Method and computer tool for synphase prediction of computer network traffic load level*

Mykola Khvostivskyi[1,*,†], Liliia Khvostivska[1,†], Iryna Dediv[1,†], Vasyl Yatskiv[2,†] and Oleksandra Kuchvara[3,†]

[1] *Ternopil Ivan Puluj National Technical University, Rus'ka str. 56, Ternopil, 46001, Ukraine*
[2] *West Ukrainian National University, Lvivska str. 11, Ternopil, 46009, Ukraine*
[3] *I.Horbachevsky Ternopil National Medical University, Ternopil, Ukraine*

Abstract

The structure of the mathematical model of computer network traffic data based on a periodically correlated stochastic process has been substantiated, which has become the basis for developing a method and a computer tool for predicting traffic load in order to optimize network functioning and improve the quality of providing Internet services to consumers.

A method and algorithm for synphase processing of computer network traffic load data have been implemented, which made it possible to obtain predictive indicators in the form of 3D synphase components and their 2D averaged estimates.

A computer (software) tool has been developed in the Matlab Guide environment for processing network traffic load data, which provides synphase load forecasting, in particular for individual elements of network equipment.

Keywords

method and computer tool, synphase prediction, computer network traffic load level, matlab guide

1. Introduction

Today, most areas of human activity are closely interconnected with the use of modern Internet technologies. This creates the need to ensure the reliability and stability of the functioning of such technologies, in particular computer networks.

One of the key parameters of a computer network is traffic, which plays an important role in the processes of assessing user activity, monitoring network operation, as well as analyzing its functioning. These procedures are aimed at optimizing the use of network resources and managing under overload conditions.

Predicting network traffic load levels in time space is one of the methods of avoiding congestion, which allows to increase the efficiency of network resource use and optimize its performance. For this purpose, various mathematical models and computational methods are used.

The application of methods for predicting the load on computer networks in telemedical systems is becoming particularly relevant, where biomedical data [6, 7, 10, 11, 13-17, 19, 20] processing requires a stable and predictable information transmission channel, which is critically important for ensuring continuous monitoring and diagnostics in real time.

Among the most well-known traffic models, one can distinguish the Poisson distribution [2], Markov processes [4-5], recovery processes and phase recovery processes [4-5], ON-OFF/IPP models [1], modulated Markov fluid model [1, 5], autoregressive models [12], stationary processes [3], fractal Brownian motion [18] and periodically correlated stochastic process (PCSP) [8].

* *CITI'2025: 3rd International Workshop on Computer Information Technologies in Industry 4.0, June 11–12, 2025, Ternopil, Ukraine*

1* Corresponding author.
† These authors contributed equally.
hvostivskyy@tntu.edu.ua (M. Khvostivskyi); hvostivska@tntu.edu.ua (L. Khvostivska); iradediv@gmail.com (I. Dediv); vy@wunu.edu.ua (V. Yatskiv); kuchvara@tdmu.edu.ua (O. Kuchvara)
0000-0002-2405-4930 (M. Khvostivskyi); 0000-0002-4997-8339 (L. Khvostivska); 0000-0002-4913-139X (I. Dediv); 0000-0001-9778-6625 (V. Yatskiv); 0000-0002-0248-3224 (O. Kuchvara)

© 2025 Copyright for this paper by its authors. Use permitted under Creative Commons License Attribution 4.0 International (CC BY 4.0).

CEUR-WS.org/Vol-4057/short4.pdf

CEUR Workshop Proceedings ceur-ws.org ISSN 1613-0073

Based on these models, various computational methods and computer (software) tools have been created for analyzing traffic data in order to predict its load. However, all of these models, with the exception of the PCSP, do not take into account the relationship between traffic values in different daily periods, which allows tracking the dynamics of traffic changes in time space. This is especially important for network load forecasting tasks.

The authors Khvostivskyi V.M., Osukhivska H.M. and Khvostovskyi M.O. used only the component method for processing traffic data, without revealing the full potential of ETSS. Therefore, the development of a method and a computer (software) tool for traffic forecasting based on the synphase method of a periodically correlated random process is an urgent task.

2. Mathematical model of computer network traffic data

To substantiate the structure of the traffic load data model as the core of the method and computer forecasting tool, real data from the Internet provider UFONet in Ternopil was used. A graphical representation of computer network traffic registered for 7 days (from 01.07.2024 to 07.07.2024) within the Park Complex residential complex is presented in Figure 1.

