A Practical Study of Finger Assignment Schemes in the Soft Handover Region with Multiple Base Stations*

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Abstract—We present the effects of correlated or/and non-identical fading channels as well as outdated/imperfect channel estimations on the performance of newly proposed finger assignment schemes for RAKE receivers in the soft handover region. The performance of these schemes were previously analyzed by the authors over independent and identically distributed (i.i.d.) Rayleigh fading channels. In this paper, we consider an exponentially decaying power delay profile among paths along with an exponential correlation among these paths. The effect of outdated/imperfect channel estimations is also evaluated. Simulation results show that our proposed schemes are still applicable to non-i.i.d. fading channels and are offering some interesting performance gains in the practical channel environments considered in this paper.

I. INTRODUCTION

Multi-path fading is an unavoidable physical phenomenon that affects considerably the performance of wideband 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 [1, Section 9.5.1]. These receivers use several baseband correlators, called fingers, to individually process multi-path signal components from different base stations (BSs) and as such, facilitate soft handover (SHO). The outputs from the different correlators are coherently combined to achieve improved reliability and performance. In the SHO region, however, due to the limited number of fingers in the mobile unit, we are faced with a problem of judiciously selecting a subset of paths for the RAKE reception in order to achieve the required performance while (i) maintaining a low complexity and low processing power consumption and (ii) using a minimal amount of additional network resources.

Recently, by considering macroscopic diversity schemes with two BSs, the authors proposed and analyzed new finger assignment schemes that maintain a low complexity and reduce the usage of network resources in the SHO region [2], [3]. The main idea behind [2], [3] is that, in the SHO region, the receiver uses the additional network resource only if needed. More specifically, with the scheme in [2], whenever

the received signal is unsatisfactory, the receiver scans the additional resolvable paths from the target BS and selects the strongest paths among the available paths from both the serving and the target BSs. It has been shown that this scheme can reduce the unnecessary path estimations and the SHO overhead compared to the conventional generalized selection combining (GSC) scheme [4]–[7] in the SHO region.

In [3], an alternative finger selection scheme for the SHO region was proposed to further reduce the SHO overhead at the expense of a certain degradation in performance. With this scheme, when the output signal-to-noise ratio (SNR) falls below the target SNR, the receiver scans the additional resolvable paths from the target BS. But, unlike the scheme in [2], the receiver compares the sum of the SNRs of the strongest paths among the paths from the target BS with the sum of the weakest SNRs among the currently used paths from the serving BS, and selects the better group. This scheme compares two blocks with equal size and as such, avoids reordering all the paths which is required for the scheme in [2]. Therefore, a reduction in path estimations, SNR comparisons, and SHO overhead can be obtained.

The schemes proposed in [2], [3] were further investigated in more practical fading environments in [8] and were generalized to the multi-BS situation in [9], [10], respectively, by developing two different path scanning schemes denoted as the full scanning scheme and the sequential scanning scheme. With the full scanning scheme, whenever the received signal becomes unsatisfactory, the RAKE receiver scans all the available paths from all potential target BSs while with the sequential scanning scheme, the RAKE receiver sequentially scans the target BSs until the combined SNR is satisfactory or all potential target BSs are scanned.

For the sake of clarity, we call the proposed scheme in [9] as the reassignment scheme and the scheme in [10] as the replacement scheme. For analytical tractability, [9], [10] assumed independent and identically distributed (i.i.d.) Rayleigh fading channels and perfect channel estimation, and as such, these papers were able to offer (i) some closed-form expressions for the statistics of the output SNR and (ii) analytical-based study of the tradeoff among error performance, path estimation load, and SHO overhead. However, there are a number of real-life scenarios in which this i.i.d.

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assumption in [9], [10] is not valid especially in multi-path diversity over frequency-selective channels and as such the study on the impact of various realistic fading channels is very important.

In this paper, we look into the schemes proposed in [9], [10] in more practical fading environments. More specifically, we consider through various computer simulations the effects of path unbalance as well as path correlation on the performance. The impact of outdated or imperfect channel estimation is also investigated. The main contribution of this paper is to present a general comprehensive framework for the performance evaluation of the reassignment and replacement schemes for non-i.i.d. fading channels and under outdated/imperfect channel estimates. More specifically, through computer simulations, we show that both schemes are also applicable to practical fading conditions. More importantly, the simulation results show that the replacement scheme shows in comparison to the reassignment scheme a considerable robustness to channel estimation errors.

