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Large-scale round-trip delay time analysis of IPv4 hosts around the globe

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Abstract: Design and optimization of many network applications, services, protocols, and routing protocols can be improved with delay-related measurement for a better operation over the Internet. Many experimental delay measurements have been performed on predetermined end-to-end connections with a less number of hosts compared to our study. This study aims to investigate up-to-date round-trip delay time measurement results over the Internet through pinging random IPv4 addresses from three vantage points located in the United States, Turkey, and Japan. Considering different time periods in a day and in consecutive 5 years, we performed a large-scale round-trip delay time analysis study by sending more than 300 million ICMP requests to randomly chosen IPv4 addresses. Approximately, 55 million unique Internet hosts replied to ICMP requests and were evaluated for the analysis. The results show that 90% of IP hosts accomplish their ICMP communication in less than 0.4 s. Mostly the propagation time on backbone links constitutes the larger part of total round-trip delay time. Distribution fitting test results demonstrate that RTTs of distributed hosts around the world could be modeled with multimodal distribution functions. Wakeby distribution function gives best results for modeling RTTs with two different modes according to the Kolmogorov–Simirnov test statistics. Our study also gives perspective about how packet delay values would be, when a message is broadcasted all over the world. Another significant finding is that it gives a point of view where to locate servers to provide a fast Internet service all over the world via Internet.

Key words: RTT, packet delay, time to live, frequency distributions, performance evaluation

1. Introduction

Delay is a ubiquitous metric in all telecommunication systems and minimization of delay has been an ongoing research topic in the field. Packet delay draws a significant amount of attention in computer networks especially on the Internet. Many factors affect the total amount of packet delay such as propagation time, processing time, queuing time, and transmission time. In packet switched networks, delay phenomenon is getting more complex due to their working mechanism. The transmitted data is divided into small packets, and the packets could reach the destination through different routes. It is probable that preceding packet might reach its destination after the next packet. Consecutive packets might experience quite different delay times. Load, services, protocols, active user numbers, and many more dynamics could affect the delay behavior. Conversely, delay also would change many important quality metrics on the Internet such as packet loss, throughput, self-similarity which is scaled by Hurst parameter [1], and shows bursty nature of network traffic [2]. Therefore, optimum characterization of delay might be problematic.

Since so many factors in IP communication directly or indirectly depend on delay, correct measurement

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and characterization of delay over the Internet is a significant research interest. Some delay definitions and associated measurement methodologies are given in related request for comments (RFC) documents of Internet engineering task force (IETF); the IP performance metric (IPPM) workgroup has mentioned one-way delay in RFC 2679 [3], and round-trip time (RTT) in RFC 2681 [4]. TCP, which is required by numerous application communications as a transport layer protocol, needs delay for the feedback mechanism to do flow control and congestion avoidance [5]. In [6], a delay-based TCP congestion control algorithm called DC-Vegas is proposed for data center applications. Relevant parameters with delay should be considered thoroughly during the design of network applications and services and tuning the parameters for the optimum performance of real-time multimedia and audio applications.

Analytical, experimental, and simulation studies have been performed for the characterization of delay since the beginning even before the Internet. A comprehensive delay measurement study [7] was carried out over the Arpanet to examine the variations of delay for different paths, and in different times of a day as early as 1971. In another study [8], the influence of packet length on delay was examined, and TCP performance was evaluated by adding a parameter related to packet length in the transmission timeout algorithm. Mentioned studies provide delay statistics of Internet between 1970s and 1980s with old networking technologies and slow backbone links. How routing and flow control mechanisms affect end-to-end delay in a NSFNET-like network was investigated in a simulation study and it was demonstrated that both link state and distance vector routing algorithms have yielded similar delay statistics [9].

With the extreme Increase of Internet users, Internet usage, and complexity of Internet topology, significance of the researches on delay has also increased. In 1995, approximately 44 million users were on the Internet. More than 4 billion users have connected to the Internet in different ways as of 2018. Via a UDP-based echo tool, an Internet behavior characterization study was conducted using the measurements of end-to-end delay and loss [10] through measurements on a particular link INRIA in France to the University of Maryland in the United States. In [11], both passive measurements and active probing were employed to measure and analyze different delay components of a router. The mentioned study aimed to perform analysis of delay between routers, which differs from our study where targets of RTTs are between end hosts. An analysis study was conducted on measured delay spaces among 3997 edge networks, quantified key parameters which are important for distributed system design, and derived a simple model of Internet delay space based on analytical findings [12]. However, their measurements targeted only DNS servers, not hosts within a local area network. Therefore, the study addressed only the delay space properties among edge networks. An empirical mixture model was proposed for large-scale RTT measurement to identify, characterize, and monitor spatial and temporal dynamics of RTTs [13]. They exploited TCP acknowledgment sequence pairs to compute RTTs while in our study we use ICMP packets for RTT measurement which also give information about host unreachability and time exceeded problems. In [14], an approach was presented via using a single packet to dissect the RTT in chunks mapped to specific portions of the path; thus, it could provide RTT estimations along portions of the slow path. A technique was presented for the analysis of Internet RTTs and its relationship with the geographic and network properties [15]. Their main interest is to determine the amount of information that a given RTT or great circle distance between geolocated hosts could give about other variables of interest.

