Field Experiment on User Collaboration for MIMO Systems

Ou ZHAO†, Xiaoliang SHI†, and Hidekazu MURATA†

† Graduate School of Informatics, Kyoto University  Yoshida-honmachi, Sakyo-ku, Kyoto 606-8501, Japan  E-mail: †contact-h28j@hanase.kuee.kyoto-u.ac.jp

Abstract  Collaborative communication working on user side have been identified as one of key technologies for next-generation networks and so that lead to dramatic improvements in both spectral and energy efficiencies. In this technology, multiple collaborative users (CUs) can be considered as a single user equipped with multiple antennas and maximize the performances of multiple-input multiple-output (MIMO) systems, only noting an assumption that the links between all of CUs are perfect. In fact, however, the unsuccessful data sharing between CUs due to, for instance, the presence of interference, may lead to packet errors, and finally decreases the number of collaborated users and further degrades the performance of MIMO systems. In the present study, in order to demonstrate and evaluate the user collaboration, we conduct field experiments to observe the states of inter-user links in MIMO systems with collaborative communications and considering the effect of interference. Experiment results indicate that the links between the CUs are not always prefect, and are significantly affected by the present interference. The results also show some state correlation on the inter-user links.

Key words  Field experiment, Collaborative communications, User collaboration, Inter-user links, MIMO

1. Introduction

The significant increasing of number of users in communications rapidly raised the demand for wireless services. In recent years, various techniques have been proposed to cope with the significantly high data rates expected in the horizon of 2020 and beyond, so that a new generation of mobile networks is envisioned, i.e., the so-called fifth-generation (5G) mobile networks [1]. Unlike previous generations of mobile networks such as long-term evolution (LTE) and LTE-Advanced standards, which relied on evolutionary technologies, 5G will support ultra-dense deployments while accommodating new emerging radio access technologies such as massive multiple-input multiple-output (MIMO), expanded spectrum, and so on [2].

Collaborative communication working on user side have been also identified as one of key potential technologies for next-generation networks that can take advantages of MIMO and so that leads to dramatic improvements in both spectral and energy efficiencies. In this technology, multiple collaborative users (CUs) can be considered as a single user (SU) equipped with multiple antennas and so that maximize the performances of MIMO systems, only noting an assumption that the links between all of CUs are perfect. In fact, however, the unsuccessful data sharing between CUs due to, for instance, the presence of interference may lead to packet errors, and finally decreases the number of collaborated users and further degrades the performances of MIMO systems such as spatial multiplex gain and diversity.

Although concentrating on the status of links between CUs is considered very necessary to evaluate the performance of collaborative communications used in MIMO systems, to the best of the authors’ knowledge, since the multiple CUs are usually considered as SU with prefect links for its simpleness, such as [3], there have been few previous studies and experiments on this topic. Therefore, on the basis of this fact, we have attempted to bridge this gap by conducting some field experiments on the inter-user links for collaborative communications in MIMO systems.

In the present study, we first introduce the collaborative communications used in MIMO systems, and then conduct the field experiments for collaborative communications to evaluate the performance of the considered system. Through the experiments, the performances of collaborative communications, such as, the number of collaborated users and its cumulative distribution function (CDF), can be observed. Furthermore, the state correlation on transmit side, so-called cross-correlation (CC), and the state correlation on receiver side, so-called auto-correlation (AC), are also shown and analyzed in the present study.

The remainder of the present study is organized as follows. In Sect. 2, we briefly introduce the collaborative communication in MIMO systems and define the system model we considered. In Sect. 3, we describe our field experiments to observe the states of inter-user links for collaborative communications. In Sect. 4, we show some results and give some nec-
2. System Model

In this study, the system model illustrated in Fig. 1 is considered. A base station (BS) with $N_t$ transmit antennas serves $K$ active users each equipped with a single antenna. All of the active users are occupying the same frequency and time resources, and the data bits in each transmitter are modulated using quadrature amplitude modulation and simply transmitted without channel coding.

Let $y_k (k \in \{1, \ldots, K\})$ be the received signal for each user $k$. The received signals of the $K$ collaborative users can be denoted as

$$y = Hx + n,$$

where $H \in \mathbb{C}^{K \times N_t}$ is a channel matrix, $x$ is an $N_t \times 1$ transmitted symbols vector, and $n$ is an $K \times 1$ noise vector [4]. After receive the transmitted signals, each user shares their received signals to the other users.

