Selective-MS Precoding for Downlink MIMO Transmissions

Document Number:
IEEE S802.16m-08/410r1

Date Submitted:
2007-05-09

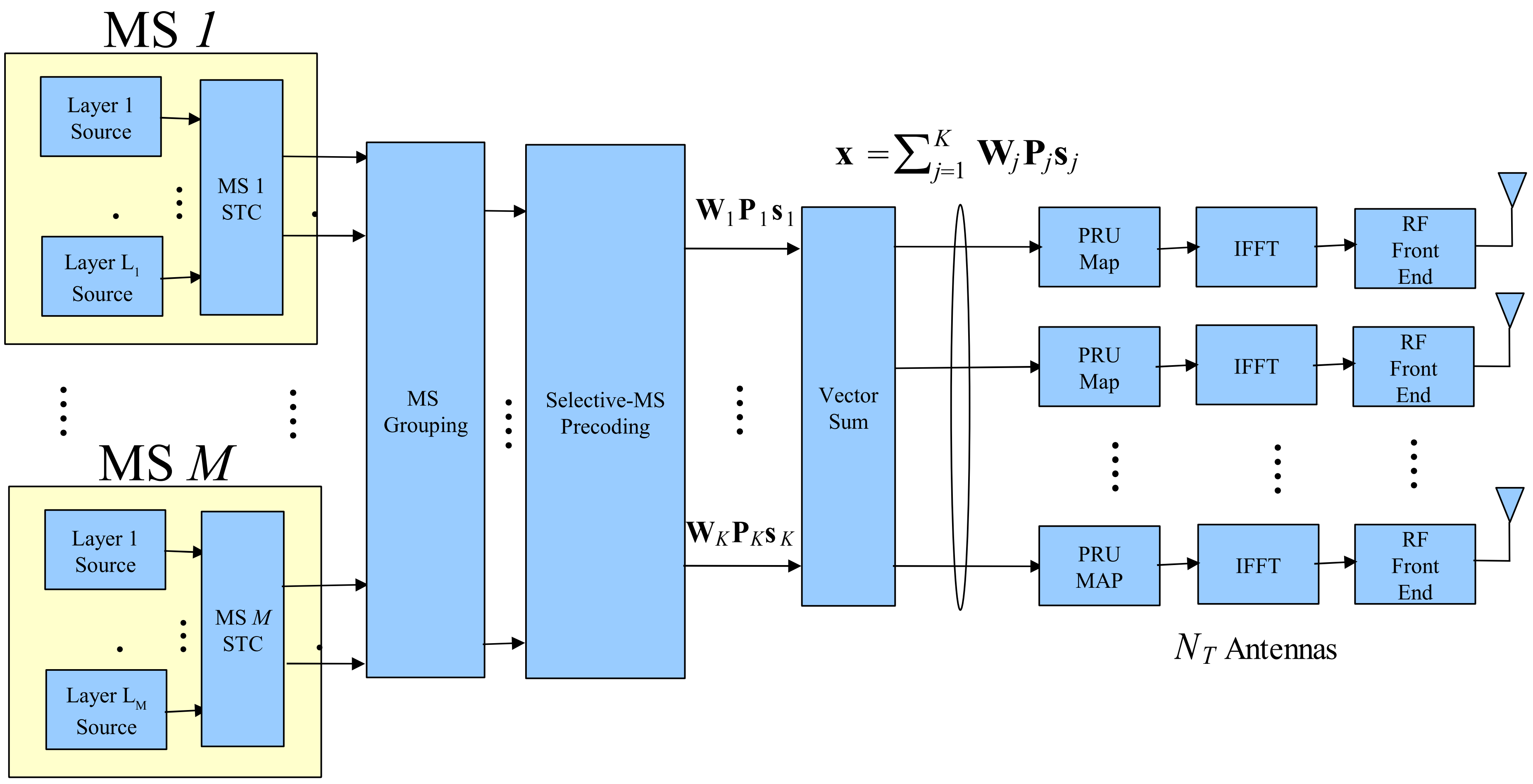
Source:
Kim Olszewski
ZTE USA, Inc. E-mail: kolszewski@zteusa.com
10105 Pacific Heights Blvd, Suite 250
San Diego, CA 92121
*<http://standards.ieee.org/faqs/affiliationFAQ.html>

