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Down-link throughput with opportunistic feedback, multi-user and diversities in Rayleigh fading environments

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ABSTRACT

This paper studies throughput of wireless systems employing opportunistic feedback, multi-user, selection combining (SC) and maximal ratio combining (MRC) diversities for transmission in Rayleigh fading environments. The first contribution of this paper is the employment of an arbitrary average branch signal-to-noise ratio (SNR) Ω which is shown to improve system throughput under specific conditions. The effects of SC and MRC on system throughput are studied with new and detailed throughput expressions for both schemes are derived and validated. Performance comparisons between SC and MRC are also made under several scenarios by varying important parameters. It is also shown that (i) MRC outperforms SC under outage and normal operating conditions as expected, (ii) the proposed system outperforms a well-known system for large values of diversity order L and (iii) for $L = 1$, the proposed system can be correctly reduced to other systems reported in the open literature which validates the current work.

Symbol/abbreviation	Meaning
η	SNR threshold
L	Diversity order
Ω	Average branch SNR
ρ	SNR at the receiver
a	Size ratio of a data packet to an overhead packet
C	Channel capacity
$f(\cdot)$	Probability density function (pdf)
$F(\cdot)$	Cumulative distribution function (cdf)
K	Number of minislots
N	Number of users
p	Channel access probability
T	Throughput
U	Number of control packets not including K
z	Capture ratio
BS	Base station
MRT	Maximal ratio transmission
SC	Selection combining
SNR	Signal-to-noise ratio

1. Protocol

Consider a frequency division duplexing (FDD) system in which the base station (BS) has one transmit antenna. Each user has L receive antennas with a maximal ratio combiner (MRC) or a selection combiner for the case of SC diversity to process L channel-fading-gain random variables, yielding a combined channel fading gain to be fed back to the BS to compute the transmission rate. It should be clear that for each separate case of SC and MRC, different throughput expressions are obtained as shown later. Practically, it may be inconvenient for mobile users to carry L antennas. As such, the roles of the BSs and mobile users may be reversed for this proposed protocol to make it practically attractive [1–3]. The proposed system can thus be considered as a single-input multiple-output (SIMO) with (i) MRC for transmission or MRT [4] and (ii) SC for transmission as shown in Fig. 1. For each case, separate expressions for capacity and hence throughput are derived.

Assumptions:

1) All users are perfectly synchronised to the BS.
2) The feedback path is delayless.
3) All users are equipped with MRCs or SCs of order L. As such, each user feeds back the combined fading gains to the BS so that the ergodic transmission rate can be computed.
4) The channel is slow fading and statistically independent from frame to frame.

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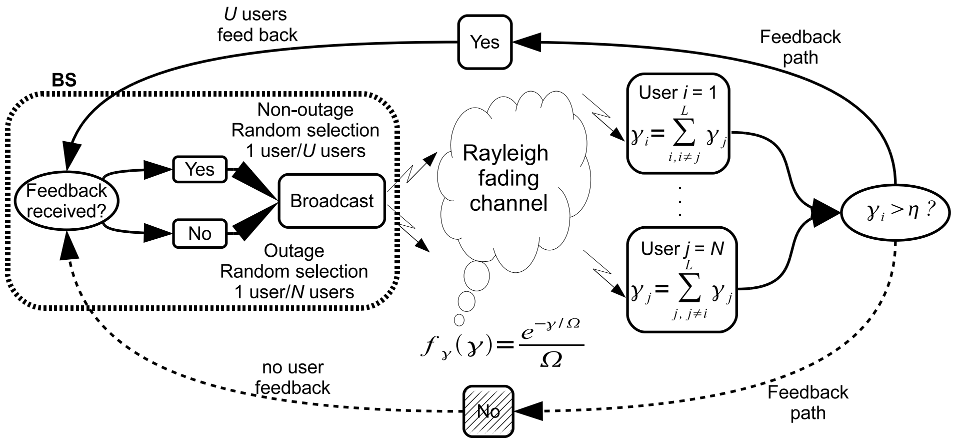

Fig. 1. A schematic block diagram of the proposed SIMO protocol.

