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Research and Realization on Fixed-point DSP of Distributed Turbo-Based Coded Cooperation

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Abstract. This paper presents a specific communication paradigm-Turbo coded cooperation exemplified by communication between two users and a destination. A corresponding model whose encoding rate and cooperation degree are free to set is proposed. By simulating in MATLAB and fixed-point DSP in various conditions including CSI and coding rates, analyzing the performance of BER and rate of information transmission, we eventually arrive at the conclusion that the source node and relay node commonly benefit from the Turbo coded-cooperation and the overall system performance improves significantly. Certain problems correlated with implantation in fixed-point DSP are discussed, such as precision in fixed-point quantification, over-flow of calculation and data storing are illustrated. The optimum proposals are also presented.

Keywords: wireless communication, cooperation diversity, channel encoding and decoding, Turbo coding, Iterative decoding

1. Introduction

The research on coded cooperation acts as an irreplaceable role in the development of B3G/4G communication system. The baseline is that every participator not only transfers its own bits but others' parity bits when it acts as a partner. If in failure, however, the system will automatically return back to non-cooperative mode.

Currently, the study of RCPC-based cooperation is highly developed including the cooperation scheme[1,2] and its performance analysis[3,4]. The RCPC-based cooperation scheme verifies that the combination of classical channel encoding and cooperation can significantly enhance system performances. Owing to the natural shortage of RCPC codes, however, the designed cooperation isn't that perfect. Thereby, the codes whose performance approach the Shannon limit, i.e., Turbo code and LDPC codes appeal to many researchers. Jannani M has ever provided a detailed illustration for the application of Turbo code in cooperation system [4].

However, with many specific issues unsolved, this technique is far away from mature. Protocols proposed recently mainly concentrate on offering the algorithmic manipulation of the BER or SER with the channel state given. Because of the hard access to the closed-form formulas, they have to be approximated by the average union bound. Once the channel between partners is poor, it turns out to be a loose specification to measure the system's actual performance especially for Turbo code. Thus, we have to turn to simulation and data analysis which act as effective and efficient methods. Consequently, it's significant to research the Turbo-based cooperation system and its implementation in software platform.

In this sense, this paper offers a detailed scheme in part II and carries out a practical simulation in DSP and MATLAB in part III. Besides, the advantages of coded cooperation over non-coded cooperation are also analyzed. In part IV, we provide a detailed description of the specific implementing issues. Part V is the conclusion.

2. Turbo Coded Cooperation Scheme

Here we simplify the communication system to a model consisting of two users and a destination. Hunter ever proposed a traditional Turbo-based cooperation scheme[5]. With certain improvement, this paper designed a Turbo-based coded cooperation model operating in half-duplex communication mode, as depicted in Fig.1. The users transmit bits on TDMA orthogonal and separate channels, meanwhile, cooperation occurs through partitioning a source node's bits but not via repetition such that part of the code word is transmitted by the user itself, while the remainder is transmitted by the partner through partial or complete decoding. And partner employs error detection to avoid error propagation. In addition, by allowing different code rates and partitions, coded cooperation provides a great degree of flexibility to adapt to channel conditions.

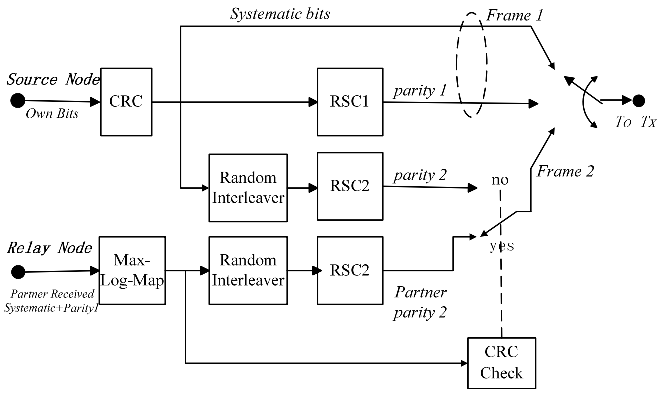


Fig. 1: Turbo encoding in a coded cooperation scheme

The two users cooperate by dividing the transmission of their N-bit ($N = N_1 + N_2$) code words into two successive time frames. In the first frame, each user transmits a code word with N_1 bits. Thus the frame itself is a valid code word which can be decoded to obtain the original information. Each user also receives and decodes the partner's transmission utilizing Max-Log-Map algorithm. If the user successfully decodes the partner's code word, determined by checking the CRC bits, the user computes and transmits N_2-bit additional parity bits for the partner's data in the second frame. If the user does not successfully decode the partner, N_2-bit additional parity bits are transmitted by the user itself. Each user always transmits a total of N bits per source block over the two frames. At the destination, the combination of the first and second frames offers the possibility of turbo decoding.

