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Research Article

Analysis of Quality of Service in Integrated IP Networks (Integrated and Differentiated Services)

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ABSTRACT

The analyses presented show that in modern computer networks, the protocols RSVP, RTP, RTCP, and MPLS ensure reliable and transparent packet transfer and maintain the required quality of service. Comparison of IP technology shows that the best result can be achieved by jointly utilizing the advantages of these technologies. Based on the analysis of integrated and differentiated services in combined ATM and IP networks, it has been shown that the use of these services enables the reservation of resources in computer networks to provide the desired level of quality of service. In a conventional or integrated network, elastic and inelastic traffic can be used.

Keywords: computer network, multichannel, Integrated services, Integrated services, probability, calculation, load, waiting places, switching devices.

The relevance of the problem

Modern computer network development technologies have become an objective factor in the movement of the global community towards the creation of a global information society. International integration of information resources and modern computer network infrastructure allow for the creation, storage, processing, transmission, and provision of effective ways to present information to users, which have become a necessary condition in the life of contemporary society.

The aim of this work is to develop methods for determining characteristics aimed at improving the functioning of modern computer networks with quality of service, focusing on enhancing their efficiency and the quality of the communication services provided. The main tasks in this regard are as follows:

- systematic analysis of the current state of the problem and trends in the development of computer networks, as well as the identification of key tasks whose resolution significantly impacts their functioning and development efficiency;
- development of methods for calculating performance quality indicators of computer networks with quality service for incoming packet streams;

An analysis of the quality of service in IP networks in modern computer networks has been conducted. The analysis includes technologies that ensure the proper functioning of modern computer networks and protocols that guarantee quality of service in these networks.

Materials and methods

The main requirements for integrated **IP-** networks are combating congestion, reducing delays, ensuring high throughput, maintaining quality of service, and fair service. As the Internet and private integrated networks grow, many new requirements come to the forefront. In recent years, the **IETF** group has developed two new traffic management standards: **Integrated Services (IS) and Differentiated Services (DS).**

The integrated services provider examines the aggregate traffic requirements and limits the supported traffic volumes to those that match the current network capabilities, reserving domain resources to deliver a specific level of quality of service in accordance with specific requirements.

In the structure of differentiated services, traffic is classified into groups. Each group is appropriately marked, and packets belonging to different groups are handled differently.

The **IETF** group is working on developing a set of standards under the general name **Integrated Services Architecture-ISA** (Integrated Services Architecture). The **ISA** architecture is broadly defined **in RFC 1633 (Integrated Services in the Internet Architecture: An Overview, July 1994).**

Traffic in a regular or combined network can be divided into two categories**: elastic** and **inelastic traffic**. Elastic traffic is called traffic that can adapt to changes in delay and bandwidth over a wide range of values. This is the traditional type of traffic supported by **IP** networks. Elastic applications include regular applications that operate using **TCP** and **UDP** protocols, email **(SMTP),** remote login **(TELNET),** network management **(SNMP),** and web access **(HTTP).** The requirements imposed by these applications vary. Thanks to the congestion control mechanisms implemented in the **TCP** protocol, when congestion occurs, there is only a moderate increase in delay, after which the data arrival rate from various **TCP** connections decreases. From the user's perspective, the level of quality of service is determined not by the delay of an individual packet, but by the total time interval required to transmit the element of the given application. For a web browser, the element is a web page. In scientific applications, a single element can consist of several megabytes of data.

Inelastic traffic poorly adapts to changes in delay and bandwidth in a combined network. Inelastic traffic imposes various demands on the combined network, including bandwidth, delay, fluctuation, and packet loss. These requirements are difficult to meet in an environment where queue-induced variable delay and packet loss due to congestion occur. During congestion, inelastic traffic will continue to exert high pressure on the combined network, and elastic traffic will simply be pushed out. A resource reservation protocol can help manage the situation by denying service requests if servicing them would leave too few resources in the combined network for elastic traffic.

Integrated services

The purpose of the Integrated Services Architecture (ISA) is to maintain different levels of quality of service in integrated IP networks. In integrated IP networks that operate on a best-effort basis, the set of tools for congestion control and service provision is limited. Essentially, routers have two tools – routing algorithms and packet dropping.

