

Performances Comparison among Smart Antenna RAKE Receiver and the other Applicable RAKE Receivers

Haiyang Fu , Xiong Liu, Wenfei Ruan, Xiangdong Jia

Nanjing University of Posts and Telecommunications, Nanjing Jiangsu, China
fuhy@njupt.edu.cn, liu_xiong86@163.com, ruanwenfei10@163.com, jiaxd@nwnu.edu.cn

Abstract—Many different types of RAKE receiver have been appeared with the development of mobile telecommunication. It is necessary to evaluate their application value. In this paper, the models of DIRAKE, CORAKE and CLRAKE receiver and their specific implementations are put forward. Moreover, their performances are also discussed when MPI and MAI exist. According to the results of performance simulation, it can be found that CORAKE receiver has better performance than CLRAKE receiver, and is easier to be realized. When the beam is formed in baseband, the performance of DIRAKE receiver is influenced greatly by the change of MS's position, which will introduce instability into the system.

Key words: Smart Antenna; CDMA; RAKE Receiver; G_{SA} ; phase-difference θ

I. Introduction

With the increasing number of wireless Internet users and the development of wireless multimedia services, 3G mobile communication system should provide high-quality and high-speed downlink data services for its users. However, in mobile communication system, due to the mobility of the terminals and the existence of many reflectors, signal received by the receiver is the superposition of multi-path signals with different time-delay and amplitude attenuation. It will cause multi-path fading and affect the performance of the receiver. Therefore, many techniques are proposed to overcome this phenomenon. However, in the mainstream of 3G standards, RAKE receiver is still widely used [1].

The classical RAKE receiver (CLRAKE) is the basic component of CDMA receiver. It can realize separation, time-delay adjustment and superposition of multi-path signals. In CDMA downlink receiver, coherent demodulation is used. Since there is a carrier phase-difference among the received multi-path signals, the coherent carrier $C_{1L}(t) = \cos w_{1L}t$ recovered in the receiver can only be synchronized with one received signal $S_1(t) = S_1 \cos w_1 t$, so coherent demodulation can be realized. But the phase-difference θ between the other carriers of multi-path signals and $C_{1L}(t)$ will introduce amplitude loss, possible polarity reverse and

interference during demodulation. Assuming the other multi-path signal being $S_2 \cos w_2 t$, then the output of the demodulator will be $S_2 \cos \theta$, and the phase-difference θ will influence the amplitude or polarity of the demodulated signal. Generally speaking, CLRAKE can use the training sequence or other channel estimation methods to estimate the polarity of $\cos \theta$. But none of them can estimate the actual value of $\cos \theta$.

References about RAKE receiver such as [2, 3, 4, 5, 6] have not yet studied the mentioned problem. References [7, 8, 9, 10] present some channel estimation methods to estimate the polarity of $\cos \theta$. The model of multi-path signal coherent demodulation RAKE receiver (CORAKE) which can realize multi-path signal coherent demodulation is put forward in this paper; it can make full use of the energy of multi-path signals.

The smart antenna (SA) technique which is based on phased array antenna can realize the directional reception, The SA can greatly reduce the influence of multi-path interference (MPI) and multi-access interference (MAI), however, it needs to detect the direction of arrival (DOA) [11, 12, 13] for the receiving signal. In the paper, the RAKE receiver based on directional reception is introduced, which is called directional RAKE receiver (DIRAKE) [14].

Reference [15] proposes a baseband signal beam-forming solution, but it doesn't give the detail solution or discuss their performance when MPI and MAI exist. Although the baseband beam-forming method can simplify the realization of DIRAKE receiver, the study results given by us shows that the method have the poor ability to inhibit the interference signal.

In this paper, the model of DIRAKE receiver, CORAKE and CLRAKE receiver and their specific realization are put forward, their performances are discussed when MPI and MAI are existed.

II. Three Resolutions of Base Station Receiver

A. The Classical RAKE Receiver (CLRAKE)

The general structure of coherent demodulation RAKE receiver for the downlink in CDMA IS-95 system is given in Figure 1. After frequency down conversion and analog / digital

transformation, $S_{AD}(t)$ about 10.7MHz could be gotten, and it can be sent into digital coherent QPSK demodulator.

