Performance Analysis of Multimedia CDMA Network with Concatenated Coding and RAKE Receiver

Jae-Sung Roh, Choon-Gil Kim and **Sung-Joon Cho,** *Member, KIMICS*

Abstract**—**In order to transmit various types of multimedia data (i.e. voice, video, and data) over a wireless channel, the coding and modulation scheme needs to be flexible and capable of providing a variable quality of service, data rates, and latency. In this paper, we study a mobile multimedia CDMA network combined with the concatenated Reed-Solomon/Rate Compatible Punctured Convolution code (RS/RCPC). Also, this paper propose the combination of concatenated RS/RCPC coder and CDMA RAKE receiver for multimedia CDMA traffic which can be sent over wireless channels. From the results, using a frequency selective Rayleigh fading channel model, it is shown that concatenated RS/RCPC coder at the wireless physical layer can be effective in providing reliable wireless multimedia CDMA network. And the proposed scheme that combine concatenated RS/RCPC coder and CDMA RAKE receiver provides a significant gain in the BER performance over multi-user interference and multipath frequency selective fading channels.

Index Terms**—**multimedia CDMA traffic, concatenated RS/RCPC coder, CDMA RAKE receiver, multi-user interference, frequency selective Rayleigh fading channel.

I. INTRODUCTION

Advances in technology enable portable computers to be equipped with wireless interfaces, allowing networked communication even while on the move. Whereas today's notebook computers and personal digital assistants (PDAs) are self contained tomorrow's networked, and mobile computers are part of a greater computing infrastructure. Key problems are that these portable wireless network devices need to handle multimedia traffic in a dynamic and heterogeneous wireless environment, and the need to operate with limited energy resources.

Next generation communication systems are expected to provide high quality transmission in form of voice, data, image and video. Reliable transmission is required to achieve such high quality multimedia services. For example, a BER as low as 10^{-7} is required for asynchronous data transmission under the harsh wireless environment conditions. Thus, sophisticated FEC (Forward Error Correction) system is needed to provide wireless multimedia services. On the other hand, CDMA has been regarded as an important part of the next generation wireless multimedia network. The proliferation of personal communication networks and an increasing demand for multimedia communications stimulate the development of wireless multimedia networking. This trend is also noticeable in wireless CDMA networks [1]-[4].

Voice and data have much different requirements for wireless transmission [5], [6]. Voice is a small volume information, and some loss of information is acceptable. However, its allowable transmission delay is severely restricted. On the other hand, data have less stringent delay constraints, while no loss is acceptable. Thus we need a transmission method that meets these different requirements simultaneously in order to enable mixed transmission in wireless multimedia CDMA networks.

Another key issue we have to take into consideration in the design of wireless multimedia CDMA system is their low quality of communication channels. In particular, the transmission error caused by multipath is an important factor that affects the design of multimedia CDMA system. Mobile channel quality changes rapidly due to various factors. When the multimedia traffic are transmitted through these channels, it is indispensable to employ an error control scheme because reconstructed multimedia traffic quality are seriously degraded by channel error.

As is well known, the CDMA system capacity is interference limited [7]. In addition, a major problem in CDMA systems is the multi-user interference effect due to which a nearby interferer can disrupt the reception of a highly attenuated desired signal. As a result, interference control of the multiple access users in the CDMA system is required. Therefore, the actual quality of service (QoS) of a CDMA system is clearly a function of the number of active multiple access users as well as the tightness of the power control in the system.

This paper presents an approach to providing robust and efficient transmission scheme in mobile multimedia CDMA network. Our purpose is to provide good multimedia traffic quality most of the time and achieve the performance improvement of multimedia CDMA signal over fading conditions. To achieve high system capacity in the mobile multimedia CDMA system, low values of signal-to-noise plus interference power ratio (SNIR) are necessary, possibly resulting in a high bit error rate (BER) for short intervals. Transmission errors typically occur during short fade intervals. Since the transmission of the information bits is frame-based, a high BER results in high block error rate and hence the use of error control techniques, such as FEC, are often used for mobile channels [8]-[10].

In this paper, we have described the concept of FEC

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codes which are obtained from low rate convolution codes by puncturing them periodically in a rate-compatible manner. This puncturing restriction produced good codes relative to the best known codes of comparable complexity. In most transmission schemes, channel rate is fixed due to modulation and channel filter requirements, changing the code rate means a change of information rate and a buffer for the incoming information stream is required.

