A study on CRC-based blind rate detection in W-CDMA

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***Abstract*—In wideband direct sequence code division multiple access (W-CDMA) mobile radio, variable-rate data (VRD) services are supported to increase the link capacity. To recover VRD at a receiver, a cyclic redundancy check (CRC)-based blind rate detection scheme was proposed that does not require the transmission of any additional information. This paper proposes a modified CRC-based blind rate detection that improves the rate detection performance when different sizes of VRD blocks are transmitted frame by frame. If difference *D* in the number of bits between two possible VRD blocks becomes a very small value, the probability of false rate detection (PFRD) increases. The proposed method suppresses such an increase in the PFRD by time-reversing the VRD transmission order of the last *R* bits. Based on the performance evaluation of the proposed method by computer simulation, when *R* is set to *L* (CRC parity bit length), PFRD is reduced by 128 times for *R* = 8 and *D* = 2.**

Keywords-W-CDMA; variable-rate data; blind rate detection; cyclic redundancy check

I. Introduction

Wideband direct sequence code division multiple access (W-CDMA) was adopted by the 3rd generation cellular mobile radio communications system [1]. The CDMA radio link capacity is limited mainly by multiple access interference (MAI) from other users in the same and other cells. The amount of MAI depends on the aggregated data rate of different users. Hence, the use of variable rate transmission (the transmission data rate can vary frame by frame) can reduce the amount of MAI, thereby increasing the link capacity [2]. In W-CDMA mobile radio, variable-rate data (VRD) services (e.g., variable-rate voice codec to reduce the average bit rate) are supported. To recover VRD at a receiver, reliable detection of the data rate is necessary. The simplest rate detection scheme is based on the rate information that is transmitted in each frame; however, this reduces the transmission efficiency. A cyclic redundancy check (CRC) [3] based blind rate detection scheme was proposed that does not require the transmission of any additional information [4].

In this paper, a modified CRC-based blind rate detection method to improve the rate detection performance is proposed. The mechanism of the cause of false rate detection is discussed and a method for reducing the probability of false rate detection (PFRD) is presented. The performance of the proposed method is evaluated by computer simulation.

II. CRC-Based Blind Rate Detection Scheme

A simplified block diagram of the W-CDMA transmitter and receiver is illustrated in Fig. 1.

A. Transmitter

At the transmitter, the VRD block in the frame is CRC-encoded. The CRC parity bits are time-multiplexed immediately after each VRD block. The CRC is used to find the correct data rate, which is unknown to the receiver, from all possible data rates. The CRC-coded VRD block is channel coded using a rate-C convolutional code and then bit interleaved. The data channel frame structure before bit interleaving is shown in Fig. 2(a). The channel coded bit stream in a frame is written row by row into an interleaver and read out column by column, where the number of columns equals the number of slots in the frame, and each frame consists of J slots. Each column corresponds to a slot and comprises a pilot of $2N_{pilot}$ bits and the coded VRD of $2(N_{slot} - N_{pilot})$ bits. The pilot is used for channel estimation for coherent Rake combining at the receiver. The data channel frame structure after bit interleaving is shown in Fig. 2(b).

The interleaved bit stream is transformed into a quadrature phase shift keying (QPSK) symbol stream and spread by a spreading code sequence. For data transmission rates less than the maximum allowable rate, each slot is partially occupied (resulting in discontinuous transmission). Owing to this discontinuous transmission, the interference to other users is reduced with a lower rate transmission. The transmission timing must be randomly shifted from user to user so that the pilot bit positions do not coincide among the users and hence, the burst interference can be transformed into approximately random noise. The spread signal is then transmitted over a multipath channel.

