A New Path Selection Scheme for Chip-level Multiple Access Systems over Long-Spread Channels

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Abstract

The soft Rake in multiple access systems such as interleave division multiple access (IDMA) is the most critical part in terms of the computational complexity. In this paper, the problem of choosing effective Rake paths in such systems among multi-path components is considered. The path selection problem is formulated as a problem with a convex objective function. A decision rule for choosing the proper path number of the soft Rake based multiuser combiner is derived. The decision rule is very simple and can get quite close to the optimal scheme that cannot be implemented in practice due to its complexity. Simulation results are presented to compare the system performance with the proposed path selection scheme and that of the conventional scheme.

Key Words: Multiuser detection, Path Selection, Rake detectors

نموذج جديد لأختيار المسار لأنظمة التعامل المتعددة ذات مستوى ال (chip) في القنوات ذات الانتشار الطويل

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الخلاصة:

الجزء الذي يقوم بأستقبال وتجميع الأشارات أو ما يسمى (Rake) في أنظمة (IDMA) هو الجزء الأكثر حرجا بالتعقيدات الحسابيه. مشكلة أختيار المسارات الفعالة من بين المركبات متعددة المسارات قد تم دراستها في هذا البحث. المشكلة تم تمثيلها وأعتبارها كمشكلة بدالة غرضية متصاعدة او متنازلة. القاعدة المستخدمة لأختيار عدد المسارات الصحيح في (Rake) قد تم أشتقاقها. قاعدة الأختيار المقترحة جدا بسيطة وجدا قريبة من الشكل النموذجي الذي لا يمكن بناءه وتطبيقه عمليا نتيجة لصعوبته. نتائج المحاكات لهذا النموذج المقترح قد تم تمثيلها ومقارنتها مع الشكل التقليدي الذي لا يحتوي على النموذج المقترح.

1. Introduction

In general, soft Rake in interleave division multiple access (IDMA) systems is employed to collect energy from different multipath components. Since a long spread channel has a wide bandwidth, the number of resolvable multipath components is usually large. A feasible implementation of multipath diversity combining can be obtained by a selective-Rake receiver, which combines the best multipath components [1]. Those best components are determined by a path or finger selection algorithm. For a maximal ratio combining (MRC) Rake receiver, the paths with highest signal-to-noise ratios (SNRs) are selected, which is an optimal scheme in the absence of interfering users and intersymbol interference (ISI) [2-4]. The path selection problem is also studied in the context of downlink code-division multiple-access (CDMA) equalization, where recursive sequential search (RSS) and heuristic arguments of interference cancellation (IC) are proposed to determine path locations [5]. The RSS algorithm selects the paths one by one in a sequential manner, which reduces the computationally complexity significantly. However, it might be quite suboptimal depending on the correlation structure of the noise components. The heuristic arguments are employed to determine path locations when the number of paths is larger than the number of multipath components, which is not applicable in our case due to a large number of multipath components in a long spread channel.

In such channels, the large path number can actually degrade the detection performance. Hence, some decision rule about the active Rake paths is necessary for such multiple access receivers. In this paper, suboptimal path decision scheme is developed to choose the best multipath components after non ideal channel estimation and provide better performance in long spread channels. In Section 2, the optimal criteria on choosing the active paths are presented in Section 3, while the corresponding suboptimal scheme is explained in Section 4. Performance results are discussed in Section 5. Finally, conclusions are drawn in Section 6.

