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A Review of Literature on Networks Performance Evaluation

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ABSTRACT

This paper demonstrates that the focus within which networks performance is evaluated is changing. We review the literature on network performance evaluation during two decades; 1998-2018 with a focus latency, throughput and jitter. Also, we analyze the literature from different perspectives such as the network performance indicators, simulation tools and models, measurement tools and models among others. We then provided a case for operational analysis for network performance evaluation.

Keywords: Networks, Performance, Simulation, Evaluation and Measurement.

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1. INTRODUCTION

When we talk about computer intensive and time critical applications, i.e. service-oriented applications and applications on demand, special attention needs to be paid to efficient network management. The aforementioned is additionally worsened by many users, the heterogeneity of applications, service providers and network infrastructure (Guoqiang & Habibi, 2002). Due to these conditions, it is necessary to detect factors determining network performance and to have an overview of performance evaluation possibilities. According to (Fortier & Michel, 2003), out of all network performance modeling and evaluation tools, the most complete overview of real performance as well as prediction of performance patterns can be provided by operational analysis. It can be used if network performance monitoring is enabled by corresponding software and hardware tools which yield necessary experimental results referring to the observed interval. Section 2 outlines the most important factors used in determining network performance. Section 3 describes arguments for performance evaluation, as well as tools, i.e. modeling and evaluation modes. Section 4 and 5 will reveal the models that have been adopted for network performance evaluation down the years.

2. NETWORK PERFORMANCE INDICATORS

Network communication is according to (Parthasarathy, 2006) limited by various factors, such as available bandwidth, network congestion, delay, server performance, and complexity of the protocol for network management. In addition to a great number of network users, there are several factors which, when combined, test usability bounds of a traditional local area network (LAN):

- Multitasking environment present in current operating systems enables concurrent network transactions
- Intensive network applications such as the World Wide Web have also been on the rise.

- Applications based on the client-server model do not require workstations to store information or to ensure space on the hard disk for their storage. Studies such as (Nieh *et al*, 2012) (Li *et al*, 2005) (Breitbart *et al*, 2001) reveal that such applications will probably be used more significantly, but in a more sophisticated form.

Also, (Guoqiang & Habibi, 2002) suggested many factors that negatively affects the performance of the LAN common medium Ethernet/802.3 such as. Ethernet uses the carrier sense multiple access/collision detect (CSMA/CD) method described in (Harfoush *et al*, 2003), and supports high transmission rates. The goal of the Ethernet is to offer the best possible delivery services and enable all devices on the common media to have equal conditions referring to data transmission. Collisions take place regularly on the Ethernet networks and can also become a major problem. A combination of powerful workstations and intensive network applications, i.e. usage of huge files, real-video, as well as demanding multimedia applications in general, requires an increasingly greater network throughput. On one hand, the number of network users is on the rise as well. On the other hand, network congestion is caused by an increase in the number of users using the network for sharing big files, access to file servers, and connection to the Internet. The consequences of the former are increased response time, slower transmissions of files, and thereby less productive network users (Zhao, Li, & Chen, 2006). However, in order to reduce network congestion, what is necessary is either a larger bandwidth or a more effective use of the available bandwidth. Network efficiency is improved significantly by monitoring and management of its performance.

3. NEED FOR NETWORK PERFORMANCE EVALUATION

According to (Fortier & Michel, 2003), computer architecture, operating system, database and LAN represent elements for improvement of efficiency of application execution. In case of improper use, efficiency might be reduced. Computer systems based on decentralized, parallel and distributed architectures are constantly being designed and brought into use (Lowekamp, 2003). Computer system components have become more complex, and at the same time requests referring to reliability and availability are higher, as in (Jain and Dovrolis, 2003) (Egyhazy and Yao, 2007).

