FINGER MANAGEMENT SCHEMES FOR MINIMUM CALL DROP IN THE SOFT HANDOVER REGION

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ABSTRACT
We propose and analyze in this paper new finger management techniques which are applicable for RAKE receivers operating in the soft handover region. These schemes employ "distributed" types of generalized selection combining (GSC) and minimum selection GSC schemes in order to minimize the impact of sudden connection loss of one of the active base stations. By accurately quantifying the average error rate, we show through numerical examples that our newly proposed distributed schemes offer a clear advantage in comparison with their conventional counterparts.

I. INTRODUCTION
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 [1, Section 9.5.1]. 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 multi-paths 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/power consumption. For instance, with generalized selection combining (GSC) [2–6] 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) [7–9] 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 scheme. More recently, by considering macroscopic diversity techniques, the authors proposed and analyzed the performance of new finger assignment schemes that maintain a low complexity and reduce the SHO overhead [10, 11]. The main idea behind [10, 11] is that, in the SHO region the receiver uses the additional network resources only if necessary. It has been shown that these schemes can reduce the unnecessary path estimations, SNR comparisons, and the SHO overhead with a slight performance loss compared to the conventional scheme GSC when they operate in the SHO region.

Bearing in mind that our previous efforts focused on schemes that minimize the use of network resources, we consider in this paper other finger management schemes that are designed to minimize call drops. More specifically, we propose two finger management schemes denoted by distributed GSC and distributed MS GSC schemes. The main idea behind these newly proposed schemes is that they try to "balance" SNR/paths among as many BSs as possible so that if the mobile unit ends up loosing connection with one BS (due for example to the corner effect), we can keep a great proportion of the total initially combined SNR, and as such, minimize the possibility of call drops. With distributed GSC, we apply the conventional GSC scheme to each BS by distributing the combined paths among the active BSs. On the other hand, with distributed MS GSC, we apply the conventional MS GSC to each BS by distributing the combined paths. The main contribution of this paper is to provide an analytical framework deriving the average error probability of our proposed schemes. Some selected numerical results show that our proposed schemes considerably outperform the conventional ones when there is a high chance of losing a BS.

The remainder of this paper is organized as follows. In Section II, we present the channel and system model under consideration as well as the mode of operation of the proposed schemes. Based on this mode of operation, we derive the expressions for the average error rate of the combined SNR in Section III. Section IV quantifies the average number of combined paths of the proposed distributed MS GSC scheme to investigate the tradeoff between complexity and performance. Finally, Section V provides some concluding remarks.

II. FINGER MANAGEMENT SCHEMES
A. Channel and System Model
We focus on the receiver operation when the mobile unit is moving from the coverage area of its serving BS to that of a target BS. Note that in the SHO region the mobile unit is of roughly the same long distance from the serving and the target BSs. Thus, we assume first that the signals from all the resolvable paths experience independent and identically distributed (i.i.d.) Rayleigh fading conditions and that the receiver oper-
ates over a “perfect” uniform power delay profile provided by a multi-path searcher in a way that the multi-path components are correctly assigned to the RAKE fingers. In this channel model, we do not consider the effect of inter-symbol/channel interferences by assuming, for example, perfect spreading codes. As such, if we let \( \gamma \) denote the instantaneous received SNR of all the available resolvable paths, then \( \gamma \) follows the same exponential distribution with common average faded SNR, \( \bar{\gamma} \).

We consider a mobile unit which is equipped with an \( L_c \)-finger RAKE receiver and is capable of despreading signals from different BSs using different fingers in order to facilitate SHO. We further assume that there are \( L_1 \) and \( L_2 \) available paths from BS1 and BS2, respectively. In the SHO region, according to the mode of operation described in the next section, at most \( L_c \) out of the \( L_1 + L_2 \) available paths are used for RAKE reception.

### B. Mode of Operation

We distinguish the combined SNRs from each BS by letting \( \gamma_{B_1} \) and \( \gamma_{B_2} \) be the combined SNRs of the paths from BS1 and BS2, respectively. In both schemes, we assume first that the receiver estimates all the resolvable paths.

1) **Distributed GSC**

With this scheme, the receiver selects and combines the \( L_{c_1} \) largest paths among \( L_1 \) ones and the \( L_{c_2} \) largest paths among \( L_2 \) ones, respectively, where \( L_{c_1} + L_{c_2} = L_c (\leq L_1, L_2) \). Hence, \( \gamma_{B_1} \) and \( \gamma_{B_2} \) are the combined output SNRs of \( L_{c_1}/L_1 \)-GSC and \( L_{c_2}/L_2 \)-GSC, respectively.

