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Re:	802.16 Working Group Letter Ballot #26a	
Abstract	We propose a BS to announce its CDD parameters if it uses CDD.	
Purpose	For inclusion in IEEE802.16Rev2	
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CDD Announcement

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1. Introduction

CDD has been proposed and implemented in most BS vendors to provide additional frequency diversity and maximize usage of Tx PAs for preamble, MAP, and SIMO zones. If the MS knows the BS has CDD, it can use this info to improve the MIMO channel estimation via robust and abundant preamble tones

- Preamble pilot tones are 3.5 dB hotter than MIMO pilot tones
- Preamble pilot tones always enjoy frequency reuse 3 therefore lower inference
- The number of preamble pilot tones is larger than the number of MIMO pilot tones, e.g., for 1024 FFT size, there are 284 preamble pilot tones vs. 120 MIMO pilot tones for PUSC
- An example is shown in the Appendix

In additional to channel estimation, MS can use the CDD announcement for other modem performance improvement

- Point to point performance will be affected by CDD. Link adaptation algorithm can be improved if CDD info is known to the MS
- BAMC selection process can also be improved with the MS knowing that the BS is using CDD
- The MS can learn the number of Tx antenna of a BS from the CDD descriptors (defined in the next slide)
  - Number of BS Tx antennas is an important piece of information for the MS. For example it can be used for setting AGC backoff in BF zones, expecting maximum BF power gain of 10log10(Nant)
- Recognizing repetition of PDP to enhance modem time domain processing

So our proposal is that if a BS uses CDD (in TDD or FDD) which artificially changes the natural channel, the mobiles want to know about it

2. Proposed Text Changes in Rev2/D2

Add the following CDD Descriptor at the end of Table 544 in Section 11.4.1 DCD Channel Encodings at Page 1072

Name	Type	Length	Value	PHY Scope
CDD Descriptor for Preamble, MAP, and SIMO zones	155	variable	Each byte represents one CDD parameter pair: 5 bits for delay in samples (1 to 32), 3 bits for power attenuation (0 to 7 dB). If the Length of this CDD Descriptor is n bytes, then the number of Tx antenna is n+1.	OFDMA
CDD Descriptor for MIMO zones	156	variable	Each byte represents one CDD parameter pair: 5 bits for delay in samples (1 to 32), 3 bits for power attenuation (0 to 7 dB). If the Length of this CDD Descriptor is n bytes, then the number of Tx antenna is 2(n+1).	OFDMA

3. Conclusion

Here we propose an optional CDD announcement for BS. If a BS is using CDD which artificially alters the channel a MS sees, the MS would like to know. The MS can choose to use or not use the CDD Descriptor info in DCD. If the MS choose not to use the extra info, CDD is transparent to the MS and the channel just appears more frequency selective.

The proposal is strictly backward compatible and the added overhead is negligible.

Appendix

Using CDD Parameters to Estimate MIMO Channel

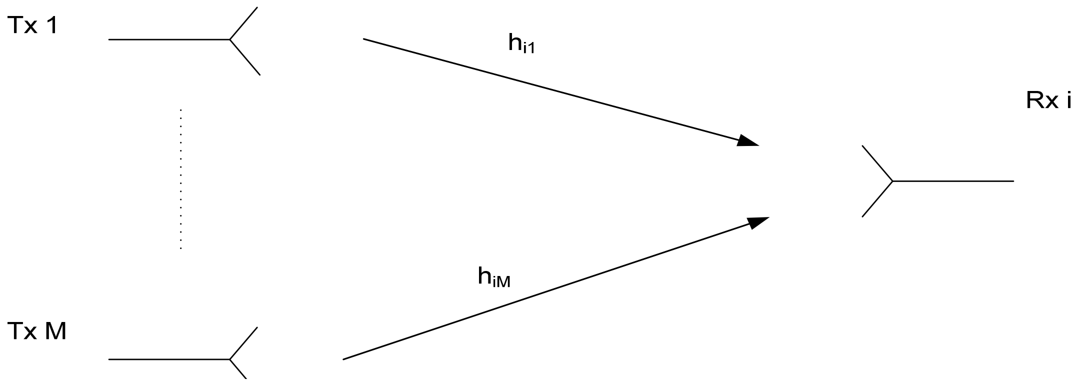

Figure 1 MxN MIMO System with Flat Fading Channel

Let's assume an MxN MIMO system with Flat Fading Channel as shown in Figure 1. Note h_{ij} refers the the channel from the j-th Tx antenna to the i-th Rx antenna. CDD is enabled on the M Tx antennas with the following parameters:

