Monitoring the Quality of Reference Synchronization Signals on the 4G Network

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Abstract. The article discusses the transition from TDM networks to networks with packet data transmission. The evolutionary path that led to the modification of the stability parameters of synchronization signals during the transition to packet networks is considered. The main parameters of the stability of synchronization signals, as well as methods of their measurements and monitoring in packet networks, are determined. The article proposes a method for mutual monitoring of distributed primary synchronization devices for their effective use under the condition of the combined use of embedded and dedicated networks. The circuit for mutual monitoring of synchronization reference signals consists of three RTP servers and does not contain the most unreliable element—the mechanism for switching to the reserve. This scheme maximizes the efficiency of using PTP servers, each of which is not just in "hot standby," but is operational and contributes directly to the stability of the reference signals.

Keywords: Synchronization, Packet Networks, Synchronization Signal, Stability Parameters, PTP Server, PTP Client, Base Station, Monitoring.

1 Introduction

With the introduction of new technologies, in particular 4G, the issues related to the section of time-frequency support of communication sessions, as well as the problems of coordinating the scales of local keepers of exact time in geographically dispersed telecommunication infrastructure, do not lose their relevance.

Measuring the parameters of stability of synchronization signals is an integral part of monitoring existing synchronization networks [1, 2]. This rule is also true when switching to packet networks. The traditional parameters of stability of synchronization signals have undergone further development when evaluated on Internet Protocol / Multiprotocol Label Switching (IP/MPLS) networks.

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With the active transition from one technology to the next generation networks, the issues of synchronization are facing specialists with increasing force, since the exact adherence to universal time ultimately translates into an increase in the availability and quality of services provided [3].

The first attempt to evaluate the stability of synchronization signals in a packet network was the templates from ITU-T Recommendation G.823 for a "classic" time-division multiplexing (Time Division Multiplexing, TDM) synchronization network. Further, a template for packet frequency synchronization was developed ITU-T Recommendation G.8261.1 [4]. These templates allow you to determine how well the packet stream passing through the network meets the criteria for the quality of synchronization of application processes, for example, a client—base station NodeB (this article discusses synchronization using the PTP protocol (Precision Time Protocol (IEEE 1588v2) from the PTP server to the PTP—clients NodeB).

The template proposed in [4] is an attempt by the International Telecommunication Union to use approaches that are applied to measurements of stability parameters of synchronization signals in Synchronization Digital Hierarchy (Synchronization Digital Hierarchy, SDH) networks, to packet networks. This pattern is a pretty rough estimate. There are no qualitative parameters like the parameters of the maximum time interval error (Maximum Time Interval Error, MTIE) and time deviation (Time Deviation, TDEV) taking into account the packet transmission medium. Also, it makes no sense to compare the measurement results in the packet network with the templates of the "classical" network: since in it the average relative frequency at any node should be equal to 1×10^{-11}, and in a packet mobile network, the limit value of the relative the frequencies in the radio segment are two orders of magnitude lower –50×10^{-9}.

It follows from this that when assessing the quality of synchronization signals in a packet network, it is advisable to abandon the traditional limits adopted in the documents of the International Telecommunication Union for the "classic" synchronization network (MTIE diagram) and go to templates that are better suited for packet networks.

2 Review of the Literature

The properties of isogenies for Weierstrass curves are well studied. Effective methods for constructing and isogenies properties of promising classes of curves in the Edwards form are much less known. The Edwards curves with one parameter, defined in [2], have very attractive advantages for cryptography: fastest exponentiation of a point [2], completeness and universality of the law of point's addition, affine coordinates of a neutral element of a points group, enhanced security against side-channel attacks [2–5]. 3- and 5-isogenies are considered in previous works [6] and [7].

The programming of group operations is accelerated due to the absence of a singular point at infinity as a neutral element of an Abelian group of points. The introduction of the second curve parameter in [8] extended the class of curves in the Edwards form and gave rise to classes of quadratic and twisted curves with new properties of interest to cryptographic applications. In this paper, the known results for the 2-isogeny of complete and quadratic Edwards curves [4, 9] are generalized to the class of twisted

Edwards curves [10, 11]. In particular, an analysis of the existing conditions of such curves over a prime field is given.

