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# Removal of Multiple Access Interference in DS-CDMA System

Shrikant J. Honade[1] And Dr. P. V. Ingole[2]

[1](Lecturer, Department of E & TC, G.H.Raisoni College of Engineering & Management, Amravati)
[2](Principal, G.H.Raisoni College of Engineering & Management, Amravati)

***Abstract-*** Multiple access interference (MAI) is a factor which limits the capacity and performance of DS-CDMA systems. MAI refers to the interference between direct-sequence users. This interference is the result of the random time offsets between signals, which make it impossible to design the code waveforms to be completely orthogonal. While the MAI caused by any one user is generally small, as the number of interferers or their power increases, MAI becomes substantial. The conventional detector does not take into account the existence of MAI. It follows a single-user detection strategy in which each user is detected separately without regard for other users. Because of the interference among users, however, a better detection strategy is one of multi-user detection (also referred to as joint detection or Interference cancelation). Here, information about multiple users is used jointly to better detect each individual user.

***Index Terms-*** Multiple Access Interference, Parallel Interference Canceller, Successive Interference Canceller, Code Division Multiple Access, Time Division Multiple Access, Frequency Division Multiple Access, Direct Sequence Code Division Multiple Access, Multiuser Detection, Base Station, Decision Feedback Equalizer, Maximum Likelihood detection, Maximum A posteriori Probability, Linear Minimum Mean Square Error, Turbo Multiuser Detection.

## I. INTRODUCTION

### *1.1. Commercial CDMA System*

The Code Division Multiple Access (CDMA) offers many advantages over TDMA and FDMA. IS-95 CDMA allows each user within a cell to use the same radio channel, and users in adjacent cells also use the same radio channel, since this is a direct sequence spread spectrum CDMA system.

CDMA completely eliminates the need for frequency within a market.

Unlike other cellular standards, the user data rate (but not the channel chip rate) changes in real-time, depending on the voice activity and requirements in the network. Also,IS-95 uses a different modulation and spreading technique for the forward and reverse links. On the forward link, the base station simultaneously transmits the user data all mobiles in the cell by using a different spreading sequence for each mobile. A pilot code is also transmitted simultaneously and at a higher power level, thereby allowing all mobiles to use coherent carrier detection while estimating the channel conditions. On the reverse link, all mobiles respond in an asynchronous fashion and have ideally a constant level due to power control applied by the base station.

The speech coder used in the IS-95 system is the Qualcomm 9600 bps Code Excited Predictive (QCELP) coder. The original implementation of this vocoder detects activity, and reduces the data rate to 1200 bps during silent periods.

IS-95 is specified for reverse link operation in the 824-849 MHz band and 869-894 for the forward link. A PCS version of IS-95 has also been designed for international use in the 1800-2000 MHz bands. A forward and reverse channel pair is separated by 45 MHz for cellular band operation. Many users share a common channel transmission. The maximum user data rate is 9.6 kb/s. User data in IS-95 is spread to channel chip rate of 1.2288 Mchip/s (a total spreading factor of 128) using a combination of techniques. The spreading process is different for the forward and reverse in the original CDMA specification. On the forward link, the user data stream is led using a rate 1/2 convolution code, interleaved, and spread by four orthogonal ling sequences (Walsh functions). Each mobile in a given cell is assigned different link sequence, providing perfect separation among the signals from different users, at least for the case where multipath does not exist. To reduce interference between mobiles that use the same spreading sequence in different cells, and to provide the desired wideband spectral characteristics (not all of the Walsh functions yield a wideband power spectrum), all signals in a particular cell are scrambled using a pseudorandom sequence of length $2^{15}$ chips.

On the reverse link, a different spreading strategy is used since each received signal arrives at the base station via a different propagation path. The reverse channel user data stream is first convolutionally encoded with a rate 1/3 code. After interleaving, each block of six encoded symbols is mapped to one of the 64 orthogonal Walsh functions, providing sixty-four-ary orthogonal signaling. A final fourfold spreading, giving a rate of 1.2288 Mchip/s, is achieved by spreading the resulting 307.2 kchip/s stream by user-specific and base-station specific codes having periods of $2^{42}$ - 1 chips and $2^{15}$ chips, respectively. The rate 1/3 coding and the mapping onto Walsh functions result in a greater tolerance for interference than would be realized from traditional repetition spreading codes. This added robustness is important on the reverse link, due to the non-coherent detection and the in-cell interference received at the base station.

