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Continuous Monitoring System for Estimation the Quality of Service of Computer Network

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Abstract: The aim of this study is to develop a method for evaluation of service quality estimations in continuous monitoring system for computer networks. The computer network is considered as dynamic system with service functionality objects. We proposed the composed concept of quality of service evaluation in conditions of continuous monitoring process. It is suggested to reduce the services state estimation to the forming of qualitative estimates of a state and calculating a trend of these estimates values. Practical significance consists in rising of networks controllability and decreasing its exploitation cost by the possibility of the service quality analysis, forecasting its changes, which allows making the appropriate control decision. The method is based on consideration the service as the functional network object describable with the set of service state indexes, which are varying in time. Quality if service is also determined by the set of these indexes and also varies in time. The suggested method allows us to estimate the service by its quality in the current time and by the forecasted quality for the next two times taking in account given values of thresholds. It is also proposed to evaluate service quality indices as quantity on time and prediction estimations. Correctness of the solutions is proved by examples.

Key words: Estimation parameters, services, quality index, quality of service, estimation of quality, monitoring

PROBLEM DESCRIPTION AND ANALYSIS OF THE KNOWN RESEARCHES RESULTS

Computer networks become inalienable part of any enterprise infrastructure today. The complexity level of computer network rises and in the same time the issues of more effective using of available information resources become up-to-date too. Information resources are inseparable from information services which provide the access to the resources (Sommers and Barford, 2004). Together with the computer network complexity the number of supported services increases and the current resource load rises (Broun *et al*., 2008). The most part of the computer networks works in the condition of tight resources that is why the problems of the estimation of supported services quality become particularly urgent. In the technical sources these problems are known as the QoS (Quality of Service) estimation.

For any computer network the problem of the selective (one-time) QoS estimation can be well-formalized and solved, e.g., in (Al Rawajbeh *et al*., 2009). In this case we obtain static estimation and an object, i.e., computer network, is considered as a static one (dynamic characteristics are not taken into account (Lu *et al*., 2009).

In the situation when the computer network is considered as a dynamic system, the problem of the QoS estimation becomes much more complicated (Schubert and Boche, 2005; Abouaissa, 2009). The fact is that a station of the dynamic system must be described with some continuous function and therefore a QoS index must be described with a continuous function or estimated with some discrete dimension intervals.

This problem is not new and there are different solutions for different classes of systems (e.g., Shiping and Greemfield, 2004) analyze the quality evaluation method of Java messages service in terms of dynamic changes o f a computer network status. Lee *et al.* (1999) described the methods of forming the quality factor for dynamic evaluation, with that it is supposed to consider latencies and rejects in the network as unique parameters determining quality (Liu *et al*., 2004). An interesting solution is described by Sayenko *et al.* (2005). It is dedicated to estimation of several services used for providing the best local resource use conditions of the network. Nevertheless, questions related to generalize formalization of the quality estimation methods still remain unstudied. In particular to provide QoS and manage it is quite difficult task. Therefore, it is a

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big challenge but it is very necessary to give affordable solution (Shirahase *et al.*, 1999). In Clark and Gilmore (2006) and Curtis and McGregor (2001) concerned with the quantitative core of an SLA (Service Level Agreement) and consider parallel structures and approaches to calculate the QoS estimations.

This study is a continuation of the article (Al Rawajbeh *et al.*, 2009) which describes a method of the quality estimation of information services in a computer network. The method is determined as a static object. It provides a generalized estimator by comparing several quality indexes.

The purpose of the article comes to searching ways to estimate network services in a dynamic change of basic characteristics of a network.

Problem formulation describes the network as an object of research. Also the concept of the service quality estimation is described. In the paragraph Computation of the service quality index the summary of the method (Al Rawajbeh *et al.*, 2009) is given. Then the choice of weights and the formation of the qualitative estimators, finding and estimating of trend are described. There is also a description of the method of service state estimation in the article as a generalization and systematization of the preceding paragraphs. After a brief analysis of the method we give an example. Finally the main scientific and practical results are formalized.

