Analysis and Research of Network Measurement Technologies

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***Abstract*—In this article, the chief research and analysis of the network performance measurement and its research trend in the world are introduced. The network measurement technologies are classified according to consultative layer and other method. Measurement technologies of network layer are emphasized. The advantages/disadvantages of the bandwidth measurement technologies and traffic measurement technologies are analyzed. The future research emphasis of the measurement technologies is summarized.**

Keywords—bandwidth measurement; traffic measurement ; network performance; active measurement; end-to-end path

I. INTRODUCTION

As the Internet goes into millions of households, networks are becoming basic facilities of our society. The heterogeneity and complexity of the network are rising. Management and control of the network become more and more difficult, and we can see the network performances are also becoming increasingly complex. Although the constructions of the network infrastructure have made considerable progress, the network quality of service provided to the user's needs and expectations is still a wide gap. Network capacity increased quickly, but the network performance has not been improved. It was reported that the satisfaction of users to the Internet was less than 40%. The measurement evaluation and upgrading of the existing network have become an important issue in the world. Internet measurement and analysis provides a technique platform for improving network management and increasing network availability. So it has become an important issue widely considered by researchers and government.

II. NETWORK MEASUREMENT DEVELOPMENT

The United States began research on network performance in 1992. With the support of the relevant institutions of the United States, UC Berkeley scientists began to research. In 1994 and 1995, after careful preparation, scientists launched a large-scale measurement by three months, and carried out a detailed analysis. The project has aroused great concern of the U.S. government. The U.S. Department of Defense decided to use the measurement platform and measurement methods in 1997, and improved on the American network conditions for sustained, large-scale measurement and analysis. The improved platform was named NIMI [1] (National Internet Measurement Infrastructure) by the United States Department of Defense. RIPE TMM project [2], European wide-area IP networks such as the ISP joint institutions RIPE (Reseaux IP Europeans) research the large-scale Internet performance monitoring project TTM (Test Traffic Measurement). It implies the clock synchronization of client host system by using GPS. The participants achieve measurement of one-way delay, packet loss rate, delay jitter, bandwidth, and other performance indicators.

China has paid more attention on research of network measurement technologies. By the support of the National Natural Science Foundation and other programs, China conducts a study of network performance measurement. In 1989, Tsinghua University created a network and protocol testing laboratory, which is the earliest institutions to carry on the research of network performance, protocols, equipment. They proposed a large-scale interconnection network performance monitor model LIPM (Large scale Internet Performance Monitor Model) [3]; A network measurement laboratory was founded by Chinese Academy of Science in 1999. They developed a large-scale Internet network measurement and analysis system NIPMAS[4] and network traffic monitor system NetTurbo. The system can monitor the large backbone network of carrier-grade, and achieve major performance status monitoring online. The researches of some universities have achieved certain results. However, there are no large-scale operators to cooperate with the measurement. The need must be strengthened in the breadth and depth of research scale.

III. THE MAIN NETWORK MEASUREMENT TECHNOLOGY

There are many classifications of network measurement technologies. According to the method obtaining probe packet, it can be divided into active measurement and passive measurement. The active measurement transmits specific probe packet to the network. By analyzing packet characteristic and change of the detected data suffered on the network, we can obtain network parameters and network performance behavior parameters. Network tool which called Ping sends an ICMP type packet, and we can get the network

round-trip delay, packet loss rate, connectivity and other parameters. The active measurement must inject additional traffic to the network, and bring effect on the actual behavior of the network and the original network behavior. The measurement results can also cause certain bias. During the network measurement, it must consider the impact caused by the network itself for measuring behavior and minimizing this effect. Passive measurement was measured by detecting the actual network traffic and packet analysis of network performance. Passive bandwidth measurement needs to capture application packets, so there are security issues. The transmission difference of request and response data packet is used as RTT, and affection of server performance to requests are ignored, so it will bring a certain degree of error. The current research of bandwidth is mainly based on active measurement way and the research of traffic is mainly based on passive measurement way. In accordance with the protocol layers, network measurement technologies were mainly classified to network layer, transport layer, application layer and other layer of network performance measurement technology. The network measurement technologies classification of protocol layer is shown in Fig.1.