2) **Distributed MS GSC**

With this scheme, the receiver selects the least number of the best paths such that the combined SNRs, \( \gamma_{B_1} \) and \( \gamma_{B_2} \), are greater than the predetermined threshold, \( \gamma_T \), and \( \gamma_T \), respectively. More specifically, starting from the best path from BS1, the receiver tries to increase the combined SNR, \( \gamma_{B_1} \), above the threshold, \( \gamma_T \), by combining an increasing number of diversity paths. This process is performed until either \( \gamma_{B_1} \) is above \( \gamma_T \), or the best \( L_c \) paths out of \( L_1 \) ones are combined. In the later case, the receiver acts as a traditional \( L_{c_1}/L_1 \)-GSC combiner. The same algorithm is applied to BS2 along with the chosen design parameters, \( L_{c_2} \) and \( \gamma_T \), where \( \gamma_{B_1} + \gamma_{B_2} = \gamma_T \) and \( \gamma_T \) is the final output threshold. Hence, \( \gamma_{B_1} \) and \( \gamma_{B_2} \) are the combined output SNRs of \( L_{c_1}/L_1 \)-MS GSC and \( L_{c_2}/L_2 \)-MS GSC, respectively.

It is important to note that, in both conventional and proposed distributed schemes, it is of course clear that MS-GSC is always outperformed by GSC, MS-GSC will use on average less number of combined paths to reach a certain threshold, and as such, save the processing power on the mobile units receiving data on the down-link. In addition, in comparison to the conventional schemes, the proposed distributed schemes with minimum call drop criterion will show better performance when the signals coming from one BS are completely lost. In the next section, we investigate this issue by exactly quantifying the average error rate of the proposed schemes in terms of the probabilities of loosing BSs.

### III. PERFORMANCE ANALYSIS

In this section, we analyze the average error rate of the proposed schemes. If we assume that \( P_1 \) and \( P_2 \) are the probabilities of loosing BS1 and BS2, respectively, then the final combined SNR, denoted by \( \gamma_t \), is mathematically given by

\[
\gamma_t = (1 - P_1)\gamma_{B_1} + P_1\gamma_{B_2} + (1 - P_2)\gamma_{B_1} + P_2\gamma_{B_2}
\]

Note that although we consider two BSs for the illustration purpose, an extension to multi-BS case is straightforward. Since two random variables, \( (1 - P_1)\gamma_{B_1} \) and \( (1 - P_2)\gamma_{B_2} \), in (1) are independent, we can express the moment generating function (MGF) of \( \gamma_t \) as a product of the MGFs of these two random variables as

\[
\mathcal{M}_{\gamma_t}(s) = \mathcal{M}_{(1 - P_1)\gamma_{B_1}}(s) \cdot \mathcal{M}_{(1 - P_2)\gamma_{B_2}}(s)
\]

The MGF-based method for the evaluation of the average error rate over fading channels can be used [12, Sec. 9.2.3]. For example, the average bit error rate (BER) of binary phase shift keying (BPSK) signals is given by

\[
P_B(E) = \frac{1}{\pi} \int_0^{\pi/2} \mathcal{M}_{\gamma_t} \left( \frac{-1}{\sin^2 \phi} \right) d\phi
\]

A. **Distributed GSC**

With the distributed GSC scheme, the MGFs, \( \mathcal{M}_{\gamma_{B_1}}(\cdot) \) and \( \mathcal{M}_{\gamma_{B_2}}(\cdot) \), in (3) are the MGFs of the \( L_{c_1}/L_1 \)-GSC and \( L_{c_2}/L_2 \)-GSC output SNRs, respectively. The general form of the MGF of \( 1/L \)-GSC for i.i.d. Rayleigh case can be found in [12, Eq. (9.430)]

\[
\mathcal{M}_{\text{GSC}}(s) = (1 - \gamma_s)^{-1} \sum_{j=0}^{L-1} \left( \frac{(-1)^j}{j!} \left( \frac{L-1}{j} \right) \right)
\]

