Testing of the Methods of Real-Time MTIE Calculation

Andrzej Dobrogowski, Michal Kasznia
Institute of Electronics and Telecommunications
Poznan University of Technology
Poznan, Poland
dobrog@et.put.poznan.pl, mkasznia@et.put.poznan.pl

Abstract-**In this paper the experimental tests of the methods enabling real-time quasi-parallel assessment of Maximum Time Interval Error (MTIE) are presented. The idea of real-time quasi-parallel computation of MTIE is introduced first. Then two methods enabling real-time MTIE calculation are described. The results of computation experiments performed using several different data sequences and different computers are included.**

I. Introduction

Maximum Time Interval Error (MTIE) describes some aspects of the quality of telecommunication network timing signal [1, 2, 3]. The MTIE is usually computed for a series of observation intervals, starting from some τ_{min} until some τ_{max}. The computation usually follows the measurement of a sequence of time error samples, which are used for the parameter's assessment. Because of rather long time of the plain computation of the parameter, several time effective methods, enabling rather fast MTIE calculation, were proposed and described in the literature [4, 5, 6]. Some methods were proposed by the authors of this paper [7, 8, 9].

Some features of one method (sequential data reduction) enabled to formulate of the idea of on-line MTIE computation, which is performed in the real time, during the measurement of time error samples, and parallel for several observation intervals [10]. Unfortunately, the application of this method may result in incorrect MTIE estimates. Because of data reduction some sample values, which affect the MTIE value, may be omitted for specific arrangement of samples and windows' (observation intervals) lengths [11]. As result, the MTIE value is underestimated. Therefore, two new methods especially oriented at the real-time quasi-parallel MTIE assessment were proposed [11]. The first solution consists in the data reduction for quasi-parallel calculation. However, this method of data reduction enables to avoid the omitting of important data. The second solution consists in the quasi-parallel calculations, performed for each observation interval independently using time effective extreme fix method [7] without the data reduction process.

In order to calculate the MTIE estimate simultaneously for several observation intervals in the real time, all necessary operations should be performed in the time period between two sampling instants, i.e. during the sampling interval τ_0. The ability of real time assessment depends on the following conditions: number and length of the observation intervals considered, computational power of the measurement equipment, and time error data behavior. In the paper the results of experimental tests of the methods proposed are presented. The calculations were performed for several different data sequences taken with sampling interval τ_0=1/30 s, which is often used in the telecommunication applications. The results of calculation using several personal computers with different processors and clock's frequency are presented and compared.

II. Methods of MTIE Assessment

A. Direct method

In international standards the maximum time interval error is defined 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

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

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.

Following directly the formula (1) in order to find the estimate of MTIE for the observation interval τ, all intervals having the width of τ, existing in the sequence of N time error samples, must be reviewed. The window having the width of $\tau=n\tau_0$ and including n+1 samples is set at the beginning of the data sequence $\{x_i\}$ and then it is shifted with the step of τ_0 to the end of the sequence. For each window's location the peak-to-peak value of time error in the window is found. The maximum peak-to-peak value found for all existing locations of the window is the value of MTIE(τ) estimate. The process of window reviewing does not depend on the data value. The complexity of calculation grows with n and therefore the direct method is really time-consuming. The idea of direct search (plain computation) of MTIE is presented in Fig. 1.

B. Boundaries decision method

In the process of the MTIE search using the boundaries decision (BD) method the window is shifted with the step of τ_0, but the decision on whole window's review depends on the values of samples at the window's boundaries [7]. Two

0-7803-9052-0/05/$20.00 © 2005 IEEE.

samples: the earliest value, which leaves the window (sample at the position k – see Fig. 1) and the new sample, which appears at the window end (sample at the position $k+n+1$) are compared with current maximum and minimum samples. The result of the comparison determines the next operation. The new extreme value must be searched when the current extreme sample leaves the window and simultaneously the new value is not the new extreme.