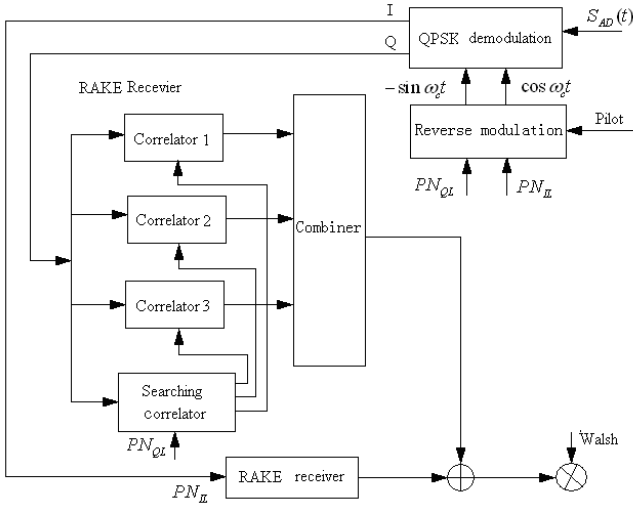


Figure 1. The coherent demodulation RAKE receiver

Coherent demodulation needs a local carrier which should be synchronized with the received signal carrier. This local carrier can be recovered from the received pilot signal by reverse modulation and can be expressed as follows:

$$C_{1L}(t) = \cos w_{C1L}t - \sin w_{C1L}t \quad (1)$$

Where w_{C1L} is the frequency of local coherent carrier. The input signals PN_{Q1L} and PN_{I1L} of the reverse modulation circuit should be synchronized with cell address code in the received pilot signal. Supposing the strongest signal and the other two multi-path signals can be expressed as follows respectively:

$$S_1(t) = D_1(t)W_1(t)PN_{I1}(t)\cos w_1t - D_1(t)W_1(t)PN_{Q1}(t)\sin w_1t \quad (2)$$

$$S_2(t) = S_1(t - t_{d1}) \quad S_3(t) = S_1(t - t_{d2}) \quad (3)$$

In which, $D_1(t)$ is user data and $W_1(t)$ presents the combination of user address code and long scrambling code sequence using in the downlink of IS-95. $PN_{I1}(t)$ and $PN_{Q1}(t)$ are short scrambling codes used as cell address code in CDMA IS-95 system.

The output signals I and Q of the QPSK demodulator are:

$$I = I_1 + I_2 \cos \theta_2 + I_3 \cos \theta_3 + Q_2 \sin \theta_2 + Q_3 \sin \theta_3$$

$$Q = Q_1 + Q_2 \cos \theta_2 + Q_3 \cos \theta_3 - I_2 \sin \theta_2 - I_3 \sin \theta_3$$

$$I_1 = D_1(t)W_1(t)PN_{I1}(t) \quad Q_1 = D_1(t)W_1(t)PN_{Q1}(t)$$

$$I_2 = D_1(t - t_{d1})W_1(t - t_{d1})PN_{I1}(t - t_{d1})$$

$$Q_2 = D_1(t - t_{d1})W_1(t - t_{d1})PN_{Q1}(t - t_{d1}) \quad (4)$$

Supposing t_{d1} is the time-delay of the second path signal

compared with that of the first one, and then the phase-difference θ_2 between the two signals should be the remainder of $[w_1(t - t_{d1}) - w_1t] / 2\pi$. The second path signal can be expressed as:

$$S_2(t) = I_2 \cos(wt + \theta_2) - Q_2 \sin(wt + \theta_2) \quad (5)$$

So the second multi-path signal can't be demodulated coherently. The output will be affected by θ , and the amplitude of I_2 and Q_2 will be reduced and their polarity may even be reversed by (4), on the other hand, it will introduce orthogonal interference between I and Q channels into the demodulated signal.

The block diagram of CLRAKE receiver is shown in Figure 2.

