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PARAMETERS OF SYNCHRONIZATION SIGNALS IN IP/MPLS NETWORKS

In the present paper, the parameters of stability of signals of synchronization are resulted in the "classic" network of synchronization (SDH is a synchronous digital hierarchy) in obedience to Recommendation of G.810.The parameters of stability of signals of synchronization are considered in the package networks of IP/MPLS in obedience to Recommendation of G.8260. Features, related to the analogy and distinction of calculations of parameters of stability in the "classic" network of synchronization and IP/MPLS networks, are showed.

Keywords: *"Classic" network (SDH), IP/MPLS network, synchronization signal, parameters of synchronization signals, parameters stability of synchronization signals, measurement of the parameters of synchronization signals.*

Introduction

Because synchronization issues are crucial for modern IP/MPLS transport networks [1–4], enhancement of the role of synchronization network is the modern trend in the development of primary network, and this trend will continue in the immediate future [2]. Moreover, synchronization problems are related not only to primary network, but are important when developing access networks with consideration for various technologies and protocols embodied in the specific IP/MPLS network [2 – 4].

Measurement of the parameters of synchronization signals is a prerequisite for the solution of synchronization problems in electric communication networks.

Because, **aim of the paper** is definition the basic parameters of the stability of synchronization signals in IP/MPLS networks, and review of features associated with the similarities and differences in the stability of the calculation parameters of the "classic" network synchronization and IP/MPLS networks.

Problem statement

Currently, in communication operator networks, more and more network segments are being deployed for communicating through IP/MPLS transport only. However, with increase in the number of devices (e.g., mobile communication base stations), synchronization problems should be considered on a systemic level rather than on case-by-case basis. To this is related some kind of local revolution in approach: arrival of some «critical mass» of users of synchronization signals in the IP/MPLS network results in the requirement for considering synchronization system as a separate component of electric communication system. With the following increase in the number of digital devices, the concepts of the development and principles of control of synchronization network start being subjected to changes. Such system-based approach may be provided by measurement of the parameters of synchronization network.

Therefore, this work is devoted to the solution of the following topical problems:

1) definition of the basic parameters of the stability of synchronization signals in IP/MPLS networks, and

2) consideration of the features associated with the similarities and differences in the stability of the calculation parameters of the "classic" network synchronization and IP/MPLS networks.

Main part

In «Definition and Terminology for Synchronization Networks» [1], TIE (Time Interval Error), MTIE (Maximum Time Interval Error) and TDEV (Time Deviation) are the three parameters used as basic criteria for evaluation of quality of synchronization signals, but only TIE function is directly measured.

1. TIE - Time Interval Error

The difference between the measure of a time interval as provided by a clock and the measure of that same time interval as provided by a reference clock. Mathematically, the Time Interval Error function TIE(t; τ) can be expressed as:

$$\begin{aligned}\mathrm{TIE}(t;\tau) &= [T(t+\tau)-T(t)]-[T_{ref}(t+\tau)-T_{ref}(t)]= \\ &= x(t+\tau)-x(t),\end{aligned} \qquad (1)$$

where τ is the observation interval; t is the time of the clock; t_{ref} is the time of the reference clock.

The magnitude of TIE is not normally important, and by convention, TIE is set to zero at the start of the measurement. It then tracks change in phase from the start of the measurement (Fig. 1).

2. MTIE - Maximum Time Interval Error

MTIE ($n\tau_0$) can be estimated by:

$$\mathrm{MTIE}(n\tau_0) \cong \max_{1\le k\le N-n}\left(\max_{k\le i\le k+n} x(i) - \min_{k\le i\le k+n} x(i)\right), \qquad (2)$$
$$n = 1, 2, ..., N-1.$$

The above is a point estimate, and is obtained for measurements over a single measurement period (Fig. 2).

