Chapter 6
TCP/IP Protocol-Based Model for Increasing the Efficiency of Data Transfer in Computer Networks

S.N. John
Covenant University, Nigeria

A.A. Anoprienko
Donetsk National Technical University, Ukraine

C.U. Ndujiuba
Covenant University, Nigeria

ABSTRACT

This chapter provides solutions for increasing the efficiency of data transfer in modern computer network applications and computing network environments based on the TCP/IP protocol suite. In this work, an imitation model and simulation was used as the basic method in the research. A simulation model was developed for designing and analyzing the computer networks based on TCP/IP protocols suite which fully allows the exact features in realizing the protocols and their impact on increasing the efficiency of data transfer in local and corporate networks. The method of increasing efficiency in the performance of computer networks was offered, based on the TCP/IP protocols by perfection of the modes of data transfer in them. This allows an increased efficient usage of computer networks and network applications without additional expenditure on infrastructure of the network. Practically, the results obtained from this research enable significant increase in the performance efficiency of data transfer in the computer networks environment. An example is the "Donetsk National Technical University" network.

DOI: 10.4018/978-1-4666-2208-1.ch006

INTRODUCTION

Intensive development of modern computer networks and programmable device systems realized from them resulted in the sharp increase of load and complexities (Network congestion) based on the stack of TCP/IP protocols. In turn, this results in substantial increase in workload in the operation of such networks. This process causes some difficulties on the hardware of a network, as well as the software applications. Thus, based on the background of intensive expansion of the global Internet infrastructure, both the magnitude of complexities and workload of corporate networks, grow substantially. Accordingly, the task of providing efficiency of the networks based on high-performance of the client-server and the distributed computing systems become more difficult. The only important reservation toward increasing the efficiency and productivity of such networks lies on improving the efficiency of data transfer within them. The Internet has pushed networking technology into the mainstream and it is without doubt the most important network, both in terms of technology advances and social impact, in the world. The number of host computers connected to the Internet continues to increase at an unceasing rate and shows no sign of slowing down (Lottor, 1992). This growth has placed strain on the network infrastructure that was built on what was, at the time ARPANET was created, experimental technology.

The Internet uses packet switching technology to transmit data, i.e. data that is to be transmitted over the Internet is split into small chunks, known as packets. These packets are then transmitted one at a time across the Internet where they are reassembled at the receiver.

The basic building blocks of the Internet are the protocols of TCP/IP suite (Petersen & Davie., 2000), which may be modeled as a stack of protocols split into several layers (Tanenbaum). The underlying protocol at the network layer, Internet Protocol or IP is a connection-less best-effort protocol, meaning it has no established connection or authentication, and it does not provide a guarantee that the data sent will reach their destination (Petersen & Davie, 2000). Reliable delivery is provided by the Transmission Control Protocol, or TCP on which great emphasis will be laid in this chapter.

However, the properties that make the Internet so effective and successful also make it vulnerable to degradation in performance or "Internet Meltdown" or "congestion collapse" (Braden. 1998). Several aspects of the underlying Internet technology are showing their age and reaching the point where other approaches need to be explored if the growth rate and stability of the Internet is to be maintained. These areas include efficiency of data transmission over a network and congestion avoidance control (Nagle, 1984). The accurate operation of TCP/IP protocols brought about the fact that based on the knowledge of complex network projects and increased number of users on a network, noticeably the network traffic grows exponentially to a critical level. Well-founded selection mode of data exchange allows, in many cases, the reduction of workload on a network, increases effective bandwidth and performance efficiency of both network as a whole and separate network hardware-software and programmable systems. The problems related to increasing performance efficiency of computer networks, were looked into and published by many researchers, notably the works conducted at the National Technical Universities in Ukraine, the «Kiev polytechnical institute», the Institute of cybernetics, Ukraine National Academy of Sciences, the Kharkov National University of Radio Electronics and in many other universities of Ukraine. Also, notable are the works of Visheneskoro, Gorodetkovo, Zaborovskovo, Kamera, Menaske, Almeydy, Steven, and many others.

However, literature review of the works carried out in this area showed that questions concerning the perfection in the modes of data exchange and their impacts on the efficiency of data transfer in a modern network application and computing network environments based on the protocol of TCP/IP were insufficiently explored and need further research. As a result of the above stated problems, it becomes necessary and important to conduct a research directed on increasing the efficiency of data transfer with increasing network throughput while maximizing bandwidth usage in modern computer network application and computing network environments. This fact led to the chosen scientific research work, which has scientific and practical importance in developing modern computing network and network application based on the TCP/IP protocols stack. The aim of this paper is to increase the efficiency of data transfer in modern network applications and computer networks based on the protocols of TCP/. In achieving the aim of this research, the following problems were treated:

- The main factors that affect the efficiency of data transfer in computer networks based on TCP/IP protocol and means of improving the efficiency of data exchange.
- Designing simulation models for investigating the efficiency of data transfer on Physical layers, Network layers and Transport layers.
- Determining the basic conformities to changes in effective bandwidth capacity on the network parameters as a result of the workload and the method of data transfer in the LAN.
- Influence of method of data transfer on the performance efficiency of corporate networks.
- Develop method of increasing the efficiency of data transfer based on the result of the research.

ANALYSIS OF THE FEATURES OF NETWORK DATA TRANSFER AND METHODS OF INCREASING THEIR EFFICIENCY

This is based on the research work on factors affecting the efficiency of data transfer in computer networks based on the TCP/IP protocols stack and the basic problems in this area were analyzed. Computer networks play an important and ever increasing role in the modern world. The development of Internet, the corporate intranet, and mobile telephones have extended the reach of network connectivity to places that some years ago would have been unthinkable. This intensive development of modern computer networks and realizing their program-hardware systems results in sharp growth, toward the increase in workload and complexities of computer networks based on TCP/IP protocols (Petersen & Davie, 2000; Tanenbaum, 2003; Lottor, 1992). Many protocols are modeled as finite state machines. The basic means of data transfer in the modern networks is the TCP/IP protocols stack (Camel, D.E., 2003). Regardless of the particular applications, the efficiency of data transfer substantially depends on the performance of the network at Physical, Network, Transport and Application Layers.

Figure 1 shows the basic component problem areas of a network, which results in ineffective realization or ineffective uses, which can negatively affect the network throughput, both in an entire network and/or separate fragments or network applications. The method of data transfer was examined as the main focus of research in this work, as its perfection enables, in many cases, a considerable improvement of network and network application performance without substantial additional expenditures. The main task of analyzing and modeling the modes of data transfer in modern computer networks based on the TCP/IP protocol is to increase the performance efficiency of the network and network application, thereby increasing their productivity. The mathematical representation of the task can be expressed in the following forms.

