Lightweight User Grouping with Flexible Degrees of Freedom in Virtual MIMO

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Abstract—**Virtual MIMO (Multiple Input Multiple Output) groups multiple single-antenna mobile devices to form an antenna array, offering higher degrees of freedom and improved spatial diversity gain as a real MIMO does, yet with much lower costs. In this paper, we focus on the user grouping problem in uplink transmission from multiple single-antenna users to one multiple-antenna base station. State-of-the-art solutions mostly target two single-antenna users, solving a pairing problem. Having more than two uplink users in a grouping has yet to be addressed.**

Intuitively, a higher the number of users in a VMIMO group enables higher spectrum efficiency and thus higher throughput gains; the group dynamics however becomes higher too, making fairness harder to be achieved with reasonable computation overhead. To address these challenges, we present a novel solution that decomposes the VMIMO user grouping into two steps. We lighten the computations in user grouping by using instantaneous signal to noise ratio (SNR) as selection criteria, and combining it with proportional fairness for larger groups of users. Lightweight computation in using instantaneous SNR in our solution allows faster grouping and feasible scheduling for a large number of users, as well as fast decision on the efficiency of the number of users in each group. We have evaluated our solution under different network configurations, and the results demonstrate that it achieves much higher data throughput as compared to existing solutions and also well preserves fairness.

Keywords: Wireless, VMIMO, uplink scheduling, Virtual MIMO, OFDM, Proportional Fair

I. INTRODUCTION

The demands for higher data rates over longer distances, scarcity of mobile wireless resources, and need for efficiency of spectrum usage [1] [2] have motivated the development of Multi Input Multi Output (MIMO) antenna over orthogonal frequency division multiplexing (OFDM) communication systems. MIMO antenna systems exploit diversity and spatial multiplexing using more than one antenna at the sending and receiving ends of a transmission, which enhances data throughput in the presence of interference and fading, with minimum additional overhead on bandwidth or transmit power.

Although the advantages of MIMO systems are highly appreciated, the complexities of implementing MIMO antenna, including physical barriers in implementing multiple antennas in small hand-held devices and driving multiple radio frequency chains, have challenged the practicality of such systems. MIMO antenna implementation requires multiple antennas on both the receiver's and sender's sides. However, the limited size of hand-held mobile devices and the limited number of antennas in each user device (often to a maximum of two) have severely defeated the MIMO gains for such users. Even if the physical challenges of implementing multiple antennas without increasing the weight and size of hand-held devices are met, spatial correlation may frequently appear on compact mobile devices, which degrades the efficiency of spatial multiplexing.

An alternative approach to provide the MIMO benefits without the physical impediments of having more antennas on one device is Virtual MIMO. Virtual MIMO creates a wide-area MIMO system by allowing multiple users, or access points, to form a virtual antenna array using the existing physical antennas on each of the user devices. Specifically, multiple single-antenna mobile devices are grouped to create an array of single antennas to act as a multiple antenna device, offering higher degrees of freedom and improved spatial diversity gain as a real MIMO does. This reduces the complexity at each device, but obviously shifts the complexity to forming the multiple antenna groups.

Grouping antennas is one of the most important problems in virtual MIMO, both in uplink and downlink scenarios. In downlink, grouping is performed by choosing the access points that can provide service to a user with multiple antennas. In uplink, grouping is performed by choosing users with similar channel qualities to connect to the access point with multiple antennas. Efficient grouping will increase the connected users' throughput. However, making the decisions only on the quality of channel may starve users with lower channel qualities. Therefore, trade-off should also be made for all of the grouped users in scheduling the uplink traffic, between the overall throughput and the individual's fairness.

In this paper we focus on the user grouping problem in uplink transmission from multiple single-antenna users to one multiple-antenna base station. The current solutions mostly target two single-antenna users, solving a pairing problem [3]. The possibility of having more than two users in a grouping has yet to be addressed, particularly with the throughput and fairness constraints. This is worthwhile because the higher the number of users in a VMIMO group, the higher the spectrum efficiency of the transmission and the MIMO throughput gains of the system. On the other hand, the wireless channel condition changes drastically for a group with multiple mobile users. The higher the number of users in a group, the higher the group dynamics is, making it harder to meet the fairness and throughput criterion together.

