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Re:	Response to the Call for Contributions on Project 802.16m System Description Document (SDD) (i.e., IEEE 802.16m-08/005).	
Abstract	This contribution proposes the technique of antenna selection at mobile station for 802.16m system description document (SDD).	
Purpose	To adopt the mobile station antenna selection technique proposed herein into IEEE 802.16m system description document (SDD).	
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Antenna Selection at the Mobile Station

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1 Overview

Antenna selection is a technique in which only a subset of available antenna elements is used for the transmission/reception of data; the subset can change according to channel conditions and interference situation. The advantage of antenna selection mainly lies in a reduction of hardware complexity, as the number of RF chains for upconversion/downconversion can be smaller: it needs to equal only the number of *used* antenna elements, not the number of *available* antenna elements. At the same time, antenna selection retains most of the benefits of large antenna arrays: the diversity order is determined by the number of *available* antenna elements. For this reason, antenna selection is now widely used for MIMO-based wireless systems: it has been foreseen in 3GPP LTE (approved at the meeting in February 2008) and has been adopted by IEEE 802.11n standard.

In IEEE 802.16e, AS is already used as a precoding scheme at the BS. However, AS is not foreseen for the MS. We therefore suggest in this document that AS at the MS is established as part of IEEE 802.16m. We also introduce the modifications of the 16e standard that would be required to make such a scheme work – and as we will see, those modifications are extremely minor. Also the hardware modifications will be shown to be trivial. The baseline configuration at the MS uses 2 receive antennas, and 1 transmit antenna. It is reasonable to have a smaller number of transmit RF chains (limiting the number of power amplifiers), but the receive *antenna elements* can serve as transmit antenna elements without extra effort. Thus, using a 1-out-of-two transmit antenna selection is a logical step to take; we will also show that AS gives significant benefits.

The remainder of this document is organized as follows: Section 2 gives a very brief summary of the current state of the art in antenna research both in the academic literature and in other standardization groups, and enumerates the main challenges. Section 3 describes the modifications of the 16e standard that are required to implement AS. Simulation results in Section 4 show the benefits that can be achieved with AS. Section 5 proposes the text change.

2 Benefits and challenges of AS at MS

In order to make explanations easier, we first describe the case where the BS has multiple antennas, but no AS (i.e., number of RF chains equals the number of antenna elements). We furthermore restrict ourselves to intuitive arguments. A mathematical theory, and references to the extensive scientific literature on the topic, can be found in the Appendix.

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2.1 1-out-of-two selection, frequency-flat case (case 1)

We first consider the situation of frequency-flat fading where the MS has two antenna elements and one RF chain. It is intuitively clear that the MS should select the antenna element with the better SINR (signal-to-noise-and-interference ratio). The question is how the better antenna element can be determined: clearly, the MS cannot measure the channels at the two antenna elements simultaneously (it has only one RF chain). Rather, the measurement has to be time-multiplexed, i.e., the MS first has to measure at one antenna element, and then, after some time, at the other. Then it decides which antenna element is better, and uses it for the remainder of the transmission time. As long as the channel stays constant during this whole process, there is no loss in optimality.

For the downlink (receive antenna selection), no extra signaling is required – the MS can autonomously decide which antenna element to use.

In a reciprocal channel, the uplink does not absolutely require control signaling (the MS uses the same antenna element as for the reception). However, there are benefits in signaling the selected antenna to the BS:

- if the BS performs channel tracking, it should be informed of changes in the antenna elements, because those changes effect an abrupt change in the channel state. Such channel tracking is useful for channel prediction, noise reduction, etc.
- if the BS is also capable of antenna selection, it has to make sure that the training signals it receives for BS – antenna selection originate from the same MS antenna.

If the channel is not reciprocal, then the MS should send out uplink training signals (either sounding signals or pilots), and then BS needs to feed back in the downlink control signaling which antenna should be used for the transmission. This signaling can be easily done as part of the MAP, as it controls the resource assignment. Due to the delay of such a feedback scheme, it is most beneficial when the users are (quasi)-stationary.

2.2 L-out-of-N selection, frequency-flat case (Case 2)

In the L-out-of-N selection, the selection of the best antenna elements is not straightforward anymore, since the SINR is not the most relevant criterion. Rather, the capacity of the link should be maximized. A brute-force approach computes the achievable capacity for all subsets with L elements and picks the best one; however, a number of more efficient algorithms have been proposed in the literature (see the work of Ghorokov et al., Gershman et al., and Choi et al. [1-3]). Note that the selection of the subset is a matter of implementation and does not have to be standardized.