d_i is the CDD delay in samples of the i-th Tx antenna, i=1,2,…,M, $d_1=0$, $1<=d_2<d_3<\ldots<d_M<=32$, (5 bits); power attenuation in dB per delay antenna are $\alpha_2^2,\ldots,\alpha_M^2$, α_i^2 Є{0, -1,…, -7}dB, i=2,3,…,M, (3 bits).
Look at the i-th Rx antenna, we have:

$$y_{ik} = p_k[h_{i1} + h_{i2}\alpha_2 e^{-j\frac{2\pi d_2 k}{N_{fft}}} + \ldots + h_{iM}\alpha_M e^{-j\frac{2\pi d_M k}{N_{fft}}}] + w_{ik}'$$

, where k is tone index, p_k is the k-th preamble pilot tone, N_{fft} is the FFT size.

In Matrix Form, across all Preamble Pilot tones, assuming N_{fft} = 1024, for the i-th Rx Antenna:

$$\begin{bmatrix} p_0 y_{i0} \\ p_3 y_{i3} \\ \cdot \\ \cdot \\ \cdot \\ p_{849} y_{i849} \end{bmatrix} = \begin{bmatrix} 1 & \alpha_2 & \cdot\ \cdot\ \cdot & \alpha_M \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 3}{N_{fft}}} & \cdot\ \cdot\ \cdot & \alpha_M e^{-j\frac{2\pi d_M 3}{N_{fft}}} \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 6}{N_{fft}}} & & \alpha_M e^{-j\frac{2\pi d_M 6}{N_{fft}}} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 849}{N_{fft}}} & \cdot\ \cdot\ \cdot & \alpha_M e^{-j\frac{2\pi d_M 849}{N_{fft}}} \end{bmatrix} \times \begin{bmatrix} h_{i1} \\ h_{i2} \\ \cdot \\ \cdot \\ \cdot \\ h_{iM} \end{bmatrix} + \begin{bmatrix} w_{i0} \\ w_{i3} \\ \cdot \\ \cdot \\ \cdot \\ w_{i849} \end{bmatrix}$$

Here we use the fact that P_k=1 or -1, i.e., P_k^2=1, $w_{ik} \equiv p_k w_{ik}'$

Juxtaposition over all Rx antennas:

$$\begin{bmatrix} p_0 y_{1,0} & \cdot\ \cdot\ \cdot & p_0 y_{N,0} \\ p_0 y_{1,3} & & p_0 y_{N,3} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ p_{849} y_{1,849} & \cdot\ \cdot\ \cdot & p_{849} y_{N,849} \end{bmatrix} = \begin{bmatrix} 1 & \alpha_2 & \cdot\ \cdot\ \cdot & \alpha_M \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 3}{N_{fft}}} & \cdot\ \cdot\ \cdot & \alpha_M e^{-j\frac{2\pi d_M 3}{N_{fft}}} \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 6}{N_{fft}}} & & \alpha_M e^{-j\frac{2\pi d_M 6}{N_{fft}}} \\ \cdot & & & \cdot \\ \cdot & & & \cdot \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 849}{N_{fft}}} & \cdot\ \cdot\ \cdot & \alpha_M e^{-j\frac{2\pi d_M 849}{N_{fft}}} \end{bmatrix} \times \begin{bmatrix} h_{11} & \cdot\ \cdot & h_{N1} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ h_{1M} & \cdot\ \cdot & h_{NM} \end{bmatrix} + \begin{bmatrix} w_{1,0} & \cdot\ \cdot\ \cdot & w_{N,0} \\ w_{1,3} & \cdot\ \cdot\ \cdot & w_{N,3} \\ \cdot & & \cdot \\ \cdot & & \cdot \\ w_{1,849} & \cdot\ \cdot\ \cdot & w_{N,849} \end{bmatrix}$$

