1 INTRODUCTION

Two papers, the "ZFBF-SUS (zero-forcing beamforming - semiorthogonal user selection)" [1] and the "RBF (random beamforming)" [2] papers, were reviewed. Both papers propose beamforming as a practical technique to exploit multiuser diversity for MIMO broadcast channels. Both can achieve asymptotic capacity of that is enjoyed by DPC (dirty paper coding).

2 THE ZFBF-SUS PAPER

The main idea for ZFBF-SUS paper is that it employs a two-step process. First a SUS (semi-orthogonal user selection) scheduling algorithm is performed to group the users such that users in the same group have near orthogonal channels. Second, it simply inverses the composite channel matrix of the user group to be the beamforming vector on the MIMO transmitter which would then zero out the cross-users interference.

It assumes the following: number of users (K) >= number of antennas (M), and all users experience homogenous independent fading, with same SNR. Perhaps most importantly it is assumed that the full and perfect CSI (channel state information) is known to base station. It focuses on long term sum rate thus it is most suitable for application without stringent delay constraint.

This paper proves that ZFBF-SUS when K is infinite the expected sum rate equals to that of DPC, which is M log (1 + P/M log K). It leverages the analytical techniques of lower bounding by the surrogate expected sum rate for the suboptimal user group ZFBF, which with the careful quantization of effective channel gain reduction and multiuser diversity gain reduction still asymptotically approaches to the expected sum rate of DPC. Intuitively ZFBF-SUS can achieve DPC capacity because with a large number of users the transmitter can choose user channels that are nearly orthogonal to each other.

A number of simulations are included in this paper. First it examine the choice in setting the degree of semi-orthogonality, alpha, noting the balance between effective channel gains and multiuser diversity gain: too large of it reduces the effective channel gains and too small of it reduces the multiuser diversity gain. For K=100 to 100,000, alpha is optimal at 0.2 to 0.4.

It compares sum-rate performance of DPC, optimal ZFBF, ZFBF-SUS, RBF, and TDMA. for K=10 to 100, and M =2 or 4, ZFBF-SUS is close to DPC, and significantly better than RBF and
TDMA. With very large $K$ (in the order of $10^4$), RBF is close to ZFBF-SUS, and significantly better than TDMA.

It also compares the fairness of users selection when users are with unequal SNRs. Two flavor of modified version of ZFBF, RR-ZFBF (round robin, where SUS is applied recursively) and PF-ZFBF (proportionally fair, where user selection is based on time-averaged weighting on realized throughput), can achieve a much more fair user selections than ZFBF-SUS.

Lastly it shows imperfect CSI degrades the performance of ZFBF.

3 THE RBF PAPER

The main idea for RBF paper is that partial channel knowledge plus using orthogonal codes can scale like DPC with full CSI. By knowing only the SINR values and the index of the users with the highest SINRs (signal to interference and noise ratio) and by assigning predetermined orthogonal beamforming codewords in MIMO transmitter to users with highest SINRs, it can achieve DPC-like capacity without the need to know the full CSI feedback from all the users.

It assumes constant block-fading channel over coherence interval, $n$ (number of users) $>> M$ (number of transmit antennas), $N$ (number of receive antennas in each users) $<= M$, and all users have the same SNR.

This paper proves the following: (1) when fixed $M$ is fixed and $n$ is increasing, the throughput scales as $M \log \log n N$, which is the same with the scaling law of DPC with full CSI, (2) As long as $M$ does not grow faster than $\log n$, throughput scales linearly with the increase of $M$, (3) When $M > \alpha \log n$, the scheduling will become fair regardless of SNRs of the users, and (4) $M = \alpha \log n$ seems to be a good tradeoff point between both fairness and linear scaling with $M$. $\alpha = \text{Rate of DPC}/M$ when $n$ approaches infinite.

It leverage fairly sophisticated distribution analytical tools including upper lower bounding, proof by contradiction, limiting distributions for the cumulative distribution of the random variables, and unique solution to the growth function. The basic intuition seems to be that when the number of users $n$ is quite large and transmit antenna number $M$ is big enough, the channels distributions tend to exhibit multiuser diversity exploitable.

This paper includes the simulations showing the sum rate curve when $M$ increases from 1 to 10 with different SNR=0,5,10dB under $n = 100$ and 500. When $M <= 4$, the throughput curve increase linear with $M$, and above 4 (which is about $\log n$) the throughput curve starts to saturates.

It also showed that when $M=5$ and $n = 100$, the scheduling of users with varying SNR ranging from 0dB to 30dB is more fair and uniform than that of $M=1$ and $n=500$ where higher SNR users
like with 30dB are strongly favored. This is due to when $M > \alpha \log n$ the system is interference dominated which makes RBF fair as a happy by-product.

4 DISCUSSIONS

The important contributions for both papers are that both papers propose a much practical and much simpler MIMO BC coding than DPC using beamforming. Both present detail analysis of how their scheme approaches or scales like DPC capacity, which establish solid theoretical foundations for these practical techniques.

The weakness for ZFBF-SUS is in its dependence of full and accurate CSI, acknowledged by the author as future improvement. The unique feature for RBF is that it requires the least amount of channel knowledge and almost at the purest form of random exploitation, yet it also does not achieve as high of capacity as the more sophisticated ZFBF-SUS despite having the same scaling trend like DPC.

While RBF involuntarily and happily avoids the fairness issue given the configuration is right, ZFBF-SUS deals with fairness issue more systematically by weighting in scheduling. Fairness is a realistic issue since not all users will have the same SNRs.

Both ZFBF-SUS and RBF requires the number of users to be large for the multiuser-diversity effect to show. Depending on the application, the users base may be large or small, for example, cellular system might be very different than WiFi or ad hoc networks, thus how to exploit multiuser diversity when users base is small can be a another step for future exploration.

5 REFERENCES
