

## On evaluating the differences of TCP and ICMP in network measurement

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### Abstract

Network measurement is an important approach to understand network behaviors, which has been widely studied. Both TCP and ICMP are applied in network measurement, while investigating the differences between the measured results of these two protocols is an important topic that has been less addressed. In this paper, to compare the differences between TCP and ICMP when they are used in measuring host connectivity, RTT, and packet loss rate, we designed two groups of comparison programs, and after careful evaluating of the program parameters, we executed a lot of comparison experiments on the Internet. The experimental results show that, there are significant differences between the host connectivity measured using TCP or ICMP; in general, the accuracy of connectivity measured using TCP is 20–30% higher than that measured using ICMP. The case of RTT and packet loss rate is complicated, which are related to path loads and destination host loads. While commonly, the RTT and packet loss rate measured using TCP or ICMP are very close. According to the experimental results, we also give some advices on protocol selection for conducting accurate connectivity, RTT and packet loss rate measurements.

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### 1. Introduction

Network measurement is an important research area and a hot topic in network community. It is an effective method to investigate network performance and behavior characteristics. It also gives straightforward guidance to the evolution of the Internet infrastructure and the enhancement of protocols [1–3].

Many outcomes have been obtained in network measurement research. The IETF IPPM work group proposed a series of RFC documents to define network performance metrics and gave recommendations on metrics measurement. Vern Paxson proposed a framework for enforcing network measurement [4]. To comprehensively understand-

ing the network performance for a long-term, researchers built large-scale network measurement systems [8]. In [6,7], the authors proposed measurement methods for delay and bandwidth metrics. Moon et al. studied on eliminating the clock errors in network measurement [5,9].

There are mainly two ways to measure the network: active and passive. Active measurement means that the user injects probe packets into the network from a probe host, and observes the response of the network to the probe packets at the probe host or destination host, to get knowledge about network performance. As it is easy to use, has accurate results, and can be flexible deployed at anywhere in the network, active measurement becomes the primary method of network measurement. For example, the ping and traceroute programs are the most frequently used active measurement tools. When conducting active measurement, particularly in measuring path RTT and packet

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loss rate, the probe packets injected into the network usually are IP packets in which encapsulated with ICMP message. This method, for it can be implemented easily, and when measuring, there is no need to install any cooperation program at the destination, has been widely applied in network measurement. But ICMP is not designed for data transmitting, and it can be easily imposed by network attack activities such as Smurf, Ping of Death, etc. Accompanying with the popularization of Internet, in considering of the security and efficiency of network, many routers and end hosts have rate limited or even blocked ICMP packets, which may lead to obtain wrong measuring results or the measurement cannot be conducted at all [8]. Therefore recently, researchers proposed to measure network using the three-way handshake process of TCP [6,10].

Replace ICMP with TCP, when measuring network performance, an accompanied question is: do there have any differences between the measured results of TCP and ICMP? If the answer is yes, then how much? From intuition, someone may say that the results of TCP are better than ICMP, on the reason of routers and end hosts rate limit or block ICMP packets. While the function of router is to transmit IP packets, in general, there should have no significant difference in processing a TCP packet or an ICMP packet. Furthermore, in the end host, the processing of an ICMP packet is simpler than the processing of a TCP packet. The results of TCP are not better than the ones of ICMP inevitably.

The significance of research on this problem is manifold. First, researchers and operators have accumulated lots of history data about network performance; most of them were collected with ICMP. While after replacing ICMP with TCP in network measurement, we can rightly analyze the newcome data with the history data, and correctly summarize network performance characteristics and its evolution, only if we understand the difference of measurement results of the two protocols. Second, some researches, e.g., [22,24], have analyzed and concluded network performance characteristics from measurement done with TCP or ICMP separately. Whether these conclusions truly reflect the network performance, whether we can apply these conclusions at large, it also needs we understand the differences of measurement results of the two protocols. Still other researches assume that there is no difference in the results of the two protocols, for example, the authors of [11] use the RTT and packet loss rate measured by ping (ICMP) to calculate and predict TCP throughput. To validate these researches, we must check this assumption. At last, in [4], the authors are aware of that; the same performance metric may have different measurement results, if it is measured using different protocols, and advise that, when discussing the measurement results, the protocol used in measuring must be pointed out. However this approach unnecessarily increases the amount of measurement, and augments the difficulty of result analysis, for people just wants to know the networks performance while not cares about protocols.

In this paper, to investigate the differences in the measurement results of some network performance metrics

such as host connectivity, RTT, and loss rate measured using TCP and ICMP, we designed two groups of comparison programs, and after carefully evaluate the values of the program parameters, we conducted lots of comparison experiments on the Internet. The results show that, it does really have some differences, when measured using TCP or ICMP. For host connectivity, the results of TCP are closer to the real status, while the results of ICMP have large errors. For a certain host set, the host connection rate of TCP and ICMP has 20–30% differences. While the case of RTT and packet loss rate is complicated, with different path loads and destination host loads, the measurement results of TCP and ICMP have different quantitative relations, but at normal, the difference is very little. According to the experimental results, we also give some advices on the selection of protocols for measuring network.

The paper is organized as follows. We summarize the related work in Section 2. In Section 3, we describe the design of test programs and two groups of comparison experiments for finding out the protocol differences. We analyze the results differences of TCP and ICMP based on the experimental results in Section 4. Finally, we conclude and discuss some future works in Section 5.

## 2. Related works

To the best of our knowledge, there has been no prior work that focused on comparing the network performance measured using TCP against which measured using ICMP. In [12], the authors proposed a high precision active measurement method, and compared the delays measured using the proposed method against passive measurement. The authors of [15] proposed a TCP-based RTT passive measurement method and compared the measured RTTs with ping. In [13], the authors compared active and passive measurement methods on packet loss rate. The authors of [14] compared two different measurement implementations of one way delay and one way loss rate metrics, which both are based on UDP. These researches mainly focus on comparison of active and passive measurement methods or implementations, they do not deal with the comparison of results measured using TCP or ICMP. In the appendix of [16], the authors compared the path minimum delays measured using TCP or ICMP, and found that they are highly correlative. The authors of [17] compared the packet loss rate measured using ping against real loss rate in the bottleneck router under TCP flow, the experiments are conducted under a single router connected mini IP network which is built by the authors. Although these researches are partially related to comparison of the results measured using TCP or ICMP, they only involve a single metric or are experimented on a single router.