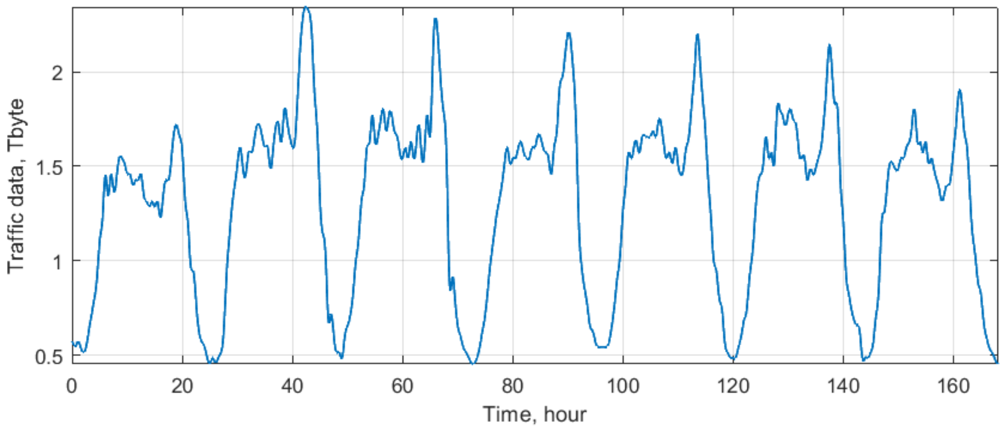

Figure 1: Traffic data of the computer network of the residential complex «Park Complex».

During the day, for each implementation, clearly pronounced peaks in traffic load data are observed (Fig. 2), which demonstrate daily changes in amplitude, time, and phase values in time space (Fig. 3).

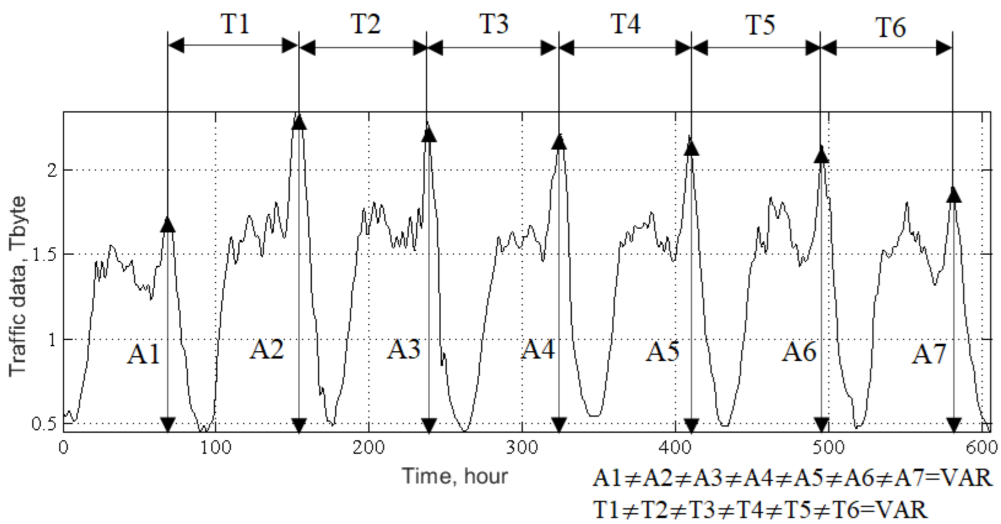

Figure 2: Variability of amplitude-temporal parameters of traffic load data.

Due to the presence of variability (Fig. 2), a deterministic approach to describing traffic load data is not correct for mathematical description of traffic load data. In this case, it is necessary to use a stochastic approach to modeling traffic load data, and on its basis to create a method and computer tool for predicting network traffic load data.

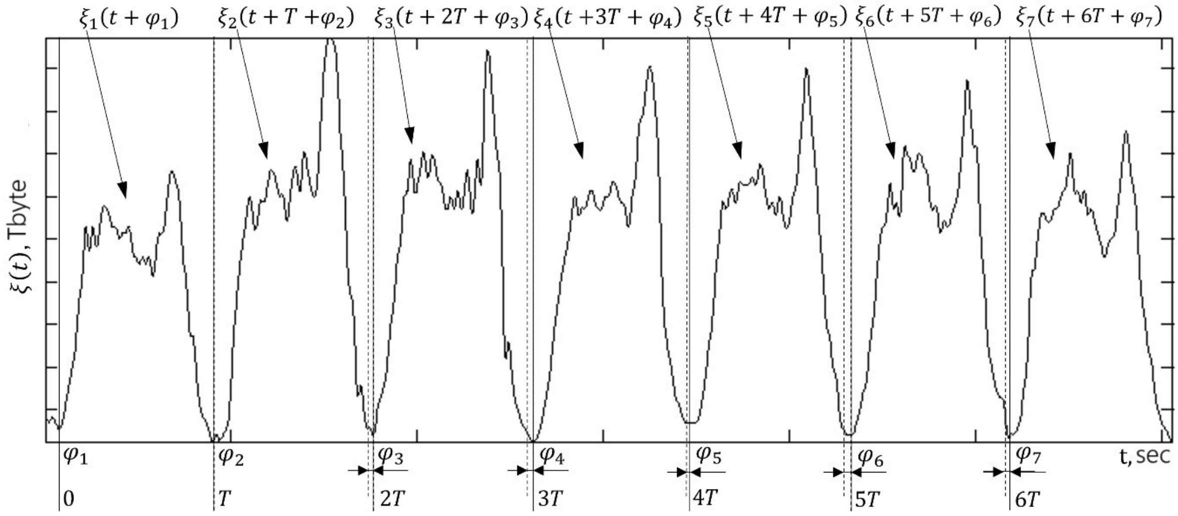

Figure 3: Time-phase structure of computer network traffic load data.