We consider a user collaboration scheme in which each CU receives signal waveforms transmitted from the BS, and broadcasts it to help other CUs decode the intended signals, using a dedicated central frequency $f$ with band $B$, separate from the access link frequency band, for instance, using 12.8 GHz or more higher frequency band for the 5G cellular network [2], to relay information. To simplify the collaboration system, we assume that each CU broadcasts the sharing data packets with user datagram protocol (UDP) one time during each frame without considering that if other CUs successfully received the sharing data packets or not.

In user collaboration, during each frame duration $T_{frame}$, $K$ CUs call transmit function to broadcast their sharing data packet in term in a time out duration $T_{out}$, and each CU synchronously receives these sharing data packets in the same time out duration under the effects of interference which is transmitted from the existing interference sources (ISs), where the sharing data packets are generated from quantized waveforms. After receiving these shared data packets, each CU processes these data and decode the intended signals transmitted from BS. An illustration of user collaboration on CU $q \in \{1, \ldots, K\}$ is depicted in Fig. 2.

3. Field experiment

The experiment parameters can be seen in Table 1. In this field experiment, 4 quadrature phase shift keying (QPSK) signals with a symbol rate of 312.5 ksymbol/s are generated using signal generators. Afterward, the signals are sent to $N_t = 4$ transmit antennas in the BS. The transmit antennas are installed in a perpendicular position. The height of the BS is 25.5 m, while the antenna gain is 5 dBi. In addition, a square root Nyquist filter with roll-off factor 0.4 is employed.

On the receiver side, $K = 6$ users are located in one car and collaborate with each other using central frequency $f = 2.4$ GHz with band $B = 20$ MHz. Universal software radio peripherals (USRP) are used as equipment to represent the users. In Fig. 3(a), each USRP uses 7 dB of antenna gain and 14 bits analog to digital converter resolution. Positions of each user terminal can be seen in Fig. 4.

Fig. 5 shows the packet used in the field experiments for the transmission between BS and CUs. First, 15 binary phase shift keying (BPSK) symbols are transmitted as the synchronization words (SW). Next, 16 BPSK symbols are used as a training sequence (TS) to obtain the channel state infor-
Fig. 4 Experimental setup of the user collaboration. The BS location is ignored since its position out of range.

Fig. 5 Packet configuration used in transmissions between BS and CUs. TS symbols and Data + CRC symbols are used in user collaboration.

Table 1 Experiment parameters.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS side</td>
<td></td>
</tr>
<tr>
<td>Number of antennas</td>
<td>$N_i = 4$</td>
</tr>
<tr>
<td>Carrier frequency</td>
<td>5.11 GHz</td>
</tr>
<tr>
<td>Symbol rate</td>
<td>312.5 ksymbol/s</td>
</tr>
<tr>
<td>Modulation</td>
<td>QPSK</td>
</tr>
<tr>
<td>Transmit filter</td>
<td>Square Root Nyquist (roll-off factor=0.4)</td>
</tr>
<tr>
<td>Antenna height</td>
<td>25.5 m</td>
</tr>
<tr>
<td>Antenna gain</td>
<td>5 dBi</td>
</tr>
<tr>
<td>ISs side</td>
<td></td>
</tr>
<tr>
<td>Interference generating</td>
<td>Iperf</td>
</tr>
<tr>
<td>IS transmission mode</td>
<td>UDP mode</td>
</tr>
<tr>
<td>Transmission rate</td>
<td>100 Mbps</td>
</tr>
<tr>
<td>Interference packet size</td>
<td>1460 B</td>
</tr>
<tr>
<td>IS transmit power</td>
<td>20 dBm (nominal)</td>
</tr>
<tr>
<td>Central frequency</td>
<td>$f = 2.412$ GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>$B = 20$ MHz</td>
</tr>
<tr>
<td>Number of ISs</td>
<td>$J = 1$</td>
</tr>
<tr>
<td>CUs side</td>
<td></td>
</tr>
<tr>
<td>Number of CUs</td>
<td>$K = 6$</td>
</tr>
<tr>
<td>Number of frames</td>
<td>$N_{\text{frame}} = 6000$</td>
</tr>
<tr>
<td>Sharing data packet size</td>
<td>1560 bits</td>
</tr>
<tr>
<td>Modulation</td>
<td>BPSK</td>
</tr>
<tr>
<td>Central frequency</td>
<td>$f = 2.412$ GHz</td>
</tr>
<tr>
<td>Bandwidth</td>
<td>$B = 20$ MHz</td>
</tr>
<tr>
<td>Duration of frame</td>
<td>$T_{\text{frame}} = 50$ ms</td>
</tr>
<tr>
<td>Duration of time out</td>
<td>$T_{\text{out}} = 20$ ms</td>
</tr>
</tbody>
</table>