3 Moving from TDM to Packet

The peculiarity of the rationing of the joints of the "classical network" of synchronization according to the norms of the International Telecommunication Union is that at the top level of the hierarchy a primary source of cesium accuracy class is placed so that the average frequency of the generating equipment of the network elements (over a large network interval) is no worse than 1×10^{-11} [5], and allowable phase wanderings (both short-term and long-term) according to the MTIE diagram [4].

The criteria for assessing the quality of TDM network synchronization signals are two parameters MTIE and TDEV [6].

In monograph [7], protocols were presented that allows generating a reference frequency in a reference generator and transmitting it to all points of a packet network (IP/MPLS).

The question arose—how to evaluate the stability of such a reference frequency? Due to the presence of the IP / MPLS packet transmission medium and the corresponding technological protocols, new measurable parameters of the stability of synchronization signals have been developed [4], which make it possible to assess the quality of stability in a packet environment.

Measurements in a packet environment are based on the calculation of all data [4] necessary not only to assess the accuracy of time comparison and to assess frequency stability but also to assess such network parameters as two-way and one-way packet delays, as well as packet delay deviation (Packet Delay Variation, PDV). The network performance is estimated by the TDEV and the minimum deviation of packet time packet (MinTDEV), calculated based on the PDV measurements from the packet timestamps relative to the local (reference) time [4]. After completing the PDV dataset measurements, the MTIE, TDEV, MAFE, FPP, FPC performance metrics are calculated.

Currently, there is no complete understanding of a clear operational list of these parameters (in contrast to the "classic" synchronization network TIE, MTIE, TDEV). At present, the parameter MAFE (Maximum Average Frequency Error) can be considered the main one for determining the quality of the synchronization signal in the packet network [8, 9].

In the last couple of years, Ukraine has been intensively implementing 3G technology on the networks of leading mobile operators. To date, the introduction and use of networks based on 4G technology have been actively started. A prerequisite for the operability of these technologies is the provision of synchronization of base stations in the transport environment of IP/MPLS networks. The most optimal technology for this is to provide synchronization using the PTP protocol, which was specially developed for solving synchronization problems in packet networks. Unlike 3G technology, 4G technology provides for the placement of a larger number of RTR servers. Also, in the case of 4G, when planning a PTP synchronization network, it is necessary to take into account the unicast (ITU-T G.8265.1) and multicast (ITU-T G.8275.1/275.2) operating modes of the equipment.

In the process of building a synchronization network using the RTR protocol, such factors have been identified that ensure the quality and reliability of this network: planning the placement of RTR servers, ensuring the necessary redundancy (both at the hardware level of the RTP server and the network level), as well as monitoring measurements parameters of stability of synchronization signals on IP networks [8].

4 Capabilities of Control Systems of Modern Synchronization Equipment

Measurements in the packet environment are based on the calculation of all data, which is necessary not only to assess the accuracy of time reconciliation and frequency stability but also to estimate parameters in the network such as one-way and two-way packet delay, as well as Packet Delay Variation and calculations from the obtained data of additional stability parameters (for example, the most recent parameter MAFE (Maximum Average Frequency Error) is of greatest interest [4–6]. Measurement of the parameters of the stability of the synchronization signals will be increasingly automated, and data processing will be increasingly efficient. The need to monitor synchronization signals will grow.

On the synchronization networks of Ukrainian operators, there are control systems for synchronization equipment of various manufacturers, for example, the most common is synchronization equipment from Microsemi (USA) and Oscillquartz (Switzerland) with the corresponding control systems TimePictra and SyncView Plus. In the latest versions of these control systems, it is possible to measure the stability parameters of the output and input synchronization signals on the network synchronization equipment using hardware implemented in this equipment and supported by the corresponding software in TimePictra and SyncView Plus control systems. That is the measurement ideology that Microsemi proposed in its TimeAnalyzer 7500 meter smoothly shifted to the synchronization network itself.