For wireless channels characterized by frequency selective Rayleigh fading, FEC alone is inefficient. Therefore, we apply the CDMA RAKE receiver to enhance the system performance and channel capacity.

The primary motivation for this work is to evaluate the BER performance of multimedia CDMA network over fading channels and in particular, to assess the performance of the concatenated RS/RCPC coder and CDMA RAKE receiver on multimedia traffic transmission quality.

II. ANALYSIS MODEL AND SNIR FOR MULTIMEDIA CDMA SYSTEM

Wireless communication is much more difficult to achieve than wired communication because the surrounding environment interacts with the signal, blocking signal paths and introducing noise and echoes. As a result wireless connections have a lower quality than wired connections: lower bandwidth, less connection stability, higher error rates, and, moreover, a highly varying quality. They need to be able to operate in environments that may change drastically – in short term as well as in long term – in available resources and available services. These factors can in turn increase communication latency due to retransmissions, can give largely varying throughput, and incur a high energy consumption. Wireless networking is a broad area, and has many applications ranging from voice communication (cellular phones) to high performance multimedia networking. In this paper we are somewhat biased towards multimedia CDMA traffic, as it is expected that the new generation of wireless networks will carry diverse types of multimedia traffic.

Three key problems in wireless multimedia networking are 1) to operate with limited energy resources, 2) the need to maintain QoS (throughput, delay, bit error rate, etc) over time-varying channels, and 3) to operate in a heterogeneous environment. These three problem-areas that are characteristic for future mobile networking are strongly correlated.

A. Analysis Model

We consider an asynchronous multimedia CDMA up-link system with K users and L Rayleigh faded paths for each user. The performance evaluation for wireless multimedia CDMA system with channel coding were carried out according to the system concept. Figure 1 shows the block diagram for the multimedia CDMA system under investigation.

In our system model, a serial binary bit sequence is input into the encoder block, which represents both RS and RCPC coder. Therefore, each transmitted information bit is encoded into a coded sequence. Concatenated RS/RCPC code schemes are applied for the transmission of the information data. The interleavers following the channel coder are used to randomize the error bursts in a transmitted data block so that the RS coder and RCPC coder, which are ideally suited to correct uncorrelated errors, can handle them better. In this analysis, we assume perfect bit interleaving and deinterleaving which means that the burst channel errors are independent during the transmission. We also assume perfect power control, thereby, implying that all the users have the same received power. After modulation and spreading, the encoded sequence is transmitted through a frequency selective Rayleigh fading and multi-user interference channel. At the receiving part, we apply a multi-finger CDMA RAKE receiver. Finally, each traffic sequence is reconstructed, possible distorted by transmission errors.

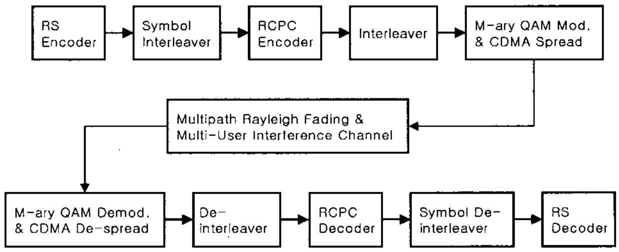

Fig. 1 Analysis model of multimedia CDMA system

B. Effective SNIR for Multimedia CDMA System

In [5], an approach was presented to study the BER performance of a voice only CDMA network. For applications where multimedia services need to be provided, there is a need for better understanding of the nature of the relationships between the different QoS requirements of the services in the system and capacity of each type of service. The work presented here provides a step in studying the interplay between different types of services in multimedia CDMA system.

We consider a CDMA network consisting of numerous mobile subscribers communicating with one base station (corresponding to a single cell). The subscribers can request voice calls as well as data calls. If the channel bandwidth is W, the approximated measure of the interference rejection capability is given by the processing gain $PN_d = W/R_d$ for data calls that are using the bit rate R_d. Similarly, the corresponding processing gain for voice is given as $PN_v = W/R_v$ where R_v is the bit rate allowed for voice. Furthermore, we will denote by K_d and K_v, the number of ongoing data calls and voice calls respectively. Since we are considering a mixed traffic (multimedia) system, typically each type of service may require a different QoS and, for this reason, we will denote the received bit energy due to each bit in a block by $E_{b,d}$ and $E_{b,v}$ for data and voice services.