PROBLEM FORMULATION AND DESCRIPTION OF THE RESEARCH OBJECT

Let us assume that a computer network Net is given. There are some users in the network $U = \{u_i\}$, $i = 1..p$. Services supported by the network are its main functional units $Stype = \{stype_j\}$ $j = 1..p$. Users request the network about granting a certain type of a service. When the request is satisfied, the network creates an instance of service $s_{i,j}$, where i is a user of a service, j is a type of a service. The quality index QoS $(s_{i,j})$ can define this service $s_{i,j}$. Hereafter, we propose to suppress indexes for service instances, assuming that any instance is defined by a service type and a user: for $\forall s_{i,j}\ \exists u_i \in Uu\ \exists stype_j \in SType$, that is why let us calling $s_{i,j}$ just s.

In most cases the quality of users' service is determined in the specific Service Level Agreement and is given as a delimitation of observable parameter, e.g., $d \le d^0$. Access latency to a resource d should not be superior to some threshold value d^0. While the network is active the access latency value is a function (Fig. 1). Therefore, values of the quality index also change in time.

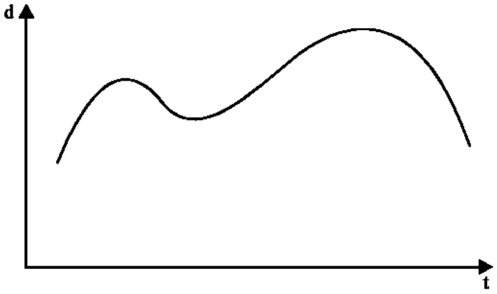

Fig. 1: Change of time latency in using some service

Thus, to evaluate characteristics of the service quality is necessary to answer questions, which determine the estimation method. Some of them are:

- How to estimate the quality index? Obviously it must be a discrete estimation in the real conditions
- At what intervals should we estimate it?
- What is considered as a point index? Should it be multiple or averaged value?
- What to do with values accumulated in time?
- What to do with obtained number results? How to estimate them?

Modern technologies for system status scanning suppose special systems of continuous network monitoring. In the context of building of such systems a solution for the service status evaluation is proposed.

So the problem formulation amounts to the development of methods for system status estimating in systems of continuous network monitoring. Basically it is supposed to use the method proposed by Al Rawajbeh *et al.* (2009).

Concept of service quality estimation in the computer network: The quality index QoS(s) is considered on basis of certain state parameters $[q_{ji}]$. These parameters obtain definite values at every instant. Every index reflexes some feature of the network.

$$QoS(s) = f(q_1, q_2, \ldots, q_n) = f(q_i) \qquad (1)$$

where, i is a sequence number of service s state index, n is a number of state indexes, QoS(s) the quality index, non-dimensional quantitative value.

For every service type $stype_i$ (and in general case for a user, i.e., an element s) delimitations, e.g., threshold values, are set. $QoS^a(s) = (q_1^a, q_2^a, \ldots, q_n^a)$, $QoS^b(s) = (q_i^b)$, $i = 1..n$ lower and higher boundaries of the state indexes. Required values of the state indexes $QoS^o(s) = (q_i^o)$, $i = 1..n$ are set in accordance with SLA for each user. In addition the relation $QoS^a(s) \le QoS^o(s) \le QoS^b(s)$ is fulfilled.

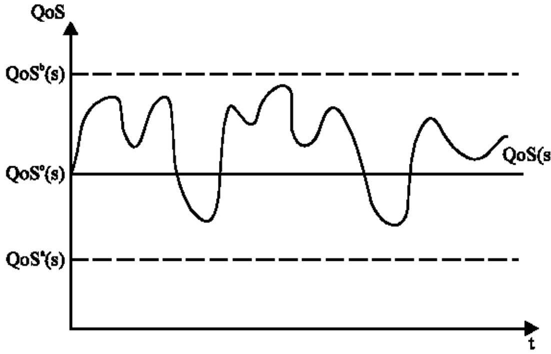

Fig. 2: Relation between quality service index and threshold estimations

Permitted deviations of required indexes are defined as $\Delta qoS(s) = (\Delta\Delta_i)$.

A relation between computational estimation QoS(s, t) and threshold estimations is depicted on the Fig. 2.

The estimation of QoS(s, t) is carried out discretely, with a specified discrimination interval and subsequent interpolation (preferably linear).

