The Performance of RAKE Receiver in Multirate Wireless Communication Systems

Kokate M. D. **Sontakke T. R.** **Bagul C. R.**

Abstract— In 3G multirate wireless communication system such as UMTS, the enhancement of data rate is performed by reducing the spreading factor. This is made by using so called variable spreading factor (VSF) codes. Small spreading factor causes the saturation of inter path interference (IPI) and near-far problem. This implies that amplitude of transmission signal has to be higher in order than constant energy per bit as required by the system. This amplitude differences due to different data rate transmissions make receiver to deal with near-far problem.
This paper investigates various limitations of novel RAKE receiver architecture in frequency selective multipath fading channel.

KeyWords:3G, WCDMA, RAKE Receiver, Multipath Diversity

I. INTRODUCTION

CDMA is secured, robust to jammer and has inherent multipath diversity exploitation mechanism. It can be implemented with universal frequency reuse, yielding to support large number of users and also offers graceful degradation in interfering environment [1]. It becomes very important when wireless channel is characterized by multipath fading environment affected by deep fade [2]. In multipath environment, fading occurs as multiple paths add constructively or destructively depending upon the situation at that instant. Diversity adds more links in wireless communication system thereby decreasing probability of occurrence of deep fade. CDMA has inherent property to exhibit multipath diversity.

By using a RAKE receiver, the multiple wireless paths are identified separately and added them up in constructive manner to achieve better SNR.

II. RAKE RECEIVER MODEL

A. Multipath Channel Model:

In multipath frequency selective channel environment, the receive signal y (t) may be modeled as [3]

$$y(t) = \sum_{i=0}^{L-i} h(i)x(t-i)$$

where h(i) is channel coefficients or tap gain and x(t) is input symbol. Here, output y(t) does not depend on current symbol x(t) but also on L-1 previous symbols i.e. L-1 symbols are interfering x(t).This is nothing but inter symbol interference (ISI), ISI occurs when signal bandwidth is much larger than the coherence bandwidth. As CDMA system is wide band system its bandwidth is greater than coherence bandwidth. This may be termed as dispersive channel [4].
Let us consider x (t) as a CDMA signal, where

$$x(m) = s_0 c_0(m)$$

where s_0 is symbol and c_0 signature of user 0 at time instant m. Passing this signal through L multipath channels (multiple taps) with AWGN n(m), we get

$$y(m) = \sum_{d=0}^{L-1} h(d)x(m-d) + n(m)$$

$$= \sum_{d=0}^{L-1} h(d)s_0 c_0(m-d) + n(m) \quad (1)$$

i. e. in effect the multipath channel offers delay in user code. RAKE receiver correlates this signal with specific user code. For better operation RAKE receiver has to be properly synchronized for all multipath components. That includes synchronization of delay d and signal phase for each component.

B. Correlation:

The correlation is performed by correlating user 0's code with received signal y(m), then signal after correlation is

$$r(0) = \frac{1}{N}\sum_{m=0}^{N-1} y(m)c_0(m)$$

$$= \frac{1}{N}\sum_{m=0}^{N-1} s_0 h(d)c_0(m)c_0(m) +$$

$$\frac{1}{N}\sum_{m=0}^{N-1}\sum_{d=0}^{L-1} s_0 h(d)c_0(m-d)c_0(m) + \frac{1}{N}\sum_{m=0}^{N-1} n(m)c_0(m) \quad (2)$$

Here, $\frac{1}{N}\sum_{m=0}^{N-1} n(m)c_0(m) = \frac{\sigma^2}{N}$

The first term in above equation contains the desired information together with diversity gain due to diversity recovering, second term is multiple access interference (MAI)and inter path interference(IPI), typically dominates the noise so that one would like to remove its influence. Its influence is felt through the cross correlations between the chip sequences and the powers of users. If one knew the cross-correlations and other powers, then one could attempt to cancel the effect of one user upon other. This is in fact, intuitive motivation for interference cancellation scheme.
Received signal after correlating with code without delay is r(0) and correlating with user code with delay of one chip is r(1) and so on, therefore, we can have

$$r(0) = s_0 h(0) + \tilde{n}(0)$$
$$r(1) = s_0 h(1) + \tilde{n}(1)$$
$$\vdots$$
$$r(L-1) = s_0 h(L-1) + \tilde{n}(L-1)$$