Find such parameters of data stream block and their sizes, at which the effective bandwidth capacity of network (Q) ➔ (tends to) maximum. Thus,

$$Q = f(Q_N, L, \lambda, n_y), \quad (1)$$

where Q_N is nominal bandwidth capacity of the network; L – size of the transmit data blocks; λ – the parameter of data stream blocks (for every node); n_y – number of active nodes in the networks. However, the properties that make the Internet so effective and successful also make it vulnerable to degradation in performance or “Internet Meltdown” or “congestion collapse” (Braden, 1998; Nagle, 1984). Several aspects of the underlying Internet technology are showing their age and reaching the point where other approaches need to be explored if the growth rate and stability of the Internet is to be maintained. These areas include efficiency of data transmission over a network and congestion avoidance control (Nagle, 1984). Based on this work the factors affecting the efficiency of data transfer in computer networks through TCP/IP protocols and related problems are analyzed.

DESIGNING SIMULATION MODELS FOR INVESTIGATING THE EFFICIENCY OF DATA TRANSFER ON PHYSICAL LAYERS, NETWORK LAYERS AND TRANSPORT LAYERS

This section is devoted to the development of simulation models for research on efficiency of data transfer at physical layer (based on the Ethernet protocol), and also – at network and transport layers (based on the TCP/IP protocols). The dynamics of the process of data exchange in a distributed computer network is so difficult, that to describe it in a comprehensive linear or nonlinear analytic functions with sufficient accuracy are extremely difficult. Therefore the factors that affect the performance of functional communication networks can be described only with the use of algorithmic simulation methods.

The development of the distributed computing environments, based on the modern infrastructure of the Internet, offers useful value in increasing the efficiency of network interaction at all levels of the TCP/IP stack: beginning from a physical level and concluding at the fast-acting of applications at physical level. However, it is on these levels that we have the most significant difficult characteristic dependence of bandwidth capacity on the chosen modes of data transfer. In response to this, multilevel simulation was designed to tackle these level problems. The developed model of link layer allows us to define the basic descriptions of and shows the most critical areas of networks in different working mode. This model was developed and realized as shown in the Simulink blocks model: «nodes» (Host) and «Channel» (Bus) (Figure 2) (John, 2005).

On the side of transport and network interrelation layers, a model was developed and realized in a SIMULINK blocks model of three units: Host, Bus and Gateway – model of data channel between local area networks with the possibility of exit to the global network. In line with this, the basic method of studying the network efficiency is by simulation methods using both specialized tools, and the universal MATLAB to investigate the

Figure 1. The factors that determines the performance of a network

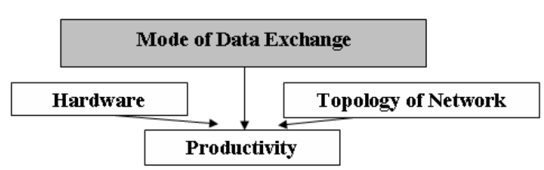
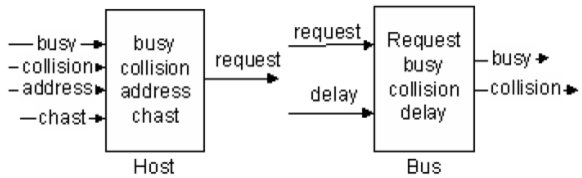


Figure 2. Structural block representation of physical layer models



effectiveness of data transfer and maximize their output.

Figure 3 shows a sample model structure of TCP/IP network, consisting of two LANs connected by gateway. The model structures of the network that allows defining the main functional elements are:

- **Host:** Point of network serving the transport layer;
- **Bus:** Medium of transmission in the LAN;
- **Gateway:** Data transmission channel between two LAN.

The model was realized based on the SIMULINK system tools with the use of S-function (Simulink™, 2000) in creating a special blocks of models and control programs. In the simulation model of "object Host", three of its main states were considered: delay, receive frame and send frame. In each state, the state algorithm of the Host unit is different in functions. Host was represented by a system of differential equation shown below:

$$\begin{cases} \overline{x}_{i+1} = \overline{G}(\overline{u}_i, \overline{x}_i, t_i); \\ \overline{y}_{i+1} = \overline{g}(\overline{u}_i, \overline{x}_i, t_i); \\ t_{i+1} = t_i + \Delta t. \end{cases} \quad (2)$$

where $\overline{x}_{i+1}, \overline{x}_i - (i + 1)$ and i are values of variable state vector of Host;

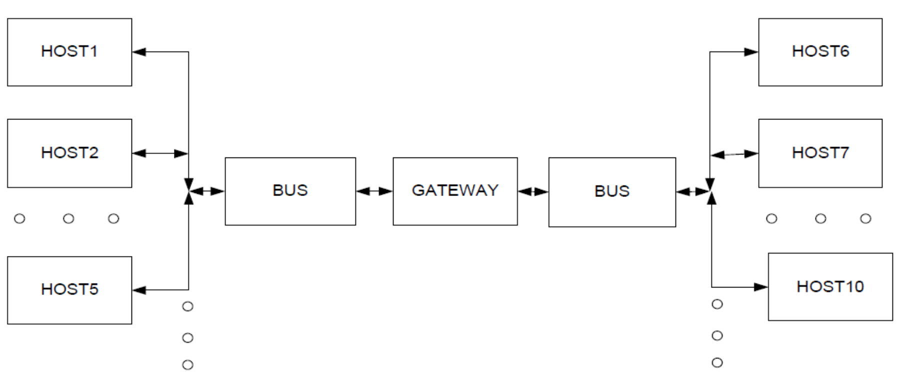
$\overline{y}_{i+1} - (i+1)$ value of variable output vector of Host;

$\overline{u}_i - i$ value of variable input vector of Host;

$\overline{G}, \overline{g} -$ vector-function;

$t_{i+1}, t_i - (i + 1)$ and i values of model time;

Figure 3. Model structure of LAN connection by gateway



Δt – simulation step.

Figure 4 shows the flowchart of the simulation model of the HOST unit showing the condition of transition from one state to another. Hence, the following values were used in computation:

Average frequency frames:

$$\lambda_{cp} = \frac{Q_T}{n_y \cdot L_{cp}}, \frac{1}{\mathcal{M}\sec} \tag{3}$$

- **Maximum frequency frames:**

$\lambda_{\max} = 1,5 \cdot \lambda_{cp}, \ \frac{1}{\mathcal{M}\sec}$, but not more than $Q_N \left(1,2 \cdot L_{cp}\right)^{-1}$.