To simplify the presentation, we assume BPSK modulation, for which the baseband-equivalent discrete-time signal transmitted by user i and received by User j ($j \neq i$, and $j = 0$ denotes the destination, $i, j = 1$ denotes the source node, and $i, j = 2$ denotes the relay node) is given by

$$y_{i,j}(n) = \alpha_{i,j}(n) e^{-j\Phi_{i,j}(n)} \sqrt{E_{b,i}} (2b_i(n) - 1) + z_{i,j}(n) \qquad (1)$$

Where $E_{b,i}$ is the transmitted energy per bit for user i, $b_i(n)$ is the BPSK modulated code bit at time n, whereas $\alpha_{i,j}(n)e^{-j\Phi_{i,j}(n)}$, as a complex random Gaussian variable, is the fading coefficient magnitude between users i and j. $\Phi_{i,j}(n)$ represents the channel fading additional phase shift obeying uniform distribution in the range of 0 to 2π and $z_{i,j}(n)$ accounts for noise and other additive interference at the receiver and is modelled as independent, zero-mean additive white Gaussian noise with variance N.

The probability density of $\alpha_{i,j}(n)$ is given by

$$P(\alpha_{i,j}(n)) = \frac{\alpha_{i,j}(n)}{\delta^2} \times e^{-\frac{\alpha_{i,j}(n)}{\delta^2}} \qquad (2)$$

with mean $E\left[\alpha_{i,j}^{2}(n)\right] = 1$.

We assume that $\alpha_{i,j}(n)e^{-j\Phi_{i,j}(n)}$ and $E_{b,i}$ are constant over n for a given channel, i.e., the channel is supposed to be slow Rayleigh fading or Gaussian. Besides, in this work we only consider the simpler case with a fixed cooperation percentage of 33%.

3. Performance Analysis

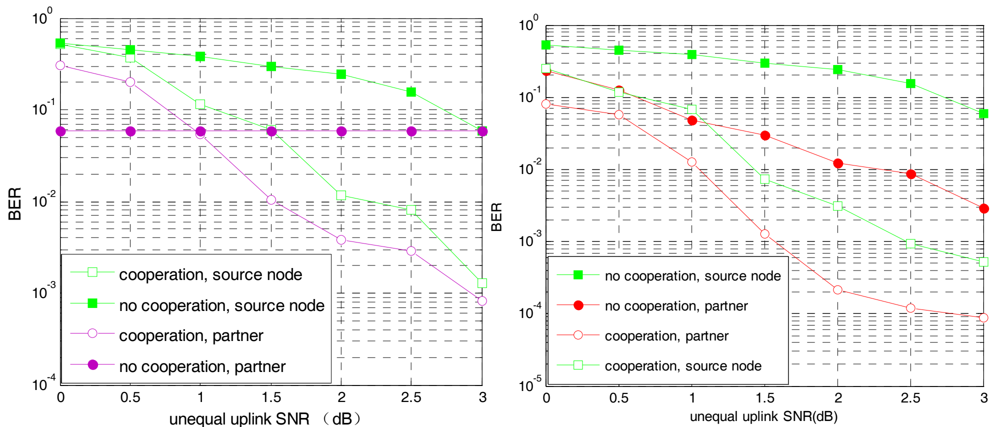
Turbo code is used as an error-correction code with the generator polynomial of a g = (7, 5), rate of 0.5, source frame length K = 256, soft input/soft output (SISO) iterated decoding by five times used Max-Log-MAP algorithm. 400 source blocks are simulated. As indicated earlier, the cooperation percentage is 33%. The baseline for all comparisons is a non-cooperative turbo coded system, therefore comparisons are fair on the basis of computational complexity as well as rate.

3.1. Realization on MATLAB in unequal AWGN channel

Fig.2 shows the simulation results for the BER in additional Gaussian White channel compared to non-cooperative turbo coding with various inter-user channel conditions. Two specific situations are simulated here.

Situation 1：Source node's channel varies from 0 dB to 3 dB, while partner's average uplink channel SNR is fixed at 3dB and the inter-user channel keeps outnumbering the source node's channel by 3dB. The BER pot against SNR is depicted in Fig. 2(a).

Situation 2：Source node's channel varies from 0dB to 3dB, while partner's uplink channel keeps outnumbering the source node's channel by 3dB and the inter-user channel is fixed at 6dB. The BER pot against SNR is depicted in Fig. 2(b).