Figure 1 shows the overall scheme of implementing the ISA architecture on a router.

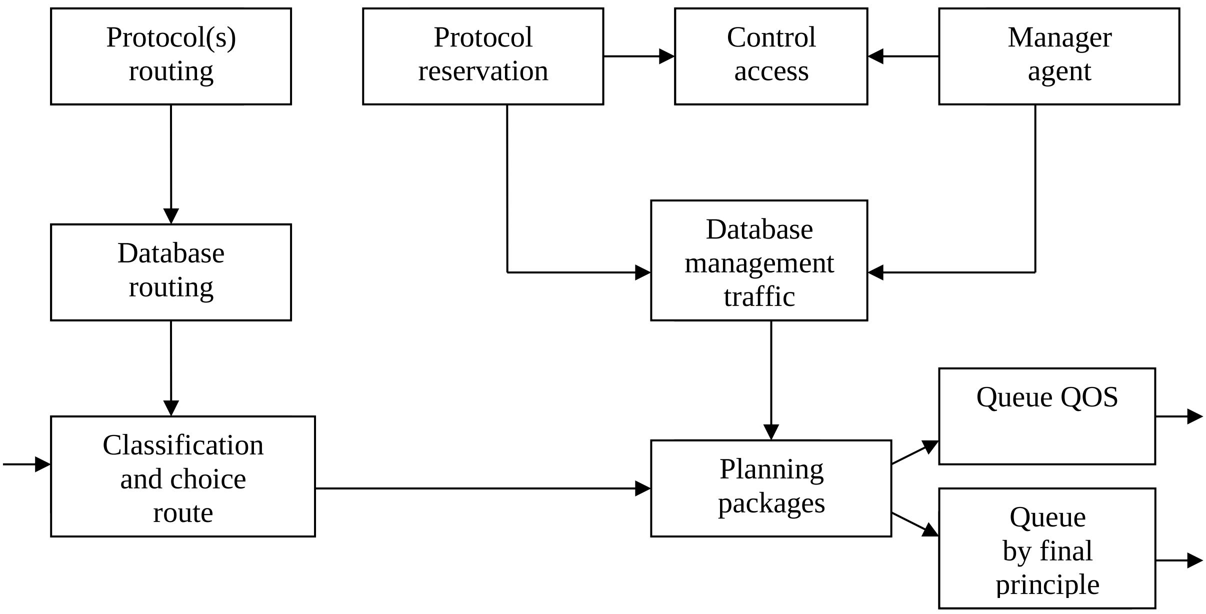

Fig. 1. Architecture of Integrated Services **ISA**

Below are the functions of the components of the **ISA** architecture:

- ***The Resource Reservation Protocol (RRP)*** is responsible for supporting stream data on end systems and on the routers along the stream's path. The **RSVP** protocol is used for this purpose. **RRP** updates the traffic management database for the packets provided to each stream.
- ***Access control (AC)***. When a new stream is requested, the **PR** calls the access control function. **AC** determines whether there are enough resources for the new stream with the requested quality of service level.
- ***Management Agent (MA).*** The Network **MA** is capable of modifying the traffic management database and managing the access control module in accordance with the access control policy.
- ***Routing Protocol (RP)***. **RP** is responsible for maintaining the routing database, which contains data about the next relay segment.

The following two fundamentally essential functions facilitate the promotion of packages:

- ***Classification and route selection.*** The choice of class is based on the fields in the headers of **IP** packets. Knowing the class of the packet and the **IP** address of the recipient, the classification and route selection function determines the address of the next relay segment for this packet.
- **Packet Scheduling (PS). PS** determines the order in which queued packets are transmitted, as well as selects packets to be discarded from the queue. Decisions are made based on the packet class.

In the **ISA** architecture service, three categories of service are defined:

- **Guaranteed service.** A guaranteed level of bandwidth or guaranteed data transfer rate is maintained. Packets can only be lost due to network failures or changes in routes.
- **Controlled Load Service (CLS).** Very similar to best-effort service under low network load conditions. There is no specified upper limit on queue delays. Queue losses are almost nonexistent. CLS is well-suited for adaptive real-time applications.

