Distributed Turbo Coding Schemes for Receive Diversity: A Modified Matched S-Random Interleaver for Half-Duplex Wireless Relay Channels

Tamer H. M. Soliman and Fengfan Yang
College of Electronic and Information Engineering,
Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
Email:t.hassan@nuaa.edu.cn; yffee@nuaa.edu.cn

Abstract —It is known that one of the essential building blocks of distributed turbo codes is the interleaver and its design uses random, semi-random (S-Random) and deterministic permutations. In this paper, a new modified matched S-random interleaver for turbo code is proposed. Then we extend the effect of this new interleaver to the relay channel to evaluate the interleaving gain in two different distributed turbo-coding schemes: distributed turbo codes and distributed multiple turbo codes for half-duplex relay system. For these schemes with half-duplex constraint, the source node transmits its information with the parity bit sequence(s) to both the relay and the destination nodes during the first phase. The relay receives the data from the source and processes it by using decode and forward protocol. For the second transmission period, the decoded systematic data at relay is interleaved and re-encoded by a recursive systematic convolutional encoder and forwarded to the destination. At destination node, the signals which are received from the source and relay nodes are processed by using turbo log-MAP iterative decoding for retrieving the original information bits. We demonstrate via simulations that the new interleaving gain has a large effect with distributed turbo coding scheme when we use only one recursive systematic convolutional encoder at both the source and relay.

Index Terms—Distributed turbo codes, interleaver, semi-random, relay channel

I. INTRODUCTION

Radio-wave propagation through wireless channels is a complicated phenomenon characterized by various effects, such as multipath and shadowing. Diversity techniques offer an effective countermeasure against multipath fading by providing the receiver with different versions of the data-bearing signal transmitted over channels with independent channel gains [1]. User-Cooperation is possible whenever the number of communicating terminals exceeds two. Therefore, a three-terminal channel is a fundamental unit in the cooperation communication. Indeed, a vast portion of the research effort has been devoted to the relay channel. The notion of relay channel, proposed by Van der Meulen [2], is a channel with three terminal nodes: source node, relay node and destination node. Cooperative relay channel communications have recently emerged to provide diversity gains or enhance the capacity of wireless systems in faded wireless links without deploying multiple antennas at the transmitter through the use of relay nodes [3]. Cover and El Gamal [4] produced the fundamental cooperative strategies and capacity bounds under additive white Gaussian-noise (AWGN) single-relay channels for deterministic relay channels as well as relay channels with feedback. Furthermore, in distributed turbo codes [5], the encoding operations for channel coding are distributed among cooperating nodes which provides a combined diversity and coding gain.

There are many fundamental relay protocols based on which the source and relay nodes can share their resources to achieve the combination between the cooperative diversity and the highest coding gain for any known coding scheme. The most popular collaborative protocols used between the source, relay and destination nodes are the decode-and-forward, estimate-and-forward (also called compress-and-forward or quantize and-forward) and the amplify-and-forward (also called scale-and-forward). Moreover, there is no single cooperation strategy known that works best for the general relay channel. Decode-and-forward strategy is considered when a message is broadcasted by the source and received simultaneous by the destination as well as relay. Once the relay has received the message, it may then forward the information to the destination after re-encoding it again. The destination can combine the information received from both the source and the relay. The decode-and-forward protocol is close to optimal when the source-relay channel is excellent, which practically happens when the source and relay are physically near each other. When the source-relay channel becomes perfect, the relay channel becomes a 2 × 1 multiple-antenna system. Various practical schemes have been proposed to exploit the benefits of cooperation among nodes [6]-[8].

In this paper, we build a newmodified matched S-random (MMSR) interleaver algorithm that has the ability to give the turbo coding system better performance in both short and long frames. Then we considera half-

---

Manuscript received February16, 2015; revised April 10, 2015.
This work was supported by the College of Electronic and Information Engineering, Nanjing University of Aeronautics and Astronautics, Nanjing, China.
Corresponding author email: t.hassan@nuaa.edu.cn
doi:10.12720/jcm.10.4.252-259

duplex decode-and-forward turbo coding relaying system. The system operates in a time-division manner. In the first time-slot of the transmission, only the source sends a coded packet representing N message bits. This transmission is received by both the relay and the destination terminals. After decoding, interleaving and re-encoding using recursive systematic convolutional (RSC) encoder, the relay node transmits its own code word to the destination node in the second time slot. Therefore, the destination considered to operate similar to receiver selection diversity scenario. It receives two noisy observation sequences which are sent from the source and the relay.

Different channels are considered, including the Rayleigh-fading channel and the AWGN channel. Large amount of research work has been done on theoretical protocols and practical strategies of various system and network models to study and improve the reliability and efficiency of relay systems. Despite that several cooperative coding principles are applied to a half-duplex relay systems in [9], [10], our approach in this paper is differentin that our proposed schemes depend mainly on improving the system performance gain due to the relay construction using good interleaver design at the relay node in order to achievea better system performance.

