Survey on Application of Communication Network Topology Simulation Technology

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Abstract. As an important part of the study of communication networks, network topology clearly reflects many structural features of communication networks from the physical level and is a major research hotspot in this field. Simulation techniques are becoming more and more widely used in the study of communication networks as computer technology advances and becomes more convenient and intuitive. This paper collates the current research results on the topology of communication networks and the effectiveness of the applications of simulation technology, reviews the current status of research in related fields at home and abroad, and summarises the application of simulation technology in topology research to provide some reference for subsequent researchers in related fields.

Keywords: communication network, topology, simulation technology.

Communication network topology refers to the physical composition pattern formed by communication devices and transmission media to represent the structural appearance of the whole network and reflect the structural relationship between the nodes. As topology adopts an abstract representation of objects, physical aspects such as size and shape are not considered, and the internship position and interrelationship of objects are described by only two elements, points and lines, so currently the basic network model is depicted mainly through various abstractions and simplifications of the actual network, on the basis of which the statistical characteristics of the network are analysed and studied, and finally the structural characteristics of the network are explored from the side The exploration is carried out [1].

Network simulation technology is a technology that simulates the network behavior through computer modeling and statistical analysis. By establishing a statistical model of network devices and simulating the connection model of transmission links, we can obtain the type of network design and optimize the data we need. With the rapid development of the Internet, network simulation technology has also become an important means to support the verification of new cyberspace security technologies, network security tests, offensive and defensive confrontation drills and network risk assessment. The current representative work of network simulation includes: CASELab proposed by the University of Victoria in Canada can simulate a network with the scale of 10000 virtual machines; The University of Houston in the United States has implemented a virtual distributed network replication technology that can parameterize link performance; The Air Force Academy of Technology has implemented a large-scale, high fidelity network node simulation platform using virtualization technology; The University of Chinese Academy of Sciences has built a TMSR nuclear power simulation system based on Openstack cloud platform that can provide simulation computing resources on demand.

Under the above research background, this paper summarizes the research status of simulation technology in the field of communication network topology from the perspective of application, as well as the main problems faced at present, trying to outline a relatively clear overview for this research direction, and provide useful reference for researchers in communication network topology, simulation technology and other related fields.

1. Research on communication network topology

A communication network is a system of communicating entities and the interactions between them. While communication networks of the same type have many similar properties, differences in topology affect the dynamical behaviour and system functionality that evolves in the same type of communication network. In practice, it is difficult to visualise the network structure and dynamics that we want from easily accessible network performance data. As a result, statistical measures and feature measures that can quantitatively characterise networks and their associated metrics have been developed and refined, greatly accelerating the research process in areas such as network topology identification. Statistical measures of network characteristics include: degree distribution, degree matching, edge weight distribution, average shortest path, average agglomeration coefficient, mediator and its distribution, association structure, modules, modules, etc.[1]. The wide range of different topological features is used as a springboard to study different phenomena and to make predictions, while the analytical methods become richer and more rigorous as the statistical features of the network become clearer.

In the analysis of network degree distribution, the common methods are: mean field method, rate equation method, master equation method, Markov chain method. A large number of studies have shown that the degree distribution of networks follows a power rate distribution, a power rate tail feature, or a power rate distribution with exponential truncation. A previous work has studied the growth networks that meet the linear optimal mode, and analytically obtained the recurrence expression of the degree distribution. On this basis, it is proved that under certain conditions, its approximate analytical solution conforms to the Mandelbrot distribution. After that, the research focus began to shift to more detailed local structure, such as the impact of sampling algorithm on network topology, the method and error of estimating the power index of network degree distribution, the existence of stability distribution, and the mathematical method of proving the small world nature.