Venue:
Macau, China

Base Contribution:
IEEE C802.16m-08/410r1

Purpose:
Consideration by the IEEE 802.16m TG for SDD contents

Conceptual Downlink MIMO Model



BS Transmit Signal

- Let N_T denote the number of BS transmit antennas.
- Let K_{active} denote the number of active MSs serviced by a BS.
- Let $N_{S,k} \leq \min(N_T, N_{R,k})$ denote the number of independent streams allocated to the kth active MS. $N_{R,k} \geq 1$ denotes the number of receive antennas for the kth MS.
- The total number of streams transmitted by the BS is the sum

$$N_S = \sum_{j=1}^{K_{active}} N_{S,j}$$

- The composite signal transmitted by the BS is defined as the N_T-by-1 vector

$$\mathbf{x} = \sum_{j=1}^{K_{active}} \mathbf{W}_j \mathbf{P}_j \mathbf{s}_j$$

where $\mathbf{W}_k$ is the N_T-by-$N_{S,k}$ linear precoding matrix, $\mathbf{P}_k$ an $N_{S,k}$-by-$N_{S,k}$ diagonal stream power loading matrix, and $\mathbf{s}_k$ an $N_{S,k}$-by-1 data symbol vector.

Received Signal for *k*th MS

- Let $N_{R,k} \geq 1$ denote the number of receive antennas for the *k*th MS.

- The total number of receive antennas distributed over all K_{active} MSs is

$$N_R = \sum_{j=1}^{K_{active}} N_{R,j}$$

- The received signal for the *k*th MS is the $N_{R,k}$-by-1 vector

$$\begin{aligned} \mathbf{y}_k &= \mathbf{H}_k \mathbf{x} + \mathbf{n}_k \\ &= \mathbf{H}_k \mathbf{W}_k \mathbf{P}_k \mathbf{s}_k + \mathbf{H}_k \sum_{j=1, j \neq k}^{K_{active}} \mathbf{W}_j \mathbf{P}_j \mathbf{s}_j + \mathbf{n}_k \end{aligned}$$

- The $N_{R,k}$-by-N_T matrix $\mathbf{H}_k$ denotes the channel matrix for the *k*th MS. The (i,j)th element of $\mathbf{H}_k$ represents the channel gain and phase associated with the signal path from BS transmit antenna j to MS receive antenna i. The MIMO channel matrices $\mathbf{H}_k$, $k = 1, 2, \ldots, K_{active}$, are assumed to be uncorrelated and of full rank.

BS Computations for *k*th MS's Precoder (1)

- The received signal for the *k*th MS is the $N_{R,k}$-by-1 vector

$$\mathbf{y}_k = \mathbf{H}_k \mathbf{x} + \mathbf{n}_k$$
$$= \mathbf{H}_k \mathbf{W}_k \mathbf{P}_k \mathbf{s}_k + \mathbf{H}_k \sum_{j=1, j \neq k}^{K_{active}} \mathbf{W}_j \mathbf{P}_j \mathbf{s}_j + \mathbf{n}_k$$

- The co-channel interference term can be eliminated if

$$\mathbf{H}_k \sum_{j=1, j \neq k}^{K_{active}} \mathbf{W}_j = \mathbf{0}$$

- Given the MS's MIMO channel matrices the BS constructs the $M_{R,k}$-by-N_T matrix

$$\tilde{\mathbf{H}}_k = \left[\begin{array}{cccccc} \mathbf{H}_1^T & \ldots & \mathbf{H}_{k-1}^T & \mathbf{H}_{k+1}^T & \ldots & \mathbf{H}_{K_{active}}^T \end{array} \right]^T$$

where $M_{R,k} = N_R - N_{R,k}$.

BS Computations for *k*th MS's Precoder (2)

- The BS computes the singular value decomposition of the $M_{R,k}$-by-N_T matrix $\tilde{\mathbf{H}}_k$ which is defined as
$$\tilde{\mathbf{H}}_k = \tilde{\mathbf{U}}_k \tilde{\mathbf{\Sigma}}_k \tilde{\mathbf{V}}_k^H$$

- Matrices $\tilde{\mathbf{U}}_k$ and $\tilde{\mathbf{V}}_k$ are $M_{R,k}$-by-$M_{R,k}$ and N_T-by-N_T unitary matrices. Matrix $\tilde{\mathbf{\Sigma}}_k$ is an $M_{R,k}$-by-N_T singular value matrix.

