Root and ccTLD DNS server observation from worldwide locations

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***Abstract*— This paper presents a simple method to measure the response time of a set of name servers from various locations around the world. The performance of the root servers is investigated by this method and compared with the country code top level domain(ccTLD) DNS servers.**

Our preliminary results obtained from 27 locations around the world identify regions under-served by the current root servers. The results also indicate that these regions are often connected better to US or Europe than to neighbor countries. We believe that larger scale measurement using this method will reveal a fairly-accurate picture of the current global DNS system.

I. Introduction

One of the most critical components of the Internet is the Domain Name System (DNS) [MD88]. It translates host names to and from IP addresses each other. As shown in figure1 it is a tree-structured distributed database. A domain may be divided into sub-domains and the administrative authority is delegated to the administrator of subdomains.

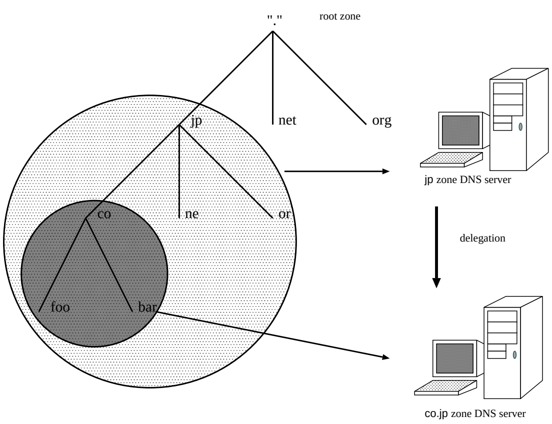

Fig. 1. The tree structure of Domain Name System

The "." is a root of the structure, called "root zone" and the single starting point of all delegations, the root zone delegates global top level domains(gTLD) such as com, net and org as shown in figure 1. It also delegates country code top level domains(ccTLDs) such as ca, uk and jp.

A zone is an administrative unit of the domain name space in which a set of name servers are authoritative for the domain as well as responsible for providing referrals of its delegated subdomains.

Currently the root zone is operated by 13 root DNS servers. The servers are placed in different locations as shown in table I ; 6 in the East Coast, 4 in the West Coast, 2 in Europe, and 1 in Japan. It is the single starting point of DNS database and a crucial point of the system.

TABLE I
Location of root DNS servers

Root DNS Server	location
a.root-servers.net	Herndon VA, US
b.root-servers.net	Marina Del Rey CA, US
c.root-servers.net	Herndon VA, US
d.root-servers.net	College Park MD, US
e.root-servers.net	Mountain View CA, US
f.root-servers.net	Palo Alto CA, US; San Francisco CA, US
g.root-servers.net	Vienna VA, US
h.root-servers.net	Aberdeen MD, US
i.root-servers.net	Stockholm, SE
j.root-servers.net	Herndon VA, US
k.root-servers.net	London, UK
l.root-servers.net	Los Angeles CA, US
m.root-servers.net	Tokyo, JP

The number, location and distribution of root name servers affect the total system performance and reliability of DNS. It is advantageous to have a root name server nearby but there is not enough data to technically investigate better root server distribution for the common good.

The goal of this project is to provide technical methods to evaluate locations of root name servers in order to better understand the performance of the root name server system and to plan for future reconfigurations. Note that this study addresses only the performance aspect. We do not discuss other important operational or political factors such as robustness and reliability.

Our focus is the root DNS servers and ccTLD DNS servers but the techniques can also be applied to other zones and servers. Developing a set of DNS measurement tools itself is a big challenge since there are known difficulties in measuring DNS [AL98], [BkcN01], [JSBM01], [DOK92], [KM01]. We intend to extend our research to more generic DNS measurement in the future.

II. Overview

We developed a simple tool to measure the response time of a set of name servers over time. Using this tool, we measured the response time of the root servers as well as the ccTLD DNS servers from various locations around the world.

From our preliminary measurement, we can identify regions under-served by the current root servers. However, the results also indicate that in these regions connectivity to neighbor countries are not so good.

These results are preliminary because the number of the measurement sites is only 27. The number is too small to understand the global DNS system. In addition, we used dialup access for measurement in the majority of the developing countries so that the reliability of the obtained data is lower for the developing countries. However, we think the result indicates the response time trend of the current DNS system and based on the result we can perform further measurement for future root DNS server location. We believe that larger scale measurement, say from a few hundreds of sites, will reveal a fairly-accurate picture of the current global DNS system. Although it requires international coordination, it would not be difficult in the Internet research community.

In this paper, we describe the probing method of root and ccTLD DNS servers. From the results we work out the trends of reachability to the root and ccTLD DNS servers from various points. Actually we do not identify specific locations suitable for a new root server in the future. However, the method provides a way for a candidate to prove

1) the region is under-served by the current root servers, and
2) the location has good connectivities to neighbor countries so that

having a root server is beneficial to the region. Thus, it becomes possible to technically compare candidate locations.

III. Methods

In this section, we describe our probe tool at first. Next we describe the measurement method using the tool. At last we describe the analyzing method from measured data.

A. Probe tool

We developed a simple DNS probe tool which measures the response time of DNS servers. The probe tool sends the same DNS queries to the pre-defined set of DNS servers at certain interval, one by one, measures response time for each query and, when all the responses are received or timed out, sends a report by e-mail shown as figure 2 to a data collection server.

```
1026688779 133.93.XX.1 eth1 A: rtt 210 ms
1026688785 133.93.XX.1 eth1 B: rtt 159 ms
1026688790 133.93.XX.1 eth1 C: rtt 250 ms
1026688793 133.93.XX.1 eth1 D: rtt 180 ms
1026688798 133.93.XX.1 eth1 E: rtt 110 ms
1026688803 133.93.XX.1 eth1 F: rtt 130 ms
1026688808 133.93.XX.1 eth1 G: rtt 228 ms
1026688812 133.93.XX.1 eth1 H: rtt 190 ms
1026688816 133.93.XX.1 eth1 I: rtt 268 ms
1026688820 133.93.XX.1 eth1 J: rtt 210 ms
1026688827 133.93.XX.1 eth1 K: rtt 264 ms
1026688830 133.93.XX.1 eth1 L: rtt 130 ms
1026688837 133.93.XX.1 eth1 M: SERVFAIL
```

Fig. 2. rootprobe report e-mail

In figure 2, the first column shows the UNIX time when a DNS query is sent and the second column shows IP address of the probing host. The third column shows the interface which DNS packets are sent through and the fourth column is the server name of the probe target. The root server names are abbreviated from “A” through “M”. The rest of the line shows the result of probe, the round trip time of a DNS query on success, and the reason of error on failure.

The probe tool does not use the resolver but crafts legitimate DNS queries and sends them directly to target name servers. The probe tool continues running for 2 weeks by default.

The probe tool is designed for easy deployment. It runs on most of UNIX variants (and Windows if a UNIX environment, cygwin, is available). It does not require root privilege so that, if one has a normal user account on a UNIX box, she can run the probe tool. The probe tool also runs behind a NAT so that it works on a laptop at a conference venue or at a wireless hot-spot.

Two variants of the probe tool, rootprobe and cctldprobe, were used to measure response times of the root servers and ccTLD DNS servers. rootprobe sends queries to the 13 root servers every 5 minutes, and cctldprobe sends queries to the 601 ccTLD DNS servers every 2 hours. Every query is sent at random interval of 3 to 7 seconds.

The e-mail reports are sent to our data collection server, and a weekly-summary for each probe is automatically created. The summaries are updated every 24 hours so that a user can see the results up to the previous day.

