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Simulation Models of RAKE Receiver in DS-CDMA Multipath Propagation Environment

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***Abstract*—In this paper some simulation models of Direct-sequence spread-spectrum (DS-SS) Code Division Multiple Access (CDMA) system, employing different spreading codes, with RAKE receiver are analyzed. Proposed RAKE receiver model includes varying number of RAKE fingers, correctly or incorrectly synchronized to multipath components delays. RAKE finger outputs are combined using Equal Gain Combining (EGC) technique. The impact of number of multipath components, number of RAKE fingers and number of users on Bit Error Rate (BER) performance is analyzed.**

***Index Terms*— EGC technique, multipath propagation, RAKE receiver, spread-spectrum.**

I. INTRODUCTION

Many modern communication systems, like wireless cellular systems, operate in environments that are interference and bandwidth limited, where propagation characteristics are more complicated and multipath-induced fading and shadowing are a common problem [1]. A great number of channel models have been proposed to describe the statistics of the amplitude and phase of multipath faded signals [2]. The rapid fluctuations of the instantaneous received signal power due to multipath effects are usually described with Rayleigh, Rician, Nakagami or Weibull model [1-3]. This paper discusses the case of Rayleigh model, proposed for radio transmission in urban areas [3] where the direct LoS (line-of-sight) component between transmitter and receiver does not exist.

In order to combat multipath fading effects and also the effects of co-channel interference, the complex receiver structures, using complicated synchronization schemes, demodulators, symbol estimators, diversity and multiple-input-multiple-output (MIMO) techniques, are often applied [4-6]. For many of these systems simulation is often necessary for the design and system performance analysis [7].

An efficient method for mitigating fading effects by using multiple receiver antennas is called space diversity [3], improving transmission reliability without increasing transmission power and bandwidth while increasing channel capacity. There are several types of space combining techniques that can be generally performed depending on the amount of channel state information (CSI) available at the receiver [3]: selection combining (SC), equal-gain combining (EGC) and maximal ratio combining (MRC). EGC involves co-phasing of the useful signal in all branches and summing them, while MRC output presents a weighted sum of co-phased signals from all branches, requiring all of the amount of CSI. Unlike pervious, SC technique processes only one of the diversity branches, generally the branch with the highest signal-to-noise ratio (SNR).

Spread-spectrum (SS) modulation is the basis of the digital cellular standards [7], providing several benefits: mitigation the effect of intersymbol interference (ISI) and narrowband interference, obtaining low probability of interceptions (LPI) and the possibility to be used as a multiple access technique. Direct-sequence (DS) is the most commonly used form of SS, where the data signal is multiplied by a pseudorandom sequence (PN), usually called the chip sequence [1]. The PN sequences are deterministic, with low correlation between shifted versions of the same sequence, and low cross correlation between different sequences. SS technique is used in CDMA systems, where time and bandwidth are used simultaneously by different users modulated by orthogonal or semi-orthogonal codes, while the receiver uses the code structure to separate out the different users [3]. The impact of number of users, channel noise effect and multipath delay spread on Bit-Error-Rate (BER) performance of CDMA systems is analyzed in [8].

For DS-SS signaling, a RAKE receiver is usually used for providing diversity by coherently combining multipath components, that would be otherwise lost [9]. The RAKE receiver searches through the different multipath delays for code correlation and thus recovers delayed signals, which are later combined with the outputs of the other independent correlators. (usually called RAKE fingers), using EGC, SC, MRC. The components arriving with different delays can be resolved if they are separated by at least one chip time. The receiver design includes a device that is dedicated to estimate time delays, usually called path searcher. The number of fingers and the delay of each finger in a RAKE receiver are

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allocated on the basis of the path searcher, while the operating parameters of the path searcher are assigned by the finger management. For terrestrial mobile radio networks, the fading rate is relatively slow, so the channel coherence time is relatively large when compared to the chip time duration. Hence, the changes of components delays are slow enough that the receiver can readily adapt to them. An adaptive RAKE structure includes choosing effective multipath components and determining the optimal number of RAKE fingers, using CSI, which can reduce computational complexity. In WCDMA downlink system receiver can estimate channel impulse response using common control channel (CPICH). All user equipments in the same cell receive same frame using CPICH as a pilot symbol sequence to estimate channel information.

