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An Evaluation of Error Performance Estimation Schemes for DS1 Transmission Systems Carrying Live Traffic

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ABSTRACT

DS1 transmission systems use framing bit errors, bipolar violations and code-detected errors to estimate the bit error rate when determining errored and severely errored seconds. Using the coefficient of variation under the memoryless binary symmetric channel assumption, a basic framework to evaluate these estimation schemes is proposed to provide a practical guideline in determining errored and severely errored seconds which are fundamental in monitoring the real-ime error performance of DS1 transmission systems carrying live traffic. To evaluate the performance of the cyclic redundancy check code (CRC), a computer simulation model is used. Several drawbacks of the superframe format in association with real-time error performance monitoring are discussed. A few recommendations are suggested in measuring errored and severely errored seconds, and determining service limit alarms through the use of the superframe format. Furthermore, we propose a new robust scheme for determining service limit alarms which take into consideration the limitations of some estimation schemes for the time interval of one second.

1. INTRODUCTION

Because of the growth and expansion of integrated digital networks, measuring real-time error performance of digital transmission systems carrying live traffic has become more important not only to system users but also to those responsible for providing and maintaining services. These continuous measurements are needed for performance assessment, verification of specifications and tariff objectives, trend analysis, trouble prevention, and availability determination [5,6,8,10]. For these reasons, it is of growing interest to install such measurement systems in digital networks [17]. Because of the huge physical range of digital networks, however, installing continuous measurement systems appears extremely costly, particularly for noncritical digital networks. To reduce the heavy cost of continuous measurement systems, a new concept of a sampling measurement system has been proposed

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[16]. The system estimates real-time error performance through the use of sampling techniques to save on the number of electronic circuits which continuous measurements would require, and provides a high confidence level of accuracy. For both continuous and sampling measurement systems, the numbers of errored seconds and severely errored seconds are estimated since any direct measurement of information bits received is extremely difficult in digital transmission systems carrying live traffic. These are fundamental in characterizing real-time error performance [17]. Despite this importance, no evaluation schemes are available in the literature.

This paper provides a basic framework for evaluating available estimation schemes for DS1 transmission systems carrying live traffic. In Section 2, we outline the framework for evaluating those estimation schemes. This is done through the use of random sampling techniques in the work of Cochran [2]. The coefficient of variation (CV) of the estimate of the crossover error probability is a fundamental concept in evaluationg the quality of the estimate. n Section 3, using the framework, we discuss evaluating estimation methods based on the measurements of framing bit errors and bipolar violations for DS1 transmission systems employing the superframe (D4) format. A new procedure for declaring and clearing alarm conditions is proposed. In Section 4, we discuss evaluation estimation schemes based on the measurements of framing bit errors, errored CRC blocks and bipolar violations for DS1 transmission systems employing the extended superframe (ESF) format. Section 5 discusses our conclusions for using the estimation schemes in real-time error performance monitoring.

2. A UNIFIED FRAMEWORK FOR EVALUATING ESTIMATION SCHEMES

A general timing framework of partitioning the live traffic bit traffic bit stream on the real-time horizon and a basic framework of evaluatiog estimation schemes are discussed in turn.

Bit errors are caused by distortion, thermal noise, hardware malfunctions, software bugs, timing jitters, envirinmental and man-made interferences, and other factors. These errors are present in the live traffic bit stream consisting of information and overhead bits, and may be detected as framing bit errors, errored CRC blocks, and/or bipolar violations. Therefore, this bit error process can be thought of as a superposition of the individual bit errors which come from these error sources in random fashions [7]. Several methods for estimation the bit error rate are available in the literature. One of them is a periodic sampling method which uses errors in some known bit patterns such as those of framing bits [3,9]. Although this method is easily implemented in practice, it has the disadvantage that the number of framing bits in too small to be representative of all the information bits in low and dribbling error environments. Another method uses line code violations such as biploar violations [7]. In most digital systems, line code violations are not transmitted through terminals and some regenerative repeaters. These violations are usually found in the wire cable link portions of digital systems and their use for system error measurements in limited. Code-based methods estimate the bit error rate using errors detected by an error detection code such as those of parity check [3,12,15] and cyclic redundancy check [19].