The server divides the collected e-mail reports for each probing host, and creates three graphs. The first graph shown in figure 3 reports the response time and loss rate of each root server. The 10th-percentile, 50th-percentile and 90th-percentile of the measured response time are reported to see variations in response time. The second graph shown in Figure 4 reports the CDF (cumulative distribution function) of the median response

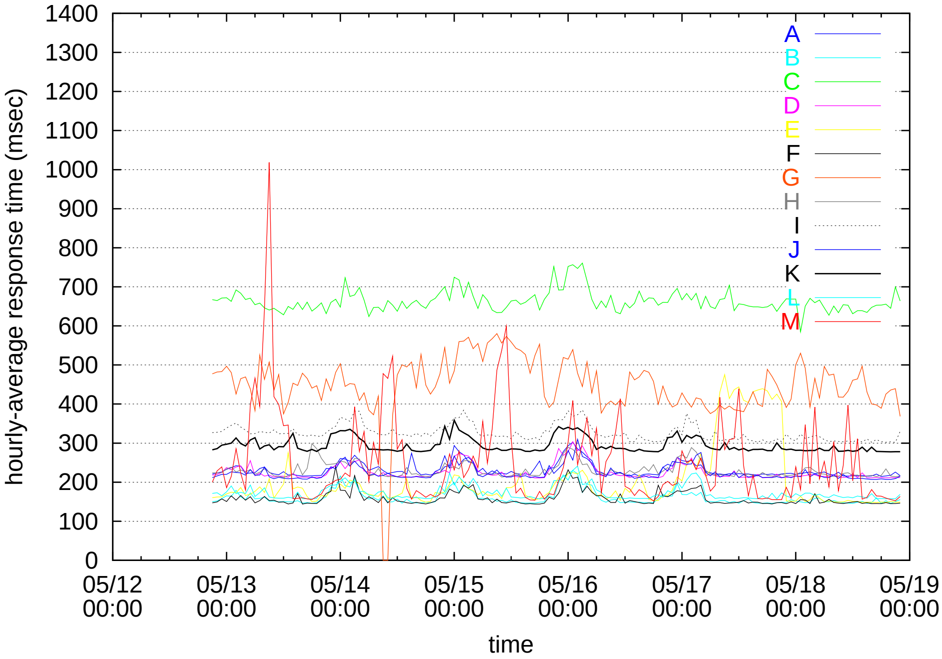

Fig. 5. hourly-average response time of the root servers

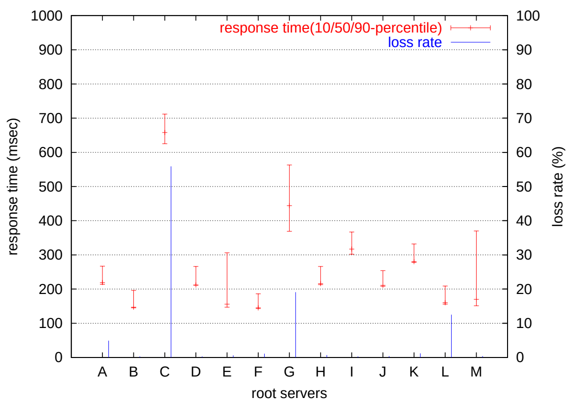

Fig. 3. measured response time and loss rate of the root servers

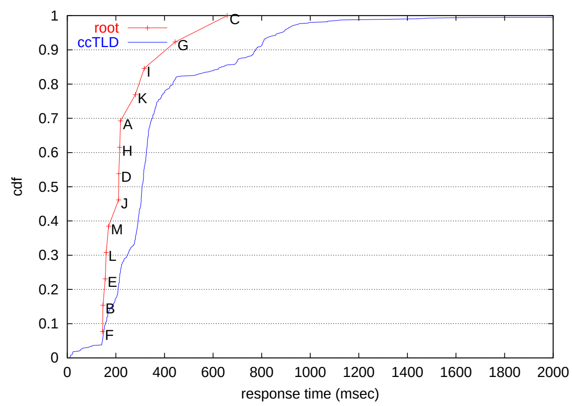

Fig. 4. response time CDF of the root servers and the ccTLD DNS servers

time of the root servers and the ccTLD DNS servers. Each root server is marked with its name in the graph to see the order of the response time as well as the distribution. The distribution of the response time of the root servers can be compared with the ccTLD DNS servers to see the relative positions of their response time. The third graph shown in Figure 5 reports the hourly-average response time of each root servers to see temporal variations in response time.

B. Modem access compensation

We used commercial dialup services to locations where we do not have collaborators, which helped us to obtain preliminary data, especially from developing countries. However, the access latency of overseas dialup is considerably larger than that of native measurement. In order to prove that DNS probe via dialup shows the same pattern as native probe, in spite of access latency, we compare the results of dialup probe v.s. native probe.

To see the effects of the compensation, we measured the differences between direct and dialup measurements on a machine in Los Angeles, US, equipped with a modem. For direct measurements, the probe tool was run natively on the machine. For dialup measurements, measurement was done in Tokyo, Japan through dialup access. Figure 6 shows dialup and native results of DNS probe.

The result shows both native and dialup probes have the same pattern with a certain latency.

Table II compares the compensated dialup results with the direct measurements. The results show that, although the tail

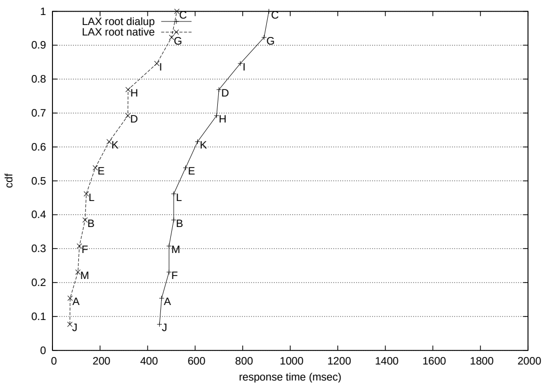

Fig. 6. native and dialup probe

of the distribution is much longer, the 10th-percentile and the 50th-percentile are within an acceptable range.

Figure 7 compares the distribution of the response time by the direct and dialup measurement of K-root.

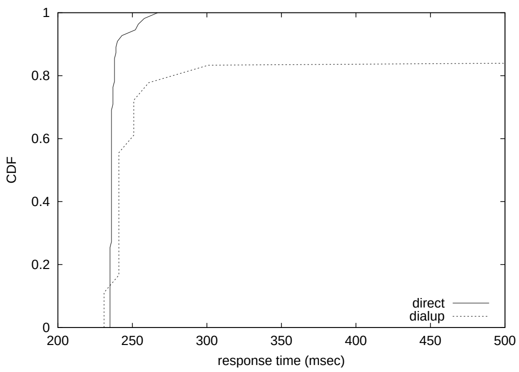

Fig. 7. comparison of the distribution of the response time by direct and dialup measurement of K-root

Thus, we decided to use the compensation method that subtract the response time of the nearest ccTLD DNS server.The nearest ccTLD DNS server means a ccTLD DNS server which has minimal round trip time from dialup point. We define such a DNS server as “nearest ccTLD DNS server”.

Although the compensation could be another source of measurement errors, we found it works better than just subtracting the latency to the first hop measured by the ping command. Still, we are less confident of the dialup results because the measurements by dialup have a limited number of sample count with much larger variations. Another factor is that the dialup service providers used for the measurement seem to have international connectivities heavily influenced by their commercial alliances.

Another issue is that we found the topological locations of commercial access points are quite different from other measurement sites such as universities. The commercial access points are often located at the edge of the ISP network and disadvantageous to measuring global DNS services.

As a result, our measurements have a bias against dialup access sites. To mitigate this bias, we used the median of latency values to the nearest ccTLD DNS server as access latency, and compensated measurements by subtracting this latency. The idea is to consider the latency to the nearest ccTLD DNS server as the latency to the backbone.

C. ccTLD DNS servers as reference points

The measured response time includes the latency of the access link so that it is difficult to compare the response time from different measurement sites, especially when the access link speed differs considerably.