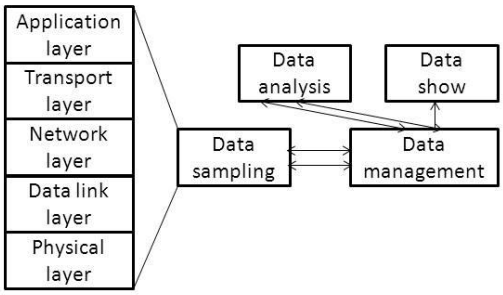

Fig.1. Network measurement technologies classification of protocol layer

A. Network Layer Measurement Technology

1) Bandwidth Measurement

As one of the core concepts of computer networks, Bandwidth is a key parameter for network routing, traffic engineering, and QoS control. It brings great significance in many aspects of protocol design, network management, QoS deployment, multicast communication and multimedia transmission. In the past ten years, the research of bandwidth measurement has always been a hot research. Existing bandwidth measurement tools and methods focused on measuring link capacity, end-to-end path capacity and effective bandwidth.

Variable definitions[5]: v_i represents the speed of signal transmission in the transmission medium; d_i represents the physical distance between router i to router i+1; b_i represents the bandwidth of link i; s^k represents the size of packet k ; t_i^k indicates the reaching time of packet k to link i. When a packet through link (L-1) router reach to link L router, the packet delay is shown in Equation (1).

$$t_l^k = t_0^k + \sum_{i=1}^{l} \left(\frac{s^k}{b^i} + \frac{d_i}{v_i} + q_i^k\right) \qquad (1)$$

$\frac{s^k}{b^i}$ of equation (1) indicates a packet transmission delay, $\frac{d_i}{v_i}$ indicates the propagation delay, q_i^k indicates the total delay of the packets lookup forwarding table and queuing in the router, t_0^k indicates the initial transmission time of packet k. With the equation, t_l^k is represented by a packet arrival time of the router in one way. To calculate the round-trip time RTT of the packet from the source to the destination, it must add the sum of the return time delay. Based on equation (1), if we know other parameter values through technical means, we can find the link bandwidth b^i more easily, which is the basic principle of the network link bandwidth measurements.

① Measurement of the link capacity. The main technologies are based on variable packet length (Variable Packet Size Probing, VPS technology)[6]. The core idea of VPS technology is to measure the round-trip time on the path of each hop link. We use the relationship of RTT and probe packet length to measure the path of each hop link capacity by linear regression technologies. A bandwidth estimation model and related algorithms of the single package model depend on whether to send enough packets to improve the accuracy of probe packets. Sending too many packets will increase the link load, and thus affect the measurement results. With the increasing number of hops link, the number of probe packets for measuring increase greatly, resulting in a more serious distortion. If congestion occurs, it will be a substantial line up, thus affecting the accuracy of bandwidth estimation.

②Measurement of the capacity of end-to-end path. Based on packet pair technology, Packet Pair is made of two equal-length and Back-to-Back data packets. Sent from the source to the destination, the two packets of composition of packet pair queued in the bottleneck link, and the link was no longer on the subsequent line. The dispersion of two packets reaching the destination should be equal to the ratio of the packet length and the bottleneck link capacity, and estimate the end-to-end path capacity. The Back-to-Back network measurement model is shown in Fig.2.

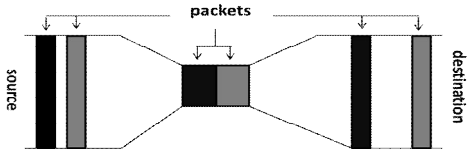

Fig.2. Back-to-Back network measurement model

In actual network, the use of the packet pair to measure the channel capacity is affected by the existence of background traffic interference on the path, and will result in estimation

errors of the channel capacity. Therefore, the present research of packet pair technologies focused on how to use the filtering method to eliminate the impact of background traffic. The end-to-end path capacity measurement tool Nettimer [7] realized by Lai and Baker filters incoming interference samples by filtering algorithm. This method assumes that the distribution of the measurement sample is a single peak, and the measurement points are distributed in the sample path capacity around the true value. By finding the most densely location of distributed sample points, we can estimate the channel capacity. Dovrolis may believe that the distribution of the path capacity measurement sample points rendering multimodal forms are due to the interference caused by the background traffic, and the most densely position of the measuring sample points distribution is not always corresponding to the true value of the path capacity. He has proposed a measure method of end-to-end path capacity called Pathrate [8].

③Measurement of the effective bandwidth of the end-to-end path. In article [9], the method of measuring effective bandwidth of the end-to-end path is divided into two categories, PRM model (Probe Rate Model) and PGM model (Probe Gap Model). PRM model use the association of transmission rate of detection stream and the effective bandwidth to measure the effective bandwidth of the end-to-end path. We can find a turning point of the transmission rate closing to the receive rates to estimate the available bandwidth.

$$\begin{array}{ll} R_i > R_0 & f(R > A) \\ R_i = R_0 & \text{otherwise} \end{array} \qquad (2)$$

In Equation (2), R_i represents the input rate, R_0 represents the output rate, A is the available bandwidth. To find the turning point of the output rate which is less than the input rate, these methods need to use the input rate of linear change iteratively to detect network.

