Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**MIMO Support at Relay Stations**
Date Submitted	**2009-01-05**
Source(s)	Alexander Maltsev, Jerry Sydir, Alexey Khoryaev, Andrey Chervyakov Intel Corporation alexander.maltsev@intel.com jerry.sydir@intel.com *<http://standards.ieee.org/faqs/affiliationFAQ.html>
Re:	SDD Change Request
Abstract	This contribution specifies MIMO support at ARS.
Purpose	For consideration and adoption into the 16m SDD document.
Notice	*This document does not represent the agreed views of the IEEE 802.16 Working Group or any of its subgroups*. It represents only the views of the participants listed in the "Source(s)" field above. It is offered as a basis for discussion. It is not binding on the contributor(s), who reserve(s) the right to add, amend or withdraw material contained herein.
Release	The contributor grants a free, irrevocable license to the IEEE to incorporate material contained in this contribution, and any modifications thereof, in the creation of an IEEE Standards publication; to copyright in the IEEE's name any IEEE Standards publication even though it may include portions of this contribution; and at the IEEE's sole discretion to permit others to reproduce in whole or in part the resulting IEEE Standards publication. The contributor also acknowledges and accepts that this contribution may be made public by IEEE 802.16.
Patent Policy	The contributor is familiar with the IEEE-SA Patent Policy and Procedures: <http://standards.ieee.org/guides/bylaws/sect6-7.html#6> and <http://standards.ieee.org/guides/opman/sect6.html#6.3>. Further information is located at <http://standards.ieee.org/board/pat/pat-material.html> and <http://standards.ieee.org/board/pat>.

MIMO Support at Relay Stations

Alexander Maltsev, Jerry Sydir, Alexey Khoryaev, Andrey Chervyakov
Intel Corporation

MIMO Support at Relay Stations

Introduction

The latest version of IEEE802.16m SDD [1] does not describe MIMO support at ARSs. The ARSs may communicate with AMSs and ARSs/ABS using multiple antenna techniques. In general case the ABS-AMS, ABS-ARS, ARS-ARS and ARS-AMS links have different propagation characteristics and the requirements that should be met. So the MIMO support at ARSs needs to be specified in SDD.

MIMO Support on Access and Relay Links

The ARSs have two types of transmission links:

- the access links – used for ARS communication with AMSs
- the relay links – used for data relaying between superordinate and subordinate stations (ARS-ARS or ABS-ARS).

For typical deployments these links have different signal propagation properties (i.e. MIMO spatial channel characteristics, channel variation in time, path losses, etc.). The ARS-AMS access links may experience almost the same spatial and multipath channel characteristics as valid for ABS-AMS links, especially in above roof-top (ART) ARSs deployments. So the existing MIMO concepts proposed for ABS-AMS links can be reused and included for support on ARS access links as well.

On the other hand the physical channel properties and the system performance requirements that should be met at relay links are significantly different from those on the access links:

- The reliable operation at *highest data rate* should be supported on relay links in all practical deployments. So the performance of relay links should be optimized for the *high SNR regions*.
- For fixed infrastructure (above and below roof-top ARS deployment scenarios) the *stationary* LOS and NLOS channels are most likely on the relay links. So *instantaneous channel realizations* can be easy measured and tracked by the system.
- For effective utilization of the relay link channel properties different antenna configurations can be applied at access and relay links. For example high gain directional antennas can be used at above roof top ARS to allow strong LOS propagation, reduce interference or provide network range extension.

Importance of MU-MIMO on Relay Links

When several first tier ARSs are placed in one sector the maximum total network/cell throughput can be significantly increased if MU-MIMO is enabled on the relay links. In such deployments the maximum spectral efficiency is limited by the throughput of the relay links i.e. between ABS and the first tier ARSs (see Figure 1.).

