

# Analysis and Examine of WAN Performance

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## Abstract

It is tried to define the concepts of WAN (Wide Area Network) performance, to construct a method for calculation of value of WAN performance and to analyze the influence of routes which transmit messages. It is also tried to show the non-regularity of using resources of the given WAN (on the effectiveness of its functioning) by the method of contours[2], method "Dephotomy"[1] and with the help of program which is constructed to tune parameters of the given WAN [3],[4]. It also contains linear and nonlinear equations of the given WAN. It gives possibility to have a quantitative estimation for variants of organization of computer networks during their development.

## Keywords:

*WAN, Network design, Communication channels, Mathematical WAN model, Unit, Transaction, Serving node, Contour*

## 1. Introduction

Now practical interest to computer networks is caused by requirements of users for informational supply. WAN creation demands high expenses, therefore each organization making the network design, wants to have adequate computer system- to obtain necessary level of network quality. Network design needs to take into consideration the specifications of the organization; for software, hardware and data flows. Therefore using standard projects lead to miss important details. That's why it is necessary to take into consideration: network structure, DB design, parameters of hardware (including communication channels), software (structure and parameters), model data flows. So it is necessary to make adequate choice of hardware and software during making the project of WAN. When making the WAN project, it is necessary to use a lot of parameters for functional mathematical WAN model which makes the calculation very complicated [2]. Therefore it is necessary to construct WAN with the help of CAD (Computer-aided Design)[3]. Now, several methods for the calculation of WAN parameters are available. In this case it is necessary to have the most important parameters, time characteristics of WAN. That is why it is reasonable to use the method of contours.

The goal is to formulate a system of interconnected definitions of performance for components and computer networks as a whole, functioning in typical modes after examining the specification of quantitative parameters of

computer networks architecture. The theory allows us to obtain quantitative estimations of computer networks performance in typical modes of functioning. The structure of the computer network defines such basic characteristics: quantity of switching nodes of network servers, groups of users and workstation groups and connection between them. The functional chart contains those elements of a network which bring substantial time delays in processing messages, in opinion of the designer. At this stage contours  $q$  and entering phases for the streams of servicing-messages are determined; it also defines intensity  $\mu_i$  servicing-messages in nodes. In the presence of nodes, having the same servicing intensity  $\mu_i$ , it is considered  $m$  types of servicing nodes (which will be defined in part3).

Network managers frequently want to understand how application traffic is impacting network performance. Using information from calculations based on proposed theory enables you to see which applications are using bandwidth, who uses bandwidth and when it is used. Knowing this, you have a lot of options when performance issues arise : queuing, rescheduling, removing unwanted traffic, reconfiguring applications that devour bandwidth [4]. The goal of making the theory of computer networks (WAN) performance is to develop the theoretical basis of calculation probability-time characteristics of functioning in separate nodes, fragments and computer networks as a whole. Therefore it allows to take into account the characteristics of hardware influenced with stacks of reports, which are used by segmentation of messages and work of users in a dialogue mode. As a result, it is necessary to have short time of data delivering and high performance of computer networks. Therefore, it is required to construct analytical models which give opportunities to make more precise and faster decisions[15],[19].

## 2. Basic Definitions of WAN

Computer network (WAN) is a technical system containing computers, connected by communication devices and liaison channels. WAN provides remote performance of information tasks of users. WAN are complex systems, therefore the efficiency of their functioning cannot be estimated with one indication, and it is necessary to use a set of characteristics. The basic

characteristics of efficiency of functioning WAN are: productivity, reliability, confidentiality of service and cost. The productivity of WAN as the system serving users should be estimated by the number total of information tasks which are carried out by the all devices included into WAN.

Productivity of the devices, carrying out the processing in WAN, is determined by technical and software means of processors, communication devices and channels. The basic problem of productivity assessment implies to the WAN necessity of defining and forming key parameters, which influence the WAN productivity and can be quantified, and also working out formulas, allowing calculating required parameters of WAN productivity. Consequently, in order to define WAN productivity it is necessary to create the model with a set of parameters, reflecting the features of WAN functioning from the point of view of its performance. In order to describe WAN performance it is necessary to define the processing unit.