II. SYSTEM MODEL

A. Channel and System Model

We assume that in the SHO region, there are \( N \) active BSs and the \( n \), \( 1 \leq n \leq N \), BS has \( L_n \) resolvable paths whose instantaneous received SNRs are \( \gamma_{j,n} \), \( j = 1, \ldots, L_n \). Next, we consider that the mobile unit is equipped with an \( L_c \) finger RAKE receiver and is capable of despeaking signals from different BSs using different fingers in order to facilitate the SHO process. In the SHO region, according to the mode of operation described in the next section, only \( L_c \) out of \( L(N) = \sum_{n=1}^{N} L_n \) paths are used for RAKE reception.

B. Mode of Operation

For convenience, let \( L_1 \) be the number of resolvable paths from the serving BS and \( L_2, L_3, \ldots, L_N \) be those from the target BSs. Without loss of generality, we assume that at first the receiver relies only on \( L_1 \) resolvable paths and as such starts with \( L_c/L_1 \)-GSC.

1) Reassignment Scheme: In the SHO region, the receiver compares the received SNR, \( \Gamma_{L_o:L_2} \), with a certain target SNR, denoted by \( \gamma_T \) where \( \Gamma_{o,b} \) is the sum of the \( o \) largest SNRs among \( b \) ones. If \( \Gamma_{L_o:L_1} \) is greater than or equal to \( \gamma_T \), a one-way SHO is used and no finger reassignment is needed. On the other hand, whenever \( \Gamma_{L_o:L_1} \) falls below \( \gamma_T \), a multi-way SHO is attempted. More specifically, we consider two different finger assignment schemes described below.

a) Case I - Full Scanning: In this case, when \( \Gamma_{L_c:L_1} < \gamma_T \), the RAKE receiver scans all possible \( L_c(N) \) resolvable paths from \( N \) BSs and reassigns its \( L_c \) fingers to the \( L_c \) strongest paths among the \( L_c(N) \) available resolvable paths (i.e., the RAKE receiver uses \( L_c/L_c \)-GSC). Hence, the final combined SNR, denoted by \( \gamma_{Full} \), is mathematically given by

\[
\gamma_{Full} = \begin{cases} \Gamma_{L_c:L_1}, & \gamma_T \leq \Gamma_{L_c:L_1}; \\ \Gamma_{L_c:L(N)}, & \Gamma_{L_c:L_1} < \gamma_T. \end{cases}
\]

b) Case II - Sequential Scanning: In this case, when \( \Gamma_{L_c:L_1} < \gamma_T \), the RAKE receiver estimates \( L_2 \) paths from the first target BS and uses \( L_c/L_2 \)-GSC. The receiver then checks whether the combined SNR, \( \Gamma_{L_c:L_2} \), is above \( \gamma_T \) or not. By sequentially adding the remaining target BSs, this process is repeated until either the combined SNR, \( \Gamma_{L_c:L_{(N)}} \), is above \( \gamma_T \) or all the \( L(N) \) paths are examined. Based on this mode of operation, we can see that the final combined SNR, denoted by \( \gamma_{Seq} \), is mathematically given by

\[
\gamma_{Seq} = \begin{cases} \Gamma_{L_c:L_1}, & \gamma_T \leq \Gamma_{L_c:L_1}; \\ \Gamma_{L_c:L_2}, & \Gamma_{L_c:L_1} < \gamma_T \leq \Gamma_{L_c:L_2}; \\ \vdots & \vdots \\ \Gamma_{L_c:L(N-1)}, & \Gamma_{L_c:L_{(N-2)}} < \gamma_T \leq \Gamma_{L_c:L(N-1)}; \\ \Gamma_{L_c:L(N)}, & \Gamma_{L_c:L_{(N-1)}} < \gamma_T. \end{cases}
\]

