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Title	**Increasing ranging opportunity by spatial orthogonality**
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Re:	TGm SDD: Other
Abstract	This contribution proposes SDD text for multi-antenna transmission on uplink ranging channel
Purpose	Comments to EEE 802.16m SDD
Notice	
Release	
Patent Policy	

Increasing ranging opportunity by spatial orthogonality

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1 Introduction

The reference system [1] specifies that initial ranging is a contention-based procedure. It means BS will allocate some time-frequency resources, i.e. ranging channels, to all the users who want to get access to the BS. Each unsynchronized user randomly selects and transmits a PN code on the ranging channel. Different users are recognized by the BS if they use different codes. However, a collision will occur if two (or more) users are transmitting the same ranging code in the same ranging channel. In this case, there would be a contention resolution procedure, during which at least one user fails. The failed users have to wait for another ranging opportunity, which delays the network entry.

In 802.16e, the ranging code set contains 256 codes, which are the superset of 4 non-overlapped groups, each for different purpose, i.e. initial ranging, periodic ranging, bandwidth request and handover ranging. To decrease the collision probability, BS has to allocate more ranging channels. The consequence is the decreased system spectrum efficiency. Thus there will be a tradeoff between increasing ranging opportunity and keeping still high spectrum efficiency.

2 Motivation

In a wireless communication system, an effective channel consists of three part: RF chain of transmitter (e.g. including DAC/filter/IF/RF), radio propagation channel and RF chain of receiver. It is well known that radio propagation channel is reciprocal between two antennas in a TDD system (see for instance [2] and references therein). For a linear time-invariant communication system, it implies that the two directional channels have the same frequency response.

Although the RF chain of transmitter and receiver at BS and MS are not exactly the same, they do not change the spectrum of the signal. The emitted signal should meet the spectrum mask requirement, so the RF chains are relative flat in the signal spectrum, and they can be regarded as a flat filter. The simulation results in [3] showed that there is no need for UE to do RF calibration.

Thus, in a WiMAX system, this channel reciprocity could be used to improve the ranging performance, especially in MIMO case. Below, a 2x2 MIMO configuration is used as example, i.e. each MS is equipped with two transmit antennas while BS has two receive and transmit antennas. This proposal could be extended to other MIMO configuration directly.

3 Increasing ranging opportunity by spatial orthogonality

Figure 1 shows the 802.16m frame structure. The location of ranging channel in uplink is just informative. The preamble is transmitted by BS in every frame. Upon the received preamble, the MS could estimate the downlink channel state information (CSI) $\hat{H}_{DL}^{k}$. Due to TDD channel reciprocity as mentioned above, this DL CSI can be used as an estimated UL channel profile, i.e. $\hat{H}_{UL}^{k} = \left[\hat{H}_{DL}^{k}\right]^{T}$. Here, $[\cdot]^{T}$ denotes the matrix transposition, and the superscript *k* denotes the k-th subcarrier. For simplicity reason, the superscript *k* will be omitted in the equations below.

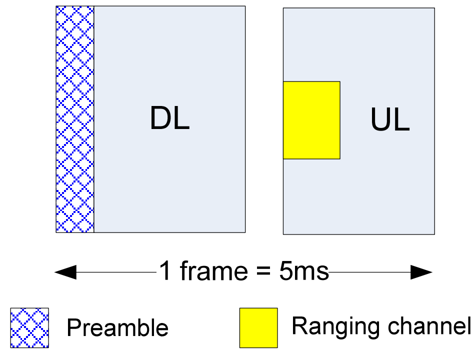

Figure 1 802.16 frame structure

Assume there are two users, each equipped with 2 transmit antennas and BS has 2 (or more) receiving antennas. The received signal vector ($y_1 \quad y_2$) on receive antenna 1 and antenna 2 could be modelled as:

$$
\begin{aligned}
Y = \begin{pmatrix} y_1 \\ y_2 \end{pmatrix} &= \underbrace{\mathbf{H}_{1,\mathrm{UL}} \cdot \mathbf{v}_1}_{r_1} \cdot x_1 + \underbrace{\mathbf{H}_{2,\mathrm{UL}} \cdot \mathbf{v}_2}_{r_2} \cdot x_2 + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix} \\
&= \underbrace{\mathbf{H}_{1,\mathrm{UL}} \cdot \begin{pmatrix} \mathbf{v}_{1,1} \\ \mathbf{v}_{1,2} \end{pmatrix}}_{\mathbf{u}_1} \cdot x_1 + \underbrace{\mathbf{H}_{2,\mathrm{UL}} \cdot \begin{pmatrix} \mathbf{v}_{2,1} \\ \mathbf{v}_{2,2} \end{pmatrix}}_{\mathbf{u}_2} \cdot x_2 + \begin{pmatrix} n_1 \\ n_2 \end{pmatrix}
\end{aligned} \tag{1}
$$