The PGM model [10] used the function relation which is established by the interval and background traffic of packet pair to measure the effective bandwidth of the end-to-end path. The measurement methods of PGM model mainly consist of Spruce and IGI. The article [11] proposed a network path available bandwidth measurement strategy named COPP. The interval of packet pair and the one-way delay variation of packet can reflect the relation of the packet transmission rate and the available bandwidth. COPP transmits the sequence of the packet pair with increasing transmission rate. Then, we find the packet pair which becomes switching points from each group of sequences. According to different levels of interference of these packet pair assigned different weights, a portion of the measurement results of available bandwidth can be obtained. The final measurement result is made of the measurement result for each sequence with its weighting factor, which is the ratio of the time from the former sent sequence to this sent sequence and the total execution time. Pathload is the main detection method based on the traffic rate. It uses a loading cycle, compares the relationship of the transmission rate of cycle traffic and the effective bandwidth of the end-to-end path, adjusts the transmission rate of the cycle traffic to approach the effective bandwidth, and gets the estimated range of effective bandwidth. TOPP [12] considers that if the transmission rate of the packet pair is greater than the effective bandwidth of the end-to-end path, the rate of the data packet pair reaching the destination will be less than the transmission rate, and vice versa. If the transmission rate of the packet pair is less than the effective bandwidth of the end-to-end path, the rate of the data packet pair reaching the destination will be equal to the transmission rate. Therefore, TOPP sends packet pair with increasing rate to establish a function relation of the transmission rate of the packet pair and the effective bandwidth, and uses regression technologies to measure the effective bandwidth.

2) Traffic Measurement

Network traffic measurement is the basis of network traffic management, especially for large and complex Internet backbone. In the present research, passive styles are more used in the measurement of the network traffic. With the development of high-speed network technology, it is extremely difficult to measure the overall network traffic directly. In addition, the maintenance and data analysis of large-scale traffic database is quite difficult. It is necessary to introduce statistical sampling method to measure traffic [13]. Using a fixed sampling interval, the cyclical sampling is a common sampling method, and the problem is that the measurement object which is not available for cycle may be interfered by cyclical measurement behavior. Random sampling is a more reasonable sampling method. RFC2330 recommended that Poisson sampling method should be used to measure the traffic of the Internet.

The sampling method of measuring network traffic can be roughly divided into two categories: one is typical sampling method based on statistics, such as simple random sampling, systematic sampling and stratified sampling; the other method is based on the actual network application, such as Poisson sampling, sampling methods based on random packet stream, adaptive sampling methods, and trajectory sampling methods based on the packet content. The differences between these two methods are not absolute. They will overlap each other, such as packet-based random sampling method is developed from the basis of the simple random sampling. There are a lot of network traffic sampling measurement methods, mainly due to the complexity of network behavior. There isn't a unified consensus to point out which network performance statistics feature is most useful. A good design sampling method depends on the amount of statistics to be collected, so the sampling method which is only designed for different application features would be the best approach. A particular sampling method for one application may be optimal, but for other applications, it may not be optimal, and needs to be further studied and improved.

The traffic measurement equipment, Cisco company's NetFlow [14], is currently widely used, and has become the industry standard. It introduces static sampling measurement mechanism ("systematic sampling") to adapt to the high speed of the network. Nonetheless, there are still following disadvantages of NetFlow sampling method. (1) The use of "1 out of N" static sampling strategy. The need to configure the sampling rate manually brings inconvenience to use: the lower sampling rate reduces the load on the system caused by the measurement process, but it will also cause a large measurement error; conversely, the higher sampling rate improves the measurement accuracy, but it will increase the processing load of the system. So, how to choose the appropriate sampling rates is difficult to select. (2) The resources flow with traffic fluctuation, so it will lack resources protection. NetFlow consumes router processor resources, memory resources of stream record and bandwidth resources of output flow records. As the number of resource consumption is proportional to the flow record, at high load conditions, especially when network traffic increased suddenly by flood attacks and other incidents, resources will be over-occupied, thus affecting the normal forwarding function of the router.

B. Transport Layer Measurement Technology

Most traffic applications currently hosted in the Internet are transmitted through TCP. For these applications, TCP throughput dominated the entire duration of the application, and directly determined the performance perceived by the user. Research on TCP performance has been an important aspect of Internet network protocol research, and TCP throughput is an important indicator to measure the TCP performance.

