XVII IMEKO World Congress
Metrology in the 3rd Millennium
June 22–27, 2003, Dubrovnik, Croatia

THE RELATION BETWEEN THE AUTOCORRELATION OF TIME ERROR SERIES AND THE MTIE COMPUTING TIME

Andrzej Dobrogowski, Michal Kasznia

Institute of Electronics and Telecommunications, Poznan University of Technology, Poznan, Poland

Abstract – In the paper the relation between the autocorrelation function of time error series and the time of data-dependent computing of the Maximum Time Interval Error (MTIE) is studied. The first section introduces the problem of time effective MTIE assessment. Then the time effective data-dependent method of MTIE assessment is described. In the next section the influence of the shape of time error series autocorrelation function on the efficiency of the data-dependent MTIE search is described. The results of the calculation experiment performed for several time error series are presented.

Keywords: time error, maximum time interval error, autocorrelation function.

1. INTRODUCTION

The quality of timing signals is essential for information transmission throughout telecommunication networks. Maximum Time Interval Error (MTIE), Allan deviation (ADEV), and time deviation (TDEV) are the parameters which give the information about the timing signal quality. Maximum Time Interval Error can be used for dimensioning the elastic buffers of the network circuitry located at the boundaries of areas timed by different time scales. ADEV and TDEV give the information about instability affecting the timing signal. The limit values of MTIE and TDEV for the particular types of clocks are defined and recommended in the telecommunication standards and requirements [1, 2, 3]. Computation of the parameter's estimates and comparing them with the limits is an essential activity in the service and maintenance of telecommunications networks, so the obvious goal is to make the computation short in time.

Some time effective methods of MTIE assessment [4, 5, 6] were proposed by the authors of the paper. The efficiency of the data-dependent methods depends on the time error data behavior. Unfortunately, for some specific data types the time of the MTIE assessment using the methods proposed is longer than using time-consuming method based directly on the parameter's estimator. One of the measures describing the data behavior is autocorrelation function. The knowledge of the autocorrelation function of data series can simplify the decision on the method used for MTIE computation. In the paper the relation between the autocorrelation function of the time error series and the time of MTIE computing is analyzed. The results of calculation of MTIE and autocorrelation function for several time error series are presented and discussed.

2. MAXIMUM TIME INTERVAL ERROR

The basic characteristic of timing (synchronization) signal, gained directly from measurement, is time error (TE). Time error is a difference between the time function of a clock (evaluated timing signal) and the time function of a reference clock (measurement reference timing signal). The value of time error measured at some network interface depends on the systematic effects (frequency offset and drift) as well as random components. MTIE estimate is calculated using a series of equally spaced time error samples (TE time series).

The maximum time interval error is defined in international standards as the maximum peak-to-peak time error variation of a given timing signal, with respect to an ideal timing signal within a particular time period [1, 2, 3]. If the results of time error function measurements $x(t)$ take the form of N equally spaced samples $\{x_i\}$, MTIE can be estimated from the formula

$$M\hat{T}IE(n\tau_0) = \max_{1\le k\le N-n}\left(\max_{k\le i\le k+n} x_i - \min_{k\le i\le k+n} x_i\right) \quad (1)$$

where $\{x_i\}$ is a sequence of N samples of time error function $x(t)$ taken with sampling interval τ_0, $\tau=n\tau_0$ is an observation interval, and n=1, 2, ..., N–1.

There are two approaches to the computation of MTIE for a given TE series: data-independent and data-dependent. Plain computation directly following the estimator formula belongs to the first category. The authors of this paper have proposed some method of MTIE computation, being an implementation of the data-dependent approach, called extreme fix method (EF) [4, 5, 6].