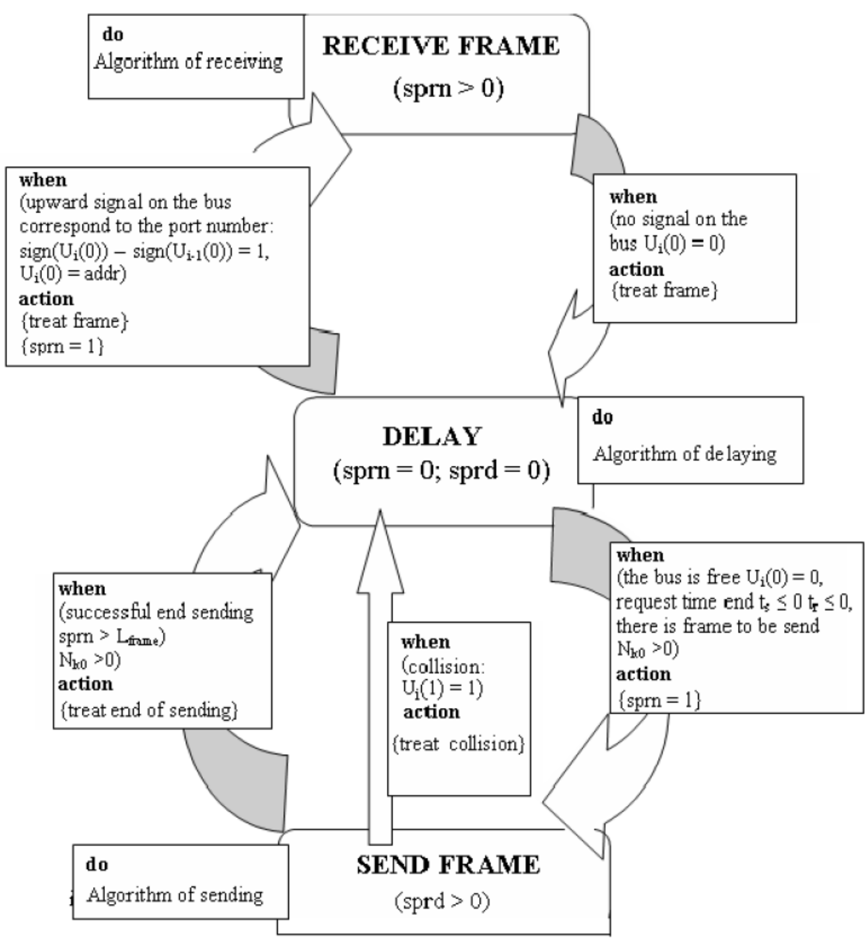
- **Minimum frequency frames:**

$\lambda_{\min} = \left(2 - \frac{\lambda_{\max}}{\lambda_{cp}}\right) \cdot \lambda_{cp}, \ \frac{1}{m\sec}$, but not less than $Q_N \left(1,2 \cdot L_{cp}\right)^{-1}$.

- **Average length of frame:**

$$L_{cp} = \frac{L_{\min} + L_{\max}}{2}, \ bit.$$

Figure 4. Flowchart of the simulation model of the HOST unit



- **Frequency frames for *i* node:** $\lambda_i = \lambda_{min} + \left(\lambda_{max} - \lambda_{min}\right) \cdot d,$ where d – variable number, evenly distributed between an intervals of 0 to 1.
- **Minimum interval between frame for *i* -node:** $\Delta t_{min} = \frac{1}{\lambda_i} - \frac{L_{max}}{Q_N}$, мsec.
- **Maximum interval between frame for *i*-node:** $\Delta t_{max} = \frac{1}{\lambda_i} - \frac{L_{min}}{Q_N}$, мsec.

The following procedures were also adopted: displacement in the receiving frame, – displacement in the sending frame. The HOST unit realizes the basic algorithmic functions of the TCP/IP and Ethernet (basic features of CSMA/CD protocol) (Stevens, 1997; Stevens, 1998; John, Anoprienko, & Rishka, 2001). Data from the bus, which are generated by known principle of data flow – Poisson principle of data flow, goes to the Host. To realize the model in the form of S-function, the structural vectors of *x, u, y* (state, input and output of the designed nodes) were developed. The *functions of mdlInit, mdlOutput, mdlUpdate,* perform the simulation action of the Ethernet network during the operation of TCP/IP protocols stack. The *mdlInit* perform the initialization function of vector state variables of S-function. The *mdlOutput* performs the calculation of *y* functions from the vector values of *x* and *u.* Vector-function $\bar{G}(\ )\ and\ \bar{g}(\ )$ were realized in the form of S-functions *mdlUpdate* and *mdlOutput*. This model sends and receives frames in packages, and generates data blocks for transmission. The frame structure was hence realized by that in Box 1.

The vector *u* consists of two components: busy signal from the bus/channel and signs of collision, which are the internal inputs from the blocks of SIMULINK model. The *y*-vector consists of three components: signal to the bus/channel, number of sending and acknowledgement information, and the delay time. The x vector consists of buffers and state variables as shown in Figure 4.

With the use of the offered simulation models on elements of TCP/IP (Nagle, 1984; Stevens, 1997; John S.N., Anoprienko, A.Y., & Niru, A., 2002) network, Figure 5, it is possible to develop a simulation model of both local and corporate networks. The efficiency of a network data transfer substantially relies on the correct choice of network parameters and this is due to the difficulties in the theoretical estimation of the actual parameters [Olifer, V.G. & OLifer, N.A. (1999)], therefore, their values can be obtained by proper simulation models.

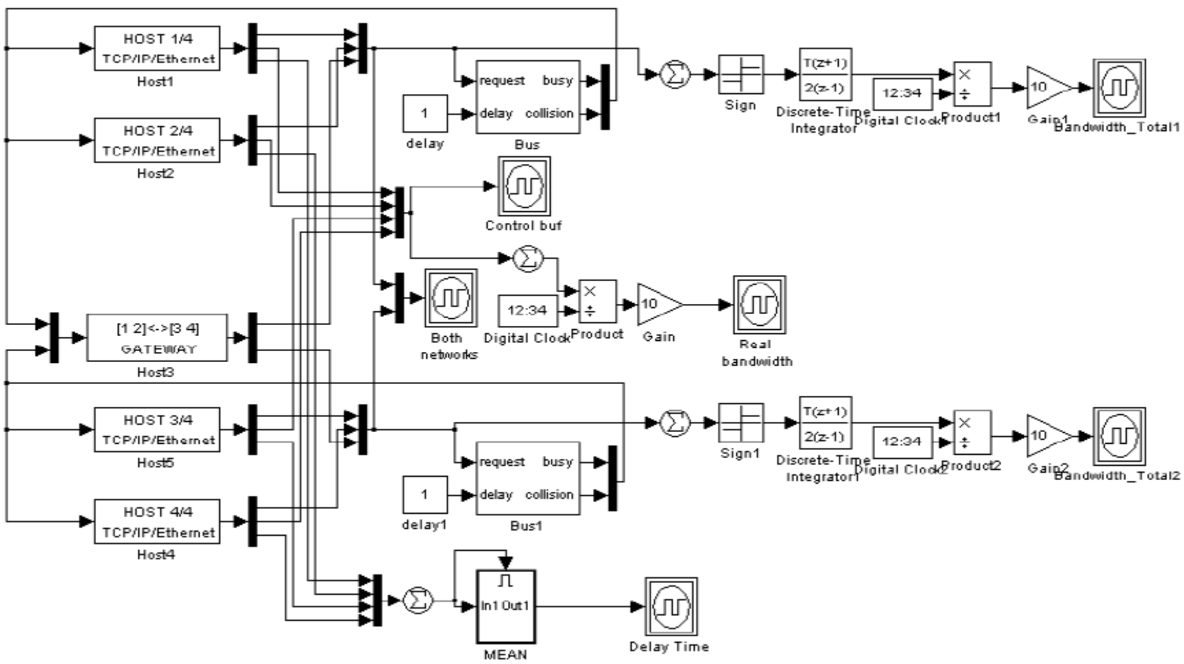
DETERMINING THE CHANGES OF EFFECTIVE BANDWIDTH CAPACITY ON THE NETWORKS PARAMETERS DUE TO WORKLOAD AND THE MODE OF DATA EXCHANGE IN LAN

This section, describes the use of MATLAB systems (SIMULINK and STATEFLOW modules) for studying the functionality of data link layer, transport layer 'TCP/IP' and analysis of some congestion control algorithms of TCP protocol and modes of data transfer. The following significant results were obtained from the work: number of sending frame per unit time; number of collisions per unit time; total bandwidth capacity of

Box 1.

