Project	**IEEE 802.16 Broadband Wireless Access Working Group** <http://ieee802.org/16>
Title	**Achievable MU-MIMO Sum Rates with Hybrid Codebook/Analog Feedback and Superposition Mapping**
Date Submitted	**2008-11-07**
Source(s)	Ron Porat Nextwave Wireless Voice: E-mail: rporat@nextwave.com; *<http://standards.ieee.org/faqs/affiliationFAQ.html>
Re:	TGm SDD: Other
Abstract	This document describes a proposal for CL-MIMO feedback
Purpose	To be discussed and adopted by 802.16m SDD
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>.

Achievable MU-MIMO Sum Rates with Hybrid Codebook/Analog Feedback and Superposition Mapping

Ron Porat

Nextwave Wireless

1. Introduction and General Simulation Assumptions

This document extends the results in C802.16m-08_914 by providing further MU simulation results with a modified mapping of the analog difference information.

The hybrid codebook/analog method as described in C802.16m-08_914 section 5 is a potential candidate for the differential mode as described in the current SDD. It uses any baseline codebook and transmits the analog difference relative to the perfect singular vector(s) as calculated by the MS to enhance performance.

In C802.16m-08_914, different subcarriers were used for feeding back the PMI and the analog difference whereas here superposition of the analog information on top of the digital information (PMI) is used.

In general, the analog difference can be superposed over any portion of the uplink control channel (fast feedback, sounding) without degrading its performance beyond a predefined set point.

Several operational scenarios are possible:

1. A PMI for a given BW is accompanied by the analog difference and sent in the same UL frame
2. A PMI for a given BW, say 4 PRB, is accompanied by multiple of analog differences for each PRB and sent in the same frame.
3. Analog difference is transmitted in consecutive frames taking advantage of low normalized Doppler (Doppler x Feedback latency product). The analog difference is relative to the initial PMI.

Following are the simulation assumptions:

- Channel configuration is assumed 4x2 in DL and 1x4 in UL.
- UL channel – Ped B, 3kmph.
- UL channel estimation – Real. Average of 4 pilots of a 16e tile (4x3).
    - Results with future 16m tiles are FFS

- CSI Feedback information –
  - Rank-1 PMI of baseline codebook (Nextwave 4bit codebook)
  - Rank-1 analog difference singular vector
- UL mapping of information – all options used one tile (8 subcarriers) for feedback.
  - 4bit PMI was assumed and was mapped to 4 subcarriers via (8,4,4) extended Hamming code and QPSK mapping
  - Analog information was superposed on top of the PMI feedback
  - Repetition was used to fill all 8 subcarriers.
- DL channel – SCM Urban Macro. Four vertically polarized antennas with 4 or 0.5 lambda spacing.
- DL Band BW – 1 or 4 PRB (assuming one precoder per band)
- DL speed and feedback delay – 3kmph, 5mS
- DL channel estimation – Per the EVM, 6dB gain from least squares CE on a midamble was assumed
- DL/UL SNR per subcarrier difference – 6dB (Assumed total power difference of 23dB with power concentration ratio of 50:1 in the UL). (Actually with truly one tile feedback that ratio is 210:1).
- Sum rate computed using RBIR assuming 1% BLER for 16e MCS with interpolation to enable ‘continuous’ MCS.
  - 16m MCS granularity is FFS but is expected to be higher than 16e and combined with HARQ-IR will enable fine granularity
- User selection:
  - 4 random users with exhaustive search
  - 10 random users with greedy selection

  An important factor to consider is the amount of feedback required in the UL to achieve a certain performance in the DL. While feedback of 10 users can improve DL MU performance it increases the UL overhead.

  In TDD, where the DL/UL frame ratio is flexible, the optimal feedback overhead for a given MU algorithm can be found.

Note that while the simulations here assume 1Tx at the MS side, WiMAX Rel1.5 calls for optional 2Tx with accompanying UL beamforming and MIMO. This feature may further improve the accuracy of any form of analog feedback. Especially, if CL-MIMO is enabled in the DL, beamforming can be supported in the UL which will improve performance even in interference limited scenarios.

2. Implementation Considerations

Superposition mapping:

The mapping for the hybrid codebook/analog used in this contribution is based on superposition of the analog information on the subcarriers carrying the PMI. The analog difference values are multiplied by a known gain and added to the QPSK modulated subcarriers carrying the PMI. In general, the analog difference can be superposed over the uplink control channel.

