Polar Coded HARQ Scheme with Chase Combining

Kai Chen, Kai Niu, Zhiqiang He and Jiaru Lin
Key Laboratory of Universal Wireless Communications, Ministry of Education
Beijing University of Posts and Telecommunications, Beijing, China 100876
Email: {kaichen, niukai, hezq, jrlin}@bupt.edu.cn

Abstract—A hybrid automatic repeat request scheme with Chase combing (HARQ-CC) of polar codes is proposed. The existing analysis tools of the underlying rate-compatible punctured polar (RCPP) codes for additive white Gaussian noise (AWGN) channels are extended to Rayleigh fading channels. Then, an approximation bound of the throughput efficiency for the polar coded HARQ-CC scheme is derived. Utilizing this bound, the parameter configurations of the proposed scheme can be optimized. Simulation results show that, the proposed HARQ-CC scheme under a low-complexity SC decoding is only about 1.0dB away from the existing schemes with incremental redundancy (HARQ-IR). Compared with the polar coded HARQ-IR scheme, the proposed HARQ-CC scheme requires less retransmissions and has the advantage of good compatibility to other communication techniques.

Index Terms—Polar codes, hybrid ARQ, rate-compatible coding, successive cancellation decoding.

I. INTRODUCTION

Polar codes are the first structured codes that provably achieve the symmetric capacity of binary-input memoryless channels (BMCs) [1]. Given a BMC \( W \), after performing the channel transform, i.e., the channel combining and channel splitting operations, over a set of independent copies of \( W \), a second set of synthesized channels is obtained. As the transformation size goes to infinity, some of the resulting channels tend to be completely noised, and the others tend to be noise-free, where the fraction of the noise-free channels approaches the symmetric capacity of \( W \). By transmitting free bits over the noiseless channels and sending fixed bits over the others, polar coding with a very large code length \( N \) can achieve the symmetric capacity under a successive cancellation (SC) decoder with both encoding and decoding complexity \( O(N \log N) \).

In delay insensitive communications, hybrid automatic repeat request (HARQ) transmission scheme is widely used to obtain a capacity-approaching throughput efficiency [2], [3], [4], [5]. There are mainly two types of HARQ schemes that are widely considered in practical systems. One is Chase combining (HARQ-CC), where each retransmission block is identical to the original code block; and the other is incremental redundancy (HARQ-IR), where each retransmission consists of new redundancy bits from the channel encoder. In [6], an HARQ-IR scheme based on polar codes is proposed. The throughput performance is claimed to be as good as those based on LDPC and turbo codes with much lower decoding complexity. Obviously, HARQ-IR has the potential of achieving better throughput compared to that with HARQ-CC. However, HARQ-CC will have lower complexity than that with HARQ-IR. That is because the use of IR requires some additional signaling (e.g., the retransmission numbers needs to be communicated to the receiver) and a much larger buffer is needed for IR. Furthermore, since each retransmission is identical, it is much easier for HARQ-CC scheme to combine with other techniques, like coded modulation and space-time coding.

Therefore, this paper focuses on providing a polar coded HARQ-CC scheme. As far as we know, this is the first HARQ-CC scheme based on polar codes. The proposed scheme is applied to both additive white Gaussian noise (AWGN) channel and uncorrelated Rayleigh fast fading channel. Given an information block with \( K \) bits, the key problem of designing an HARQ-CC transmission scheme is to construct a rate-compatible punctured polar (RCPP) code with proper code length \( N \), or equivalently, the code rate \( R = \frac{K}{N} \). The RCPP codes over AWGN channel are well studied in [7]. Given an AWGN channel and a specific RCPP code, the block error rate (BLER) can be accurately predicted under the framework of channel polarization over parallel channels [8].

The code construction and performance evaluation methods of RCPP codes are extended to the Rayleigh fading channels. Utilizing these techniques, the code length \( N \) can be optimized to maximize the throughput of the proposed HARQ scheme.

The remaining sections of the paper are organized as follows. Section II gives a general description of the proposed scheme. Section III reviews the underlying RCPP codes and extends the results to fading channels. Section IV provides the simulation results of the proposed HARQ-CC scheme, and compares it with the existing HARQ-IR scheme based on polar codes, turbo codes and LDPC codes. Finally, Section V concludes the paper.
II. The Proposed Scheme

This section gives an overall description of the proposed polar coded HARQ-CC transmission scheme.