The phase φ_n (Fig. 3) refers to a certain numerical value n, which quantitatively characterizes the measure of the time shift relative to the beginning of fluctuations in the values of traffic load data for the nth day relative to the previous days $(n\text{-}1)T$.

Based on the analysis of the time-phase structure of the traffic load data (Fig. 3), it was found that for the nth day, which is localized in the time intervals of the period T, there is a variability of the phase values φ_1–φ_{10} for the data $\xi_1(t)$–$\xi_{10}(t)$. The fact of such variability indicates that the mathematical model of traffic load data should provide the possibility of studying the variability of time dependencies for each of the nth days to provide a procedure for predicting the behavior of the network and its components in the future.

The model of network traffic load data behavior, presented as a PCSP, allows you to effectively take into account the daily repetition (periodicity) of the signal realization, its time-amplitude variability (stochasticity), and also provides the use of methods and algorithms to study their relationship using the following expression [9]:

$$\xi(t)=\sum_{k\in Z}\xi_k(t)e^{-j2\pi k/T}, \quad (1)$$

where $\xi_k(t)$ – stationary stochastic components of daily network traffic data;

$e^{-j2\pi k/T}$ – repeating component of network traffic data with an interval of T=24 hours.

The network traffic data model (1) provides extensive processing and analysis capabilities, including synphase, filtering, and component processing, to obtain quantitative and informative indicators. These indicators reflect the level of mutual correlation of the amplitude-time characteristics of traffic at different times of the day.

Studying the level of stochasticity of mutual correlation between network traffic data indicators at different times of the day allows for load forecasting, determining in advance the optimal operating modes of network equipment. This helps ensure stable and high-quality provision of communication and information services to network users.

3. Method for predicting computer network traffic load

The methods (tools) of the PCSP are distinguished by high efficiency, as they implement three key approaches to processing network traffic data: synphase, component and filter. The main difference between synphase and component processing is the processing sequence: synphase processing, the traffic covariance is first determined, after which the corresponding frequency components are calculated using the Fourier transform. In contrast, component and filter processing immediately perform an estimate of the covariance in the frequency domain.

Synphase processing of network traffic data is based on the assumption that informative traffic features can be represented as functions with recurring, time-dependent characteristics in the form of synphase components:

$$\hat{B}_k(u)=\frac{1}{T}\int_0^T \hat{b}_\xi(t,u)e^{-j2\pi k/T}, \qquad (2)$$

where $\hat{b}_\xi(t,u)=lim\sum_{k=0}^{N-1}\overset{0}{\xi}(t+u+kT)\overset{0}{\xi}(t+kT)$ - parametric covariance;

T — period of load traffic data equal to the duration of a day;

u — time shift.

Synphase components allow us to isolate characteristic features of network traffic data, which helps to increase the accuracy of predicting its load in the general context.

4. Computer network traffic load prediction algorithm

The main stages of synphase traffic forecasting include the following structural elements:

- Synphase processing of computer network traffic data according to expression (2), which calculates an informative forecast indicator in the form of synphase components.
- Evaluation of the synphase components calculated at the previous stage, the form and value of which make it possible to forecast the traffic load of a computer network.
- The process of making a decision based on the shape and indicators of the estimated synphase components regarding the forecast of computer network traffic load.

The foundation of synphase processing is: the procedure of centering relative to the mean; the formation of stationary components; the calculation of synphase components by correlation and Fourier transformation. These operations determine the computational complexity of the synphase processing process, which is illustrated in Fig. 4.

