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Re:	DL MIMO Rapporteur Group Discussions
Abstract	A consolidated SDD text on the DL MIMO schemes based on DL MIMO SDD text proposals submitted to the 802.16m email reflector is provided in this draft.
Purpose	For review and discussion in the Project 802.16m DL MIMO Rapporteur Group
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Patent Policy	

Final Draft: SDD Text on Downlink MIMO

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In order to provide a general framework, SDD text for the DL MIMO Scheme in this draft has been organized by function. Reference to specific solutions and terminology has been avoided. Dependencies on text in the SDD that is still under development have been captured in notes wherever applicable.

[*Chair's Notes: After Draft #3 was released, we realized that in the .16e spec (and Rev2), the word "layer" is used instead of the word "codeword", and the word "stream" is used instead of the word "layer". We need to follow the same terminology, since .16m and .16e will belong in the same standard.*

The Pilot section is being handled by discussion within the DL_PHY group, and we will need to match text in the Pilot section with that developed by the DL_PHY group.

Signaling support for MIMO should be coordinated with DL control channel design.]

11.x DL MIMO Transmission Scheme

11.x.1 DL MIMO Architecture and Data Processing

The architecture of downlink MIMO on the transmitter side is shown in the Figure 1.
In SU-MIMO, only one user is scheduled in one Resource Unit (RU). In MU-MIMO, multiple users can be scheduled in one RU.
If vertical encoding is utilized, there is only one encoder/modulator block (one "layer"). If horizontal encoding is utilized, there are multiple encoders/modulators (multiple "layers").