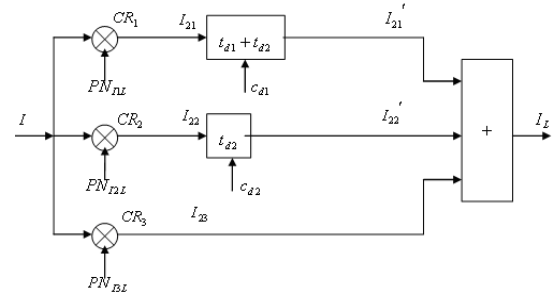


Figure 2. CLRAKE receiver in the chip class

To simplify the block diagram, low-pass filters after each correlator are omitted here. Control signals C_{d1} and C_{d2} of time-delay circuit can be produced through the comparison among PN_{I1L} , PN_{I2L} and PN_{I3L} . The output I_{21} of correlator CR_1 in Figure 2 is:

$$I_{21} = PN_{I1L} \times I = D_1(t)W_1(t) + PN_{I1L} [I_2 \cos \theta_2 + I_3 \cos \theta_3 + Q_2 \sin \theta_2 + Q_3 \sin \theta_3] \quad (6)$$

Since PN_{I1L} is not synchronized with short PN sequences in I_2 , I_3 , Q_2 and Q_3 , these four signals cannot be de-scrambled, which will then present as CDMA self-interference by MAI_{s1} ,

$$MAI_{s1} = PN_{I1L} \times [I_2 \cos \theta_2 + I_3 \cos \theta_3 + Q_2 \sin \theta_2 + Q_3 \sin \theta_3] \quad (7)$$

The output of CR_2 should be:

$$I_{22} = PN_{I2L} \times I = D_1(t - t_{d1})W_1(t - t_{d1})\cos \theta_2 + PN_{I2L} \times [I_1 + I_3 \cos \theta_3 + Q_2 \sin \theta_2 + Q_3 \sin \theta_3] \quad (8)$$

For the random of path delay, $\cos \theta_2$ has a probability of 1/2 to be negative. When it happens, the output signal of the second path I'_{22} will become reversed with that of $D_1(t)W_1(t)$. Under this circumstance, the expected signal will be reduced rather than be enhanced. Therefore, the

polarity of $\cos \theta_2$ in CLRAKE receiver should be estimated to diminish its ill effect. However, when $\cos \theta_3$ is considered, the efficiency of CLRAKE receiver will be even worse. The last item in (8) represents MPI in CDMA.

Although it takes the CLRAKE receiver in downlink for example, it can also apply to 3G uplink receiver since it transmit uplink pilot in the 3G system.

B. CORAKE with three-path Coherent Demodulation

The QAM coherent demodulation of the CORAKE receiver is shown in Figure 3.

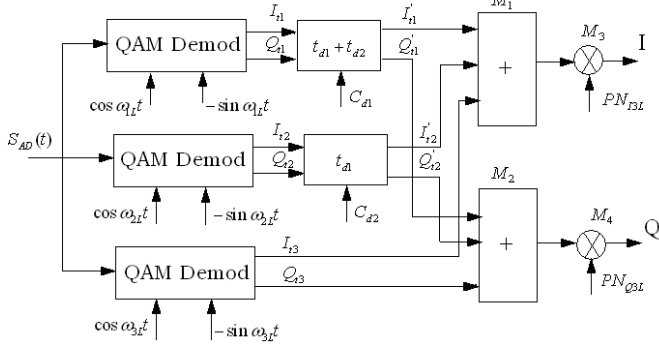


Figure 3. CORAKE with 3-path carrier coherent demodulation

When the 3 local coherent carriers are synchronized with that of the three-path receiving signals, then there are:

$$I_{t1} = I_1 + I_2 \cos \theta_2 + I_3 \cos \theta_3 + Q_2 \sin \theta_2 + Q_3 \sin \theta_3 \quad (9)$$

The other signals Q_{t1} , I_{t2} , Q_{t2} , I_{t3} , Q_{t3} have the similar expression. The RAKE receiving part of I channel in the three-path CORAKE is shown in Figure 3. After introducing CORAKE receiver, the performance degradation in CLRAKE receiver resulted from the loss factor $\cos \theta$ in non-coherent demodulation can be avoid.