A. Notations

We use calligraphic characters, such as \( \mathcal{X} \), to denote sets. Let \(|\mathcal{X}|\) denote the number of elements in \( \mathcal{X} \). We write lowercase letters (e.g., \( x \)) to denote scalars, bold-face lowercase letters (e.g., \( \mathbf{x} \)) to denote vectors, and \( x_i \) to denote the \( i \)-th element of \( \mathbf{x} \). For any \( i \leq j \), \( x_{ij} \) denotes a subvector of \( \mathbf{x} \), i.e., \( x_{ij} = (x_i, x_{i+1}, \ldots, x_j) \). Throughout this paper, the base of the logarithm is 2.

B. Polar Coded HARQ-CC Transmission

A source block \( \mathbf{u} \) which consists of \( K \) information bits and \( M - K \) frozen bits (usually are set to all-zero bits) is fed into a polar encoder, where \( M \) is the code length of the base code and its value is restricted to some power of 2. The encoded sequence \( \mathbf{v} \) of \( M \) bits is punctured into a punctured codeword \( \mathbf{x} \) of \( N \) bits, \( N \leq M \). The mapping from the \( K \)-length information block to the \( N \)-length codeword is in fact an encoding procedure of a RCPP code \([7]\). The block \( \mathbf{x} \) is buffered and sent over the channel.

At the receiver, the received signals of the \( t \)-th transmission and the corresponding log-likelihood ratios (LLR) are respectively written as \( \mathbf{y}(t) \) and \( \mathbf{r}(t) \), where \( t = 1, 2, \ldots \) denotes the number of transmission trials. The content of the buffer at the receiver is the combined LLRs \( \mathbf{r} \) of the received code bits. After the first transmission, the content of the LLR buffer is initialized as \( \mathbf{r} \leftarrow \mathbf{r}(1) \). The polar decoder tries to perform the decoding process based on \( \mathbf{r} \). If the receiver fails to decode the codeword, i.e., the estimated source block \( \hat{\mathbf{u}} \) is not equal to \( \mathbf{u} \) which can be usually detected by a cyclic redundancy check (CRC) failure, an NACK (negative acknowledgement) is sent to the transmitter through the feedback channel. And then, the \( N \) encoded bits \( \mathbf{x} \) are retransmitted. The new received signals \( \mathbf{y}(2) \) are translated to LLRs \( \mathbf{r}(2) \) and the LLRs of the first two transmission are combined, i.e., the content of the received LLR buffer is updated as \( \mathbf{r} \leftarrow \mathbf{r} + \mathbf{r}(2) \), where the operation \( + \) of two vectors denotes the termwise addition. The polar decoder tries to decode \( \hat{\mathbf{u}} \) according to the updated \( \mathbf{r} \). This process continues until the transmitter receives an ACK (acknowledgement), or a maximum number of permitted transmissions \( T \) is achieved.

A block diagram of the proposed HARQ-CC scheme is shown in Fig. [1].

C. Channel Model

Without loss of generality, only binary phase shift keying (BPSK) is considered in this paper. When transmitting a RCPP codeword \( \mathbf{x} \) over the channel, the receiving signals at the \( t \)-th transmission \( \mathbf{y}(t) \) are as follows:

\[
y_i(t) = a_i(t) \cdot s_i + z_i(t)
\]

where \( t \in \{1, 2, \ldots, T\}, i \in \{1, 2, \ldots, N\}, s_i = 1 - 2x_i \) is the signal after BPSK modulation, \( z_i(t) \) is the Gaussian noise with zero mean and variance \( \sigma^2 \), i.e., \( z_i \sim N(0, \sigma^2) \) and \( a_i(t) \) is the fading factor with average power gain \( E[a_i^2(t)] = 1 \).

During the whole transmission procedure, the noise variance \( \sigma^2 \) of the Gaussian noise is supposed to be constant and is known to both the transmitter and receiver. However, the instant values of \( a_i \) are only available at the receiver, while the transmitter only has a prior knowledge of the probability distribution function (PDF) of the fading factor.

In this paper, the proposed scheme is applied to the transmissions over AWGN channel and uncorrelated Rayleigh fast fading channel.