For this purpose, we first introduce the design of MMSR interleavers in compared with different turbo coding interleavers [11]-[13]. Secondly, we have conducted a series of numerical simulations to study the effect ofusing this MMSR interleaver at the relay system comparing our results with using different other interleavers. From our results, we showed that the interleaving gain at the relay has a better effect on the distributed turbo codes (DTC) scheme with best performance given by MMSR interleaver while for the distributed multiple turbo codes (DMTC) scheme, there is no interleaving gain and the performance nearly the same.

The remainder of this paper is organized as follows. In Section II the system model is introduced. In Section III the designed algorithm of MMSR interleaver is presented. Section IV is used to provide the detailed analysis of the DTC and DMTC schemes. Simulation and performance evaluation of the proposed schemes are explored in Section V. Finally, conclusions are made in Section VI.

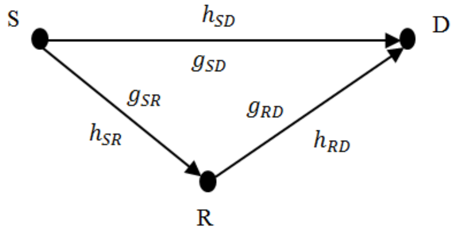


Fig. 1. Therelay channel system.

II. THE SYSTEM DESCRIPTION

The relay system shown in Fig. 1 consists of three nodes: a source node *S*, a relay node *R*, and a destination node *D*. This system has three directed transmission links: the links from source to destination, source to relay, and relay to destination link. We suppose that all the channel links in Fig. 1 are with independent fading on all three links, and their average SNRs are denoted by γ, γ_{SR} and γ_{RD} , respectively. With $\gamma_{SR} = g_{SR}\gamma$ and $\gamma_{RD} = g_{RD}\gamma$ where g_{SR} and $g_{RD}$are the source-relay and relay-destination channels gain, respectively.

Typically, the source to relay and the relay to destination links have a larger SNR than the direct link, i.e., $g_{SR} \geq 1$ and $g_{RD} \geq 1$, where the gains may be due to shorter transmitter-receiver separation. The overall SNR is defined by the SNR of the source to destination link, i.e., by γ.

Two phases are required to complete the transmission. During the first phase, the source broadcasts its information to both relay and destination. In the second phase, the relay decodes the received data from the source by using decode-and-forward protocol and after interleaving it transmits its parity sequence generated from the processed data to destination while the source is in silent mode during this phase. In the first time slot, the received signal *z* at the relay node is given by:

$$z = \sqrt{P_0}h_{SR}x_1 + n_1 \tag{1}$$

wherex_1 is the symbol transmitted from the source with source transmitted power P_0 during the first slot, n_1 is the AWGN term, and h_{SR} is the source-relay channel response. When an AWGN channel is considered, h_{SR} =1. On the other hand, when a Rayleigh fading channel is considered, h_{SR} is a zero-mean complex Gaussian random variable with unit variance, and n_1 is also a zero-mean complex Gaussian random variable with variance of $N_0/2$ per dimension. The received signal at the destination node during the first and second time slots is given by:

$$y = r_{SD} + r_{RD} = \sqrt{P_0}h_{SD}x_1 + \sqrt{P_0}h_{RD}x_2 + n \tag{2}$$

wherex_1 and $x_2$are the symbols transmitted from the source and relay nodes, respectively, both with transmitted power P_0. The source-destination and relay-destination channel coefficients are unity for an AWGN channel, or zero-mean complex Gaussian fading coefficients with unit variance for a Rayleigh fading channel. The noise n has the same distribution as n_1. We consider the case that the source to relay link is ideal, i.e., $g_{SR} = \infty$. Also we assume that n, n_1, h_{SR},h_{SD}, and $h_{RD}$are independent of each other, and all the channel coefficients are assumed to be known perfectly at the receiver sides and unknown at the transmitter sides.

III. MODIFIED MATCHED S-RANDOM (MMSR) INTERLEAVER

In turbo codes, an interleaver can be designed to break low weight input sequence patterns, which produce low weight parity-check sequences at the output of one of the constituent encoders, so that the input sequences to the other constituent encoder will generate high weight parity-check sequences. The weight distribution of error correcting codes can be used to compute the error performance bounds for the performance evaluation of any linear block codes. Turbo codes can be represented as an equivalent block code if its constituent convolutional encoders are terminated to the all-zero state.

Here the MMSR interleaver design will depend on the combination between S-Random and matched interleavers. The S-Random constraint spreads the element positions such that any two elements within a window of size S will not be located in a window of size S in the interleaved sequence. In our design of MMSR interleaver, we modify the designed algorithm in [14] in large frames depending mainly on removing bad low weights (two, three and four) input sequences that have significant contribution to the error performance with less complexity as follows.