Just like in Case 1, the downlink does not require any special signaling. For the uplink, a signaling (from MS to BS) of the chosen subset is advantageous for the reciprocal case; and for the non-reciprocal channel signaling (from BS to MS) which subset is to be used is mandatory. Suggestions for the signaling format will be presented in Sec. IV.

2.3 Frequency-selective case – selection without joint scheduling (Case 3)

The situation becomes more complicated when the propagation channels are frequency selective. Let us assume that frequency scheduling (i.e., which subcarriers are to be used) has already been done, so that the only remaining question is which antenna subset to use (the more general case of joint scheduling and AS will be treated below).

Different antenna elements can be optimal at different frequencies. However, each RF antenna element can only be connected to one antenna element at a time, so the MS has to choose the antenna subset that is optimum in a “frequency-integrated” manner. The selection of the optimum antenna subset is again up to the implementer, while nothing in the feedback changes. It is noteworthy that in the frequency-selective case, AS loses some of its benefits, but it still provides better SNR (typically 2 dB) than the no-selection case. This is true both for PUSC/FUSC permutations, and for AMC

2.4 Frequency-selective case – joint selection and scheduling (Case 4)

By providing multiple antenna subsets to choose from, the scheduler now has a larger ensemble (all subchannels on the antenna subsets) to assign the data streams to. Note the restriction that all assigned data streams have to be on one antenna subset. Optimum assignment in this enlarged ensemble naturally gives higher multi-user diversity gain, enables interference reduction, etc. Again, the algorithm by which the BS does the optimum scheduling is outside the scope of the standard.

The joint selection and scheduling requires more extensive training. The BS has to be aware of the transfer function to each of the antenna subsets *for the whole system bandwidth*. For the uplink, this implies that channel sounding signals covering the whole bandwidth have to be sent from each possible subset, or – more efficiently – from each antenna element. For the downlink in the nonreciprocal case, the MS needs to obtain CSI (channel state information) for the whole bandwidth from the preambles, and feed back this information to the BS.

2.4.1 Static vs. moving users

For the frequency-selective case, it is important to decide whether the CSI should be obtained from preamble/midamble/sounding or from the pilot tones. The former case allows to acquire CSI over the whole system bandwidth, and is thus enables joint scheduling and selection. However, the overhead is significant. Also, the preamble is repeated only once every 5 ms, so that acquiring the complete CSI can take tens of milliseconds. The exhaustive sounding is thus suitable only for static users (given the fact that in the important urban scenarios, 50-70 % of users are static, this case should be provided for in the standard).

Pilot tones are much more frequent, so that AS can be adapted within each frame. However, we can really only acquire CSI for the already-chosen subchannel (in the case of PUSC/FUSC, channel interpolation might be possible). Furthermore, remember that a chosen antenna as to be used on *all* subcarriers during a given OFDM symbol. Thus, when we switch antennas to sound a new antenna subset, we also have to transmit the payload data on that antenna (which in turn might require a change in the modulation and coding scheme). It is thus necessary that the BS and MS agree (via control signaling) on the pattern with which the antennas be switched, and which modulation/coding schemes are to be used on the chosen antenna elements.

Clearly, AS based on preamble, and based on pilots, are optimum under different circumstances, and for different MSs. It is thus recommended that the standard supports a flexible (adaptive) use of both of those schemes.

3 Standard modifications to enable AS at the MS

Antenna selection (AS) at the MS can be performed in both downlink (DL) and uplink (UL).

- **DL receive antenna selection**

As mentioned in section **Error! Reference source not found.**, no explicit signaling is needed to let the MS start receive antenna selection.

- **UL transmit antenna selection**

BS initiates an uplink MS transmit antenna selection by transmitting an Antenna_Selection_Control_IE to the targeted MS. This new IE assumes the format an OFDMA UL-MAP extended IE format, as shown in Table 1. The "UL_AS_Indication" field, when set to 1, indicates that the MS should perform uplink transmit antenna selection in the current frame.

Table 1: proposed OFDMA antenna selection control IE

Syntax	Size (bit)	Notes
Antenna_Selection_Control_IE() {	-	-
Extended UIUC	4	Antenna selection control = 0x0B
Length	4	Length = 0x01
UL_AS_Indication	1	Indicates whether mobile station shall perform uplink transmit antenna selection in the current frame.
UL_AS_Selection	7	The value of this field indicates which antenna set shall be chosen by the MS for uplink transmission.
}		

If "UL_AS_Indication" field is set to 0, then the MS uses the "UL_AS_Selection" field to determine the antenna set selected by the BS. More specifically, the value of the "UL_AS_Selection" field indicates which antenna set has been selected for future transmission. For example, if "UL_AS_Indication" field is "0x01", this means that the antenna set switched to immediately after using the original antenna set should be chosen for subsequent uplink transmission. To make the MS use the same antenna set, the BS sends "0x00".