In the aspect of network connectivity enhancement, Chen et al[2] proposed edge adding strategies based on degree centrality, proximity centrality, intermediate centrality and feature vector centrality respectively to deal with network attacks; Jiang et al[3] changed the network topology by randomly adding edges, low degree adding edges and low intermediate adding edges to enhance the network performance; Cao et al [4] comprehensively studied random edge adding strategy, high dielectric edge connecting strategy and low polarization edge connecting strategy, and considered the cost of network connection; Ghosh et al [5] proposed an edge adding method based on greedy strategy. The objective function is to maximize the second largest Laplacian eigenvalue, and each edge adding selects the edge that can maximize the eigenvalue; Kim et al[6] considered the second small eigenvalue of Laplace matrix and designed a more concise network edge adding strategy based on dichotomy; Shi et al[7] proposed a strategy to protect key nodes, adding redundant edges between key nodes of the network to improve the robustness of scale-free networks; Zhao et al proposed the random local reconnection method, which is used when the network reconnection requires edge addition.

In terms of topology optimization and remodeling, Liu et al[8] built a large-scale UAV network for 6G communication. Under the condition that high-density sensor nodes or terminals are scattered in the urban and suburban areas, and using the normally deployed UAVs as relay nodes, they collected data or forwarded control messages, and finally gathered the information in the region to the gateway node or server platform at the center of the network, Except for UAVs, other terminal nodes randomly and irregularly generate data packets and upload them to the cloud composed of UAVs. UAVs transmit the data generated by nodes to a network center in a multi hop manner, that is, the network node; Zhang et al[9] proposed a topological structure modeling method for spatial information networks based on multi-layer networks. On the basis of analyzing the multi-layer characteristics of spatial information networks, they first modeled the spatial information network nodes, focusing on describing the spatial location and load function attributes of entities, and then divided links into two categories by considering the type of interactive information between entities of spatial information networks and the spatial location of interactive nodes, and built the edge connection model of spatial information networks, Finally, the network layer of the multi-layer model of spatial information network is described from four dimensions of spatial distribution, functional networking, task networking and time-varying topology, and the multi-layer topology model of spatial information network is constructed; Yang et al[10] put forward a mechanism that can self optimize the reconfiguration of network topology according to the fluctuation of network traffic. They used DDPU algorithm to optimize the training process and SDN controller to provide topology configuration, so as to continuously train the relationship between topology and traffic distribution, and achieve automatic optimization and reconfiguration of network topology, thereby improving network performance; Cui et al[11] proposed a topology optimization control algorithm based on improved particle swarm optimization for multi unmanned vessel networks, and constructed a topology optimization model for multi unmanned vessel networks by comprehensively considering network connectivity, link communication quality, network connection revenue and network connection cost.

In terms of topology analysis and positioning, Huang et al[12] proposed a topology positioning method for mobile communication network communication nodes based on adaptive hierarchical routing detection. The Sink node grouping coordination mechanism was used to design the load balance control of the communication network. At the same time, the shortest transceiver path optimization method was used to design the adaptive networking of communication nodes, calculate the correct transfer probability density function of network link nodes, and solve its optimal value, with this as the optimization goal, hierarchical route detection is carried out to achieve topology location of communication nodes; Liang[13] proposed a new heuristic analysis method of ship communication network topology structure. The network node cluster layout was constructed by calculating extreme coordinates. The topology structure was coarsened and the multi-layer path of the structure was divided in the network node cluster layout. The communication network topology structure was analyzed by confirming the placement position of the topology node.

2. Research on communication network simulation technology

As a new network planning and design technology, network simulation technology provides an objective and reliable quantitative basis for network planning and design with its unique method, shortens the network construction cycle, improves the scientific decision-making in network construction, and reduces the investment risk in network construction[14]. Network simulation technology has become the mainstream technology in network planning, design and development.