C. Extreme fix method

In the process of the MTIE search using the extreme fix (EF) method some window's locations are excluded from inspection if the peak-to-peak value for each of these locations is not greater than the value found until now, or if a greater peak-to-peak value may be found for the successive window's locations. The EF method is based on fixing the positions of minimum and maximum samples for a given window's location. 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. 2). Within the interval between the starting position of the previous window's location and the p_1 position there are no "more extreme" values than the ones which have already been found. 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. Two samples: the earliest value, which leaves the window and the new sample, which appears at the window's right end are compared with current maximum and minimum samples. The result of the comparison determines the next operation. The new extreme value should be searched when the current extreme sample leaves out the window and, simultaneously, a sample entering the window is not the new extreme.

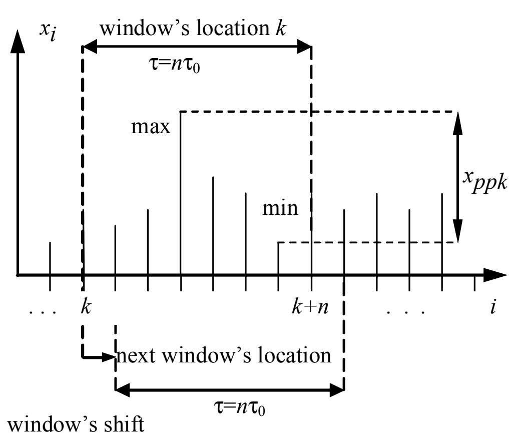

Fig. 1. The idea of direct search for MTIE

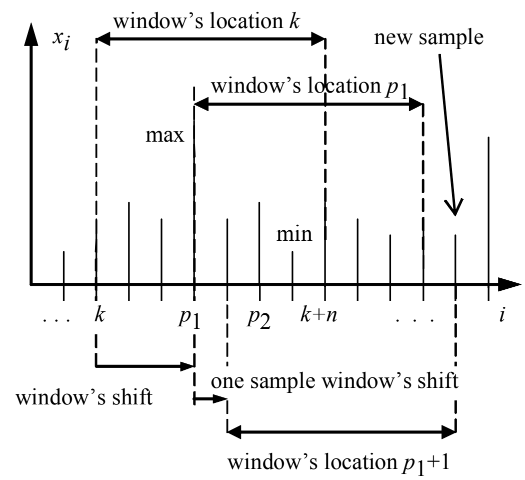

Fig. 2. The window's shift in the extreme fix method

D. Methods with sequential data reduction

The methods with sequential data reduction were dedicated especially for the MTIE assessment for a series of observation intervals, starting from some τ_{min} until some τ_{max}. The methods follow the suggestion according to which during the MTIE search process for some observation interval τ_i ($\tau_i>\tau_{min}$) we find the extreme samples for some window's location from the set of extreme samples found previously during the MTIE search for the smaller observation interval τ_{i-1} ($\tau_i>\tau_{i-1}$). Only these samples may influence the MTIE value for the observation interval τ_i. Other time error samples in the data sequence do not matter in the MTIE search process. Therefore, we can reduce the number of time error samples used for the MTIE calculation.

Two methods with sequential data reduction were proposed by the authors of this paper. The first method, called EFSDR, uses extreme fix search for the raw data sequence as well as for the reduced data [8]. Unfortunately, it may produce errors and the final MTIE value may be underestimated. In order to avoid the errors, the rules of the extreme searching were changed. The second method – direct search with sequential data reduction (DSDR) – uses plain computation at each level of the procedure (for raw and reduced data) [11]. Another method was proposed by Bregni and Maccabruni in [6]. This method uses binary decomposition of the data sequence. It is characterized by some limitations: the number of data in the time error sequence and the lengths of observation intervals considered should be a power of 2.

III. Real-time MTIE calculation

The formula of the MTIE estimator allows to perform the calculation of the parameter in the real-time, during the time error measurement. In this way we can observe the value of the parameter during the long lasting measurement process. Any possible wrong behavior of the analyzed signal (recognized, if MTIE exceeds the limit) enables applying proper activity of a maintenance team. Therefore, there is no necessity to wait until the two processes – the measurement followed by the parameter's computation – are completed.