To characterize the bit error process, a general timing framework of partitioning the live traffic bit stream on the real-time horizon is used in [17]. The bit stream on the real-time horizon at an arbitrary or predetermined starting point is partitioned into consecutive intervals of fifteen minutes. Each of these intervals is also partitioned into 900 contiguous subintervals of one second. This subinterval is used as a unit for calculating the respective numbers of errored and severely errored seconds [5,17]. Error performance data for each interval can be represented in terms of these subintervals [14]. A subinterval is said to be an errored second (ES) if it contains one or more bit errors. Note that each bit error contributes to exactly one subinterval. On the other hand, a subinterval is said to be an error free second (EFS) if it contains no errors. Note that a subinterval is either an ES or EFS. A subinterval of one second is said to be a severely errored second (SES) if the bit error rate for the subinterval is greater than or equal to 10^{-3} where the bit error rate is the ratio of the number of bit errors to the number of bits received for the subinterval, that is, 1544000. These definitions are further specified by the estimation schemes.

Because of the difficulty of directly measuring live traffic information bits, the bit error rate is usually replaced with its estimate. Whether or not a subinterval is an ES is also indirectly determined. The specifics of the estimation and determination are discussed in Sections 3 and 4. The alarm state is declared when each of the ten most recent subintervals is an SES [5,17]. Because the bit error rate is calculated after the time of the subinterval has expired, it takes ten seconds to declare the alarm state. Once the alarm state is declared, it is cleared only when the bit error rate for each of the ten most recent subintervals is less than 10^{-3} [5,17]. A subinterval is called a failed second (FS) when it is in the alarm state. For each interval, the number of EFSs can be obtained by subtracting the number of ESs from 900.

With this timing framework for real-time error performance monitoring, we provide below a basic framework of evaluation estimation schemes. A bit is said to be measurable if it can be determined whether it is in error. For example, all the framing bits are measurable. For further discussion, consider a sample of n bits out of N contiguous bits received. Let the sample ge $\{x_i\}_i=1, \ldots, n$ where x_i assumes to be one if the i^{th} bit is in error; otherwise zero. Let ε_n be defined as follows:

$$\varepsilon_n = (x_1 +, \ldots, + x_n)/n. \tag{2.1}$$

Note that ε_n is indeed the bit error rate. The assumption of the memoryless binary symmetric channel (MBSC) with the crossover error probability ε is equivalent to the random sampling assumption and thus the set $\{x_i\}$ are independent, identical Bernoulli random variables with mean ε and variance $\varepsilon(1-\varepsilon)$. Note that the number of bit errors follows the binomial distribution and Poisson for a sufficiently large N [1]. Furthermore, the variance of ε_n, $\mathrm{Var}(\varepsilon_n)$, is given by [2]:

$$\mathrm{Var}(\varepsilon_n) = \frac{N-n}{(N-1)n}\varepsilon(1-\varepsilon) \tag{2.2}$$

With the Prior error probability ε, the variance of the sample mean can be reduced by increasing the sample size n. For example, if $n=N$, $\mathrm{Var}(\varepsilon_n)$ turns out to be zero. Let V be such that:

$$V = \frac{N-n}{(n-1)N} \epsilon_n (1-\epsilon_n) \tag{2.3}$$

Then V is an unbiased estimate of Var (ϵ_n) and thus can be used in place of the variance of the sample.

Let γ be a relative accuracy bound and $(1-\alpha)$ be the confidence level such that

$$\Pr\{\, |z-\epsilon| / \epsilon < \gamma \,\} \geq 1-\alpha \tag{2.4}$$

By the Central Limit Theorem [1], the distribution of the sample mean follows the normal distribution and thus we have :

$$\Pr\left\{ \frac{|z-\epsilon|}{\sqrt{\mathrm{Var}(\epsilon_n)}} \leq \frac{\epsilon\gamma}{\sqrt{\mathrm{Var}(\epsilon_n)}} \right\} \geq 1-\alpha \tag{2.5}$$

Let u be the standard value corresponding to the $(1-\alpha)$ level. Then we have the following relationship :

$$u < \epsilon\gamma / \sqrt{\mathrm{Var}(\epsilon_n)} \tag{2.6}$$

Substituting Var (ϵ_n) by (2.2) and after some algebraic manipulations, we have :

$$\frac{(N-n)(1-\epsilon)}{n(N-1)\epsilon} \leq \frac{\gamma^2}{u^2} \tag{2.7}$$

The left hand side of (2.7) is the squared coefficient of variation (SCV) of the sample mean which is defined as the ratio of the variance to the squares mean of the estimate. As shown in (2.7), a CV can be related to a combination of an accuracy bound and a confidence level which determines a minimal sample size. For example, the combination of $\gamma = 0.2$ and $\alpha = 5\%$ results in a CV of 0.102 as shown in Table 2.1. Because of this property, the CV is used to evaluate estimation schemes.

