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Purpose	
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# CDD Parameters in DCD to Improve MIMO Channel Estimation

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## 1. Introduction

CDD has been proposed and implemented in some BS vendors to provide additional frequency diversity 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

So the proposal is that if BS uses CDD, the MS would like to know.

## 2. Using CDD Parameters to Estimate MIMO Channel

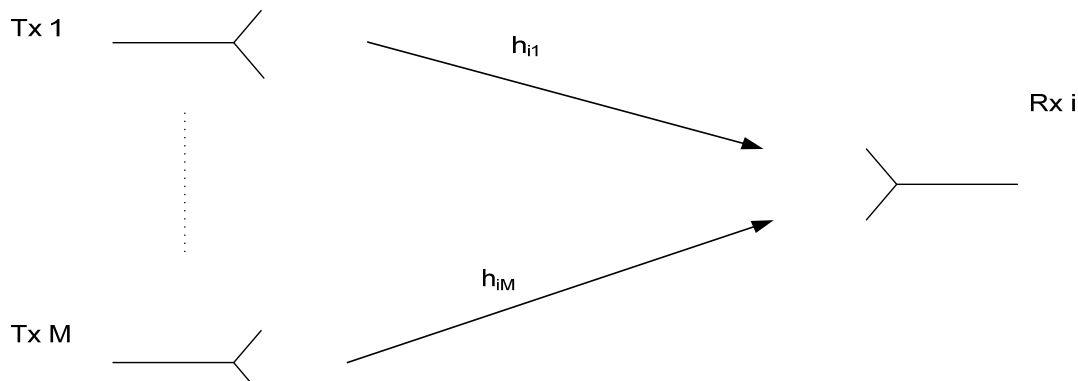


Figure 1 MxN MIMO System with Flat Fading Channel

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,  $i=1,2,\dots,M$ ,  $d_1=0$ ,  $1 \leq d_2 < d_3 < \dots < d_M \leq 32$ , (5 bits).

$\alpha_2^2, \dots, \alpha_M^2, \alpha_i^2$  are the power attenuation in dB per delay antenna and  $C \in \{0, -1, \dots, -7\}$  dB,  $i=2,3,\dots,M$ , (3 bits).

Look at the i-th Rx antenna, we have:

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

, 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:

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

Here we used 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:

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

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  $\tau_l$ . Again  $k$  is tone index.

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

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

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

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

Where

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

Then we look at all the Rx antennas:

$$Y_{284 \times N} = \begin{bmatrix} A & D_2 A & D_3 A & \dots & D_L A \end{bmatrix} \times \tilde{H}_{ML \times N} + W_{284 \times N}$$

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

Or in compact form below. Note now the channel dimension is  $ML \times N$ .

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

Again we have the MMSE estimation of the frequency selective channel

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

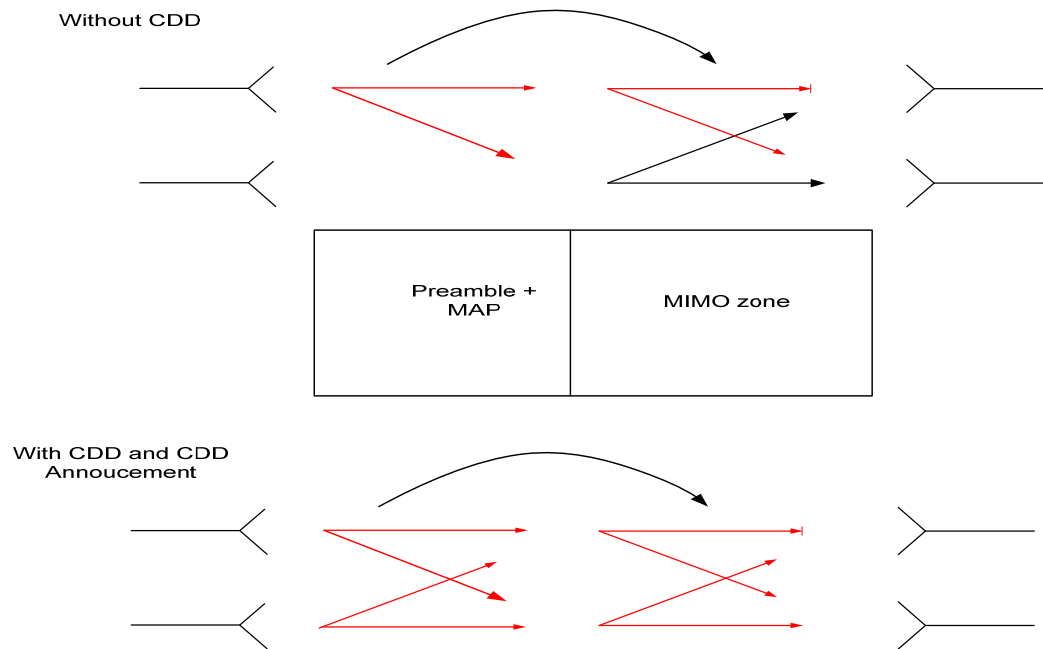


Figure 2 Channel Estimation Tracking for No-CDD, CDD with Announcement.