The signal received by the BS can therefore be written as $y = H(s + e \cdot g) + n$ where s carries the digital information mapped for example to QPSK, e carries the analog information and g is a predefined known gain.

On average, for 4-bit codebooks (Nextwave, Motorola, Samsung, LGE, Huawei) the average power of a rank-1 singular vector difference element relative to 1 is -10.5dB for uncorrelated antennas, reducing further for correlated antennas. For 16e 6/3-bit codebooks that number is -11.9/9.3dB for uncorrelated antennas. For NSN 6bit codebook that number depends on alpha and is between those numbers.

Therefore, the analog difference can be multiplied by a certain gain before being superposed on top of the digital information. In this simulation gain factor of 2.5 (8dB) was used.

As can be seen in 914 chapter 3, SNR=1dB is required for PER=0.01 of the digital information for this particular coding and tile structure. Therefore no degradation of the digital information reliability is expected. Currently, stronger coding is proposed for 16m FFB channel which will allow even higher gain for the superposed analog information

CINR issues:

Three options were simulated:

1. ‘Genie knowledge’ – Here the assumption is that the BS knows the per subcarrier channel to each user and the broadband SNR per user (which is fed back as part of regular ‘open loop’ CQI feedback and includes inter-cell interference). This is the case in TDD systems where the BS is assumed to learn the channel via sounding symbol and assuming low normalized Doppler. The simulation results further assume that:
    a. One rank-1 precoder for the simulated band was used at the BS and per subcarrier MMSE processing at the MS.
    b. The BS is therefore capable of calculating the achievable sum rate using the above assumptions and chooses the combination of users that achieves the highest sum rate.
2. BS based ‘FDD knowledge’ – Here the assumption is that the BS sees a ‘masqueraded’ 1 antenna MS with one vector channel per band given by the product of:
    a. Square root of the CINR value fed back by the MS – this is the post rank-1 precoding CINR for CL-SU-MIMO. In the simulation the MS rounds this value to the nearest dB and feeds it back error free.

   b. Strongest singular vector (SV) – this is fed back by the MS in one of the forms discussed above

   In this case the feedback is harmonized between SU and MU in FDD CL-MIMO and the BS calculates the achievable rate in the same way as in 1) but assuming ‘flat fading’ MSs.

   It was found in the simulation that this yields somewhat higher sum throughput than ‘Genie knowledge’ because of underestimation of the inter-user interference effects in a simplified ‘flat fading’ representation of the band.

3. MS based – as per the current SDD, the MS knows the per subcarrier channel and assumes unitary precoding. This method was found to be problematic with MMSE (ZF) beamforming as was implemented in these simulations.

   The MS assumes that 4 users are scheduled and feeds back pessimistic CINR to the BS. In reality the MMSE algorithm only typically schedules 2 users, rising to 3 users at the highest SNR. In this case each user will be able to support a much higher rate than predicted by the MS and if the BS takes the MS recommendation as is and schedules only 2 or 3 users, a huge loss in sum throughput will occur.

Simulations show that the rates of ‘FDD’ and ‘Genie’ knowledge are close in cases where the strongest singular vector per subcarrier doesn’t vary too much across the band of interest.

3. Simulation results

The simulations show results for several scenarios. The solid lines show the ‘Genie knowledge’ CINR assumption and the dashed lines show ‘FDD knowledge’ as explained above. While the link can only sustain the rate as determined by ‘Genie’ knowledge the ‘FDD knowledge’ curve is shown in order to understand the rate mismatch that will happen in reality.

The simulation with one subcarrier, while not realistic for FDD, shows what can be achieved in TDD if the BS also calculates a precoder per subcarrier.

Clearly, with un-correlated antennas, and even with perfect knowledge of V, performance deteriorates rapidly with the increase of BW due to poor interference nulling using one precoder per band at the BS. It is therefore recommended that in this case the system will support MU-MIMO operation over one PRB. This is also the case for SU-MIMO but is much more pronounced in a MU setting due to interference effects.

