 Opportunistic Multiuser Beamforming for Wireless Networks

Waqar Ahmad Malik¹, Sardar Ali²
¹National University of Computer & Emerging Sciences Peshawar, Pakistan
²CECOS University of IT & Emerging Sciences Peshawar, Pakistan
Email: waqar.malik@nu.edu.pk, sardar33@gmail.com

Abstract—In this paper a successful extension of previously proposed scheme known as Opportunistic Beamforming (OB) is discussed. The previous proposed scheme of OB has an obvious problem concerning fairness amongst the users. To overcome this problem we propose a new Opportunistic algorithm for multiuser environment. The proposed scheme can be interpreted as Opportunistic Multiuser Beamforming (OMB), i.e. to access multiusers simultaneously. Secondly in this paper a Transmission Scheduler is proposed which fairly selects multiusers simultaneously by comparing the signal-to-interference-plus-noise ratio (SINR) of users, which is fed back to the transmitter by every user. This scheme has the capability of communicating fairly with simultaneous multiuser exploiting multiuser diversity while not requiring a tight feedback at the transmitter. The simulation results are computed by using MATLAB. The result shows that by increasing the number of users in a cell and keeping the number of transmitting antennas constant at the base station, the average sum rate for the system is improved.

Keywords: Multi-user diversity, Opportunistic Beamforming (OB), Opportunistic Multi-user Beamforming (OMB), Multiple input single output (MISO), Transmission Scheduler, Wireless channel.

I. INTRODUCTION

In past the wireless communication channel was considered to be a foe due the facts that the average performance was dominated by the deep fade of channel, the rate reduction due to uncertainty of channel state and finally the average capacity was inferior to non-fading channels. The traditional view of fading is a source of unreliability to be compensated by various diversity and power control techniques [1].

Presently, fading is considered as the source of randomization to get significant capacity boost, even beyond the non-faded channel such as opportunistic communication. Dynamic rate and power allocation can be performed over the dimensions of time, frequency, antennas and users in a wireless system. In a fading environment, sometimes the channel may be strong somewhere and opportunistic schemes can be chosen to transmit in only those channel states. For fast fading, the ability to track the channel at the transmitter can increase point-to-point capacity by opportunistic communication (a) transmitting at high rates when the channel is good (b) at low rates or not at all when the channel is poor. The performance of opportunistic communication is attained by the fluctuations of the fading channel. In contrast, the multi-user setting put forward a chance of “which user(s) to transmit” instead of only the “when to transmit” [1]. This allows the system to benefit from a multi-user diversity effect i.e. probabilistically looking for having its channel state at its peak. Thus allowing only one user to transmit at the time, multi-user capacity can be achieved.

Multi-user diversity was proposed [2] for the uplink, where the best strategy is to always transmit to the user with the best channel and similarly for downlink practically in the context of IS-CDMA standard [3, 4]. A method for downlink of opportunistic beamforming via phase randomization is presented and investigated the problem of scheduling and rate feedback in the case of MIMO channels [2]. The same performance results for opportunistic beamforming and co-phasing were obtained by employing large number of transmit and one receive antenna and concluded that opportunistic MIMO can achieve high spectral efficiencies than opportunistic beamforming [5].

In this paper, it is aimed to observe the reliability of opportunistic beamforming when exposed to multi-user environment. The Opportunistic Multi-user Beamforming (OMB) caters simultaneously multi-users at a time by transmitting multi beams from the base station. The Signal-to-interference-plus-noise ratio (SINR) is fed back to the base station by all the users which provide the transmitter to beamform those users who come under the beamforming configuration. The instantaneous SINR near to its peak is done through multi-user transmission scheduler.

Using this scheme, the receivers have to tracks say ‘M’ separate beams and feed back SNR of each on each of the beams. The receivers could only estimate and feed back the best SNR and the beam which yield this SNR without much degradation in performance [6]. Thus, with almost the same amount of feedback as the single beam (serving single user) scheme, the multi-user beam-forming scheme yields a total throughput in a system with a large number of users equal to that of the information theoretic limit with full feedback at high SNR.
II. MULTIUSER DIVERSITY

MIMO communication links offer significant advantages in terms of rate and reliability. In cellular systems, however, gains may be limited due to fading and interference. An inherent form of diversity is present in a wireless network with multiple users. Due to fading, a user’s channel undergoes periods of severe decay but also experiences channel gain at any instant. In case of many users, different users experience peaks in the channel quality at different times. The multi-user diversity presented a power scheme for maximizing the information theoretical capacity of the uplink of a single cell with time varying channels [2].