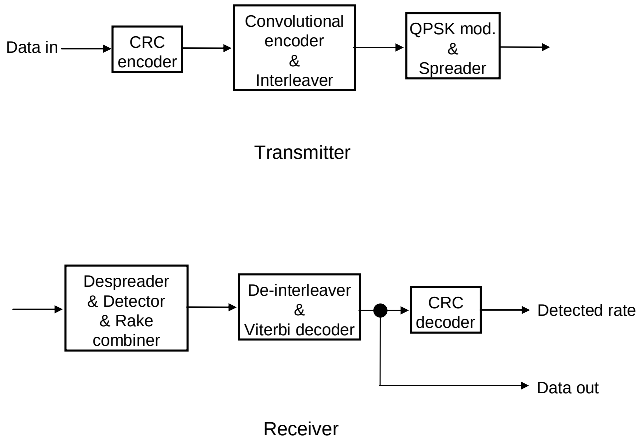
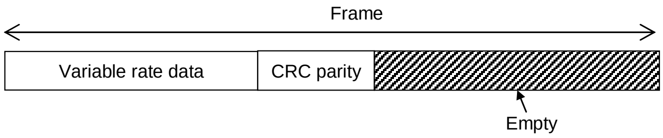
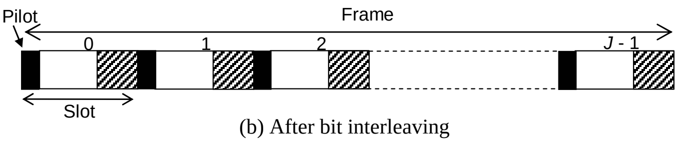


Figure 1. Block diagram of W-CDMA transmitter and receiver



(a) Before bit interleaving



(b) After bit interleaving

Figure 2. Data channel frame structure

B. Receiver

At the receiver, the received multipath QPSK signal is despread and resolved into N path components using a matched filter. A channel estimator estimates the n-th path complex path gain using the received pilot. At the Rake combiner, the received signal samples associated with the N resolved paths are weighted by the complex conjugate of their estimated path gains in order to remove fading-induced random phase variations and then they are summed coherently. The Rake combiner output samples are soft QPSK demodulated and then de-interleaved for subsequent soft decision Viterbi decoding.

C. Blind rate detection

Viterbi decoding is continuously performed, and at each possible end bit position, the surviving path ending at the 'zero' state is traced back to recover the hypothetical data sequence. The hypothetical data sequence at each end-bit position is error-detected by a CRC code and if no error is detected, that hypothetical data sequence is declared to be the correct sequence and Viterbi decoding stops. The data block with a rate having no CRC error is output as the received data block.

III. Probability of False Rate Detection (PFRD)

The PFRD with VRD transmission over a two-path (N = 2) Rayleigh fading channel with equal average power is evaluated by computer simulation. Other-user interference and transmit power control are not considered. Convolutional coding with the rate of 1/3 and a constraint length of seven bits was used. The spreading chip rate is 8.192 Mchip/s. One of the 128-chip orthogonal Gold sequences is used for spreading. Other parameters assumed in the simulation are J = 16, N_{pilot} =2, N_{slot} =40 for the frame length of 10 ms, and the slot length of 0.625 ms. Therefore, the simulated channel has the maximum allowable data rate of 36.2 kbit/s with the CRC parity of 16 bits. Here, we assume VRD transmission with eight rates, 4, 8, 12, 16, 20, 24, 28, and 32 kbit/s, where each rate occurred with equal probability and the numbers of VRD bits before convolutional encoding are 40, 80, 120, 160, 200, 240, 280, and 320, respectively.

A. PFRD

The simulated average PFRD is plotted in Fig. 3 as a function of the number, M, of possible rates with the CRC parity bit length, L, as a parameter for the total received signal energy per information bit-to-noise spectrum power density ratio (E_b/N_0) = 12 dB and the maximum Doppler frequency, f_D, of 64 Hz. The figure shows that if the CRC parity bits are time multiplexed immediately after the VRD block, the PFRD mainly depends on L and M. The larger L becomes, the smaller PFRD becomes and if M is increased, the PFRD increases.