There are also many works have been done on bandwidth measurement. Typical bandwidth measurement tools include pathchar [25], nettimer [26], pathrate [27], etc. for path capacity measurement, and pathchirp [28], pathload [29], Spruce [30], etc. for available bandwidth measurement.

Generally, for measuring bandwidth, these tools have to send a lot of probe packets in a short time, with a specific packets sending pattern, for example, packet pair or packet train. As large amount of ICMP packets send in a short time may be treated as network attack activities, and TCP protocol should control the packets sending rate by its congestion control mechanism, most of the bandwidth measurement tools are implemented based on UDP, although several tools such as pathchar, may partially depend on ICMP. The essential differences of these tools lie in the packets sending patterns they adopted, not in the protocols they implemented. Consequently, evaluating performances of these tools is an interesting and valuable work. The authors of [31] compared several bandwidth tools on high speed links (1000 Mbps), with reproducible cross traffic. The authors of [32] conducted a similar work mainly in a 10 Mbps network, with a focus on the types of cross traffic. These works are helpful for tools usage, and also show direction for further improvement of bandwidth measurement techniques.

In this paper, we took factors such as path loads, destination host loads which may impact the measurement results into account, when selecting experiment paths and hosts; and based on lots of experiments executed on the Internet, we analyzed and compared the differences in connectivity, RTT and loss rate measurement using TCP and ICMP.

### 3. Experiments design

For comparing the difference of TCP and ICMP in network measurement, we designed two groups of comparison programs: host connectivity comparison program and RTT, loss rate comparison program. The experiments are mainly completed with four PCs which all located at a same LAN in the campus network of Hunan University, these four PCs have the same configuration with P4 1.4 GHz CPU, 256 MB memory, and RED HAT LINUX7.2 operating system. We denote them as source host HNU1 to HNU4 in this paper. The campus network of Hunan University is connected to the Internet with 100 Mbps link speed. The probe packets size is 64 bytes. All experiments had been done from Jun. 18, 2005 to Sept. 14.

In addition, to validate whether the experimental results are related to the location of source hosts, we also select a PC located at the Institute of Software of the Chinese Academy of Science, to execute some experiment. We denote this PC as IOS1 in this paper. The results from HNU1–HNU4 and IOS1 show that the locations of source hosts have no effect on results, so we do not select more source hosts from the Internet to execute our experiments.

#### 3.1. Measurement progress

One of the most frequent used network measurement tools using ICMP is ping program. Ping can be used to

measure host connectivity, RTT and packet loss rate, it measures based on ICMP Echo request/reply mechanism. The measuring process is shown in Fig. 1. When measuring, the source host sends an ICMP Echo request packet to the destination host, if the destination receives this packet, it will respond with an ICMP Echo reply packet back to the source, then we have a RTT value for the path from the source to the destination, and the destination host is accessible. If the source does not receive response from the destination in a certain period, then it concludes that the probe packet is lost, there is no way to connect to the destination. We denote the method that measures using ICMP Echo request/reply as Iping.

In [6,10], the authors proposed another measurement method which based on TCP SYN/ACK, it makes use of the three-way handshake process of TCP. The measuring process is shown in Fig. 2. When measuring, the source host sends a TCP SYN packet to the destination host, requesting to establish a connection; if the destination host allows establish the connection, it responds the source with a TCP SYN-ACK packet, otherwise responds with a TCP RST packet. After the source host received the SYN-ACK or RST packet sent from destination, a RTT value for the path from source to destination path is calculated, and the destination host is accessible. If the source does not receive response from the destination in a certain period, then it concludes the probe packet is lost; there is no way to connect to the destination. One thing must be noted is that, when the source receives a SYN-ACK packet, it must send a RST packet to the destination to break down the established connection, to void continuous measurement process

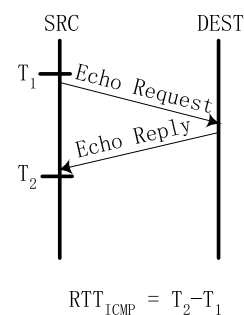


Fig. 1. The measurement process of ICMP.

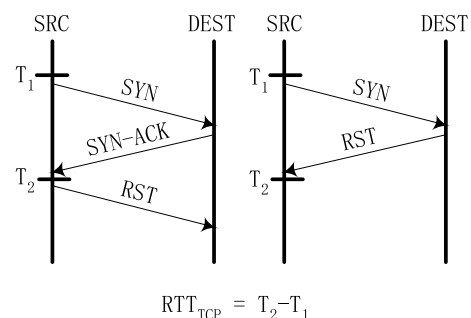


Fig. 2. The measurement process of TCP.

has been treated as a SYN-Flood attack by the destination, and refuses to respond the probe packet. We denote the method that measures using TCP SYN/ACK as Tping.

### 3.2. Connectivity measurement comparison program

The processes of the program comparing connectivity results of TCP and ICMP are as follows: To a certain destination, the program first measures the host connectivity using Tping, then waits for a while, and measures the host connectivity using Iping. The measuring processes that use Iping or Tping are shown in Figs. 1 and 2. We use the connection rate calculated after measuring a lot of destination hosts to compare the differences of Tping versus Iping in connectivity measurement.

#### 3.2.1. Destination host sets selection

The selection of destination hosts may affect the accuracy of comparison experiment. To find out the real difference of Iping and Tping in connectivity measurement, we build two destination host sets. One set is the top 500 web-sites from [18]. This set presents the difference of Tping and Iping in probing connectivity of web servers, and we denote it as TOP500 in this paper.

Beside the web servers, there still are a large number of other servers and clients on the Internet. To make the experiment more commonly, we need experiment more amounts and more types destination hosts. An ideal approach is to randomly select a good many of IP addresses from the IPv4 address space. But till now, a great part of the IPv4 address space still are unused, this approach may lead both the results of Tping and Iping have many hosts which are reported cannot connect, and conceals the difference of Tping and Iping. So we collect 50,000 IP addresses or host names using the approach mentioned in [21] for comparison experiment, and we denote this host set as LARGE in this paper.