where $\mathbf{H}_{j,\mathrm{UL}} \in C^{2\times 2}$ is the uplink channel from j-th user, x_j and $\mathbf{v}_\mathbf{j} = \left[\mathbf{v}_{\mathbf{j,1}} \quad \mathbf{v}_{\mathbf{j,2}}\right]^{T}$ are the ranging code and precoding matrix of the j-th user, n_k is the thermal noise on the k-th receive antenna, j = 1,2, k = 1, 2.

If $\mathbf{u}_\mathbf{1}$ is orthogonal to $\mathbf{u}_2$, i.e. $\mathbf{u}_1 \perp \mathbf{u}_2$, then the signals from two users can be separated by the BS receiver with two antennas. The $\mathbf{u}_1$ and $\mathbf{u}_2$ can be any orthogonal vectors, e.g. $[\mathbf{u}_1 \quad \mathbf{u}_2] = \frac{1}{\sqrt{2}}\begin{bmatrix} 1 & 1 \\ 1 & -1 \end{bmatrix}$ or $[\mathbf{u}_1 \quad \mathbf{u}_2] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$. Let us assume that $[\mathbf{u}_1 \quad \mathbf{u}_2] = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ are the orthogonal vectors. To compute $\mathbf{v}_\mathbf{j}$, firstly, a user randomly selects an orthogonal vector, say $\mathbf{u}$, such that $\mathbf{u} = [1\ 0]^{\mathrm{T}}$ or $\mathbf{u} = [0\ 1]^{\mathrm{T}}$. Based on the selected $\mathbf{u}$, the user calculates $\mathbf{v}_\mathbf{j}$ by solving the equation (2)

$$
\mathbf{u} = \mathbf{H}_{\mathbf{j},\mathbf{UL}} \cdot \mathbf{v}_\mathbf{j} = \hat{\mathbf{H}}_{\mathbf{j},\mathbf{DL}}^{\mathbf{T}} \cdot \mathbf{v}_\mathbf{j} \tag{2}
$$

Thus it can be seen that by using the estimated downlink channel information and doing precoding, the two users transmitting the same ranging code could be separated spatially. From this point of view, the ranging opportunity is doubled and the collision probability decreases by half ideally.

Since in a WiMAX system, there are also users equipped with only one transmit antenna. In this case, the BS will receive the same signal on both antennas. To differentiate the users equipped with one and two transmit antennas, we can partition the ranging codes into two sets. One set of codes are used by 1 Transmit antenna MS, while another set of codes are used by 2 Transmit antenna MS.

3 Simulation results

Simulation assumptions are listed in Table 1.

Table 1 Initial ranging simulation assumptions

Ranging channel	similar to 802.16e, but with localized subcarrier allocation. 1 ranging channel per frame.
Ranging code	Same as 802.16e, i.e. PN code with length of 144
Ranging code set	8 codes are used
Number of users	2, 4
Timing offset	0 ~ 31 samples
Antenna configuration	SISO, MIMO 2x2
Orthogonal vector used in case of MIMO	[1 0; 0 1]
False alarm rate	1%
Channel estimation	Real channel estimation from DL preamble
Channel type	Ped B, 3km/h
Measurement	Detection rate vs. Es/No
Time spacing between DL preamble and UL ranging channel	24 OFDM symbols
Collision	Users choose the same ranging code in case of SISO, or choose the same ranging code and same orthogonal vector in case of MIMO.
Correct detection	If no collision, the ranging code (and orthogonal vector) is correctly detected in case of SISO (and MIMO).
Detection rate	$\dfrac{\sum_{i=1}^{frameNum} \text{correct detections(i)}}{\text{Active user number} \times \text{frameNum}}$
False alarm	The event of detecting a ranging code (and orthogonal vector) when it is not transmitted.
False alarm rate	$\dfrac{\sum_{i=1}^{frameNum} \text{false detections(i)}}{\text{non-used ranging codes} \times frameNum}$

The detection rate of 2 and 4 users are shown in the Figure 2 and Figure 3 respectively. Obviously, MIMO brings at least diversity gains compared with SISO case. And as the number of users increases, which resulting in more collisions, more gains are produced since the ranging opportunities are doubled in case of MIMO by spatial orthogonality. When evaluating detection rate at 0.8, in case of 2 users our proposal has gains ~3.5dB over SISO. While in case of 4 users, our proposal has gains more than 8dB.