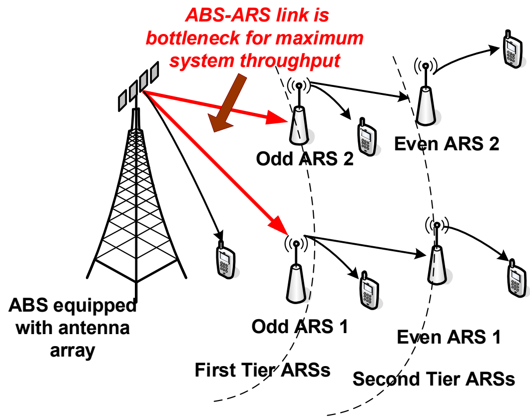

Figure 1: MU-MIMO on relay links

The link between ABS and first tier ARSs is the bottleneck for the whole system performance since the total amount of data that reaches all AMSs is bounded by the amount of traffic that is transmitted by the ABS. To overcome this issue and significantly increase the cell spectral efficiency the MU-MIMO approach should be supported on the first tier relay links.

SU and MU-MIMO Schemes on ABS-AMS Links

The MIMO techniques described in IEEE 802.16m SDD are designed to improve system performance on the access links (ABS-AMS) at *low and medium* SNR range. The majority of proposed MIMO concepts are based on the usage of codebooks for MIMO precoding at ABS/AMS. The codebook based techniques are reasonable for MIMO support at access links since it allows significant reduction of feedback information providing acceptable performance characteristics. However the large quantization loss due to usage of small size codebook based schemes in application to SU-MIMO and MU-MIMO schemes on relay links may result in substantial degradation of spectral efficiency at high SNR. Since reliable data transmission with high spectral efficiency is the main design goal on relay links the Closed Loop MU-MIMO scheme that uses more accurate precoding vector approach is required.

MU-MIMO Simulation Results on Relay Links

To illustrate the degradation of codebook based approach when it is used for MU-MIMO on relay links we have evaluated the DL sum-rate capacity for typical ART and BRT deployments with 2 and 3 relay stations[3]. The linear antenna array with 4 TX antennas was applied at ABS. The channel models used for relay link simulation are described in IEEE 802.16m EVM document. The MU-MIMO simulation results with codebooks were obtained using 6 bit codebook defined in IEEE 802.16 Rev2. The following MU-MIMO approaches based on TX ZF algorithm [4] were evaluated:

- Base mode. In this mode the ZF algorithm was directly applied to the best 6-bit codebook vectors [6] indicated by each of ARSs.
- Adaptive mode. For each ARS the 16e codebook was transformed using quantized TX correlation matrix [8].
- Differential mode. Additionally to the base codebook the 3-bit polar cap differential codebook [7] was applied. The angle between of outer codeword and the center of the cap was fixed to 30 degrees.
- ZF of SVD vectors (ideal case). In this mode it was assumed ZF is applied to the perfect SVD (singular value decomposition) precoding vectors corresponding to maximum singular value of MIMO channel between ABS and each ARS.

- ZF of SVD vectors with quantized precoding weight feedback. The elements of SVD precoding vector were quantized with 8 bits (5 bits per phase and 3 bits per amplitude) and 10 bits (6 bits for phase and 4 bits for amplitude) uniform quantization grid.

The results of sum-rate capacity evaluation for all these methods are shown in Figure 2- Figure 4 below.

