History of the Root Server System

A Report from the ICANN Root Server System Advisory Committee (RSSAC)
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Preface

This is a Report to the Internet community from the ICANN Root Server System Advisory Committee (RSSAC). In this Report, the RSSAC provides an overview of the organizational history of the root server system.

The RSSAC advises the Internet community and ICANN Board of Directors on matters relating to the operation, administration, security, and integrity of the Internet's Root Server System. This includes communicating with the technical and ICANN communities on matters relating to the operation of the root servers and their multiple instances, gathering and articulating requirements to offer to those engaged in technical revisions of the protocols and best common practices related to the operation of DNS servers, engaging in ongoing threat assessment and risk analysis of the Root Server System, and recommending any necessary audit activity to assess the current status of root servers and the root zone. The RSSAC has no authority to regulate, enforce, or adjudicate. Those functions belong to others, and the advice offered here should be evaluated on its merit.

A list of the contributors to this Report is at end of this document.

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1. Introduction

The Domain Name System (DNS) is a globally distributed, loosely coherent, scalable, reliable, and dynamic database that provides a look up mechanism for translating objects into other objects (e.g. domain names to IP addresses). The root servers are the entry point to the system, as resolution for the domain name system starts at a root server in the absence of other information.

In recent years, there has been renewed interest in understanding the history and evolution of the root server system. In this report the RSSAC, in collaboration with root server operators, takes on the task of producing a report to inform the community on the current root server system, and its history from beginnings to present day.

The report is organized in the following way. Section 2 describes a chronological history of the root server system from its origin to its current structure. This description is divided into historical periods and also includes key events. Section 3 describes the current operators, and their histories in operating the root service. Finally, based on the histories provided in section 2 and 3, section 4 draws some conclusions.

This report focuses on the social and organizational history of the root server system. Specific technical aspects are covered only when they have an impact on the social and organizational history. Readers will find some technical events missing from this report. Notably absent are the introduction of IPv6 addresses for root servers, the DNSSEC signing of the root zone, the introduction of internationalized top level domain names (IDNs), and the introduction in 2013 of new generic top level domains (gTLDs). These are discussed elsewhere, and did not have a significant impact on how DNS root servers are managed or used. Similarly, this report does not cover the formation and development of the Root Server System Advisory Committee (RSSAC), those will be the subject of a separate effort.

2. History of Root Servers

2.1. Root Servers in Early Days of the DNS (1983 – 1986)

In 1983, Jon Postel and Paul Mockapetris published a series of RFCs that laid out the design of the Domain Name System (DNS) and the transition plan to DNS for the ARPAnet.[1,2]

To test the DNS software and further develop the Domain Name System, Jon Postel and Paul Mockapetris set up the first root server in 1984 at Information Sciences Institute

[1] See RFCs 881, 882 and 883

[2] Although the DNS was officially defined in RFC 881, 882 and 883, significant preparatory work by many contributors influenced its design. Some of these work is documented in RFC 805 and RFC 819.

(ISI) at University of Southern California (USC). The server was running on a PDP-10[3] mainframe computer with software developed by Mockapetris called JEEVES. Since ISI was providing service to the ARPAnet at the time, in 1985 an additional root server was added at ISI to better serve the ARPAnet. In 1985, as the JEEVES software matured, SRI International hosted an additional root server. SRI International at the time was the Network Information Center (NIC) for the Defense Data Network (DDN), responsible for handling the registration of hosts and maintenance of the hosts.txt file.

Doug Kingston and Mike Muuss at the Ballistic Research Laboratory (BRL) in the U.S. Army played an important role in the ongoing development of the Berkeley Internet Name Domain (BIND) package.[4] To assist in the further development of DNS and to provide a root server for MILNET in the event that MILNET[5] had to be disconnected from the ARPAnet, BRL volunteered in 1985 to host a root server,[6] making it the first root server running BIND on a Unix operating system.

Thus by 1985, there were four root name servers, listed below in Table 1.