Combining a subset of the available resolved multipath components for reducing RAKE receiver complexity is presented in [10], called partial RAKE. A generalized RAKE receiver for interference suppression is proposed in [11], while an adaptive generalized RAKE receiver employing practical algorithms for finger placement and weight computation is given in [12]. A chip level equalization on each RAKE finger to cancel multiaccess interference (MAI) in multipath channel is presented in [13], while the combining smart antenna beamforming and RAKE receiver for WCDMA is given in [14]. The BER performance of RAKE receiver in reverse link over a frequency selective multipath Rayleigh fading channel is evaluated in [15].

This paper describes a DS-SS cellular system that uses the RAKE receiver to provide path diversity. In proposed model input data signal is multiplied by the spreading sequence (using different spreading codes), while the resulting signal is subject to multipath fading, modeled as two-tap Rayleigh channel. Two RAKE correlators are used, one to recover each multipath component. At the receiver, these modulated signal are combined using EGC, to produce the recovered data signal. The receiver structure is than analyzed under multi-tap propagation conditions, with number of RAKE fingers less or equal to number of multiple paths. The BER performance analysis for different cases is given, for single-user scenario, and also for multi-user scenario. In proposed model MIMO concept, channel coding, interleaving and algorithms for channel estimation are not considered. It is shown [10-12] that applying optimal energy allocation algorithm including reallocation weight factors for effective RAKE fingers, some BER performance advantages can be obtained.

Paper is organized as follows: Section I presents the system model, while the RAKE receiver concepts are given in Section II. Simulation results showing the overlay of individually recovered RAKE finger signals and the combined output signal, including BER performance, are presented in Sections III and IV, for 2-finger and 3-finger RAKE receivers, using different spreading codes, for different number of multiple paths introduced into the channel. Some concluding remarks are given in Section V.

II. System Model

A received signal in a baseband DS-SS CDMA system can be modeled as:

$$x(t)=\sum_{l=1}^{L} x_l(t)+n(t) \quad (1)$$

where $x_l(t)$ presents the received signal contribution from the l-th user, l=1, 2,...L, where L is number of users and $n(t)$ presents additive white Gaussian noise (AWGN). A spreading waveform $C_l(t)$ for l-th user can be modeled as:

$$C_l(t)=\sum_{n=0}^{SPF-1} c_l(n)\cdot g(t-nT_C) \quad (2)$$

where T_C presents the chip period with spreading factor SPF defined as SPF=T/T_C with data symbol period T. A unique pseudorandom noise (PN) code sequence for l-th user is presented by $c_l(t)$, while $g(\cdot)$ is the chip pulse waveform. The received signal contribution from the l-th user is:

$$x_l(t)=\sum_{k=-\infty}^{+\infty} s_l(t)\left(h_l(t-kT)\otimes C_l(t-kT)\right) \quad (3)$$

where $\{s_l\}$ is the data bit stream. The channel effect is modeled by convolution between the channel impulse response $h_l(\cdot)$ and the l-th user spreading waveform $C_l(t)$.

The most common spreading codes are Walsh-Hadamard codes, which are orthogonal:

$$\sum_{n=1}^{SPF} c_i(n)\cdot c_j(n)=0, \quad \forall i\neq j \quad (4)$$

System model is presented in Fig. 1, including transmitter, channel and receiver.