To address these challenges, we present a novel solution that

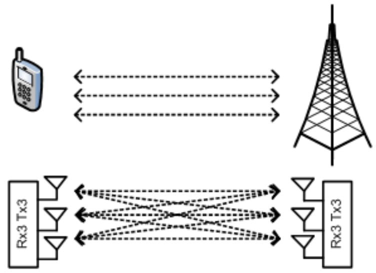

Fig. 1. Downlink & Uplink MIMO Systems

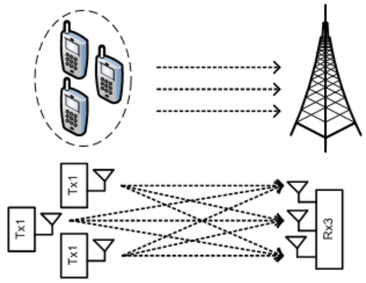

Fig. 2. Single Cell Uplink Virtual MIMO

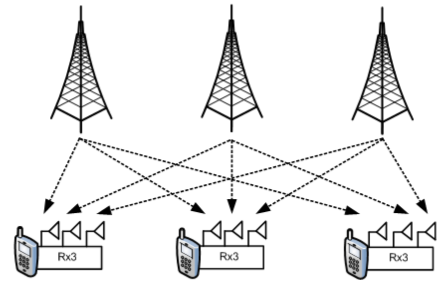

Fig. 3. Multi-Cell Downlink Virtual MIMO System

decomposes the VMIMO user grouping into two steps. We first ensure the proportional fairness in assigning a scheduling time slot to a group of users. Then, we choose the uplink grouping of the users within each large user group and a round robin process among the smaller groups with variable number of users, using the instantaneous Signal to Noise Ratio (SNR) values. Lightweight computation in using instantaneous SNR in our solution allows faster grouping and feasible scheduling for a large number of users, as well as fast decision on the efficiency of the number of users in each group. The fairness and quality decisions made in different steps of the solution also enables extendibility to larger number of users.

We have evaluated our proposed solution under different network configurations to examine practicality of the solution. We check diverse wireless networks using MIMO antenna systems in different bands, with varying user dynamics. The simulation results demonstrate that our solution achieves much higher data throughput as compared to existing solutions. It also follows fairness criteria to make sure the users are not starved in different grouping scenarios.

The rest of this paper is organized as follows. In section II we quickly review the uplink virtual MIMO and multi-cell MIMO solutions, then we discuss the strengths and shortcomings of state-of-the-art uplink user grouping solutions. Section III offers an overview of our VMIMO system model, followed by our grouping problem formulation. Our VMIMO clustering, grouping, and scheduling algorithms are discussed in IV. We evaluate our proposal in V through simulations and analyze the performance improvement. Section VI concludes the paper and outlines the proposed future work.

II. Virtual MIMO Systems: An Overview

Grouping multiple streams and forming virtual groups for higher transmission efficiency have been addressed in different types of communication systems in the literature, including wireless systems with code division multiple access sharing [4], wireless local area networks [5], wireless sensor networks [6], cognitive radio networks [7] [8], long term evolution (LTE) of 3GPP macrocells [9] [10] [11], and LTE femtocells [12]. The gains of such virtual multiple antenna systems, even with early simple implementations and idealized analysis, has motivated their consideration as the future of the communication systems [13].

As the future is towards using virtual multi-user MIMO, solving problems associated with multiple independent users has attracted significant interest. Examples include square error minimization on downlink multiuser MIMO using duality between the downlink and uplink and mean square error feasible regions [14], mean square minimization for each receiver branch [15], duality for multiuser MIMO beamforming [16], queueing model for multi-rate multi-user MIMO systems [17], increasing the number of antennas sending at a given time by zero forcing current transmissions [18], and solving the problem of limited feedback in multi-user MIMO systems using alternating codebooks [19].

A great amount of research has also been performed on analytical modelling [20] [21] and measurements [22] [23] on virtual MIMO systems. The impact of a random distribution of nodes on the overall performance of virtual MIMO [21], and traffic load, distance and throughput tradeoffs among the single user and multi-user MIMO systems [24] are analyzed. Multi-user MIMO measurements have been conducted in an urban macrocellular environment [23] and a 4×4 virtual MIMO [22].

Virtual MIMO systems need cooperation among the users with distributed antennas to re-use the data on the receiver side. This means different designs are needed for uplink and downlink as the grouping is on different set of users. In downlink MIMO, multiple access points are providing access to a single user, which will still need to have multiple antenna to use this functionality. However, each of the antennas are used for downloading a different stream from the associated access point. Virtual MIMO at the uplink is provided by grouping single antenna user devices into groups that together act like a multiple antenna transmitter. The same grouping is not as efficient in downlink as the users will have to communicate to find each others' channels to use the transmitted data. Figures 1, 2, and 3 illustrate the communication among multiple antennas in a MIMO, an uplink virtual MIMO, and a multi-cell MIMO system, respectively. Tx and Rx denote the transmit and receive antennas, respectively. We next categorize the researches into downlink and uplink VMIMO in more detail.

