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Abstract	This document contains a new multiple-access transmission scheme that can simultaneously achieve both diversity and multiplexing gain in the multi-user domain, by generating multiple random beams. The proposed scheme can be applied to both the FDD and TDD modes of IEEE P802.16e/D3
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Multi-antenna scheme for band AMC channel in OFDMA PHY - Multiuser diversity and multiplexing(MUDAM)

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1. Motivation

The capacity of wireless systems has been increased significantly with the development of two advanced technologies; the use of multiple antennas known as multi-input multi-output (MIMO) [1-3] and packet scheduling known as opportunistic scheduling or multi-user diversity (MUD) [4-10]. Since the MUD scheme can provide large diversity gain and multi-antenna schemes can provide spatial multiplexing gain, we can achieve both diversity and multiplexing gain by the combination of two schemes. In IEEE P802.16-REVd/D5 and IEEE P802.16e/D3, there are no specific AAS or MIMO multiplexing schemes based on the multiuser diversity (MUD) scheme.

In this contribution, we propose a new multiple-access transmission scheme that can simultaneously achieve both diversity and multiplexing gain in the multi-user domain, by generating multiple random beams. Multiple beams are generated by using multiple antennas so that the users encounter multiple channels at the same time, enabling the use of multi-user diversity through each of these multiple channels. Although the SNR of each channel is reduced in proportion to the number of beams, multiple beams are generated so that the multiplexing gain is larger than the decrease of SNR, increasing the overall system capacity. The proposed scheme works well in both Rician and Rayleigh fading channels regardless of the channel correlation and it is applicable to both MIMO and multi-input single-output (MISO) systems, enabling the use of receivers with flexible antenna structure. Therefore the proposed scheme can be applied to both the FDD and TDD modes of IEEE P802.16-REVd/D5 and IEEE P802.16e/D3.

2. MUDAM: principles of operation

The MUD is a novel scheme that exploits independent channel characteristics of each user. It allows a user in the best channel condition to send the signal, achieving a system capacity larger than that in additive white Gaussian noise (AWGN) channel with the same average signal-to-noise power ratio (SNR) [6-8]. However, when the channel gain has a small fluctuation and/or varies slowly as in fixed wireless or nomadic channel, the MUD may not provide significant capacity improvement. To overcome this problem, the base station can utilize multiple antennas with randomly generated weights, known as opportunistic or random beamforming [8, 9]. It was reported that the opportunistic beamforming can provide a diversity gain larger than the space-time coding (STC) [6, 8]. Moreover, it can provide a diversity gain even when the channel is completely correlated because the channels of each user are still independent. However, this scheme may not be effective in fast Rayleigh fading channel. The opportunistic beamforming does not fully utilize the multiplexing and diversity in the multi-antenna domain, but it only exploits the multi-user diversity.

(1) System Models

For ease of description, we first consider an (*M*x1) MISO system with a beamformer whose weight vector is $\mathbf{w}(t) = [w_1(t), w_2(t), ..., w_M(t)]^T$. The received signal of the *k*-th user can be represented as

$$y_k(t) = \mathbf{h}_k^H(t)\mathbf{w}(t)s(t) + z_k(t), \qquad k = 1,\ 2,\ \ldots,\ K \tag{1}$$

where K is the number of users, $\mathbf{h}_k^H(t) = [h_{1,k}^*(t), h_{2,k}^*(t), ..., h_{M,k}^*(t)]$ denotes the MISO channel, $s(t)$ is the transmitted signal and $z_k(t)$ is the noise term represented as a zero mean complex circular-symmetric Gaussian process with the variance σ_z^2. Here the superscript * and H denote complex conjugate and conjugate of the transpose, respectively. We assume that the channel $h_{m,k}^*(t)$ has flat fading in a block-fading model (*i.e.*, the channel is unchanged during each slot time T and varies independently between the slot times), the channels of each user are independent, and the transmit power is fixed to P at all times, *i.e.*, $E\left\{\left\|\mathbf{w}(t)s(t)\right\|^2\right\} = P$, where $E\{x\}$ denotes the expectation of x. We also assume that instantaneous channel quality information such as the SNR is available at the base station. The base station assigns the channel resource to a user in the best channel quality at each time, exploiting the user diversity.