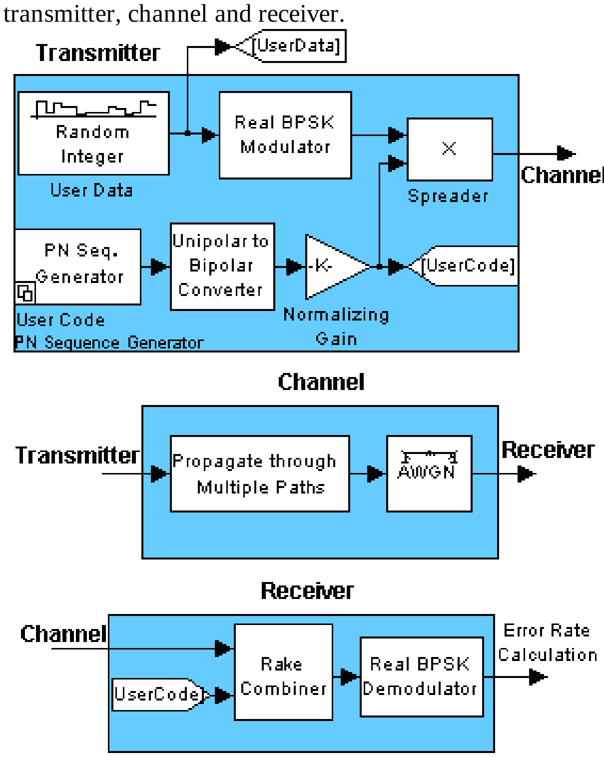

Fig. 1. System model

III. Receiver Model

The RAKE receiver uses multiple correlators with one finger for each path, with assumption that the time delay of each multipath component is determined. Each single Rake finger is an independent receiver for the signal from a specific path, which correlates with spreading code.

The finger outputs are combined coherently and synchronously by RAKE combiner, using some combining schemes (SC, EGC, MRC) to improve the received signal quality. The channel parameters are assumed known in the despreading and demodulation process, although in practice the impulse response of the channel is typically estimated using pilot symbols or a pilot channel. In order to combat multi-user and multipath interference, channel has to be estimated at regular intervals.

In this model EGC technique is used, combining all finger outputs with equal weighting. The RAKE output can be presented as:

$$r_l(k) = \sum_{m=1}^{M} a_{ml}^{*} \left(\int_{kT}^{(k+1)T} x(t)\cdot c_l(t-kT)\,dt \right) \qquad (5)$$

where M is number of RAKE fingers and weighting coefficient a^{*}_{ml} for m-th finger and l-th user is a^{*}_{ml}=1, for EGC combining scheme. In each RAKE finger the received signal is multiplied by spreading code $c_l(t)$ to detect each user, and after that is integrated, as it is presented in Fig. 2.

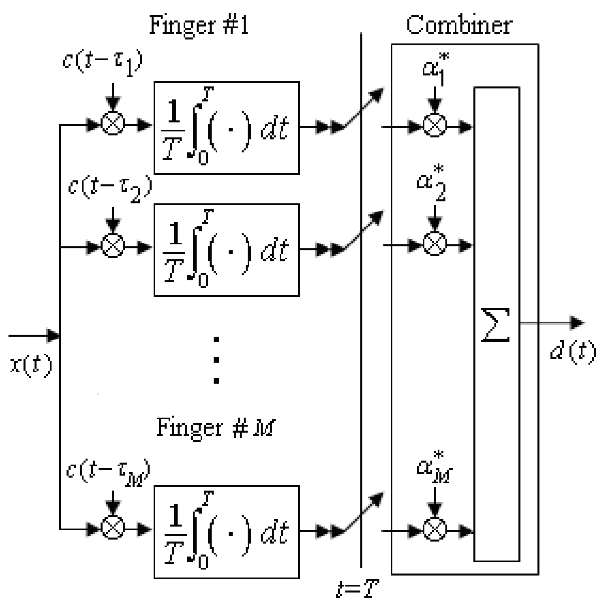

Fig. 2. RAKE receiver structure

Optimal coherent combining contains phase rotation of fingers and scaling according to signal strength, provided by RAKE receiver. It is shown that MRC technique provides the best performance, but MRC coefficients correspond to the relative amplitudes of the pulse replicas received by each finger, making this technique very difficult to implement. In this model, EGC technique is chosen to be applied because its performance is quite close to that of MRC, but the complexity is reduced when compared to MRC, because all finger outputs are combined with equal weighting. The simplest implementation of RAKE receiver uses SC combining, with choosing the finger with the strongest signal, but with less performance improvement when compared to MRC and EGC combining technique.