A. Downlink

Most of the works on downlink VMIMO have focused on grouping the access points to provide access to a single user. It is also referred to as multi-cell MIMO [25]. Gesbert et al. [25] provided a comprehensive review of all downlink multi-cell MIMO theories, techniques, and solutions incorporated in current practical systems. Ramp et al. [26] also examined it in cooperative cellular networks. Solutions in the literature vary from opportunistic medium access control design [27], to joint solutions for increasing throughput and minimizing power [28] [29], interference, or mean square error [14].

An important problem in multi-cell MIMO is the complexity in synchronization among the cells, as well as complexities on the user side to use the downloaded data. Badic et al. [9] investigated the impact of feedback and user pairing schemes on receiver performance in long term evolution of 3gpp (LTE) systems, emphasizing the tradeoff between receiver performance and complexity. The complexity is even higher when the users also have to be grouped to sending antenna array groups. An example research on this topic is user pairing control for reducing the interference in the cell-edge in multi-cell MIMO [30]. Lan et al. [31] proposed a group competition-based selection. The first user is chosen based on having the largest channel gain, and the rest of the group members are selected using an orthogonality threshold. The best group having the highest overall rate is then selected as the final user set. Fairness is not considered in their work. The details of how the users collect the channel information in the user side, which is the significant challenge for grouping users for downlink VMIMO, is not discussed either. Other solutions for downlink VMIMO include precoding techniques for reducing the signal to interference and noise ratio of multiple data streams [32], and beamformeing design solutions with different design constraints [29].

B. Uplink

In uplink virtual MIMO, multiple users each with a single antenna operate at the same time to increase the aggregate uplink throughput, which can also be viewed as a form of spatial division multiple access. Researches on uplink MIMO range from power allocation [33] to multi-cell uplink coordination [34]. Particular focuses have been on grouping the users and scheduling the grouped users for higher throughput, while keeping such promises as fairness and power constraints.

Saad et al. [35] proposed a game theoretic approach for distributed clustering to form uplink coalitions by collaborating users in time division multiple access, and designed the signalling among the users for such decision making. They considered fairness in their utility function and payoff, but the throughput is not explicitly considered or measured. Such distributed decision for group forming also introduces a high complexity and message passing requirements to the system. The need for such distribution is not justifiable given the low number of users in uplink coalitions as well as the cost and complexity of distribution.

Most of the research in grouping users only considered two users, and discussed pairing and scheduling for the users [3] [36] [37]. Traditionally the uplink scheduling was done by a proportional fair scheduler, which prevents starving users by choosing only those with high quality connections. The same approach has been adopted in user pairings, known as *double proportional fair scheduling*.

Chen et al. [3] presented the most famous pairing algorithm. The algorithm uses the proportional fairness to decide the first user, and a modified proportional fairness criterion to choose the pairing user. This pioneer work was followed by a series of pairing algorithms [38], including combined optimization of user pairing and spectrum allocation [39], and robust pairing for changing channel conditions [37]. Li et al. [36] proposed a pairing scheduling that combines the advantages of the proportional fair and maximum rate rules, using successive interference cancellation to meet the tradeoff between aggregate throughput and user fairness. Wang et al. [40] proposed a pairing scheduling based on selecting the first user with proportional fairness and pairing users with a fairness adjustable mechanism that also considers the channel orthogonality and system capacity.

The focus on pairing in the state-of-the-art solutions, rather than considering higher number of users, is the high complexity of grouping and scheduling, making them impractical with more users. Our solution, while ensuring the fairness and providing higher throughput, incorporates a lightweight decision making scheme that makes it practical for higher number of users. This will increase the efficiency in spectrum usage, as the higher number of antennas directly translates into higher throughput.

III. System Model and Problem Statement

We consider a single access point scenario, where there is no cooperation or interference from the neighbouring access points anywhere in the region covered by the access point of interest. There are U users in the sensing range of the access point, and all have uplink data to send to the access point. Each user has only one transmit antenna. The access point is equipped with k receiver antennas. An access point scheduler chooses $U_g \leq k$ users to share the same time-frequency resource blocks for their uplink transmission to the access point as if there are U_g transmit antennas in the uplink.

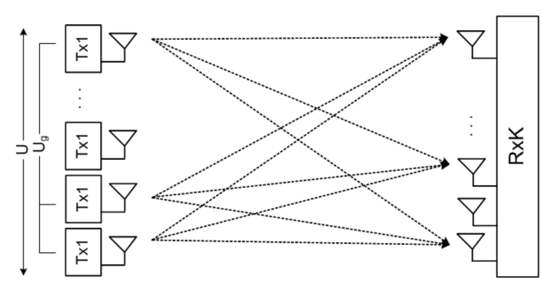

Fig. 4. Uplink VMIMO User Grouping Problem

Figure 4 illustrates the conceptual model of our uplink VMIMO system. Tx and Rx denote the transmitting and receiving antennas, respectively. The different set of arrows show the transmissions for each set of transmitting and receiving antennas. We assume perfect channel information, as well as perfect phase, symbol, and frame synchronization. These perfect assumptions are common practice when their estimation is not the main subject of interest.