One way to compensate for the access link speed is to use other reference points, ideally, distributed around the world. By comparing with reference points, we can obtain the relative performance of the root servers. This allows us to do measurement by dialing up to a commercial modem access point in a target city where we do not have collaborators. Although measurements may not be accurate due to long dialup delay and a limited number of sampling count, we can obtain a rough idea about the performance observed from those cities.

Another important factor is that measurements of the ccTLD DNS servers show the connectivities of the measurement sites to other countries. In particular, connectivities to neighbor countries are important to consider a site as a candidate for hosting a root server or other TLD servers.

In our measurements, the ccTLD DNS servers are used as reference points. Most ccTLD zones have multiple servers; one or more in US or Europe and one or more in their country or neighbor countries. As a result, the majority of the ccTLD DNS servers are in the Internet core but the rest of the servers are distributed around the world. From a given measurement site, the ccTLD DNS servers are divided into 3 groups: nearby servers, servers in the Internet core, and the rest of the servers widely-distributed behind the Internet core.

Currently, there are 243 ccTLD zones which have 601 unique server addresses in total. We have manually investigated the locations of the ccTLD DNS servers using traceroute and the whois database, and found that the servers are distributed in 154 countries. As Figure 8 shows, 149 servers (24.2%) are in US, 25 servers (4.1%) are in UK but 200 servers (32.5%) in Others are distributed in 119 countries.

Note that the distribution of the ccTLD DNS servers does not have any meaning for comparison with the root servers but we use it simply because the servers of the ccTLD DNS zones have wider distribution than those of other zones. We currently measure the response time of all the ccTLD DNS servers, but it is also possible to select a subset of the servers so as to represent different regions in the world. Probably, it is better to carefully select a subset of the ccTLD DNS servers to reflect the distribution of the Internet users but we did not do so in this measurement to avoid a bias in selecting particular servers.

TABLE II

10TH/50TH/90TH-PERCENTILE OF DIRECT AND DIALUP RESPONSE TIME OF ROOT SERVER

	A	B	C	D	E	F	G
direct	72/72/73	134/135/136	489/521/551	315/315/315	176/178/190	110/111/112	443/499/530
dialup	70/90/1330	121/141/151	521/541/581	321/331/12291	181/191/5521	111/121/1981	461/521/3890
	H	I	J	K	L	M	
direct	315/316/322	423/437/510	71/71/72	235/236/239	138/140/143	105/105/105	
dialup	311/321/331	411/421/501	71/81/3036	231/241/2061	131/141/3084	111/121/6341	

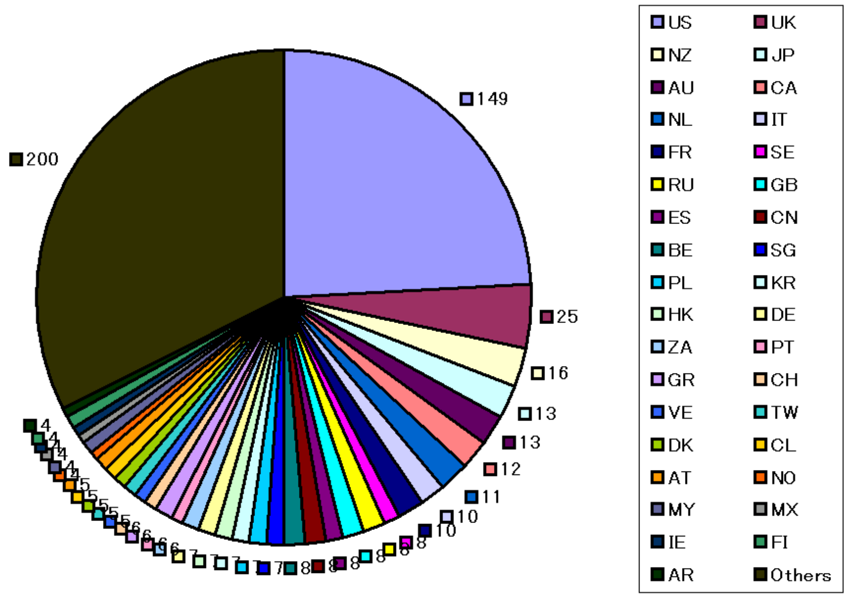

Fig. 8. distribution of the unique ccTLD DNS servers

IV. MEASUREMENTS

We measured the response time from 27 different locations around the world from April to June in 2002. The dialup measurement points have much fewer samples since the measurement period was limited to a few hours.

The measurement sites consist of universities, data center, home and dialup. The majority of the measurement points in the developed countries are universities. On the other hand, the majority of the measurement points in the developing countries are by dialup, and thus, the measurements are less accurate.

Although the measurement points are classified by their country codes, the data does not necessarily reflect a typical view from the country because the measurement points are selected based on ease of access and have different access line types and topological positions in the Internet. The time of measurement also varies for different locations. Nonetheless, the results shows a real view of a set of servers observed from different locations around the world.

A. Dialup points

We used commercial dialup point in developing countries and the countries where we could not find a collaborator. Table III shows dialup points which we used. Some of the ISPs are world wide companies. However, most of the ISPs are domestic ISPs.

TABLE III

ROOT AND CCTLD PROBE DIALUP POINTS

country	provider	IP address
Algeria(DZ)	GECOS NET	80.78.138.186
Australia(AU)	Pacific Internet Australia	210.23.149.202
Brazil(BR)	Teleservice S/C	200.211.206.59
Canada(CA)	Teleglobe	216.6.44.164
Chile(CL)	IFX Networks Chile S.A	200.73.43.177
China(CN)	JiTong Communication Beijing Corporation	203.93.165.152
Italy(IT)	VIA NET.WORKS UK	213.2.220.253
Kenya(KE)	UUNET Kenya	195.202.85.218
Mexico(MX)	AVANTEL	200.39.233.210
Poland(PL)	Advanced Technology Manufacturing, Inc.	157.25.168.85
Korea(KR)	SKTELINC	211.39.49.86
SouthAfrica(ZA)	Storm Internet (PTY) Ltd.	196.22.220.243
Ukraine(UA)	Global Ukraine	195.123.249.39

Dialing from Japan, Tokyo, we performed dnsprobe to root DNS servers and ccTLD DNS servers using the dialup points. The nearest ccTLD DNS servers are shown in table IV. We used them to compensate dialup access latency.

B. Root Servers

Table V summarizes the median response time of the root servers observed from different locations around the world. Here, the response time is compensated by subtracting the latency to the nearest ccTLD DNS server as described in

TABLE V

MEDIAN RESPONSE TIME (MSEC) OF THE ROOT SERVERS MEASURED FROM DIFFERENT LOCATIONS

measurement	root servers												
point	A	B	C	D	E	F	G	H	I	J	K	L	M
US(OR)	88	22	520	75	16	24	385	80	203	89	163	38	134
US(CA)	79	21	545	67	2	2	374	72	183	79	152	24	123
US(CA)	72	135	521	315	178	111	499	316	437	71	236	140	105
US(PA)	2	70	430	6	64	76	315	4	116	3	79	75	192
US(MD)	4	67	477	1	70	82	275	5	135	2	89	92	189
US(MA)	22	76	449	9	70	82	200	15	131	23	93	94	192
CA*	140	200	570	140	371	181	461	160	220	120	191	200	330
MX*	110	91	101	100	131	100	290	90	200	81	170	100	211
UK	190	179	542	105	170	170	310	114	57	110	72	184	254
FR	116	188	540	108	193	148	397	152	32	112	32	179	251
CH	96	178	514	112	163	158	258	115	58	96	27	199	300
IT*	200	251	630	150	270	220	347	160	100	170	70	220	331
PL*	170	220	660	140	361	200	361	150	90	150	80	230	356
UA*	180	501	620	440	270	250	620	451	350	160	350	500	590
CN*	280	401	930	220	551	400	591	470	371	480	351	151	421
CN*	750	670	1190	720	250	360	910	720	820	710	521	660	540
KR*	310	220	980	291	281	201	671	290	400	291	360	231	220
JP	178	140	614	169	102	100	430	170	270	170	230	137	1
NZ	209	137	648	202	146	135	434	206	307	201	270	150	160
AU*	360	270	800	381	390	250	705	320	480	321	440	250	200
ZA*	348	388	808	308	489	378	498	298	338	308	378	389	508
KE*	329	359	489	250	-	340	480	369	399	350	360	330	490
DZ*	210	280	630	181	250	250	351	180	140	180	100	280	350
BR*	140	161	541	111	161	151	101	101	211	101	181	181	251
BR	140	198	555	149	190	194	327	125	248	141	216	196	303
AR	171	203	613	163	222	220	364	167	270	163	243	203	322
CL*	140	220	571	140	210	180	481	140	250	140	220	181	310