Multi-user diversity helps us in two different ways. Firstly, one can pick the user(s) that is/are in favorable channel condition and results in increasing the network throughput for the forward link. Secondly, one can exploit the multi-user diversity to decrease the feedback requirements in the reverse link [5]. The transmitter pre-codes in a pseudorandom fashion and that user is picked whose ratio of instantaneous data rate to its own average data rate is the largest [6].

III. BEAMFORMING

Beamforming is a signal processing technique used with arrays of transmitters or receivers that controls the directionality of a radiation pattern. Receiving a signal, beamforming can increase the gain in the direction of desired signals and decrease the gain in the direction of interference and noise. While transmitting a signal, beamforming can increase the gain in the desired direction to be sent. It is obtained by creating beams and nulls in the radiation pattern.

The method involves diversity combining and beamforming using antenna array instead of cell splitting. The use of cell splitting increases capacity by increasing the number of base stations and is cost effective. On the other hand, using antenna arrays, beam-forming technique improves reliability and capacity of the system in two different ways. a) Diversity combining or Beamforming techniques can combine the signals from multiple antennas in such a way that mitigates multi-path fading effects. b) Beamforming using antenna arrays can provide capacity improvement through reducing interference.

IV. OPPORTUNISTIC BEAMFORMING

The opportunistic beamforming is a multiple input single output system that provides higher diversity on the downlink in slow fading systems [6]. The diversity gain results in higher data rates for the users. This scheme does not require any extra hardware changes and can be easily implemented in the cellular systems of common usage. It is the interesting feature of the opportunistic beamforming.

To achieve higher data rate, reliable and a system with high spectral efficiency the exploitation of multiuser diversity has received considerable attention in recent times. The concept of opportunistic communication is a practical consideration of a system to benefit from use of multiuser diversity.

V. SYSTEM MODEL

Suppose the transmitter or a base station has employed M antennas and entire network has N receivers or mobile users having 1 antenna each as shown in Fig.1.

For the purpose of correspondence the system is referred as (M, 1) system where a and b are considered to be the Rayleigh faded channels.

Suppose $H_k$ denotes the Mx1 channel matrix for the $k$-th user, the received signal strength is

$$Y_k = \sqrt{S_k} H_k X_k + Z_k$$

Where $X_k$ is (Mx1) transmitted vector carrying information to user. $E\{X_k X_k^T\} \leq P$, P is transmit power from the base station that is assumed to be fixed, $E\{\cdot\}$ denotes expectation, and $X_k^T$ is conjugate transpose of $X_k$. Assume the elements of $H_k$ and $Z_k$ are $CN(0,1)$ which are mutually independent. And $CN(\mu,\sigma^2)$ denotes a circularly symmetric complex Gaussian random variable with mean $\mu$ and variance $\sigma^2$. All users are assumed to have independent channels.

In order to increase the probability of users in deep fade, extra fluctuations are introduced at transmit antennas. These fluctuations are introduced by randomly generated complex weights at transmitter that are $\phi_1, \phi_2, ..., \phi_M$ as depicted in the figure. The randomly generated weights are normally distributed with mean $\mu=0$ and variance $\sigma^2=1$.
VI. CAPACITY GAIN THROUGH OMB

The above-mentioned assumed model assumed here can be interpreted as Multiuser MISO scheme different from the system for single user of cellular network with the receiver being equipped with one receiving antenna. The Opportunistic multi-user beamforming (OMB) provide access to the network opportunity to all the users simultaneously. The multi-user system plays an important role to achieve the sum capacity gain for a system. This capacity gain is directly related to the number of users in a wireless network served simultaneously.