The weight $\mathbf{w}(t)$ can be generated in a random manner as

$$w_m(t) = \sqrt{\alpha_m(t)} e^{j\theta_m(t)}, \qquad m = 1, 2, ..., M \tag{2}$$

where $\alpha_m(t)$ and $\theta_m(t)$ are random processes in the range of $0 \le \alpha_m(t) \le 1$ and $0 \le \theta_m(t) < 2\pi$. We assume that $\sum_{m=1}^{M} \left|\sqrt{\alpha_m(t)}\right|^2 = 1$ for normalization of the total transmit power. Since the effective channel response of the k-th user is given by

$$\begin{aligned} h_k^*(t) &= \mathbf{h}_k^H(t)\mathbf{w}(t) \\ &= \sum_{m=1}^{M} h_{m,k}^*(t)\sqrt{\alpha_m(t)} e^{j\theta_m(t)}, \end{aligned} \tag{3}$$

it can be controlled by adjusting $\alpha_m(t)$ and $\theta_m(t)$. The MUD gain increases by inducing a larger fluctuation in the effective channel. Although the capacity of the STC in the MISO system is bounded by that in AWGN channel, the random beamforming scheme can outperform the single-input single-output (SISO) system in AWGN channel by exploiting the MUD [6,7]. However, the channel fluctuation may not be increased by a random beamforming method when the channel has Rayleigh fading. Thus, this scheme can be effective only when applied to fixed wireless or nomadic systems.

(2) Multi-user multiplexing using multiple random beams

We consider a MUD system with a novel multiplexing scheme in the multi-user domain, using multiple random beams. The term ‘random’ is used since multiple beams are generated using a method similar to the random beamforming. Since the proposed scheme can achieve the multiplexing gain in the multi-user domain, not in the multi-antenna domain, it can also provide the multi-user multiplexing gain regardless of the channel correlation.

A. Multi-user diversity and multiplexing (MUDAM)

As depicted in Fig. 1, we assume that the base station is transmitting B signals { $d_1(t), d_2(t), ..., d_B(t)$ } to K users through B beams with weight vector { $\mathbf{w}_1(t), \mathbf{w}_2(t), ..., \mathbf{w}_B(t)$ } at the same time. In this case, (1) can be rewritten as

$$y_k(t) = \mathbf{h}_k^H(t)\sum_{b=1}^{B} \mathbf{w}_b(t) d_b(t) + z_k(t), \qquad k = 1,\ 2,\ \ldots,\ K. \tag{4}$$

where $d_b(t) \in \{s_1(t), s_2(t), ..., s_K(t)\}$, $b = 1, 2, ..., B$. We assume that each signal has the same power σ_s^2. Let $\mathbf{g}_i(t)$ denote the channel response of the user in the best condition through the i-th beam $\mathbf{w}_i(t)$, *i.e.*, $\mathbf{g}_i(t) \in \{\mathbf{h}_1(t), \mathbf{h}_2(t), ..., \mathbf{h}_K(t)\}$, $i = 1, 2, ..., B$.

Assume that the scheduler selects user p (*i.e.*, $k = p$) for the *i*-th beam (*i.e.*, $b = i$). That is, the base station transmits the user signal $s_p(t)$ using the *i*-th beam $\mathbf{w}_i(t)$ (or $d_i(t) = s_p(t)$ and $\mathbf{g}_i(t) = \mathbf{h}_p(t)$). The received signal $r_i(t)$ through the *i*-th beam, corresponding to the received signal of user *p*, can be represented as

$$\begin{aligned} r_i(t) &= y_p(t) \\ &= \mathbf{h}_p^H(t)\left[\mathbf{w}_i(t)s_p(t) + \sum_{b=1,\neq i}^{B} \mathbf{w}_b(t)d_b(t)\right] + z_p(t) \\ &= \mathbf{g}_i^H(t)\mathbf{w}_i(t)d_i(t) + \sum_{b=1,\neq i}^{B} \mathbf{g}_i^H(t)\mathbf{w}_b(t)d_b(t) + z_p(t) \end{aligned} \quad (5)$$

where the first term is the signal, the second term is the interference due to multi-beam multiplexing and the third term is the noise. The resulting signal to interference plus noise power ratio (SINR) through the *i*-th beam during this slot time can be represented as

$$\mathrm{SINR}_i = \frac{\left|\mathbf{g}_i^H \mathbf{w}_i\right|^2 \sigma_s^2}{\sum_{b=1,\neq i}^{B} \left|\mathbf{g}_i^H \mathbf{w}_b\right|^2 \sigma_s^2 + \sigma_z^2}. \quad (6)$$

Note that the time index *t* is omitted in (6) for ease of description because the weight vector $\mathbf{w}_i(t)$ and the channel $\mathbf{g}_i(t)$ are assumed to be unchanged during each slot time.