5) The data for each user is infinitely back-logged.

For normal operation when there are effective users whose channel gains are larger than a channel-gain threshold η:

1) The BS broadcasts to all users and waits for their responses.
2) Users individually estimate their combined channel gains $\gamma_1, \gamma_2, \ldots, \gamma_{N-1}, \gamma_N$ and only the ones with channel gains larger than or equal to a threshold η respond to the BS with their user identification information and random access probability p in K uplink feedback minislots.
3) For the case of MRC, users estimate their individual channel gains by summing L individual branch gains using their available MRCs. For Rayleigh fading environments, the probability density function (pdf) of the resultant combined channel gain is a chi-square distribution of $2L$ degrees of freedom.
4) For the case of SC, users estimate their individual channel gains by selecting the highest gains of the L individual branches using their available SCs.
5) If the BS captures multiple users, it randomly selects one of them for transmission by broadcasting a control message. This is the captured primary user responsible for all communications with the BS from this point.
6) The selected user informs the BS of the MRC/SC channel gains to determine the transmission rate.

For operation in an outage condition when all users' channel gains are smaller than the threshold η and the BS has not yet captured any user for transmission:

1) The BS broadcasts to all users and waits for their responses.
2) Users individually estimate their channel gains $\gamma_1, \gamma_2, \ldots, \gamma_{N-1}, \gamma_N$ which are all smaller than the threshold η. Then the system may be said to be in an outage situation.
3) The BS randomly selects one primary user out of the total N users for transmission. The BS requests the user's channel quality information (CQI) which may include the received SNR or alternative channel quality indicators.
4) The selected user feeds back the resultant fading gain to the BS which determines the transmission rate.

Opportunistic feedback has been effectively employed to (i) improve throughput [5–8], (ii) achieve efficient resource sharing [8–11] and (iii) effective routing [12–14]. However, the capture effect has not been employed in the reported works until preliminary results were reported in [15] in Rayleigh fading environments. It should be noted that the authors of [15] considered throughput with capture effect, opportunistic feedback and user diversity in Rayleigh fading without linear diversities to more effectively combat fading. In other words, the capture effect with SC and MRC have not been employed in the open literature. Thus, the main contributions of this paper are:

1) To extend the results published in [15] using SC and MRC;
2) To show the effectiveness of the proposed method over the method reported in [16].

The paper is organised as follows. The channel capacity employing SC is obtained in Section 3. Section 4 derives the compact form expression of the channel capacity as a function of relevant parameters such as $\eta, \Omega, L, \rho, p, z, K, a$. Main results are discussed in Section 5. The paper is concluded in Section 6 with an outline of possible future work.

2. Definition of throughput and the capture ratio *z*

The capture ratio z is defined as the ratio of the power of the captured user u to the total interference power of the feedback users, i.e. users whose channel fading gains exceed the threshold η [15, (1)]

$$z \triangleq \frac{\alpha_u}{\sum\limits_{\substack{n\in\phi \\ n\neq u}} \alpha_n}, \tag{1}$$

where ϕ is the set of all feedback users, n is a user index of the set and α_n is the uplink received signal power at the BS from user $n \in \phi$. Assigning z larger than a certain value ensures that the receiver can correctly decode messages, hence successful transmission. There are basically two major cases

1) $z \geq 1$: The signal power of user u is greater than that of other users in the set ϕ and this user is likely to be captured by the receiver. This scenario is considered in this paper.
2) $0 < z < 1$: The signal power of user u is not dominant in the set ϕ in which other users also have comparable signal power with user u, resulting in multiple captured users. In this paper, this scenario is not considered.

It should also be noted that the effects of the capture ratio z are independent from those of the channel fading gain threshold η which is primarily used to control the number of feedback users to the BS to reduce feedback traffic and hence to improve system downlink throughput. The capture ratio z is employed so that successful message decoding at the receiver is achieved. In this paper,