Channel Estimation can be further improved if preamble pilot tones are used with MIMO pilot tones. The final MIMO Channel Coefficient Matrix  $H$  is estimated from both Preamble and MIMO pilot tones. 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.

### 3. Corner Case of A CDD Delay Collides With A Multi-path

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

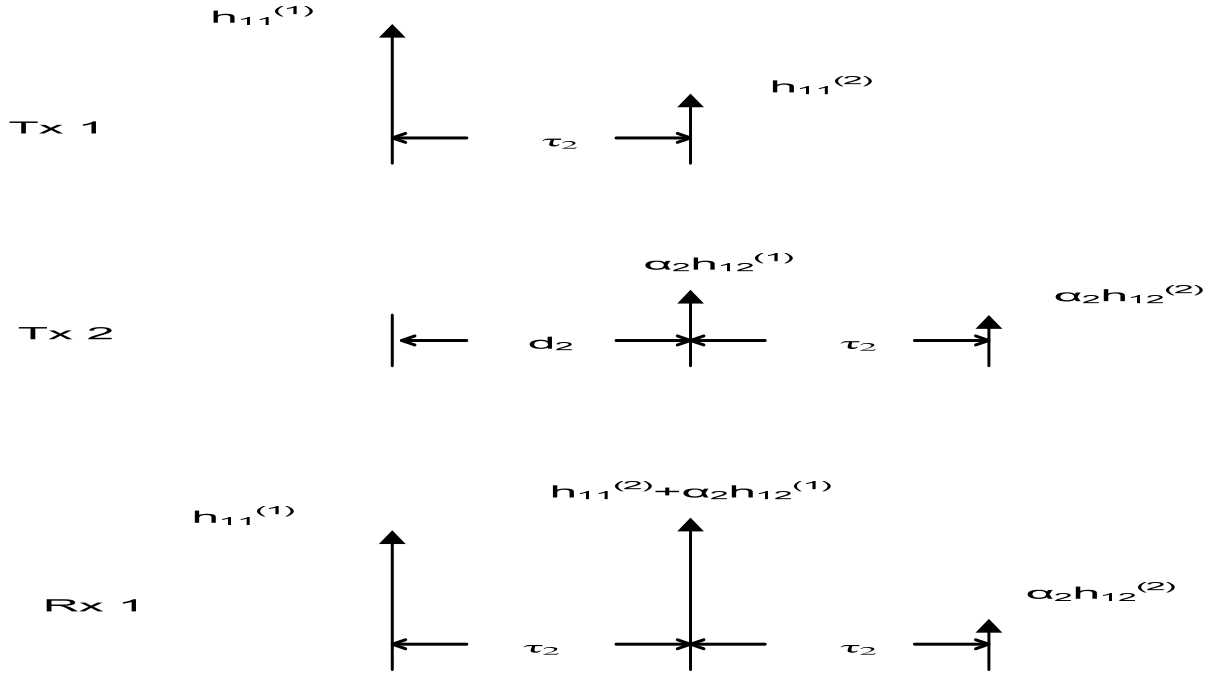


Figure 3 Corner Case of One CDD Delay Collides with One Multipath

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

Here instead of getting the complete estimations of  $\{ h_{11}^{(1)}, h_{12}^{(1)}, h_{11}^{(2)}, h_{12}^{(2)}, h_{21}^{(1)}, h_{22}^{(1)}, h_{21}^{(2)}, h_{22}^{(2)} \}$ , but rather 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.



