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Performance of adaptive mobile terminal selection schemes for collaborative MMSE linear MIMO detection

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Abstract: In collaborative multi-input multi-output detection, a virtual terminal consisting of neighboring mobile stations (MSs) is formed. This virtual terminal acts as a single MS with a large number of antennas. In this system, received signals of MSs in collaboration with each other are shared through short-range wireless communications. In this paper, in order to reduce the amount of collaboration traffic, simple adaptive MS selection schemes are studied by an urban measurement campaign using a software-defined testbed operating at 5.1 GHz. The MS selection schemes perform close to the full collaboration scheme, and outperform the round-robin scheme.

Keywords: multi-user MIMO, transmission experiment, interference cancellation, terminal collaboration, collaborative reception, measurement campaign

Classification: Wireless Communication Technologies

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1 Introduction

Multi-user multiple-input multiple-output (MU-MIMO) transmission has been actively investigated to improve the spectrum efficiency in wireless communications. Thanks to the precoding techniques, mobile stations (MSs) can be simplified at the expense of high mobility.

Mobile terminal collaborated multiple-input multiple-output (MIMO) reception is a form of distributed MIMO transmission, in which a base station transmits multiple signal streams to a virtual terminal with a large number of receive antennas [1, 2, 3]. This virtual terminal consists of neighboring MSs in collaboration with each other. For this collaborated MIMO reception, group mobility is one of possible use cases because precoding is not required [4, 5].

In this system, terminal subset selection can be applied to reduce the amount of required traffic for collaboration when a sufficient number of terminals are available [6, 7]. This terminal subset selection takes into account the channel condition between the base station and the virtual terminal.

Antenna selection for a single-user MIMO scenario is well investigated [8]. A simple antenna selection scheme is proposed in [9] for linear MIMO receivers. However, most of the studies are not verified in actual environments.

In this letter, simple antenna selection schemes are employed for MS selection for collaborative minimum mean-square error (MMSE) linear MIMO detection. A software-defined radio based testbed is used to conduct a measurement campaign. Through filed experiments, their performance is studied.

2 Collaborative MMSE linear MIMO detection

A base station (BS) with M transmit antennas serves L active MSs out of N candidate MSs. The transmission between BS and MSs occupies the same frequency and time resources to create an multi-user MIMO scenario. First, BS transmits M independent signal streams. On the receiver side, L MSs share their

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received signals and equivalently increase the number of their receive antennas. Each MS is equipped with one receive antenna. Let $\mathcal{L} \subseteq \mathcal{N}$ denote the set of selected MSs where $\mathcal{N}$ is the set of all MSs.

Let $\boldsymbol{y}_{\mathcal{L}} = [y_1, y_2, \ldots, y_L]^{\mathrm{T}}$ where y_l is the received signal of the lth MS in $\mathcal{L}$. The received signals of the selected MSs can be written as

$$\boldsymbol{y}_{\mathcal{L}} = \boldsymbol{H}_{\mathcal{L}}\boldsymbol{x} + \boldsymbol{n}_{\mathcal{L}} \tag{1}$$

where $\boldsymbol{H}_{\mathcal{L}} \in \mathbb{C}^{L\times M}$ is an $L \times M$ matrix of a wireless channel, $\boldsymbol{x} \in \mathbb{C}^{M\times 1}$ is an $M \times 1$ vector of transmitted symbols, and $\boldsymbol{n}_{\mathcal{L}} \in \mathbb{C}^{L\times 1}$ is an $L \times 1$ vector of noise. In this letter, the performance of MMSE linear MIMO detection by MS collaboration is investigated. The estimated SINR at the ith MS in $\mathcal{L}$ assuming equal transmit power for each stream can be given as [10]

$$\gamma_{\mathcal{L},i} = \boldsymbol{h}_i^{\mathrm{H}} \left(\sum_{l=1, l\neq i}^{L} \boldsymbol{h}_l \boldsymbol{h}_l^{\mathrm{H}} + \sigma^2 \mathbf{I} \right)^{-1} \boldsymbol{h}_i \tag{2}$$

where $(.)^{\mathrm{H}}$ denotes the Hermitian operation, $\boldsymbol{h}_i$ is the ith column of $\boldsymbol{H}_{\mathcal{L}}$, σ^2 is the noise variance, and $\mathbf{I}$ is the $L \times L$ identity matrix. Note that there are $L = |\mathcal{L}|$ SINR values for each $\mathcal{L}$.