A. Bad Weight-2 Input Sequences

Bad input sequences are those that produce low weights at encoder's outputs. The bad weight-2 sequence (00 ... 00100100 ... 00) with the minimum distance between two one's (μ) generates a finite output code words. This bad weight-2 input sequence (U_2)forces the encoder back to the all-zero state without any trellis termination and can be represented by a simple polynomial of (D) as.

$$U_2(D) = (1 + D^{3k})D^{\tau} \tag{3}$$

where, $k \geq 1$and time delay $\tau \geq 1$. Fig. 1 shows that the overall weight of any generated code word is the summation of the input weight, weight of first parity and weight of second parity. For breaking bad weight-2 inputs, we need that $d > d_{max}^{w=2}$, where $d_{max}^{w=2}$ is the maximum weight generated by the bad weight-2 input sequence that should be eliminated by our interleaver design. For the minimum parity check weight generated by weight-2 input (z_{min}), the parity-check sequences generated by the input sequence in (3) can be expressed as.

$$w(p_j) = k_j(z_{min} - 2) + 2 \tag{4}$$

where, k_j=1, 2, 3... and j=1, 2. So for breaking bad low weight-2 input sequences we need:

$$d = 2 + (k_1(Z_{min} - 2)) + (k_2(Z_{min} - 2)) > d_{max}^{w=2} \tag{5a}$$

$$6 + (k_1 + k_2)(Z_{min} - 2) > d_{max}^{w=2} \tag{5b}$$

$$k_1 + k_2 > \frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} \tag{5c}$$

Since (k_1=1, 2, 3…), so for $k_1 = 1$ (for the worst case).

$$k_2 > \frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} - 1 \tag{6}$$

Multiplying both sides byμ, we have.

$$\mu\, k_2 > \mu \left[\frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} - 1\right] \tag{7}$$

Thus, by applying the S-random constraint we can get:

$$|\pi(i_1) - \pi(i_2)| \geq (S + 1), \text{whenever} |i_1 - i_2| \leq S \tag{8}$$

$$\mu k_2 \geq S + 1, for\ \mu k_1 \leq S \tag{9}$$

From (7) and (9) we have that:

$$(S + 1) > \mu \left[\frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} - 1\right] \tag{10}$$

$$S > \mu \left[\frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} - 1\right] - 1 \tag{11}$$

Therefore, the minimum value of S for S-Random constraint that allows breaking of bad weight-2 sequences is given as.

$$S_{min}^{w=2} = \mu \left[\frac{d_{max}^{w=2} - 6}{(Z_{min} - 2)} - 1\right] - 1 \tag{12}$$

B. Bad Weight-3 Input Sequences

For bad weight-3 input sequences that generate low weight code words, Table I indicates the weight-3 input sequences that can generate code words with most significant contribution to the error performance of 4-state $(1, 1 + D^2/1 + D + D^2)$ turbo codes.

The mapping from one of these weight-3 input sequences at the first constituent encoder to another bad weight-3 input sequence for the other constituent encoder is very easy to be prevented. As an example for having the output weight ($d = 9$) codewords, first it can be produced by an input weight $w = 3$ and parity check weights as$P_1 = 2$ when $P_2 = 4$ or $P_1 = 4$ for$P_2 = 2$. For the first case, the input sequence of the first encoder is (111); its parity sequence (101) with $P_1 = 2$ and with output sequence (111011). The input sequence of the second encoder will be (10101 or 110001) to make$P_2 = 4$.This mapping can be easily prevented by a very simple S-Random constraint. Also for the second case when the input sequence of the first encoder is (10101 or 110001) giving output sequence (1101100111 or 111000010111) with $P_1 = 4$. Also the mapping from these sequences to (111) sequence at the input of the second encoder can be broken easily by S-Random constraint with $S_{min}^{w=3}$ ≥10, where $S_{min}^{w=3}$ is the minimum value of S to allow breaking of bad weight-3 input sequences.

TABLE I: BAD WEIGHT-3 INPUT SEQUENCES THAT GENERATE SIGNIFICANT LOW WEIGHT CODEWORDS.

Input weight (w)	Output weight (d)	Parity weights	Input sequences
3	7	2	111
	9	2	111
		4	10101 – 110001
	11	2	111
		4	10101 – 110001
		6	100000011 -110000001
	13	2	111
		4	10101 – 110001
		6	100000011 – 110000001
		8	110000000001

C. Bad Weight-4 Input Sequences

Similar to weight-2 input sequences with overall output code words weight($d = 4 + P1 + P2$), so we have.

$$d = 12 + (k_3 + k_4 + k'_3 + k'_4).(Z_{min} - 2) \qquad (13)$$

where k_3, k_4, k'_3 and $k'_4 = 1,2,3,\ldots$. For the output codeword weight to be greater than the maximum weight generated by the bad weight-4 input sequences that should be eliminated ($d^{w=4}_{max}$), the condition is given as: $d > (d^{w=4}_{max})$, thus.