Network simulation technology has the following characteristics:

(1) The simulation is based on statistical model, and the randomness of statistical multiplexing is accurately reproduced;

(2) The new simulation experiment mechanism makes it possible to obtain highly reliable results in a highly complex network environment;

(3) Its prediction function is incomparable to any other method, which can verify the actual scheme or compare many different design schemes;

(4) It can be used for optimization and expansion of existing networks as well as design of new networks, especially for design and optimization of large and medium-sized networks, providing reliable quantitative basis for network planning and design[15];

(5) The initial application cost is not high, the built network model can be used continuously, and the later investment will continue to decline[16].

The applications of network simulation technology include: planning and forecasting capacity; analyze the fault; analyze end-to-end performance; analyze the impact of new services and users on the network; optimize the cost performance of network design; forecast the growth of business volume; guide the construction of new networks [17].

At present, more mature network simulation simulators include OPNET, TOSSIM, QualNet, NS-2, NS-3, GloMoSim, NCTUNS, GTNets (including RT IKit library), OMNET++, SSFNet, J-Sim, MATLAB and Yans [18]. Due to the unique characteristics of the communication network, these commonly used simulators have some limitations in use. As a result, a simulation platform for simulator function expansion has emerged, a simulation platform for communication network performance analysis and system testing has been developed, and a network simulation platform integrating multiple simulation tools has also been developed.

Table 1. Comparison of typical network simulators

Name	Computer language	Advantage	Shortcoming
NS-2	C++, OTCL	Open source, with extended sensor modules; Support various business models and communication protocols; Adopt object-oriented technology; Strong ability to process results.	The simulation speed is too slow to simulate large-scale networks.
OMNeT++	C++, NED	The non-commercial version is open source, and the simulation speed of the simulation component with flexible configuration is one order of magnitude higher than that of NS2.	Multimedia service is not supported.
OPNET	C/C++	Pay attention to QoS evaluation.	There is no energy model to evaluate the effectiveness of energy consumption.
TOSSIM	NesC	TinyOS Moters is used for bit level simulation.	There is no energy model to evaluate the effectiveness of energy consumption.
GloMoSim	Parsec	Concurrent multithreading provides a powerful message receiving mechanism.	Only pure wireless network emulation is supported.

OPNET is produced by OPNET Technologies Ins in the United States and is mainly used for large-scale network topology construction and experiments. This model uses the network state model based on discrete event drive to build a virtual network. Relying on the efficiency of discrete event drive, the generated network model and the data communication in the model can reach the characteristic standard of the real network, so that it can be applied to professional network architecture design and experiment [19]. The platform has been widely used in network design, structural topology, data transmission and network pressure experiments.

Table 2. Standard process of simulation modeling based on OPNET

Step	Concrete content
1	The network environment is built through the network module of OPNET, which needs to define the basic communication protocol, network capacity and other relevant parameters.
2	Through the node module of OPNET, the device nodes in the model are defined. This process mainly realizes the hierarchical division and equipment attribute customization in the data transmission process, sets and plans the main components, data messages, statistical information and other parameters of node equipment, and designs them as a whole to ensure the stability of the entire network.
3	The last step in the design of the entire network model is to use the state transition diagram to set the communication rules and states between modules, nodes, and communication media, use C/C++to drive the logical state of the main nodes, and use the wiring method to identify the connection relationship between data transmission and media.

In the process of designing the model using OPNET, the nodes, connection media, working protocols, logical layering and other attributes within the model need to be designed according to the actual network attributes, and the components can be assigned and connected at will, and can be added, deleted and modified according to the existing physical equipment, fully realising the customised modelling of the whole network equipment. In the process of data generation and collection, it is necessary to rely on the efficiency of discrete event-driven, so that the generated network model and the data communication within the model can reach the characteristic standards of the real network and be able to carry out network processing and simulation of massive data, and its hybrid modelling mechanism makes the compatibility of the network greatly improved and can realize the development and application of user-customized network modelling.