This eventually is a receive diversity.

$$\begin{bmatrix} r(0) \\ \vdots \\ r(L-1) \end{bmatrix} = \begin{bmatrix} h(0) \\ \vdots \\ h(L-1) \end{bmatrix} s_0 + \begin{bmatrix} \tilde{n}(0) \\ \vdots \\ \tilde{n}(L-1) \end{bmatrix}$$

This is nothing but a linear combining of various paths.
In vector form it is

$$\mathbf{r} = s_0\mathbf{h} + \tilde{\mathbf{n}} \quad (3)$$

The net statistic of RAKE combining may be

$$\bar{\mathbf{r}} = \mathbf{W}^{\mathbf{H}}\mathbf{r} \quad (4)$$

Where weight W maximizes the SNR such that (Maximal Ration Combiner)

$$\mathbf{w}_{\mathbf{optimal}} = \frac{\mathbf{h}}{\|\mathbf{h}\|} \quad (5)$$

$$\bar{\mathbf{r}} = \frac{\mathbf{h}^{\mathbf{H}}}{\|\mathbf{h}\|}\mathbf{r}$$

$$= \frac{\mathbf{h}^{\mathbf{H}}}{\|\mathbf{h}\|}(\mathbf{h}_0\mathbf{s}_0 + \tilde{\mathbf{n}}) \quad (6)$$

signal to noise ratio at output of MRC RAKE is

$$\text{SNR} = \frac{\|\mathbf{h}\|^2}{\frac{\sigma^2}{N}} \quad (7)$$

The correlation is performed by multiplying the received signal in each branch with a copy of the desired user's code. The performance of such a receiver depends only on the amount of auto correlation and cross correlation with other codes. If the channel impulse response and propagation delay be properly estimated, the receiver performance becomes optimal.

If we assume a Rayleigh fading channel such that the tap gains h(i) are i. i. d. and energy is spreaded equally among all the L taps, then error probability can explicitly calculated as [5][9]

$$P_e = \left(\frac{1-\mu}{2}\right)^L \sum_{l=0}^{L-1} \binom{L-1+l}{l} \left(\frac{1+\mu}{2}\right)^2 \quad (8)$$

where

$$\mu = \sqrt{\frac{SNR}{1+SNR}}$$

III. LIMITATIONS

In the time-varying frequency-selective channel environment, the orthogonality of the spreading codes is not maintained at the receiver end. This technique is not completely useful to increase performance of conventional RAKE receivers in the multipath fading channels. Smaller the spreading factor, the smaller is the bit time interval. In effect this leads to near far situation. Unfortunately, the conventional RAKE receiver exhibits a near-far resistance equal to zero. i.e. it is not near far a resistant receiver.

Hence performance of conventional RAKE receiver is limited because of the followings:

- Multiple access interference (MAI)
- Near-far resistance
- Inter-path interference (IPI)

A. Multiple Access Interference Limit:

The RAKE receiver utilizes the cross correlation property and does not have any inherent capability to take into account other users information and thus to suppress multiple access interference (MAI) [1] [3]. Unfortunately, time-varying wireless communication channel does not assure the received codes orthogonality or low cross correlation.

Even though low complexity of the conventional RAKE receiver relies exclusively on the statistical parameters of the desired user and so find difficulties in handling the MAI. In fact, as it is possible to see in figure 1 when the number of users increases the probability of error of the conventional RAKE receiver shows an irreducible error floor. For high quality communication, it is mandatory to find better trade-off between system cost and performance.