A general procedure of the real-time quasi-parallel MTIE calculation for a series of observation intervals is as follows:

1. Measure a new time error sample.
2. Compare the new sample with current maximum and minimum.
3. If current window's location is filled out with samples, fix the extremes for this location.
4. Check if the current window's location is filled out with samples for the next longer observation interval.
5. If so, find the extremes for this location and check the conditions for the next longer observation interval.
   If no, measure a new sample.
6. When the measurement is finished, continue the computation for the remaining locations of each longer observation interval.

The choice of the algorithm suited for the real-time parallel calculations is very important. If we want to calculate the MTIE estimate simultaneously for several observation intervals, all necessary operations should be performed in the time period between two successive sampling instants, i.e. during the sampling interval τ_0. Therefore, the calculation algorithm should be time effective in order not to exceed the sampling interval. Two methods of the real-time MTIE calculation were proposed by the authors of this paper [11]: direct search with sequential data reduction and extreme fix search independent for each observation interval. The principles of both methods will be presented below

A. Real-time direct search with sequential data reduction

In the case of real-time calculation using DSDR method, the computation for the first (shortest) observation interval begins with the first measured time error sample. Each new sample measured is compared with current maximum and minimum values, until the first window's location is filled out by the samples. Then the extreme values for this location are fixed. Each successive measured sample creates a new window's location (one-sample window's shift), which must be analyzed. In order to avoid the reviewing process of each window's location representing the first observation interval, some features of boundaries decision method are applied for the DSDR procedure. The decision on window's review at its next location depends on what has happened at the window's boundaries. The extreme samples found during such BD search create new sequences, having usually a reduced total number of items, as compared with the raw data sequence. The reduced data sequences are used for the MTIE estimate calculation for the observation intervals longer than τ_{min}. The first location of the next longer window is not analyzed until all samples situated in this location are reviewed by the preceding window.

The example of real-time MTIE calculation using DSDR method for the observation intervals having 6, 8, and 10 samples is presented in Fig. 3-5. The early stage of the process is presented in Fig. 3. Fourteen samples were measured and the first location of the 8-sample window can be analyzed, because all samples situated in this location were analyzed by the preceding 6-sample window. The 10-sample window has not been activated yet. The middle stage of the process is presented in Fig. 4. All windows are activated. The end of the time error measurement is presented in Fig. 5. The parameter's value for the 6-sample observation interval is known immediately, but the computation for both of the longer observation intervals must be completed off-line.

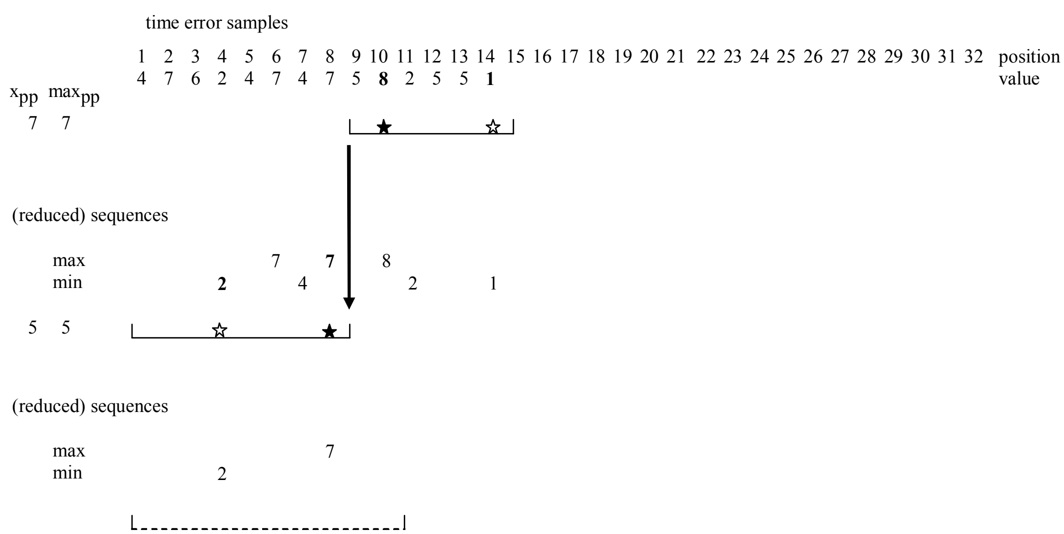

Fig 3. Real-time MTIE computation using direct search with sequential data reduction for observation intervals having 6, 8 and 10 samples – early stage of the measurement process, 14 samples are measured, first location of 8-sample window is considered

