TELETRAFFIC FORECASTING IN MEDIA SERVICE SYSTEMS

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ABSTRACT

Context. The development of information and communication technologies has led to an increase in the volume of information sent over the network. Media service platforms play an important role in the creation and processing of bitrate in the information network. Therefore, there is a need to develop a methodology for predicting bitrate in various media service platforms by creating an effective algorithm that minimizes the forecast error.

Objective. The aim of the work is to synthesize in analytical form the state transition matrix of the Kalman filter for non-stationary self-similar processes when predicting the bitrate in telecommunication networks.

Method. A methodology has been developed for predicting teletraffic in media service platforms, based on a modification of the Kalman filter for non-Gaussian processes. This methodology uses an original procedure for calculating statistics, which makes it possible to reduce the filtering and forecast error that arises due to the uncertainty of the analytical model of the process under study. The methodology does not require knowledge of the analytical model of the process, as well as strict restrictions on its stochastic characteristics.

Results. A methodology for estimating and forecasting bitrate in telecommunication systems is proposed. This methodology was used to study teletraffic processes in the media service platforms Google Meet, Zoom, Microsoft Teams. The passage of real bitrate through the specified media service platforms was studied. A comparison of real teletraffic with predicted teletraffic was carried out. The influence of the order of the state transition matrix of the Kalman filter on the error of estimation and prediction has been studied. It has been established that even a low (second) order of the state transition matrix allows one to obtain satisfactory forecast results. It is shown that the use of the proposed methodology makes it possible to predict traffic with a relative error of the order of 3–4%.

Conclusions. An original algorithm for assessing and forecasting the characteristics of media traffic has been developed. Recommendations for improving the technology for building media service platforms are formulated. It is shown that the bitrates generated by various media service platforms, in the case of applying the proposed estimation and forecasting methodology, are invariant with respect to the type of stochastic processes being processed.

KEYWORDS: Kalman filter, teletraffic, media platform, stochastic process, self-similar process.

INTRODUCTION

The beginning of the fourth industrial revolution (Industrie 4.0) has created new preconditions for the development of digital and intelligent production and devices that interact with each other and provide personalized product output. One of the most important components of Industrie 4.0 is not the product, but the data. Digitaliza-
The purpose of the work is to synthesize in analytical form the state transition matrix of the Kalman filter for non-stationary self-similar processes when predicting the bitrate in telecommunication networks.

1 PROBLEM STATEMENT

We consider a self-similar process that describes the behavior of traffic in media service platforms of telecommunication networks. This process is fractal in nature and, therefore, cannot be processed by classical methods, inherent in Gaussian processes.

To solve the problem, it is proposed to use a modification of the Kalman filtering method, which does not require knowledge of the process under study in analytical form. This approach is invariant to the type of stochastic process and removes the restrictions imposed on its characteristics.

The solution to the problem is sought by approximating the state transition matrix of the Kalman filter by an n-th order Taylor series at each reference point.

2 REVIEW OF THE LITERATURE

In recent years, well-known media platforms such as Microsoft Teams, Zoom, Google Meet, etc. have been widely used. When many users work simultaneously in some segments of the information and telecommunications network, overload or a significant delay may occur when processing information in the media service platform [28].

In this regard, there is a need to develop methods for optimal network traffic control in order to eliminate these negative phenomena, an integral attribute of which is the process of forecasting traffic flows.

Neural networks are currently most often used to predict network traffic, and the forecast is based on the long short-term memory (LSTM) of the neural network [1–10, 12–14, 16–23, 25–27]. In some cases, such a model is used independently [9,10, 14, 18, 21, 23, 25]. However, its composition with other models is more common: with recurrent neural networks (RNN) [3,6, 13, 16, 17, 19, 20, 22]. Less commonly used are approaches such as machine learning (ML) [5, 24], clustering model [12], and deep learning method of convolutional neural network (CNN) [27].

Forecasting methods using neural networks have a significantly complicated computational procedure; in addition, the choice of input layers and input values is, as a rule, subjective.

The use of the classical Kalman filtering method [29] also has its disadvantages, associated primarily with the requirement of the Gaussian nature of the process under study and knowledge of the analytical expression of the state transition matrix.
3 MATERIALS AND METHODS

The classical Kalman filtering method assumes knowledge of the initial values of the process under study and its description in analytical form, which allows one to determine the state transition matrix. In practice, as a rule, we are not able to obtain an analytical expression of the process being processed, since this process has not yet been studied.

The structure of the telecommunications system model includes traffic sources (voice traffic and video traffic) and the Internet network, which connects traffic receivers and transmitters with media service platforms. Using specialized programs, you can obtain data about teletraffic on the network. Estimation and forecast of teletraffic characteristics can be obtained using the Kalman filtering procedure. In this case, the obtained data can be used as input measurements for the Kalman filter. Kalman filters use system state information as well as measurements to estimate the current state of the system. It calculates a real-time forecast of the state of the system, taking into account new data and measurements. The resulting forecast allows the system to adapt to changes in traffic and promptly identify anomalies or problems in the telecommunications network.