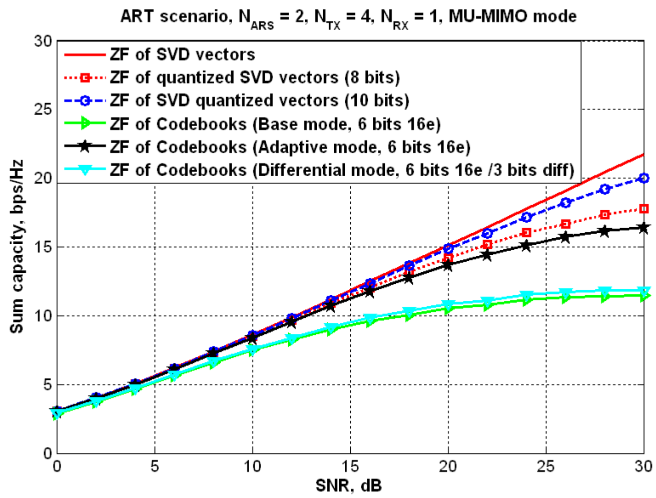

Figure 2: MU-MIMO with 2 ARSs in ART scenario

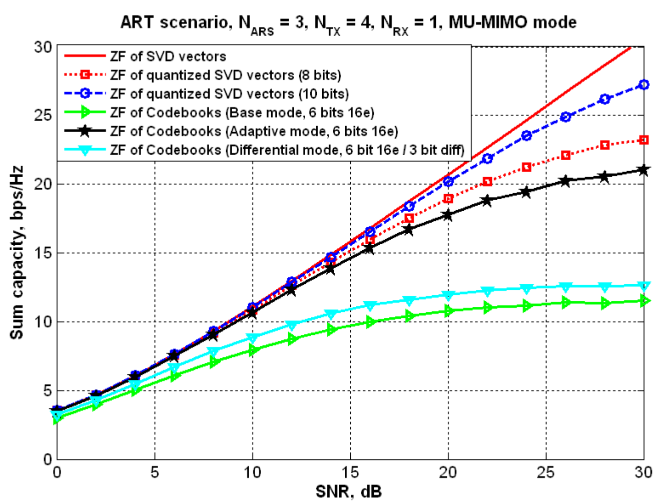

Figure 3: MU-MIMO with 3 ARSs in ART scenario

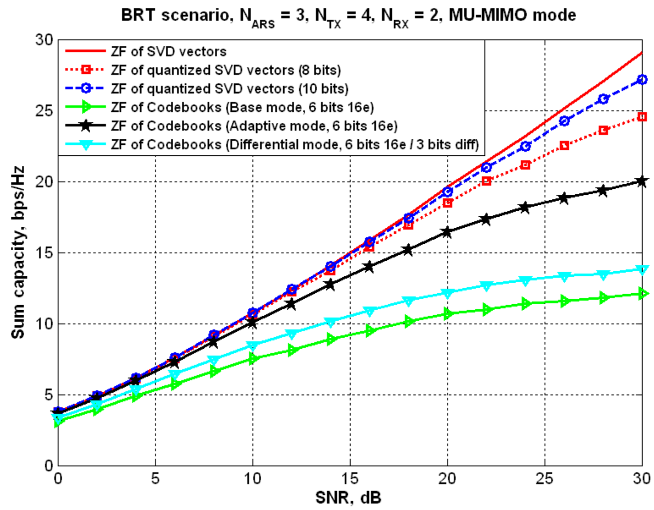

Figure 4: MU-MIMO with 3 ARSs in BRT scenario

Figure 2-Figure 4 show that at high SNR (more than 20 dB) the codebook based approach for realization of MU-MIMO on relay links leads to the sum capacity floor. It is known from the literature [5] that for effective realization of the MU-MIMO schemes the number of feedback bits should be linearly scaled with increase of SNR (in dB). This results in exponential growth of the number of required codebook vectors. So the base codebook approach will not be practical for MU-MIMO on relay links.

The differential codebook [7] does not provide substantial enhancement on relay links due to lack of accuracy. It is optimized for fast tracking of a non-stationary channel between the ABS and AMS. The adaptive codebook approach [8] uses long-term feedback of average TX correlation matrix, describing statistical behavior of non-stationary ABS-AMS channel. In stationary channels (relay link) the TX correlation matrix is composed from multiplication of instantaneous MIMO channel realizations. For such a case instead of sending back the quantized TX correlation matrix the direct feedback of channel precoding vector is preferable because of smaller feedback overhead.

So to avoid significant loss in spectral efficiency on relay links at high SNR region the accurately quantized precoding weigth vectors feedback is recommended.