$$k_3 + k_4 + k'_3 + k'_4 > \frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} \qquad (14)$$

Since (k_3, k_4=1, 2, 3…), so for $k_3 = k_4 = 1$.

$$k'_3 + k'_4 > \frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - 2 \qquad (15)$$

From (14), by multiplying both sides by μ, we have.

$$\mu(k'_3 + k'_4) > \mu\left[\frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - 2\right] \qquad (16)$$

By using the weight-4, the S-Random constraint is given as.

$$|\pi(i_1) - \pi(i_3)| and\ |\pi(i_2) - \pi(i_4)| \geq (S + 1) \qquad (17)$$

where, $|i_1 - i_2| and\ |i_3 - i_4| \leq S$.

$$\mu k'_3 \geq (S + 1) \qquad (18a)$$

$$\mu k'_4 \geq (S + 1) \qquad (18b)$$

From (18a) and (18b) we have.

$$\mu k'_3 + \mu k'_4 \geq 2(S + 1) \qquad (19)$$

$$\mu(k'_3 + k'_4) \geq 2(S + 1) \qquad (20)$$

And from (16) & (20),

$$2(S + 1) > \mu\left[\frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - 2\right] \qquad (21)$$

$$S > \frac{\mu}{2}\left[\frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - 2\right] - 1 \qquad (22)$$

So, the minimum value of S for S-Random constraints that allows breaking of bad weight-4 sequences will be:

$$S^{w=4}_{min} = \frac{\mu}{2}\left[\frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - 2\right] - 1 \qquad (23)$$

By modifying the value of S in the MMSR interleaver designed algorithm with $S^{w=2}_{min}$, $S^{w=3}_{min}$ and $S^{w=4}_{min}$, the interleaver has the ability to eliminate bad low weights (2, 3 and 4) input sequences giving better performance especially with long frames. The designed algorithm can be simplified as follows:

1) *First step: S-random interleaver constraint*

- First, we select the starting value of S as $S = \sqrt{(N/2)}$ and a specific number of iterations (determines how many main loops can occur before failure).
- Calculate $S^{w=2}_{min}$ and $S^{w=4}_{min}$ from Eq. (12) and (23) respectively.
- Pick the first position randomly from the set φ= {1, 2, 3… N} as ($pos_1 = rand(1\!:\!N)$) and erase this selection (pos_1) from the set φ.
- Each random selection of the next position is compared to the S previously selected one. If the current selection is equal to any of the S previous selections within a distance of $\pm S$, then the current selection is rejected and selects another one. If not then pick the current selection, erase it from the remaining set i.e. ($\varphi - selections$) and then go to the next selection and so on. If no possible selection converges with the requirements under the defined number of iterations, then the value of *S is* reduced by 1 and starts the new search again until a satisfying selection is made at a certain value of *S* ($Sgen$).

2) *Second step: Code Matched constraint:*

- Check whether the designed S-Random constraint satisfies breaking of the bad low weights (2, 3 and 4) input sequences by checking the following condition:

$$Sgen \geq \max(S^{w=2}_{min}, S^{w=4}_{min}) \qquad (24)$$

- If the condition is satisfied, then end the design and save the current mapping as an interleaver output.
- Otherwise, go to step (d) with extra conditions for each selected position. The following conditions need to be satisfied for both weight-2 and weight-4.

weight-2 input sequences:

$$k_2 > \frac{d^{w=2}_{max} - 6}{(Z_{min} - 2)} - k_1 \qquad (25)$$

weight-4 input sequences:

$$k'_3 + k'_4 > \frac{d^{w=4}_{max} - 12}{(Z_{min} - 2)} - (k_3 + k_4) \qquad (26)$$

IV. PROPOSED DISTRIBUTED TURBO CODING SCHEMES BASED ON MMSR INTERLEAVER

A. DTC Scheme

The major difference between distributed coding and conventional channel coding schemes is that in distributed coding, the overall code word is constructed in a distributed manner. That is, different parts of the code word in distributed coding are transmitted by different nodes through independent wireless links. This creates additional degrees of freedom, but also poses challenges in code construction.

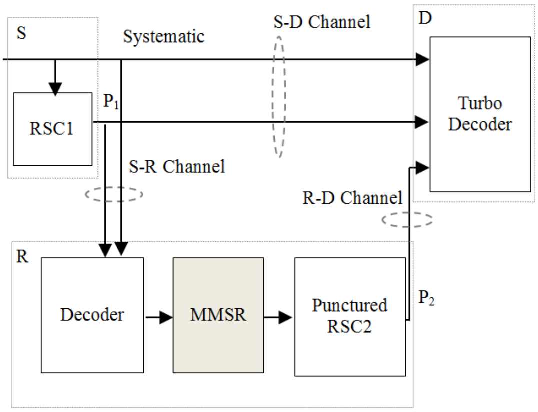


Fig. 2. Theproposed DTC scheme with an interleaver at the relay node.