1) AWGN Channel: When the fading factor \( a_i(t) = 1 \) for all \( i \in \{1, 2, \ldots, N\} \) and \( t \in \{1, 2, \ldots, T\} \), the signal model defined in equation (1) degrades into a transmission over a binary-input AWGN channel. The symmetric capacity of a binary-input AWGN channel \( W \) with noise variance \( \sigma^2 \) is [9]

\[
I_G(\sigma^2) = -\int_{-\infty}^{+\infty} p(y) \cdot \log p(y) dy = \frac{1}{2} \log 2\pi e\sigma^2 \tag{2}
\]

where

\[
p(y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{(y-a)^2}{2\sigma^2}}
\]

2) Uncorrelated Rayleigh Fast Fading Channel: In this scenario, for \( i \in \{1, 2, \ldots, N\} \) and \( t \in \{1, 2, \ldots, T\} \), all the \( a_i(t) \) in (1) are i.i.d. and are with PDF

\[
p(a) = 2a \exp(-a^2) \tag{4}
\]

Given a Rayleigh fast fading channel \( W \) with noise variance \( \sigma^2 \), the ergodic capacity of \( W \) can be calculated as

\[
I_R(\sigma^2) = \int_0^{+\infty} I_G(\sigma^2/a^2) p(a) da \tag{5}
\]

III. RATE-COMPATIBLE PUNCTURED POLAR CODES

The proposed HARQ transmission scheme is based on the RCPP codes introduced in [7].

Similar to constructing a conventional polar code, after performing the channel transform over \( M = 2^{[\log N]} \) independent uses of the original channel \( W \), where \( [\cdot] \) is the ceiling function, we get \( M \) successive uses of synthesized binary-input channels \( W^{(i)}_M \) for \( i = 1, 2, \ldots, M \). Given a symmetric BMC \( W \), let \( a \) denote the probability density function (PDF) of the log-likelihood ratio (LLR) of the received bit when a bit zero is transmitted. The reliability of \( W \) can be measured as the error probability

\[
P_e(W) = \int_{-\infty}^0 a(z)dz \tag{6}
\]

Let \( a^{(i)}_M, i = 1, 2, \ldots, M \) denote the LLR PDFs of the received bit from \( W^{(i)}_M \) when all-zero information bits are transmitted. After calculating \( a^{(i)}_M \) by density evolution (DE) [10], the reliabilities of \( W^{(i)}_M \) are determined by (6). In transmitting a binary information block of \( K \) bits, the \( K \) most reliable
polarized channels $W^{(i)}_M$ with indices $i \in A$ are selected to carry the $K$ information bits, where $A \subset \{1, 2, \cdots, M\}$ and $|A| = K$, and these channels are called information channels; and the others are called frozen channels and are used to transmit a fixed sequence.

Different from the conventional polar codes, $M-N$ output bits of the polar encoder should be punctured when dealing with a RCPP code. Therefore, before performing the channel transform, the underlying channel uses corresponding to these punctured bits should be replaced by virtual channels [8], which have the same input and output alphabets as $W$ but with zero capacities. As for determining the positions of the punctured bits, without loss of generality, the quasi-uniform puncturing scheme in [7] is adopted in this paper which is claimed to be an efficient and empirical good solution. The punctured positions are represented by an $M$-dimensional binary vector $p$ (which is called puncturing pattern), where the 0s indicate the positions of the punctured bits and 1s indicate the positions of the reserved bits. Given the length of base code $M$ and the length of punctured code $N$, the puncturing pattern $p$ can be determined as follows:

Algorithm 1 Determine the Puncturing Pattern [7]
Input: Code length of the base code $M$;
      Code length of the punctured code $N$;
Output: Puncture pattern $p$;
1: Initialize $p$ as a $M$-length all one vector, i.e., for all $i \in \{1, 2, \cdots, M\}$, set $p_i \leftarrow 1$;
2: Set the first $M-N$ elements of $p$ as zeros, i.e., for $i \in \{1, 2, \cdots, M-N\}$, set $p_i \leftarrow 0$;
3: Perform the bit-reversal permutation on $p$.
4: return $p$.

More details of RCPP codes can be found in [7].

Similar to the conventional polar codes [11], RCPP codes can also be decoded using SC decoding algorithm. The BLER of a RCPP code under SC decoding can be evaluated as

$$P_B(N, K, M, A) = \sum_{i \in A} P_e \left( W^{(i)}_M \right)$$  \hspace{1cm} (7)

Note that, the performance of the RCPP codes relies heavily on the puncturing patterns. However, only the puncturing scheme in Algorithm [7] is considered in this paper, and the puncturing pattern $p$ can be uniquely determined by $M$ and $N$. Therefore, $P_B$ in (7) does not involve a $p$ in the parameter list.

