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# Method for QOE monitoring and increasing in cellular networks based on QOE-to-QoS mapping using spline approximation

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article

## Abstract

The current level of development of the cellular services market, qualitative changes in the means and methods of providing services, and the increased volume and diversity of information circulating in cellular networks have evoked the need for service quality assessment system improvement. To maintain competitiveness, the main efforts of operators are aimed at improving quality and increasing the service life of subscribers in the network by ensuring the required level of customer satisfaction in high-quality services through a system of organizational–technical and socioeconomic measures to bring the achieved level of quality-of-service (QoS) provision in accordance with the existing, emerging, or projected needs of subscribers. To achieve improved QoS provision, a functional relationship between network parameters has been established: The impact of key performance indicators on a key quality indicator through the use of cubic Hermitian splines (CHS) has been determined. The use of splines, as a signal model, can significantly improve the quality of signal processing due to the continuity of values and partial derivatives in the joints of spline gluing. CHS are characterized by calculation simplicity, as they provide high-speed computing, which, in turn, is important for real-time work when processing large data sets. Experimentally, it was shown that the use of splines allows for the ability to calculate statistical estimates of the required parameters of spline approximations, but also their confidence intervals, which increases the accuracy and probability of further calculations and is a distinct advantage of this approach. Also, the methods of service quality management through machine learning have been improved, which are effective tools for modeling integrated indicators of communication services quality control, monitoring their condition in terms of final copies of services, determining the causes of degradation, and reporting. It monitors the service performance provided by the cellular operator. Finally, the method checks the readiness and availability of services, detects network nodes through which quality degradation occurs, collects various quality metrics, and compares them with pre-installed quality indicators.

**Keywords:** 5G, Mobile network, QoE, QoS, Estimation, Spline approximation, Monitoring, Cellular network

## 1 Introduction

Permanent and balanced development of the communications domain is inseparably connected with increasing subscriber volume and provided services. On the one hand, there is user interest for new service receiving, while on the other hand, competition forces providers to permanently bring in new suggestions for the connection market [1].

Cellular connection service market modern development level, qualitative changes of devices and service supply method, and increasing the information volume and multidimensionality that circulates in the cellular networks have been put forward for service quality evaluation system modernization problems that define implementation levels of competitive advantages by cellular connection providers.

In the name of competition preservation, providers are increasing the quality and size of network user servicing duration with the development of special loyalty programs and the creation of effective promotion systems of existing and brand-new additional cellular connection services [2].

The high-quality service required for high user satisfaction levels is complex and searches for a system of organizationally technical and socially economical events in the name of achieved service quality level reduction with respect to current, inceptive, or forecasted user requirements. Exposed circumstances defined the actuality of problem development connected to the evaluation and control of cellular connection quality.

### 1.1 General methods for QoE and QoS definition

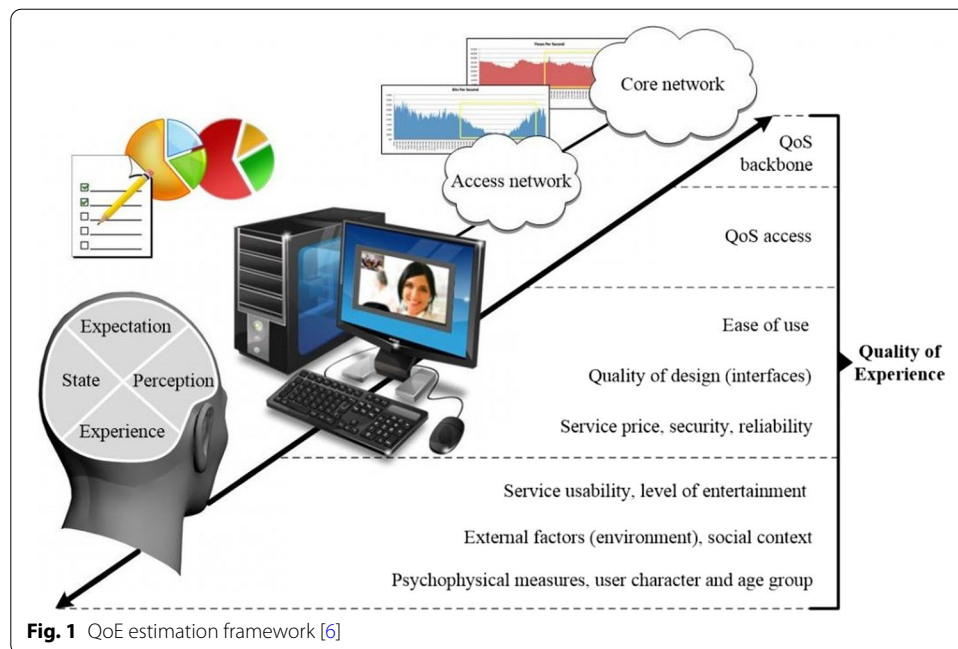
4G system key productiveness indicators (KPIs) [3, 4] connected to network productivity are derived from previous KPI systems, where network productivity was considered a key factor in network measurements. Cellular network providers define several limit values for each KPI, below which a network would be considered ineffective. With increased income, providers are constantly oriented to QoE end-users, but problems remain because of the user culture and requirements changing it as a driving force of cellular broadband connection and IP transformation.

