Summary of the doctoral dissertation

Title: Data transmission quality assurance in a computer network in a decentralized manner using agent-based methods and machine learning.

Abstract:

Modern networks guarantee efficient and effective data transmission between various types of users - from individual to corporate. For many years, work has been carried out on the definition and implementation of mechanisms and architectures that would ensure the differentiation of the quality of data transmission services and, additionally, the possibility of defining and implementing the transmission in accordance with specific QoS (Quality of Service) parameters.

Data transmission service providers typically charge based on the maximum data rate that can be obtained. Unfortunately, in reality this data rate is rarely available, mainly due to the temporary excessive load on individual nodes and links in the network. The instantaneous bandwidth is determined by the least efficient transmission link between the sender and the receiver. Various methods and architectures have been defined to allow network traffic management using different approaches to the concept of service types, priorities and categories of data sent. For classic IP networks, the IntServ and DiffServ service models were proposed, for multi-service networks, the complete ATM technique was defined, superseded by MPLS. Currently, innovative concepts are used, such as Software-Defined Networking (SDN), in which the transport layer is separated from the control layer, thus obtaining better network efficiency.

A multi-agent system can be used to implement a network management system. The use of this type of system will allow solution decentralization, i.e. one in which there is no central controller. Systems with a centralized controller are more prone to failure and make it difficult to expand the network. Therefore, a decentralized system using a multi-agent environment should be created, under which the user pays for the required transmission quality - this quality is guaranteed by continuous monitoring of network parameters and, if necessary, reconfiguration (changing the currently used transmission paths so as to adjust the transmission parameters to the required quality). By using market-based pricing, it is possible to dynamically shape the prices of quality parameters. The above topic is important from the point of view of computer networks, and above all, price-shaping operators and users requiring specific transmission quality.

The paper proposes a solution thanks to which the quality of the data transmission service is guaranteed. This solution uses a multi-agent system to manage the network, and resources are not wasted due to redundant resource reservation. The use of this type of system allowed to obtain a decentralized solution, i.e. one in which there is no central controller. Considering the described issues related to ensuring the quality of data transmission, a solution was proposed which is a decentralized system using a multi-agent environment, in which the user pays for the required transmission quality - this quality is guaranteed by continuous monitoring of network parameters such as bandwidth, delay, jitter, packet loss ratio and, if necessary, reconfiguration, i.e. changing the currently used routes so as to adjust the transmission parameters to the required quality. In the presented work, the solution was limited to the most popular network architectures, i.e. the IP protocol and the Ethernet standard as well as local networks. In Ethernet/IP networks, routing protocols are used, within the framework of which the transmission path depends solely on the transmission target. The differentiation of

transmission paths in conjunction with the quality monitoring of each of them allows to guarantee certain parameters to the user. In the presented solution, the path depends not only on the target, but also on the transmission source, and even a specific service. The presented solution allows for the dynamic purchase of a data transmission service with specific quality parameters. By applying tariffs based on market methods, it is possible to dynamically shape prices of parameters related to the quality of transmission. Innovative is the use of the agent-based approach in the computer network to dynamically define routing tables and differentiate packet transmission paths based on user requirements. Another innovative element is the use of Machine Learning (ML) to translate parameters describing the quality of transmission on a certain scale. Thanks to this approach, a more reliable description of the quality of the data transmission service was obtained.

The subject matter presented in the paper is important from the point of view of rational resource management in computer networks and from the point of view of providing services in accordance with customer requirements. Thanks to the application of the proposed solution in the LAN, the customer always receives the service at the level that is expected by him and consistent with the fee paid. This avoids the problem of redundant resource reservation or provision of the service at an unacceptably low level due to insufficient resources. With a further increase in the number of network users (devices), rational resource management may turn out to be a significant issue.

The following thesis was put forward in this work:

It is possible to differentiate the quality of the service, which is data transmission, by using a multi-agent system to control the network so that the service is performed at the level expected by the user.

As part of the entire work, numerous experiments were carried out, and the obtained results allowed to conclude that the thesis was formulated correctly. The use of a multi-agent system for network control in conjunction with machine learning used in the case of transforming parameters describing transmission quality and using agents for dynamic pricing allowed to obtain a solution that can be used to guarantee the quality of data transmission service.

The work was organized as follows:

The first chapter presents techniques related to transmission quality assurance used in modern computer networks. Techniques of the so-called QoX describing different approaches to quality, an agreement on the quality of IT services and various routing techniques that can be used as part of a quality assurance system are presented. This chapter also describes the RSVP protocol that allows resource reservation. It also describes a technique that serves as a model for quality assurance systems. Another important element described in the first chapter are network standards within which quality assurance mechanisms have been defined.

