A Practical Estimate Methodology for MRTIE and Related Issues

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Abstract

Among the quantities defined in literature, Maximum Relative Time Interval Error (MRTIE) has gained general acceptance as one of the main time domain measurement techniques characterizing timing performance in telecommunication networks. In this paper we discuss some features of MRTIE and we provide a suitable practical estimate methodology, also describing an experimental test-bed. Real measurement results, obtained by testing synchronization units of widely deployed switching equipments, are hereby showed. Moreover, some key features and critical issues of MRTIE quantity measurement approach are pointed out.

1. Introduction

Quite since the introduction of Pulse Code Modulation (PCM) and the ensuing worldwide spreading of digital communication networks, the problem of performance evaluation of network synchronization techniques has become more and more treated.

Formerly, even with PCM equipments bits arriving at input ports from different network nodes must be available as much as possible at the right time, in order to avoid bit losses or empty slots in the subsequent multiplexing and/or switching operations (*slips*) [R1][R2][R3][R4][R5].

Henceforth, Synchronous Digital Hierarchy (SDH), defined by CCITT in [R6][R7][R8] and which is going to be the world telecommunications backbone over the next decades, heavily relies on a common, highly stable synchronization source to ensure the claimed performance objectives are met.

It appears therefore essential, in modern networks, to adequately synchronize clocks in different (and often far!) locations. Master-slave synchronization strategies and related schemes are now widely accepted as the most adequate to deal with many problems [1][2][3]. Anyway, timing signal distributing still remains an issue [4].

Indeed, mainly, network elements designed for other purposes are currently employed to transfer timing, while cascaded slave clocks add several inaccuracies. Specifications for synchronization units and definitions of timing signal stability parameters in a SDH network are a very hot topic for discussions both in Academia and in standardization Technical Committees. Present Recommendations [R9][R10], specifying synchronization interfaces and timing requirements in a synchronous network, are currently still under study, and the whole subject is not well understood nor issues themselves are very well stated. It is somehow surprising that there's not a general agreement yet on which is the *best* parameter characterizing the frequency stability of a timing source in the time domain, at least for telecommunication engineering purposes.

In this paper we discuss some features of the *Maximum Relative Time Interval Error* (MRTIE) parameter, as defined by [R1], and we provide a practical estimate methodology for this quantity, describing an experimental test-bed based on a high performance time counter instrument. Real measurements results, obtained by testing common synchronization units, are hereby showed. Moreover, some critical issues of MRTIE quantity measurement approach to timing performance specification and evaluation are pointed out.

2. Definition of MRTIE

Among the various quantities defined in literature [5][6][7][R11], M[R]TIE has historically gained general acceptance as one of the main time domain measurement techniques characterizing timing performance in telecommunication networks.

The optional bracketed [R] (Relative) is used to distinguish the reference timing signal: if present, the reference timing signal is the input to a timing unit (slave clock) and the signal under test is the network element output; otherwise, the reference is considered to be ideal. In this paper we always deal with MRTIE measurements. Nevertheless, for the sake of simplicity, we shall often refer to the reference signal as the ideal absolute time t, omitting non-essential [R]s in formulas and thus avoiding the burden of repeating the same considerations for both Relative and non quantities.

Let the **Time Error** stochastic process

$$x(t) = \mathrm{TE}(t) = \mathrm{T}(t) - t \qquad (1)$$

be the difference between the **Time** $\mathrm{T}(t)$ generated by the clock under test and the absolute time t, while the **Time Interval Error** process

$$\mathrm{TIE}_t(S) = \mathrm{TE}(t+S) - \mathrm{TE}(t) = \left(\mathrm{T}(t+S) - \mathrm{T}(t)\right) - S \qquad (2)$$

be the error committed by the clock in measuring the interval $[t, t+S]$. The function $\mathbf{MTIE}_t\mathbf{(S)}$ is defined as

$$\mathrm{MTIE}_t(S) = \max_{t \le \xi \le t+S}\left[\mathrm{TE}(\xi)\right] - \min_{t \le \xi \le t+S}\left[\mathrm{TE}(\xi)\right] \qquad (3)$$

and thus represents the maximum error committed by the clock under test in measuring a time interval over the whole interval $[t, t+S]$ (Fig. 1). In other words