After substitution of (4) into (3) and some manipulations, (3) specializes to

\[
P_B(E) = \left( \frac{L_1}{L_{c_1}} \right) \left( \frac{L_2}{L_{c_2}} \right) \prod_{i=0}^{L_{c_1} - 1} \prod_{j=0}^{L_{c_2} - 1} \left( \frac{(-1)^{i+j}}{1 + i/L_{c_1}} \right) \frac{1}{1 + j/L_{c_2}}
\]

\[
\times \frac{1}{\pi} \int_0^{\pi/2} \prod_{n=1}^{4} \left( \frac{\sin^2 \phi}{\sin^2 \phi + c_n} \right)^{\gamma_n} d\phi,
\]

\[\footnote{1For example, in the case of N BSs, \( \gamma_t = \sum_{n=1}^{N}(1 - P_n)\gamma_{B_n} \) where \( P_n \) is the probability of loosing \( n \)-th BS and \( \gamma_{B_n} \) is the combined SNR of the paths from the \( n \)-th BS.}
where
\[
    c_1 = \frac{(1 - P_1)\gamma}{1 + i/L_{c_1}}, \quad c_2 = \frac{(1 - P_2)\gamma}{1 + j/L_{c_2}},
\]
\[
    c_3 = (1 - P_1)\gamma, \quad c_4 = (1 - P_2)\gamma,
\]
\[
    r_1 = 1, \quad r_2 = 1, \quad r_3 = L_{c_1} - 1, \quad r_4 = L_{c_2} - 1.
\]

Since the integral in (5) can be found in closed form (see [12, Eq. (5A.74)]), (5) presents the final desired closed-form result for the average BER of the distributed GSC scheme.

Fig. 1 shows the average BER of BPSK of the proposed distributed GSC scheme as a function of the average SNR per path, \(\gamma\), over i.i.d. Rayleigh fading channels. For comparison purpose, we also plot through computer simulations the average BER of the conventional GSC scheme. Note that the conventional GSC scheme acts as \(L_c/(L_1 + L_2)\)-GSC where \(L_c = L_{c_1} + L_{c_2}\) while the distributed GSC scheme uses the combinational form of \(L_{c_1}/L_1\)-GSC and \(L_{c_2}/L_2\)-GSC, and as such, a certain number of paths from one BS are always secured. Therefore, we can clearly see from this figure that by evenly distributing paths to BSs, the distributed GSC scheme shows a comparable or better performance in comparison to the conventional GSC scheme especially when the probability of loosing one BS is increasing. To better illustrate the benefit of our proposed scheme, we present in Fig. 2 the average BER in terms of the probability of loosing BS2, \(P_2\), for fixed values of \(\gamma\). We can observe from this figure that, for example, for our chosen set of parameters, the proposed distributed scheme outperforms the conventional scheme when \(P_2 > 0.5\).

### B. Distributed MS GSC

Similar to the distributed GSC scheme, we just need to replace the MGFs, \(M_{\gamma_1}(\cdot)\) and \(M_{\gamma_2}(\cdot)\), in (3) with the MGFs of the \(L_{c_1}/L_1\)-MS GSC and \(L_{c_2}/L_2\)-MS GSC output SNRs, respectively. The general form of the MGF of \(i/L\)-MS GSC for i.i.d. Rayleigh case is given by [9, Eq. (35)] as shown in (6) at the top of the next page². Thus, substituting (6) into (3), we can obtain the average BER of the distributed MS GSC scheme.

In Fig. 3, we compare the average BER of the distributed MS GSC scheme with the conventional MS GSC scheme as a function of \(\gamma\) for different values of \(P_2\). Note that, unlike conventional GSC, the conventional MS GSC scheme does not necessarily combine all the \(L_c\) best paths if the channel is of satisfactory quality compared to the output threshold. In some cases, for example, using only a few best paths out of all the available paths can be enough to meet our threshold. However, in this case, the conventional MS GSC scheme has the drawback of having a high chance of loosing the few combined paths which can come from only one BS. Curves for the conventional MS GSC in Fig. 3 manifest indeed this phenomenon. For the distributed MS GSC scheme, we distribute the combined paths as well as the threshold between two BSs as evenly as possible, and as such, acquiring at least one best path from each BS is guaranteed. Hence, we can clearly see from this figure a great amount of performance improvement of the proposed scheme in comparison to the conventional scheme as \(P_2\) increases. This performance gain comes at the cost of an increase in the processing power, which will be investigated in the next section. Fig. 4 presents the average BER in terms of the probability of loosing BS2, \(P_2\), for fixed values of \(\gamma\). As expected, the proposed distributed MS GSC scheme outperforms the conventional scheme for higher values of \(\gamma\) and \(P_2\).