In the uplink virtual MIMO, one resource block, which is traditionally allocated to one users, is scheduled for concurrent uplink transmission of more than one user to improve the spectral efficiency. The scheduled users transmit their signals

TABLE I
DEFINITION OF PARAMETERS

Symbol	Description
k	Number of antennas in the access point
μ	Number of transmit antennas
ν	Number of receive antennas
u	Uplink user
n	Transmission subcarrier
N	Number of subcarriers
N_0	White noise
U	Set of users in the system
U_s	Cluster of users to be scheduled
U_g	Group of users selected for transmission
p_u	Path loss for user u
Δt	Scheduling period
$x^t_{U_s}$	Scheduling variable
$b^t_{U_s}$	Bandwidth share variable
α^i	Weight of clustering parameter i
q^i_u	Clustering cirteria parameter i for user u
γ_{U_s}	Current mean of parameters in U_s
C_{U_s}	Estimated capacity for group U_s

independently over different antennas to achieve the spatial multiplexing of an MIMO system. Therefore, the access point should employ advanced receiver structures to differentiate the data streams being transmitted from different users. For this purpose, we consider using a semi-definite relaxation decoder (SDR) at the receiver [41]. The SDR decoder is a recent solution for multiuser detection, which can provide a very competitive performance in approximating maximum likelihood detection in MIMO systems at low computational cost.

Our goal is to choose the U_g users out of U possibilities while scheduling each *resource block* (RB) to have the highest uplink throughput over the N available subcarriers:

$$argmax_{U_g \subseteq U_s} \sum_{U_s \subset eq U} log(C(U_g)) \tag{1}$$

where $C(U_g)$ is the throughout of the simultaneous transmission to group U_g. An efficient grouping algorithm should maximize the total throughput for all users at the same time without starving some users with lower quality connections. We maximize $log(C(U_g))$ to achieve the proportional fairness, and to reduce the aggressiveness of the grouping towards high bandwidth. This means serving each user in a group with a fair portion of throughput. Thus, while achieving the aforementioned goal in equation (1), the system will be fair among the users. For easier reference, table I summarizes the variables used in our system model and formulation.

IV. LIGHTWEIGHT FAIR MULTI-USER GROUPING

Our lightweight fair multi-user algorithm groups $|U_g|$ users for each scheduling time Δt. The selection criteria should meet the fairness requirements among the users while maximizing the uplink throughput of the VMIMO system for them. We meet these requirements with first clustering the users to smaller groups of U_s in the sensing region of the access point. This is specially important in cellular networks. We use a simple k-mean clustering algorithm [42], for clustering the users:

$$argmin_{u \in U_s} \sum_{i=1}^{|U|/|U_s|} \sum_{u \in U_s} \|\alpha^i q^i_u - \gamma_{U_s}\| \tag{2}$$

where $|U|$, and $|U_s|$ denote the total number of users and users within the selected group respectively. These numbers are available to access points based on their connected users. q^i shows the ith clustering criteria and α^i shows it's weight in the clustering algorithm. γ_{U_s} is the current mean of the cluster. Our criteria are received signal power, location, and velocity information of the users, all available at the access point.

A. Proportional Fairness: Clusters

After we cluster the users, we assign each set of users in a cluster to a specific scheduling period using a proportional fair scheduling algorithm. We define the proportional fairness for a group of users as the following:

$$\begin{aligned} max \quad & \sum_{U_s \in U_s} log(w_{U_s} x^t_{U_s} b^t_{U_s}) \\ & \sum_{U_s \in U_s} x^t_{U_s} = 1 \\ & b^t_{U_s} = \frac{C_{U_s}}{U_s \in U_s x^t_{U_s}} \\ & x^t_{U_s} \in \{0,1\} \end{aligned} \tag{3}$$

where $x^t_{U_s}$ is the selection variable that shows the cluster U_s will be scheduled within the scheduling period t. C_{U_s} is an estimated capacity of transmission for group U_s. w_{U_s} is the weight assigned to group U_s, showing the importance of group to the scheduling algorithm. Because $x^t_{U_s}$ takes integer values, optimization (3) is an integer linear program, which is NP-hard in general. We can approximate the solution by relaxing $x^t_{U_s}$ which yields in a 2-approximation of the proportional fair scheduling that can be solved within polynomial time.

