Joint Source and Channel Coding Based Rate Detection Scheme for Variable-Rate Data Transmission

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Abstract

In this paper, we propose a novel joint source and channel coding based rate detection algorithm for variable-rate data transmission in DS-CDMA communication systems. In the proposed algorithm, the rate sequence redundancy is exploited for further improving the false rate detection performance. We use voice transmission as an example and model the rate sequence from the vocoder's output as a first-order Markov process. Simulated results in terms of false rate detection rate in a one-path Rayleigh fading channel are presented.

1. Introduction

Direct sequence code division multiple access (DS-CDMA) is emerging as the predominant radio access technology for the third generation cellular communications systems [1-2]. The link capacity of a DS-CDMA system is mainly limited by the multiple access interference from other users transmitting at the same carrier frequency in the same and adjacent cells. DS-CDMA can make use of variable-rate data transmission to effectively reduce the mutual interference and as a result increase the link capacity. To avoid frame overhead, the rate information of transmitted data is not explicitly provided to the mobile stations in cellular communication systems like IS-2000 CDMA [2]. Therefore, a blind rate detection is required based on received frames of data on a frame-by-frame basis.

In recent years, several blind rate detection algorithms (BRDA) have been proposed for variable-rate data transmission systems (see, for example, [3]-[6]). In those BRDAs, it is implicitly assumed that the rate sequence is independent. However, it is found that for voice transmission, the rate sequence from a vocoder's output is strongly correlated. It has been known for some time that any redundancy in the source can be utilized to combat the effect of channel noise at the receiver. Techniques for utilizing the source statistics by the receiver are usually referred to joint source and channel coding (JSCC). In this paper, we present a new application of the JSCC concept, that is, a JSCC based Rate Detection Algorithm (JSCC-RDA) for variable-rate data transmission in the CDMA communication systems. In this JSCC-RDA, the rate sequence redundancy instead of the traditionally used bit sequence redundancy is exploited for improving the false rate detection performance of a basic BRDA like the one proposed in [3].

2. System Description

The forward traffic channel of Radio Configuration 1 in the IS-2000 CDMA standard [2] is used to illustrate the idea of the proposed JSCC-RDA. The block diagram of a JSCC-RDA for variable-rate transmission in DS-CDMA is shown in Fig.1. The 8 kbps Qualcomm Code Excited Linear Predictive (QCELP) vocoder is used as the source coder, which compresses input digitized speech into data frames at four variable rates depending on the voice activity. As given in Table 1, the four vocoder rates are 8550, 4000, 2000, and 800 bps. Before convolutional encoding, CRC and tail bits are added to the compressed speech data. The rate-1/2 convolutional code with the generating polynomial (751,563) is used. After the convolutional encoding, the data rates become 9600, 4800, 2400 and 1200 bps corresponding to the four vocoder data rates of 8550, 4000, 2000, and 800 bps, respectively. The code symbol repetition rate on the forward traffic channel varies with data rate. Code symbols are not repeated for 9600 bps data rate. Each code symbol at the 4800 bps data rate occurs two times. Similarly, each code symbol at the 2400 bps and 1200 bps data rate occurs four times and eight times, respectively. After the symbol repetition, the symbol rate is kept constant at 19200 bps regardless of the source data rate. After symbol repetition, the symbol sequence is interleaved to increase time diversity for the purpose of error correction. For simplicity, we make the usual assumption of infinite interleaving depth. In our simulation, however, the bit reversal interleaver specified in the IS-2000 CDMA standard is used. The interleaved frame is covered by a channel specific Walsh code of length 64. Then the Walsh-covered symbol sequence is quadrature-spread by the I-channel and Q-channel PN sequences and is QPSK modulated, as shown in Fig.1.