1	2	3	4	5	6		
To whom	N – frame 0 – acknowledgement	From whom	N package	Number of Frames	1	…	1

Figure 5. Model of SIMULINK with two local area networks connected by gateway



the network; effective bandwidth capacity of the network (without taking into account the unsuccessful attempts of frame transmission) and mean delay time of data block transmission.

The results of the research work, using developed models for investigating the modes of data transfer at link layer are shown in Figures 6 and 7. It is seen from these graphs, how increase in collisions reduces the effective bandwidth capacity of the network. From the simulation results, it is seen that the workload efficiency of the network goes well up to 60% on the Ethernet Technology with the traffic transmission (Olifer, V.G. & OLifer, N.A., 1999; Matloff, 2000; John, S. N., Anoprienko, A. A., Okonigene, R. E., 2010). With further increase of the workload, practically there was no increase in the effective bandwidth capacity. This result agrees with an established fact, which confirms the accuracy of the model for Ethernet Technology traffic. On the quality of the workload, the frequently occurring parameters of file sizes were shown – from 0.1 Kbytes to 2 Mbytes and parameters of data stream block λ, provided by a given file size of intensive network workload.

In a whole from the results of simulation, that during the workload on a network to about 60% of the Ethernet technology (as seen in Figure 7) on the divided segment gets well along with the transmission of traffic generated by the end ports. However, at the growth of intensive generated traffic to such size, when the coefficient use of the network approaches 1, probability of frame collision is so multiplied that most frames, which some station try to send, run into other frames, causing collisions (Olifer, V.G. & Olifer, N.A., 1999; Floyd, 1991; Floyd & Fall, 1999).

During simulation the files for transmission are adopted, on every station generated as Poisson flow (Klienrok, L., 1979; Lebedev, A.I. & Sherniavskovo, E.A., 1986). Amount of files m, which is necessary to send at an interval of time ΔT, distributed by the law of Poisson:

$$P_m = \frac{a^m}{m!} e^{-a} \tag{4}$$

Figure 6. Change in the ratio of effective bandwidth capacity to expected bandwidth depending on the relative growth of the workload on the network (Q_{TN})

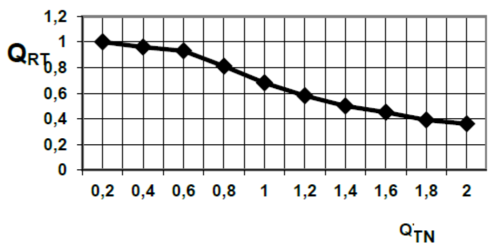
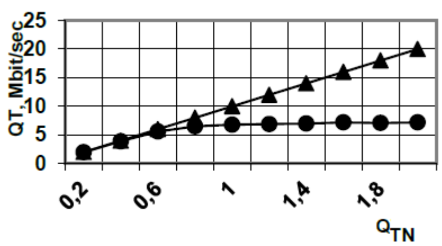


Figure 7. Dependence of bandwidth capacity of the Ethernet network on Q_{TN}



where a – average number of files which is necessary to be send at an interval of time ΔT;

Probability that for Poisson flow in a given small area with change in time ΔT occurs an event, i.e. probability of receiving a data block in the TCP buffer, is determined by the below formula:

$P(\Delta T) \approx \lambda \Delta T$.

The above formula helps in realizing the principal features of TCP/IP protocol when an event takes place at the transport layer. Files for transmission on every node were generated as poison stream (in general, this may not be the only files, but practically any data blocks, generated in the process of network data exchange).

Thus, the following parameters were used:

Q_{RT} – the ratio of effective bandwidth capacity to expected bandwidth capacity.

Q_{TN} – the ratio of expected bandwidth to nominal bandwidth capacity.

$Q_1 = \frac{Q_T}{n_y} = \lambda \cdot L_{cp}$ – expected bandwidth capacity on a node with uniform workload from all the nodes,

where Q_T is the expected bandwidth capacity of the network; n_y – number of active nodes in the network; λ – parameter of data blocks stream (for every node); L_{cp} – average frequency frame size.

Then, $\lambda = \frac{Q_T}{n_y \cdot L_{cp}}$ for uniform workload from different nodes on expected bandwidth capacity on a node is determined by the following expression:

$$Q_1 = \frac{Q_T}{n_y} \cdot b; \ b \in [b_{min}; b_{max}],$$

where b is the random variable, evenly distributed with the expected value equal to one, hence $(b_{max} + b_{min})/2 = 1$.

The ratio of the maximum workload on a node to the minimum is determined by a formula: $k = b_{max}/b_{min}$, then $b_{min} = 2/(1 + k)$; $b_{max} = k \cdot b_{min}$.

Data block length is a random number evenly distributed within a range from L_{min} to L_{max}: $L_{cp} = Q_I/\lambda$; $L = L_{min} + d \cdot (L_{max} - L_{min})$, where d is the random number evenly distributed in an interval between 0 to 1.

The efficient performance of computer network based on obtainable results from simulation of the distributed computer systems and networks can be estimated by the following basic relationships:

Real bandwidth:

$$Q_R = \frac{1}{T} \sum_{i=1}^{n} \sum_{j=1}^{N} L_{ij}, \ Mbit / \sec. \quad (5)$$

where,

- **Q_R:** Effective l bandwidth;
- **L_{ij}:** Data block size;
- **T:** Simulation time;
- **N:** Number of data blocks successfully sent to i-nodes.

Total bandwidth:

$$Q_{\text{Total}} = Q_N \frac{T_s}{T}, \ Mbit / \sec. \quad (6)$$

where

- **Q_{Total}:** Total bandwidth;
- **T_s:** Sending time.

Average delay time:

$$\Delta T = \frac{1}{N_y} \sum_{i=1}^{n} \sum_{j=1}^{N} \frac{\Delta T_{ij}}{N}, \ \sec. \quad (7)$$

where ΔT_{ij} – delay time in generating j data block in i node

$$\Delta T_{ij} = T_{send} - (L_{ij} + N_{ij} \cdot S_E)/Q_N \quad (8)$$

where

- **T_{send}:** Time between first and last transmitted data block;
- **S_E:** Length of header frame;
- **N_{ij}:** Number of frames in a packet

Figure 8 shows the simulation results of the dependence of Q_{RT} on expected bandwidth capacity Q_T. It is seen that with L = 0.4 Kbytes, data block size practically has no effect on the effective bandwidth capacity. Analysis of the graph concludes that as Q_T increases to 10 Mbit/s, the effective traffic also increases. Reduction of the effective bandwidth capacity takes place when the standard speed of Ethernet transmission (10 Mbit/s) is exceeded. This shows how an irrational file size affects the network performance in a corporate network. The Q_{RT} correlation in Figure 9 shows that as L > 0.4 Kbyte the coefficient of traffic falls, regardless of the size of data block. From the statistical result, the generalized dependence is shown on the Figure 9.