User demands and network quality expectations are constantly increasing, which creates a brand new definition of network quality. In some cases, despite the fact that network KPIs point to good network productivity, many providers are still dealing with user complaints about background noise during voice calls and slow webpage loading.

QoE foresees complex psychological and physiological factors [5]. When the question is about service provider or about some concrete network productivity, QoE belongs to end-user satisfaction (Fig. 1) [6].

Factors influencing QoE can be divided into technical and nontechnical [7]. Technical are factors connected to terminals and networks, and nontechnical are factors that are connected to politics and services provided by cellular operators. It is difficult to quantitatively define QoE value through network monitoring, and there is a not unified criterion for QoE measurement at the domain [8].

For the evaluation of the values received by service quality monitoring results, statistical data must be calculated with reference to measurements on real traffic [9]:



1. for output requests in representative summation of basic stations to representative summation of destinations;
2. test calls in the representative population of base stations or publicly used separate networks of portable (cellular) connections to the representative population;
3. combinations of the above-mentioned variants.

Usage of test calls or linkings for data transfer is often quite expensive. Observations based on signal information are cheap but are unreliable.

Measurements on real traffic and inner service quality automatic control are accomplished with the help of special technical instruments that do not allow staff interference to support rate and service quality parameters control.

By utilizing the test (control) calls, availability rates, for example “time of the call ending,” are being evaluated. Control calls accomplished on the answering machine are connected to the international telephone network, or the public uses networks of portable (cellular) connections for the monitoring procedure [10].

An external method could be statistical data exchange with the administrations of other providers of international and national networks.

Each method has its advantages and disadvantages. With the exception of service quality being received by multiple methods, the following sources are also being used:

- user complaints;
- information from other cellular connection providers;
- domain statistical reports of cellular connection providers;
- reports of connection providers accomplishing traffic transit through the network of another provider interested in high-quality service for their users;
- data regarding traffic volume measurement.

Statistical methods for designated information processing are used in [11]. With a limited quantity of observations, given methods can generally adopt valid solutions regarding service quality. For clarity, during statistical data processing, tabular and graph-analytical methods for received materials representation are being used. For example, for the readiness rates calculation statistical telecommunication technical device demurrage data, telecommunication networks and systems unpreparedness data are being used. During processing, a time frame is chosen for statistical data processing. Herewith, statistics are based on the results of week and month time frame measurements, neglecting detailed data and statistical method usage.

Mobile network operators (MNOs) are also using smaller or larger data gathering periods. Quarter term data that are able to provide adequate information are optimal for the majority of service quality parameters [12].

Statistical data analysis methods are also used in calculating several values and availability parameters (percentage of faults, effective call, or connection attempts, etc.), quality of voice information transferring, and other rates characterizing quality of provided services.

An additional type of user preference examination is a reference analysis about the low-quality service. User reports have been documented, and MNO has procedures for received data processing. User report analysis is used for service quality rate and user service quality definition.

MNOs are obliged [13] to collect the statistics of service quality rates for the aim of internal control (audit) within the limits of current enterprise quality control system.

However, effectiveness rate monitoring is not enough for service quality amelioration. Providers are often having problems with identification or problems that occur with wireless networks, nucleus, or service network. The basic goal of the work is taking place in instrument development that would control and evaluate network status by active testing and passive monitoring. When service quality deteriorates, instruments are needed to analyze the problem from the service layer to the bottom layer, finding the primary cause of service degradation in such a way.

## 1.2 Related work

However, in [11] the whole evaluation process has been presented, and it does not include the influence of different user factors for QoE. The forecast model in [11] was optimized in the development [14, 15], considering user viewing time, pause time, and other factors [16, 17]. However, there is no concrete formula, it was just proved that taking into account user behavior factors can increase the QoE forecasting model accuracy. The hypothesis about the existence of training connection between the application network traffic behavior and each respective QoE marker represented in [18] is a new approach. This approach works in the following way: First, the control system data are gathered, where the provider has some service traffic, as the QoE metrics of service. Next, the machine training algorithm is used to learn the dependency function between these rates [19]. The given method fits as the provider for quality support, as the infiniteness of network service providers allows them to analyze different anomalies at furnished services. Furthermore, it could help in diagnosing poor quality using the significant network functions definition. Nonetheless,

these methods have limits because of the uncertainty of given data, bad modeling of the behavior of users at needed service and different training methods have different influences on the analysis quality. More complicated training methods can further increase QoE model certainty.

