A MLSE receiver for the GSM digital cellular system

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Abstract: **In this paper, we propose a new type of MLSE receiver for the GSM system. The MLSE receiver consists of a new type of MLSE equalizer with soft-decision outputs, a channel decoder with soft-decision inputs, and others. The MLSE equalizer directly computes a soft-decision value from the hard-decision symbol sequence, so that it does not require reliability memories. As a result of computer simulations, we have confirmed the MLSE receiver satisfies GSM receiver specifications.**

I. INTRODUCTION

In digital cellular mobile communication systems, intersymbol interferences due to time-variant multipath fading must be compensated by the application of adaptive equalizers [1]. In order to achieve the best possible performance in terms of Bit Error Rate (BER), Maximum Likelihood Sequence Estimation (MLSE) equalizers [2] are usually adopted. Since MLSE equalizers estimate transmitting symbol sequence by using the Viterbi algorithm, they are often called Viterbi equalizers.

In pan-European GSM digital cellular systems, a receiver consists of an equalizer, a channel decoder, and others. The channel decoder decodes channel codings including Forward Error Correction (FEC) codings. In the GSM system, receiver performances in terms of Frame Erasure Rate (FER), BER, etc., are specified at the output of the channel decoder [3]. In order to achieve these performances, an equalizer with soft-decision outputs and a channel decoder with soft-decision inputs is required. A MLSE equalizer with soft-decision outputs is called the Soft Output MLSE (SO-MLSE) equalizer.

In this paper, we study SO-MLSE receivers which include SO-MLSE equalizers. In order to get soft-decision outputs, SO-MLSE equalizers generally use the Soft Output Viterbi Algorithm (SOVA) [4]. In this case, a soft-decision value relates to the reliability of the corresponding hard-decision symbol that results from the conventional Viterbi algorithm. However, a relatively large reliability memory that is represented by a matrix and a relatively strong processing element is required.

In order to solve these problems, we propose a new type of SO-MLSE equalizer without reliability memories. This equalizer directly computes a soft-decision value from the hard-decision symbol sequence, and the calculation amount is relatively small. A computer simulation comparison of the proposed SO-MLSE receiver and conventional SO-MLSE receiver will be discussed in this paper. The corresponding analysis shows that the proposed SO-MLSE receiver satisfies GSM receiver specifications and performs as well as the conventional receiver.

II. SYSTEM DESCRIPTION

Fig. 1 shows a functional diagram of a transmitter. Although there are many channels in the GSM system, we presuppose the full rate speech traffic channel (TCH/FS) as a representative of all in this paper.

The RPE-LTP speech coder, of which the output bit rate is 13.0 kbps, is used in the TCH/FS [5].

The channel coder consists of a block coder, a convolutional coder, and a interleaver [3]. Output bits of the speech coder are classified to three parts: 50 class 1a bits (most important bits), 132 class 1b bits, and 78 class 2 bits (least important bits). Class 1a bits are protected by three parity bits used for error detection in the block coder, and then class 1a and 1b bits are encoded with the 1/2 rate convolutional code in the convolutional coder. Thereafter, convolutional coded bits and class 2 bits are interleaved.

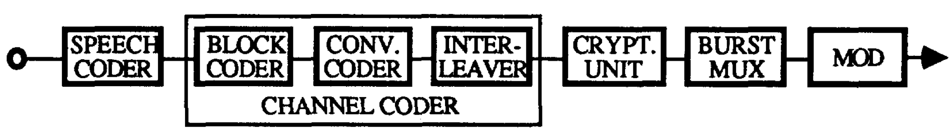

Fig. 1 Functional diagram of a transmitter

Fig. 2 shows a configuration of the normal burst that is used to carry data on the TCH/FS [3]. The burst multiplexing unit makes up successive bursts and frames.

The modulation scheme is GMSK with BT = 0.3, and modulation symbol rate is 270.833 kbps [3].

Fig. 3 shows a general functional diagram of a receiver. In this paper, we adopt a MLSE equalizer as the equalizer after the coherent detector. The coherent detector in Fig. 3 detects in-phase and quadrature signals without carrier synchronization.

Table I shows receiver performance specifications for the TCH/FS [3]. RBER in Table I is the residual bit error rate, which is defined as the ratio of the number of errors detected over the frame defined as "good" to the number of transmitted bits in the "good" frame. The value of "a" must be chosen among 1.0 to 1.6, and can be different for each propagation condition but must remain the same for FER and RBER (class 1b) for the same channel condition. TU50, RA250, and HT100 in Table I are typical urban condition, rural area condition, and hilly terrain condition, respectively [3]. All values in Table I are specified under the reference sensitivity level of -104 dBm.

As Table I shows, receiver performance in the GSM system is specified at the output of the channel decoder. Hence, we have to evaluate the equalizer ability with channel decoder.

III. SO-MLSE RECEIVERS

A. Conventional SO-MLSE Receiver

In order to satisfy the FER specification for certain propagation condition under the RBER (class 2) value for the same condition in Table I, we have to adopt a channel decoder with soft-decision input. Hence, the equalizer has to supply soft-decision output to the channel decoder.