（a） BER situation 1 (b) BER situation 2

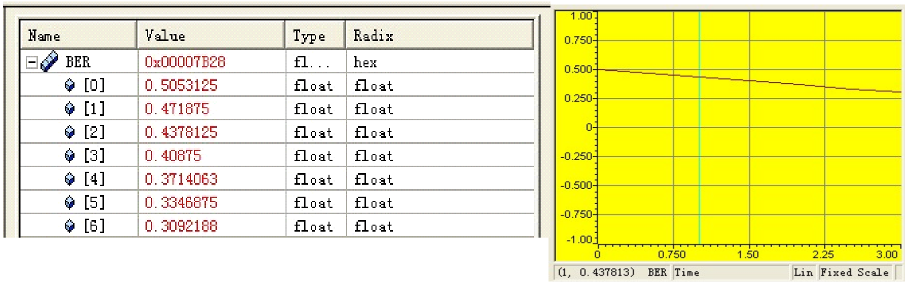
Fig.2: unequal channel simulation in MATLAB

As shown in Fig. 2, coded cooperation yields significant gain due to the increased diversity. The node in worse channel acquires performance improvement by cooperating with the one in better channel and node whoever has a better channel sacrifices performance by cooperation. Interestingly, when the both channels are better and better, node who has a better channel also improves somewhat, despite cooperating with relay node that has a poorer uplink channel. This illustrates that even a user with a very good uplink channel has a strong motivation to cooperate, which is an important practical result. Consequently, provided that the worsening performance remains acceptable, this constitutes a better overall system performance since the worst node has improved significantly.

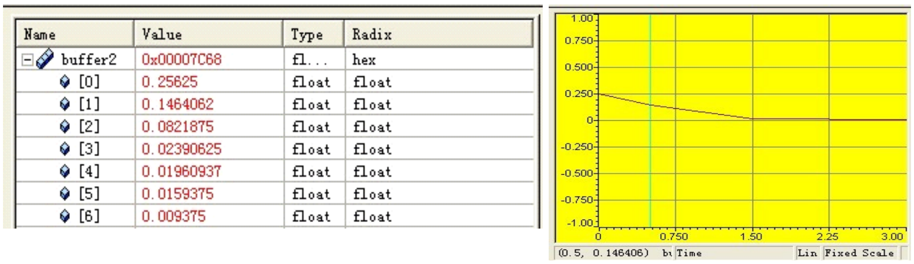
3.2. Realization on fixed-point DSP in equal AWGN and slow fading Rayleigh channel

The fixed-point DSP TMS320C6416 processor can work at 720MHz and its clock period is shortened by comparing other DSP. We carry out this implementation so as to prepare the cooperation scheme for the following hardware transplantation and corresponding research.

Simulation is operated on CCS 3.3. Here we assume that the node and partner have equal channel, varying simultaneously from 0 dB to 3 dB, while the average inter-user channel is fixed at one certain value. The BER plot against SNR is depicted in Fig. 3. The inter-user channel is fixed at 0 dB (Fig. 3(a)) and 7 dB (Fig. 3(b)). Other situations are the same as part 3.1.



(a) 0dB inter-user equal AWGN channel ,simulation in DSP



(b) 7dB inter-user equal AWGN channel, simulation in DSP

Fig.3: Turbo coded cooperation in slow fading. Users have equal uplink SNR

Performance comparison between Fig. 3(a) and Fig. 3(b) shows that the better the inter-channel is, the more remarkable the diversity gain the system obtains. This is reasonable since when the inter-channel is poor, the probability that the partner successively decodes the received signals is quite slight. Thus, nodes are more likely to work in non-cooperation mode and vice versa.

In addition, it can be concluded from Fig. 3(b) that when the uplink SNR is up to 1.5dB, the plots tend to be flat which means that the performance is approaching a saturation mode. All these cases provided us a communication strategy that, we can estimate the CSI, set an upper limit for transmit power and then obtain the optimal performance with the transmit power being as low as possible.