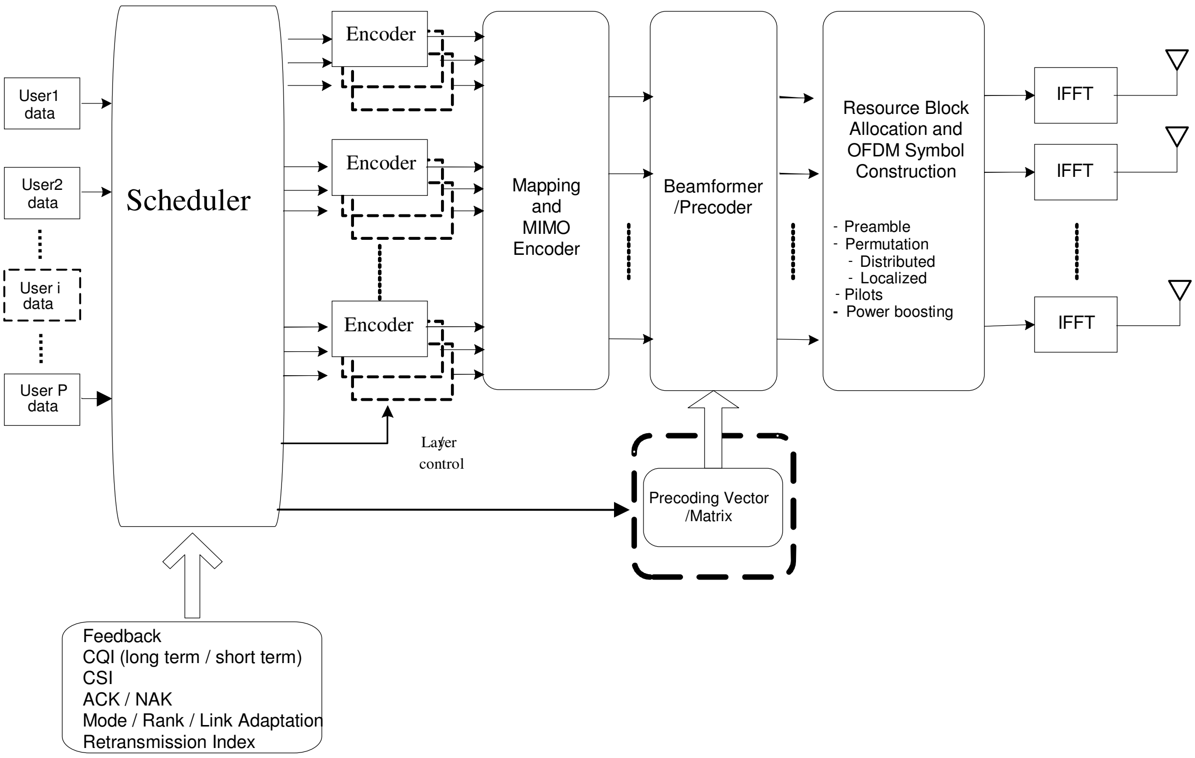

Figure 1: MIMO Architecture

The encoder block contains the channel encoder, interleaver, rate-matcher, and modulator for each layer.

The MIMO encoder block maps L (≥1) layers onto M (≥L) streams, which are fed to the precoding block.

The precoding block maps streams to antennas by generating the antenna-specific data symbols according to the selected MIMO mode.

The OFDM symbol construction block maps antenna-specific data to the OFDM symbol. The permutation and pilot insertion are implemented in this block.

The feedback block contains feedback information such as CQI and CSI from the MS.

The scheduler block will schedule users to resource blocks and decide their MCS level, MIMO parameters (MIMO mode, rank). This block is responsible for making a number of decisions with regards to each resource allocation, including:

- ***Allocation type***: Whether the allocation in question should be transmitted with a distributed or localized allocation
- ***Single-user (SU) versus multi-user (MU) MIMO***: Whether the resource allocation should support a single user or more than one user
- ***MIMO Mode***: Which open-loop (OL) or closed-loop (CL) transmission scheme should be used for the user(s) assigned to the resource allocation.
- ***User grouping***: For MU-MIMO, which users should be transmitted to on the resource allocation

- ***Rank selection***: For SU-MIMO, the spatial multiplexing factor or number of streams to be used for the user allocated to the resource allocation. For MU-MIMO, the number of users sharing the resource allocation.
- ***MCS level per layer***: The modulation and coding rate on each layer must be determined.
- ***Pilot boosting***: The power boosting value to be used on the data and pilot symbols.
- ***Band selection***: If localized resource allocation is used, where in the frequency band should the localized allocation be placed.

11.x.1.1. Antenna Configuration

The BS employs a minimum of two transmit antennas. The MS employs a minimum of two receive antennas. The antenna configurations are (N_T, N_R) = (2, 2), (4, 2), (4, 4), (8, 2), and (8, 4), where N_T denotes the number of BS transmit antennas and N_R denotes the number of MS receive antennas. (8,8) with 8 streams is FFS.

11.x.1.2. Layer to Stream Mapping

The number of spatial streams, M, for SU-MIMO is $M \le \min(N_T, N_R)$, where M is no more than 4. MU-MIMO can have up to 2 streams with 2 Tx antennas, and up to 4 streams for 4 Tx antennas and 8Tx antennas.

For SU-MIMO, Vertical encoding (SCW) is employed. [The support of horizontal encoding (MCW) for SU-MIMO is FFS]. For MU-MIMO, MCW (or horizontal) encoding is employed at the base-station while only one layer is transmitted to each mobile station.

11.x.1.3. Stream to Antenna Mapping

The stream to antenna mapping depends on the MIMO scheme used. The mapping can be defined using the following equation

$$\mathbf{y} = \mathbf{P} \times \mathbf{S}(\mathbf{x}),$$

where $\mathbf{P}$ is a pre-coding matrix, $\mathbf{S}(\mathbf{x})$ is an STC matrix, and $\mathbf{x}$ is the input layer vector.

11.x.1.4. Resource mapping

The following table illustrates the MIMO mode permutation for various MIMO schemes.