- **Service with maximum effort (i.e., on a residual basis).**

An important component of the implementation of the integrated services architecture is the queuing discipline used on routers. Traditionally, routers use the **FIFO (First In, First Out)** queuing discipline on each output port, and a separate queue is maintained. When a new packet arrives and is directed to the outgoing port, it is placed at the end of the queue. In [5], a scheme called **Fair Queuing (FQ)** is proposed. In such a scheme, the router serves multiple queues for each output port. In this case, it is possible to maintain one queue for each source, as proposed in [4], or one queue for each flow.

A significant drawback of the fair queuing scheme is that short packets receive lower quality service. Flows with a larger average packet size receive a larger share of the bandwidth compared to flows with a smaller average packet size. The reason for this is that each queue transmits one packet per cycle. This drawback can be overcome with the **Bit-Round Fair Queuing (BRFQ)** scheme, where not only packet identifiers but also packet lengths are taken into account during packet scheduling [6]. **BRFQ**, which emulates bit-level discipline, allows entire packets to be transmitted instead of individual bits. The **BRFQ** scheme is more advanced compared to **FIFO** and **FQ** schemes in the sense that it fairly allocates available resources among all active flows passing through the node. However, the **BRFQ** scheme is not capable of providing different amounts of resources to different flows. To transmit traffic with varying levels of quality of service, the ability for differentiated resource allocation is necessary.

Differentiated services

As the load on the Internet and the variety of applications increase, the urgent need to provide different levels of quality of service for various traffic streams also grows. The **Differentiated Services (DS)** architecture, described in **RFC 2475**, is designed to provide a mechanism for maintaining a range of network services. The characteristics of differentiated services contribute to their efficiency and ease of implementation. The format of the **DS** field is defined in **RFC 2474**. The first 6 bits form the **DS** code, and the last 2 bits are currently unused. The

DS code represents a label used for classifying packets. With a 6-bit code, it is theoretically possible to identify 64 different traffic classes [4 – 9, 14].

The Differentiated Services domain consists of a continuous set of interconnected routers. Routers in the **DS** domain are either edge nodes or internal nodes. As a rule, internal nodes implement simple packet processing mechanisms based on the values of their fields. These mechanisms include queue discipline, which provides service based on the values of the DS field, as well as packet dropping rules that determine which packets should be dropped first in case of buffer overflow. On border nodes, mechanisms known as behavior at the transit segment are also implemented. Two standards have been released that describe types of behavior on the relay segment: expedited forwarding **(RFC 2598)** and assured forwarding **(RFC 2597**). In addition, edge nodes contain more complex coordination mechanisms necessary to provide the required service.

The traffic conditioning function of differentiated services is shown in **Fig. 2.**

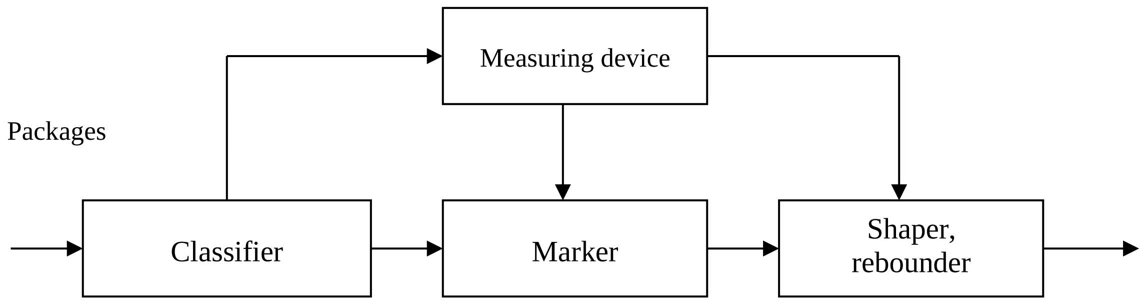

Fig. 2. Scheme for coordinating differentiated services traffic

The **classifier** divides the delivered packets into different classes. The classifier can separate traffic based solely on the DS code value, or based on several packet header fields, or even by the content of the packet payload.

The **meter measures** the provided traffic for compliance with the profile. The meter determines whether this class of packet flow is within the established limits.

