APPLICATION OF STRUCTURED QUEUING NETWORKS IN QOS ESTIMITION OF TELECOMMUNICATION SERVICE

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ABSTRACT

We present the structured queuing network as effective mathematical model of telecommunication system; this model is oriented on the analysis of delay in telecommunication networks. A set of special components are identified for providing structurization of such models. QoS parameters: the average delivery time and the utilization coefficient are calculated for MPEG video LAN implementing structured queuing model. In this paper, we propose the use of structured queuing networks to model high speed communication networks, which is more adequate than conventional analytical models, and expends less computational time than simulation models.

Keywords: QoS; *Modeling; Structured Queuing Networks; Closed Heterogeneous Queuing Networks*

1. INTRODUCTION

During analysis and design of asynchronous telecommunication networks using different protocols of packet switching, the development of mathematical tool for delay analysis of data transmission over such networks is actually. This task is especially actually for communication networks, which had been increased the productivity for providing various multimedia services. Traffic of services in telecommunication network, by nature, has synchronous character, but passed by asynchronous mode, and functioning of these services substantially sensitive to delay of traffic and, especially sensitive to Jitter.

Real telecommunication network have large dimension, irregular, dynamically change structure and provide a set of services with heterogeneous traffic. The evaluation of delay in such networks is very serious task. Difficulty of their estimation is caused by the fact, that information elements of traffic undergo casual delay during transmission over network. This delay is formed by sum of delays produced by each component of the network which contribute in the routing process of traffic elements.

Routing, in general, considered to be random and depends on the current status of the network. Thus, the average delay and Jitter values of delivery time for some information element of traffic is determined by the distribution of delay probabilities to all possible routes in the network.

In order to support multimedia traffic over digital networks, it is important to assure service qualities; delay, jitter and bandwidth. In general, modeling of digital networks supporting multimedia traffic is complex and thus QoS estimation is challenging.

For the estimating of QoS in high speed telecommunication network, the simulation methods using queuing analysis, Markov models can be applied [1] [2]. Also, in paper [3], simulation study of the VoIP packet traffic on a network of routers has been used to investigate QoS of Internet voice communication (VoIP). In works [4]–[7] Markov models and queuing analysis have been used to model the transmission of multimedia data over communication networks over various architecture (GSM and CDMA wireless networks, ATM -networks, and others). There were a lot of works, which investigate transmission of multimedia traffic over IP–networks [8]–[13].

Usually simulation methods are used to research such communication networks. But this approach has a series of limitations. These models either suppose fixed structure of modeled network, do not take account of transferring multimedia traffic, nor do not consider transport and network protocols. In addition simulation methods are complicated. There are great difficulties in adequate representation of the transmission of multimedia traffic by analytical models. In this paper, we propose the use of structured queuing networks to model such high speed communication networks, which is more adequate than conventional analytical models, and expends less computational time than simulation models.

The complexity of QoS estimation over communication network arises from several factors. Some of them are listed below:
– Large scale communication network and its complex topology;
– Large number of clients;
– Complex distributed operating algorithms in communication equipments;
– Unreliability of communication equipments;
– Stochastic and heterogeneous traffic characteristic;
– Service of real-time and multi-media applications.

Currently there are only a few models for some communication networks with particular topologies, in which distribution functions for delays are obtained analytically. Even analysis of mean values of these delays is very complex and challenging for general networks.

This paper is organized in 5 sections: parameters and characteristics of closed heterogeneous queuing networks, the structured queuing networks as model of telecommunication system; estimation method of telecommunication system quality parameters, an example network and simulation results and conclusion.

2. PARAMETERS AND CHARACTERISTICS OF QUEUING NETWORKS

Depending on the presence of different classes of jobs, queuing networks are classified to homogeneous and heterogeneous networks [04]. In heterogeneous networks, unlike homogeneous, the jobs, which circulate over the network, have different routes and spend different service time in nodes of their routes. The set of jobs which have identical routes and the same service time in nodes of their routes forms class. Depending on the presence of an external source of jobs in network structure, the queuing networks are separated to open, closed, and hybrid types. In closed queuing network, unlike in open, a constant number of jobs always circulate. In hybrid service network, the number of jobs of one class is constant, and of other classes is not. Recently the closed heterogeneous networks extensively have been implemented. The stationary distribution of closed heterogeneous networks statuses is invariant with respect to distribution function within first two moments of distribution. Furthermore, it is always possible to approximate an open network by closed, replacing the source of jobs by a node and increasing the number of circulating jobs in the network.