TABLE IV

NEAREST CCTLD SERVERS

country	nearest ccTLD DNS server	median RTT
Algeria(DZ)	Liberia(LR) - 193.0.0.193	1599ms
Australia(AU)	Macedonia(MK) - 130.130.64.1	569ms
Canada(CA)	Burkina Faso(BF) - 199.202.55.2	369ms
Chile(CL)	Chile(CL) - 200.73.8.7	569ms
China(CN)	Taiwan(TW) - 159.226.6.178	279ms
Italy(IT)	Ecuador(EC) - 216.200.119.128	539ms
Poland(PL)	Poland(PL) - 157.25.5.30	519ms
SouthAfrica(ZA)	Mauritius(MU) - 196.7.0.137	901ms
Ukraine(UA)	Ukraine(UA) - 193.193.193.100	539ms

section III-B. The measurement points are shown by their country codes. The dialup points are marked with '$*$' after the country code.

Figure 11, 12 and 9 shows that countries in Oceania, Africa and South America do not have a root server within 100msec range. On the other hand, the universities in East-Coast have 4 root servers within 10msec range. Currently, 6 root servers in East-Coast are geographically closely located. As shown in figure 10 US and Canada have good connectivities to many root servers, especially US has several root servers at both East and West coast, and thus all states of US have good connectivities to 11 root servers within 200msec.

As shown in figure 14 European countries have good connectivities to I and K root servers.

It is also observed that Asian countries and Oceanian countries do not have good connectivity to M root server in Tokyo as shown in figure 13 and 11. However, it is known that universities in these Asian cities are much closer to

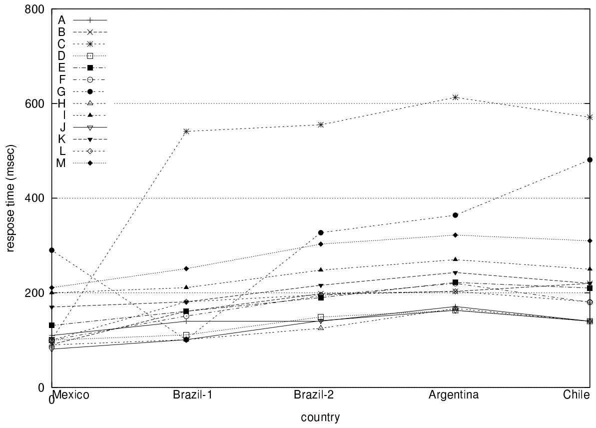

Fig. 9. observation from South America region

M root server. We believe that these dialup access points do not have good international connectivity compared with universities or other commercial services, which shows a difficulty in using commercial dialup access services for this type of measurements.

Throughout the measurement period, C root DNS server has poor connectivity in the all figures. We heard that C root DNS server had been overloaded for months because of a lack of appropriate resource allocation caused by procedural difficulties after the host company filed for protection under Chapter 11. The problem of C root DNS server was resolved in the end of June 2002 but the results in this paper do not

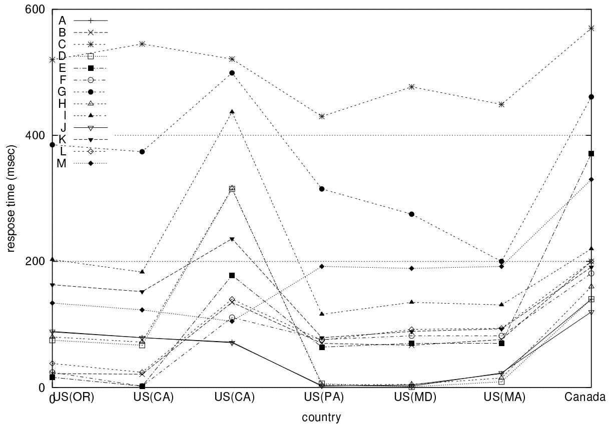

Fig. 10. observation from North America region

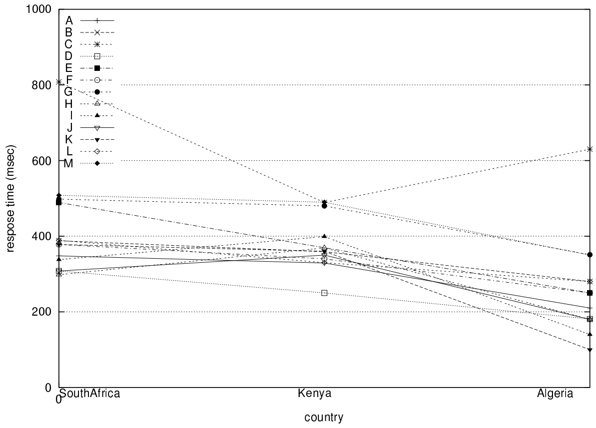

Fig. 12. observation from Africa region

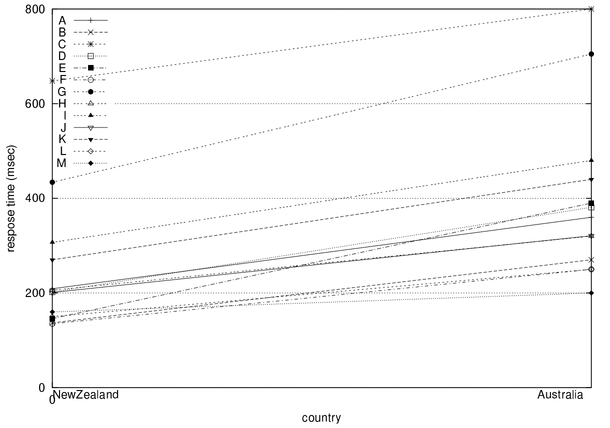

Fig. 11. observation from Oceania region

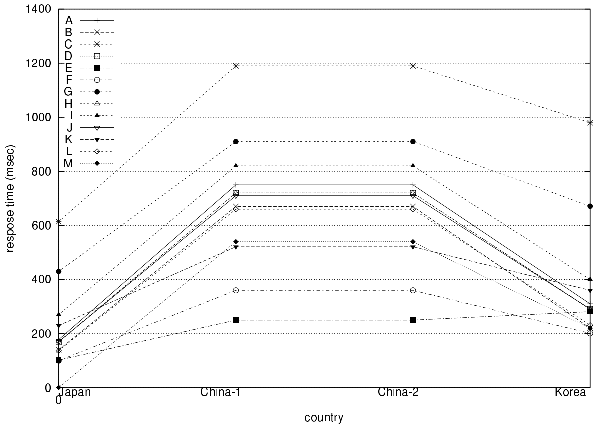

Fig. 13. observation from Asia region

include data after that.

The CDF graphs without compensation dialup latency of the response time from the 27 locations are shown in figure 16, 17 18 and 19. All the CDF graphs show that most of the countries have better connectivity to the root servers than the ccTLD servers, as the root server graph is at the left side of the ccTLD server graph. The graphs also show the countries with steeper slopes of lines have smaller variations to all the root DNS servers such as US, Mexico, UK, France, Switzerland, Italy, Brazil, Argentina, Chile and Japan.