The **marker** manages traffic, re-marking packets with various codes as necessary.

The **shaper manages** traffic by delaying packets as necessary so that the flow of packets of this class does not exceed the traffic rate specified in the profile of this class. The traffic shaper can absorb traffic spikes with its buffer and distribute the received packets over a longer period of time.

The **dropper** discards packets when the speed of packets of this class exceeds the speed specified in the profile of this class.

In the document **RFC 2598**, **expedited forwarding (EF)** is defined as a mechanism that can be used to **provide a so-called premium service.**

When managing traffic that is provided with a premium service, special measures must be taken to ensure that packet queuing does not lead to exceeding the specified limits for delay, loss, and jitter**. RFC 2598** notes that the desired effect can be achieved using a simple priority scheme, in which **EF** traffic is given absolute priority over other traffic. However, in a simple priority scheme, there is a risk of destroying the packet streams of other types of traffic. Thus, a more complex queuing policy may be required.

The deployment of high-speed local and global networks and the increase in the bandwidth of Internet lines and other unified networks have made it possible to use IP networks for transferring real-time traffic. In real-time traffic, each data block has a delivery deadline, meaning that after a certain period, such data becomes useless.

The server generates audio data that must be transmitted at a rate of 65 Kbps. The digitized audio signal is transmitted in packets containing 160 bytes of data, with one packet being sent every 20 ms. To compensate for the uneven arrival of data created by the combined network, incoming streams are buffered, slightly delayed, and then transmitted to the audio playback software at a constant rate. Real-time interaction requirements are listed in [5], including small fluctuations, low latency, adaptability to dynamically changing network and traffic conditions, modest buffer size requirements in the network, high network utilization, etc.

Conclusion

These works, in the overwhelming majority, do not take into account the characteristics of the modern global network, including the wide variety of information stream service disciplines, the use of high-speed digital communication channels, packet switching methods, cell switching, label switching, etc. Therefore, the theoretical results obtained cannot be directly used to study and calculate the quality performance indicators of such networks.

Analysis of technologies ensuring the quality of computer network functioning shows that all these protocols collectively ensure the timely delivery of packet streams and require preliminary calculation of the quality characteristics of modern computer networks. Analyses show that the combined use of **ATM** and **IP** technologies achieves the best results in combating congestion, reducing delays, and ensuring high throughput.

An analysis of combined **IP** networks has been conducted. The main requirements of **IP** networks are combating congestion, reducing delays, ensuring high throughput, maintaining quality of service, and fair service. An analysis of integrated **(IS)** and differentiated service **(DS)** has been conducted.

Results and discussions

The discussion of results and their comparison with the conclusions of other researchers plays an undeniable role in advancing scientific knowledge and understanding the complex issues of corporate computer network performance. By analyzing the data obtained in previous sections and comparing it with the findings of other researchers, it is possible to identify common patterns, key differences, and additional aspects of this problem. The research problem lies in finding optimal solutions to ensure the efficient operation of corporate computer networks under various loads and traffic conditions. The increase in the number of users, active use of online services, and other factors create a load on network resources and can lead to a decrease in the quality and speed of network user service.

The reference book by Bessler R., Deutsch A. is dedicated to the design of communication networks. The book presents an extensive amount of material on methods for optimal design of communication networks [1].

Huseynov Z.N, Mammadov M.I., Ismayilov T.A. Modelingand analysis of the characteristics of multichannel and multi-node computer networks with priority service. Investigated methods for increasing network bandwidth by optimising resources at different network levels, but did not sufficiently examine the impact of different types of data on the optimisation results [2].

Z. Huseynov, T. Ismayılov, S. Babayeva, S. Baratzade, N. Baratzade. Development of an Analytıcal model and Optımısatıon of computer networks wıth a queue prıorıty to one server In this research work, the possible maximum information transfer rate in a client-server architecture computer network with prioritized requests to a single server was mathematically calculated and examined. Mathematical models were constructed, formulas describing the dependencies of variables on each other and their impact on the result were derived, and graphs were created based on them. The network's efficiency was determined under various loads based on the obtained data [3].

