Non-Coherent Joint Receiver for MIMO Channels

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Abstract
In this paper we present a non-coherent receiver for the joint recovery of spatially multiplexed digital signals. A quasi-static multiple-input multiple-output (MIMO) flat (non-frequency selective) channel model is considered. This simulation model also incorporates an uncompensated frequency offset term, and compares the frame error rate performance of the proposed scheme with that of the existing MIMO receivers. Simulation results indicate that the proposed receiver out-performs the conventional sequential decoder and the traditional joint maximum likelihood receiver. The performance improvement is higher for frequency offsets.

1. Introduction

Today there is an increasing need for higher bit rates through wireless channels. Multipath propagation through wireless channels can significantly limit the maximum achievable bit rate for a given bandwidth. It is not possible to attain high spectral efficiencies using purely temporal and/or frequency diversity schemes. A solution to this problem comes from the spatial dimension. Various research studies have shown that employing multiple antennas at the receiver can significantly improve performance without any increase in bandwidth. Spatial multiplexing at the transmitter, on the other hand, allows transmission of multiple symbols at the same time within the same bandwidth. A combination of multiple transmit/receive antennas and multiplexing will therefore provide a good performance and also a higher spectral efficiency.

Another major issue in any communication system is the frequency and clock synchronization between the transmitter and the receiver. For example, in the case of Wireless LAN systems like Hiperlan or IEEE 802.11, there may not be a continuously running frequency tracking loop (PLL) at the receiver and uncompensated frequency offsets are unavoidable. A receiver that is insensitive to this frequency offset is therefore essential.

In this paper, we propose a novel non-coherent joint receiver that is well suited for such applications. The performance of this receiver is compared with that of other conventional MIMO receivers for a quasi-static channel and for various frequency offsets.

2 . Signal and Channel Model

The system comprises of 2 transmitters and 3 receivers. A single data stream is de-multiplexed into 2 sub streams, each of which is fed into the respective transmitter. All transmitters operate cochannel with synchronized symbol timing. The collection of 2 transmitters can be considered as a vector valued transmitter.

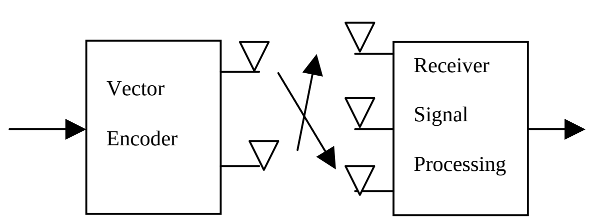

Figure 1: Multiple-Input Multiple-Output (MIMO) channel model – 3x2 example

The channel is assumed to be flat, i.e., the delay spread of the channel is significantly small compared to the symbol duration. The received signal at each antenna port is therefore a linear combination of all the transmitted signals. The Nx1 received vector **r** can be represented as

$$\mathbf{r} = \mathbf{H}\,\mathbf{d} + \mathbf{n} \qquad (1)$$

where **H** represents the 3 x 2 channel matrix, **d** represents the 2 x 1 data vector, and **n** represents 3 x 1 vector of white noise samples. The elements of **H** are assumed to be samples of an independent, circularly symmetric, complex Gaussian random process with a variance 0.5 per dimension.

We have considered a quasi-static channel where the channel coefficients vary independently from burst to burst, but remain constant within a burst(slot). We assume a frame format similar to the ANSI-136 TDMA standard [7]. A frame comprises of 6 slots, each with 162 symbols. Every slot has a 14 symbol preamble sequence to provide channel identification and synchronization information. All the symbols are drawn from a $\pi/4$-shifted DQPSK alphabet [7].

We have considered two receiver models:

(i) Coherent: where the receiver lies in perfect frequency synchronization with the transmitter (Δf=0Hz)

(ii) Non-coherent: where an uncompensated frequency offset, say ΔfHz, exists between the transmitter and the receiver. This frequency offset leads to a constant phase rotation of the channel matrix at the rate of Δf Hz**.**

3. Decoding Algorithms :

3.1 *VBLAST:*

The Vertical-Bell labs layered space-time architecture (V-BLAST), as it is called, decodes symbols sequentially. Ordering is done based on the highest post detection SNR [4]. Zero forcing nulling is employed to cancel out the other (weaker) symbol and the desired symbol is decoded. The effect of the decoded symbol is then removed from the received signal and the resulting residual is used to decode the other (weaker) signal. The primary advantage of this method is the low complexity. But it is generally very sensitive to the rank of the channel (condition number of **H** in (1)).

3.2 *Joint Decoding Algorithms:*

The optimal joint decoding method for a wireless channel is the ideal Maximum Likelihood (ML) decoder. Here, the channel coefficients are assumed to be known precisely at all instants of time. The symbols from both the transmitters are decoded jointly using the minimum distance between the received signal and the estimate as the metric. But in a wireless scenario, it is almost impossible for a receiver to have the knowledge of accurate channel state information all the time. A practical way of implementing this receiver is to estimate the channel at the beginning of every slot, and use this estimate in decoding. This method works well when the channel estimates are good but the performance drops to that of VBLAST when the channel estimates are inaccurate and/or when there is a lack of synchronization between the transmitter and the receiver.