B. Nearness block size effect

In the above simulation, the difference, D, in the number of bits between the two possible VRD blocks is 40 bits at minimum (i.e., much greater than L) for the case of eight variable rates (M = 8). On the other hand, if D becomes a much smaller value, the PFRD further increases even though both L and M do not change at all. We consider the case of D between two VRD blocks with 3^{rd} rate and 4^{th} rate changes from D = 40 bits by 1 to 10 bits when M = 8 and L = 14. Figure 4 shows the average PFRD for each candidate block size of 150, 151, 152, …, 158, and 159 bits instead of 120 bits for the 3^{rd} rate when the VRD with a 160-bit block (i.e., 4^{th} rate) is transmitted for all cases. Figure 4 shows that the PFRD approaches 0.5 when D decreases to one bit. This is called the "nearness block size effect" in this paper. Since the probability becomes smaller than 10^{-3}, the PFRD depends on L and M is not shown in Fig. 4.

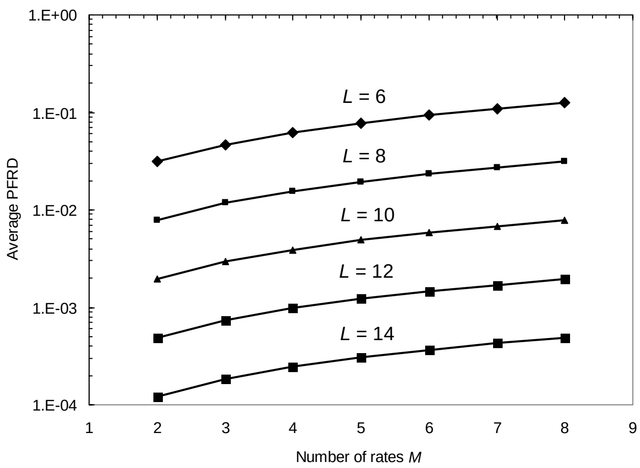


Figure 3. PFRD performance

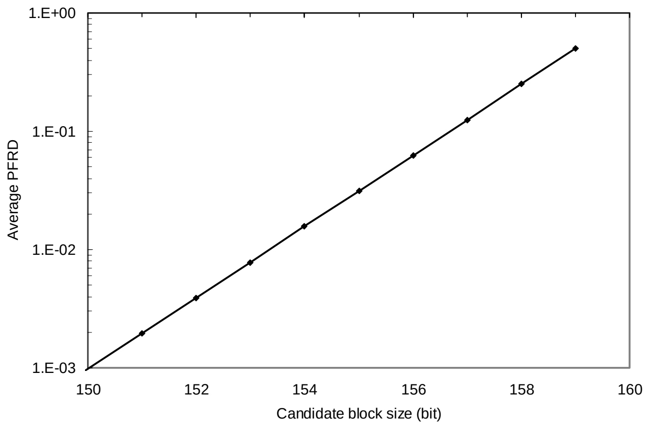


Figure 4. Increase in PFRD due to "nearness block size effect"

C. Mechanism of "nearness block size effect"

VRD bits and CRC parity bits are denoted by D_n, $n = 0$ to 7, and P_m, $m = 0$ to 3, respectively, and 8-bit VRD and 4-bit CRC parity ($L = 4$) are assumed. Here, we consider transmission of the data sequence (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1, P_0). First, we consider the case that VRD bits and CRC parity bits are transmitted in normal order.

If the end bit position is not correctly detected, the recovered data sequence should be incorrect. However, false detection occurs with some probability. If the detected VRD length is one-bit shorter (or the detected end bit position is one-bit shorter than the correct position), the Viterbi decoded data sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1). P_0 = "0" occurs with the probability of 1/2 if the transmitted data are random. Therefore, with the probability of 1/2, the data sequence (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1) is declared to be the correct sequence although this sequence is actually incorrect; thus, the PFRD is 1/2. On the other hand, if the detected VRD length is one-bit longer (or the detected end bit position is one-bit longer than the correct position), the Viterbi decoded data sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1, P_0, E_0). E_0 = "0" occurs with the probability of 1/2 since E_0 is a contribution from the noise. Therefore, with a probability of 1/2, the data sequence (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1, P_0, E_0) is declared to be the correct sequence although this sequence is actually incorrect; thus, the PFRD is 1/2.

