

New Soft-Output MLSE Equalization Algorithm for GSM Digital Cellular Systems

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Abstract

In this paper, we propose a new SO-MLSE(soft-output maximum likelihood sequence estimation) equalizer, which can be used in GSM digital cellular system. It uses complex correlation of training sequence to obtain the channel information and the equalization is performed by MLSE using Viterbi algorithm. In order to generate a soft-decision input to channel decoder (Viterbi decoder), the soft-output equalization algorithm is needed. The adopted algorithm doesn't require to modify the structure of HO-MLSE(hard output MLSE) equalizer, that is, SO-MLSE equalizer can be implemented by adding soft-output generation block to HO-MLSE equalizer. This algorithm uses the outputs of matched filter and HO-MLSE equalizer. It turns out that the complexity of proposed SO-MLSE equalizer is simpler than those of other SO-MLSE equalizers and its performance is almost the same as those of others. Finally, the proposed SO-MLSE equalizer is also implemented as a prototype with ADSP-2101 16-bits fixed point digital signal processing chip.

I. INTRODUCTION

In the mobile radio communication system, the receiver must mitigate severe signal impairment arising from delay spread and multipath fading. Multipath signals with delay spread cause intersymbol interference(ISI), which necessitates the use of an equalizer in the receiver. Equalizer is a diversity technique, which removes the distortion from ISI. The higher complexity equalizer is needed as the occupied frequency band of transmitted signal is getting bigger,

such as GSM digital cellular system which uses 200 kHz frequency band and 270.833 data rate. In the receiver of digital cellular system, an equalizer is implemented with channel decoder, for example, Viterbi decoder. In order to achieve higher channel coding gain, it is desirable to employ the soft-output equalizer, which provides soft-decision input to channel decoder.

This paper is organized as follows. In section II, the GSM system is introduced and the proposed SO-MLSE Equalization algorithm is described in section III. The performance of proposed algorithm which are obtained by computer simulation and the features of prototype implementation by DSP chip are provided in section IV. Finally, some conclusions are presented in section V.

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II. GSM SYSTEM

The GSM Pan-European digital cellular system has been standardized by the European PTT administrations to be operated in the 900 MHz frequency band. The main feature of this system is the use of TDMA scheme in transmission with eight speech channels on the same RF carrier, a gross transmission bit rate of 270.833 kbps and GMSK(Gaussian minimum shift keying) modulation. The TDMA frame is divided into 8 timeslots, each 0.577ms long. Each timeslot is reserved to an user to transmit a data packet composed of 148 bits as in fig. 1. Its physical content is called a burst.

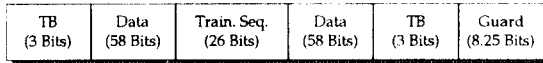


Fig. 1. Normal Burst Structure

In the GSM system, 20ms speech block is encoded into 50 class 1a bits, 132 class 1b bits and 78 class 2 bits. Class 1a bits are protected by three parity bits for error detection in the block coder, and then class 1a and class 1b bits are encoded with 1/2 rate convolutional code. The output bits of convolutional encoder and class 2 bits are interleaved[1].

III. PROPOSED SO-MLSE EQUALIZER

Fig. 2 shows a block diagram of the receiver which is used in the performance evaluations of the proposed SO-MLSE equalizer. The received signal is coherently demodulated, the intersymbol interference from multipath fading is mitigated by equalizer and then errors which occurred in transmission are detected or corrected by channel decoder.

Fig. 3 shows functional block of the proposed SO-MLSE equalizer. The proposed SO-MLSE equalizer consists of matched filter, CIR(channel impulse