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$$\mathrm{MTIE}_t(S) = \max_{\substack{t \le \xi \le t+S-s \\ 0<s\le S}} \left[\mathrm{TIE}_\xi(s)\right] \qquad (4)$$

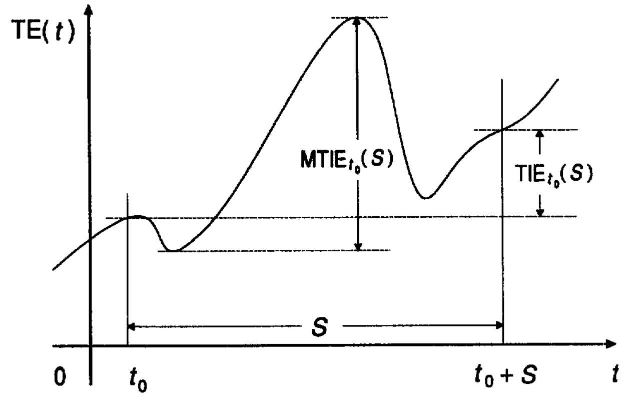

Fig. 1: Definition of MTIE$_t$(S)

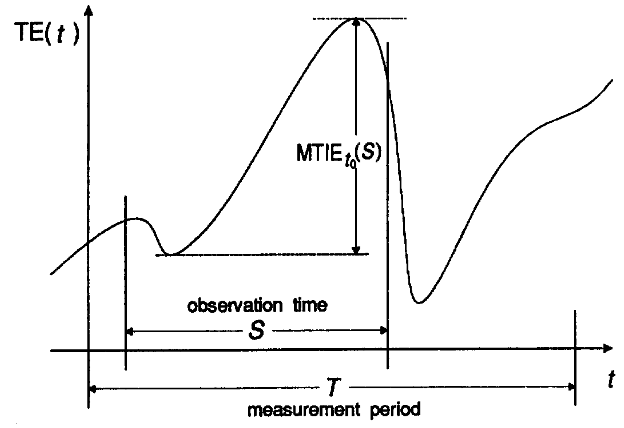

Fig. 2: ANSI definition of MTIE(S,T)

In synchronization standard documents, a slightly different notation is adopted: MTIE(S,T) is defined as the maximum TIE for all possible measurements or observation intervals S, within the measurement period T [R12] (Fig. 2). It should be noted that international synchronization interfaces standards specify MTIE simply as a function of S, thus implicitly assuming

$$\mathrm{MTIE}(S) = \lim_{T\to\infty} \mathrm{MTIE}(S,T) \qquad (5)$$

In other words, to assert the MRTIE compliance of a timing unit with CCITT specifications, one should verify that, for every S, MRTIE(S) keeps below the permissible limits *for all the device life*. Thus, how can we designe a practical procedure to check MRTIE(S) compliance over a finite interval T ? Is it possible to guess if a certain T is big enough to get trustworthy results?

3. MRTIE Measurement Methodology and Test Bed

Let us suppose we sample the process *x(t)*, i.e. the output Time Error of the device under test (a slave clock) with respect to the input time t (supposed ideal as stated above), at the rate $1/\tau_0$ over a period T. Letting $N_{TOT} = T/\tau_0 + 1$ be the total number of available samples, and $N = S/\tau_0 + 1$ be the number of samples available in the window of span S, to obtain rigorously the MRTIE(S,T) we must compute the following expression

$$\mathrm{MRTIE}(S,T) = \max_{j=1}^{N_{TOT}-N+1} \left[\max_{i=j}^{N+j-1} (x_i) - \min_{i=j}^{N+j-1} (x_i) \right] \qquad (6)$$

It is obvious that this approach tends to be completely unmanageable as the duration T of the test increases, even though more efficient computing algorithms are available. Hence it follows the need for a simpler, practical to implement technique to estimate the MRTIE of a timing signal, even for longest measurement periods.

