Turbo Coded Cooperation using the Forced Symbol Method

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Abstract—Diversity is an effective technique in limiting the deleterious effects of fading, hence improving the data rate as well as the bit error rate performance. Transmit diversity is impractical in some scenarios where mobile units, due to size, hardware complexity and other constraints cannot accommodate multiple antennas. Recently, cooperative diversity has been introduced where single-antenna mobiles achieve uplink transmit diversity by relaying each other’s messages. A particularly powerful variation of this principle is coded cooperation which partitions the codewords of each mobile and transmits portions of each codeword through independent fading channels. Coded cooperation framework has been easily extended using turbo codes, since cooperative coding contains two code components. This paper presents an extension to turbo coded cooperation using the forced symbol method. Simulation results show that the proposed method outperforms the conventional turbo coded cooperation under different inter-user channel SNRs.

Index Terms— Cooperation, diversity, quasi-static fading, repeated decoding.

I. INTRODUCTION

The mobile wireless channel suffers from multipath fading, which causes the signal attenuation to vary significantly over a given transmission [1] and makes it extremely difficult for the receiver to determine the transmitted signal, unless the receiver is provided with some form of diversity. Transmit diversity methods have been studied extensively as a means to combat the deleterious effects of multipath fading in wireless fading channels [2]-[4]. Due to size, hardware complexity and/or other constraints, transmit diversity methods are not applicable to many wireless communication systems. For example in the uplink of a cellular communication system, where the size of the mobile is a limiting factor. However, most wireless systems operate in a multi-user scenario. Cooperation among users has been suggested in [5]-[7], where mobiles share their antennas to achieve uplink transmit diversity. Diversity is achieved by transmitting a user’s data through different paths. Coded cooperation proposed in [8] combines cooperative diversity with channel coding. In this scheme, cooperation occurs through puncturing a user’s codeword such that part of the codeword is transmitted by the user itself while the remainder of the codeword is transmitted by the partner. To avoid error propagation, detection is employed at the partner. An extension to the coded cooperation framework is presented in [9] where the application of turbo codes (TC) [10] in coded cooperation is investigated. The performance of turbo codes presents a flat part or error floor for moderate to high SNRs. It is known that the error floor of turbo codes mainly depends on the distance properties of the code. Several methods amongst which, increasing the minimum distance or free distance of the code determined by the interleaver can be used in order to reduce the error floor. The design of interleavers which produce high free distances is a tricky task. Previous works have been conducted in order to lower the error floor using various methods. In [11]-[13], a serial concatenation of high rate algebraic outer code was introduced. A method for reducing the error floor based on distance spectrum analysis is developed in [14]. This method gets rid of the contribution of lowest distances to the error performance at the cost of the code rate reduction. A new method has been proposed in [15] to lower the error rate without modifying the encoder and decoder structure, namely without changing the interleaver. This method termed Forced Symbol Method (FSM) also improves the error rate performance in the waterfall region. Prior to that, an earlier version of the FSM was introduced [16].

In this paper, we propose a turbo coded cooperation using the Forced Symbol Method in quasi-static fading. We show that the proposed scheme outperforms the conventional turbo coded cooperation introduced in [9]. The remainder of this paper is organized as follows. In Section II, we give a description of the forced symbol method [15]. The proposed scheme is then introduced in Section III and computer simulations are presented in Section IV. Finally, conclusions are drawn in Section V.

II. BACKGROUND

The FSM [15]-[16] improves the error floor as well as the waterfall floor region of turbo codes without modifying the encoder structure. This method requires the use of an error detection, and in this case, a CRC code is used. The use of CRC code leads to a small reduction in the code rate and SNR, which can be negligible if the frame length is long enough. In general, the use of an n-bit CRC in an N-bit information word length, reduces the code rate by a factor of

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We use a "genie" CRC here for error detection, that is, the decoded codeword is compared to the transmitted sequence and there is no reduction in the code rate. In [15], it is noted that the 16-bit CRC should provide essentially the same performance as the genie for improvements up to four orders of magnitude.