Fig. 4 shows a functional diagram of the conventional SO-MLSE equalizer. Generally, all circuits in Fig. 4 are digitally processed.

In Fig. 4, the impulse response estimator estimates the impulse response $h(k)$ of the transmission line from the part of training sequence in the received burst. In this paper, "k" is a variable that represents the time. Since the auto-correlation function of the training sequence becomes ideal delta function, it is easy to estimate the impulse response from correlation between the received signal and the complex conjugate replica of the training signal.

The matched filter is a complex FIR digital filter with five taps. Tap coefficients $C(n)$ of the filter are directly determined from the impulse response $h(k)$.

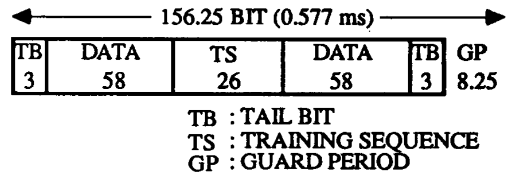

Fig. 2 Configuration of the normal burst

TABLE I
RECEIVER PERFORMANCE FOR THE TCH/FS

	static	TU50	RA250	HT100
FER	0.1 a %	6 a %	2 a %	7 a %
RBER (class 1b)	0.4 / a %	0.4 / a %	0.2 / a %	0.5 / a %
RBER (class 2)	2 %	8 %	7 %	9 %

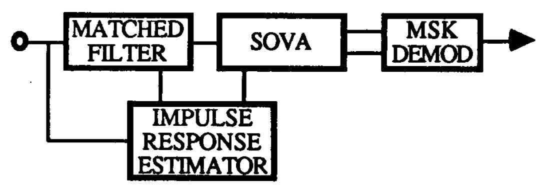

Fig. 4 Functional diagram of the conventional SO-MLSE equalizer

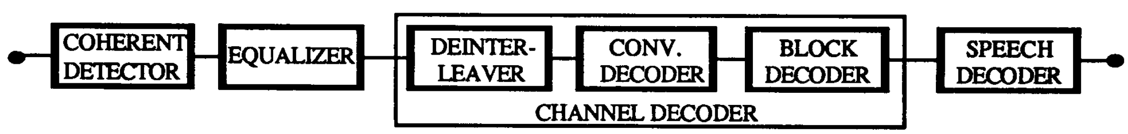

Fig. 3 General functional diagram of a receiver

The SOVA block estimates transmitted symbols with corresponding reliability values using SOVA [4]. In this paper, the degree of SOVA is 4, i.e., the number of state is 16. The SOVA can be formulated as follows:

1) Classical Viterbi Step:

For each state $\sigma(k)$:

Compute accumulated metric values:

$J[\sigma(k-1),\sigma(k)] = J[\sigma(k-1)] + F[\sigma(k-1),\sigma(k)]$

for both transitions $[\sigma(k-1),\sigma(k)]$.

Find the path metric:

$J[\sigma(k)] = \max\{J[\sigma(k-1),\sigma(k)]\}$

Store $J[\sigma(k)]$ and corresponding estimated symbol, i.e., hard-decision value $u[\sigma(k)]$.

Where:

$$F[\sigma(k-1),\sigma(k)] = \mathrm{Re}\{\overline{\alpha}(k)[z(k) - \sum_{m=1}^{4} s(m)\alpha(k-m)]\}$$

$$s(m) = \sum_{n=0}^{4} C(n)h(m-n)$$

$\alpha(k)$: a symbol at time k :that represents $\sigma(k)$

$z(k)$: a value of matched filter output signal

$\overline{x}$ denotes the complex conjugate of x.

2) Reliability Step:

For each state $\sigma(k)$:

Compute a difference of metrics:

$\Delta = \max\{J[\sigma(k-1),\sigma(k)]\} - \min\{J[\sigma(k-1),\sigma(k)]\}$

and store Δ.

Initialize reliability value:

$L[\sigma(k)] = +\infty$

For $l = k$ to 0:

Compare the two paths merging in $\sigma(k)$;

if $u[\sigma(l)]|_{path1} \neq u[\sigma(l)]|_{path2}$ then update

$L[\sigma(l)] \equiv \min\{L[\sigma(l)],\Delta\}$

Where, in practice, we may take " l " only after the time which the two paths merging.

From above mentioned reliability step, it is shown that the conventional SO-MLSE equalizer requires a relatively large reliability memory that represented by a matrix (the data length x the number of state). Since the comparison of two sequences is required at every state and time, it requires relatively strong processing elements.

The MSK demodulator decodes MSK and differential logic. Since the MSK logic itself is a differential logic, reliability values are not influenced by this logic. If we define a hard-decision value as ± 1 after the decoding of MSK and differential logic, a soft-decision value is obtained from multiplication of this hard-decision value and the corresponding reliability value.