The data-dependent EF method is based on fixing the positions of minimum and maximum samples for a given window's location (Fig. 1). After finding the positions of the extremes, the window's shift to the position of the first extreme (denoted as p_1) is performed (Fig. 1). There are no extreme values in the distance between the starting position of the previous window's location and the p_1 position. After the shift, the peak-to-peak value for the window's location p_1 should be found. Because the samples between the position p_1 and the last sample in the previous window's location ($k+n$) were reviewed and the extreme values are known, they are excluded from inspection. The one-sample window's shift is performed when the first sample in the window is the extreme sample. What will be done next depends on the values at the boundaries of the window: the sample p_1, which has just left the window, and the new sample p_1+n+1, which has just came into the window. The comparison of these values may result or not in the review process of the window's location p_1+1.

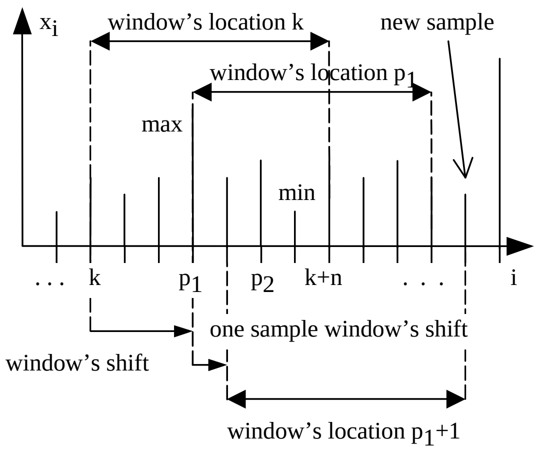

Fig. 1. The window's shift in the extreme fix method

3. DATA DEPENDANCE OF MTIE COMPUTING TIME

The MTIE computing time using the EF method strictly depends on the data behavior. The method is very effective for the data arrangement enabling considerable window's shifts over the data sequence, i.e. the extreme samples (minimum and maximum) should be located close to the end of the window's location. This arrangement occurs in the case of data showing short-term variations (e.g. periodic changes or random behavior). If the long-term behavior or monotonic change dominates the short-term behavior, this method loses its efficiency [4]. In this case one of the extreme samples is positioned as the first sample in window's location (for majority of window's locations) and the one-sample window's shift must be done. As result, the extreme samples must be searched for majority of window's locations and the speeding mechanism of the EF method does not operate.

Several data sequences, representing a different type of time error behavior, were used in the experiment. Five sequences represent typical phase noises: white phase modulation (WPM), flicker phase modulation (FPM), white frequency modulation (WFM), flicker frequency modulation (FFM), and random walk frequency modulation (RWFM). The power spectral density of these noises is described by the power law model [1, 2, 3]. Other sequences were obtained from the real world measurement of timing signals. The first sequence (MSG, Fig. 2) was obtained from the comparison of two independent internal oscillators of measurement systems, the second one (GPS, Fig. 3) was obtained from the comparison of two oscillators disciplined by the GPS signals, and the third one was obtained from the measurement of the oscillator disciplined by the DCF-77 signal with GPS signal as a reference (DCF, Fig. 4). Each sequence contains 120001 samples which correspond to the measurement time of 4000 s with sampling interval of 1/30 s. For comparison purposes, we created also artificially a sequence which data arrangement forces the calculation algorithm to make considerable window's shifts: the values of even samples (positive) increase, and the values of odd samples (negative) decrease. As result, the extreme samples are located at the end of the window's location. First samples of this sequence (denoted as ART) are presented in Fig. 5.