2. Selective-Rake Paths

The soft Rake and IC concepts in IDMA systems [7], [8] are combined together to allow each arriving multipath signal to be individually detected and summed to provide more accurate signals. In such IC detectors in **Figure.(1),** the signal-to-interference-noise ratio (sinr) for the log-likelihood ratio combining (LLRC) algorithm after observing $\mathbf{r}$ is defined for the real transmission as [7]

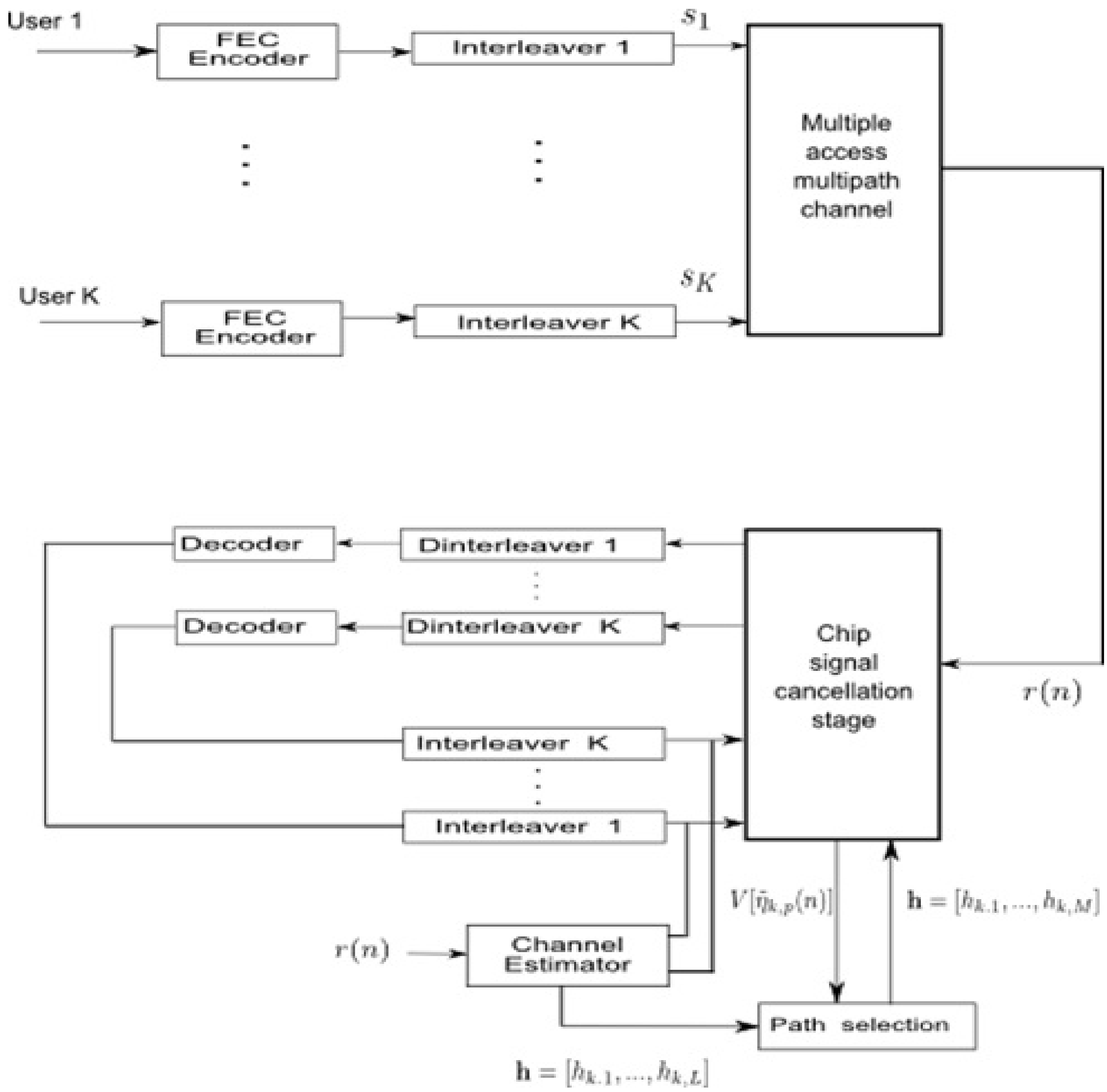

Fig .(1) IDMA system with the proposed path selection scheme (where FEC denotes forward error correction code).