Oscilloquartz once produced the OSA5565 SyncTester, which was able to perform TIE (Time Interval Error) measurements and calculate the classic MTIE (Maximum Time Interval Error) and TDEV (Time Deviation) parameters. This device is still sometimes used on networks. However, Oscilloquartz did not make a measuring instrument for IP network performance, but quite successfully implemented the measuring function in the SyncView Plus control system. Prerequisites for measuring the stability of synchronization signals are the presence of appropriate licenses on network devices and the appropriate software in the SyncView Plus control system.

Microsemi simply “transferred” the functions of the TimeAnalyzer 7500 to network devices, such as the TP5000 RTP server, the TP500 RTP client, and the TP4100 aircraft. Such measurements also require the appropriate licenses on network devices and the appropriate software in the TimePictra management system, namely TimeMonitor. Unfortunately, the disadvantage is that not all older Microsemi devices support the stability measurement function. Since there are different versions of the hardware implementation, for example, in the equipment of the RTP server TP5000, it is not always possible to organize measurements using the control system (even if the operator has all the software licenses).

TimePictra and SyncView Plus control systems allow us to carry out such “internal” measurements in packet networks, namely measurements of PDV, packet MTIE, packet TDEV, packet minTDEV. Thus, based on synchronization equipment control systems, it is possible to create a system of “full-fledged” monitoring of the stability of synchronization signals, but today, with certain limitations. Thus, such restrictions include the inability to calculate the MAFE parameter, restrictions on the maximum time of measurements, and restrictions related to the volume and storage time of the results.

5 Method for Mutual Monitoring of the Quality of Timing Reference Signals

Monitoring is the constant monitoring of the quality of reference signals at critical points of the synchronization network to timely identify the deviation of their parameters from regulatory requirements.

The monitoring system should not be equated with the Management System for Synchronization Network, which is a set of ways and means to manage the network to ensure its maximum efficiency. So, the control system necessarily contains a monitoring tool.

The modern synchronization network includes two components: a synchronization network control system and a system for measuring the parameters of synchronization signals [2, 5].

The branched topology of modern synchronization networks does not allow us to fully predict their behavior in the event of one or more failures. In the case of further reconfiguration of the network, loops may be formed in the propagation of synchronization signals, as a result of which the entire synchronization network may “degrade” in any area or completely. Real-time monitoring of synchronization signal parameters is used to combat such undesirable consequences. To do this, the parameters of the synchronization signals are measured at all sections of such a network, both at the output of the synchronization equipment and other junctions of the synchronization. In essence, these measurements are measurements of frequency and parameters of its stability, that is, frequency measurements [6].

As a rule, in practice they usually talk about frequency instability (Frequency Instability) and adhere to the principle: to reduce long-term instability, you should increase the accuracy. This principle is based on the conclusion that long-term changes in frequency are due to various internal and external destabilizing factors, which are the cause of systematic deviations [5]. By minimizing and controlling them, we improve both accuracy and long-term stability. Accuracy cannot be better than long-term stability. For example, in several nodes of the asynchronous communication network, it is not so much the accuracy of the frequency that matters, but the well-coordinated stability over time.

There are requirements regarding time. If the course of the local clock is to be consistent with the nominal time scale from the remote source, certain means of regular time corrections and adjustments to the local clock frequency should be provided. Synchronize frequency—means to adjust the frequency of the generator so that it is the same for all clocks, synchronize time—synchronize the clock readings with the nominal time scale (usually UTC Coordinated Universal Time) and, synchronize clock (synchronize clock)—means to synchronize both frequency and time. The purpose of remote time reconciliation is to calculate the divergence of the scales.

If the control systems of the synchronization network of different manufacturers of synchronization equipment today can not provide “full” monitoring, then there is a need for dedicated monitoring systems for synchronization signals and the relevance of such monitoring in IP networks increases significantly.