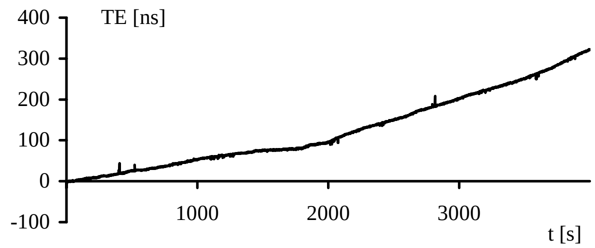

Fig. 2. MSG time error sequence

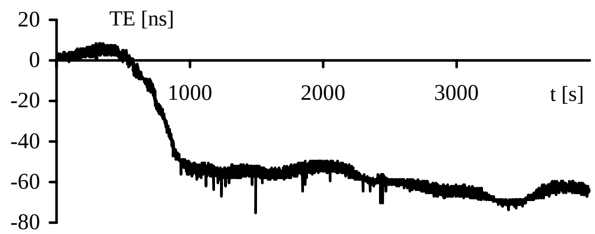

Fig. 3. GPS time error sequence

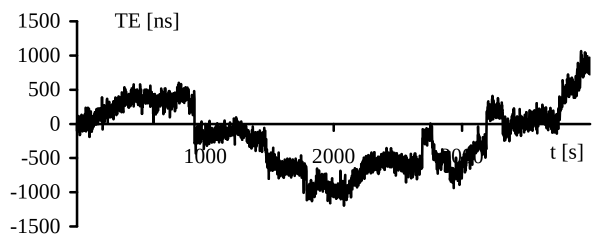

Fig. 4. DCF time error sequence

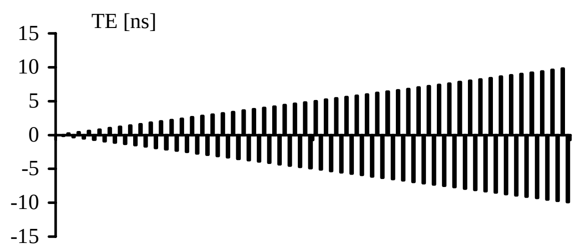

Fig. 5. ART time error sequence

In Table I the time of MTIE calculation for some selected observation intervals (window's length) for the time error sequences is presented [7]. The calculations were performed using personal computer with Pentium II 450 MHz microprocessor.

TABLE I. Time of MTIE calculation for some chosen observation intervals (in seconds)

TE series	observation intervals [s]				
	0.1	1	10	100	1000
WPM	7.64	4.15	3.19	2.85	1.88
FPM	8.07	5.03	4.62	4.64	2.55
WFM	9.30	10.30	18.86	67.30	191.88
FFM	12.37	29.60	196.46	1420.84	4689.74
RWFM	16.21	53.11	415.46	3860.53	24699.14
MSG	6.80	6.36	2.66	5.03	8.40
GPS	6.45	4.60	2.65	4.42	10.41
DCF	9.32	6.47	5.08	8.28	15.14
ART	5.44	3.73	3.63	3.68	3.68

The data-dependent EF method of MTIE assessment is very effective for the time error series showing short-term random behavior like white phase modulation (which is present in the WPM, FPM, MSG, GPS and DCF sequences) or for the time error series showing very specific short-term behavior (sequence ART). For the sequences showing long-term or monotonic behavior (especially for the RWFM sequence) the EF method is not time effective.

3. RELATION BETWEEN THE AUTOCORRELATION AND MTIE COMPUTING TIME

The efficiency of the EF method depends on the dynamics of time error variations. Therefore, we can expect that there is a relation between a measure of the dynamics and the MTIE computing time. The autocorrelation function of the time error series can serve as some measure of the dynamics of time error variation and therefore it seems to be helpful for evaluating the time efficiency of the data-dependent MTIE assessment. The dominating value of autocorrelation function for zero shift indicates the presence of white noise, which makes the EF computation fast. The large value of autocorrelation function for non-zero shifts indicates the long–term behavior, which makes the data-dependent MTIE search slower.

The autocorrelation function computed for the time error series considered in the previous section is presented in Fig. 6-14.