The Rayleigh fading channel based on Jakes' model [8] is considered in this paper. A matched filter rake receiver with the maximal ratio combining is employed to provide multipath diversity. Since no explicit rate information is transmitted, the data rate of the de-interleaved symbol sequence is first detected by a basic BRDA. In this study, the fine-tuned BRDA proposed by Cohen and Lou in [3], called Cohen's BRDA, is used. The output rate sequence of Cohen's BRDA is denoted by $\hat{\boldsymbol{r}}$. Conventionally, the received symbol sequence is decoded according to the detected rate $\hat{\boldsymbol{r}}$ of the basic BRDA. In this paper, the detected symbol sequence $\hat{\boldsymbol{r}}$ is fed into the JSCC decoder which exploits the rate sequence redundancy for further improving the false rate detection performance. This is based on the fact that for voice transmission, there exists a strong correction among neighboring data rates. The output rate sequence of the JSCC

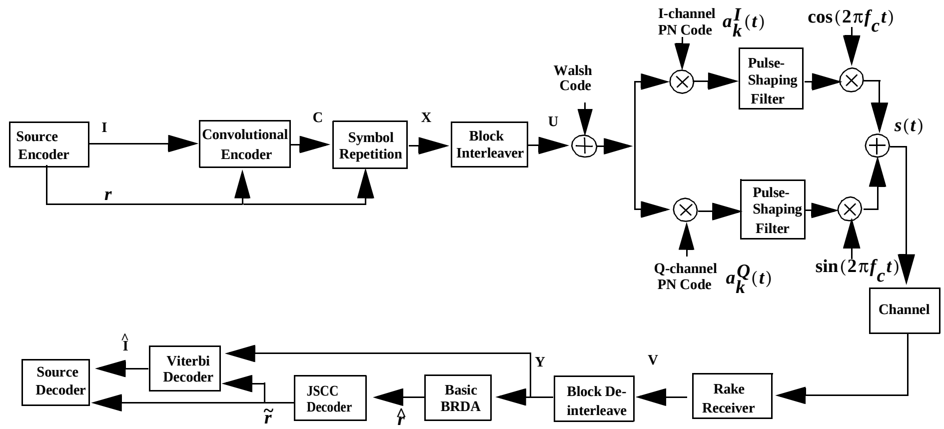

Fig.1 JSCC based rate detection for variable-rate transmission in DS-CDMA

decoder is denoted by $\tilde{\boldsymbol{r}}$. The received symbol sequence is decoded according to the detected rate sequence $\tilde{\boldsymbol{r}}$ of the JSCC decoder. Finally, the detected data rate $\tilde{\boldsymbol{r}}$ and the decoded bit sequence are fed to the source decoder for reconstructing speech.

In Fig.1, the vocoder acts as a joint source/channel coder. The vocoder is a source encoder because it generates a data rate sequence and compresses the digitized speech. It also functions like a channel encoder regarding the data rate sequence because the data rate sequence contains redundancy. The vocoder and the JSCC decoder are discussed in the following two sections.

Table 1: Variable traffic channel data rates

Rate Notation m	**Source Data Rate (bps)**	**Channel Data Rate (bps)**
1	8550	9600
2	4000	4800
3	2000	2400
4	800	1200

3. JSCC Encoder - Variable-Rate Vocoder

The 8 kbps QCELP vocoder [7] is used as the JSCC encoder. This vocoder produces a variable output data rate based on speech activity. The definition of data rates is given in Table 1. The rate notation of m=1, 2, 3, and 4 corresponds to the vocoder data rates of 8550, 4000, 2000, and 800 bps, respectively. For typical two-way telephone conversations, the average data rate is reduced by a factor of two or more with respect to the maximum data rate. The detailed description of the 8 kbps QCELP vocoder is provided in [7].

