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ROZPRAWA DOKTORSKA

Modelowanie dynamiki transmisji internetowych za pomocą aproksymacji płynnej.

Modelling the dynamics of internet transmissions using fluid-flow approximation.

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Abstract of the doctoral thesis

Modelling the dynamics of internet transmissions using fluid-flow approximation.

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The aim of the work is to develop methods and software tools to model extensive and complex (heterogeneous) computer networks, in particular the Internet, and to apply them to the analysis of selected scenarios of Internet transmission dynamics. The obtained solutions can be used, among others, to describe the work of TCP connections and compare variants of traffic control in this protocol. This allows for a more accurate understanding of the phenomena occurring in the network and the evaluation of transmission intensity regulation mechanisms used to improve the quality of Internet services and prevent the degradation of traffic parameters.

The current literature on transients in wide area networks is relatively limited and does not meet the needs of rapidly developing telecommunications networks. There is an urgent need to develop advanced tools and methods that will be able to effectively analyse the functioning of large network configurations and predict their behaviour in extreme conditions. Traditional techniques become insufficient here.

The work formulates the thesis that the fluid flow approximation method, after developing appropriate methods and software tools, is an effective way to study wide area networks, taking into account the transients occurring in them. It is also proposed that concurrent processing can be used to numerically solve equations constituting a fluid flow approximation model. When modelling computer networks with hundreds of thousands or millions of nodes and flows, it is necessary to process large volumes of data, which is why another thesis was put forward that it is possible to use technologies appropriate for databases and data warehouses for modelling using fluid flow approximation, storing data obtained during modelling and knowledge extraction. concerning the state of the computer network described by the model.

The use of fluid flow approximation in network modelling requires estimation of the error size and limitations of the method. For this purpose, a numerical comparison of the fluid flow approximation and an alternative method, the diffusion approximation, was made for various queue management algorithms on the example of a single node. The results indicate that the fluid flow approximation method introduces a greater error than the diffusion approximation but is computationally simpler than it. At the same time, it has been shown that the introduction of active queue management in nodes and traffic control through the congestion window mechanism can improve the accuracy of the fluid flow model.

The application of the work required a review of the literature concerning not only the methods, tools and models used in the evaluation of the operation of computer networks, but also the available real Internet-scale topologies that can be used to simulate the operation of the designed network protocols and models. Structures created using topology generators do not always reflect the modern nature of the network, which is constantly growing and evolving.

The topologies obtained from mapping real networks represent the real state of the network at a given point in time. Research has shown that in addition to using the full topology, smaller fragments can also be determined from it. However, care must be taken during the reduction not to significantly distort the structure of the network. Regardless of the method of obtaining the topology, the parameters of nodes, flows and routes are required to perform modelling. The work proposes a method that allows to create connection routes using the Dijkstra algorithm and generate the necessary parameter values based on the recommended values for any network topology.

A significant part of the work is devoted to the presentation of new methods for determining the fluid flow approximation model. Methods of task decomposition and approximation parameters are characterized in accordance with the models of concurrent programming and the architecture of the multiprocessor system used. In order to evaluate the efficiency of the proposed concurrent method, a number of studies were carried out regarding the optimization of the solution, comparison of the efficiency of methods depending on the way of saving the result data, the operating system libraries used, various multiprocessor systems, methods of distributing work to individual processors and methods of dividing the task. The conducted research showed a significant impact of work and data decomposition on the computation time. It was shown that the performance scalability of a parallel program depends not only on the increase in the number of processors, but also on the use of vector operations and the current version of the operating system or its components. It can improve performance results by several or several tens of percent.

Research has also indicated that the operating system tries to maximize CPU utilization by balancing the loads on the available cores. With the increase in the number of processors, it turns out that it may be more profitable to reach for data located on other nodes of the system (remote memory) than multi-thread context switching on the same CPU. Work distribution rules are most useful for a multiprocessor system with several or more nodes. If the available system is smaller, the use of work distribution mechanisms will not bring the expected benefits. It has been determined that the best method of thread distribution is the rule of assigning threads to selected nodes of a multiprocessor system with their placement using a round-robin algorithm controlled by the numactl program.

Much better results are obtained by decomposing the data. Research has shown that due to the need to use multiple thread synchronization and both parametric and numerical dependencies (algorithm stepping), only partial acceleration of the modelling time can be achieved, and the efficiency of the concurrent solution decreases with the increase in the number of threads on which the algorithm is run. The best solution found was the division of one- and two-dimensional data vectors, one element per thread according to the round-robin algorithm. The advantage of this approach is that there is no need to consider the size and division of the data. At the same time, it is the best solution in the given conditions and recommended in the fluid flow approximation model, because it gives a solution more than twice as fast as the internal simulation time. Therefore, it allows to analyse phenomena in the network faster than they actually occur. If it is possible to model the network faster than the actual elapse of time, then in addition to backward analysis, one can try to predict the state of the network, detect congestion and excessive load earlier.

As an alternative method of determining the fluid flow approximation model, the use of database technologies that enable efficient data collection and storage was proposed. Technologies are not designed to generate numerical results, but according to the paradigm of moving the code as close to the data as possible, intensive and costly calculations should be performed in the database layer.

So far, however, no method has been developed that would allow defining and saving the problem of fluid flow approximation in a language understandable for database systems or data warehouses.

However, apart from modelling capabilities, databases and data warehouses can support network analytics as data stores that can be queried to answer questions about the health of the network: global, granular, instantaneous, and average. The analysis of both the general picture and a specific fragment allows for better and more accurate conclusions regarding the phenomena occurring in the network, their moments, causes and effects. The data models and methods developed on the example of the SAP HANA platform made it possible to model, store and process fluid flow approximation data in the database. The selected platform was to support building solutions based on database procedures, the process of loading data into the database (ETL), stream and graph processing. Research has shown that, unfortunately, not all technologies could be used to their full extent. In terms of modelling performance, all alternative modelling methods remained significantly slower than the concurrent method. The advantage of the database solution is the simplicity of modifying algorithms stored in the form of database procedures and the speed of extracting knowledge about the state of the computer network. The work showed the validity of the use of databases, but it requires further search for technologies that will allow to achieve a satisfactory modelling time.

The presented solutions made it possible to carry out a quantitative analysis of transient states in a network consisting of over one hundred thousand nodes and several tens of thousands of flows for new fluid flow approximation models: a model detailing the classical model, a model with dynamic switching of network node parameters depending on the transmission intensity, and a model of an energy-saving node in the fluid flow approximation. The proposed innovative approaches allowed for the analysis of selected network scenarios in order to assess the local and global impact of individual parameters of nodes and flows on the state of the Internet-scale network. The work, which resulted in a network model of unprecedented size, opens up new possibilities in the field of modelling and evaluating the effectiveness of wide area networks.

The results obtained have been published in the following peer-reviewed journals and conference proceedings:

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