We will consider a desired data user and treat all other data users as well as voice users as interferers. The selection of a desired data user is arbitrary since, without loss of generality, we assume all data users to belong to the same class of service. Based on the QoS requirement for data calls, we will formulate a condition for outage of data calls where the effect of voice calls is also considered. With direct sequence binary signal, we obtain the ratio of the despread bit energy to noise plus interference power at the desired user as

$$\left(\frac{E_b}{\eta}\right)_d = \frac{E_{b,d}/N_o}{1+\alpha+\beta} \tag{1}$$

$$\alpha = \frac{1}{PN_d}\sum_{i=1}^{K_d-1} a_{d-i}\, E_{b,d-i}/N_o \tag{2}$$

$$\beta = \frac{1}{PN_v}\sum_{j=1}^{K_v-1} a_{v-j}\, E_{b,v-j}/N_o \tag{3}$$

where, N_o is the background noise power spectral density and η is the total noise plus interference spectral density ($\eta = N_o + I_o$). The parameters PN_d and PN_v are defined by the ratio between the spreading bandwidth and the average bit rate: $PN_d = W/E[R_d]$ and $PN_v = W/E[R_v]$. The bit rate variability is in the a. The variables a_{d-i} for data user i and a_{v-j} for voice user j are defined as $a_{d-i} = R_{d-i}^{(c)}/E[R_d]$ and $a_{v-j} = R_{v-j}^{(c)}/E[R_v]$, where $R_{d-i}^{(c)}$ and $R_{v-j}^{(c)}$ are the current data and voice gross bit rates of user i and j, respectively. In other words, a is the current gross bit rate normalized with respect to the average gross bit rate.

III. ERROR RATE ANALYSIS OF MULTIMEDIA CDMA/M-ARY QAM SYSTEM

A. BER Analysis of Multimedia CDMA System in AWGN Channel

In order to analyze the performance of our system, we approximate the interference from other users as Gaussian noise and then apply the union upper bound on the bit error probability for multimedia CDMA M-ary QAM system in AWGN channel.

The BER of multimedia CDMA M-ary QAM in AWGN with square signal constellations and Gray encoding is well approximated at large E_b/η by

$$P_b = \alpha_M\, erfc\left(\sqrt{\beta_M \cdot k \cdot R_C \cdot E_b/\eta}\right) \tag{4}$$

$$\alpha_M = \frac{2}{\log_2 M}\left(1 - \frac{1}{\sqrt{M}}\right) \tag{5}$$

$$\beta_M = \frac{3}{2(M-1)} \tag{6}$$

where, E_b/η is the effective signal to noise plus interference power ratio, k is the number of bit ($k = \log_2 M$), and R_C is the code rate of channel coder. The effective signal to noise plus interference power ratio to be used in the bit error rate calculations is given by Equation (1).

B. Effects of RCPC Coder and RAKE Receiver

First, we consider the effect of RAKE receiver in frequency selective Rayleigh fading channel. In this case, the definition of the channel which changes to a wide-sense stationary uncorrelated scattering (WSSUS) frequency-selective Rayleigh-distributed fading channel with L number of paths. In mobile communication, multipath fading can cause a big loss in the signal strength. The fading loss can be compensated by special processing. First, part of fading loss can be compensated by efficient error correction coding. Second, if the delays, amplitudes and phases of the resolvable multipath signals can be estimated, then these signals can be combined in an optimum manner so that the SNR loss may be completely recovered. The technique is called diversity combining and the resulting receiver structure is called the RAKE receiver. The optimum receiver is the tapped delay line receiver shown in Fig. 2 This receiver coherently collects the signal energy from all the resolvable multipath signals that carry the same data and fall within the span of the delay time. The correlation functions are matched to the multipath fading signals. Therefore, the tapped delay line receiver of figure 2 is called the RAKE matched filter receiver.

