one or multiple users. The former approach is often referred to as serial- or successive-interference cancellation (SIC), while the latter approach is known as parallel interference cancellation (PIC) [12].

SIC: Typically, the IC process is performed by ordering users (hence referred to as 'ordered SIC') based on their signal-to-interference-plus-noise ratio (SINR). The idea is to exploit the near-far-effect among users, which make the SINRs of different users' imbalanced. If the first user is decoded successfully, interference from this user is computed and removed from the received signal before attempting to decode the next user. This process is continued until all the users are decoded, or an unsuccessful decoding attempt is met. Another common implementation of SIC is enhanced SIC, which is similar to the ordered SIC except when a decoding attempt fails, the receiver attempts to decode the next user in the order. Also, the decoding order is revised each time a UE is decoded successfully. This process is continued until all the users are decoded or no additional user can be decoded.

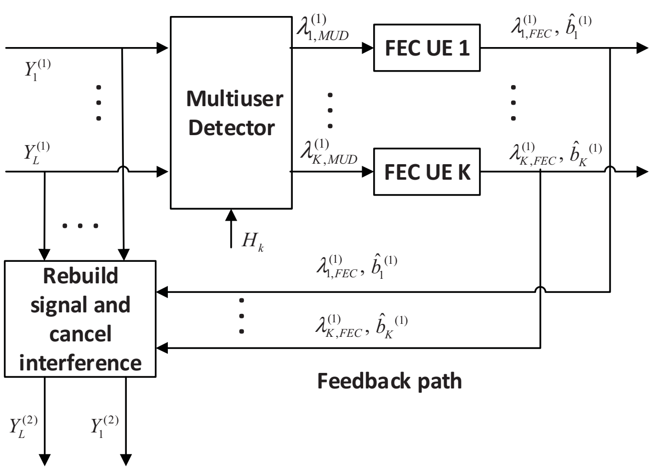

Figure 1: Basic architecture of parallel interference cancellation NOMA receiver

PIC: In PIC, the decoder attempts to decode all the users simultaneously. Compared to SIC, the decoding latency is lower as multiple users can be decoded in each attempt. A variant of PIC is to consider a subset of users in each decoding attempt, which is referred to as group PIC.

The basic architecture of PIC receiver is shown in Figure 1. In the ith attempt, the MUD calculates the posteriori log-likelihood ratios (LLRs) $\lambda_{k,MUD}^{(i)}, k \in \{1, 2, \ldots, K\}$, based on the received signal $Y_l^{(i)}, l \in \{1, 2, \ldots, L\}$. Here K is the total number of users/layers and L is the number of antennas at the receiver. Typically, MUD should also be given the channel estimates $H_k, k \in \{1, 2, \ldots, K\}$, noise variance, modulation scheme. Subsequently, $\lambda_{k,MUD}^{(i)}$ is used by FEC to calculate extrinsic LLRs $\lambda_{k,FEC}^{(i)}$ and decoded bits $\hat{b}_k^{(i)}$. In practice CRC is performed on $\lambda_{k,FEC}^{(i)}$ to test if users were correctly decoded. Next decoded bits $\hat{b}_k^{(i)}, k \in \mathcal{D}^{(i)}$ and/or FEC output bit LLRs $\lambda_{k,FEC}^{(i)}$ are used to compute and cancel the interference from $\mathcal{D}^{(i)}$, where $\mathcal{D}^{(i)}$ denotes the successfully decoded UEs in all previous iterations. This gives the effective received signal $Y_l^{(i+1)}$ for the $i+1$th decoding attempt. This process is continued iteratively until all the users are correctly received or terminated after a fixed number of iterations. The number of iterative decoding attempts required to successfully receive all the users is highly dependent on the number of UEs/layers using the same time-frequency resources, code rate, modulation scheme. Typically, 3-5 iterations seem to be sufficient to give an acceptable performance.

Based on how soft information $\lambda_{k,FEC}^{(i)}$ and decoded bits $\hat{b}_k^{(i)}$ from FEC decoders are used for the PIC process, three different approaches can be identified, namely hard PIC, soft PIC, and hybrid PIC.