According to Shannon the maximum achievable rate on a communication channel is the maximum capacity for a channel if occupied by single a user.

\[ \text{Capacity} = \log_2(1 + \text{SNR}) \]

The sum capacity of the system can be increased by implementation of multiuser diversity i.e. if more than one user is intended to provide service then the Sum Capacity is incremented with proper proportion. Evidently, the limit of maximum achievable capacity cannot be upgraded. Indeed, the factor of accessing multi-users gives boost to the system capacity concurrently.

For example a wireless network of \('N'\) users and the scheduler employed at the transmitter opportunistically selects two users at a time to communicate with then the sum capacity of a system communicating with user1 and user2 is doubled:

\[ \text{Sum Capacity} = \log_2(1 + \text{SNR}(1))(1 + \text{SNR}(2)) \]

Where SNR1 and SNR2 are respective signal to noise ratios of user1 and user2, feedback to the transmitter. Hence capacity can be increased \('N'\) times by opportunistically selecting \('N'\) users at a time as in the equation

\[ \text{Sum Capacity} = \log_2(1 + \text{SNR}(1))(1 + \text{SNR}(2)) ... (1 + \text{SNR}(K)) \]

VII. TRANSMISSION SCHEDULING

Multiple antennas are assumed at base station and the transmission scheduling is based on exploitation of multiuser diversity. The artificially introduced fluctuations in a pseudorandom fashion enhances the channel instantaneous SNR over its average value. The overall time varying channel signal-to-interference-plus-noise ratio (SINR) is tracked by each user and is fed back to the base station to form a basis of scheduling. The channel tracking is done through a single pilot signal which is repeated at the different transmit antennas.

Transmission is scheduled to users when their respective channels are near their own peaks. It should be noted that it is not necessary for the users to have the same peak values in order to allow transmission. However, the users chosen by the scheduler would have their maximum instantaneous values for their respective channels. In fact, transmission is made to the users having their channels near to its best values.

The requirement for a scheduler to extract such multi-user diversity benefits is that each receiver tracks its own SINR through a downlink pilot signal, and feed back its instantaneous channel quality to the base station.

Suppose a multi-user MISO system having total of 10 users (say) and each user being equipped with single antenna. If 3 antennas are employed at transmitting end and all the antennas being varied by randomly generated complex weights. The randomly generated weights are normally distributed with mean \(\mu=0\) variance \(\sigma^2=1\). Thus the random complex weight matrix is

\[
\begin{bmatrix}
  -0.1130 - 0.0659j & -0.5102 + 0.3739j & 0.0568 + 0.1735j \\
  -0.4453 - 0.8031j & -1.777 - 0.6110j & -0.0288 + 0.1859j \\
  -0.4453 - 0.8031j & -1.777 - 0.6110j & 0.0568 + 0.1735j
\end{bmatrix}
\]

Weights for Antenna1 Weights for Antenna2 Weights for Antenna3

The matrix shows three different antenna weight vectors for all the three antennas. This information is sent over wireless channel that produce more fluctuations. Assuming the channel to be Rayleigh faded then the resultant estimated channel at the receiver end produces a matrix of the form

\[
\begin{bmatrix}
  1.5208 + 0.0189j & -0.0072 - 1.1812j & -0.1341 + 0.4448j \\
  -1.0477 - 1.4474j & -1.6047 + 1.2044j & -0.4660 + 0.1731j \\
  -0.6806 + 1.2348j & -0.4935 - 0.1412j & -0.0313 + 0.1893j \\
  -0.7196 + 4.7540j & 3.2431 - 2.1578j & -0.3628 - 0.3431j \\
  0.8536 - 0.9844j & -0.0273 - 1.2061j & -0.0388 - 0.0232j \\
  -0.6727 - 0.2638j & -0.4891 - 0.4814j & 0.0248 - 0.0855j \\
  0.5964 + 0.9054j & 0.2756 - 0.1568j & 0.0777 + 0.1396j \\
  -0.2807 - 0.5021j & -0.2585 - 0.3732j & -0.1019 + 0.1375j \\
  0.5385 - 0.3396j & 0.2513 - 0.7751j & 0.1164 + 0.0284j \\
  -0.2798 - 0.3809j & -0.1873 - 0.4552j & -0.1427 + 0.2841j
\end{bmatrix}
\]