On the basis of the Q-learning algorithm in [20], an HTTP adaptive streaming (HAS) client configured to the network status has been proposed. Considering the speed demands for video, network capacity, and repeated buffering, an equation for MOS [21, 22] receiving in [18] has been proposed.

Karim et al. [23, 24] proposed the model for QoS and QoE measurements of image formats in social cloud computing, but did not propose any model for mapping of these estimated parameters. A method for QoE assessment for videos in social clouds was developed in [25]. Similar method [26] was also proposed for calling services in social network and cloud gaming [27]. Some dependences between QoE and QoS were investigated in [28], but these studies were related mostly to the physical KPIs.

### 1.3 Problem statement

The aim of this paper is monitoring and increasing of the service extension quality of cellular connection providers based on interconnections installed between the key quality rates using spline approximation.

To achieve these goals, the following interconnected problems must be solved in this development:

1. To analyze modern cellular connection systems for the aim of structural system definition, that are in charge of service providing quality control and pointing of its disadvantages.
2. To define basic key effectiveness rates of the cellular network that have significant influence on service, providing quality to the users by cellular connection providers.
3. Method development of dependency between cellular network parameters for service providing quality evaluation.
4. To develop experimental research of the novel method.

## 2 Method of service quality control

The previous year's tendency, associated with the increasing telecommunication services market, has significantly changed the cellular providers' strategy. For the protection of market share, providers are forced to not only modernize technically provided cellular services that are being provided to the user, but also understand their support services with such challenges as [29]:

- user loyalty increasing;
- new user attraction;
- fast solutions of emerging problems;
- monitoring of service quality in online mode;
- decreasing demurrage time during failures.

The service quality control method, based on machine training, is an effective instrument for integral connection service quality control indicator modeling, monitoring of its status in the context of service-end specimen, searching for degradation reasons, and reporting the organization. It looks after the supplier by the provider service working capacity. Furthermore, this method determines service readiness and availability and locates the network nodes through which quality degradation takes place.

During method development, the following basic goals are being set:

1. Quick use starting: availability of a typical template set of quality values and reports.
2. Flexible solution: quick creation of new service types and quality rates, thus adaptation to the cellular connection provider individual demands.
3. Integration with any OSS/BSS provider system.
4. Each SLA-type control.

Service quality control method's graphic representation is shown in Fig. 2.

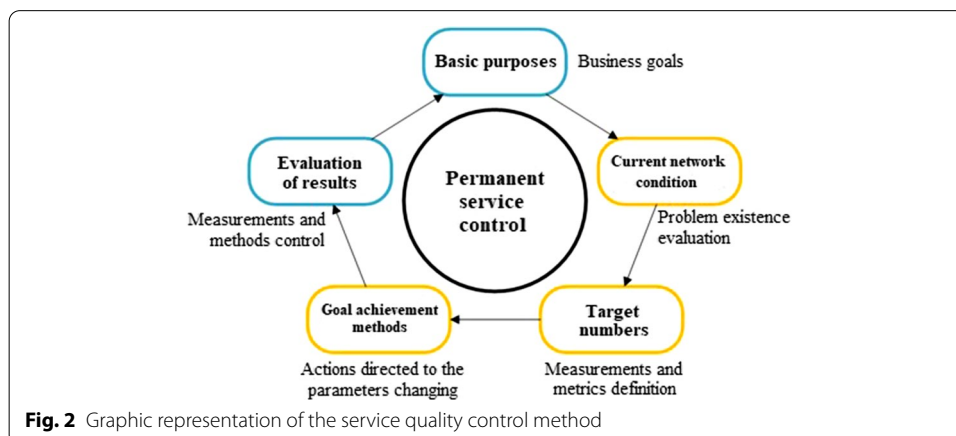
A significant place in the control process is taken by user satisfaction characteristics definition process, or QoE. Herewith, each network service provider strives to objectify the QoE parameter evaluation. So, the designed method has been proposed to be used at the given development (Fig. 3).