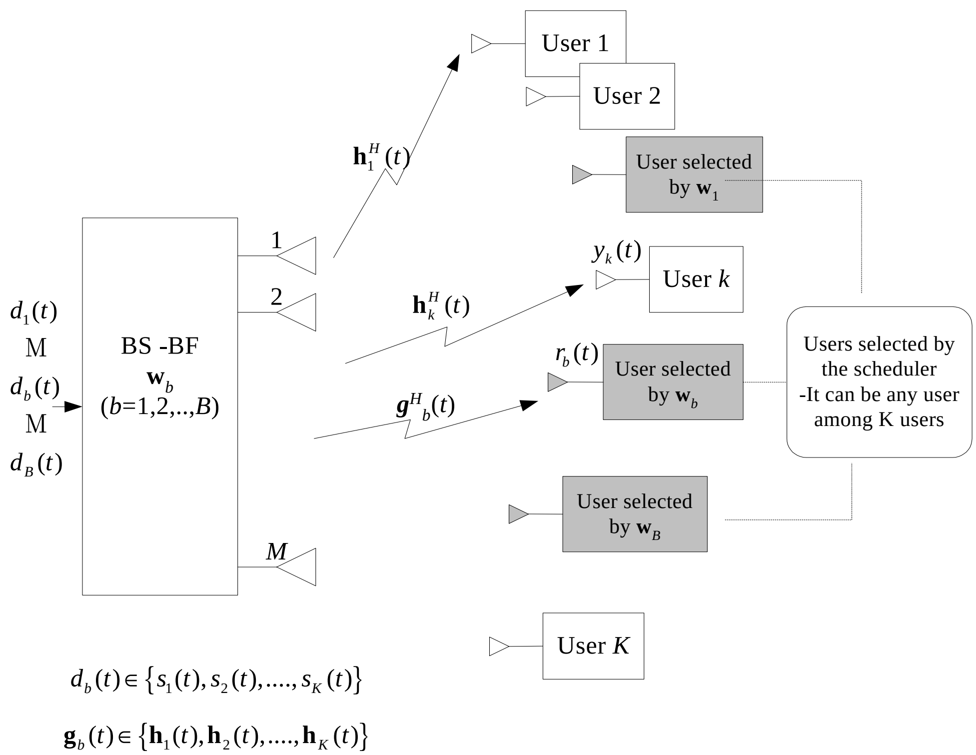


Fig. 1: A multi-user multiplexing system with multiple beams

The multiple beams can be generated in a successive manner, reducing the signaling burden for feedback of the channel information. As an example, the beam generation procedure of the proposed MUDAM scheme with two antennas is depicted in Fig. **2**. The first random beam $\mathbf{w}_1$ is generated with no constraint. Then, all the users report their SNR's to the base station as in other conventional MUD schemes. The scheduler selects the best user through the first beam. The selected user reports its channel response $\mathbf{g}_1$ to the base station. The base station generates the second beam $\mathbf{w}_2$ with constraint $\mathbf{g}_1^H \mathbf{w}_2 = \varepsilon$. Thus, the interference from the second beam to the first beam can be controlled to maintain the SINR at a certain level. Since the interference from the first beam to the second beam is not controlled, the user channel selected by the scheduler can be in poor condition. However, the performance degradation due to this effect is negligible unless K is too small.