If the "UL_AS_Indication" field is set to 1, it indicates that the MS should perform an AS-training in the current frame, i.e., send out a (pre-determined) training sequence (e.g., UL pilot) that allows the BS to determine the best antenna subset for future use.

- **Basic capability negotiation**

During the network entry, MS and BS shall exchange their capability of supporting antenna selection during the basic capability negotiation process. That is, MS reports its capability of supporting downlink MS receive antenna selection and uplink MS transmit antenna selection by using the one reserved bit in "OFDMA SS demodulator for MIMO support" and "OFDMA SS modulator for MIMO support" TLV, respectively, in the SBC-REQ message. Similarly, BS indicates its capability of supporting downlink MS receive antenna selection and uplink MS transmit antenna selection by using the one reserved bit in these two TLVs in the SBC-RSP message.

4 Performance for antenna selection

Figure 1 demonstrates how MS antenna selection can improve the performance at link level of a MIMO system. As shown in Figure 1, MS antenna selection outperforms the non-AS case in terms of BER, in both correlated and uncorrelated channel models. Antenna selection in correlated channel even outperforms the non-AS case in uncorrelated channel at high SNR, since AS gives a larger diversity gain.

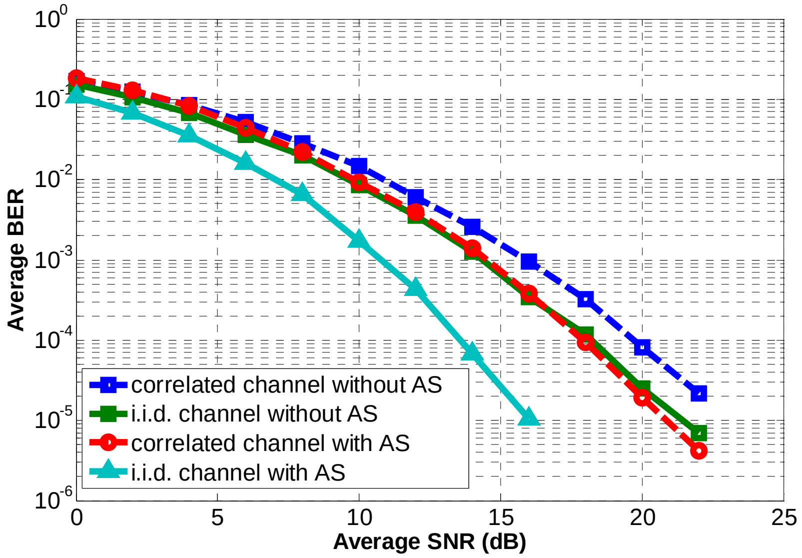

Figure 1: Average BER

Table 2: Parameters for link-level simulation used in Figure 1

Traffic	Downlink
Permutation	FUSC
Number of transmit antenna at MS	2
Number of transmit RF chain at MS	2
Number of receive antenna at MS	4
Number of receive RF chain at MS	2
Number of transmit antenna at BS	4
Number of transmit RF chain at BS	4
Number of receive antenna at BS	4
Number of receive RF chain at BS	4
Fading	Rayleigh
Path loss	3.7
Distance between MS and BS	500m

Figure 2 through Figure 5 provide system level performance results for antenna selection. The simulation is conducted in OPNET WiMAX model. Figure 2 plots the instantaneous throughput over time when the MS and the BS are 700 meters apart. As the channel gain for a particular propagation path varies with time, its associated SNR fluctuates accordingly. This results in the variation of throughput. When antenna selection is not applied, a fixed antenna element continuously transmits data. As shown in the figure, the instantaneous throughput varies over a wide range from 0 to 6 Mbps, with an average of 3 Mbps. When antenna selection is enabled at the MS, the antenna element with the best channel gain (and highest SNR) is selected for UL data transmission. The resultant instantaneous throughput is much more stable and hovers around 6 Mbps. The AS mechanism with 4 antennas has double the throughput of a terminal with only a single antenna.

