Turbo-BLAST with Iterative Channel Estimation in a Correlated Fast Fading Channel

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***Abstract*— This paper describes an iterative interference canceling receiver for MIMO channels where the channel is correlated and the fading is fast. The receiver estimates the complex channel coefficients by utilising periodically inserted pilot bits and the iterative receiver removes interference over iterations. Channel estimation is improved over iterations by utilizing the data estimates from the previous iteration. A low complexity system results with performance close to optimal.**

I. EXTENDED ABSTRACT

There are currently three popular implementations of BLAST: Diagonal-BLAST [1], Vertical-BLAST (V-BLAST) [2] and more recently, Turbo-BLAST (T-BLAST) [3]. All these systems use n_T transmit antenna and n_R receive antenna, where $n_R \geq n_T$. In all implementations the data stream to be transmitted is split up into n_T parallel sub-streams and an array of antenna are then used to transmit the sub-streams while the total transmit power is held constant. Each antenna uses the entire channel bandwidth and simultaneously with the other antenna.

The digital information is transmitted across an independent continuous correlated Rayleigh fading channel. The $n_R \times n_T$ channels, at time i, are represented by an $n_R \times n_T$ matrix, $\mathbf{H}_i$, with each element of the matrix being zero-mean complex white Gaussian random variables taken from a continuous function generated using the Jakes model [5]. Let $\mathbf{x}_i = [x_{1,i}, x_{2,i}, \ldots, x_{n_T,i}]$ be the $n_T \times 1$ vector representing the transmitted signal at time i, $\mathbf{r}_i$ the $n_R \times 1$ received vector and $\mathbf{n}_i$ the $n_R \times 1$ vector representing the white Gaussian noise with zero mean and variance σ_N^2. The received vector is then given by:

$$\begin{aligned}\mathbf{r}_i &= \sqrt{\frac{\rho}{n_T}}\mathbf{H}_i\tilde{\mathbf{x}}_i + \mathbf{n}_i \\ &= \mathbf{H}_i\mathbf{x}_i + \mathbf{n}_i \qquad (1)\end{aligned}$$

A. Iterative Receiver

Figure 1 shows the structure of the iterative receiver used in our TURBO-BLAST system. The main components of the receiver are the n_T parallel detectors followed by n_T parallel decoders and the channel estimator.

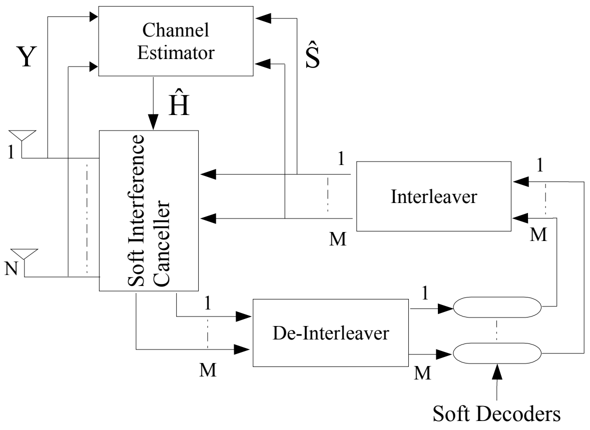

Fig. 1. TURBO-BLAST Iterative Receiver Structure

1) Detector: The major source of error in BLAST is the co-antenna interference (CAI) created by using the n_T transmitting antennas simultaneously. Our detector performs interference cancelation on each sub-stream using estimates of the interferers, i.e. estimates of the other streams. These estimates are generated using the a-priori probabilities which are output as a-posteriori probabilities by the n_T parallel decoders in the previous iteration.

$$E[\tilde{x}_k] = \sum_{\tilde{x}_k \in \{+1,-1\}} \tilde{x}_k P(\tilde{x}_k), \qquad k = 1, 2, \ldots, n_T \qquad (2)$$

After interference cancelation has been performed the decision statistic for the k^{th} information bit is given by:

$$\mathbf{u}_k = \mathbf{h}_k x_k + \sum_{\substack{j=1 \\ j \neq k}}^{n_T} \mathbf{h}_j (x_j - E[x_j]) + \mathbf{n} \qquad (3)$$

where $\mathbf{h}_k$ is the k^{th} column of the channel matrix $\mathbf{H}$ and $\mathbf{h}_k^H$ denotes the Hermitian or conjugate transform of $\mathbf{h}_k$. On the first iteration the estimates of the interferers is zero. However after several iterations the estimates of the interferers, approaches the true value. i.e $E[x_k] \rightarrow x_k$.