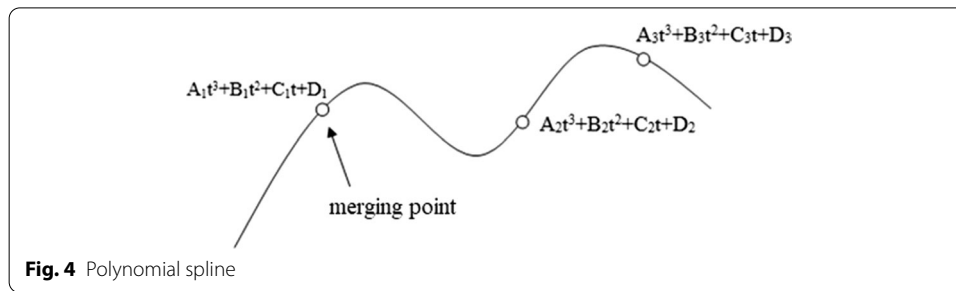
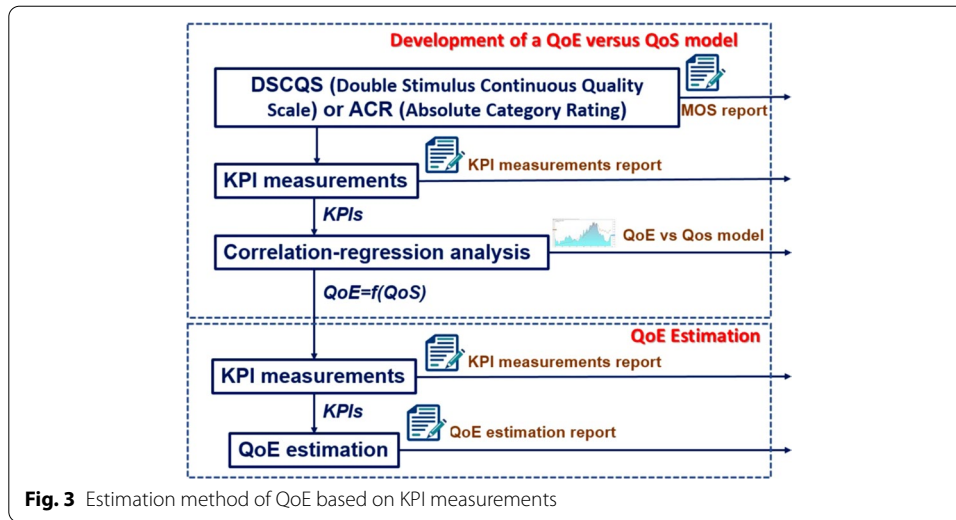
## 2.1 Definition of functional dependency between network parameters based on the spline utilization

To provide quality by increasing the use of the developed method (Fig. 3), the functional dependence between network parameters must be defined, or the influence of KPI on key quality indicator (KQI) must be defined [30].

The challenge of functional dependency installation between parameters KPI and KQI could be solved using spline utilization. Using splines, condition [31] must be strictly utilized, which provides steadiness and differentiability (natural smoothness) into merging point (Fig. 4).

It must be mentioned that a basic advantage of splines is calculation simplicity and analysis. Simultaneously, this class of mathematical instrument is considered the best of the linear instruments of approximation.





Over the last years, much research has been focused on developing and analyzing the variety of splines used for a large spectra of applicable goals [32, 33]. However, there is a problem in the understanding of such a form of spline construction that provides effective work during programming.

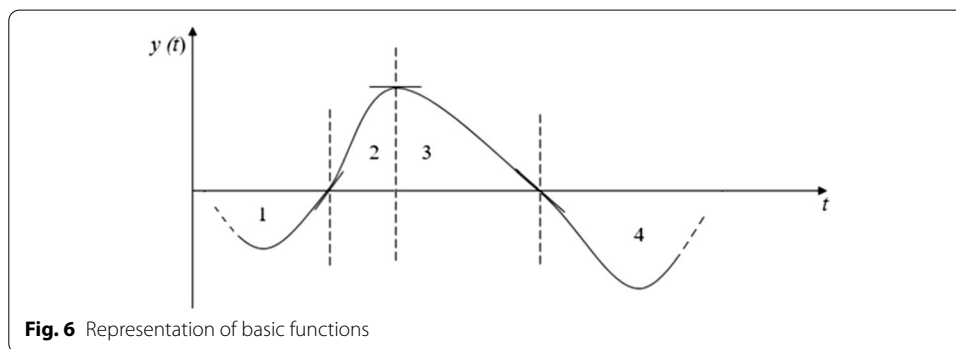
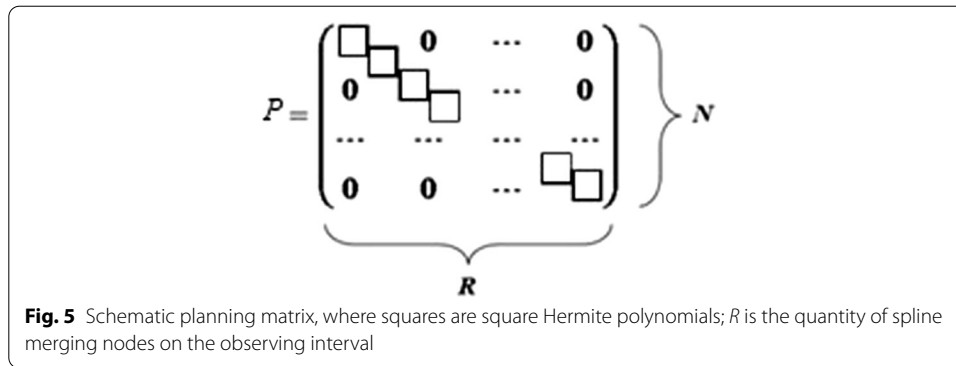
At the same time, numerous developments of many authors indicate smoothing features of splines that provide minimal values of root-mean-square failures [34, 35]. Nevertheless, such splines cannot provide guarantees for formal, theoretically proven speed work during the processing of large data arrays.