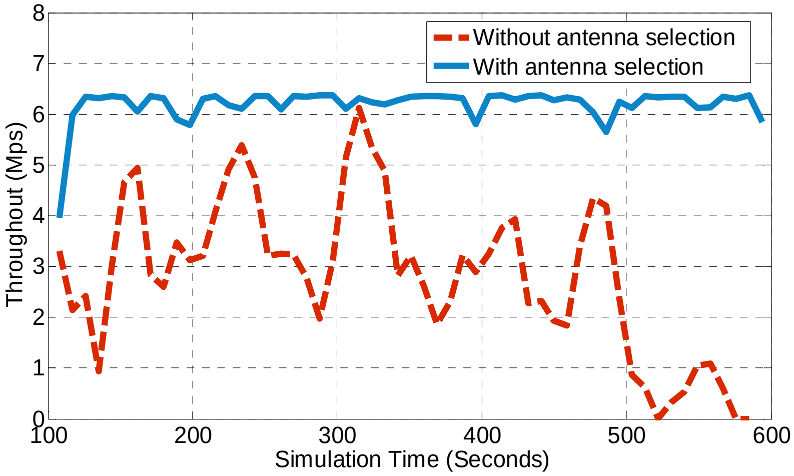

Figure 2: Instantaneous throughput with ARQ

Figure 3 and Figure 4 illustrate the cumulative distribution function (CDF) of the packet delays experienced by an ARQ-enabled MS without and with antenna selection, respectively. The two figures clearly demonstrate that antenna selection can significantly lower system latency. This is because of the better channel gain achieved by antenna selection, which considerably reduces the number of retransmissions.

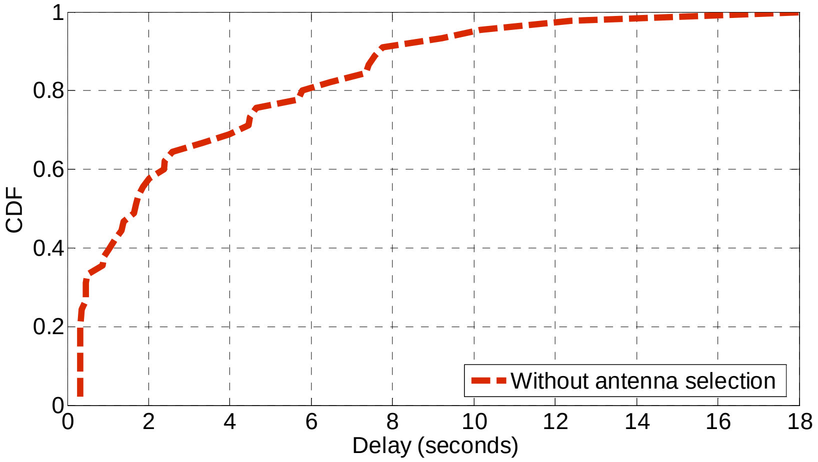

Figure 3: Delay CDF without antenna selection

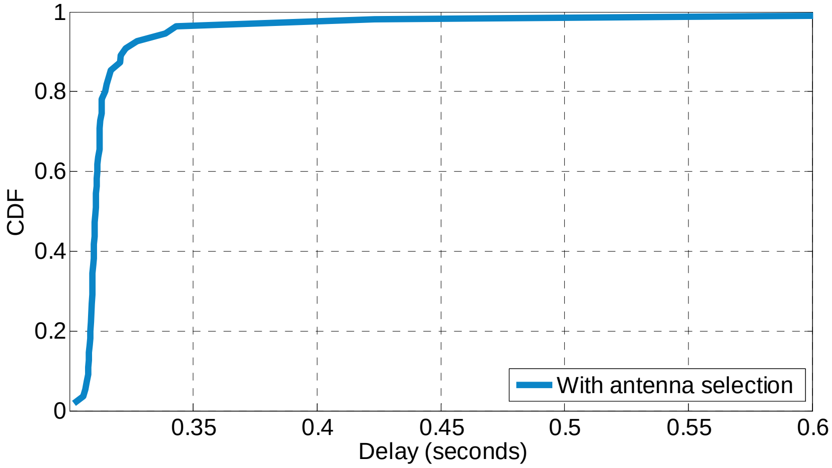

Figure 4: Delay CDF with antenna selection

In Figure 5, the average throughput is plotted as a function of the BS to MS distance. When compared with no-antenna selection, using antenna selection clearly increases the average throughput. In the figure, antenna selection, in fact, enhances the system throughput by as much as 100% in specific situations. At the same time, we also observe for small BS-MS distances, e.g., 500 meters or less, the throughputs with and without antenna selection are quite similar despite the difference between the corresponding SNR values. This saturation in throughput for high SNRs occurs because of the limitation on throughput imposed by the maximum modulation constellation size.