$$sinr_{k,p}(n) = \frac{E\left(\left(\dfrac{2h_{k,p}h_{k,p}s_{k,p}(n)}{V[\tilde{\eta}_{k,p}(n)\,]} \right)^2 |r \right)}{E\left(\left(\dfrac{2h_{k,p}\{\tilde{\eta}_{k,p}(n) - E[\tilde{\eta}_{k,p}(n)]\ \}}{V[\tilde{\eta}_{k,p}(n)\,]} \right)^2 |r \right)}, \qquad \ldots\ldots\ldots\ldots\ldots (1)$$

where p is the physical propagation path, $E(.)$ is the mean, $V(.)$ is the variance, $\{h_{k,p}s_{k,p}(n)\}$ and $\{\tilde{\eta}_{k,p}(n) - E[\tilde{\eta}_{k,p}(n)]\}$ are the signal and distortion components of user k at time n, respectively. Since $s_{k,p}(n) = \pm 1$, the signal power is written as

$$E(\,|h_{k,p}s_{k,p}(n)\,|^2) = |h_{k,p}|^2, \qquad \ldots\ldots\ldots\ldots\ldots (2)$$

and the average noise power can be approximated as

$$\mathbf{E}\left(\ \left|\tilde{\boldsymbol{\eta}}_{\mathbf{k,p}}(\mathbf{n})-\mathbf{E}\left[\tilde{\boldsymbol{\eta}}_{\mathbf{k,p}}(\mathbf{n})\right]\right|^{2}\right)\approx \boldsymbol{V}\left[\tilde{\boldsymbol{\eta}}_{\boldsymbol{k,p}}(\boldsymbol{n})\right] \qquad \ldots\ldots\ldots\ldots\ldots(3)$$

The average $sinr_{k,p}$ over n, is denoted by $SINR_{k,p}$ can be written as [7]

$$SINR_{k,p} = E\left(sinr_{k,p}(n)\right) = E\left\{\frac{|h_{k,p}|^2}{V[\tilde{\eta}_{k,p}(n)\ ]}\right\},$$

$$=\frac{|\boldsymbol{h}_{\boldsymbol{k,p}}|^{2}}{\sum_{\boldsymbol{k'=1,k'\neq k}}|\boldsymbol{h}_{\boldsymbol{k',p}}(\boldsymbol{n})|^{2}\boldsymbol{E}\left[\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k'}}(\boldsymbol{n})\right)\right]+\boldsymbol{\sigma}^{2}}, \qquad \ldots\ldots\ldots\ldots\ldots(4)$$

where

$$\boldsymbol{E}\left(\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k}}(\boldsymbol{n})\right)\right) = \frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{n=1}}^{\boldsymbol{N}}\left(\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k}}(\boldsymbol{n})\right)\right), \qquad \ldots\ldots\ldots\ldots\ldots(5)$$

for the BPSK signaling, and

$$\boldsymbol{E}\left(\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k}}(\boldsymbol{n})\right)\right) = \frac{\mathbf{1}}{\boldsymbol{N}}\sum_{\boldsymbol{n=1}}^{\boldsymbol{N}}\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k}}^{\boldsymbol{I}}(\boldsymbol{n})\right)+\boldsymbol{V}\left(\boldsymbol{s}_{\boldsymbol{k}}^{\boldsymbol{Q}}(\boldsymbol{n})\right), \qquad \ldots\ldots\ldots\ldots\ldots(6)$$

for the QPSK mapping. Thus, the overall $\mathrm{SINR_k}$ can be expressed as

$$\mathbf{SINR_k} = \sum_{\boldsymbol{p=1}}^{\boldsymbol{P}}\mathbf{SINR}_{\mathbf{k},\boldsymbol{p}}, \qquad \ldots\ldots\ldots\ldots\ldots(7)$$