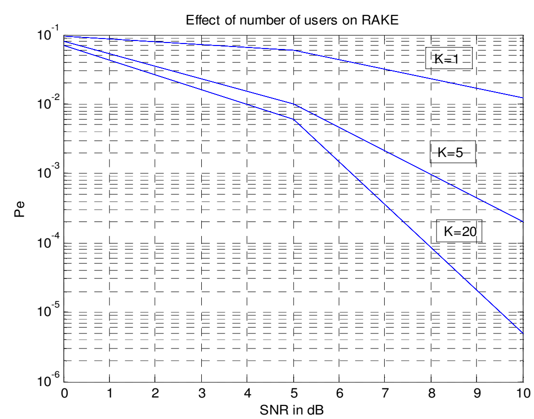

Figure 1: Probability of error of the conventional RAKE receiver as a function of the number of users

B. Near-far Problem:

A near-far problem occurs when one or more users are received with a higher power level than the desired user. Near–far issue limits the RAKE receiver performance. In a typical urban cells environment, there is a dynamic range of power obtained at the base station from different users.

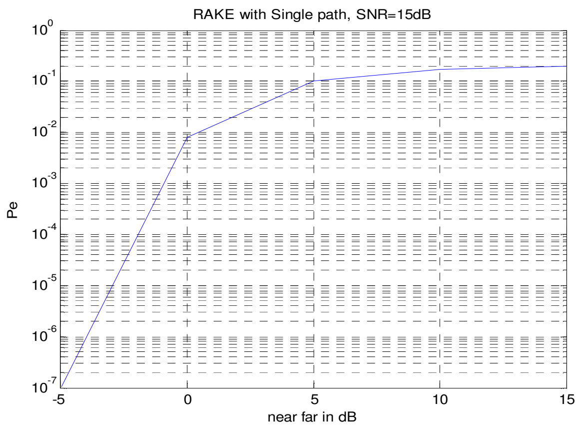

Figure 2: Probability of error of the RAKE receiver as a function of the ratio between the interfering user and the desired user energy

It is possible to demonstrate that even in two-user AWGN system the conventional RAKE receiver performance is completely deteriorated by an enough high interfering user energy [1]. In fact, in such a case the probability of bit error is upper bounded by

$$Q\left(\frac{A_1 - |r_{12}| A_2}{\sigma}\right)$$

Where A_i express the amplitude of user i, r_{12} is the cross-correlation value between code1 and code 2 and σ is the noise standard deviation. Taking the user 1 as desired user, it is easy to show that if

$$A_2 > \frac{A_1}{|r_{12}|}$$

Then

$$\lim_{\sigma > 0} P(\sigma) = \frac{1}{2}$$

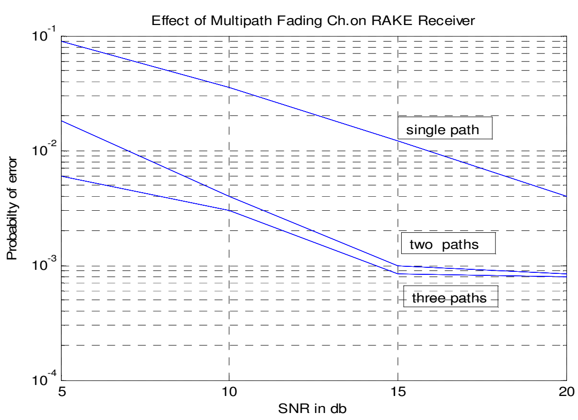

Figure 3: Probability of error of the conventional RAKE for different SNR (L=2, K=10).

Because of power imbalances it is important to analyze the performance of multiuser detectors. The performance of RAKE receiver under near far situation in static and fading channels is shown in figure 2 and 3 respectively.

C. Diversity limit:

In a multipath static channel environment, multipath diversity won't work effectively as other paths do not increase the diversity order of the system but only the interference level (figure 4). On the contrary, in a multipath fading channel each resolvable path carries an independent fading process, so that a higher diversity order can be reached [3].For most, 3G systems use two transmit antenna diversity. Space transmit diversity is preferred over orthogonal transmit diversity. [6]

Institutively, for L resolvable paths are available at the receiver, the probability to have all replicas in a deep fade condition is lower than the single-path case (figure 5).