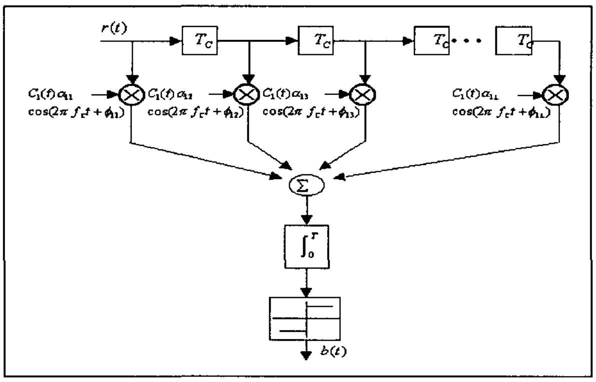

Fig. 2 RAKE matched filter receiver with demodulation

In order to assess the expression of fading channel, the probability density function (pdf) of γ must be determined. γ denotes the overall signal-to-noise plus interference power ratio at the output of the RAKE corresponding to the receiving antenna and is given by

$$\gamma = \sum_{k=0}^{L-1} \gamma_k \tag{7}$$

where, L is the number of fingers in the RAKE and γ_k is the signal-to-noise plus interference power ratio of the k-th path.

We can obtained from the pdf of γ, which is given by

$$f(\gamma) = \sum_{k=0}^{L-1} \frac{\pi_k}{\overline{\gamma_k}} \exp\left(-\frac{\gamma_k}{\overline{\gamma_k}}\right) \tag{8}$$

where,

$$\pi_k = \prod_{\substack{i=0\\ i\neq k}}^{L-1} \frac{\overline{\gamma_k}}{\overline{\gamma_k} - \overline{\gamma_i}} \tag{9}$$

The average signal-to-noise plus interference power ratio of the k-th path ($\overline{\gamma_k}$) is as follow.

$$\overline{\gamma_k} = \frac{\exp[-k \cdot \beta_d]}{\sum_{k=1}^{L} \exp[-k \cdot \beta_d]} \qquad (10)$$

where, β is the decaying index of MIP (Multipath Intensity Profile) channel model and $\sum_{k=1}^{L} \overline{\gamma_k} = 1$.

The bit error probability of M-ary QAM signal in frequency selective Rayleigh fading channel is obtained when the conditional error probabilities in (4) is averaged over the probability density function γ as follow.

$$P_{bf} = \int_0^{\infty} P_b \cdot f(\gamma) d\gamma \qquad (11)$$

Second, we consider the effect of RCPC code in fading channel. Variability in QoS might be due to the type of multimedia traffic, changes of the wireless link, re-routing of traffic due to handoff, and limited channel bandwidths. Issues relating to end-to-end QoS provisioning in wireless multimedia networks and interworking of PCS-to-ATM are discussed in [1]. Here, the focus is on BER performance of multimedia (mixed voice/data) CDMA system using RCPC coding at the radio physical layer. This type of RCPC coding scheme can support a broad range of QoS levels consistent with the requirements of multimedia services. Code rate puncturing is a procedure used to periodically discard a set of predetermined coded bits from the sequence generated by an encoder for the purposes of constructing a higher rate code. With the rate-compatibility restriction, higher rate codes are embedded in the lower rate codes, allowing for continuous code rate variation within a data frame. The performance of RCPC code on a fading channel is difficult to analyze satisfactorily except under ideal conditions such as the assumption of infinite interleaving. The theoretical BER performance results that are presented in this paper assume hard decision decoding, and no knowledge of the channel state information (YHAN). With the Viterbi decoding the usual optimality criterion is a large free distance d_{free}, a small number of paths a_d, and a small information error weight c_d on all paths with $d \geq d_{free}$. More specifically, one has Viterbi's upper bound to an error event probability

$$P_{E-RCPC} \leq \frac{1}{P} \sum_{d=d_{free}}^{\infty} a_d \cdot p_d \qquad (12)$$

and for the bit error probability

$$P_{b-RCPC} \leq \frac{1}{P} \sum_{d=d_{free}}^{\infty} c_d \cdot p_d \qquad (13)$$

where, P is the number of information bits per time unit, i.e. puncturing period, d_{free} is the free distance of RCPC code, p_d is the probability that the wrong path at distance d is selected. The so-called distance spectra $\{a_d\}$ and $\{c_d\}$, which should be as small as possible, depend only on the code structure. Tables of the RCPC codes for determining $\{a_d\}$, $\{c_d\}$, and P_d are presented in [9].