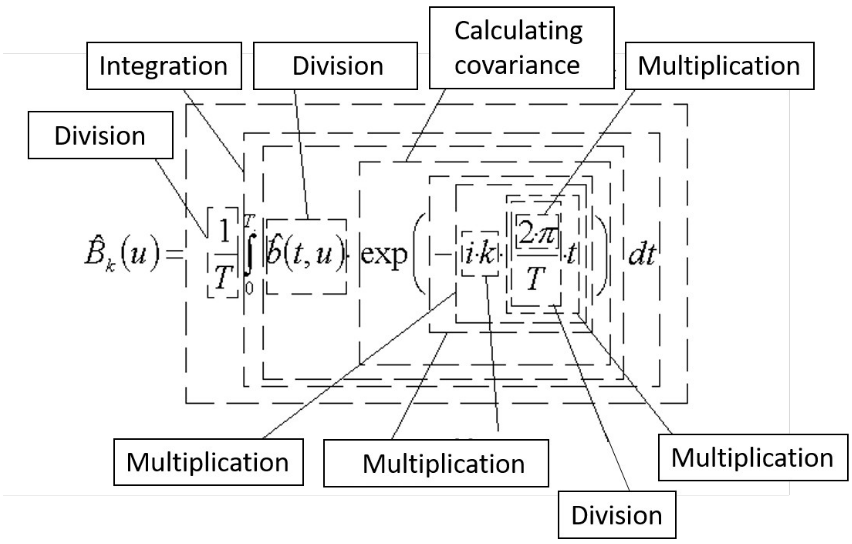

Figure 4: Computational complexity of expression (2) for calculating synphase components.

Given the complexity of the expression characterizing the synphase method of processing computer network traffic data, a sequence of synphase processing was developed, which is presented in Fig. 5.

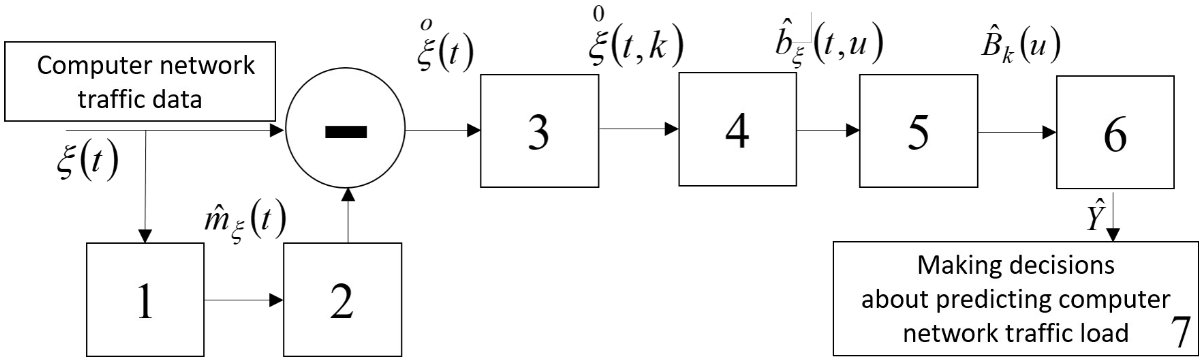

Figure 5: Synphase processing sequence as a basis for synphase prediction of computer network traffic load.

Fig. 5 shows the key stages of synphase processing of network traffic data:

1 – Calculating average traffic load data statistics of computer network $\hat{m}_\xi(t)$;

2 – Extended over a period T, the average value of computer network traffic data $[\hat{m}_\xi(t)\hat{m}_\xi(t)\hat{m}_\xi(t)...\hat{m}_\xi(t)]$;

$\ominus$ – Centering $\overset{0}{\xi}(t)$ (subtraction of the extended average values of the data $[\hat{m}_\xi(t)\hat{m}_\xi(t)\hat{m}_\xi(t)...\hat{m}_\xi(t)]$ from the computer network traffic load data $\xi(t)$;

3 – stationary components are taken through the kth period $\overset{0}{\xi}(t,k)$;

4 – calculation of covariance $\hat{b}_\xi(t,u)$;

5 – calculation of synphase components $\widehat{B}_k(u)$ as Fourier transforms of the covariance $\hat{b}_\xi(t,u)$;

6 – estimation of synphase components $\widehat{B}_k(u)$;

7 – making a decision on the level of computer network traffic load forecasting based on the estimated $\widehat{B}_k(u)$.

The sequence shown in Fig. 5 provides the possibility of developing an algorithm for synphase processing of traffic data for the further development of a computer tool for predicting the traffic load of a computer network.

Fig. 6 presents an algorithm for synphase processing (synphase prediction core) of computer network traffic data.

The implemented algorithm (Fig. 6) allows you to programmatically create a computer system for synphase processing of network traffic, focused on calculating synphase components, which act as indicators for effective prediction of computer network traffic load.

