Optimization of RAKE reception in Soft Handover Region

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Abstract- *MULTI-PATH fading is an unavoidable physical phenomenon that affects considerably the performance of wireless communication systems. While usually viewed as a deteriorating factor, multi-path fading can also be exploited to improve the performance by using RAKE type of receivers in the soft handover region. We propose and analyze new finger assignment scheme which are applicable for RAKE reception. These employ GSC and minimum selection GSC scheme in order to choose an acceptable base station and its corresponding paths. We investigate the average error rate performance as well as the average number of estimated and combined paths of the proposed scheme over Rayleigh fading channels. We show that the proposed scheme provides a significant performance improvement as well as optimization of power consumption.*

Keywords- Fading channels, RAKE receiver, Generalized selection combining(GSC), minimum selection GSC, and Performance analysis.

I. INTRODUCTION

RAKE reception is a technique which uses several baseband correlators called fingers to individually process multi-path signal components. The outputs from the different correlators are coherently combined to improve the signal-to-noise ratio (SNR) and to therefore lower the probability of deep fades. Since they rely on resolvable multipaths to operate, RAKE receivers are used in conjunction with wideband systems. such as wideband code division multiple access (WCDMA).

In the soft handover (SHO) region, there is a large number of available resolvable paths coming from the serving base station (BS) as well as the target BS while the number of fingers in the mobile unit is very limited due to hardware and battery life time constraints. Hence, the RAKE receiver needs to judiciously select a subset of paths in order to achieve the required performance with a low complexity/processing-power consumption. For instance, with generalized selection combining (GSC) which is a generalization of selection combining (SC), the receiver chooses a fixed number of paths with the largest instantaneous SNR from all available diversity paths and then combines them as per the rules of maximal ratio combining (MRC). As a power-saving implementation of GSC, minimum selection GSC (MS GSC) was recently proposed and studied. With MS GSC, after examining and ranking all available paths, the receiver tries to raise the combined SNR above a certain threshold by combining in an MRC fashion the least number of the best diversity paths, and as such, MS GSC can save considerable amount of processing power by keeping less MRC branch active on average in comparison to the conventional GSC.

The aim of this work is to develop new variants of RAKE combing in the soft handover (SHO) region by applying the innovations of GSC and MS GSC schemes.While it is possible to use paths from different base stations (BSs) when the mobile is in the SHO region, we rather propose in this paper several schemes which are designed to select paths from only one BS in order to minimize the use of network resources and facilitate the process of synchronization which tends to be complicated when the combined multi-paths come from different BSs. Through the mathematical analysis as well as numerical examples, we show that the proposed schemes save a considerable amount of complexity in terms of the average number of estimated and combined paths compared to the conventional GSC and MS GSC schemes but at the cost of an expected performance degradation that will be quantified in this paper.

II. SYSTEM MODEL

A. System and Channel Model

We assume that the RAKE combining schemes proposed in this work are implemented in a discrete-time fashion. More specifically, short guard periods are periodically inserted into the transmitted signal. During these guard periods, the receiver performs a series of operations, including path estimations and combined SNR comparisons with respect to the predetermined SNR threshold. Once the suitable paths and corresponding BS are selected, they are used throughout the subsequent data burst. Because of some hardware constraints, we assume that the receiver can only afford Lc RAKE fingers, where $Lc \leq L$and L is the number of available paths from each BS. If we assume that there are N BSs in the

SHO region, among them the receiver chooses and uses only one BS whose resolvable paths are acceptable for data transmission based on the mode of operation that will be described in the next section.

Let γl denote the instantaneous received SNR of the l th resolvable path, $l = 1, 2, \cdot \cdot \cdot, L$. We adopt the block fading model where the fading coefficients are assumed to be constant through the data burst period. As such all the diversity paths experience almost the same fading conditions and maintain therefore the same SNR during the data burst and its preceding guard period. Moreover, the fading conditions are assumed to follow the Rayleigh model and to be i.i.d. across the diversity paths and between different guard periods and data bursts. As such, the faded SNR, γl, follows the same exponential distribution with the common average faded SNR, γ.

B. Mode of Operation

When the conventional GSC scheme is used in the SHO region regardless of the origin of the combined paths, the receiver has to monitor simultaneously all the paths from all the BSs. To obtain desired savings in processing power and complexity of implementation in the mobile, we propose three different variants of the conventional GSC or MS GSC scheme. The proposed schemes are designed to just find and lock on the suitable resolvable paths of a certain BS.

