# Pilot-Channel Aided SIC for Uplink WCDMA Systems over Multipath Fading Channels

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## ABSTRACT

In this paper, we examine the performance of the pilot-channel aided successive interference cancellation scheme in asynchronous WCDMA systems over multipath fading channels. Three types of cancellation-ordering method are compared where the cancellation order is decided based on either average power or instantaneous RAKE output strength with various updating rate. The scheme performs pilot-channel signal removal before data detection to alleviate the interferences from other users' pilot channels and thus can achieve better performance on user data detection. With the investigation and comparison through computer simulations, the scheme with three types of ordering method are shown to perform variously due to different grouping interval and power distribution ratio over both AWGN and Rayleigh fading channels.

**Keywords**: WCDMA, successive interference cancellation (SIC), ordering, pilot channel, 3G, multipath, channel estimation errors.

## 1. INTRODUCTION

Direct-sequence code division multiple access (DS/CDMA) technique has attracted considerable attention due to its potential of high capacity and robust performance in fading channels [1], [2]. However, the capacity of a CDMA system is primarily limited by the multiple access interference (MAI). Furthermore, high-power users can seriously corrupt users with low receiving power, which is known as the "near/far" problem. Therefore, much attention has been devoted to receiver designs that are capable of canceling multiuser interference [2]. The successive interference cancellation (SIC) takes a serial approach to cancel MAI as well as detect user data. It has the advantage of simplicity, robustness and superior performance over parallel interference cancellation (PIC) in Rayleigh fading channel [3], [4] and non-equal user-power profile. To determine the cancellation order in SIC, several methods were presented [5]- [7]. In a recent work [8], the effects of these three types of ordering method on hard-decision- based SIC with equal received power over AWGN and Rayleigh fading channel for an asynchronous system are examined. The simulation results show that reordering after each cancellation provides the best performance in both channels, while reordering based on short term average power outperforms ordering each bit and almost performs the same as reordering after each cancellation in fading channel. In this paper, bit error rate (BER) of three types of cancellation-ordering method are examined and discussed over multipath fading channels under the restriction of fixed total transmit power. The first type of ordering decides the cancellation order according to average power. The second type of ordering decides the cancellation order based on the total signal strength of the RAKE bank outputs at the first stage of SIC. In the third type of ordering, user with maximum total signal strength found at the RAKE output is to be detected after each cancellation. In addition to showing that the cancellation order affects the BER of SIC, the grouping interval and power distribution ratio also have much to do with the performance.

In the third generation mobile communication systems (WCDMA) [8], data signal and pilot signal are transmitted simultaneously by QPSK modulation in the uplink. However, not only the traffic-channel signals but the pilot-channel signals as well are interfered by other users' pilot and traffic signals under asynchronous reception as shown in [7]. In this investigation, the pilot-channel signals of all users are removed from the received signal before entering the successive cancellation units for data detection in order to alleviate interference from pilot signals of other users.

The paper is organized as follows. System model is described in Section II. In Section III, we present the pilot-channel aided SIC scheme employing three types of ordering method suitable for the system. Computer simulations are performed in Section IV. The main results are summarized in Section V.

## 2. SYSTEM MODEL

Consider an asynchronous CDMA system with QPSK modulation. The transmitter model for the k-th user is shown in Fig. 1. The equivalent complex baseband representation of the transmitted signal at the mobile station is given by

$$s_k(t) = \acute{s}_k(t) + j\sqrt{Pt_k}\beta_{pi}A_{Pilot}(t)C_{scramb,k}(t) \quad (1)$$

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where the traffic channel signal

$$\acute{s}_k(t) = \sqrt{Pt_k}\beta_d C_{OVSF}(t)B_k(t)C_{scramb,k}(t). \quad (2)$$

$Pt_k$ is the transmitted signal power, and $\beta_c = \beta_{pi}/\beta_d \leq 1$ denotes the pilot-to-traffic amplitude ratio where $\beta_d^2 + \beta_{pi}^2 = 1$ . $C_{OVSF}(t) = \sum c_{OVSF}\left[n_c\right] p_c(t - n_c T_c)$ where is the orthogonal variable spreading factor (OVSF) code with period equal to *SF*, and $SF = T_b/T_c$ is the spreading factor for user data [8]. $B_k(t) = \sum B_k\left[n_c\right] p_b(t - n_b T_b)$ is the traffic -channel signal, where $b_k$ is the binary data signal taking the values ±1 with equal probability. $A_{pilot}(t) = \sum a_{pilot}\left[n_{pi}\right] p_{pi}(t - n_{pi} T_{pi})$ is the uncoded pilot signal modulated at Q-channel and has the same characteristic as $B_k(t)$ but with a symbol period equal to $T_{pi}$. $C_{scramb,k}(t) = \sum (c_{k,I}\left[n_c\right] + j c_{k,Q}\left[n_c\right]) p_c(t - n_c T_c)$ is the complex scramble sequence, where $\{c_{k,I}\left[n\right]\}$ and $\{c_{k,Q}\left[n\right]\}$ are the Gold sequences with period equal to one frame long and composed of *N(SF)* chips, and $N$ denotes bit number in a frame [8]. $p_c$ , $p_b$ and $p_{pi}$ are unit power pulses with duration $T_c$ , $T_b$ and $T_{pi}$, respectively. After passing through a multipath fading channel, the received signal containing $K$ users in the system is represented as