In this paper, we propose a modification of the Kalman filter, which consists in approximating the state transition matrix at each reference point by a Taylor series. This approach has one significant drawback due to the divergence of the filtering procedure (due to the finite order of the polynomial) when processing non-stationary processes. It would seem that this drawback can be eliminated by increasing the order of the approximating polynomial. However, it has been established (easy to verify in practice) that as the order of the polynomial increases, the filter becomes more prone to self-excitation, since this increases the depth of feedback and, consequently, a large number of poles and zeros appears, leading to an increase in the probability of self-excitation. Therefore, a low order of the polynomial should be chosen, and to eliminate the divergence of the filter, an original procedure for detecting a disorder in the filtering process is proposed.

The procedure is as follows. Along the time series, a time window is allocated, with a dimension of, for example, ten samples. A certain threshold is assigned, with a dimension, for example, seven. In this case, each new sample is accompanied by a shift of the window one sample forward. Within the window between two adjacent samples, the difference between the true (measured) signal and its filtered (predicted) value is determined and the sign of this difference is determined. Next, statistics are calculated, which is the algebraic sum of positive and negative signs. The calculated statistics are compared with the threshold and, if its value is equal to or exceeds the threshold value, a decision is made to disturb the filter. In this case, the transition to the beginning of the time window occurs, the initial filter parameters are set, and filtering is repeated within the window boundaries, and the previously obtained values are replaced with the current ones. In this case, a slight increase in the variance of the estimation noise is possible; however, studies have shown that this increase is small and can be neglected. Next, filtering occurs as usual until a new disorder occurs. Thus, the considered procedure allows us to avoid the divergence of the filtering process, that is, the bias of the estimate, and to study non-stationary processes with a significant degree of correctness.

In analytical form, the modified Kalman filter can be represented as follows. For the case of discrete measurements of the signal \( S_n \), which is an additive mixture,

\[
S_n = X_n + Q_n,
\]

where \( X_n \) is the useful signal, \( Q_n \) is additive noise with mathematical expectation \( \mathbb{E}(Q_n) = 0 \) and variance \( R \), the Kalman filtering procedure can be represented in the following form

\[
\bar{X}_n = F_n \bar{X}_{n-1} + P_n H_n^{-1}(S_n - H_n F_n \bar{X}_{n-1});
\]

\[
P_n = (A_n^{-1} + H_n^{-1} R^{-1} H_n)^{-1};
\]

\[
A_n = F_n P_{n-1} F_n';
\]

where index "T" means the transposition of the matrix.

The procedure for detecting a filter discord comes down to calculating statistics of the form

\[
B_M = \sum_{l=1}^M h_l, \quad B_0 = 0, \quad I = 1,2,...,M ;
\]

\[
h_l = \text{sgn}(S_l - \bar{X}) = +l, \quad S_l - \bar{X} \geq 0 ;
\]

\[
h_l = \text{sgn}(S_l - \bar{X}) = -l, \quad S_l - \bar{X} < 0
\]

on the interval \([n - M, n]\). Values determined on this interval \((B_m - \min B_m)\) and \((\max B_m - B_m)\) are compared with the threshold \( h \). When the value \( h \) exceeds one of the quantities, a decision is made on discord, the filter parameters are assigned initial values, and filtering continues from moment \( n - M \).

The above algorithm was once used by the authors to study processes in blast furnace production, but it has never been used to study temporary self-similar traffic.

4 EXPERIMENTS

During the experiment, teletraffic analysis was carried out in the following media service platforms: Microsoft Teams, Google Meet, Zoom. For this purpose, the cross-platform client-server program iperf3 was used, which allows testing network throughput. With its help, the maximum network bandwidth was measured and load testing of the communication channel was carried out. Statistical information about the state of the communication channel was collected using the Wireshark traffic analyzer program, which allows us to view all traffic passing through the network in real time. Various types of traffic were considered: audio traffic; audio traffic plus video traffic with minimal change over time; audio traffic...
plus video traffic with a maximum change in video image in video time [30].

This information served as the basis for forecasting the bitrate in the media service platform under study. Based on the same information, the relative forecast error was calculated.

5 RESULTS

A study was conducted of the dynamic changes in voice and video traffic over time (Fig. 1–6). Here the real traffic statistics are shown in red; traffic estimate is shown in blue; the predicted bitrate is shown in green.

The dependence of traffic intensity (bit/s) on time at the input of the Google Meet media service platform was obtained for real statistics, estimation and forecast.

The studies were carried out for the case of voice traffic (Fig. 1).

The dependence of traffic intensity on time at the output of the Google Meet media service platform was studied for real statistics, estimated and forecast. The studies were carried out for the case of voice traffic (Fig. 2).

The dependence of traffic intensity on time at the input of the Zoom media service platform was obtained for real statistics, estimated and forecast. The studies were carried out for the case of voice traffic (Fig. 3).

The dependence of traffic intensity on time at the output of the Zoom media service platform was studied for real statistics, estimated and forecast. The studies were carried out for the case of voice traffic with minimal changes in the video image over time (Fig. 4).

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The dependence of traffic intensity on time at the input of the Microsoft Teams media service platform was obtained for real statistics, estimated and forecast. The studies were carried out for the case of voice traffic only (Fig. 5).