Table 1: List of Root Servers in 1985[7,8]

Name	IP Address	Software	Organization
SRI-NIC	10.0.0.51 26.0.0.73	JEEVES	SRI International
ISIB[9]	10.3.0.52	JEEVES	Information Sciences Institute, University of Southern California
ISIC	10.0.0.52	JEEVES	Information Sciences Institute, University of Southern California
BRL-AOS	192.5.25.82 128.20.1.2	BIND	Ballistic Research Laboratory, US Army

[3] Interview with Paul Mockapetris, 13 August 2015.
[4] The Berkley Internet Name Domain (BIND) package was originally written for the BSD UNIX operating system as a Berkeley graduate student project under a grant from DARPA. Mike Karels at University of California Berkeley maintained the code. Doug Kingston and Mike Muuss at Ballistic Research Laboratory (BRL) later contributed significantly to the development of BIND.
[5] The MILNET, which was split from the original ARPANET in 1983, is the operational, unclassified network component of the Department of Defense Network.
[6] See http://marc.info/?l=namedroppers&m=95837667426459&w=2.
[7] See http://www.donelan.com/dnstimeline.html.
[8] See http://marc.info/?l=namedroppers&m=95837667426588&w=2
[9] As DNS was at an early stages of development, root name servers at ISI tended to change machines frequently. In November 1986 ISIB was retired, and replaced by another server named ISIA. In October 1987, ISIC (C.ISI.EDU) was retired as well.

When the Domain Name System drafts were first circulated for discussion, there was widespread agreement in the ARPAnet community[10] that it was a promising solution to address the bottleneck of maintaining and distributing the hosts.txt file. Thus, Postel laid out a timeline and plan in RFC 881 for the ARPAnet to transition to the Domain Name System. Although the plan was delayed due to the introduction of TLDs, and was subsequently revised in RFC 897 and RFC 921, the transition did happen. By March 1987, SRI-NIC was named SRI-NIC.ARPA, ISIC was named C.ISI.EDU, BRL-AOS was named BRL-AOS.ARPA, and ISIA was named A.ISI.EDU.[11]

2.2. Expanding Root Service for MILNET and NSFNET (1986 – 1990)

In 1986, with the ARPAnet transition to domain names well underway, attention turned to MILNET's[12] transition. In October 1986, at the IETF 6 meeting, a workshop on "Name Domains for MILNET" was convened by Doug Kingston from BRL.[13] The primary focus was to explore the transition to Domains in the MILNET. The group proposed a three-step transition for MILNET: (1) Deploy root servers across MILNET, and remove non-Domain names from the host table; (2) Assist MILNET in installing standard resolvers and servers then serve only domain-style names (3) ensure the NIC no longer supports the host table.

During the workshop and also in mailing list discussions afterwards, Gunter Air Force Station was mentioned as a possible root server location because of its ability to serve MILNET.[14] Eventually GUNTER-ADAM was added as a root server in November 1987.

In 1986, NSFNET went online. Built as a "network of networks" and developed in phases, NSFNET connected supercomputer centers in the U.S. and a variety of regional research and education networks, extending the Internet's reach throughout the United States.[15]

As NSFNet traffic and registrations grew, some cases of poor DNS service due to the limited number and reach of root servers came to people's attention. To address this issue, in July 1987, at the IETF 7 meeting, the name domain planning working group held a one-hour session to discuss root servers.[16] Attendees included Doug Kingston (Ballistic Research Laboratory), Walt Lzaear (MITRE), Mark Lottor (SRI International), Louis Mamakos (University of Maryland), Mary Stahl (SRI International), Steve Wolff

[10] Interview with Paul Mockapetris, 13 August 2015.
[11] See https://www.ietf.org/rfc/rfc1033.txt
[12] The MILNET was split from the original ARPANET in 1983, as the operational, unclassified network component of the Department of Defense Network (DDN), while ARPANET remained an advanced network R&D test bed for DARPA.
[13] See IETF 6 Proceedings: http://www.ietf.org/proceedings/06.pdf.
[14] See http://marc.info/?l=namedroppers&m=95837759026807&w=2
[15] See http://www.nsf.gov/od/lpa/news/03/fsnsf_internet.htm.
[16] See IETF 7 Proceedings: http://www.ietf.org/proceedings/07.pdf.