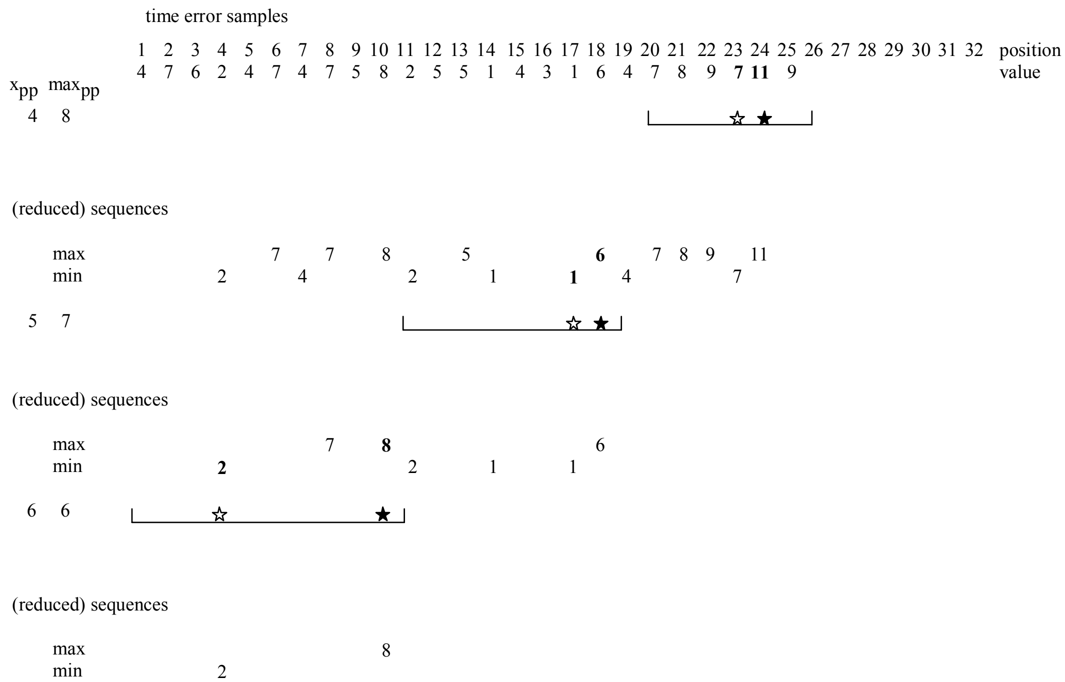

Fig 4. Real-time MTIE computation using direct search with sequential data reduction for observation intervals having 6, 8 and 10 samples – middle stage of the measurement process