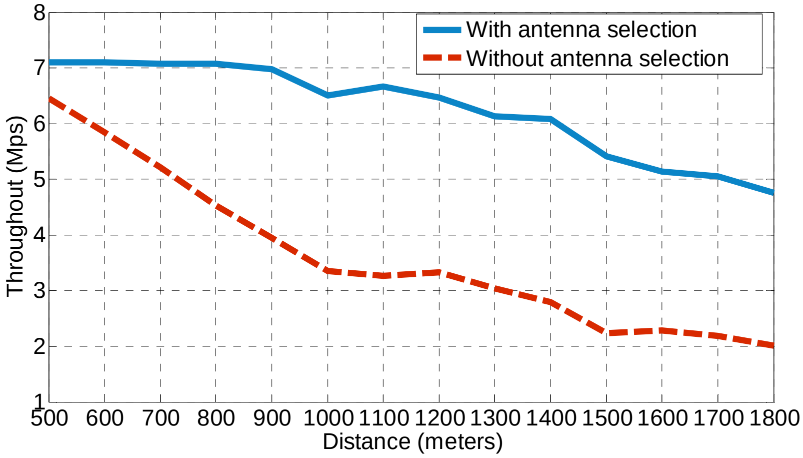

Figure 5: Throughput improvement enabled by antenna selection

Table 3: Parameters for system-level simulation used in Figure 2 through Figure 5

Coherence Time	50 milliseconds
Distance between MS and BS	500 ~1800m
MS Transmit Power	50 mW
BS Antenna Gain	15 dB
MS Antenna Gain	-1 dB
Number of Antennas	4
Number of RF chains	1

Modulation & Coding Rate	64QAM, CC1/2
Scheduling Type	rtPS
OFDMA FFT Size	2048
Path Loss Model	Free Space
UL to DL Bandwidth Ratio	1/3
Permutation	PUSC
Traffic direction	UL
Frame duration	5ms
ARQ Mechanism	Go-Back-N (window size 512 blocks)

5 Proposed Text Change

8.4 WirelessMAN-OFDMA PHY

8.4.5.4.4.1 UL-MAP Extended IE format

[Revise table 365 as follows]

Table 365—Extended UIUC code assignment for UIUC = 15

Extended UIUC (hexadecimal)	Usage
01	Power control IE
…	…
0A	UL Allocation Start IE
0B	*UL antenna selection control IE*
0C…0F	Reserved

[Insert subclause 8.4.5.4.29 as follows]

8.4.5.4.29 UL antenna selection control IE

This IE may be transmitted by BS to initiate an uplink MS transmit antenna selection.

Table 424a—UL antenna selection control IE format

Syntax	Size (bit)	Notes
Antenna_Selection_Control_IE() {	*-*	*-*
Extended UIUC	*4*	*Antenna selection control = 0x0B*
Length	*4*	*Length = 0x01*
UL_AS_Indication	*1*	*Indicates whether mobile station shall perform uplink transmit antenna selection in the current frame.*
UL_AS_Selection	*7*	*The value of this field indicates which*

		antenna set shall be chosen by the MS for uplink transmission.
}		

If "UL_AS_Indication" field is set to 0, the MS uses the "UL_AS_Selection" field to determine the antenna set selected by the BS. More specifically, the value of the "UL_AS_Selection" field indicates which antenna set has been selected for future transmission. For example, if "UL_AS_Indication" field is "0x01", this means that the antenna set switched to immediately after using the original antenna set should be chosen for subsequent uplink transmission. To make the MS use the same antenna set, the BS sends "0x00".

If "UL_AS_Indication" field is set to 1, it indicates that the MS should perform an AS-training in the current frame, i.e., send out corresponding UL pilot that allows the BS to determine the best antenna subset for future use.

[Insert subclause 8.4.8.7 as follows]

8.4.8.7 Antenna Selection at the MS

In order to enhance throughput and reduce complexity, the IEEE 802.16m standard supports antenna selection at the mobile station. As an example, Figure xxx shows the structure of a transmitter in a 1-out-of-2 selection system.