Considering [36] spline advantages, it would make sense to use them for defined problem solving.

There are many different ways of spline construction on the basis of their species [34], and the most are local cubic Hermite splines (CHS) [35]. It differs from global versions by the calculation simplicity and effect that it guarantees high-speed work during calculations that, in return, are significant for the work in real time during large data array processing.

For the construction of CHS, merging nodes are located in such a way that spline on the whole interval satisfies conditions of a least squares method (LSM):





$$\sum_{i=1}^N [Sp_i - y_i]^2 = \min, \quad (1)$$

where  $N$  is the quantity of counts on the observing interval;  $i$ —count sequential number;  $Sp_i$ —spline;  $y_i$ —input data.

After defining Formula (1), it can be shown that the summarized square excursion from the function approximated by  $y_i$  is minimal.

By the next step, planning matrix  $P$  that has block-diagonal structure later on the local function features can be calculated (Fig. 5).

For this, the grid of nodes  $\Delta_R$  was found, onto which a spline was constructed. It must be noticed that observing grid  $\Delta_N$  and grid of nodes are not necessarily equal, or, in other words, on each grid section, several observations can be located defining the dependency behavior.

Each row for CHS consists of four basic functions, where an approximate view is represented in Fig. 6. Each has a form of cubic polynomials sewed together by the conditions of polynomial steadiness and steadiness of the polynomial first derivative in merging node.

Let us rewrite expression (1) in matrix view:

$$[Sp - Y]^2 = \min \quad (2)$$

where  $Y$  is the input data vector.



$$Y = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_N \end{bmatrix},$$

where  $y_1$ - $y_N$  are the input data values.

Let us describe  $Sp$  spline in the following way:

$$Sp = P * A \quad (3)$$

where  $P$  is the planning matrix;  $A$  is an ordinate vector of spline node merging.

For the construction of the whole CHS, the  $A$ -spline ordinate vector of the merging nodes must be calculated and it has the form of:

$$A = \begin{bmatrix} a_1 \\ a_2 \\ \vdots \\ a_R \end{bmatrix}$$

where  $a_1$ - $a_R$  are the rates of the spline merging nodes ordinates.

The node ordinate evaluation can be found by the method of least squares, where their optimal rates are constructed relative to maximum verisimilitude.

Sought parameters can be found by way of matrix equation system solving. Considering the (3) expression, the  $A$  vector can be found:

$$A = \left( P^T * P \right)^{-1} * P^T * Y \quad (4)$$

Let us introduce the following markers. Let us assume that

$$C = P^T * P, \quad (5)$$

$$B = P^T * Y \quad (6)$$

Considering expressions (5) and (6), let us rewrite expression (4) in a simplified view:

$$A = C^{-1} * B$$

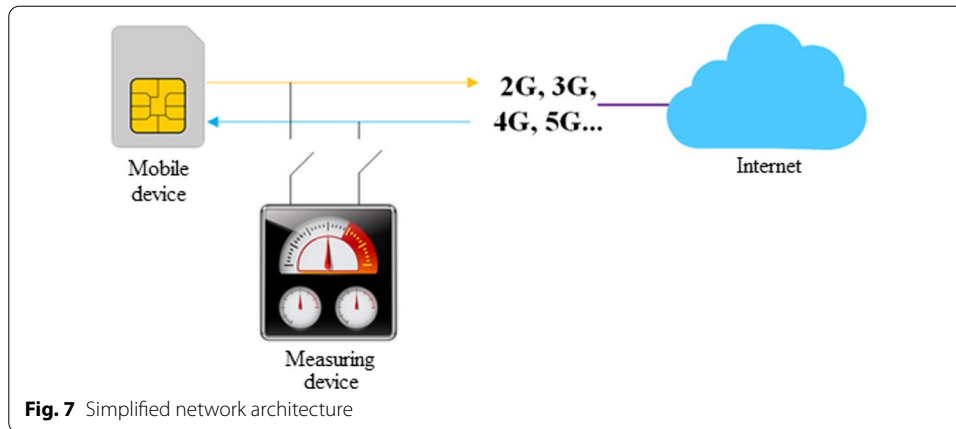
where  $C^{-1}$  is the correlation failure matrix LSM.