Most of the experimental delay measurements have been performed on predetermined end-to-end Internet connections. In addition, characterization of delay efforts on the Internet has considered only the measurement results of those particular links. Considering the heterogeneity, complexity, and magnitude of the Internet, more comprehensive measurement studies are required to characterize the delay over the Internet. This study aims to conduct an RTT delay analysis considering more than 55 million IP hosts randomly distributed around the world. Three geographical locations, Fujisava in Japan, Kayseri in Turkey, and Birmingham in Alabama US are chosen to carry out the delay measurements through randomly pinging IPv4 addresses. The results of this experimental delay study shed lights upon

- how big packet delay values would be if it comes to broadcast a message all over the world,
- how geographical separation affects the delay results,
- how delay results change with different times in a day, and on different days,
- how RTTs differ over the course of 5 years with developing network technologies and increasing backbone and access link speeds,
- to model RTTs of IP hosts around the world for distributed system analysis and simulation studies,
- to find out optimum locations for servers to give a fast Internet service over the world, and
- how different delay components such as propagation time and transmission time affect the total packet delay.

2. Measurement data

The first dataset is obtained from open public traces of MAWI working group of Japan's WIDE Project [16] via filtering of ICMP packets. These public traces contain daily Internet traffic of WIDE backbone, intentionally generated abnormal traffic for research purposes, and ICMP ping packets of ANT project. Starting in 2011, ANT Project team [17] of Information Science Institute (ISI) has been collecting data about IPv4 address spaces via pinging random IPv4 addresses from Fujisawa-Shi, Kanagawa of Japan for their Internet censuses study. The main factor we benefit from WIDE traces is the existence of high number of IPv4 hosts scanned in a short period of time. The ping packets are being sent from Fujisawa through 150 Mbps incoming/outgoing transit link of WIDE to the upstream ISP which is in operation since 2006. The packets are captured in 15 minute intervals. More than 300 million packets with a volume of nearly 30 GB traffic are captured in 15 minute intervals. In each trace, more than 20 million ICMP packets exist. Approximately, 4 million ICMP requests take ICMP reply in each 15 minute intervals. Most of ICMP requests do not take any reply packet due to a firewall or unreachability of hosts at that specific time. Due to the privacy of individual IP addresses, MAWI randomly scrambles any individual IP address to further protect privacy.

Although WIDE traces made many contributions to our study, they also restrict our analysis in some ways. Due to IP address anonymization policy of MAWI, we could not trace the IPv4 hosts' geographical locations, and point out the delay differences of particular locations to the measurement point. To overcome this difficulty, a pinging tool is designed with Python for sending pings to randomly generated IPv4 addresses. We take advantage of threading module in our tool to run multiple threads concurrently. If threading module is not used, we would have to wait for each pinging result to send another ping which makes the pinging rate very slow. We determine threading number 100, which means sending 100 ICMP pings, and waits for the ICMP responses from them before sending another 100 pings. 100 is determined as optimum threading number after carrying out some experiments. The pinging tool could send 100,000 ICMP packets approximately in 3 h with Intel Core i5-2430 CPU 2.40 GHz, 12 GB RAM laptop computer. While sending ICMP ping packets to randomly generated IPv4 addresses, the Wireshark capturing tool captures the network traffic for the assessment of RTT delays. Wireshark could export captured ICMP traffic in XML format. We build another tool in Python to obtain the RTT delay and geographic location of IPv4 addresses from exported XML files. Running our pinging tool, we take measurements from Erciyes University in Turkey, and University of Alabama at Birmingham in USA through 100 Mbit/s Internet connections. To observe the effect of Internet access speed on delay results, we also run the tool through 8 Mbit/s. ADSL (asymmetric digital subscriber line) connection speed in Kayseri, Turkey. In total, we scan more than 1 million IPv4 addresses with the designed pinging tool.