The QCELP vocoder uses an adaptive algorithm to determine the data rate for each frame. The algorithm computes the speech energy of the current frame, denoted by *R(0)*, and keeps a running estimate of the background noise energy, denoted by B_i. The data rate is then selected based on three thresholds which "float" above the background noise estimate. The detailed description of the three thresholds is given in [7]. Fig.2 shows an example of voice data rate generation. Fig.2 (a) represents a 5000 ms speech signal. Fig.2 (b) displays the estimated speech energy *R(0)*, the three rate decision thresholds, T_1, T_2, and T_3, and the background noise estimate B_i corresponding to the speech signal shown in Fig.2 (a). When no speech is present in the first 800 ms, the background noise estimate follows the input signal energy *R(0)*. As seen in Fig.2 (b), the estimated signal energy *R(0)* is below all the three thresholds and as a result the lowest rate (m=4) is selected during this period (see Fig.2 (c) in the first 800 ms). When a voiced sentence (from 800 ms to 2000 ms in Fig.2) sounds, the signal energy *R(0)* increases and surpasses the thresholds T_1, T_2, and T_3. In sequence, the selected rates are the third rate (m=3), the lowest rate (m=4), the full rate (m=1), and so on.

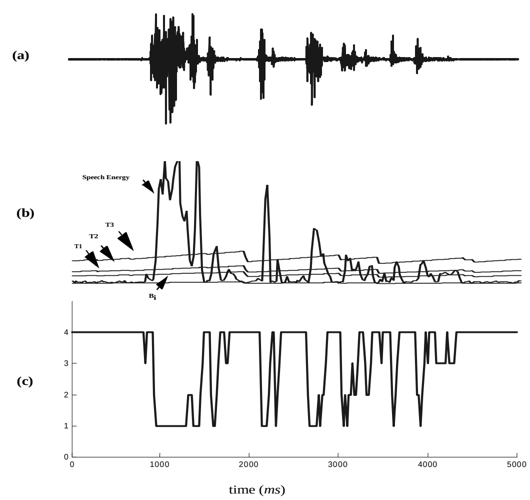

Fig. 2 An example of rate generation: (a) speech signal in 5000 ms, (b) speech energy, rate decision thresholds and background noise energy (c) data rate

For an input speech sequence, the QCELP vocoder generates a rate sequence, denoted as $\boldsymbol{r}=\{r_1, r_2, ..., r_i, ...\}$. Data rates of 8550 bps, 4000 bps, 2000 bps and 800 bps are denoted by r^1, r^2, r^3 and r^4, respectively. Let us denote the encoded rate sequence as r_i, where i is the rate index and $r_i \in \{r^1, r^2, r^3, r^4\}$. The rate sequence is generated using the 8 kbps QCELP vocoder based on two-way conversations.

The training sequence used to generate the rate sequence includes 16 minutes of male's and female's conversations. The rate transition probability is the probability of a current rate conditional on a previous rate, denoted by $p(r_i|r_{i-1})$. The current rate and the previous rate can be one of the four rates. Therefore, there are 16 entries in the rate transition probability matrix. The rate transition probability of the rate sequence generated from the QCELP vocoder is shown in Table 2.

The rate transition can be drawn in a trellis diagram as shown in Fig.3. A circle represents a rate and a branch represents a transition from one rate to another. Each branch is labelled with a rate transition probability. In structure, this rate transition diagram is similar to the trellis diagram representing a convolutional or trellis code.

Table 2: Rate transition probability

$P(r_i\|r_{i-1})$	r_i			
r_{i-1}	r^1=8550 bps	r^2=4000 bps	r^3=2000 bps	r^4=800 bps
r^1=8550 bps	0.9424	0.0576	0.0000	0.0000
r^2=4000 bps	0.2881	0.2494	0.4600	0.0000
r^3=2000 bps	0.2546	0.1626	0.2393	0.3436
r^4=800 bps	0.1282	0.1068	0.2479	0.5171

