論 文

An Embedded Timing Loss Detector for Robust Data Transmission

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ABSTRACT

Unlike voice communication, data transmission, can be seriously affected by transient channel impairments. In some cases, timing synchronization between the transmitter and the receiver may not be recovered in the presence of these kinds of impairments without a forced reinitialization process. Therefore, it is highly desirable for data communication equipment to have an efficient timing loss detector for robust recovery. In this paper, one such detector is proposed for data transceivers having a secondary channel embedded in the main channel. A known sequence multiplexed with the secondary channel data is repeatedly sent through the embedded secondary channel. For continuous *watch-dog* like operation, the detection is sequentially performed based on a modified up/down counter scheme. The performance of the proposed detector is analytically evaluated in closed form.

要 約

음성 통신과는 달리 데이타 신호전송은 불규칙하게 순간적으로 발생하는 선로장애에 크게 영향을 받는다. 이런 장애로 인해 때로는 송수신기 사이의 동기를 잃게되어, 강제적으로 재 동기시키지 않는한, 회복이 스스로 되지 못한다. 따라서 이러한 순간적인 장애에 의한 동기 손실에 적절히 대처하기 위해 데이타통신 장비에 효율적인 검출기가 필요된다. 본 논문에서는 부속데이타 채널이 주데이타 채널에 같이 통합되어있는 데이타 송수신기에 적당한 검출기를 설계하였다. 검출용 신호를 원래의 부속채널 데이타와 함께섞어 기존 채널의 운영에 영향이 없게 부속채널을 통해 보낸다. 데이타 전송중에 계속해서 동작하도록, 변형된 up/down 카운터를 이용한 검출방식을 사용한다. 설계된 검출기의 성능이 수학적으로 분석되었다.

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I. Introduction

Although transient disturbances such as impulse noise, gain hits, drop outs and phase hits are regulated, they still account for a substantial portion of the performance degradation when signals are transmitted through a network. In voice communication, these types of transient impairments can cause audible clicks or pops and have a negligible affect on the listeners on the telephone lines. However, transient impairments can seriously affect data communication since they can cause a loss of the timing information and thus loss of system synchronization.

Moreover, when a signal is transmitted through a digital carrier system such as T1, it can be impaired by another transient impairment called a slip which is an intended insertion or deletion of a single data frame in the digital switching operation to avoid loss of network synchronization due to either the lack of frequency synchronization of clocks at various network nodes, or phase wander and jitter on the digital bit stream [1]. Like other forms of transient noise, slips cause occasional audible clicks and do not, seriously hinder voice communications [2]. However, even though the slip rate is regulated and is acceptably low, a single slip can seriously affect data communication. For example, a slip affects Group 3 facsimile transmission, where a maximum of eight horizontal scan lines can be missed [3]. Experimental results on voiceband modems indicate that a single slip causes a long burst of errors over a time period of up to several seconds, depending on the type of the modem and its data rate [4]. In some cases, the modem never recovers from a slip and requires a forced manual reset. Therefore, it is highly desirable for a data transceiver to have a detector for robust recovery from a loss of synchronization due to such catastrophic transient impairments.

High speed data transceivers (or modems) usually have a secondary channel to provide an additional path for servicing other functions, such as network management. The secondary channel can be implemented using a frequency division multiplexing method. However, to maximize the use of the channel bandwidth and to reduce the implementation cost, the secondary channel is often embedded into the main channel. Using a time division multiplex (TDM) method, for example, the secondary channel data is synchronously multiplexed into the main channel data before being modulated. The required bandwidth of an embedded secondary channel can be obtained at a small additional cost to the main channel signal-to-noise ratio (SNR) without increasing the main channel bandwidth and can be flexibly adjusted without great difficulty.

The characteristics of a synchronous TDMed signal can be used for detecting a loss of system synchronization caused by fatal transient impairments. After being multiplexed with the secondary channel data, a predetermined sync code word (SCW) is repeatedly transmitted through the embedded secondary channel. Each bit of the SCW is sufficiently separated during transmission. Unless the receiver is operating properly (*i.e.*, is synchronized with the transmitter), the SCW cannot be correctly received (after being demultiplexed from the main channel data). This aspect will be used for detection of sudden timing (or sync.) loss caused by a fatal transient impairment.