Or written in the compact form below. Note the matrix dimensions in subscripts

$$Y_{284 \times N} = A_{284 \times M} \cdot H_{M \times N} + W_{284 \times N}$$

Then we have the MMSE channel estimation:

$$\hat{H} = (A^* A + \sigma^2 I)^{-1} A^* Y$$

Now let's look at the case of frequency selective channel. $h_{ij}^{(l)}$ refers the channel coefficient of the j-th Tx antenna, the i-th Rx antenna, and the l-th path with delay τ_l. Again k is tone index.

$$h_{i1}[k] = h_{i1}^{(1)} + h_{i1}^{(2)} e^{-j\frac{2\pi\tau_2 k}{N_{fft}}} + \ldots + h_{i1}^{(L)} e^{-j\frac{2\pi\tau_L k}{N_{fft}}}$$

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$$h_{iM}[k] = h_{iM}^{(1)} + h_{iM}^{(2)} e^{-j\frac{2\pi\tau_2 k}{N_{fft}}} + \ldots + h_{iM}^{(L)} e^{-j\frac{2\pi\tau_L k}{N_{fft}}}$$

Similar to the approach in flat fading channel, we look at the i-th Rx antenna:

$$\begin{bmatrix} p_0 y_{i0} \\ p_3 y_{i3} \\ . \\ . \\ p_{849} \; y_{i849} \end{bmatrix} = \begin{bmatrix} A & D_2 A & D_3 A & . & . & D_L A \end{bmatrix} \times \begin{bmatrix} h_{i1}^{(1)} \\ . \\ h_{iM}^{(1)} \\ h_{i1}^{(2)} \\ . \\ h_{iM}^{(2)} \\ . \\ h_{i1}^{(L)} \\ . \\ h_{iM}^{(L)} \end{bmatrix} + W_{284 \times 1}$$

Where

$$D_l \equiv \begin{bmatrix} 1 & 0 & . & . & 0 \\ 0 & e^{-j\frac{2\pi\tau_l 3}{N_{fft}}} & . & . & . \\ . & . & e^{-j\frac{2\pi\tau_l 6}{N_{fft}}} & . & . \\ . & . & . & . & 0 \\ 0 & . & . & 0 & e^{-j\frac{2\pi\tau_l 849}{N_{fft}}} \end{bmatrix}$$

Then we look at all the Rx antennas:

$$Y_{284\times N} = \begin{bmatrix} A & D_2A & D_3A & . & . & D_LA \end{bmatrix} \times \tilde{H}_{ML\times N} + W_{284\times N}$$

Where the i-th column of $\tilde{H}_{ML\times N}$ is $\begin{bmatrix} h_{i1}^{(1)} \\ . \\ h_{iM}^{(1)} \\ h_{i1}^{(2)} \\ . \\ h_{iM}^{(2)} \\ . \\ h_{i1}^{(L)} \\ . \\ h_{iM}^{(L)} \end{bmatrix}$ for i=1,2,…,N

Or in compact form below. Note now the channel dimension is MLxN.

$$Y_{284\times N} = \tilde{A}_{284\times ML} \cdot \tilde{H}_{ML\times N} + W_{284\times N}$$

Again we have the MMSE estimation of the frequency selective channel

$$\hat{\tilde{H}} = (\tilde{A}^{*} \tilde{A} + \sigma^{2} I)^{-1} \tilde{A}^{*} Y$$

