An Optimum Interference Mitigating Combining Scheme for the CDMA Downlink With the Same Complexity as MRC

Ning Kong, Ian Riphagen, Michiel Lotter, and Pieter van Rooyen

***Abstract*—This letter presents a new optimum interference mitigating combining (OIMC) scheme for the code-division multiple-access downlink RAKE receiver. The OIMC scheme optimizes the RAKE weights and maximizes the signal-to-interference-plus-noise ratio (SINR) at the RAKE combiner output. Unlike other interference mitigation schemes, the new scheme does not need to estimate the interference or data correlation matrix (and its inverse) of the received signal to render a reliable and low complexity receiver. The OIMC scheme mitigates interference by inversely proportionately weighting the finger output by its associated interference power, while simultaneously mitigating multipath fading. The interference power is found to be directly related to the finger's associated multipath channel gain, rendering the OIMC scheme with the same order of complexity as a maximal ratio combining (MRC) scheme. Under realistic channel conditions, simulation results show that the proposed OIMC scheme always outperforms MRC with a gain of up to more than 1 dB.**

***Index Terms*—Maximal ratio combining (MRC), optimum combining, signal-to-interference ratio, RAKE.**

I. Introduction

MANY near–far resistant/interference suppressing code-division multiple-access (CDMA) receivers have been proposed over the last two decades. Due to complexity and other practical reasons, the conventional maximal ratio combining (MRC) RAKE receiver is still the receiver of choice in CDMA mobile handsets. The number of weights assigned in an MRC RAKE receiver is usually equivalent to, or less than, the number of multipath components received. It is much less than the number of weights (taps) in a minimum mean squared error (MMSE) [1] or minimum signal-to-interference-plus-noise ratio (MSINR) [2] receiver, which has a length proportional to the length of the orthogonal variable spreading factor (OVSF) code. Aware that MRC only combats fading, research has been conducted to enhance the MRC RAKE receiver to mitigate interference [3]. These finger-weight based optimum combining (OC) techniques have been implemented at base stations and handsets with multiple antennas, where spatial correlation between the antennas is used to suppress interference. Interference suppression is, therefore, accomplished at the expense of higher cost and complexity. Single antenna interference suppression has been proposed by virtue of the generalized RAKE (G-RAKE) [4]. It has been shown in [5] that the G-RAKE is equivalent to a linear MMSE chip level equalizer which is more complex than MRC and the proposed OIMC scheme.

In this letter, the OIMC receiver is analyzed and the compatibility of the proposed technique to the conventional MRC downlink RAKE receiver with a single antenna is shown. Starting with the finger outputs, interference correlation among fingers is analyzed. It is shown that the interference among fingers are approximately uncorrelated due to the fact that spreading codes are uncorrelated at nonzero T_c shifts caused by the channel multipath delays. We also show that the average interference power for each finger is the total average multiple access interference (MAI) power per finger, weighted by the channel instantaneous gain (the magnitude square), and that the total average MAI power is the same for all fingers. Therefore, instead of trying to estimate the interference power, we only need to estimate the instantaneous channel gain, which can easily be obtained from the received pilot channel [8]. Thus, the optimum finger weight is simply the MRC weight, scaled inversely by the sum of the other multipath channel gains. This inverse scaling can be further simplified by proportionally scaling the MRC weight by its own channel gain, which renders an optimum Wiener weight with the same complexity of MRC weights. OC schemes require data or interference correlation estimation and have the inherent disadvantages of higher complexity, sample support problems and difficulty to converge to the MRC RAKE receiver in the absence of interference [6]. The latter disadvantage results from computing the correlation matrix and its inverse on the received data or its interference. The OIMC receiver has a lower cost, higher reliability and converges to MRC when there is no interference. Our analysis shows, using the Schwartz inequality and simulations, that the SINR of MRC is upper bounded by the SINR of the proposed OIMC scheme.

This letter is organized as follows. Section II presents the system model and, for simplicity reasons and without loss of generality, we assume that the downlink is from one base station (BS). Other BS signals will have the same effect as the BS of interest in either handoff or nonhandoff mode. Section III derives the closed-form expressions of the OIMC weights and the corresponding optimum SINR, while Section IV provides simulation results using typical Third-Generation Partnership Project (3GPP) fading channel models. Section V presents our conclusions.

II. System Model

The BS downlink system model is shown in Fig. 1. The lowpass equivalent signal can be written as

$$s(t) = \sum_{k=0}^{K-1} \sum_{n=-\infty}^{\infty} A_k b_{k\lceil \frac{n}{N} \rceil} p_n w_{kn} h(t - nT_c)$$

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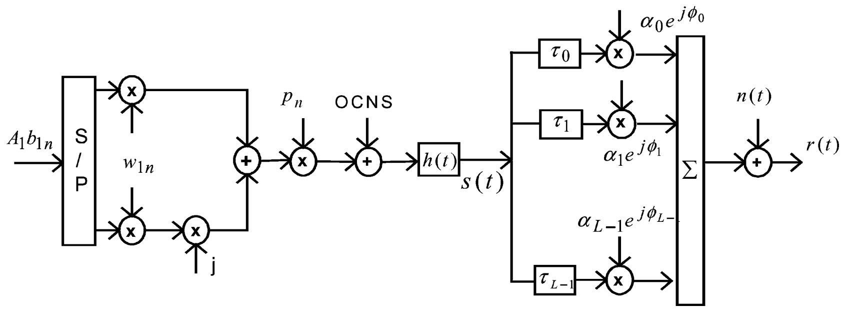