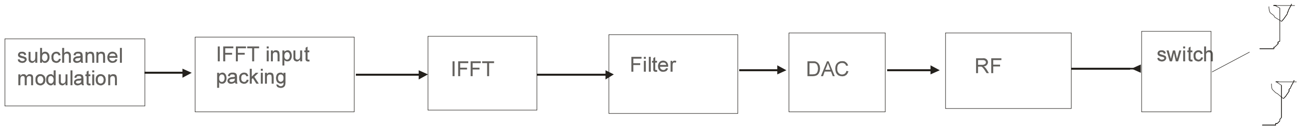

Figure xxx: Structure of a transmitter in a 1-out-of-2 antenna selection system

During the connection setup, AS capabilities and parameters shall be exchanged. During data transmission, signalling to effect AS training and notify the MS about which antennas to use is done according to subclause ?

11. TLV encodings

11.8.3.7.5 OFDMA SS demodulator for MIMO support

[Revise the table as follows]

Type	Length	Value	Scope
176	3	Bit #0 2-antenna STC matrix A … Bit #21: Concurrent allocation support in a DL PUSC STC zone with dedicated pilots *Bit #22: Capable of DL MS receive antenna selection* #23: *Reserved*	SBC-REQ (See 6.3.2.3.23) SBC-RSP (See 6.3.2.3.24)

[Insert the following paragraph at the end of 11.8.3.7.5]

If bit #22 is set to 1, it means that DL MS receive antenna selection is supported by the station that transmit this TLV. If bit #22 is set to 0, then DL MS receive antenna selection is not supported.

11.8.3.7.16 OFDMA SS modulator for MIMO support

[Revise the table as follows]

Type	Length	Value	Scope
177	2	Bit #0: Capable of 2-antenna STC Matrix A … Bit #8: Capable of disabling UL subchannel rotation Bit *Bit #9: Capable of UL MS transmit antenna selection* #*10*-15: *Reserved*	SBC-REQ (See 6.3.2.3.23) SBC-RSP (See 6.3.2.3.24)

[Insert the following paragraph at the end of 11.8.3.7.16]

If bit #9 is set to 1, it means that UL MS transmit antenna selection is supported by the station that transmit this TLV. If bit #9 is set to 0, then UL MS transmit antenna selection is not supported.

6 Appendix: Theory of antenna selection

Antenna subset selection is an attractive solution to the complexity issue of MIMO systems, and furthermore greatly improves the throughput/reliability tradeoff [4-8] and references therein). In such subset selections, the number of RF chains is smaller than the actual number of antenna elements. The RF chains are connected to the "best" antenna elements, where "best" depends on the channel state (i.e., can vary with time). In many scenarios, judicious antenna selection may incur little or no loss in system performance, while significantly reducing system cost (compared to full-complexity systems with the same number of antenna elements). Moreover, theoretical analysis showed that antenna selection maintains the high data rate of spatial multiplexing MIMO systems, and improves diversity order in each data stream without complex space-time processing at transmitters and receivers [9] (compared to a full-complexity system with the same number of RF chains). The increased diversity order boosts performance especially at high SNR.

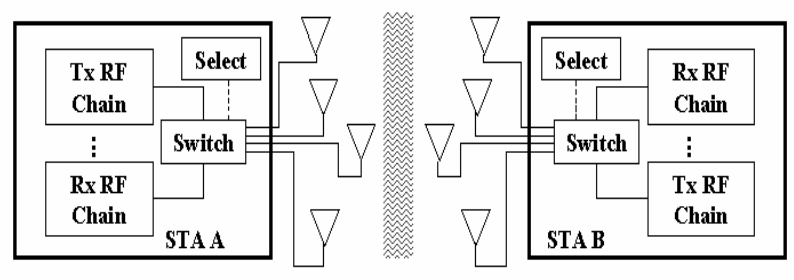

Figure 6: Antenna selection system model

In the MIMO-OFDM system applying AS (Figure A1), the transmit station A (STA A) has a set of N_A antennas with $n_A \le N_A$ transmit RF chains, while N_B and n_B are similarly defined at the receive station B. Antenna switches are applied so that the optimal subset of antennas are selected and connected to the RF chains, based on current channel state information (CSI). In general each AS training cycle consists of an *AS training phase* and a *data transmission phase*, though those phases can be interlaced. Several *AS training fields* are transmitted in each AS training phase, each of them is transmitted from and/or received by one subset of available antenna elements. The period of one AS cycle (training plus data transmission) is denoted as T_{AS}. The computation of the best antennas is based on the channel state information between all N_A transmit and all N_B receive antenna elements, on all OFDM subcarriers. This channel state information is estimated from all the AS training fields within one training cycle. In the data transmission phase, a relationship between a transmitted signal and a received signal in each OFDM subcarrier (for denotation simplicity we omit the subcarrier index here) can be expressed as:

