Enhanced Soft-Handover for DS-CDMA Systems using Complementary Error Correction Codes

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Abstract—In order to enhance soft-handover performance in the downlink of DS-CDMA systems, we propose to use different codes at the base stations in the active set to encode the information sequence targeted to a mobile station. For reliable information recovery, in case all links except one happen to be simultaneously in deep fade, self-decodable complementary punctured convolution codes, inspired from Hybrid ARQ III, are used. When turbo-decoding is feasible at the mobile station, new complementary codes, using different interleavers followed by a common systematic recursive convolutional encoder, are proposed for an additional enhancement in performance. Experimental evaluation of the enhancement in performance provided by complementary coding is carried for both Gaussian and multipath Rayleigh fading channels. The proposed coding schemes can provide very significant gains. In some cases, gains around 4 dB can be achieved.

Index Terms—Soft-handover, DS-CDMA, Complementary punctured convolutional codes, Turbo-coding.

I. INTRODUCTION

Soft-handover is used in DS-CDMA systems to increase network capacity and coverage and improve quality of service. During soft-handover, a mobile station (MS) near the cell boundary communicates simultaneously with two or more base stations, known as its active set, in order to provide more robustness against call dropping, reduce the generated multiple access interference, and increase coverage and capacity. In a conventional downlink DS-CDMA soft-handover, base stations in the active set use the same code to encode and transmit the information sequence targeted to a mobile station, in order to fight against shadowing and Rayleigh fading through macro-, micro- and multipath-diversity [1]. From an error correction coding point of view, using the same code in all base stations (BSs) in the active set to encode the transmitted information sequence can be viewed as trivial (spatial) repetition coding. For an additional enhancement of procured soft-handover gain, we propose in this paper to use different codes at the base stations, to encode the information sequences targeted to the mobile station in soft-handover. This novel proposal finds its roots in space-time coding and cooperative networking. On the one hand, in space-time coding, different multiple redundant copies of the information sequence are transmitted to the receiver, using multiple transmit antennas, with the hope that at least one of them survive deep Rayleigh fading and allow reliable decoding [2] [3] [4]. However, while space-time coding only provides micro- and multipath diversity, by using collocated antennas, soft-handover can even provide macro-diversity, when non collocated active set base stations antennas are used. On the other hand, in cooperative networking, single-antenna mobile stations share both antenna and different space-time signal processing in order to construct virtual multiple antenna arrays, allowing them to exploit spatial diversity for combating hostile fading channels. Nevertheless, in cooperating networks, non collocated cooperating mobile stations cannot relay other mobile stations information sequences if they are deemed to be receiver in error, while the base stations involved in a soft-handover receive errorless copies of the information sequence from the core network and unconditionally transmit them to the mobile station.

In this work, we first expose the complementary punctured convolutional (CPC) codes inspired from HARQ III. The aim of using CPC codes is to take benefit from their complementarities. We use non identical self-decodable CPC codes in all active set BSs, avoiding by the way any repetition coding. We also propose in this paper, new complementary codes based on recursive systematic convolutional (RSC) codes and interleaving. These codes are intended for MSs with turbo-processing capabilities.

The use of different coding schemes at the BSs (different puncturing for CPC codes and different interleaving for our new complementary codes) requires extra signaling between the radio access network and the MS, which can be implemented in the same way as in adaptive modulation and coding in HSDPA, where extra signaling is used to chose adequate modulation and coding, based on transmission link quality.

The paper is organized as follows. Section II describes the transmission system model in conventional soft-handover. In section III, we describe the CPC codes. Section IV describes the new complementary codes based on RSC codes and their use in soft-handover. The system performance over Gaussian and Rayleigh channels are presented in section V. Finally, section VI draws some conclusions.

II. SOFT-HANDOVER SYSTEM MODEL

In conventional soft-handover, involved base stations in the active set of an MS send the same copies of the coded packets,
and as such can be viewed as trivial spatial repletion coding. This repetition coding ensures macro- and micro-diversity. In case all links except one happen to be simultaneously in deep fade, the receiver can decode the received packet. The number of base stations involved in soft-handover can reach up to six base stations collocated or no collocated BSs. To illustrate the principles of our coding approaches and evaluate their performance, we concentrate on active set with only two BSs. Notice that active sets with two BSs are the most common and the easiest to study. Our approaches can be easily extended to active sets with more than two BSs. To illustrate the principles of our coding approaches and evaluate their performance, we concentrate on active set with only two BSs. Notice that active sets with two BSs are the most common and the easiest to study. Our approaches can be easily extended to active sets with more than two BSs.