$$r(t) = \sum_{k=1}^{K}\sum_{p=1}^{P}\sqrt{Pr_{k,p}(t)}e^{j\phi_{K,P}(t)}s_k(t - \tau_{k,p}) + n(t) \quad (3)$$

where the received signal power $Pr_{k,p}(t) = Pt_k(t)\left|\alpha_{k,p}(t)\right|$. $\sqrt{\alpha_{k,p}(t)}e^{j\phi_{k,p}(t)}$ is the complex channel distortion of the $k - th$ user at $p - th$ path which comes from short-term fading assuming that it is constant over one symbol period, i.e., $Pr_{k,p}(t) = Pr_{k,p}^{(n)}$ for $nT_b \leq t < (n+1)T_b$, and $\sum_{p=1}^{P}\left|\alpha_{k,p}^{(n)})\right| = 1$ . $n(t)$ is the complex AWGN with zero mean and one-sided power spectral density $N_0$ . $\tau_{k,p}$ are uniformly distributed random variables in $[0, Tb]$ for asynchronous case. In this paper, we assume $\tau_{k,p}$ are already known but $\sqrt{\hat{P}r_{k,p}^{(n)}}e^{j\hat{\phi}_{k,p}^{(n)}}$ denote estimates of $\sqrt{Pr_{k,p}^{(n)}}e^{j\phi_{k,p}^{(n)}}$ for all users.

## 3. PILOT-CHANNEL AIDED SUCCESSIVE INTERFERENCE CANCELLATION

In SIC, although data signals of the detected user are respread and cancelled from $r(t)$, the current detected user data signals are still interfered by uncancelled signals from the next bits of previously detected users due do asynchronous reception. A group of $G$ bits of a user are detected in the sequel to alleviate these interferences [6]. After pilot channel signal removal (PCSR), with the $m - th$ to the $(m + G - 1) - th$ bits of the $J - th$ user as the bits and the user of interest, the remaining signal $\hat{r}'(t)$ becomes

$$\begin{aligned}\hat{r}'(t) &= \sum_{k=1}^{K}\sum_{p=1}^{P}\sqrt{\alpha_{k,p}^{(n)}}e^{j\phi_{k,p}^{(n)}}\acute{s}_k(t - \tau_{k,p}) \quad (4)\\ &+ \sum_{k=1}^{K}\sum_{p=L+1}^{P}j\sqrt{Pr_{k,p}^{(n)}}e^{j\phi_{k,p}^{(n)}}\beta_{pi}A_{pilot}(t)C_{scramb,k}(t)\\ &+ \epsilon_{pi}(t) + n(t)\end{aligned}$$

where $L$ denotes the RAKE finger number, and

$$\begin{aligned}\epsilon_{pi}(t) &= \sum_{k=1}^{K}\sum_{p=1}^{L}\Big\{j\Big(\sqrt{\hat{P}r_{k,p}^{(n)}}e^{j\hat{\phi}_{k,p}^{(n)}} - \sqrt{Pr_{k,p}^{(n)}}e^{j\phi_{k,p}^{(n)}}\Big)\\ &\times\beta_{pi}A_{pilot}(t)C_{scramb,k}(t)\Big\} \quad (5)\end{aligned}$$

denotes the residual pilot signal coming from channel estimation errors. The real part of the correlator output after path combining is thus defined as

$$\begin{aligned}Y_J^n &= \sum_{l=1}^{L}Re\Bigg\{\frac{\sqrt{\hat{P}r_{J,l}^{(n)}}e^{-j\hat{\phi}_{J,l}^{(n)}}}{2\beta_d T_b}\int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}}\hat{r}'(t)\\ &\times C_{OVSF}(t - \tau_{J,l})C_{scramb,J}^{*}(t - \tau_{J,l})dt\Bigg\}\\ &= b_J[n]\sum_{l=1}^{L}Pr_{J,l}^{(n)} + Re\{MAI_{\hat{b}J}^{(n)} + I_{\hat{b}J}^{(n)}\} + \epsilon_J(t) \quad (6)\end{aligned}$$

where $m \leq n \leq m + G - 1$ and $(x)^*$ denotes the complex conjugate of $x$. Besides,