IV. Simulation Results for 2-RAKE Receiver

In proposed model two Rayleigh fading paths with different delays are introduced into the channel. At the receiver side, two RAKE fingers are used, synchronized to each multipath component. The outputs of both fingers are combined using EGC to obtain a better estimate of the transmitted data. MIMO concept, channel coding, interleaving and alorithms for channel estimation are not considered in this model.

The outputs of two individual RAKE fingers and the EGC combined output, compared with input signal are illustrated in Fig. 3, Fig. 4, and Fig. 5, respectively. In the simulation process, the sampling rate is set to 10x's the chip rate, while the chip time is short compared to the path delays.

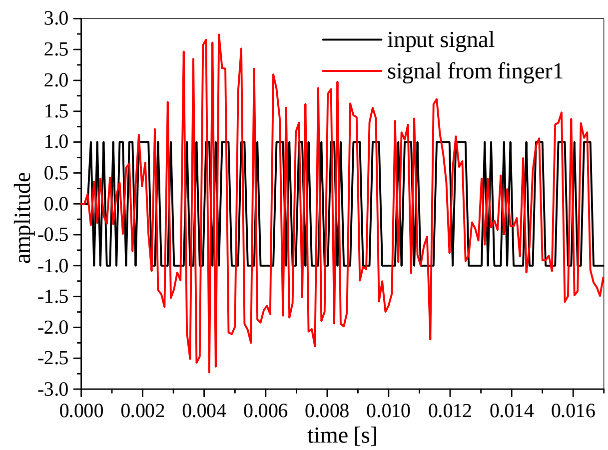

Fig. 3. Input signal and the first finger output signal

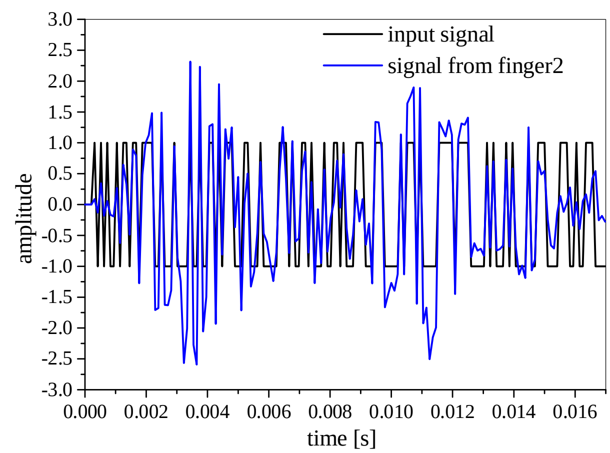

Fig. 4. Input signal and the second finger output signal

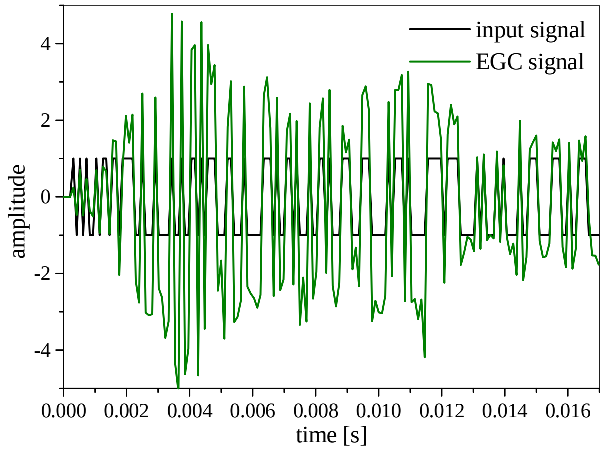

Fig. 5. Input signal and EGC combined output signal

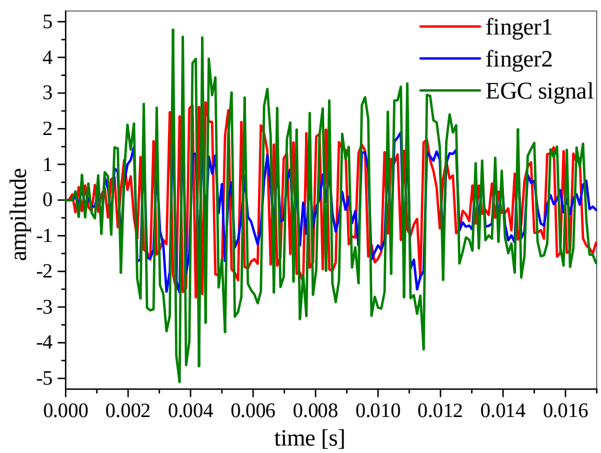

Fig. 6. Comparison of individually recovered RAKE finger signal and EGC combined output signal