During remote service on the user's computer the request for processing is formed. This request is transferred through channels as a message. The processing of the request in each computer is carried out according to the program of service given by the user (for example, by the kind of processing included into the list of the menu). According to the type of the program for processing the request the computer carries out the certain number of calculating operations. The processing of the message in devices of switching and in channels first of all depends on the volume of the message, measured in bits. Computer networks carry out functions of transferring and processing of data and carry out request transformation to the message and vice versa[5],[17],[21]. The designation of functionally connected requests and messages we shall call *transaction* defined by two parameters: the volume of the data and the number of the computing operations, which are necessary for processing[15],[16],[19],[18],[20]. That is why we shall consider transactions of different types as the served units of work, which determine the WAN performance. For processing transaction in a channel and in a switching device it is necessary to allocate the resource of bandwidth for the period required for transferring the volume of the data, included into the transaction. For processing transaction in the computer it is necessary to allocate a calculating resource for the period of performing the required number of computing operations. Thus, the processing of transaction of any form can be characterized by the invariant characteristic – the time of the presence of transaction in a *servicing node*. WAN performance from the point of view of the user should characterize the speed of processing the transaction of the type, which is considered. From the point of view of the manager of a network WAN performance should reflect the ability of all the WAN

resources to process transactions at the stipulated speed of service. As a unit of performance we can use both the intensity estimating the number of transactions, processed in a unit of time, and the time during which transaction is processed.

However, it is necessary to point out, that the presence of various types of transactions in WAN may result in the ambiguity of these ratings. Therefore: the structure, the communications and the characteristics of the kind and name of subscribers, and the routes of transactions should be defined. The presence of different requirements and application of decomposition of various degree at the description of processing transactions in WAN results in the necessity of using several ratings of WAN performance forming *system of concepts of WAN performance* to which first of all [6],[7],[8] :

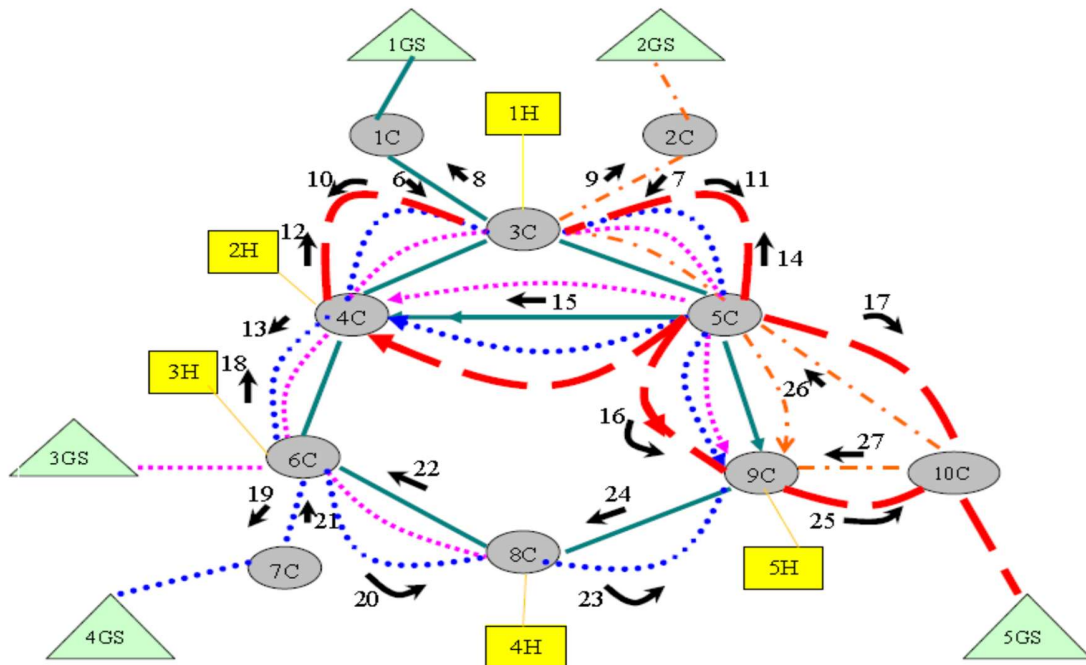
- WAN performance of elements,
- WAN performance of nodes,
- Complex WAN performance,
- Working WAN performance,
- Peak WAN performance,
- Limiting of WAN performance for considered

type of transactions at peak loading.