3.3 *Non-coherent Joint Decoder:*

A non-coherent decoder based on a sub-optimal Viterbi algorithm (SNVA) was proposed in [2] for flat fading Rician channels .A joint decoding algorithm based on [2] was proposed in [3] for efficient recovery of cochannel signals in a mobile environment. This Joint SNVA (J-SNVA) can be extended to a system with spatial multiplexing and diversity reception. The detector will have a single stage trellis with M^2 parallel transitions, where M is the alphabet size. For a $\pi/4$-shifted DQPSK signaling M = 4, and therefore, we get 16 parallel transitions. The survivor metric $\eta(N)$ at any time N is given by

$$\eta(N) = | A(N) |^2 / B^2(N) \qquad (2)$$

$$\text{where } A(N) = \sum_{k=0}^{N-1} r_1^H(k)\, r(k) \qquad (3a)$$

$$\text{and } B^2(N) = \sum_{k=0}^{N-1} | r_1(k) |^2 \qquad (3b)$$

where A(N) is the cross-correlation between the received vector r(k) and it's estimate $r_1(k)$, and $B^2(N)$ is the energy in the estimate. Here $r_1(k)$ is computed using the estimated channel information. The metrics for the parallel transitions ,at any time N, can be calculated (for j = 1,2,….16)

$$A_j(N+1) = \gamma A(N) + r_{1j}^H(N)\ r(N)$$
$$B_j^2(N+1) = \gamma B^2(N) + | r_{1j}(N) |^2$$

where $0<\gamma<1$ is a "forgetting factor". Since SNVA remembers the infinite past, for a time varying channel a forgetting factor is employed. The value of the forgetting factor can be optimized based on the knowledge of the channel conditions. The survivor metric is computed from the below maximization

$$\eta(N+1) = \max\ | A_j(N+1) |^2 / B_j^2(N) \qquad (4)$$

for j = 1,2,….16, and the corresponding survivor symbol is decoded.

4. Channel Estimation and Tracking

It is clear from the previous section that a channel estimate is needed to compute the received signal estimate $r_1(k)$. IS-136 frame format provides 14 symbols exclusively for training at the beginning of every slot. In addition to estimation, an adaptive tracking scheme might be required for a fading channel and/or when frequency synchronization between the receiver and transmitter is not perfect. A window based method is used for estimation and tracking purposes.

4.1 *Window Based Estimation & Tracking:*

The correlation properties of the training sequences are exploited in this window based estimation (WBE) and tracking procedure. The collection of received vectors (for the duration of the 14 training symbols) is cross-correlated with the collection of training symbols. The resulting matrix can be represented as

$$\mathbf{X} = \mathbf{R}\,\mathbf{Q}^{\mathbf{H}} + \mathbf{N} \qquad (5)$$

where $\mathbf{X}$ is the 3 x 2 cross correlation matrix, $\mathbf{R}$ is the 3 x 14 matrix of symbols received during the training period. Here, $\mathbf{Q}$ is the 2 x 14 matrix of training symbols and $\mathbf{N}$ is the 3 x 14 matrix resulting from the cross correlation of training symbols with noise. Neglecting the effect of noise and assuming that the channel remains almost constant for the duration of the training symbols, substituting for $\mathbf{R}$ from (1), we get

$$\mathbf{X} = \mathbf{H}\,\mathbf{P} \qquad (6)$$

where $\mathbf{P}$ is a 2 x 2 matrix obtained by multiplying $\mathbf{Q}$ with $\mathbf{Q}^{H}$. From (6), it is clear that, assuming $\mathbf{P}$ is invertible, $\mathbf{H}$ can be obtained by post-multiplying $\mathbf{X}$ with $\mathbf{P}^{-1}$ as

$$\mathbf{X}\,\mathbf{P}^{-1} = \mathbf{H}\,\mathbf{P}\,\mathbf{P}^{-1} = \mathbf{H} \qquad (7)$$

From the 15^{th} symbol onwards, the WBE enters a decision directed tracking mode wherein the decisions of the transmitted symbols are used in tracking the channel. In order to reduce complexity the window length of 10 is used in the tracking mode. Diagonal loading (weighting the leading diagonal entries) is employed to reduce the condition number of $\mathbf{P}$, and ensure that it is always invertible.

5. Simulation Results

The frame (actually slot) error rate performance of the various decoding methods were studied using computer simulations. Simulations were carried out over 10000 channel realizations and both Frame Drop Rate (FDR) and the Symbol Error Rate (SER) were calculated for every case. However, for brevity, we choose to plot only the FDR performance. We have considered a quasi-static channel where the channel coefficients vary independently from slot to slot but remain constant within a slot. In the non-coherent case, the uncompensated frequency offset leads to a constant phase rotation of the channel coefficients at the rate of Δf Hz. For the quasi-static case, estimation of the channel is sufficient and no further tracking is required; whereas, for the non-coherent case, tracking is essential.