(National Science Foundation), Marty Schoffstall (Rensselaer Polytechnic Institute), Hans-Werner Braun, and a few others. The goal of the meeting was to select root servers that would provide improved service to the NSFNET. The participants discussed and agreed on three new nameservers.
These were:

- University of Maryland, chosen in large part because it was in a position to service the NSFNET, ARPANET, MILNET and SURANET all equally well.
- NASA Ames, chosen because it was an ideal location due to its connection to MILNET, ARPANET, NASA-SCINET, NSFNET and BARRNET.
- Rensselaer Polytechnic Institute, which was part of the New York State Education and Research Network. It was also one of the first Internet Service Providers in the United States.[17]

These locations, in addition to GUNTER ADAM (US Air Force Networking Group) were chosen, and servers were expected to be operational by IETF 8.

In November 1987, C.ISI.EDU was retired from root server duty. As agreed, four additional root servers were added. Their IP addresses, software and organizations are listed in the table below.

Table 2: List of Root Servers in Nov 1987[18]

Name	IP Address	Software	Organization
SRI-NIC.ARPA	10.0.0.51 26.0.0.73	JEEVES	SRI International
A.ISI.EDU	26.2.0.103	JEEVES	Information Sciences Institute
C.NYSER.NET	128.213.5.17	BIND	RPI
TERP.UMD.EDU	10.1.0.17 128.8.10.90	BIND	University of Maryland
GUNTER-ADAM.ARPA	26.1.0.13	JEEVES	U.S. Air Force Networking Group
NS.NASA.GOV	128.102.16.10	BIND	NASA Ames
BRL-AOS.ARPA	192.5.25.82 128.20.1.2	BIND	Ballistic Research Laboratory, US Army

[17] see http://www.rpi.edu/dept/NewsComm/Magazine/Sep00/Pioneers.html.
[18] See http://marc.info/?l=namedroppers&m=95837781927013&w=2

In November 1988, DDN implemented phase two of the MILNET Domain Name Implementation with DDN MGT Bulletin 42.[19] As a result, SRI-NIC.ARPA was renamed to NIC.DDN.MIL, BRL-AOS.ARPA was renamed to AOS.BRL.MIL, and GUNTER-ADAM.ARPA was renamed to GUNTER-ADAM.AF.MIL.[20,21]

In April 1990, as part of phasing out the ARPAnet DDN issued Management Bulletin 72 that announced the following changes:[22]

- The new address for host NIC.DDN.MIL would be 192.67.67.20.
- The old ARPAnet address for the NIC, 10.0.0.51 would be discontinued on 1 June 1990, the old MILNET address for the NIC, 26.0.0.73 would be discontinued on 1 June 1990.
- The NIC's root domain name would run on a new host, NS.NIC.DDN.MIL at address 192.67.67.53. The old server, running on NIC.DDN.MIL, would be discontinued on 1 June 1990.

Thus, by November 1990, there were 7 root servers, listed in Table 3 below.

Table 3: List of Root Servers in November 1990[23]

Original Name	New Name	IP Address	Organization
SRI-NIC.ARPA	NS.NIC.DDN.MIL	192.67.67.53	SRI International
A.ISI.EDU	A.ISI.EDU	26.2.0.103 128.9.0.107	Information Sciences Institute
C.NYSER.NET	C.NYSER.NET	192.33.4.12	RPI
TERP.UMD.EDU	TERP.UMD.EDU	128.8.10.90	University of Maryland
GUNTER-ADAM.ARPA	GUNTER-ADAM.AF.MIL	26.1.0.13	U.S. Air Force Networking Group
NS.NASA.GOV	NS.NASA.GOV	128.102.16.10 192.52.195.10	NASA Ames Research Center
BRL-AOS.ARPA	AOS.BRL.MIL	192.5.25.82 128.20.1.2	Ballistic Research Laboratory, US Army