B. Proposed SO-MLSE Receiver

Fig. 5 shows a functional diagram of the proposed SO-MLSE equalizer. Instead of the SOVA block in the conventional SO-MLSE equalizer, there are two blocks: the classical Viterbi Algorithm (VA) block and the reliability computation block.

The VA block estimates transmitted symbols, which can be formulated as same as the classical Viterbi step in the previous section.

The reliability computation block makes a sequence of reliability value from the sequence of estimated symbol that is estimated in the VA block. The reliability computation block can be formulated as follows:

1) Reliability Computation:

Compute the metric of the estimated symbol sequence: $J[\{\alpha(k)\}]$, where:

$\{\alpha(k)\}$: the estimated symbol sequence.

For each time k:

Make a modified sequence:

$\{\alpha'(k)\} = \{\cdots,\alpha(k-1),-\alpha(k),\alpha(k+1),\alpha(k+2),\cdots\}$

Compute the metric of $\{\alpha'(k)\}$: $J[\{\alpha'(k)\}]$.

Compute the reliability value:

$L(k) = J[\{\alpha(k)\}] - J[\{\alpha'(k)\}]$,

Where:

$$J[\{\alpha(k)\}] = \sum_{k\in I} 2\,\mathrm{Re}\{\overline{\alpha}(k)z(k)\} + \sum_{k\in I}\sum_{m\in I} \overline{\alpha}(k)s(k-m)\alpha(m)$$

I indicates the boundary that the actual sequence is transmitted.

Reliability value $L(k)$ can be computed by modifying above equations.

2) Simple Reliability Computation

For each time k:

Compute the reliability value:

$$L(k) = 4\,\mathrm{Re}\{\overline{\alpha}(k)[z(k) - \sum_{m=-4}^{4} s(m)\alpha(k-m)]\}$$

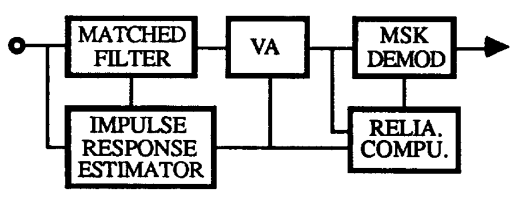

Fig. 5 Functional diagram of the proposed SO-MLSE equalizer

IV. SIMULATION RESULTS

Fig. 6, 7, and 8 show simulation results under GSM specified propagation conditions: TU50, RA250, and HT100, respectively. These figures show the proposed SO-MLSE receiver performs as well as conventional SO-MLSE receiver.

Although receiver performance specifications in Table I are specified under the reference sensitivity level which expressed in terms of dBm, we express the abscissa of these figures as signal to noise ratio Eb / No in terms of dB. Where, Eb is the signal energy per one bit, No is the double-sided spectral density of white Gaussian noise. If we assume the noise figure of the receiver is 6.5 dB, we can convert the reference sensitivity level of -104 dBm into the reference Eb / No of 9.0 dB. From Fig. 6, 7, and 8, we can confirm the proposed SO-MLSE receiver satisfies receiver performance specifications in Table I under the reference Eb / No of 9.0 dB.

V. CONCLUSIONS

We propose a new type of SO-MLSE receiver which the equalizer directly computes a soft-decision value from hard-decision symbol sequence. The proposed SO-MLSE receiver does not require reliability memories and strong processing elements. As a result of simulations, we have confirmed the SO-MLSE receiver satisfies GSM receiver specifications.

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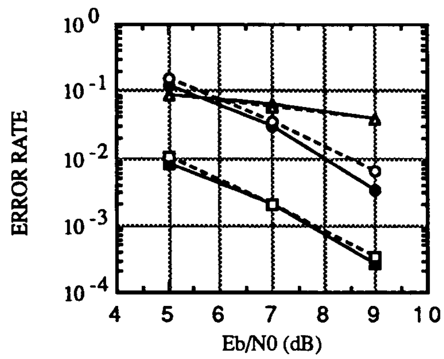

Fig. 6 Simulation results under TU50

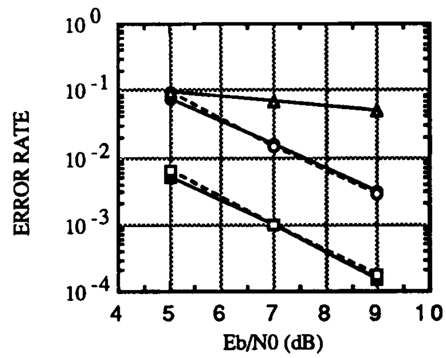

Fig. 7 Simulation results under RA250

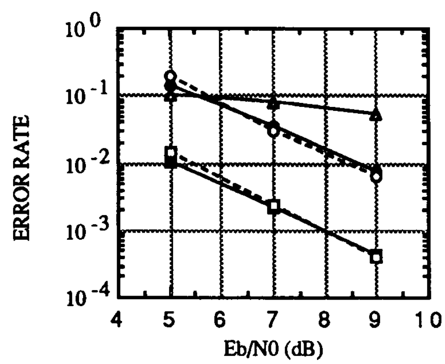

Fig. 8 Simulation results under HT100