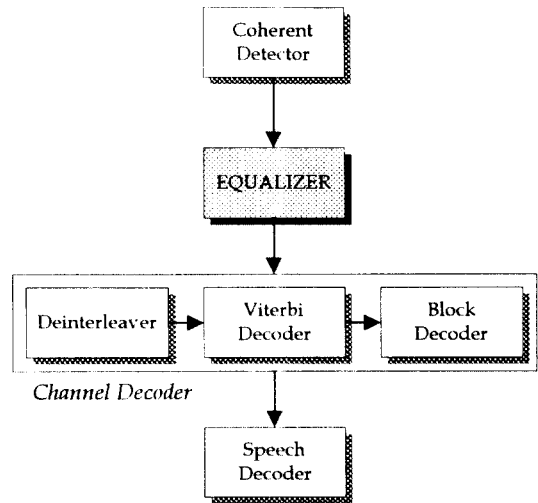


Fig. 2. Block Diagram of SO-MLSE Receiver

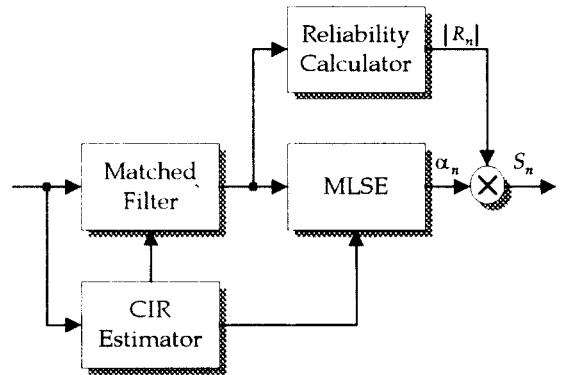


Fig. 3. Functional Block Diagram of the Proposed SO-MLSE Equalizer

response) estimator, MLSE block using Viterbi algorithm and reliability calculator block.

A. Channel Estimators

The MLSE algorithm needs the knowledge of the CIR, and the computation of the CIR, $h(t)$ is performed by using the complex correlation, $R_{rv}(t)$ between the 16 samples of the locally generated training sequence $v(t)$ and the 26 samples of the received

signal $r(t)$.

It is worth noting that $R_{rv}(t)$ actually represents the convolution between the overall CIR, $h(t)$ that we want to estimate and the autocorrelation $R_{vv}(t)$ of the training sequence is as follows.

$$\begin{aligned}
 R_{rv}(t) &= \int r(t+\tau)v^*(\tau) d\tau \\
 &= \iint r(t+\tau-\alpha)h(\alpha)v^*(\tau) d\tau d\alpha \\
 &= R_{vv}(t) * h(t)
 \end{aligned} \tag{1}$$

where $R_{vv}(t)$ turns out to be delta function within the $-5T \sim 5T$ bits around its central value, so that we can consider that $R_{rv}(t)$ equals to $h(t)$ within this range.

In GSM digital cellular system, an equalizer must handle the intersymbol interference which occurs within $-5T \sim 5T$ bit period time delay. But the processing elements and hardware complexity of equalizer which uses a Viterbi algorithm become double as the maximum delay spread causing intersymbol interference increases by one bit.

Considering the performance and the complexity, we assume that the maximum delay spread is 4 bits, that is, only five consecutive samples of $h(t)$, alternately real and imaginary, namely

$$\begin{aligned}
 h(t) &= \sum_{i=-1}^1 h^i(t-2iT)\delta(t-2iT) \\
 &+ j \sum_{i=0}^1 h^Q(t-2iT+T)\delta(t-2iT+T)
 \end{aligned} \tag{2}$$

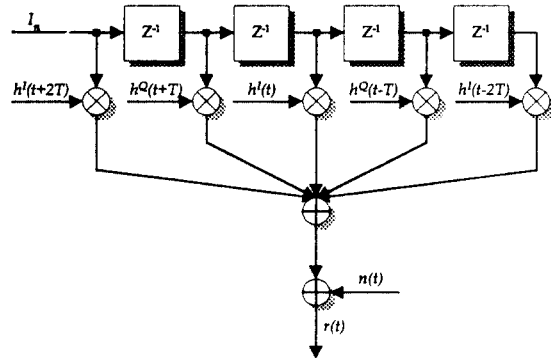


Fig. 4. Discrete Time Model of Channel

have to be considered and passed to the equalizer. To do this, an energy window of five symbol periods slides along $h(t)$ in order to find the sequence of five samples with maximum energy[2].

Using the selected sequence of five samples, we can construct the discrete time model of channel as fig. 4.