Table 2.1 : Maximal CVs for Satisfying the Ratio of $\gamma / u_{1-\alpha}$

$1-\alpha$ ($u_{1-\alpha}$)	γ				
	0.1	0.2	0.3	0.4	0.5
99.9% (3.29)	0.030	0.061	0.091	0.122	0.152
99.0% (2.58)	0.039	0.078	0.117	0.156	0.195
98.0% (2.33)	0.043	0.086	0.129	0.172	0.215
95.0% (1.96)	0.051	0.102	0.153	0.204	0.255
90.0% (1.64)	0.061	0.122	0.183	0.244	0.305
85.0% (1.44)	0.069	0.139	0.208	0.278	0.347
80.0% (1.28)	0.078	0.156	0.234	0.313	0.391

Let C_V be a given maximal CV. Then, from (2.7), we have a minimal sample size n ;

$$n=\frac{N(1-\varepsilon)}{1-\varepsilon+(N-1)\varepsilon C_V} \tag{2.8}$$

3. EVALUATING ESTIMATION SCHEMES BASED ON THE D4 FORMAT

The frame format for DS1 transmission systems carrying the bit rate of 1544 kbp/s has evolved since 1962. The D4 format has been a standard for many years [18] and is still being used widely. Framing bit errors and bipolar violations are used in determining the ES and SES. In this section, we the framing bit measurement in conjunction with determining the number of ESs and SESs.

3.1 Measurement of Framing Bit Errors

One superframe of the D4 format is composed of 12 frames, each of which is an ordered sequence of 193 consecutive bits. The first bit of each frame is called a framing bit designated for frame synchronization and other purposes [4], and the following 192 bits constitute 24 consecutive individual channels, each of which contains eight comtiguous bits. Each superframe has the fixed framing bit pattern of 100011011100 which consists of 101010 and 001110. While frames are synchronized, errors are measured in such a way that each received framing bit is directly compared with its anticipated bit value. If they are not the same, one framing bit error has occurred. Otherwise, no errors have occurred. When the frames are not synchronized, framing bit errors cannot be measured. In this case, each superframe is defined as an out of frame (OOF) error. The frame synchronization is lost from when three errors in five consecutive framing bits occur until the reframe is completed [22].

For the interval of t seconds, an estimate of the bit error rate can be computed by dividing the number of the observed framing bit errors by the total number of framing bits observed for t seconds. Note that the estimate is unbiased. Using (2.3) and the Central Limit Theorem, a confidence interval of the estimate can be obtained. Before using the

Table 3.1 : The CV for Each Estimate Based on t Second Measurement

ϵ	Measurement Length t in Seconds									
	1	2	3	4	5	6	7	8	9	10
10^{-1}	.033	.024	.019	.017	.015	.014	.013	.012	.011	.011
10^{-2}	.111	.078	.064	.055	.050	.045	.042	.039	.037	.035
10^{-3}	.352	.249	.203	.176	.158	.144	.133	.125	.117	.111
10^{-4}	1.115	.788	.644	.558	.499	.455	.421	.394	.372	.353
10^{-5}	3.526	2.494	2.036	1.763	1.577	1.440	1.333	1.247	1.175	1.115
10^{-6}	11.15	7.885	6.438	5.576	4.987	4.553	4.215	3.943	3.717	3.526

interval, it is highly desirable to examine the coeffliciemt of variation of the estimate. To evaluate the estimation scheme based on framing bit errors, we calculate the coefficient of variation for each bit error rate and each measurement length.