$$\begin{aligned}MAI_{\hat{b}J}^{(n)} &= \sum_{l=1}^{L}\sqrt{Pr_{J,l}^{(n)}}\\ &\times\Bigg\{\sum_{p=1,p\neq1}^{P}\sqrt{Pr_{J,p}^{(n)}}e^{-j(\phi_{J,l}^{(n)} - \phi_{J,p}^{(n)})}\acute{\lambda}_{J,p;J,l}^{(n)}(\tau_{J,p;J,l})\\ &+ \sum_{k=1,k\neq J}^{K}\sum_{p=1}^{P}\sqrt{Pr_{k,p}^{(n)}}e^{-j(\phi_{J,l}^{(n)} - \phi_{k,p}^{(n)})}\acute{\lambda}_{k,p;J,l}^{(n)}(\tau_{k,p;J,l})\\ &+ j\beta_c\sum_{k=1,k\neq J}^{K}\sum_{p=L+1}^{P}\Big[\sqrt{Pr_{k,p}^{(n)}}e^{-j(\phi_{J,l}^{(n)} - \phi_{k,p}^{(n)})}\\ &\times\acute{\mu}_{k,p;J,l}^{(n)}(\tau_{k,p;J,l})\Big]\Bigg\} \quad (7)\end{aligned}$$

where $\acute{\lambda}_{k,p;J,l}^{(n)}(\tau_{k,p;J,l})$ and $\acute{\mu}_{k,p;J,l}^{(n)}(\tau_{k,p;J,l})$ denote interferences from the $p - th$ path of the $k - th$ users' traffic-channel and pilot-channel, respectively, and they are defined as follows.

$$\begin{aligned}\acute{\lambda}_{k,p;J,l}^{(n)}(\tau_{k,p;J,l}) &= \frac{1}{2T_b}\int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}}\Big\{b_k(t - \tau_{k,p})\\ &\times\ C_{OVSF}(t - \tau_{k,p})C_{OVSF}(t - \tau_{J,l})\\ &\times\ C_{scramb,k}(t - \tau_{k,p})\\ &\times\ C_{scramb,J}^{*}(t - \tau_{J,l})dt\Big\} \quad (8)\end{aligned}$$

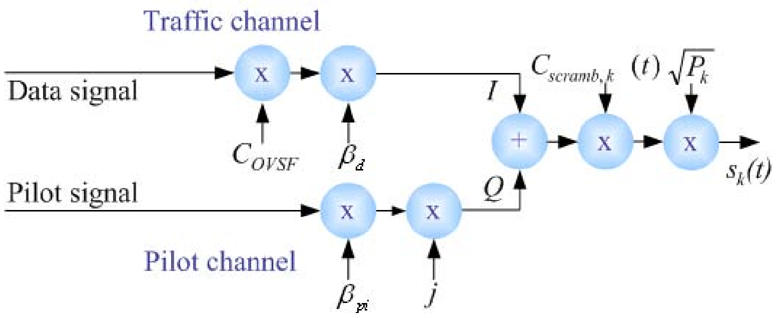

***Fig.1:*** *Transmitter model for the k-th user.*

and

$$\begin{aligned} \acute{\mu}^{(n)}_{k,p;J,l}(\tau_{k,p;J,l}) &= \frac{1}{2T_b} \qquad (9)\\ &\times \left\{ \int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}} A_{pilot}(t-\tau_{k,p}) \right.\\ &\times C_{OVSF}(t-\tau_{J,l})\\ &\times C_{scramb,k}(t-\tau_{k,p})\\ &\times \left. C^{*}_{scramb,J}(t-\tau_{J,l})dt \right\} \end{aligned}$$

Besides, the noise induced interference is given by

$$\begin{aligned} I^{(n)}_{\hat{b},J} &= \sum_{l=1}^{L} \left\{ \frac{\sqrt{\hat{P}r^{(n)}_{J,l}}e^{-j\hat{\phi}^{(n)}_{J,l}}}{2\beta_d T_b} \right.\\ &\times \int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}} \Big[ n(t)C_{OVSF}(t-\tau_{J,l})\\ &\times \left. C^{*}_{scramb,J}(t-\tau_{J,l}) \Big] dt \right\}, \qquad (10) \end{aligned}$$

and $\epsilon_J(t)$ , induced from channel estimation errors, are expressed as follows.