C. Connectivities to Neighbor Countries

Figure 15 illustrates the connectivities among regions. The measurement sites are on the x-axis, and the ccTLD DNS servers are on the y-axis. Both the measurement sites and the ccTLD DNS servers are sorted by geographical regions; from North and Central America, Europe, Asia, Oceania and Polynesia, Africa to South America. Note that many small countries in West Indies and Polynesia are emphasized in this plot since each unique ccTLD DNS server is counted as one.

The plot becomes darker as the response time becomes smaller. If the connectivities within a region is good, the corresponding area becomes dark.

We did not exclude the ccTLD DNS servers placed outside of their own countries so that the order of the ccTLD DNS servers does not exactly reflect the geographical locations. Still, the majority of the ccTLD DNS servers are placed in their own countries or neighbor countries so that we can obtain a rough estimate of the connectivities of the regions to the rest of the world.

The dark area in the upper left of the center shows that connectivities are fairly good among European countries. On the other hand, the connectivities are not so good within Asia, Africa and South-America.

V. CONCLUSION

In this paper, we have described a simple method to measure the response time of the root servers from various locations around the world.

Our preliminary results confirm that regions in Oceania, Africa, South America and part of Asia are under-served by the current root servers. However, the results also indicate that these regions are often connected better to US or Europe than to neighbor countries.

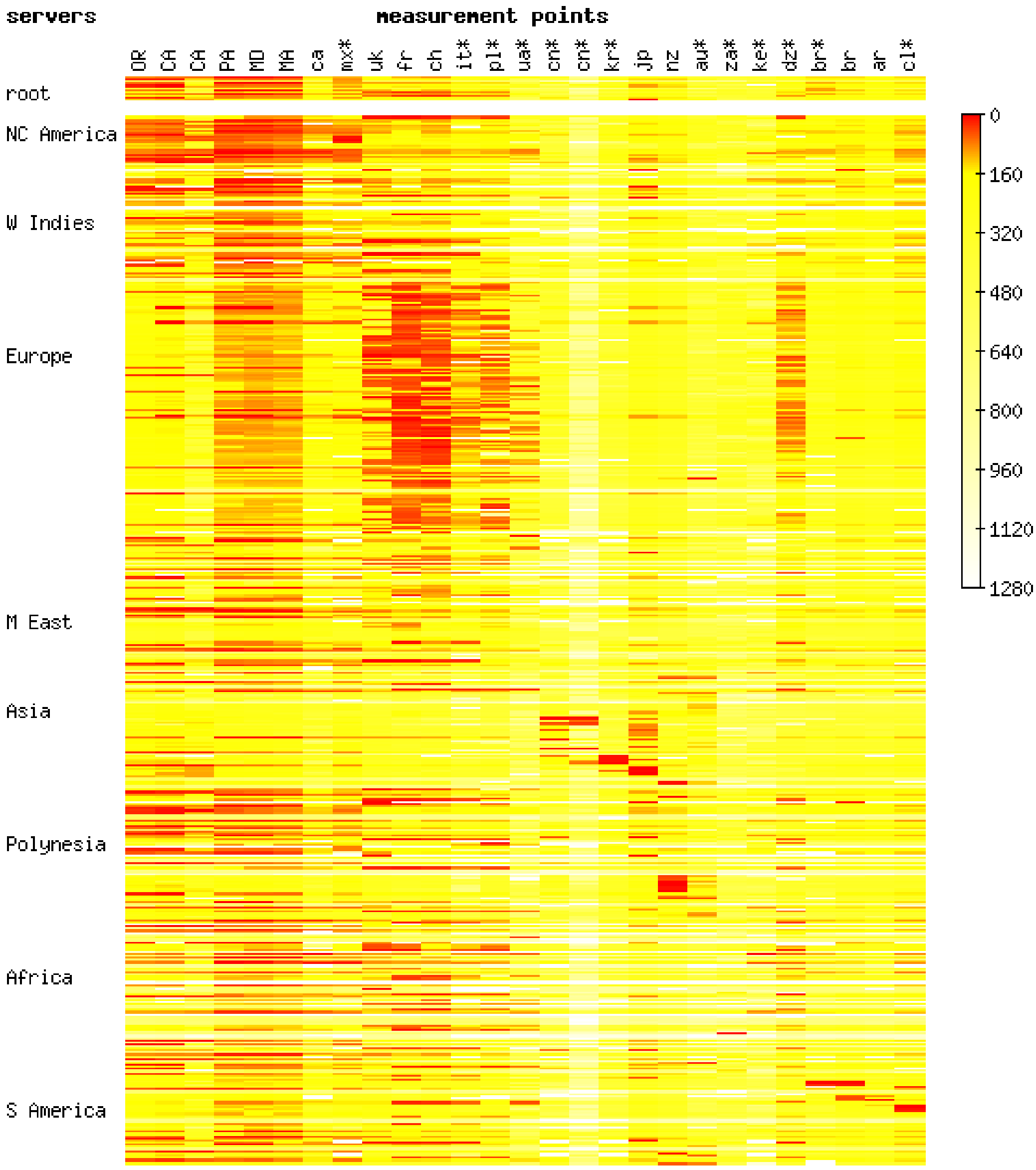

Fig. 15. response time of root and ccTLD DNS servers sorted by geographical regions

Although our preliminary results are limited by the small number of measurement sites and by the use of dialup access, we believe that larger scale measurement will reveal a fairly-accurate picture of the current global DNS system. Such measurement would be valuable for planning future reconfigurations of the globally-shared DNS services. However, operational or political factors would be more critical to the operation of these important DNS servers.

Another important factor to consider is server selection algorithms in recursive name servers [SCSY03]. The server placement is often discussed assuming that the a user selects the best performing server among a set of servers. However, the widely-deployed DNS implementations employ slightly different algorithms which provides better stability in the face of load fluctuations. Thus, it is important to take server selection algorithms into consideration when planning the placement of name servers.

The probe tools and the latest results are available from http://mawi.wide.ad.jp/mawi/dnsprobe/

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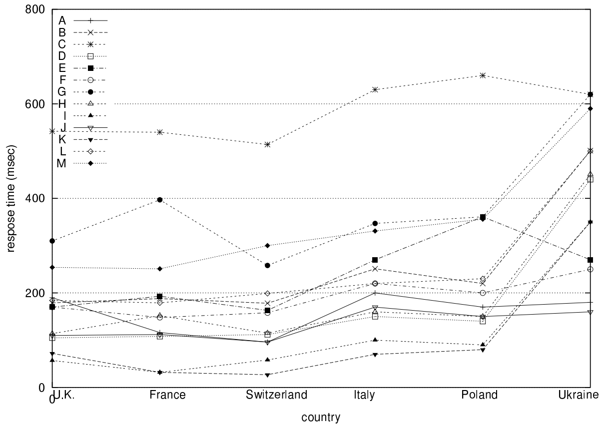

Fig. 14. observation from Europe region

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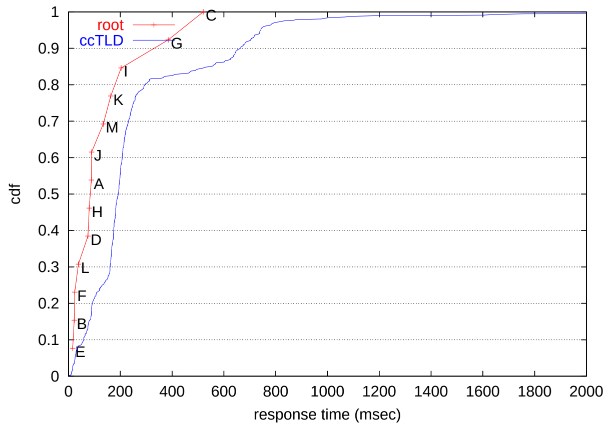

