# Two-Stage Detection using ISI Cancelling for Multipath Fading Channels

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## ABSTRACT

A simple detection scheme which can be easily implemented without maximum likelihood sequence estimation (MLSE) is proposed. It has a two-stage structure and makes final decisions after eliminating inter-symbol interference (ISI) due to both past and future symbols by using tentative decisions. Computer simulation results demonstrate that the proposed scheme can have a comparable performance to that of a tentative decision (TD)-MLSE when the number of resolvable channel paths is two, although its performance degrades as the number of resolvable channel paths increases.


**Keywords**: Two-stage Detection, ISI Cancellation, Adaptive MLSE, Multipath Fading

## 1. INTRODUCTION

The adaptive MLSE implemented by using the Viterbi algorithm (VA) has been employed as a powerful technique for sequence detection in uncertain environments [1]-[5]. The algorithms in [1]-[2], which will be referred to as the tentative decision (TD)-MLSE, use tentative decision values obtained by tracing back the survival path with minimum metric value at each time. Although a decision delay is inevitable for reliable tentative decisions, it tends to make the channel tracking performance degrade. As an alternative technique for eliminating decision delay, per-survivor processing (PSP) algorithm [3] in which channel parameters are estimated for all surviving path at each time was used. In [4]-[5], some techniques for reducing computational complexity of PSP-MLSE were introduced. Nevertheless, these MLSE-based receivers still require heavy computational complexity and large memory size for storing path history in practical implementation.

In this correspondence, we propose a simple two-stage detection scheme which can be easily implemented without MLSE. At the first stage, tentative decisions are obtained by eliminating ISI due to past symbols, and by using them ISI terms due to future symbols are estimated. The final decision is made after eliminating ISI due to both past and future symbols at the second stage. It is shown through computer simulation that the proposed scheme can have a comparable performance to that of TD-MLSE when the number of resolvable channel paths is two, although its performance degrades as the number of resolvable channel paths increases.

## 2. SYSTEM MODEL AND TD-MLSE

We consider a packet-based communication system over multi-path Rayleigh fading channels, where the packet length is denoted by $L_{seq}$. A baseband received signal sampled at $t = kT$ can be written as

$$r_k = \mathbf{d}_k^T \mathbf{h}_k + \eta_k \qquad (k = 0, \cdots, L_{seq} - 1) \tag{1}$$

where $\mathbf{d}_k = [d_k, d_{k-1}, \cdots, d_{k-L+1}]^T$; $d_k$ represents an $M$-ary PSK (or DPSK) symbol; $\mathbf{h}_k = [h_{k,0}, h_{k,1}, \cdots, h_{k,L-1}]^T$; $h_{k,n}$ is the impulse response of the equivalent channel at time $k$ due to an impulse that was applied $n$ time units earlier; $\eta_k$ is additive white Gaussian noise (AWGN) with variance $\sigma^2$.

Adaptive MLSEs can be efficiently implemented by using the VA with $M^{L-1}$ states and a channel estimator. Each state $\mathbf{s}_i$ in the VA consists of $(L-1)$ $M$-ary symbols, expressed as $\mathbf{s}_i = [s_{i,1}, s_{i,2}, \ldots, s_{i,L-1}]$. The transition from the state $\mathbf{s}_i$ to $\mathbf{s}_j$ can occur if $s_{i,l} = s_{j,l+1}$ for $1 \le l \le L-2$. The corresponding transition vector $\mathbf{x}(\mathbf{s}_i, \mathbf{s}_j)$ is defined as $\mathbf{x}(\mathbf{s}_i, \mathbf{s}_j) = [s_{j,1}, s_{i,1}, \ldots, s_{i,L-2}, s_{i,L-1}]^T$. The number of possible transition vectors is $M^L$ and $\mathbf{d}_k$ in (1) is one of them. If the estimate $\hat{\mathbf{h}}_k$ of the channel parameter $\mathbf{h}_k$ is given, the VA computes the branch metric $|r_k - \mathbf{x}(\mathbf{s}_i, \mathbf{s}_j)^T \cdot \hat{\mathbf{h}}_k|^2$ for each transition, which requires $M^L \times (L+1)$ complex multiplications and $M^L \times L$ complex additions at each time instant $t = kT$. Based on the branch metrics, the VA determines and stores a survivor, a path with the smallest metric, for each state. At the end of the recursion for a received packet, the most likely sequence is determined by tracing back the path associated with the survivor with the smallest metric. Thus, memory for storing $M^{L-1} \times L_{seq}$ survivors are required in total.