The FSM involves the following steps as described [15]. Firstly, the received sequence is decoded normally, that is, using a standard decoding algorithm (MAP, Log-MAP algorithms ...). Second, in the case of error detection, find a few positions in the decoded sequence, that are most likely to have bits in error, with order of the positions based on their increasing reliability values. The reliability values correspond to the a posteriori log-likelihood ratios (LLRs) i.e. intrinsic plus extrinsic values, produced on the last iteration by the turbo decoder. One at a time and in the increasing order of reliability values, each potential bit/symbol position that is found to have a bit/symbol error respectively is flipped to the opposite value obtained after the first decoding. The newly received codeword with forced bit or symbol is decoded once again. The decoding on the newly received codeword, obtained after each bit flipping is repeated until all candidate bit positions have been tested. The candidate bit positions can vary but should be less than the frame length. Another stopping criterion of the repeated decoding is based upon successful decoding. The iterative decoding in this method is allowed to use the new information, that is, the positions of least reliable bits obtained from the first decoding, to make better decisions. The use of this new information and the error detection allows for an improvement of the reliability of the soft output values, hence an improvement of the error performance. It should be noted that the FSM does not require the determination of all bits errors in the decoded frame, only a few probable bit errors. For more clarity, the pseudo-code of the FSM as proposed in [15] is repeated here.

Let \( u \) and \( y \) be the information frame and the received codeword respectively. For simplicity assume the use of antipodal signaling that maps the bit \( b \) to \((-1)^b\). Let \( E \) be a real number greater than \( d_{\text{min}} \). To force the turbo decoder to decide for the bit \( b_i \) at position \( i \) in \( u \), it is sufficient to insert the impulse \( I_i = (-1)^b E \) at position \( i \) in \( y \), in other words to flip the bit in the corresponding received codeword. Let \( \Omega \) be the set of positions in the decoded frame, \( \hat{u} \), that are most likely to have bits errors. Let \( L \) be the number of elements in \( \Omega \). The positions of interest are recorded in \( \Omega \) according to their increasing reliabilities (i.e. position \( \Omega(i) \) is more likely to have error than position \( \Omega(i+1) \)). In the sequel, \( j \) is the position of the bit forced to change or flip.

1. Set the noise variance \( \sigma^2 \), if it is required for iterative decoding;
2. Choose \( E \) (such that \( E > d_{\text{min}} \));
3. Iterative decoding of \( y \Rightarrow \hat{u} \);
4. If (error detected)

\[
\frac{N-n}{N}.
\]

\[
determine \Omega;
\]
\[
set i = 0;
\]
\[
while ((error detected) \text{ and } (i < L))
\]
\[
- set j = \Omega(i);
\]
\[
- set z = y(j);
\]
\[
- set y(j) = -(1)^{y(j)} E;
\]
\[
- \text{iterative decoding of } y;
\]
\[
- set y(j) = z;
\]
\[
set i = i + 1;
\]
end while

end if

III. IMPLEMENTATION OF FSM IN CODED COOPERATION

The implementation of coded cooperation using FSM is discussed in this section and shown in Fig. 1. Coded cooperation employed here uses the conventional turbo codes [9]. As shown in Fig. 1, the codeword of length \( N \) resulting from the first frame is obtained using the first Recursive Systematic Code (RSC) encoder [10] and sent together with the systematic bits in the first time frame by either user. It is assumed that the partner receives the other user’s bits in the same time frame and decodes using a soft Viterbi decoder. It will then check for errors. If it checks YES, it will then recalculate its second parity bits and send it to the destination in the second time frame. Otherwise, the user itself will recalculate its second parity bits and send it to the destination. In both cases, the destination receives the systematic, first and second parity bits and turbo decoding can be naturally used in this case to decode the received bits. FSM described above is used at the destination. The FSM algorithm can also be used at the partner, in order to improve the performance of the system.