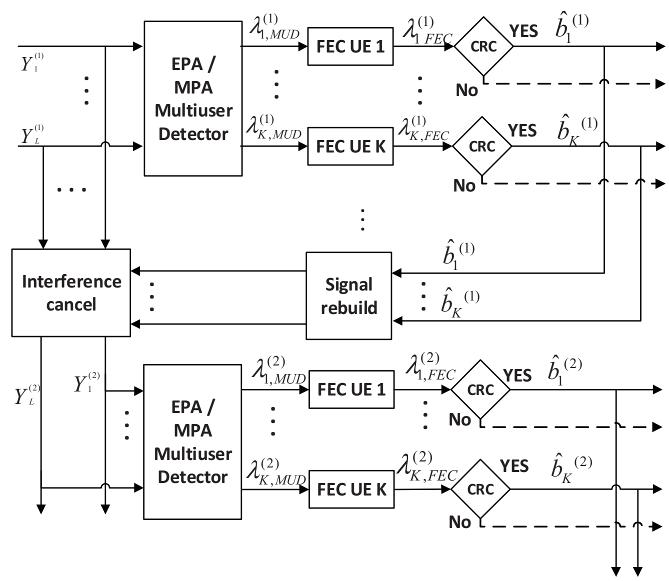

Figure 2: Hard parallel interference cancellation receiver

Hard PIC: In this receiver, FEC will only feedback binary bits $\hat{b}_k, k \in \{\mathcal{D}^{(i)}\}$ of correctly decoded users. Figure 2 shows the basic operation of the hard PIC receiver. At each iteration, the PIC receiver uses decoded bits to estimate, and hard cancel, interference caused by the decoded users/layers. The resulting signal is then used to compute the effective signal for the next decoding iteration. This approach has often a high complexity due to signal reconstruction of the decoded users for cancellation. It is worth to mention that due to signal rebuild step, there are some additional decoding delay.

Soft PIC: The FEC feedback includes all the log likelihood ratios (LLRs) of all users regardless of their decoding status (CRC fails or passes) as shown in Figure 3. This is clearly suboptimal as the LLR of all users, regardless of whether they are decoded successfully, are considered for interference estimation. However, signal reconstruction is not required for the soft PIC receiver which results in less complexity.

Hybrid PIC: Figure 4 shows the basic operations of the hybrid PIC receiver. As the name describes, the foundation of this scheme is based on using both soft and hard interference estimation and cancellation. In this receiver, binary bits of decoded users $\hat{b}_k, k \in \{\mathcal{D}^{(i)}\}$ and soft LLRs of undecoded users $\lambda_{k,FEC}^{(i)}$, $,k \notin \{\mathcal{D}^{(i)}\}$ are used for IC. This approach gives additional performance gains compared to hard PIC due to the addition of soft information from undecoded users in the subsequent IC iteration [12]. Due to the combined use of hard and soft information, a hybrid PIC has a higher performance and a higher complexity compared to both hard and soft PIC receivers.