The experiment of LARGE set, if is executed by a single host, will persist 90 h. The consumed time makes the experiment difficult. Because the hosts HUN1-HUN4 have the same configuration and can be seen as located at the same location in the Internet, they may have no distinct measurement results; and the results of TOP500 set experiment conducted on IOS1 also show that the location of source host has no relation to experiment results. So we divide the LARGE set into four sub-sets, and execute one sub-set experiment on HUN1-HUN4 separately, to reduce the time needed for LARGE set experiment. After dividing, one experiment of LARGE set needs about 23 h.

#### 3.2.2. Setup of test parameters

Several parameters of the test program also may have effect on the experiment accuracy. The first parameter is the wait time  $t_{\text{wait}}$  between Iping and Tping probing. If we set  $t_{\text{wait}}$  too small, the latter probe packet may be affected by the former probe packet [20], makes the results inac-

curate; while if we set  $t_{\text{wait}}$  too large, then the network status and destination host status changed, comparison of the results loses meaning. In [20], the authors found that, when the interval between the send times of two successive probe packet (i.e.,  $t_{\text{wait}}$ ) is equal to 500 ms, the latter packet will almost never be affected by the former packet, which means that 500 ms may be a rough minimum bound of  $t_{\text{wait}}$ . Furthermore, as network status keeps stable on the time scale of minutes [19], we set  $t_{\text{wait}}$  to 1 s. One similar parameter of the test program is the wait time between the probing of two different destination hosts, for the same reason, we set it to 1 s too.

Another parameter may affect the experiment accuracy is  $t_{\text{out}}$ , which means the duration the source wait for response after it send a Tping or Iping probe packet. Too small  $t_{\text{out}}$  may exaggerate the loss event during experiment, the results are smaller than the real status, and the experiment is inaccurate. While large  $t_{\text{out}}$  add unnecessary experiment time. To set a proper  $t_{\text{out}}$ , we first set  $t_{\text{out}}$  to 5 s, and measure the RTT of hosts in TOP500, most hosts have RTT no more than 2 s, so we set  $t_{\text{out}}$  to 3 s.

The last parameter may affect the experiment accuracy is  $c_{\text{re}}$ , the repeat probing times when the source received no answer. If we set  $c_{\text{re}}$  to 1, then we may exaggerate the loss event during experiment, the results are smaller than the real status, while repeats probe too much when the source faces loss, it also adds unnecessary experiment time. Analysis of results of RTT experiment discussed later show that, in the normal network status, the frequency of three continuous packets lost is tiny, so we set  $c_{\text{re}}$  to 3.

### 3.3. RTT and loss measurement comparison program

The processes of the program comparing RTT and loss rate results of TCP and ICMP are as follows: To a certain destination, the program first measures RTT using Tping, then waits for a while, and measures RTT using Iping, we denote the two probing as a probe packet pair; at last, the program waits 3 s and repeats the above process. The measuring processes that use Iping and Tping are shown in Figs. 1 and 2. If the source host gets no response after sending probe packet in a certain period, then it judges it detects a loss event.

The parameters  $t_{\text{wait}}$  and  $t_{\text{out}}$  of the program also have effect on experiment results, the setup of these parameters are similar with which in connectivity comparison program, excepts the  $t_{\text{out}}$  is set to 5 s to accommodate very large RTT appeared in experiment, although it is scarcely.

## 4. Results analysis

### 4.1. The Differences in connectivity measurement

#### 4.1.1. Data collection

We repeat connectivity comparison experiment many times with TOP500 set on source hosts HNU1–HNU4 and IOS1 at different date. While the experiments with



LARGE set are only repeated several times on source hosts HNU1–HNU4, for it needs too much time.

In every test, we record destination hosts count ( $h_{\text{dest}}$ ), actually probed hosts count ( $h_{\text{prb}}$ ), the amount of hosts which respond to both Tping and Iping ( $h_{\text{both}}$ ), the amount of hosts only respond to Tping ( $h_{\text{tcp}}$ ), the amount of hosts only respond to Iping ( $h_{\text{icmp}}$ ), and the amount of hosts respond to none ( $h_{\text{none}}$ ). We compare the difference of connectivity results measured using Tping and Iping by calculating host connection rate of Tping and Iping. If we do not care about whether the hosts respond to neither Tping nor Iping are really inaccessible, the connection rate of Tping or Iping can be computed using the following formulas, and we denote them as nominal connection rate.

$$R_{\text{TCP}} = (h_{\text{both}} + h_{\text{tcp}}) / h_{\text{prb}} \times 100\% \quad (1)$$

$$R_{\text{ICMP}} = (h_{\text{both}} + h_{\text{icmp}}) / h_{\text{prb}} \times 100\% \quad (2)$$

The nominal connection rate ascribes causes of hosts respond to neither Tping nor Iping to the protocols cannot probe the host connection, this may underestimates the connection probing capability of Tping or Iping. In fact, these hosts are unaccessible even using web browser, i.e., these hosts real have connection problems, while it is not the protocols do not probe their connectivity. Reasonable comparison of the results must be based on the connectible hosts, So we must calculate the connection rate after exclude the really inaccessible hosts, using the following formulas, we denote them as real connection rate.

$$\text{TR}_{\text{TCP}} = (h_{\text{both}} + h_{\text{tcp}}) / (h_{\text{prb}} - h_{\text{none}}) \times 100\% \quad (3)$$

$$\text{TR}_{\text{ICMP}} = (h_{\text{both}} + h_{\text{icmp}}) / (h_{\text{prb}} - h_{\text{none}}) \times 100\% \quad (4)$$

The TOP500 set experiment times of each host are list in Table 1. There are totally 239 experiments. As discussed in Section 3.2.2, the program parameters  $t_{\text{out}}$  and  $c_{\text{re}}$  may have effect on the results, we compound three parameters cases with different values of  $t_{\text{out}}$  and  $c_{\text{re}}$ , and repeat experiments under each case, to find out the proper parameters set for final comparison. The detailed compounding of parameters are as follows: Case 1 set  $t_{\text{out}}$  to 3 s and  $c_{\text{re}}$  to 1; Case 2 set  $t_{\text{out}}$  to 3 s and  $c_{\text{re}}$  to 3; Case 3 set  $t_{\text{out}}$  to 5 s and  $c_{\text{re}}$  to 3.