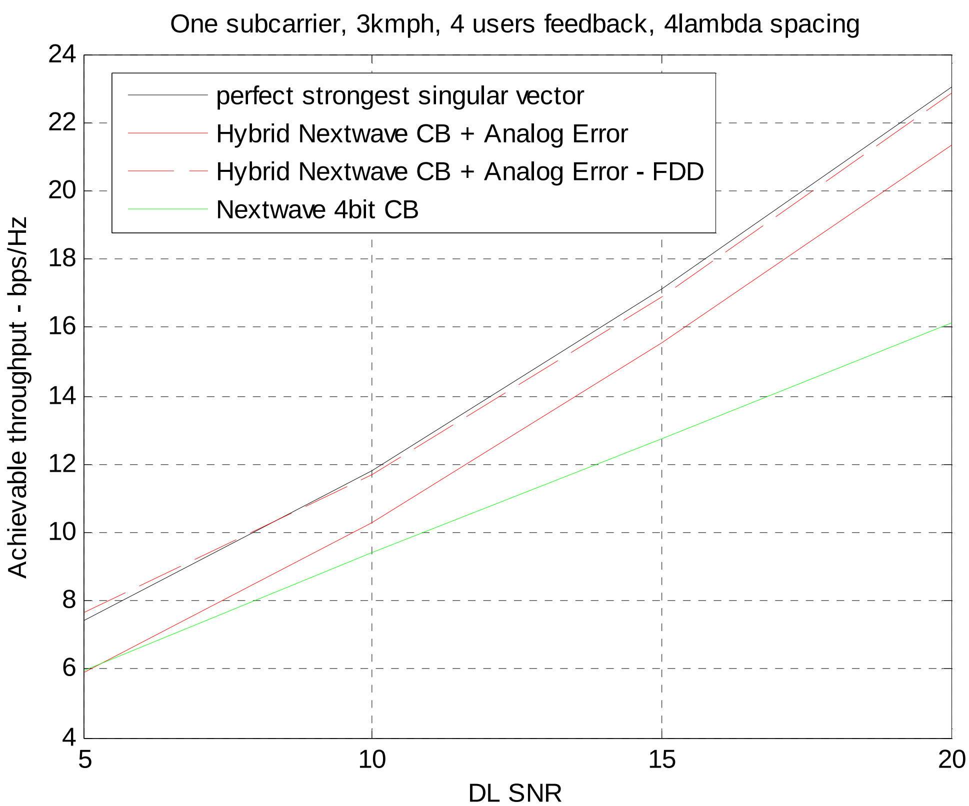
It can also be seen that the mismatch between ‘Genie’ and ‘FDD’ knowledge increases with increasing BW for uncorrelated antennas. This is a result of the convexity of the (constrained) capacity formula (RBIR) and Jensen’s inequality.

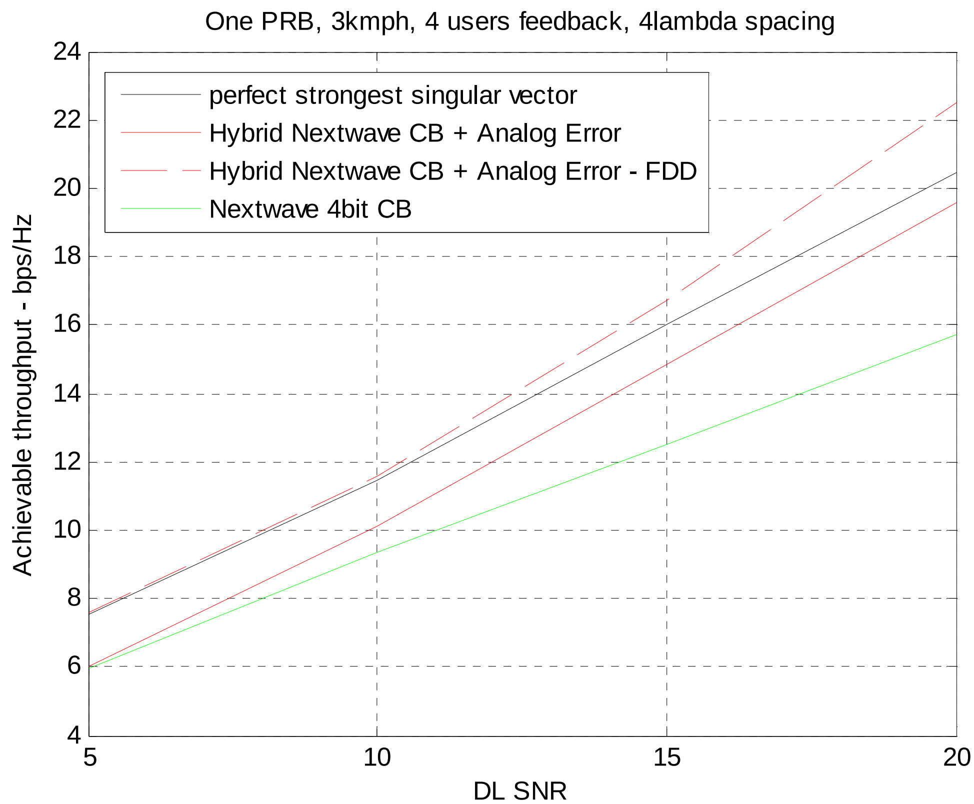
With large BW (four PRB) and widely varying spatial signatures of MSs over that bandwidth, the SINR per subcarrier fluctuates much more and can’t be accurately estimated at the BS by a simplified assumption of a MS with an average gain and spatial signature.

