Efficient Phase Estimation Using Turbo Decoding
In Satellite Communications System

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ABSTRACT
Phase estimation is a critical issue for turbo code implementation because good performance of turbo codes always implicitly assumes complete phase synchronization. Phase offset changes fast and must be treated on a symbol basis with much more complicated modeling. In this paper, we present and analyze an efficient phase synchronization method based on PSP (per-survivor processing) for modern satellite systems with multimedia services. When the PSP estimator is implemented by hardware, the complexity is significantly increased. To relieve this complexity, we propose novel synchronization method by changing the number of path according to condition of channels. The number of calculation is reduced consequently and the performance maintains similar to existing PSP because the number of path decrease for various kinds of scenarios of channel conditions. Both theoretical and simulated results are presented for varying simulation parameters. The proposed technique can be applied to the turbo coding-based satellite multimedia communication systems.

I. INTRODUCTION

In the future multimedia wireless communication system, supporting higher power efficiency and serving high reliable data rate transmission are required. The power needed to reliably transmit a signal can be reduced by using coding techniques. Turbo coding is well known as the most strong error correction code, which are capable of closely approaching the Shannon bound. However, in actual situation, the performance of turbo coded systems in wireless packet data transmission usually assumes that the channel has not been estimated and synchronized. The synchronization of the phase in rapidly changing fading environment can cause particular problems.

There are several phase estimation algorithm for optimal turbo coded system. In [1], the phase estimation algorithm is proposed to use maximum-likelihood estimator. In [2], the estimator is designed based on a pseudo-maximum-likelihood approach using soft output. It makes parameter while iterative turbo decoding is accomplished. This technology is simple at hardware implementation, but there is a decrease of performance in the time varying channel. The technique illustrated in [3] use viterbi algorithm. The tentative decisions are extracted at a smaller delay than that destined for the actual output. Thus trade off decision reliability with estimate timeliness, striving to contain error propagation effect. Unfortunately, it does not estimated well in low SNR. To overcome this problem, the per-survivor processing(PSP) is proposed [4]. PSP embeds the data-aided channel estimation into the viterbi algorithm. Each state in the PSP has a separate estimator which is based on the survivor path leading to that state. The phase estimator update in the PSP for each state is carried without any decision delay. When PSP estimator is implemented by hardware, the complexity is increased in spite of the wonderful performance. To, decrease this complexity, we proposed new synchronization method changing the number of path according to condition of channels. The number of calculation is reduced consequently and the performance maintains similar to existing PSP because the number of path decrease according to the situation of the channel.

In addition, we can improve performance of PSP applying optimal step size of LMS estimator.

The paper is organized as follow. Section II introduces conventional PSP algorithm. In section III, we present a new phase estimation based PSP algorithm. Simulation results and discussions are provided in Section IV. Finally, our work is summarized in Section V.

II. PSP PHASE ESTIMATION

Assuming symbol timing recovery in the receiver, the k samples at the output of the matched filter feeding the VA decoder can be expressed as

\[ r_k = c_k e^{j\theta_k} + w_k \]  \hspace{1cm} (1)

Where \( w_k \) denotes the additive white Gaussian noise (AWGN) with zero mean and variance equal to \( 2/N_0 \), \( c_k \) denotes the transmitted data symbol and \( \theta_k \) is phase offset.

In TD, the data symbol \( c_k \) is replaced with a low delay tentative decision. But, in PSP, each survived data sequence in the trellis produces its own estimated value. Exactly, each state performs parallel phase estimation
according to survivor path. Note that in PSP no tentative decision must be taken since every hypothesized data sequences.

At each discrete time instant $k$ the VA updates the path metrics by performing the add-compare-select (ACS). The branch metric pertaining to the transition $S_k \rightarrow S_{k+1}$ at time $k$ is presented by

$$BM(S_k \rightarrow S_{k+1}) = |r_k e^{-j\hat{\theta}(S_k)} - c(S_k \rightarrow S_{k+1})|^2$$

(2)

Where $\hat{\theta}(S_k)$ denoted the phase estimate associated to the survivor path ending at state $S_k$.

We use the least mean square (LMS) algorithm to estimate the next value of phase, such as

$$\hat{\theta}_{k+1} = \hat{\theta}_k + \Delta (r_k - \hat{\theta}_k c)c^*$$

(3)

Where $\hat{\theta}_k$ is estimated phase at time index $k$, is step size of LMS algorithm and $c$ is correspond to symbol at each state. We illustrate concept of PSP in Fig 1.

![Fig. 1. Concept of Per Survivor Processing](image)

**III. PROPOSED PSP PHASE ESTIMATION**

In proposed PSP algorithm, we embedded the LMS estimator into the MAX-Log-MAP to perform phase estimation and decoding process jointly. The Max-Log MAP algorithm is a good compromise between performance and complexity. The performance is better than the standard SOVA algorithm and reaches nearly the optimal performance results of the MAP/Log-MAP algorithm.