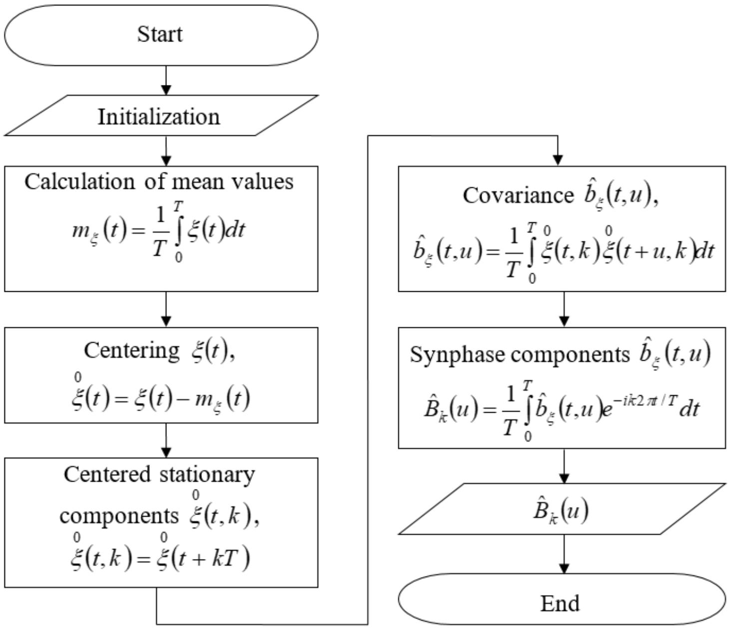

Figure 6: Algorithm for synphase prediction of computer network traffic data.

5. Computer tool (software) for predicting computer network traffic load

The GUIDE utility, as a component of the MATLAB environment, allows you to programmatically implement a computer system with a graphical interface for predicting computer network traffic according to the developed algorithm (Fig. 6).

Fig. 7. shows the appearance of the computer system and the result of predicting computer network traffic load.

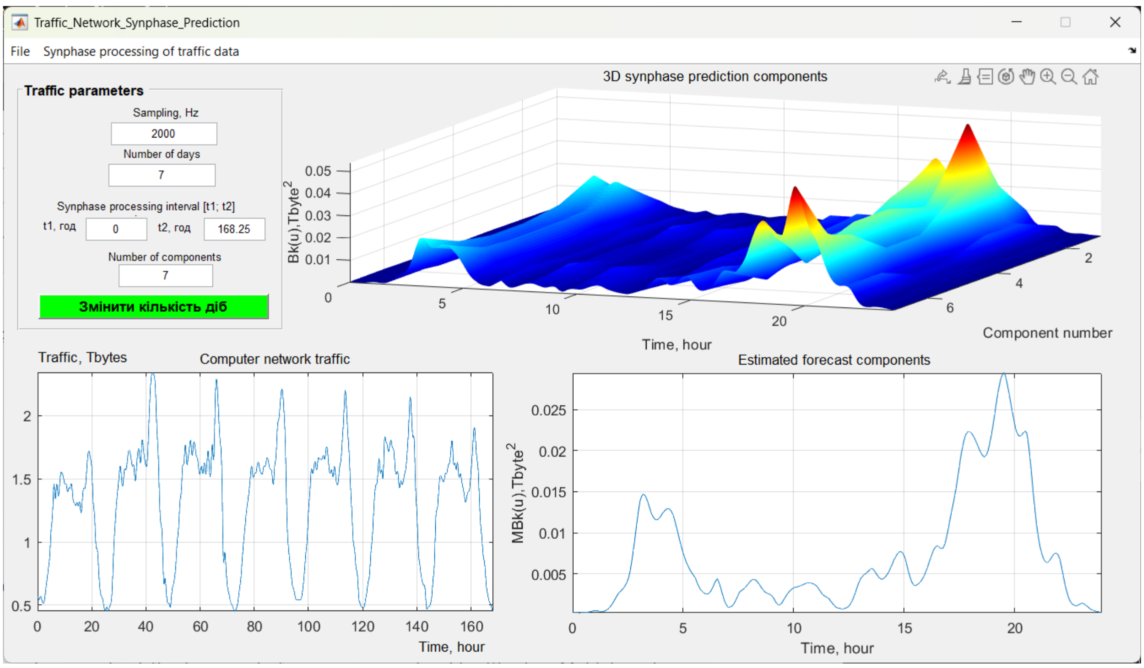

Figure 7: The result of the computer system for predicting computer network traffic data (registration period from 01.07.2024 to 07.07.2024) (Residential complex "Park Complex", Ternopil).

An enlarged fragment of the result of processing computer network traffic data is shown in Fig. 8 (3D views in different projections are presented).