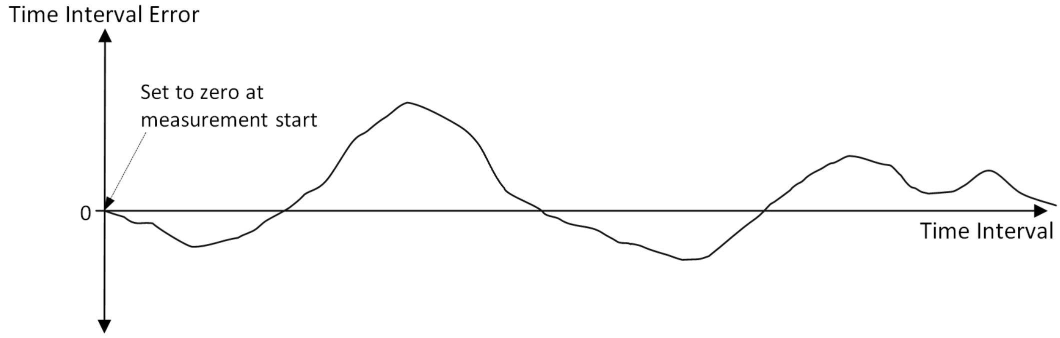
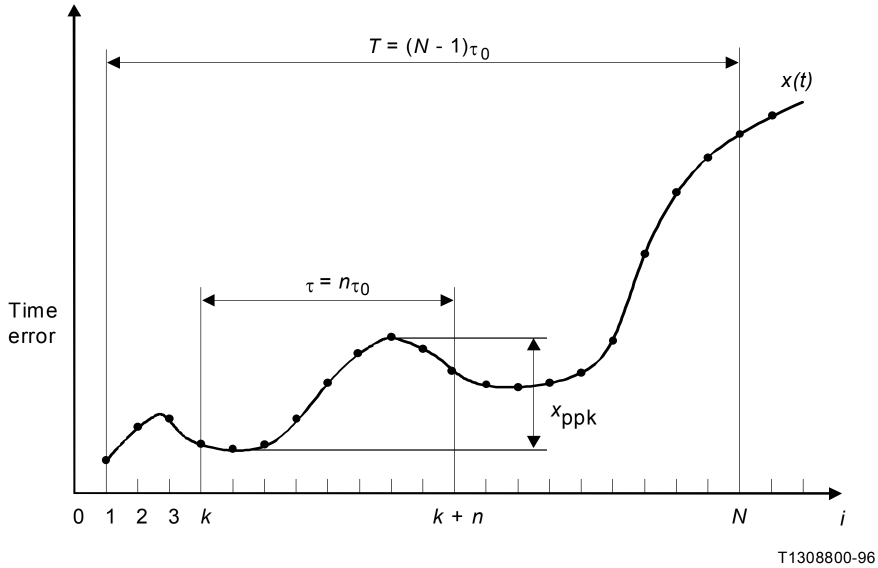


Fig. 1. The magnitude of TIE



τ_0 is the sample period; n is the number of samples in each observation interval;
τ is the observation interval, equal to $n\tau_0$; n is the total number of samples;
t is the measurement period; x_i – is the i-th time error sample; x_{ppk} is the peak-to-peak x_i within k-th observation; MTIE (τ) is the maximum x_{pp} for all observations of length τ within T

Fig. 2.The point estimate, and is obtained for measurements over a single measurement period

Frequency offset and drift

For observation intervals τ where a constant frequency offset dominates, the MTIE(τ) behaves as τ.

For observation intervals τ where a linear frequency drift dominates, the MTIE(τ) is not theoretically bounded τ From the measurement viewpoint this circumstance is expected to cause increasing value of estimated MTIE (τ) as the total observation time, (i.e. the length N of the x_i data) is increased.

The behaviour of MTIE(τ) is substantially independent of sampling period τ_0. MTIE (and MRTIE) is well-suited for characterization of buffer size.

3. TDEV - Time Deviation

TDEV($n\tau_0$) may be estimated by:

$$\mathrm{TDEV}(n\tau_0) \cong \cong \sqrt{\frac{\sum_{j=1}^{N-3n+1}\left[\sum_{i=j}^{n+j-1}\left(x_{i+2n}-2x_{i+n}+x_i\right)\right]^2}{6n^2\left(N-3n+1\right)}}, \quad (3)$$

where n = 1, 2, ..., integer part $E(N/3)$, τ_0 is the sample period; n is the number of samples in each observation interval; τ is the observation interval, equal to $n\tau_0$; N is the total number of samples; t is the measurement period; x_i is the i-th time error sample.

Noise performance

The TDEV(τ) converges for all the major noise types affecting actual timing signals. In Table 1, the characteristic slopes of TDEV(τ), for different noise types, are reported. The TDEV(τ) allows to discriminate between WPM and FPM noises.

Table 1

The characteristic slopes of TDEV(τ), for different noise types

Noise process	Slope of TDEV(τ)
WPM	$\tau^{-1/2}$
FPM	τ^{0}
WFM	$\tau^{1/2}$
FFM	τ
RWFM	$\tau^{3/2}$

Frequency offset and drift

Any constant frequency offset of a timing signal, relative to the reference clock, has no influence on TDEV (τ).

