Adaptive rate coding for wideband CDMA Wireless networks

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ABSTRACT

One method of optimizing throughput for a wireless system while maintaining a certain level of performance is to design the error control system so that it offers two or more different rate codes. The system uses channel-state information to determine which of the various codes should be used at any given moment. In order to minimize system complexity, the same encoder and decoder are used for the different rate codes. This paper presents a method of comparing the performance of the system for different rate convolutional codes. Results will show the optimal code rate for various channel conditions and the gain in throughput by using adaptive rate codes in a wideband CDMA system.

I. INTRODUCTION

Wideband CDMA (WCDMA) is defined as a direct sequence spread spectrum multiple access (DS-CDMA) scheme where the information is spread over a bandwidth of approximately 5 MHz or more. In the search for the most appropriate multiple access technology for third generation wireless systems, a number of new multiple access schemes have been proposed. WCDMA is one of the air interface technologies selected for the third generation wireless systems [1].

The nominal bandwidth for all third generation (3G) proposals is 5 MHz. The reasons for choosing this bandwidth are (i) data rates of 144 and 384 Kbps, which are the main targets of 3G systems, are achievable within 5 MHz bandwidth with a reasonable capacity, (ii) lack of spectrum calls for reasonably small minimum spectrum allocation, especially if the system has to be deployed within the existing frequency bands occupied already by second generation systems, and (iii) the 5 MHz bandwidth can resolve (separate) more multipaths than narrower bandwidths, increasing diversity and thus improving performance[1].

The first and foremost challenge in the design of a digital cellular system is the efficient usage of the available spectrum to accommodate the ever-increasing number of users. It should be kept in mind that this should be achievable with no loss in power or transmission quality. The nature of a mobile wireless channel varies with (i) signal-to-interference plus noise (SINR) ratio, (ii) path loss and (iii) multipath interference.

Error control codes are used to format the transmitted information so as to increase its immunity to noise. The increase in immunity to noise is accomplished by inserting controlled redundancy into the transmitted information stream (either as additional bits or as an expanded channel signal set), allowing the receiver to detect and possibly correct errors. The amount of redundancy inserted is usually expressed in terms of the code rate $R$. The code rate is the ratio of the number of data symbols ($k$) transmitted per code word, to the total number of symbols ($n$) transmitted per code word. Convolutional codes and concatenated convolutional codes (or Turbo codes) have been proposed for the WCDMA systems. This paper will focus on the use of convolutional codes.

Fixed rate coding provides coding for worst case performance using a fixed code rate. The disadvantage with fixed rate coding is that bandwidth is wasted for good channel conditions. Moreover fixed rate coding fails to adapt to the time varying nature of the mobile radio channel. The code rate needs to be changed according to channel conditions to keep the performance or throughput at a desired level. To maximize performance on a time-varying channel, adaptive rate schemes are employed.
II. SYSTEM PERFORMANCE

Communication between two parties using convolutional codes consists of the exchange of a single code word of unbounded length. The decoder actually releases information bit estimates before the entire convolutional code word has been received. Because of these reasons, the analysis of the performance of convolutional codes focuses solely on the instantaneous bit error rate (bit error rate), which is defined as the average number of erroneous information bits emerging from the decoder per information bit decoded. This paper will present the upper bounds on the decoded bit error rate for an Additive White Gaussian Noise Channel (AWGN).

The source-to-sink transmission $T$ of a signal flow graph is the “signal” appearing at the sink node per unit signal input at the source node. The generating function, or weight enumerator of the encoder graph is given by

$$T(X, Y) = \sum_{i=1}^{\infty} \sum_{j=1}^{\infty} a_{i,j} X^i Y^j$$

where $a_{i,j}$ is the number of code words in the convolutional code with weight $i$ that corresponds to information sequences of weight $j$. Mason’s formula to determine the transmission of a signal flow graph is discussed in [2].

The transmission of a signal flow graph for a rate $-\frac{1}{2}$ convolutional encoder is given by

$$T(X, Y) = X^6 (Y + Y^3) + X^8 (3Y^2 + 5Y^4 + 2Y^6) + X^{10} (8Y^3 + 21Y^5 + 16Y^7 + 4Y^9) + ...$$

The above generating function tells us that there are two code words of weight 6: one corresponding to an information sequence of weight 1 ($X^6 Y$), the other corresponding to an information sequence of weight 3 ($X^6 Y^3$). There are then ten code words of weight 8, and 49 of weight 10, and so on.