The above investigation can easily be extended to the case of an arbitrary length for the detected VRD length. If the detected VRD length is D bits shorter or D bits longer, the PFRD becomes 2^{-D}. The results shown in Fig. 4 confirm the above analysis.

IV. METHOD FOR REDUCING PFRD

The technique for reducing the PFRD performance degradation due to the nearness block size effect is described below. The degradation due to the nearness block size effect is reduced by time-reversing the VRD transmission order of the last R bits (R >1) including the CRC parity bits. We consider the transmission of the data sequence (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_1, P_0). Before transmission, the transmission order of the last 2 bits is time-reversed as (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_0, P_1) at the transmitter.

If the detected VRD length is one-bit shorter, the Viterbi decoded data sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_0) at the receiver and the last 2 bits are re-time-reversed for CRC error detection. Then, the re-time-reversed sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_0, P_2). False detection will occur if $P_0 = P_1 = P_2$ = "0". This occurs with the probability of 1/8 if the transmitted data are random. On the other hand, if the detected VRD length is one-bit longer, the Viterbi decoded data sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_0, P_1, X_0) at the receiver and the last 2 bits are re-time-reversed for CRC error detection. Then, the re-time-reversed sequence becomes (D_7, D_6, D_5, D_4, D_3, D_2, D_1, D_0, P_3, P_2, P_0, X_0, P_1). The false detection will occur if $P_0 = P_1 = X_0$ = "0". This occurs with the probability of 1/8 if the transmitted data are random and since X_0 is a contribution from the noise. The above discussion shows that the PFRD can be reduced by a factor of 4 using time-reversed transmission.

The average PFRD that can be achieved using the proposed time-reversed transmission is plotted in Fig. 5 with the number, R, of bits to be time reversed as a parameter. The figure shows that as R becomes larger, the PFRD for each value of the difference, D, in the number of bits between the two possible VRD blocks becomes lower. Figures 3 and 5 show that if R is set to L, the PFRD due to the nearness block size effect is reduced by 128 times for $R = 8$ and $D = 2$. This time-reversed transmission with $R = L$ has been adopted in the W-CDMA-based 3rd generation mobile radio systems [5]. Furthermore, if more reliable VRD transmission is required, R can be set to a larger value than L. On the other hand, if the minimum difference in the block lengths is much larger than L, we do not need to consider employing such a time reversed transmission.

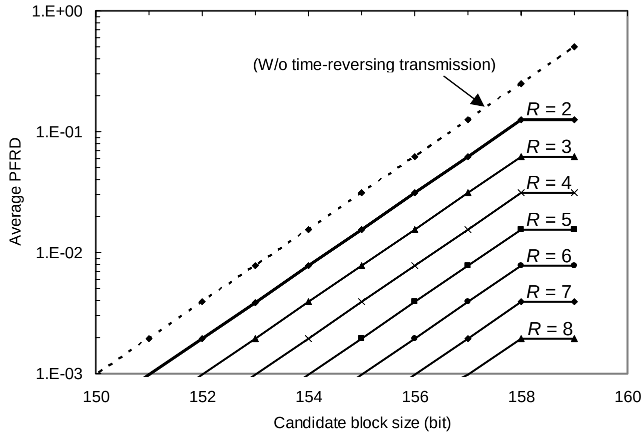


Figure 5. Effect of time reversed transmission

V. CONCLUSION

We investigated the false rate detection in the CRC-based blind-rate detection scheme for VRD transmission in W-CDMA mobile radio and revealed the mechanism of the false rate detection due to the nearness block size effect, i.e., the PFRD increases if difference D in the number of bits between two possible VRD blocks becomes a very small value. The PFRD is 2^{-D} for the case that the detected VRD length is D-bits shorter or longer. An effective method to reduce the false rate detection due to the nearness block size effect was proposed and time-reversing the VRD transmission order of the last R bits was applied in the method. From the performance evaluation of the proposed method by computer simulation, the reduction in the false rate detection dependent on R is confirmed. When R is set to L (CRC parity bit length), the PFRD is reduced by 128 times for $R = 8$ and $D = 2$.

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