To investigate whether the changes of network status along with the lapse of time in a day have effect on experiment, we also repeat experiment at each host in a day with interval of 2 h. Fig. 3 is the results of experiment done on HNU1, the four curves, from up to down, are the  $\text{TR}_{\text{TCP}}$ ,  $R_{\text{TCP}}$ ,  $\text{TR}_{\text{ICMP}}$ ,  $R_{\text{ICMP}}$  in a day. As shown in Fig. 3, the network status changes have no significant effect on connectiv-

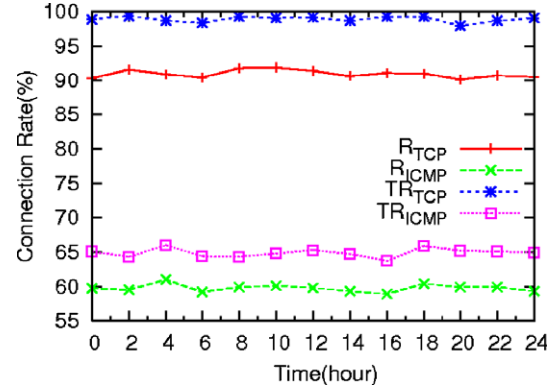


Fig. 3. Connection rate measured on HNU1 in a day for TOP500.

ity measurement. The other hosts have similar results, and for space limitation, we do not present them at here. This result indicates that we can analyze the results of experiments with no care of what time the experiments have been done, for we do the experiments listed in Table 1 at different day and different time.

#### 4.1.2. The effect of test parameters

Table 2 lists the real connection rate of TOP500 at HNU2 under different parameters cases; other source hosts have similar results. As can be seen from it, all the statistics of real connection rate measured under case 1 are lower than that measured under case 2 and case 3, for example, the mean  $\text{TR}_{\text{TCP}}$  under case 1 is lower than that under case 2 and case 3 with 4.4%. In addition, the results measured under case 2 and case 3 are more stable than which measured under case 1, e.g., the difference of maximum and mean is 4.1% when measured under case 1, while which is only 0.8% when measured under case 2. The difference of case 1 and case 2 lies in the value of  $c_{\text{re}}$ , which in case 1 is 1 and in case 2 is 3. This indicates that small  $c_{\text{re}}$  actually makes the experiment results unstable and lower than the real conditions.

Furthermore, from Table 2, we also noticed that the results measured under case 2 and case 3 almost have no difference, this reveals that to set  $t_{\text{out}}$  to 3 s is enough to eliminate the effect of large network delay on experiment. Set  $t_{\text{out}}$  to 3 while not 5 s saves much time when do experiments, especial for the LARGE set.

This shows that, to do experiments under case 2 gets stable and accurate results and saves experiment time. So we only select the results measured under case 2 to analyze the differences of TCP and ICMP in the connectivity measurement on TOP500, and only do experiment under case 2 for LARGE set.

#### 4.1.3. The differences in connectivity measurement

Table 3 lists the final results of connection rate of TOP500, which measured under case 2. The actually probed hosts count ( $h_{\text{prb}}$ ) is smaller than destination hosts count ( $h_{\text{dest}}$ ), it is because some host name in the TOP500 can not be resolved by the DNS. The  $\text{TR}_{\text{TCP}}$  is about

Table 1  
Experiment count for TOP500

	HNU1	HNU2	HNU3	HNU4	IOS1
Case1	8	13	5	10	6
Case2	32	28	43	24	26
Case3	8	12	9	11	4

Table 2

The real connection rate measured on HNU2 for TOP500 under different parameter case

Case	Test count	Mean TR <sub>TCP</sub>	Max. TR <sub>TCP</sub>	Min. TR <sub>TCP</sub>	Mean TR <sub>ICMP</sub>	Max. TR <sub>ICMP</sub>	Min. TR <sub>ICMP</sub>
Case 1	13	94.6	98.7	91.3	63.1	65.7	59.1
Case 2	17	99.0	99.8	98.0	65.0	66.0	63.7
Case 3	12	99.0	99.6	98.1	65.1	66.0	63.8

Table 3

The connection rate results for TOP500 set

Src host	$h_{\text{dest}}$	$h_{\text{prb}}$	Response				Connection rate (%)			
			$h_{\text{both}}$	$h_{\text{tcp}}$	$h_{\text{icmp}}$	$h_{\text{none}}$	$R_{\text{TCP}}$	$R_{\text{ICMP}}$	TR <sub>TCP</sub>	TR <sub>ICMP</sub>
HNU1	500	485	285	160	3	37	91.8	59.9	99.3	64.3
HNU2	500	486	285	156	6	39	90.7	59.9	99.0	65.0
HNU3	500	483	283	155	4	42	90.5	59.3	99.1	64.9
HNU4	500	484	287	158	4	35	91.9	60.1	99.1	64.8
IOS1	500	491	290	160	3	38	91.6	59.7	99.3	64.7

99%, while TR<sub>ICMP</sub> is only 65% around. This means that the connectivity measured using TCP is far more accurate than which measured using ICMP. For the TOP500 host set, the difference of them is 35% approximately. Even the nominal connection rate, which ascribes cause of hosts respond to neither Tping nor Iping to the protocols cannot probe the host connection, Tping's is still upwards of 90%, which higher than Iping's with 30% nearly.

Then we can conclude that, when measuring connectivity, using TCP is more accurate than using ICMP, the connection of 99% web servers can be correctly measured using TCP, while ICMP may improperly estimates about 34% servers which in fact are online as inaccessible. The main reason for the large errors of ICMP in measuring connectivity may be that many web servers or routers in the Internet rare limit or even block ICMP packets. Furthermore, although the connection rate of TCP reaches 99%, there still have few hosts that do not respond to Tping but respond to Iping. These hosts may deploy some security policies to prevent TCP SYN-Flood attack, while do not block ICMP packets. To improve the accuracy of connectivity measurement, we can use TCP, and complement with ICMP.