For WIDE traces, Wireshark protocol analyzer application is used to filter ICMP replies and corresponding ICMP requests from the captured traces. WIDE traces consist of more than 40 application protocols traffic and millions of packets. Considering all filtering operations for WIDE traces, it takes approximately 25–30 h to get corresponding ICMP requests and reply packets in two separate files for a single captured trace with Intel Core i7-3770 CPU 3.40 GHz, 16 GB RAM desktop computer. Using a database application, corresponding ICMP requests and ICMP replies are matched.

3. Analysis results

There are 41,196,168 ICMP packets on 5 November 2014, 15 min long WIDE trace. Following the methodology given in the previous section, 8,325,138 unique ICMP request-reply matchings are obtained. Calculated RTT times for each public domain source are shown in Figure 1. Each dot represents a unique IPv4 host RTT delay.

It is observed that most of the RTT times are smaller than 1 s. Despite this fact, some hosts experience RTT delay as long as 15 min. It is likely that this is due to the ICMP messages are being handled with very low priority by some hosts or intermediate routers leading to the long delays. The empirical studies on delay suggest that the delay metric should indicate the quantity of delay experienced by most packets in the network and not to be sensitive to statistical outliers [18, 19]. For the traceability of the significant results, we focus on the particular time region of the distribution curves where most of the hosts concentrate to ignore statistical outliers. Only in 0.4 s, 7,513,062 of 8,325,138 hosts accomplish their ICMP request-reply communication in November 5th, 2014 WIDE trace. Due to the huge amount of hosts, we benefit from frequency distribution graphics of RTT results. Figure 2 shows the RTT frequency distribution of IPv4 hosts in between 0 and 0.5 s.

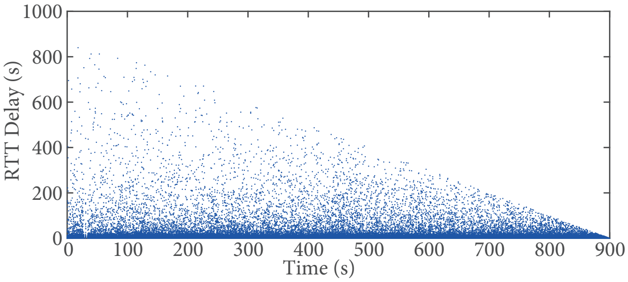

Figure 1. Round trip times of random IP hosts (November 5th, 2014, 14.00-14.15, WIDE Trace).

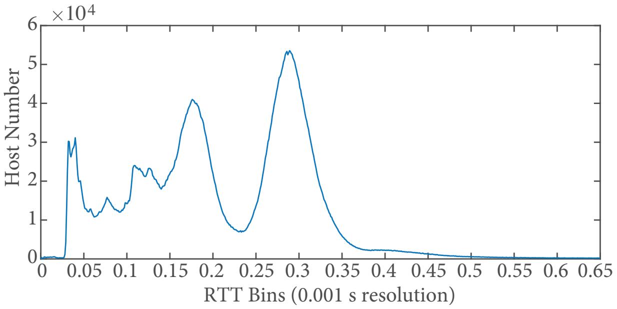

Figure 2. RTT frequency distribution of IP hosts with 0.01 s bin size (November 5th, 2014, 14.00-14.15, WIDE Trace).

Considering hosts could be anywhere in the world, in 0.4 s 90% of hosts achieve communication. The wavy form of distribution demonstrates that there must be some kind of variations in the polled host geographic locations. Variations might be caused by continental, territorial, or regional separations. Similar curves occur in other day traces of MAWI, as well. To track the geographical locations of IP hosts and get their delay results, we run our pinging tool at University of Alabama at Birmingham (UAB) in USA and Erciyes University (EU) in Turkey through 100 Mbit/s Internet connections. At the end of 100,000 random IPs scanning at UAB, 9149 unique IP host results are obtained. Frequency distribution of RTTs with respect to some countries are exhibited in Figure 3. In this representation, the first curve mostly belongs to USA-located IP hosts. The second curve is mostly formed by Europe and South Africa. The third and fourth ones generally belong to Korea- and China-located hosts. In Figure 4, continent-based distribution curves confirm this finding. It is obvious that continental and territorial separations cause the delay difference in graphics by creating dips and peaks regarding the host numbers in that region. The obtained results also shed light upon WIDE-based distribution curves and make them more meaningful. Via the evaluation of graphical results, we could say that there is approximately 0.1 s delay difference between US and Europe countries, 0.2–0.25 s between US and China, 0.175 s between US, Japan and Turkey. Reasonably, signal is transmitted to Japan and Turkey through opposite directions.