Theoretically, if the channel attenuation of each path is perfectly estimated, for the MRC and LLRC, $\mathrm{SINR_k}$ increases as the number of the Rake path increases [6]. Nevertheless, if the channel attenuation is not perfectly estimated, signal power of the added paths will become noisy. The increase of path number can actually degrade the Rake performance. Therefore, the optimal criteria on choosing the active paths should be

$$\mathbf{SINR_p} < \mathbf{SINR}_{\boldsymbol{p+1}}, \qquad \ldots\ldots\ldots\ldots\ldots(8)$$

the (8) always holds with perfect channel estimation, and it gives a general procedure for detecting the active paths. In addition, a poor choice of paths will lead to either the inclusion of inactive paths or exclusion of some active paths from the group of paths being estimated.

3. Path Selection Scheme

By adding path selection scheme in **Figure .(1),** the receiver can choose the best M Rake paths and reduce computations of the detection process. The algorithm choose the active set of multipath components, $\mathrm{P} = [\mathrm{p}_{1,} \ldots, \mathrm{p}_{\mathrm{L}}]$, from the L received multipath samples, where each path must have enable/disable switch. The positions of the most active paths are calculated and compared the value of the RHS of (7) for, $(\frac{\mathrm{L}!}{\mathrm{M}!(\mathrm{L}-\mathrm{M})!})$, combinations. Therefore, this requires the development of an activity threshold to enable discrimination between active and inactive taps.

To achieve this, the $\mathrm{SINR}_{\mathrm{k},p}$ cost function enjoys the property of structural consistency, which is minimized by the parameter vector that includes only the active taps. To make it applicable for different channels conditions, the effective $\mathrm{SINR}_{\mathrm{k,p}}^{\mathrm{eff}}$ for each path is considered as

$$\mathbf{SINR}_{\mathbf{k,p}}^{\mathbf{eff}} = \frac{\mathbf{1}}{\mathbf{J}}\sum_{j=1}^{J} \boldsymbol{SINR_{k,p}(j)}, \qquad \ldots\ldots\ldots\ldots\ldots \quad (\mathbf{9})$$

where J is the frame length. The most active tabs are estimated by introducing some term that penalizes cost function. For simplicity, we can use some of the well-known penalizing cost functions in [9]. The alternative cost function for each path is

$$\mathbf{SINR}_{\mathbf{k}}^{\mathbf{alt}} = \sum_{p=1}^{p} (\mathbf{SINR}_{\mathbf{k,p}}^{\mathbf{eff}} - \boldsymbol{c} \log \boldsymbol{\sigma}) \qquad \ldots\ldots\ldots\ldots\ldots \quad (\mathbf{10})$$

where c ε [0,10] is constant and σ^2 is the white noise variance. It is clear that the RHS of (10) is a monotonically increasing function of P as long as $\mathrm{SINR}_{\mathrm{k,p}}^{\mathrm{eff}} > c \log \sigma$. This lead to consider all the path indices for which

$$\mathbf{SINR}_{\mathbf{k,p}}^{\mathbf{eff}} > c\, \mathbf{log}\, \boldsymbol{\sigma} \qquad \ldots\ldots\ldots\ldots\ldots (\mathbf{11})$$

Although, it is a lower bound on the activity measure for the active taps. A smaller c leads to detection of all the active taps but also to an increase in the risk of including one or more of the inactive taps in the group of most active taps. The threshold factor c for activity measurement varies for different noise factors. The path location estimates are obtained by the indices of the elements of the indices which satisfy (11).

4. Performance Results

In this section, simulations have been performed to evaluate the performance of various path selections for IDMA system in Fig.1. The channel estimation in [8] is considered to track time-variations in the channel coefficients. The soft decisions together with the known training sequence are used to obtain an estimate of the channel by means of least mean square (LMS) filtering. In these simulations, there are two or four equal energy users $K = 2, 4$ in the system and 256 bits are encoded by the rate $1/2$ convolutional code with the generator polynomial $[23, 35]_8$, resulting in 522 coded bits. The coded bits are further encoded by the rate $1/8$ repetition code that gives 4167 coded bits. The scrambling codes are randomly generated. The interleaved chips after QPSK modulation are linearly superimposed and transmitted with equal power allocation and uniform phase distribution.