It can also be noticed that  $C^{-1}$  is independent of input countings and can be calculated preliminarily and interweaved in the calculating device memory.

For the CHS using the evaluation of modeling dependency between cellular network parameters, KPI and KQI can be utilized.

### 3 Experimental research

Within the developmental limitations, the service of Internet access based on the 3G cellular connection technology was checked [32]. The loading of the video file on the mobile device from the Internet has been done (Fig. 7).



The KPI parameters were fixed on the measuring device: input stream speed  $Y1$ , outgoing stream speed  $Y2$ , delay  $Y3$ , the power of signal  $Y4$ ; on the side of user—KQI parameter—video file loading time  $Y5$ .

The experiment consisted of 100 tests. Data were received at unchangeable external conditions for experimental clarity support.

As indicated, the main task is establishing a functional relationship between the parameters of the network KPI and KQI. First of all, it is necessary to approximate the parameters using CHS.

We present the values of the measured parameters in matrix form. For compactness of material, 1 and 100 values are resulted:

1. input stream speed, Mb/s:  $Y1 = [1.5649452272; \dots 0.5580357144]$ ;
2. outgoing stream speed, Mb/s:  $Y2 = [0.9987815608; \dots 0.421874176]$ ;
3. delay, ms:  $Y3 = [165; \dots 184]$ ;
4. power of the signal, dBm:  $Y4 = [-67; \dots -55]$ ;
5. video file loading time, s:  $Y5 = [0.1180952384; \dots 2.5355704696]$ ;

Let us calculate planning matrix:

$N = 50$ ;

$t = 1:N$ ; coordinates of countings of the observing function;

$tu = 1:(N - 1)/9:N$ ; coordinates of spline merging nodes;

$[nill, n] = \text{size}(t)$ ; quantity of observing countings;

$[nill, r] = \text{size}(tu)$ ; spline merging node quantity;

$p = \text{creat\_ps}(tu, t, n, r, 2)$ ; matrix of planning, parameter 2-cubic spline;

$$p = \begin{pmatrix} 1.0000 & 0 & 0 & 0 & 0 & 0 \\ 0.8026 & 0.2112 & -0.0138 & 0 & 0 & 0 \\ 0.5900 & 0.4527 & -0.0427 & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & -0.0427 & 0.4527 & 0.5900 \\ 0 & 0 & 0 & -0.0138 & 0.2112 & 0.8026 \\ 0 & 0 & 0 & 0 & 0 & 1.0000 \end{pmatrix}$$

On the basis of received data for each parameter, the spline merging nodes ordinate vector could be calculated and the approximation procedure by using the CHS could be proceeded:

1. input stream speed  $B = p^*Y1$ ;

$$COB = ((p^*p)^{-1});$$

$$A1 = COB * B; \text{ordinates of the spline merging nodes}$$

$$SP1 = p * A1; \%SPLINE$$

2. outgoing stream speed  $B = p^*Y2$ ;

$$COB = ((p^*p)^{-1}); A2 = COB * B;$$

$$SP2 = p * A2;$$

3. delay  $B = p^*Y3$ ;

$$COB = ((p^*p)^{-1}); A3 = COB * B;$$

$$SP3 = p * A3;$$

4. power of the signal  $B = p^*Y4$ ;

$$COB = ((p^*p)^{-1}); A4 = COB * B;$$

$$SP4 = p * A4;$$

5. video file downloading time  $B = p^*Y5$ ;

$$COB = ((p^*p)^{-1}); A5 = COB * B;$$

$$SP5 = p * A5;$$

In Fig. 8a, the result of input stream speed data approximation process by the cubic hermit spline with marking of the spline merging nodes is depicted. The graph in Fig. 8b shows the results of outgoing stream speed data approximation by the CHS with merging node marking. In Fig. 8c, approximation result of the experimental test delay data can be seen. In Fig. 8d, the result of signal power data approximation is shown. Correlating the data of delay and signal power, it can be seen that they are intercorrelating. In Fig. 8e, the approximation result of KQI parameter by the CHS with marked spline merging nodes can be seen.

The next step is the definition of the influence degree of the KPI parameters on KQI:

$PP = [SP1, SP2, SP3, SP4]$ ; matrix of KPI approximated parameters.