The Local coherent carrier $C_{IL}(t)$ can be recovered by the circuit presented in Figure 4.

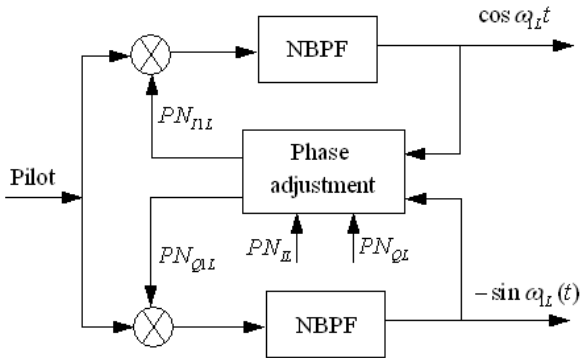


Figure 4. The local coherent carrier recovery circuit

The downlink pilot signal can be expressed as follows

$$S_{pilot} = PN_I \cos w_1 t - PN_Q \sin w_1 t \quad (10)$$

Where $PN_I = \pm 1$, as well as for PN_Q . Local PN_{IL}

and PN_{QL} are converted into PN_{IL1} and PN_{QL1} after phase adjustment, which are synchronized with PN_I and PN_Q in the received signal S_{pilot} . There is:

$$S_{pilot} \times PN_{IL1} = \cos w_1 t - PN_{IL1} PN_{QL1} \sin w_1 t \quad (11)$$

The recovered carrier $\cos w_1 t$ can be used as the local carrier $\cos w_{1L} t$ of QAM demodulator after being processed in the narrow band filter NBPf.

C. The Directional RAKE Receiver (DIRAKE) in Baseband

The basic structure of SA is 8-element circular array (AE), which are separated by $\lambda/2$ on a circle. When the main beam towards the direction of ϕ_n , the electric current phase of signal received by the kth AE is:

$$\alpha_{nk} = \mu a \sin \theta_n \cos(\phi_n - \phi'_k), \quad k=1,2,\dots,8 \quad (12)$$

Where $\mu = 2\pi / \lambda$ let $a = \lambda/2$, $\theta_n = \pi/2$, $\phi'_k = 2\pi * (k-1) / N = \pi(k-1) / 4$, then,

$$\alpha_{nk} = \pi \cos(\phi_n - \phi'_k) \quad (13)$$

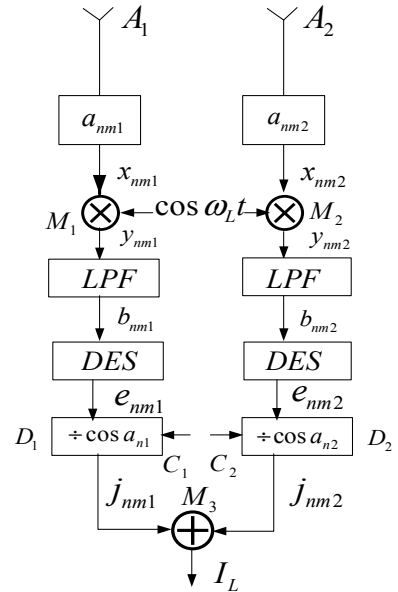


Figure 5. The beam-forming of receiving signal in baseband

Considering single path and supposing that SA directionally receives the signal of user1 in path 1, when the baseband implementation as Figure 5 is adopted, the expression of x_{11k} is shown as follows:

$$x_{11k}(t) = \sum_{n=1}^N D_n(t) W_n(t) PN_{In}(t) \cos(w_1 t + a_{n11}), \quad (14)$$

As well as for $x_{112}(t)$ to $x_{118}(t)$.