3.1 Modelling Tools for Network Performance Evaluation

The general types of modeling tools in (Fortier and Michel, 2003) are analytic, simulation, test bed and operational analysis. Analytic modeling tools refer to a skill of describing a model by means of mathematical expressions. If the system can be considered as a set of queues by which service delivery time and waiting time may be defined analytically, then queuing analyses can be applied to problem solving. Simulation implies that a real system model is shown by means of a certain programming language for simulation execution. Simulations further enable laboratory conditions for system testing without influencing the real system. Test beds are used for studying system components and their mutual interaction in order to reach the heart of the real system. They are made of prototypes and parts of components of the real system. This method is focused on a subset of the whole systems. It might be used for the analysis of various components of networks. Compression and simplification of the system have been said not to be important in operational analysis, but rather getting information from the real system (Papagiannaki *et al*, 2005). Analysis of this information provides a good projection of future behavior, i.e. system operation. Operational analysis covers the aspects of measurement and estimation of the real system. The measurements are carried out by using software and hardware monitoring devices.

Hardware monitoring devices include probes and sensors, counters, as well as devices for data display and recording. Software monitoring records certain events and information about the system state. The results of the analysis can be used for improving performances and setting up new bounds of the system, i.e. for improvement of the existing system.

3.2 Review of Relevant Simulation Tools

- Network Simulator-2 (NS-2): Network Simulator-2 (NS-2) is one of the most popular open source discrete event network simulators. NS-2 provides substantial support for simulation of TCP, routing and multicast protocols over wired and wireless networks. The first version of NS, known as NS-1, was developed at Lawrence Berkeley National Laboratory (LBNL) in the 1995-97 timeframe. Hence NS-1 was also known as the LBNL Network Simulator. NS-2 is the second version of Network Simulator (NS) project, which is supported through Defense Advanced Research Project Agency (DARPA). The current version of NS-2 is 2.34. In NS-2, a network animator (NAM) provides packet-level animation and protocol specific graph for design and debugging of network protocols (Begg and Kelvin, 2006).
- Network Simulator-3 (NS-3): Network Simulator-3 (NS-3) is also an open sourced discrete-event network simulator which targets primarily for research and educational use. Both simulation and emulation studies can be carried out using NS-3. The architecture of NS-3 is shown in figure 2.2. The goal of the NS-3 project is to create an open simulation environment for networking research that will be preferred inside the research community. The first release, NS-3.1 was made in June 2008 and afterwards the project continued making quarterly software releases and more recently has moved to three releases per year. NS-3 made its fifteenth release (NS-3.15) in the third quarter of 2012. (Thontadharya and Shwetha, 2012).
- NetSim: NetSim is a popular network simulation tool used for network lab experimentation and research. It is a stochastic discrete event simulator developed by Tetcos, in association with Indian Institute of Science with the first release in June 2002. Various technologies such as Wireless Sensor Networks, Wireless LAN, WiMAX, TCP, IP, etc. are covered in NetSim. The code for NetSim has been written in C and Java. NetSim provides network performance metrics at various abstraction level such as Network, sub-network, Node and a detailed packet trace (Johannes *et al*, 2008).
- J-Sim (Java-Simulator)*:* J-Sim is a network simulator written in Java and is built according to the component based software paradigm, which is called Autonomous Component Architecture (ACA). In J-Sim, each component can be atomic or composed of other components interconnected through ports. J-Sim ports support one-to-one, one-to-many and many-to-many connections. J-Sim protocol architecture comprises of two layers, the lower layer called Core Service Layer (CSL) consists of network to physical layers and the higher layer consists the remaining of Open System Interconnection (OSI) layers (Anis and Izzat, 2017).
- OMNeT++ is an extensible, modular, component-based C++ simulation library and framework, primarily for building network simulators. OMNeT++ provides component architectures for models, which are programmed in C++ and then assembled into larger components/models. OMNeT++ is not a simulator in itself but rather a simulation framework. Instead of containing explicit and hardwired support for computer networks or other areas, it provides the infrastructure for writing such simulations. Specific application areas are catered by various simulation models and frameworks, most of them are open source. These models are developed completely independently of OMNeT++ and follow their own release cycles (Christhu, 2015).

