Capacity Maximization via Selection of Uniformly Distributed User for Uplink MIMO Communication over $\eta$-$\mu$ Fading Channel

Theerasak Sangyam†  Chalie Charoenlarpnopparut†  Prapun Suksompong†  Kamol Kaemarungsi‡  Kazuhiko Fukawa∗

†School of Information, Computer, and Communication Technology, SIIT, TU, Thailand  
‡Embedded System Laboratory, NECTEC, NSTDA, Thailand  
∗Signal Processing Laboratory MCRG, Tokyo Tech, Japan

th.sangyam@gmail.com,  
{chalie, prapun}@siit.tu.ac.th,  
kamol.kaemarungsi@nectec.or.th,  
fukawa@radio.ss.titech.ac.jp

Abstract

In this work, our objective is to analyze the performance, by deriving the average channel capacity, of the uplink MIMO communication system when $\eta$-$\mu$ fading channel is applied comparing to Rayleigh fading channel. In addition, the uniformly distributed user locations and user selection with capacity maximization are also used in the simulation. We are also investigating on 4 main schemes which are single-user (SU), multi-user (MU), single-input single-output (SISO) and multiple-input multiple-output (MIMO). The results shows that the performance of uplink communication system over $\eta$-$\mu$ fading channel is better than Rayleigh fading channel in SU scheme but worse in MU scheme. However, the increasing in the number of antennas and the number of user yield the better performance.

Keywords: Capacity maximization, Uplink communication, Uniformly distributed user, $\eta$-$\mu$ distribution

1 Introduction

Social network, e-commerce and video streaming have become a part of our daily life, which bring us to an emerging technology of wireless communication. While the number of users is increasing rapidly every day, the amount of data to be transmitted is also increased, especially for video streaming or video conference. Wireless communication has been used to substitute wired communication since it has lower infrastructure cost and takes less space. Moreover it is very convenient due to its mobility. The requirement of wireless communication system design is to achieve the highest performance i.e., reliability, capacity and range. For single-input single-output (SISO) system, there is strong tradeoff between reliability, capacity and range. On the other hand, multiple-input multiple-output (MIMO) system can improve these three parameters simultaneously. In addition, MIMO system increases the spectral efficiency and reduces the effects of the fading due to the increased diversity [1].

Single-user (SU) MIMO scheme has been studied in many wireless communication standards as well as IEEE 802.11n standard. In the past decade, multi-user (MU) has been considered as an interesting transmission technique for MIMO wireless communication. Numerical results from [2] show that MU MIMO scheme yields lower collision probability and shorter delay performance than SU MIMO scheme. Furthermore, in other cases of high SNR values and a small number of contending stations, MU MIMO also yields better throughput performance. In IEEE 802.11ac standard, only downlink MU MIMO precoding scheme has been implemented. Uplink MU MIMO precoding scheme is still not included. However, its application is necessary as shown in the usage model of IEEE 802.11ac standard from 802.11ac Taskgroup (TGac) which includes wireless display, distribution of HDTV, rapid upload/download, backhaul, outdoor campus/auditorium and manufacturing floor [3].

Most of the research topics on wireless communication, especially for wireless local area network (WLAN) are mainly focused on downlink transmission scheme as in [4–8]. This re-
search poses a challenge to authors when trying to find any related works and practice. Currently, there are only a few number of collective works dealing with uplink transmission scheme. As it is necessary to implement the uplink MU MIMO precoding scheme, user selection for uplink MU MIMO system and uniformly distribution of users in a square room is studied in this work. By comparing to the previous work [9] which investigated only on Rayleigh fading channel, we extend our work to $\eta$-$\mu$ fading channel.

The remaining of this paper is organized as follows. System model and fading model are provided in section 2 and 3 respectively. Simulation result shows in section 4. Finally, we summarizes the paper into section 5.