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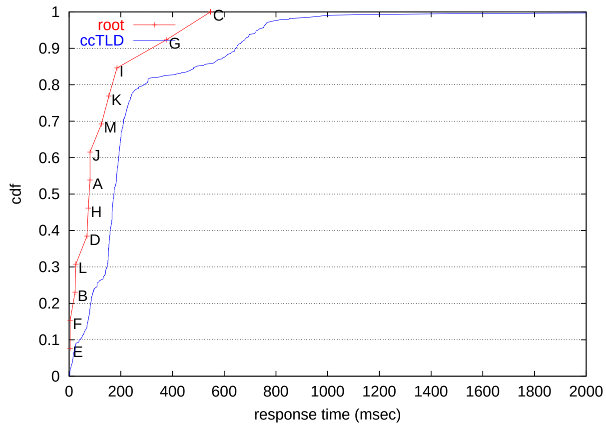

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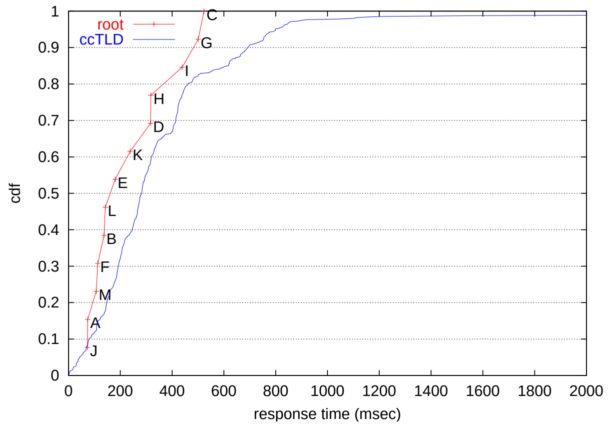

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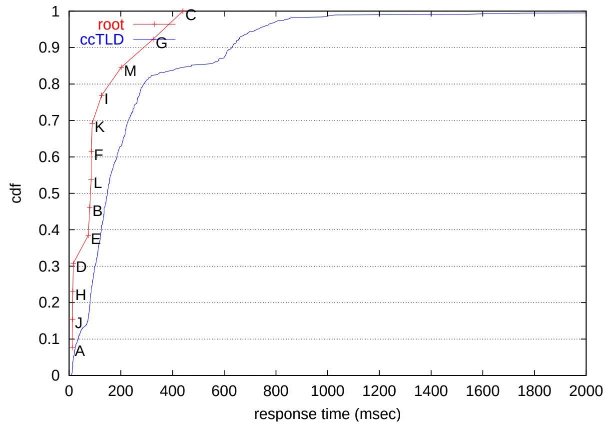

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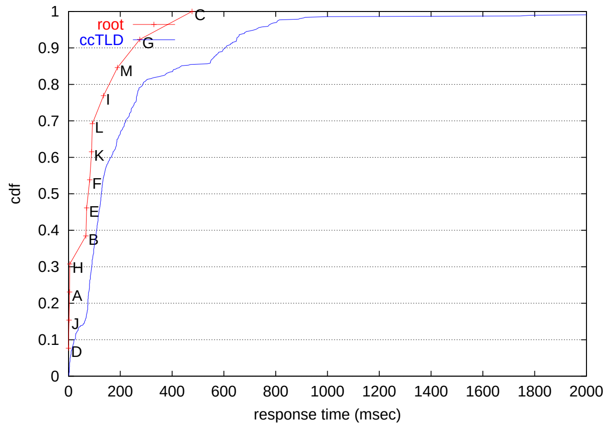

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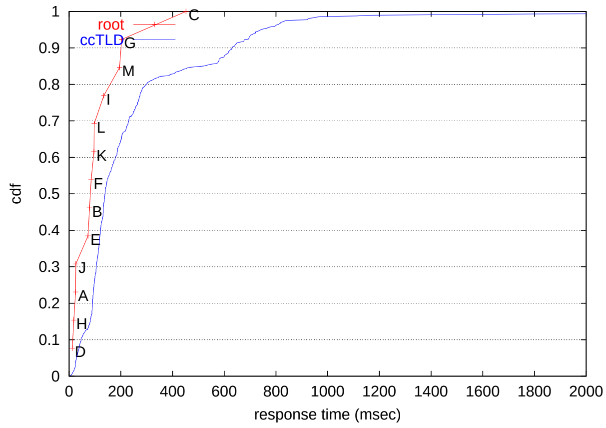

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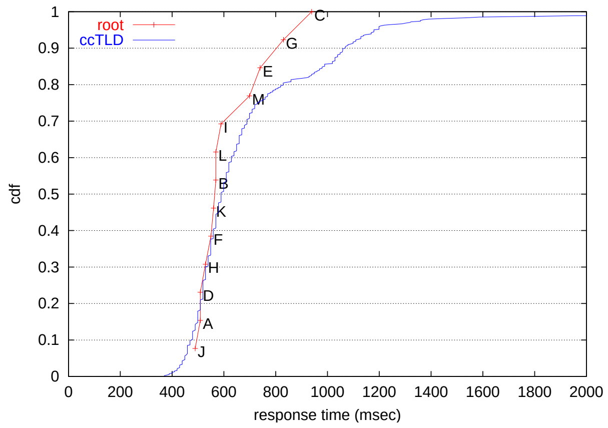

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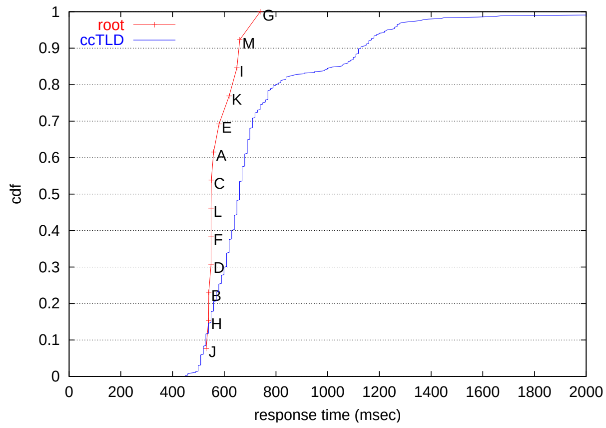

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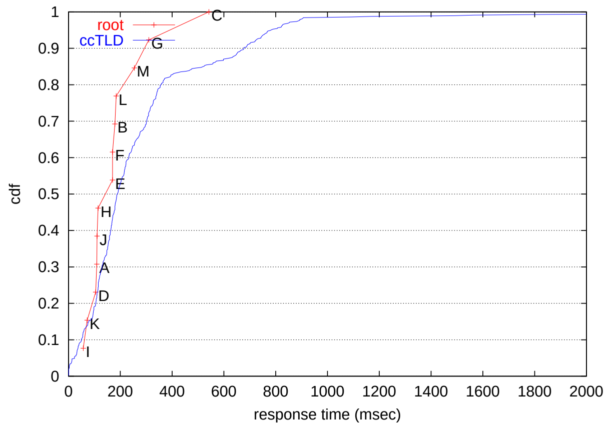
Fig. 16. median response time of root and ccTLD DNS servers (1/4)



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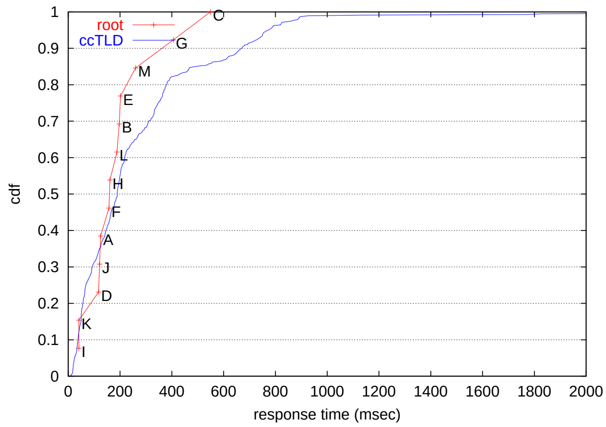