$$\mathbf{r}_B = \mathbf{F}_B^H [\tilde{\mathbf{H}}_{AB}(t)\mathbf{F}_A \mathbf{s}_A + \mathbf{n}], \qquad (1)$$

where $\mathbf{r}_B$ is a $n_B \times 1$ received signal vector, $\mathbf{s}_A$ is a $n_A \times 1$ transmitted signal vector, and $\tilde{\mathbf{H}}_{AB}(t)$ is a $N_B \times N_A$ *equivalent-baseband time-varying channel matrix containing the complete physical channel responses and the effect of the antennas as well as the impulse responses of the transmit and receive RF chains*, where *t* represents the time. A noise vector **n** has $N_B \times 1$ entries that are independent and identically distributed (i.i.d.) zero-mean circular complex Gaussian random variables with variance N_0. $\mathbf{F}_A$ is a $N_A \times n_A$ transmit antenna selection matrix, and $\mathbf{F}_B$ is a $N_B \times n_B$ receive antenna selection matrix. Both $\mathbf{F}_A$ and $\mathbf{F}_B$ are submatrices of an identity matrix, representing antenna selection. The equivalent channel matrix after antenna selection is a $n_B \times n_A$ matrix $\mathbf{H}_{SL} = \mathbf{F}_B^H \tilde{\mathbf{H}}_{AB}(t)\mathbf{F}_A$, which is a *submatrix* of the *complete channel matrix* $\tilde{\mathbf{H}}_{AB}(t)$. The superscript '*H*' denotes the conjugate transpose. As mentioned earlier, the equivalent channel $\tilde{\mathbf{H}}_{AB}(t)$ also includes the impact of the RF responses:

$$\tilde{\mathbf{H}}_{AB}(t) = \mathbf{C}_{B,Rx}(\mathbf{F}_B)\mathbf{H}_{AB}(t)\mathbf{C}_{A,Tx}(\mathbf{F}_A), \qquad (2)$$

where $\mathbf{H}_{AB}(t)$ is the physical propagation channel, $\mathbf{C}_{A,Tx}(\mathbf{F}_A)$ is a $N_A \times N_A$ diagonal matrix whose *i-th* diagonal element $[\mathbf{C}_{A,Tx}(\mathbf{F}_A)]_{ii}$ describes the RF response corresponding to the *i-th* transmit antenna element, which is a function of the antenna selection matrix $\mathbf{F}_A$: if the *i-th* row in $\mathbf{F}_A$ contains all zeros, the *i-th* antenna is not selected, so $[\mathbf{C}_{A,Tx}(\mathbf{F}_A)]_{ii} = 0$; if the element at the *i-th* row and *l-th* column of $\mathbf{F}_A$ is one, the *i-th* antenna is selected and is connected to the *l-th* transmit RF chain during the data transmission phase. Then $[\mathbf{C}_{A,Tx}(\mathbf{F}_A)]_{ii} = \alpha_{li}^{(Tx)}$, which is a complex number characterizing both the amplitude attenuation and phase shift of the RF response (seen at baseband) corresponding to the connection between transmit RF chain *l* and antenna element *i*. $\mathbf{C}_{B,Rx}(\mathbf{F}_B)$ is similarly defined: $[\mathbf{C}_{B,Rx}(\mathbf{F}_B)]_{jj} = \beta_{li}^{(Rx)}$ if the element at the *j-th* row and *l-th* column of $\mathbf{F}_B$ is one. Here $\mathbf{C}_{A,Tx}(\mathbf{F}_A)$ and $\mathbf{C}_{B,Rx}(\mathbf{F}_B)$ are diagonal, since we assume perfect separations among different RF chains. In reality, a 30—40 dB of cross-talk mitigation is achievable, so the off-diagonal entries in $\mathbf{C}_{A,Tx}(\mathbf{F}_A)$ and $\mathbf{C}_{B,Rx}(\mathbf{F}_B)$ can be approximately assumed to be zero.