In the case of AWGN channel, the BLER performance under SC decoding [7] can be evaluated efficiently by Gaussian approximation (GA) of DE [11]. As shown by the results in [11], the estimated BLER in (7) obtained by GA is very accurate in practical signal-to-noise ratio (SNR) regimes.

In the case of uncorrelated Rayleigh fast fading channel, since the instant fading factors are not available at the receiver, the existing construction method of RCPP codes cannot be employed directly. In this paper, we propose to construct RCPP codes by approximating the fading channel $W$ with $\sigma^2$ using an AWGN channel $W_{eq}$ with $\sigma^2_{eq}$, where the capacity of $W_{eq}$ equals to the ergodic capacity of $W$, i.e.,

$$I_G(\sigma^2_{eq}) = I_R(\sigma^2)$$ \hspace{1cm} (8)

where $I_G$ and $I_R$ are calculated as $\frac{2}{\pi}$ and $\frac{1}{2}$, respectively. The code construction and performance evaluation is then performed over the equivalent AWGN channel $W_{eq}$ in the same way as that of the AWGN case. The BLER performances over Rayleigh fading channels of a set of RCPP codes with $N = 1024$ and the corresponding bounds (7) obtained by the equivalent AWGN channels are shown in Fig.2. The bounds and the simulation curves are matched quite well.

IV. DESIGN AN HARQ-CC SCHEME OF POLAR CODES

Designing an optimal HARQ-CC scheme is equivalent to constructing a RCPP code that can maximize the throughput efficiency. This section first gives an approximation bound of the throughput efficiency under a specific configuration of the underlying RCPP code, then the construction algorithm of the proposed HARQ-CC scheme is described in detail.

A. An Approximation Bound of Throughput Efficiency

Similar to the HARQ-IR scheme in [6], the throughput efficiency of a specific HARQ-CC scheme can also be estimated by an approximation bound.

To transmit an information block of $K$ bits with the proposed HARQ-CC scheme which allows at most $T$ transmissions, we need to search for the optimal code length of the underlying RCPP code. After $t$ transmissions, a total of $t$ (noised) copies of the codeword $x$ are received from the channel. Let $E_t$ with $t = 1, 2, \cdots, T$ denote the event that the information block cannot be correctly decoded after the first $t$ transmissions, and $\overline{E}_t$ denote the complementary event of $E_t$. We write $Pr(E_t)$ to denote the probability of event $E_t$. Particularly, we write $E_0$ to denote the event that the information block cannot be decoded by the receiver before transmitting any bits. Obviously, $Pr(E_0) = 1$.

When transmitting information blocks of $K$ bits, the average numbers of the successfully received information bits $E[K]$ is

$$E[K] = K \cdot (1 - Pr(E_T \cap E_{T-1} \cdots \cap E_0))$$ \hspace{1cm} (9)
and the total transmitted bits $E[N]$ is

$$E[N] = \sum_{t=1}^{T} N \cdot \Pr(E_t \cap E_{t-1} \cap E_{t-2} \cap \cdots \cap E_0) + N \cdot \Pr(E_T \cap E_{T-1} \cdots \cap E_0)$$  \hspace{1cm} (10)$$

Then, the throughput efficiency can be written as

$$\eta = \frac{E[K]}{E[N]}$$  \hspace{1cm} (11)$$

Obviously, we have

$$\Pr(E_t \cap \cdots \cap E_0) \leq \Pr(E_t)$$  \hspace{1cm} (12)$$

Similar to that in [6], we would like to use the following approximation

$$\Pr(E_t \cap \cdots \cap E_0) \approx \Pr(E_{t-1}) - \Pr(E_t)$$  \hspace{1cm} (13)$$

After the $t$-th transmission over AWGN channel with $\sigma^2$, the received LLR vector $r$ after Chase combing is equivalent to that received after one transmission over an AWGN channel with Gaussian noise variance $\sigma^2/t$. When transmitting over the Rayleigh fading channels, the problem will be much more complex because the equivalent fading factor after Chase combing is no longer Rayleigh distributed, and the PDF of the equivalent fading factor is in the form of $t$ self-convolutions of $\mathcal{N}(0,1)$. For the ease of performance evaluation, we always use equivalent AWGN channels to approximate the fading channels when constructing the RCPP codes. After $t$ transmissions, the decoding is performed based on the combined LLRs of $t$ (noised) copies of the identical codeword $x$ received from the channel. Thus, when the channel is with Gaussian noise variance $\sigma^2$, $\Pr(E_t)$ in [12] and [13] is in fact the BLER of the RRCP code when transmitting over an equivalent AWGN channel with an noise variance $\sigma^2/t$ (or $\sigma_{eq}^2/t$ for fading channel). So, for both scenarios of AWGN and Rayleigh fading channels, the values of $\Pr(E_t)$ can be efficiently evaluated by [7] using GA as introduced in section [3].