To extract the desired signal from (3) we use Maximum Ratio Combining (MRC). The output of the detector, for the k^{th} information bit, is given by:

$$d_k = \Re\{\mathbf{h}_k^H \mathbf{h}_k x_k + \mathbf{h}_k^H \sum_{\substack{j=1 \\ j \neq k}}^{n_T} \mathbf{h}_\mathbf{j}(x_j - E[x_j]) + \mathbf{h}_k^H \mathbf{n}\} \tag{4}$$

The second term represents the CAI and goes to zero as the estimates of the interferers improves and so we are left with only the signal and the noise term. Allowing us to achieve n_R fold receive diversity.

2) Decoders: The decoders are identical Maximum A-Posteriori decoders using the BCJR algorithm [6], [7]. The decoded output is produced by making hard decisions on the probabilities of the information bits.

B. Channel Re-estimation

Time multiplexed pilots are used on the first two iterations of the receiver. On the third and subsequent iterations we propose a new technique to re-estimate the channel matrix using the interference canceled sub-streams produced by the detectors and the soft estimates of the coded bits produced by the decoders. Let $\mathbf{u}_k$ be the interference canceled signal for the k^{th} data bit, as defined by (3). The estimate of the k^{th} column of the channel matrix $\mathbf{H}$, at time i, is given by:

$$\hat{\mathbf{h}}_{k,i} = \sqrt{n_T}\, \mathbf{u}_{k,i} E[\tilde{x}_{k,i}] \tag{5}$$

where $E[\tilde{x}_k]$ is as defined in (2). Clearly the channel estimate will contain an error due to imperfect interference cancelation and noise. To improve the channel estimate we average out the M previous estimates using a Moving Average Process. So the channel estimate for the i^{th} time instant is given by:

$$\tilde{\mathbf{H}}_i = \sum_{j=0}^{M-1} \hat{\mathbf{H}}_{i-j} \tag{6}$$

where $\hat{\mathbf{H}}_i = [\hat{\mathbf{h}}_{1,i}, \hat{\mathbf{h}}_{2,i}, \ldots, \hat{\mathbf{h}}_{n_T,i}]$, from (5).

C. Numerical Results

The TURBO-BLAST system simulated used 4 antennas at transmitter and receiver. The block length of each sub-stream was 200 bits, giving a total packet size of 800 bits. The channel code was a G[7,5] convolutional code, rate 1/2, and BPSK modulation. Two channels were simulated with maximum doppler shift frequencies of 100 Hz and 200 Hz, which correspond to speeds of 35 mph (60 km/hr) and 70 mph (100 km/hr) at a carrier frequency of 2 Ghz. The symbol period used was $41\mu s$ (corresponding to IS-136 standard [8]). The proportion of pilot symbols was 4 pilot bits for for 76 coded bits and 4 pilot bits for 40 coded bits for the 100 Hz and 200 Hz frequencies, respectively. This was based on the results in [4]. The transmit power was normalised such that this remains constant and independent of the number of transmit antenna. The receive diversity gained was also taken into account. The following three configurations were simulated:

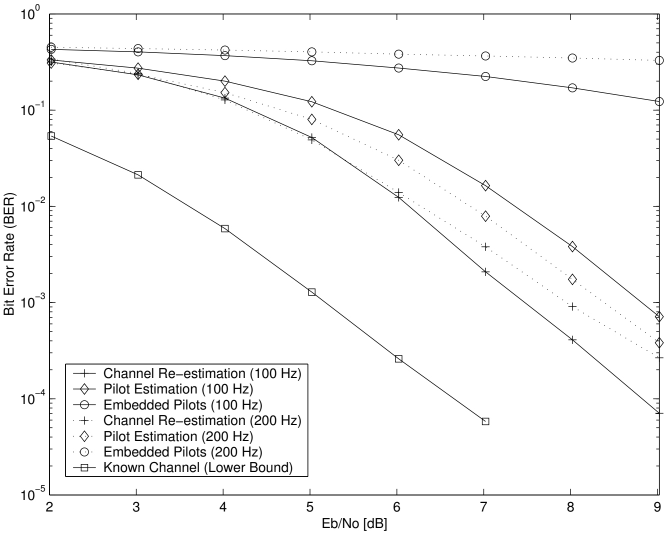

Fig. 2. BER vs. E_b/N_o

D. Bit Error Rate Performance

Figure 2 shows the receiver BER performance versus E_b/N_0. The receiver for the 100 Hz case was run for 4 iterations while in the 200 Hz case the receiver reached its best performance in 3 iterations. The value of M for the re-estimation scheme, found by experimentation to provide the lowest MSE, was 20 and 12 for the 100 Hz and 200 Hz channel, respectively. The performance plots are not adjusted for this power loss from the pilot of 0.23dB and 0.46dB, respectively. Our scheme's performance is within 2dB of perfect channel knowledge while the embedded pilot schemes performance is very poor, not achieving a BER below 10^{-1}. Significant improvements using channel re-estimation over iterations of up to 1.5dB is possible compared to just utilizing the pilot bits for channel estimation.

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