The closed heterogeneous queuing networks are generally defined by the following set of parameters [15], [016]:

$$\Gamma = \left\langle L, K, \vec{r}, \vec{W}, \vec{D}, \vec{A}, \boldsymbol{\mu}, \boldsymbol{\Theta}, \vec{\pi} \right\rangle \qquad (1)$$

Where

L — represents the number of queuing systems (nodes);

K — the number of job classes;

$\vec{N} = \{N_k\}$, $N_k \geq 0$ — the initial distribution of $N = \sum_{k=1}^{K} N_k$ jobs of K classes;

$\vec{r} = \{r_i\}$, $r_i > 0$ — the victor of service devises number in a node;

$\vec{W} = \{W_i\}$, — the victor of distribution function (d.f) types for random values (r.v), which determine the service time period for jobs in nodes;

$\vec{D} = \{D_i\}$, — the victor of service disciplines for jobs in nodes;

$\boldsymbol{\mu} = \{\mu_{i,k}(\vec{n})\}$ — the matrix function of service intensity of jobs, where $\mu_{i,k}(\vec{n}) \geq 0$ — the service intensity of job within k-class in i-node, in conditions, that network is in some status $\vec{n}$ taken from status space $\boldsymbol{\Omega}$, that is $\vec{n} \in \boldsymbol{\Omega}$ determines some allowed distribution of N jobs by nodes and classes;

$\boldsymbol{\Theta} = (\theta_{i,k;j,l})$ — the route matrix, where an element $0 \leq \theta_{i,k;j,l} \leq 1$ determines the transition probability of job within k-class, and which is completely served by i-node, to a node with number j and to a class with number l;

$\vec{\pi} = \{\pi_k\}$, $k = \overline{1,K}$, — the victor of priority levels of job class. Here we denote $i, j = \overline{1,L}$, and $k, l = \overline{1,K}$.

Depending on the value ratio of parameters in Γ (expression 1) various methods of queuing networks analysis are used, among which arise exact and approximate methods [15]. These methods provide the calculation of the following basic characteristics of networks functioning in the stationary mode:

$\overline{n}_{i,k}^{\langle u \rangle}$ — mathematical expectation (m.e.) of job number within k-class, existing in i-node;

$\overline{n}_{i,k}^{\langle v \rangle}$ — m.e. of job number within k-class, served in i-node;

$\overline{n}_{i,k}^{\langle w \rangle}$ — m.e. of job number within k-class, waiting in the queue of i-node;

$\lambda_{i,k}$ — job stream intensity within k-class in i-node;

$\overline{v}_{i,k}$ — m.e. of service time of job within k-class in i-node;

$\overline{u}_{i,k}$ — m.e. of existence time of job within k-class in i-node;

$\overline{w}_{i,k}$ — m.e. of existence time of job within k-class in the queue of i-node;

$\overline{t}_{i,k}$ — m.e. of cyclic time of job within k-class that served in i-node;

$\overline{\tau}_{i,k;j,l}$ — m.e. of transition time of job within k-class that served in i-node into l-class and j-node.

3. THE STRUCTURED QUEUING NETWORKS AS MODEL

In the technology of design and development of telecommunication networks an important place is allocated for the use of the specialized software programs in modeling. The effectiveness of the modeling scheme in a given application is defined by the set of basic mathematical models implemented and the representation methods of these models.

Various types of queuing networks occupy one of the main places in modeling process. Furthermore, the increase of computer productivity and the development of effective methods of network analysis enable sharply increase the dimension of models, thus providing their adequacy. For this reasons, the structurization mechanism of queuing networks appears. The development of structurization mechanism of queuing networks pursues the following purposes:

- providing adequacy in the description and presentation of models for real telecommunication networks containing similar components;
- providing the structurization of models with large dimension, facilitates their development and debugging;
- providing the possibility of creation of libraries for standard models;
- providing the realization of hybrid modeling methods for the decomposition of models with large dimension.

For this purpose, we present the structured queuing network (figure 1), in the structure of which except the usual components (nodes (nd), we propose a set of service devices (sv) and job queues (buffers) (bf), jobs (d) within classes (cl), job sources (sr), also a set of specialised components defined: the distribution of job streams (db), which provide compounding and division of different job stream types; modulus (md), which compound in their structure a group of components with different types, and representing subnetwork; couplers (inputs (ic) and outputs (oc), depending on the job stream direction), which determine the location of subnetwork in the queuing network structure, and formed by a pair of components (plugs and sockets); input plug (ip), determine the input job stream to the module; output plug (op), determine the output job stream from the module; input socket (is), determine the job streams directed into the module; output socket (os), determine the job streams directed from the module; plug and socket contacts, which determine some homogeneous elementary stream in heterogeneous structure.