We also seen from Table 3 that, both the source hosts HNU1–HNU4 which locate at the same LAN and the host IOS1, have similar results, i.e., the experiment results are not related to the location of source hosts. Therefore, although the experiments are mainly completed at one place on the Internet, the conclusions are universal.

The experiments of LARGE set repeat four times on source hosts HNU1–HNU4, the results are shown in Table 4. The connection rate of both TCP and ICMP increased more or less, especially Iping, the  $R_{\text{ICMP}}$  increased to 75%, the TR<sub>ICMP</sub> increased to 81%. The cause of large increased Iping connection rate may be that, general hosts in the Internet have less chance to be attacked than web servers, then less of them block ICMP packets. But the connection rate of TCP is still higher than ICMP with 20% for TR<sub>TCP</sub> and with 18% for  $R_{\text{TCP}}$ . Then we can conclude from Table 3 and Table 4, To any hosts on the Internet, measuring its connectivity using TCP can achieve accuracy higher than 99%, while using ICMP have large errors, the connection rate measured using TCP is higher to 20–30% than which measured using ICMP.

#### 4.2. The differences in RTT measurement

##### 4.2.1. Data collection

As shown in Figs. 1 and 2, the measured values of RTT and loss rate are mainly decided by the transmitting performance of routers in the path and the responsiveness of destination hosts. If there have differences in the RTT and loss rate measured using TCP and ICMP, it may be under different network loads, the routers provide different transmitting performance to TCP and ICMP; or affected by host's load, destination hosts respond to the packets of TCP or ICMP with different speed. In general, the mean

Table 4

The connection rate results for LARGE set

Test no.	$h_{\text{dest}}$	$h_{\text{prb}}$	Response				Connection rate (%)			
			$h_{\text{both}}$	$h_{\text{tcp}}$	$h_{\text{icmp}}$	$h_{\text{none}}$	$R_{\text{TCP}}$	$R_{\text{ICMP}}$	TR <sub>TCP</sub>	TR <sub>ICMP</sub>
1	50,000	49,104	36,829	9034	231	3010	93.4	75.5	99.5	80.4
2	50,000	49,066	37,446	8725	139	2756	94.1	76.6	99.7	81.2
3	50,000	49,125	36,764	8774	276	3311	92.7	75.4	99.4	80.9
4	50,000	49,094	37,324	8971	233	2566	94.3	76.5	99.5	80.7

Table 5  
Path performance level divisions

Performance level	Level 1	Level 2	Level 3	Level 4	Level 5
RTT range	<30 ms	30–100 ms	100–900 ms	900–1500 ms	1500–3000 ms
Evaluation	Excellent	Good	Moderate	Bad	Poor
Host notation	L1A, L1B	L2A, L2B	L3A, L3B	L4A, L4B	L5A, L5B

RTT is a token of the performance baseline of a path at regular load. To find out the difference of RTT and loss rate measured using TCP or ICMP under different path conditions and host statuses, according to the RTTs of TOP500, and based on the subjective judgment, we divide the mean RTT into five levels, to present five kinds of typical path packet transmitting performance separately. Then, based on mean RTT to the host, we select two destination hosts for each level from TOP500 to measure their RTT and loss rate. The division of path performance level is shown in Table 5, the last row of it present the notations used for selected hosts at each level.

The hosts in TOP500 usually have high load, to make the experiment general, we need some light loaded hosts in experiment. But it is not so easy to find such hosts on the Internet, through measuring, the mean RTT of the path from HNU1–HNU4 to IOS1 is about 246 ms, then we select IOS1 as a light loaded hosts at level 3. However, there are no light loaded hosts at the other performance levels, this may have some effects on the final comparison of RTT and loss rate measured using TCP and ICMP.

The mean RTTs to every host and path lengths are listed in Table 6. The complete route to several hosts cannot be probed, and then we list the maximum path length we can probe. Table 6 shows that the path performance division using mean RTT is consistent with path length on the whole.

We use the test program mentioned in Section 3.3 to measure the RTT and loss rate of TCP and ICMP. In general, the network status and host loads are varied with time in a day, and then every measurement lasts 24 h to cover all the status of network and hosts. The experiments are main-

ly completed on source hosts HNU1–HNU4, for every selected destination hosts, we repeat 8 times at different day. To validate whether the location of source host have effect on the experiment, we also execute several measurements on IOS1, and the results indicate there is no effect.

#### 4.2.2. The difference in RTT measurement

We use measured mean RTT to compare the quantitative difference of RTTs measured using TCP and ICMP, the results are shown in Table 7. For small delay paths, the mean RTTs measured using Tping have no significant difference compared with which measured using Iping, but the IOS1 is an exception, with mean RTTs of Iping is larger than that of Tping with several millisecond. While for large delay paths, the mean RTTs measured using TCP is larger than which measured using Iping with tens of millisecond. The other statistics of measured RTT such as median, 25 percentile, 75 percentile, etc. have similar characteristics, although the minimum RTTs of Tping and Iping are basically equal, as shown in Table 8, also with the exception of IOS1.

The minimum RTT comprises of the fixed delays of the path, which presents the static performance of the path; while the mean RTT include the effects of the path loads and host loads at statistical meaning, which presents the dynamic performance of the path. The ratio of them can reflect the effect of path loads and host loads have on measured RTT in the rough, we define the ratio as RTT expanding ratio  $\alpha$  as in the formula given below.

$$\alpha = \text{RTT}_{\text{mean}} / \text{RTT}_{\text{min}} \quad (5)$$

Table 6  
The mean RTT and path length of selected destination hosts

Host notation	Mean RTT (ms)	Path length (hop)	Host notation	Mean RTT (ms)	Path length (hop)
L1A	9.4	8	L1B	22.3	12
L2A	37.7	12	L2B	68.6	>13
L3A	280.1	14	L3B	265.4	>14
L4A	1262.4	19	L4B	1104.7	>21
L5A	2244.5	21	L5B	2139.3	>22
IOS1	246.2	15			

Table 7  
Mean RTTs measured using Tping and Iping (ms)