Simulation results show that the combined output presents less errors than the output of each individual branch (finger). The comparison of individually recovered RAKE finger signal and the combined output signal is given in Fig. 6. It can be concluded that the combined output should produce fewer errors than the output of each individual finger, presenting path diversity.

V. Simulation Results for 3-RAKE Receiver

When multipath components delays are estimated, a separate correlator is dedicated to recover each resolvable component. In this model there would be three such dedicated correlators, each one processing a delayed version o the same chip sequence. Since arriving chips form a PN sequence, each correlator (finger) attempts to correlate these chips with the same appropriately synchronized PN code. At the end of a symbol interval (hundreds or even thousands of chips per symbol), the outputs of the fingers are coherently combined and a symbol detection is made.

Proposed model considers different spreading techniques: the orthogonal codes (Walsh-Hadamard), psudo-random (PN) sequences and Kasami sequences. Performance analysis for those three cases is presented in Fig. 7, Fig. 8, and Fig. 9, respectively.

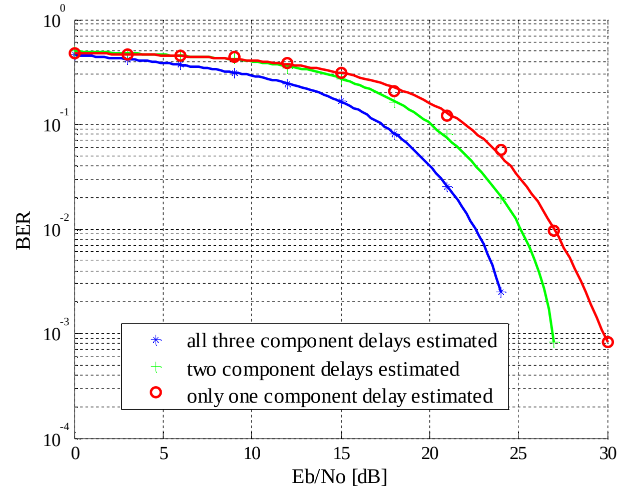

Fig. 7. BER performance analysis, using orthogonal codes (Walsh-Hadamard)