### 3. Representation of graphical model of WAN for peak loading of 30 subscribers

Graphical model serves for the formalized representation of functional model and allows determining all parameters and characteristics for the mathematical description of model symbolically. Construction of the graphical model begins with uniform numbering of all servicing nodes. Each node is designated by a pointer  $k_i$ ,

where  $i = \overline{1, N}$  and  $N = \sum_m N_m$ . Then the number of nodes in each contour and the values of probabilities  $\langle p_i, j, q \rangle$  are described and obtained. The numbering representation allows writing down all the initial data for calculation of characteristics. An example of numerical models is shown in Figure 1.



**Figure 1** The tested WAN structure ( functional scheme)

Host (servers 1H, 2H,3H,4H,5H) in a remote access mode through communication channels (1K - 22K) and switching nodes (1C-10C) serve user's workstation (1S - 30S) in a dialogue mode. Also there are five groups (1GS - 5GS) which contain workstation:

- Number of servers (Host machines)  $N_h= 5$ ;
- Number of switching nodes  $N_c= 10$ ;
- Number of workstations group  $N_g=5$ ;
- Number of user's workstation  $N_s=30$ , and they are distributed in five groups  $N_{s1}= 4$  (in the first group),  $N_{s2}= 6$  (in the second group),  $N_{s3}= 8$  (in the third group),  $N_{s4}= 6$  (in the fourth group),  $N_{s5}= 6$  (in the fifth group).

Transition to a functional chart of the computer network reflects requirements of the designer or the researcher to construct detailed elaboration of model to some degree, i.e. the functional chart contains those elements of a network which bring substantial delays of time in processing messages, in opinion of the designer. At this stage contours  $q$  and entering phases for the streams of servicing-messages are determined; it also defines intensity

$\mu_i$  servicing-messages in nodes. In the presence of nodes, having the same servicing intensity  $\mu_i$ , it is considered  $m$  types of servicing nodes.

At the given stage three types of devices are selected:

**- Server characteristics**

$m=1$ , a server (H),  $\mu_1= 6$  1/s - intensity of service,  $N_1= 5$  - Number;

**- Communication channel characteristics**

$m=2$ , communication channels (K),  $\mu_2= 4$  1/s,  $N_2= 22$ ;

**- Characteristics of WAN users, which are working in dialog mode**

$m=3$ , workstations (S),  $\mu_3= 0.333$  1/s ,  $N_3= 30$ .

Delays for service in switching nodes are considered by parameters of the related communication channels.

**- Traffic of users' routes**

Groups of users in dialog mode communicate with appropriate file servers. Scheme of the communication for tested WAN can be presented as following:

G1 ↔ H4 (contour q=1) : Server H4 serves groups G1

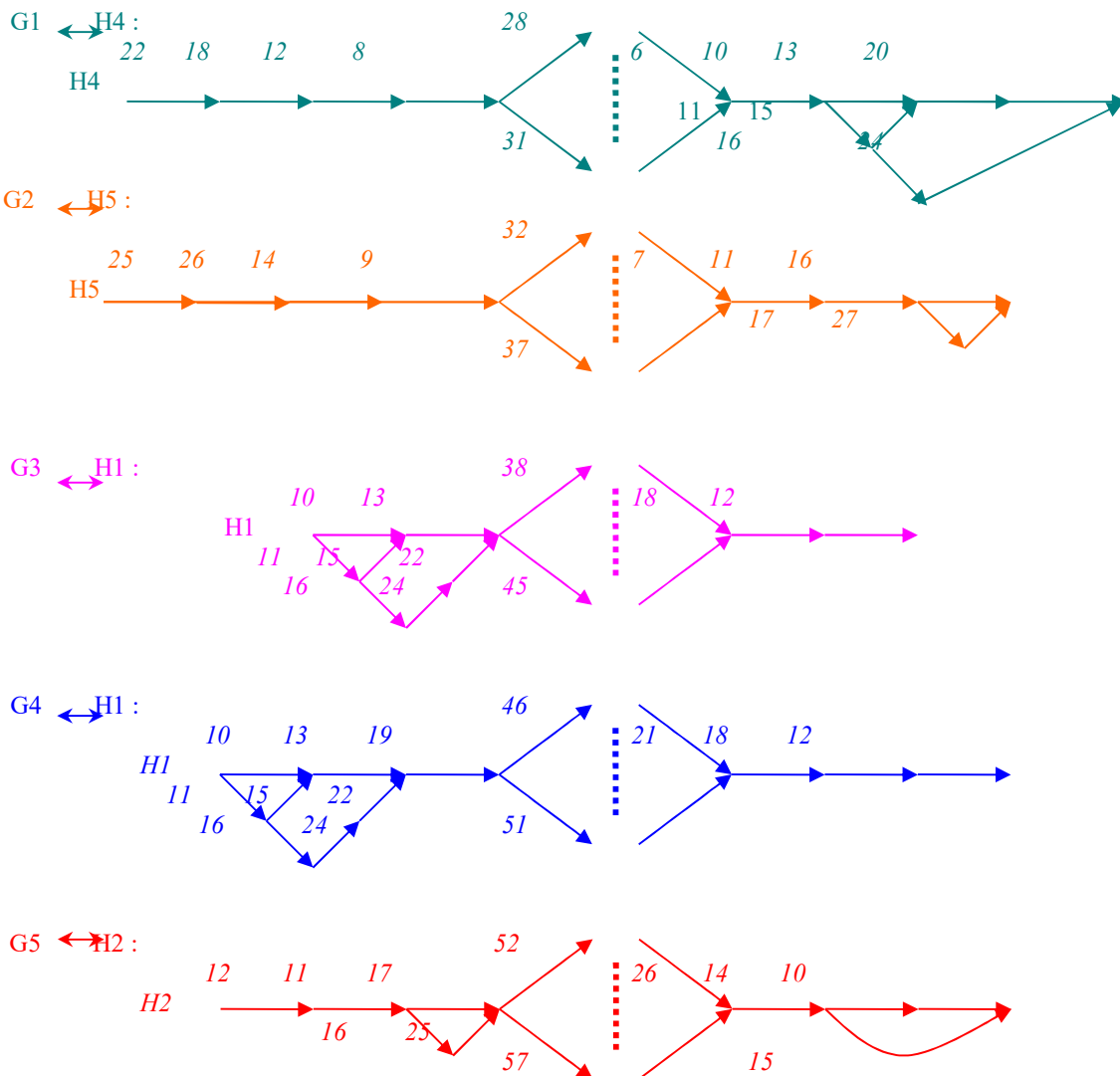
G2 ↔ H5 (contour q=2) : Server H5 serves groups G2

G3 ↔ H1 (contour q=3) : Server H1 serves groups G3

G4 ↔ H1 (contour q=4) : Server H1 serves groups G4

G5 ↔ H2 (contour q=5) : Server H2 serves groups G5

In the given WAN the initial variant of routes for all of contours was set by a principle "equal loading of communication channels". The routes of the tested WAN are shown as follow:



**Figure 2-** Graphical model of contours in the given WAN

#### 4. Substituting of the linear equations

In a basis of substitution of the linear equations the condition is that for the established process of movement of messages of one contour  $q$  quantity included in node  $k_i$  messages is equaled to quantity of messages of its leaving and acting on the entrance of the following node  $k_j$ . Then for each contour  $q$  of each node  $k_i \in q$  it is possible to write down the relationship:

$$\lambda_{j,q} = p_{i,j,q} \sum_{k=1}^D \lambda_{i,q} \quad (1),$$

$D$  - quantity of arches coming to the node

The solving of the linear equations of balance is directed to the definition of coefficient  $a_{i,j}$  basic intensity. In connection with the contour WAN usually has the simple form, it is better for calculation of values  $a_{i,j}$ , substitute  $\lambda_{0,q} = 1$  (base intensity of a stream of messages) and to use a method of substitution.