Fig. 1. WCDMA cellular downlink.

where A_0 is the amplitude of the pilot, A_k is the amplitude of data channel k, $h(t)$ is the pulse shaping filter, p_n is the complex psuedonoise (PN) scrambling code, K is the total active data/sync channels, w_{kn} is the channelization code (Walsh code) for channel k with $k = 0$ assigned to the pilot, N is the number of chips per Walsh code or the spreading gain, $b_{k\lceil n/N \rceil}$ is the complex I and Q data of user k at bit time $\lceil n/N \rceil$, and b_0 is the known pilot data. The channel impulse response is $c(t) = \sum_{l=0}^{L-1} \alpha_l e^{j\phi_l} \delta(t - \tau_l)$, where α_l is a Rayleigh distributed random variable representing the fading envelope of the lth path and ϕ_l is a uniformly distributed random variable over $[0, 2\pi)$ representing the phase rotation introduced by the lth path. Downlink interference from other users is modeled as an orthogonal channel noise source (OCNS) represented by $s(t)$ with $\mathrm{k} \neq 1$ (where $\mathrm{k} = 1$ is assumed to be the reference user). The received low-pass equivalent signal is the following composite multipath and multiuser signal:

$$r(t) = \sum_{l=0}^{L-1} \alpha_l e^{j\phi_l} \sum_{k=0}^{K-1} \sum_{n=-\infty}^{\infty} A_k b_{k\lceil \frac{n}{N} \rceil} p_n w_{kn} \times h(t - nT_c - \tau_l) + n(t) \quad (1)$$

where $n(t)$ is the additive white Gaussian noise (AWGN) to model the intercell interference and it is much greater than the receiver thermal noise and is ignored in the subsequent analysis. The RAKE receiver will independently demodulate each of the multipath components assuming perfect timing obtained from the searcher and tracked further by a delay lock loop [7]. The demodulation of each multipath consists of a matched filter, despreading and dechannelization before combining with the other multipath signals. These finger outputs are further weighted and combined to maximize the SINR. Assuming the desired user is the first user $k = 1$, the ith demodulated multipath output or finger output can be written as

$$x_i = \sum_{n'=0}^{N-1} \left[r(t)^* h(-t)|_{t=n'T_c+\tau_i} \right] p_{n'} w_{1n'} \qquad i = 1, 2, \ldots, L \quad (2)$$

where $*$ denotes convolution (with the matched filter), n' accounts for the N accumulation, where N is the OVSF code. The OIMC weights to combine these finger outputs are derived in the next section.

III. Derivation of OIMC Weights

Expanding x_i in (2), we have

$$\begin{aligned}
x_i &= \sum_{n'=0}^{N-1} \left[r(t)^* h(-t)|_{t=n'T_c+\tau_i} \right] p_{n'} w_{1n'} \\
&= \sum_{n'=0}^{N-1} \Bigg[\sum_{l=0}^{L-1} \alpha_l e^{j\varphi_l} \sum_{k=0}^{K-1} \sum_{n=-\infty}^{\infty} A_k b_{k\lceil \frac{n}{N} \rceil} p_n \\
&\qquad \times w_{kn} h(t - nT_c - \tau_l) + n(t) \Bigg]^* \\
&\qquad \times h(-t)|_{t=n'T_c+\tau_i} \Bigg] \\
&\quad \times p_{n'} w_{1n'} \\
&= \alpha_i e^{j\varphi_i} A_1 b_1 N R(0) + \sum_{l \neq i}^{L-1} \alpha_l e^{j\varphi_l} \sum_{n'=0}^{N-1} \sum_{n=-\infty}^{\infty} \sum_{k=0}^{K-1} \\
&\quad \times A_k b_{k\lceil \frac{(n)}{N} \rceil} p_n p_{n'} w_{kn} w_{1n'} \\
&\quad \times R(nT_c - n'T_c + \tau_l - \tau_i) \\
&\quad + \sum_{n=0}^{N-1} n(t)^* p_n w_{1n} h(-t)|_{t=nT_c+\tau_i} \\
&= \alpha_i e^{j\varphi_i} A_1 b_1 N R(0) + \sum_{l \neq i}^{L-1} \alpha_l e^{j\varphi_l} \sum_{k=0}^{K-1} A_k \beta_{k1li} + n_i \\
&\equiv d_i + i_i + n_i
\end{aligned}$$