Noting that N=1544000t and n =8000t, we get the SCV of the estimate for the interval of t seconds as follows :

$$SCV=\frac{192(1-\varepsilon)}{(1544000t-1)\varepsilon} \tag{3.1}$$

The CV of each estimate based on the measurement of framing bit errors pbserved for t seconds is summarized in Table 3.3. For example, at the bit error rate of 10^{-2} and with one second measurement, the CV is 0.111. As shown in the table, the smaller the bit error rate is, the larger the CV is obtained. In the meantime, the longer the measurement period, the smaller the CV.

Table 3.2 : Expected Rates of Errored Seconds by Framing Bit and Bit-by-Bit Measurements

ϵ	Framing Bit (%)	Bit-by-Bit (%)	Relative Difference (%)
10^{-7}	0.08	14.31	0.56
$5x10^{-7}$	0.40	53.79	0.74
10^{-6}	0.80	78.65	1.01
$5x10^{-6}$	3.92	99.96	3.92
10^{-5}	7.69	100.00	7.69
$5x10^{-5}$	32.97	100.00	32.97
10^{-4}	55.07	100.00	55.07
$5x10^{-4}$	98.17	100.00	98.17
10^{-3}	99.97	100.00	99.97

In low error environments, the number of framing bits is too small to be repreaentative of all the information and overhead bits. With a measurement length of ten seconds, most CVs still seem too high. Even though the accuracy of the estimate is not critical, the measurement of framing bits errors, however, provides a very poor estimate of errored seconds as shown in Table 3.2. In the vicinity of 10^{-6}, the measurement provides about 1.01% level of the actual number of errored seconds. The relative difference r of those of ESs observed by the framing bit measurement and bit-by-bit comparison is given by :

$$r=\frac{1-(1-\varepsilon)^n}{1-(1-\varepsilon)^N} \tag{3.2}$$

where N and n denote 1544000 and 8000, respectively. The ratio r may be thought of as a conditional probability that a subinterval of one second is determined as an errored second