C. BER of Multimedia CDMA System with Concatenated Coder and RAKE Receiver

One special subclass of the BCH is the particularly useful nonbinary set called RS(Reed-Solomon) code. For RS codes the code minimum distance is given by $d_{\min} = R_n - R_k + 1$ where R_k is the number of data symbols being encoded, and R_n is the total number of code symbols in the encoded block. The RS code is capable of correcting any combination of t or fewer symbol errors, $t = (R_n - R_k)/2$.

Given the received effective signal to noise plus interference power ratio and a symbol deinterleaver is placed between the RCPC decoder and RS decoder to distribute the consecutive errors to different RS codewords. The total error probability of concatenated RS/RCPC code accounts for both decoder failure probability and decoder error probability. The BER of concatenated RS/RCPC code is then given by

$$P_{eb} \leq \frac{1}{2^k - 1} \left(\frac{2^{k-1}}{2^k - 1} \right) \sum_{i=t+1}^{2^{k-1}} i \binom{n_2}{i} P_S^i (1 - P_S)^{n_2 - i} \qquad (14)$$

where, $P_S = 1 - (1 - P_{b-RCPC})^k$ is the symbol error probability at the input of the RS decoder and P_{b-RCPC} is the BER at the output of the RCPC decoder. P_S is characterized by the effective signal to noise plus interference power ratio E_b/η and k.

IV. NUMERICAL RESULTS

In this paper, we investigate the performance of a FEC coding scheme that is based on concatenated RS/RCPC coding at the wireless multimedia CDMA system. From the analysis model, we compute the BER for the wireless mixed traffic, and the results are depicted in figures. For comparison, we consider the various system parameters.

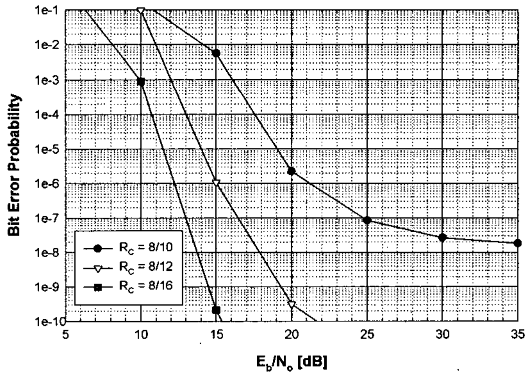

Fig. 3 BER performance of concatenated RS/RCPC coded DS/CDMA 16 QAM system according to the RCPC code rate (R_C) in frequency selective Rayleigh fading channel ($W = 10$ MHz, $R_d = 64$ kbps, $R_v = 9.6$ kbps, $K_d = 5$, $K_v = 10$, $L = 4$, $\beta = 0.1$, $t = 2$)

Fig. 3 shows the BER performance of concatenated RS/RCPC codes on multimedia (mixed data/video) CDMA 16 QAM system using basically the same encoder and the same Viterbi decoder with memory $M=4$, period $P=8$, and rates $R_C = P/(P+j)$, $j=2,4,8$ can cover a SNR between 13 and 25 dB to achieve a BER of 10^{-7}. This means that the same link can serve users with a gain variance of 12 dB by adaptively changing the rate between 8/10 and 8/16 at the expense of throughput.

Fig. 4 shows BER performance of concatenated RS/RCPC coded CDMA 16 QAM system employing RAKE receiver as a function of the number of RAKE fingers and average E_b/N_o in frequency selective Rayleigh fading channel. The number of RAKE fingers is assumed to be equal to the number of multipath components. The mean value of the multipath components is assumed to follow an exponential power delay profile, and a path-loss exponent value of 0.1 has been assumed. Also, the system performance improves as the number of RAKE fingers increases, but the incremental improvement decreases.