- Jacobi rotations can be used to compute the singular value decomposition of matrix $\tilde{\mathbf{H}}_k$. $M_{R,k} = N_R - N_{R,k}$ and $N_{R,k}$ are small (e.g. $M_{R,k} \leq 4$ and $N_T \leq 4$) so the BS computations for $\tilde{\mathbf{H}}_k$ are practical BS computations.

BS Computations for *k*th MS's Precoder (3)

- From $\tilde{\mathbf{V}}_k$ the BS constructs the N_T-by-$(N_T - M_{R,k})$ matrix
$$\tilde{\mathbf{V}}_k^0 = \begin{bmatrix} \tilde{\mathbf{v}}_{k,M_{R,k}+1} & \ldots & \tilde{\mathbf{v}}_{k,N_T-1} & \tilde{\mathbf{v}}_{k,N_T} \end{bmatrix}$$

- The orthonormal vectors within $\tilde{\mathbf{V}}_k^0$ form an orthonormal basis for the null space of $\tilde{\mathbf{H}}_k$ hence $\mathbf{H}_j\tilde{\mathbf{V}}_k^0 = \mathbf{0}$ for all $j \neq k$.

- A condition for the N_T-by-$(N_T - M_{R,k})$ matrix $\tilde{\mathbf{V}}_k^0$ to exist is that
$$N_T > M_{R,k} = N_R - N_{R,k}$$

BS Computations for *k*th MS's Precoder (4)

- Hence to ensure that $N_T > M_{R,k}$ the number of BS transmit antennas N_T must be as large as the *total* number of receive antennas N_R for all active MSs.

- We let $N_T = N_R$ and $N_{R,k} = N_{S,k}$ then the column dimension of $\tilde{\mathbf{V}}_k^0$ becomes $N_T - M_{R,k} = N_{S,k}$. The BS sets the precoder matrix for the *k*th MS to be the N_T-by-$N_{S,k}$ matrix

$$\mathbf{W}_k = \tilde{\mathbf{V}}_k^0$$

- The equality $\mathbf{H}_k\mathbf{W}_j = \mathbf{0}$ will be true for all $j \neq k$. Hence the co-channel interference term can be eliminated and the received signal for the *k*th MS will be

$$\mathbf{y}_k = \mathbf{H}_k\mathbf{W}_k\mathbf{P}_k\mathbf{s}_k + \mathbf{n}_k$$

MS Grouping for Selective-MS Precoding (1)

- The proposed method requires full rank MIMO channel matrices $\mathbf{H}_k$, $k = 1, 2, \ldots, K_{active}$.
- The full rank MIMO channel matrices $\mathbf{H}_k$ must also be uncorrelated.
- These conditions assure that precoder design matrix $\tilde{\mathbf{H}}_k$ defined above will have full rank.
- Selective-MS precoding will help assure that these conditions are met. It will also decrease the number of BS computations required for precoding.
- In selective-MS precoding a subset of the K_{active} active MSs is selected or scheduled to receive data for a DL subframe. The selected subset is called an MS spatial group.

MS Grouping for Selective-MS Precoding (2)

- A spatial MS grouping of active MSs is a set partition

$$\mathcal{G} = \{G_1, G_2, \ldots, G_{N_G}\}$$

where G_i denotes an MS spatial group and N_G the number of groups.

- Each MS spatial group G_i is a subset of the active MS set

$$\mathcal{M} = \{MS_1, MS_2, \ldots, MS_{K_{active}}\} = \bigcup_{i=1}^{N_G} G_i$$

where MS_i denotes the ith active MS.

- The total number of MS receive antennas N_R associated with a spatial group G_i must be less than or equal to N_T (i.e. $N_R \leq N_T$ constraint above). The MS spatial groups are disjoint.