The measurement technique we conceived is based on the methodology showed in Fig. 3. In order to estimate the quantity MRTIE(S,T), M independent measures each one of duration S are accomplished in sequence, over a total measurement period T. If we neglect dead times between measurements, we can also let $T \cong M \cdot S$.

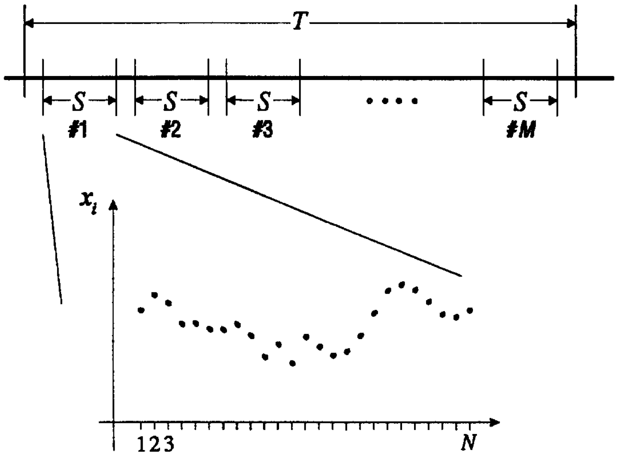

Fig. 3: MRTIE(S,T) measurement methodology

Every k-th S wide measure spans N samples x_i, and leads to

$$\mathrm{MRTIE}_k(S) = \max_{i=[1..N]_k} \{x_i\} - \min_{i=[1..N]_k} \{x_i\} \qquad (7)$$

where $i = [1..N]_k$ means "for every i in the k-th window". The MRTIE(S,T) value is finally estimated evaluating

$$\widehat{\mathrm{MRTIE}}(S,T) = \max_{k=[1..M]} \left[\mathrm{MRTIE}_k(S)\right] \qquad (8)$$

To perform efficiently data acquisition and processing we conceived the high precision test-bed outlined in Fig. 4.

It is mainly based on a high performance and highly sophisticated time counter instrument, comparing the input and output timing signals $CK_{Ref}(t)$ and $CK_{Test}(t)$ of the device under test, and drived via a GPIB IEEE488.2 interface by a personal computer running a software developed *ad hoc* for this purpose.

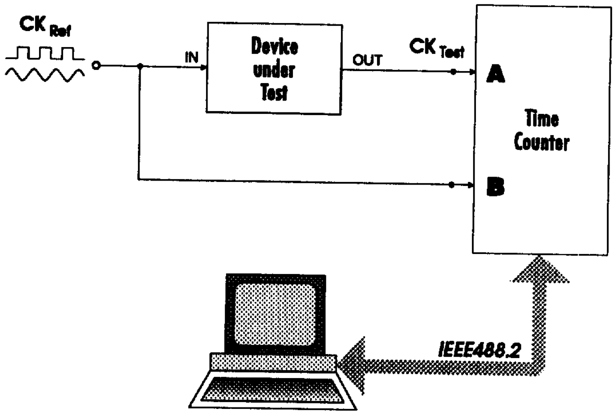

Fig. 4: MRTIE measurement test-bed

The time counter measures time intervals between two trigger events, e.g. two consecutive signal zero-crossings on input channels A and B. The time counter resolution is 200 ps, while the total measure error does not exceed 1 ns.