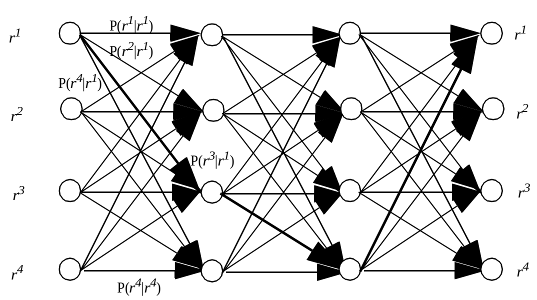

Fig. 3 Rate trellis diagram

4. JSCC Decoder

Due to the channel noise, the detected data rate $\hat{r}_i$ by the basic BRDA may not be same as the transmitted rate r_i. The cross-over probability between the transmitted and detected rates is denoted by $Q(\hat{r}_i|r_i)$, where $r_i, \hat{r}_i \in \{r^1, r^2, r^3, r^4\}$. Both a sequence maximum *a posteriori* (MAP) algorithm and an instantaneous MAP algorithm [9] can be used in the JSCC decoder. The sequence MAP decoder introduces a large delay while the instantaneous MAP decoder does not introduce any extra delay. Due to the delay constraint, therefore, the instantaneous MAP algorithm is used in our JSCC based rate detection scheme.

The instantaneous MAP decoder makes a decision on $\tilde{r}_n$ as soon as $\hat{r}_n$ is received. This problem was studied for vector quantization by Phamdo and Farvardin in [9]. The algorithm is briefly described as follows. The most probable transmitted rate at time n is

$$\tilde{r}_n = \arg \max_{\mathbf{r}_n \in R^n} Pr\{r_n|\hat{\mathbf{r}}_n\}\,. \tag{1}$$

where $R \in \{r^1, r^2, r^3, r^4\}$. (1) is equivalent to

$$\tilde{r}_n = \arg \max_{\mathbf{r}_n \in R^n} Pr\{\hat{\mathbf{r}}_n, r_n\}. \tag{2}$$

The objective function to be maximized at time n is denoted by

$$f^n(r_n) \equiv Pr\{\hat{\mathbf{r}}_n, r_n\}\,. \tag{3}$$

$f^n(r_n)$ can be expressed as the sum of the joint probabilities:

$$\begin{aligned} f^n(r_n) &= \sum_{\mathbf{r}_{n-1} \in R^{n-1}} Pr\{\hat{\mathbf{r}}_n, r_n, \mathbf{r}_{n-1}\} \\ &= \sum_{\mathbf{r}_{n-1} \in R^{n-1}} Pr\{\hat{\mathbf{r}}_n, \mathbf{r}_n\}\,. \end{aligned} \tag{4}$$

Each term in the summation can be expanded using the definition of rate transition probability

$$f^n(r_n) = \sum_{\mathbf{r}_{n-1} \in R^{n-1}} Pr\{\hat{\mathbf{r}}_n|\mathbf{r}_n\}Pr(\mathbf{r}_n)\,. \tag{5}$$

For a discrete memoryless channel, we can have the following:

$$f^n(r_n) = \sum_{\mathbf{r}_{n-1} \in R^{n-1}} \left(\prod_{i=1}^{n} Q(\hat{r}_i|r_i)\right)\left(\prod_{i=1}^{n} P(r_i|r_{i-1})P(r_0)\right). \tag{6}$$

Taking out the common factor $Q(\hat{r}_n|r_n)$ results in

$$\begin{aligned} f^n(r_n) &= Q(\hat{r}_n|r_n) \sum_{\mathbf{r}_{n-1} \in R^{n-1}} P(r_i|r_{i-1}) \times \\ & \sum_{\mathbf{r}_{n-2} \in R^{n-2}} \left(\prod_{i=1}^{n-1} Q(\hat{r}_i|r_i)\right)\left(\prod_{i=2}^{n-1} P(r_i|r_{i-1})P(r_0)\right). \end{aligned} \tag{7}$$

Comparing (6) and (7), we can see that the second summation in (7) is just $f^{(n-1)}(r_{n-1})$. Hence, the instantaneous MAP decoder can be implemented using the following recursion:

$$\begin{aligned} f^{(1)}(r_1) &= Q(\hat{r}_1|r_1)P(r_0), \\ f^{(n)}(r_n) &= Q(\hat{r}_n|r_n) \sum_{\mathbf{r}_{n-1} \in R^{n-1}} P(r_i|r_{i-1}) \times f^{(n-1)}(r_{n-1})\,. \end{aligned} \tag{8}$$