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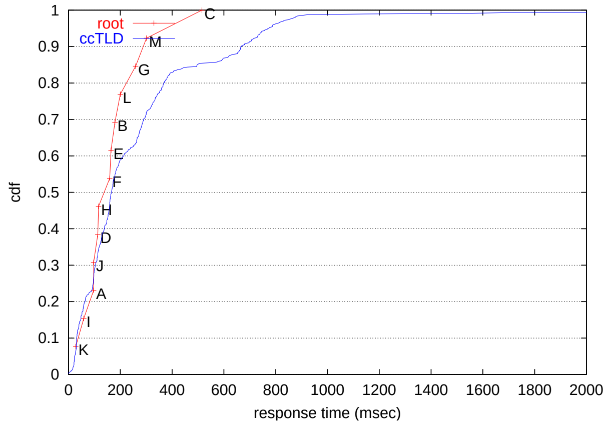

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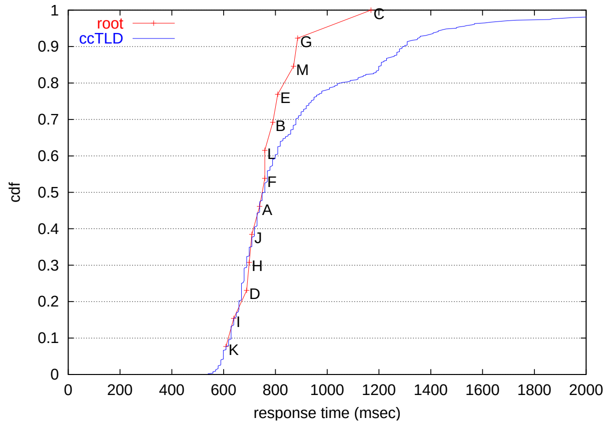

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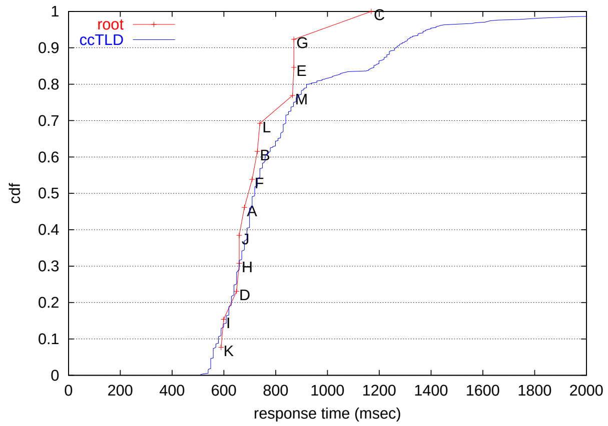
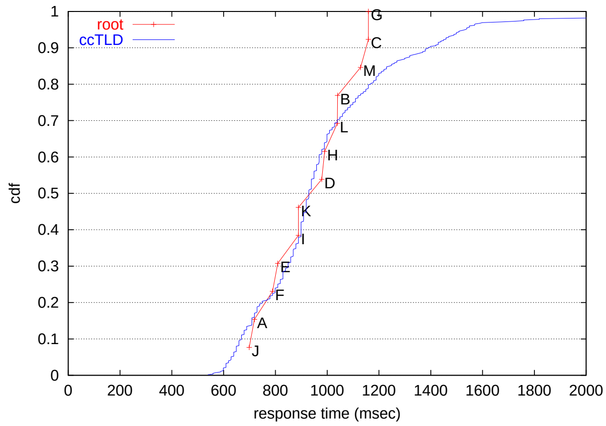
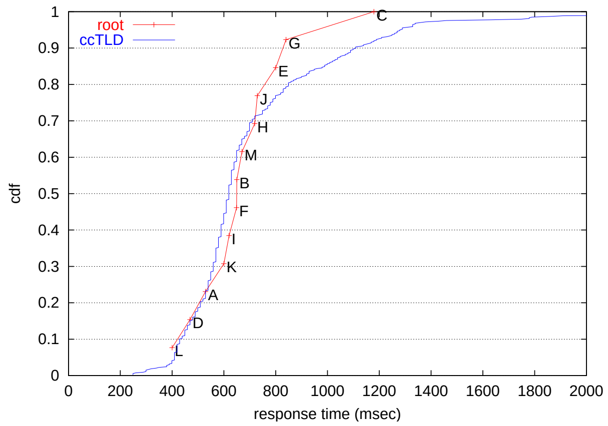


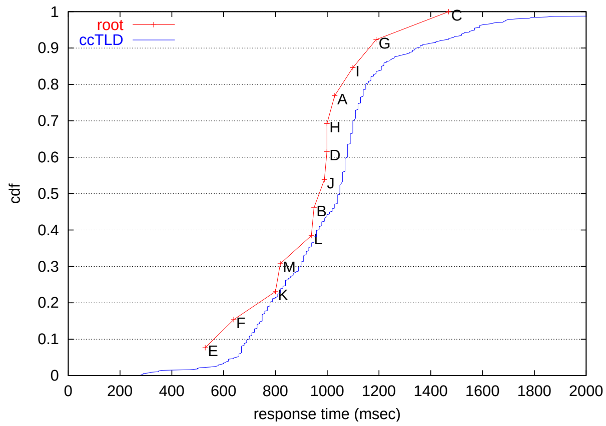
dialup, Torun, Poland



dialup, Ukraine

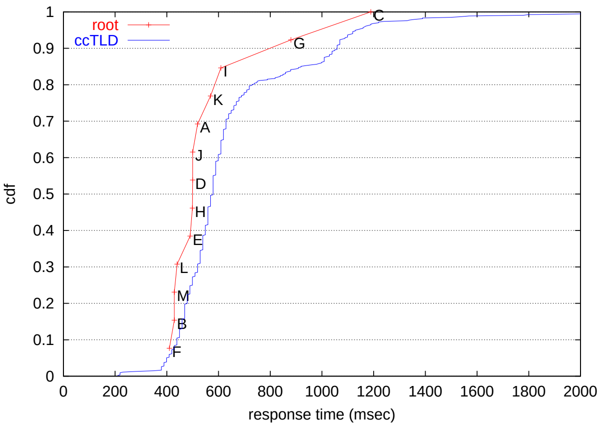


dialup, Shanghai, China

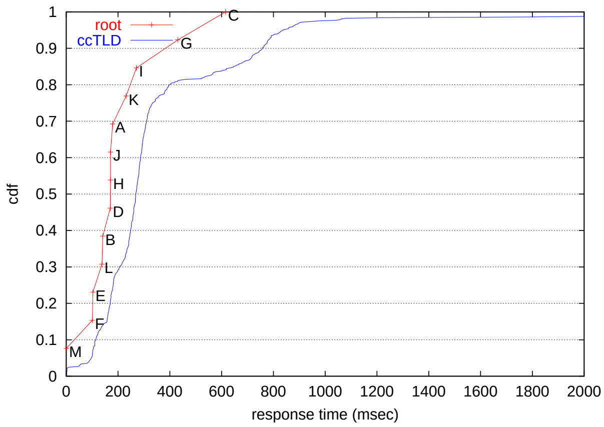


dialup, Beijing, China

Fig. 17. median response time of root and ccTLD DNS servers (2/4)



dialup, Seoul, Korea



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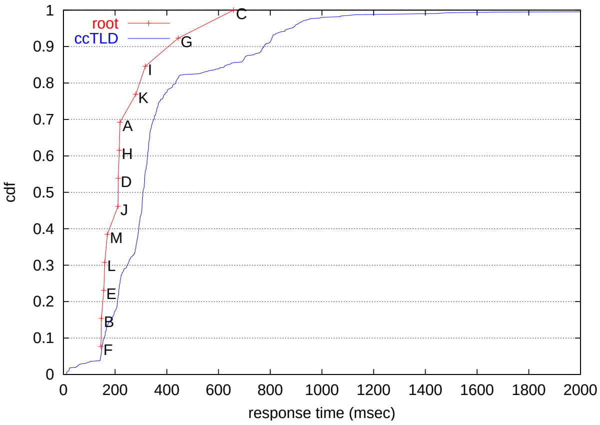