$$\begin{aligned} \epsilon_J(t) &= \sum_{l=1}^{L} Re \left\{ \frac{\sqrt{\hat{P}r^{(n)}_{J,l}}e^{-j\hat{\phi}^{(n)}_{J,l}} - \sqrt{Pr^{(n)}_{J,l}}e^{-j\phi^{(n)}_{J,l}}}{2\beta_d T_b} \right.\\ &\times \int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}} \Big[ \hat{r}^{'}(t)C_{OVSF}(t-\tau_{J,l})\\ &\times C^{*}_{scramb,J}(t-\tau_{J,l}) \Big] dt + \left\{ \frac{\sqrt{Pr^{(n)}_{J,l}}e^{-j\phi^{(n)}_{J,l}}}{2\beta_d T_b} \right.\\ &\times \int_{nT_b+\tau_{J,l}}^{(n+1)T_b+\tau_{J,l}} \Big[ \epsilon_{pi}(t)C_{OVSF}(t-\tau_{J,l})\\ &\times \left.\left. C^{*}_{scramb,J}(t-\tau_{J,l}) \Big] dt \right\} \right\} \qquad (11) \end{aligned}$$

As successive interference cancellation is performed to achieve better performance, signals are detected in the order of their strength since the user with large received signal power is more reliable but interferes other users more seriously as shown in (7). Thus, after ranking the cancellation order based on the adopted cancellation-ordering method, the initial data decision $\hat{b}_{SIC;<u>}[n]$ can be obtained with

$$\hat{b}_J[n] = sgn\{Y^{(n)}_J\} \qquad (12)$$

when user $J$ is decided to be detected first, where $< u >= J$ denotes that user $J$ is to be detected in the $u-th$ order, and $sgn\{.\}$ is the sign function. With $\hat{r}^{'}(t)$ in (4) replaced by $\hat{r}^{'}_{SIC;<u>}(t)$,

$$\hat{r}^{'}_{SIC;<u>}(t) = \hat{r}^{'}(t) - \sum_{k=<1>}^{u-1} \hat{C}_{data,k}(t) \qquad (13)$$

where

$$\begin{aligned} \hat{C}_{data,k}(t) &= \sum_{p=1}^{L} \left\{ \sqrt{\hat{P}r^{(n)}_{k,p}}e^{-j\hat{\phi}^{(n)}_{k,p}}\beta_d \hat{b}_{SIC;k}[n] \right. \qquad (14)\\ &\times \left. C_{OVSF}(t-\tau_{k,p})C_{scramb,k}(t-\tau_{k,p}) \right\}\\ &= \sum_{p=1}^{L} \sqrt{\alpha^{(n)}_{k,p}}e^{-j\phi^{(n)}_{k,p}} \acute{s}_k(t-\tau_{k,p}) + \acute{\epsilon}_k(t), \end{aligned}$$

and $nT_b + \tau_{k,p} \leq t < (n+1)T_b + \tau_{k,p}$. $\hat{b}_{SIC;k}[n]$ is data decision of user $k$, and $\acute{\epsilon}_k(t)$ denote interferences from channel estimation and bit decision errors with the following expression.

$$\begin{aligned} \acute{\epsilon}_k(t) &= \beta_d \sum_{p=1}^{L} \left\{ \left( \sqrt{\hat{P}r^{(n)}_{k,p}}e^{-j\hat{\phi}^{(n)}_{k,p}} - \sqrt{Pr^{(n)}_{k,p}}e^{-j\phi^{(n)}_{k,p}} \right) \right.\\ &\times \left. \hat{b}_{SIC;k}[n] + \sqrt{Pr^{(n)}_{k,p}}e^{-j\phi^{(n)}_{k,p}} \left( \hat{b}_{SIC;k}[n] - b_{SIC;k}[n] \right) \right\}\\ &\times C_{OVSF}(t-\tau_{k,p})C_{scramb,k}(t-\tau_{k,p}). \qquad (15) \end{aligned}$$

The real part of correlator output of the u-th cancelled user after path combining thus becomes

$$\begin{aligned} Y^{(n)}_{SIC_{<u>}} &= b_{<u>}[n] \sum_{l=1}^{L} Pr^{(n)}_{<u>,l} + Re\Big\{ MAI^{(n)}_{\hat{b}SIC_{<u>}}\\ &+ I^{(n)}_{\hat{b}SIC_{<u>}} \Big\} + \epsilon_{SIC,<u>}(t). \qquad (16) \end{aligned}$$

We can find that

$$
\begin{aligned}
MAI_{\hat{b}SIC_{<u>}}^{(n)} &= \sum_{l=1}^{L} \sqrt{Pr_{<u>,l}^{(n)}} \\
&\times \left\{ \sum_{p=1,p\neq l}^{P} \left[ \sqrt{Pr_{<u>,p}^{(n)}} e^{-j(\phi_{<u>,l}^{(n)} - \phi_{<u>,p}^{(n)})} \right. \right. \\
&\times \left. \acute{\lambda}_{<u>,p;<u>,l}^{(n)} (\tau_{<u>,p;<u>,l}) \right] \\
&+ \sum_{k=<u+1>}^{<K>} \sum_{p=1}^{P} \left[ \sqrt{Pr_{k,p}^{(n)}} e^{-j(\phi_{<u>,l}^{(n)} - \phi_{k,p}^{(n)})} \right. \\
&\times \left. \acute{\lambda}_{k,p;<u>,l}^{(n)} (\tau_{k,p;<u>,l}) \right] \\
&+ \sum_{k=<1>}^{<u-1} \sum_{p=L+1}^{P} \left[ \sqrt{Pr_{k,p}^{(n)}} e^{-j(\phi_{<u>,l}^{(n)} - \phi_{k,p}^{(n)})} \right. \\
&\times \left. \left. \acute{\lambda}_{k,p;<u>,l}^{(n)} (\tau_{k,p;<u>,l}) \right] \right\}
\end{aligned}
\tag{17}
$$