1) Variant 1- Based on Temporal Diversity: With this scheme, the receiver sequentially applies the MS GSC scheme to each BS. More specifically, after examining and ranking the L paths of the currently used BS, the receiver raises the combined SNR above a certain threshold by combining in an MRC fashion the least number of the best diversity paths. If the *Lc/L*-MS GSC output SNR of the current BS is above the threshold, then the receiver continues to use it for data reception. On the other hand, if the combined output SNR of the best Lc paths from this BS is still below the target threshold, the receiver tries to find an acceptable BS by sequentially examining in the same way the other $N – 1$ BSs. This process is repeated until either an acceptable BS is found or all N BSs have been examined. In the later case, since every output SNR of the Lc best paths from each BS is known, the receiver uses the BS whose *Lc/L*-GSC output SNR is largest.

With this Variant, the receiver applies the MS GSC mode of operation to one BS and switches to a new one if this BS is unacceptable. Therefore, if we let γ denote the final combined SNR, then the probability density function (PDF) of γ, $f\gamma(x)$, as

$$f_{\gamma}(x)=\begin{cases}\dfrac{1-[F_{\Gamma_{Lc}}(\gamma_T)]^{N}}{1-F_{\Gamma_{Lc}}(\gamma_T)}f_{\gamma_{MS}}(x), x\geq\gamma_T; \\ N[F_{\Gamma_{Lc}}(x)]^{N-1}f_{\Gamma_{Lc}}(x), x<\gamma_T\end{cases} \quad (1)$$

where $f_{\gamma_{MS}}(.)$ and $f_{\Gamma_{Lc}}(.)$ are the PDFs of *Lc/L*-MS GSCand *Lc/L*-GSC output SNRs respectively.

2) Variant 2 - Based on Space Diversity: Instead of using MS GSC on each BS sequentially as it was the case in the previous variant, the receiver estimates at first with this variant all NL available paths from all BSs and compares the maximum of the strongest paths from each BS with the target SNR, i.e.,$\max\{\gamma_{(1)}^{1},\gamma_{(1)}^{2},...\gamma_{(1)}^{N}\} \gtrless \gamma_T$, where $\gamma k(i)$ is the ith order statistics out of L ones from the kth BS such that $\gamma_{(1)}^{k}\geq,\gamma_{(2)}^{k} \geq ,..., \geq\gamma_{(L)}^{k}$. If $\max\{\gamma_{(1)}^{1},\gamma_{(1)}^{2} \dots \gamma_{(1)}^{N}\}\geq \gamma_T$, then this strongest path and its corresponding BS will be used for data reception. Otherwise, the tested combined SNR becomes the maximum of the sums of two strongest paths, i.e., $\max\{\Gamma_2^1,\Gamma_2^2,.....,\Gamma_2^N\} \cdot \gamma_T$, where $\Gamma_i^k(=\sum_{a=1}^{i}\Gamma\gamma_{(a)}^{k})$ is the partial sum of the first i order statistics. By adding the next strongest paths, this process is repeated until either the acceptable best partial sum is found or all of these partial sums are less than γ_T , i.e., $\max\{\Gamma_{Lc}^1,\Gamma_{Lc}^2,.....,\Gamma_{Lc}^N\} < \gamma_T$. In the later case, similar to Variant 1, the receiver chooses the BS whose *Lc/L*-GSC output SNR is the largest. then the probability density function (PDF) of γ as

$$f_{\gamma}(x)=\begin{cases}\dfrac{1-[F_{\Gamma_{Lc}}(\gamma_T)]^{N}}{1-F_{\Gamma_{Lc}}(\gamma_T)}f_{\gamma_{MS}}(x) \\ +\sum_{i=2}^{L_c}N[F_{\Gamma i,\Gamma i-1}(x,\gamma_T)]^{N-1} \\ \times\dfrac{d}{dx}F_{\Gamma i,\Gamma i-1}(x,\gamma_T), x\geq\gamma_T; \\ N[F_{\Gamma_{Lc}}(x)]^{N-1}f_{\Gamma_{Lc}}(x), x<\gamma_T\end{cases} \quad (2)$$