Fig. 2 shows the block diagram of a DTC system. In a DTC scheme, two RSC encoders are used at the source node and the relay node.

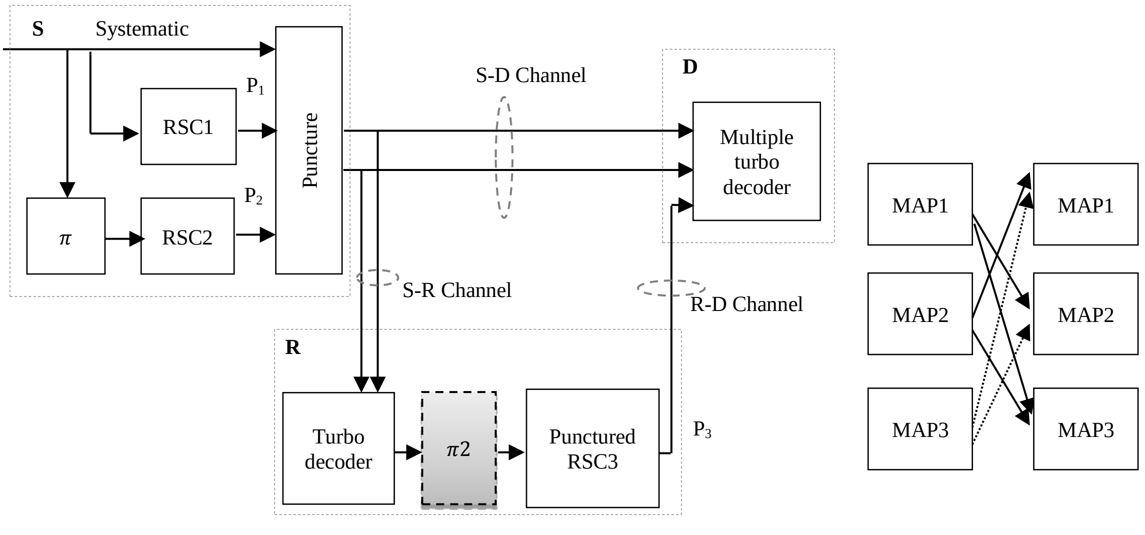
The source broadcasts the coded signals by the first RSC1 to both the destination and relay. The relay decodes the received signals, interleaves and re-encodes them using punctured RSC2 as shown in Fig. 2.

The designed MMSR interleaver will be used at the relay and compared with other interleavers to measure the effect of better interleaver gain on the system performance. The destination receives two noisy observation sequences consisting of a coded signal transmitted from the source and the second parity transmitted from the relay. Although the source to destination link rate is (1/2), the overall system rate from the destination point of view is ($R_{overall}$=1/3).The overall average SNR is defined by that of the source to the destination link, given by γ. Also we assume that, the relay is located close to the destination node with relay to destination link gain ($g_{RD} = 1$ dB).After decoding, the relay can transmit the received data with little power which may add additional diversity to the destination. The overall system is thus similar to an ideal receiver diversity system.

B. DMTC Scheme

Fig. 3. depicts the system diagram for the proposed DMTC scheme. Here in this DMTC scheme turbo code is used at the source which consists of two simple constituent RSC1 and RSC2 encoders with simple random interleaver (π) and puncturing of alternate parity bits as shown in Fig. 3 (a). The source node transmits coded symbols to both the relay and the destination nodes during the first transmission period. The relay performs parallel decoding with concatenated codes. The relay then re-encodes the information bits using a RSC3 code after interleaving using MMSR interleaver π_2 during the second transmission period. The resultant symbols transmitted from the source and relay nodes can be viewed as the coded symbols of a three component parallel-concatenated encoders. Thus, at the destination, the punctured turbo code is equipped with more parity bits. The destination receives two noisy faded versions of parallel concatenation of three recursive binary convolutional encoders with different interleaver effects.

Iterative decoding at the destination involves three maximum a posteriori (MAP) decoders, with extrinsic information exchange between modules in the manner of multiple-turbo decoder [15]. As shown in Fig. 3 (b) the extrinsic output of each MAP decoder is fed in to the other two MAP decoders. In the first time slot, the received source-destination outputs feed the first and second MAP decoders and the extrinsic output of the MAP1 will be fed as a priori input to MAP2 and MAP3, while the extrinsic output of the MAP2 will be fed as a priori input to MAP1 and MAP3. In the second time slot, the received relay-destination output feed the third MAP3 decoder and its extrinsic output is fed as a priori input to MAP1 and MAP2.



(a)

(b)

Fig. 3. DMTC scheme with an interleaver at the relay node (a) DMTC and (b) parallel concatenated decoder.