For the computation of the branch metrics at time $k+1$, the TD-MLSE estimates $\hat{\mathbf{h}}_{k+1}$ by using a tentative decision value obtained by tracing back the path associated with the survivor with the smallest metric at time $k$. Here, increasing the duration of back-tracing, say $D$, decreases the probability of decision error, but degrades the channel tracking performance ($D$ is called the decision delay).

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## 3. TWO-STAGE DETECTION USING ISI CANCELLING

For $0 \leq i \leq L-1$, the equation (1) can be rewritten by

$$\begin{aligned} r_{k+i} &= \sum_{j=1}^{i} d_{k+j} h_{k+i,i-j} + d_k h_{k+i,i} \\ &\quad + \sum_{j=1}^{L-1-i} d_{k-j} h_{k+i,i+j} + \eta_{k+i} \\ &= F_{k,i} + d_k h_{k+i,i} + P_{k,i} + \eta_{k+i} \end{aligned} \tag{2}$$

where $F_{k,i}$ and $P_{k,i}$ denote ISI terms due to future symbols and past symbols, respectively ($F_{k,0} = P_{k,L-1} = 0$). It is clear that the set of $\{r_{k+L-1}, \cdots, r_k\}$ contains information on $d_k$ and more reliable decision can be obtained by eliminating ISI terms of both $F_{k,i}$ and $P_{k,i}$. That is, the proposed decision rule can be described by

$$\hat{d}_k = dec\left[\sum_{i=0}^{L-1} (r_{k+i} - F_{k,i} - P_{k,i}) \cdot h^*_{k+i,i}\right] \tag{3}$$

where $dec[\cdot]$ is the decision function for the employed modulation scheme. For the practical use of (3), we should estimate $F_{k,i}$, $P_{k,i}$, and $h_{k+i,i}$ $(0 \leq i \leq L-1)$.

At the instance of detecting $d_k$, suppose $\{r_{k+L-1}, \cdots, r_k\}$, a channel estimate $\hat{\mathbf{h}}_k = [\hat{h}_{k,0}, \hat{h}_{k,1}, \cdots, \hat{h}_{k,L-1}]^T$, and previous decision values $\{\hat{d}_{k-1}, \cdots, \hat{d}_{k-L+1}\}$ are given. Then, the operation of the proposed scheme is described in the following procedure.

*Stage1: ISI estimation and tentative decision*

step 1: $\hat{P}_{k,i} = \sum_{j=1}^{L-1-i} \hat{d}_{k-j} \hat{h}_{k,i+j}$

step 2: $\tilde{d}_{k+i} = [r_{k+i} - \hat{P}_{k,i}] \cdot \hat{h}^*_{k,i}$

step 3: $\hat{F}_{k,i} = \sum_{j=1}^{i} \tilde{d}_{k+j} \hat{h}_{k,i-j}$

where for each step, $i = 0, \cdots, L-1$.

*Stage2: ISI cancellation and final decision*

$$\hat{d}_k = dec\left[\sum_{i=0}^{L-1} \left(r_{k+i} - \hat{F}_{k,i} - \hat{P}_{k,i}\right) \cdot \hat{h}^*_{k,i}\right]$$

Note that $\{\tilde{d}_{k+i}\}$ denotes tentative decisions of future symbols, which are used in computing $\hat{F}_{k,i}$. Similarly to the decision delay in TD-MLSE, the proposed scheme has a prediction delay of maximum $(L-1)T$ since $\hat{h}_{k,i}$ is used as an estimate of $h_{k+i,i}$ $(0 \leq i \leq L-1)$ in the *Stage1*. In addition, it is clear that the proposed scheme can be implemented without both computing branch metrics and storing path history.