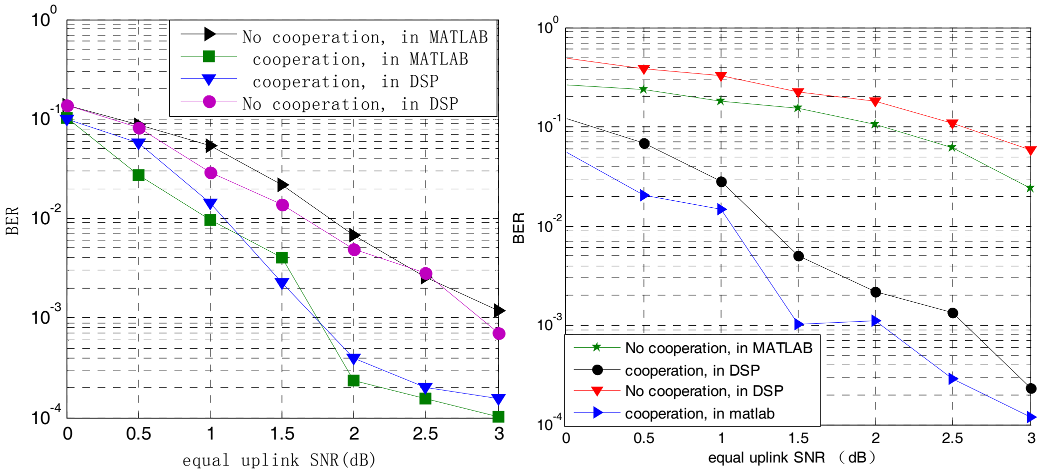
3.3. Realization on fixed-point DSP and MATLAB in equal AWGN and slow fading Rayleigh channel

In order to comprehensively analyze the effects caused by uplink channel SNR, fading magnitude and the two communication modes—cooperation and non-cooperation, we remove inter-user channel situation from the consideration and suppose that the inter-user channel is ideal, such as a noiseless inter-user channel.

Fig. 4 shows the BER plot against SNR simulated in both MATLAB and DSP. All channels have equal mean SNR varying from 0 dB to 5 dB. Comparison of simulation results in DSP and MATLAB.

(1) BER performance evaluation

Some conclusions can be acquired as follows: (1) these curves indicate the improvement in BER performance that coded cooperation provides over the non-cooperative system. For example, in Fig.4(b)，when the SNR is10^{-2}, the cooperative system obtains 2.5dB SNR gains, thus the requirements for declined indirectly. (2) By comparing with the curves in Fig.4(a) with those in Fig.4(b), we can indicate that the Rayleigh fading leads to the impairment of the system BER performance， in which case we have to rise the transmit power to compensate the side effect caused by the fading and further improve the BER performance as well as the communication reliability. (3) The DSP simulation effect is in some sense similar to but generally poorer than that in MATLAB since DSP is a practical simulation platform when MATLAB is actually an ideal simulation tools.



(a) BER vs. SNR, AWGN,
Perfect inter-user channel

(b) BER vs. SNR, Rayleigh fading,
perfect inter-user channel

Fig.4: BER curves simulated in AWGN and Rayleigh fading channel

(2) Information transmission rate analysis

The overall clock period consumed during the simulation can be provided by the execution time statistical module embedded in CCS 3.3. Ours turns out to be 99 M clock cycles. Considering that TMS320C6416 works at 600MHz, the outcome of the system delay is 167ms and the corresponding information transmission rate is 618.4Kb/s, which can basically meet the demand of voice and medium speed communication system.

4. Implementation Issues

With the iterative proceeding of Turbo decoding algorithm, forward metrics A_k and the backward one B_k will be greater and greater before the LLRS can be calculated. When the iterative length comes to a certain length, the data flow naturally appears resulting in the performance worsening of the whole decoder. Consequently, data flow must be in consideration. The general way is to normalize these specifications to unity. However, the experimental simulation demonstrates that it will lead to divergence of Turbo decoding algorithm and that the decoding performance will worsen. As an alternative, the overflow can be eliminated through simultaneously subtracting A_k and B_k from a constant at certain recursion intervals. This proves to be rational.

$$LLR = \max_{m=0,1,\cdots,M}(A_k^1(m)+B_k^1(m)) - \max_{m=0,1,\cdots,M}(A_k^0(m)+B_k^0(m)) \quad (3)$$

As depicted in Eq. (3), we can come to the conclusion that the LLRs is determined by the separate difference of the variables A_k and B_k rather than the variables' original value. We can choose two available constants, say $A_k^1(0)$、 $B_k^1(0)$,and then update the variables A_k and B_k via the two following Eq.（4）and Eq.（5）:

$$A_k^i(m)' = A_k^i(m) - A_k^1(0) \quad (4)$$

$$B_k^i(m)' = B_k^i(m) - B_k^1(0) \quad (5)$$

With the knowledge that both the dynamic range of the variables A_k and B_k are finite, the newly updated A_k and B_k are mostly likely to fall within a tolerance that hardly overflow in the following manipulation.

5. Conclusions

In this paper we present an improved Turbo coded cooperation and have it implemented in MATLAB and DSP. It verifies that coded cooperation yields significant gain performance improvement due to the increased diversity provided by coded cooperation scheme. Besides, the DSP simulation effect in some sense approaches but slightly poorer than that in MATLAB. And the simulation results in DSP indicate that information transmission rate can basically meet the demand of voice and medium speed communication system.

6. Acknowledgement

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