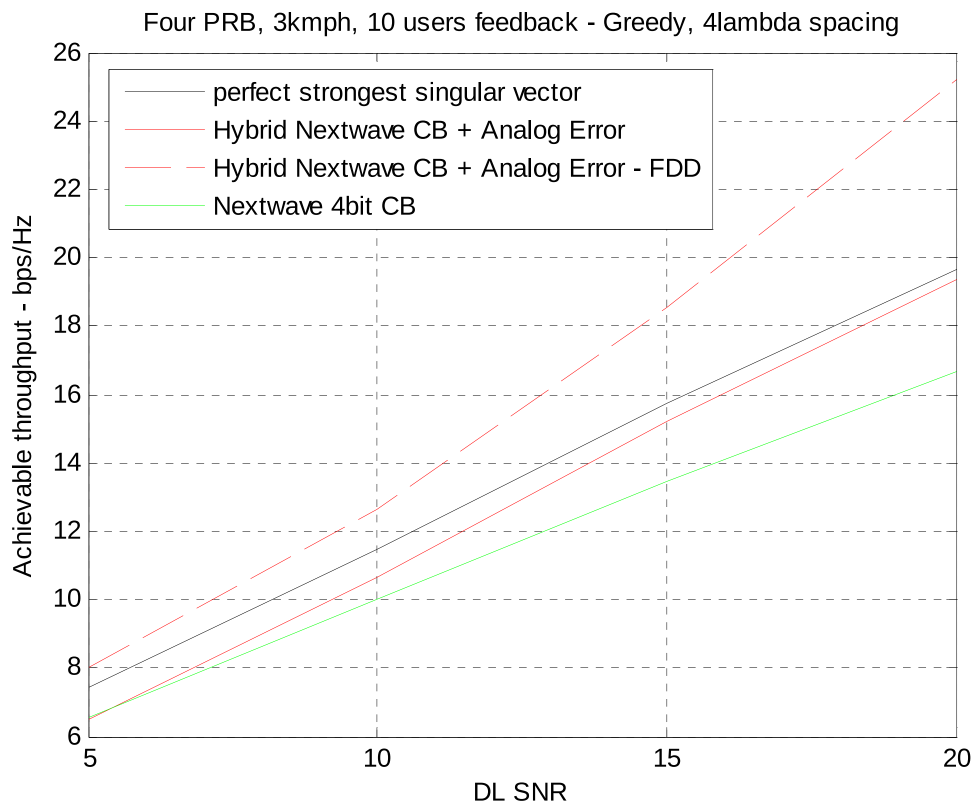
The MMSE(ZF) MU algorithm then ends up scheduling more users. For example with BW=1PRB and SNR=20dB the probability of 3 scheduled users increased to 20% from 2% in the results shown. That in turn will cause the SINR MSs see to be lower than estimated by the BS.