On the other hand, in the *m-th* AS training field, a relationship between a transmitted signal and a received signal can be expressed as:

$$\mathbf{r}_{B\_T}(m) = \mathbf{T}_B^H(m)[\tilde{\mathbf{H}}_{AB}(t_m)\mathbf{T}_A(m)\mathbf{s}_{A\_T} + \mathbf{n}], \qquad (3)$$

where t_m is the time at which the *m*-th training field is received, $\mathbf{s}_{A\_T}$ and $\mathbf{r}_{B\_T}$ are the training and received vectors; $\mathbf{T}_A(m)$ and $\mathbf{T}_B(m)$ are the predetermined antenna mapping matrices in the *m*-th AS training field, indicating the (pre-determined) connections of all the available RF chains to the *m*-th antenna subset. All these antenna subsets are typically mutually exclusive. For example, if $N_A = 4, n_A = 2, N_B = 2, n_B = 2$, in the case of disjoint antenna subset training, we have 2 training fields with the transmit antenna mapping matrices:

$$\mathbf{T}_A(1) = \begin{bmatrix} 1 & 0 \\ 0 & 1 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \text{ and } \mathbf{T}_A(2) = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix}.$$

Then there are totally $M = \lceil N_A / n_A \rceil \lceil N_B / n_B \rceil$ training fields, where $\lceil x \rceil$ is the smallest integer larger than or equal to *x*. STA B can estimate the complete channel matrix (which will be used for AS computations) by combining the *M* training fields.

The time-variation in $\mathbf{H}_{AB}(t)$ (c.f. (2)) is a key factor for designing AS training protocols. It has to be assured that the training and subsequent data transmission occurs within a time that is (much) shorter than the coherence time of the channel. Formulating this mathematically, we denote t_0 as the time when AS computation is conducted (see Figure 2); then the channel estimation used for AS computation is heavily distorted if $\mathbf{H}_{AB}(t)$ varies significantly within $|t_0 - t_m|$ $\exists m \in [1, M]$; similarly, during the data transmission phase ($t \geq t_0$), the previously selection result gets stale if $\mathbf{H}_{AB}(t)$ varies significantly within $|t - t_0|$.

To illustrate different kinds of distortions imposed on AS channel estimations, we investigate an exact expression for the complete channel matrix: by ignoring channel estimation errors, the estimated subchannel by training field *m* is

$$\begin{matrix} \tilde{\mathbf{H}}'_{AB}(m) = \mathbf{T}_B^H(m)\mathbf{C}_{B,Rx}(\mathbf{T}_B(m))\mathbf{H}_{AB}(t_m)\cdot \\ \mathbf{C}_{A,Tx}(\mathbf{T}_A(m))\mathbf{T}_A(m) \end{matrix}, \qquad (4)$$

so the AS computation is conducted based on the following estimated complete channel matrix:

$$\tilde{\mathbf{H}}'_{AB} = \mathbf{C}'_{B,Rx}\mathbf{H}_{AB}^{\text{comb}}\mathbf{C}'_{A,Tx}, \qquad (5)$$

where the diagonal matrix $\mathbf{C}'_{A,Tx}$ contains all non-zero diagonal values: $[\mathbf{C}'_{A,Tx}]_{ii} = [\mathbf{C}_{A,Tx}(\mathbf{T}_A(m))]_{ii}$, if the *i-th* antenna element is trained by the *m-th* training field, and $\mathbf{C}'_{B,Rx}$ is similarly defined; $\mathbf{H}_{AB}^{\text{comb}}$ is a composite physical channel matrix, in which the *k-th* column/row is equal to $\left[\mathbf{H}_{AB}(t_m)\right]_{*k}$ or $\left[\mathbf{H}_{AB}(t_m)\right]_{k*}$ if it is trained in the *m-th* training field. AS computation is based on the estimated complete matrix $\tilde{\mathbf{H}}'_{AB}$ in (5). When using a selection criterion X (**A**), the selection can be expressed as:

$$\{\mathbf{F}_{A,opt}, \mathbf{F}_{B,opt}\} = \arg\max_{\mathbf{F}_A, \mathbf{F}_B} X(\mathbf{F}_B^H \tilde{\mathbf{H}}'_{AB} \mathbf{F}_A). \qquad (6)$$

For example, if the criterion is the maximization of the capacity, we have [10]

$$X(\mathbf{A}) = \log_2 \left| \mathbf{I} + (\rho_0 / n_A)\mathbf{A}\mathbf{A}^H \right|, \qquad (7)$$

where ρ_0 is the average received signal-to-noise ratio.

The inaccuracy in the physical channel due to time variation can be expressed by:

$$\mathbf{H}_{AB}^{\text{comb}} = \mathbf{H}_{AB}(t_0) + \Delta\mathbf{H}_{AB}, \qquad (8)$$

which may distort $\tilde{\mathbf{H}}'_{AB}$ in (5), and is named *additive distortion*.

7 Reference

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