Protocol	L1A	L1B	L2A	L2B	IOS1	L3B	L3A	L4B	L4A	L5B	L5A
Tping	7.4	22.1	37.8	66.9	237.6	255.4	274.1	1030.1	1423.1	2244.5	2072.1
Iping	8.1	22.5	37.3	67.5	243.4	255.9	273.6	1014.8	1262.5	2222.5	2051.9

Table 8  
Minimum RTTs measured using Tping and Iping (ms)

Protocol	L1A	L1B	L2A	L2B	IOS1	L3B	L3A	L4B	L4A	L5B	L5A
Tping	2.74	3.43	26.59	29.57	223.4	33.9	48.6	37.65	23.77	57.43	27.61
Iping	2.78	3.41	26.71	29.53	225.1	34.2	48.5	37.32	23.79	57.52	27.55

Table 9  
The RTT expanding ratio for the paths to destination hosts

Protocol	L1A	L1B	L2A	L2B	IOS1	L3B	L3A	L4B	L4A	L5B	L5A
Tping	2.7	6.4	1.4	2.3	1.1	7.5	5.6	27.4	59.9	39.1	75.0
Iping	2.9	6.6	1.4	2.3	1.1	7.5	5.6	27.2	53.1	38.6	74.5

Small  $\alpha$  means the mean RTT is close to minimum RTT, the loads of path and destination host only have little effect on the measured RTT; while large  $\alpha$  means the mean RTT is far apart to minimum RTT, the loads of path and source hosts have high effect on the measured RTT. Table 9 lists the  $\alpha$  of every host for Tping and Iping. We can see from it, that small delay path has small  $\alpha$ , while large delay path has  $\alpha$  exceed 20.

Therefore, for the large delay path in experiment, the loads of path and destination host may have large effect on RTT measurement. In general, the routers give TCP packet higher transmitting priority, the effect of path on RTT measured using TCP should less than which measured using ICMP. While for the large delay path in experiment, the RTT measured using Tping is larger than which measured using Iping, it may because of that, and the loads of destination host reach or exceed its process capability. In this situation, due to the process of TCP packet is more complicated than ICMP packet, the response of destination host to TCP packet will be slower than to ICMP packet. For the small delay paths in experiment, the loads of destination host are although high, while are still in the process ability of it, so there is little difference in the mean RTT measured using TCP and ICMP.

Hence, for the path destined to high load host, whether the host loads reach its process capability has large effects on the quantitative relation of RTT measured using TCP and ICMP. If the loads of the host reach or exceed the process capability, the RTT measured using TCP will be larger than which measured using ICMP; if the load of the host does not reach its process capability, then the RTT measured using TCP and ICMP are basically the same. The RTT expanding ratio  $\alpha$  can reflect whether the host load reaches its process capability roughly.

We also find from Table 9 that, for the path to IOS1, the mean RTT have fewer difference with minimum RTT, it is because of that, the IOS1 almost has no loads, the measured RTT mainly affects by the loads of path. For the path to IOS1, both the mean RTT and minimum RTT measured using Tping are smaller than which measured using Iping several millisecond. In fact, the other statistics of this path

have similar characteristics. This indicates that for the path to light load host, the RTT measured using TCP is smaller than using ICMP.

Based on Tables 7–9, we can conclude that, for the path destined to light loaded host, the RTT measured using TCP will smaller than which measured using ICMP. While for the path to high loaded host, the quantitative relation of RTT measured using TCP and ICMP is determined by the RTT expand coefficient  $\alpha$ , when  $\alpha$  is smaller than 20, the RTT measured using TCP and ICMP are basically the same; if  $\alpha$  is larger than 20, the RTT measured using TCP may larger than which measured using ICMP. For accurately measuring the path RTT, we can select the measuring protocols according to  $\alpha$ , for the path have  $\alpha$  smaller than 20, using TCP, when  $\alpha$  is larger than 20, using ICMP.

#### 4.2.3. Similarity in statistics

Fig. 4 shows the Tping and Iping RTT time series of the path to host L2A in 24 h. The time series of RTT measured using Tping and Iping are very similar. In fact, this characteristic appears for almost all hosts in experiment, including IOS1, i.e., in the most case, Tping and Iping can measure the same RTT time series trend.

But this is not true for the path to host L4A. Fig. 5 shows the Tping and Iping RTT time series of the path to host L4A in 24 h. The RTT measured using Tping varied sharply along with time line; while the RTT measured using Iping are far more stable. We find that the path to L4A has large loss rate, for Tping, to 32%, Iping, 42%. This means that the path is very congested, however, the loss rate of the path to the last router in the route to L4A, is only 7%. Then the high loss rate is due to that L4A host is overloaded. In the host, the process of TCP packet is more complicated than ICMP packet; when the host is overloaded, the response time of it to TCP packet varied sharply, while to ICMP packet keep relative stable, although with high loss rate.

Another special RTT time series occurs in the path to host L3B, as is showed in Fig. 6. The measured RTT seems to be related to the measuring time. In most time duration, measured RTT is larger than minimum RTT. The observation



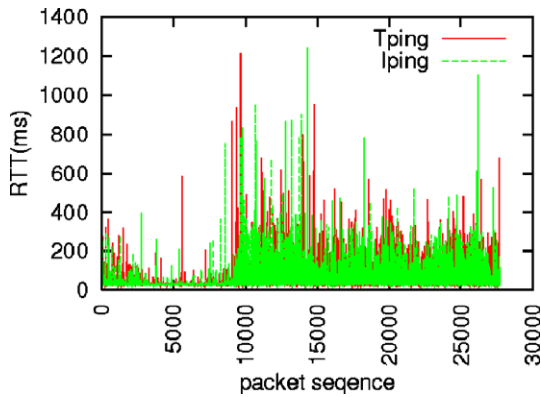


Fig. 4. One RTT time series for the path to L2A.