Within every measurement cycle, the N samples x_i are *not* stored by the instrument nor transferred to the computer memory. Instead, a histogram of the measured values is built real time, directly via hardware, thus achieving the highest sampling rate. More formally, during the k-th measurement the instrument just increases the elements of the vector

$$\mathbf{n} = \left\{ n_1, n_2, \cdots, n_{N_{bins}} \right\} \tag{9}$$

where the j-th element

$$n_j = \text{total number of samples } x_i \;\Big|: X_j < x_i \le X_{j+1} \tag{10}$$

tells us how many measured values fell in the j-th of the available N_{bins} bins. This procedure is outlined in Fig. 5.

In the maximum resolution instrument configuration, we have $N_{bins} = 2000$ bins and the total histogram span is equal to 400 ns. Up to $2 \cdot 10^9$ samples x_i can be processed to build one histogram, at the maximum rate of 1 sample every about 200 ns. This means that, testing for example a typical clock signal at frequency $f_0 = 2.048$ MHz, we are able to measure exactly the MRTIE in a S wide window for $S \le 1000$ s, sampling the phase shift at the maximum rate, i.e. at *every* signal edge ($\tau_0 \cong 488$ ns).

The results of every histogram (e.g. simply the maximum and the minimum measured values of x_i) are then transferred to the personal computer for storing and post-processing, thus allowing us to repeat this measure for whichever M times we want.

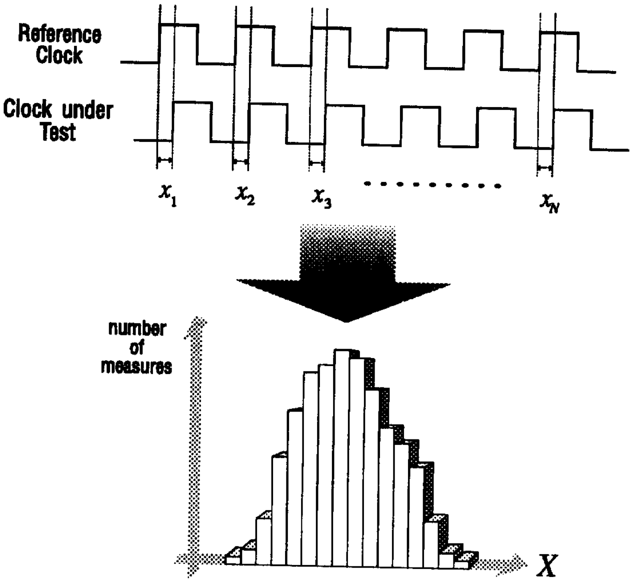

Fig. 5: Sampling of *x(t)* and data histogram storing

4. Measurement Results

Hereby we show some real measurement results, obtained by testing the Synchronization Units (operating in slave mode) of two widely deployed digital exchange equipments, comparing their master timing input signals with the output ones.

Measurements were accomplished in nearly ideal conditions. Both input and output timing signals are 2.048 Mbit/s HDB3 and are compliant with [R13].

The Synchronization Units of these equipments are very complex machines, mainly based on one (or more) Digital Phase Locked Loops (DPLL) [8] and with hardware redundancy for greater reliability. Thus, we must keep in mind that measured results may be considerably different from those evaluated through theoretical models based on the classical theory of Analog PLLs, and on the well known *power-law* frequency domain *x(t)* noise model [5] [R11].

We then applied the described methodology to the aforementioned practical case, in order to find an answer, or at least some directions, to the following questions:

- ☐ which is the dependence of MRTIE(S,T) on both the parameters S and T?
- ☐ as the assumption (5) is not feasible for practical measurement purposes, is it possible to give a rule of thumb for determining an appropriate minimum value of the measurement period T, large enough to get trustworthy results for MRTIE(S)?

The graphs of Fig. 6 show a typical output of our test-bed after having run a test campaign of M=50 measurements each of duration S=100 s, i.e. each spanning about $N \cong 10^8$ samples measured on the 2.048 Mbit/s HDB3 data channel carrying an *Alarm Indication Signal* (AIS).