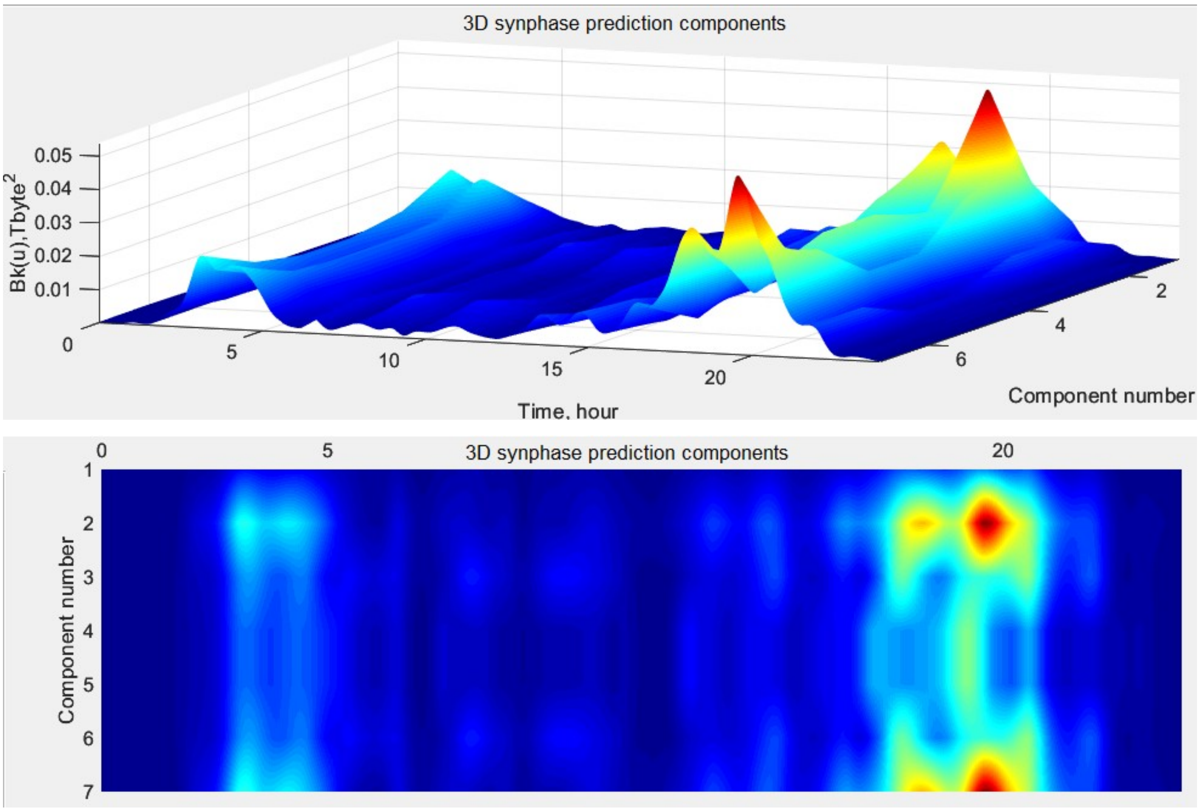

Figure 8: Synphase 3D components of computer network traffic data.

An enlarged fragment of the averaged synphase 3D components is shown in Fig. 9.

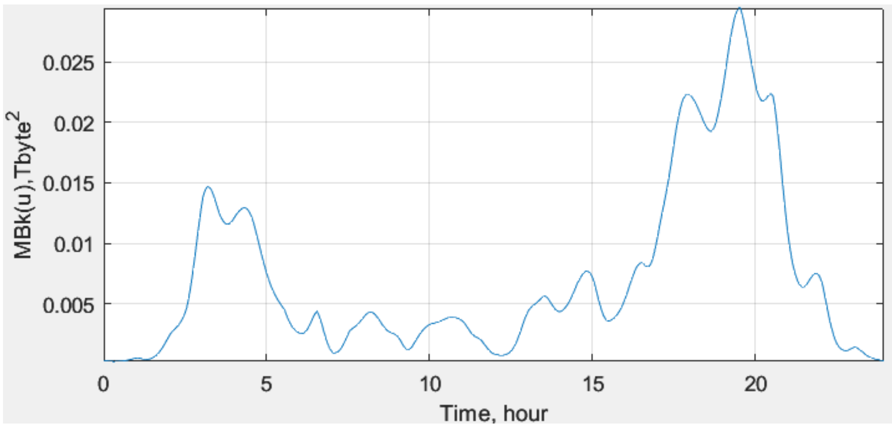

Figure 9: Averaged synphase 3D components of computer network traffic data.

According to the synphase components of the traffic data, which are shown in Fig. 8-10, it was found that in the period from 03:00 to 05:00 and from 17:00 to 22:00, an increase in the traffic load by consumers is observed. At these times, provider should activate the operation of most of the network equipment to avoid overload modes on their functioning. At other times, providers should transfer a significant part of the network equipment to the economical consumption mode in order to save electricity and increase the resource of equipment operation. In order to verify the correctness of the decision made, test data of unchanged traffic was created within 7 days, the results of its synphase processing were obtained using the implemented program (Fig. 10).