and

$$
I_{\hat{b}SIC_{<u>}}^{(n)} = I_{\hat{b}_{<u>}}^{(n)} \tag{18}
$$

Besides,

$$
\begin{aligned}
&\epsilon_{SIC,<u>}(t) \\
&= \sum_{l=1}^{L} Re \left\{ \frac{\sqrt{\hat{P}r_{<u>,l}^{(n)}} e^{-j\hat{\phi}_{<u>,l}^{(n)}} - \sqrt{Pr_{<u>,l}^{(n)}} e^{-j\phi_{<u>,l}^{(n)}}}{2\beta_d T_b} \right. \\
&\times \int_{nT_b+\tau_{<u>,l}}^{(n+1)T_b+\tau_{<u>,l}} \left[ \hat{r}'_{SIC;<u>}(t) C_{OVSF}(t - \tau_{<u>,l}) \right. \\
&\times \left. C_{scramb,}^{*}(t - \tau_{<u>,l}) \right] dt + \left\{ \frac{\sqrt{Pr_{<u>,l}^{(n)}} e^{-j\phi_{<u>,l}^{(n)}}}{2\beta_d T_b} \right. \\
&\times \int_{nT_b+\tau_{<u>,l}}^{(n+1)T_b+\tau_{<u>,l}} \left[ \left( \epsilon_{pi}(t) - \sum_{k=<1>}^{<u-1>} \acute{\epsilon}_k(t) \right) \right. \\
&\times \left. \left. \left. C_{OVSF}(t - \tau_{<u>,l}) C_{scramb,<u>}^{*}(t - \tau_{<u>,l}) \right] dt \right\} \right\}
\end{aligned}
\tag{19}
$$

which comes from all channel estimation and data decision errors of previous processes. After a hard decision, the data decision $\hat{b}_{SIC;J}[n]$ has the same definition as $\hat{b}_J[n]$ in (12) except that $Y_J^{(n)}$ is replaced by $Y_{SIC\ J}^{(n)}$. As described, the SIC detects user data in a dedicated order. In the following, the pilot-channel aided SIC scheme with three types of ordering is described.

### 3.1 Ordering Based on Average Power (Type I)

In the first method, the cancellation order is decided based on the average power measured over a long period of time. The user index and the corresponding channel estimates of the user with maximum average power are sent to correlator. Then the data signal is respread and cancelled as shown in (14) and (13), respectively. When a group of $G$ bits of user data is processed, $G$ bits of the user with second largest average power are to be detected, respread and cancelled from the remaining signal $\acute{r}_{SIC;<2>}(t)$ of the previous stage. This process continues until all users are detected. In this way, tremendous computations can be saved in ranking the cancellation order.

### 3.2 Ordering Based on RAKE Outputs Each G-bit Interval (Type II)

This type of ordering is similar to that proposed in [7]. At first, the cancellation order is decided according to the descending strength of $\sum_{n=m}^{m+G-1} \left| Y_k^{(n)} \right|$ for all $k$. After that, processes in Type II are the same as that in Type I according to the order record.

### 3.3 Ordering Based on RAKE Outputs After Each G-bit Cancellation (Type III)

In this type of ordering method, after each detection and cancellation of a group of $G$ bits of a user in stage $< u >$, the user with maximum $\sum_{n=m}^{m+G-1} \left| Y_k^{(n)} \right|$ is always found and chosen as the $< u+1 > -th$ detected and cancelled user. The process continues until all users are detected. This type of ordering takes the most computational complexity and time.