3) Variant 3 - Mixture of Variants 1 and 2: This scheme works as a combinational form of Variants 1 and 2. The receiver starts to use Variant 1 with 1/*L*-MS GSC to find the acceptable strongest path. More specifically, the receiver selects the strongest path of the current BS, $\gamma_{(1)}^{1}$, and switches to the strongest path of the second BS, $\gamma_{(1)}^{2}$, if

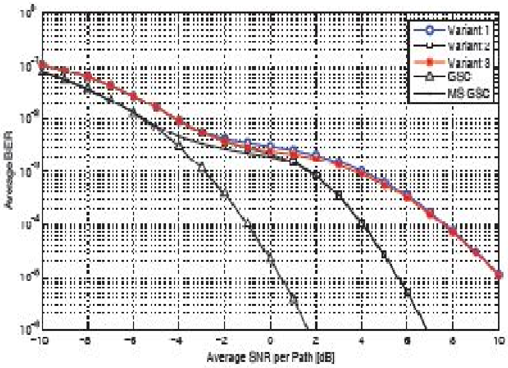
γ_1 (1) < γ_T. This process is continued up to the *N*th BS. If it turns out that the strongest path of all *N* BSs are below the target SNR, then the receiver applies Variant 2 by starting to check the sum of two strongest paths, i.e., $\max\{\Gamma_2^1, \Gamma_2^2, \ldots\ldots, \Gamma_2^N\} \gtrless \gamma_T$, since all *NL* available paths have already been estimated. Hence the probability density function (PDF) of γ as

$$f_\gamma(x) = \begin{cases} \dfrac{1-[F_{\Gamma_{L_c}}(\gamma_T)]^N}{1-F_{\Gamma_{L_c}}(\gamma_T)} f_{\Gamma_1}(x) \\ +\sum_{i=2}^{L_c} N[F_{\Gamma i,\Gamma i-1}(x,\gamma_T)]^{N-1} \\ \times \dfrac{d}{dx} F_{\Gamma i,\Gamma i-1}(x,\gamma_T), x \geq \gamma_T; \\ N[F_{\Gamma_{L_c}}(x)]^{N-1} f_{\Gamma_{L_c}}(x), x < \gamma_T \end{cases} \quad (3)$$

III. PERFORMANCE ANALYSIS

A. Average Bit Error Rate

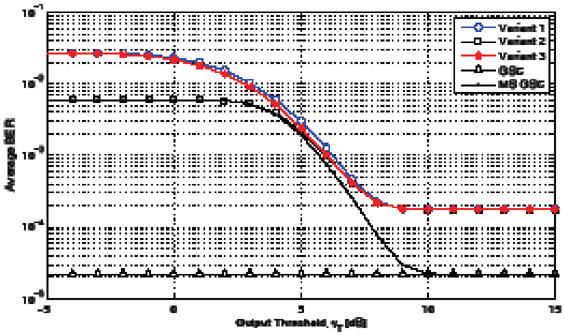
We apply the results from the previous section to the well known PDF-based approach in order to obtain the average bit error rate (BER) of our proposed combining schemes over i.i.d. Rayleigh fading channels. In Fig shown, we compare the average BER of binary phase shift eying BPSK) versus (a) the average SNR per path, *γ*, with γ_T = 5 dB and (b) the output threshold, γ_T , with *γ* = 0 dB when used in conjunction with the proposed schemes over i.i.d. Rayleigh fading channels when *N* = 4, *L* = 6, and *Lc* = 4. For comparison purpose, we also plot the average BER of the conventional *Lc*/*NL*-GSC and *Lc*/*NL*-MS GSC. As shown in the statistics derived in the previous section, when the channel quality is poor, i.e., low average SNR region in Fig. (a) and high threshold region in Fig(b), all proposed schemes show the same performance. However, as the channel quality improves, we can observe a certain performance gap between the different variants. More specifically, in this latter case, Variant 2 acts as MS GSC while Variants 1 and 3 are quite outperformed. This arises with Variants 1 and 3 because when the channel conditions are good, there is a high probability that the strongest path of the first scanned BS is good enough to reach the target SNR while for Variant 2, the receiver always seeks the best strongest path from all BSs. Hence, we can expect that Variant 2 is performing some unnecessary path estimations compared to Variants 1 and 3, but by doing so reduces the number of combined paths. We investigate in what follows this tradeoff by exactly quantifying the average number of estimated and combined paths of the proposed schemes.