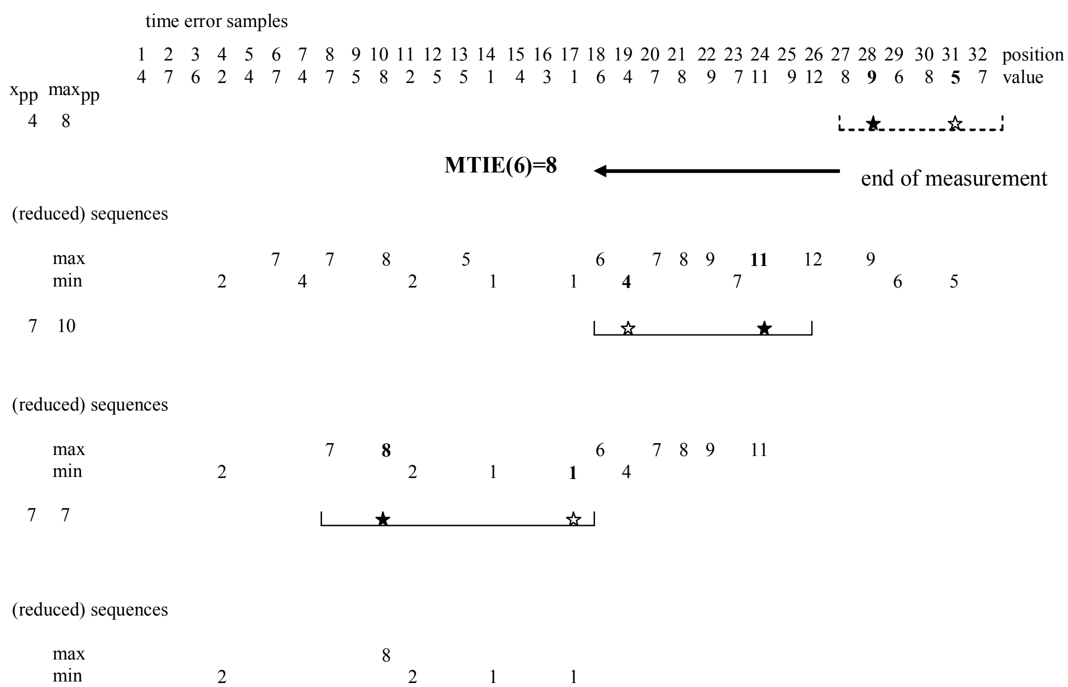

Fig 5. Real-time MTIE computation using direct search with sequential data reduction for observation intervals having 6, 8 and 10 samples – end of measurement, 6-sample window just arrives at the end of the sequence, other windows should be shifted off-line

B. Real-time extreme fix method

In the case of real-time calculation using EF method, the computation procedures for each observation interval run independently. Window's locations of longer observations intervals are analyzed after filling out by the samples without waiting for the analysis by the preceding shorter windows. All windows are activated after filling out their first locations by the samples. The extremes found for some observation interval do not affect the calculation process for other observation intervals.

The example of real-time MTIE calculation for observation intervals having 6, 8, and 10 samples using EF method is presented in Fig. 6-8. The early stage of the process is presented in Fig. 6. Ten samples were measured and all windows are activated. The extreme samples (black and white stars) in the relevant window's locations are found and the next window's locations are set (dashed line). The middle stage of the process is presented in Fig. 7. The end of the time error measurement is presented in Fig. 8. After analysis of the last window's locations, the parameter's value for each observation interval is known without any delay.

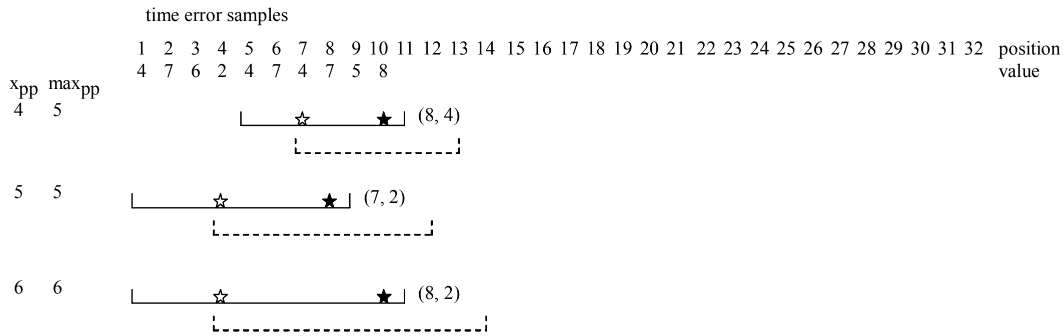

Fig. 6. Real-time MTIE computation using independent EF search for observation intervals having 6, 8 and 10 samples – early stage of the measurement process, 10 samples are measured, all window's locations are considered