Let $\mathcal{L}^*$ be the selected set of MSs by adaptive MS selection. A simple adaptive MS selection scheme based on the estimated SINR can be given as

$$\mathcal{L}^*_{\mathrm{SINR}} = \arg \max_{\substack{\mathcal{L}\subseteq\mathcal{N} \\ |\mathcal{L}|=L}} \min_{1\leq i\leq L} \gamma_{\mathcal{L},i}. \tag{3}$$

This scheme only concerns about the smallest SINR $\min_i(\gamma_{\mathcal{L},i})$ of each set. The set $\mathcal{L}^*_{\mathrm{SINR}}$ has the largest $\min_i(\gamma_{\mathcal{L},i})$.

As a refined scheme, an estimated bit error rate (BER) based adaptive MS selection scheme can be given as

$$\mathcal{L}^*_{\mathrm{BER}} = \arg \min_{\substack{\mathcal{L}\subseteq\mathcal{N} \\ |\mathcal{L}|=L}} \sum_{i=1}^{L} \frac{1}{2} \mathrm{erfc}\left(\sqrt{\frac{\gamma_{\mathcal{L},i}}{2}}\right). \tag{4}$$

This scheme gives the set of MSs which has the smallest sum of estimated bit error rates. Eq. (4) assumes quadrature phase shift keying (QPSK) transmission. The extension to another modulation scheme is straightforward.

The estimated signals $\hat{\boldsymbol{x}}$ are obtained by exploiting the correlation of the received signals as

$$\hat{\boldsymbol{x}} = \boldsymbol{H}_{\mathcal{L}^*}^{\mathrm{H}} \boldsymbol{R}_{yy}^{-1} \boldsymbol{y}_{\mathcal{L}^*} \tag{5}$$

where $\boldsymbol{R}_{yy}$ is the correlation matrix of the received signal vector $\boldsymbol{y}_{\mathcal{L}^*}$.

3 Experimental setup

Fig. 1 shows a frame structure of the experimental system. The downlink packets at a symbol rate of 312.5k symbols/s are transmitted from four ($M = 4$) antennas in BS. Each of these packets contains 15 binary phase shift keying (BPSK) symbols as a synchronization word (SW), 16 BPSK symbols as a training sequence (TS), 15 QPSK symbols for control signaling (CTRL), and 80 QPSK symbols as data including the cyclic redundancy check (CRC) code. The correlation matrix $\boldsymbol{R}_{yy}$ is

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calculated using these 80 symbols. After initial timing acquisition by using SW, each MS knows the frame timing, and adheres to the frame structure.

An IEEE 802.11n access point (5 GHz) in the vehicle is used for MS collaboration among six ($N = 6$) personal computers controlling MSs. Each MS executes a user datagram protocol (UDP) broadcast system call in a predetermined order for exchanging the training signals and the data signals as shown in Fig. 1. These signals are sampled, quantized and represented with a 8-bit complex word per symbol with 16-bit gain information per packet, and then transmitted for MS collaboration as payloads of standard UDP packets (20 bytes IP header, 8 bytes UDP header, and the payload). In this experiment, the channel matrix is estimated by a simple correlation technique using the training signals from other MSs (“$\mathcal{N}$” in Fig. 1). MS1 takes control of MS selection based on the estimated channel matrices. The selected MSs are informed by the standard transmission control protocol (“CTRL” in Fig. 1), and broadcast their data signals (“$\mathcal{L}^*$” in Fig. 1).

