Title:	Receiver Implementation for System-Level Simulations
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1. SUMMARY

This contribution describes a procedure for implementing a linear MMSE receiver model at the system level and is a follow up to [1] and [2]. This receiver method is recommended as a baseline for system-level simulations.

2. COMPUTING RECEIVER THROUGHPUT

This procedure computes the receiver throughput on a TTI basis. A simple block diagram of the receiver processing is provided in Figure 1.

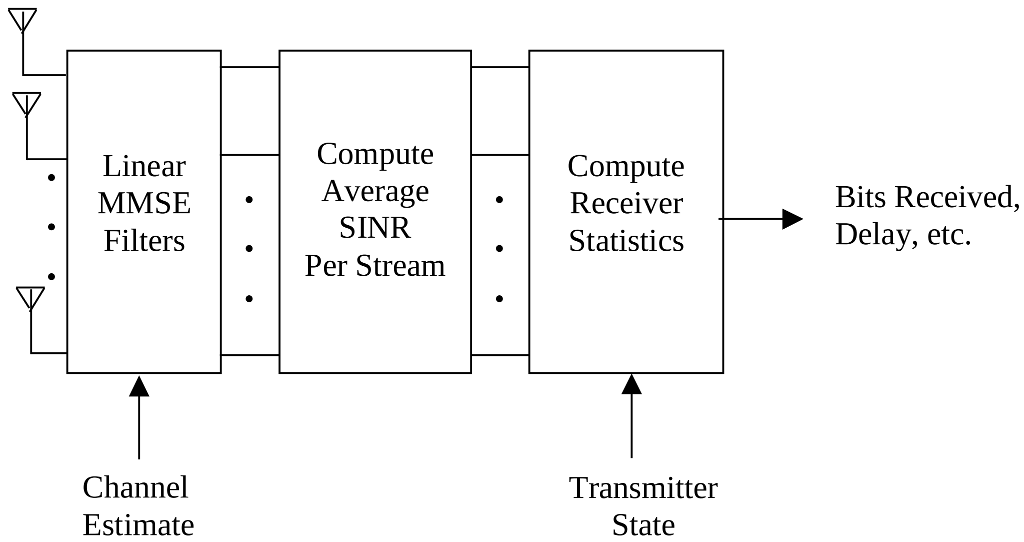

Figure 1. Mobile receiver processing.

Step 1: Determine the transmitter state.

Modulation and coding selection (MCS) feedback delay and errors will degrade system performance. In the simulation, the MCS should be determined from information that is appropriately delayed and includes the effect of feedback error. The method to compute the MCS requested by the mobile can be based on Step 2 of this procedure.

Step 2: Map the receiver SINRs over the TTI interval to a packet error rate given the transmitter state and the ARQ state.

The details for computing SINR for a linear MMSE receiver at a single instant in time are provided in Section 3. The mapping should handle ARQ schemes and support various mobile velocities. The details of this method are FFS.

Step 3: Determine if the received packet is in error.

Given the packet error rate, perform a random experiment to determine if the received physical layer packet is in error. If the packet is in error and an ARQ scheme is employed, information about the current packet is stored for combining with the next transmission. Each transmitted packet is explicitly simulated in this procedure.

Step 4: Send an ACK/NACK to the base station.

After transmission of a packet, the transmitter must be informed about the status of the packet before it can either transmit a new packet or retransmit the failed packet. Because the mobile must signal this information to the base, there will be some feedback delay and errors. The simulator should model these effects, retransmitting based on delayed and possibly erroneous ACK/NACK signaling.

Step 5: Compute receiver statistics.

The simulator should keep track of how much data is successfully received, the number of TTIs that were used for transmission to the mobile, the number of TTIs that were not used for transmission to the mobile, and the amount of time it took to receive each packet. These values determine the data rate for a mobile and the delays produced by the physical layer.

The above procedure can be extended to the MIMO case when multiple simultaneous data streams are intended for a single user. The extension is highly dependent on the specific MIMO implementation and is not discussed here.

3. COMPUTING SINR AT THE RECEIVER

This proposed procedure generates SINR values at the output of a linear MMSE receiver for a single instant in time. This procedure is an extension of the work done in 3GPP2 [3]. The length of time for which the SINR values are valid is a function of how fast the channel is changing. Note that this procedure computes the SINR *before* any ARQ repeat and combine scheme is applied. Also, this procedure is intended as a baseline and does not mandate a particular receiver architecture.

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:

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

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

where $\mathbf{G}_i^{(j)}$, $1 \le i, j \le M$ 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, 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 desired user (which is considered interference to the primary data stream). If the composite channel response is limited to K samples, 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.

Note that in the above formulation, the vector $\mathbf{x}$ has M(N+K-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. The exact algorithm for computing channel estimation error is FFS.

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 $\mathbf{G}^{(j)}$, $x^{(j)}(d)$ 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.

4. CONCLUSIONS

A procedure for implementing a linear MMSE receiver model at the system level was presented. Additional details, such as the channel estimation procedure, and the specifics of mapping SINR to packet error rate, are left open for further study.

5. REFERENCES

[1] Motorola, SCM-063, "Performance Comparison of Rake and MMSE Equalizers," October 10, 2002.

[2] Motorola, SCM-056, "A Proposed Receiver for System-Level Evaluations," September 17, 2002.

[3] 3GPP2 WG5 Evaluation AHG, 1xEV-DV Evaluation Methodology – Addendum (V6), July 25, 2001.