Previous research in this industry has already discovered some aspects and approaches to solving communication network performance problems. For example, L. Peterson and B. Davie investigated the effect of routing protocols on network performance, showing that some protocols may be more efficient in large networks, and some may interfere with the fast operation of the network [4]. Insufficient attention was paid to the issue of the impact of changing conditions within the network on the effectiveness of different network protocols.

Dr. Douglas Comer, Distinguished Professor of Computer Science at Purdue University and former VP of Research at Cisco, is an internationally recognized expert on computer networking, the TCP/IP protocols, and the Internet [5]. The author of numerous refereed articles and technical books, he is a pioneer in the development of curriculum and laboratories for research and education. A prolific author, Comer's popular books have been translated into over 15 languages, and are used in industry as well as computer science, engineering, and business departments around the world. His landmark three-volume series Internetworking With TCP/IP revolutionized networking and network education. His textbooks and innovative laboratory manuals have and continue to shape graduate and undergraduate curricula.

The fifth edition of one of the best Russian textbooks on network technologies, translated into English, Spanish, Portuguese, and Chinese, reflects the changes that have occurred in the field of computer networks over the 6 years since the preparation of the previous edition[6]: overcoming the 100 Gbit/s speed barrier by local and global networks and mastering terabit speeds; increased efficiency and flexibility of primary optical networks due to the emergence of reconfigurable optical add-drop multiplexers (ROADM) and the application of superchannels based on a flexible frequency plan; the development of network function and service virtualization techniques, which has led to the proliferation of cloud services; the emergence of security issues as a top priority.

R. Ghimire and R. Noor [7] present two approaches to the study – quantitative and qualitative. The quantitative approach is aimed at analysing the results obtained as a result of experiments, surveys, or simulations, while the qualitative approach is aimed at obtaining a deeper understanding of the problem. The researchers also note the importance of studying the literature to understand the main problems in the field of research. The study of literature is indeed an important stage of research, and the use of both quantitative and qualitative approaches can be useful to get a complete picture of the problem. The researcher analyses the problem and considers the available resources using a qualitative approach. In conclusion, the author suggests further work on the application of the proposed RED algorithm in real time to compare the simulation results with real data. Thus, a comprehensive approach to the investigation of the problem, using both qualitative and quantitative methods, is presented, and the importance of studying the literature to understand the main problems in the field of research is emphasised.

The paper by Fuente Maria Jose Pardo, David de la Fuente. Optimizing a priority discipline queueing model using fuzzy set theory. Investigates the possibilities of improving the performance of communication networks by optimising routing [8].

The study considers the effectiveness of quality of service (QoS), which is also the basis of this paper. O. Bonaventure [9] provided a comprehensive insight into the principles, protocols, and practices of computer networks. The book is intended for students who want to learn about computer networks, and covers all the material for the first semester course on network technologies for undergraduate or postgraduate students. The author discusses changes in the approach to teaching computer networks in connection with the development of the Internet and the availability of a large amount of information. The researcher notes that today's students are experienced Internet users and can easily check the information received from teachers due to the availability of information on the Internet. The author also notes that there are many challenges for teachers related to teaching students in conditions of availability of a large amount of information. One of the interesting points is the mention that the authors of textbooks on computer networks have begun to revise their approach to learning, starting with the applications that students use, and then explaining the Internet protocols, removing one level after another. This kind of work is a general set of knowledge about the work of the Internet, which is suitable for study by both students and people of a higher technical level.

The document [10] authored by M. Kartashov is a mathematical reference book specialising in the section of probability theory. In particular, this source describes the Poisson distribution law, which simplifies the process of calculating the applied characteristics of the network induced in this work.

S. Prakash explored the possibility of using cloud technologies to optimise the performance of communication networks [11]. The researcher analysed the advantages and limitations of this approach and made recommendations for their implementation. The paper omitted the issue of the efficiency of cloud storage in conditions of using large amounts of data and a high level of load on them.

Z. N. Huseynov, M. N. Mammadov, A. Q. Masimov, S. Baratzade, N. A. Masimli in this article showed that to ensure the necessary level of service quality for requests, it is necessary to increase the number of waiting places at individual network nodes. Analysis of a single-channel multi-node network with a limited queue and absolute priority shows that the quality of service for requests in such networks heavily depends on the load of individual priorities[12].