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In this section, we present the characteristics and construction of the CPC codes to be used later in this paper to assess the gains achieved by our concept. The new complementary codes, based on RSC and interleaving, will be presented in the next section. CPC codes are derived from a rate \( \frac{k}{n} \) convolutional code called original code. The original code is a conventional convolutional code with constraint length \( K \) and memory \( m = K - 1 \). The CPC codes extracted from the original code must satisfy the equivalence and complementary criteria stated below.

### III. Complementary Punctured Convolution Codes

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#### A. Equivalent Punctured Convolutional Codes

A punctured convolutional code can be obtained from an original code by deleting some bits from the each coded packet according to a puncturing pattern represented by a puncturing matrix \( P \). We obtain a new code with rate \( \frac{p}{w(P)} \), where, \( p \) is the number of columns of \( P \) and \( w(P) \) is the Hamming weight of \( P \).

Two punctured codes are said to be equivalent if the columns of the puncturing matrix of one code are cyclically shifted versions of the columns of the puncturing matrix of the other code [5]. In this study, we choose a rate 1/2 original code and apply different puncturing patterns to obtain rate 5/6 codes of puncturing matrices

\[
P_1 = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 \\ 1 & 0 & 0 & 1 & 1 \end{pmatrix} \quad P_2 = \begin{pmatrix} 0 & 1 & 1 & 1 & 0 \\ 1 & 1 & 0 & 0 & 1 \end{pmatrix}
\]

and

\[
P_3 = \begin{pmatrix} 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 \end{pmatrix}
\] (1)
are equivalent.

Equivalent codes have the same distance properties and hence yield the same error correction performance. With a puncturing matrix of p columns, one can construct at most p distinct equivalent codes.

B. Complementary Punctured Convolutional Codes

Let \( C_i, i=1,2, \ldots, r \), be \( r \) equivalent codes and let \( P_i \) be the puncturing matrix associated to code \( C_i \). Define the matrix \( P \) as

\[
P = \sum_{i=1}^{r} P_i
\]

(2)

The \( r \) codes \( C_i, i=1,2, \ldots, r \), are said to be complementary if every element of matrix \( P \) is greater than or equal to 1. This means that when the complementary codes are combined together, the resulting code, with puncturing matrix \( P \), contains the original rate. As an example, consider the rate 5/6 punctured code obtained from a rate-1/2 original code with puncturing matrix \( P \). The RSC code derived from the conventional NRNSC code specified by the generating polynomials \( g_1 = [1011] \) and \( g_2 = [1101] \), or, equivalently, in compact form, \( G = [g_1, g_2] \). The RSC encoder associated to this NRNSC encoder is represented by \( G = [1, g_2/g_1] \).

When we use interleaving prior to RSC encoding at one of the two base stations in the active set, the resulting encoding scheme could be interpreted as a turbo encoding scheme [6]. Accordingly to this global turbo-encoding structure, it is necessary to perform turbo-decoding to keep a reasonable decoding complexity at the MS.

B. Decoding

The general structure of the iterative turbo-decoder is shown in Figure 5. In this figure, two component decoders are linked by interleavers. Each decoder takes three inputs: the observations of the systematic bits, the observations of the parity bits of the corresponding component encoder and the extrinsic information from the other component decoder. Each component decoder provides soft outputs for the decoded information bits.

![Fig. 4: RSC code with \( r = 1/2 \) and constraint length \( K = 4 \)](image)

The decoder operates iteratively. In the first iteration the first component decoder takes exclusively the observations at the output of the channels, and produces soft outputs for the information bits. Subsequently, these soft outputs are used, as additional information, by the second decoder to calculate more reliable soft outputs of the information bits. In the second iteration, the first component decoder decodes the channel observations with now with additional extrinsic information computed from the soft outputs generated at the first iteration by the second decoder. Afterwards, the second decoder uses the extrinsic information immediately provided by the first component decoder. This cycle is repeated a given number of times, which can be increased to improve performance. To keep complexity reasonable, we use 8 iterations in our work.
Many decoding algorithms, like the Maximum A Posteriori (MAP), Log-MAP or Max-Log-MAP algorithms could be used for turbo-decoding at the MS. However, for implementation complexity, we restrict ourselves to the simpler Soft-Output Viterbi Algorithm (SOVA) [8] [9].

In this paper, we combine the observations of the systematic bits coming from both BSs to compute the systematic information needed at the input of each component decoder. Optimal combining is achieved using MRC.

As in the case of complementary punctured convolutional codes, our new complementary codes do not lead to any extra complexity. First of all, the coding process in the BSs is simplified since basic RSC coding is used instead of more complicated conventional turbo-coding. Secondly, in the MS, the iterations of the turbo-decoding process use the same trellis and almost the same branch metrics and metric computations as in the conventional case.

V. SIMULATION RESULTS

In this section we discuss the performance of the proposed coding schemes showed by the simulation results. In our performance evaluation, we consider successively an AWGN channel and a multipath Rayleigh fading channel.

