Opportunistic beamforming for MIMO downlink systems with adaptive receive antennas selection

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Abstract— **Opportunistic beamforming is a technique which uses multiple transmit antennas at the base station to induce random fading in a real system, where the environment has little sacttering and or the fading is slow, in order to exploit multiuser diversity. In this paper, opportunistic beamforming is proposed to be combined with receive antennas selection at each mobile terminal.The proposed receive antennas selection algorithms use a predetermined threshold. The use of multiple antennas at each mobile improves the performance of the system especially when there is insufficient number of users. We show also that the total average throughput can be maximized at an optimal threshold. The result of simulations confirm that the proposed scheme enhance the total throughput of the system.**

I. Introduction

The performance of multiple input multiple output (MIMO)systems over traditional single input single output (SISO) systems in terms of capacity gain and diversity gain has been shown by several studies. Particularly in the case of downlink systems where a single base station communicates simultaneously with multiple users, MIMO can significantly enhance the sum-rate capacity. Such multi-user MIMO systems motivate many searchers to study the benefits of a new form of diversity called multiuser diversity. This concept of this type of diversity is first introduced by Knopps and Humblet in [8]. In fact, different users in a wireless multi-user system have independent fading processes. If each mobile terminal estimates its instantaneous channel quality (SNR) and feed it back to the base station,a scheduler in the base station can uses this information and transmits to the user with the best channel quality. Using this technique, the over all system throughput is proven to be maximized. The amount of multiuser diversity depends on the rate and dynamic range of channel fluctuations. In the environment where the channel fluctuations are slow can be fastened artificially in order to exploit multi-user diversity. For that case, Viswanath, Tse, Loria propose to use opportunistic beamforming in [7]. This technique induces random fading in a real system, where the environment has little scattering and or the fading is slow in order to implement multiuser diversity.

An enhancement of opportunistic beamforming scheme is proposed in [9], where pipe selection is combined with multiuser diversity to over come the scheduling latency issue for delay sensitive traffic. Interestingly, in [3] a reduced feedback for opportunistic beamforming is proposed. Several extensions of opportunistic beamforming using multiple beams were investigated in [1], [2]. Recently oppotunistic beamforming and scheduling scheme was proposed in [4] for MIMO-SDMA downlink systems. Signals received from all antennas of a chosen mobile terminal are jointly exploited to improve the effective SINR through the use of low complexity linear combining techniques.

This paper proposes to use opportunistic beamforming with multiple antenna selection at each mobile terminal. In fact, an additional antenna at each mobile can be viewed as a virtual user. Since the gain of multiuser diversity depend greatly on the number of user, the sum rate of the system will be increased specially in the case when the number of user in cell is small. Antenna selection,or precisely the principle to use L out from N antennas known as "Hybrid selection/maximum ratio combining" is studied by in [6], [5]. This approach aims to maintain the high potential data rate of MIMO system and reduces the cost of these systems in terms of size, power and hardware by decreasing the number of RF chains. Therefore, antenna selection is a low cost and low complexity alternative method to obtain the advantages of multiple antennas systems.

The remainder of this paper is organized as follows: while section II deals with the system model and a review of opportunistic beamforming, section III presents the proposed scheme followed by section IV with simulations results. The paper finally draws the conclusions in section V.

II. Opportunistic beamforming

We consider a downlink system where a base station is equipped with N_t transmit antennas communicates with K users. Each of K mobile terminals has one receive antenna. We note $h_{nk}(t)$ the complex channel gain from n antenna to the kth user in time slot t. In time slot t, the same block $x(t)$ of symbols is transmitted from all of the antennas except that it is multiplied by a complex number $w_n(t) = \sqrt{\alpha_n(t)}e^{j\theta_n(t)}$ at antenna n, for $n = 1, ..., N_t$, such that $\sum_{n=1}^{N_t} \alpha_n(t) = 1$, preserving the total transmit power. The received signal at user k is given by

$$y_k(t) = h_k^T w(t)x(t) + b_k(t) \tag{1}$$

where

$$h_k^T := [h_{1k}(t), h_{2k}(t), ..., h_{N_t k}(t)]$$

is the channel vector and

$w(t) := [\sqrt{\alpha_1(t)}e^{j\theta_1(t)}, \sqrt{\alpha_2(t)}e^{j\theta_2(t)}, ..., \sqrt{\alpha_{N_t}(t)}e^{j\theta_{N_t}(t)}]^T$

and $b_k(t) \sim N(0, \sigma^2)$ is the corresponding noise. The overall channel gain is $h_k^T(t)w(t)$. The signal-to-noise ratio(SNR) of user k is $SNR_k(t) = \frac{|h_k^T(t)w(t)|}{\sigma^2}$. We assume that the receivers can perfectly track the overall(SNR)or effectively the fading processes $h_k(t)_t$, then the maximum long-term average sum-capacity of the channel can be achieved by the transmission strategy which schedules at any one time the best user.