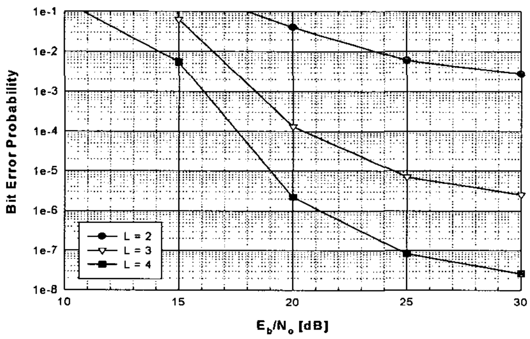

Fig. 4 BER performance of concatenated RS/RCPC coded DS/CDMA 16 QAM system according to the number of RAKE branch (L) in frequency selective Rayleigh fading channel ($W=10$ MHz, $R_d=64$ kbps, $R_v=9.6$ kbps, $K_d=5$, $K_v=10$, $R_C=8/10$, $\beta=0.1$, $t=2$)

Fig. 5 shows the average BER versus various number of error correction (t) in the RS code. Note that as the number of error correction increases, the BER performance of concatenated RS/RCPC coded multimedia CDMA 16 QAM system enhances quite rapidly.

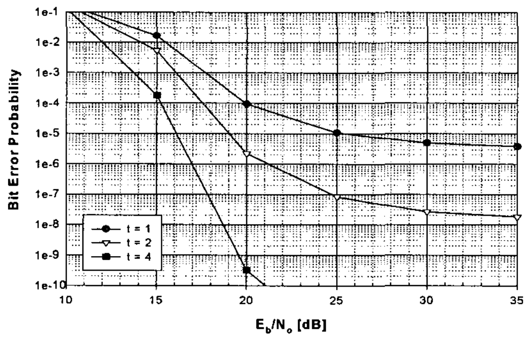

Fig. 5 BER performance of concatenated RS/RCPC coded DS/CDMA 16 QAM system according to the number of error correction (t) in frequency selective Rayleigh fading channel (W=10MHz, R_d=64kbps, R_v=9.6 kbps, $K_d=5$, $K_v=10$, $R_C=8/10$, $\beta=0.1$, $L=4$)

Fig. 6 shows the BER performance of concatenated RS/RCPC coded DS/CDMA 16 QAM system according to the decaying index of MIP channel model (β) in frequency selective Rayleigh fading channel. From the figure, as the decaying index (β) of MIP channel model decreases, the BER performance of concatenated coded multimedia CDMA system with RAKE receiver enhances.

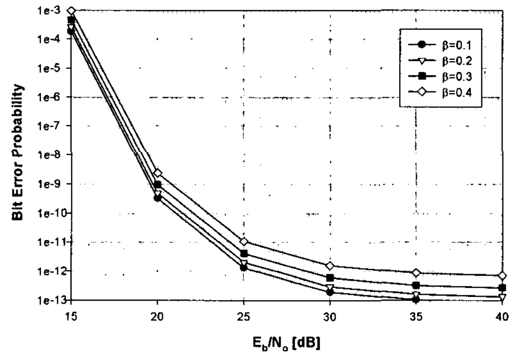

Fig. 6 BER performance of concatenated RS/RCPC coded DS/CDMA 16 QAM system according to the decaying index of MIP channel model (β) in frequency selective Rayleigh fading channel ($W=10$ MHz, $R_d=64$kbps, $R_v=9.6$kbps, $K_d=5$, $K_v=10$, $R_C=8/10$, $t=4$, $L=4$)

V. CONCLUSION

In this paper, we investigate the use of concatenated coding techniques for multimedia CDMA communication system over wireless channels. There has been considerable interest in using concatenated codes to achieve the low BER requirement in multimedia CDMA system.

In this paper, upper bound for concatenated RS/RCPC coded multimedia CDMA system is derived. And we have computed the bit error probability between various system parameters and concatenated RS/RCPC codes constraints. Voice and data have much different requirements for wireless transmission. Thus we need a transmission method that meets these different requirements simultaneously in order to enable mixed transmission of voice and data in wireless multimedia CDMA networks. Transmission errors typically occur during short fade intervals, and this paper presents an approach to providing robust and efficient transmission of mixed voice and data transmission. From the results, we know that the concatenated RS/RCPC coder provides a very flexible design methodology for error control of multimedia traffic in CDMA system. And the proposed scheme that combine concatenated RS/RCPC coder and CDMA RAKE receiver provides a significant gains in the BER performance.

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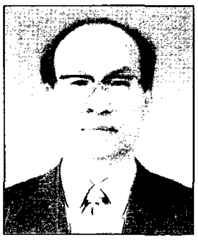

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