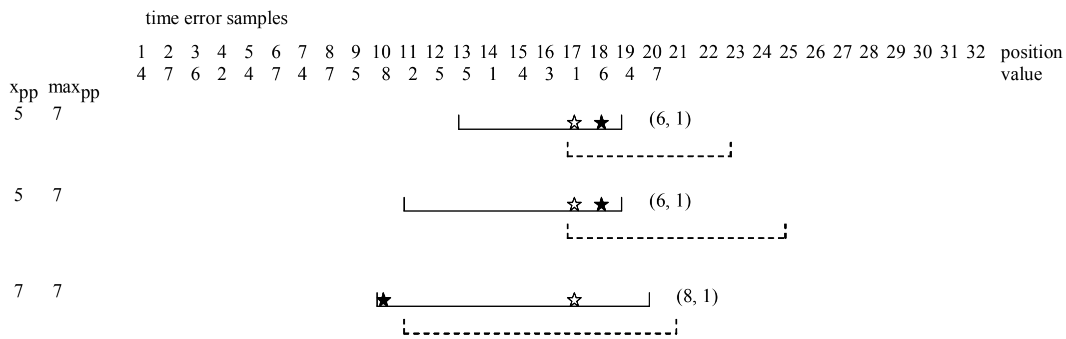

Fig. 7. Real-time MTIE computation using independent EF search for observation intervals having 6, 8 and 10 samples – middle stage of the measurement process

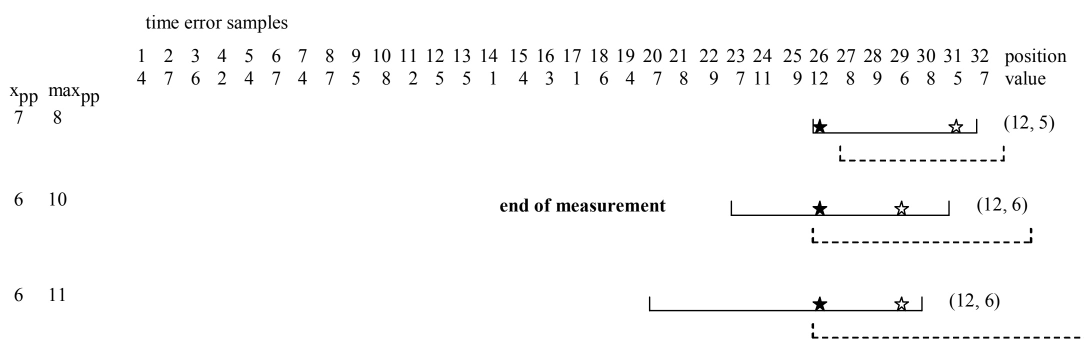

Fig. 8. Real-time MTIE computation using independent EF search for observation intervals having 6, 8 and 10 samples – end of the measurement, windows will be shifted to the end of the sequence and the final MTIE values will be known

IV. CALCULATION EXPERIMENT

Both methods of real-time MTIE calculation described above were tested in the calculation experiment. The calculations were performed off-line but the on-line work was imitated. Three different time error sequences were used. The first time error sequence represents one of typical noises of the timing signals – white phase modulation (WPM, Fig. 9). The second sequence was obtained from the comparison of two different GPS disciplined oscillators (Fig. 10). The third sequence (denoted as MSG, Fig. 11) was obtained from the measurement of the signal generated by the internal oscillator of some measurement system. The time error samples were taken with the sampling interval τ_0=1/30 s during the period of 4 000 s. The length of the time error sequences is 120 001 samples.

The calculations were performed for changing numbers of observation intervals arranged in the logarithmic scale in a range between 0.1 s and 1000 s. The starting (smallest) observation interval was τ_{min}=0.1 s (4 samples). The longest observation interval was changed from 1 s till 1000 s. The calculations were performed for 5 observation intervals per decade (21 intervals for the whole range) and for 2 observation intervals per decade (9 intervals for the whole range).

Three computers were used in the experimental tests: two personal computers with Pentium IV 1.4 GHz and Pentium IV 3.0 GHz, and one laptop PC with Pentium III 1.0 GHz. The observed quantity was the maximum time of calculation for sampling interval. We have assumed that this time cannot exceed the length of sampling interval τ_0=1/30 s = 0.0333… s.