The BER performance of four schemes are compared using four consecutive frames (superframe). The first frame is for full collaboration ($L = 6$). The second and the third frames are for the adaptive MS selection schemes ($L = 4$) based on SINR $\mathcal{L}^*_{\mathrm{SINR}}$ and based on BER $\mathcal{L}^*_{\mathrm{BER}}$, respectively. The fourth frame is for a round-robin scheme ($L = 4$) where all of the possible subsets of ${}_6\mathrm{C}_4$ are examined in a predetermined order. MSm takes care of linear MMSE detection of the mth stream ($1 \leq m \leq M$).

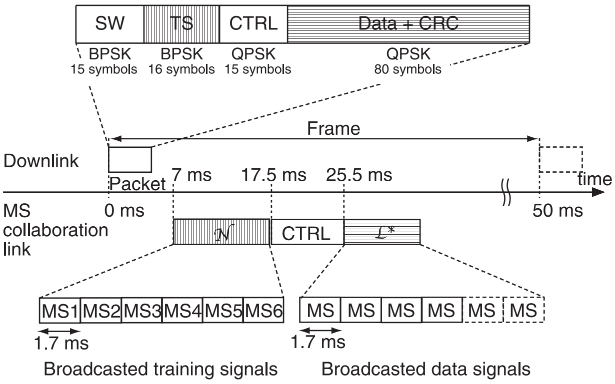

Fig. 1. Frame and packet structure.

BS in this experiment is located at a building in Kyoto University. The height of BS antennas (5 dBi, omni-directional) is 25.5 m above the ground. Four antennas are arranged in a square as shown in Fig. 2(a). The carrier frequency is 5.11 GHz ($\lambda = 5.87$ cm). The equivalent isotropically radiated power is 1 W.

As MSs, six universal software radio peripherals are placed on the seat-back tables as shown in Fig. 2(b). The MS antenna is an omni-directional monopole antenna (3 dBi). The vehicle moves along the measurement course consisting of two sections A and B. The vehicle speed is around 15 km/h in section A, and around 45 km/h in section B.

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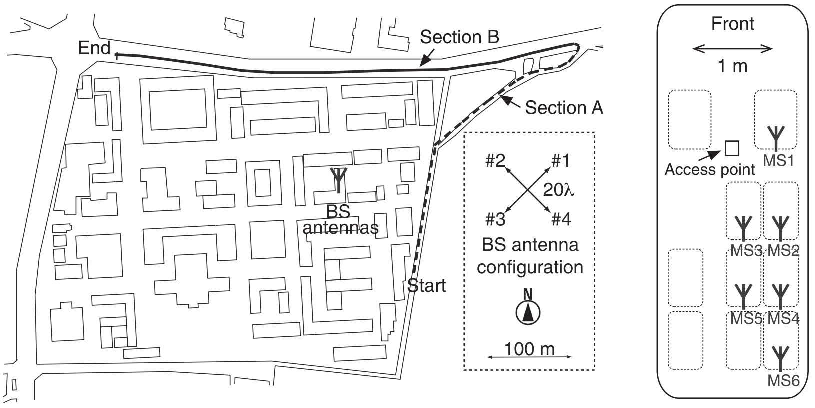

(a) Measurement course

(b) MS positions in vehicle

Fig. 2. BS, MS and measurement course.

4 Experimental results

The results obtained through the field experiment can be seen in Fig. 3. All of the processes including collaboration and MIMO detection are carried out within one frame period in realtime fashion. The MS collaboration link cannot always deliver the required data on time. In the case of $L = 4$, all of the required data signals are available in around 98% of the frames. In the case of $L = 6$, it is around 97%.