## 4. SIMULATION RESULTS AND DISSCUSSIONS

***Table 1:*** *Simulation Parameters.*

| | |
|---|---|
| Chip Rate ($1/T_b$) | 3.84Mhz |
| Carrier Frequency | 2GHz |
| Spreading Factor ($SF$) | 16 |
| Bit Rate ($1/T_b$) | 240 Kbps |
| Scramble Sequence Length ($N$) | 38400 Chips |
| Frame Period ($NT_c$) | 10 ms |
| Pilot-to-Traffic Gain ($\beta_c$) Ratio | 2/3 |
| User Number ($K$) | 8 |
| Average Signal-to-Noise Ratio ($SNR$) | 20 dB |
| Multipath Number | 4 |
| Relative Path Gain | 0, -3, -6, -9 dB |
| Doppler Shift ($f_d$) | 222 Hz |
| Vehicular speed ($v_s$) | 120 Km Per Hour |
| MA Window Used in Channel Estimation ($W$) | 128 Bits |

The multipath fading channel used for simulation is assumed to have four paths with relative power 0dB, -3dB, -6dB, and -9dB and with one chip separation, respectively, and total power of all paths is normalized to unity. A L-finger RAKE receiver is used to

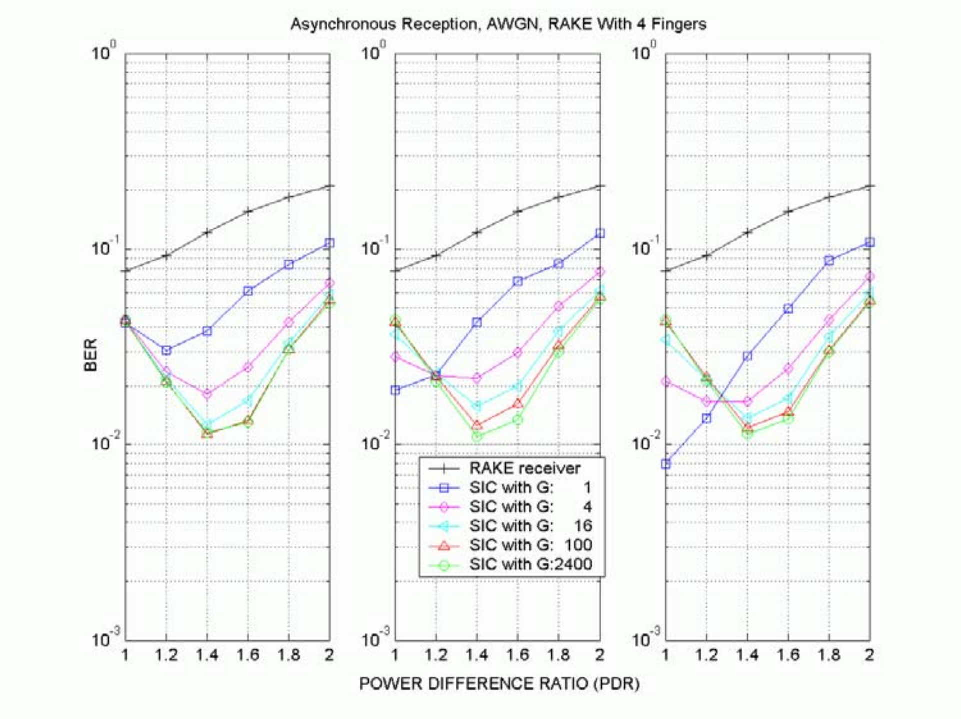

***Fig.2:*** *BER versus grouping interval with different PDR for (a) Type I, (b) Type II, and (c) Type III SIC.*

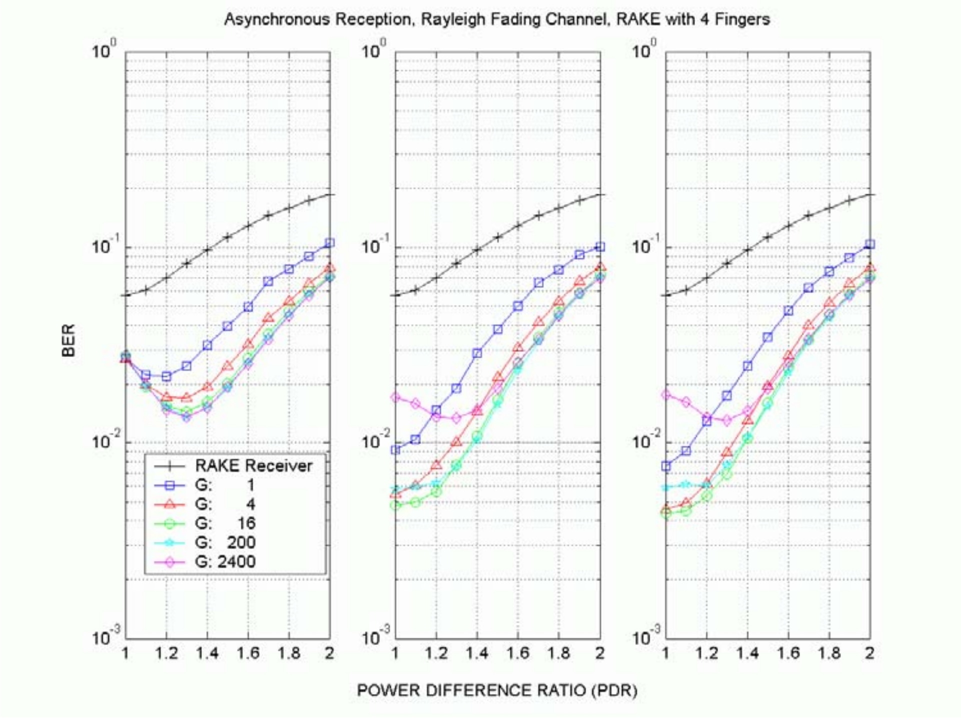

***Fig.3:*** *BER versus G with different PDR for (a) Type I, (b) Type II, and (c) Type III SIC.*

perform path combination for each user, and the moving average method with window length $W$ is adopted to attain channel estimates. Besides, power distribution ratio ($PDR$) is defined as $PDR = P_k/P_{k+1} \geq 1$ where $1 \leq k \leq K-1$. For sake of justice, the total transmit power of $K$ users in the system are $K$ for all $PDR$, and $P_K = K(PDR-1)/[(PDR)^K - 1]$. The general simulation parameters are summarized in TABLE. 1 if they are not explicitly specified in the text.