The two CPC codes, with puncturing matrices \( P_1 \) and \( P_3 \), given in (1), are assumed to be used in the two BSs of the active set. The received signals from both BS1 and BS2 can be expressed as

\[
r_k^1 = \sqrt{E_1} s_k^1 + n_k^1 \quad \text{and} \quad r_k^2 = \sqrt{E_2} s_k^2 + n_k^2
\]

where \( s_k^i \) is the normalized energy QPSK symbol transmitted during the \( k \)-th symbol period by the \( i \)-th BS, \( n_k^i \) is a complex additive white Gaussian noise with variance \( N_0 \), \( E_i \) is the symbol energy and \( E_{b_i} = E_i/2 \) is the binary energy.

To assess the achieved diversity gain when one of the links between the BSs and the MS happens to be in deep fade, we use different BSs’ symbol energies and measure this difference as

\[
\delta = 10 \log_{10} \left( \frac{E_1}{E_2} \right)
\]  

We simulate the bit error rate (BER) as a function of the signal-to-noise ratio \( E_{b1}/N_0 \), taken relatively to the first BS, and take \( \delta \) as parameter.

Figures 6 and 7 compare the performances of the conventional soft-handover and the proposed CPC coding scheme, on the AWGN channel. From these figures, we notice that the proposed coding scheme using CPC codes provides a noticeable enhancement in performance, in terms of BER, relatively to the conventional single code soft-handover. Indeed, the proposed coding scheme achieves about a 3 dB gain for cases \( \delta \) between 0 and 3 dB. When \( \delta \) becomes large, the MS connection is practically established with one and only one BS, namely BS1. Hence, as can be expected, the provided gains with respect to conventional soft-handover coding are reduced. Fortunately, only values between -3 and +3 dB are allowed in practice during the soft-handover state.

![Fig. 6: BER performance for a single code and two complementary codes with puncturing matrices \( P_1 \) and \( P_3 \) operating on AWGN channels with \( \delta = 0 \) and 2 dB](image)

Figures 8 and 9 show the performances on a multipath Rayleigh fading channel. We take different values for the mobile speed \( v \) and set the carrier frequency to 2 GHz, to examine the Doppler effect on the received signal. These figures show that, in the presence of a Rayleigh channel, the proposed coding scheme provides better performances than the conventional case. In the presence of multipath Rayleigh channel, we observe larger gains than Gaussian case. Gains around 4 dB are achieved. In other hand, when the mobile speed increases, the achieved gain increases.

![Fig. 7: BER performance for a single code and two complementary codes with puncturing matrices \( P_1 \) and \( P_3 \) operating on AWGN channels with \( \delta = 3 \) and 20 dB](image)

Now we study the proposed new complementary codes based on codes RSC codes preceded by an interleaver in one of two base stations of the active set. We compare the proposed coding scheme with a turbo coding using the same RSC with \( K = 4 \) at both BSs and convolutional code with the same decoding complexity, with generating polynomials \( G_1 = 561 \) and \( G_2 = 753 \), and constraint length \( K = 9 \). We show in figures 10 and 11 the performances of the three coding schemes on the AWGN channel. We consider a packet of 1000 information bits and use random interleaving [10] in order to benefit from the turbo effect.

Figure 10 and 11 show the performances of the proposed coding scheme based on RSC, compared to a turbo coding...
Fig. 8: BER performance for a single code and two complementary codes with puncturing matrices $P_1$ and $P_3$ operating on Rayleigh channels with, $v = 10$ Km/h, and $\delta = 0$ dB

Fig. 9: BER performance for a single code and two complementary codes with puncturing matrices $P_1$ and $P_3$ operating on Rayleigh channels with, $v = 60$ Km/h, and $\delta = 0$ dB

(TC) and convolutional coding (CC). These figures show that, the proposed RSC coding scheme achieves a gain of 0.5 dB compared to turbo coding scheme with the same rate and the same order of complexity in the presence of soft-handover. The proposed RSC coding scheme also shows an improvement in performance compared to the convolutional code since a gain of 1.6 dB is achieved at a BER of $10^{-5}$.

VI. CONCLUSION

In this work, we have proposed two coding schemes in soft-handover, whereby different complementary codes are used at the BSs of the active set of an MS. We have compared each coding scheme to its counterpart in conventional soft-handover. For the first coding scheme which uses complementary punctured convolutional codes case, we have shown significant gains compared to conventional soft-handover convolutional coding, in the presence of Gaussian and Rayleigh channels. For the second coding scheme, composed of new complementary codes based on recursive systematic convolutional coding and interleaving, we have obtained smaller but still interesting performance gain with respect to conventional UMTS turbo-coding and convolutional coding with the same complexity.

REFERENCES