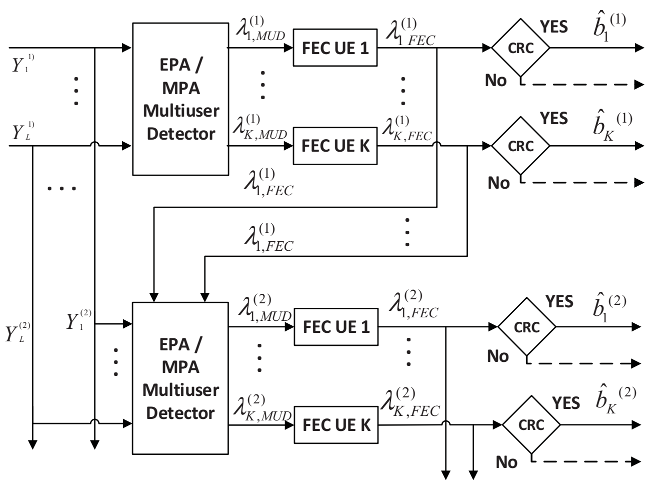

Figure 3: Soft parallel interference cancellation receiver

III. Reduced Complexity Interference Cancellation Receiver

Hard PIC receiver outperforms soft PIC receivers by hard-cancelling interference from users previously decoded at each iteration. To achieve this, a hard PIC receiver requires additional hardware and complex computations compared to the soft PIC receiver. As shown in Figure 4, at each decoding iteration, 'signal rebuild' and 'interference cancel' functions are employed to reconstruct and remove the interference from the received signal . Meanwhile, the soft PIC receiver is simple as it performs IC by only relying on soft LLRs from FEC. In this case, output LLRs from FEC is used as priori likelihood probabilities at the MUD for the next iteration.

The basic operation of the proposed low complexity receiver, that is based on a simple modification of LLR feedback, is shown in Figure 5. In this receiver, LLRs from successfully decoded users are sorted and feedback to the core MUD after modifying LLRs with appropriate values to cancel interference using MUD. In other words, if a user's payload is successfully decoded, all of its associated LLR values are maxed to indicate ultimate confidence of those values in adjusting the LLRs of undecoded users. For example, all positive LLRs can be fixed to 100 and negative LLRs can be fixed to -100. With this modification, the MUD can start the subsequent iterations with appropriate a priori likelihood probabilities. Although this is not as effective as hard cancellation, it enhances interference estimation accuracy and decoding capability at no additional cost.

The MODIFIED FEEDBACK LLR receiver can also be extended to use the soft output LLRs of erroneously decoded users, however we did not observe any significant improvement in the performance.

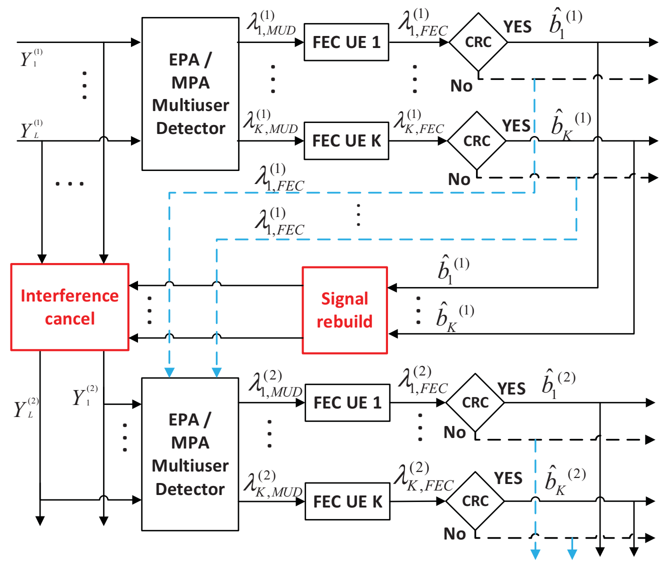

Figure 4: Hard (without dashed blue lines) and hybrid parallel interference cancellation receiver