where d_i is the desired term for the ith finger output, i_i is its interference, and n_i is the noise resulting from $n(t)$. The interference is produced by the nonzero part of $\beta_{k1li} \equiv \sum_{n'=0}^{N-1} \sum_{n=-\infty}^{\infty} b_{k\lceil n/N \rceil} p_n p_{n'} \, w_{kn} w_{1n'} R_{nn'li}, k = 0, 1, \ldots, K-1$. This part would be zero if $\tau_i = \tau_j$, for $i \neq l$ which would result in $n' = n$ since $R_{nn'li} \equiv R(nT_c - n'T_c + \tau_l - \tau_i)$ and $R(\cdot)$ is the autocorrelation function of the Nyquist chip matched filter. However, in reality, $\tau_i \neq \tau_j$, for $i \neq l$, or $n' \neq n$ then $\beta_{k1li} \neq 0$. In other words, the orthogonality is destroyed by the multipath delays. Hence, i_i is completely the multipath interference from the lth path to the ith path from the interfering users, the pilot, as well as the desired user onto itself, i.e., $k = 0, 1, \ldots, K$. If we model the PN sequence and the product of PN and Walsh sequences as a binary random sequence taking on values ± 1 equally likely, β_{k1li} has the following property (see (3), located at the bottom of the following page), which will be used in deriving interference correlation among fingers. Note that $\sum_{n'=\tau_i}^{N-1+\tau_i} \sum_{n=-\infty}^{\infty} R^2(n - n' - \tau_l - \tau_i) = \sum_{n'=\tau_i}^{N-1+\tau_i} \sum_{n=-\infty}^{\infty} R^2(n - n') = N$ comes from the fact that τ_l and τ_i are measured by integer multiple of T_c

and a change of variable. This result was previously obtained by an alternate derivation in [7, p. 32, eq. (2.27)]. The L weights, denoted by $\mathbf{w} = (w_0, w_2, \ldots, w_{L-1})$, are chosen to maximize the SINR of the combined L signal components, denoted by $\mathbf{d}^T = A_1 b_1 N(\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}})^T = A_1 b_1 N(\alpha_0 e^{j\varphi_0}, \alpha_1 e^{j\varphi_1}, \ldots, \alpha_{L-1} e^{j\varphi_{L-1}})$, wehre the superscript T denotes transpose and L combined multipath interference-plus-noise terms from L fingers denoted by

$$(\mathbf{i}+\mathbf{n})^T = \left(\sum_{l \neq 0}^{L-1} \alpha_l e^{j\varphi_l} \sum_{k=0}^{K-1} A_k b_k \beta_{k1l0} + n_1, \ldots \right.$$
$$\left. \sum_{l \neq L-1}^{L-1} \alpha_l e^{j\varphi_l} \sum_{k=0}^{K-1} A_k b_k \beta_{k1lL-1} + n_{L-1} \right), \text{i.e.,}$$

$$\mathrm{SINR} = \frac{E\left(\|\mathbf{w}^H \mathbf{d}\|^2\right)}{E\left[\|\mathbf{w}^H (\mathbf{i}+\mathbf{n})\|^2\right]} = \frac{\mathbf{w}^H E(\mathbf{d}\mathbf{d}^H)\mathbf{w}}{\mathbf{w}^H E\left[(\mathbf{i}+\mathbf{n})(\mathbf{i}+\mathbf{n})^H\right]\mathbf{w}}$$
$$= \frac{\mathbf{w}^H (\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}})(\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}})^H \mathbf{w} N P_s}{\mathbf{w}^H \mathbf{R}_{i+n} \mathbf{w}} \quad (4)$$

$\mathbf{R}_{i+n}$ is the multipath interference plus noise correlation matrix and

$$\mathbf{R}_{i+n} = (r_{ij}) = E(i_i i_j) + E(n_i n_j) \quad (5)$$

where, in (4), the superscript H denotes the complex conjugate transpose and the weights are updated at the same rate as the MRC weights. The expectation is over the data, which is assumed to have a much greater rate of change than the fading rate, which is true for a practical CDMA cellular system. Making use of (3), we can evaluate (5) by realizing (6), located at the bottom of page. The sum of all uses' transmitted power, including the pilot and the desired user, can be written as $c \equiv N \sum_{k=0}^{K-1} A_k^2$ and $\sum_{k=0}^{K-1} A_k^2$. Two observations from (6) are evident. The first is that the multipath interference contributed by different fingers is approximately uncorrelated, and secondly, the multipath interference power at each finger is a product of c, which is common to all fingers, and the sum of all the other multipath channel gains. $E(n_i n_j)$ is the correlation of the thermal noise between fingers and can be written as

$$E(n_i n_j) = E\left(\begin{pmatrix} \sum_{n'=0}^{N-1} n(t)^* p_{n'} w_{1n'} h(-t)|_{t=n'T_c+\tau_i} \\ \times \sum_{n=0}^{N-1} n(t)^* p_n w_{1n} h(-t)|_{t=nT_c+\tau_j} \end{pmatrix} \right)$$
$$= \sum_{n'=0}^{N-1} \sum_{n=0}^{N-1} \delta(n'T_c + \tau_i - nT_c - \tau_j) p_{n'}$$
$$\times w_{1n'} p_n w_{1n} R(n'T_c + \tau_i - nT_c - \tau_j)$$
$$= \begin{cases} \sum_{n=0}^{N-1} (p_n w_{1n})^2 = N\sigma_n^2, & \text{if } n = n', i = l \\ 0, & \text{otherwise.} \end{cases}$$