For observation intervals τ where a linear frequency drift dominates, the TDEV(τ) behaves as τ^2.

For observation intervals where the WPM noise dominates, the behaviour of TDEV(τ) significantly depends on sampling period τ_0.

TDEV gives more information on the clock noise than MTIE, but it is not suited for buffer characterization. TDEV is sensitive to systematic effects, which might mask noise components; Adequate filtering must be done on the measured signal before processing TDEV calculation. Diurnal wander is an example of systematic effect.

TDEV result coming out of network measurement could be heavily influenced by systematic effects.

In [5] Packet TIE(Packet Time Interval Error), Packet MTIE (Packet Maximum Time Interval Error), Packet TDEV (Packet Time Deviation), Packet FFO (Packet Fractional Frequency Offset) are considered.

Packet metrics are the application of conventional metrics such as TIE, MTIE, TDEV and FFO to time error sequences created by the measurement of the transit delays of timing packets.

Such time error sequences may be pre-processed by use of packet selection and/or packet filtering before computation of the relevant metrics (Fig. 3). Such metrics are denoted with the prefixes “pktselected” (if only packet selection is involved) and “pktfiltered” (if filtering is involved, e.g. the low-pass action of a PLL).

Hence, pktTIE is the raw TIE sequence created from the packet measurements, pktselectedTIE is the TIE sequence following packet selection, and pktfilteredTIE is the TIE sequence following packet filtering.

$$\text{pktfilteredTIE}(t,\tau) = x(t + \tau) - x(t); \quad (4)$$

$$\text{pktfilteredMTIE}(n\tau_0) \cong \max_{1\le k\le N-n}\left[\max_{k\le i\le k+n} x_i - \min_{k\le i\le k+n} x_i\right], n = \overline{1, N-1}; \quad (5)$$

$$\text{pktfilteredTDEV}(n\tau_0) = \sqrt{\frac{1}{6n^2}\left\langle\left[\sum_{i=1}^{n}\left(x_{i+2n} - 2x_{i+n} + x_i\right)\right]^2\right\rangle}; \quad (6)$$

$$\text{pktfilteredFFO}(N_0) \cong \frac{6x10^{-9}}{n\tau_0}\sum_{i=1}^{n} x_i\left(\frac{2i}{(n^2-1)} - \frac{1}{n-1}\right), \quad (7)$$

where τ_0 is the sample period; n is the number of samples in each observation interval; τ is the observation interval, equal to $n\tau_0$; N is the total number of samples; t is the measurement period; x_i is the i-th time error sample;

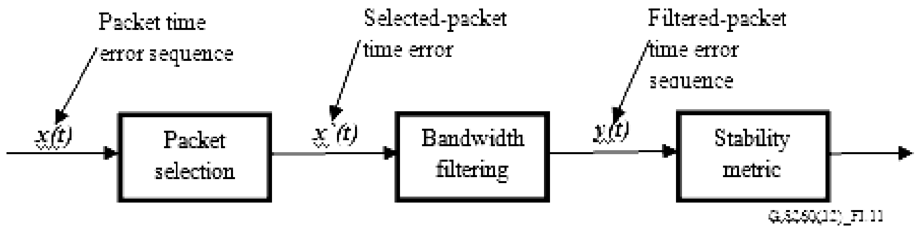


Fig. 3. Use of packet selection and/or packet filtering before computation of the relevant metrics

In [5] MATIE (Maximum Average Time Interval Error) metric, MAFE (Maximum Average Frequency Error) metricare considered.

MATIE($n\tau_0$) may be estimated by:

$$\text{MATIE}(n\tau_0) \cong \max_{1\le k\le N-2n+1}\frac{1}{n}\left|\sum_{i=k}^{n+k-1}(x_{i+n} - x_i)\right| \quad (8)$$

forn = 1, 2, ..., integer part $(N/2)$;

$$\text{MAFE}(n\tau_0) = \frac{\text{MATIE}(n\tau_0)}{n\tau_0}, \quad (9)$$

where τ_0 is the sample period; n is the number of samples in each observation interval; τ is the observation interval, equal to $n\tau_0$; n is the total number of samples; t is the measurement period; x_i is the i-th time error sample.

MATIE predicts the largest difference in averaged time interval error that occurs between adjacent averaging windows of width τ. MAFE predicts the maximum frequency error calculated from the largest difference in averaged time interval error observed between adjacent averaging windows of width τ.