The dependence of traffic intensity on time at the input of the Microsoft Teams media service platform was studied for real statistics and forecast. The studies were carried out for the case of video traffic with a maximum change in the video image over time (Fig. 6).

6 DISCUSSION

In this work, we implemented a method for estimating and forecasting non-stationary time series based on a polynomial representation of the state transition matrix of the Kalman filtering procedure. The problem of filter discord due to the finite order of the approximating polynomial was solved by means of an original algorithm for detecting discord in tempo with the process. The algorithm is quite simple and does not require large time and software resources. It should also be noted that the proposed modification removes the requirements for stationarity and normality of the processed processes, as well as for knowledge of the initial conditions.

The analysis of the dependence of traffic intensity on time showed that the assessment of incoming traffic and traffic forecast in media service platforms (Fig. 1, Fig. 3) have relative errors of 4.44% and 0.64%, respectively. At the same time, traffic leaving the media service platform has a significantly lower level of relative errors,
0.028% and 0.037%, respectively. This indicates fairly accurate forecasting.

The analysis of experimental data showed that the method can be effectively (with a small error) used to predict teletraffic in media service systems.

In addition, since the stochastic characteristics of the processes under study differ from classical Gaussian ones, it can be argued that the proposed estimation and forecast procedure is invariant to the stochastic properties of the processes and does not require strict restrictions.

CONCLUSIONS

The explosive and self-similar type of traffic in modern information and communication networks requires the development of forecasting methodology to prevent network “overload”. The analysis of teletraffic in media service platforms requires special attention. The development of a universal methodology for analyzing traffic behavior in media service platforms will make it possible to “include” various methodology in order to prevent “overload” of the network.

Traffic forecasting allows network operators to monitor the health of the network and respond to the occurrence of anomalies or problems, including reporting a cyber-attack on the network. Traffic forecasting methodology allows you to plan customer service, including setting limits on the volume of traffic during peak load.

The scientific novelty of the results obtained lies in the fact that for the first time an original methodology for predicting bitrate in various media service platforms was proposed, and proposals were also developed for choosing the optimal characteristics of the signal model to achieve a minimum prediction error.

The practical significance of the results obtained is that an original algorithm for estimation and predicting the characteristics of media traffic has been developed. Recommendations for improving the technology for building media service platforms are formulated. It is shown that the bitrates generated by various media service platforms, in the case of applying the proposed estimation and forecast methodology, are invariant with respect to the type of stochastic processes undergoing assessment and forecast. The results obtained can be applied to the study of fractal random processes.

Prospects for further research is research in the direction of comparative analysis of forecasting results for various types of approximating polynomials.

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Прогнозування телетрафіки в медіасервісних системах

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Анотація

Актуальність. Розвиток інформаційно-телекомунікаційних технологій призвело до зростання обсягу інформації, що пере- силається через мережу. Медіасервіси платформи відіграють важливу роль у створенні та обробці бітрову інформації в інформаційній мережі. Тому існує необхідність у розробці методики прогнозування бітрову в різних медіасервісних платформ шляхом створення ефективного алгоритму, що мінімізує помилку прогнозу.

Мета. Метою роботи є синтез в аналітичній формі матриці переходу фільтра Калмана для нестационарних самоподібних процесів при прогнозуванні бітрову в телекомунікаційних мережах.

Метод. Розроблено методику прогнозування телетрафіки в медіасервісних платформах, засновану на модифікації фільтра Калмана для негаусівських процесів. Ця методика використовує орієнтуальну процедуру підрахунку статистики, яка дозволяє знижувати помилку фільтрації та прогнозу, що виникає внаслідок невизначеності аналітичної моделі досліджуваного

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процесу. Методика не вимагає знання аналітичної моделі процесу, а також жорстких обмежень на його стохастичні характеристики.

Результати. Запропоновано методику оцінки та прогнозу бігруту в телекомунікаційних системах. Дана методика застосована для дослідження процесів телетрафіку в медіаєрвісних платформах Google Meet, Zoom, Microsoft Teams. Досліджено проходження реального бігруту через зазначені медіаєрвісні платформи. Проведено порівняння реального телетрафіку з прогнозованим телетрафіком. Досліджено вплив порядку матриці переходу фільтра Калмана на похибки оцінки та прогнозу. Встановлено, що навіть невисокий (другий) порядок матриці переходу дозволяє отримати задовільні результати прогнозу. Показано, що застосування запропонованої методики дозволяє прогнозувати трафік з відносною помилкою близько 3–4%.

Висновки. Розроблено оригінальний алгоритм оцінки та прогнозу характеристик медіаефекту. Сформульовано рекомендації щодо удосконалення технології побудови медіаєрвісних платформ. Показано, що бігрут, що породжуються різними медіаєрвісними платформами, у разі застосування запропонованої методики оцінки та прогнозу інваріантний щодо типу оброблюваних стохастичних процесів.

КЛЮЧОВІ СЛОВА: фільтр Калмана, телетрафік, медіаєрвісна платаformа, стохастичний процес, самообмінний процес.

ЛІТЕРАТУРА