MIMO Scheme	Resource Mapping
Open-loop SU-MIMO	Distributed or Localized
Closed-loop SU-MIMO	Localized
MU-MIMO	Localized

The support of distributed resource channels for closed-loop SU-MIMO and MU-MIMO is FFS.

11.x.1.5. Pilots

11.x.1.6. Signaling support for MIMO

11.x.2. Transmission for Data Channels

11.x.2.1. Single-user MIMO

Single-user MIMO schemes are used to improve per-link performance.

Both open-loop single-user MIMO and closed-loop single-user MIMO are supported for the antenna configurations specified in Section 11.x.1.1. A variety of transmission modes are supported in each case.

For open-loop single-user MIMO, both spatial multiplexing and transmit diversity schemes are supported. Note that in the case of open-loop single-user MIMO, CQI and rank feedback may still be transmitted to assist the base station's decision of rank adaptation, transmission mode switching, and rate adaptation.

For closed-loop single-user MIMO, codebook based precoding are supported for both TDD and FDD systems. CQI, PMI, and rank feedback can be transmitted by the mobile station to assist the base station's scheduling, resource allocation, and rate adaptation decisions. Note that the CQI, PMI, and rank feedback may or may not be frequency dependent.

For closed-loop single-user MIMO, sounding based precoding are supported for TDD systems. The mobile station may transmit CQI and rank information to assist the base station's scheduling, resource allocation, and rate adaptation decisions. Note that the CQI and rank feedback may or may not be frequency dependent.

As described in section 11.x.1, the overall structure of MIMO processing has two parts. The first part is the MIMO encoder and second part is the precoder.

The MIMO encoder is a batch processor that operates on M input symbols at a time. The input to the MIMO encoder is represented by an $M \times 1$ vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ \vdots \\ s_M \end{bmatrix},$$

where s_i is the i-th input symbol within a batch. The output of the MIMO encoder is an $M \times N_F$ MIMO STC matrix $\mathbf{z} = \mathbf{S}(\mathbf{x})$, which serves as the input to the precoder. The output of the precoder is denoted by a matrix $N_T \times N_F$ matrix

$$\mathbf{y} = \begin{bmatrix} y_{1,1} & y_{1,2} & \cdots & y_{1,N_F} \\ y_{2,1} & y_{2,2} & \cdots & y_{2,N_F} \\ \vdots & \vdots & \ddots & \vdots \\ y_{N_T,1} & y_{N_T,2} & \cdots & y_{N_T,N_F} \end{bmatrix},$$

where $y_{i,j}$ is the output symbol to be transmitted via the i-th physical antenna on the j-th subcarrier. Note N_F is the number of subcarriers used to transmit the MIMO signals derived from the input vector **x**. For open-loop SU-MIMO, the rate of a mode is defined as $R = M / N_F$.

11.x.2.1.1. Open-loop SU-MIMO

A number of antenna configurations and transmission rates are supported in open-loop SU-MIMO. Among them, 2Tx antennas with rate 1 transmission and 4Tx antennas with rate 1 transmission are defined as Transmit Diversity modes. The operation of these modes is specified in Section 11.x.2.1.1.1. The other modes, including 2Tx antennas with rate 2 transmission, 4Tx antennas with rate 2 transmission, 4Tx antennas with rate 3 transmission, and 4Tx antennas with rate 4 transmission, are defined as Spatial Multiplexing modes. The operation of these modes is specified in Section 11.x.2.1.1.2. The dimensions of the vectors and matrices for open-loop SU-MIMO are shown in the following table:

Table 1. Matrix dimensions for open-loop SU-MIMO modes

N_T	Rate	M	N_F
2	1	2	2
4	1	2	2
8	1	2	2
2	2	2	1
4	2	2	1
8	2	2	1
4	3	3	1
8	3	3	1
4	4	4	1
8	4	4	1