### IV. AVERAGE NUMBER OF COMBINED PATHS WITH DISTRIBUTED MS GSC

As mentioned earlier, in comparison to the conventional GSC scheme, the conventional MS GSC scheme can save receiver processing power by using the least number of combined paths while keeping the combined SNR above a predetermined output threshold. As a quantification of this power savings with MS GSC, the average number of combined paths was analyzed and given by [9, Eq. (16)]

\[
    \overline{N}_{\text{MSGSC}} = 1 + \sum_{i=1}^{L_c-1} F_{\gamma_1;L_1+L_2}(\gamma_T),
\]

where \(\gamma_T\) is the sum of the \(i\) largest SNRs among \(j\) ones and \(F_{\gamma_1;L_1+L_2}(\gamma_T)\) is the well-known CDF of \(i/j\)-GSC output SNR which can be found in [12, Eq. (9.440)].

Since we are distributing MS GSC selection algorithm to each BS, we can easily obtain the average number of combined paths with distributed MS GSC as

\[
    \overline{N}_{\text{D-MSGSC}} = (1 - P_1) \left( 1 + \sum_{i=1}^{L_{c_1}-1} F_{\gamma_1;L_1}(\gamma_{T_1}) \right) + (1 - P_2) \left( 1 + \sum_{i=1}^{L_{c_2}-1} F_{\gamma_2;L_2}(\gamma_{T_2}) \right),
\]

where \(\gamma_{T_1} + \gamma_{T_2} = \gamma_T\).

Fig. 5 shows the average number of combined paths with the conventional and the distributed MS GSC schemes as a function of the output threshold, \(\gamma_T\). As we can see, in both cases the average number of combined paths decreases as \(P_2\) increases, but increases as the output threshold increases since the receiver has to combine more paths to raise the combined SNR above the output threshold. Considering Fig. 3 together with Fig. 5, we can observe the complexity tradeoff issue between the proposed and the conventional schemes. For example, if the output threshold is set to 10 dB, for \(\gamma = 5\) dB and \(P_2 = 0.9\), the proposed scheme and the conventional scheme show \(1.2 \times 10^{-4}\) BER and \(1.7 \times 10^{-2}\) BER, respectively, while the proposed scheme requires on average only around 0.5 more combined paths than the conventional scheme.

### V. CONCLUSION

In this paper, we proposed new finger management schemes for RAKE reception in the SHO region. In particular, we considered distributed versions of the conventional GSC and MS GSC schemes in order to minimize the possibility of call drops in case that one of the active BSs is lost with a certain probability. We provided an analytical framework for the assessment.
of the proposed schemes by offering generic expressions for the average BER of the proposed distributed schemes for i.i.d. Rayleigh fading environments. We showed through numerical examples that in comparison to the conventional schemes, the proposed distributed schemes offer better error performance when there is a considerable chance of loosing the signals from one of the active BSs.

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Figure 1: Average BER of BPSK versus the average SNR per path, $\bar{\gamma}$, of distributed GSC (D-GSC) and conventional GSC (C-GSC) for various values of $P_2$ over i.i.d. Rayleigh fading channels when $L_1 = L_2 = 6, L_{c1} = L_{c2} = 2, P_1 = 0$.

Figure 2: Average BER of BPSK versus the probability of losing BS2, $P_2$, of distributed GSC (D-GSC) and conventional GSC (C-GSC) for various values of $\bar{\gamma}$ over i.i.d. Rayleigh fading channels when $L_1 = L_2 = 6, L_{c1} = L_{c2} = 2, P_1 = 0$.

Figure 3: Average BER of BPSK versus the average SNR per path, $\bar{\gamma}$, of distributed MS GSC (D-MS GSC) and conventional MS GSC (C-MS GSC) for various values of $P_2$ over i.i.d. Rayleigh fading channels when $L_1 = L_2 = 6, L_{c1} = L_{c2} = 2, P_1 = 0, \gamma_T = 10$ dB, and $\gamma_{T1} = \gamma_{T2} = \frac{\gamma_T}{2}$.

Figure 4: Average BER of BPSK versus the probability of losing BS2, $P_2$, of distributed MS GSC (D-MS GSC) and conventional MS GSC (C-MS GSC) for various values of $\bar{\gamma}$ over i.i.d. Rayleigh fading channels when $L_1 = L_2 = 6, L_{c1} = L_{c2} = 2, P_1 = 0, \gamma_T = 10$ dB, and $\gamma_{T1} = \gamma_{T2} = \frac{\gamma_T}{2}$.

Figure 5: Average number of combined paths versus the output threshold, $\gamma_T$, of distributed MS GSC (D-MS GSC) and conventional MS GSC (C-MS GSC) for various values of $P_2$ over i.i.d. Rayleigh fading channels when $L_1 = L_2 = 6, L_{c1} = L_{c2} = 2, P_1 = 0, \bar{\gamma} = 5$ dB, and $\gamma_{T1} = \gamma_{T2} = \frac{\gamma_T}{2}$. 