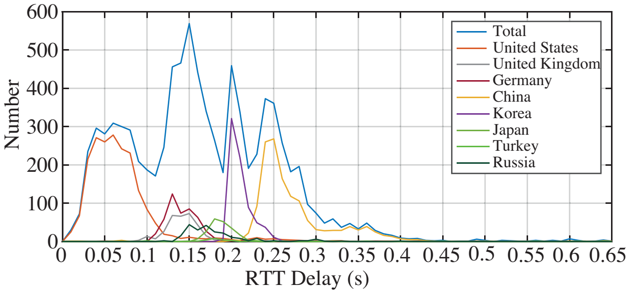

Figure 3. Country-based RTT frequency distribution of IP hosts with 0.01 s bin size (March 3rd, 2018, 11:40-14:45, UAB Trace).

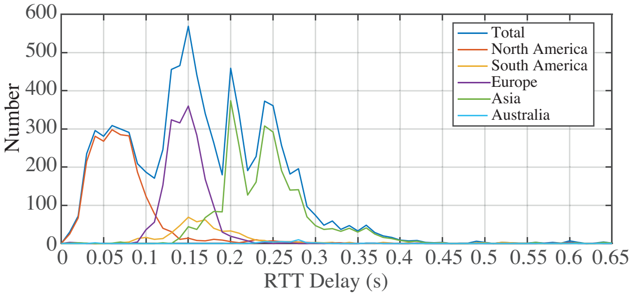

Figure 4. Continent based RTT Frequency Distribution of IP Hosts with 0.01 Second Bin Size (March 3rd, 2018, 11:40-14:45, UAB Trace)

Another pinging is carried out via running pinging tool at Erciyes University through 100 Mbit/s, and 8 Mbit/s Internet connections in Kayseri, Turkey. After 200,000 random IP scanning through 100 Mbit/s and 8 Mbit/s data-rate, 17,627 and 17,497 unique host results are computed, respectively. In Figures 5 and 6, the first, second, and third curves mostly belong to Europe, America, and East Asia, respectively. Considering the midpoints of peaks, we could say that there is approximately 0.05 s between Germany and Turkey, 1.25 s between Turkey and US, and 0.3–0.35 s delay difference between China and Turkey. 8 Mbit/s access speed adds 0.025 s extra delay compared to 100 Mbit/s access speed due to transmission delay on links. Transmission delay is the time which is required to push packet's bits into the link. It is reverse proportional to data-rate of the link as seen in Eq. (1):

$$D_t = N/R, \tag{1}$$

where Dt is the transmission delay in seconds, N is the number of bits in packet, and R is the data-rate of the link.

Similar analysis is carried out for 06-07-08 November 2014 WIDE traces, and 7,813,997, 9,417,923, 8,211,807 unique ICMP request-reply matchings are obtained, respectively. The main reason for the selection of the mentioned dates is high pinging rate on these days compared to the other days in MAWI archive. Main parts of curves resemble each other and give almost similar distributions. Figure 7 reveals that waviness exists in all distributions with the exact same form at the exact same time. Due to the scrambling policy of IP addresses by MAWI to protect users' IP privacy, countries could not be traced by IPs. However, considering the pinging is carried out in Japan and with the assessment of our pinging tool results, it is obvious that second and third

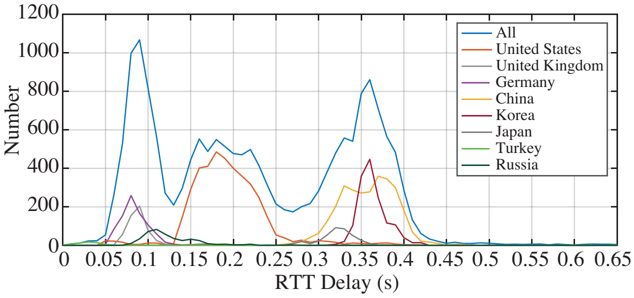

Figure 5. RTT frequency distribution of IP hosts with 0.01 s bin size through 100 Mbit/s (March 8th, 2018, 13:30-20:00, EU Trace).