The choice of the discrimination interval is performed depending on the task of monitoring (maximum loads monitoring, standard monitoring, monitoring of configuration changes result).

As point values we take QoS(s, t) = QoS(s[t_k]), where, [t_k] is a discrete point of measurement, we choose some averaged value QoS(s[t_k]). With that:

$$QoS(s,[t_k]) = f(q_1[t_k],q_2[t_k],\ldots,q_n[t_k]) \tag{2}$$

The index QoS(s,[t_k]), accumulated in the process of state parameters measuring, is maintained only during some history, which is determined by a task type and taking into account the effect of information aging.

Bearing in mind that a problem of the index value control is up-to-date in the systems of continuous monitoring, we propose to use qualitative values instead of numerical values of the quality index. In addition we put a new scale for estimation of the quality index.

We propose to use the numerical values of the quality indexes to form an estimation of a process behavior trend QoS(s, t_k), in view of the information aging for the set of history of discrete values QoS(s,[t_k]).

The main requirements to the method of service quality estimation are:

- Non-resource-intensiveness, for on-line computation performing
- Interpretability, visualization

Computation of the service quality index: The service quality index QoS(s) is a non-dimensional quantitative value, calculated on the basis of predefined indices of a process observed and its characteristics. As a basis we take the method proposed by Al Rawajbeh *et al.* (2009).

QoS(s) = f(q_1, q_2,..., q_n) is correct. We use the weighted sum of normalized state estimations as the function f(), then:

$$Q\tilde{o}S(s) = \frac{\sum_{i=1}^{n} w_i \tilde{q}_i}{\sum_{i=1}^{n} w_i} \tag{3}$$

where, $Q\tilde{o}S(s) \in [0, 1]$, $\tilde{q}_i \in [0, 1]$.

The index (Eq. 3) is considered on the interval of rated values [q_i^a, q_i^b], specified for the network and the index q_i. Values $\tilde{q}_i$ should be homogeneous to give us the possibility to use the Eq. 3.

Homogeneity is considered in terms that $\tilde{q}_i$ should be defined on the interval [0, 1] and for every $\tilde{q}_i$ the relation: $\tilde{q}_i \rightarrow opt \sim \tilde{q}_i \rightarrow max$, must be fulfilled, i.e., an optimal value for the index can be found only when it increases. We use the operation of normalization and rate setting in order to ensure homogeneity $\tilde{q}_i$ of all the state indexes. The constraint $\tilde{q}_i \rightarrow max$ provides the normalization and the generation ($q_i \in [-\infty, \infty]$)→($\tilde{q}_i \in [0, 1]$) provides the rate setting. Normalized and rated estimation results from the generation:

$$\tilde{q}_i = \left(\frac{q_i - q_i^a}{q_i^b - q_i^a} \right) \tag{4}$$

Forming and choice of the weight numbers: Weight numbers make it possible to increase or lessen the influence of any factor on the value of generalized estimation. Usually the weight number w_i is set on the interval $w_i \in [0, 1]$ that is why it is interpreted as the coefficient of reduction for some factor. In such a case the following formula is used in Eq. 3.

In general cases the number can be set in integers in any rank scale. If so we can use such a transformation formula:

$$w_i = \frac{w'_i - w'_{min}}{w'_{max} - w'_{min}}$$

where, w'_i is any rank, w'_{min} are boundary values of the evaluation scale we use for rank evaluation.

Such an approach allows the administrator to use more flexible rules of displaying the value of any index to evaluate the state of the service.

Forming of qualitative evaluation: According to the Eq. 3 we get the value of quality index for QoS(s) in current time. When in the system of current monitoring this value conveys nothing and what is more the stored values remain unused. Instead it is better to use the value $Q_1(s)$, which reflects the relative state of service in current moment of time with reference to boundary values. To calculate the comparative value we use the boundary values according to the specifications for the index q_i-$\{q_i^a, q_i^b, q_i^o \Delta q_i\}$.

In general case it is impossible to set the QoS specifications in advance because of the low interpretability of this parameter. In the same time we can concretely and accurately set the same specifications for q_i index. But if we need qualitative evaluations for QoS(s) index we should take relative values QoS(s) instead of absolute q_i values.