QualNet[20] is a fast and accurate development and simulation system for wireless, wired and hybrid dynamic networks. --It has been used in more than 50 countries worldwide. The main focus is on the optimisation of wireless mobile communication networks, which has resulted in a significant increase in simulation speed and a high level of simulation accuracy through the modelling of radio channels and RF technology. QualNet is several times faster than other simulators for small-scale network models of the same complexity, tens of times faster than other simulators for large-scale networks, and up to a thousand times faster than other simulators if QualNet uses parallel simulation mechanisms. Masking, adding and removing certain protocol modules. Standard inter-layer interfaces for TCP/IP protocol stacks are supported, eliminating the need for users to develop this type themselves.

NS [21] originated in 1986 as the Real Network Simulator project, and in 1995 joined the US DARPA-supported project VINT (the Virtual InterNet Tested) with the support of Xerox as the foundation and core part of the VINT project. In the process of incorporating the work of researchers from around the world, NS has evolved from its original version to a more mature version, NS-2, an object-oriented, discrete-event driven network simulator written in C++ and Otcl. Ns-2 is available under a variety of platforms, including UNIX, LINUX and Windows. Ns-2 simulation software is a software package that includes components such as Tcl/Tk, Otel, NS, Tclcl etc. NS-3 uses C++ to modularise components and describes topologies directly in C++. The current NS-3 is still much less modular than NS-2, but work on porting NS-2 modules over has been progressing steadily. In addition, NS-3 itself has a number of modules under development, notably: a simulation and real-time scheduling module, a synchronous Posix-like API, integration of NSC, the source of network simulation, a visualisation module, IPv6, integration of practical applications, parallel simulation, a statistical analysis module, a Wimax module, an underwater acoustics module, etc.

OMNET++ [22] (short for Objective Modular Network Testbed in C++) is an open source, component-based, modular open network simulation platform for large networks. OMNEST is a commercial version of OMNET++. OMNEST can be used in a wide range of discrete event simulation applications: communication networks, protocols, queuing networks, telecoms networks, and other networks. protocols, queuing networks, telecommunication networks, satellite communication networks, naval and air force data chains, sensor networks, army tactical communication networks, electronic countermeasures systems, hardware systems and any other simulation system suitable for the application of discrete-event processing.

GTNetS [23], known as The Georgia Tech Network Simulator, is a network simulator developed by the MANIACS research group led by Dr. George Riley at the Georgia Institute of Technology in the USA, primarily for medium and large scale network research, including support for distributed simulations (requires the RTI Kit GTNetS is a full-featured network simulation environment designed to create an exact approximation of the real network, allowing the simulation to accurately reflect real network conditions and facilitating code portability between the simulated and real environment. In GTNetS, there are clear boundaries between the layers of the protocol stack. Packets contain a series of protocol data unit PDUs that are stripped or added as the Packets move up and down the stack. The Node object Node can be bound to multiple network interfaces, each of which in turn can be bound to an IP address and physical link, much like the structure of a computer + network card in a real world environment. Transport layer protocol objects are bound to ports in a similar way to real network protocols (TCP), and connections are made between transport layer protocol objects via source IP, source port, destination IP, and destination port. The interface between the application layer and the transport layer protocol uses the familiar UNIX-like sockets API to connect, and the application layer can host a variety of protocol objects, including both simulated and real data.

3. Communication network topology simulation technology applications

Network simulation techniques are currently used in all aspects of topology research, not only to simulate the topology as a whole to validate new communication networks, but also to make effective suggestions for optimising the network topology at the algorithmic level in terms of some of the characteristic quantities. At the same time, with the increasing demand for network simulation, it is also a key research area to ensure that the mapping between the network topology map to be simulated and the computational clusters is reasonable and efficient, and that the resource requirements and load balance of the network simulation are guaranteed.