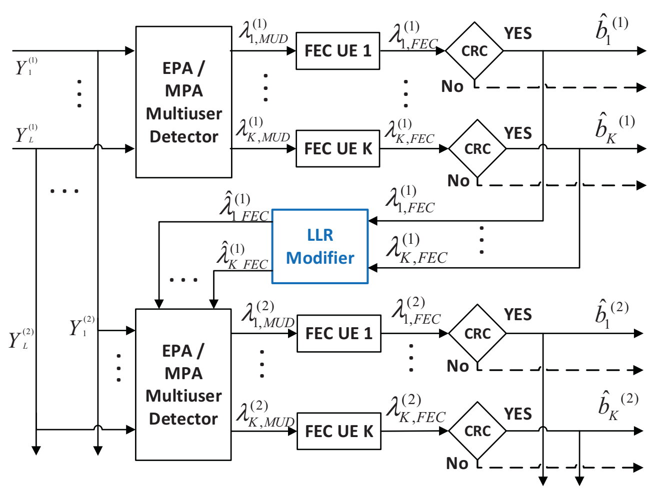

Figure 5: Modified feedback LLR parallel interference cancellation receiver

Table 1: Simulation parameters

Parameter	Values / Assumptions
NOMA scheme	Sparse code multiple access (SCMA) [17]
Carrier frequency	700 MHz
Number of uplink UEs	{6, 12} for TBS20, {6,8} for TBS60
Antenna configuration	1TX-2RX
Waveform	CP-OFDM
Modulation / Codebook	TBS20: 8 points codebook with spreading 4 and 50% sparsity TBS60: 8 point codebook with spreading 4 and 50% sparsity [17]
Propagation channel and UE velocity	TDL-C, 300 ns in TR38.901, 3km/h
Payload Size	20, 60 bytes plus 16 bits CRC
Channel coding	NR Rel-15 LDPC
MUD	EPA with maximum 5 EPA loops
Bandwidth	6 resource blocks (RBs)
Channel estimates	Ideal and NR-DMRS
NR-DMRS overhead	1 every 7 symbols
Power control	Perfect

IV. Evaluation Results

For evaluation, an NR-based uplink NOMA system with K synchronous users is assumed.

Table 1 summarizes the simulation parameters. The SCMA receiver is an EPA-based detector with a fixed 5 iterations [14]. The number of FEC outer loop iterations are limited to 5.

We consider two typical mMTC transport block sizes (TBSs), 20 bytes and 60 bytes in our simulations with different overloading conditions (i.e. number of users concurrently using the same time-frequency resources). The FEC rate is chosen appropriately to match the payload, allocated bandwidth, modulation (codebook), spreading, and demodulation reference signal (DMRS) overhead. Both ideal channel estimates (ICE) and realistic channel estimates (RCE) are considered to show the impact of channel estimation errors on the performance of PIC receivers. The BLER performance of the new PIC scheme is compared against hard PIC receiver. Also, hybrid PIC receiver is included as a reference. Both hard and hybrid PIC receivers require signal re-construction for interference cancellation. Therefore, PIC operation is complex and demand more hardware compared to the proposed modified feedback LLR PIC receiver.

Figures 6 and 7 compare the BLER performance of three PIC receivers, namely, hybrid PIC, hard PIC, and the proposed modified feedback LLR (modified LLR PIC) receiver, considering ICE and RCE respectively. For the evaluation, a low code rate is assumed, therefore the payload size of 20 bytes is selected. As demonstrated in the figures, the performance of the proposed modified feedback LLR PIC matches the performance of the more complex hybrid PIC in both low and high interference scenarios. Furthermore, the above observation holds true in both ICE and RCE conditions.