- OPNET (Optimized Network Engineering Tools) was created by OPNET technologies in 1986. The Latest version of OPNET Modeler Suite is 18.0.3 which was recently released in April 2015. Now, OPNET is part of Riverbed Application and Network Performance Management Solutions (Koksal, 2008). OPNET is a discrete event simulator and is available both in 32-bit as well as 64-bit for Windows and Linux Operating System. OPNET Riverbed modeler makes use of Object Oriented technology to create mapping from the graphical design to the implementation of the real system. OPNET models the network in a hierarchical approach which somewhat matches to hierarchical structure of Internet: Networks, Satellites and Nodes. OPNET basically supports three types of Links: Point-to-Point, Bus and Wireless. Wireless Link is basically used in Wireless, Mobile or Satellite Network. Although, OPNET has various libraries for Wireless and Wired networks, it also supports Wireless Sensor Networks.

3.3 Review of Other Tools Used for Network Performance Evaluation

- Drift Analyzer: Accurate time measurements result in accurate experimental results. In order to achieve that, the system clocks of the two measurement end points should be synchronized. Clock synchronization is the most important preliminary step in applications where decision making is dependent upon accurate measurement of arrival and departure time of packets. Drift Analyzer is a tool that caters to this requirement as it implements a simple algorithm based on request response packet timestamps (Ravindranath *et al*, 2013).
- Netperf: Netperf is a benchmarking tool that is widely used for measuring the performance of different kinds of networks. It enables measurement of metrics such as unidirectional throughput and also end to end latency for a connection. Furthermore, it supports measurements on protocols like TCP, UDP and SCTP for both IPV4 and IPV6 and also provides tests specific to them (Annis and Izzat, 2017).
- TCPdump: TCPdump is a free software distributed under BSD license. It is a powerful, command line based packet analyzer used for capturing and analyzing packets over the network to which the computer is attached. It allows the user to sniff the network, that is, to intercept and print the packets being transmitted or received by the computer. It reads the packets from the network interface it is attached to or from a file containing previously captured packets. It can print the contents of the network packets and can print its output to the standard output or to a packet capture file. It also allows the users to configure a BPF based filters (McCanne and Jacobson, 1993) to reduce the number of packets captured and displayed to the user in circumstances when there is a huge volume of network traffic.
- Ping: Ping is a networking utility that is used to test the reach-ability of remote computers on an Internet Protocol based network and also for measuring the Round Trip Time for packets sent to these computers from the local host. Ping is based on ICMP Echo request and reply messages. It transmits the echo request message to the remote computer and waits for the corresponding response. The time duration from the transmission to reception is measured as the Round Trip Time and any packet losses are also recorded. It gives the results in the form of a summary containing the minimum, average and maximum values of Round trip time measured along with the standard deviation for the same. It also shows the packet loss statistics if any. This tool is easy to use and can be employed to generate baseline RTT values for a particular connection quickly.

- Mpstat: Mpstat is a command line based tool for UNIX like operating systems that provides its users, statistics related to CPU usage on the screen. It is usually used to monitor the computer's performance and also to generate CPU related statistics as well.
- TRoTTEr: TCP Round Trip Time Estimator (TroTTEr) is a tool that is used for estimating and monitoring round trip times which is essential for understanding network performance as well as to measure the performance of services implemented over the network.
- VirtOCalc: VirtOCalc is a tool used to calculate network latency due to. It is widely known that the development of hardware and software virtualization revolutionized the Software and IT industry and ushered in the era of cloud computing. Virtualization enables optimum utilization of hardware resources and minimizes resource wastage. If enough network and storage resources are provisioned, a server with a decent hardware configuration can be used to provision multiple virtual machines that could in theory, provide a better overall performance than the single host. However, virtualization carries with it the added burden of processing overheads which are a natural result of sharing the host hardware and network resources between the guest machines.

4. MEASUREMENT MODELS FOR PERFORMANCE EVALUATION

In measurement models, desired metrics are obtained from measurements of the system measured in either an operational or a controlled environment. This technique inherently yields the most believable results. However, measurement based evaluation is a very expensive technique and moreover since it requires an actual system, evaluation is not applicable during system design. Table 1 on the next page shows some performance evaluation studies based on measurement.