2 System Model

An efficient uplink multiuser MIMO protocol in IEEE 802.11 WLANs was studied in [10] and two main problems were considered. They are synchronized transmission among the stations and spatial compatibility between the transmitting stations. We choose to base our solution on the scheme discussed above, whose one of the main objectives is to increase the network throughput.

![Uplink MU MIMO system](image)

Figure 1. Uplink MU MIMO system.

Figure 1 shows the uplink MU MIMO system from [11] with a based station (BS) with $M$ receive antennas and $K$ mobile stations (MS) or users each with $N$ transmit antennas. The users are allowed to transmit data simultaneously. $x_i$ is the input data stream vector of length $N$ from user $i$; $F_i$ is $N \times N$ linear precoder; $H_i$ is $M \times N$ uplink MU MIMO channel matrix between user $i$ and BS; $n$ is zero mean white complex Gaussian noise vector. Then, the received signal vector $r$ of length $M$ at the BS can be written as

$$r = \sum_{i=1}^{K} H_i F_i x_i + n$$  

(1)

In [10], the BS calculates the channel state information (CSI) upon the receiving pilot signals which are sent from all users that request to transmit data and then selects the group of users that give the maximum channel capacity from all possible groupings. The capacity is calculated by

$$C_g = \log_2 \det (I_{KN} + H_g H_g^H)$$  

(2)

where $(\cdot)^H$ denotes for Hermitian transposition; $I_{KN}$ is $KN \times KN$ identity matrix; and $H_g$ is $KN \times M$ channel matrix of user group $g$ which can be found by

$$H_g = \left[ \frac{P_1}{N \sigma_i^2} h_1^T \ldots \frac{P_i}{N \sigma_i^2} h_i^T \ldots \frac{P_K}{N \sigma_K^2} h_K^T \right]^T$$  

(3)

where $h_i^T$ is $M \times N$ channel coefficients between user $i$ and BS; $\sigma_i^2$ is the noise power and $P_i$ is the transmission power; and $(\cdot)^T$ denotes the transpose operation.

Similar to [10], a group of users which gives the highest channel capacity among all possible $C(R, K)$ groups is allowed to transmit the data. Here, $R$ is the number of all users requested to transmit data. In our simulation, a room size of $5 \times 5$ square meters is used while all MSs are located on the same level, 1 meter below the ceiling while a BS is installed at the center of the room. The rest of this section explains how to calculate capacity.

Reference SNR is assumed in the range from 0 dB to 20 dB with the incremental step of 1 dB. This reference SNR is located at 1 meter below the BS i.e., it is on the same level as the MSs. From this value, reference power can be obtained when noise power $\sigma_i^2$ is assumed to be 1. Then random locations of each user are uniformly generated in the square room. So the actual transmission power of each user can be calculated using simplified path loss model (4) from [12]:

$$P = P_{ref} \beta \left[ \frac{d_0}{d} \right]^\gamma$$  

(4)
where \( P \) and \( P_{ref} \) are transmission and reference power respectively. \( \gamma \) is the path loss exponent and \( \beta \) is the unitless constant. \( d_0 \) and \( d \) are a reference distance for the antenna farfield and transmission distances accordingly.

Channel \( H_i^T \) is also generated randomly depending on the fading model for each user and its size is depending on the number of transmit and receive antennas. In this paper, the number of transmit antennas are the same for every user. With assumption of noise power is equal to 1, the channel matrix \( H \) can be calculated from (3). Finally, the channel capacity \( C_0 \) can be calculated by substitute \( H \) into (2). Then the channel capacity is calculated repeatedly 100,000 times. Then those values are averaged for each reference SNRs.

3 Fading Model

3.1 Rayleigh Distribution

This fading is most commonly and widely used as it is the statistical model for the effect of a propagation environment for non-line-of-sight (NLOS) wireless communication. The probability density function (pdf) of Rayleigh distribution, \( f_R(r) \), is

\[
f_R(r) = \frac{2r}{\sigma^2} e^{-r^2/\sigma^2}, \quad r \geq 0
\]

where \( \sigma^2 \) is the variance. The Rayleigh distribution has an independent Uniformly distributed phase.