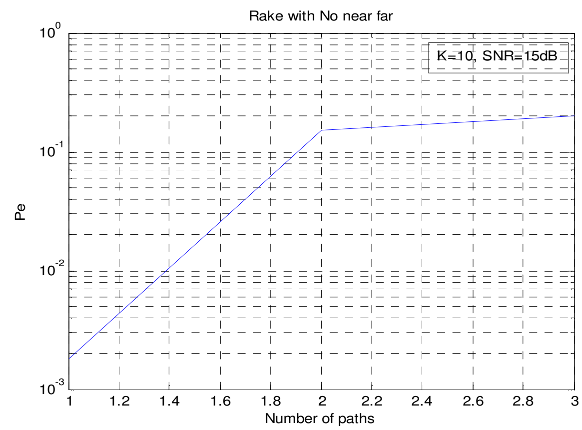

Figure 4: Probability of error of the conventional RAKE receiver as a function of the number of resolvable paths. Static Channel No near far

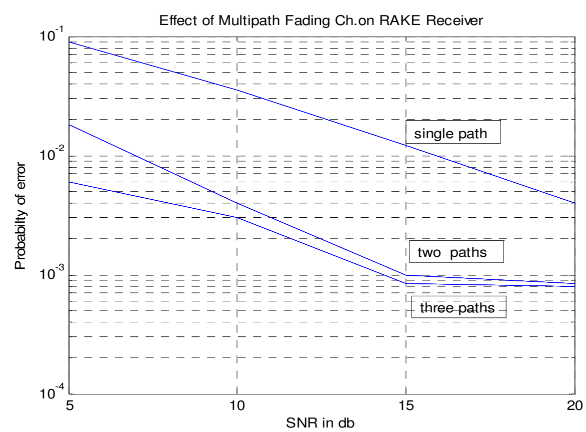

Figure 5: Probability of error of the conventional RAKE receiver as a function of the SNR for different number of resolvable paths(L). No near far

Obviously multipath diversity is advantageous in the case that it does not increase interference, whereas the interference level due to multipath increases proportionally to diversity order. Since interference results in an error floor, a lower diversity order, that causes less interference, may overcome a higher diversity order scheme in the high SNR region.

Performance of RAKE Receive diversity as shown in figure 6 is better than Almouti transmit diversity [11].

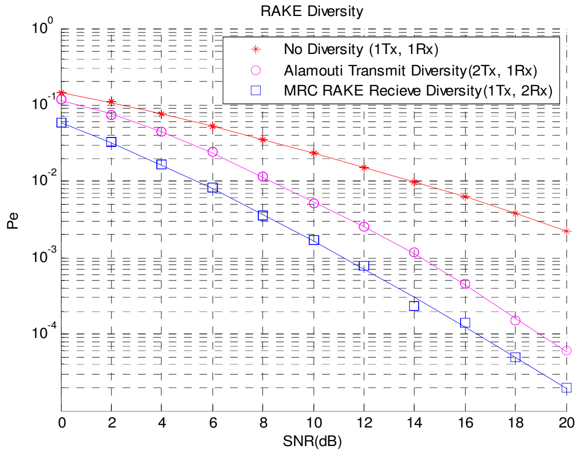

Figure 6: SNR vs Probability of Error

D. *Inter Path Interference:*

IPI occurs when the spreading factor is not enough to assure a perfect autocorrelation function of the channel paths [7]. In fact, small spreading factors result in more covariance, i.e. some correlation among paths is introduced and thus some multipath diversity is lost [8]. Moreover, as it has been illustrated before, IPI limits the diversity gain that is possible to reach to exploit the multipath nature of the channel.

Multiuser detectors like decorrelating receiver or the minimum mean square error (MMSE) receiver offer higher performance in terms of error probability and capacity with a linear increase in complexity. Their performance is based on the precise knowledge of the desired user distorted by the time varying channel [9].