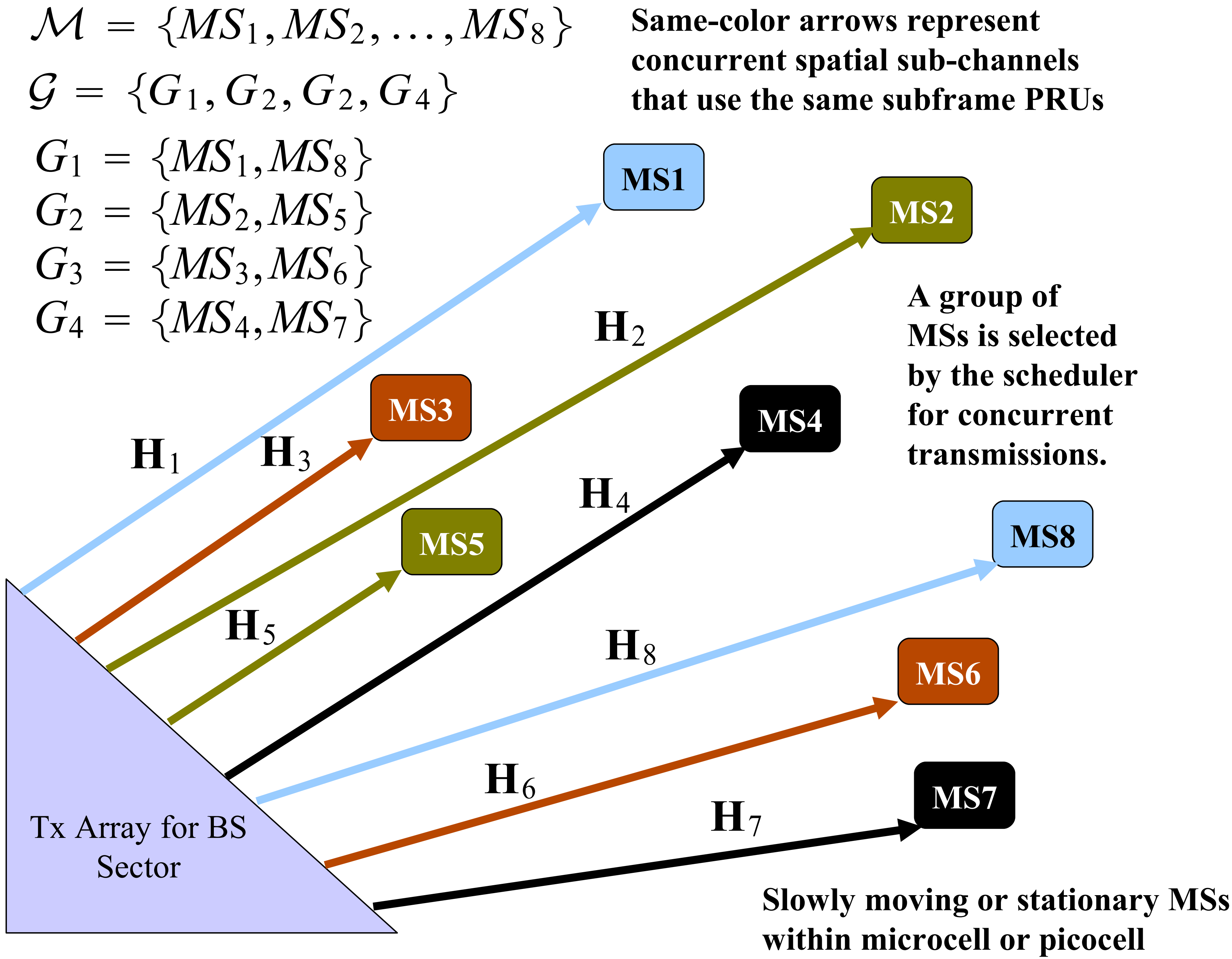
MS Grouping for Selective-MS Precoding (3)

- MSs within a group G_i will have uncorrelated channels $\mathbf{H}_k$.
  - MSs with channel cross correlations that are below a pre-defined threshold are placed in the same MS group.
  - MSs that have highly correlated channels are placed into different spatial MS groups.

- MSs within a spatial MS group can share the same physical layer resource units within a subframe. Hence an increase in spectral efficiency.