III. Opportunistic beamforming with receive antennas selection

With opportunistic beamforming, the base station uses random beams. Such scheme requires very large number of users in the system in order to achieve the performance of the true beamforming. However, if the mobile terminals are equipped with $N_r > 1$,signals received by these receive antennas can be exploited in order to increase the throughput of the system.

We consider now a downlink of wireless communication system where a base station with $N_t$transmit antennas communicates with K mobile terminals equipped with $N_r > 1$ antennas. To avoid the complexity of users terminal and the highest consumption of energy, the number of receive antennas is limited to 3.

The channel vector for n^{th} receive antenna belonging to the user k is denoted as

$$H^{[k,n]} = [h_1^{[k,n]}, h_2^{[k,n]}, ..., h_{N_t}^{[k,n]}]$$

The received signal at antenna n for user k is

$$y^{[k,n]} = H^{[k,n]}wx + b^{[k,n]} \quad (2)$$

To assure fairness between users, we use the proportional fair scheduling algorithm which schedule transmission to a user only when its overall channel SNR is near its peak. Let $R_k(t)$ be the data rate that user k's channel can support at time t. It is given by the Shannon limit $\log_2(1+SNR)$. Under the proportional fair algorithm with averaging time scale $t_c = \infty$, the long term average throughput of user k $T_k(t)$ exists [10]. In time slot t,the scheduling algorithm simply transmits to the user with the largest

$$\frac{R_k(t)}{T_k(t)}$$

The average throughput $T_k(t)$ can be updated using an exponentially weighted low-pass filter .

$$T_k(t+1) = \begin{cases} (1-\frac{1}{t_c})T_k(t) + \frac{1}{t_c}R_k(t), k = k^* \\ (1-\frac{1}{t_c})T_k(t), k \neq k^*. \end{cases}$$

The long term total average throughput of the system can be obtained by $\sum_{k=1}^{K} T_k(t)$.

Our proposed scheme is a combination between opportunistic beamforming and receive antennas selection according to a predetermined threshold. The receiver starts by checking at the beginning of each time slot if an arbitrary selected antenna is above the predetermined threshold. If this happens, the receiver will be connected to this selected antenna until the end of the time slot. Otherwise the receiver switches to examine the quality of an other antenna. If also the SNR of that antenna is not above the predefined threshold, the receiver combine the already examined antennas according to MRC (Maximum Ratio Combining) rule and check if the resulting SNR exceed the predermined threshold. Otherwise the receiver switches to examine the quality of an other antenna. If all antennas SNR fail to exceed the predetermined threshold, the receiver combine them as per the rules of MRC. As such method selection reduces not only the average amount of processing power but also the average number of channel estimation per time slot. Following the idea described above, we formalize the algorithm as follows:

Receive antennas selection algorithm

- $j \in \{1, 2, ..., N_r\}$
- choose the threshold S
- initialize $j = 1$
- label1: if $snr_j \geq S$, break
- else combine $snr^{MRC}_{1 \leq i \leq j}$
- if $((snr^{MRC} \geq S) or (j = N_r))$, break
- else
- update $j := j + 1$ and go back to label1

The receive antenna selection algorithm described above authorize indirectly transmission to users under a predetermined threshold. In order to show the influence of the threshold on the throughput efficiency and energy efficiency, we adopt the following receive selection algorithm based on the fact that if all combined antennas of the receiver fail to exceed the predetermined threshold, the user is eligible for transmission. Following the idea described above, we formalize the algorithm as follows:

Proposed receive antennas selection algorithm

- $j \in \{1, 2, ..., N_r\}$
- choose the threshold S
- initialize $j = 1$
- label1: if $snr_j \geq S$, break
- else combine $snr^{MRC}_{1 \leq i \leq j}$
- if $snr^{MRC} \geq S$, break
- else
- if (j=Nr)
- set $snr := 0$, all antennas of user k are idle
- else
- update $j := j + 1$ and go back to label1