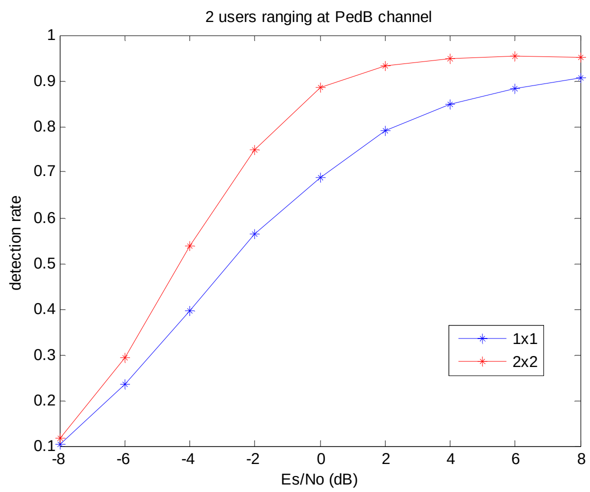

Figure 2 Detection rate of 2 users, PedB 3km/h

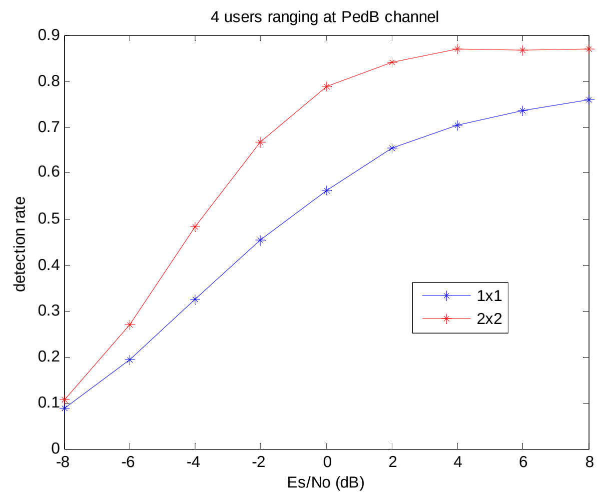

Figure 3 Detection rate of 4 users, PedB 3km/h

4 Conclusions

From the above simulation results, it can be concluded that multi-antenna for uplink ranging not only brings diversity gains, but also the ranging opportunity gains. Thus we propose to support multi-antenna in uplink ranging. The detailed proposed text are described below.

5 Reference

[1] 80216m-08_003r4, “The Draft IEEE 802.16m System Description Document,” July 29, 2008.

[2] Glenn S. Smith, “A direct derivation of a single-antenna reciprocity relation for the time domain,” IEEE Transactions on Antennas and Propagation, vol. 52, no. 6, pp. 1568–1577, June 2004.

[3]. Jiann-Ching Guey, “Modeling and evaluation of MIMO systems exploiting channel reciprocity in TDD mode”, VTC2004-Fall, vol 6, 2004, no. 12, pp. 4265-4269.

6 Proposed Text for SDD

Add a new chapter under 11.9.2.4 and 11.12.3.

--Start of the text--

11.9.2.4.1.2 PHY structure

The multi-antenna should be supported by both BS and MS for the uplink ranging channel transmission, to increase the ranging opportunity by spatial orthogonality.

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11.12.3 Transmission for Control Channels

11.12.3.1 Transmission for UL ranging channel

Precoding is used for UL ranging channel and contention-based bandwidth request channel for TDD system. The unitary codebook $\mathbf{U}=\{\mathbf{u_1},\mathbf{u_2},\cdots,\mathbf{u_N}\}$ (TBD) is predefined, where $\mathbf{U}\in C^{N_R\times N}$. N_R is the receive antenna number at BS and N is the number of vectors in $\mathbf{U}$. For MS *j* equipped with multiple transmit antennas, when performing UL ranging or contention-based bandwidth request, a codeword $\mathbf{u_i}\in\mathbf{U}$ is randomly selected. And the precoding vector $\mathbf{v_j}$ is calculated according to equation 11.12.3.1-1

$$\mathbf{u_i}=\mathbf{H_{j,UL}}\cdot\mathbf{v_j} \qquad \text{(Equation 11.12.3.1-1)}$$

, where $\mathbf{H}_{UL,j}$ is the UL channel response of MS *j*.

--End of the text--