$AA = ((PP^*PP)^{-1}) * PP^*SP5$ ; coefficients of KPI parameters analytical connection to KQI

$$AA =$$

$$- 1.6011$$

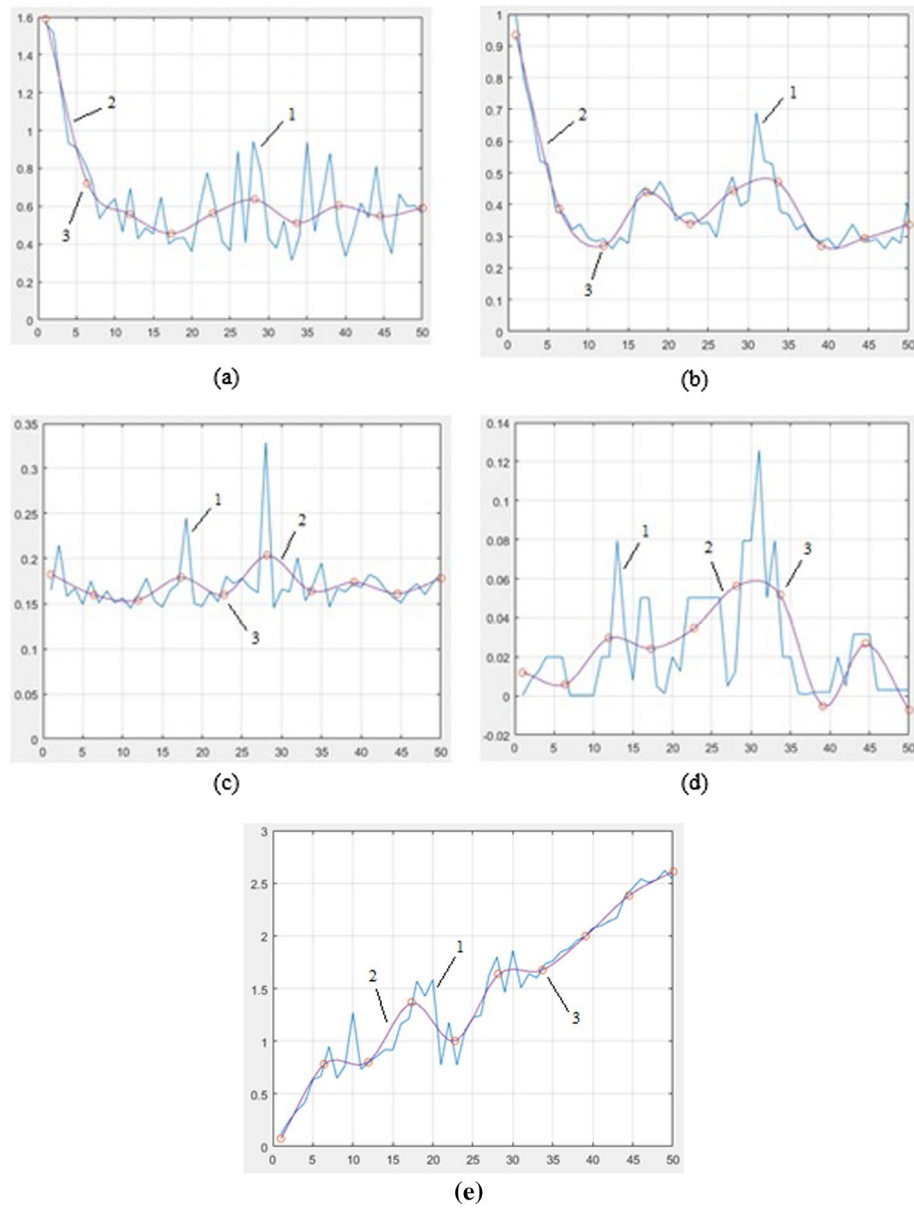
$$- 0.9741$$

$$18.3845$$

$$- 11.4475$$

Analytical connection coefficients can be found under the condition that root-mean-square forecast failure of the KQI parameter from the KPI parameters would be minimal.

On the basis of received data, a conclusion can be drawn that the greatest influences on the video loading time are the delay value and value of signal power.

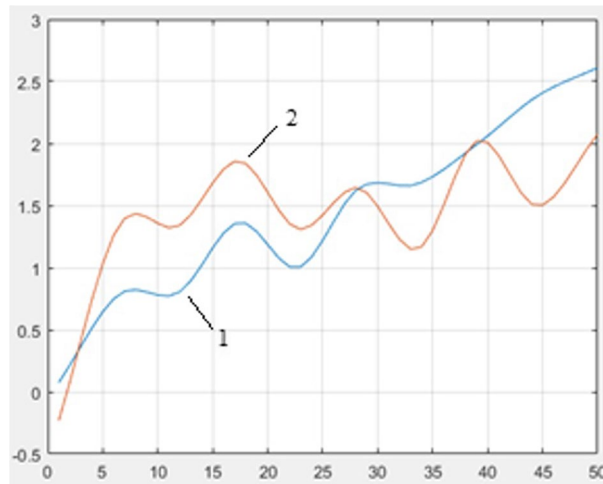


**Fig. 8** Input stream speed approximation: 1—curve of measured values; 2—curve of approximated values; 3—merging nodes (**a** input stream speeds; **b** output stream speeds; **c** delays; **d** powers of signal; **e** video file loading time)