In **Figure.(2),** the performance after 8 iterations is plotted on the 24 paths fixed channel defined in **Figure.(3) (a).** The energy of the channel coefficients is exponentially decaying and modeled using equal probability. It can be observed that the performance of the 24 paths is slightly better than that of $5 - 20$ paths and it is worse with the 2 paths. However, the performance gain with $5 - 20$ paths is about 0.5 dB at level 10^{-3}. The system algorithm with 24 paths takes long time to simulate since it needs to perform search over all different path combinations. The system with proposed algorithm that choose $5 - 20$ paths takes less time and complexity, therefore it is much convenient than the optimal approach with 24 paths for the system implementation.

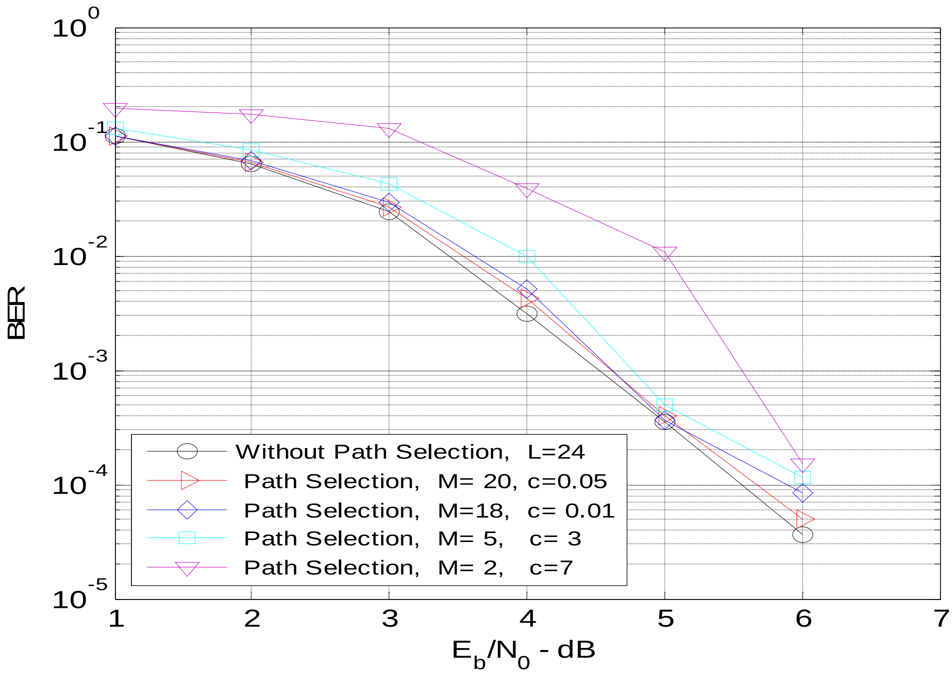

Fig.(2) The IDMA performance with K=4 over a time invariant multipath channel, where L is 24 and M for path selection algorithm is 20, 18, 5, 2.