According to different measurement principle, throughput measurement technologies can be divided into two categories: direct measurement technologies and indirect measurement technologies based on the model. The basic idea of direct measurement technologies is to establish a TCP connection for measuring, transfer a large file through TCP connection, and obtain throughput measurements of the end-to-end path. This method will produce large test traffic, result to a great impact on the network, and not be suitable for use in high-speed networks and long-line measurement environment. The basic idea of the indirect measurement technologies is to build throughput-related model, and then measure the relevant parameters of the model, calculate an approximate throughput by the model. This method does not require transmission of large amounts of data, which will not take up a lot of bandwidth, and can realize online real-time measurement.

Because of the limitations of the measurement principle, the measurement results of the indirect measurement method are affected by the model and model parameters. Among them, the loss mechanism is the key to derive TCP throughput model, and directly affects the accuracy of the model. Especially in wireless network, due to multipath propagation, interference and affection of cell switching, the wireless link has a higher bit error rate. The loss of the packet is likely to be caused. The loss mechanism of existing models used in the derivation analysis model is not very accurate, especially in the wireless environment with low-bandwidth and high error rates, such as MANET, WSN. The actual value of the error is greater. It is difficult to measure some model parameters accurately in the measurement of the actual network [15]. Therefore, choosing the exact loss mechanism to derive TCP throughput analysis model, and achieving accurate online measurement of TCP throughput based on this model, must be solved in monitoring network performance.

C. Application Layer Measurement Technology

Performance-oriented business network will represent mainstream of the next generation Internet regulation field. Researchers will focus on Application Performance Management, and develop the corresponding theory. Application Performance Measurement is different from traditional network performance monitoring. It focuses on a particular business performance indicators. So the traditional network measurement method does not apply to application performance measurement.

Streaming Media business is considered to be the mainstream application on the next Internet. Being different from the simple application of streaming media, streaming business application which fees to users needs to provide appropriate quality of service. It is strict to network bandwidth, packet loss, delay, jitter and other network performance requirements. The current Internet is difficult to provide QoS guarantee. It leads to that large-scale commercial application of streaming media can't meet user's demand for quality of service. Therefore, how to monitor and protect the performance and quality of service of streaming media business is one of the key issues to be resolved. The use of the method or tool of current international application layer performance measurement is to test before deployment with stress to service, and position the performance limit applications system, such as the maximum number of connections supported by services, which can't reflect the actual performance of the end-user, and they are concerned about precisely by the users. A method for measuring the end-user must be found. The method can reflect the final performance situation of the streaming media application. The measurement results directly reflect the performance of the service got by the user. However, more factors affect client QOS performance, so it is difficult to use measurement results to analysis application performance. Especially in China, this research is still in its infancy.

IV. ANALYSIS AND SUMMARY

A. Analysis of Network Measurement Technology

According to obtained packet style, network measurement technologies mainly consist of active measurement technology and passive measurement technology. Active measurement technologies are commonly used in measuring network bandwidth. Passive measurement technologies are commonly used in measuring network traffic. In the measurement of bandwidth, the main three types are followed. The first measurement model based on variable package is mainly used

to measure the link bandwidth. The second is based on the packet pair measurement model, and we can directly measure the bottleneck bandwidth on one path. The third is the model based on packet interval and packet rate model, mainly used to measure the available bandwidth. However, all three methods have their pros and cons. (1)The variable package measurement model needs to send large amounts of data, which affect the normal operation of the network. (2)In the available bandwidth measurement based on packet interval (PGM), the probe packet pair interval is vulnerable interfered on the path by background traffic and packet anomalies, resulting in the available bandwidth overvalued or undervalued. (3)The problem of the available bandwidth measurement based on the packet rate (PRM) is that the unexpected background flow may cause the above of interference, the determination distortion of the relationship of the transmission rate and available bandwidth, leading to measurement error; while constantly approaching process is not equivalent to the continuous improvement of measurement accuracy, convergence conditions and the running time is not easy to determine.

B. Research Emphasis of Network Measurement Technology

In the current traffic measurement, most network traffic sampling measurement method just usually apply to a single point measurement. But these methods merely rely on a single point of network traffic measurement. Gathering information is not comprehensive, and it can't fully reflect the network characteristics increased by the IPv6 network of the huge address space. Further, the sampling measurement technology is mostly based on the desired network characteristics to set parameters and sampling strategy previously. This sample measurement is relatively simple to achieve, but can not be well adapted to the real-time change of network conditions, particularly in the bustier network traffic case. With the continuous expansion of network size and application, characteristics of network traffic are becoming increasingly complex and difficult to predict, and static sampling methods can not meet the implementation of the effective and accurate network measurements of the large-scale high-speed network. Thus, adaptive sampling measurement methods which are suitable for multi-point measurements become the focus of future research directions.

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