The module of structured network defines the subnetwork, which described by all above mentioned types of components, including the modules. The network related to the inside defined module as super-module, but the module defined in the structure of this module considered as submodule. When the module inters or exits the jobs always change class to sub-module or super - module class correspondingly. When the job served in module and continue serving in super-module it directed to the output plug, accordance to which an output socket is placed. For the beginning of job service in a sub-module the job directed into the input socket, accordance to which an input plug is placed in a sub-module. The number of contacts in corresponding plugs and sockets should coincide, and it is defined by the number of elementary job streams, which form a homogeneous stream on socket. Thus, the module has a set of sockets by means of which it is included in the structured network. Modules are the basic components of the structured queuing networks which provide structurization. Modules can be enclosed in other modules and can contain sub-modules. The module can be removed from the structured network by the separation of the sockets placed on the contour of the given module, and can be replaced with other module according to the stipulated sockets. The components of structured queuing network are defined by corresponding set of parameters.

We supposed that the parameters of components depend on the status of the queuing network defined by a set of variables used for the description of functioning process of the network. On the status of the network can depend: parameters of streams routing from sources, nodes and jobs and distributors; intervals of service duration in devices and intervals between adjacent jobs in streams forthcoming from sources; service disciplines of jobs in node devices; a set of classification attributes of jobs (class number, priority level, task number). For the description of these dependences in the structured queuing network we introduce an auxiliary component — the status of model which defines some aggregated queuing network status, when defined parameter values of components.

In the time of analysis and calculation of the structured network we transform it to non structured queuing network determined by expression (1). Distributor in the structured network is reflected as a node in non structured network which has infinite buffer size and the duration of service is constant and equals zero. Plugs and sockets are reflected in non structured network by distributors with fixed routes for jobs, and their contacts by additional job classes determined both in the module, and super-module.

Probabilistic-time characteristics which related to the structured components are determined depending on the type of these components.

Let to some distributor db from the structured queuing network corresponds one node from non-structured network with number i_{db}, and to module md correspond a set of nodes, distributors, input and output plugs, modules and job classes, the numbers of which constitute the multitude $\mathbf{nd}_{md}$, $\mathbf{db}_{md}$, $\mathbf{ip}_{md}$, $\mathbf{op}_{md}$, $\mathbf{md}_{md}$, $\mathbf{cl}_{md}$, correspondingly. Then the mean value of jobs with all classes in this system, in buffer of this system and in service devices equals zero, $\overline{n}^{\langle u\rangle}_{i_{db},k} = \overline{n}^{\langle w\rangle}_{i_{db},k} = \overline{n}^{\langle v\rangle}_{i_{db},k} = 0$. The mean sojourn time for job in this node, in buffer and in service device also equals zero, $\overline{u}_{i_{db},k} = \overline{w}_{i_{db},k} = \overline{v}_{i_{db},k} = 0$. The intensity of job stream with k-class, enters corresponding distributor, determined by the following expression

$$\lambda_{i_{db},k} = \sum_{i=1}^{L}\sum_{l=1}^{K} \lambda_{i,k} \cdot \theta_{i,l;i_{db},k} . \quad (2)$$

The mean sojourn time $\overline{u}_{md,k}$ for job with k-class, $k \in \mathbf{cl}_{md}$ in module md determined as the average of incoming and outgoing streams intensity of all transition time for job with k-class between input and output plugs of this module as follows

$$\overline{u}_{md,k} = \frac{1}{\sum_{i\in\mathbf{ip}_{md}}\sum_{l\in\mathbf{cl}_{md}}\lambda_{i,l}\cdot\sum_{j\in\mathbf{op}_{md}}\sum_{l\in\mathbf{cl}_{md}}\lambda_{j,l}} \cdot \sum_{i\in\mathbf{ip}_{md}}\lambda_{i,k}\cdot\sum_{j\in\mathbf{op}_{md}}\sum_{l\in\mathbf{cl}_{md}}\overline{\tau}_{i,k;j,l}\cdot\lambda_{j,l} . \quad (3)$$

The mean number $\overline{n}_{md,k}$ of jobs with k-class, $k \in \mathbf{cl}_{md}$ residing in module md defined as the sum of mean number of jobs with k-class in all components of this module

$$\overline{n}_{md,k} = \sum_{i\in\mathbf{nd}_{md}} \overline{n}_{i,k} + \sum_{i\in\mathbf{md}_{md}} \overline{n}_{i,k} . \quad (4)$$

Similarly, other Probabilistic-time characteristics may be constructed, related to some module of the structured network, which are defined as some functional from component characteristics, constitute this module.