[19] See http://marc.info/?l=namedroppers&m=95837806326964&w=2
[20] See https://github.com/sergev/4.4BSD-Lite2/blob/master/etc/namedb/root.cache
[21] See http://marc.info/?l=namedroppers&m=95837784627013&w=2
[22] See DDN MGTM Bulletin 72, http://marc.info/?l=namedroppers&m=95837797326928&w=2
[23] See http://cd.textfiles.com/internetinfo/inet/ddn-news/ddn-mgt-bulletin-72.txt

2.3. Expanding Root Service Outside North America (1991)

As the Internet in Europe developed in the late 1980s, there was an increasing need to have one or more root name servers in Europe to reduce the dependency on the few, expensive, and unstable Internet links to the USA. At RIPE 1 on 22 May 1989 this issue was discussed.[24] The list of sites mentioned as possible root server hosts included: the Royal Institute of Technology (KTH, the technical university) in Stockholm, Sweden; Centrum Wiskunde & Informatica (CWI, the national research institute for mathematics and computer science), in Amsterdam, The Netherlands; and Conseil Européen pour la Recherche Nucléaire (CERN, the European physics research centre) in Geneva, Switzerland/France.

At the time, the network operations center at the Royal Institute of Technology (later named the KTHNOC) operated three major networks in the area: the Swedish University Network (SUNET), the Swedish academic network, and the Nordic University Network (NORDUnet) connecting SUNET to its siblings in the other Nordic countries. Due to early adoption of the TCP/IP protocol suite in the Nordic region, NORDUnet was a very large "patch" on the European Internet map, and serviced a large number of European users. The KTHNOC also managed domain names for Sweden (.SE), and IP allocations for users in Sweden and within NORDUnet.

KTH/NORDUnet turned out to be a favorable location to host a root service because:

- NORDUnet was the first international wide-area multi-protocol network in the world, supporting TCP/IP, X.25, NJE of EARN, and DECnet protocols. The adoption of TCP/IP by NORDUnet allowed it to connect with the U.S Internet seamlessly.
- NORDUnet was one of the very few European networks to get a connection to the U.S Internet. Via a 56 kbit/s satellite link to the John Von Neumann Center in Princeton, New Jersey, NORDUnet was connected to the U.S Internet in 1988.[25]
- NORDUnet had good connectivity to the rest of the Europe (EUnet, CERN).
- The staff operating NORDUnet had experience from operating DNS services for other high-profile domains, e.g., the national TLD for Sweden.

On July 28, 1991, the server NIC.NORDU.NET was added to the root zone and became the first non-US root server.

[24] See https://www.ripe.net/participate/meetings/ripe-meetings/ripe-1
[25] See http://www.nordu.net/history/TheHistoryOfNordunet_simple.pdf

2.4. DDN-NIC Changes to Network Solutions (1991 - 1992)

In 1991, the Defense Information Systems Agency awarded the NIC contract to Government Systems, Inc. (GSI), it in turn outsourced the contract to Network Solutions, Inc. (NSI). A few changes happened:[26]

- The root server ns.nic.ddn.mil changed from 192.67.67.53 to 192.112.36.4.
- A.ISI.EDU was retired, and a new root server KAVA.NISC.SRI.COM would run at address 192.33.33.24, and take the place of A.ISI.EDU.

The list of root servers as of October 1991 is listed in the table below.

Table 4: List of Root Servers in Oct 1991

Name	IP Address	Organization
NS.NIC.DDN.MIL	192.112.36.4	Network Solutions, Inc.
KAVA.NISC.SRI.COM	192.33.33.24	SRI International
C.NYSER.NET	192.33.4.12	NYSERnet
TERP.UMD.EDU	128.8.10.90	University of Maryland
NS.NASA.GOV	128.102.16.10 192.52.195.10	NASA Ames Research Center
NIC.NORDU.NET	192.36.148.17	NORDUnet
AOS.BRL.MIL	192.5.25.82	Ballistic Research Laboratory, US Army

2.5. InterNIC (1993)

Since the 1980s, the registration of domain names was performed by the DDN-NIC under contract by the Department of Defense. This was because most registrants were military users and awardees. By the early 1990s, due to the rapid growth of the NSFNET, academic institutions comprised the majority of new registrations, and the military was no longer willing to fund the registration for these names. The U.S. Federal Networking Council (a group of government U.S. agencies involved in networking) asked the National Science Foundation (NSF) to assume responsibility for non-military Internet registration.[27]