Another essential element of the reverse link is tight control of each subscriber's transmitter power, to avoid the "near-far" problem that arises from varying received powers of the users. A combination of open-loop and fast, closed-loop power control is

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used to adjust the transmit power of each in-cell subscriber so that the base station receives each user with the same received power. The commands for the closed-loop power control are sent at a rate of 800 bits/s, and these bits are stolen from the speech frames. Without fast power control, the rapid power changes due to fading would degrade the performance of all users in the system.

At both the base station and the subscriber, RAKE receivers are used to resolve and combine multipath components, thereby reducing the degree of fading. RAKE receiver exploits the multipath time delays in a channel and combines the delayed replicas of the transmitted signal in order to improve link quality. In IS-95, a three finger RAKE is used at the base station. The IS-95 architecture also provides base station diversity during "soft" handoffs, whereby a mobile making the transition between cells maintains links with both base stations during the transition. The mobile receiver combines the signals from the two base stations in the same manner as it would combine signals associated with different multipath components.

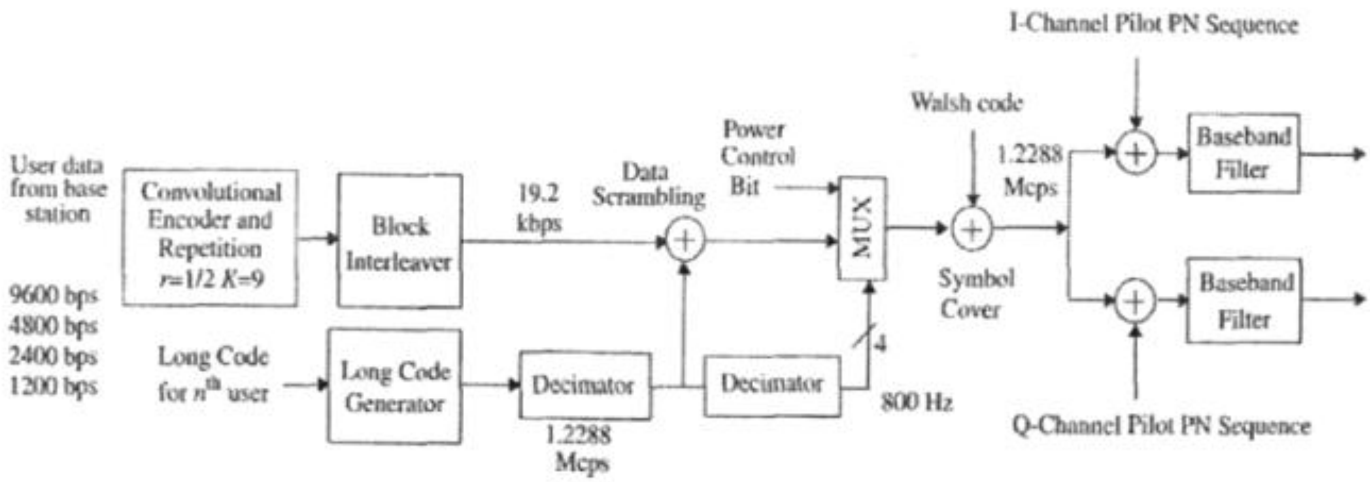


FIGURE 1.1: IS-95 FORWARD CHANNEL BLOCK DIAGRAM

*1.2 PROBLEMS IN CDMA SYSTEMS*

- A conventional DS/CDMA system treats each user separately as a signal, with other users considered as noise or MAI - multiple access interference
- Capacity is interference-limited.
- Near/far effect: users near the BS are received at higher powers than those far away.
- suffer degradation in performance.
- Need tight power control?