On the basis of the above-mentioned data, the statistical equalization of the KQI parameter time rows can be completed, or, in other words, the equalization of KQI process physics on the basis of already determined approximated KPI parameters (Fig. 9).

$$\Phi = (PP * AA - SP5)^2 = \min$$

$$KQI = KPI(1) * AA(1) + KPI(2) * AA(2) + KPI(3) * AA(3) + KPI(4) * AA(4)$$



**Fig. 9** The result of KQI parameter alignment: 1—curve of approximated values; 2—curve of aligned values

$$SP5E = SP1 * AA(1) + SP2 * AA(2) + SP3 * AA(3) + SP4 * AA(4);$$

The use of splines allows the ability to not only find statistical estimations of the spline approximation required parameters, but also their confidence intervals, which increases the accuracy and probability of further calculations, which is a definite advantage of the chosen approach.

In our case, it allows us to receive the KQI forecast from the KPI changing. At the perspective of discovery, under such conditions, the next step would be the realization of concrete parameter KPI selection for the modernization and increased user service providing quality level.

#### 4 Conclusions

The cellular network key effectiveness indicators (KPI) and quality indicators (KQI) have been considered in current development, and the hierarchy of their interaction that defines product quality for the satisfaction of some adequate level designed by the cellular provider has been defined. It is mentioned that during the selection of some indicators, needed for an adequate service quality evaluation, it is necessary to minimize their quantity and take into account possible “cross-point” influencers of the separate KPI on several different KQI. The parameters and quality indicator summation are needed to reflect all basic interaction quality criteria of cellular instruments with telecommunication network and of user with telecommunication service as product, that is designed by cellular provider, respectively, to ETSI TS 102 250-1.

In the development, for the aim of the interdependence between QoE and QoS parameters definition, polynomial splines with basic matrix disengaged structure were used. They provide high-speed work during spline calculation, which, in return is very important for real-time work during large data array processing.

In addition, a universal form of spline construction is presented for applications in telecommunications, primarily for efficient operation during programming. Namely, a

clear software implementation of splines in the MATLAB programming environment is presented.

Therewith, modeling by the developed spline constructing form has been accomplished. In this result, it allows for the determination of the analytical function of the polynomial spline and proves effective filtration features and spline smoothing. Calculated results of root-mean-square departure of polynomial spline from useful signal  $\sigma_s = 0.0082$  are approximately 30 times less than root-mean-square departure of noisy signal from useful signal  $\sigma_n = 0.2313$ , which shows the effective statistical alignment of the noisy signal.

To achieve the task of improving the quality of services, a method is proposed for determining the functional dependency between network parameters, i.e., the impact of key performance indicators on a KQI through the usage of CHS. This method evaluates the degree of influence of each of the KPI parameters on the KQI parameter with a future average data forecast, which leads to the implementation of the choice of a certain KPI parameter for its further improvement or optimization. At the same time, the developed method differs in simplicity of calculations due to what provides high-speed calculation that, in turn, is important for work in real time during large data set processing.

#### Abbreviations

5G: Fifth generation of mobile networks; BSS: Base station subsystem; CHS: Cubic Hermitian splines; HAS: HTTP adaptive streaming; KPI: Key productiveness indicator; KQI: Key quality indicator; LSM: Least squares method; MNO: Mobile network operator; MOS: Mean opinion score; OSS: Operation support system; QoE: Quality of experience; QoS: Quality of service; SLA: Service-level agreement.

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#### Author contributions

JAA participated in the definition of the main idea of the research, design of the study and performed the statistical analysis, contributed to the definition of the most relevant KPIs and KQIs, and performed editorial work. RO has developed the estimation method of QoE based on KPI, contributed to the design of the study, performed editorial work, and helped to draft the manuscript. AA contributed to the definition of functional dependency between network parameters based on the spline utilization, performed experimental studies and analysis, and contributed to the analysis of general methods for QoE and QoS definition. SB participated in the definition of functional dependency between network parameters based on the spline utilization and performed related works analysis. All authors read and approved the final manuscript.

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#### Availability of data and materials

Data sharing is not applicable to this article as no data sets were generated or analyzed during the current study.

#### Declarations

##### Competing interests

There are no competing interests.

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