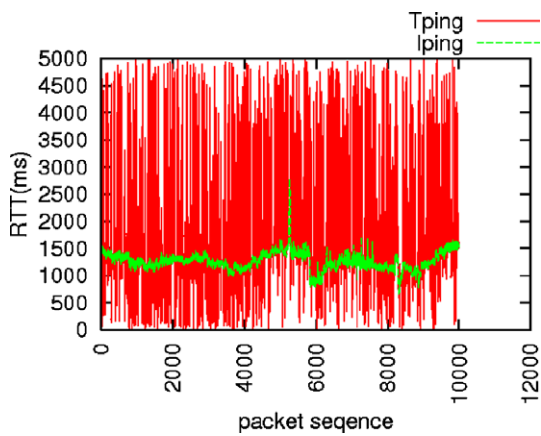


Fig. 5. One RTT time series for the path to L4A.

of [22,23] said that, at any time, we can measure the path minimum RTT within a short time duration with high probability; it is also an premise assumption of the bandwidth measurement tools such as Pathchar [7], which based on variable packet size technology, have made to the network path property. Obviously, to the path destined to L3B, we cannot measure the minimum RTT at most time period. Although it is not closely relate to the work of this article, why the RTT of the path to L3B are so time related, and how many paths

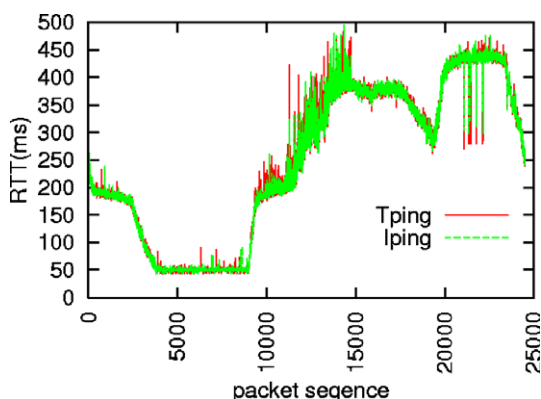


Fig. 6. One RTT time series for the path to L3B.

in the Internet have such a characteristic, this may be problems need further research.

The cumulate distribution function (CDF) and frequency distribution of RTT measured using Tping and Iping are also very similar, as an example, we show the RTT distributions of one measurement of the path to L2A in Fig. 7. the CDF and frequency distribution curves of RTT measured using Tping and Iping are nearly superposed. All the other hosts, except L4A, have such characteristic too, i.e., at the normal case, Tping and Iping can measure very similar RTT distribution characteristics.

#### 4.2.4. The correlation between RTT values

To inspect whether the RTT measured using Tping and Iping in a packet pair is correlated, we also draw the scatter plot of the RTTs for consecutive Tping and Iping, and also calculate the correlation coefficient of them. Fig. 8 is the RTT scatter plot of the measurement corresponding to Fig. 4. It shows that the RTTs measured using TCP and ICMP in a packet pair are nearly not correlative. In fact, the correlation coefficient of RTT measured using Tping and Iping is only 0.034. Although the time series, CDF and frequency distribution are very similar for RTTs measured using Tping and Iping, they are not correlative in a packet pair.

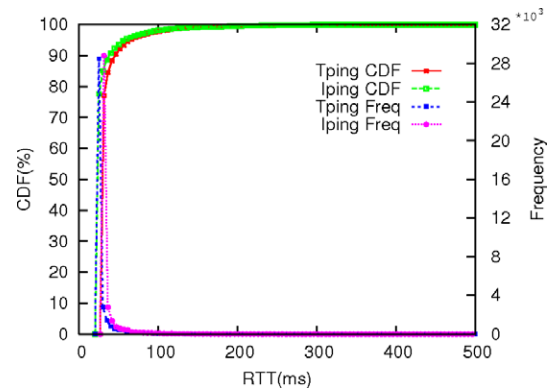


Fig. 7. The RTT CDF and frequency distribution of the path to L2A.

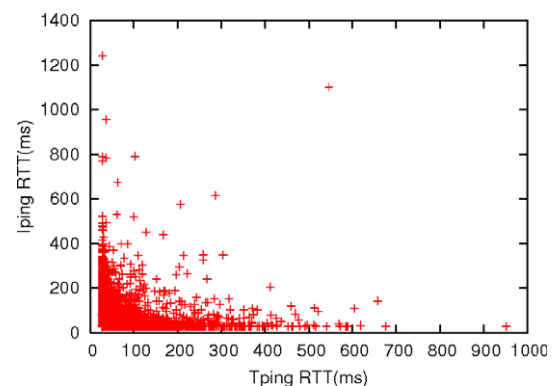


Fig. 8. The scatter plot of Tping RTT versus Iping RTT.

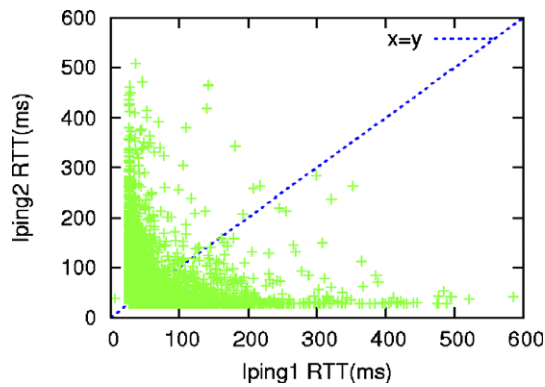


Fig. 9. The scatter plot of RTT in an ICMP packet pair.

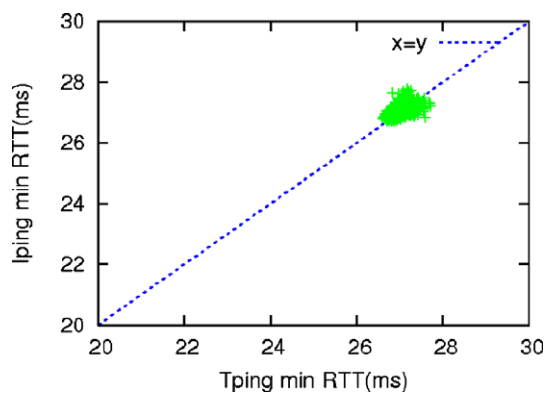


Fig. 10. The minimum RTT scatter plot of Tping versus Iping.