On a given frequency resource k [size is FFS], the precoding matrix **P** can be defined using the following equation:

$$\mathbf{P}(k) = \mathbf{D}(k)\mathbf{W}(k).$$

The precoder is composed of two matrices. The first matrix $\mathbf{W}(k)$ is an $N_T \times M$ matrix, where N_T is the number of transmit antennas and M is the numbers of layers. The matrix $\mathbf{W}(k)$ is selected from a predefined unitary codebook, and changes every u subcarriers. [The detailed unitary codebook, and the parameter u are FFS.] The second matrix $\mathbf{D}(k)$ is an $N_T \times N_T$ diagonal matrix as follows,

$$\mathbf{D}(k) = \begin{bmatrix} e^{j\theta_0 k} & 0 & \cdots & 0 \\ 0 & e^{j\theta_1 k} & \cdots & 0 \\ \vdots & \vdots & \ddots & \vdots \\ 0 & 0 & \cdots & e^{j\theta_{(N_T-1)} k} \end{bmatrix}$$

where k denotes frequency resource index and $\theta_i, i = 0, 1, 2, ..., N_T - 1$ denotes the phase shift for the i-th transmit antenna. [The value of the phase shift θ_i is FFS.]

11.x.2.1.1.1. Transmit Diversity

The following transmit diversity modes are supported for open-loop single-user MIMO:

- 2Tx rate-1: STBC/SFBC
- 4Tx rate-1: STBC/SFBC with precoder
- 8Tx rate-1: STBC/SFBC with precoder

In Transmit Diversity mode, the MIMO encoder generates 2Tx STBC/SFBC, and then multiplied by $N_T \times 2$ unitary matrix and $N_T \times N_T$ diagonal matrix as described in section 11.x.2.1.1.

For the transmit diversity modes, the input to the MIMO encoder is represented a 2×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}.$$

The output of the MIMO encoder is a 2×2 matrix

$$\mathbf{z} = \begin{bmatrix} s_1 & s_2 \\ -s_2^* & s_1^* \end{bmatrix}.$$

For the 2Tx rate-1 mode, the output of the precoder is a 2×2 matrix

$$\mathbf{y} = \mathbf{z}.$$

For the 4Tx rate-1, the output of the precoder is a 4×2 matrix

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 4×2 unitary precoder and **D** is a 4×4 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

For the 8Tx rate-1, the output of the precoder is a 8×2 matrix

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 8×2 unitary precoder and **D** is a 8×8 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

11.x.2.1.1.2. Spatial Multiplexing

The following spatial multiplexing modes are supported for open-loop single-user MIMO:

- Rate-2 spatial multiplexing modes:
  - 2Tx rate-2: rate 2 SM
  - 4Tx rate-2: rate 2 SM with precoding
  - 8Tx rate-2: rate 2 SM with precoding
- Rate-3 spatial multiplexing modes:
  - 4Tx rate-3: rate 3 SM with precoding
  - 8Tx rate-3: rate 3 SM with precoding
- Rate-4 spatial multiplexing modes:
  - 4Tx rate-4: rate 4 SM
  - 8Tx rate-4: rate 4 SM with precoding

For the rate-2 spatial multiplexing modes, the input to the MIMO encoder is represented as a 2×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix}.$$

The output of the MIMO encoder is a 2×1 vector

$$\mathbf{z} = \mathbf{x}.$$

For the 2Tx rate-2 mode, the output of the precoder is a 2×1 vector

$$\mathbf{y} = \mathbf{z}.$$

For the 4Tx rate-2 mode, the output of the precoder is a 4×1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 4 × 2 unitary precoder and **D** is a 4 × 4 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

For the 8Tx rate-2 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 8 × 2 unitary precoder and **D** is a 8 × 8 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

For the rate-3 spatial multiplexing modes, the input to the MIMO encoder is represented as a 3 × 1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \end{bmatrix}.$$