Considering the limitations of q_i let us calculate the corresponding values for QoS(s), that is $QoS^a(s) = 0$ the lowest operating limit, $QoS^b(s) = 1$ the highest operating limit. The term operating means that $QoS^a(s)$, $QoS^a(s)$ are set in such a conditions that any q_i changes within the acceptable range $[q_i^a, q_i^b]$.

It is important to mark that when we use the method of continuous monitoring, the value QoS(s) may be greater than 1 and lesser than 0. In the course of functioning of the system the values of q_i may exceed the range of $[q_i^a, q_i^b]$ and than QoS(s) can be either $QoS(s)<0$ or $QoS(s)>1$.

That is why it is considered that the system is in the state of relatively normal functioning if the following constraints are performed:

$$0 < QoS(s,[t_k]) < 1 \tag{5}$$

$$\forall i \; 0 < \tilde{q} < 1 \tag{6}$$

The Eq. 6 is more strict than the Eq. 5.

The system should function in such a way that SLA demands are fulfilled. Than we can calculate the next two values that correspond to the required range of value. Thus, we have (q_i^o) and $(\Delta\Delta_i)$, so $QoS^c(s)$ and $QoS^d(s)$ correspondingly the highest and the lowest boundaries will be acquired as:

$$q_i^c = q_i^o - (g_i) * \Delta q_i \tag{7}$$

$$q_i^d = q_i^o + (g_i) * \Delta q_i \tag{8}$$

Where:
1, if $q_i \rightarrow opt \sim q_i \rightarrow max$
-1, if $q_i \rightarrow opt \sim q_i \rightarrow max$
$G = (g_i)$; $g_i = \{\}$

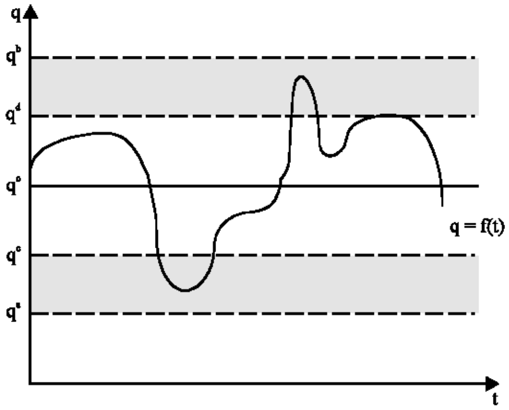

Fig. 3: The correlation of limitations and service state measure

Table 1: Qualitative estimates of a service state

Rating $Q_1(s)$	Condition
Very bad	$QoS(s)<0$
Bad	$0<QoS(s)<QoS^c(s)$
Normal	$QoS^c(s)<QoS(s)<QoS^d(s)$
Good	$QoS^d(s)<QoS(s)$
Very good	$QoS(s)>1$

$$QoS^c(s) = \frac{\sum_{i=1}^{n} w_i \tilde{q}_i^c}{\sum_{i=1}^{n} w_i} \tag{9}$$

$$QoS^d(s) = \frac{\sum_{i=1}^{n} w_i \tilde{q}_i^d}{\sum_{i=1}^{n} w_i} \tag{10}$$

The correlation of threshold indexes of state with varying in time measure of state is shown on Fig. 3.

Qualitative estimates are suggested to be formed on the ground of some scale (Table 1). The following values of the estimation are acceptable:

$$Q_1(s) \in \{ \text{<perfect>}, \text{<good>}, \text{<satisfactory>}, \text{<bad>}, \text{<very bad>} \}$$

Trend estimation: All the previous results have covered derivation of pointed estimates and did not take into account dynamics of the process. It is quite enough for solution of the current monitoring tasks for QoS(s). Using of $QoS(s, [t_k])$ the cumulative results over some interval $[T_o, T_n]$ allows forecasting of current values and estimating a trend of the process. The general purpose of such operation consists in more exact estimation of the current situation. In this case, it is suggested to forecast by two steps forward. We use a linear regression which is built on the ground of least-squares method to calculate the forecasting estimates on the dataset (history) with

Table 2: Qualitative estimates of a forecasting state

Estimate $Q_2(s)$	Condition
Very bad	$QoS'(s)<0$
Bad	$0<QoS'(s)<QoS^c(s)$
Normal	$QoS'(s)>QoS^c(s)$

length r = 5. Quantity r = 5 is accepted as axiomatically correct for QoS calculation processes. The point is that dataset with length $r \le 3$ is not initially representative, but with r = 10 it is excessive big as there is an actual amount for QoS values in the interval $[t_{k-2}, t_{k+1}]$ on the subset $\{t_{k-2}, t_{k-1}, t_k, t_{k+1}\}$.