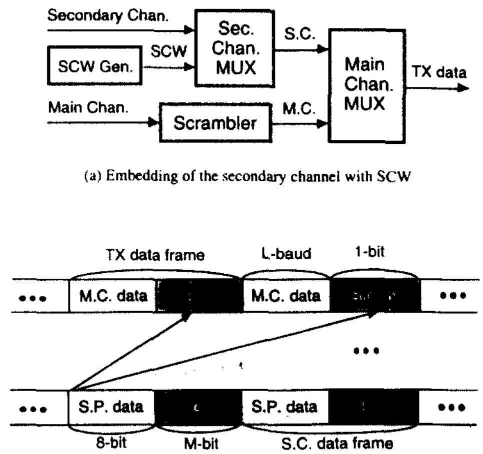
The proposed detector is composed of two processes: the detection and the confirmation process. We first monitor the errors in the received SCW that occur during each SCW frame interval. If the Hamming distance between the received SCW and the reference SCW exceeds a threshold, the receiver's performance is considered to have degraded unacceptably due to a sudden transient impairment (*i.e.*, timing is lost). Since a single decision is not reliable, additional confirmation of a timing loss is required. In order to continuously run the detector as a *watch-dog* processor during data transmission and for implementation efficiency, we devise the use of a sequential confirmation test based on a simple modified up/down counter scheme. Once a loss of synchronization is confirmed, the transceiver needs to initiate a retrain.

The detector operation based on as up/down counter scheme is easy to describe. However, its performance is not easy to analyze because of the boundary conditions at the normal (sync) state and the abnormal (sync lost) state. Statistical analysis of this count scheme can be fairly well formulated in a matrix form by using a probability generating function (PGF)[5]. To the best of the author's knowledge, however, no formal solution has been presented in closed form. Using a PGF method, the detection performance is analytically evaluated by modeling the detection problem as a simple hypothesis test against another simple alternative.

Section 2 briefly explains how the SCW can be efficiently sent through an embedded secondary channel. The proposed sequential detection scheme is described in Section 3. In Section 4, the performance of the detector is analytically evaluated in terms of the average detection time. Some numerical results are also presented.

Ⅱ. The embedded secondary channel

To make embedding the secondary channel independent of the main channel data rate, we consider a baud rate based embedding scheme. Each bit of the secondary channel data is synchronously inserted into the main channel data stream after every L bauds of the main channel data, as depicted in Fig. 1. That is, the main channel needs to send one more bit per symbol during the L-th baud interval. The additional bit may result in fractional bits per symbol. However, fractional bits per symbol can be handled without expanding the main channel bandwidth by using a frame based signal encoding/mapping algorithm such as shell mapping [6] or modulus conversion [7]. These signal mapping algorithms have been proposed to encode fractional bits per symbol to provide flexibility in data rate and symbol rate. Embedding an additional bit in every L-th baud costs approximately $3/L$ dB of additional SNR on the average. With proper choice of the multiplexing index L, the embedded secondary channel can



(a) Embedding of the secondary channel with SCW

(b) Synchronous multiplexing of the secondary channel data

Fig. 1. Embedded secondary channel

have a bandwidth larger than one required for the secondary port data which is usually less than 150 bps when the secondary port is used for digital network management. The marginal bandwidth can be easily provided for and can be used for other purposes, for example sending the SCW.

Assume that B is the baud (symbol) rate of the main channel and that the maximum data rate of the secondary port is V bps. Then, the embedded secondary channel has a channel bandwidth of W (B/L) bps, and the remaining bandwidth of $(W-V)$ bps can be used for sending the SCW. Each SCW is multiplexed with the secondary port data before being embedded into the main channel data, as shown in Fig. 1. For ease of implementation, an M-bit SCW can be sent after 8 bits of secondary port data have been transmitted, where M is an integer less than or equal to $8(W-V)/V$. It takes $T(=L(M+8)/B)$ seconds for a single secondary channel data frame to be sent. For example, when $B=2400$, $L=10$, and $V=110$, the bandwidth of the embedded secondary channel is 240 bps and the bit size M of a SCW can be up to 9. The main channel requires an additional 0.3 dB of SNR to embed this secondary channel without a degradation in performance.