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\text{Fig. 1. Implementation of turbo coded cooperation with the forced symbol method (FSM).}
\]

IV. SIMULATION RESULTS

In this section, we present the simulation results of the proposed scheme under quasi-static (slow) fading. Prior to that, performance results of the FSM applied to single binary turbo codes are presented. We use an eight-state turbo code with generator polynomials \((1, 15/13)\) and code rate 1/3. The information length is 1024 bits and the log-MAP algorithm is used with a maximum of 8 iterations. The transmission is assumed to be over an AWGN channel.
Fig. 2 shows the FER performance of turbo codes with FSM. We observe an improvement in the waterfall region. We denote by FSM(L), the error performance obtained by testing the least reliable L bits or symbols in the decoded sequence. The simulation results show that FSM(1) outperforms FSM(0) which is the standard decoding. FSM(16) outperforms FSM(4) and FSM(0) by 0.15dB and 0.5dB respectively. The overall code rate is $1/3$, with a 33% level of cooperation. The source block code length is 128 bits.

The turbo coded cooperation with FSM applied at the destination is implemented and the simulation results in Fig. 3 show that there is slight improvement, about 0.1dB gain at $10^{-4}$ under various inter-user SNRs channel. This is predictable, since the inter-user channel under various SNRs is not improved and remains the same as in the case of the conventional turbo coded cooperation. Fig. 3 shows the comparison of the FER performance between the conventional turbo coded cooperation and the turbo coded cooperation with FSM under various inter-user SNRs.

Instead of using the FSM algorithm at the destination, we apply the method at each user (two-user cooperation) in order to improve the inter-user channel quality. By doing so, the perfect inter-user channel SNR is considered as the bound for the proposed scheme, namely any inter-user channel (6dB or 12dB) performs better than the perfect inter-user channel. The FSM applied at the users is almost similar to the one applied at the destination. The algorithm used for the FSM is similar to the one described in Section II except that, in this case, the Viterbi decoding algorithm for convolutional codes is employed rather than the iterative decoding used for turbo codes. By applying the FSM at each user, we correct some bit errors, hence improve the quality of the inter-user channel. This means that, a 6dB inter-user channel with FSM at the users can perform as good as or better than 12dB inter-user channel not employing the FSM.

Fig. 4 shows the FER performance of the turbo coded cooperation with FSM at each user and the conventional turbo coded cooperation under 6dB inter-user channel SNR. The turbo coded cooperation with FSM(16) outperforms the conventional turbo coded cooperation with standard decoding by 3dB at high SNR values. This is an impressive improvement over the conventional turbo coded cooperation scheme.

Fig. 5 shows the FER performance of turbo coded cooperation with FSM at each user under the 6dB and 12 dB inter-user channels versus the conventional turbo coded cooperation scheme under the same inter-user channel SNRs including the perfect inter-user channel. It is noted that the 6dB inter-user SNR with FSM(16) performs as good as the 12dB inter-user channel with standard decoding for low to moderate SNR values and outperforms it for high SNRs by approximately 1 dB. The turbo coded cooperation with FSM(16) under the 12dB inter-user channel SNR performance as good as (overlap) the perfect inter-user channel, which confirms our predictions. We also note that the turbo coded cooperation with FSM(16) under the perfect inter-user SNR performs as the bound of the proposed scheme.

V. CONCLUSIONS

In this paper, a modified turbo coded cooperation scheme is proposed. This scheme combines turbo coded cooperation and the FSM. The proposed scheme presents some performance improvement over the conventional turbo coded cooperation when applied at the users. This works by flipping the bit that is likely to be in error and decode one more time (decode iteratively). By doing so, the inter-user channel improves, hence the FER performance improves as well. This improvement comes at a cost of some processing delay due to the additional FSM algorithm at the users or destination, requiring more decoding whenever a bit is in error.
Fig. 4. FER performance comparison between turbo coded cooperation with standard decoding and FSM under the 6dB inter-user channel.

Fig. 5. FER performance comparison of the turbo coded cooperation with standard decoding and FSM(16) under various inter-user channel SNRs.

REFERENCES


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