MAFE is well-suited for the characterization of frequency error. MAFE is not suited for the study of noise processes, unlike the complementary TDEV metrics. MAFE with floor-based selection is sensitive to a small number of low-lying outlier

In [5] FPC (Floor Packet Count), FPR (Floor Packet Rate), FPP (Floor Packet Percentage)are considered.

Define the minimum observed delay (or the observed floor delay) as:

$$d_{min} = \min_{0\le i<N} x_i . \quad (10)$$

Then, define the indicator function which performs floor packet selection:

$$\varphi_F(i,\delta) = \begin{cases} 1; & \text{if } x_i \le d_{min} + \delta; \\ 0; & \text{otherwise,} \end{cases} \quad (11)$$

$$\text{for } 0 \le i < N.$$

Note that this equation assumes that packet delay is always greater than d_{min}.

Then:

$$FPC(n, W, \delta) = \sum_{j=n-(K-1)}^{n} \varphi_F(j,\delta) \quad (12)$$

$$\text{for } (K-1) \le n < N;$$

$$FPR(n, W, \delta) = \frac{FPC(n, W, \delta)}{W} \quad (13)$$

$$\text{for } (K-1) \le n < N;$$

$$FPP(n, W, \delta) = \left(\frac{\tau_P}{W}\right) \times FPC(n, W, \delta) \times 100\ \% \quad (14)$$

$$\text{for } (K-1) \le n < N,$$

where:

τ_P is the sample period;

δ is the cluster range

W is the window interval

K is the number of samples in each window interval

n is the last sample in the current window interval

N Is the total number of samples;

x_i is the i-th time error sample.

This category of metrics is suitable for use as a PDV network limit, and is used in [6, 7].

These metrics require a long enough measurement period such that the observed floor delay would give a good enough estimation of the absolute floor delay. The minimum measurement period depends on the type of network considered. Long measurement periods, for instance over one or several days, should be favoured in order to study diurnal PDV effects.

These metrics may be sensitive to a small number of low-lying outliers.

These metrics are sensitive to non-stationary network conditions, such as floor delay steps of significant amplitude. For example, these may occur during network re-routing events.

These metrics are mainly intended to be used as post-processing metrics. The use of these metrics for real-time processing subject to inaccuracy because the minimum observed delay may change during the measurement period.

These metrics can be used to study the PDV noise produced independently by the forward or the reverse direction of a packet timing flow. Consideration of the combined effect of both directions is for further study.

In [1, 5] TE (Time Error), cTE (Constant Time Error), dTE (Dynamic Time Error), Max|TE| (Maximum Absolute Time Error) are considered.

The time error of a clock with respect to a time standard, is the difference between the time of that clock and the time indicated by the time standard.

For a synchronized clock (i.e. one locked to the reference with no long-term time error drift), a model for expressing the time error of a clock as a function of time is given by the following equation from [1]:

$$x(t) = x_0 + \frac{\phi(t)}{2\pi\nu_{nom}}, \quad (15)$$

where:

$x(t)$ is the time error function;

x_0 is the mean value of the time error function;

$\phi(t)$ is the random phase deviation component;

ν_{nom} is the nominal frequency.

For measurement purposes, this may be split into three components (Fig. 4):

1. **cTE:** the mean value of the time error function. Limits are usually specified in fractions of a second For a clock measurement (e.g. BC or TC), the cTE may be estimated by averaging a period of over 1000s For network limits, the averaging period will be considerably longer

2. **dTE:** the change of time error of the clock. dTE may be represented using a TIE (Time Interval Error) sequence. Limits may then be specified using MTIE and TDEV masks. The data may be filtered before calculating - consult the relevant standard for the appropriate filtering recommendation.

3. **Max|TE|:** the maximum absolute value of the time error function. Limits are usually specified in fractions of a second. The data may be filtered before calculating - consult the relevant standard for the appropriate filtering recommendation.

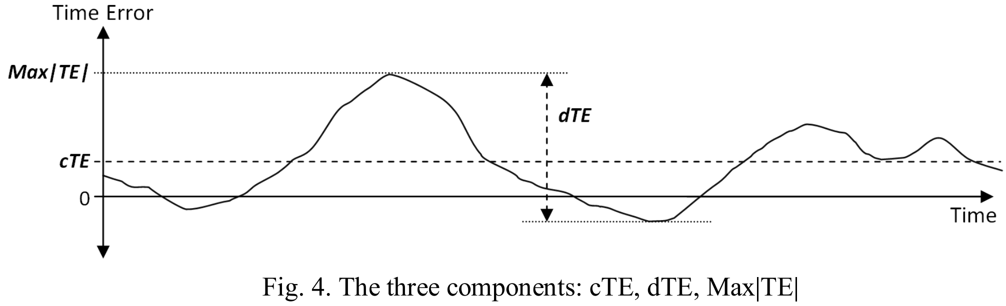


Fig. 4. The three components: cTE, dTE, Max|TE|

In [1, 8] FFO (Fractional Frequency Offset) is considered.