The second chapter contains the characteristics of agent systems, which describe the concept of an agent system, market methods of goods allocation with particular emphasis on the theory of games, negotiations and auctions, which constitute an important element of this work. The application of agents in solutions related to computer networks was presented.

The third chapter presents the concept of agent-based transmission quality assurance in computer networks. This chapter is divided into several sections. The first section presents the Pay&Require (P&R) concept as a solution enabling the provision of data transmission services at the level expected by the customer. This goal was achieved by differentiating the transmission paths. The choice of paths is dictated by the measured parameter values describing the transmission quality, such

as bandwidth, delay, jitter and packet loss rate. In traditional computer networks, packets are routed based on the destination of the transmission. In the presented solution, the decision regarding routing is made not only on the basis of the target, but also the source of the transmission. Thanks to this, for different sources and the same transmission target it is possible to use different paths through which packets will be sent.

In the second section of the third chapter, a description of the emulator created for the purpose of research is presented. The emulator is a complete solution - a computer network in which Pay & Require was used. The third section presents the general concept of the experiment in which the NS3 simulator was used. The algorithm used in the experiments was also presented. In order to verify the sense of the concept, a series of tests was carried out with the use of an emulator created for the purposes of this study and a reliable simulator.

A very important element of the solution presented in this paper was the use of agents. The fourth section describes the types of implemented agents.

The fifth section describes the concept of using ML to translate parameters describing the quality of transmission on a certain scale. The quality of data transmission is described by the values of several parameters, i.e. bandwidth, delay, jitter and packet loss ratio. It is difficult for the customer and when used in the system to understand the combination of the values of the individual parameters. Therefore, the parameters were translated to a certain scale. It was decided to use machine learning.

The fourth chapter presents the results of the conducted experiments. This chapter has been divided into several sections. The emulation results are presented in the first section. The emulation was performed for two different networks - consisting of 4 routers and 9 routers. In both cases, the paths selected depending on the customer and his expectations regarding the quality of transmission were verified. For a smaller network, i.e. with 4 routers, selected paths were checked for:

- network operating with maximum parameters,
- a network where the quality parameters of individual links have deteriorated. The deterioration of the parameters was obtained by emulating a high traffic volume on a given link.

As part of the emulation, the average transmission delay and the average transmission time of a file of a certain size were verified for a network consisting of 4 routers and various link parameters. It was noticed that the values obtained for different clients depended on the chosen path and its parameters. The difference in the results obtained for individual customers resulted from the expectations as to the quality of transmission. As the results obtained for the network consisting of 4 routers showed that the differentiation of transmission paths has an impact on the transmission quality, further studies were carried out - for a larger network, i.e. consisting of 9 routers. Also, in the case of these studies, the choice of paths was first verified depending on the client's expectations and path parameters.

Subsequent tests were carried out with the use of the NS3 simulator. Their purpose was to confirm the correctness of the obtained results by using a well-known tool. The obtained results are presented in the second section of the chapter four. Also, in the case of simulation, two experiments were carried out - the first for a network consisting of 4 routers, the same as in the case of emulation. For a reliable analysis, the results obtained for a network consisting of 4 routers were compared with the emulation results. The same dependence was shown both in the case of emulation and simulation - the obtained results depend on the paths through which the data is sent, i.e. the customer's expectations regarding

the quality of transmission. Another experiment was carried out with the use of a network consisting of 12 routers. The choice of paths depending on the link parameters was verified. The results concerning the average delay and the average transmission time for the network in which Pay&Require was not used and in which the concept was used are presented. The differences in the measured times were again found as expected.

The third section presents the results of research on auctions and market pricing of the service, which is data transmission with specific parameters describing the quality of transmission. In turn, the fourth section presents the results of research on the use of ML for the translation of parameters describing the quality of transmission on a certain scale.

The last chapter is a summary of all the work. First, this chapter presents the conclusions of the research and responds to the thesis. The chapter was then divided into two sections. The first one describes the original elements of the work, and the next one collects and describes the directions of further research.

The following elements of the work were considered original:

- Quality assurance of data transmission based on differentiation of transmission paths.
- Using a multi-agent system for network management.
- Use of auctions to price definition of data transmission services.
- The use of machine learning to transform the parameters describing the transmission quality on a certain scale.