The result allows the analysis of two regions of Q_{RT} (Q_T) dependence:

- First – with Q_T less than a threshold value (in this case 3,2 Mbit/s), described by $Q_{RT} \approx 1$ regardless of Q_T;
- The second region is described by exponential regressive dependence:

$$Q_{RT} = 1,29 \cdot e^{-0,079 Q_T};$$

Selection of the regressive dependence ΔT (QT, L) allows the following formula to be obtained:

$$\Delta T = 0,00311 \bullet Q_T + 0,000044\, Q_T \bullet L_{cp},\ sec.$$

The modes of file transfer were analyzed in the following sequence:

1. Data transmission time (T_2);
2. Required bandwidth capacity of a network (workload on a network) (Q_T):

$$Q_T = \frac{I}{T}, \text{ Kbyte/sec,}$$

Figure 8. Dependence value Q_{RT} on Q_T for different transmit data block sizes

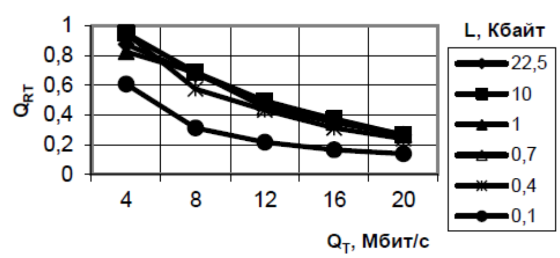
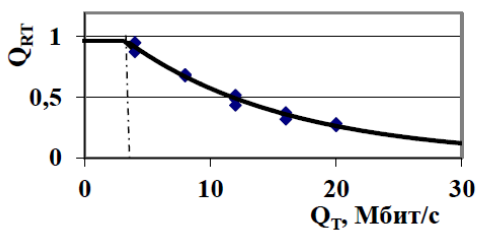


Figure 9. Regressive dependence value of Q_{RT} on Q_T



where

- **I:** General information to be transmitted, Kbytes
- **T:** Time of data transfer, sec.

Time of data transfer was determined by the following formula:

$T_2 = (\Delta T + T_{transmission})\, n_f$, sec

where

- $n_f = I/L$**:** Number of files passed by every network;
- **ΔT:** Time delay in data transfer due to collisions and other problems;
- $\mathbf{T_{transmission}}$**:** Spontaneous time of direct data exchange, $T_{transmission} = I/Q_N$.

Then, the optimum spontaneous condition will be

$$\frac{T_2}{T} = Q_T \left[\frac{1}{Q_N} + \frac{\Delta T}{L} \right] \quad (9)$$

The analysis of the relationship between total time needed for data transmission and the effective time of transfer reveals three main modes of operations as shown in Figure 10.

First: The effective rate of data transfer is less than the rate that it is generated, and the output of the distributed structure is limited by the bandwidth capacity of the network. It results in substantial under-utilization of computing potential of the distributed environment. But in this case, it is possible to select the region of possible workload, for a bandwidth capacity of the network.

Second: The actual rate of data transfer corresponds to the set workload, fulfilling the maximum burst performance of the distributed environment.

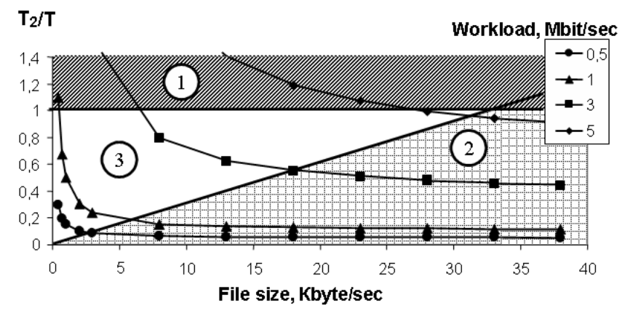
Third: Actual rate of data transfer is greater than the rate of generating the data, but due to irrational file size, the operation of the network is not optimum. From well-known simulation results, in a distributed network environment with workload greater than 60% of nominal data rate, the data transfer records substantial loss of efficiency. The achieved dependences allow the execution of concrete estimation of the loss, which is shown in Figure 11.

In the whole analysis, this shows the role of bandwidth usage for efficient data transfer in wireless network in relation to how the method of data exchange affect the efficiency in a corporate network ; the key issue being the Network performance and time delay in file transfer. Based on the shown results, recommendations can be made on the method of increasing the efficiency in data transfer.

THE IMPACT OF METHOD OF DATA TRANSFER ON THE PERFORMANCE EFFICIENCY OF CORPORATE NETWORKS

In this section, specialized means was used in analyzing, modeling and researching of data exchange in large-scale corporate computer network (for example the network infrastructure of DonNTU). Very large corporate intranet networks and the Internet make the development of analytic models very difficult and in such circumstances; simulation models are a viable alternative to understand the behavior of these networks with data

Figure 10. Relationship between send time and the time for generating data file size for different workload on the network



transfer in a corporate intranet. Research work on data transfers (John, S.N., Anoprienko, A.Y., & Rishka, S.V., 2001; John, 2005) in a network using analytical approach allows approximate estimate of the workload of two layer channels in corporate network `as shown in Figure 12. However, large corporate networks such as universities, as a rule, have greater number of levels, which substantially hampers the use of analytical methods and requires application of multilevel simulation design of network infrastructure. As a result, a professional simulation packet, NetCracker, was deployed. Thus a research on workload of an external channel was carried out in a corporate intranet using the following parameters:

- Size of the send files,
- Number of connections,
- Time domain between the transmissions of the files.

Developed in the simulation is a model containing 4 levels that consists of 11 campuses/buildings of 1100 complex networks. Figure 13 shows the obtained result from which it is seen that with increase in transmit file size (at a fixed parameter of data flow), workload on a channel and the effective bandwidth capacity increase toward maximum level (ranging from 128 to 1024 Kbytes for different networks), hence affecting the effective bandwidth capacity and shows a fall in the bandwidth. The obtained relation allows us to show how an increase in transmit file sizes certainly affects the effective bandwidth capacity of a network.

The dependence of bandwidth capacity of external channel of a corporate network using average file sizes from different number of network connections with constant workload on a channel is shown in Figure 14. From the graph it is seen that a change of transmit file size from 128 – 512 Kbytes has no significant impact on the bandwidth capacity of the external channel both with the partial workload of the channel (15 connections, Q_{TN} = 0,61), and actual workload (30 -150 connections, Q_{TN} = 15).