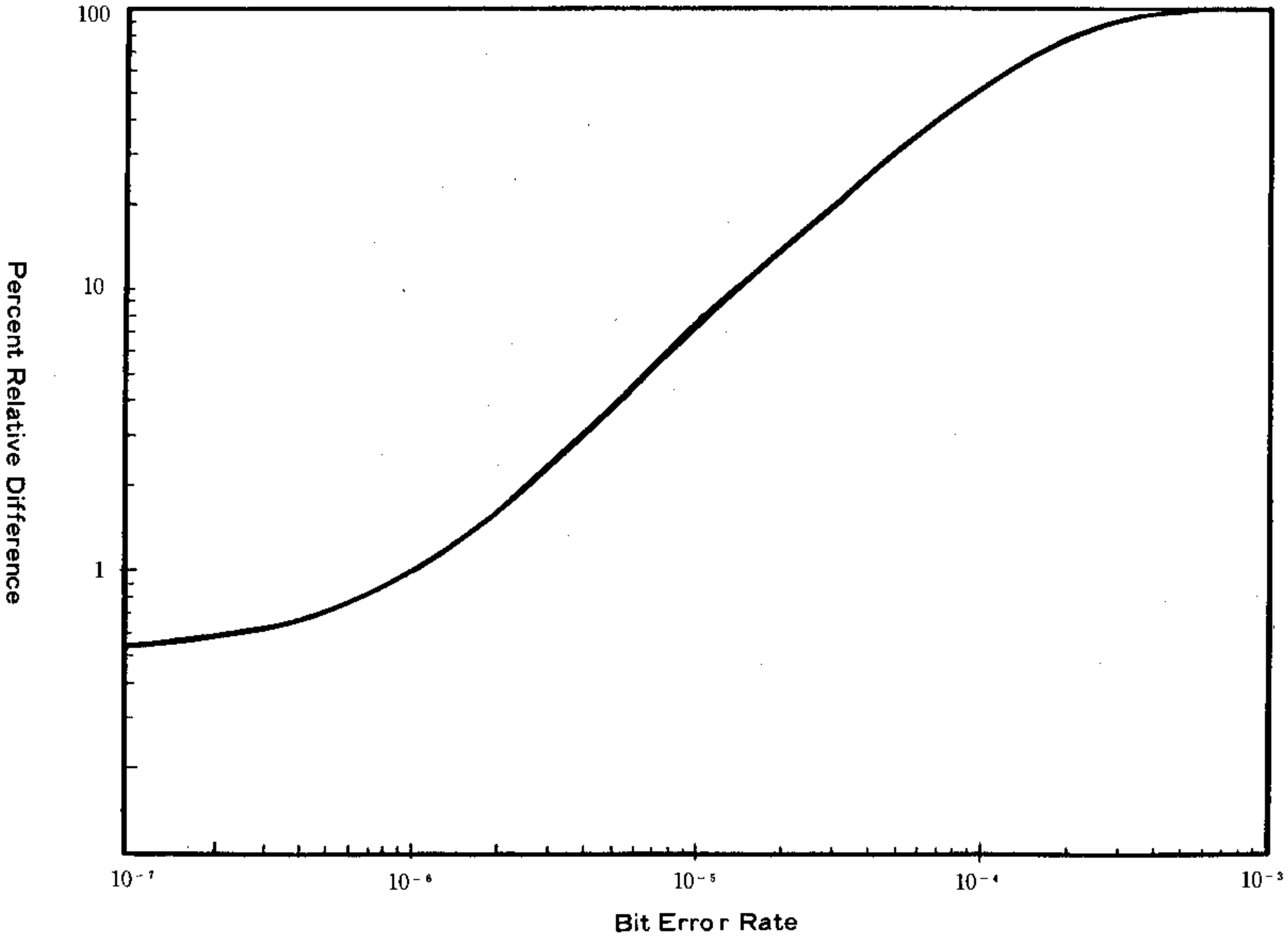

Figure 3.1 : Percent Relative Difference of Framing Bit to Bit-by-Bit Measurements for DS1 Signal

by the measurement of framing bit errors when the subinterval contains at least one error. As ϵ approaches zero, the relative difference becomes n/N, that is, 0.52%.

The expected percentage of errored seconds measured by framing bit errors is summarized for each bit error rate in Table 3.2. Each entry in the third column indicates the expected percentage of ESs measured by the bit-by-bit comparison technique. Note that the last column is obtained by dividing the second column by the third one, resulting in vector of the relative difference. As shown in Figure 3.1, the relative difference falls within 10% for error environments worse than $3x10_{-4}$.

This significant difference demonstrates that the measurement of framing bit errors based on each individual interval of one second may give a misleading result. To overcome this drawback, the following adjustment procedure is proposed. A length of the measurement interval, asy T=900 seconds, is determined. Next accumulate the framing bit errors for the interval. Then calculate the bit error rate ϵ_t for the interval by dividing the number of errors by the number of bits observed for the interval. Then the estimated number of errored seconds, T_e, can be obtained as follows:

$$Te = \{T[1-(1-\epsilon_t)^{1544000}]\} \tag{3.3}$$

where $\{a\}$ denotes the largest integer such that

$$a-1/2 < \{a\} \leq a+1/2.$$

For other appliations the length T of measurement can be obtained as follows:

$$T = \frac{\epsilon\,SCV + 192\ (1-\epsilon)}{1544000\,\epsilon\,SCV} \tag{3.4}$$

where SCV and ϵ are given parameters.

A new alarm procedure based on the moving average is provided below[23]. Let F_t be the number of framing bit errors for the subinterval t. Then the moving average, M_t, is given by:

$$M_t = \sum_{j=0}^{9} F_{t-j}/80000 \tag{3.5}$$

At the end of the subinterval t, the service limit alarm is determined as follows: If $M_t \geq 10^{-3}$ then indicate the alarm. Otherwise reset the alarm. An alternative formula for (3.5) is given by:

$$M_t = M_{t-1} + (F_t - F_{t-10})/80000 \tag{3.6}$$

3.2 Measurement of Biploar Violations

Alternate mark inversion (AMI) is a line code which has the capability of detecting the violation of its polarity constraint such that any two consecutive pulses have opposite polarity. A bipolar violation (BPV) is defined as the occurrence of two consecutive pulses having the same polarity. Note that any single deletion or insertion of one pulse results in exactly one bipolar violation. On the other hand. multiple errors may not produce even a single bipolar violation while reversing the polarity of a pulse creates two bipolar violations without any errors. In practice, however, the rate of bipolar violations is generally accepted to be close to the bit error rate. Excessive zeros are measured along with bipolar violations in order to detect the loss of signal which is defined as the absence of pulses for 150 milliseconds [10]. Considering the constraint of a maximum of fifteen zeros in DS1 transmission systems, the loss of signal may be thought of as an error burst. Because of continued emphasis on using Tl links for data communications, providing the 64 kbp/sclear channel capability has added importance. Because of restrictions on the number of consecutive zeros, information bits may be forced to have a minimum content of ones. The bipolar with 8-zero substitution (B8ZS) code proposed by AT & T is perhaps the most popular one. B8ZS is a form of AMI which replaces strings of eight consecutive zeros with a code of 000V10V1 where V denotes an intentional bipolar violation.

Because of its simplicity and practicality, the measurement of bipolar violations is widely accepted in practice. This measurement has several advantages. Unlike that of framing bit errors, the measurement is direct since each pulse is inspected. This inspection is carried out even if the signal is unframed. The measurement at a local monitoring point provides timely monitoring real-time error performance of the local T1 span. Framing bit errors and errored CRC blocks are propagated over the global path since they are usually not corrected. Biploar violations are removed by intermediate multiplexers for transmission at higher data rates over radio or fiber. For this reason, bipolar violations are used to monitor the error performance of a local T1 span rather than an end-to-end T1 path. Since these measurements are direct, a sampling measurement approach has been proposed to help reduce the costs associated with live traffic error performance monitoring [16,24].

4. EVALUATING ESTIMATION SCHEMES BASED ON THE ESF FORMAT

A framing format called the ESF format was proposed by AT & T in 1979 and was adopted as a standard [19]. The ESF format is expected to supersede the D4 format because of its advantages such as error detection capability for information bits and terminal-to-terminal data communications service. The ESF format uses the CRC-6 code for error detection.

4.1 Measurement of Framing Bit Errors

One extended superframe is composed of 24 frames, each of which is an ordered sequence of 193 bits. Unlike the D4 format, the first bit of each frame is used for the purpose of data communications and CRC-6 error detection also. Note that the 24 information channels are identical to those of the D4 format. Each extended superframe has the fixed framing bit pattern of 001011 and the framing bits appear in frames 4, 8, 12, 16, 20 and 24 of the superframe. Noting that $N=1544000t$ and $n=2000t$, we get the SCV of the estimate for the interval of t seconds can be stated as follows :

$$SCV=\frac{768\ (1-\varepsilon)}{(1544000t-1)\ \varepsilon} \tag{4.1}$$

The CV of each estimate based on the measurement of framing bit errors observed for t seconds is summarized in Table 4.1. As in Section 3.1, similar comments can be made. Framing bit errors are significant in determining out of frame (OOF) errors where CRC-6 errors cannot be measured. OOF errors are observed when three errors in five consecutive framing bits occur until frames are resynchronized [22].

Table 4.1 : The CV for Each Estimate Based on t Second Measurement

ϵ	Measurement Length t in Seconds									
	1	2	3	4	5	6	7	8	9	10
10^{-1}	.067	.047	.039	.033	.030	.027	.025	.024	.022	.021
10^{-2}	.222	.157	.128	.111	.099	.091	.084	.078	.074	.070
10^{-3}	.705	.498	.407	.352	.315	.288	.266	.249	.235	.223
10^{-4}	2.230	1.577	1.288	1.115	.997	.910	.843	.788	.743	.705
10^{-5}	7.053	4.987	4.072	3.526	3.154	2.879	2.666	2.494	2.351	2.230
10^{-6}	22.30	15.77	12.88	11.15	9.974	9.105	8.430	7.885	7.434	7.053

4.2 Measurement by the CRC-6 Code

In this section we discuss the error detection capability of the CRC code in association with ESs and SESs.

Each superframe has the six cyclic redundancy check bit positions which appear in frames 2, 6, 10, 14, 18 and 22. At each monitoring terminal, a 6-bit check vector calculated from the 4608 information bits in the previous superframe is stored and then compared with the check vector received from the current superframe. If the comparison shows a difference in the check vectors, an errored CRC block (ECB) is said to be detected. Otherwise, no ECB is considered to be detected. Note that a CRC block contains 4614 bits. Here an ES can be specified as a subinterval of one second where at least one ECB is detected by the code. Furthermore, an SES can be defined as a subinterval where 320 or more ECBs are detected. This definition is commonly used [17].