The upper graphs depict the 50 histogram summarizing results (i.e., for every histogram, its maximum, minimum, mean values and its standard deviation). On the X axes we put the measurement sequence numbers $k=1..M$, while the dimension of the quantities on the Y axes is, obviously, [ns].

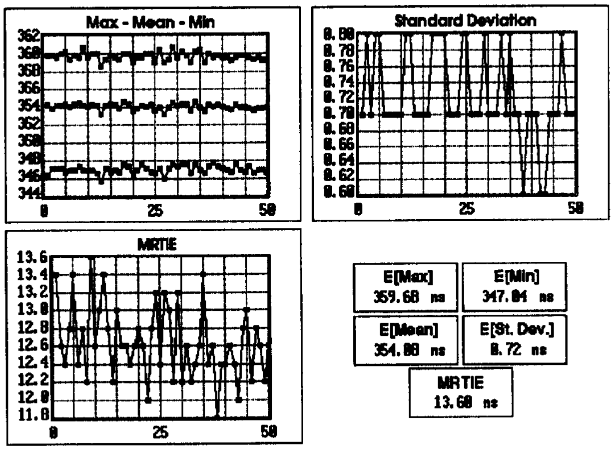

Fig. 6: Example of measurement results for S=100 s, M=50

It is worth remarking that these two first graphs may give us important directions on possible measurement mischances: such a trend as the one plotted in Fig. 6 may reassure us about the *"stationarity"* of the process $x(t)$ during the test time, while ramps or steps may indicate misbehavings in the normal operation of the device under test, perhaps due to micro-interruptions on the line carryng the reference input timing signal.

Eventually, the left-lower graph depicts for every histogram, in the same way, the 50 measured values of $\mathrm{MRTIE}_k(S)$, evaluated according to the definition (7). The maximum of them is thus reported as MRTIE(S=100s,T=5000s).

In Fig. 7 and Fig. 8 we plot some measured values of MRTIE as a function respectively of S and T. In the former graph curves, the product $T=S\cdot M$ is kept constant, while the latter graph curves group measurements accomplished with the same S=1s. Results concerning the two mentioned Synchronization Units (SU1 and SU2) are plotted together. Though these graphs are simply examples of our measurement campaign, they may be considered as typical trends.

Considering this graphs, it is important to remark once again that we are dealing with slave clocks operating in normal conditions. Hence, the raising of MRTIE(S,T) is not due to any frequency drift (a costant frequency drift would lead to a linear increase of phase shift and thus of MRTIE(S) with S), but only to the noise introduced by the unit under test.

A quick look of the showed graphs leads to some considerations.

- ☐ There is some increasing trend in the measured values of MRTIE(S,T=const) with S (Fig. 7). This is not surprising, since as we broaden the window S it is more likely to include higher phase noise peaks in the measured results. Moreover, increasing S allows the measurement to include slower phase changes, i.e. due to kinds of noise with the power spectrum gathered at the lowest frequencies (viz. as $1/f$, $1/f^2$ and so on).
- ☐ The increasing trend of MRTIE(S=const,T) with T is normally insignificant (Fig. 8), but sometimes else it may be more notable (compare in Fig. 7 the curves SU1,T=5000s and SU1,T=100s), or even dramatic (we witnessed a wide collection of such measurements, mainly due to some misoperations of the devices under test). The reason is that, increasing the number M of measurements, it becomes more likely to include sporadic higher noise peaks which may occur very seldom.