The main purpose of the study by L. Yangyong [13] is the use of genetic algorithms to optimise the planning of the distribution network in order to reduce electricity losses. The paper explores how to intelligently optimise the plan by extracting relevant, analysing examples and experimental data, obtaining some data to simulate a real situation using sandbox modelling and genetic algorithm modelling. The thesis that a genetic algorithm can be an effective tool for optimising the planning of power distribution networks is quite interesting and innovative. For more accurate optimisation, it is necessary to take into account not only energy losses, but also other factors such as cost and environmental consequences. In addition, more sophisticated machine learning algorithms, such as neural networks, need to be used for more accurate results. In general, the authors' research is interesting and important in the context of optimising power distribution networks. However, for more accurate results, additional factors must be considered and more complex machine learning algorithms must be used. In the context of this study, the analysis of electrical networks can serve as a basis for monitoring the efficiency of computer networks, the principle of operation of which is similar.

In this book, an attempt is made to describe various protocols such as DSS-1, QSIG, DPNSS, X.25, TCP/IP from a unified perspective [14]. Significant attention is given to the open V5 interface, whose role in the development of communication networks appears extremely promising... For engineers and researchers engaged in the study, development, and operation of telecommunications systems. The book will be useful for students and graduate students in the relevant fields.

The main research topic of the book by L. Kleinrock [15] is the creation of a mathematical theory of computer networks, which eventually led to the development of the Internet. The author discusses the key concepts that have made the Internet network technology so powerful, including on-demand access, large shared systems, and distributed management. The author also describes the nature of data transmission and the problems that had to be overcome in order to develop a convincing body of knowledge confirming the need for data transmission networks. Additionally, the author addresses the issue of optimal design of these networks, paying special attention to the choice of bandwidth of each channel, the choice of routing procedures, and topological design. The development of a mathematical model is indeed an important step in optimising the performance of computer networks, and in its course, it is necessary to consider all possible indicators, risks, and limitations. The research is also related to network performance optimisation, and therefore, the ideas presented by L. Kleinrock are interesting, in particular, for this study.

The main purpose of the study by R. de Moraes and F. Vasques [16] is to propose and analyse solutions that allow implementing network management systems supported by networks with uncontrolled access, such as packet-switched networks. The paper discusses the evaluation of various communication methodologies on the quality of service offered to a particular management application and the impact of communication parameters on management stability. The document also highlights the problems of implementing control systems in distributed, asynchronous network environments and building reliable systems from unreliable components. The implementation of network-based management systems that do not require access control is an important task in the management of large-scale communication systems and network-based management systems. However, it is worth noting that some aspects, such as security and data protection in network-based management systems that do not require access control, have not been considered in this paper. Although these aspects are not considered in the context of this study, they are also important and should be taken into account when implementing such systems.

The paper authored by K. Rege [17] is devoted to the theory of multiclass queues and its application in the analysis of the performance of computer systems. The paper presents the results of analytical studies, and examples of the use of these results in real systems. Models of multiclass queues are described, which allow analysing computer systems with different types of resources and transactions. The paper also discusses the limitations and problems associated with the use of such models and suggests methods and approximations to solve them. The author of this study agrees that analytical queue models can be very useful for evaluating the performance of computer systems. However, these models have their limitations and approximate methods and simulations may be necessary to evaluate the performance of more complex systems.

The research carried out in this paper is also related to the analysis of the performance of computer systems, and, therefore, the paper provides valuable information for researchers in this field. Especially interesting is the example which illustrates how analytical results can be used together with approximate methods and simulations to evaluate the performance of complex systems.

Summing up, when analysing the results of this study and comparing them with the findings of other researchers, the importance of an integrated approach to analysing the performance of communication networks is emphasised. Single factors are not sufficient to fully understand the complex dynamics of networks. The conclusions of this study enrich and expand the existing knowledge in this field, providing a deeper understanding of the impact of various parameters on the effectiveness of communication networks. It is important to note that the main focus of this study is on the hardware component of computer networks, which is not the only one affecting its speed and efficiency.

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