In practice, we can control the power of the interference as

$$\mathbf{g}_i^H \mathbf{w}_b = \varepsilon, \text{ for } i < b \tag{7}$$

where $\mathbf{g}_i^H \mathbf{w}_b = 1, \text{ for } i = b.$ The multiple beams can be generated using a weight vector $\mathbf{W}$ satisfying

$$\mathbf{G}^H \mathbf{W} = \mathbf{F} \tag{8}$$

where **W** is the multi-beam weight matrix defined by

$$\mathbf{W} = \left[\mathbf{w}_1, \mathbf{w}_2, ..., \mathbf{w}_B\right], \tag{9}$$

G is the selected channel matrix defined by

$$\mathbf{G} = \left[\mathbf{g}_1,\ \mathbf{g}_2,\ ...,\ \mathbf{g}_B\right], \tag{10}$$

and **F** is the constraint matrix defined by

$$\mathbf{F} \triangleq \begin{bmatrix} 1 & \varepsilon & \varepsilon & \cdots & \varepsilon \\ \times & 1 & \varepsilon & & \varepsilon \\ \times & \times & \ddots & & \vdots \\ \vdots & & & 1 & \varepsilon \\ \times & \times & \cdots & \times & 1 \end{bmatrix}. \tag{11}$$

Here $\times$ denotes the gain term not controllable.

B. Capacity gain by MUDAM

The system capacity, defined by the maximum achievable transmission rate, can be represented as [8]

$$C = \frac{1}{L} \sum_{l=1}^{L} \max_k \left\{ \log_2 \left(1 + \mathrm{SNR}_k(l)\right) \right\} \tag{12}$$

where l is the slot time index and $\mathrm{SNR}_k(l)$ represents the channel SNR of the k-th user at the l-th slot time. Let $\mathrm{SINR}_{b,k}(l)$ be the SINR of the k-th user by the b-th beam at the l-th slot time. Then, the capacity of the proposed MUDAM scheme can be represented as

$$C_M = \frac{1}{L} \sum_{l=1}^{L} \sum_{b=1}^{B} \max_k \left\{ \log_2 \left[1 + \mathrm{SINR}_{b,k}(l)\right] \right\} \tag{13}$$

If multiple beams are properly designed with constraint (8), it can be assumed that the average SINR of each beam is equal to the SNR of a single beam system divided by the number of multiple beams in an average sense, *i.e*.,

$$E\left\{ \max_k \left[\mathrm{SINR}_{b,k}(l)\right] \right\} = \frac{1}{B} E\left\{ \max_k \left[\mathrm{SNR}_k(l)\right] \right\} \triangleq \zeta \,. \tag{14}$$

Then, the capacity of the single beam and multi-beam scheme can be represented respectively as

$$C = \log_2 \left(1 + B\zeta\right) \tag{15}$$

$$C_M = B \log_2 \left(1 + \zeta\right) \tag{16}$$

It can easily be shown that, for $\zeta \geq 0$,

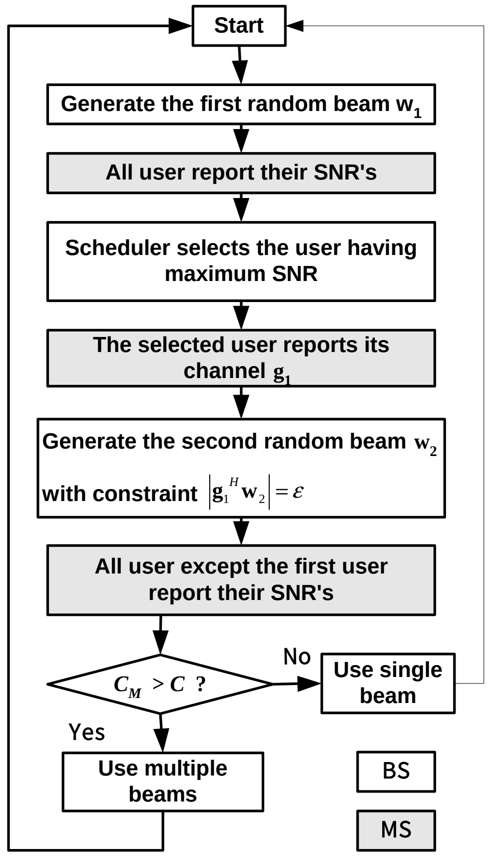


Fig. 2: Procedure of the proposed MUDAM scheme with two beams

$$
\begin{aligned}
C_M - C &= B\log_2(1+\zeta) - \log_2(1+B\zeta) \\
&= \log_2\left[\frac{(1+\zeta)^B}{1+B\zeta}\right] \\
&= \log_2\left[1 + \frac{1}{1+B\zeta} \cdot \sum_{j=2}^{B} \binom{B}{j} \cdot \zeta^j\right] \geq 0.
\end{aligned}
\tag{17}
$$

Thus, the proposed scheme can always provide a system capacity higher than the single beam scheme, provided that the constraint (8) is satisfied.