The next step is to use a lightweight physical layer grouping algorithm, and to schedule each group of VMIMO users to transmit on the same channel to the receiver antenna array.

B. Throughput Maximization: Grouping Within Clusters

We schedule the selected users within each cluster in a round robin basis in the resource blocks within the given scheduling period. We need the round robin procedure because we have flexible number of users chosen to transmit at each resource block. Therefore, if we have a higher number of users selected for transmission, we will have a few resource blocks left at the end of the scheduling period. Other reasons for using a simple round robin are our prior application of proportional fairness at cluster level, and keeping it simple for group level. We re-schedule the U_s members to fill out the unused resource blocks in a round robin scheduler.

The physical layer of uplink virtual MIMO model is represented as a $k \times k$ MIMO-OFDM system where up to $|U_g| \leq k$ selected users form a group of decentralized transmitters. The throughput of such a system is given by:

$$C = \frac{1}{N} \sum_{n \in N} \sum_{u \in U_g} log_2[1 + \frac{E_s p_u \lambda_u(\mathbf{H}(\mathbf{n}))}{|U_g| N_0}] \tag{4}$$

where μ is the number of transmit antennas after k user selection, p_u is the path loss of the sender u, and E_s is the average transmitting signal energy at one symbol time which is a constant value, being identical for all of the users. N_0 is the single side spectral density of additive white Gaussian noise (AWGN). $\lambda_u(\mathbf{H}(\mathbf{n}))$ is the link capacity of the nth subcarrier with an optimal receiver. The group of the selected users is reflected in the usage of the nth subcarrier, and N is the total number of subcarriers.

The users are each equipped with a single transmit antenna, and the access point is equipped with k receive antennas. The received vector $\mathbf{y}(n) \in \mathbb{C}^{k\times 1}$ at nth subcarrier can be written as:

$$\mathbf{y}(n) = \mathbf{H}(n)\mathbf{x}(n) + \mathbf{D}\mathbf{w}(n) \tag{5}$$

where μ denotes the transmit, and ν denotes the receive antenna. In our uplink VMIMO model, we assume that $\nu \in \{1, \cdots, k\}$ and μ is any possible combination of $\binom{|U_s|}{k}$. $\mathbf{D}$ is a diagonal matrix with diagonal elements representing the variables of the system including the effect of path loss, transmit power, transmit antenna gain, receive antenna gain, and receiver noise figure. With a perfect power control (PPC) mechanism through the access point, all the elements of the diagonal matrix $\mathbf{D}$ will be identical. $\mathbf{w}$(n) is the noise in the frequency domain. $\mathbf{H}(n) \in \mathbb{C}^{k\times k}$ and its entries, $H_{\nu,\mu}$, contain the frequency response of $h_{\nu,\mu}$:

$$H_{\nu,\mu}(n) = \sum_{l=0}^{L} h_{\nu,\mu}(l) e^{-2\pi \jmath l n/N} \tag{6}$$

where l is channel tap, and $L+1$ denotes the number of paths between the transmitter and receiver antennas.

For decoding the data, the access point uses the SDR decoder for multiuser detection. Recently, quasi-maximum-likelihood detection based on semidefinite relaxation (SDR) shows near-maximum likelihood (ML) performance with a worst case complexity of $O(k^{3.5})$ [41].

$$\begin{aligned} \min_{\mathbf{x}(n)} \quad & \|\mathbf{y}(n) - \mathbf{H}(n)\mathbf{x}(n)\|^2 \\ \text{s. t.} \quad & \mathbf{x}(n) \in \mathcal{A}_x^k. \end{aligned} \tag{7}$$

where $\mathbf{x}(n)$ belongs to the finite alphabet constellation set $\mathcal{A}_x^k$. Define $\mathbf{X} \triangleq \mathbf{x}(n)\mathbf{x}^{\mathcal{H}}(n)$, so $\text{rank}(\mathbf{X}) = 1$. It is proved that if rank constraint can be relaxed in (7) then (7) is solved by semidefinite programming (SDP) [41], but at the second step the rank-1 constraint is satisfied through the randomized rounding procedure applied to the SDP results. The main advantage of using SDR is its polynomial complexity [41]. The decision metric here is the instantaneous SNR over a single subcarrier, as given by the second term in equation (4), or:

$$\text{SNR}(n) = \frac{\text{tr}(\mathbf{H}(n)\mathbf{H}^{\mathcal{H}}(n))}{N_0 \text{tr}(\mathbf{D})} \tag{8}$$

1) Maximum Summation of Instantaneous SNR: The maximum summation of instantaneous SNR can be defined as a metric for user selection within a given cluster. The following problem $\mathcal{G}$ formulates it:

$$\mathcal{G}: \max_{k,\mu \in \binom{|U_s|}{k}} \sum_{n=1}^{N} \text{SNR}(n) \tag{9}$$

This provides a low complexity, low feedback grouping algorithm that is ideal for wireless networks with lower user dynamics, including wireless local area networks.