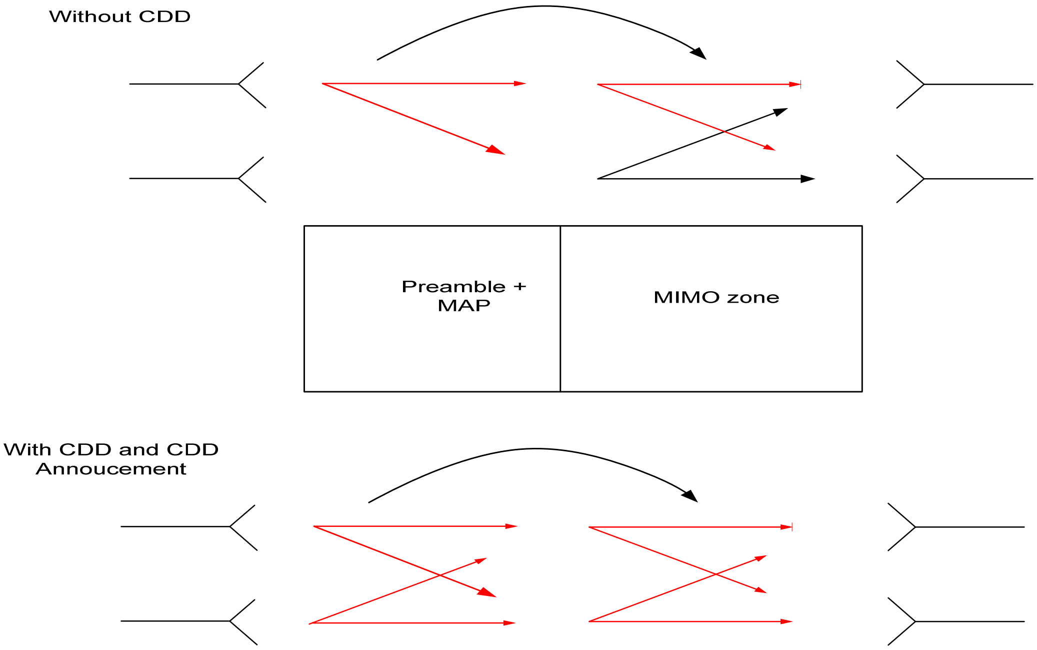


Figure 2 Channel Estimation Tracking for No-CDD (top), and CDD with Announcement (bottom)

Channel Estimation can be further improved if preamble pilot tones are used with MIMO pilot tones. **<u>The final MIMO Channel Coefficient Matrix H is estimated from both Preamble and MIMO pilot tones</u>**. **<u>The CE from preamble provides a strong anchor into the MIMO zone</u>**. Top part of Figure 2 shows without CDD channel estimation tracking is only possible for part of the channels. Bottom part of Figure 2 shows with CDD and CDD announcement, full channel tracking is possible. Note with CDD and no CDD announcement, no channel tracking is possible due to the artificial modification of channel by BS and not known to MS.