However, there are a lot of problem in hardware implementation, since the calculation of channel estimation used in the high-speed fading environment is very complicate. So we propose the modified PSP estimation algorithm by decreasing the complexity.

The main steps of proposed phase estimation are such as:

**Step 1 : Forward recursion updating**

Calculate the forward recursion metric, $\alpha_{k,i}^j(m) \rightarrow \alpha_{k,i}^j(m)$, at each M survivor state.

**Step 2 : Most probable state detection**

Search the state with the maximum value of probability among the M state at time $k$. The maximum state is best survivor state.

$$\hat{S}_k^* = \max_m \{ \alpha_{k-1}^j(m) \} \quad m \in M_k^*$$

(4)

**Step 3 : Comparing each M survivor metrics**

Compare best survivor metric with the other survivor metrics.

**Step 4 : Selecting state of the number of $i$**

PSP estimation is applied to state of the number of $i$ the difference of metric with best survivor metric is most small. And the other metric is applied estimation value of best survivor state. LMS algorithm with selected $i$ states :

$$\hat{\theta}_{k+1} = \hat{\theta}_k + \Delta (r_k - \hat{\theta}_k c)c^*$$

The other states :

$$\hat{\theta}_{k+1}(S_i) = \hat{\theta}_{k+1}(S_{i_{best}})$$

Like this step, the calculated amount can be changed fluidly by presuming a channel. Thus, hardware complexity is decreased. In Fig. 2., we illustrate the proposed PSP estimation.

Additionally, we can fine that the performance of conventional PSP is improved when we put the optimal step size into the LMS estimator. The accuracy and the convergence properties of LMS determine the overall performance of the PSP algorithm. In the time-varying channel, the convergence rate of LMS is governed by the step-size parameter, which determines the tracking ability and convergence rate of the LMS.

The simulation results are shown in Fig. 4,5 and 6.

![Fig. 2. Concept of Proposed PSP algorithm](image)
IV. SIMULATION RESULTS

The performance of conventional PSP with non-optimal step size, conventional PSP with optimal step size, and proposed PSP with optimal step size were compared by computer simulation. The 3GPP turbo code is used for a simulation. The block size of input data is 424 bits, and the turbo code rate is 1/2. QPSK modulation is considered on AWGN channel. The different phase offset $\beta$ are considered 0.1 degree/symbol, 0.2 degree/symbol, and 0.36 degree/symbol. The variance of phase noise is 10 degree and the number of turbo decoder iteration is 10.

In Fig. 4, the performance of PSP estimations are compared with different step size. When the phase offset is 0.1 degree/symbol and the variance of phase noise is 10, the optimal step size is 0.2. In Fig. 5, the performance of PSP estimations are compared with different step size. When the phase offset is 0.2 degree/symbol and the variance of phase noise is 10, the optimal step size is 0.2. In Fig. 6, the performance of PSP estimations are compared with different step size. When the phase offset is 0.36 degree/symbol and the variance of phase noise is 10, the optimal step size is 0.25.

As shown results, it is noted that step size gives larger difference between non-optimal PSP estimator and optimal PSP estimator. PSP estimation with non-optical step size is able to measure just 5 degrees of variance of phase noise but the proposed one makes possible to estimate 10 degrees of variance.

Proposed PSP estimation reduce the complexity but have a disadvantage that the efficiency become worse in the fine channel. It happened because of the burst error which is occurred as wrong estimated value of symbol. Also, if the repetition times of estimation are increased from 5 to 10, the capability might be better, so it will be possible to reduce the complexity, if the repetition times are variable depending on the channels. Later, if the Variable Step Size LMS estimation application is used in each state, the efficiency will be better because it is possible to use optimal step size in the individual survivor paths.

The optimal step size of PSP estimation following to phase noise and variance is seen in Table 1.
TABLE 1. The optimal step size of PSP estimation.

<table>
<thead>
<tr>
<th>Iteration</th>
<th>Phase noise (degree)</th>
<th>Variance (degree)</th>
<th>Step size (degree)</th>
</tr>
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<tr>
<td>5, 10</td>
<td>0.1</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>0.15</td>
</tr>
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<td></td>
<td></td>
<td>10</td>
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<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>0.25</td>
</tr>
</tbody>
</table>

V. CONCLUSIONS

In this paper, we proposed efficient phase estimation method based on PSP in the mobile multimedia channel.

Although the PSP estimation method is good performance in the mobile channel, there are a lot of problem in hardware implementation, since the calculation of channel estimation used in the high-speed fading environment is very complicate. So we propose the modified PSP estimation algorithm by decreasing the complexity.

As shown results, it is noted that step size gives larger difference between non-optimal PSP estimator and optimal PSP estimator. Proposed PSP estimation reduce the complexity but have a disadvantage that the efficiency become worse in the fine channel. It happened because of the burst error which is occurred as wrong estimated value of symbol. Also, if the repetition times of estimation are increased from 5 to 10, the capability might be better, so it will be possible to reduce the complexity, if the repetition times are variable depending on the channels. The proposed technique can be applied to the turbo coding - based satellite multimedia communication systems.

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REFERENCE