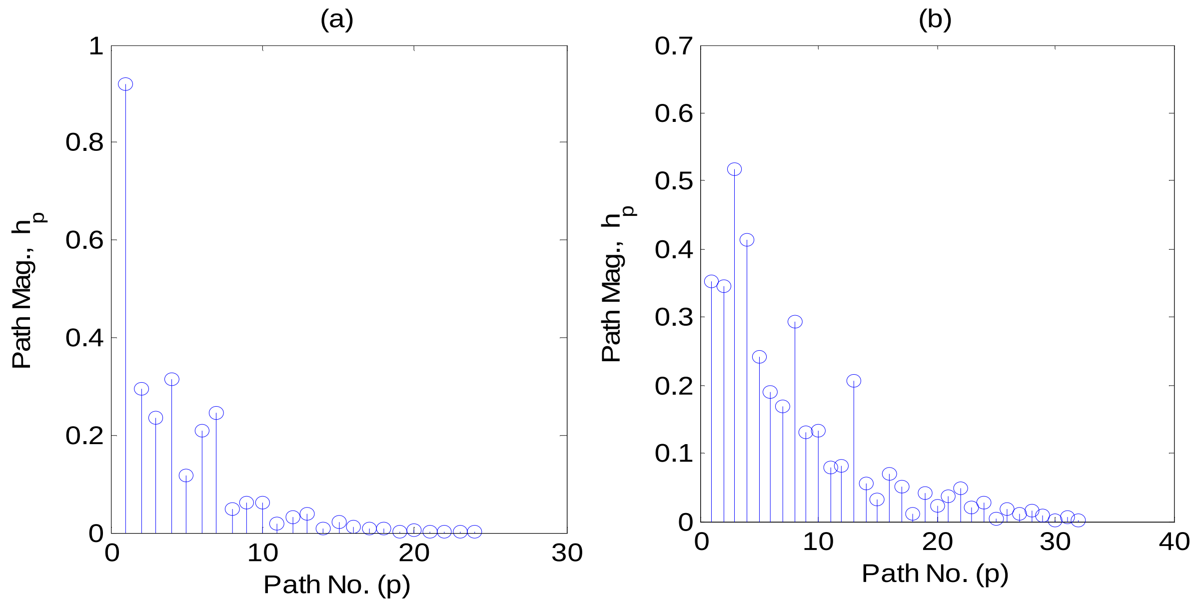

Fig .(3) Multipath flat-fading channel with (a) L=24, and (b) L=32.

In Figure.(4), the effects of choosing different numbers of paths using (11) on the $SINR^{eff}$ and threshold factor are examined. It is expected that an increase in the L will lead to a better $SINR^{eff}$ performance. However, channel estimation can never be perfect in practice. If we increase improper paths, the output $SINR$ of the added paths will be decreased and the estimation errors will be increased and those errors will degrade the detection performance.