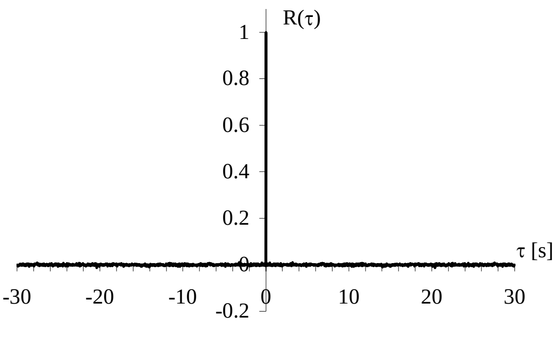

Fig. 6. Autocorrelation for the WPM sequence

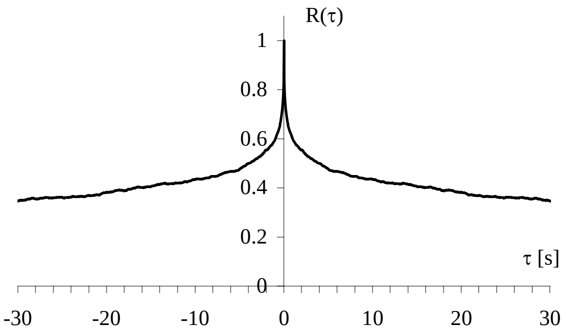

Fig. 7. Autocorrelation for the FPM sequence

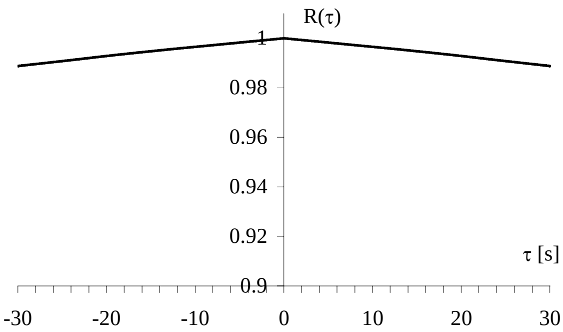

Fig. 8. Autocorrelation for the WFM sequence

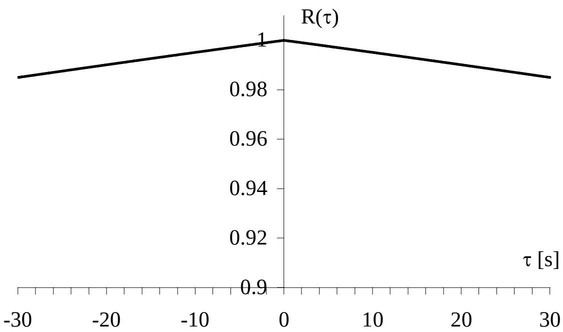

Fig. 9. Autocorrelation for the FFM sequence

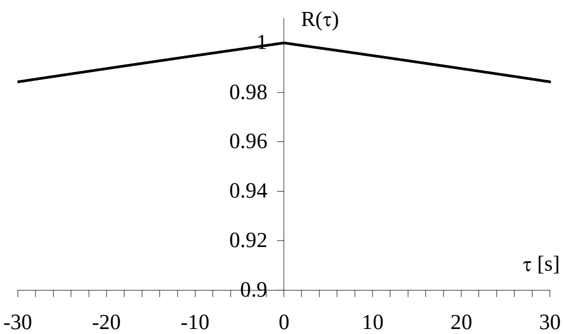

Fig. 10. Autocorrelation for the RWFM sequence

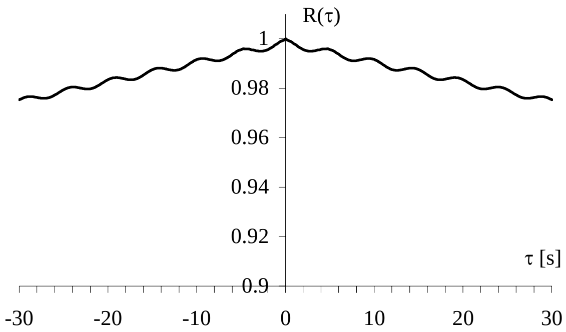

Fig. 11. Autocorrelation for the MSG sequence

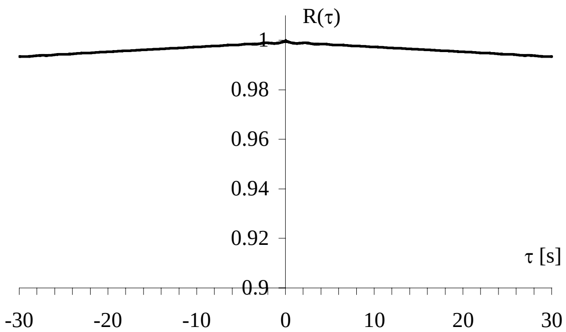

Fig. 12. Autocorrelation for the GPS sequence

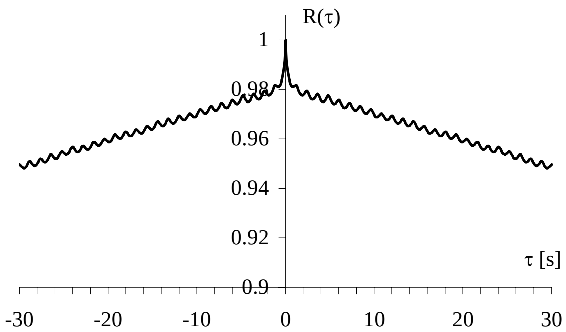

Fig. 13. Autocorrelation for the DCF sequence

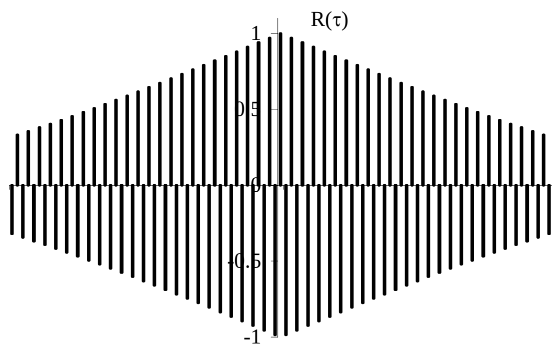

Fig. 14. Autocorrelation for the ART sequence

The results of the autocorrelation calculation do not confirm the presumption that the autocorrelation function may be a universal indicator of data-dependent MTIE computing time. The autocorrelation function can play the indicator's role only for the sequences showing pure power law noise behavior, like WPM, FPM, WFM, FFM or RWFM sequences. The peak for zero shift in the autocorrelation function for the WPM and FPM sequences results in short MTIE computing time. The wide autocorrelation function for the WFM sequences indicates longer calculation time. It is difficult to deduce the difference in the MTIE computing time for the WFM, FFM, and RWFM sequences based on the differences in the shape of the autocorrelation function (the shape is almost the same – Fig. 8-10), although we obtained considerably different MTIE computing time. For the DCF sequence the peak for zero shift exists in the autocorrelation function, and the MTIE computing time is rather short. In opposite, the peak does not exist in the autocorrelation for the GPS and MSG sequences, for which the computing time is comparable with computing time for DCF or WPM series. The presence of systematic components in the GPS and MSG sequences does not affect the MTIE computing time, but influences on the autocorrelation function: the shape of the autocorrelation function is falling down slowly. Despite that, the presence of short-term components in both sequences results in the computing time comparable with computing time for the WPM sequence.

The autocorrelation function for the ART sequence is wide, but it has the peak for zero shift and changes the sign. The MTIE computing time is very short. Unfortunately, if we change the direction of MTIE search and start the procedure from the end of the sequence, the calculation time is very long, although the autocorrelation does not change.

Because the time of the autocorrelation function computing for the whole time error series is very long, only short segments of the MSG and GPS series were used. The autocorrelation function for the segments of 900 samples is presented in Fig. 15 and 16. The systematic effects existing in the MSG and GPS sequences do not affect the autocorrelation function computed for the short observation time, and the peak for zero shift exists for both sequences. The variations of both autocorrelation functions indicate the periodic changes of the TE sequences, which can speed up the MTIE computation.