Therefore, the correlation matrix is a simple diagonal matrix, given by $\mathbf{R}_{i+n} = \mathrm{diag}(c\sum_{l \neq 1}^{L} \alpha_l^2 + N\sigma_n^2, \; c\sum_{l \neq 2}^{L} \alpha_l^2 + N\sigma_n^2, \cdots, c\sum_{l \neq L}^{L} \alpha_l^2 + N\sigma_n^2)$. Let $\mathbf{z} = \mathbf{R}_{i+n}^{1/2}\mathbf{w}$, then (4) can be rewritten as, $\mathrm{SINR} = (\mathbf{z}^H \mathbf{R}_{i+n}^{-1/2} (\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\phi}})(\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\phi}})^H \mathbf{R}_{i+n}^{-1/2}\mathbf{z})/(\mathbf{z}^H\mathbf{z}) N P_s$.

$$E\left(\beta_{k_1 1 l_1 i_1} \beta_{k_2 1 l_2 i_2}\right) =$$
$$\sum_{n'=\tau_i}^{N-1} \sum_{n=-\infty}^{\infty} \sum_{n_1=0}^{N-1} \sum_{n_1'=-\infty}^{\infty} E\left(b_{k\lceil\frac{n}{N}\rceil} p_n p w_{k_1 n} w_{1n'} p_{n_1} p_{n_1'} w_{k_2 n_1} w_{1n_1'}\right) R_{nn'l_1 i_1} R_{n_1 n_1' l_2 i_2}$$
$$= \begin{cases} \left[\sum_{n'=\tau_i}^{N-1} \sum_{n=-\infty}^{\infty} E\left(b_{k\lceil\frac{n}{N}\rceil} p_n p_{n'} w_{k_2 n} w_{1n'}\right)^2 R_{nn'li}^2 \right] \\ = \sum_{n'=\tau_i}^{N-1} \sum_{n=-\infty}^{\infty} R^2(n - n' - \tau_l - \tau_i) = \sum_{n'=0}^{N-1} \sum_{n=-\infty}^{\infty} R^2(n - n') = N, & \text{for } n' = n_1', n = n_1, k_2 = k_1 \\ & l_1 = l_2 = l, \; i_1 = i_2 = i \\ 0, & \text{otherwise} \end{cases} \quad (3)$$

$$E(i_i i_j) = E\left(\sum_{l_1 \neq i}^{L-1} \alpha_{l_1} e^{j\varphi_{l_1}} \sum_{k_1=0}^{K-1} A_{k_1} \beta_{k_1 1 l_1 i} \sum_{l_2 \neq j}^{L-1} \alpha_{l_2} e^{-j\varphi_{l_2}} \sum_{k_2=0}^{K-1} A_{k_2} \beta_{k_2 1 l_2 j} \right)$$
$$= \sum_{l_1 \neq j}^{L-1} \sum_{l_2 \neq i}^{L-1} \sum_{k_1=0}^{K-1} \sum_{k_2=0}^{K-1} \alpha_{l_1} e^{j\varphi_{l_1}} \alpha_{l_2} e^{-j\varphi_{l_2}} A_{k_1} A_{k_2} E\left[(\beta_{k_1 1 l_1 i} \beta_{k_2 1 l_2 j})\right]$$
$$= \begin{cases} \sum_{\substack{l_1 = l_2 = l \\ l \neq j \\ l \neq i}}^{L-1} \sum_{\substack{k_2 = k_1 = k \\ k=0}}^{K-1} \alpha_l^2 A_k^2 E(\beta_{k1lj} \beta_{k1li}) = \begin{cases} \sum_{l \neq j}^{L} \sum_{k=0}^{K-1} \alpha_l^2 A_k^2 N = c \sum_{l \neq j}^{L} \alpha_l^2, & i = j \\ 0, & i \neq j \end{cases} \\ 0, \quad \text{If } l_1 \neq l_2, k_2 \neq k_1 \end{cases} \quad (6)$$

Using the Schwarz inequality, the OIMC weights, denoted by $\mathbf{w}_{\mathrm{OIMC}}$, occurs when $\mathbf{z} = \mathbf{R}_{i+n}^{-1/2}\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\phi}}$, or

$$\begin{aligned}\mathbf{w}_{\mathrm{OIMC}} &= \mathbf{R}_{i+n}^{-1}\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}} \\ &= \mathrm{diag}\left(\frac{1}{c\sum\limits_{l\neq 0}^{L-1}\alpha_l^2 + N\sigma_n^2}, \frac{1}{c\sum\limits_{l\neq 1}^{L-1}\alpha_l^2 + N\sigma_n^2} \cdots \frac{1}{c\sum\limits_{l\neq L-1}^{L-1}\alpha_l^2 + N\sigma_n^2}\right)\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}}. \end{aligned} \tag{7}$$