By this means for the estimation of service Q(s) state we add the estimation of the state of a forecasting measure of quality $Q_2(s)$ (Table 2). $QoS'(s) = QoS(s, [t_{k+2}])$ current moment of time t_k. Estimate possesses three states:

$$Q_2(s) \in \{< \text{Very bad} >, < \text{bad} >, < \text{normal} >\}$$

ESTIMATION METHOD

The estimation method will be presented as a list of operations:

- Choosing an observable service $s_{i,j}$ of a definite type $stype_j$, for some user $s_{i,j}$
- Determining a vector $(q_1, q_2,..., q_n)$ of state measures for chosen instance of a service $s_{i,j}$
- Defining a new significance weighting coefficient w_i for each measure
- Performing the operations of fixing and normalizing in conformity with Eq. 4
- Calculating a quality measure QoS(s) Eq. 3
- Determining quality measures for thresholds Eq. 7-10 and form the conditions for quality estimate $Q_1(s)$ receiving subject to threshold requirements
- Calculating an estimate of forecasting state $Q_2(s)$
- Determining a final state of the system in a functional form $Q(s) = (Q_1(s, [t_k]), Q_2(s, [t_k]))$

Analysis of method: The described method possesses the following characteristics:

- Operability of calculation, not resource-intensively it is attained by a small number of analyzable values
- Possibility of a threshold specifying-minimal and maximal acceptable measures of quality given by a set of state measures are taken into account in this method
- Possibility of operating with the different types of indexes to form a complex estimation. Quality index is calculated from a set of parameters conditioning quality of service by Al Rawajbeh *et al.* (2009)
- Possibility of changing the influence of different service parameters on final estimation. Indexes weights can vary with priorities variations
- SLA requirements accounting
- Possibility of forecasting an index by two steps forward
- Possibility of the service state detection (whether it is enhancing or impairing)
- Good interpretability (possibility to present graphics or estimation scales on the method's operation results)

EXAMPLE

Service s is a TCP service. Program application is an IP Telephony application stype=<TCP,IP phone>.

State indexes are defined as $QoS(s) = (q_i) = (b, d)$, where, b is a data transferring rate in kbps; dis a latency (time interval between sending and receiving data in msec) Table 3.

There are indexes measured for time t_k, where, k = 1..5. The current time is t_k, k = 5.

There are threshold values of state indexes, QoS optimal state indexes and acceptable variation of state indexes given:

$$QoS^a(s) = (100\ \text{kbps}, 150\ \text{m sec}),\ QoS^b(s) = (390\ \text{kbps}, 25\ \text{m sec}),$$
$$QoS^o(s) = (150\ \text{kbps}, 60\ \text{m sec}),\ \Delta QoS(s) = (10\ \text{kbps}, 10\ \text{m sce})$$

We have to estimate a service state by determining the quality in the current time k = 5, determine a trend and also estimate the forecasted value.

Let's intake the weight coefficients on the ground of an expert estimation on the interval [0, 1]: W = (0,2;0,8).

Let's represent Eq. 2 as a matrix with given values, then norm and normalize state indexes Eq. 4.

$$QoS(s,[t_k]) = \begin{pmatrix} 300 & 30 \\ 320 & 36 \\ 325 & 40 \\ 381 & 60 \\ 390 & 90 \end{pmatrix}$$

$$Q\tilde{o}S(s,[t_k]) = \begin{pmatrix} 0.69 & 0.96 \\ 0.75 & 0.912 \\ 0.78 & 0.88 \\ 0.97 & 0.72 \\ 1.00 & 0.48 \end{pmatrix}$$

Meanwhile number of columns equals to number of state indexes Eq. 2 and number of rows equals to length of a values changing history Eq. 5:

Table 3: Values of data transferring rate and s_i Latency for service in times t_k

k	b $[t_k]$ (kbps)	d$[t_k]$ (m sec)
1	300	30
2	320	36
3	325	40
4	381	60
5	390	90

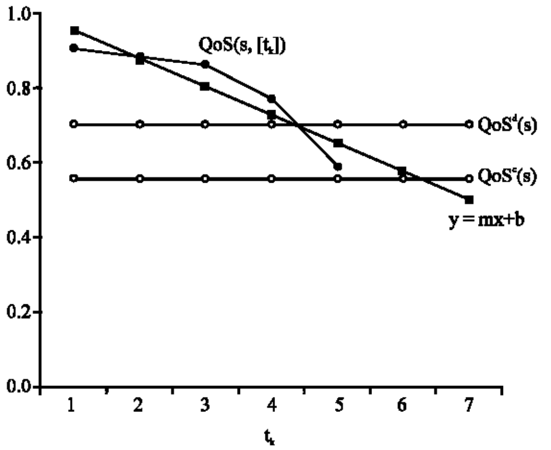

Fig. 4: Correlation of thresholds, approximating function and quality indexes values

Calculating quality index by (3): $Q\tilde{o}S(s) = Q\tilde{o}S(s, [t_5])$ = 0,58

Determining quality indexes for thresholds: $QoS^a(s) = 0$, $QoS^b(s) = 1$, q_1^c = 140 kbps; q_2^c = 70 m sec.

q_1^d = 160 kbps; q_2^d = 40 m sec by Eq. 8 meanwhile G = (1,-1). Calculating quality indexes for required quality thresholds: $QoS^c(s) = 0.56$ by Eq. 9, $QoS^c(s) = 0.7$ by Eq. 10.

Determining quality estimation in consideration of threshold requirements: according to Table 1 the condition $0<QoS(s)<QoS^c(s)$ holds, which corresponds to $Q_1(s)$=<normal> estimate.

Let's calculate forecasting state value by determining numerical values of quality indexes for times t_k, where, k = 1..5: $Q\tilde{o}S(s, [t_k])$ - (0.9; 0.88; 0.85; 0.76; 0.58).

Determining the process trend for suggested technique of estimation. Use a linear regression y = mx+b to obtain QoS(s, $[t_k]$) values for points [k+1] and [k+2]. m and b coefficients are determined on the ground of dataset with length r = 5 by least-squares method: m = -0.08; b =1.03. Meanwhile linear function takes on form y = -0.8x+1.03. The correlation between QoS(s, $[t_k]$) values, regression function values and thresholds is presented on Fig. 4.

According to the Table 2 obtaining $Q_2(s)$=<bad>, as the condition $0<QoS'<QoS^c(s)$ holds.

Thus the system state for a point of current monitoring estimates as $Q(s) = Q_1(s, [t_k]), Q_2(s, [t_k]) = =$ (<normal>, <bad>). The summary is that the system requires the control action to avoid further quality deterioration.

RESULTS

There is a service state estimation method within the bounds of continuous monitoring systems creation and development suggested. Service is considered as the functional network object describable with the set of service state indexes, which are varying in time. Quality if service is also determined by the set of these indexes and also varies in time. The suggested method allows us to estimate the service by its quality in the current time and by the forecasted quality for the next two times taking in account given values of thresholds..

The scientific novelty: It consists in the further development of service state estimation method. It is suggested to reduce the services state estimation to the forming of qualitative estimates of a state and calculating a trend of these estimates values.

Practical significance: It consists in rising of networks controllability and decreasing its exploitation cost by the possibility of the service quality analysis, forecasting its changes, which allows making the appropriate control decision.

Comparing with the best analogs: The given work can be regarded as the further development of the ideas stated by Al Rawajbeh *et al.* (2009), which allows us to determine the dynamic changes in quality of service. Unlike the works (where estimation is performed only for specified service types (Shiping and Greemfield, 2004) or on the ground of previously defined service state parameters (Lee *et al.*, 1999), this method suggests a generalized formal apparatus for the estimation of services quality. The results can be used together with the methods (Sayenko *et al.*, 2005) for the estimation and control of quality provided.

Directions of further research: The further work will be directed to determining of policy rules influence on services quality (under specified quality requirements) methods creation.

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