The most probable transmitted symbol at time n is:

$$\tilde{r}_n = \arg \max_{\mathbf{r}_n \in R^n} f^{(n)}(r_n). \tag{9}$$

Implementation of the instantaneous MAP decoder using the recursion (8) requires $2(S^2+S)$ words of memory for storing $P(.|.)$, $Q(.|.)$, $f^{(n)}(.)$, $f^{(n-1)}(.)$, S^2+S multiplications, S^2-S additions, and S-1 comparisons per unit time, where S is the number of data rates. The complexity in terms of memory locations, multiplications, additions and comparisons is given Table 3 for different data rate cases. If we consider each multiplication, addition or comparison as one operation, the required operations are 35 for four data rates or S=4. This is equivalent to 0.00175 MIPS given a 20 ms frame. This complexity is very minimal or negligible compared to the capacity of a digital signal processor used in mobile handheld devices, which commonly has over 50 MIPS of processing power.

Table 3: Complexity of instantaneous MAP decoder

Number of States *S*	Memory (words)	Number of Multiplications	Number of Additions	Number of Comparisons
2	12	6	2	1
4	**40**	**20**	**12**	**3**
6	84	42	30	5
8	144	72	56	7

5. Simulated Results

In this section, we present the results of a software simulation of the JSCC-RDA with Cohen's BRDA shown in Fig.1. The IS-2000 forward traffic channel system with Radio Configuration 1 in a one-path Rayleigh fading channel is used in this simulation. The one-path Rayleigh fading channel specified in the IS-2000 CDMA standard [10] is a standardized channel model for cellular communication systems. The Viterbi decoder with a maximum decoding depth of 96 is used. In compliance to the IS-2000 CDMA standard, two power control symbols are inserted into the modulation symbol stream in every power control group at the transmitter. The power control symbols are extracted from the received modulation symbol stream and replaced with the value of zeroes in the receiver side.

Simulated false rate detection rate (FRDR) of the proposed JSCC-RDA with Cohen's BRDA in the one-path Rayleigh fading channel is given in Fig.4, where the FRDR of Cohen's BRDA is labeled as "Cohen only", and the FRDR performance of Cohen's BRDA with the JSCC-RDA is labeled as "Cohen+JSCC". It is evident that the proposed JSCC-RDA significantly improves the FRDR performance of Cohen's BRDA. For example, there is about 2 dB gain in terms of the required E_b/N_t at an FRDR of 10^{-2} .

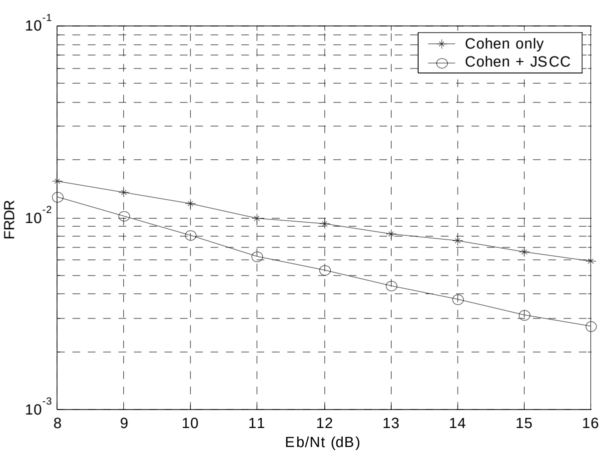

Fig.4 FRDR of JSCC-RDA with Cohen's BRDA in the one-path Rayleigh fading channel

6. Conclusions

In this paper, we have proposed a novel JSCC-RDA for improving the FRDR performance of a basic BRDA. This is a new application of the JSCC concept to the blind rate detection problem. The proposed JSCC-RDA is applied to Cohen's BRDA. It should be straightforward to apply the proposed JSCC-RDA to other basic BRDAs given in [4]-[6]. As seen in Fig.1, the JSCC-RDA can be viewed as a value-added device to any basic BRDA for improving the system performance in the presence of channel noise. Furthermore, the complexity of the JRDDDA is very minimal. Although the proposed JSCC-RDA is studied in the case of variable-rate transmission for voice application, the algorithm can be extended to other applications such as image and video.

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