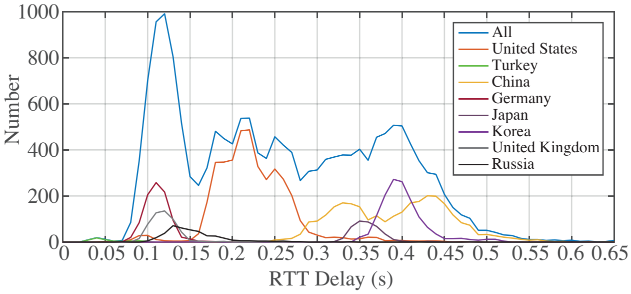

Figure 6. RTT frequency distribution of IP hosts with 0.01 s bin size through 8 Mbit/s (March 7th, 2018, 00:00-05:40, ADSL connection).

curves belong to hosts mostly located in America and Europe, respectively.

Table 1. Summary information of ICMP packets for different times in a day, WIDE Traces (02.12.2015)

Time Interval	Total ICMP packets	Request- Reply Matching
00.00–00.15	22,764,400	3,949,096
00.15–00.30	26,415,27	3,957,438
12.00–12.15	24,556,763	3.976.507
18.00–18.15	23,929,802	3,920,760

Considering different times on the same date by choosing distant and close time periods, the frequency distributions of RTTs are derived. Summary information for the analyzed traces is given in Table 1. Generally, MAWI archieve provides the network traffic for each day captured between 14.00 and 14.15. However, the archive provides most recent 24 h long traces on 2-3 August, 2015. To make delay comparison between different times in a day, the 2 August 2015 trace is chosen which is being one of the most recent 24 h long traces for the time when analysis was carried out. Figure 8 reveals that only the below section of 0.15 s differs, beyond 0.15 s almost nothing changes. The number of internet users may change for a specific territory by being at night or daytime. Small delay values mostly belong to close Internet connections to the capturing point. Therefore, distribution differs by being in busy or free hours for close public domain sources. The distributions for faraway host connections do not change much. Considering the countries being in different time zones at a specific time, statistical average of them gives almost the same curves.

Table 2. Summary information of ICMP packets over the course of 5 years (14.00–14.15)

Date	Total ICMP packets	Request–reply matching
17.10.2011	18,143,816	2,034,406
27.10.2012	17,459,815	2,302,187
06.10.2013	22,640,963	3,430.711
06.11.2014	37,217,261	7,813,997
02.12.2015	24,679,692	3,975,852

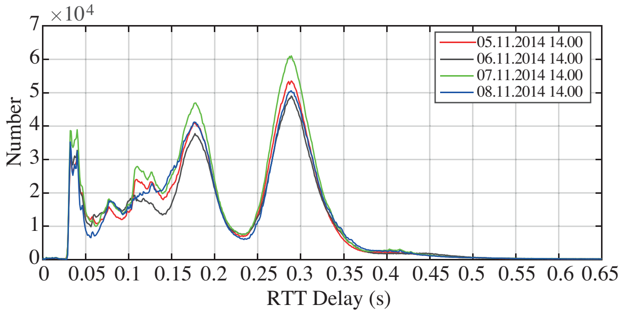

Figure 7. RTT frequency distributions of the consecutive day traces with 1 ms bin size (WIDE Traces).

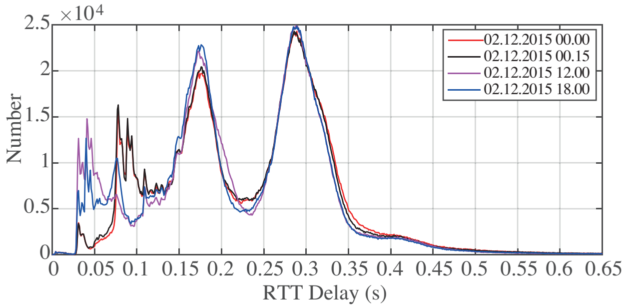

Figure 8. RTT frequency distributions of distant and close time interval on a day (2 December 2015 WIDE Traces, 1 ms bin size).

The traces in Table 2 are analyzed to observe RTT delays over the course of 5 years. We want to shed light upon how RTTs differ during 5 years span with developing network technologies, increasing backbone, and access link speeds. Except for a slight magnitude difference and a slight shift to the left in the second and third curves, main parts keep their shape as could be seen in Figure 9. The magnitude difference in 2014 line is due to the high pinging rate in this year. However, there is a little shift to the left in the second and third curves, which demonstrates a little decline in round-trip delay. We could say approximately 5–25 ms decline is experienced in RTT times from year 2011 to 2015. The obtained frequency distribution graphics exhibit that there are concentrations on polled host geographic locations especially in Europe and USA. To give an Internet service all over the world, locating servers in these locations is a good choice in terms of giving a fast service to a high number of Internet users.