The output of the MIMO encoder is a 3 × 1 vector

$$\mathbf{z} = \mathbf{x}.$$

For the 4Tx rate-3 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 4 × 3 unitary precoder and **D** is a 4 × 4 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

For the 8Tx rate-3 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 8 × 3 unitary precoder and **D** is a 8 × 8 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

For the rate-4 spatial multiplexing modes, the input to the MIMO encoder is represented as a 4×1 vector

$$\mathbf{x} = \begin{bmatrix} s_1 \\ s_2 \\ s_3 \\ s_4 \end{bmatrix}.$$

The output of the MIMO encoder is a 4 × 1 vector

$$\mathbf{z} = \mathbf{x}.$$

For the 4Tx rate-4 mode, the output of the precoder is a 4 × 1 vector

$$\mathbf{y} = \mathbf{z}.$$

For the 8Tx rate-4 mode, the output of the precoder is a 8 × 1 vector

$$\mathbf{y} = \mathbf{D} \times \mathbf{W} \times \mathbf{z},$$

where **W** is a 8 × 4 unitary precoder and **D** is a 8 × 8 diagonal delay matrix. Note that **W** and **D** may be frequency dependent as described in section 11.x.2.1.1.

11.x.2.1.2. Closed-loop SU-MIMO

11.x.2.1.2.1. Precoding technique

In FDD and TDD systems, unitary codebook based precoding are supported.

In TDD systems, sounding based precoding is supported.

11.x.2.1.3. Feedback for SU-MIMO

In FDD systems and TDD systems, a mobile station may feedback the following information in SU-MIMO mode:

- Rank (Wideband or sub-band)
- Sub-band selection
- CQI (Wideband or sub-band, per CW or per user)
- PMI (Wideband or sub-band)

For codebook based precoding, the feedback from a mobile station shall be based on the same codebook as used by base station for transmission.

The feedback information may be transmitted via a physical layer control channel or via a higher layer signaling message.

In TDD systems, a mobile station may transmit a sounding signal on the uplink.

11.x.2.2. Multi-user MIMO

Multi-user MIMO schemes are used to enable a resource allocation to communicate data to two or more MSs. 802.16m uses Multi-user MIMO to boost system throughput.

Multi-layer transmission with one layer per user are supported for MU-MIMO. MU-MIMO includes the MIMO configuration of 2Tx antennas to support up to 2 users, and 4Tx or 8Tx antennas to support up to 4 users.

11.x.2.2.1. Precoding technique

The basic precoding techniques for MU-MIMO are codebook based precoding and vendor-specific adaptive precoding / beamforming. Up to four MSs can be assigned to each resource allocation.

In MU-MIMO systems, the received signal of the f-th subcarrier in the i-th MS can be described as:

$$\mathbf{y}_{i,f} = \mathbf{H}_{i,f} \sum_{j=1}^{K} \mathbf{V}_{j,f} \mathbf{x}_{j,f} + \mathbf{n}_{i,f}$$

where K is the number of the allocated users, $\mathbf{V}_{j,f}$ is the precoding matrix of the f-th subcarrier for the transmit signal to the j-th MS, $\mathbf{x}_{j,f}$ is the transmit signal of the f-th subcarrier to the j-th MS and $\mathbf{n}_{i,f}$ is the noise of the f-th subcarrier in the j-th MS.

If the assembled precoding matrix, $\mathbf{V}_f = [\mathbf{v}_{1,f} \ldots \mathbf{v}_{K,f}]$, is unitary, it is defined as unitary MU-MIMO, where the precoding vectors are orthogonal to each other to further simplify the processing. If the precoding matrix is non-unitary, it performs non-unitary MU-MIMO. With uplink sounding, the transmitter precoding is vendor-specific (either unitary or non-unitary). Note that beamforming is enabled with this precoding mechanism. Non-linear precoding is FFS.

11.x.2.2.2. Unification with SU

Predefined and flexible adaptation between SU-MIMO and MU-MIMO are supported.