As mentioned before, the selected user SINR of some beams can be low due to the effect of uncontrolled gain χ in (11) particularly when the number of users is small. In this case, it may not be possible to obtain a desirable gain because (14) may not be valid. Thus, it needs to test whether $C_M \geq C$ to verify the validity of the proposed multi-beam mode, as illustrated in Fig. **2**.

C. Generation of multiple random beams

We consider the generation of such multiple beams in a random manner. We assume that the channel condition is unchanged during the feedback process as in the opportunistic beamforming.

The base station generates the first beam weight $\mathbf{w}_1 = [w_{1,1}, w_{2,1}, \dots, w_{M,1}]^T$ in a random manner as

$$w_{m,1} = \sqrt{\alpha_{m,1}} e^{j\theta_{m,1}}, \qquad m = 1, 2, \dots, M \tag{18}$$

where $\alpha_{m,b}$ and $\theta_{m,b}$, b=1,…,B, are time-variant random processes in each time slot, having a value between 0 and 1, and 0 and 2π, respectively. Let $\mathbf{g}_1$ be the channel impulse response (CIR) of the first user selected by the scheduler. Then, the base station generates the next random beam weight $\mathbf{w}_2$ such that $\mathbf{g}_1^H \mathbf{w}_2 = \varepsilon$. Note that the beam generator needs only the CIR of the selected users. Since the weight $\mathbf{w}_2$ is an M-dimensional vector with a single constraint (*i.e.*, an under-determined system), the rest (M-1) elements of $\mathbf{w}_2$ can be determined by (18). Thus, we need to solve a single equation satisfying

$$\mathbf{g}_1^H \mathbf{w}_2 = \varepsilon \tag{19}$$

or

$$\sum_{m=1}^{M-1} g_{m,1}^* \sqrt{\alpha_{m,2}} e^{j\theta_{m,2}} + g_{M,1}^* w_{M,2} = \varepsilon \tag{20}$$

Then, we have

$$w_{m,2} = \begin{cases} \dfrac{1}{\sqrt{p_2}} \cdot \sqrt{\alpha_{m,2}} e^{j\theta_{m,2}}, & m = 1, 2, \dots, M-1 \\ \dfrac{1}{\sqrt{p_2}} \cdot \dfrac{1}{g_{M,1}^*} \cdot \left[\varepsilon - \left(\displaystyle\sum_{m=1}^{M-1} g_{m,1}^* \sqrt{\alpha_{m,2}} e^{j\theta_{m,2}} \right) \right], & m = M \end{cases} \tag{21}$$

where the constant $1/\sqrt{p_2}$ is for normalization, making $\|\mathbf{w}_2\|^2 = 1$.
Similarly, the weight of the b-th beam can be generated by determining ($M-b+1$) elements randomly and the rest (b-1) elements are determined by solving the following equations,

$$\mathbf{g}_i^H \mathbf{w}_b = \varepsilon, \quad i = 1, 2, \dots, b-1 \tag{22}$$