Supposing that the local carrier of the down conversion is $\cos w_L t$, when $w_L = w_C$, there is:

$$y_{11k}(t) = x_{11k}(t) * \cos a_{n11} \quad (15)$$

Neglecting the influence of 1/2 coefficient, after the low pass filter (LPF) and de-spread by $W_{1L} \times PN_{11L}$, for the AE_1 , there is:

$$y_{111} = D_1 \cos a_{111} + \sum_{n=2}^N D_n W_n PN_{1n} W_{1L} PN_{11L} \cos a_{n11} \quad (16)$$

From the above, the information for carrier phase shift turns into the amplitude loss of baseband signal after the down converter. All of $\cos a_{111}, \cos a_{112}, \dots, \cos a_{118}$ would be less than 1, which will make the amplitude of expected signal decline. In Figure 5, after the processing of divider $D_1, D_2, \dots, D_8$ and the adder M_3 , there is:

$$I_L = Y_{11} = 8D_1 + \sum_{k=1}^8 \sum_{n=2}^N D_n W_n PN_{1n} W_{1L} PN_{11L} \left(\frac{\cos a_{n1k}}{\cos a_{11k}} \right) \quad (17)$$

Where the first part is the output of user 1 in signal path 1 after beam-forming, the second part is the self-interference, here only one-path interference of (N-1) users is considered. If there are 3 path signals for each user, the total number of self-interference component is $H=N*3-1$. Considering the value of $\cos a_{n1k} / \cos a_{11k}$ may be larger than 1, hence the value of self-interference in baseband beam-forming may be amplified. However, the problem can be avoided in the beam-forming solution of carrier phase-shift. If adopting coherent demodulation for some-path it will reduce the interference of other paths.

III. Performance Simulation and Analysis

A. The SNR Gain of CORAKE Compared with CLRAKE

Assuming the average power of user's data is P and attenuation factors in each path is α_1, α_2 and α_3 respectively.

The output signal power in each finger of CLRAKE is:

$$\begin{aligned} S_1 &= (\sqrt{P} \cdot \alpha_1)^2 & S_2 &= [\sqrt{P} \cdot \alpha_2 \cos \theta_2]^2 \\ S_3 &= [\sqrt{P} \cdot \alpha_3 \cos \theta_3]^2 \end{aligned} \quad (18)$$

Using the similar method, the expression of both noise power and signal power in CORAKE receiver and CLRAKE

receiver can be deduced respectively, where the effect of loss factor will be omitted.

The SNR gain G_s for CORAKE receiver compared with the CLRAKE receiver is presented in Figure 6, in which $\theta_2, \theta_3 \in [0, \pi]$. The result is similar when $\theta_2, \theta_3 \in [-\pi, 0]$.

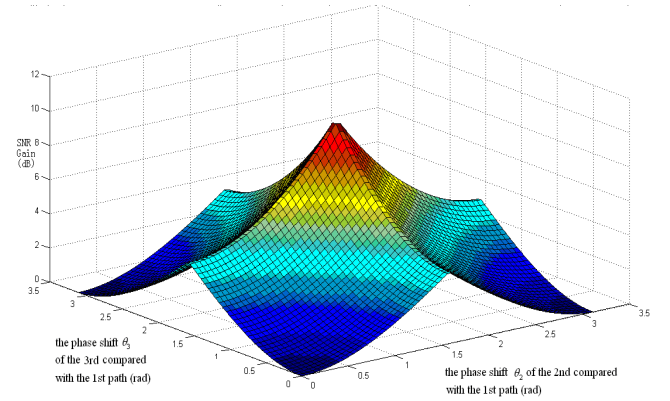


Figure 6. The G_s of CORAKE receiver with 3-path

From the result above, we can conclude that the performance of CORAKE receiver is much better than that of CLRAKE receiver. When $\theta_2 = \theta_3 = \pi/2$, the SNR gain will reach its maximum about 10.5dB.

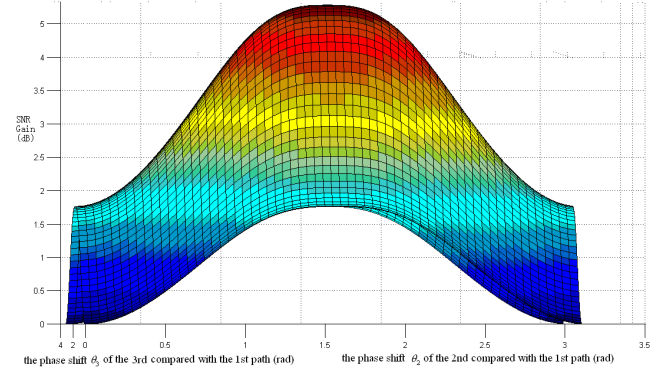


Figure 7. The G_s over the CLRAKE with maximum SNR merge

In Figure 7, the G_s for CORAKE receiver compared with CLRAKE receiver with maximum SNR merge is about 4.7dB.