#### 5. Substituting of the nonlinear equations

For each contour is substituted its nonlinear equation. The basis of substituting of each nonlinear equation has a condition which for the established process of movement of messages of one contour  $q$ , the number of messages in one contour does not change and is equal to the sum of mathematical favorite of messages of the considered contour in all nodes of the network. Then for each contour it is possible to write down:

$$p_{i,j,q} = \frac{1}{k} \quad (2),$$

$k_i \in q$ , all nodes belonging to a contour.

$$n_{i,q} = \frac{\lambda_{i,q}}{\mu_i - \gamma_i \sum_q \lambda_{i,q}} \quad (3)$$

mathematical favorite of the number of messages in the node  $k_i$ .

$$\gamma_i = \frac{\left( \sum_q n_q \right) - 1}{\sum_q n_q} \quad (4)$$

coefficient of queue limitation

It is necessary to note that the number of messages in a contour  $n_q$  is equal to the number of workstations in a contour, thus it is supposed, that each subscriber sends one message in the network and waits for the answer (in a dialogue mode). For solving of systems of small dimension it is better to use method "Dephotomy", in other case it is required to use other methods, i.e. method "Tangent"[4].

#### 6. Determination of functional network computer characteristics

For determination of functional characteristics the following relationships are used:

- Average time of the response of messages of the closed contour  $q$ , containing  $n_q$  messages, which each of them is generated by the node  $k_i$

$$t_{i,q}^d = \frac{n_q}{\lambda_{i,q}} - \frac{1}{\mu_{i,q}} \quad (6),$$

average time of the response of messages

$$\rho_i = \sum_q \rho_{i,q} \quad (7),$$

-coefficient of loading of the node  $k_i$

$$\rho_{i,q} = \frac{\lambda_{i,q}}{\mu_i} \quad (8),$$

loading of the node  $k_i$  in a contour  $q$ .

#### 7. Input of network structure

The following data are supposed as inputs :

- Number of servers (hosts)  $N_s$ ;
- Number of switching nodes  $N_p$ ;
- Number of user's groups  $N_g$ ;
- Number of workstations in each working group  $N_w$ ;

- Intensity of service in a server  $\mu_s$ ;
- Intensity of service in communication channels  $\mu_p$ ;
- Intensity of service in workstations  $\mu_g$ ;
- Position of nodes of the network.

### 8. Input of routes of contours

Here the user is offered to enter sequence of steps of a contour at the first (from a server to a workstation) and the second (from a workstation to a server) phases. For this purpose steps are numbered consistently, from the unit. And if from any node goes a branch, then all initial arches (the source ones) are given identical numbers. Each step correspond to the arch through which passes a contour. In the program the structure is such designed that the values can be entered by the users themselves. Filling of the given structure is required from the user, thus the further study of method of contours described before are fully-automated.

For base intensity of a contour  $\lambda_{0,q}$  intensity of a stream of messages of a server is accepted. With use of the structure described above, consistently beginning from the

node to which the server is connected, coefficient  $a_{ij}$  base intensity for each of the arch (communication channel) is calculated, and probability of transitions from i-th arches to j-th are calculated automatically by the formula:

$$P_{i,j,q} = \frac{1}{k} \tag{9}$$

which k-number of the arches that are starting from the corresponding node, belonging to the contour q, that is to say transitions have the same probability.

On the basis of the formula (4), it is settled the calculation of coefficients  $\gamma_i$  for each node of a network. Here it is necessary to note that, for workstations this coefficient is always equal to zero, thus in a contour which is passing through the separate workstation, there is only one message.