Note that comparing (7) with MRC weights, denoted by $\mathbf{w}_{\mathrm{mrc}} = \boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\phi}}$, OIMC weights the finger output by its interference and thermal noise power. Intuitively, and consistent with (7), it is better to weight the finger less when it has more interference. Note also that $\mathbf{w}_{\mathrm{OIMC}}$ converges to $\mathbf{w}_{\mathrm{mrc}}$ if there is no multipath interference. To estimate c in (7) is potentially complex. However, if we reasonably assume that a cellular system is interference limited, then $\mathbf{R}_{i+n}$ can be simplified to $\mathbf{R}_{i+n} = \mathbf{R}_i = c\mathrm{diag}(\sum_{l\neq 0}^{L-1}\alpha_l^2\ \sum_{l\neq 1}^{L-1}\alpha_l^2, \cdots, \sum_{l\neq L-1}^{L-1}\alpha_l^2)$. This simplification is not accurate, when the intercell interference is stronger than the intracell interference. However, since the thermal noise power is common to all fingers, discarding $N\sigma_n^2$ does not affect the right proportion in weighting every finger. Therefore, even in the noise limited case, the weights should be still right (unless $N\sigma_n^2$ becomes much greater than the multipath interference which will not happen due to handoff. Furthermore, c can be discarded since it is common to all fingers without affecting the SINR or the bit-error rate (BER) of the combiner. The OIMC weights can now be written as $\mathbf{w}_{\mathrm{OIMC}} = \mathrm{diag}(1/\sum_{l\neq 0}^{L-1}\alpha_l^2,\ 1/\sum_{l\neq 1}^{L-1}\alpha_l^2 \cdots 1/\sum_{l\neq L-1}^{L-1}\alpha_l^2)\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\phi}}$ and the ith finger weight is

$$\mathbf{w}_{\mathrm{OIMC}_i} = \frac{\mathbf{w}_{\mathrm{mrc}_i}}{\left(\sum\limits_{l\neq i}^{L}\alpha_l^2\right)} = \frac{\mathbf{w}_{\mathrm{mrc}_i}}{\left(\sum\limits_{l\neq i}^{L}|\mathbf{w}_{\mathrm{mrc}_l}|^2\right)}. \tag{8}$$

The weights only rely on the channel impulse response, in other words, it does not need any more information than conventional MRC. The optimum SINR denoted by $\mathrm{SINR}_{\mathrm{OIMC}}$ is simply $\|\mathbf{w}_{\mathrm{OIMC}}\|^2$ or

$$\begin{aligned}\mathrm{SINR}_{\mathrm{OIMC}} &= (\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}})^H\mathrm{diag} \\ &\times\left(\frac{1}{c\sum\limits_{l\neq 0}^{L-1}\alpha_l^2 + N\sigma_n^2}, \frac{1}{c\sum\limits_{l\neq 1}^{L-1}\alpha_l^2 + N\sigma_n^2}, \cdots, \frac{1}{c\sum\limits_{l\neq L-1}^{L-1}\alpha_l^2 + N\sigma_n^2}\right)\boldsymbol{\alpha}\mathbf{e}^{\mathbf{j}\boldsymbol{\varphi}}NP_s \\ &= \sum_{i=0}^{L-1}\left(\frac{|w_{\mathrm{mrc}i}|^2}{c\sum\limits_{l\neq i}^{L}\alpha_l^2 + N\sigma_n^2}\right)NP_s = \sum_{i=0}^{L-1}\left(\frac{\alpha_l^2}{c\sum\limits_{l\neq i}^{L}\alpha_l^2 + N\sigma_n^2}\right)N^2P_s.\end{aligned} \tag{9}$$

The SINR of MRC is given by

$$\begin{aligned}\mathrm{SINR}_{\mathrm{MRC}} &= \frac{\left(\mathbf{w}_{\mathrm{mrc}}^H\mathbf{w}_{\mathrm{mrc}}\right)^2N^2P_s}{\mathbf{w}_{\mathrm{mrc}}^H\left(c\sum\limits_{l\neq 0}^{L-1}\alpha_l^2 + N\sigma_n^2, \cdots, c\sum\limits_{l\neq L-1}^{L-1}\alpha_l^2 + N\sigma_n^2\right)\mathbf{w}_{\mathrm{mrc}}} \\ &= \frac{\|\mathbf{w}_{\mathrm{mrc}}\|^4N^2P_s}{\sum\limits_{i=0}^{L-1}\left(c\sum\limits_{l\neq i}^{L-1}\alpha_l^2 + N\sigma_n^2\right)w_{\mathrm{mrc}i}^2} \\ &= \frac{\left(\sum\limits_{i=0}^{L-1}\alpha_l^2\right)^2N^2P_s}{\sum\limits_{i=0}^{L-1}\left(c\sum\limits_{l\neq i}^{L-1}\alpha_l^2 + N\sigma_n^2\right)\alpha_l^2}.\end{aligned} \tag{10}$$