V. SIMULATION RESULTS

A. Direct-Link Analysis

In this section, the performance of the MMSR interleaver is presented by analyzing the results from BER curve where the simulations are run for different interleaver lengths of (256, 400, 1024 and 2048 bits). We use turbo decoder that consists of parallel concatenated soft-output decoders, each of which decodes part of the overall code and then passes soft reliability information in an iterative scheme. The component soft-output algorithm described in the original turbo code paper [12] is usually known as the MAP or forward backward algorithm. Usually, for implementation of a turbo-decoder, its simplified version called the Log-MAP algorithm working in the logarithmic domain is implemented where multiplication is converted to addition. It has equivalent performance of MAP algorithm without its problems in practical implementation.

Fig. 4 shows that the MMSR interleaver has good random distributed characteristics when compared with the uniform random interleaver in addition to its matching the designed distribution.

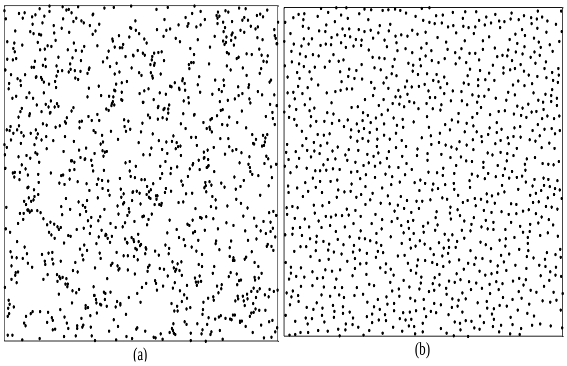


Fig. 4. Graphical representation of (a) Uniform Random and (b) MMSR interleavers with length N=1024 bits.

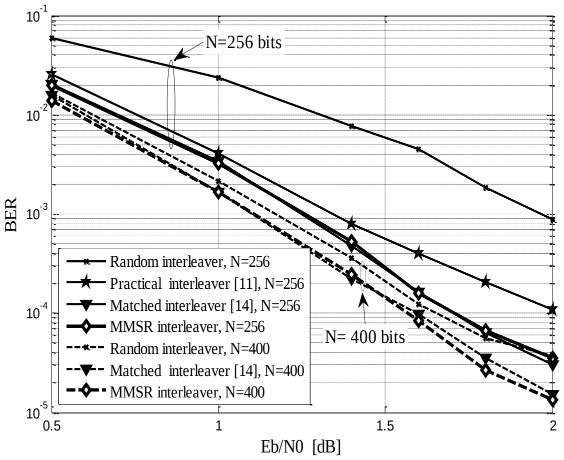


Fig. 5. BER performance comparison between 4-states rate 1/3 turbo code with MMSR, Matched, Random and Practical interleavers at N=256 and 400 bits.

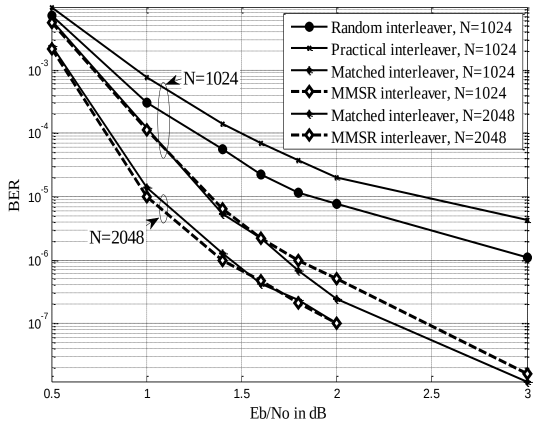


Fig. 6. BER performance comparison between 4-states rate 1/3 turbo code with MMSR, Practical, Matched and Random interleavers at N= (1024 and 2048) bits.

For direct SD link simulation, we use the rate 1/3 turbo code consistingof two RSC encoders each with code rate $R = 1/2$. The coded bits are transmitted over AWGN channel; and eight log-MAP decoding iterations are performed at the decoder. The BER curves are shown in Fig. (5) and Fig. (6) which depict the proposed MMSR interleaver against the random, practical [11] and code matched [14] interleavers.

The results of the simulations depict a better performance of the designed MMSR interleaver than those performances of practical and random interleavers. Although we can observe the same performance of MMSR and code matched interleavers for all simulated frame lengths (256, 400, 1024 and 2048 bits) as shown in Fig. (5) and Fig. (6), but the algorithm needs less time for conversion with fewer constrains compared with that of the matched interleaver algorithm specially for long frame lengths (1024 and 2048 bits) as the probability that $Sgen \geq \max(S_{\min}^{w=2}, S_{\min}^{w=4})$ increases andonly the S-Random constrain is sufficient for the algorithm to build the needed interleaving sequence.