Ⅲ. The timing loss detector

Under normal transceiver operating, the transmitted SCW can be correctly received when no fatal transient impairments occur. The only exception is when a bit loss event with a duration exactly equal to a multiple of the time span of a secondary channel data frame occurs. However, since this has a very low probability, we can neglect this case. Since a single secondary data frame spans a time interval of $(M+8)L$ bauds, if a SCW is properly received, the transceiver said to be well synchronized during this SCW time interval. We first consider a detection process based on a single SCW. The final decision whether or not the timing sync is lost can be made using these SCW test results. A simplified block diagram of the proposed detector is shown in Fig. 2.

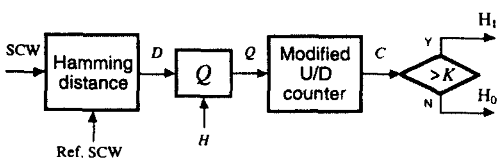


Fig. 2. A block diagram of the proposed detector

Whenever an M-bit SCW is received, it is compared with the transmitted (reference) SCW by measuring the Hamming distance D, which can be easily calculated by using a look-up table. If D is larger than a threshold H, it is assumed that a transient impairment occurred during the transmission of this data frame. The threshold level H should be chosen so as to accommodate the channel bit error rate (BER) under the worst permissible operating condition.

Since this single test cannot satisfy the required detection performance, multiple tests are required for reliable confirmation. In addition, when the receiver performance temporarily deteriorates due to a transient impairment, the transceiver may recover from a loss of synchronization after a while. Since it usually takes a fair amount of time for the transceiver to retrain, it is desirable for the detection time to be determined by considering the average self recovery time.

A sequential test based on the *c-successive* counter or *up/down* counter scheme is widely used for confirmation of PCM frame synchronization [5, 8]. The c-successive counter scheme declares a loss of frame synchronization if bad frames (*i.e.*, $D>H$) are received c times in a row. The content of the counter increases by ℓ, if $D>H$, and decreases by n if not. The up/down counter declares a confirmation if its content exceeds a threshold K, The c-successive counter scheme may not be efficient if a small SCW size M is used. For efficient confirmation even under high BER conditions, and for simplicity of implementation, we use a simple up/down counter scheme, where ℓ and n are set to the same value of 1. When the receiver is in normal operating condition, D is usually less than H, *i.e.*, the content of the counter C can be decreased without bound. Since the confirmation test should detect a true loss of synchronization as fast as possible, the content of the counter is bounded so that C has non-negative vlaue. The counter updating algorithm can be summarized as follows. Set $C(0)=0$. Then, at time $t=kT$, $k=1, 2, \cdots$,

$$C(k)=C(k-1)+Q(k);$$
$$C(k)=0, \quad \text{if } C(k)<0, \tag{1}$$

where $Q(k)$ is the output of the temporary timing loss (performance degradation) detector,

$$Q(k)=\begin{cases} 1, & \text{if } D(k)>H, \\ -1, & \text{otherwise.} \end{cases} \tag{2}$$

If $C(k)$ becomes larger than a threshold K, a true loss of synchronization is verified and the transceiver needs to retrain in order to recover. The threshold level K should be determined so that the confirmation process guarantees the desired detection criteria such as the true and false detection time. The design of these parameters, M, H and K, will be discussed in the next section.

Ⅳ. Performance Analysis

The statistical analysis of a sequential detector based on a up/down counter scheme can be formulated in a matrix form by using a PGF method. However, the boundary conditions at the normal (sync) state S and the abnormal (sync lost) state F make the analytical design difficult. In order to analytically design the detector parameters for a given set of conditions, we evaluate the performance of the proposed detector in closed form. We begin by modeling the detection problem as a simple hypothesis test against another simple alternative. Let H_0 be the null hypothesis corresponding to the normal condition and H_1 be the alternative corresponding to the sync lost condition due to a transient impairment.