Figure 11. Graph of network throughput/bandwidth of workload on TCP/IP LAN

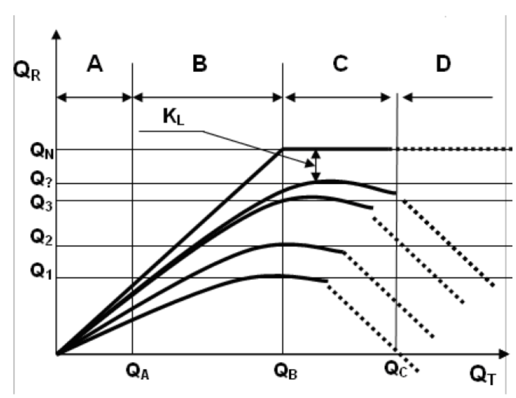
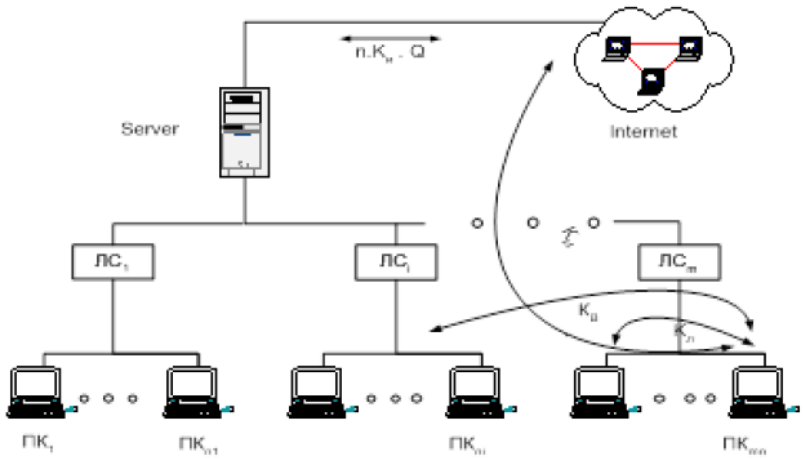


Figure 12. Analytical scheme of network



With further increase in workload to the channel the bandwidth capacity of channel begins to decrease (in this case at an average transmit files size of more than 512 Kbytes). Thus, for a corporate network in a given condition, exceeding the maximum transmits file size results in significant reduction in the efficiency of data transfer. For the purpose of verification and authentication of the obtained results, the actual experiment model was conducted, to investigate the impact of transmit file sizes on the efficiency of sent files to the server from one campus to the workstation in another campus.

During the processes of transmission, the transaction time and average bandwidth performance were recorded. The result of the experimental model was compared with the calculated results. Figure 15 shows the dependences on different send file sizes in the experiment. The Graph of Q_R (L) is obtained from calculation of 15 connections and time of transfer of files, evenly distributed with an interval of 1-19 seconds. The analysis of dependences confirms in conclusion the existing of rational maximal file size, thus in this experimental model is equal to 512 Kb.

DEVELOPED METHOD OF INCREASING THE EFFICIENCY OF DATA TRANSFER BASED ON THE RESULT OF THE RESEARCH

This section, describes the method of increasing the efficiency of network data transfer based on using the developed models and corresponding results. Also shown is the corresponding different methodical means of designing and analyzing the network infrastructure with the purpose of providing an increase in the efficiency of data transfer based on the TCP/IP protocols stack.

From the summary of the results of sections 2 – 5, it is possible to conclude that, the method of data transfer can substantially have impact on the performance efficiency of the TCP/IP network as shown in the figures, (Figure 16 and 17). As a whole, summarizing the results of the researches, the three-dimensional dependences represented in Figure 16 and 17, show how the method of data exchange affects the bandwidth capacity of a network. The main source of obtaining all these results was through imitational simulation.

Figure 13. Dependence graph of bandwidth capacity of external channel of a corporate network based on an average file size and different number of network connections

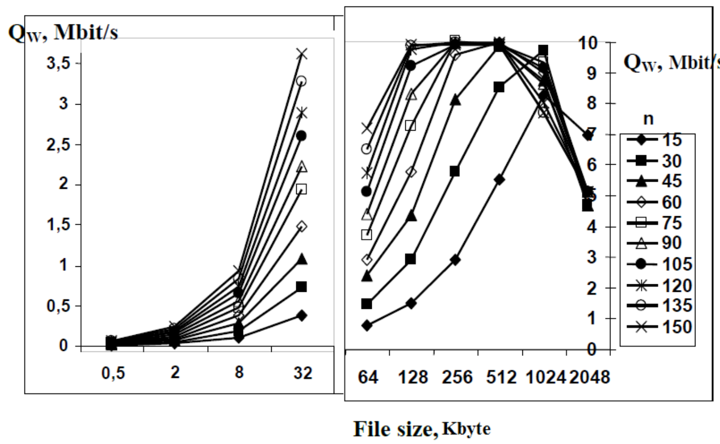


Figure 14. Dependence of bandwidth capacity of external channel on a corporate network based on an average file size, different number of network connections, and workload capacity

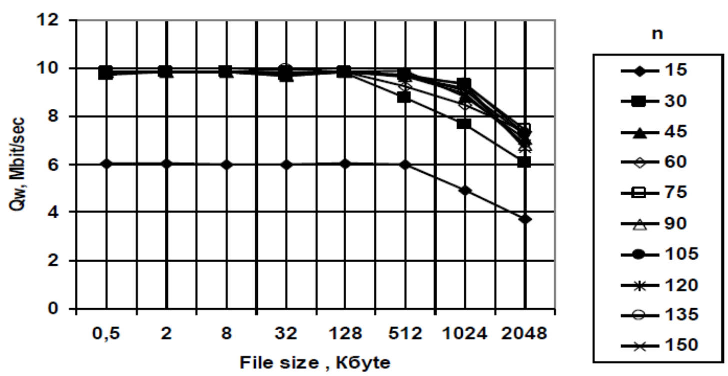
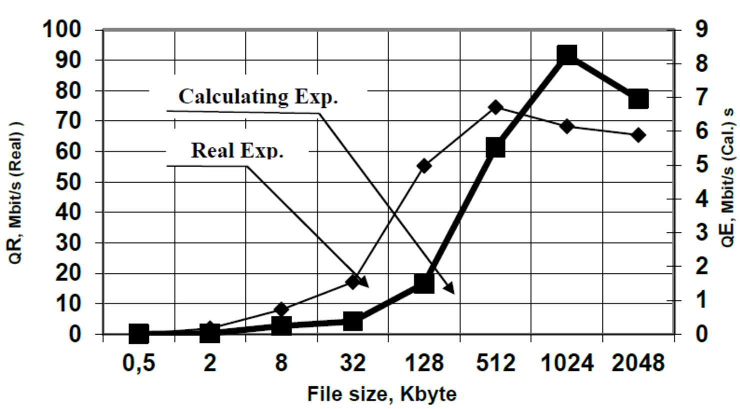


Figure 15. Research result of workload from main computing network system obtained by model and the computer



Thus, the achieved results offer a special method of increasing the efficiency of data transfer in a distributed computer network. The essence of the offered method is in the confidence derived from both the analytical and experimental methods, and also from complex simulation models, for deciding the most effective means of data transfer for a given computer network utilization and network applications [John S.N., Anoprienko A.Y. & Rishka S.V. (2001), John S. N., Anoprienko A. A., & Okonigene R. E., 1, (2010)]. To implement this method, the following execution sequence is offered:

1. First determine the characteristics of different means of data transfer and investigate the network structure using the physical and transport level models developed in this research work.
2. Determine possible variants of network structure or network application.
3. Investigate the different options of realizing the key result of the distributed computer networks using NetCracker simulation tool.
4. Clarify, where necessary, a separate characteristic of the data transfer method in a critical through productivity fragments of an investigated network structure.
5. Recommend the best format of data transfer in a computing network within the framework of the investigated network applications.