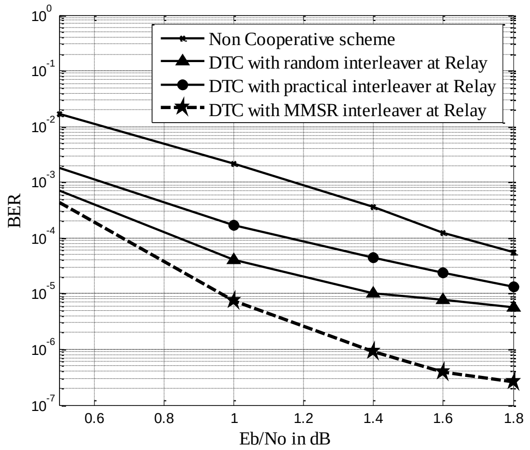


Fig. 7. BER performance of DTC in AWGN channel.

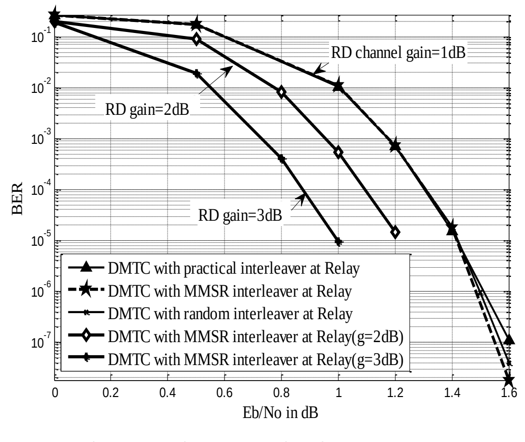


Fig. 8. BER performanceof DMTC in fast fading channel.

B. Relay-Link Analysis

In the DTC scheme, the source node transmits the systematic and first parity bits using RSC1 with generators of (1,5/7). The relay node then transmits second parity bits corresponding to the interleaved message using an interleaver size of N=1024 bits. Thus, at the destination we can have an overall rate-1/3 turbo code.

The destination node applies 8-iterations of log-MAP decoding after collecting the systematic information bits and the first parity bits from the source in the first time slot, and the second parity bits transmitted from the relay node in the second time slot.

Fig. 7 depicts the BER performance of the DTC system in AWGN channel with the interleaving gain effect of various interleaver types at the relay. From the simulation results, it is clear that the performance of the DTC scheme is better than the non-cooperative system. Also when the relay node uses MMSR interleaver, the improvement from the non-cooperative system is about (1.1 dB) at (BER = 10^{-4}), and improvement of (0.5 dB) and (0.2 dB) for practical and random interleavers, respectively.

For the simulation of the DMTC scheme, at the source we have used a turbo code with two parallel identical (1,5/7) polynomial-RSC encoders, random interleaver with size of N=1024 bits and punctured code rate R=1/2. Fig. 8 shows the interleaving gain effect on the system BER performance using different interleaver types at the relay node (practical, random and MMSR interleavers). It is observed that the performances of the three interleavers are almost identical. However, for the higher values of relay-destination channel gain one notices a better difference in performance.

C. Complexity Analysis

This technique permits to improve the spread properties in a very fast way, and to construct interleavers with large frame sizes having very good spreading properties with a computational complexity that is competitive with the direct matched interleaver generation [14]. As we mentioned before, the designed algorithm depends on both the S-Random and mapping constraints.

We will assume that the complexity can be approximated as the number of searching operations executed on mapping condition. But we have proved that once the condition of $Sgen \geq \max(S_{min}^{w=2}, S_{min}^{w=4})$ is satisfied, we need only the s-random constraint to eliminate bad (weight-2, 3 and 4) input sequences while for the matched interleaver we need both S-Random and mapping conditions which needs a very exhaustive search in each step for rectifying these two conditions together. Hence, in our algorithm the exhaustive search of rectifying the mapping conditions can be ignored that makes the proposed algorithm less complex than the matched interleaver with same error performance especially at long frames.

The complexity reduction achieved with our proposed Algorithm, with respect to the basic matched interleaver technique, is really impressive. Actually it must be underlined that, in order to achieve the best performance with small frames, it would never be possible to cover the small block sizes interleaver with a single s-random constraint, but also with the help of mapping condition.

VI. CONCLUSION

The interleaver plays a vital role in the performance improvement of turbo coding system and its application in relay channel. In this paper, we have presented a new efficient algorithm for turbo MMSR interleaver that combines the S-random constraint with matched interleaver algorithm which gives better performance with a very simple design, especially for long frames. In addition, the performance of MMSR interleaver is nearly the same with that of code matched interleaver at different frame sizes with less complex design. Then we extend the gain of the MMSR interleaver in two turbo relay schemes: DTC and DMTC. It is established that the use of MMSR at the relay node has a large effect on the BER performance of DTC. But comparing the use of different interleaver types at the relay node in DMTC schemeshows that the error performance is nearly the same.