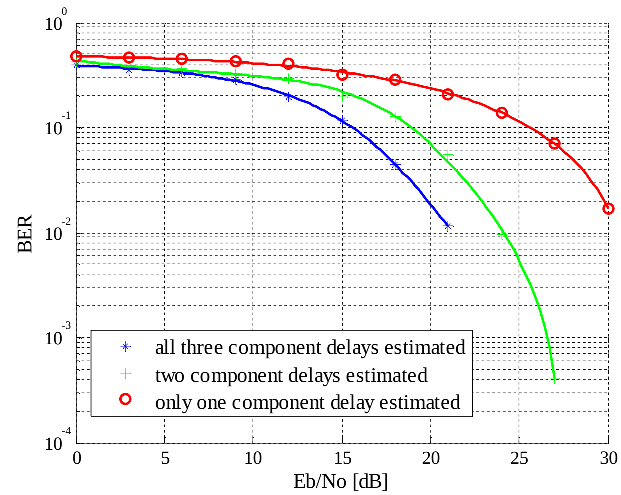

Fig. 8. BER performance analysis, using PN sequences

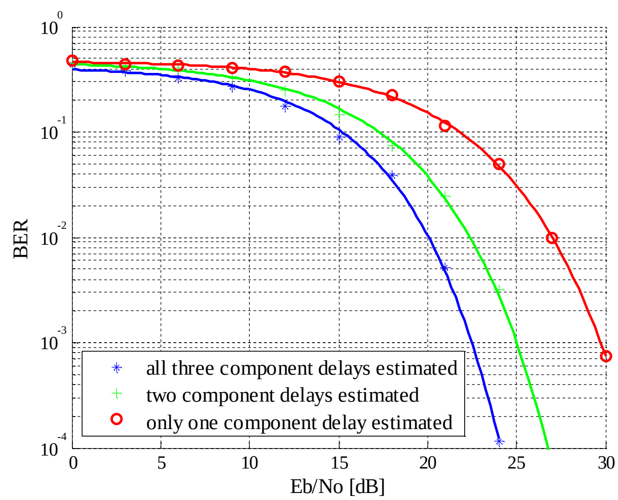

Fig. 9. BER performance analysis, Kasami sequences

BER performance analysis is given in the case when all three component delays are correctly estimated, in the case when two component delays are correctly estimated and in case when only one component delay is correctly estimated, as presented in Fig. 7, Fig. 8, and Fig. 9, for different spreading sequences. As it was expected, the case when all component delays are correctly estimated shows the best

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performance. It can also be concluded that the increase of mismatch between the channel path delays and RAKE receiver estimated delays makes BER performance degradation.

It is shown that correlation properties of Kasami sequences provide a good balance between the ideal cross-corelation properties of orthogonal codes and the ideal auto-correlation properties of PN sequences, which is important for user seapration in multi-user systems. Model presented in this parer can easily be enlarged to multi-user scenario, with different spreading sequences for each of them.

Performance analysis for case when number of RAKE fingers is lower than the multipath components number is presented in Fig. 10. This scenario is more realistic, from the point of view of power consumption issues and design complexity.

For 3-finger RAKE receiver, with different number of multiple paths (N_{path}=3, 4, 5 and 6, with different delays) introduced into the channel, BER performance analysis is presented in Fig. 10. It is assumed that all component delays are correctly estimated.

It can be concluded that increasing number of multiple paths produces BER performance degradation, as it was expected.

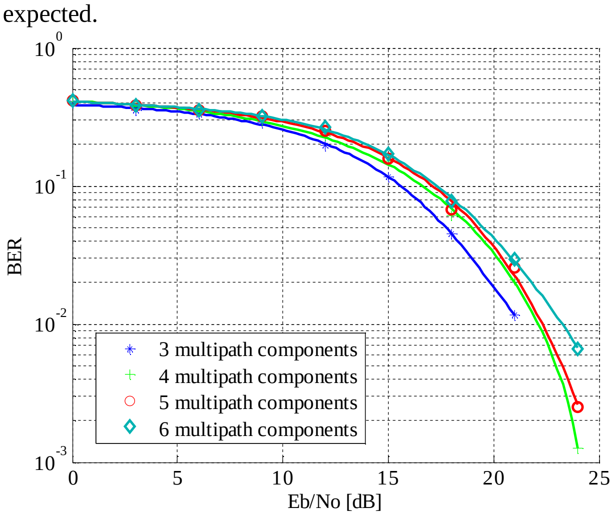

Fig. 10. BER performance of 3-RAKE receiver in multipath channel (including up to 6 multiple paths)

In Fig. 11. and Fig. 12, BER performance analysis for multi-user scenario (under previously defined propagation conditions) is presented, with conclusion that increasing number of users makes BER performance degradation.