IV. Simulation results

In this section, we use computer simulation to confirm the performance of the proposed schemes in slow fading Rayleigh environments. The simulation is conducted for $N_t = 6$ transmit antennas and $N_r = 1, 2, 3$ receive antennas. Figure 1 shows significant enhancement in throughput when antenna selection is used at the receiver side compared to random beamforming using one receive antenna. It is evident that the throughput with $N_r = 3$ is higher than that with $N_r = 2$ for the same amount of total transmission power. This is because

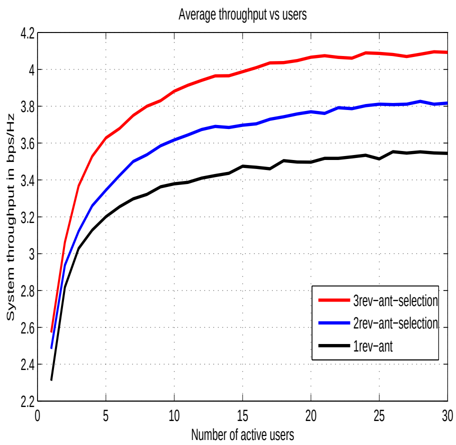

Fig. 1. Comparison of total average throughput in b/s/Hz achieved by different number of receive antennas under SNR of 10 dB

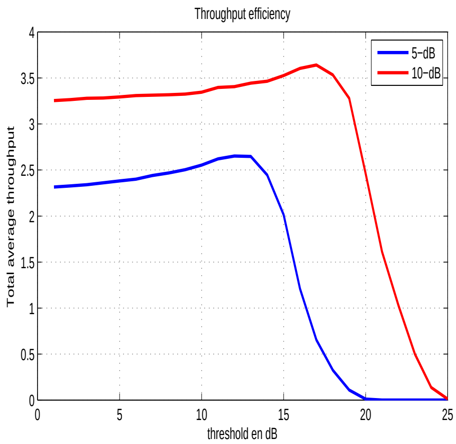

Fig. 2. Total average throughput in b/s/Hz with 3 receive antennas selection

an additive antenna at the mobile station is viewed as an effective user and augment the probability that there is a user which its channel vector is perfectly aligned to a random beam especially for small number of mobile terminals.

Figure 2 shows the performance in terms of total average throughput versus thresholds for different SNR (5, 10 dB) and for K=10. Two important results should be observed. First, as we can see that there is an optimal threshold that maximize the total average throughput. Secondly, results also show that the optimal threshold depend on the transmit power. The results in this figure indicate that the optimal threshold is 17 dB for SNR=10 dB and 13 dB for SNR=5 dB.

Figure 3 shows the average number of the activated antennas of one user versus thresholds at SNR=10 dB. For low thresholds the user activate one receive antenna. When the value of the threshold increases, the number of the activated antennas increases until the maximum,i.e three receive antennas at the threshold 23 dB in our case. After that value all antennas can not satisfy the quality needed. So all antennas are idle.

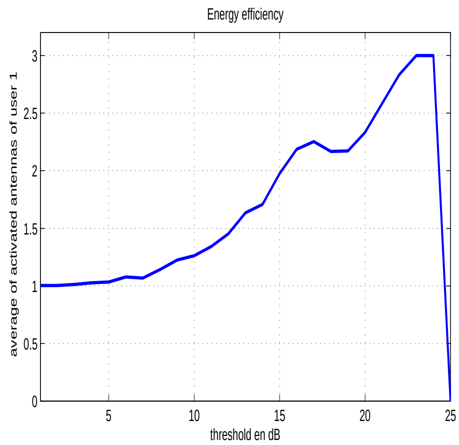

Fig. 3. Average of activated antennas of user 1 at 10 dB SNR

V. Conclusion

In this paper we have proposed a generalization of opportunistic beamforming by using multiple receive antennas selection. The proposed scheme enable a significant performance improvement in terms of total system throughput as compared to conventional opportunistic scheme especially for small number of users. The selection of receive antenna is done arbitrary and according to a predetermined threshold. This method avoid as to check always all the receive antennas. In this manner we reduce the complexity of the MIMO downlink scheme in terms of consumption of energy and cost.

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