Since each bit of a SCW is transmitted exactly L-baud time intervals apart, where L is moderately large, the test statistic Q of (2) can be treated as an independent binomial random variable. Let q_j be the BER of the received data under the hypothesis H_j, and $p_j=1-q_j$, for $j=0, 1$. For given threshold H and SCW bit size M, the probability λ_j that a bad frame is detected, *i.e.*, $q=1$, by each test is given by

$$\lambda_j = \text{Prob}\{q=1 \mid H_j\} = \sum_{i=H+1}^{M} \binom{M}{i} p_j^{M-i} q_j^i, \qquad (3)$$

under the hypothesis H_j, $j=0, 1$.

For a given threshold K, the confirmation process based on the modified up/down counter by (1) can be represented by an equivalent finite state machine as depicted in Fig. 3, where λ is equal to λ_0 and λ_1 under H_0 and H_1, respectively, and $\mu=1-\lambda$. When the channel has no fatal transient impairments, the state machine usually resides in the normal state S. When the machine reaches the final state F, a loss of synchronization is declared.

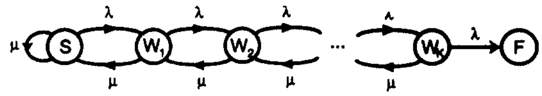


Fig. 3. An equivalent state diagram

The states $\{W_i\}$, $i=1, \cdots, K$, are intermediate transition states. The average true (under H_1) or false (under H_0) detection time T_D is equivalent to the mean time of first transition from state S to F. Using a PGF, the mean time T_D can be analytically calculated.

The timing transition of each state for a given value of K, can be represented by its nearest neighbors states as

$$\begin{aligned} S(z) &= 1+\mu z^{-1}[S(z)+W_1(z)] \\ W_1(z) &= \lambda z^{-1} S(z)+\mu z^{-1} W_2(z) \\ W_2(z) &= \lambda z^{-1} W_1(z)+\mu z^{-1} W_3(z) \\ &\vdots \\ W_{k-1}(z) &= \lambda z^{-1} W_{K-2}(z)+\mu z^{-1} W_K(z) \\ W_K(z) &= \lambda z^{-1} W_{K-1}(z) \\ F(z) &= \lambda z^{-1} W_K(z), \end{aligned} \qquad (4)$$

where z^{-1} denotes the time delay corresponding to the test interval T. For an intermediate state W_i, $i=1, 2, \cdots, K$, define the transfer function $G_i(z)$ by

$$G_i(z) = \frac{W_{K-i+1}(z)}{W_{K-i}(z)} \qquad (5)$$

Then, the state flow between the states can be represented by an equivalent transfer function as shown in Fig. 4. From Eq. (4), $G_i(z)$ can be expressed by

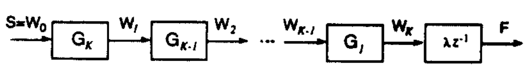


Fig. 4. An equivalent state transfer function

$$G_i(z)=\frac{\lambda z^{-1}}{1-\mu z^{-1}G_{i-1}(z)}, \quad \text{for } i=2, 3, \cdots, K, \quad (6)$$

where $G_1(z)=\lambda z^{-1}$.

Let $G_i^N(z)$ and $G_i^D(z)$ be the numerator and the denominator of the i-th intermediate state transfer function $G_i(z)$, respectively. It can be shown that the denominator $G_i^D(z)$ is expressed in terms of a sum of power series as

$$G_i^D(z)=\sum_{j=0}^{\kappa}\alpha_{i,j}(-\mu\lambda)^j z^{-2j}, \quad (7)$$

and the numerator $G_i^N(z)$ is given by

$$G_i^N(z)=\lambda z^{-1}G_{i-1}^D(z). \quad (8)$$

Here, the coefficients $\{\alpha_{i,j}\}$ can be recursively calculated using

$$\alpha_{i,j}=\begin{cases}\alpha_{i-2,j-1}+\alpha_{i-1,j}, & j=1, 2, \cdots, \kappa;\\ 0, & \text{otherwise,}\end{cases} \quad (9)$$