2) Individual Values of Instantaneous SNR: Solving problem $\mathcal{G}$ for grouping k users can effectively, and fairly, improve the capacity of the virtual MIMO system over user pairing. Being very lightweight, however, comes with a few drawbacks, including fluctuations in the SNR values after making the decision, and potentially less fairness among the users. This is particularly important for cellular networks with higher user dynamics within long scheduling periods. We use individual values of instantaneous SNR for grouping algorithm in such situations.

Algorithm 1: Lightweight Fair Grouping Algorithm

Inputs:
Set of U users;
Path loss values for U users;
N: number of subcarriers;
Δt scheduling frame;
Output: Scheduled groups of users within the given Δt scheduling time consisting of $N_{\Delta t}$ resources blocks
Begin:
Cluster the users in the U to smaller groups U_{s_i} using received signal power, location, and velocity information and k-mean clustering;
$U_s(\Delta t) = U_{s_i}$ using Proportional Fair scheduling;
for *each scheduling duration* Δt, *and group* $U_s(\Delta t)$ **do**
  Start Robin Scheduling for $U_s(\Delta t)$ as follows:
  $U_s = U_s(\Delta t)$;
  for $i = 0$ *to* $N_{\Delta t}$ **do**
    Perform grouping algorithm within the cluster as follows:
    Pick $U_g \leq k$ based on equation (10):
    $\max_{k,\mu \in \binom{U}{k}} \min_{n=1,\cdots N} SNR(n)$;
    if $U_g \geq U_s$ **then**
      $U_g = U_s$;
    Assign RB_i for group U_g;
    Mark RB_i as used;
    $U_s - = U_g$;
    if $U_s == 0$ **then**
      Perform Round Robin: $U_s = U_s(\Delta t)$;

Achieving the highest throughput over the N subcarriers translates into the largest minimum instantaneous SNR over N subcarriers. Our goal is to choose k and μ to have the highest minimum $\text{SNR}(n)$, for $n = 1, \cdots N$, where N is the number of subcarriers. We find the k^* and μ^* are the solution of the following problem:

$$\mathcal{P}: \max_{k,\mu \in \binom{|U_s|}{k}} \min_{n=1,\cdots N} \text{SNR}(n) \tag{10}$$

For example if we assume the values of $k = 2$ and $k = 3$, meaning 2×2 and 3×3 VMIMO, we can easily show that with PPC, where all received signals have the same received signal values, $D = \sigma^2\mathbf{I}$,

$$\max_{\mu \in \binom{|U_s|}{3}} \min_{n=1,\cdots N} \text{SNR}(n) > \max_{\mu \in \binom{|U_s|}{2}} \min_{n=1,\cdots N} \text{SNR}(n) \tag{11}$$

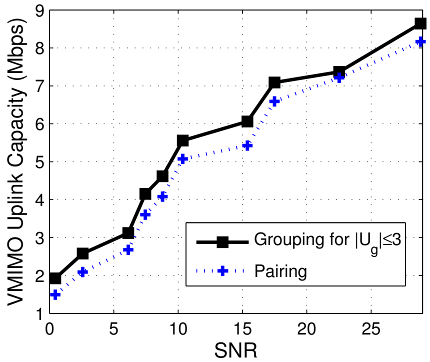

Fig. 5. Average Capacity of VMIMO systems

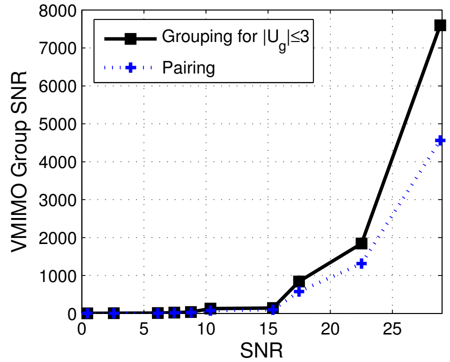

Fig. 6. Group Transmission SNR : Equation (8)