Table 1: Some Performance Evaluation Studies Based On Measurement.

Evaluation Model	Analyzed Variables	Methods	Results	Author(s)
Network Performance Evaluation of Latest Windows Operating Systems	One-Way Delay, Jitter, throughput and CPU usage	Windows XP, Vista and 7 were evaluated using the distributed internet traffic generator (D-ITG in terms of network delay, jitter and throughput. Also, CPU usage was measured to get insight into CPU availability during network testing. Experiment was conducted with OWD and RTT meter for TCP and UDP running over the IPv4 and IPv6, respectively	Newer versions of Windows OSs (Vista and 7) with fully support for IPv6 have enhanced performance for IPv6 networking in terms of the network delays.	(Josip, Goran, & Hocenski, 2012)
Measurement and Analysis of Networking Performance in Virtualized Environments	Bandwidth and round trip time	Drift analyzer was run as a preliminary step to ensure accurate measurement of clock offset between the Host machine and the test VM which ensured accuracy of further measurements.	There is a direct dependence of achievable throughput and round trip times on the amount of CPU resources allocated to the VM.	(Maneesh, 2014)

		VirtOCalc which provides precise measurements of the time taken by the packets between the virtual machines and the host was also used to find out how virtualization overheads affects the end to end latency for an application hosted on the cloud. Mpstat tool was used to record the CPU utilization of each processor core of the Cloudlet Host.	The busier the VM, the lower the performance metrics values became	
Throughput Measurement in 4G Wireless Data Networks: Performance Evaluation and Validation	Bandwidth	Iperf and OOKLA network measurement tools were used to accurately measure the 4G wireless network bandwidth at user end.	Both Iperf and OOKLA are appropriate for measuring 4G network bandwidth. They provide more accurate results when they are deployed together.	(Saeid, Zohreh, Shen, Ali, & Steven, 2015)
Comparative packet-forwarding measurement of three popular operating systems	Throughput, packet loss, delay, and CPU availability	This paper measured and compared the network performance (with respect to packet forwarding) of three popular operating systems when used in today's Gigabit Ethernet networks. Specifically, the paper compares the performance in terms of packet forwarding of Linux, Windows Server and Windows XP. Both kernel- and user-level packet forwarding were measured and hosts where subjected to different traffic load conditions.	Measurement results indicate that Linux has the best packet-forwarding performance on the kernel level in terms of throughput, packet loss and delay. However, Windows Server had smallest delays and highest throughput when forwarding packets on the user level	(Salah & Hamawi, 2009)
Performance Evaluation of Recent Windows Operating Systems	CPU scheduling, memory management, graphic subsystem management, hard disk drive management and network performance.	Performance measurement is done with the set of benchmark applications in three experiments. These experiments determine how Operating system performance varies in different network environments.	Windows 7 and especially Windows Vista do not provide a better overall performance on the high-end computer system compared to Windows XP.	(Josip, Goran, & Hocenski, 2012)

Impact of CPU-bound Processes on IP Forwarding of Linux and Windows XP	Throughput, packet loss, round-trip delay, and CPU availability	The performance of Linux and Windows XP when used in private homes or small- to medium-sized business network environments was compared experimentally. In particular we measured the packet-forwarding performance of a typical PC when deployed as a standalone or shared server	Linux substantially outperforms Windows XP under almost all traffic load conditions thereby making Linux the preferred platform of choice for standalone and shared networking servers.	(Khaled & Mohamed, 2010)

5. SIMULATION MODELS FOR NETWORKS PERFORMANCE EVALUATION

A simulation model is a computer program, written in a general purpose or specific simulation language. Simulation implements the most important aspects of the system under study, often in a simplified manner and it allows for a greater level of detail than analytical modeling (Vasudha, 2012). Simulation is a reliable performance evaluation technique which abstracts a real system and models it in a basic level. It replicates the real system's behavior with real environment settings. Simulation is a low cost technique compared to real time measurement and hence widely used method of performance evaluation technique. Computer and communication systems are dynamic, stochastic, discrete-state and discrete-time systems.
A discrete event simulation of such systems needs to modify the model's state only at discrete times, between these times the state is guaranteed not to change (Egyhazy and Yao, 2007). Table 2 shows some performance evaluation studies based on measurement.