Corner Case of A CDD Delay Collides With A Multi-path

As an example: 2x2 MIMO, 2 path channel, shown in Figure 3

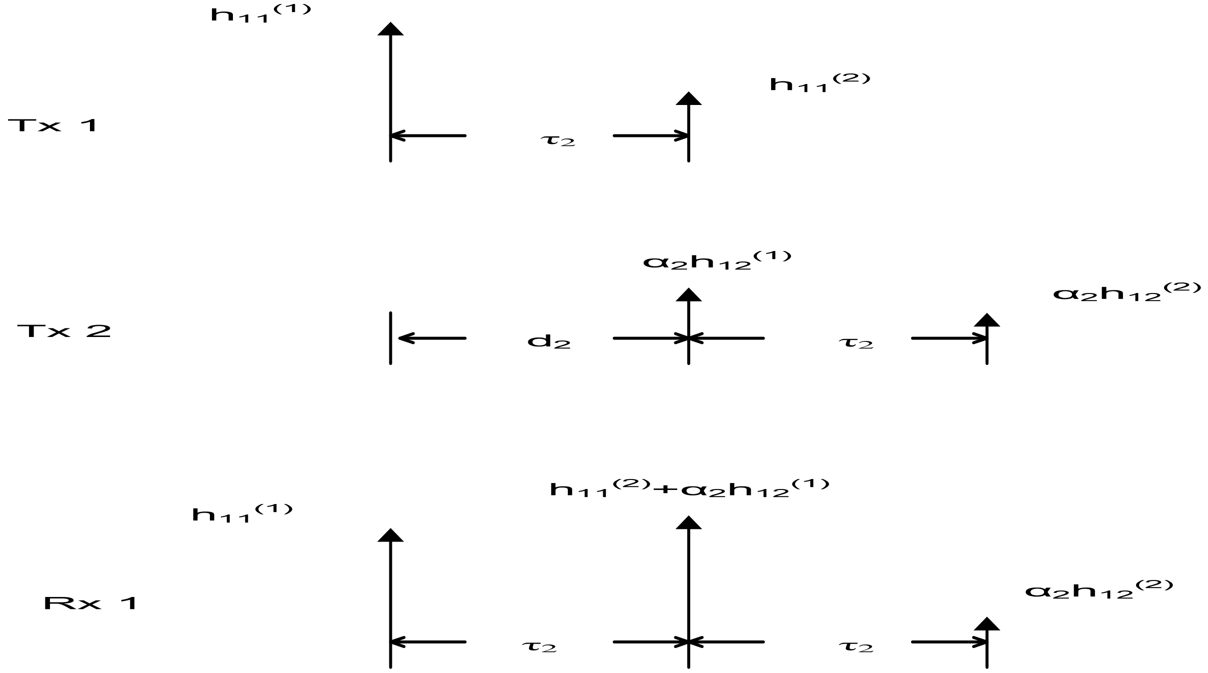


Figure 3 Corner Case of One CDD Delay Collides with One Multipath

$$\begin{bmatrix} p_0 y_{1,0} & p_0 y_{2,0} \\ p_3 y_{1,3} & p_3 y_{2,3} \\ . & . \\ . & . \\ p_{849} y_{1,849} & p_{849} y_{2,849} \end{bmatrix} = \begin{bmatrix} 1 & \alpha_2 & 1 & \alpha_2 \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 3}{N_{fft}}} & e^{-j\frac{2\pi\tau_2 3}{N_{fft}}} & \alpha_2 e^{-j\frac{2\pi(d_2+\tau_2)3}{N_{fft}}} \\ . & . & . & . \\ . & . & . & . \\ 1 & \alpha_2 e^{-j\frac{2\pi d_2 849}{N_{fft}}} & e^{-j\frac{2\pi\tau_2 849}{N_{fft}}} & \alpha_2 e^{-j\frac{2\pi(d_2+\tau_2)849}{N_{fft}}} \end{bmatrix} \times \begin{bmatrix} h_{11}^{(1)} & h_{21}^{(1)} \\ h_{12}^{(1)} & h_{22}^{(1)} \\ h_{11}^{(2)} & h_{21}^{(2)} \\ h_{12}^{(2)} & h_{22}^{(2)} \end{bmatrix} + \begin{bmatrix} w_{1,0} & w_{2,0} \\ w_{1,3} & w_{2,3} \\ . & . \\ . & . \\ w_{1,849} & w_{2,849} \end{bmatrix}$$

$$= \begin{bmatrix} 1 & 1 & \alpha_2 \\ 1 & e^{-j\frac{2\pi d_2 3}{N_{fft}}} & \alpha_2 e^{-j\frac{2\pi(d_2+\tau_2)3}{N_{fft}}} \\ . & . & . \\ . & . & . \\ 1 & e^{-j\frac{2\pi d_2 849}{N_{fft}}} & \alpha_2 e^{-j\frac{2\pi(d_2+\tau_2)849}{N_{fft}}} \end{bmatrix} \times \begin{bmatrix} h_{11}^{(1)} & h_{21}^{(1)} \\ \alpha_2 h_{12}^{(1)} + h_{11}^{(2)} & \alpha_2 h_{22}^{(1)} + h_{21}^{(2)} \\ h_{12}^{(2)} & h_{22}^{(2)} \end{bmatrix} + \begin{bmatrix} w_{1,0} & w_{2,0} \\ w_{1,3} & w_{2,3} \\ . & . \\ . & . \\ w_{1,849} & w_{2,849} \end{bmatrix}$$

Here instead of the complete estimations of $\{ h_{11}^{(1)}, h_{12}^{(1)}, h_{11}^{(2)}, h_{12}^{(2)}, h_{21}^{(1)}, h_{22}^{(1)}, h_{21}^{(2)}, h_{22}^{(2)} \}$, we get a majority of the channel estimations $\{ h_{11}^{(1)}, \alpha_2 h_{12}^{(1)} + h_{11}^{(2)}, h_{12}^{(2)}, h_{21}^{(1)}, \alpha_2 h_{22}^{(1)} + h_{21}^{(2)}, h_{22}^{(2)} \}$. **Complete estimation of H is achieved via using both Preamble pilot tones and MIMO pilot tones**. **The channel estimates from preamble provide a strong anchor before entering the MIMO zones.**

SINR Comparison for Preamble Pilot and MIMO Pilot

Assume preamble is transmitted at P dBm, MIMO zone is transmitted at about P-4 dBm.

SINRpreamble_pilot = P – pathloss – Interference (Reuse 3) – noise

SINRmimo_pilot = P–4 + 10lg(120/840) + 10lg(16/9) +3 – pathloss – Interference (Reuse 1) - noise

Using the fact that Interference (Reuse 1) is typically about 10 dB higher that Interference (Reuse 3)

- ⇨ SINRpreamble_pilot - SINRmimo_pilot = 17 dB!