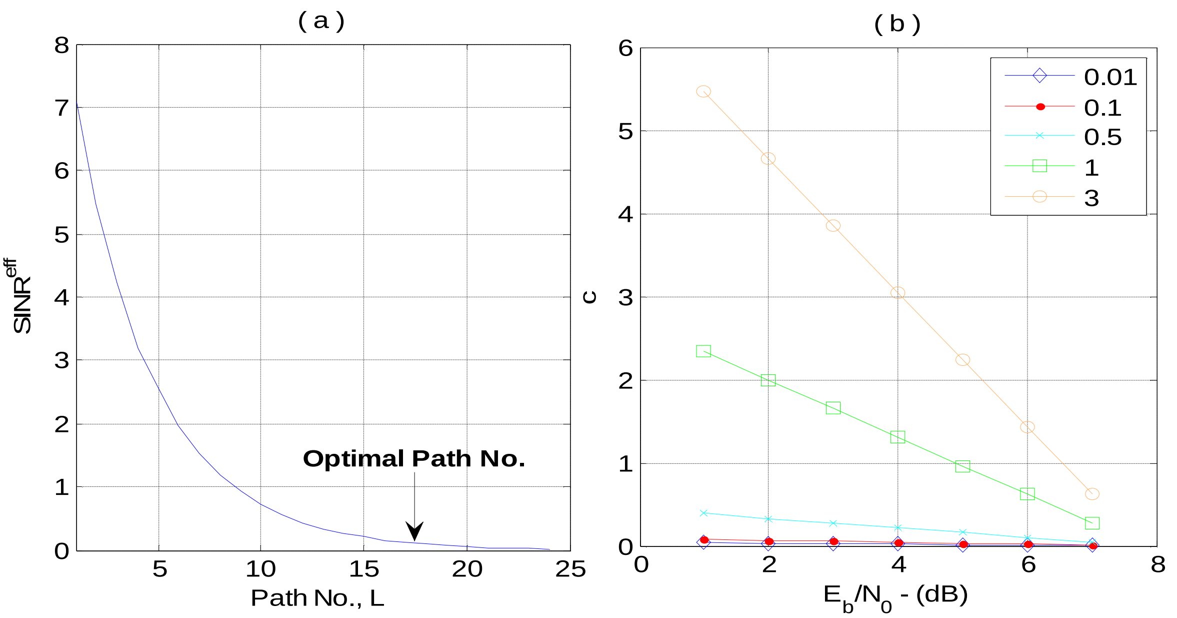

Fig .(4) The effects of choosing (a) L and (b) c using (11) and (9), respectively on the SINR.

Figure.(5) shows the performance results of the proposed algorithm on 10 multipath time varying channel. Fig.6 plots the performance results of the proposed algorithm on 32 multipath channel in **Figure.(3) (b).** The simulation parameters were designed as the case in **Figure.(2).** However, since the most paths have a small signal energy or noise that degrades the performance, the performance of 32 paths is close to that with 21 paths. Moreover, the proposed algorithm is able to cancel out these unwanted paths through the implementation of the interference cancellation stage. Since the channel is exponentially decaying and most of the significant taps are already combined by the algorithm, the improvement using non optimal path selection over the conventional technique decreases as L increases.

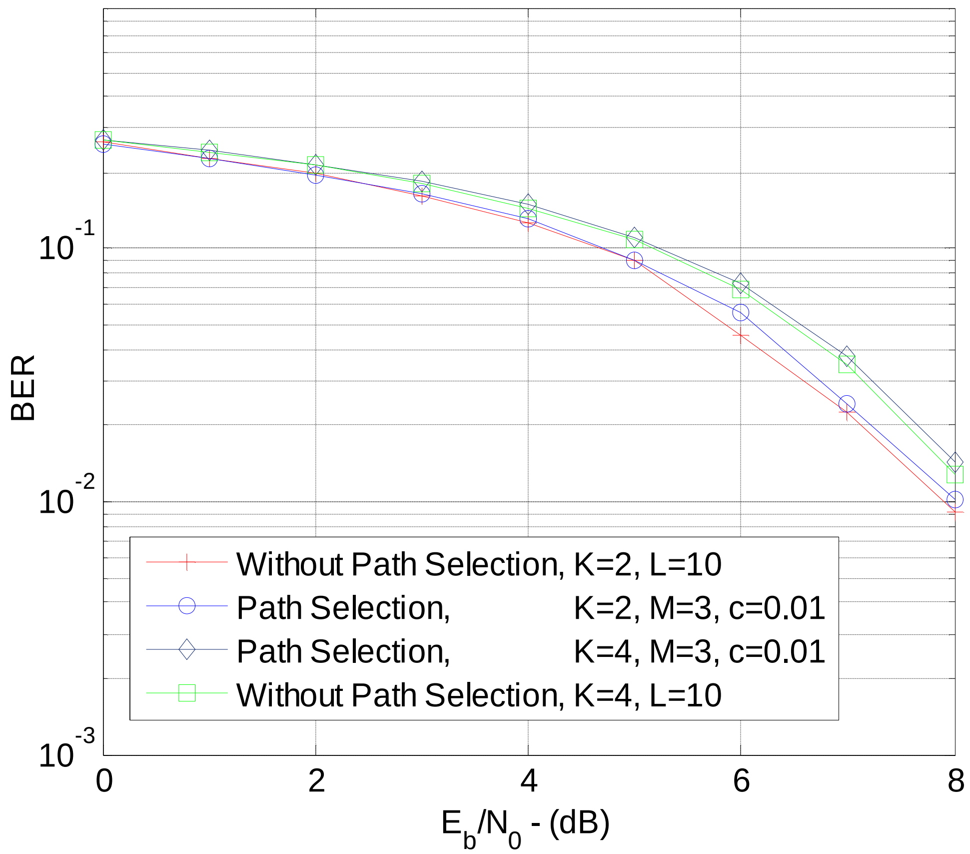

Fig .(5) BER performance for coded IDMA system with $K = 2, 4$ active users over a frequency selective multipath fading channel, where L is 10 and M for path selection algorithm is 3.