where $\alpha_{i,0}=1$, for all i, and κ is the largest integer $\leq i/2$. Note that, in Fig. 4, the normal state $S(z)$ is replaced with an equivalent state $W_0(z)$ given by

$$W_0(z)=\frac{1}{1-\mu z^{-1}-\mu z^{-1}G_K(z)} \quad (10)$$

The PGF $F(z)$ of timing transition from state S to F, for a given K, is

$$F(z)=W_0(z)\,\lambda z^{-1}\prod_{i=1}^{K}G_i(z). \quad (11)$$

Using Eqs. (8) and (10), we can have

$$F(z)=\frac{(\lambda z^{-1})^{K+1}}{(1-\mu z^{-1})G_K^D(z)-\mu z^{-1}G_K^N(z)} \quad (12)$$

From Eqs. (7) through (9), the denominator of $F(z)$, $F^D(z)$, can be represented in closed form,

$$F^D(z)=(1-\mu z^{-1})\sum_{j=0}^{\kappa_1}\alpha_{K,j}(-\mu\lambda)^j z^{-2j}$$

$$-\mu\lambda z^{-2}\sum_{j=0}^{\kappa_2}\alpha_{K-1,j}(-\mu\lambda)^j z^{-2j}, \quad (13)$$

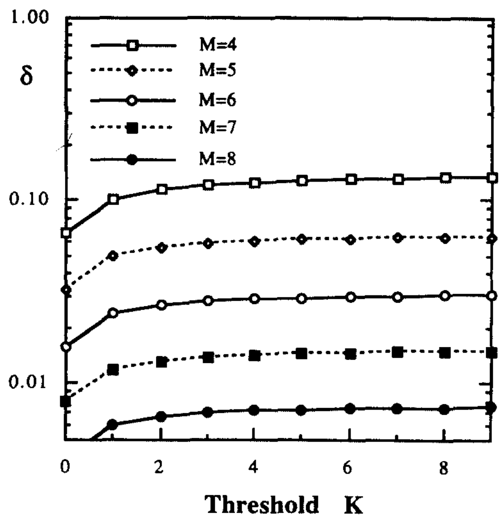
where κ_1 and κ_2 are the largest integers $\leq K/2$ and $\leq (K-1)/2$, respectively. The average detection time T_D is calculated by taking the derivative of $F(z)$ with respect to z and then evaluating it at $z=1$, *i.e.*,

$$T_D=-\frac{\partial}{\partial z}\frac{(\lambda z^{-1})^{K+1}}{(1-\mu z^{-1})\sum_{j=0}^{\kappa_1}\alpha_{K,j}(-\mu\lambda)^j z^{-2j}-\mu\lambda z^{-2}\sum_{j=0}^{\kappa_2}\alpha_{K-1,j}(-\mu\lambda)^j z^{-2j}}\Bigg|_{z=1}\cdot T. \quad (14)$$

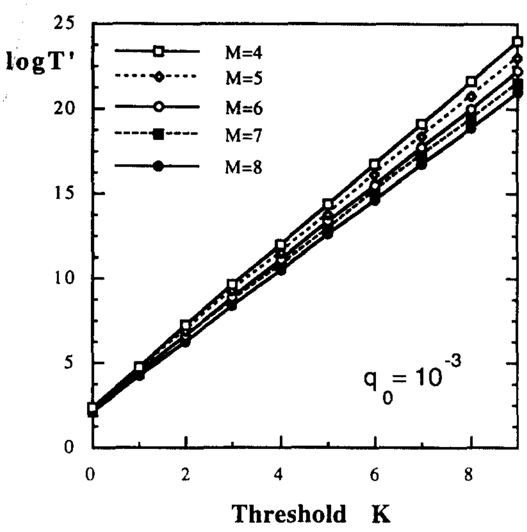
The detector performance associated with the design parameters is evaluated in terms of the false and true detection time. Because of the random nature of the data, the BER q_1 under hypothesis H_1 can be assumed to be 0.5. Assume also BER $q_0=10^{-3}$ is the worst permissible operating condition. Fig. 5 plots the average detection times versus the threshold level K for various bit sizes M of the sync code word with the threshold $H=0$. For a given K, it takes at least $(K+1)T$ seconds for the detector to confirm a loss of synchronization. To examine how many tests are required in addition to (K+1) tests under H_1, Fig. 5.(a) plots the additional average detection time δ normalized by the minimum time $(K+1)T$, *i.e.*, the average true detection time under H_1 will be