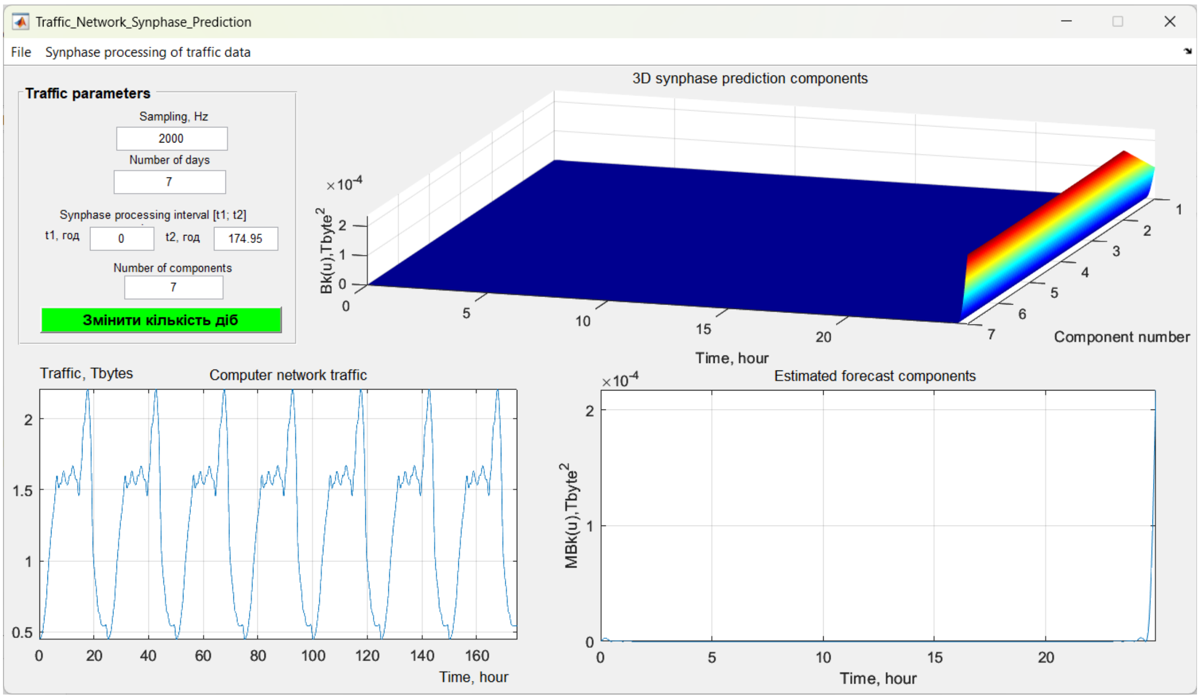

Figure 10: Results of synphase forecasting of constant computer network traffic load.

Based on the processing of stable traffic data (Fig. 10), it was ascertained that the synphase components are at zero level both in the 3D representation and in their averaged form.

In the case of variable computer network traffic data (Fig. 8-10), an increase in the power level of synphase components is observed depending on time (an increase in traffic consumption by consumers), with the main localization on 3D components and in their averaged implementation.

Such variability of the characteristics of synphase components reflects the dynamics of the traffic load of the computer network in the future, which is relevant for the forecasting problem.

Conclusions

The calculated synphase components of computer network traffic data submitted via the PCSP numerically reflect the future behavior of network load by consumers, thereby providing a clear solution to the problem of predicting network traffic load in order to optimize the functioning of network equipment based on the power of synphase components.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

References

[1] Abdelnaser A. Traffic Models in Broadband Telecommunication Networks. Department of Electrical Engineering. 1996. P.82-89.

[2] Chen T. (2012). Network Traffic Modelling. P.46. DOI: 10.1002/9781118256107.ch21.

[3] Chen T.M. (2007). The Handbook of Computer Networks. Southern Methodist University.

[4] Czachórski, Tadeusz & Grochla, Krzysztof & Józefiok, Adam & Nycz, Tomasz & Pekergin, Ferhan. (2011). Performance Evaluation of a Multiuser Interactive Networking System: A Comparison of Modelling Methods. Computer and Information Sciences II - 26th International Symposium on Computer and Information Sciences, ISCIS 2011. 215-221. DOI: 10.1007/978-1-4471-2155-8-27.