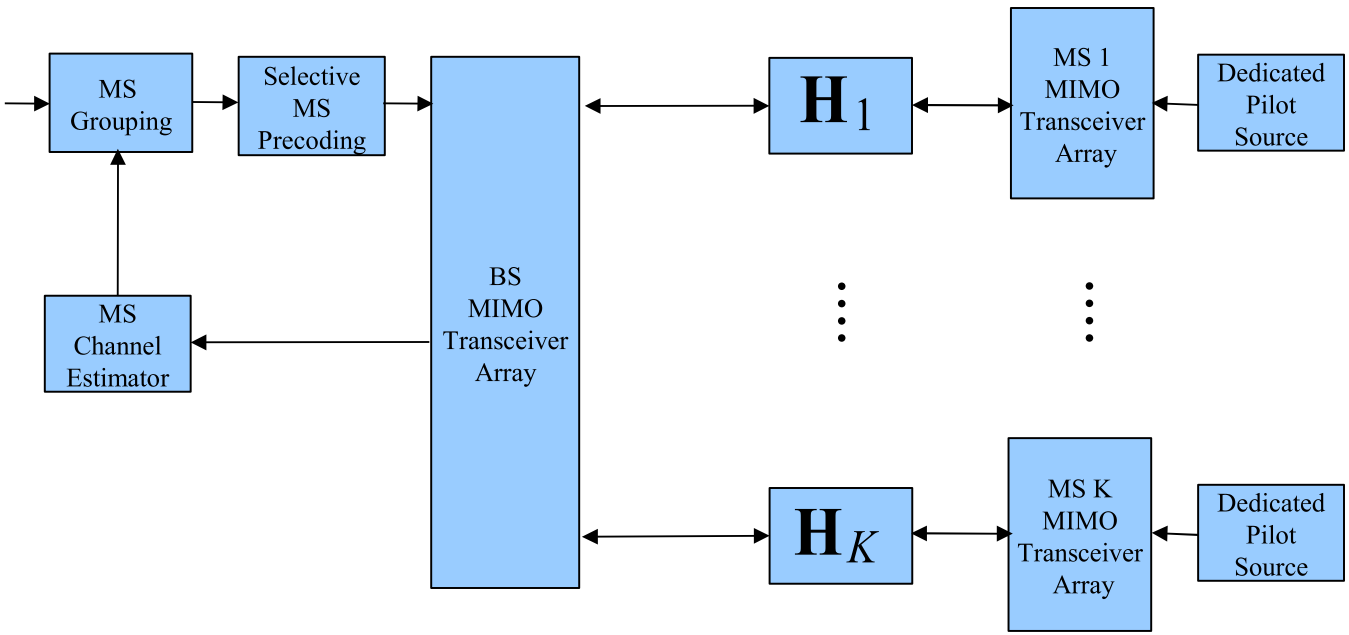
- The larger an MS group the greater the gain in spectral efficiency and throughput. On the other hand, smaller MS groups allow the BS to transmit with higher average power per MS.

- Finding the optimum MS grouping $\mathcal{G}$ requires a comparison between all possible MS groups. This may not be practical so reduced complexity algorithms are required to find a sub-optimal MS grouping. Many sub-optimal MS grouping algorithms are proposed in the literature.