In Fig. 3, BER of MIMO detection and the received signal power from BS are shown. The BER is averaged over ten consecutive superframes and over four streams for each scheme. The received power is averaged over four MSs (MS1,2,3,4). This figure also shows the cumulative distribution function (CDF) of 10-superframe and 4-stream averaged BER in section A and B. As can be seen, the SINR based adaptive MS selection scheme (“4MS-MaxMinSINR” in Fig. 3) and the BER based adaptive MS selection scheme (“4MS-MinError” in Fig. 3) perform close to the full collaboration scheme (“6MS-FullCollabo” in Fig. 3), however, there is some room for improvement in the low BER region. The advantage of the BER based scheme over the SINR based scheme is not clear. From the figure, it can be seen that both adaptive MS selection schemes can offer significantly better BER performance over the round-robin scheme (“4MS-Round-Robin” in Fig. 3).

5 Conclusion

This letter presented the field experimental results of collaborative MMSE linear MIMO detection with adaptive MS selection. In this system, collaborating MSs in group mobility share their received signals through a wireless local area network. Our field experiments show that two adaptive MS selection schemes perform close to the full collaboration scheme, and outperform the round-robin scheme.

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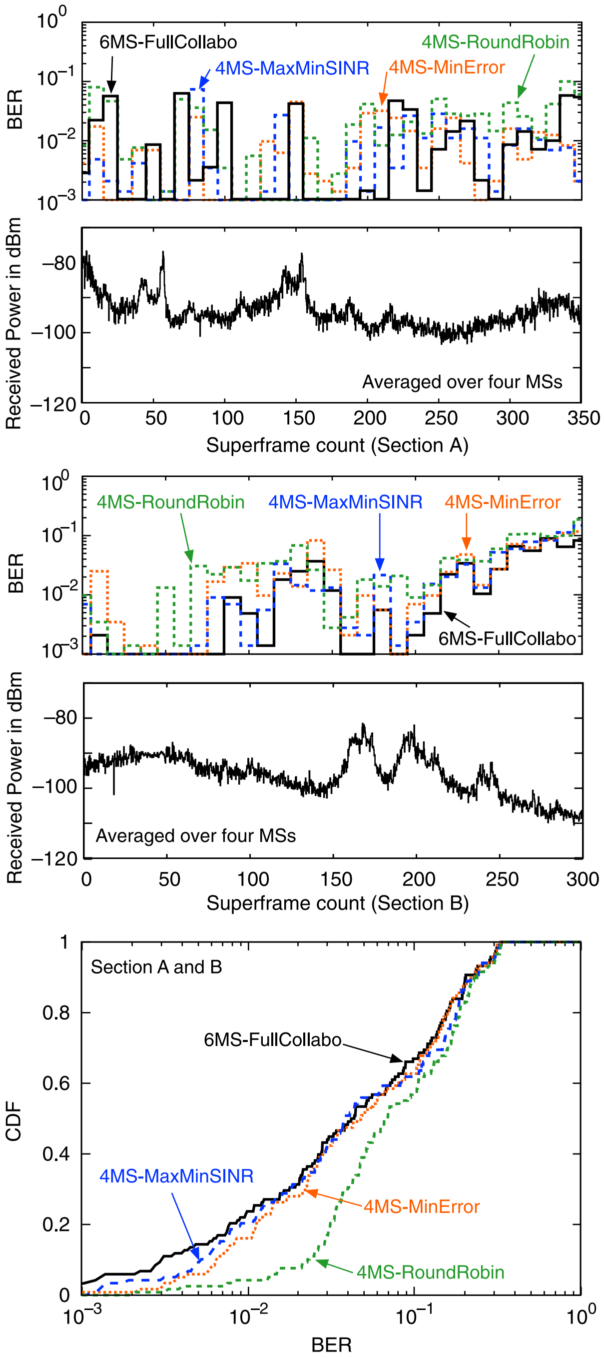

Fig. 3. Measured BER, received signal power and CDF of BER.

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