SOLUTIONS AND RECOMMENDATIONS

The validity and authenticity of the results of this work is provided by concrete application methods of computer network theories and network mass service, automata theory, probability theory and statistical methods, and also – simulation techniques, and confirmation by both experimental models and co-ordination of the results obtained in the modeling process with theoretical calculations. Authenticity of the results is confirmed by the positive results obtained from the application of the developed models and methods in an actual computer network environment, for example, the Donetsk National Technical University (DonNTU). The practical usefulness of the obtained results is in the realization of functional simulation models of computer networks and network applications at different network layers and using them to analyze the work-load per channel and elements of network infrastructure for different modes of data transfer. The result is also use-

Figure 16. The dependence of network bandwidth capacity on the number of connections at different time interval of file transfer

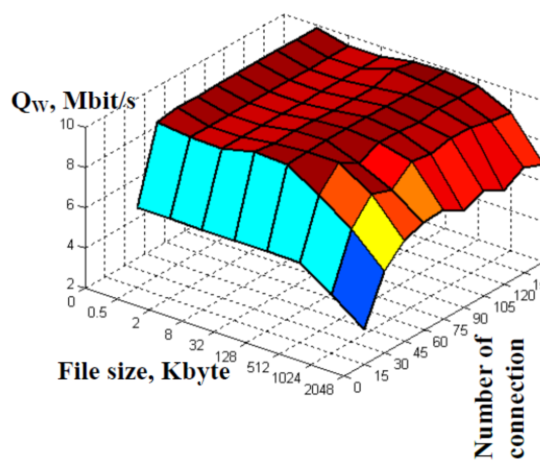
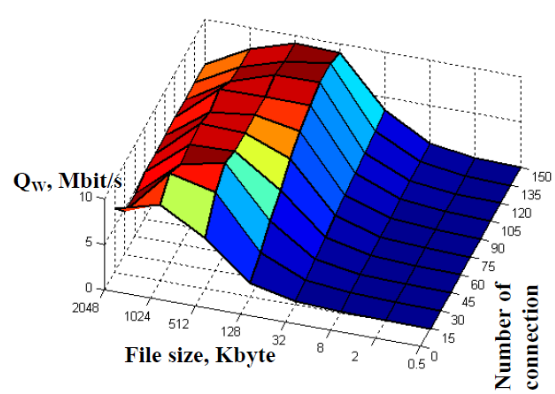


Figure 17. The dependence of network bandwidth on number of connections and transmit file size



ful in developing multilevel simulation model of corporate network infrastructure that allows effective researching the mode of data rate and search for the most rational variants in the use and development of the networks. The methods and results of this work are novel and have been applied for the first time in complex corporate network infrastructure, such as University and Corporate Network.

FUTURE RESEARCH

We recommend improved high-level method for designing and analyzing the efficiency of computer networks based on a hybrid of different models and analytical methods, adequately taking into account, the influence of mode of data transfer towards in the performance of corporate networks based on TCP/IP protocol. A unified mode of data transfer framing across a network, dynamic bandwidth provisioning on a packet-by-packet basis, and hybrid data-mixing capability that will maximize bandwidth usage and yields major efficiency in wired and wireless equipment and operation of the computer networks.

CONCLUSION

The scientific innovation of the achieved results shows that, for the first time, special complex simulation models were designed for analyzing and for multilevel modeling processes of data transfer in computer networks based on the protocols of TCP/IP, which fully and accurately allows us to determine the co-existing factors exchange such as formation of data flow, network topology, function of network protocols and internet collaboration/support which influence efficiency of data transfer. The characteristic change in effective bandwidth capacity obtained for different modes of data transfer in LAN and WAN, for a given condition of a network utilization agrees with the achieved results. For the first time, based on using the developed simulation models to conduct the complex research on performance efficiency of computer networks (local and corporate network) for different modes of data transfer, which allows obtaining the complex dependences, shows how the real bandwidth capacity and change in the average transmit data block changes the real bandwidth capacity and, accordingly the efficiency performance of networks and network applications. Based on the statistical analysis from the obtained simulation results, an expression to estimate the actual evaluation of the given value of prescribed Q_T, L and other parameters of data stream flow were analyzed. For the first time, a proposed method for increasing efficiency of data transfer in networks based on the use of complex simulation models and improved modes of data transfer and provides an improved efficiency in operation of network by an average of 10 – 15%.

REFERENCES

Arpaci. (2001). *Congestion avoidance in TCP/IP networks.* Retrieved from http://www.csc.gatech.edu/~mutlu/arpaci_thesis.pdf

Braden. (1998). Recommendations on queue management and congestion avoidance in the internet. *RFC 2039.*

Camel, D. E. (2003). *Principles, protocols, and structure*. Networks TCP/IP.

Floyd & Fall. (1999). Promoting the use of end-to-end congestion control in the internet. *ACM/IEEE Transactions on Networking, 7*(4), 458–473.

Floyd. (1991). Connections with multiple congested gateways in packet-switched networks part 1: One-way traffic. *ACM Computer Communication Review, 21*(5), 30–47.

Grossglanster & Bolot. (1996). On the relevance of long range dependence in network traffic. In *Proceedings of ACM SIGCOMM '96.* San Francisco, CA: ACM.

Huang, P., & Heidemann, J. (2000). Capturing TCP burstiness for lightweight simulation. In *Procceedings of Engineering and Networks Laboratory*. Zurich, Switzerland: IEEE.

John, S. N., Anoprienko, A. A., & Okonigene, R. E. (2010). Developed algorithm for increasing the efficiency of data exchange in a computer network. *International Journal of Computers and Applications*, *6*(9), 16–19. doi:10.5120/1103-1446.

John, S.N., Anoprienko, A.Y., & Niru, A. (n.d.). Multilevel simulation of networks on the base of TCP/IP protocols stack using Matlab/Simulink environment. *Cybernetic and Computing Texnika, 39*, 271–297.

John, S.N., Anoprienko, A.Y., Rishka, S.V. (n.d.). Simulating of university network infrastructure. *Kremeshuk State Technical University, 2*(11), 271–297.

John. (2005). Increasing the efficiency of data exchange in a computer network based on the protocol of TCP/IP suite. *Information, Cybernetics, and Computing Engineering, 93*, 256-264.

Klienrok, L. (1979). *Computing systems with queuing*.

Lebedev, A. I., & Sherniavskovo, E. A. (1986). Probability method in computing texnika: Educational manual for institutes of higher learning on special. *Computer*.

Lottor. (1992). Internet growth (1981-1991). *RFC 1296.*

Matloff. (2000). *Some utilization analyses for ALOHA and CSMA protocols.* Davis, CA: University of California at Davis.