4. ESTIMATION OF QUALITY PARAMETERS

The primary goal of modeling and analysis of telecommunication systems is the estimation of quality parameters which this system can provide to subscribers. Two most important quality parameters are the transit delay of transport blocks of the data transmitted over established connection, and also the Jitter of this delay. The estimation of these parameters is especially important in analysis and planning of telecommunication systems which provide the sensitive to time delays- multimedia service.

Most naturally the transit delay is defined as the average transition time of jobs [17] between corresponding job classes and between corresponding nodes of the queuing network (corresponding element of the characteristic $\boldsymbol{\tau} = \left\{\overline{\tau}_{i,k;j,l}\right\}$). The job stream between these nodes and classes in the queuing network displays the stream of transport blocks between server in telecommunication network and subscriber. Consequently, the estimation of Jitter is displayed as the dispersion of transit delay.

Consider an estimation of dispersion $D\left[\tau_{i,k;j,l}\right]$ for the random value (r.v.) $\tau_{i,k;j,l}$, which determines the transition time of some job with k-class, serviced in i-node into j-node and l-class. We assume that, this given r.v. is determined for a multiservice network. Which means, that r.v. $u_{i,k}$ (existence time of job within k-class in i-node) are independent. The r.v. $\tau_{i,k;j,l}$ itself is the sum of random values $u_{i,k}$. Thus, with the assumption of their independence, dispersion $D\left[\tau_{i,k;j,l}\right]$ equals to the sum of dispersions of job existence time in all systems over route between corresponding nodes and classes

$$D\left[\tau_{i,k;j,l}\right] = \sum_{(q,p)\in \mathbf{R}[i,k;j,l]} D\left[u_{q,p}\right], \quad (5)$$

where $\mathbf{R}\left[i,k;j,l\right]$ is a set pair of nodes and classes, which determines the job route between these nodes and classes, $(i,k) \in \mathbf{R}\left[i,k;j,l\right]$, $(j,l) \notin \mathbf{R}\left[i,k;j,l\right]$. Dispersion $D\left[u_{i,k}\right]$ of existence time for job with k-class in i-node may be estimated by the approximation of this job service process to equivalent service process of queuing system with $M/M/1$ type. Then, this dispersion is defined as follows

$$D\left[u_{i,k}\right] = \frac{\overline{v}_{i,k}}{\left(1-\rho_{i,k}\right)^2}. \quad (6)$$

5. EXAMPLE NETWORK AND CALCULATION RESULTS

The above presented methodology is approved by Example computer network (LAN) shown on figure 2, for the transmission of MPEG program (film) on demand.

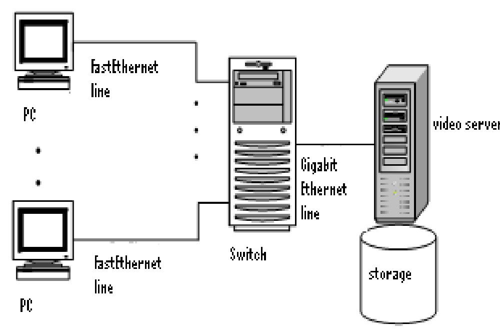

Figure 2. Conceptual LAN model

For the calculation of the number of users, which can receive video films simultaneously, we design a calculation program using MathCAD software and obtain the following results figure 3-4. Figure 3 shows the average delivery time of different I, P and B video frames, according to MPEG-4 standard, transmitted from server to PC, depending on the number of simultaneously receiving films users. Figure 4 represents the utilization coefficient of different LAN components, namely server, switch, Gigabit Ethernet, FastEhernet and PC, depending on the number of simultaneously receiving films users.

The calculation program designed for the structured queuing network model, which applied to the example communication LAN clearly and easily outputs the shown results, from which, it is seen that the average delivery time of I-frame (for example) is greater than for Bframe. This result is intuitively, acceptable due to the difference in size. Also, figure 4 impresses the bottleneck of the modeled LAN, which is the FastEthernet channel. With increasing the number of simultaneously receiving films up to approximately 195 clients the utilization coefficient approaches 0.8.