Proposed Solution

The proposed technical solution is to quantize each element/weight of the precoding vector using a predetermined high resolution grid. The quantized precoding weight feedback mechanism is supported by IEEE 802.16 Rev2 standard for fast feedback MIMO. This approach can be extended to support SU-MIMO and MU-MIMO on relay links in IEEE 802.16m systems with relays stations. The high order quantization of each precoding vector element allows the transmitter to apply a more accurate precoding vector, achieving higher spectral efficiency in SU/MU-MIMO mode on the relay link. The proposed approach does not produce a large feedback overhead on fixed relay links due to the stationary behavior of these links. Feedback is not required very often. For example the ABS-AMS channel (3km/h) produces Doppler spread about 7Hz and needs 6 bits for each codebook index feedback. Assuming 0.1 Hz Doppler spread [9] for ABS-ARS channel the quantized precoding weight feedback will require 40bits = 4antennas * 10bits. In this case the total feedback required for relay link (40bits*0.1Hz) will be in 10 times less than for access link (6 bits*7 Hz). The amount of feedback on relay links can be further reduced by differential adjustment to the previous precoding vector.

References

[1] IEEE 802.16m System Description Document (IEEE 802.16m-08/003r7)
[2] IEEE 802.16m System Requirements Document (IEEE 802.16m-07/002r8)
[3] IEEE 802.16m Evaluation Methodology Document (IEEE 802.16m-08/004r5)
[4] Spencer Q. H., Peel C. B., Swindlehurst A. L., Haardt M., *"An introduction to the multi-user MIMO downlink,"* IEEE Commun. Mag., vol. 42, no. 10, pp. 60–67, Oct. 2004
[5] Jindal N., "MIMO Broadcast Channels with Finite Rate Feedback," *IEEE Trans. on Inform. Theory*, 2006.
[6] IEEE Standard for Local and metropolitan area networks Part 16: Air Interface for Broadband Wireless Access Systems (802.16Rev2/D9 Jan 09)
[7] IEEE contribution C80216m-09_0058r4 "Differential feedback for IEEE 802.16m MIMO Schemes"
[8] IEEE 802.16m-09/0331r2 "Proposed Text of DL MIMO Transmission Scheme Section for the IEEE 802.16m Amendment"
[9] IST-4-027756 WINNER II, D1.1.2 v1.2, "WINNER II Channel Models", https://www.ist-winner.org/, September 2007.

Text Proposal

[Insert the following text into SDD definition section 3.1]

Access link: A radio link between an ABS or ARS and an AMS, or between an ABS or ARS and a subordinate ARS during network entry. The access link is either an uplink or downlink.

Relay link (R-link): A radio link between an ABS and an ARS or between a pair of ARSs. This can be a relay uplink or downlink.

[Insert the following text into section 15 of the SDD]

15.4.x MIMO Support

The ABS and ARS supports DL/UL MIMO transmission on access links and relay links. The relay MIMO architecture is based on the MIMO architecture defined in section 11.8.1.

15.4.x.1 ARS Antenna Configuration

ARSs can use different or the same antennas for access and relay links.
The antenna configurations used by the ARS on the access link are the same as those used by the ABS (see section 11.8.1.1).
On the relay link the ARS may use a single (directional) antenna for data transmission/reception. The supported antenna configurations on relay links are 1, 2 and 4 antennas.

15.4.x.2 MIMO Transmission on Access Links

On the access link, ARSs support the SU-MIMO and MU-MIMO schemes and feedback mechanisms that are specified for MIMO transmission between ABS and AMS (see section 11.8 and 11.12).

15.4.x.3 MIMO Transmissions on Relay Links

All of the MIMO schemes described in sections 11.8 and 11.12 can be used on relay links. Different MIMO schemes may be used on different relay links within a sector. In addition to the MU-MIMO feedback mechanisms described in section 11.8, a quantized weight precoding feedback mechanism is supported on the relay link. When this feedback mode is used each ARS calculates the desired transmit precoding vector and quantizes each element of precoding vector using predetermined quantization grid. The precoding vector can be calculated for each or several sub-bands/CRUs. The quantized precoding weight information is sent back to the transmitter side, where it is used for calculation of MU-MIMO precoding matrix. The same approach with quantized weight precoding feedback can also be exploited as a precoding vector for CL SU-MIMO. To minimize the amount of feedback information using quantized weight precoding feedback approach the differential adjustment to the previous precoding vectors can be exploited. The differential adjustment to previous feedback information can be implemented periodically or event-driven.