In [5, 6], a scheme for monitoring signals using the RTP protocol was proposed, and a slightly modified scheme for the NTP protocol was proposed in [7, 8]. The essence of this scheme was to reconcile/measure signals from three sources to determine the emergency and efficient switching to the reserve. Also, this monitoring option can be used to effectively reconcile timelines (which, incidentally, is currently not allowed by any NTP server management system).

The scheme (Fig. 1) for mutual monitoring of the quality of reference signals on the 4G network can include two local sources of synchronization signals: one based on a GPS receiver, the second based on a local RTP1 server, which is connected to the calibration circuit. Also, an averaging circuit can be included in the specified scheme, which serves to preprocess the reference signals received from the remote PTP2 and PTP3, before these signals are fed to the network of 4G base stations.

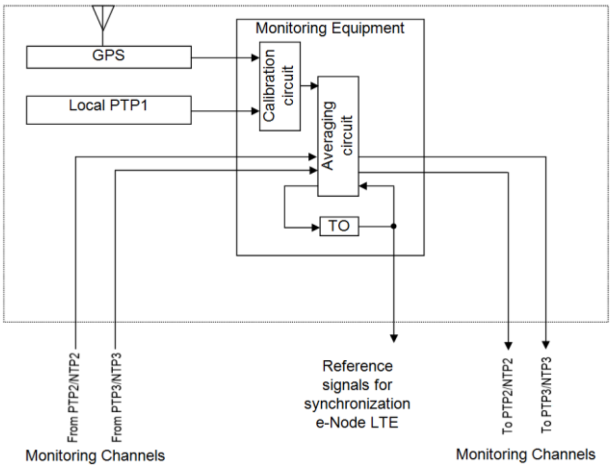

Fig. 1. Monitoring the quality of PTP/NTP reference signals.

The calibration signal is used in the averaging circuit to generate the LOC control signal. The stability of the resulting signal after such processing turns out to be no worse than the short-term stability of the local crystal oscillator, during the average time of the stability of the local PTP1 and the long-term stability of the GPS receiver [8, 9].

In the presence of several RTR servers on the network, the selection of the best quality is achieved using a phase-locked loop (PLL) with multiple inputs, which is digitally controlled by a tuned oscillator. In such a system, one of the input signals from the crystal oscillator ensures stability over short measurement intervals. The local GPS receiver, and in the event of an emergency, one or two remote RTR servers, contributes to the stability of the resulting output signal over the intervals of average operating time. In such a phase-locked loop system with many inputs, the stability of the resulting signal at the output turns out to be no worse than the stability of any of the existing sources, and they all serve to adjust the output signal.

A local quartz tunable TG generator with better short-term stability of frequency f_1 is connected directly to the output of the control loop. The signals from the GPS and the local PTP server are used to fine-tune the signal through a calibration circuit that generates the first reference signal at f_{10} for the closed-loop averaging circuit.

The closed control loop considered in this work includes two digital integrators, a weighting summation circuit. The main reference signal comes from the calibration circuit to the summation weight circuit. Signals with good average time stability are fed to the inputs of digital integrators and are used as the second and third reference signals with frequencies f_2 and f_3, respectively.

The time constants of the calibration circuit and control loops are chosen such that the prevailing influence of each of the reference signals is selective and generally maximizes the overall stability of the output signal.

The synchronism condition in such a network for each node is:

$$A\sum_{n}\int_{0}^{t}\left(f_n - f_1\right)dt - B_1\left(f_1 - f_{10}\right) - C\frac{df_1}{dt} + A\sum_{n} b_{1no} = 0$$

where

A is a constant transmission coefficient;

B_1 is a constant coefficient characterizing the inertia of the calibration circuit;

C is a constant coefficient that determines the rate of change in the frequency of the tunable generator of the generator;

b_{1no} is the initial state of the digital integrator.

In digital integrators of a two-input control loop, it is preferable to use the relative frequency calculation:

$$\int_{0}^{t}\left(f_2 - f_1\right)dt$$

rather than phase and time, since the frequency error is limited, so rounding and overflow errors are avoided when calculating the relative frequency. For the integral of the frequency error to be equal to the time error up to a constant, the frequency error should be calculated at zero dead time.