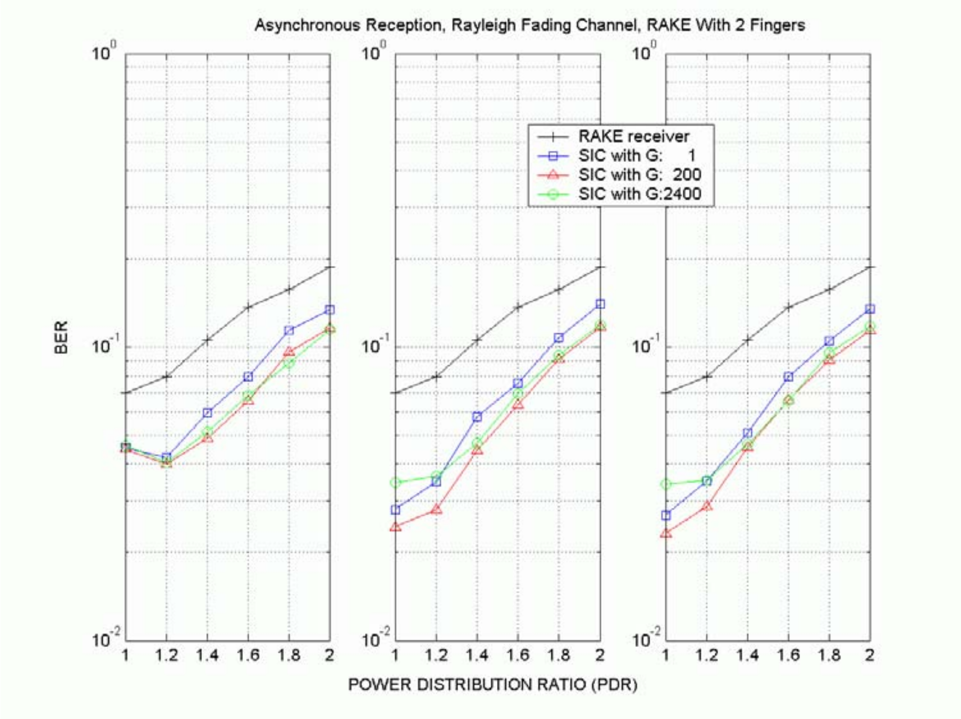

***Fig.4:*** *BER versus grouping interval with different PDR for (a) Type I, (b) Type II, and (c) Type III SIC.*

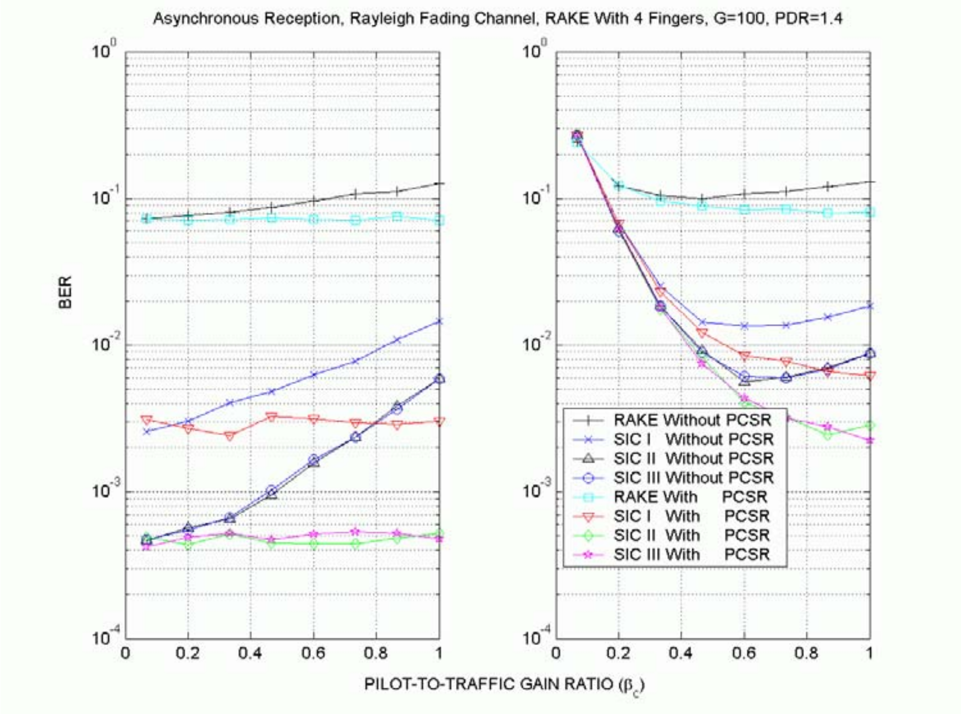

***Fig.5:*** *BER comparison with/without pilot channel signal removed with different $\beta_c$ for (a) known channel parameters and (b) estimated channel parameters.*

### 4.1 AWGN-Only Channel

In Fig. 2, a four-finger RAKE is used for path combining for all users. The influence of various grouping interval $G$ and $PDR$ on the BER in AWGN channel are examined. Type III SIC is shown to outperform the other two types of ordering method, especially only when $PDR$ is close to 1 and grouping interval $G$ is small. However, the BER difference of these three types of ordering method is not explicit when $G$ is larger than 16 or when $PDR$ increases. This is because that the influence of varying AWGN decreases at first stages as $PDR$ increases and the influence of asynchronous reception decreases as $G$ increases, and thus all three types of ordering method have almost the same cancellation order.

### 4.2 Rayleigh Fading Channel

When it comes to Rayleigh fading channel in Fig. 3, a four-finger RAKE is still used for path combining for all users. We find that all three types of SIC perform much better than the RAKE receiver. Type III SIC outperforms Type II SIC, and Type II SIC outperforms Type I SIC when $G$ is smaller than 16 and $PDR$ is not too large. Besides, Type I SIC cannot perform like Type II and Type III SIC since its cancellation order cannot reflect the channel variation due to Rayleigh fading. We observe that Type II and Type III SIC achieve their best performance when $16 < G < 200$ , which takes about 1/10 period of $1/f_d$ (Doppler frequency). And, as expected, performances of Type II and Type III SIC become worse when $G$ is larger than $16 \sim 200$ with the same reason as that in Type I SIC. Thus, a suitable $G$ that makes a compromise between asynchronous reception and channel variation due to Rayleigh fading channel is needed.

In Fig. 4, only the first two paths are combined by a two-finger RAKE. The results are similar to those in Fig. 3 except that the influence of grouping interval decreases and large degradation occurs in Type II and Type III SIC.