B. The SNR Gain of DIRAKE Compared with CLRAKE

Considering that the maximum user number $N=8$, the number of maximum multi-path component is 3, so 7 other users will generate 21 interference signals. Supposing that their DOA ϕ_{nm} distributed uniformly in space,

$$\phi_{nm} = 2\pi \times [3(n-2) + m] / 21, \quad n=2, 3, \dots, 8, \quad m=1, 2, 3 \quad (19)$$

At the same time, the carrier phase-shift φ_{nm} of the 21 interference signals are also uniformly distributed.

$$\varphi_{nm} = 2\pi \times [3(n-2) + m] / 21, \quad n=2, 3, \dots, 8, \quad m=1, 2, 3 \quad (20)$$

As for the expected signal, supposing that the carrier phase-shift of the second path and the third path corresponding to main path is $\varphi_{12} = \varphi_{13} = \pi/4$, the DOA of these two signals are $\phi_{12} = \pi/4$, $\phi_{13} = 3\pi/4$ respectively.

When the SA beam-forming in baseband is used in the supposed situation, the received signal of DIRAKE receiver is

$$I_L = 8D_1 + \sum_{m=1}^3 \sum_{k=1}^8 \sum_{n=2}^8 D_{nm} W_{nm} PN_{l_{nm}} W_{1L} PN_{11L} \cos \theta_{nmk} / \cos \alpha_{11k} \\ + \sum_{m=2}^3 \sum_{k=1}^8 D_{1m} W_{1m} PN_{11m} W_{1L} PN_{11L} \cos \theta_{1mk} / \cos \alpha_{11k} \quad (21)$$

Where the second term in the right of the equation is the interference of other user's multi-path signal, and the third term is MPI of the expected, and

$$\theta_{nmk} = \varphi_{nm} + 2\pi \frac{r}{\lambda} \cos\left(\frac{2\pi k}{8} - \phi_{nm}\right) \\ \alpha_{11k} = 2\pi \frac{r}{\lambda} \cos\left(\frac{2\pi k}{8} - \phi_{11}\right) \quad (22)$$

The processing model of three-path signals for CLRAKE receiver is given in Figure 8,

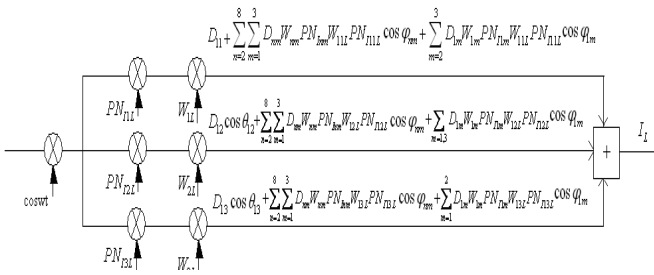


Figure 8. The model of three-path signals for CLRAKE

The output signal of CLRAKE receiver is

$$I_L = \sum_{m=1}^3 D_{1m} \cos \varphi_{1m} + \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{11L} PN_{11L} \cos \varphi_{nm}$$

$$+ \sum_{m=2}^3 D_{1m} W_{1m} PN_{11m} W_{11L} PN_{11L} \cos \varphi_{1m} \\ + \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{12L} PN_{112L} \cos \varphi_{nm} \\ + \sum_{m=1,3} D_{1m} W_{1m} PN_{11m} W_{12L} PN_{112L} \cos \varphi_{1m} \\ + \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{13L} PN_{113L} \cos \varphi_{nm} \\ + \sum_{m=1}^2 D_{1m} W_{1m} PN_{11m} W_{13L} PN_{113L} \cos \varphi_{1m} \quad (23)$$