The code has difficulty converting the number of detected errored CRC blocks (DECBs) into its equivalent bit error rate [21] since a closed relationship between the crossover error probability and the number of DECBs is unknown [11,21]. Because of this difficulty, computer simulations were performed to assess the error detection performance of the code in association of ESs and SESs. For each run, the simulation time was set to 900 seconds (300,000 CRC blocks), which is listed in Table 4.2 below.

Table 4.2 : Simulation Setups for the ESF Format

Simulation Run	Simulated Bit Error Rate	Simulation Length in Seconds (CRC Blocks)
1	10^{-6}	900 (300,000)
2	10^{-5}	900 (300,000)
3	10^{-4}	900 (300,000)
4	10^{-3}	900 (300,000

Random errors was generated by using the exponential distribution based on DRAND48( ), a uniform random number generating function of the Lattice C compiler. The distance between two consecutive bit errors was assumed to follow the exponential distribution. For details of the computer simulation, refer to [11]. The simulation results are summarized in Tables 4.3 and 4.4. Table 4.3 shows clearly that all the simulated ESs were detected by the code. This is a welcomed feature of the code, particularly for the real-time error performance nonitoring of the live traffic digital signals. At the bit error rate of 10^{-6}, 716 ESs are detected to demonstrate that this measurement is far superior to the measurement based on the framing bits discussed in Section 3.1.

Table 4.3 : Dectection Statistics for ESs, and ECBs and DECBs for one Second

Statistics	Simulated Bit Error Rate			
	10^{-6}	10^{-5}	10^{-4}	10^{-3}
Errored Seconds				
Detected	716	900	900	900
Simulated	716	900	900	900
Errored CRC Blocks				
Detected	1,413	13,495	110,587	297,027
Simulated	1,413	13,497	110,987	292,665
Detected/Errored	100%	99.99%	99.64%	98.53%

The error bursts in low random error environments turn out to be a single eror and thus all the error bursts are detected by the code. Note that any error bursts of length 6 or less ane detected by the code where an error burst of length b is defined as any pattern of errors in a CRC block for which the number of bits between the first and last errors inclusive is b [20]. Furthermore, the length of the error burst in high random error environments becomes far larger than seven and thus the fraction of undetected error bursts tends to be upperbounded by 2^{-6} [11]. This was also supported by the simulation result. Because of these properties, the probability that an errored second is undetected by the code is conjectured to be small enough for error performance monitoring [11]. Note that the table shows that the ratio of the DECBs to ECBs decreases as the bit error rate