B. Matched Filter

The matched filter makes the receiver insensitive to the symbol timing and carrier phase in the coherent demodulator, if it is provided that the matched filter is correctly adapted and its time span is long enough to include all of the significant samples of the CIR. This matched filter is constructed from estimated CIR as equation (3).

$$h_{MF}(t) = h^*(-t) \tag{3}$$

C. Maximum Likelihood Sequence Estimation

Using the outputs of the matched filter and channel coefficients, the MLSE algorithm estimates sequence whose joint probability density function in equation (4) is maximized.

$$\begin{aligned}
 p(\mathbf{P}_N/\mathbf{I}_N) &= \\
 &\left[\prod_{k=1}^N 2\pi\lambda_k \right]^{-1} \cdot \exp \left\{ -\frac{1}{2} \frac{\sum_{k=1}^N \left| r_k - \sum_n I_n h_{kn} \right|^2}{\lambda_k} \right\}
 \end{aligned} \tag{4}$$

where $\mathbf{R}_N = (r_1, r_2, \dots, r_N)$ is the observable random variable obtained by project $r(t)$ onto the set of orthonormal functions, $\mathbf{I}_N = (i_1, i_2, \dots, i_N)$ is a transmitted sequence and λ_k 's are the eigenvalues of the integral equation. This joint probability density function can be simplified as follows.

$$\mathbf{J}_n(\mathbf{I}_n) = \mathbf{J}_{n-1}(\mathbf{I}_{n-1}) + \text{Re} \left\{ J_n^*(2Y_n - I_n X_0 - 2 \sum_{m=1}^L I_{n-m} X_m) \right\} \tag{5}$$

where I_n are the transmitted symbol sequence.

The variable Y_n can be generated by passing $r(t)$

through a filter matched to $h(t)$ and sampling the output at the symbol rate $1/T$ as equation (6). And the variable X_n represents the samples of the auto-correlation function of $h(t)$ in equation (7)[3].

$$Y_n = Y(nY) = \int_{-\infty}^{\infty} r(t) h^*(t - nT) dt \quad (6)$$

$$X_n = X(nX) = \int_{-\infty}^{\infty} h(t) h^*(t - nT) dt \quad (7)$$

In the GSM digital cellular system, I_n is alternately real and imaginary and L is a number of intersymbol interference bits, which must be handled in the equalizer.

D. Soft-Output Algorithm

With the estimated symbols sequence by the MLSE block and outputs of matched filter, soft-decision input to channel decoder can be obtained as following:

$$S_n = |R_n| \cdot \alpha_n \quad (8)$$

where R_n is a output of reliability block, $\alpha_n = \{ +1, -1 \}$ is hard output of MLSE block and S_n is soft-decision output. In reliability block, outputs of machted filter are used as inputs and inputs scaling is performed.

The adopted new soft-output algorithm doesn't require to modify the structure of HO-MLSE equalizer, so that SO-MLSE equalizer can be constructed by adding soft-output generation block to HO-MLSE equalizer.

IV. IMPLEMENTATION AND RESULTS

For the performance evaluation of proposed SO-MLSE equalizer, simple GSM digital cellular system simulation software is developed in IBM-PC. This software includes

- (2, 1, 5) Convolutional Encoder
- $K=5$ Viterbi Decoder
- $BT=0.3$ GMSK Modulator
- GSM Channel Simulator

- HO-MLSE, SO-MLSE Equalizer

and the ADSP-2101 DSP board which is based on IBM-PC is implemented. Fig. 5 shows the block diagram of implemented ADSP-2101 DSP board.

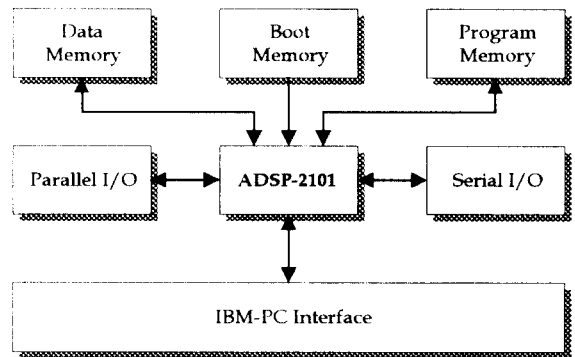


Fig. 5. Block Diagram of ADSP-2101 DSP Board

Using the developed evaluation kits, HO-MLSE equalizer and proposed SO-MLSE equalizer performance are simulated in urban area with 50 km/h vehicle speed(TU50), hilly terrain area with 100 km/h vehicle speed(HT100) and rural area with 250 km/h vehicle speed(RA250).