Therefore, the throughput efficiency in [11] can be approximately calculated as

$$\eta \approx \frac{K \cdot (1 - \Pr(E_T))}{\sum_{t=1}^{T} N \cdot (\Pr(E_{t-1}) - \Pr(E_t)) + N \cdot \Pr(E_T)}$$

$$= \frac{K \cdot (1 - \Pr(E_T))}{N \cdot \left(1 + \sum_{t=1}^{T-1} \Pr(E_t)\right)}$$  \hspace{1cm} (14)$$

Since the substitution of $\Pr(E_t)$ for $\Pr(E_t \cap \cdots \cap E_0)$ in [12] is an upper bound, and the approximation $\Pr(E_{t-1}) - \Pr(E_t)$ for $\Pr(E_t \cap E_{t-1} \cap \cdots \cap E_0)$ in [13] is usually also an upper bound, the approximation of the throughput efficiency in [14] tends to be a lower bound of $\eta$.

**B. Searching for the Optimal HARQ-CC Scheme**

Utilizing [14], an HARQ-CC scheme with information block size $K$ can be constructed via a greedy search. Given the length of the (punctured) codeword $N$, the code length of the base code $M$ is restricted to the least available value that is larger than $N$, i.e., $M = 2^{\log N}$, and the puncturing pattern is determined by Algorithm [1]. The information channel indices $A$ of the RCPP code are selected to minimize the BLER of the first transmission attempt. The BLERs after $t$ transmissions with $t = 1, 2, \cdots, T$ can be evaluated by [7] using GA. Then, the throughput efficiency can be estimated by [14]. All the potential configurations of the code length $N$ taking values from $K$ to $\lceil Q/T \rceil$ are checked, where $Q$ is the number of permitted transmitted bits during the entire transmission procedure and $\lfloor \cdot \rfloor$ is the floor function. Finally, the optimal configuration of the code length $N$ with the highest throughput efficiency is recorded.

The search algorithm is summarized in Algorithm [2]. The inputs include the information block length $K$, the number of the permitted transmitted bits $Q$, the maximum number of transmission trials $T$ and the variance of Gaussian noise $\sigma^2$ ($\sigma_{eq}^2$ for the case of Rayleigh fading channel). The algorithm outputs the optimal (punctured) code length $N$.

**Algorithm 2 Design a Polar Coded HARQ-CC Scheme**

**Input:** Information block length $K$;
- Maximum number of transmission trials $T$;
- Number of permitted transmitted bits $Q$;
- Variance of Gaussian noise $\sigma^2$ ($\sigma_{eq}^2$ for Rayleigh fading case);

**Output:** Length of the punctured codeword $N$;

1: Initialize the $N \leftarrow 0$, $M \leftarrow 0$, and the optimal throughput efficiency $\eta_{opt} \leftarrow 0$;
2: for $n \leftarrow K : \lfloor Q/T \rfloor$ do
3: \hspace{0.5cm} if $\frac{K}{n} \leq \eta_{opt}$ then
4: \hspace{1cm} Terminate the searching loop;
5: \hspace{0.5cm} end if
6: \hspace{0.5cm} The length of the base code is set as $m \leftarrow 2^{\lceil \log(n) \rceil}$;
7: \hspace{0.5cm} Construct a set of information channel indices $A$ under the channels with parameter $\sigma^2$;
8: \hspace{0.5cm} Allocate a temporary $T$-dimensional vector $q$;
9: \hspace{0.5cm} for $t \leftarrow 1 : T$ do
10: \hspace{1cm} Estimate the error probability after $t$ transmissions, i.e., $q_t \leftarrow P_B(n, K, m, A)$, where the underlying channel is with parameter $\sigma^2$;
11: \hspace{1cm} end for
12: \hspace{0.5cm} Calculate the throughput of the temporary scheme:
13: \hspace{1cm} $\eta = \frac{K \cdot (1 - \sum_{t=1}^{T} q_t)}{n \cdot \left(1 + \sum_{t=1}^{T-1} q_t\right)}$  \hspace{1cm} (15)$$
14: \hspace{1cm} if $\eta > \eta_{opt}$ then
15: \hspace{1.5cm} Record the optimal code length $N \leftarrow n$;
16: \hspace{1.5cm} Update the optimal throughput efficiency $\eta_{opt} \leftarrow \eta$;
17: \hspace{1cm} end if
18: \hspace{0.5cm} end for
19: \hspace{0.5cm} return $N$;