## 4. SIMULATION RESULTS

To examine the performance of the proposed scheme, computer simulations were performed for a packet-based communication system over multi-path Rayleigh fading channels. The modulation scheme was DQPSK and the data sequence was arranged into 200 symbol packets ($L_{seq} = 200$), in which the first 20 symbols were a training sequence. We considered two-path and three-path Rayleigh fading channels: the maximum delay spread was set at $2T$; a normalized uniform delay power profile was assumed; a normalized Doppler frequency ($f_D T$) was set at 0.00343.

The TD-MLSE receiver employing VA with 16 states ($M = 4$ and $L = 3$) was considered and for the duration of back-tracing, both $D = 0$ and $D = 2T$ were used. For both the TD-MLSE and the proposed scheme, the channel parameters were estimated by using the Recursive Least Squares (RLS) algorithm with a forgetting factor of 0.65 [6].

Fig. 1 and Fig. 2 compares bit error rate (BER) performance in 2-path and 3-path Rayleigh fading channel, respectively. As expected, the TD-MLSE with $D = 2T$ provides a significant BER improvement over the TD-MSLE with $D = 0$. In the 2-path channel, the performance of the proposed scheme approaches that of the TD-MLSE with $D = 2T$ as $E_b/N_o$ increases: when a raw BER is chosen as a performance measure in multi-path fading environments, $E_b/N_o$ around (or over) 20dB is a reasonable consideration [1]-[6]. In the 3-path channel, the proposed scheme reveals a somewhat large performance degradation, compared to the TD-MLSE with $D = 2T$. This is due to the fact that since tentative decisions

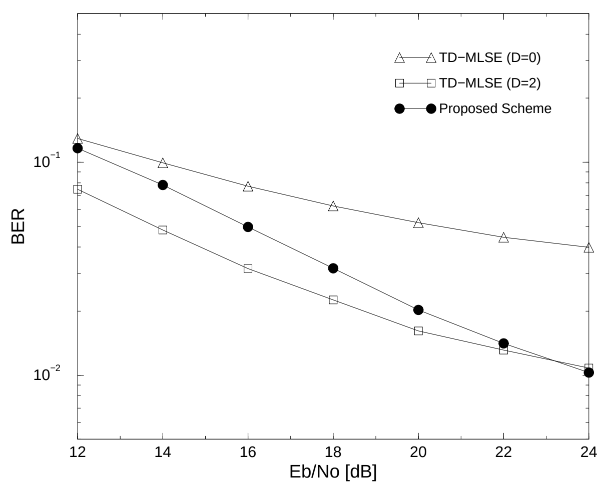


***Fig.1:*** *BER performance in 2-path Rayleigh fading channel ($f_D T = 0.00343$).*

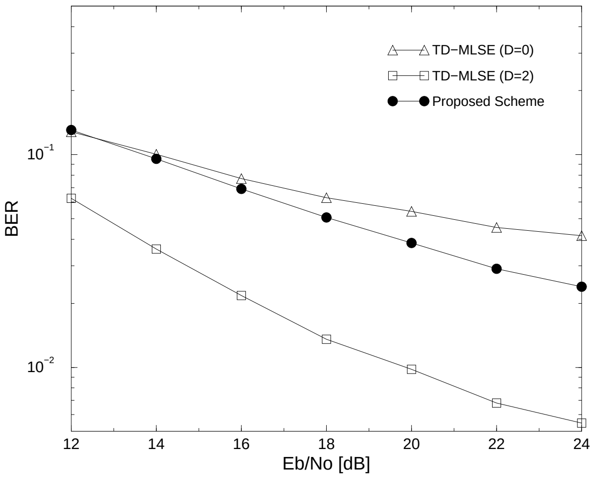


***Fig.2:*** *BER performance in 3-path Rayleigh fading channel ($f_DT = 0.00343$).*

in the *Stage1* are obtained by eliminating only the ISI due to past symbols, their reliability decreases as the number of resolvable channel paths increases.

## 5. CONCLUSION

A simple detection scheme which can be easily implemented without MLSE was proposed for multipath fading environments. It has a two-stage structure and makes final decisions after eliminating ISI due to both past and future symbols. The simulation results show that the proposed scheme has a comparable performance to that of the TD-MLSE with $D = 2T$ in the 2-path channel, but its performance degrades when the number of resolvable channel paths increases. Consequently, we may expect the proposed scheme to be useful for low-cost wireless applications in the fading channel environments where the number of resolvable channel paths is small.

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