To find out the cause of the lack of correlation between Tping and Iping in a packet pair, we slightly modified the test program, made it sends two TCP packets or two ICMP packets in a probe packet pair. Fig. 9 shows the scatter plot of the case that both the packets in a probe packet pair are ICMP packets; the correlation coefficient of them is 0.041. The case of TCP has similar results. Therefore, the lack of correlation shown in Fig. 8 occurs for the measurement method, and is not due to the protocols used in the measurement method.

While the minimum RTTs measured using Tping and Iping are strongly correlative. Fig. 10 shows the scatter plot of minimum RTT measured using Tping and Iping in one-

minute interval, the data is from the same measurement we draw Fig. 4. The other measurements for all hosts in our experiments have the same results. In Table 10, we list the correlation coefficient of minimum RTT measured using Tping and Iping in one-minute interval for all hosts we experimented.

#### 4.3. The difference in loss rate measurement

The packet loss rate measured using Tping and Iping for all experimented hosts are listed in Table 11. For most destination hosts, the loss rate measured using Tping is very close to which measured using Iping. For the high loaded hosts with small path RTT, the loss rate measured using Tping is larger than which measured using Iping slightly; while if the path RTT is large, then the Tping measured loss rate is smaller than Iping measured slightly. But for the hosts have light loads, such as IOS1, although the RTT is relative small, the Iping measured loss rate is still larger than Tping measured with about 2%.

For the routers may rate limit the transmitting of ICMP packets, we assume that the probability of an ICMP packet has been dropped by the router is larger than that of a TCP packet. While the destination host is light loaded, it has enough process capability to respond to any protocol types packets; and then we can assume that in this case, the probability of an ICMP packet has been dropped by the host is equal to that of a TCP packet, and the probability is small. While the host is high loaded, and the loads are still in the process capability of it, for the process of TCP packets in the host is more complicated than that of ICMP packets, we can assume that the probability of an ICMP packet has been dropped by the host is less than that of a TCP packet. If the load exceed the process capability of the host, it may rate limit the response to ICMP packets, for ensuring the service performance provided to TCP packets, then we can assume in this case, the probability of an ICMP packet has been dropped by the host is larger than that of a TCP packet.

The high loaded hosts in experiments, when they have small path RTT, we can know from Table 6, the path length is short too. Then the effect of routers on loss rate can be omitted, the measured loss rate is mainly affected

Table 10

The correlation coefficient for minimum RTT measured using TCP and ICMP in a minute

	L1A	L1B	L2A	L2B	IOS1	L3A	L3B	L4A	L4B	L5A	L5Bs
R	0.735	0.812	0.776	0.764	0.854	0.811	0.998	0.599	0.673	0.714	0.738

Table 11

Packet loss rate (%) measured using TCP and ICMP

	L1A	L1B	L2A	L2B	IOS1	L3B	L3A	L4B	L4A	L5B	L5A
Tping	0.56	2.58	1.22	0.59	1.67	0.76	2.43	4.21	31.64	3.75	10.24
Iping	0.52	2.56	0.92	0.53	3.02	0.95	2.65	4.87	42.92	3.96	10.63

by the destination hosts, so the loss rate measured using Tping is slightly larger than measured using Iping, according to the assumptions made above. When the path RTT is large, the path length also long, now the effect of routers on loss rate can not be omitted, then the loss rate measured using Tping is slightly smaller than measured using Iping. While the light loaded hosts such as IOS1, according to the assumptions made above, the measured loss rate is mainly affected by the path, then the loss rate measured using Tping is slightly smaller than measured using Iping too. Consequently, if the destination host has light load, using TCP to measure loss rate is more accurate, while for high loaded hosts, ICMP may be a better choice; however, if the host is overloaded, then still TCP become the better choice.

Although there exist differences in the loss rate measured using Tping and Iping, the difference is very little. For high loaded hosts, the difference is not exceeding 1%, exclude the host L4A, which we speculate it may be overloaded. The light loaded host, also have the difference of only 1–2%. But they have no correlation. For example, for the measurement correspond to Fig. 4, both the Tping and Iping measured 27741 times, Tping loses 163 packets, and Iping loses 145 packets, while the count of the event that TCP packet and ICMP packet in a packet pair both lose is only 39, i.e., most loss events of Tping and Iping have happened solely. The experiments for the other hosts also have this characteristic.

## 5. Conclusions

For quantitatively investigating the differences of network performance measured using TCP and ICMP, we have designed two groups of comparison tests, and done a large amount of experiments on the Internet, to find out the differences of TCP and ICMP when used to measure some basic network performance metrics such as host connectivity, RTT and packet loss rate. The experiment results show that, there really has difference, when using TCP or ICMP in network measurement.

For connectivity measurement, TCP can get results more reach the real status, while ICMP may produce larger errors. For the TOP500 hosts set in experiment, the difference of measured connection rate measured using TCP or ICMP is more than 30%, for the LARGE hosts set, the difference also reaches 20%. Hence, to measure host connectivity using TCP will have more accurate results.

The difference of RTT and packet loss rate is complicated; path load and destination host load have great effect on it. For the light loaded hosts the measured RTT using TCP is smaller than which measured using ICMP with several milliseconds. While for the high load hosts, if the RTT expanding ratio  $\alpha$  is smaller than 20, the RTT measured using TCP and ICMP are basically the same, however, if the  $\alpha$  is larger than 20, then the RTT measured using TCP will be larger than that measured using ICMP. When measure RTT, We can select protocols based on the value of  $\alpha$ .

For the light loaded hosts, the packet loss rate measured using ICMP is larger than using TCP. While for the high loaded hosts, if the path RTT is small, the loss rate measured using TCP is larger than using ICMP slightly; if the path RTT is large, then the loss rate measured using TCP is smaller than using ICMP. We can select the protocols used in packet loss measurement based on the path RTT.

However, at normal state, the time series, CDF, frequency distribution of RTT measured using TCP and ICMP are very similar, the minimum RTT measured using either of them are also very correlated, and the difference in measured loss rate is very slight.

The probe packet size is only set to be 64 bytes in our experiments, as the next steps, we will repeat the experiment with more packet sizes to find out whether the packet length has effect on the difference of TCP and ICMP when using in network measurement. We also plan to experiment more metrics on this problem.

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