where

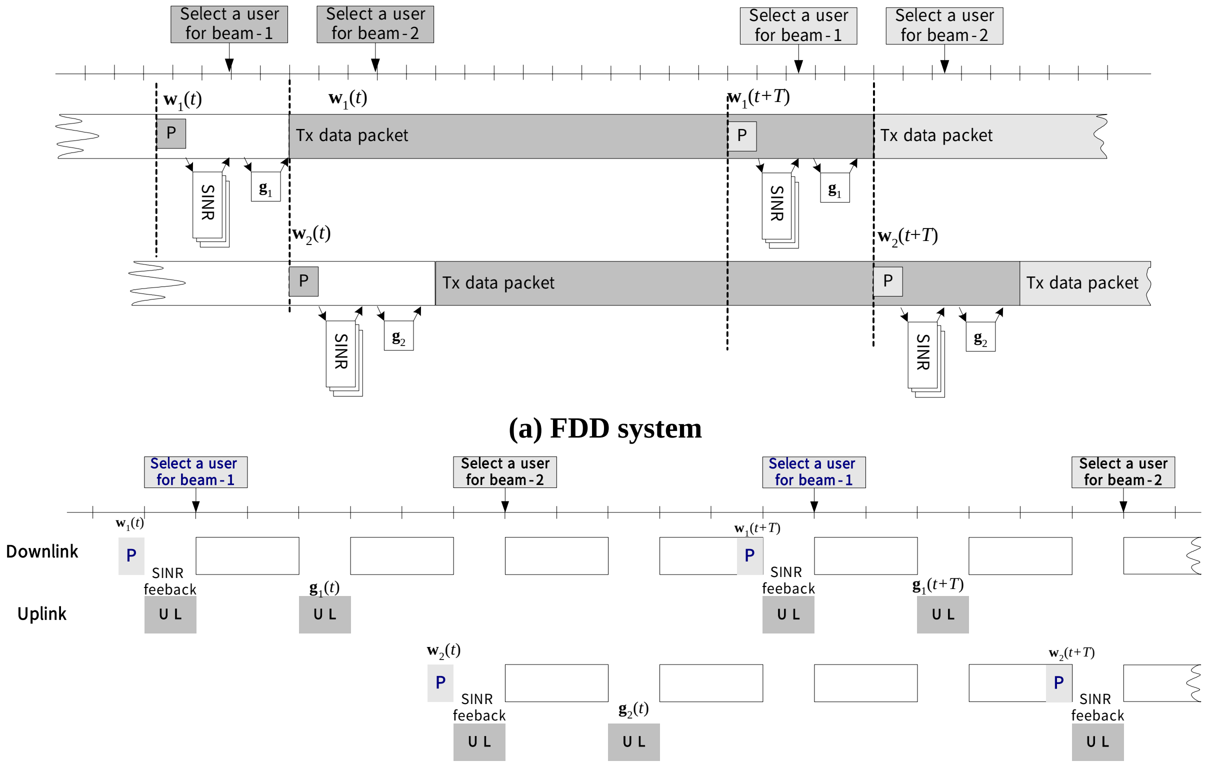
$$\mathbf{w}_b = \begin{bmatrix} \mathbf{w}_{rand} \\ \mathbf{w}_{sol} \end{bmatrix} \tag{23}$$

$$(\mathbf{w}_{rand})_m = \frac{1}{\sqrt{p_b}} \cdot \sqrt{\alpha_{m,b}} e^{j\theta_{m,b}}, \qquad m = 1, 2, \dots, M-b+1 \tag{24}$$

$$\mathbf{w}_{sol} = \frac{1}{\sqrt{p_b}} \begin{bmatrix} g_{M-b+2,1}^* & g_{M-b+3,1}^* & \cdots & g_{M-1,1}^* & g_{M,1}^* \\ g_{M-b+2,2}^* & g_{M-b+3,2}^* & \cdots & g_{M-1,2}^* & g_{M,2}^* \\ \vdots & & & & \vdots \\ g_{M-b+2,b-2}^* & & & \ddots & g_{M,b-2}^* \\ g_{M-b+2,b-1}^* & g_{M-b+3,b-1}^* & \cdots & g_{M-1,b-1}^* & g_{M,b-1}^* \end{bmatrix}^{-1} \begin{bmatrix} \varepsilon - \sum_{m=1}^{M-b+1} g_{m,1}^* \sqrt{\alpha_{m,b}} e^{j\theta_{m,b}} \\ \varepsilon - \sum_{m=1}^{M-b+1} g_{m,2}^* \sqrt{\alpha_{m,b}} e^{j\theta_{m,b}} \\ \vdots \\ \varepsilon - \sum_{m=1}^{M-b+1} g_{m,b-1}^* \sqrt{\alpha_{m,b}} e^{j\theta_{m,b}} \end{bmatrix} \tag{25}$$

where the constant $1/\sqrt{p_b}$ is for normalization, making $\|\mathbf{w}_b\|^2 = 1$.

Fig. 3 (a) and (b) show the frame structures of the MUDAM scheme using two beams in FDD and TDD system, respectively. Each frame or packet can be considered as a sub-channel or sub-band in the OFDMA system. Unlike the FDD system, the TDD system requires multiple frames to employ the proposed MUDAM scheme since the feedback signaling is possible only in the uplink (UL) duration. However, it is still applicable to mobile environment unless the frame length is too long. For example, it is applicable to nomadic environments even when the TDD frame length is 5 msec.