Simulation results are shown in Fig. 6, 7, 8. In

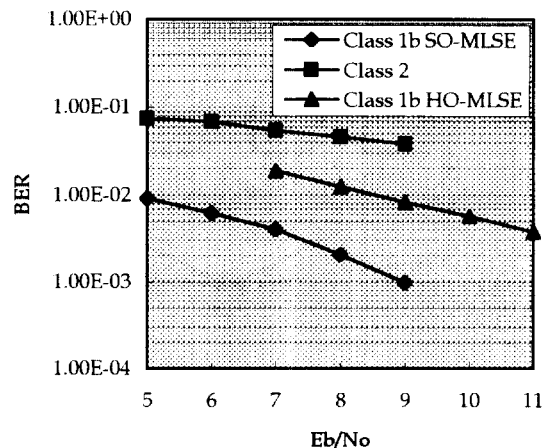


Fig. 6. Performance of Equalizer in TU50

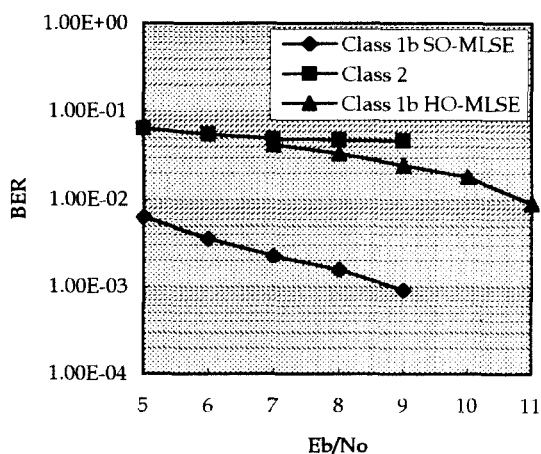


Fig. 7. Performance of Equalizer in HT100

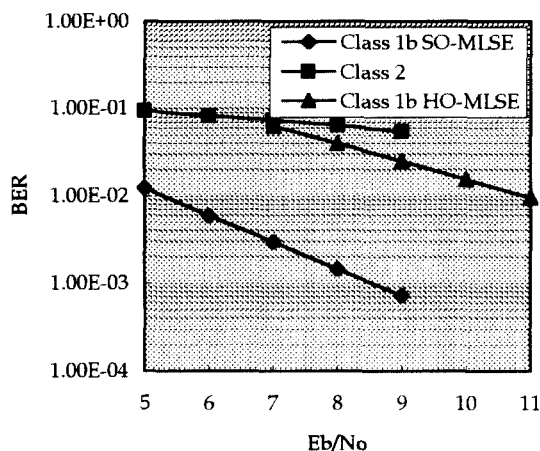


Fig. 8. Performance of Equalizer in RA250

these figures, performance of the proposed SO-MLSE equalizer is much better than those of HO-MLSE equalizer and requirement of GSM digital cellular system recommendation is also satisfied. And the complexity of proposed SO-MLSE equalizer is simpler than those of other SO-MLSE equalizers, but its performance is almost the same as those of others[4].

Further, the proposed SO-MLSE equalizer is also implemented as a prototype with ADSP-2101 16-bits fixed point digital signal processor.

The features of the SO-MLSE equalizer prototype is as follows :

- ADSP-2101 Clock Speed : 20MHz
- Available Instruction Cycles : 92,000
- Source Code Length : 700 Lines
- Implemented Instruction Cycles : 70,000
- Optimized Instruction Cycles : about 50,000

V. CONCLUSIONS

In this paper, SO-MLSE equalizer which can be used in GSM digital cellular system is proposed. The proposed SO-MLSE equalizer uses only output of matched filter and MLSE block for generation of soft-outputs, so that the proposed SO-MLSE equalizer doesn't need an additive memory for storage of reliability information and the additional processing elements for generation of soft-output are ignorable.

Performance of proposed new SO-MLSE equalizer is almost the same as those of others and satisfy the performance specification that GSM digital cellular system requires in the standard definition manual[1] [4]. Therefore, the proposed new SO-MLSE equalizer can be used efficiently in GSM digital cellular system.

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