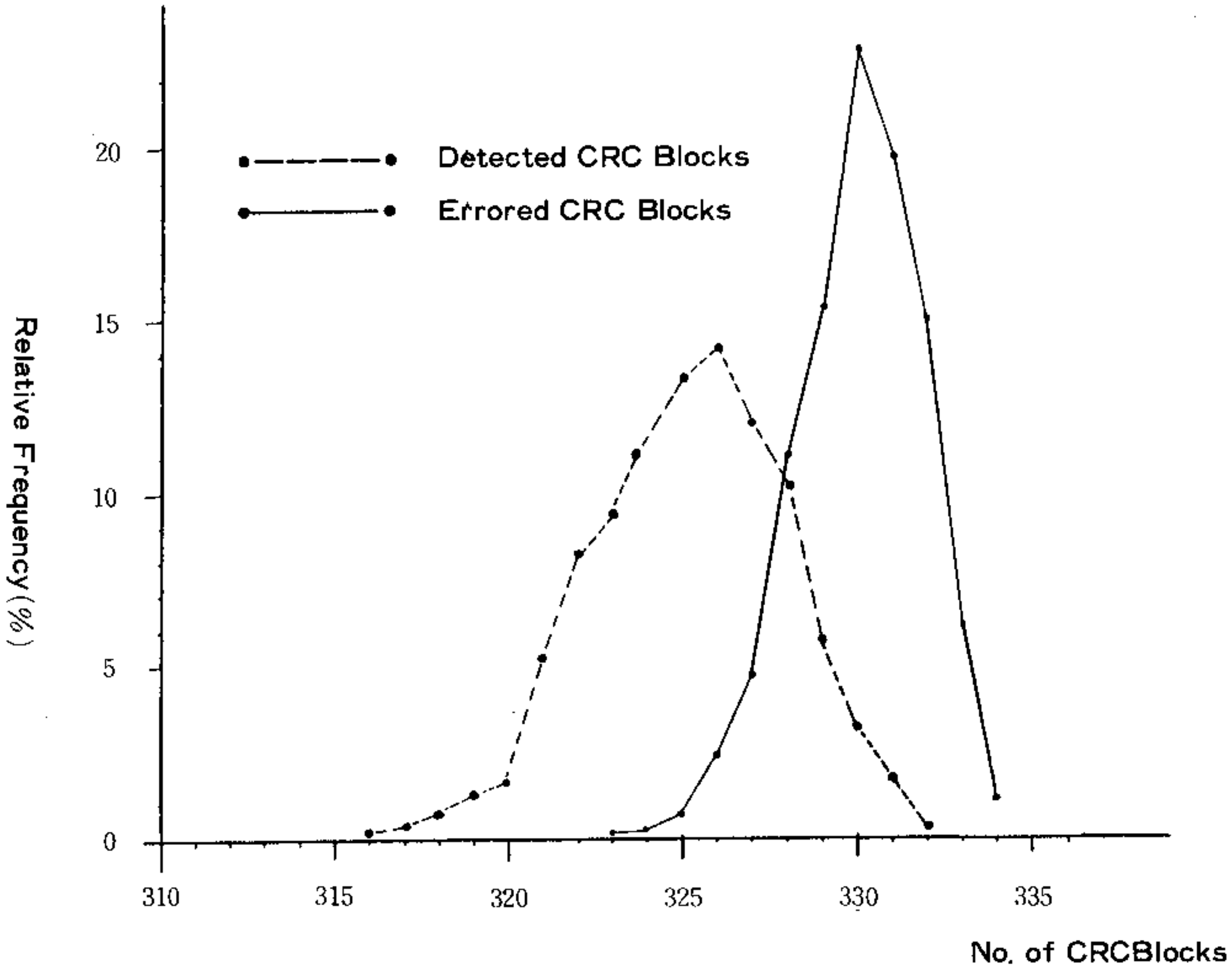

Figure 4.1 : Simulated Distributions of Errored and Detected CRC Blocks for the Interval of One Second : Bit Error Rate=10^{-3}.

becomes higher.

Table 4.4 shows that the distributions of ECBs and DECBs are almost identical in low random error environments while those of ECBs and DECBs become distinct. At the bit error rate of 10^{-3}, the distribution of ECBs is centered around 330 while that of DECB is centered around 326. As shown in Figure 4.1, for 97.34% of 900 seconds, 320 or more ECBs are detected at the bit error rate which is a threshold value for determining the SES.

Table 4.4 : Simulation Results for ECBs and DECBs for One Second

Statistics	Simulated Bit Error Rate			
	10^{-6}	10^{-5}	10^{-4}	10^{-3}
Mean				
Detected	1.570	14.994	122.873	325.183
Errored	1.570	14.996	123.264	330.030
Standard Deviation				
Detected	1,226	3.826	8.698	2.753
Errored	1,226	3.824	8.670	1.852
Coefficient of Variation				
Detected	0.781	0.255	0.071	0.009
Errored	0.781	0.255	0.071	0.006

5. CONCLUSIONS

Despite several limitations of the bit error in characterizing the error performance of digital networks [13], it has been widely used in determining several threshold errored seconds in the telecommunications industry [3,8,14,17]. Along with this trend, several estimation schemes are discussed in association with determining the errored second and severely errored second. The extended superframe format is highly recommended because its superior error detection capability produces the respective accurate estimates of errored and severely errored seconds which are fundamental parameters for monitoring real-time error performance. Along with these measurements, the measurement of bipolar violations can be also used for monitoring error performance of local T1 spans.

Considering that many existing DS1 circuits support the D4 format, we recommend several suggestions to improve serious drawbacks associated with the measurement of framing bit errors. They include calculation the number of errored seconds in low bit error environments, determining the service limit alarms and utilizing the measurement of bipolar violations.

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