(a) FDD system

(b) TDD system

Fig. 3: Generation of multiple beams in a (2x1) MISO system

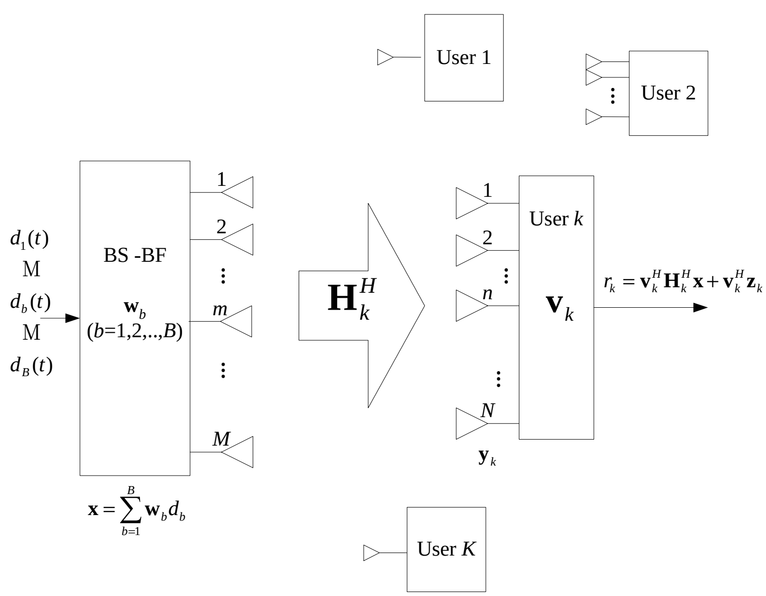


Fig. 4: The extension to the MIMO system with an equivalent MISO channel

D. Extension to MIMO systems

The proposed scheme can be applied to an (MXN) MIMO system in a straightforward manner as depicted in Fig. 4, where the transmitted signals are multiplexed as

$$\mathbf{x}(t) = \sum_{b=1}^{B} \mathbf{w}_b(t) d_b(t) \quad . \tag{26}$$

The received signal of user k with an N-element receive antenna array can be represented as

$$\mathbf{y}_k(t) = \mathbf{H}_k^H(t) \sum_{b=1}^{B} \mathbf{w}_b(t) d_b(t) + \mathbf{z}_k(t), \qquad k = 1, 2, \ldots, K \tag{27}$$

where $\mathbf{z}_k$ denotes the noise vector. Assume that the receiver is exploiting the receive antenna diversity such as the maximum ratio combining with combining weight $\mathbf{v}_k(t) = [v_{1,k}(t), v_{2,k}(t), ..., v_{N,k}(t)]^T$.

The output of the combiner can be represented as

$$\begin{aligned} r_k(t) &= \mathbf{v}_k^H(t) \mathbf{H}_k^H(t) \sum_{b=1}^{B} \mathbf{w}_b(t) d_b(t) + \mathbf{v}_k^H(t) \mathbf{z}_k(t) \\ &= \mathbf{h}_k^H(t) \sum_{b=1}^{B} \mathbf{w}_b(t) d_b(t) + z'_k(t) \end{aligned} \tag{28}$$

where $z'_k(t) = \mathbf{v}_k^H(t) \mathbf{z}_k(t)$. Thus, the proposed MUDAM scheme can be applied to the MIMO system assuming an equivalent MISO channel

$$\begin{aligned} \mathbf{h}_k^H(t) &= \mathbf{v}^H(t) \mathbf{H}_k^H(t) \\ &= \left[\sum_{n=1}^{N} v_{n,k}^*(t) h_{n1,k}^*(t), \sum_{n=1}^{N} v_{n,k}^*(t) h_{n2,k}^*(t), ..., \sum_{n=1}^{N} v_{n,k}^*(t) h_{nM,k}^*(t) \right]. \end{aligned} \tag{29}$$

3. Performance evaluation

The performance of the proposed MUDAM scheme is verified by computer simulation. The simulation results are obtained by averaging over 1000 independent channel realizations per user. We assume that channels of all the users are mutually independent and have the same average SNR. It is assumed that the channel has flat Rayleigh fading.

Fig. **5** compares the performance of the proposed MUDAM and single beam (opportunistic beamforming) schemes, when a (2x1) MISO system is employed in Rayleigh fading channel at 20 dB SNR. The proposed MUDAM scheme is designed with $\varepsilon = 0.01$. It can be seen that the proposed MUDAM scheme always provides a capacity larger than the single beam scheme.