In Algorithm [2] the outer loop at line 2 is executed $\lceil Q/T \rceil - K + 1$ times. An early termination is given in line 5 to line 7: if the potential code length $n$ is too large to get the higher
throughput than the already obtained optimal configuration, the search procedure is then terminated. The most expensive operations are the BLER estimations in line 12 to line 14. According to \(\text{II}1\), the complexity of evaluating \(\text{II}3\) using GA is \(O(N \log N)\). Taking the outer loop of \(n\) into account, the overall complexity of Algorithm \(\text{II}4\) is upper bounded by \(O(\left(\frac{Q^2}{T} - QK\right) \log \left(\frac{Q}{T}\right))\).

In comparison, the construction complexity of HARQ-IR of polar codes is claimed to be \(O\left(\frac{Q^2 \log Q}{T}\right)\) \(\text{II}6\). Note that, under the context of HARQ-CC, \(Q\) is at least \(T\) times larger than \(N\). Therefore, the construction complexity of the proposed polar coded HARQ-CC scheme is much lower than that of the HARQ-IR in \(\text{II}6\).

V. SIMULATION RESULTS

In this section, the performance of the proposed polar coded HARQ-CC scheme is evaluated via simulations over AWGN and Rayleigh fading channels. All the RCPP codes are with information block lengths \(K = 1024\) and decoded by SC algorithm. The proposed HARQ-CC schemes are constructed with the number of permitted transmitted bits \(Q = 16384\) and maximum number of transmission trials \(T = 6\).

Fig. 3 shows the throughput efficiency of the proposed HARQ-CC scheme over BI-AWGN channels, where the polar codes are with \(K = 1024\), and results for RCIRA codes are from \(\text{II}4\) \((K = 512)\) and RCPT codes are from \(\text{II}5\) \((K = 1024)\).

| SNR(dB) | N   | SNR(dB) | N   | SNR(dB) | N   |
|--------|-----|---------|-----|---------|-----|
| -2.00  | 2489| 5.00    | 1280| 6.21e-001| 4.09e-001|
| -1.00  | 2048| 4.00    | 1184| 9.00    | 10.00|
| 0.00   | 1808| 5.00    | 1120| 10.00   | 1025|
| 1.00   | 1583| 6.00    | 1072|         |      |
| 2.00   | 1420| 7.00    | 1046|         |      |

TABLE I

Configurations of HARQ-CC over AWGN channels with \(K = 1024, Q = 16384\) and \(T = 6\)

| SNR(dB) | HARQ-CC | HARQ-IR |
|---------|---------|---------|
| -2.00   | 4.18e-002 | 1.042   |
| 0.00    | 3.23e-002 | 1.032   |
| 2.00    | 2.81e-002 | 1.028   |
| 4.00    | 2.24e-002 | 1.022   |
| 6.00    | 1.11e-002 | 1.011   |
| 8.00    | 4.71e-003 | 1.005   |

TABLE II

BLER at the first transmission and the average number of transmissions of polar coded HARQ-CC and HARQ-IR over AWGN channels with \(K = 1024, Q = 16384\) and \(T = 6\)
An HARQ-CC scheme of polar codes is proposed. As far as we know, this is the first HARQ-CC scheme based on polar codes. Simulation results show that, the proposed scheme is only about 1.0 dB away from the existing polar coded HARQ-IR scheme. But the new proposed polar coded HARQ-CC scheme requires less retransmissions and has the advantage of good compatibility to other transmission techniques.

**VI. Conclusions**

An HARQ-CC scheme of polar codes is proposed. As far as we know, this is the first HARQ-CC scheme based on polar codes. Simulation results show that, the proposed scheme is only about 1.0 dB away from the existing polar coded HARQ-IR scheme. But the new proposed polar coded HARQ-CC scheme requires less retransmissions and has the advantage of good compatibility to other transmission techniques.

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