11.x.2.2.3. Feedback for MU-MIMO

11.x.2.2.3.1. CQI feedback

CQI feedback should be designed to reduce the feedback overhead. For CQI feedback, the mobile station measures the downlink pilot channel, computes the channel quality index (CQI), and reports the CQI on the uplink feedback channel. Both wideband CQI and subband CQI may be transmitted by a mobile station. Wideband CQI is the average CQI of a wide frequency band. In contrast, sub-band CQI is the CQI of a localized sub-band.

11.x.2.2.3.2. CSI feedback

Channel state information feedback may be employed for MU-MIMO. Codebook-based feedback is supported in both FDD and TDD. Sounding-based feedback is supported in TDD.

The codebook is composed of a subset of the unitary matrices defined in the SU-MIMO codebook.

11.x.2.3. Rank and Mode Adaptation

To support the numerous radio environments for 802.16m systems, MIMO mode adaptation is supported. BSs and MSs may adaptively switch between DL MIMO techniques depending on parameters such as antenna configurations and channel conditions. Parameters selected for mode adaptation may have slowly or fast varying dynamics. By switching between DL MIMO techniques an 802.16m system can dynamically optimize throughput or coverage for a specific radio environment.

The MIMO modes include transmit diversity, spatial multiplexing, etc. The adaptation of these modes is related with the channel information, MS speed and average SINR. Switching between SU-MIMO and MU-MIMO is also supported.

Both dynamic and semi-static adaptation mechanisms are supported in 16m. For dynamic adaptation, the mode/rank may be changed frame by frame. By this mechanism, good performance can be achieved with higher feedback overhead. For semi-static adaptation, MS may request adaptation. The decision of rank and mode adaptation is made by the BS. The adaptation occurs slowly, and feedback overhead is less.

11.x.3. Transmission for Control Channel

11.x.3.1. Transmission for Broadcast Control Channel

A SU open-loop technique that provides diversity gain will be used here. The detailed transmit diversity scheme for the Broadcast Control Channel is FFS.

11.x.3.2. Transmission for Unicast Control Channel

A SU technique that provides diversity or beamforming gain will be used here. The detailed transmit diversity scheme for Unicast Control Channels is FFS.

11.x.4. Advanced Features

11.x.4.2 Multi-cell MIMO

Multi-cell MIMO techniques are supported for improving sector throughput and cell-edge throughput through multi-BS collaborative precoding, network coordinated beamforming, or inter-cell interference nulling. Both open-loop and closed-loop multi-cell MIMO techniques can be considered. For closed-loop multi-cell MIMO, CSI feedback via codebook based feedback or sounding channel will be used. The feedback information may be shared by neighboring base stations via network interface. Mode adaptation between single-cell MIMO and multi-cell MIMO is utilized.

11.x.4.1. MIMO for Multi-cast Broadcast Services

Open-loop spatial multiplexing schemes as described in Section 11.x.2.1.1.2 are used for MBS. The MBS data shall contain at most two layers and shall contain up to two codewords. The transmission format for multi-layer transmission includes a primary layer and a secondary layer. The primary and secondary layers may use different modulation and coding and/or power offsets in order to enable efficient interference cancellation at the mobile station.

The pilots for each layer are transmitted using the same time-frequency positions and the same scrambling code from all the BSs in a MBS zone. This provides for an overall composite channel estimate for the signal received from multiple base stations transmitting the same content in the broadcast zone. The pilots for different layers are located at different time-frequency positions.

Appendix:

The desired properties of the codebook are:
- Good performance in uncorrelated, correlated, and dual-polarized channels
- Low feedback and signaling overhead
- Low computational complexity
- Low memory requirement
- Low PAPR / Power balanced

The following codebook should be considered:
- DFT-based codebook
- 16e codebook

The desired properties of the uplink sounding signals are:
- Low cross-correlation sequences
- Low PAPR
- Low overhead