To find base intensity of contours, it is necessary to make and solve systems of the nonlinear equations. For solving of the system it would be possible to use an iterative method "Dephotomy", but since structure of the network is too complex, the method "Dephotomy" gives significant errors of result. It has been proved during preparing of the research work, therefore has been decided to use in the this work the method of step-by-step approximation that has

allowed to increase essentially accuracy of result of calculation of base intensity of contours when increasing the time of calculation is insignificant. Thus the routes of contours can be varied, and the equations should be made for each contour automatically, therefore is better to divide each equation into three statements:

- For server S

$$n_{s,q} = \frac{\lambda_{s,q}}{\mu_s - \gamma_s \sum_q \lambda_{s,q}} \tag{10}$$

and  $\lambda_{0,q} = \lambda_{s,q}$

- For working group G

$$n_{g,q} = \frac{\lambda_{g,q}}{\mu_g} \tag{11}$$

- For communication channels

$$n_{k,q} = \sum_{i=1}^k \frac{\lambda_{i,q}}{\mu_i - \gamma_i \sum_q \lambda_{i,q}} \tag{12}$$

k-number of communication channels in a contour  
Hence, the nonlinear equation for the contour q will look

like as follow:  $n_q - n_{s,q} - n_{g,q} - n_{k,q} = 0$

$$F(\lambda) = n_q - n_{s,q} - n_{g,q} - n_{k,q} = 0 \tag{13}$$

And exactly under these formulas, with the help of a method of step-by-step approximation, we will calculate base intensity  $\lambda_{0,q}$ . To use this method, it is necessary at first to determine borders of intervals of search of base intensity of contours and the size of the step. The bottom border is always equaled to zero, and the top border is equaled to the minimal intensity of service in a contour.

In the previous point has been calculated base intensity of contours, therefore calculation of intensity  $\lambda_{i,q}$  is reduced to simple multiplication of corresponding factors  $a_{ji}$  base intensity by intensity  $\lambda_{0,q}$ .

Calculation of coefficients of loading  $\rho_{i,q}$  is made for each node and each contour under the formula (8).

Calculation of the general coefficients of loading of nodes

$P_i$  is made under the formula (9).

Calculation of average of responses time of messages of a contour is made under the formula (5), when in a workstation is generated one message. Then the formula (5) will look like as follow:

$$t_q^d = \frac{1}{\lambda_{g,q}} - \frac{1}{\mu_{g,q}} \quad (14), \lambda_{g,q} - \text{intensity of a stream of messages through one workstation of user's group.}$$

### 9. Implementation

Before construction of WAN it is possible to predict approximately only its perspective performance. Usually the organization planning the construction of a network, wished to have the certain quality warranties, because WAN creation demands the certain expenses. Therefore it is necessary to model computer networks because it is possible to calculate expenses for WAN construction before purchasing of the equipment. Each organization possesses its own specification, and hardware should be selected under specific aims and problems. Usually in such cases it is possible to use well known variants of hardware distribution, but it is not always directing to the result. In designing computer networks at various stages it is necessary for developer to generate variants of design decisions, to calculate functional characteristics for each variants of the computer network. For increasing of accuracy of definition of functional characteristics of the computer network it is necessary to use the high amounts of parameters of mathematical model which describes functioning computer network. As the calculational relationships are complicated, it increases volume of calculations. To overcome those difficulties it is possible to create the computer network CAD.

Now there is a wide scale of separate techniques. Each of them allows to determine, exact and sufficient set of functional characteristics of the computer network. On the base of user requirements which represent the time characteristics which are the main estimations of quality of functioning, in the article the attention is given to the method of the contours [2],[9], allowing to determine these parameters of computer network. When using of the method of contours the main task is to solve nonlinear equations

system. As a result when traffic of a network is large, method of “Dephotomy”[1],[6],[7] doesn't answer to find the decision for solving.