*1.3 MULTIUSER DETECTION*

- Multiuser detection considers all users as signals for each other for joint detection.
- Reduced interference leads to capacity increase.
- Alleviates the near/far problem.
- MUD can be implemented in the BS or mobile, or both
- In a cellular system, base station (BS) has knowledge of all the chip sequences
- Size and weight requirement for BS is not stringent

Therefore MUD is currently being envisioned for the uplink (mobile to BS)

*1.4 SUCCESSIVE INTERFERENCE CANCELLERS*

- Successively subtracting off the strongest remaining signal
- Cancelling the strongest signal has the most benefit
- Cancelling the strongest signal is the most reliable cancellation
- An alternative called the Parallel Interference Cancellers simultaneously subtract off all of the users' signals from all of the others
- Works better than SIC when all of the users are received with equal strength (e.g. under power control).

## II. LITERATURE REVIEW

*2.1 CDMA*

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One important property of the air interface of a cellular telephone system is the multiple access method. Each user of the cellular system is given a channel, and all users get different channels. The way in which these channels are different is determined by the multiple access method. .

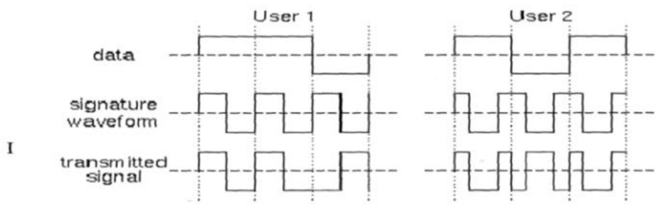


FIGURE 2.1: CDMA

In a cellular system employing Direct Sequence Code Division Multiple Access, all users use the same frequency at the same time. Before transmission, the signal from each user is multiplied by a distinct signature waveform. The signature waveform is a signal which has a much larger bandwidth than the information bearing signal from the user. The CDMA system is thus a spread spectrum Technique. All users use different signatures waveforms to expand their signal bandwidth. The procedure is depicted in fig. 2.1 for a two-user case. Notice the phase shifts in the transmitted signal is due to the negative pulses in the data stream.

*2.2 The conventional receiver*

At the base station, the sum of all the broadband signals is received. To demodulate signals from a specific user, the received signal is correlated with the signature waveform of that user. The procedure is illustrated in fig. 2.2 by correlating the sum of all the above signals with the respective signature waveforms. Under ideal conditions, the correlation between different signature waveforms is zero; in that case, the output of the correlator will be the transmitted signal of the desired user as depicted in fig. 2.2. This correlation receiver is known as the conventional receiver.

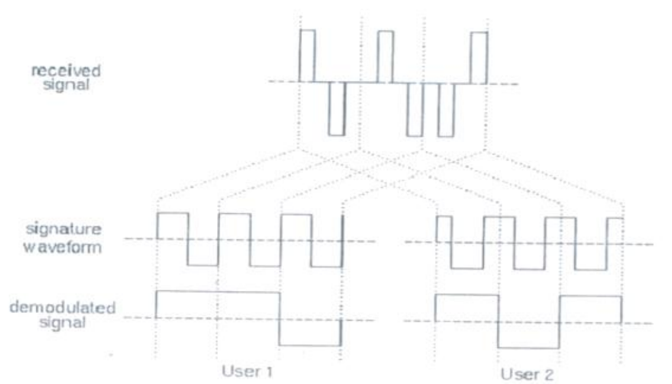


FIGURE 2.2: CONVENTIONAL RECEIVER

*2.3 Disadvantages with the conventional receiver*

The conventional receiver has some serious drawbacks. The underlying assumption is that the signals from different users are uncorrelated. In this case the conventional receiver is optimum. In practice the signals from different users will be correlated, which means the conventional receiver will be suboptimum. Still the conventional receiver will still work rather well under these two conditions:

- The correlation between the signature sequences is small.
- The signals from different users are received with approximately the same power.

The first condition can be fulfilled by careful design of the code sequences that determine the signature waveforms. The second condition can be fulfilled by accurate power control. The base station measures the received power of all the transmitting signals. By sending power control commands to all the mobiles telling them to increase their transmit power, the received power levels of all the users can be kept at approximately the same level. Without power control, the received power levels may by 60 dB or more. If the power of the received signals differs significantly, it suffers from the near-far problem.
Code sequence design also has problems. It turns out that the correlation between signals from different users is critically dependent on the relative delays of the signals from different users. It is possible to design codes that are orthogonal, i.e. have zero cross correlation if the signals arrive at the base station synchronously. It is however impossible to design code sequences (with finite length) that have very low cross correlation for all relative delays.