$$T_D=(1+\delta)(K+1)T. \quad (15)$$

It can be seen that, if the threshold level is not very small, the amount of the additional test time δ is almost constant for a given SCW size M, *i.e.*, the average detection time is likely to be linearly proportional to the threshold level K. This implies that, for a given K, the smaller the SCW size M, the larger the true detection time T_D. However, since the test interval T also increases as the SCW size M increases, the use of a small M can result in a shorter true detection time T_D than that of a



(a) Additional average detection time δ



(b) Average false detection time

Fig. 5. Average detection time of the detector

large M. Fig. 5.(b) shows the average false detection time normalized by T, T', which is plotted in the common logarithmic scale. It can be seen that the average false detection time is logarithmically proportional to the threshold K for a given M. In addition, a smaller size of the SCW results in larger false detection time. However, the variance of the detection time using an SCW with small bit size significantly increases as the threshold K increases and it may not be desirable to use an SCW with too small a bit size. The maximum and minimum values of K are thus determined by the desired true and false detection time, respectively.

As another performance measure of the detector, the miss detection probability associated with various bit sizes M is plotted in Fig. 6, when the threshold levels H and K are set to values of 0 and 5, respectively. The result is numerically obtained by considering all kinds of possible events at each detection time k. It can be seen that, if a smaller bit sizes is used, more tests are needed in order to achieve the same detection performance. Moreover, a smaller bit size results in larger variance in the detection time. Note that the staircase-like shapes of the detection probability curves are due to the up and down counting nature. Also note that a larger bit size is required for a larger threshold K to obtain the same detection performance. However, the proposed detector can have a reasonable performance without using an excessively large bit size of the code word. For example, when $B=2400$, $L=10$, $M=7$ and $K=5$, (*i.e.*,

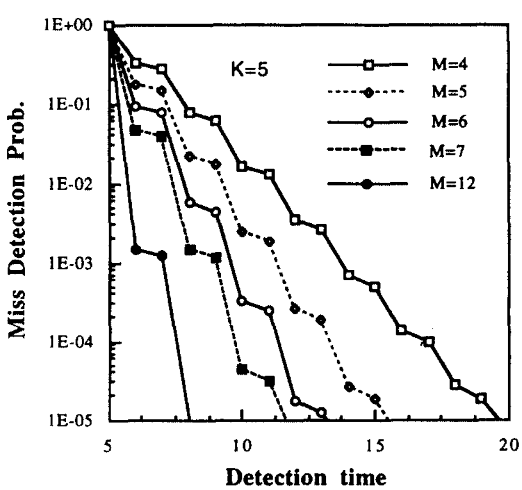


Fig. 6. Miss detection probability when $K=5$

$T=62.5(msec)$), a fatal transient impairment can be detected on the $(K+1)$-th test(the minimum trial) with a detection probability larger than 95%. With these values, it takes about 380.4($msec$) on the average for the detector to confirm a true loss of synchronization. Also the average false detection time is several years even when $q_0=10^{-3}$. In practice, it is desirable to set the threshold K to be large enough so that the average detection time is longer than the time taken by the receiver to recover without a retrain.

V. Conclusion

In this paper, an efficient scheme has been proposed for detecting a loss of system synchronization due to fatal transient impairments. Since the required bandwidth can be provided with a small amount of additional SNR, the proposed detector can be implemented without affecting the main channel performance. Moreover, the detector operation is transparent to the main and the secondary channel operation. The performance of the detector based on a modified up/down counter scheme has been analytically evaluated in terms of the average detection time. The derived results can be applied to analytical design of other synchronization problems such as a PCM frame synchronization detector in digital carrier systems.

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