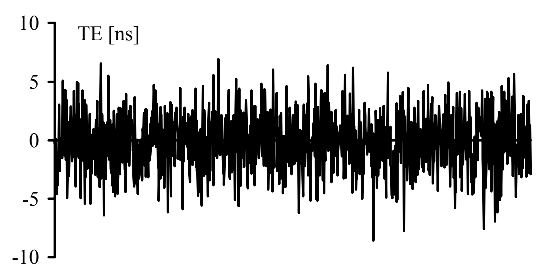

Fig. 9. WPM time error sequence

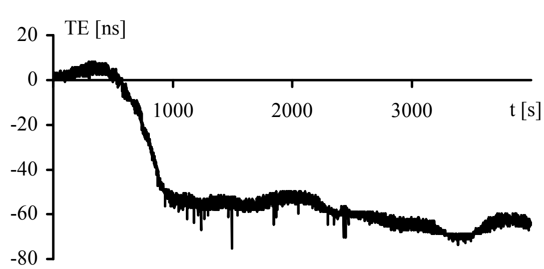

Fig. 10. GPS time error sequence

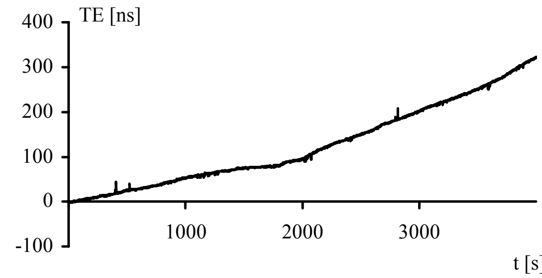

Fig. 11. MSG time error sequence

The time of calculation using DSDR method for the computer with Pentium IV 1.4 GHz microprocessor is presented in Table I (5 intervals per decade) and Table II (2 intervals per decade). The maximum calculation time per sampling interval does not exceed the sampling interval in the case of WPM and GPS time error sequences for all ranges of observation interval. In the case of MSG sequence (showing monotonic change of time error process, caused by the difference between frequencies of the compared oscillators) the maximum time exceeds the limit for the whole range of observation intervals (21 intervals from 0.1 s till 1000 s). Surprisingly enough the reduction of the intervals' number within the same range does not improve the results – the observed time is longer than for greater number of intervals. In such a case, the data reduction process is not as effective as in the case of greater number of intervals. As result, the longest observation intervals work on more numerous sequences.

Similar results were obtained using the computer with Pentium IV 3.0 GHz microprocessor (see Table III and Table IV). Application of the laptop PC with Pentium III 1.0 GHz microprocessor brings satisfactory results for the WPM and GPS sequences for the whole range of observation intervals (see Table V and Table VI). The limits were exceeded for the MSG sequence for the intervals' ranges 0.1 s – 1000 s and 0.1 s – 100 s.

TABLE I. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM IV 1.4 GHZ

Number of intervals	**Range of intervals [s]**	**WPM**	**GPS**	**MSG**
		t-max [s]	t-max [s]	t-max [s]
6	0.1-1	0.0034	0.0034	0.0034
11	0.1-10	0.0044	0.0056	0.0078
16	0.1-100	0.0066	0.0100	0.0296
21	0.1-1000	0.0078	0.0142	0.0614

TABLE II. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM IV 1.4 GHZ

Number of intervals	**Range of intervals [s]**	**WPM**	**GPS**	**MSG**
		t-max [s]	t-max [s]	t-max [s]
3	0.1-1	0.0012	0.0017	0.0017
5	0.1-10	0.0022	0.0033	0.0060
7	0.1-100	0.0044	0.0076	0.0352
9	0.1-1000	0.0056	0.0236	0.0934

TABLE III. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM IV 3.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
6	0.1-1	0.0028	0.0022	0.0027
11	0.1-10	0.0044	0.0044	0.0071
16	0.1-100	0.0055	0.0077	0.0247
21	0.1-1000	0.0071	0.0110	0.0549

TABLE IV. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM IV 3.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
3	0.1-1	0.0017	0.0017	0.0017
5	0.1-10	0.0022	0.0033	0.0055
7	0.1-100	0.0028	0.0055	0.0330
9	0.1-1000	0.0033	0.0220	0.0934

TABLE V. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM III 1.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
6	0.1-1	0.0056	0.0044	0.0044
11	0.1-10	0.0078	0.0078	0.0100
16	0.1-100	0.0110	0.0132	0.0340
21	0.1-1000	0.0132	0.0176	0.0758