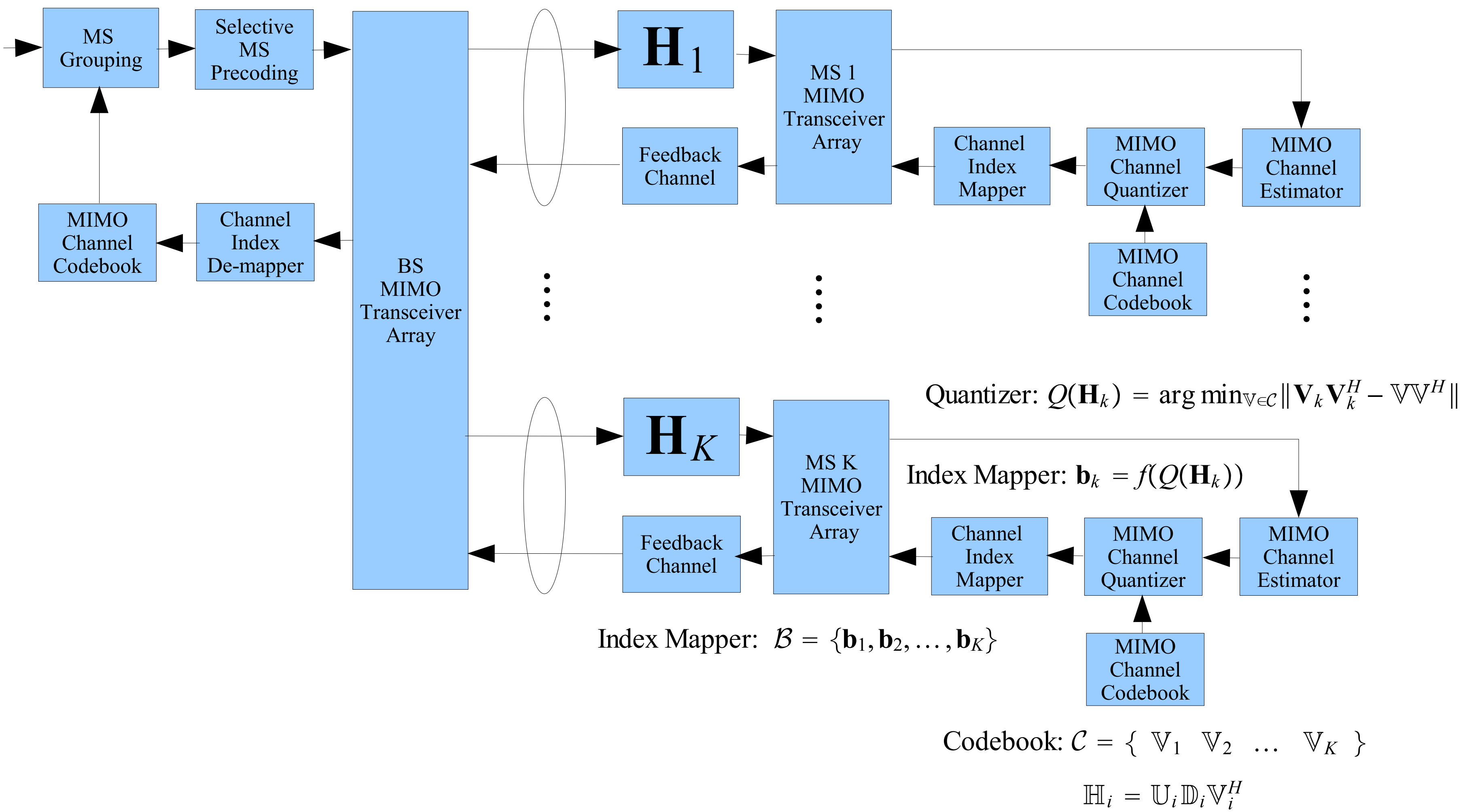


$\mathcal{M} = \{MS_1, MS_2, \ldots, MS_8\}$
$\mathcal{G} = \{G_1, G_2, G_2, G_4\}$
$G_1 = \{MS_1, MS_8\}$
$G_2 = \{MS_2, MS_5\}$
$G_3 = \{MS_3, MS_6\}$
$G_4 = \{MS_4, MS_7\}$
Same-color arrows represent concurrent spatial sub-channels that use the same subframe PRUs
MS1
MS2
$\mathbf{H}_2$
A group of MSs is selected by the scheduler for concurrent transmissions.
MS3
MS4
$\mathbf{H}_1$
$\mathbf{H}_3$
$\mathbf{H}_4$
MS5
MS8
$\mathbf{H}_5$
$\mathbf{H}_8$
MS6
$\mathbf{H}_6$
$\mathbf{H}_7$
MS7
Tx Array for BS Sector
Slowly moving or stationary MSs within microcell or picocell

Open-loop Selective-MS Precoding



Closed-loop Selective-MS Precoding



Proposed Text

11. Physical Layer

11.x Downlink MIMO

11.x.y. Downlink MIMO Adaptation

To provide spatial multiplexing (SM) and spatial diversity (SD) gains in numerous radio environments, BSs and MSs will be able to switch between DL MIMO techniques depending on downlink MIMO channel conditions. By switching between DL MIMO techniques an IEEE 802.16m system can dynamically optimize spectral efficiency and/or coverage for a specific radio environment.

11.x.y Downlink Precoding

Open- and closed-loop precoding techniques may be used to increase the spectral efficiency of downlink transmissions. Using precoding identical physical layer resource units (PRUs) may be used to transmit different downlink data. The identical PRUs may be concurrently transmitted to one or more MSs. Linear precoding may be combined with other MIMO techniques designed for SM gain or SD gain.

11.x.z Selective-MS Downlink Precoding

Open- and closed-loop selective-MS precoding are BS-centric precoding techniques that eliminate co-channel interference between MSs concurrently receiving downlink data. Since selective-MS precoding is base station centric it may also be used to facilitate BS-to-BS cooperation techniques for interference mitigation.

In selective-MS precoding a BS groups its active MSs into disjoint subsets called MS spatial groups. MSs within the same MS spatial group will have uncorrelated downlink MIMO channels. MSs that have highly correlated downlink MIMO channels will placed into different spatial MS groups. Different precoding matrices will be assigned to all MSs within an MS spatial group. MSs within a spatial MS group may share the same physical layer resource units (PRUs). The allocated PRUs may be concurrenly transmitted thereby increasing downlink spectral efficiency. For each downlink subframe a BS scheduler will select which of the MS spatial groups will be allocated available PRUs.

References

See IEEE C802.16m-08/410r1 for details

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