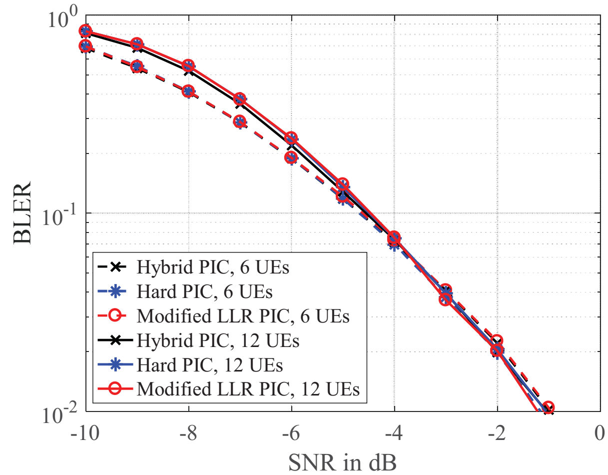

Figure 6. BLER vs SNR in TDL-C, TBS20, ICE, 1Tx2Rx

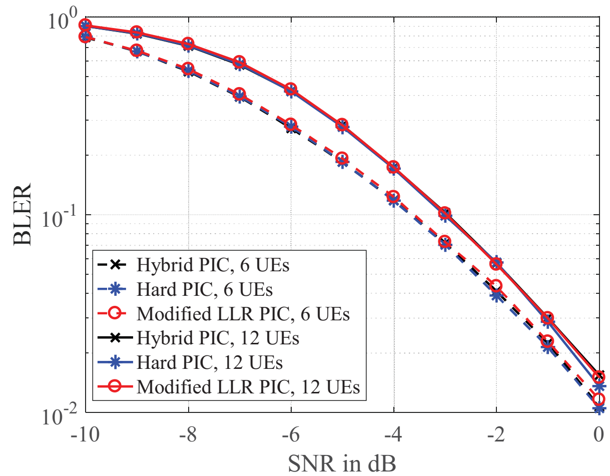

Figure 7. BLER vs SNR in TDL-C, TBS20, RCE, 1Tx2Rx

Figures 8 and 9 demonstrate evaluation results for when a higher code rate is assumed. In both cases, we can observe that the proposed modified feedback LLR PIC receiver yields a very similar performance as the more complex hard PIC receiver in both low and high interference scenarios. This clearly shows effectiveness of the proposed modified feedback LLR PIC receiver.

As shown in Figure 8, under the ICE assumption, a performance gap of 0.25-0.5 dB between the proposed modified feedback LLR PIC receiver and the hybrid PIC receiver can be observed. However, as demonstrated in Figure 9, the performance gap is significantly reduced under RCE assumption. In the case of low interference, the gap is essentially negligible. As for the high interference case, the residual gap of 0.2 dB can be attributed to the reduced capability of the decoder due to use of a higher code rate. Therefore, the iterative interference estimation and cancellation of the proposed modified feedback LLR PIC receiver is not as effective as the case with lower code rate.

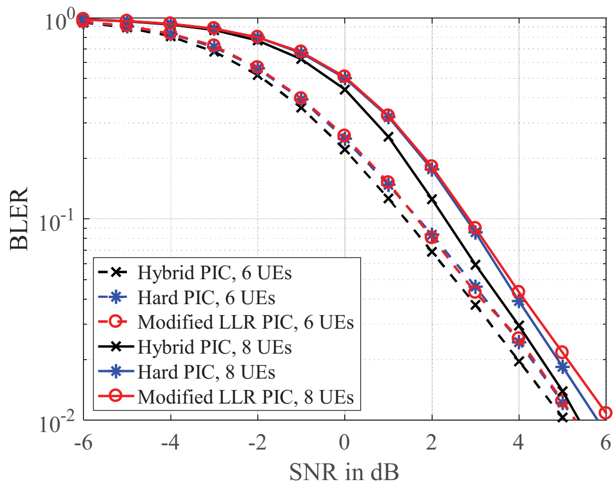

Figure 8. BLER vs SNR in TDL-C, TBS60, ICE, 1Tx2Rx

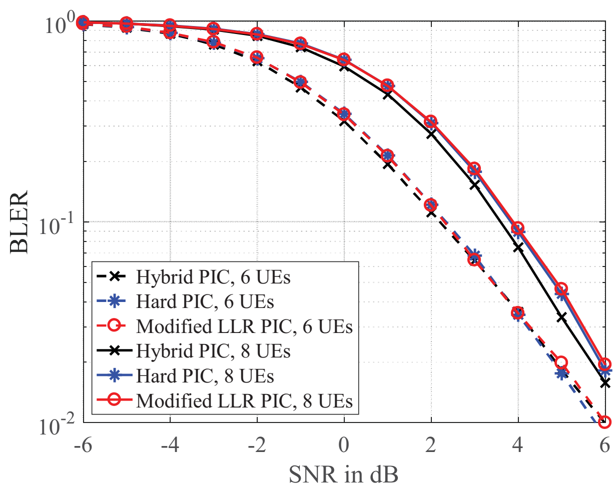

Figure 9. BLER vs SNR in TDL-C, TBS60, RCE, 1Tx2Rx

V. Final Remarks

In this paper, we investigated the performance of a simplified version of an iterative PIC NOMA receiver. The proposed low complexity receiver is based on feedback of modified LLR values of successfully decoded users. For low code rates, as demonstrated by our evaluation results, the performance of the proposed receiver matches the performance of the more complex hybrid PIC in both low and high interference scenarios. For high code rates, real channel estimation reduces the performance gap between the proposed receiver and the hybrid PIC receiver to about 0.2 dB that is observed only in high interference scenario.

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