ACKNOWLEDGMENT

This work is sponsored by the College of Electronic and Information Engineering of Nanjing University of Aeronautics and Astronautics. Authors would like to thank anonymous reviewers fortheir valuable suggestions and comments that help in this work.

REFERENCES

[1] J. G. Proakis, *Digital Communication*, 4thed. New York: McGraw-Hill, 2001.

[2] E. C. van der Meulen, "Three-terminal communication channels," *Adv. ppl. Prob.*, vol. 3, pp. 120–154, 1971.

[3] J. N. Laneman and G. W. Wornell, "Distributed space-time-coded protocols for exploiting cooperative diversity in wireless networks," *IEEE Trans. Inform. Theory*, vol. 49, pp. 2415–2425, Oct. 2003.

[4] T. M. Cover and A. El Gamal, "Capacity theorems for the relay channel," *IEEE Trans. Inf. Theory*, vol. 25, no. 5, pp. 572–584, 1979.

[5] B. Zhao and M. Valenti, "Distributed turbo coded diversity for relay channel," *Electronics Letters*, vol. 39, no. 10, pp. 786 – 787, May 2003.

[6] D. Gunduz, E. Erkip, A. Goldsmith, and H. V. Poor, "Reliable jointsource-channel cooperative transmission over relay networks," *IEEE Trans. Inf. Theory*, vol. 59, no. 4, pp. 2442–2458, 2013.

[7] M. Janani, A. Hedayat, T. E. Hunter, and A. Nosratinia, "Coded cooperation in wireless communications: Space-time transmission and iterative decoding," *IEEE Trans. Signal Process*, vol. 52, no. 2, Feb. 2004.

[8] W. Liang, S. Xin Ng, J. Feng, and L. Hanzo, "Pragmatic distributed algorithm for spectral access in cooperative cognitive radio networks," *IEEE Trans. on Comm.*, vol. 62, no. 4, pp. 1188-1200, April 2014.

[9] J. Merlin, W. Hamouda and, F. Takawira, "Relay selection for coded cooperative networks with outdated CSI over nakagami-m fading channels," *IEEE Trans. Wireless Comm.*, vol. 13, no. 5, pp. 2362–2373, May 2014.

[10] Z. Zhang and T. M. Duman, "Capacity-approaching turbo coding for half-duplex relaying," *IEEE Trans. Comm.*, vol. 55, no. 10, Oct. 2007.

[11] D. Wang and H. Kobayashj, "On design of interleavers with practical size for turbo codes," in *Proc. IEEE International Conference on Communications*, 2000, vol. 2, pp. 618–622.

[12] C. Berrou, A. Glavieux, and P. Thitimajshima, "Near Shannon limit error-correcting coding and decoding: Turbo-codes," in *Proc. Int. Conf. Communications*, Switzerland, May 1993, pp. 1064–1070.

[13] F. J. Escribano and A.Tarabl, "Interleaver design for parallel concatenated chaos-based coded modulations," *IEEE Comm. Letters*, vol. 17, no. 5, pp. 834–837, May 2013

[14] W. Feng, J. Yuan, and B. S. Vucetic, "A code-matched interleaver design for turbo codes," *IEEE Trans. Comm.*, vol. 50, pp. 926–937, June 2002.

[15] B. Zhang, H. Chen, M. El-Hajjar, R. Maunder, and L. Hanzo, "Distributed multiple-component turbo codes for cooperative hybrid ARQ," *IEEE Signal Process.Lett.*, vol. 20, no. 6, pp. 599-602, June 2013.

Tamer H. M. Soliman(Alsharkia Egypt, 18/1/1978) received the B.S. in communication and Radar engineering from MTC, Cairo, Egypt in 2000. He received his M.S. in applications of error correction codes in satellite communication from faculty of engineering, Alexandria University, Alexandria, Egypt, in 2011. He is currently in Ph.D. degree in NUAA (Nanjing University of Aeronautics and Astronautics). His major research interests are information theory and channel coding specially coded-cooperative diversity, turbo coding and secured chaotic techniques.

Fengfan Yang received the B.Sc., M.Sc., and Ph.D. degrees from Nanjing University of Aeronautics & Astronautics (NUAA), Northwestern Polytechnical University and Southeast University in 1990, 1993, and 1997 in P. R. China, respectively, all in electronic engineering. He has been with College of Information Science and Technology, Nanjing University of Aeronautics & Astronautics sinceMay 1997. From October 1999 toMay2003, he was a research associate at Centre for Communication Systems Research, University of Surrey, UK, and Department of Electrical and Computer Engineering (ECE), McGill University, Canada. He currently spends one year sabbatical leave as a visiting scholar at ECE, McGill University. His major research interests are information theory and channel coding, especially at iteratively decodable codes, such as turbo codes and LDPC codes, and their applications for mobile and satellite communications.