Also, the output signal of DIRAKE receiver is:

$$I_L = 8 \sum_{m=1}^3 D_{1m} \cos \varphi_{1m} + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{11L} PN_{11L} \frac{\cos \theta_{nmk}}{\cos \alpha_{11k}} \\ + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{11L} PN_{11L} \frac{\cos \theta_{nmk}}{\cos \alpha_{11k}} + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{12L} PN_{112L} \frac{\cos \theta_{nmk}}{\cos \alpha_{12k}} \\ + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{12L} PN_{112L} \frac{\cos \theta_{nmk}}{\cos \alpha_{12k}} + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{13L} PN_{113L} \frac{\cos \theta_{nmk}}{\cos \alpha_{13k}} \\ + \sum_{k=1}^8 \sum_{n=2}^8 \sum_{m=1}^3 D_{nm} W_{nm} PN_{l_{nm}} W_{13L} PN_{113L} \frac{\cos \theta_{nmk}}{\cos \alpha_{13k}} \quad (24)$$

Here only coherent demodulation is used for path 1 signal, $\cos \varphi_{11}=1$, both $\cos \varphi_{12}$ and $\cos \varphi_{13}$ don't equal to 1. The purpose of that is to compare it with CLRAKE in which only coherent demodulation for 1-path signal can be realized. But it is easy to realize coherent demodulation of 3-path signals in DIRAKE, in which the performance will be improved further. Where,

$$\alpha_{12k} = 2\pi \frac{r}{\lambda} \cos\left(\frac{2\pi k}{8} - \phi_{12}\right), \quad \alpha_{13k} = 2\pi \frac{r}{\lambda} \cos\left(\frac{2\pi k}{8} - \phi_{13}\right) \quad (25)$$

From the analysis above, we can get the simulation result shown in Figure 9 and Figure 10.

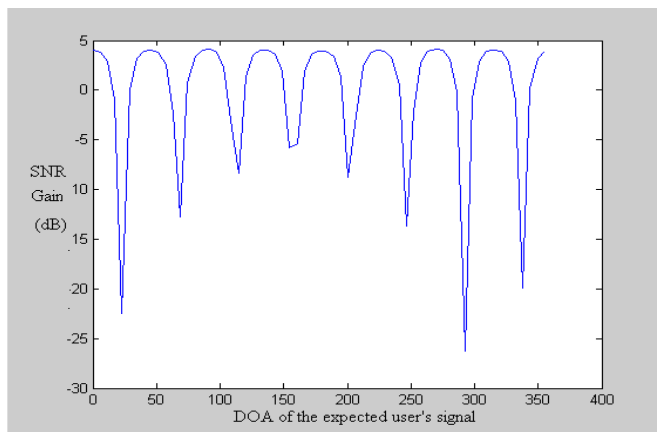


Figure 9 The G_{SA} of the DIRAKE with single-path over the CLRAKE with 3-path

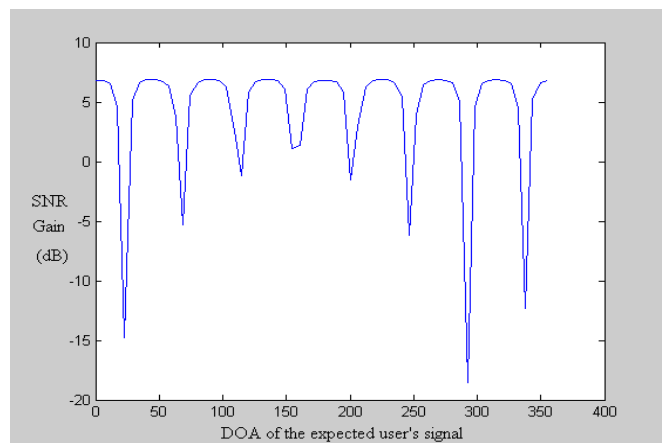


Figure 10. The G_{SA} of the DIRAKE over the CLRAKE for 3-path

Assuming that the DOA of the other 2-path are $\pi/4$ and $3\pi/4$ respectively, the result of simulation gives the relation between G_{SA} and the DOA of the first path. Because baseband beam-forming can't utilize the inhibition of coherent demodulation to MPI and MAI, the G_{SA} will be influenced greatly by the change of MS's position; therefore, the performance of DIRAKE is unstable.