6. CONCLUSION

Practical experience in modeling of real telecommunication systems shows, that adequate model with large dimension, determined by number of nodes L and number of job classes K, exceeds the possibility of modern computing means. Consequently, the implementation of decomposition methods in telecommunication system modeling is practically the unique way for the solution of this problem. This modeling approach is validated and approved by real LAN and the obtained results are clearly demonstrating the applicability of the structured queuing networks for the modeling of communication networks.

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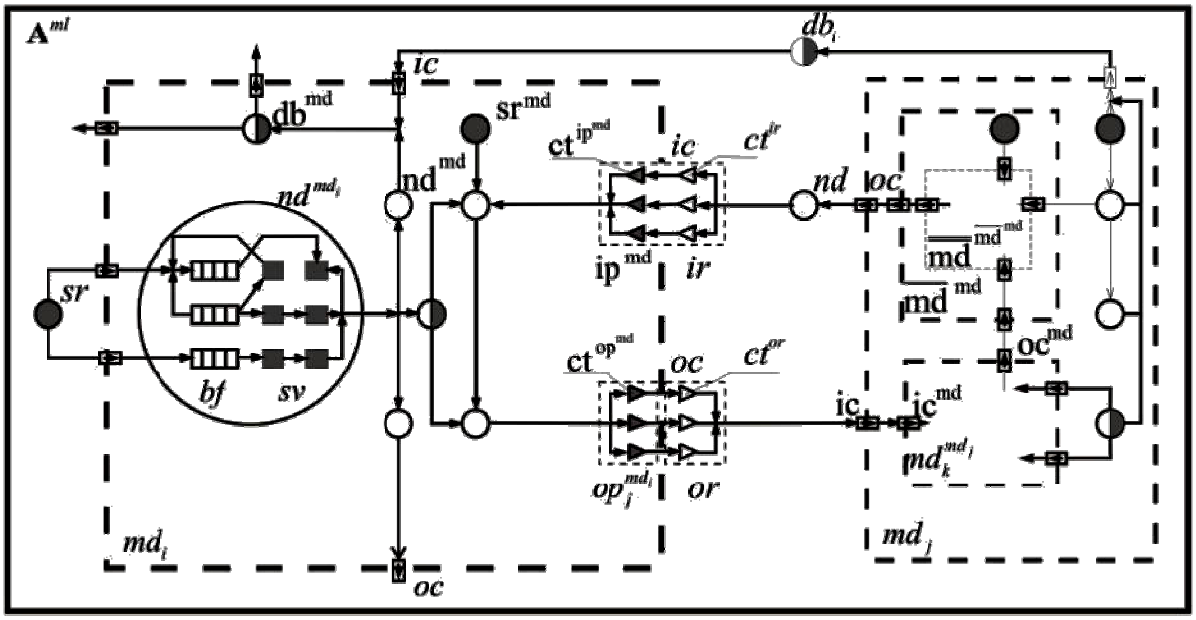