In a simulation study of the complete topology, Zhang et al [9] used the communication network, navigation network, sensing network and user network as the main functional sub-networks, and each functional network followed the scheme of "sky network and ground station" and "communication through backbone nodes" between functional networks to build a typical spatial information network experiment case network. "The navigation network provides ephemeris information to the platforms in the network, the communication network and the sensor network; the nodes in the sensor network sense the target and transmit the target trajectory information to the user through the satellites in the network, the ground platform and the communication network; the nodes in the communication network are interconnected internally and are responsible for the integrated information transmission with other subnetworks; the navigation network, the sensor network and the user network are interconnected. integrated information transmission, and three functional subnetworks such as navigation network, sensing network and user network are fused and collaborated through the communication network to form a typical space information network with target sensing and information transfer capabilities; Yang et al[10] built a reconfigured network simulation environment and DRL Agent model based on OMNeT++ discrete event simulator and TensorFlow open source ML platform, respectively, modeled after The topology of a 14-node and 3-node degree scale network was established based on the common data centre optoelectronic hybrid interconnection network architecture, where all Top of Rack Switches (ToR) were connected adjacent to each other to form a fixed ring structure, and all ToRs were connected to OCS upwards through optoelectronic conversion interfaces, and topology reconfiguration could be achieved by reconfiguring the internal cross-connections of OCS to The topology can be reconfigured by reconfiguring the internal cross-connections of the OCS to meet the communication requirements of different applications.

In terms of simulation research on topological feature quantities and related optimization algorithms, Wu et al [24] proposed a method for topological diagnosis of power communication networks based on the influence of network nodes, taking into account the scale characteristics and aggregation characteristics of the neighbours of network nodes, using multi-attribute decision theory, and selecting the degree-free network and small-world network with similar characteristics to power communication networks as simulation means, through the the calculation of the similarity of two node attributes quantitatively analyzed the size of the influence of different attributes on the nodes, determined the influence of each node on the whole network, and used the node influence to diagnose and analyze the anti-destructiveness and robustness of the network; Dong et al[25] introduced the hierarchical declustering structure into the study of information interaction topology, and at the same time, with the combined optimization objectives of improving the formation range and reducing the total communication cost of the formation A hierarchical distributed information interaction topology generation algorithm was proposed and validated by algorithm simulation with OMNeT+; Cui et al[11] used Matlab2012a software to verify the EM-DPS O-based multi-USV network topology optimization control algorithm by comparing it with the DPSO-based multi-USV network topology optimization control algorithm and the DSPSO-based multi-USV network topology optimization control algorithm network topology optimization control algorithm. The comparison of simulation results proves that the algorithm can obtain the global optimal solution of the model, ensure the diversity of particle populations and speed up the convergence of the model.

In terms of configuration optimization research on communication network topology simulation, Wang et al [26] proposed a virtual network mapping algorithm based on virtual topology preconfiguration and reusability techniques to improve mapping fairness; Zhu et al[27] proposed a nonlinear partitioning method for network routing simulation tasks, which can effectively reduce the computational overhead of distributed network simulation in heterogeneous computing environments; Li et al [28] referred to second-generation non-dominated sorting genetic algorithm to propose a multi-objective switched Ethernet topology optimization method based on 0-1 mapping matrix; Peng[29] established a network topology consistent and energy-efficient virtual network mapping model based on the network topology properties and the energy consumption characteristics of physical nodes and network devices in the underlying physical network, which effectively increased the number of dormant physical nodes and dormant physical links and significantly reduced the resource cost and system energy consumption of virtual network mapping; Liu et al[30] proposed a mapping method for virtual network topology of multi-scale fusion simulation based on lightweight virtualization and full virtualization, which ensures load balancing among computing clusters while reducing remote communication, greatly improves the performance of network simulation, and enables fast mapping of virtual network topologies of different scales.

4. Epilogue

This paper collects and organises literature on communication network topology research, communication network simulation technology research and the application of simulation technology in the field of topology research to understand the current status of research in related fields and to provide some reference for subsequent research in the application of communication network topology simulation.

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