The smaller the coefficient A, the greater the inertia of the system. Since in the conditions of trouble-free operation, a local PTP server (PTP1) is selected then the remote servers PTP2 and PTP3. And, the more B_1, the greater the inertia of the system. Therefore, the time constant τ_1 of the control loop, including the averaging circuit and the TG, is equal to:

$$\tau_1 = \frac{B_1}{A}$$

If $C \neq 0$, then not only the frequency control of the synchronization device is described, but also the intensity of its frequency change df_1/dt. If $C = 0$, then the equation reflects the drift of the synchronization device frequency ($f_n - f_{10}$) from its calibrated nominal value f_{10}.

Also, during monitoring, the values of the MAFE parameter (n_0) can be calculated, which will give a complete picture of the quality of signals from three RTP servers [10].

The scheme shown in Figure 1 is used to pre-process the reference signals received from remote PTP2 and PTP3 sources before these signals are presented to the network. The calibration signal is used in the averaging circuit to generate a control signal for the local adjustable generator (designated as "TO" in the circuit). The stability of the resulting signal after such processing is not worse than the short-term stability of the local quartz oscillator "TO," the average hourly stability of the local PTP1, and the long-term stability of the GPS receiver or receiver of any other GNSS (Global Navigation Satellite System).

It should be noted that measurements of PDV values are possible here for both NTP and PTP signals. And further calculations of such stability parameters as MAFE.

If there are several NTP or RTR servers on the network, the choice of the best quality is achieved with the help of a multi-pass system of phase auto-tuning of the PLL frequency with digital control of the tuned generator. In such a system, one of the input signals from the quartz generator "TO" provides stability at short intervals of measurement. The local GPS receiver contributes to the stability of the resulting output signal at average hourly intervals, and in case of its failure—one or two remote NTP or RTP servers. In such a high-pass phase-locked loop system, the stability of the resulting output signal is no worse than the stability of any of the operating sources, and they all serve to adjust the output signal [9].

The local quartz tuning generator "TO" with the best short-term frequency stability is connected directly to the output of the control loop. The GPS signals and the local NTP or RTP server are used to adjust the signal through the calibration circuit, which forms the first reference signal for the closed-loop averaging circuit. The calibration time constants and control loops are selected so that the predominant influence of each of the reference signals is selective and generally maximizes the stability and accurate timestamp of the output signal.

Fig. 2–4 shows the results of measurements obtained by carrying out measurements on the network of the company PrAT "Kyivstar." Fig. 2 shows the PDV (t) graph, which is used to calculate the MAFE (τ) parameter according to [4]. The graph shown in Fig. 3 gives an idea of the behavior of the relative frequency over time. Fig. 4 shows the sync packet delay distribution function.

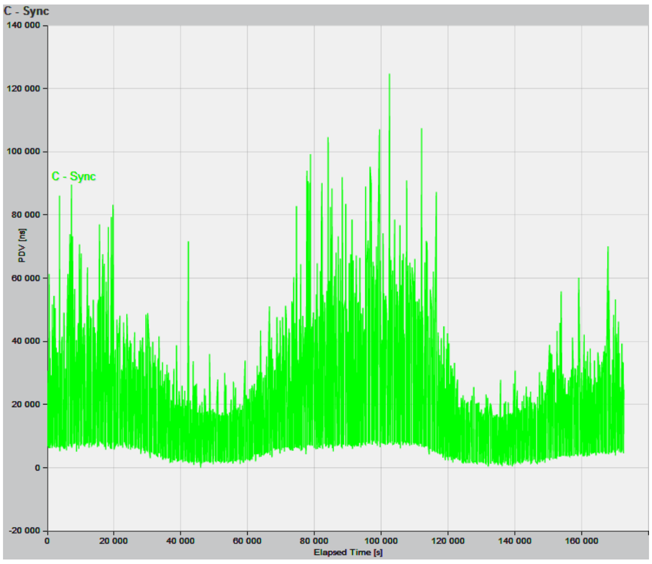

Fig. 2. PDV parameter measurements.