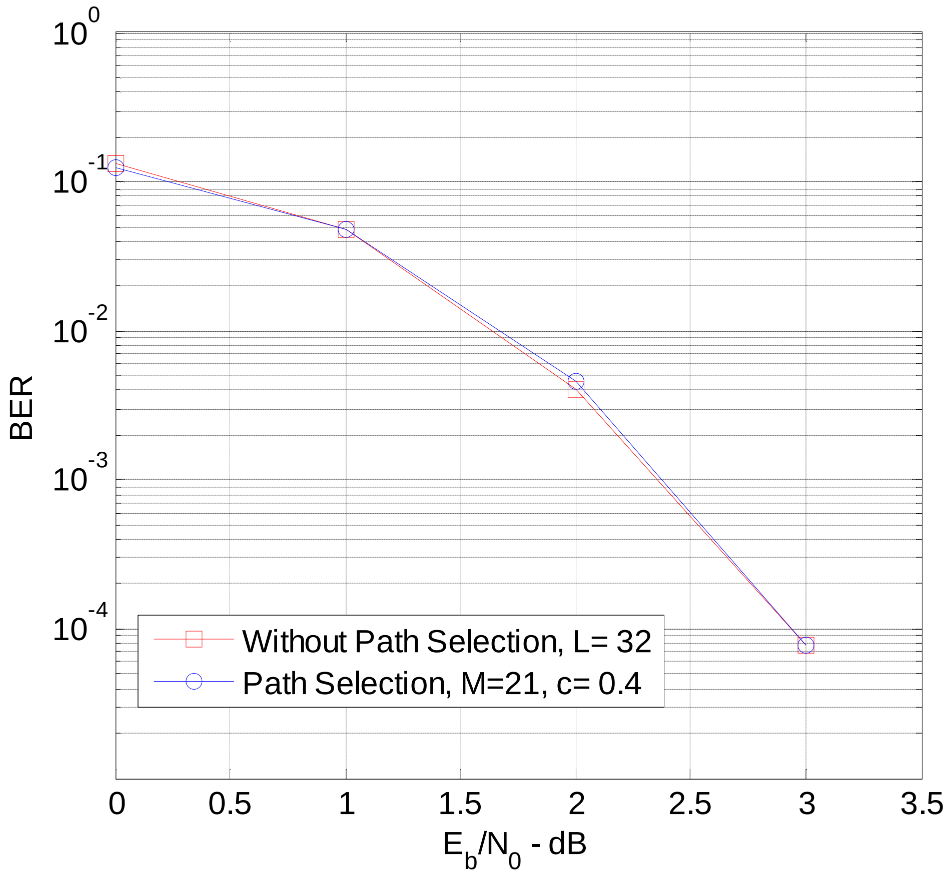

Fig .(6) The IDMA performance with $K = 4, 2$ over a flat multipath fading channel, where L is 32 and M for path selection algorithm is 21.

5. Conclusions

In this paper, optimal and suboptimal path selection schemes for soft Rake based multiuser receivers in long spread channels have been considered. Since long spread channels have large numbers of multipath components, only a subset of those significant components can be used due to complexity constraints. The selection of the optimal subset of multipath components is important for the performance of the receiver. The optimal solution to the path selection problem requires exhaustive search which becomes prohibitive for such multiuser systems. Therefore, we have proposed very simple path selection decision rule, which can be implemented easily and, as a result, the complexity is greatly reduced with limited performance degradation when compared to that obtained with optimal detection using all paths. The results also show that the proposed structure with channel estimation is able to achieve a quick start using only a small number of training symbols and it is a promising approach for system implementation with a low complexity receiver structure.

6. References

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