[26] See http://marc.info/?l=namedroppers&m=95837800227020&w=2
[27] See http://www.nsf.gov/od/lpa/news/03/fsnsf_internet.htm

In 1992, after a solicitation process (NSF 9224), [28] the NSF awarded three five-year cooperative agreements, to American Telephone and Telegraph Company (AT&T), General Atomics (GA), and Network Solutions, Inc. (NSI). The contracted parties were to provide directory and database services, information services, and non-military registration services, respectively. These companies adopted the name InterNIC for their joint role.

Around the time Network Solutions won the bid to manage the domain registration service, it asked Jon Postel (IANA) about adding ns.internic.net as a root name server.[29] Postel agreed and IANA added ns.internic.net as a root server in April 1993, with IP address 198.41.0.4.

In May 1994, KAVA.NISC.SRI.COM at SRI International was retired due to lack of funding, and NS1.ISI.EDU was added as a root server to replace it.[30]

In 1994, Paul Vixie and Rick Adams asked Jon Postel (IANA) on behalf of Internet Software Consortium (ISC) to add a root server at ISC. Postel agreed and IANA added NS.ISC.ORG in September 1994 as a root server. ISC is the organization coordinating the ongoing development and distribution of the most used name server software, BIND, after taking over responsibility for BIND from Digital Equipment Corporation.

In October 1994, C.NYSER.NET changed to C.PSI.NET,[31] as part of the commercialization of the Internet Service Provider (ISP).[32] In 1995, PSINet was listed on NASDAQ as PSIX, becoming the first commercial ISP to go public.

2.6. Renaming Root Servers to root-servers.net (1995)

By April 1993, the number of root name servers had grown to an extent where the size of a root hints response was approaching the limit of 512 bytes. Bill Manning and Paul Vixie developed a plan to rename all root servers under the root-servers.net domain. This would allow the use of DNS label compression to fit all the names within 512 bytes. Postel (IANA) agreed with the plan and Mark Kosters began the renaming phases in 1995. Table 5 below lists this renaming.

[28] See http://www.nsf.gov/pubs/stis1992/nsf9224/nsf9224.txt.
[29] Interview with Mark Kosters.
[30] See http://marc.info/?l=namedroppers&m=95837825027198&w=2
[31] See http://marc.info/?l=namedroppers&m=95837827527231&w=2
[32] Although C.NYSER.NET changed to C.PSI.NET in 1994. The actual transition might have happened earlier. By one account, in late 1989, PSI acquired NYSERNet assets and established an ongoing outsourcing contract with NYSERNet. This acquisition gave PSINet commercial access to what would come to be known as the Internet. It is unclear whether the root server operated by NYSERNet was part of this transaction.

Table 5: Renaming of Root Servers in 1995

Original Name	New Name	Organization
NS.INTERNIC.NET	A.ROOT-SERVERS.NET	InterNIC (operated by NSI)
NS1.ISI.EDU	B.ROOT-SERVERS.NET	Information Sciences Institute
C.PSI.NET	C.ROOT-SERVERS.NET	PSINet
TERP.UMD.EDU	D.ROOT-SERVERS.NET	University of Maryland
NS.NASA.GOV	E.ROOT-SERVERS.NET	NASA Ames Research Center
NS.ISC.ORG	F.ROOT-SERVERS.NET	Internet Software Consortium (ISC)
NS.NIC.DDN.MIL	G.ROOT-SERVERS.NET	GSI (operated by NSI)
AOS.ARL.ARMY.MIL	H.ROOT-SERVERS.NET	Army Research Lab (ARL)
NIC.NORDU.NET	I.ROOT-SERVERS.NET	NORDUnet

At the time, each letter identified a particular server machine. Today each letter identifies a single IPv4 address and, in most cases, a single IPv6 address at which the service is provided under the responsibility of a single root server operator.