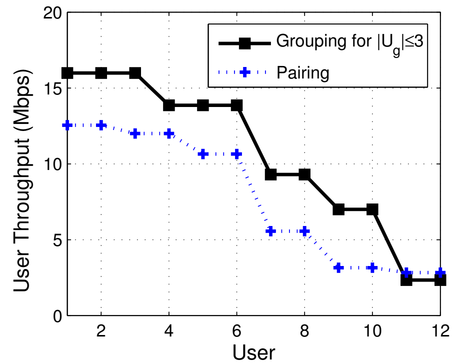

Fig. 7. Sorted User Uplink Throughputs for $|U_s| = 12$

TABLE II
SIMULATION SETTINGS - SAME FOR BOTH SCENARIOS

Parameter	Sim (1)	Sim (2)
FFT Size	16	
User Antennas	1 Tx	
AP Antennas	3 Rx	
Receiver	SDR	
Power control	without PPC	
Channel estimation	Ideal	
$\|U\|$	120	
$\|U_s\|$	≤ 12	
Access point range	500m	135m
Carrier frequency	2.0GHz	2.4GHz
User velocity	0 - 60km/hr	0

However, without PPC, different channel gains for the users may cause degradation in the higher values of k compared to lower ones. This happens when one of the users in the group has a significantly lower channel quality, or higher velocity. When we have different average received SNR values, e.g. for $k = 2$ or $k = 3$ at each time-slot, the user selection is performed by solving the problem $\mathcal{P}$, and the number of grouped users is variable by the channel conditions of the users.

Solving equation (10) improves the throughput or minimizes the bit error rate of the system significantly as it receives the new values of the SNR while performing the round robin scheduling on the previous users. Since the calculations are made at each step of the round robin for choosing the next U_g out of the given U_s, these updates do not add to the computational complexity of the algorithm.

On the other hand, this algorithm requires computing all of the combinations of number of the users in U_s to be considered as candidates for U_g . First, since the U_s is small, and this computation is done on the U_s members to determine U_g members, it will introduce a very high time complexity to the system. Second, the size of U_s and U_g are fairly adjustable and if there is a need for larger sets of U_s, an approximation on grouping different levels of SNR threshold will solve the problem with a high precision. Algorithm 1 summarizes our lightweight fair grouping algorithm, briefly presenting our clustering and grouping steps of VMIMO user grouping.

V. PERFORMANCE EVALUATION

In this section we evaluate our solution and also compare it with proportional fair pairing algorithm. The first part of our simulator consists of a detailed yet simplified model of user dynamics in wireless networks. This part simulates our users movement and its effect on the grouping. We use random movement pattern for users within the access point sensing region. Therefore, when a user is going out of the region with the current speed and direction, we change the direction of movement so that the user stays within the sensing range of the access point. It computes the physical layer SNR, path loss, and frequency selective channel quality index feedback values for every single user separately and registers them in a file. We use the time and frequency selective channel frequency index and path loss feedback values for the users from the first part of the code output and run the scheduling part with MATLAB.

Scheduling is over the given values from the first part of the simulation, so although scheduling is not real-time over the given trace of user movements and their channel values, it performs it within real-time implementation deadlines. It has two parts of user clustering and proportional fair scheduling, and then applying the VMIMO transmission grouping as proposed in our algorithm. Accordingly, our simulation consists of these two steps implemented in the MATLAB where the scheduling for a random data bits are done using the user information from the C file.

A. Simulation Settings

Virtual MIMO can be used for a wide range of wireless networks. We provide two different set of parameters to simulate both cellular networks and wireless local area networks using the virtual MIMO antenna system given the proposed scheduling. We evaluate the bandwidth and fairness for both of the simulation scenarios. Users will be fairly static in the wireless local network scenario, but they are highly dynamic within the cellular network. We Table II summarizes our simulation settings.

As we discussed earlier, our physical layer VMIMO user grouping algorithm can provide different degrees of freedom, and also based on the number of users in the cell, we can choose different sizes for U_g and U_s in the clustering algorithm