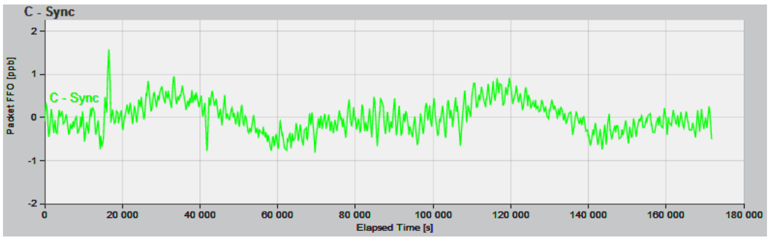

Fig. 3. Relative frequency over time.

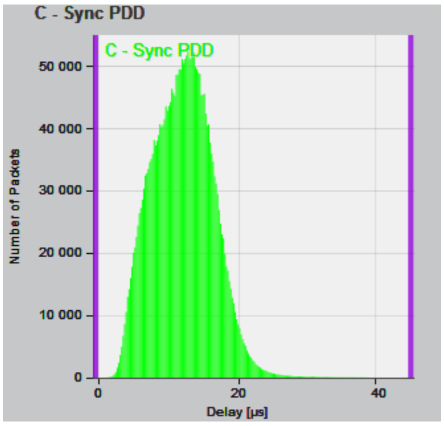

Fig. 4. Sync packet delay distribution function.

By organizing such monitoring on an ongoing basis, it becomes possible to reserve the reference signals of 4G base stations in a certain section of the network from three RTR servers. It is noteworthy that in case of emergencies, switching to the reserve is avoided at the maximum signal quality [11].

The proposed scheme, in addition to solving the accident rate of the device and the formation of the resulting stable signal to the network, makes it possible to measure the stability parameters of synchronization signals from three sources, to match phase synchronization from three sources. The question arises of how to manage measurements at a distance and where to process and then save the measurement results. Measurements at these three points of the network are possible if there are measuring instruments in them, or use the capabilities of the control system of the network synchronization equipment at these points. In both cases, the measurement results are accumulated directly on the measuring devices or network equipment. Subsequently, these results should be sent to a centralized server. In existing synchronization networks management systems such as SyncView Plus and TimePictra, this functionality does not exist and is not expected. That is, it is necessary to additionally develop software for analysis (for example, calculating the MAFE parameter [5]) and storing measurement data.

The problem that arises in the case of implementing this scheme is the processing of the obtained measurement results and their analysis and storage. With the current state of information databases and approved ITU-T Recommendations [10–12, 15–21], this task does not cause significant difficulties. But it is also necessary to present an algorithm for interaction between the three signal sources and the central server. According to this algorithm, a decision on the operability of each of the three servers will be made according to the majority rule. This is also a pure software task. Here it is advisable to use the same concept as in the case of developing the hardware part of the monitoring system, namely the majority rule for evaluating three devices. This will make it possible to more dynamically control the measurement process itself—to configure measurement tasks, to evaluate the serviceability of the measuring equipment even during measurements. Partially, in this case, the capabilities of synchronization network management systems can be used, but nothing prevents you from doing it separately—all communication protocols over IP are open, and security will be preserved by the closedness of internal industrial IP networks of telecom operators [2, 10, 11, 15–21].

In [12] the very prototype of the algorithm for such interaction is given. The evaluation of three NTP servers relative to the fourth was taken as a basis. The direct analogy with three source devices and a fourth central server. For clarity of demonstration of the prototype, public NTP servers on the public Internet (by the project www.pool.ntp.org) are used. It is problematic to use PTP servers for this since it is necessary to use the hardware resource of the central server (in general, RTP servers in the public version are rarely found). The prototype is implemented in the Python programming language 3.6.4 (the listing of the prototype code is given in Section 2 of Monograph [12], if necessary, the authors can provide the algorithm code upon request, since the volume of our publication does not allow placing it here). By the central server, NTP was selected in Kyiv from the same project www.pool.ntp.org, namely at www.time.in.ua. This is a Stratum 1 primary server based on GPS receivers.