*2.4 A Multiuser Detection Problem*

Due to the problems with the conventional receiver mentioned above, a different type of detector has been derived. These detectors, which do not treat other users as noise, but as digital signals are called multiuser detectors.

Different Types of Multiuser Detectors: Most multiuser detectors are used in conjunction with the conventional receiver. This means that the received signal is first correlated with each of the signature waveforms. The output from this bank of correlators is treated as a vector. The multiuser receiver then performs some linear or non-linear transformation on this vector. Several multiuser detectors of this kind have been proposed. Usually, some letters need not be known, whereas others must be estimated. Unfortunately, some of: necessary parameter estimation may be difficult in a situation where there is a near-problem. This is true in particular for estimation of the propagation delay, which is necessary for most of the multiuser detectors in this category.

Other multiuser detectors do not operate on the output from the bank of correlators. Instead the demodulated wideband signal is sampled at a high rate and fed an adaptive discrete time filter. The coefficients of the filter are adjusted so that the put of the filter resembles some known training sequence, which is transmitted before transmission of the actual message. These coefficients are then used during the remainder of the transmission.

Amazingly enough, these detectors need no side information except the training sequence. Still, they have some problems. The use of these detectors place severe restrictions on the choice of spreading codes. Also the detectors may not be able to adapt to changing transmission conditions due to fading.

*2.4.1 A Multi-variable Decision Feedback Equalizer operating on the correlator outputs*:

As an example of a multiuser detector that operates on the output from the bank of correlators, a multivariable decision feedback equalizer (DFE) is studied. Decision feedback equalizers were first derived in the 1960's. They were then used to mitigate inter-symbol interference, which was a major problem for construction of high speed telephone line modems.

For application as a multiuser detector in an asynchronous DS-CDMA system, the DFE has to be extended to have multiple inputs as well as multiple outputs. For this purpose the vector of sampled correlator outputs as the output of a discrete time variable channel model was used. Also the transmitted symbols of all users at a certain time instant in a vector were collected. The situation is depicted in the figure2.3.


FIGURE 2.3: DS-CDMA TRANSMITTER

Note that both input and output of the filter are vectors.
By using the information about the transmission and reception in a DS-CDMA it is possible to relate the output to the input. This relation will be a discrete time multivariable FIR-filter with the number of inputs and the number of outputs equal to the number of users.

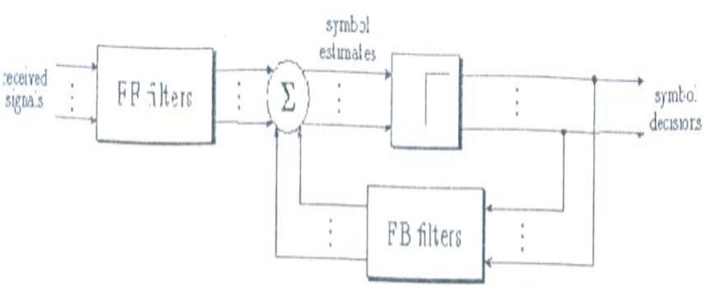


FIGURE 2.4: MULTIVARIABLE DFE

The vector of correlator outputs are used as input to the feed forward filter, which suppresses most of the inter-symbol interference and cross-couplings in the channel. From outputs of the feed forward filter, the outputs from the feedback filter remove the act of symbols that have been previously detected.

Author observed that if graphically multivariable DFE in a CDMA scenario with two users is tried, the received powers of the two users will differ by 20 dB. and the codes used were Gold codes, which is a common choice in CDMA systems. The signal to noise ratio is varied between 5 and 20 dB, and counted the number of errors in the symbol decisions. The performance of the multivariable DFE was compared to the performance of the conventional receiver, and also to the performance of the decorrelating detector, a linear multiuser detector.

The performance of the DFE is superior to the performance of the conventional detector. This is natural, since the performance of the conventional detector is limited by interference from the other user. This is in contrast to both the DFE and the relating detector, which strangely enough have the same performance. It should be however that the decorrelating detector cannot be implemented without modification in a real system, since it is a block detector. In a block detector, an entire sequence is received and demodulated simultaneously. It is then implicitly assumed that the transmission begins and ends at specified instances, which are not separated too far apart, will not be the situation in a real system: in a CDMA system, transmission takes place continuously.