4. Results

In this study, we concentrate on the probability distribution of number of collaborated users and the state correlation of inter-user links. From the view of CU $q$, the number of collaborated users on $n_{\text{frame}}^{\text{th}}$ is calculated by

$$N_{\text{CU},q,n_{\text{frame}}} = \sum_{k=1}^{K} \xi_{k,n_{\text{frame}}}^{q},$$

where $\xi$ denotes the status of the received sharing packets, i.e., denoting "1" to represent that a CU receives a packet transmitted from another CU without any error, otherwise, denoting "0" to represent an unsuccessful transmission. Hereafter, the CDF of the number of collaborated user on CU $q$, i.e., $\text{CDF}_q$, can be obtained by processing $N_{\text{CU},q,n_{\text{frame}}}$ over all of $N_{\text{frame}}$ frames. For better understanding the results obtained from experiments, in Fig. 6, we show three average CDFs of the number of collaborated users with and without the effect of interference. The average CDF, i.e., $\text{CDF}$, can be calculated by

$$\text{CDF} = \frac{1}{K} \sum_{q=1}^{K} \text{CDF}_q.$$
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The figure strongly indicates that the collaborative communication between users is not always prefered, in other word, the number of collaborated users is not always equal to K, in particular, when the interference is considered in the systems. These facts further clarify that study on collaborative communication for MIMO systems is necessary, and also demonstrate that the effect of interference on the performances of collaborative communications is significant and should not be ignored.

To further analyze the states of inter-user links, we obtain the auto- and cross-correlation in these states. In the present study, the auto-correlation (AC) $\Theta_{q',q'}$, $q, q' \in \{1, \ldots, K\}$ is defined as the normalized Phi correlation [5] between two state sequences $\Xi_{m}$ and $\Xi'_{m}$, where $\Xi_{m}$ represents a binary state sequence of link between CU $q$ and CU $k$, and can be mathematically expressed as

$$\Xi_{m} = \{\xi_{q,k}, \ldots, \xi_{q,m,\text{frame}}, \ldots, \xi_{q,k,\text{frame}}\};$$  \hspace{1cm} (4)

the cross-correlation (CC) $\Theta_{q',q'}$ is naturally defined as the normalized Phi correlation between two state sequences $\Xi_{q,k}$ and $\Xi'_{q,k'}$ with $k, k' \in \{1, \ldots, K\}$.

In Fig. 7, we describe some measured values for AC and CC with considering the effect of IS at position A and B. Each correlation coefficient $\Theta_{q',q'}$ or $\Theta_{q,k'}$ is plotted corresponding to the distance between CU $q$ and $q'$, or CU $k$ and $k'$. For better understanding, we average these measured values for AC and CC, respectively, corresponding to each inter-user distance $d_{q'q}$ or $d_{kk'}$.

The figure shows that there are two different types of correlation changes in inter-user links. The AC maintains high values because a transmitted sharing packet is received through some similar channel attenuations, i.e., the environment in vehicle has higher spatial correlation; on the other hand, although two sharing packets experience the similar channel attenuations, they may be transmitted in-

dependently in time since each CU calls transmit function sequentially. Thereby, CC is lower than AC.

5. Conclusion

In order to demonstrate and evaluate the user collaboration, in the present study, we conducted a field experiment to observe the states of inter-user links in MIMO systems with collaborative communications and considering the effect of interference. The field experiment results indicated that the links between the users are not always prefered, and are significantly affected by the present interference. The results also show some correlation characteristics on the states of the inter-user links for better understanding the collaboration techniques.

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References