As a check, comparing (9) and (10), by the Schwarz inequality, gives

$$\begin{aligned}&\sum_{i=0}^{L-1}\left(c\sum_{l\neq i}^{L-1}\alpha_l^2 + N\sigma_n^2\right)|w_{\mathrm{mrci}}|^2\sum_{i=0}^{L-1}\frac{1}{\left(c\sum\limits_{l\neq i}^{L}\alpha_l^2 + N\sigma_n^2\right)}|w_{\mathrm{mrci}}|^2 \\ &\geq\left(\sum_{i=0}^{L-1}\frac{1}{\sqrt{\left(c\sum\limits_{l\neq i}^{L-1}\alpha_l^2 + N\sigma_n^2\right)}}\times\sqrt{\left(c\sum_{l\neq i}^{L-1}\alpha_l^2 + N\sigma_n^2\right)|w_{\mathrm{mrci}}|^2}\right)^2 = \|\mathbf{w}_{\mathrm{mrc}}\|^4.\end{aligned} \tag{11}$$

Therefore, $\mathrm{SINR}_{\mathrm{MRC}} \leq \mathrm{SINR}_{\mathrm{OIMC}}$ with equality if $c\sum_{l\neq i}^{L}\alpha_l^2 = c\sum_{l\neq j}^{L}\alpha_l^2$ for $i \neq j$, which is true only when there is no multipath interference or all the multipaths have the same instantaneous power. Note that it can be easily shown that (11) holds also for the simplified weight case. The optimum weights in (8) can be simplified further by noting that $\sum_{l\neq i}^{L}\alpha_l^2 > \sum_{l\neq k}^{L}\alpha_l^2$, if and only if $\alpha_k^2 > \alpha_i^2$. Therefore,

$$\mathbf{w}_{\mathrm{OIMC}_i} = \frac{\mathbf{w}_{\mathrm{mrc}_i}}{\sum\limits_{l\neq i}^{L}\alpha_l^2} = \frac{\mathbf{w}_{\mathrm{mrc}_i}}{\sum\limits_{l\neq i}^{L}|\mathbf{w}_{\mathrm{mrc}_l}|^2} \approx \alpha_i^2\mathbf{w}_{\mathrm{mrc}_i} = |\mathbf{w}_{\mathrm{mrc}_i}|^2\,\mathbf{w}_{\mathrm{mrc}_i}. \tag{12}$$

From (12) is clear that the OIMC weights are simply the MRC weights scaled inversely by the interference power which can be simplified equivalently by scaling its own channel gain. This results in our simple OIMC RAKE receiver shown in Fig. 2, where the received composite signal is first descrambled independently by each finger based on its timing, then despread (denoted by Σ_2 for data and Σ_1 for pilot). The finger outputs are then weighted by the OIMC weights. Note also $\mathbf{w}_{\mathrm{OIMC}}$ does not mitigate intercell interference.

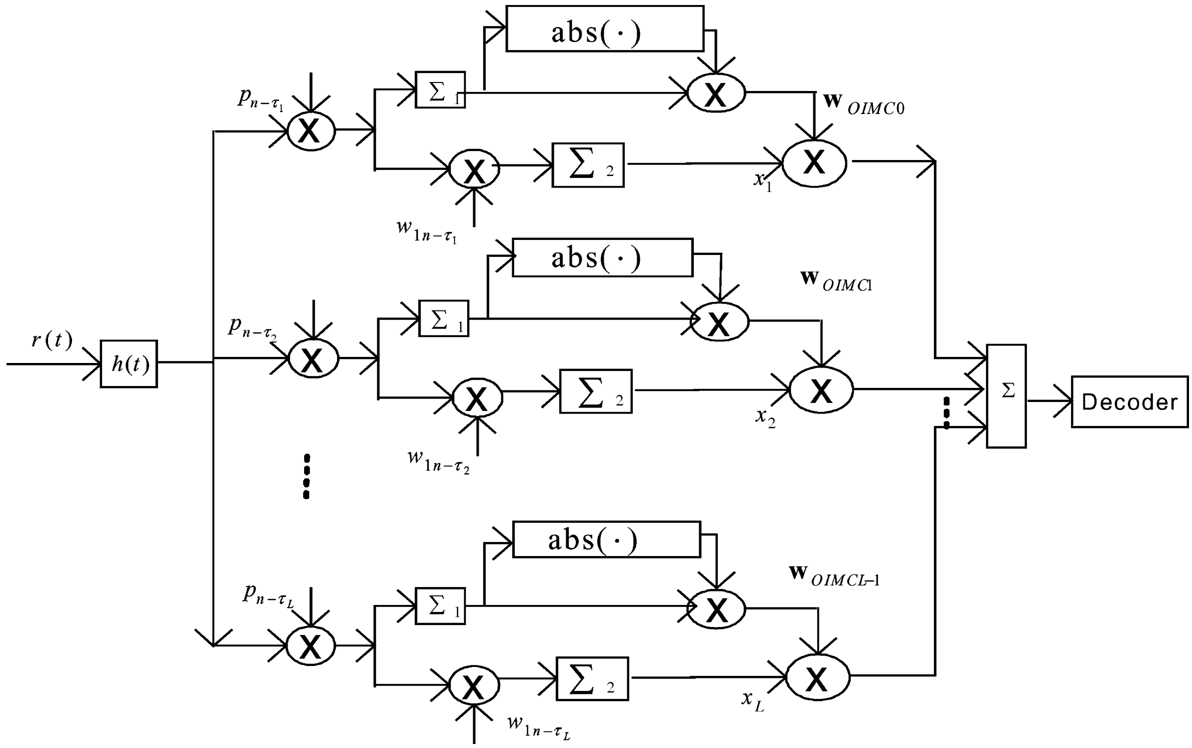

Fig. 2. Structure of the OIMC RAKE receiver.