Table 2: Some Performance Evaluation Studies Based On Measurement

Evaluation Model	Analyzed Variables	Methods	Results	Author(s)
Analysis of RIP, OSPF and EIGRP Routing Protocols using OPNET	Convergence Activity, Convergence duration and routing tables	The study implemented three Network Topologies (Small Ring, Small Mesh, and Large Mesh) in setting up the various protocol and simulation parameters as well as five routers to configure the small ring topology and a Failure Recovery Node was also implemented between two of the routers in order to evaluate convergence time when a link fails	EIGRP is the best routing protocol because it has the best convergence and bandwidth efficiency in all the scenarios. OSPF is better for large topologies, while RIP is only suitable for small networks.	(Kiavash *et al*, 2010)
Performance Issues and Evaluation considerations of web traffic for RIP & OSPF Dynamic Routing	Wireless LAN media access delay, throughput, HTTP traffic sent and received, Client HTTP page,	Study evaluated the performance of Wireless and Wired computer networks with a combination of the conventional model of RIP and OSPF Routing protocols. The study used OPNET to evaluate performance parameters such as wireless LAN media access delay and	Study concluded that there is a significant improvement in Server HTTP task proceeding time with the same server HTTP load. Similarly, the performance is observed to be better for	(Vasudha, 2012)

Protocols for Hybrid Networks Using OPNET	Object response time and Server HTTP task processing time	throughput by varying conventional and the integrated proposed protocol	combined RIP and OSPF dynamic routings protocol with significant change in client HTTP page and object response time, which has been reduced by the order of 2sec.	
Comparing OSPF Routing Protocol with other Interior Gateway Routing Protocols	Hop count, convergence, Routing advertisements, metric calculation and route computation	Conducted a theoretical study that compared OSPF routing protocols with other Interior Gateway Routing Protocols using parameters such as hop count, convergence, Routing advertisements, metric calculation and route computation	Study concluded that OSPF is better than IGRP, EIGRP and IS-IS	(Anuj, 2010)
Design and Implementation of a Hybrid Network for Different IP Routing Protocols and Comparative Study Thereof	Download and upload response time, ATM Cell delay and Remote Login Response time.	Study used OPNET to implement two scenarios. The first scenario was a hybrid network with RIP Routing protocol, while the second scenario was a hybrid network with RIP and IGRP Routing Protocols. The study also implemented HTTP and FTP applications to run on light load for both scenarios environments.	The study reveals that a Network having RIP & IGRP routing protocols is useful to increase the FTP download/Upload Response time. Also, the FTP and REMOTE LOGIN traffic sent and received is less in case of using both IP routing protocols at the same time in same network.	(Manju, 2010)

6. CONCLUSION

This paper presents a review of network performance evaluation models and tools. Most empirical studies are based on the simulation and measurement models. As the measurement framework is usually based on existing infrastructure as well as the complexities (several hops, downtime etc.) involved in measuring enterprise networks, the studies that have employed it have mainly focused on how the architecture of various operating systems affects networks performance. On the other hand, studies based on simulation are able to provide more details due to the flexibility of simulators as well as the level of abstraction they provide. However, most of the networks performance evaluation studies based on simulation models have been carried out in isolation, and as a result have resulted in conclusions that are skewed to individual contexts and scenarios. Also, a lot of the topologies that have been employed in several simulation studies are unrealistic and often do not parallel network setups in the real world. In terms of tools used for networks performance evaluation, it is obvious that there is no single preferred tool to be used for evaluation. Each tool is best suited for different scenarios that they are to be utilized in. In terms of further research, there is a need for a study that provides a universal approach for evaluation by combining several protocols and metrics as well as employing a topology that can parallel real world networks.

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