Assuming that a BPSK modem is used for communication across an AWGN channel with one-sided noise spectral density $N_0$, the instantaneous bit error rate is given by

$$P_b \leq \frac{1}{k} e^{\frac{d_{\text{free}} E_b}{N_0}} \left( \frac{2d_{\text{free}} E_b}{N_0} \right) \left( \frac{\partial T(X, Y)}{\partial Y} \right)_{X=e^{-\frac{E_b}{N_0}}, Y=1}$$

where $d_{\text{free}}$ is the minimum Hamming distance between all pairs of complete convolutional code words, $E_b$ is the signal energy per binary symbol and $k$ is the number of inputs to the convolutional encoder [2].

III. RATE COMPATIBLE CONVOLUTIONAL CODES

A family of punctured codes is rate compatible if the code-word bits from the higher-rate codes are embedded in the lower-rate codes. Rate-compatible punctured convolutional (RCPC) codes are a subclass of punctured convolutional codes. They provide an efficient means of implementing a variable-rate error control system using a single encoder/decoder pair. The rate compatibility constraint increases the system throughput since in transition from a higher to a lower rate code, only incremental redundancy digits are retransmitted [4]. RCPC codes are suitable for applications where different levels of error protection are needed within an information sequence or block [5].

Puncturing is defined as the systematic deletion of one or more parity coordinates in every code word in a code. Puncturing is applied to convolutional codes in a very natural way: given a fixed encoder structure, higher-rate codes are achieved by periodically deleting bits from one or more of the encoder output streams. If the higher-rate codes are not sufficiently powerful to decode channel errors, only supplemental bits, which were previously punctured, have to be transmitted in order to upgrade the code. To obtain a better correction power of the code during transmission of an information frame, we need to change the code rate according to the channel conditions [3].
IV. CHANNEL ESTIMATION AND RATE ADAPTATION

For a specific communication channel, a channel state estimator (CSE) can estimate the nature of the channel. A punctured convolutional code is assigned to each channel state. During transmission, the CSE continuously estimates the current channel state, based on the number of erroneous bits received. Once the state of the channel has been estimated, the CSE makes a decision whether to change the code and the corresponding messages are sent to the encoder and the decoder [4].

One of the basic procedures for error control coding is FEC (Forward error correction). This procedure maintains a constant system throughput, though on channels with high error rates complex codes are required to keep the probability of uncorrected errors negligible. Adaptive error protection is obtained by changing the code rates. It is desirable to modify the code rates without changing the basic structure of the encoder and decoder. Punctured convolutional codes are ideally suited for this application. They allow almost continuous change of the code rates while the same decoder does the decoding. Changing the number of deleted digits varies the code rate. The disadvantage of punctured convolutional codes compared to other convolutional codes with the same rate and memory order is that the error paths can be typically long [4].

Adaptive rate coding is a promising method for error control on channels with time-varying statistics. If the code parameters are chosen according to the actual channel state, a specified error rate can be attained with a high throughput and without affecting the complexity of decoding. By applying punctured codes with variable code rate, the same encoder and the same maximum likelihood decoder with Viterbi algorithm are used [4].

V. SIMULATION RESULTS

This paper presents the variation of instantaneous bit error rate (BER), $P_b$ versus $E_b/N_0$. The received energy per code word bit $E_b$ varies with code rate $R$, though the received energy $E_s$ per information bit is a constant for different rates.

The two are related by the expression $E_b = RE_s$. In soft decision decoding, the received signals are sent directly to the decoder without being quantized. The minimum free distance, denoted by $d_{\text{free}}$ is the minimum Hamming distance between all pairs of complete convolutional code words. The bit error rate is plotted for different rate convolutional codes. It is observed that BER decreases as the code rate decreases. The optimum code rate optimizes system throughput, which is equal to the code rate, for a given error performance for given channel conditions.

VI. CONCLUSION

Choosing the optimum code rate, which produces a desired bit error rate, maximizes the throughput of a wireless system. We presented comparisons of the performance of rate compatible convolutional codes over an AWGN channel. These codes can be used in a wideband CDMA system. The gain in throughput increases as the code rate increases.

VII. FUTURE WORK

A channel estimator will be incorporated to estimate the nature of the channel. Depending on this estimate, the CSE makes a decision whether to change the code rate. RCPCs will be used for an adaptive rate coding technique in the wideband CDMA system. A constant encoder-decoder pair will be used for performing rate adaptation using rate compatible punctured convolutional codes. The gain in throughput will be measured for the different rate codes.

REFERENCES