Generally speaking, large $\beta_c$ results in better channel parameters estimation, however, it also results in worse data detection as shown in Fig. 5 For the pilot-channel aided SIC with three types of ordering method and RAKE receiver, those with pilot-channel signal removed (PCSR) outperform those without PCSR, especially when $\beta_c$ is large. Besides, Type II and Type III SIC still perform better than Type I SIC and RAKE receiver with or without channel estimation errors.

## 5. SUMMARY

In this paper, the pilot-channel aided SIC is shown to alleviate interferences from traffic-channel as well as pilot-channel signals of other users in the received signals. With the pilot-channel signal removed, increasing pilot-channel transmit signal improves channel parameters estimation without degrading data detection even under the restriction of fixed total transmit power of all users. Besides, performances of pilot-channel aided SIC are compared by using different cancellation-ordering method for uplink WCDMA system over multipath fading channels. Type I SIC decides the cancellation order according to average power. Type II SIC decides the cancellation order based on total signal strength of the RAKE bank outputs at the first stage. In Type III SIC, user with maximum total signal strength found at the RAKE output is detected after each cancellation. In addition to showing the superiority over the conventional receiver in simulation results, the influences of grouping interval and power distribution ratio on the BER are examined and discussed. When power distribution ratio and grouping interval are all equal to 1, Type III SIC has the best performance while Type I SIC has the worst performance, which matches the results shown in [8]. When power distribution ratio is not equal to 1, however, Type III SIC outperforms Type II SIC and Type II SIC outperforms Type I SIC under AWGN only channel when grouping interval is small. And as grouping interval increases, all three types of ordering method perform almost the same. When it comes to Rayleigh fading channel, Type II SIC and Type III SIC benefit when grouping interval is small enough to track the channel variation rate and large enough to alleviate interference due to asynchronous reception.

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