### 10. The Research Results

In the basis of the method of calculation of computer network performance the method of contours is taken place [2], [9], [14]. In the following example the values of service intensity are accepted:

$$\mu_1 = \dots = \mu_5 = 6 \text{ 1/c}; \quad \mu_6 = \dots = \mu_{27} = 4 \text{ 1/c}; \quad \mu_{28} = \dots = \mu_{57} = 0,333 \text{ 1/c.}$$

According to the basic WAN definitions in the part 2 ,we can get the following numerical values for the given WAN performance.

The WAN performance of  $M^N$  nodes, in our example does not depend on contours and can be written as following :

$$\mu_1^N = \dots = \mu_5^N = 6, \mu_6^N = \dots = \mu_{27}^N = 4, \mu_{28}^N = \dots = \mu_{57}^N = 0,333 \text{ 1/c.}$$

The values  $M^N$  are used as the initial data for the further calculations.

It is necessary to note that the following symbols show:

$M^N$  –WAN performance of nodes

$\mu^N$  - WAN performance of nodes' intensity

Complex  $M^C$  WAN performance is written for each contour q and in our example for q=1 it is possible to write as following :

$$\mu_1^C = 6, \mu_6^C = 4, \mu_{28}^C = 0,333$$

1/c . $M^C$  allows calculating the minimal time of delivery transactions for each contour q.

It is necessary to note that the following symbols define:

$M^C$  –Complex WAN performance

$\mu^C$  - Intensity of transactions in complex WAN performance

Working  $M^W$  WAN performance is determined for  $\eta = 50\%$  and in our example:

$$\{N_q^W\} = \{2,3,4,3,3\}, NQ = 5, \{\lambda_q^W\} = \{0,171; 0,179; 0,248; 0,225; 0,184\} /c, \lambda^W = 3,0991/c; \{t_q^W\} = \{2,84; 2,595; 2,366; 2,916; 2,436\} c$$

Which  $M^W$  -defines working WAN performance

$\eta = 50\%$  -defines the mean value of WAN performance

$N_q^W$  – defines the number of transactions for working WAN performance in the appropriate contour

$t_q^W$  –defines the response time of system for working WAN performance in the appropriate contour

$NQ$  – defines the number of contours

- Peak WAN performance, is determined for  $\eta = 100\%$  and in our example:  $\{N_q^P\} = \{4,6,8,6,6\}, NQ = 5, \{\lambda_q^P\} = \{0,136; 0,150; 0,190; 0,175; 0,139\} /c, \lambda^P = 4,8461/c; \{t_q^P\} = \{4,353; 3,667; 4,02; 4,634; 4,171\} c$

The following symbols define:

$\eta = 100\%$  -Total value of WAN performance

$N_q^P$  - Number of transactions for peak WAN performance in the appropriate contour

$t_q^P$  - The response time of system for peak WAN performance in the appropriate contour

$\lambda_q^P$  - Intensity of transactions for peak WAN performance in the appropriate contour

$NQ$  –The number of contours

- Limiting of WAN performance at limiting time of reaction of system  $\hat{t}_q^L = 7,2 c$ .

In our example:  $\{N_q^L\} = \{6,9,12,9,9\}, NQ = 5, \{\lambda_q^L\} = \{0,1056; 0,120; 0,140; 0,131; 0,1\} /c, \lambda^L = 5,4691/c; \{t_q^L\} = \{6,456; 5,361; 6,511; 7,165; 7,028\} c$ .

The following symbols define:

$\hat{t}_q^L$  - Limiting time of reaction of system

$N_q^L$  - Number of transactions for limiting of WAN performance in the appropriate contour

$\lambda_q^L$  - Intensity of transactions for limiting of WAN performance in the appropriate contour

$t_q^L$  - The response time of system for limiting of WAN performance in the appropriate contour

The result of the test is given in the following graphs[14] and further graphs as the results of the test are submitted