In Figures 10 and 11, time to live histograms are obtained for two separate WIDE traces which belong to 2015 and 2011. This graph would demonstrate any changes in hop counts in 5 years span. At the capturing point, ICMP requests have a TTL of 59. Taking into consideration the WIDE backbone, it takes 5 hops to reach the capturing point for each ICMP requests. Approximately 15% of hosts send ICMP replies to these requests. TTL field in the ICMP replies give information about after how many hops ICMP replies reach the capturing point. Generally, routers generate ICMP packets with 64, 128, and 256 TTL according to their internetwork operating systems (IOS). Concentration of hosts close to the mentioned TTL values demonstrate that return way includes only a few hops. These two histograms reveal that generally hosts send ICMP packets with a TTL value of 64. Considering the graphical results of RTT, we could say there is no sharp change in hop counts in 5 years.

Geographical dispersion of polled hosts is separated with long haul backbone links such as Trans-Pacific link between USA and Japan. Considering the graphical distribution curves, propagation latencies on backbone links constitutes larger part of the packet delay. Verifying this outcome, another experiment is carried out via the exploitation of ICMP Time-Exceeded (ICMP-TE). ICMP-TE messages are particular communication packets to express inaccessibility of hosts in terms of hop count limitations. In TCP/IP, the source host sends TCP packets with a certain TTL value. Each router on the way processes the IP packet to find suitable interface to the destination and decrease the TTL value by one. If the packet could not reach its destination when the TTL reaches zero, the packet is discarded, and the router notifies the source host with an ICMP-TE packet. In this implementation, ICMP request packets are sent with 64 TTL from UAB at Alabama through 100 Mbit/s connection. When we get an ICMP-TE packet, it means associate ICMP request could not reach its destination

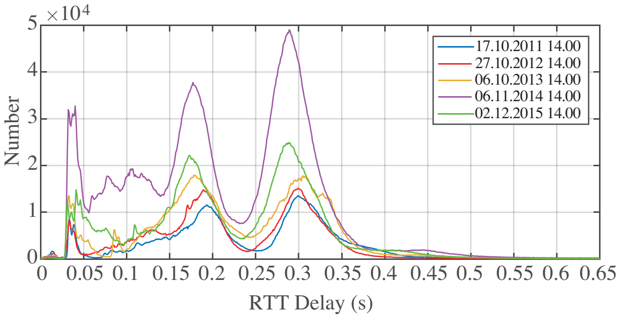

Figure 9. RTT frequency distributions over the course of 5 years with 1 ms bin size (WIDE Traces).

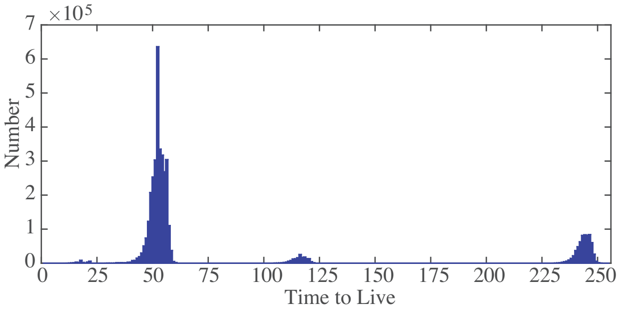

Figure 10. TTL histogram (17.12.2015, 00.00–00.15, WIDE Trace).

after passing through 64 routers on its way. That is, the packet experiences 64 times processing and queuing delay on its departure direction, plus it also experiences extra processing, and queuing delays on arrival. Taking into consideration the remaining TTL counts in Figures 11 and 12 for ICMP reply packets, ICMP-TE packets experience far more processing and queuing delay than normal ICMP reply-request communication. In Table 3, after the elimination of statistical outliers, average delay values of ICMP-TE packets and reachable IP hosts are exhibited. Close RTT quantities confirm that, compared to processing and queuing delay of routers, propagation delay on backbone links constitute larger portion of the packet delay.

Table 3. Average Delay Results

Country	Average delay of ICMP-TE	Average delay of ICMP replies
United States	0.089648	0.068918
China	0.298578	0.273885
Japan	0.197671	0.196551
Korea	0.209898	0.208769
Germany	0.149887	0.143816
United Kingdom	0.154946242	0.143905
Turkey	0.17466	0.177749
Russia	0.196591121	0.17887

Average delay versus TTL graphic also verify this finding. Most of the ICMP reply packets have the remaining TTL values close to 64, 128, and 256 due to passing through only a few routers on their arrival. Considering the close sections to these points in Figure 12, the average delay increases very little with decreasing TTL. That is, with increasing hop counts, a slight increase occurs in delay quantity which doesn't affect much compared to propagation and transmission delay on links.

