Title:	MMSE Appendix Text with Ray Mapping
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1. SUMMARY

This contribution provides revised text for the MMSE Appendix A found in the SCM text [1]. The major revision is the inclusion of a ray mapping procedure based on [2]. In addition, some minor editorial revisions are provided for clarity. Changes to the current text are indicated in red.

2. REVISED TEXT FOR MMSE APPENDIX A

The following text is a preliminary description of the MMSE receiver. The receiver designs described here are exemplary receiver structures only, for use in calibrating and assessing link and system performance; their use is not implied as mandatory for any present or future receiver minimum performance requirement.

This procedure generates SINR values at the output of a linear MMSE receiver for a single instant in time. A single user's traffic channel is modeled per sector in this example.

Step 1: Given the space-time propagation model and transmitter state, form a channel (expressed here as one or more convolution matrices) relating all transmitting sources and receive antennas from every sector in the system.

At the UE, the received samples are represented as a column vector,

$$\begin{aligned}\mathbf{r} &= [\mathbf{r}_1^T, \mathbf{r}_2^T, \cdots, \mathbf{r}_M^T]^T \\ &= [r_1(1), r_1(2), \cdots, r_1(N), r_2(1), r_2(2), \cdots, r_2(N), \cdots, r_M(1), r_M(2), \cdots, r_M(N)]^T,\end{aligned}$$

where M is the number of receive antennas at the UE, and N is the number of received symbols per antenna[1]. This received time-space vector is related to the transmitted symbols as follows:

$$\mathbf{r} = \mathbf{G}^{(1)}\mathbf{x}^{(1)} + \sum_{j=2}^{J} \mathbf{G}^{(j)}\mathbf{x}^{(j)} + \mathbf{n} = \begin{bmatrix} \mathbf{G}_1^{(1)} \\ \mathbf{G}_2^{(1)} \\ \vdots \\ \mathbf{G}_M^{(1)} \end{bmatrix} \cdot \mathbf{x}^{(1)} + \sum_{j=2}^{J} \begin{bmatrix} \mathbf{G}_1^{(j)} \\ \mathbf{G}_2^{(j)} \\ \vdots \\ \mathbf{G}_M^{(j)} \end{bmatrix} \cdot \mathbf{x}^{(j)} + \begin{bmatrix} \mathbf{n}_1 \\ \mathbf{n}_2 \\ \vdots \\ \mathbf{n}_M \end{bmatrix}$$

where $\mathbf{G}_i^{(j)}$, $1 \le i \le M$, $1 \le j \le J$ are Toeplitz convolution matrices defining the channel between the i-th receive antenna and the j-th transmitted data stream, $\mathbf{x}^{(j)}$ is the j-th transmitted data stream (a vector of complex symbols), J is the total number of data streams in the system, and $\mathbf{n}$ is the vector of noise samples. The $j = 1$ data stream is the primary data stream intended for the user. The j-th data stream can be a transmission from an interfering base station, another sector of the desired base station, or another data stream intended for the

[1] Actually, this is the number of received samples per antenna, if more than one sample per symbol is collected.

desired user (which is considered interference to the primary data stream). If the composite channel response is limited to K samples for all transmitted streams, then each of the convolution matrices has N rows by (N+K-1) columns,

$$\mathbf{G}_i^{(j)} = \begin{bmatrix} g_i^{(j)}(K) & g_i^{(j)}(K-1) & \cdots & g_i^{(j)}(1) & 0 & 0 & \cdots & 0 \\ 0 & g_i^{(j)}(K) & g_i^{(j)}(K-1) & \cdots & g_i^{(j)}(1) & 0 & \cdots & 0 \\ \vdots & \vdots & \ddots & \ddots & \cdots & \ddots & \cdots & 0 \\ 0 & 0 & \cdots & 0 & g_i^{(j)}(K) & g_i^{(j)}(K-1) & \cdots & g_i^{(j)}(1) \end{bmatrix},$$

and $\mathbf{g}_i^{(j)}$ is the vector of discrete channel samples of length K. The channel samples can be expressed as:

$$g_i^{(j)}(m) = \sum_{l=1}^{L} h_{i,l}^{(j)} \cdot s\left((m-1)\cdot T_s - \tau_{i,l}^{(j)}\right),$$

where T_s is the receiver channel sampling interval (interval between MMSE taps, either equal to the chip interval or half of the chip interval), $h_{i,l}^{(j)}$ and $\tau_{i,l}^{(j)}$ are the complex amplitude and delay of the l-th ray for the i-th receive antenna and the j-th transmitted data stream, and

$$s(t) = s_{tx}(t) \otimes s_{rx}(t),$$

where $s_{tx}(t)$ is the continuous time version of the transmit filter, and $s_{rx}(t)$ is the continuous time version of the receive filter. Since the channel delays, $\tau_{i,l}^{(j)}$, are quantized to the nearest 1/16th chip interval, a discrete-time version of $s(t)$ (with 16 samples per chip) can be stored and accessed in an efficient implementation.

Note that in the above formulation, the vector $\mathbf{x}$ has $M(N+K\text{-}1)$ rows, and thus, it is longer than the received vector, $\mathbf{r}$. Also, the vector $\mathbf{x}$ will be interleaved with zero values if a fractionally-spaced approach with more than one received sample per symbol is used.

Step 2: Using the above channel, produce an estimate of the channel.

$$\hat{\mathbf{g}}_i^{(j)} = \mathbf{g}_i^{(j)} + \Delta\mathbf{g}_i^{(j)},$$

where $\Delta\mathbf{g}_i^{(j)}$ is a vector representing the channel estimation error for the i-th receive antenna and the j-th transmitted data stream. The estimation error is due to noise and interference in the pilot channel and can also be due to the channel estimator's inability to track a fast fading channel.

Step 3: Using the estimated channel, compute the SINR per data stream at the output of the MMSE filters.

$$SINR_j = \frac{\left| \mathbf{f}_j^H \hat{\mathbf{\Omega}}_j^{-1} \hat{\mathbf{f}}_j \right|^2}{\hat{\mathbf{f}}_j^H \hat{\mathbf{\Omega}}_j^{-1} \mathbf{\Omega}_j \hat{\mathbf{\Omega}}_j^{-1} \hat{\mathbf{f}}_j},$$

where

$$\mathbf{\Omega}_j = \mathbf{G}^{(j)} E\left[\mathbf{x}^{(j)} \mathbf{x}^{(j)H}\right] \mathbf{G}^{(j)H} - \mathbf{f}_j E\left[x^{(j)}(d) x^{(j)}(d)^*\right] \mathbf{f}_j^H + \sum_{\substack{m=1 \\ m \neq j}}^{J} \mathbf{G}^{(m)} E\left[\mathbf{x}^{(m)} \mathbf{x}^{(m)H}\right] \mathbf{G}^{(m)H} + E\left[\mathbf{n}\mathbf{n}^H\right],$$

$\hat{\mathbf{\Omega}}_j$ is an estimate of $\mathbf{\Omega}_j$, $d = \max\left(\lceil (N-K)/2 \rceil + K, K\right)$, $\mathbf{f}_j$ is the *d*-th column of $\mathbf{G}^{(j)}$, $\hat{\mathbf{f}}_j$ is the *d*-th column of $\hat{\mathbf{G}}^{(j)}$ containing channel estimate $\hat{\mathbf{g}}^{(j)}$, $x^{(j)}(d)$ is the *d*-th element (desired symbol) of the $\mathbf{x}^{(j)}$ data stream vector, and $SINR_j$ represents the SINR for the *j*-th transmitted data stream in the system. In this example, the primary data stream sent to a user will be $j = 1$. In a MIMO system where multiple data streams are sent to a single user, the second stream could be $j = 2$, etc.

3. REFERENCES

[1] SCM-111, “Spatial Channel Model Text Description,” February 2003.

[2] SCM-092, Motorola, “Details on Mapping Channel Rays to Samples for System Simulations,” January 2003.