2) Replacement Scheme: For simplicity, if we let

\[
Y = \sum_{i=1}^{L_c} \gamma_{i:L_1}
\]

and

\[
W_n = \begin{cases} \sum_{i=L_c-L_n+1}^{L_c} \gamma_{i:L_n}, & n = 1; \\ \sum_{i=L_n+1}^{L_c} \gamma_{i:L_n}, & n = 2, \ldots, N, \end{cases}
\]

where \( \gamma_{i:L_n} \) is the \( i \)th order statistics out of \( L_n \), then the received output SNR after GSC is given by \( Y + W_1 \). At the beginning of every time slot, the receiver compares the GSC output SNR, \( Y + W_1 \), with \( \gamma_T \). If \( Y + W_1 \) is greater than or equal to \( \gamma_T \), a one-way SHO is used and no finger replacement is needed. On the other hand, whenever \( Y + W_1 \) falls below \( \gamma_T \), the receiver attempts a two-way SHO by starting to scan additional paths from the target BSs. More specifically, we consider two different scanning schemes described below.

a) Case I - Full Scanning: In this case, when \( Y + W_1 < \gamma_T \), the RAKE receiver at once scans all target BSs and compares all \( W_n \), that is, the sum of the \( L_n \) smallest paths among the \( L_c \) currently used paths from the serving BS (i.e., \( W_1 \)) and the sums of the \( L_n \) strongest paths from each target BS (i.e., \( W_{i:2} \leq i \leq N \)). Then, the receiver replaces \( W_1 \) with the largest one. Hence, the final combined SNR, denoted by \( \gamma_{Full} \), is mathematically given by

\[
\gamma_{Full} = \begin{cases} Y + W_1, & Y + W_1 \geq \gamma_T; \\ Y + \max\{W_{i:2}, \ldots, W_N\}, & Y + W_1 < \gamma_T. \end{cases}
\]

Note that even in the case of \( Y + W_1 < \gamma_T \), no replacement occurs if \( W_1 = \max\{W_{i:2}, \ldots, W_N\} \).

b) Case II - Sequential Scanning: In this case, when \( Y + W_1 < \gamma_T \), the RAKE receiver estimates \( L_2 \) paths from the first target BS and replaces \( W_1 \) with \( W_2 \). The receiver then checks whether the combined SNR, \( Y + W_2 \), is above \( \gamma_T \) or not. By sequentially scanning the remaining target BSs, this process is repeated until either the combined SNR, \( Y + W_{(N)} \), is above \( \gamma_T \) or all the \( N \) BSs are examined. In the later case, since the SNRs of all the paths are known, the receiver
selects the largest $W_n$. Based on this mode of operation, we can see that the final combined SNR, denoted by $\gamma_{\text{Seq}}$, is mathematically given by

$$\gamma_{\text{Seq}} = \begin{cases} 
Y + W_1, & Y + W_1 \geq \gamma_T; \\
Y + W_i, & Y + W_j < \gamma_T, Y + W_i \geq \gamma_T \\
Y + \max\{W_1, \ldots, W_N\}, & Y + W_n < \gamma_T \\
\end{cases}$$

for $j = 1, \ldots, i - 1$ and $i = 2, \ldots, N$; (6)

for $n = 1, \ldots, N$.

III. EFFECT OF PATH UNBALANCE/CORRELATION

In practice, the i.i.d. fading scenario on the diversity path is not always realistic due to, for example, the different adjacent multi-path routes with path-loss and the resulting unbalance and correlation among paths. In this section, we assess through some computer simulations the effect of non-identically distributed paths with correlation on the performance of both the reassignment and the replacement schemes. More specifically, instead of the uniform power delay profile (PDP) considered in [9], [10], we now consider an exponentially decaying PDP, for which $\bar{\gamma}_j = \bar{\gamma}_1 e^{-\delta(j-1)}$ where $\bar{\gamma}_j(1 \leq j \leq L_\nu, 1 \leq n \leq N)$ is the average SNR of the $j$-th path out of total available resolvable paths from each BS and $\delta$ is the average fading power decaying factor. For the correlated paths, we consider the exponential correlation models where an exponential power correlation coefficient, $\rho^{j-j'}$ for $\rho \in [0, 1]$, between any pair of paths, $\gamma_j$ and $\gamma_{j'}$, from a certain BS is assumed. Note that $\delta = 0$ means identically distributed paths and $\rho = 0$ means independent fading paths. When we set $\delta = 0$ and $\rho = 0$, we revert to the i.i.d. fading channels.