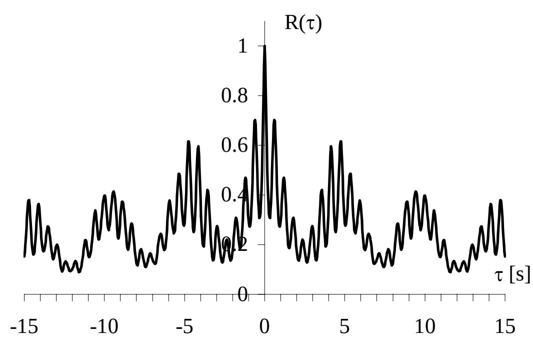

Fig. 15. Autocorrelation for the short segment of the MSG sequence

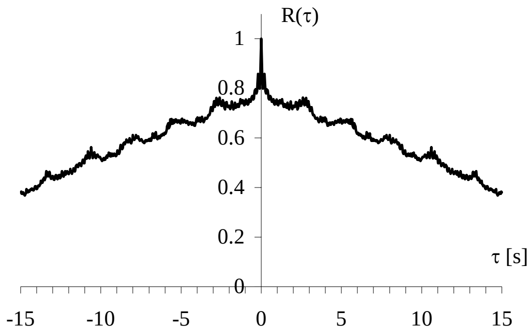

Fig. 16. Autocorrelation for the short segment of the GPS sequence

4. CONCLUSIONS

In the paper we investigate the relation between the autocorrelation function of the time error series and the MTIE computing time of the EF method. The obvious relation exists only for the time error sequences showing pure power law noise behavior. We can differentiate the MTIE computing time using the autocorrelation function for the WPM, FPM and WFM series. For the time error sequences, obtained from the real world measurement and containing systematic effects, the relation is rather obscure. The presence of the systematic effects may strongly influence on the autocorrelation (like for MSG and GPS series), but it does not affect the MTIE computing time considerably. On the other hand, we find the dependance between the shape of the autocorrelation function and the MTIE computing time in the case of the DCF time error sequences presented in the paper. Unfortunately, the time of the assessment of the autocorrelation function for the whole time error series may unacceptably long. Therefore some rule of thumb is suggested. We estimate the value of the autocorrelation function for a randomly choosed rather short segment of data (about 1000 samples). If the shape of the autocorrelation function reveals the peak centered at zero shift or changes of the function sign or the periodic variations, we may conclude, that the data-dependent MTIE calculation using EF method will be time effective.

REFERENCES

[1] ETSI EN 300 462, "Generic requirements for synchronization networks" (1998).
[2] ITU-T Rec. G.810 Considerations on Timing and Synchronization Issues (08/96).
[3] ANSI T1.101-1999, Synchronization Interface Standard.
[4] A. Dobrogowski, M. Kasznia, "Time effective methods of calculation of Maximum Time Interval Error", *IEEE Trans. Instrum. Meas.*, vol. 50, no. 3, pp. 732-741, June 2001.
[5] A. Dobrogowski, M. Kasznia, "Maximum Time Interval Error Assessment Based on the Sequential Reducing Data Volume", *IEEE Trans. Ultrason., Ferroelect., Freq. Contr.*, vol.49, no. 7, pp. 987-994, July 2002.
[6] A. Dobrogowski, M. Kasznia, "Data-dependent search for Maximum Time Interval Error", *Proc. of the 12th IMEKO TC4 Int. Symp.*, vol. 2, pp. 322-326, Zagreb, 25-27, September 2002.
[7] A. Dobrogowski, M. Kasznia, „Impact of time error data type on the efficiency of Maximum Time Interval Error assessment", unpublished.

Authors: Andrzej Dobrogowski, Michal Kasznia, Institute of Electronics and Telecommunications, Poznan University of Technology, ul. Piotrowo 3A, 60-965 Poznan, Poland, phone: +48 61 6652 293, fax: +48 61 6652 572, e-mail: dobrog@et.put.poznan.pl, mkasznia@et.put.poznan.pl