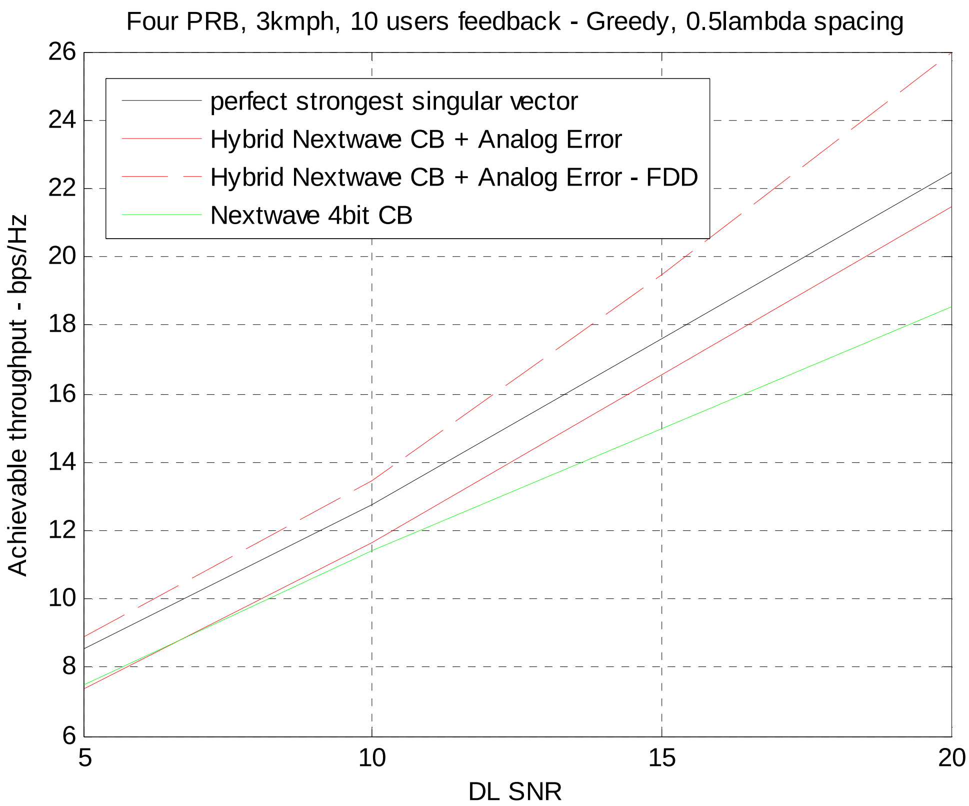
However, three things can help:

1. HARQ – it's better for the BS to have an upper bound of the CINR in order for the system to benefit from HARQ.
    a. In addition, 'soft NACK' based IR-HARQ can further improve performance by giving the BS more accurate information as opposed to simple binary ACK/NACK (see contribution 826). The exact performance is FFS.
2. More sophisticated processing at the MS (ML) can handle interference better than MMSE especially if the number of interferers is one or two (and the number of desired streams is one).
3. Somewhat different post rank-1 precoding CINR feedback in SU vs. MU setting in FDD. This is FFS.




One PRB, 3kmph, 4 users feedback, 4lambda spacing
perfect strongest singular vector
Hybrid Nextwave CB + Analog Error
Hybrid Nextwave CB + Analog Error - FDD
Nextwave 4bit CB
Achievable throughput - bps/Hz
DL SNR
24
22
20
18
16
14
12
10
8
6
4
5
10
15
20


Four PRB, 3kmph, 10 users feedback - Greedy, 4lambda spacing
perfect strongest singular vector
Hybrid Nextwave CB + Analog Error
Hybrid Nextwave CB + Analog Error - FDD
Nextwave 4bit CB
Achievable throughput - bps/Hz
DL SNR
26
24
22
20
18
16
14
12
10
8
6
5
10
15
20



4. Proposed text

Section 11.8.2.1.3 Feedback for SU-MIMO

Add at line 23:

The differential mode can be supported via a mobile station feeding back the unquantized difference between the channel singular vector(s) and the corresponding PMI that was fed back in the standard mode. The BS can add this information to create a more accurate precoder.
The mapping of the differential mode information can be done via superposition over the UL control channel (fast feedback, sounding) or in separate subcarriers allocated to it in the UL control channel.

Section 11.8.2.2.3.2 CSI Feedback

Add at line 38:

The differential mode can be supported via a mobile station feeding back the unquantized difference between the channel singular vector(s) and the corresponding PMI that was fed back in the standard mode. The BS can add this information to create a more accurate precoder.
The mapping of the differential mode information can be done via superposition over the UL control channel (fast feedback, sounding) or in separate subcarriers allocated to it in the UL control channel.

Section 11.8.4.1 Multi-cell MIMO

Add at line 5:

Codebook based CSI feedback may be enhanced using a differential mode.
The differential mode can be supported via a mobile station feeding back the unquantized difference between the channel singular vector(s) and the corresponding PMI that was fed back in the standard mode. The BS can add this information to create a more accurate precoder.
The mapping of the differential mode information can be done via superposition over the UL control channel (fast feedback, sounding) or in separate subcarriers allocated to it in the UL control channel.