TABLE VI. TIME OF CALCULATION USING DSDR METHOD FOR COMPUTER WITH PENTIUM III 1.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
3	0.1-1	0.0022	0.0022	0.0022
5	0.1-10	0.0044	0.0044	0.0078
7	0.1-100	0.0056	0.0088	0.0362
9	0.1-1000	0.0066	0.0264	0.1154

The time of calculation using the EF method is presented in the Tables VII, VIII, and IX. Satisfactory results were obtained for WPM and GPS sequence for the ranges of observation intervals from 0.1 s up to 100 s and for MSG sequence for the range of 0.1 s – 10 s. The reduction of number of intervals (Table IX) does not improve the results in the case of WPM and GPS sequences, but it helps in the case of MSG sequence. Because of rather poor results obtained with the use of EF method, this method was not tested using laptop PC with Pentium III 1.0 GHz microprocessor.

TABLE VII. TIME OF CALCULATION USING EF METHOD FOR COMPUTER WITH PENTIUM IV 1.4 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
6	0.1-1	0.0009	0.0010	0.0009
11	0.1-10	0.0038	0.0045	0.0051
16	0.1-100	0.0230	0.0286	0.0460
21	0.1-1000	0.2054	0.2066	0.2538

TABLE VIII. TIME OF CALCULATION USING EF METHOD FOR COMPUTER WITH PENTIUM IV 3.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
6	0.1-1	0.0006	0.0008	0.0007
11	0.1-10	0.0027	0.0034	0.0039
16	0.1-100	0.0165	0.0209	0.0364
21	0.1-1000	0.1412	0.1455	0.1802

TABLE IX. TIME OF CALCULATION USING EF METHOD FOR COMPUTER WITH PENTIUM IV 3.0 GHZ

Number of intervals	Range of intervals [s]	WPM	GPS	MSG
		t-max [s]	t-max [s]	t-max [s]
3	0.1-1	0.0006	0.0005	0.0007
5	0.1-10	0.0021	0.0026	0.0036
7	0.1-100	0.0134	0.0154	0.0318
9	0.1-1000	0.1324	0.1329	0.1346

V. CONCLUSIONS

Both methods described in the paper enable real-time quasi-parallel computation of MTIE. The sequential data reduction applied in the DSDR method results in better behavior for the widest range of observation intervals in comparison with the EF method. The range and length of observation intervals strongly limit the application of both methods in the real time. The computational power of equipment and sampling interval are also the factors limiting the application of the real-time calculation methods.

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] S. Bregni, "Measurement of Maximum Time Interval Error for telecommunications clock stability characterization," IEEE Trans. Instrum. Meas., vol. 45, No. 5, pp. 900-906, 1996.

[5] S. Bregni, P. Tavella, "Estimation of the percentile Maximum Time Interval Error of gaussian white phase noise," Proc. of IEEE ICC'97, vol. 3, pp. 1597-1601, Montreal, Canada, June 1997.

[6] S. Bregni, S. Maccabruni, "Fast computation of Maximum Time Interval Error by binary decomposition," IEEE Trans. Instrum. Meas., vol. 49, No. 6, pp. 1240-1244, Dec. 2000.

[7] 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.

[8] A. Dobrogowski, M. Kasznia, "Maximum Time Interval Error assessment with on-line data preprocessing," Proc. of the 2001 IEEE Frequency Control Symposium, pp. 167-174, Seattle, 6-8 June 2001.

[9] A. Dobrogowski, M. Kasznia, "Maximum Time Interval Error assessment based on the sequential reducing data volume," IEEE Trans. Ultras. Ferr. Freq. Contr., vol. 49, no. 7, pp. 987-994, July 2002.

[10] A. Dobrogowski, M. Kasznia, "Quasi-parallel computation of Maximum Time Interval Error estimates," Proc. of the 2002 IEEE Frequency Control Symposium, pp. 733-738, New Orleans, 29-31 May 2002.

[11] A. Dobrogowski, M. Kasznia, "Some problems and their solutions in quasi-parallel MTIE assessment," Proc. of the 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control Joint 50th Anniversary Conference, pp. 494-499, Montreal, 23-27 August 2004.