The above (MxS) order matrix can be referred as the resultant channel matrix where:

\(M = 10\) (i.e. Number of Users)
And
\(S = 3\) (i.e. Number of Antennas)

The values in the first column are due to the Antenna1, second column is due to Antenna2 and vice versa. All the 10 rows are the resultant channel responses received by each user. Now all users have three different complex numbers, one being the required signal and the other two as interferences. Each user estimates its Signal-to-interference-plus-noise ratio (SINR) and re-transmit it to the transmitter.
When all the users have retransmitted their respective SINR then the transmitter has the following available information.

\[
\begin{bmatrix}
1.8738 & 0.8190 & 1.4885 \\
1.0402 & 1.5081 & 4.1032 \\
7.5807 & 0.1694 & 0.2820 \\
1.7734 & 0.9061 & 15.1846 \\
1.1686 & 0.8593 & 1.4565 \\
1.1166 & 0.9099 & 0.4861 \\
11.7186 & 0.1110 & 0.1222 \\
1.6349 & 0.6521 & 0.2946 \\
0.6248 & 1.6526 & 0.6994 \\
1.0231 & 1.1857 & 0.6948
\end{bmatrix}
\]

SINR of User1  SINR of User2  SINR of User3

Now the transmitter chooses the best users having its channel at peak. Therefore three users selected by the transmission scheduler are now:

User No = 7 with SINR = 11.7186
User No = 9 with SINR = 1.6526
User No = 4 with SINR = 15.1846

This way the transmission scheduler picks the users and hence the number of users can be simultaneously selected is equal to the number of multiple transmitting antennas employed in the system.

VIII. RESULTS AND SIMULATION

The simulation results show the Average sum rate of 1000 runs of the proposed algorithm against SNR. In all the simulations the maximum users taken in to consideration are 1000.

In figure 3, 4 and 5 it is observed that by increasing the number of users from 100 to 1000 and keeping the Number of transmit antennas constant, the average sum rate for the system increases.

Furthermore, it is observed that for 200 users and No of antennas = 2, the average sum rate approaches its maximum value of 9 bits/s/Hz. While by increasing the No of transmit antennas to 3 the average sum rate reduces to a value of 7.8 bits/s/Hz for same No of users. And finally, for No of transmit antennas = 4, average sum rate reduces to its minimum value of 7.2 bits/s/Hz. It shows that by increasing the number of transmit antennas the average sum rate is reduced. By lesser number of transmit antennas the system is more effective, which shows the merit of the proposed algorithm.
TABLE I: AVERAGE SUM RATE FOR DIFFERENT NO OF USERS UTILIZING TWO TRANSMIT ANTENNAS

<table>
<thead>
<tr>
<th>Number of Users</th>
<th>Average Sum Rate (b/Hz/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>9</td>
</tr>
<tr>
<td>200</td>
<td>9.8</td>
</tr>
<tr>
<td>500</td>
<td>10.7</td>
</tr>
<tr>
<td>1000</td>
<td>11.3</td>
</tr>
</tbody>
</table>

TABLE II: AVERAGE SUM RATE VS NO OF TRANSMIT ANTENNA FOR 100 NO OF USERS

<table>
<thead>
<tr>
<th>Number of transmit antennas</th>
<th>Average Sum Rate (b/Hz/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>7.7</td>
</tr>
<tr>
<td>4</td>
<td>7.2</td>
</tr>
</tbody>
</table>

XI. CONCLUSION

In this paper we elaborate that by using Opportunistic Multi-user Beamforming (OMB), the performance of a wireless network is improved in two ways: firstly, using lesser number of transmit antennas at the base station, as the highest average sum rate as shown in table II was achieved utilizing only two 2 transmit antennas. Secondly, simultaneous users can access the network by using the OMB algorithm.

However, the number of users scheduled be communicated simultaneously in the same time slot is a tradeoff between overall performance of system and the number of antennas employed.

In future such algorithm can be proposed to further improve the system by catering simultaneous users by deploying lesser number of transmit antennas.

REFERENCES