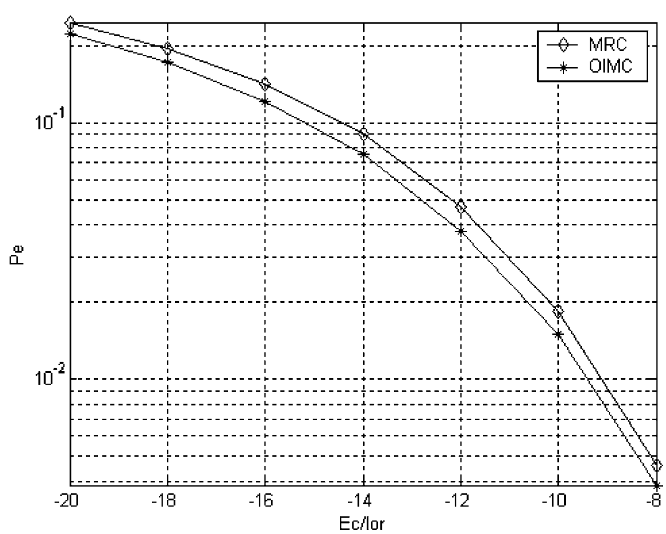

Fig. 3. Performance comparison of OIMC and MRC with different DPCH power, channel $\mathrm{MIP} = [0\ \ -3\ \ -6\ \ -9]$, $\mathrm{SNR} = 6$ dB, and $\mathrm{SF} = 32$.

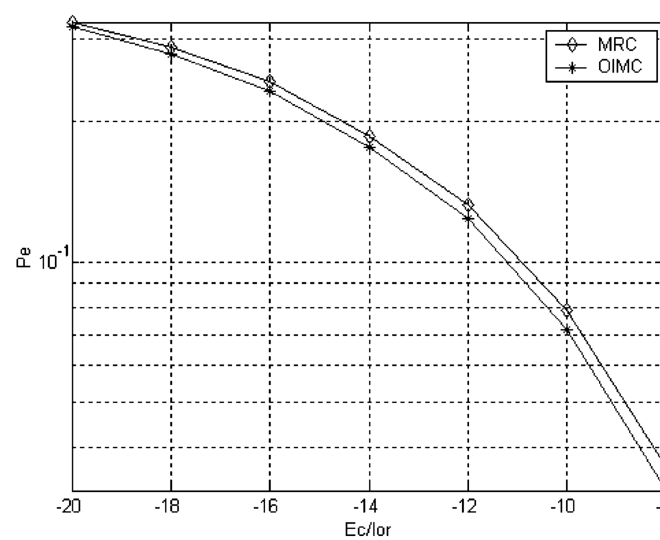

Fig. 4. Performance comparison of OIMC and MRC with different DPCH power, channel $\mathrm{MIP} = [0\ 0\ 0]$, $\mathrm{SNR} = -3$ dB, and $\mathrm{SF} = 16$.

IV. Simulation Results

We have simulated and compared the uncoded BER of MRC and OIMC for different 3GPP channel conditions [8]. The OIMC scheme always outperforms MRC. In the simulations, we have assumed perfect channel estimation for both OIMC and MRC and enabled four dedicated physical channels (DPCHs). We have used the Bounoli (independent binary random variables) sequence as the cell-specific scrambling code and power control is not applied. Fig. 3 depicts the BER of both MRC and OIMC under varying desired DPCH (Ec/Ior) powers (a percentage of the total power, as defined in [8]) with channel MIP being $[0\ \ -3\ \ -6\ \ -9]$ dB. Since the total power for all DPCHs is a constant, increasing the desired DPCH power is equivalent to decreasing the other users' interference power. It can be seen that the gain of the OIMC scheme is about 0.4 dB over MRC with $\hat{I}_{\mathrm{or}}/I_{\mathrm{oc}} = 6\ \mathrm{dB}$. $\hat{I}_{\mathrm{or}}/I_{\mathrm{oc}}$ in the 3GPP system is defined as the SNR (signal-to-thermal-noise ratio to model the intercell interference) in [8]. In Fig. 4, the channel MIP is [0 0 0] dB and the SNR is fixed at -3 dB, which is approximately a noise limited region. In this case, the BER decreases only