3.2 \( \eta-\mu \) Distribution

The \( \eta-\mu \) distribution is a general fading distribution for NLOS applications. It is more flexible because it uses two parameters to adjust behavior of the distribution.

It appears in 2 different formats. Format 1, the in-phase and quadrature components of the fading signal within each cluster are assumed to be independent from each other and to have different powers. \( 0 < \eta < \infty \) is the scattered-wave power ratio between the in-phase and quadrature components of each cluster of multipath. Format 2, the in-phase and quadrature components of the fading signal within each cluster are assumed to have identical powers and to be correlated with each other. \( -1 < \eta < 1 \) is the correlation coefficient between the scattered-wave in-phase and quadrature components of each cluster of multipath. In this work and the rest of this paper, we consider only on Format 1.

For a fading signal with envelope \( R \) and normalized envelope \( \hat{R} = R/\bar{r} \), \( \bar{r} = \sqrt{E(R^2)} \) being the rms value of \( R \), the \( \eta-\mu \) pdf, \( f_P(\rho) \), can be found in [13] as

\[
f_P(\rho) = \frac{4\sqrt{\pi} \mu^{1+\frac{1}{2}} h^\mu}{\Gamma(\mu)H^{\mu-\frac{1}{2}}} \rho^2 e^{-2\mu\rho^2} I_{\mu-\frac{1}{2}}(2\mu H \rho^2)
\]

and the phase pdf, \( f_\Theta(\theta) \), can be found in [14] as

\[
f_\Theta(\theta) = \frac{(h^2 - H^2)\mu \Gamma(2\mu)\sin(2\theta)^{2\mu-1}}{2^{2\mu}\Gamma^2(\mu)(h + H\cos(2\theta))^{2\mu}}
\]

where \( h = 2^{\eta+1} + \eta^2 \) and \( H = \frac{\eta+1}{4} \) in Format 1; \( \Gamma(\cdot) \) is the Gamma function; \( I_\nu(\cdot) \) is the modified Bessel function of the first kind and order \( \nu \); and \( \mu > 0 \) is given by

\[
\mu = \frac{E^2(R^2)}{2V(R^2)} \left[ 1 + \left( \frac{H}{h} \right)^2 \right]
\]

4 Simulation Result

Comparison of the performance over Rayleigh and \( \eta-\mu \) fading channel with \( \eta = 1 \) and \( \mu = 0.5 \) which is equivalent to Rayleigh fading distribution and \( \eta = 2 \) and \( \mu = 1 \) which used in [15] are show as Figures 2 to 5.

Figures 2 and 3 show the simulation results of uplink SU (1 user) communication scheme with better result when \( \eta = 2 \) and \( \mu = 1 \) while Figures 4 and 5 are the simulation results of uplink MU (4 users) communication scheme with worse result when \( \eta = 2 \) and \( \mu = 1 \) comparing to Rayleigh fading.

On the other hand, Figures 3 and 5 show the simulation results of uplink MIMO (2 transmit and 2 receive antennas) communication scheme which yield better results than the simulation results of uplink SISO (1 transmit and 1 receive antenna) communication scheme as shown in Figures 2 and 4.

5 Conclusion

From the previous section, we may conclude that the performance of uplink communication over \( \eta-\mu \) fading channel is achieved in SU scheme
while MU scheme yields a little worse results comparing to Rayleigh fading channel. Nevertheless, the increasing in the number of antennas and the increasing in the number of user give the better capacity as shown in [9].

6 Future Work

In this work, we only used some specific value of $\eta$ and $\mu$. Thus, in the future work, we may vary these values to analyze the behavior or to find the best appropriate value according to our model.

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References