#### 4. SINR Comparison for Preamble Pilot and MIMO Pilot

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

$$\text{SINR}_{\text{preamble\_pilot}} = P - \text{pathloss} - \text{Interference (Reuse 3)} - \text{noise}$$

$$\text{SINR}_{\text{mimo\_pilot}} = P-4 + 10\lg(120/840) + 10\lg(16/9) + 3 - \text{pathloss} - \text{Interference (Reuse 1)} - \text{noise}$$

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

$$\Rightarrow \text{SINR}_{\text{preamble\_pilot}} - \text{SINR}_{\text{mimo\_pilot}} = 17 \text{ dB!}$$

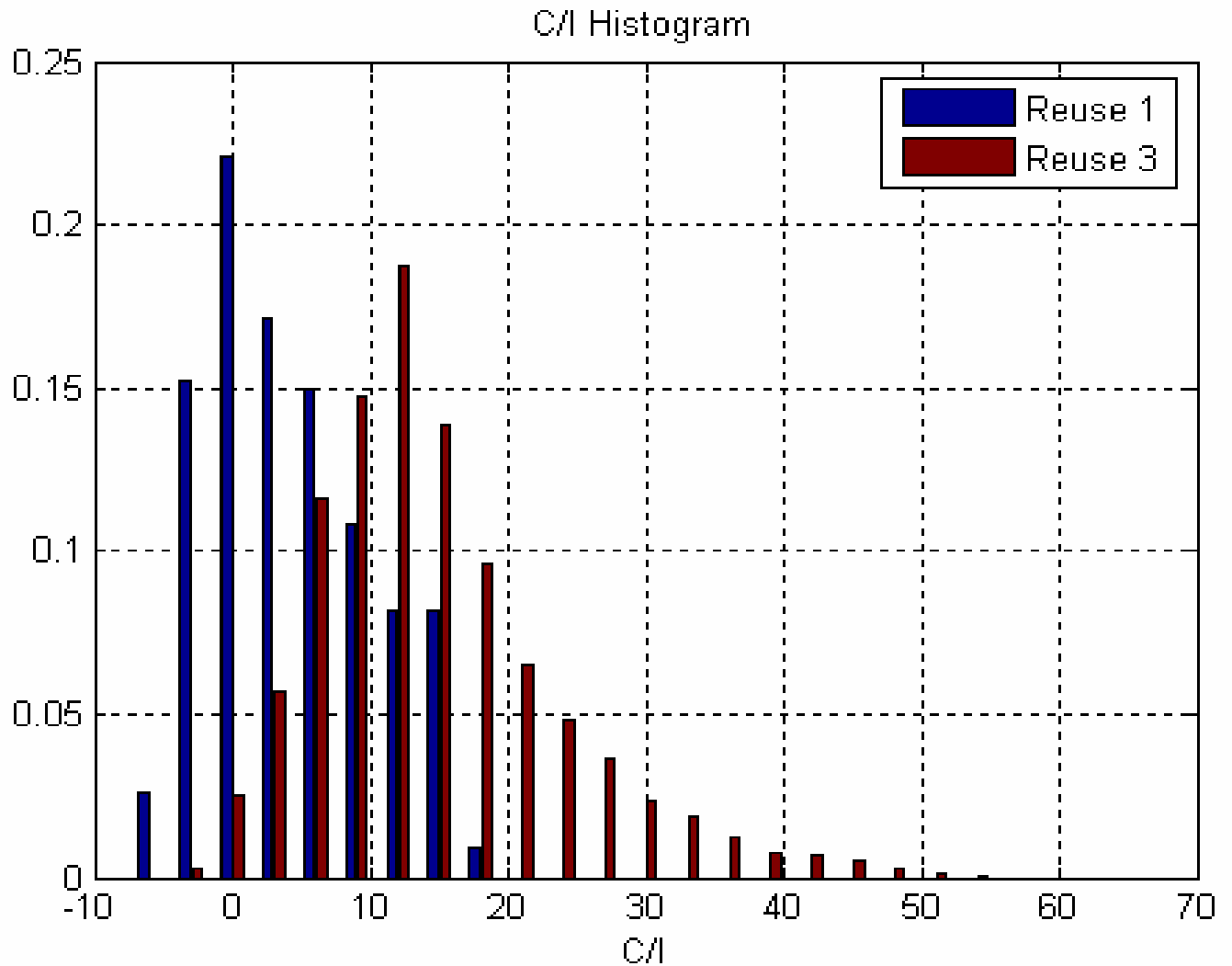


Figure 4 Reuse 1 vs Reuse 3 C/I Histogram

## 5. Proposed Text Changes in Rev2/D1

Add the following CDD Descriptor at the end of Table 615 in Section 11.4.1 DCD Channel Encodings at Page 1181

Name	Type	Length	Value	PHY Scope
CDD Descriptor	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)	OFDMA

## 6. Conclusion

Here we propose an optional CDD announcement for BS. If 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.

In additional to channel estimation, MS can use the CDD announcement for other modem performance improvement. For example, point to point performance will be affect by CDD. Link adaptation algorithm (e.g., ECINR) can be improved if CDD info is known to the MS.

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