IV. CONCLUSIONS

In this paper, the performances of 3 RAKE receivers are discussed when MPI and MAI exist. By the result of performance simulation, it can be found that CORAKE receiver have better performance than that of CLRAKE receiver, it can get a higher gain G_S and is easier to implement. Besides, CORAKE receiver can make better use of multi-path signal energy and eliminate the impact of non-coherent carrier demodulation loss factor existed in the CLRAKE receiver. However, the DIRAKE receiver in baseband can't utilize the inhibition of coherent demodulation to MPI and MAI, and the G_{SA} of DIRAKE receiver is influenced greatly by the change

of MS's position, which will induce great instability to the system.

REFERENCES

- [1] John G. Proakis. "Digital communications", 4th ed.[J] Boston : McGraw-Hill, 2001.
- [2] GEORGE L.TURIN. Introduction to Spread-Spectrum Antimultipath Techniques and Their Application to Urban Digital Radio PROCEEDINGS OF THE IEEE VOL.68, NO.3.MARCH 1980:328-353.
- [3] Nazli Guney, Hakan Delic. Transmitter-Receiver Rake Diversity Combining for Ultra-Wideband Communications [J]. IEEE 2007.
- [4] Said E.El-Khamy, Khalid S.Ba-Hajjaj. Spatial Path Separation and Path Diversity in 3G Multimedia Mobile Communications Using Intelligent Pre-Rake Processing in MISO channels[J].25th NATIONAL RADIO SCIENCE CONFERENCE(NRSC 2008) March 18-20,2008:C49 1-10.
- [5] Boris D. Andreev, Edward L. Titlebaum, E by G.Friedman. LOW POWER FLEXIBLE RAKE RECEIVERS FOR WCDMA[J]. ISCAS 2004.2004 IEEE:IV-97-IV-100.
- [6] Junhui Zhao,Wang Dongming,You Xiaohu. A improved algorithm research about RAKE receiver in CDMA system[J]. Journal of applied sciences,2004(3):298 - 302.
- [7] Athanasios Doukas, Georgios Panitsas, Christos Masouros, Grigorios Kalivas. Low Complexity Rake Receiver and Channel Estimator Implementation for DSS-CDMA Systems[J]. IEEE Ninth International Symposium on Spread Spectrum Techniques and Applications 2006,IEEE 2006 : 31-35.
- [8] Ratnam V. Raja Kumar, Amit Kumar. Development of a CDMA System with Rake Receiver for the Third Generation Wireless Communication Systems [J]. ICPWC'2002, IEEE 2002:309-313.
- [9] H. Andoh, M. Sawahashi, F. Adachi. Channel Estimation Using Time Multiplexed Pilot Symbols for Coherent Rake Combining for DS-CDMA Mobile Radio[J]. IEEE 1997 :954-958.
- [10] Lasse Harju, Milka Kuulusa, Jari Nurmi. FLEXIBLE IMPLEMENTATION OF A WCDMA RAKE RECEIVER [J].IEEE 2002:177-182.
- [11] Liangyi Ma.The smart antenna IS-95 and the third CDMA application in wireless communication[M]. Beijing: mechanical industry press ,2002: 179-193.
- [12] Xianzhong Xie.TD-SCDMA the third generation mobile communication technology and implementation[M]. Beijing:electronic industry press,2004 : 28-40.
- [13] Ayman F. Naguib, Aroryaswami Paulraj and Thomas Kailath.Performance of CDMA Cellular Networks with Base-Station Antenna Arrays: the Downlink[J]. IEEE 1994.
- [14] Josef Johannes Blanz, Apostolos Papathanassiou. "Smart Antennas for Combined DOA and Joint Channel Estimation in Time-Slotted CDMA Mobile Radio Systems with Joint Detection"[J]. IEEE transactions on vehicular technology,Vol.49, No.2. 2000.
- [15] Seungwon Choi and Donghee Shim. A Novel Adaptive Beamforming Algorithm for a Smart Antenna System in a CDMA Mobile Communication Environment[J]. IEEE Trans. on Vehicular technol.,vol.49.NO.5. September 2000.