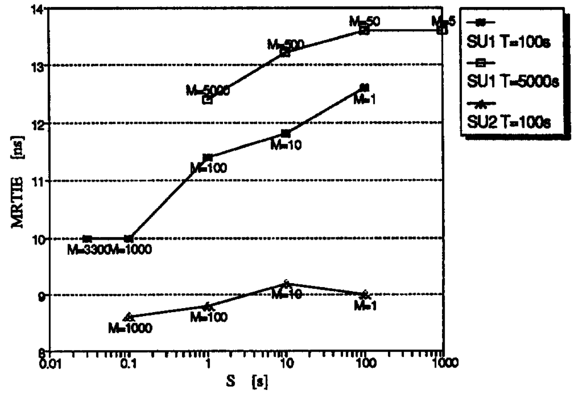

Fig. 7: Measured values of MRTIE(S,T=const) plotted as function of S

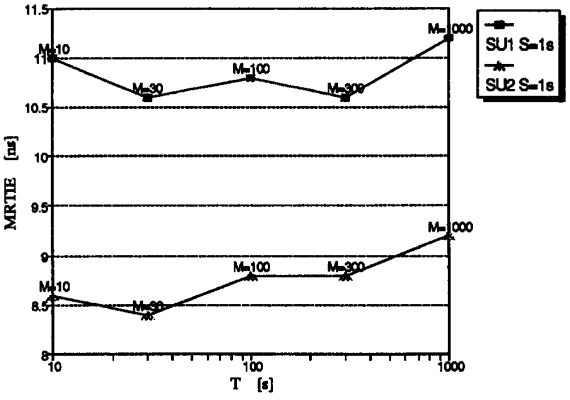

Fig. 8: Measured values of MRTIE(S=const,T) plotted as function of T

Finally, on the ground of our practical experience, we can point out that it is not possible to give a direction in choosing a *right* T for measuring MRTIE(S). Indeed, it will always be possible, repeating indefinitely our S wide measurements, to capture some glitch and thus obtain a larger value for MRTIE(S), even though in *normal* operation conditions we can expect that MRTIE(S,T) really converges to some saturation value for $T\rightarrow\infty$.

5. MRTIE Key Features and Critical Issues

In this final section we outline key features of M[R]TIE, and we express few considerations about some critical issues arising in the M[R]TIE approach to modern network timing interfaces specification.

First, we must point out that M[R]TIE was mainly conceived considering conventional plesiochronous networks. In these networks, the main target is to control slips. Assuming that a given M[R]TIE(S) is not exceeded, at the input timing interface, means that certain buffer thresholds will not be overflowed during S, thus allowing us to suitably design buffers in order to control bit slips.

Nevertheless, while unpredictable events may lead to exceed thresholds we designed, M[R]TIE characterization states *if* these thresholds are exceeded, but provides no information at all about *when* or *how often* they do. By the way, this strongly impacts on SDH networks design, where we are mainly interested in limiting the pointer justification rate. M[R]TIE, alone, is absolutely not adequate to deal with this issue; hence the need for jointly specifying at least one complementary quantity too, such as TVAR [9].

A second key feature of M[R]TIE is that it simply captures $x(t)$ peaks. The measured value records any glitch occurred during the test period, thus being very sensitive to any practical measurement mischance, such as thermal shocks. This means not only that we must accomplish measurements in very controlled conditions, but also that we should always associate measurement results MRTIE(S) with the key information T (the total test duration). An attempt to deal with this issue of M[R]TIE approach is made in [9], where a new quantity (ZTIE) is defined in order to complement TVAR with a smarter peak power measure.

6. Conclusions

In this paper we discussed some features of MRTIE, historically one of the main time domain measurement techniques characterizing timing performance in telecommunication networks. A practical estimate methodology for it was provided, jointly with an experimental test-bed. Real measurement results, obtained by testing synchronization units of widely deployed switching equipments, were hereby showed. Furthermore, some key features and critical issues of MRTIE quantity measurement approach were pointed out.

Acknowledgments

The authors carried out their work in the frame of the *National Study Group on Network Synchronization*, established by SIP and joined by SIRTI, CSELT and FONDAZIONE UGO BORDONI. They want thus to thank a lot the components of the Group for their invaluable help provided through discussions.

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