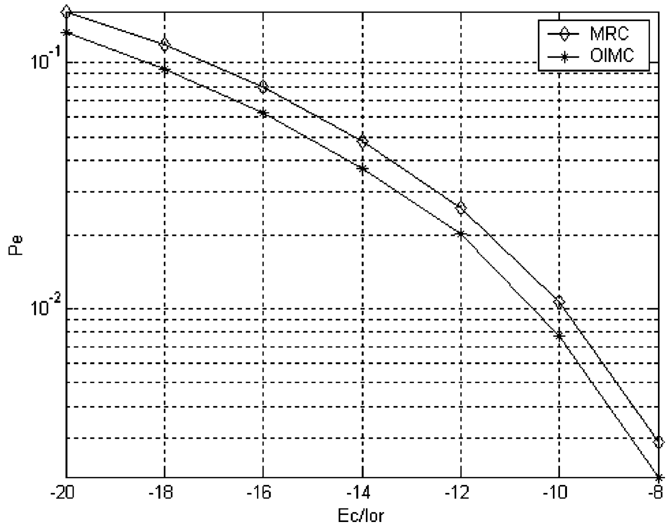

Fig. 5. Performance comparison of OIMC and MRC with different DPCH power, channel $\mathrm{MIP} = [0\ \ -10]$, $\mathrm{SNR} = 9$ dB, and $\mathrm{SF} = 16$.

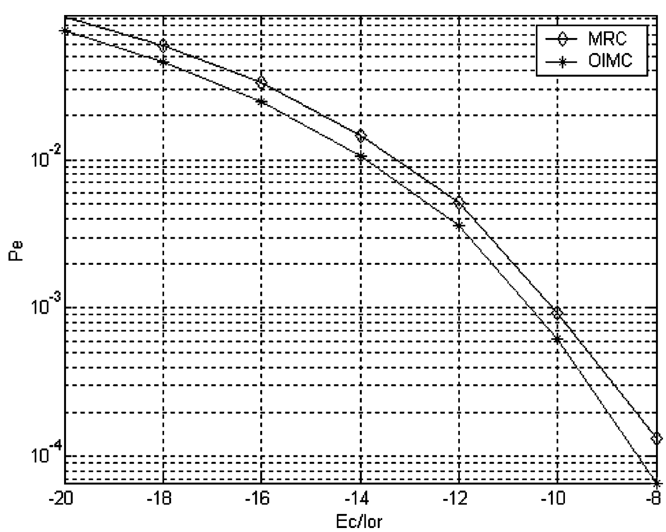

Fig. 6. Performance comparison of OIMC and MRC with different DPCH power, channel $\mathrm{MIP} = [0\ \ -10]$, $\mathrm{SNR} = 9$ dB, and $\mathrm{SF} = 32$.

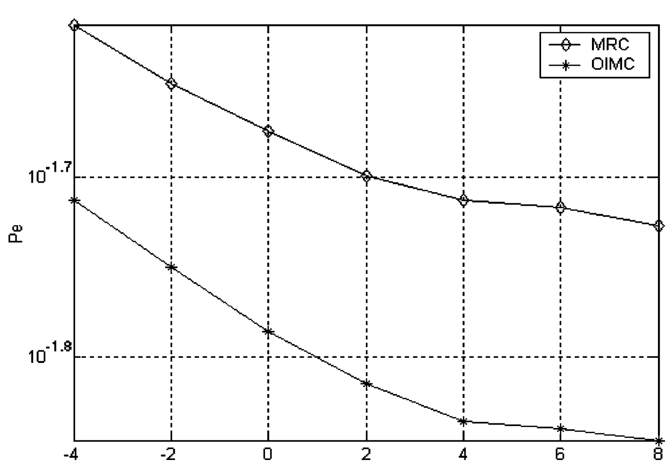

Fig. 7. Performance comparison of OIMC and MRC at different SNR values, with channel $\mathrm{MIP} = [0\, -3\, -6\, -6]$, $\mathrm{Ec/Ior} = -10$ dB, $\mathrm{Doppler} = 100$ Hz, and $\mathrm{SF} = 32$.

slightly as the Ec/Ior increases. It is clear that the gain of OIMC over MRC is still about 0.5 dB for the reason explained earlier. In Fig. 5, the channel MIP is $[0\ -10]$ dB and the SNR is fixed at 9 dB. The gain of OIMC over MRC is about 1 dB. In Fig. 6, channel MIP and SNR is the same as in Fig. 5, but the spreading factor (SF) is increased from 16 to 32. It is clear that under these circumstances, the BER drops into the 0.1% region, with the OIMC gain over MRC in the region of 0.7 dB. The OIMC gain is decreased slightly as the desired Ec/Ior increases or equivalently the interference power decreases. This is consistent with our theoretical result, since MRC is optimum without any interference. In Fig. 7, the BER of both schemes, under the channel MIP $[0\ \ -3\ \ -6\ \ -9]$ dB and $\mathrm{Ec/Ior} = -15$ dB, are plotted against $\hat{I}_{\mathrm{or}}/I_{\mathrm{oc}}$. As can be seen from Fig. 7, the performance is interference limited since the BER decreases very little as SNR increases. In this interference limited case, OIMC performs more than 3 dB better than MRC.

V. Conclusion

In this letter, we have proposed a finger-weight-based interference combining scheme for the CDMA downlink with complexity similar to conventional MRC. The resulting OIMC RAKE receiver has a greater SINR or lower BER than that of the MRC RAKE receiver. Simulations have shown that our proposed optimum RAKE receiver always performs better than the MRC RAKE receiver under interference and equally well under noise limited conditions.

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