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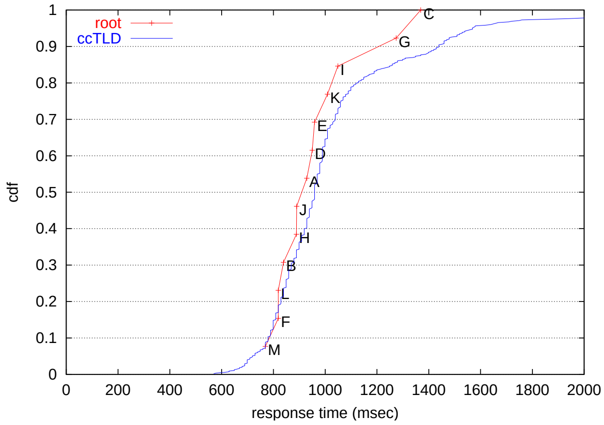

dialup, Canberra, Australia

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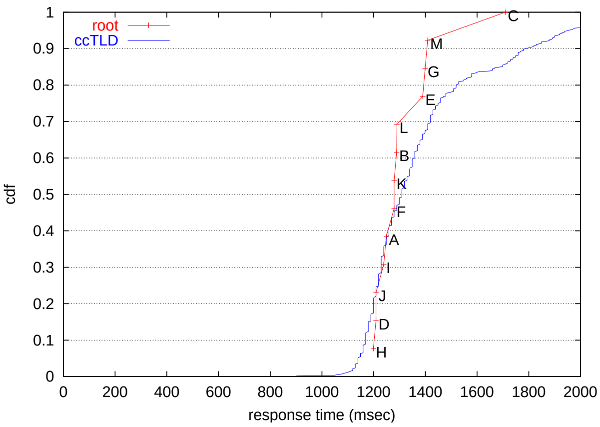

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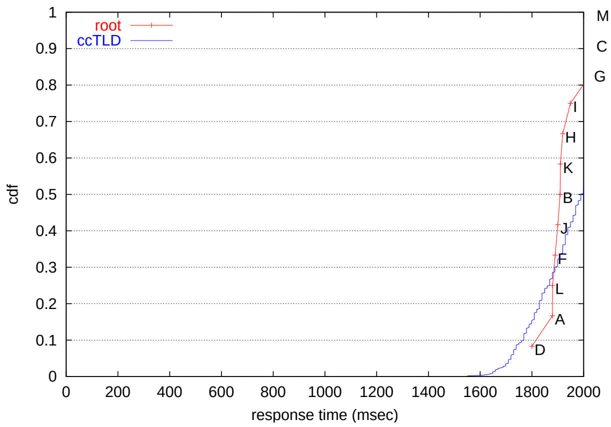

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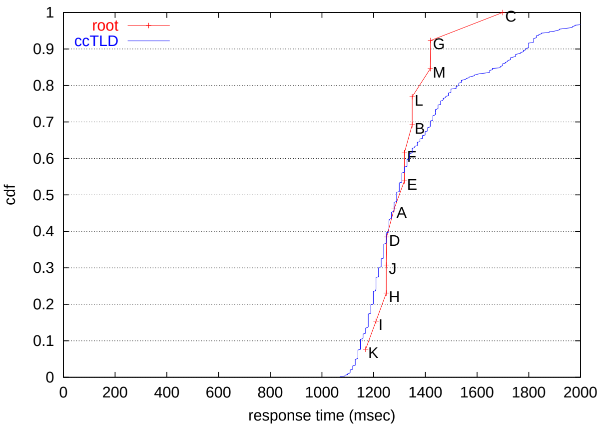

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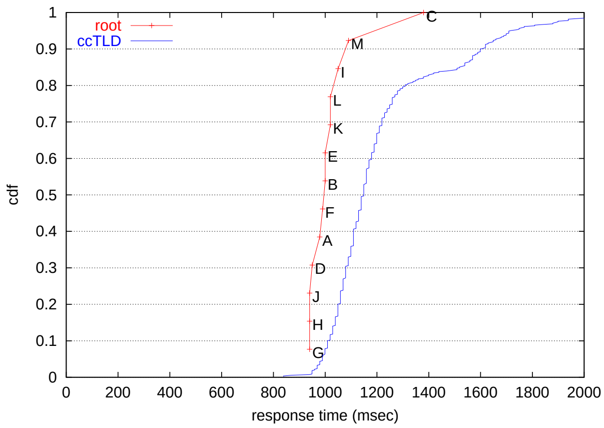
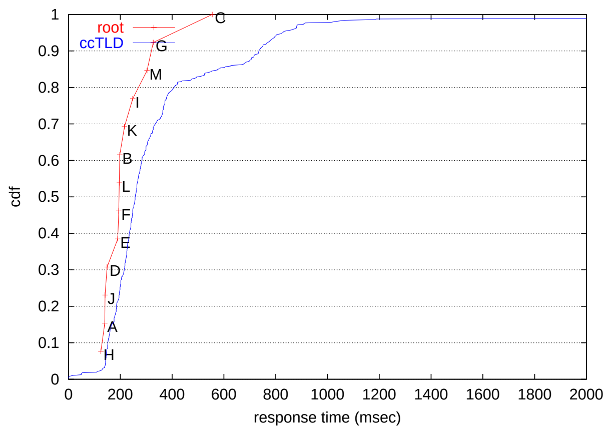
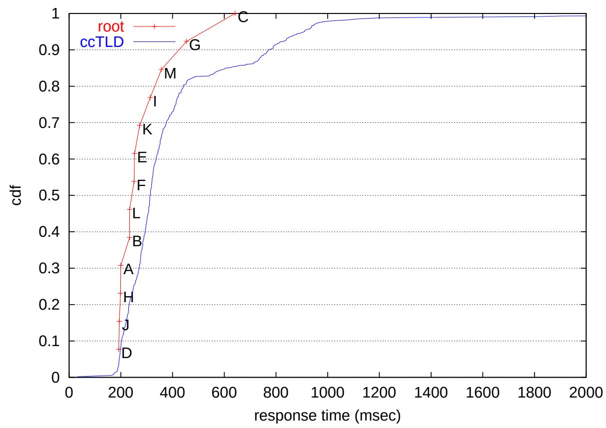


dialup, Salvador, Brazil

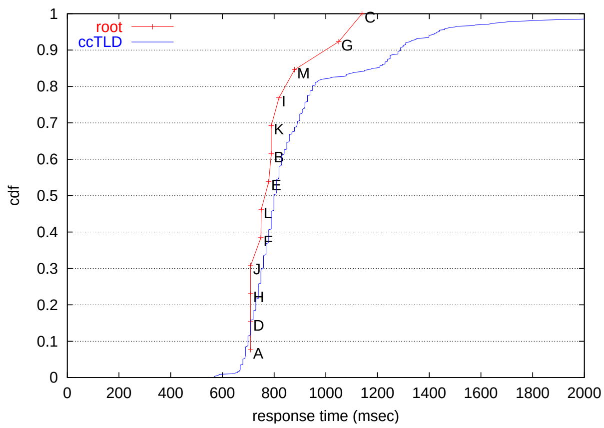
Fig. 18. median response time of root and ccTLD DNS servers (3/4)



data center, Sao Paulo, Brazil



home, Buenos Aires, Argentina



dialup, Talca, Chile

Fig. 19. median response time of root and ccTLD DNS servers (4/4)