(a) Average BER versus *γ* when γ_T = 5 dB

B. Average Number of Estimated and Combined Paths

From channel estimation complexity and processing power consumption perspectives, it is of interest to study the statistics of the number of estimated paths, N_E, and combined paths, Nc, per data burst. Note that both N_E and Nc are discrete random variables (RVs) with a certain probability mass function (PMF) that we will calculate for each variant. We then deduce the average number of estimated paths, $\overline{N_E}$, as well as the average number of combined paths, $\overline{N_c}$, per data burst. The average number of estimated paths can be calculated as



(b) Average BER versus γ_T when *γ* = 0 dB

$$\overline{N_E} = \sum_{k=1}^{N} kl \Pr[N_E = kl] \qquad (4)$$

where $\Pr[N_E = kl]$ is the PMF of *NE*. Based on the mode of operation of each variant, we can express the PMFs of Variants 1 and 3 as respectively, while the number of estimated paths of Variant2 is deterministic and equal to *NL* since at first all paths are estimated in order to take the best strongest path among all paths.

$$\Pr[N_E^{Var1} = kL] = \begin{cases} 1 - F_{\Gamma_{Lc}}(\gamma_T), k = 1; \\ [F_{\Gamma_{Lc}}(\gamma_T)]^{k-1}[1 - F_{\Gamma_{Lc}}(\gamma_T)], 1 < k < N; \\ [F_{\Gamma_{Lc}}(\gamma_T)]^{N-1}, k = N \end{cases} \quad (5)$$

And

$$\Pr[N_E^{Var3} = kL] = \begin{cases} 1 - F_{\Gamma_1}(\gamma_T), k = 1; \\ [F_{\Gamma_1}(\gamma_T)]^{k-1}[1 - F_{\Gamma_1}(\gamma_T)], 1 < k < N; \\ [F_{\Gamma_1}(\gamma_T)]^{N-1}, k = N \end{cases} \quad (6)$$

The average number of combined paths is a more interesting metric for the system designers because less number of combined paths leads to considerable saving in mobile receiver processing power. It can be obtained by

$$\overline{Nc} = \sum_{l=1}^{Lc} l \Pr[Nc = l] \quad (7)$$

where $\Pr[Nc = l]$ is the PMF of *NC*. Following the mode of operation of Variants 1, 2, and 3, we have

$$\Pr[N_C^{Var1} = kL] = \begin{cases} [1 - F_{\Gamma_1}(\gamma_T)]\dfrac{1-[F_{\Gamma_{Lc}}(\gamma_T)]^N}{1 - F_{\Gamma_{Lc}}(\gamma_T)}, l = 1 \\ [F_{\Gamma_{l-1}}(\gamma_T) \; - F_{\Gamma_l}(\gamma_T)], \\ \times \dfrac{1-[F_{\Gamma_{Lc}}(\gamma_T)]^N}{1 - F_{\Gamma_{Lc}}(\gamma_T)}, 1 < l < Lc; \\ [F_{\Gamma_{Lc-1}}(\gamma_T) \; - F_{\Gamma_{Lc}}(\gamma_T)] \\ \times \dfrac{1-[F_{\Gamma_{Lc}}(\gamma_T)]^N}{1 - F_{\Gamma_{Lc}}(\gamma_T)} + [F_{\Gamma_{Lc}}(\gamma_T)]^N, l = Lc \end{cases} \quad (8)$$

and

$$\Pr[N_C^{Var2} = l] \quad (9)$$

$$= \Pr[N_C^{Var3} = l]$$

Substituting (5) and (6) into (4), and (8) and (9) into(7), we can obtain $\overline{N_E}$ and $\overline{Nc}$ for all variants of conventional GSC and MS GSC.

This will be proceeded in forthcoming days.

IV. CONCLUSION

In this paper we have proposed a finger assignment scheme for RAKE receivers in the soft handover region. In this scheme the receiver checks the GSC and minimum selection GSC output SNR from the serving BS. We derived the statistics of the average error rate of the proposed scheme as well as optimized the processing power . we showed that the proposed schemes save a considerable amount of complexity in terms of the average number of estimated and combined paths compared to the conventional GSC and MS GSC schemes.

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