In Fig. 1, we plot the average BER of BPSK versus $\bar{\gamma}_1$ of the replacement and the reassignment schemes over an exponentially decaying PDP with an exponential correlation across the multi-paths. These results show that the PDP and the correlation among paths induce a non-negligible degradation in the performance and therefore must be taken into account for the accurate prediction of the performance of proposed schemes. In all cases, we can see the same relationship between the replacement and the reassignment schemes as observed in [10].

IV. EFFECT OF OUTDATED OR IMPERFECT CHANNEL ESTIMATIONS

In general, diversity combining techniques rely, to a large extent, on accurate channel estimation. As a typical first step in performance analysis, perfect estimation was assumed so far. However, in practice these estimates must be obtained in the presence of noise and time delay. Hence, the effects of channel estimation error or channel decorrelation on the performance of diversity systems is of interest. In this section, we study the effect of outdated or imperfect channel estimates on the performance. For simplicity, all the diversity paths are assumed to be i.i.d. Let $\gamma^\uparrow$ be the estimated received signal power. Due to imperfect or outdated channel estimates, $\gamma^\uparrow$ may or may not be the same as $\gamma$. Hence, we can assume that $\gamma^\uparrow$ is the correlated sample from $\gamma$ with a power correlation factor, $\rho^\uparrow \in [0, 1]$, between $\gamma$ and $\gamma^\uparrow$. Here, $\rho^\uparrow$ can be viewed as a measure of channel fluctuation rate and a measure of the channel estimation quality as well. As an example, from the well-known Clark’s model, we know $\rho^\uparrow = J_0^2(2\pi f_D)$ [1], Section 2.1.1] where $J_0(\cdot)$ is the zero-order Bessel function of the first kind, $\tau$ is the time delay, and $f_D$ is the maximum Doppler frequency shift. Note that $\rho^\uparrow = 0$ means completely outdated channel estimates while $\rho^\uparrow = 1$ an up-to-date and perfect channel estimates.

Fig. 2 compares the effect of the correlation factor, $\rho^\uparrow$, on the average BER of BPSK of the replacement and the reassignment schemes with the full scanning for several values of the output threshold, $\gamma_T$, over i.i.d. Rayleigh fading channels. We can see from these curves that in all cases the diversity gain offered by the proposed schemes decreases as $\rho^\uparrow$ decreases, as expected. It is very notable that contrary to the analysis over perfect channel estimations, the replacement scheme shows a lower error probability than the reassignment scheme when $\rho^\uparrow = 0$ and 0.5 for $\gamma_T = 5$ and 15 dB. Recall that the replacement scheme compares two sums of paths from the serving and target BSs while the reassignment scheme relies on the SNR of each path. Therefore, the replacement scheme is more robust to the channel estimation errors especially when the comparisons of the two sums are needed. In other words, the more often the combined SNR is below the threshold, the less sensitive to the channel estimation error the replacement scheme is while the more sensitive the reassignment scheme is.

V. CONCLUSION

In this paper, we examined the effects of various practical considerations on the performance of some newly proposed finger assignment schemes for RAKE reception in the SHO region which were previously analyzed over ideal i.i.d fading environments [9], [10]. Through computer simulations, we considered the impact of an exponentially decaying PDP as well as a fading correlation among paths. The effect of outdated or imperfect channel estimations was also evaluated. In summary, with the analytical methods presented in [9], [10] and the simulation results presented in this paper, we are providing a general comprehensive framework for the assessment of the proposed finger assignment schemes.

REFERENCES


Figure 1. Average BER of BPSK versus the average SNR of first path, \( \gamma_T \), of the Reassignment (RA) and Replacement (RP) schemes over non-identical exponentially correlated Rayleigh fading channels when \( N = 4, L_1 = \cdots = L_4 = 5, L_c = 3, L_o = 2 \), and \( \gamma_T = 5 \) dB.

Figure 2. Average BER of BPSK versus the average SNR per path, \( \gamma_T \), of the Reassignment (RA) and Replacement (RP) schemes for the Full Scanning with outdated channel estimation over i.i.d. Rayleigh fading channels when \( N = 4, L_1 = \cdots = L_4 = 5, L_c = 3, \) and \( L_o = 2 \).