The performance of a practical implementation of the decorrelating detector is then over bounded by the performance indicated in the graph. Also, the correlating detector has been shown to perform very badly in a situation where the propagation delay has been estimated inaccurately. Thirdly, the complexity of the DFE is lower than the complexity of the decorrelating detector.

*2.4.2 A Multiuser Detector operating directly on the wideband signal:*

As previously stated, multiuser detector operating on the output of the correlator rely on accurate estimation of among other things the propagation delay. To circumvent the problem of propagation delay estimation, also multiuser detector operating directly on the wideband signal is devised. But the disadvantages associated such a detector: lack of flexibility in the code selection part and inability to cope fast fading were avoided. A multiuser detector for application in mobile radio must be able to adapt to rapid changes in transmission conditions. A multiuser detector fulfilling these conditions would be an ideal candidate for practical implementation. Such a detector can in fact be devised. By rewriting the system for transmission reception in a CDMA system, it becomes clear that the author is dealing with a pie equalization problem rather than a complex detection problem. There are only two differences from the equalization problems considered since the 1960's:

- The channel has several inputs, one for each user and
- The output of the channel must be sampled much more rapidly than once per symbol.

The situation considered is as depicted in figure 2.5.

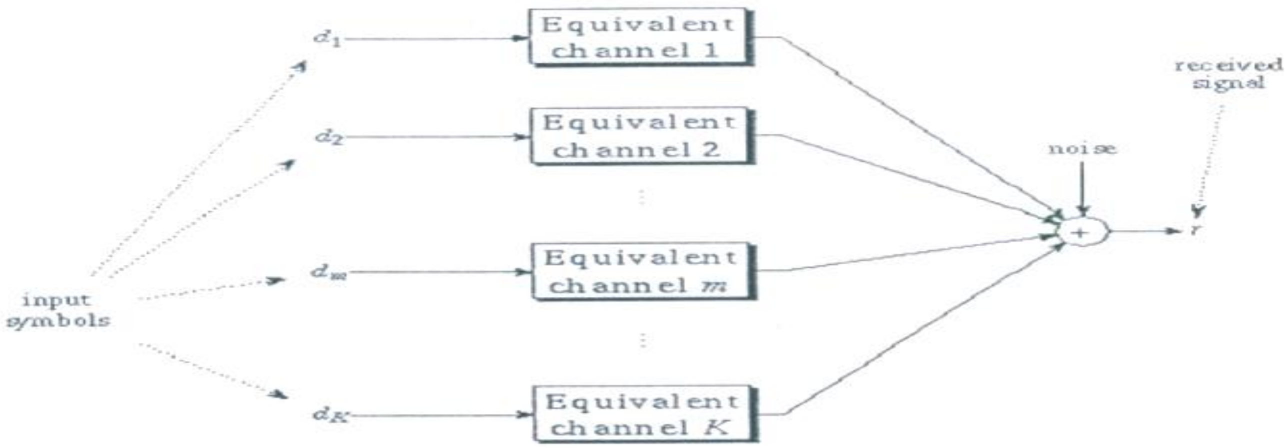


FIGURE 2.5: CDMA TRANSMITTER-RECEIVER

These equivalent channels are discrete time FIR filters. The coefficients of these filters will depend on two things

- The codes that are used and
- The physical channel.

The former is known at the receiver, while the latter must be estimated using a training sequence. This estimation problem is relatively simple and does not suffer from the near-far problem.
Based on knowledge of the channels, a number of different detectors can be designed. All of them have counterparts among equalizers used to combat inter-symbol interference. Examples of such detectors are

- Fractionally spaced linear equalizers,
- Fractionally spaced decision feedback equalizers (DFE's) and
- Detector based on the Viterbi algorithm.

The performance of the DFE to the performance of a single-user under the same conditions is compared. Graphically it can be proved that the performance of the system will be satisfactory, despite the heavy load and the severe near-far situation. The difference between the DFE and the single user case is rather large, but the system in which the DFE operates is very heavily loaded.
Direct sequence code division multiple-access (DS-CDMA) has been selected as the fundamental signalling technique for third generation (3G) wireless communication system, due to its advantages of soft user capacity limit and inherent frequency diversity. However, it suffers from multiple-access interference (MAI) caused by the non-orthogonality of spreading codes, particularly for heavily loaded systems. Therefore, techniques for mitigating the MAI, namely multiuser detection, have been the subject of intensive research effort over the past two decades. It is well known that multiuser detection can substantially suppress MAI, thus improving system performance. Maximum likelihood (ML) multiuser detection was proposed in the early 1980s, and achieves the optimal performance at the cost of prohibitive computational cost when the number of users is large.