In case of the joint SNVA, the optimal forgetting factor $0<\gamma<1$ is computed for every SNR. Simulation results confirm that the ideal ML is the best method of signal recovery. For $\Delta f = 0$, as shown in Figure 2, practical ML and SNVA are almost similar, and better than VBLAST. Both SNVA and practical ML approach ideal ML with increasing SNR. This is because the channel estimates approach the actual value as SNR increases. Performance of practical ML gradually degrades as frequency offset between the transmitter and the receiver increases. For example, with Δf = 75Hz, as in Figure 3, (which corresponds to a phase

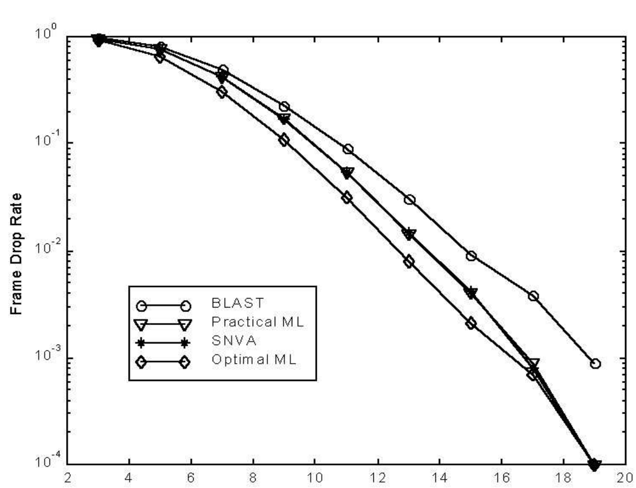

Figure 2 . FDR for a Quasi-Static Channel (Δf=0Hz)

variation of nearly 1 deg per symbol), J-SNVA is better than the practical ML by more than 2dB (at a FDR of 10^{-2}). For a phase variation at the rate 2 deg per symbol, as in Figure 4, (i.e., Δf=150Hz), practical ML performance approaches that of VBLAST. SNVA , on the other hand, performs closer to ideal ML even under such a large frequency offset.

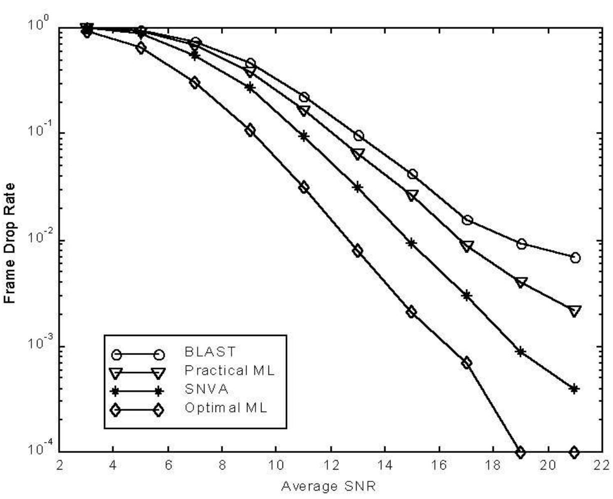

Figure 3. FDR for offset Δf = 75 Hz

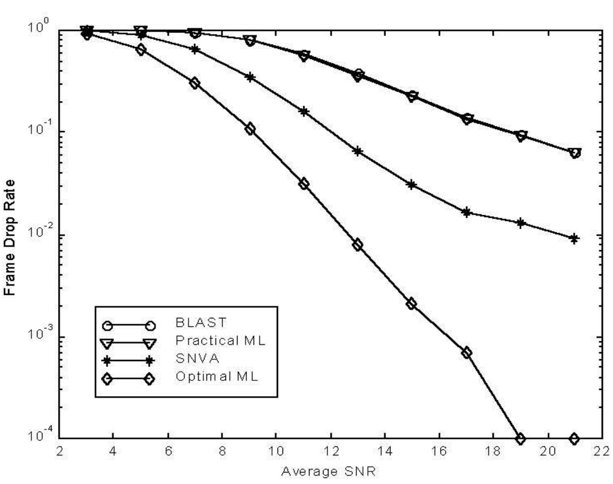

Figure 4. FDR for offset Δf = 150 Hz

6. Conclusions

In this paper, we presented a novel non-coherent receiver that jointly decodes co-channel spatially multiplexed signals. Computer simulations show that the performance of this joint detector (J-SNVA) approaches that of the ideal ML detector when exact synchronization is maintained between the transmitter and the receiver. In the presence of uncompensated frequency offset between the transmitter and the receiver, J-SNVA still performs closer to the ideal ML receiver while the other joint receivers fail. Reducing the complexity of the proposed J-SNVA, especially for higher order signal constellations, is an interesting future extension of this work.

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