4. Distribution fitting

In this section, our aim is to obtain a probability distribution function to model the RTTs of IPv4 hosts around the world. Since RTTs of distributed Internet hosts exhibit nondeterministic behavior, it would be an efficient way to model them with distribution functions. The results of this study will help in distributed system analysis and simulation studies. As could be noted in obtained frequency distribution in previous section, there are 3

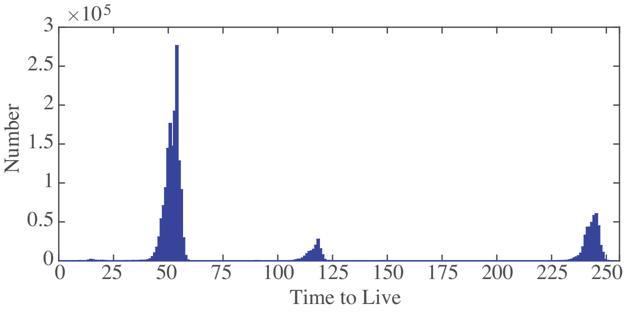

Figure 11. TTL histogram (17.10. 2011, 14.00–14.15, WIDE Trace).

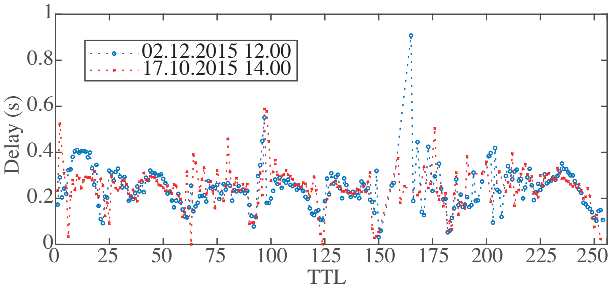

Figure 12. Average delay variation with the remaining TTL.

main curves in all distributions which lead us to use multimodal distributions for modeling RTTs. To do so, we separate calculated RTT space into three parts. For the distribution fitting purpose, we benefit from WIDE traces due to the high pinging rate in them. Considering the obtained distribution graphics, it could be said that the first curve ends at 0.1 s. The second curve is between 0.1 and 0.25 s and after this point, the third curve starts. To eliminate statistical outliers, we take into consideration between 0.25 and 0.45 s for the third curve sample space. In the distribution fitting procedure, we test 73 different distribution functions for finding the optimum model for RTTs of Internet hosts around the world. For the selection criteria of goodness of fitting, the Kolmogorov–Smirnov is used to determine the optimum distribution function.

It is difficult to model RTTs below 0.1 s with a particular distribution function. As mentioned previously, this part of the obtained frequency distributions changes considerably over the course of 5 years and also different times in a day. Distribution fitting results demonstrate that there is no particular distribution function which could model RTTs below 0.1 s. According to the Kolmogorov–Simirnov test results, the Wakeby distribution gives the best results for modeling RTTs between 0.1 and 0.25 s. The Wakeby distribution is a five-parameter probability distribution defined by Eq. (2)

$$\chi = \zeta + \frac{\alpha}{\beta}(1 - (1 - U)^{\beta}) - \frac{\gamma}{\delta}(1 - (1 - U)^{-\delta}), \tag{2}$$

where U is a standard uniform random variable. The parameters β, γ, and δ are shape parameters. ζ and α are location parameters.

According to the test results for modeling the RTTs between 0.1 and 0.25 s, the span for the distribution parameters β, γ, δ, ζ, and α vary in the ranges [2.9–7.6], [0.01–0.05], [-0.42–0.02], [0.1], and [0.21–0.39] for the analyzed traces, respectively. Figure 13 shows the histogram and fitted distribution for the RTTs between 0.1 and 0.25 s of 2 December 2015 trace.

The obtained results show that Wakeby distribution could also model efficiently RTTs between 0.25 and 0.45 s. The span for the Wakeby distribution parameters β, γ, δ, ζ, and α vary in the ranges [4.2–20], [0.03–0.05], [-0.18–0.08], [0.25], and [0.13–0.65] between the mentioned time span, respectively. Figure 14 shows the calculated histogram and fitted distribution for the RTTs of 2 December 2015 trace. We obtain similar distribution fitting graphics for other day traces.