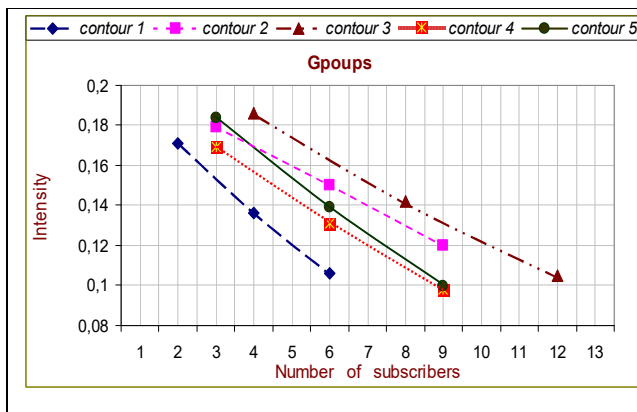


Figure 3- Transaction intensity, being serviced in different contours depends on

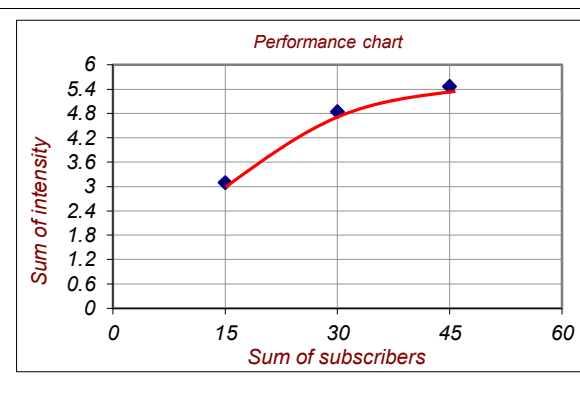


Figure 4- Total performance of WAN depends on number of subscribers

number of subscribers in appropriate group

(working, peak and limiting)

Subscribers in the given WAN use the dialog interaction with servers, therefore functioning modes: working, peak and limiting- depend on the number of active subscribers.

- in working mode  $\{N_q^w\} = \{2,3,4,3,3\}$ , it means 15 subscribers;
- in peak mode  $\{N_q^p\} = \{4,6,8,6,6\}$ , it means 30 subscribers;
- in limiting mode  $\{N_q^l\} = \{6,9,12,9,9\}$ , it means 45 subscribers;

When number of subscribers grows (from the subscribers' point of view) the network performance decreases (Figure 3) because the number of transactions in the network grows and in result the volume of queues also grows and (from the point of view of system administrator) total network performance increases (Figure 4)[14].

## 11. Conclusion and Future Directions

The offered method of calculation of WAN performance allows [22]:

- To give the developers and system administrators an opportunity to estimate quantitatively functioning computer network performance[15].
- To have a quantitative estimation for various variants of organization of computer network during development and modernization computer network.
- To determine "bottleneck" places in computer network and to offer the proved solutions based on their elimination by providing of additional resources or realization of reconfiguration computer network [5],[17],[21].

Currently there are a number of projects which are using the WAN emulator for their performance analysis. Amongst them is the Prospero Resource Manager, a scalable resource manager which can allocate resource and processing power from large networks [10]. A performance analysis of C-Slip is in progress. C-Slip claims to be efficient over phone lines. But with digital phones lines, small data packets are collected in bulk and send over phone together. Is C-Slip still efficient with under greater network delay? The question is yet to be answered. A study on RSVP,

a real-time wide area multicasting protocol is planned [11]. Through simulation, RSVP is supposed to provide reliable and fair multimedia communication. This fact is yet to be verified. A study on TCP Vegas, a TCP optimized for wide-area networking, is to take place soon [12]. TCP Vegas claims to have good throughput over wide-area network. However if the entire Internet implements TCP Vegas, does TCP Vegas still perform better in throughput? Lastly a study of phase effects in packet-switched gateway is also planned [13]. Floyd and Jacobson claim phase effects occur on the Internet from their simulation and theoretical derivation. Nobody has ever been able observe it on the Internet due to its random nature. Thus we plan to create an environment pure enough to verify or disprove this claim. We hope that in the future all of the above questions will be answered. As our emulator matures, we would expect more applications to take advantage of our emulated WAN environment.

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