The three servers under investigation are the selected three remote NTP servers according to the www.pool.ntp.org project in different parts of the world—South America, Asia, and Europe (Fig. 5).

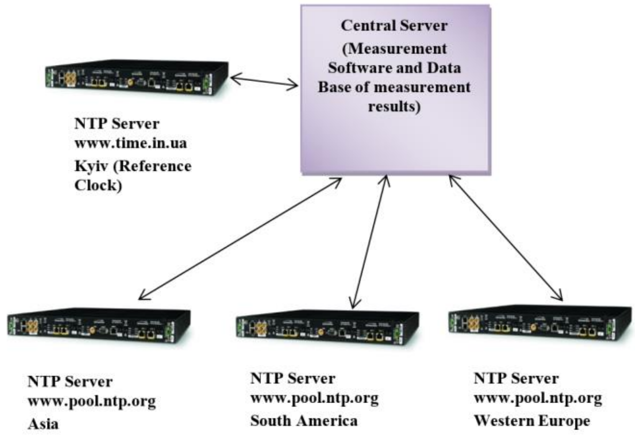

Fig. 5. Scheme of organization of monitoring according to the project www.pool.ntp.org.

The program initiates a connection with all four NTP servers according to the data entered by the user—how many measurements need to be taken and after what time. Then it compares the time from three remote servers about the reference server in Kyiv. Calculates the delay, and displays the measurement results—date and time from each in several formats and the delay relative to the reference server. If you accumulate enough measurements, then the delay should be up to 3 s (which is a lot even for the public Internet, but it all depends on the quality of the Internet at the place where the measurement is made). When all the cycles that the user-specified when entering the number of measurements have been completed, the program stops.

This prototype demonstrates the monitoring capabilities of the majority rule. If enough data is accumulated, you can create a graph, or fill out datasets for later analysis.

On real networks of telecom operators with working NTP servers, the delays will be already millisecond, and the accuracy will be at the microsecond level [1, 5–7].

It should be noted that the increase in the efficiency of the proposed circuit is directly related to the assessment of the stability of the reference signals, which depends on the parameters of the carrier frequency. In turn, the solution of scientific problems on the assessment of the carrier frequency of these signals involves the choice of the assessment parameter and the methodology for their determination. As such a technique in work for signals that are transmitted in burst mode, it is proposed to use the maximum likelihood rule using a sliding fast Fourier [13]. In this case, the reference signal synchronization system itself can be improved by the open-loop synthesis method, which is described in sufficient detail in [14].

6 Conclusions

To apply existing experience in perspective and overcome misconceptions based on incorrect assumptions, each company must realize its needs and develop its measurement techniques, justify norms, and limit ratios.

A mutual monitoring scheme is proposed, which consists of three RTR servers and does not contain the most unreliable element—a reserve switching mechanism. The considered scheme is the most optimal for building synchronization networks for 4G technology. This scheme maximizes the efficiency of using PTP servers, each of which is not just in “hot standby,” but is operational and contributes directly to the stability of the reference signals.

To illustrate the operation of the proposed scheme, a software prototype of the interaction between the three NTP nodes and the central server was developed, which is presented in the final part of section 2 of the Monograph [9]. The NTP protocol was chosen to be available on the public Internet. The prototype is implemented in the Python programming language version 3.6.4.

The sources used in the proposed monitoring scheme may not necessarily be primary, and there may be significantly more than one such scheme on the network (especially a large network). Thus, IP networks can implement a full-fledged system for monitoring the parameters of synchronization signals.

The main parameters of the stability of synchronization signals are given for a qualitative assessment of the monitoring of the synchronization network. The main operational stability parameter is MAFE. With it, you can quickly assess the signal quality. The indicator has masks for two modes of MPLS-network operation (up to 5 and up to 10 RTP signal re-reception by routers).

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