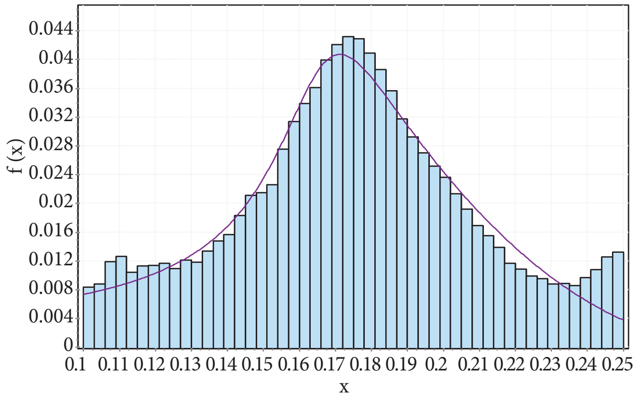

Figure 13. PDF modeling of RTTs between 0.1 and 0.25 s (02.12.2015 12.00–12.15 Trace, WIDE Trace).

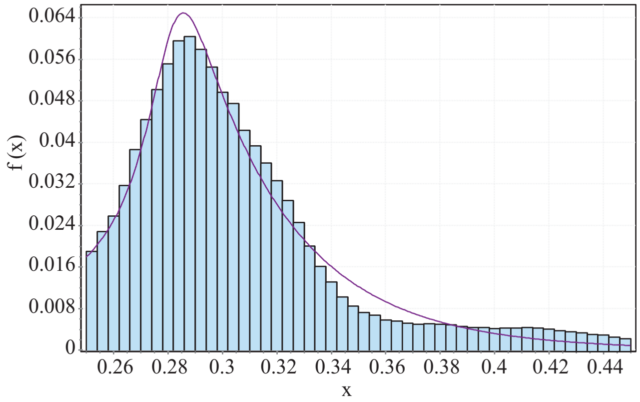

Figure 14. PDF modeling of RTTs between 0.25 and 0.45 s (02.12.2015 12.00-12.15, WIDE Trace).

5. Conclusion

Understanding the global Internet condition and ensuring the good functioning of time-sensitive application over the Internet require monitoring delays continuously. This study evaluates up-to-date round-trip time delay results of more than 55 million Internet hosts around the world. Round-trip times are obtained through pinging random IPv4 addresses from three vantage points located in Turkey, Japan, and USA. Considering pinged hosts could be anywhere in the world, only in 0.4 s 90% of the total hosts completes their ICMP request-reply communication. Comparative graphical distribution results from the pinging at Fujisawa, Japan shows a slight decrease occurring in round-trip delay over the course of 5 years. The results of pinging at Birmingham, AL, US demonstrate that approximately 0.1 round-trip packet delay occurs between US and Europe, 0.2–0.25 s between US and China and 0.175 s between US and Turkey through 100 Mbit/s connection. 8 Mbit/s Internet access speed adds 0.025 s extra delay compared to 100 Mbit/s connection due to transmission delay. The experiment with ICMP reply and ICMP time exceeded packets demonstrate that compared to processing and queuing delay of intermediate routers and end hosts, propagation time on backbone links constitutes larger part of the total packet delay. Three main separations on distribution curves which exhibits mostly the concentrations on polled host geographic locations in Europe, East Asia, and North America demonstrates that locating servers in these regions is a good choice in terms of giving a fast Internet service to a high number of Internet users. RTTs distribution fitting results demonstrate that RTTs of hosts around the world should be modeled with multimodal distribution functions. While there is no particular distribution function which model below 0.1 s, the Wakeby distribution could model between 0.1 and 0.25 s and 0.25 and 0.45 s with two different modes according to the Kolmogorov–Smirnov test statistics. This study also gives perspectives about Internet usage in different countries, which is also an indicator of development rate. The obtained round-trip time distribution curves of more than 55 million unique hosts on the Internet over the course of 5 years exhibits that the number of Internet connection is higher in North America especially in US, Europe and east Asia especially in China, Korea, and Japan.

To overcome the difficulty with the MAWI traces about tracking the geographical location of IPv4 addresses, we design a pinging tool for our experiments. The usage of threading module in the pinging tool helps to obtain a high rate pinging. In future studies, we will modify the pinging tool to obtain higher rates which also increases the reliability of the obtained results. We also plan to send pings to IPv6 hosts on the Internet for our future delay measurement researches. IPv4 and IPv6 hosts packet delay comparison with respect to geographical location would be helpful to assess the performance of two Internet protocols.

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