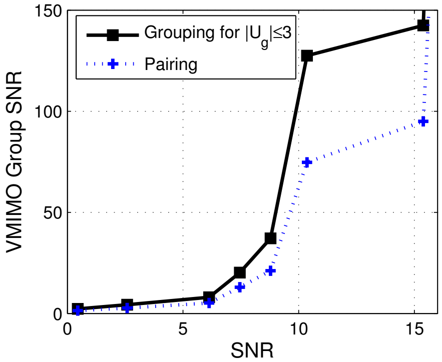

Fig. 8. SNR(n) of VMIMO Systems

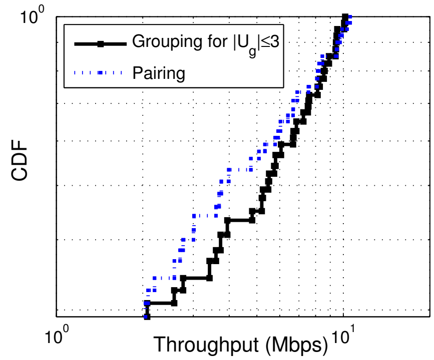

Fig. 9. Uplink Throughputs in an LTE Cell

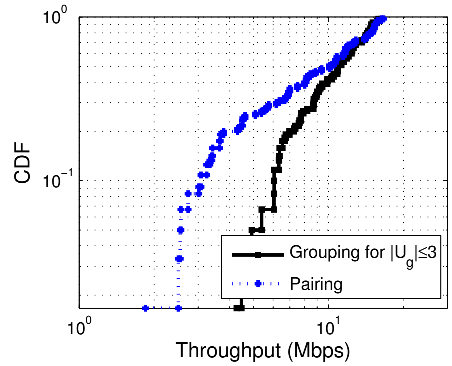

Fig. 10. Uplink Throughputs in a WLAN

and grouping algorithm to facilitate the scheduling. It is intuitive, and has been proven by the MIMO theory [18], that the higher the number of users grouped in the VMIMO transmission U_g, the higher the capacity and throughput of the transmission. Therefore, we only compare the results of our grouping with $k = 3$ and $|U_g| \leq$ which means choosing 2 or 3 users to transmit at the same time. Throughout the simulations we will monitor the throughput and fairness of this scenario and compare it to the double proportional fair pairing algorithm.

B. Simulation Results

We first compare the results of the physical layer grouping module only. Figures 6 and 5 illustrate the SNR(n) and capacity over the VMIMO channels our grouping algorithm for $U_s = 12$ and $U_g \leq 3$, and compare it to double proportional fair pairing [3]. Our method provides degree of freedom, but we focus on $U_g \leq 3$ as selecting the larger number of user makes the system more complex for real-time applications. The results are averaged over 10 different simulations with different combination of randomly placed users. Figure 8 also provides a more detailed look at the SNR(n) values for lower values of SNR.

We observe that our flexible grouping algorithm at the physical layer, which gathers the users three-user or two-user groups, provides a higher VMIMO capacity, throughput, and higher shared signal strength than the pairing algorithm. Another observation is the nodes with higher instantaneous SNR values benefit more throughput increase compared to the pairing algorithm. However, the users with very low instantaneous SNR values may experience an slight drop in throughput compared to the pairing algorithm. This means that the algorithm favours the users with higher instantaneous SNR values. This is because in the trade-off between fairness and throughput, our physical layer flexible grouping algorithm is more aggressive towards getting higher throughput for the VMIMO system. This is on the physical layer grouping algorithm only, and as we will see in the next simulations, can be solved in the proportional fair cluster scheduling.

We observe that the throughput of the users have been increased on average. This increase has been mostly on the low SINR users. On the other hand, we know that our grouping algorithm favours the users with higher instantaneous SNR values. Therefore, this is the result of the proportional fairness in the cluster level.

Figures 9 and 10 also illustrate the throughput of users in a cellular settings and a wireless local network setting as done in simulation settings (1) and (2), respectively. We can see that our grouping algorithm fairly treats the users while increasing the bandwidth. We can argue that this is because of applying the proportional fairness at the cluster level, in contrast to finding each user using proportional fairness for a pairing as it is done in the pairing algorithm. This way, all of the poor signal users get the same chance to transmit. Also, when scheduled within the same cluster, the round robin scheduling within a cluster may bring chances of more scheduled resource blocks for a user of poor signal reception.

VI. Conclusion

In this paper, we examined the implementation of Virtual MIMO antenna systems with varying scales of users. We expanded the traditional pairing and scheduling that have been largely based on two users towards larger group of users. We developed a light-weight fair scheduling algorithm to organize the users to achieve VMIMO functionalities. With minimum overhead, our solutions ensures that the higher the number of users in each group, the higher the efficiency of the transmission, and the higher the throughput of the uplink VMIMO system is.

We evaluated the performance of proposed solution through extensive simulations. The results suggest that it achieves up to 30% increase in throughput and, with lower delay owing to grouping a higher number of users together, while keeping the fairness criteria. This enables checking the higher degrees of freedom for more transmission capacity. There are a number of possible future avenues toward improving our design including energy aware scheduling, and reducing the computation even further by feedback from the clustering algorithm. In particular, we are currently working on further improvement on the approximation algorithm for scheduling to exclude a number of decisions between degrees of freedom based on the feedback from clusters.

Moreover, it is worth noting that the proposed algorithm, although initially for for multiple users with a single antenna, works for higher number of antennas on each user. This is achieved by assuming different streams being sent on each antenna of a specific user. In that case assuming each of the multiple antennas on a user device can be assumed as a single user with single antenna to use the same algorithm for grouping and uplink scheduling.

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