Minaev, A., Bashkov, E., Anoprienko, A., Kargin, A., Teslia, V., & Babasyuk, A. (2002). Development of internet infrastructure for higher education in Donetsk region of the Ukraine. In *Proceedings of ICEE 2002 Manchester International Conference on Engineering Education.* Manchester, UK: ICEE.

Nagle. (1984). Congestion control in IP/TCP internetworks. *RFC 896.*

Olifer, V. G., & Olifer, N. A. (1999). Principles of technologies, protocols–SPB. *Computer Networks*.

Petersen & Davie. (2000). *Computer networks: A systems approach*. San Francisco, CA: Morgan Kaufmann.

Simulink™. (2000). *Design and simulate continuous and discrete time systems.* Retrieved from http://www.mathworks.com/products/Simulink™

Stevens, W.R. (1997). TCP slow start, congestion avoidance, fast retransmit, and fast recovery algorithms. *RFC 2001*.

Stevens, W. R. (1998). *The protocols* (*Vol. 1*). TCP/IP Illustrated.

Tanenbaum. (2003). *Computer networks.* Upper Saddle River, NJ: Prentice Hall Inc.

Vehel & Sikdar. (2001). A multiplicative multifractal model for TCP traffic. In *Proceedings of IEEE ISCC'01.* IEEE. Retrieved from http://citeseer.ist.psu.edu/vehel01multiplicative.html

ADDITIONAL READING

Ahn, D. Liu, & Yan. (1995). Experience with TCP Vegas: Emulation and experiment. In *Proceedings of ACM SIGCOMM '95*. Boston: ACM.

Allman, Paxson, & Stevens. (1999). TCP congestion control. *RFC 2581*.

Bochmann & Sunshine. (1980). Formal methods in communication protocol design. *IEEE Transactions on Communications*, *28*(4), 624–631. doi:10.1109/TCOM.1980.1094685.

Boggs, M. (1988). Measured capacity of an ethernet: Myths and reality. In *Proceedings of ACM Sigcomm* (pp. 222–234). Kent: ACM.

Braden. (1989). Requirements for internet hosts-Communication layers. *RFC 1122*.

Brakmo & Peterson. (1995). TCP Vegas: End to end congestion avoidance on a global internet. *IEEE Journal on Selected Areas in Communications*, *13*(8), 1465–1480. doi:10.1109/49.464716.

Chiu & Jain. (n.d.). Analysis of the increase and decrease algorithms for congestion avoidance in computer networks. *Computer Networks and ISDN Systems, 17*, 1-14.

Floyd. (1991). Connections with multiple congested gateways in packet-switched networks part 1: One-way traffic. *ACM Computer Communications Review, 21*(5), 30-47.

Heidemann, Obraczka, & Touch. (1997). Modeling the performance of HTTP over several transport protocols. *IEEE/ACM Transactions on Networking*, *5*(5), 616–630. doi:10.1109/90.649564.

Hoe. (1996). Improving the start-up behavior of a congestion control scheme for TCP. In *Proceedings of ACM SIGCOMM'96*. Stanford, CA: ACM.

IEEE. (1998). Carrier sense multiple access with collision detection (CSMA/CD) access method and physical layer specifications. *IEEE*. Retrieved from http://standards.ieee.org/catalog/IEEE802.3.html

IEEE. (1998b). Token ring access method (ISO/IEC 8802-5: 1998 and 8802-5: 1998/Amd 1). *IEEE*. Retrieved from http://www.8025.org/802.5/documents/

Jacobson, Braden, & Borman. (1992). TCP extensions for high performance. *RFC 1323*.

Jacobson. (1988). Congestion avoidance and control. In *Proceedings of ACM SIGCOMM '88,* (pp. 314-329). ACM.

Jain. (1994). *FDDI handbook: High-speed networking using fiber and other media.* Reading, MA: Addison-Wesley.

Kleinrock & Tobagi. (1975). Packet switching in radio channels: Part I -- Carrier sense multiple-access modes and their throughput-delay characteristics. *IEEE Transactions on Communications*, *23*(12), 1400–1416. doi:10.1109/TCOM.1975.1092768.

Lakshman & Madhow. (1994). Performance analysis of window-based flow control using TCP/IP: The effect of high bandwidth-delay products and random loss. *IFIP Transactions*, *26*, 135–150.

Lam. (1980). A carrier sense multiple access protocol for local networks. *Computer Networks, 4*, 21-32.

Mahdavi & Floyd. (1997). *TCP-friendly unicast rate-based flow control.*

Mathis, Mahdavi, Floyd, & Romanow. (1996). TCP selective acknowledgment options. *RFC 2018*.

Metcalfe & Boggs. (1976). Distributed packet switching for local computer networks. *Communications of the ACM*, *19*(7), 395–404. doi:10.1145/360248.360253.

Molle. (1987). Space time analysis of CSMA protocol. *IEEE Journal on Selected Areas in Communications*.

Nielsen, Gettys, Baird-Smith, Prud'hommeaux, Lie, & Lilley. (1997). Network performance effects of HTTP/1.1, CSS1, and PNG. *W3C Document*.

Pickholtz, Schilling, & Milstein. (1982). Theory of spread spectrum communication-A tutorial. *IEEE Transactions on Communications*, *30*(5), 855–884. doi:10.1109/TCOM.1982.1095533.

Postel & Reynolds. (1983). Telnet protocol specifications. *RFC 854*.

RFC 793. (1981).*Transmission control protocol*. IETF.

Rom & Sidi. (1990). *Multiple access protocols: Performance and analysis*. New York: Springer-Verlag.

Shenker, Zhang, & Clark. (1990). Some observations on the dynamics of a congestion control algorithm. *ACM Computer Communications Review, 20*(4), 30-39.

Socolofsky & Kale. (1991). *A TCP/IP tutorial. RFC 1180*. IETF.

Spurgeon. (n.d.). *Charles Spurgeon's ethernet web site.* Retrieved from http://wwwhost.ots.utexas.edu/ethernet/ethernet-home.html

Stevens. (1994). Volume 1: The protocols. In *TCP/IP Illustrated.* Reading, MA: Addison-Wesley.

Sunshine & Dalal. (1978). *Connection management in transport protocols. Computer Networks*. Amsterdam: IOS Press.

Zhang, Shenker, & Clark. (1991). Observations on the dynamics of a congestion control algorithm: The effects of two way traffic. In *Proceedings of ACM SIGCOMM '91*. Zurich, Switzerland: ACM.

KEY TERMS AND DEFINITIONS

Algorithmic Simulation Method: Procedural sequence method of modeling.

Data Transmission Time: Delivery time of the data.

Effective Bandwidth Capacity: Actual data transfer rate per unit time.

Efficiency of Data Transfer: Effective delivery of transmitted/sent data with respect to time and quality.

Internet Meltdown or Congestion Collapse: Degradation in performance of the network.

Modes of Data Transfer: Method and medium of data transfer.

Network Throughput: Measured performance of the network.

Probability of Frame Collision: Chances of frames colliding as a result of intensive growth of generated data.

TCP/IP Protocols Suite: Transport Control Protocol/Internet Protocol Suite (connection-oriented and connection-less transport processes).

Workload: Total number of users on the network.