The FFO (Fractional Frequency Offset) or FFD (Fractional Frequency Deviation) is defined as the difference between the actual frequency of a signal and a specified nominal frequency, divided by the nominal frequency. Mathematically, the fractional frequency offset (or deviation) can be expressed as:

$$FFO = \frac{f - f_{nom}}{f_{nom}}, \quad (16)$$

where f is the actual frequency; f_{nom} is the nominal frequency.

Calculation from sampled time delay data (such as might be represented by packet time error sequences) can be obtained by using the following equation from GR-1244-CORE:

$$FFO(t) \cong \frac{6x10^{-9}}{n\tau_0}\sum_{i=1}^{n} x_i\left(\frac{2i}{(n^2-1)} - \frac{1}{n-1}\right), \quad (17)$$

where:

τ_0 is the sample period;

n is the number of samples in each observation interval;

τ is the observation interval, equal to $n\tau_0$;

x_i is the i-th time error sample.

This metric gives a good indication of the frequency error generated by a packet timing flow.

The packet time-error sequence may be filtered and/or a subset of packets selected prior to calculation.

Conclusions

In the present work, the following conclusions and results were obtained:

1) In «Definition and Terminology for Synchronization Networks» [1], TIE (Time Interval Error), MTIE (Maximum Time Interval Error) and TDEV (Time Deviation) are the three parameters used as basic criteria for evaluation of quality of synchronization signals, but only TIE function is directly measured.

2) In Recommendation G.8260 are considered: Packet TIE (Packet Time Interval Error), Packet MTIE (Packet Maximum Time Interval Error), Packet TDEV (Packet Time Deviation), Packet FFO (Packet Fractional Frequency Offset), MATIE (Maximum Average Time Interval Error) metric, MAFE (Maximum Average Frequency Error) metric, FPC (Floor Packet Count), FPR (Floor Packet Rate), FPP (Floor Packet Percentage)TE (Time Error), cTE (Constant Time Error), dTE (Dynamic Time Error), Max|TE| (Maximum Absolute Time Error).

3) The features connected with analogy and distinction of calculations of parameters stability of synchronization signals are shown TIE, MTIE and TDEV in the “classic” network and Packet TIE, Packet MTIE and Packet TDEV in IP/MPLS networks.

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ПАРАМЕТРЫ СИГНАЛОВ СИНХРОНИЗАЦИИ В IP/MPLS СЕТЯХ

Н.В. Федорова, Д.А. Демин

Приведены параметры стабильности сигналов синхронизации в “классической” сети синхронизации (СЦИ - синхронная цифровая иерархия) согласно Рекомендации G.810. Рассмотрены параметры стабильности сигналов синхронизации в пакетных сетях IP/MPLS согласно Рекомендации G.8260. Показаны особенности, связанные с аналогией и различием вычислений параметров стабильности сигналов синхронизации в “классической” сети и сетях IP/MPLS.

Ключевые слова: *“Классическая” сеть (СЦИ), IP/MPLS сеть, сигнал синхронизации, параметры сигналов синхронизации, параметры стабильности сигналов синхронизации, измерения параметров синхронизации.*

ПАРАМЕТРИ СИГНАЛІВ СИНХРОНІЗАЦІЇ У IP/MPLS МЕРЕЖАХ

Н.В. Федорова, Д.О. Дьомін

Наведено параметри стабільності сигналів синхронізації у “класичній” мережі синхронізації (СЦІ - синхронна цифрова ієрархія) згідно Рекомендації G.810. Розглянуто параметри стабільності сигналів синхронізації у пакетних мережах IP/MPLS згідно Рекомендації G.8260. Показано особливості, що пов’язані з аналогією та відмінністю розрахунків параметрів стабільності сигналів синхронізації у “класичній” мережі та мережах IP/MPLS.

Ключові слова: *“Класична” мережа (СЦІ), IP/MPLS мережа, сигнал синхронізації, параметри сигналів синхронізації, параметри стабільності сигналів синхронізації, вимірювання параметрів синхронізації.*