When the channel is fully correlated, the channel element $\{h_{1,k}, h_{2,k}, ..., h_{M,k}\}$ experiences the same fading null or peak. Thus, the correlated channel may have peaks higher than an independent channel. As a result, the beamforming method can provide a larger capacity gain in correlated channel as depicted in Fig. 6. It can be seen that the proposed MUDAM scheme works well regardless of the channel correlation condition, outperforming the previous scheme.

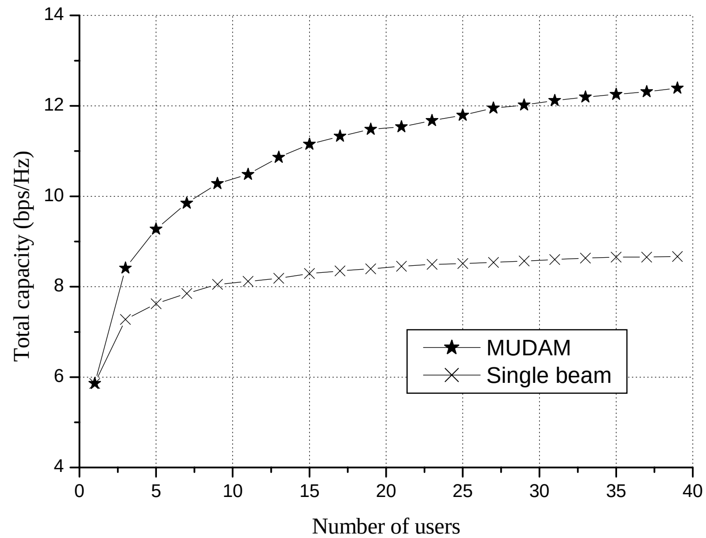


Fig. 5: The capacity of (2x1) MISO systems in Rayleigh fading channel at 20dB SNR

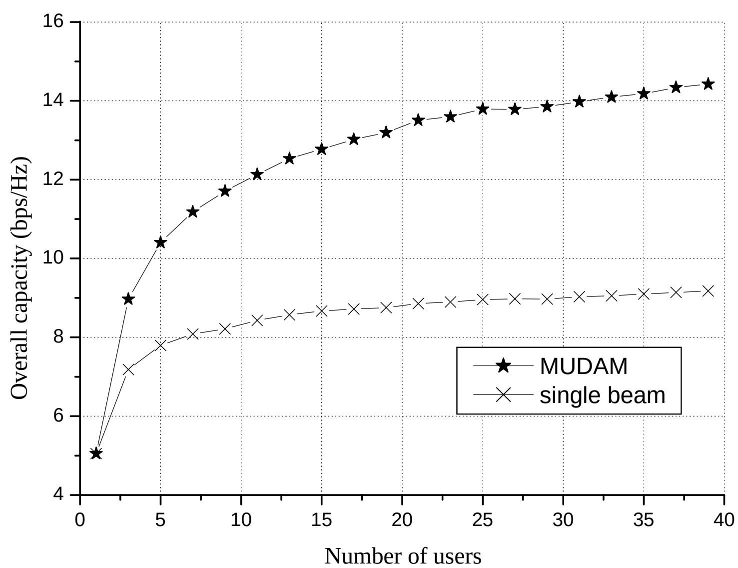


Fig. 6: The capacity of (2x1) MISO systems in fully correlated channel (Rayleigh fading at 20dB SNR)

We have shown the proposed MUDAM scheme can provide the multiplexing gain in both Rician and Rayleigh fading channel regardless of channel correlation, unlike the opportunistic beamforming scheme. Simulation results show that the proposed MUDAM scheme can provide a system capacity larger than the opportunistic beamforming scheme, yielding a maximum gain practically achievable in multi-user and multi-antenna systems. And the proposed MUDAM scheme can be applied to the MIMO as well as MISO systems, enabling the use of receivers with flexible antenna structure.

The proposed scheme can be applied to current IEEE P802.16-REVd/D5 and IEEE P802.16e/D3 without significant changes and regardless of the duplexing method. The proposed scheme can provide a large improvement of the system capacity and therefore, it can support more subscribers in the hot spot without the increase of the complexity of the subscriber station.

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