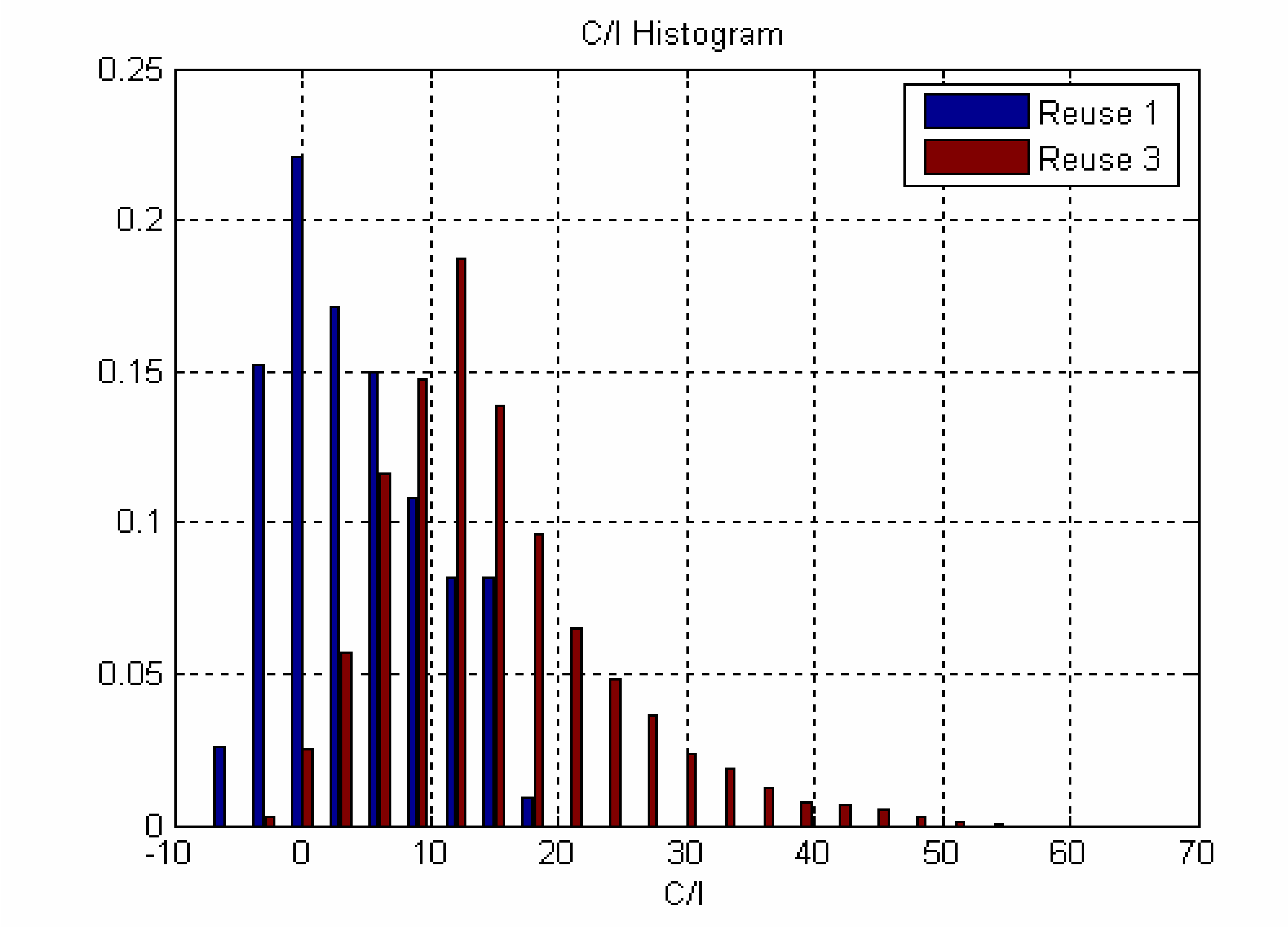


Figure 4 Reuse 1 vs Reuse 3 C/I Historgram

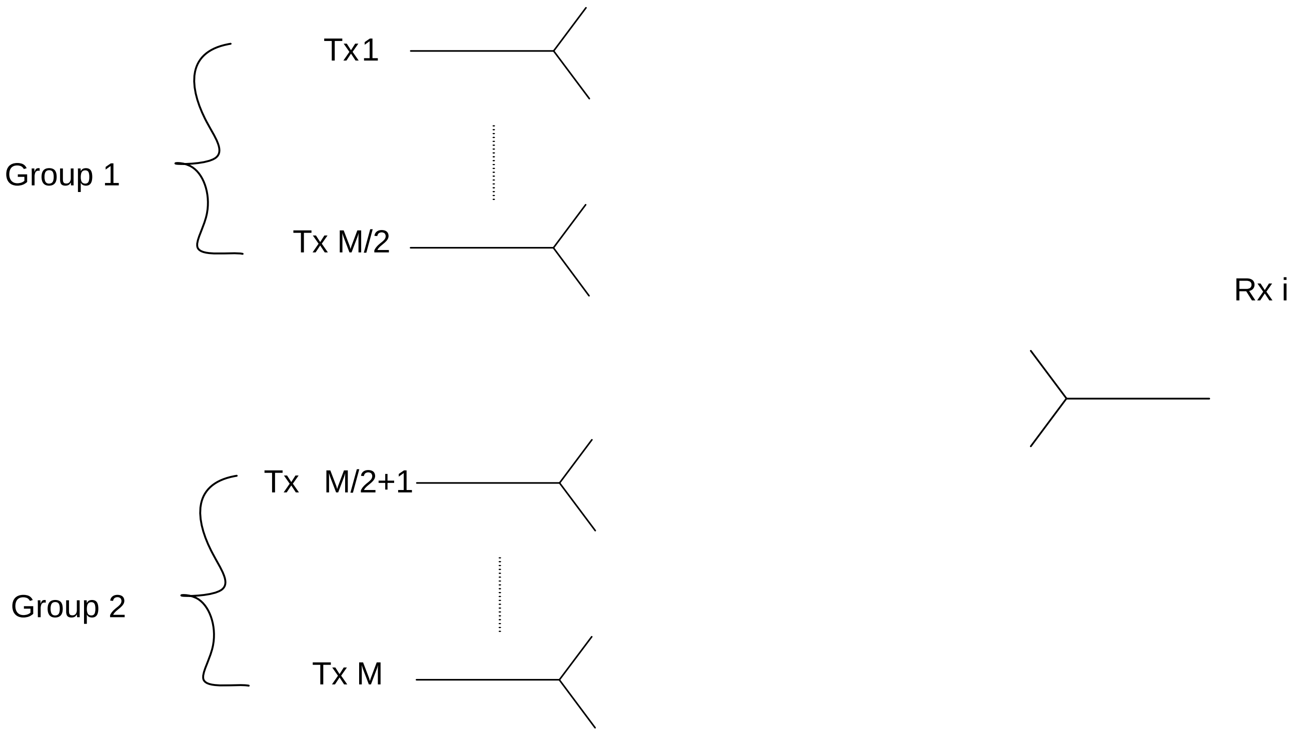
Simulation Results

1024 FFT, PUSC, 2x2 Alamouti, high correlation, $I_{mimo} – I_{pre}$ = 10dB, 6 symbol MAP, CDD delay = 8 samples

MCS	SINR Gain of w/ over w/o CDD Announcement at BLER = 10% [dB]	
	PedB 3 km/hr	VehA 60 km/hr
QPSK 1/2	1.26	1.06

CDD in MIMO Zones

For BS with 4 or more antennas, CDD maybe used in MIMO zones to enable 2x2 MIMO:



$$p_k y_{ik} = [h_{i1} + h_{i2}\alpha_2 e^{-j\frac{2\pi d_2 k}{N_{fft}}} + \ldots + h_{iM/2}\alpha_{M/2} e^{-j\frac{2\pi d_{M/2} k}{N_{fft}}}] + w_{ik}$$

$$p_{k'} y_{ik'} = [h_{i,M/2+1} + h_{i,M/2+2}\alpha_2 e^{-j\frac{2\pi d_2 k'}{N_{fft}}} + \ldots + h_{iM}\alpha_{M/2} e^{-j\frac{2\pi d_{M/2} k'}{N_{fft}}}] + w_{ik'}$$

Pk and Pk' are MIMO zone pilot tones on two different frequencies but the same symbol. All the h's (or most of them in the corner case discussed before) are known from the preamble which provide a strong anchor into the MIMO zone