In recent years, the turbo principle, namely the iterative exchange of soft lion among different blocks in a communication system to improve the system performance, has been applied to combine multiuser detection with channel decoding. In such turbo multiuser detectors, the outputs of channel decoders are fed back to the multiuser detector, thus enhancing the performance iteratively. Turbo multiuser detection based on the maximum Aposterior probability (MAP) detection and decoding criterion has been proposed in together with a lower complexity technique based on interference cancellation and LMMSE filtering. Further simplification is obtained by applying parallel interference cancellation (PIC) for multiuser detection, where the decisions of the decoders are directly subtracted from the original signal to cancel the MAI.
Practical wireless communication systems usually experience fading channels, whose state information is unknown to the receiver. Thus practical systems need to detection and decoding with uncertain channel state information. In the context short code CDMA systems, blind multiuser detection can be accomplished without explicit channel estimation by using subspace and other techniques.

## III. DESIGN METHODOLOGY

Let us consider channel-coded CDMA systems operating over multipath fading channels whose channel state information is unknown to the receiver. To demodulate and decode such systems, we will apply the turbo principle to both channel estimation and multiuser detection. Consider a receiver that feeds back decisions from channel decoders to both an ML channel estimator and a PIC multiuser detector. The iteration will be initialized with training symbol based channel estimation and a non-iterative multiuser detection. The dissertation will be focused mainly on the performance analysis of such structures using semi-analytic methods. Here the contributions to the variance of the channel estimation error due to noise and decision feedback error, and the variance of the residual MAI after PIC will be analysed. Then this analysis will be used to describe the decoding process as an iterative mapping. Here conditions assuring convergence of this iterative mapping to a unique fixed point is proposed. Computation of the asymptotic multiuser efficiency (AME) of this overall system, under some mild assumptions on the channel decoders will be done. The analysis in this dissertation will be carried on large samples and large system analysis.

## IV. EXPECTED RESULTS

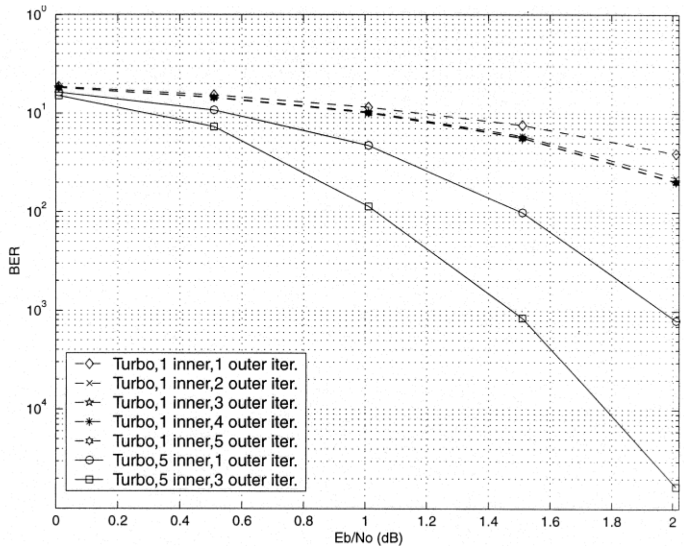


Fig4.2: BER performance comparison between the turbo multiuser receiver with five inner iterations and one inner iteration, K = 6, processing gain N = 16, vehicle speed = 120 km/h, data rate = 9.6 kb/s, carrier frequency = 2.0 GHz.

## V. CONCLUSION

Multiuser detection holds much promise for improving Direct Sequence CDMA performance and capacity. Although multiuser detection is currently in the research stage, efforts to commercialize multi-user detectors are expected in the coming years as DS-CDMA systems are more widely deployed. The success of these efforts will depend on the outcome of careful performance and cost analysis for the realistic environment.

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