For two-user scenario two distinct PN sequences are used for spreading, with the conclusion that the individual user performance has now worsened for same channel conditions. Better user separation is obtained using Kasami sequences, providing a good balance between the ideal cross-correlation properties of orthogonal codes and the ideal auto-correlation properties of PN sequences.

The comparison of BER performance for single-user and two-user scenario, using Kasami sequences, is presented in Fig. 11.

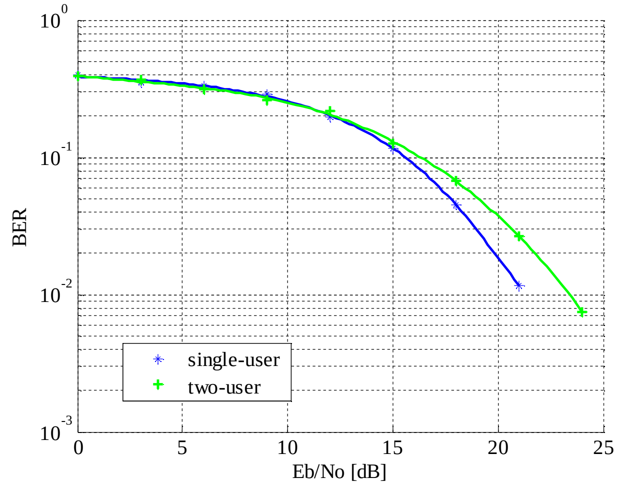

Fig. 11. Comparison of BER performance for single-user and two-user scenario

The comparison of BER performance for single-user, two-user, and three-user scenario, using Kasami sequences, for same propagation conditions, is presented in Fig. 12.

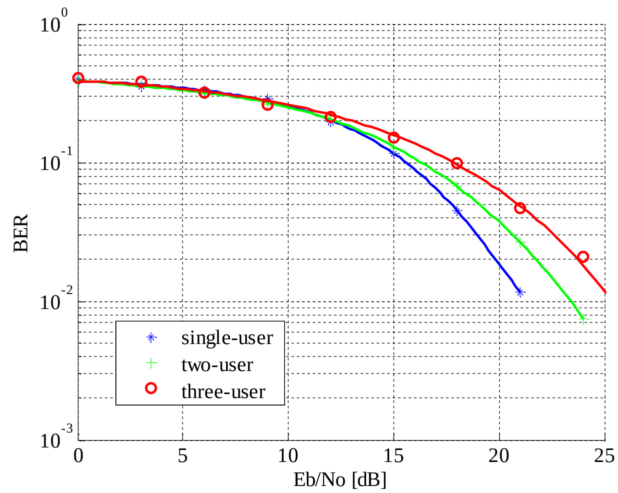

Fig. 12. Comparison of BER performance for single-user, two-user, and three-user scenario

Thus it can be concluded that BER performance of RAKE receiver will degrade if number of users increases.

VI. CONCLUSION

This paper presents a DS-SS cellular system using the RAKE receiver to provide path diversity. In proposed model input data signal is multiplied by the spreading sequence, using different spreading codes, while the resulting signal is subject to multipath propagation. Different number of RAKE fingers are used for recovering multipath components, while the RAKE finger outputs are combined using EGC technique.

BER performance of RAKE receiver is analyzed for different number of RAKE fingers (less or equal to number of multiple paths), using different spreading sequences, for single-user and multi-user scenario. Simulation results show that increasing number of users makes BER performance degradation, while increasing number of RAKE fingers provides better performance. It is also shown that increasing mismatch between the channel path delays and RAKE receiver estimated delays makes BER performance degradation.

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