Convention Rake Detector is channel phase sensitive similar to Post combining blind adaptive single user, pre combining blind adaptive single user detector [10]. The LMMSE adaptive receivers maintain better performance than RAKE in phase erroneous situation due to their intrinsically near-far resistance and MAI mitigation capabilities.

IV. Conclusion

Because of operative simplification, low complexity and implied receive diversity, this novel architecture of RAKE receiver used in most of DS CDMA systems. In this paper probability of error (P_e) is taken as measure of performance. One may treat other measures like asymptotic multiuser efficiency etc. Its performance is limited because of MAI, near far problem and IPI. Different solutions like LMMSE, multiuser detectors may be considered for high speed multirate communication.

References

[1] S. Verdu, *Multiuser Detection*, Cambridge University Press, Cambridge, UK, 1998

[2] P. A. Bello, "Characterisation of randomly Time-Variant linear channels," *IEEE Tr. On Comm.*, vol.16, pp.68-71, 1968

[3] John J. Proakis, *Digital Communication*, Third Edition, McGraw Hill International Edition, 1995

[4] Theodore S. Rappaport, *Wireless Communications -Principles and Practice*, Second Edition, Pearson Education Asia, 2002

[5] David Tse, Pramod Vishwanath, *Fundamentals of Wireless Communication*, Cambridge University Press,2005

[6] Clint Smith, Daniel Collins, *3G Wireless Networks*, McGraw Hill International Edition, 2002

[7]Hooli K., Juntti M., Latva-Aho M., "Inter-path interference suppression in WCDMA systems with low spreading factors", *Vehicular Technology Conference*, IEEE VTS, pg 421-425, 1999

[8] Hueda K.R., Roriguez C., Marques C., "New Interpath interference model for DS-CDMA indoor transmission with distributed antennas", *PIMRC, IEEE International symposium,*vol.1, pg. 92-97, 2000

[9] Juntti M. and Latva-Aho M., "Bit-error probability analysis of linear receivers for cdma systems in frequency-selective fading channels," *IEEE Trans. on Comm.*, vol.47, no.12, pp.1788-1791, Dec1999

[9] R. Lupas and S. Verdu, "Linear multiuser detectors for synchronous code division multiple access channel," *IEEE Trans. on Inf. Theory*, vol.35, no.1,pp. 123-136, Jan1989

[10] M. D. Kokate, T.R. Sontakke, P.W. Wani, "Precombining adaptive LMMSE detection for ds-cdma systems in time varying channels: Non blind and blind approach," *WEC (5),* 2005, pp. 198-200

[11] S.M. Almouti, "A simple transmit diversity technique for wireless communication," *IEEE Journal on selected Areas in Communication*, vol. 16, no.8, October 1998

Author's Details

Kokate M.D.
Working with K.K. Wagh College of Engineering Education and Research, Nashik as Professor in Electronics and Telecomm. Department. Total 22 years of teaching experience in the field Engineering education. Principal of K.K. Wagh Polytechnic during April2005 to April 2012. Fellow of IETE and Chairman of IETE Nashik sub center from 2009 onward.

Sontakke T.R.
Passed B. E.(Elect) in June 1971,from Govt. College of Engineering Aurangabad and M.Tech. in June 1973, from Nagpur University with specialization in power systems. He did Ph. D from Indian Institute of Technology Mumbai, in 1980. He was Director of S.G.G.S., Nanded an autonomous body under Govt. of Maharastshtra.
Published number of papers in national and international journals. Wrote many books in Electronics Engineering field. Guided many PG, PhD students. Worked on various research projects funded by govt. of India. Presently he is Principal of Alard College of Engineering, Pune
He was chairman/member of various government constituted bodies/ committees.

Bagul C. R.
Holds bachelor's degree in Electronic and Telecommunication from Pune University, Pune 2012. Pursuing Post graduation in VLSI and Embedded System in K. K. Wagh Institute of Engg. Education and Research, Nashik