[5] Domańska J., Domański A., Czachórski T. (2011). Internet Traffic Source Based on Hidden Markov Model. NEW2AN, volume 6869 of Lecture Notes in Computer Science, Springer. P. 395-404. DOI: 10.1007/978-3-642-22875-9_36.
[6] Dozorska O., Yavorska E., Dozorskyi V., Nykytyuk V., Dediv L. The Method of Selection and Pre-processing of Electromyographic Signals for Bio-controlled Prosthetic of Hand // Proc. of the 2020 IEEE 15th International Conference on Computer Sciences and Information Technologies (CSIT). – Lviv-Zbarazh, Ukraine, 23–26 Sept. 2020. P. 188–192. DOI: 10.1109/CSIT49958.2020.9321935.
[7] Dozorskyi V., Dozorska O., Yavorska E., Dediv L., Kubashok A. The Method of Detection of Speech Process Signs in the Structure of Electroencephalographic Signals. Proceedings of the 2nd International Workshop on Information Technologies: Theoretical and Applied Problems (ITTAP 2022). CEUR Workshop Proceedings. Ternopil, Ukraine, November 22-24, 2022. Vol. 3309. P. 387–395. ISSN 1613-0073.
[8] Khvostivskyy M., Osukhivska H., Khvostivska L., Lobur T., Velychko D. Mathematical modelling of daily computer network traffic. ITTAP-2021: Information Technologies: Theoretical and Applied Problems. The 1st International Workshop (November 16-18, 2021). Ternopil, UKRAINE. P.107-111. DOI: 10.1425/jsdtl.
[9] Khvostivska L., Khvostivskyi M., Dediv I., Yatskiv V., Palaniza Y. Method, Algorithm and Computer Tool for Synphase Detection of Radio Signals in Telecommunication Networks with Noises. Proceedings of the 1st International Workshop on Computer Information Technologies in Industry 4.0 (CITI 2023). CEUR Workshop Proceedings. Ternopil, Ukraine, June 14-16, 2023. P.173-180. ISSN 1613-0073.
[10] Khvostivskyi M., Yavorska E., Kinash R., Boyko R. Mathematical, Algorithmic and Software Support for Phonocardiographic Signal Processing to Detect Mitral Insufficiency of Human Heart Valves. 3rd International Workshop on Information Technologies: Theoretical and Applied Problems (ITTAP 2023). CEUR Workshop Proceedings. Ternopil 22 November 22-24, 2023. Vol 3628, P. 350-357. ISSN 1613-0073.
[11] Khvostivskyi M., Khvostivska L., Dediv I., Yavorskyi I., Uniiat S. Medical Computer System for Diagnosing the State of Human Vessels. 1st International Workshop on Bioinformatics and Applied Information Technologies (BAIT 2024). CEUR Workshop Proceedings. Zboriv, Ukraine, October 02-04, 2024. Vol. 842. P.196–207. ISSN 1613-0073.
[12] Li M., Claypool M., Kinicki R., Nichols J. Characteristics of streaming media stored on the Web. ACM Transactions on Internet Technology. 2005. P. 601-626. DOI: 10.1145/1111627.1111629.
[13] Lytvynenko, I., Horkunenko, A., Kuchvara, O., & Palaniza, Y. (2019). Methods of processing cyclic signals in automated cardiodiagnostic complexes. In CEUR Workshop Proceedings (Vol. 2516, pp. 116–127). 1st International Workshop on Information-Communication Technologies and Embedded Systems (ICT and ES 2019), Mykolaiv, Ukraine, November 14–15, 2019. ISSN: 16130073.
[14] Martsenyuk, V., Sverstiuk, A., & Gvozdetska, I. S. (2019). Using Differential Equations with Time Delay on a Hexagonal Lattice for Modeling Immunosensors. In Cybernetics and Systems Analysis (Vol. 55, Issue 4, pp. 625–637). Springer Science and Business Media LLC. DOI: 10.1007/s10559-019-00171-2.
[15] Martsenyuk, V., Soldatkin, O., Klos-Witkowska, A., Sverstiuk, A., & Berketa, K. (2024). Operational stability study of lactate biosensors: modeling, parameter identification, and stability analysis. In Frontiers in Bioengineering and Biotechnology (Vol. 12). Frontiers Media SA. https://doi.org/10.3389/fbioe.2024.1385459.
[16] Martsenyuk V., Bahrii-Zaiats O., Sverstiuk A., Dzyadevych S., Shelestovskyi B. Mathematical and Computer Simulation of the Response of a Potentiometric Biosensor for the Determination of α-chaconine (2023) CEUR Workshop Proceedings, 3468, pp. 1 – 11.

[17] Martsenyuk, V., Klos-Witkowska, A., Sverstiuk, A., Bahrii-Zaiats O., Bernas, M., Witos, K. Intelligent big data system based on scientific machine learning of cyber-physical systems of medical and biological processes. CEUR Workshop Proceedings, 2021, 2864, pp. 34–48.
[18] Reichl P.A. Generalized TES Model for Periodical Traffic. IEEE International Conference. 1998. 5 p. DOI:10.1.1.23.6258.
[19] Tymkiv P., Leshchyshyn Y. Algorithm Reliability of Kalman Filter Coefficients Determination for Low-Intensity Electroretinosignal. CADSM 2019, February 26 – March 2, 2019, Polyana-Svalyava (Zakarpattya), UKRAINE. pp. 14-18. DOI: 10.1109/CADSM.2019.8779259.
[20] Tymkiv P., Kłos-Witkowska A., Andrushchak I. Optimization Methods for Determining Coefficients of Mathematical Model of Electroretinosignal for Detection of Neurotoxicity Risks. Proceedings of the 1st International Workshop on Computer Information Technologies in Industry 4.0 (CITI 2023). Ternopil, Ukraine, June 14-16, 2023. P.109-116. ISSN 1613-0073.