Figure1. Structured queuing network model

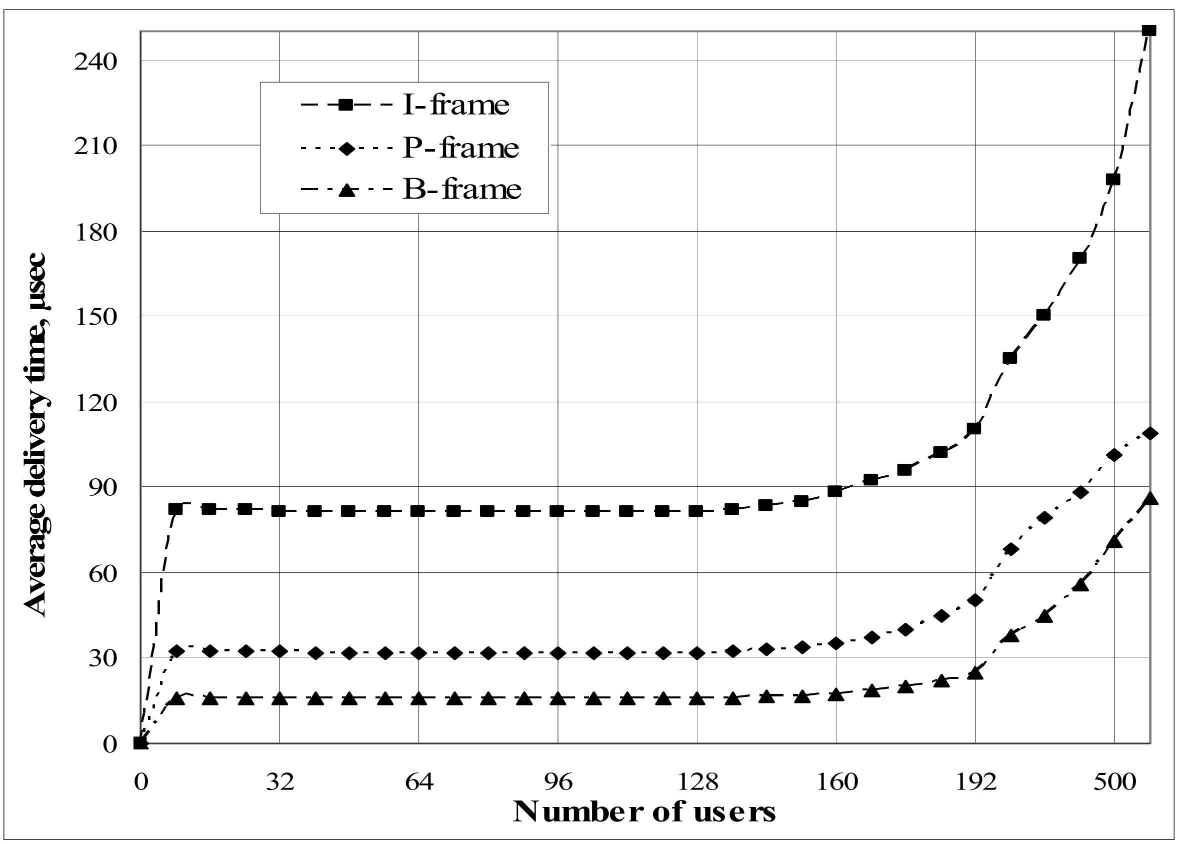

Figure.3.Tthe average delivery time of different video frames, depending on the number of users

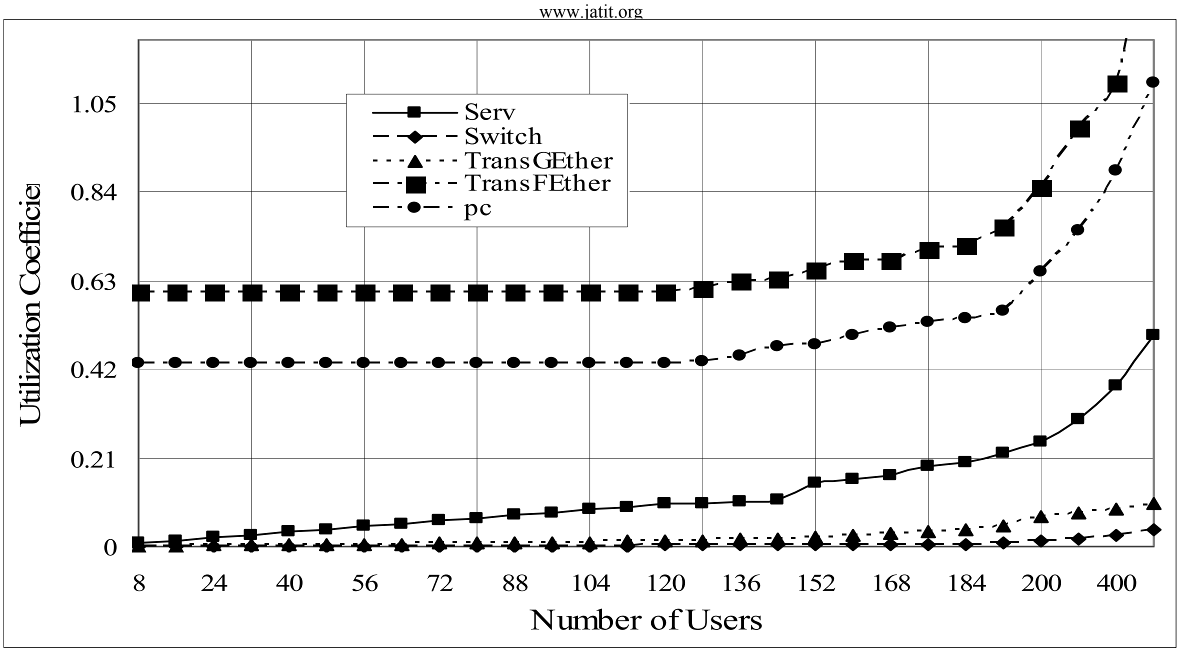

Figure 4. Utilization coefficient of different LAN components, depending on the number of users