2.7. Adding Root Letters J, K, L and M

By moving to root-servers.net, operators were able to take advantage of DNS label compression, leaving room for four additional root servers to fit within a 512 byte DNS response. In January 1997, servers J-Root, K-Root, L-Root, and M-Root, were added serving exclusively the root zone. Postel (IANA) asked Network Solutions Inc. to set up two additional servers with the intention to move them to suitable operators quickly thereafter, and kept two more servers at USC-ISI with the same intentions. J-Root and K-Root were set up at Network Solutions on the US East Coast, while L-Root and M-Root were at USC ISI on the US West Coast.

From interviews, it appears that Jon Postel developed and used a few simple criteria in selecting organizations to host these new servers:[33]

[33] Interview with Bill Manning, Suzanne Woolf. August 2015

- *Need:* The need for root server service. At the time, Europe had one operator. As the European Internet developed another root server would be useful. There were also no root servers in Asia, so clearly a root server there was needed. The primary tool that Postel used to determine the need was Larry Landweber's International Connectivity Map.[34]
- *Connectivity*: The potential operator must have good connectivity both to the internal infrastructure[35] (internal connectivity), and to the world (external connectivity).
- *Community consensus:* The potential operator should demonstrate the widest possible support from the community being served.
- *Commitment to send and respond to traffic without filtering.* The operator must be able to answer every DNS query and send responses back unfiltered.

For the European region, a number of parties expressed their willingness to operate a second root name server. Jon Postel (IANA) encouraged all parties to seek consensus about the matter. After thorough discussion there was consensus that the RIPE NCC was the appropriate organization to operate the server because of its neutrality and technical expertise. In particular the RIPE NCC was understood to be able to flexibly change the server's deployment following changes in Internet topology.[36]

In the Asia Pacific Region, the Widely Integrated Distributed Environment (WIDE) organization was chosen. These selections provided additional organizational diversity in the operation of root servers. Operators now included educational institutions, governments, commercial companies and not-for-profit service organizations.

In May 1997, K-Root (K.ROOT-SERVERS.NET) moved to London LINX managed by RIPE NCC. In August 1997, M-Root (M.ROOT-SERVERS.NET) moved to Japan managed by WIDE.

2.8. Root Server Meeting and Planning After Postel's Death

With K-Root and M-Root assigned, there still remained two additional root servers to be assigned. Unfortunately, Jon Postel died on October 16, 1998, and there was no one to drive the process to assign these additional root servers. J-Root stayed with NSI and remained with Verisign who had acquired Network Solutions in 2000.

[34] See http://pages.cs.wisc.edu/~lhl/maps/
[35] For example, connectivity within the country, within the region or within certain geography.
[36] At the time all deployments were unicast. The RIPE DNS working group suggested deploying near or at one of the existing open exchange points. Consequently, the first deployment was at the LINX in London. The LINX contributed hosting and local hands, while the RIPE NCC provided the hardware and covered operations. This choice re-emphasized the independence of the location of the operator and the server itself. This was followed shortly thereafter by deployment of a hot stand-by at the AMS-IX.

Prior to Postel's death, it was planned that USC would transfer certain responsibilities, assets, and personnel to ICANN. In 1999, this transfer occurred, which included L-Root.

The root server operators met for the first time as a formal group in December 1998 at IETF 43, shortly after Postel's death. They agreed to the following principles:

- Operate reliably, for the common good of the Internet
- IANA as the source of the root data,
- Sufficient investment to operate responsibly,
- Proper notice and commitment to facilitate transition when needed, and
- Recognize the other root server operators.

Several root server operators eventually produced similar statements that operationalized these principles. (e.g. B-root,[37] C-Root[38]).

The root sever operators also agreed to meet regularly as a group (root ops) to share information about root server operations, and to provide the Internet community more information about the operation of the root servers. To this end, a website was eventually created listing all the operators, their operation information, and their news.[39] The root ops group has been meeting regularly at IETF meetings till this day.

3. Current Root Server Operators and Organization Histories

This section, provided by individual root server operators, contains statements that describe the current operators, their histories in operating the root service, and what they see as major commitments for operation of the root service. The information provided is included verbatim.

3.1. A-Root

Verisign operates A-Root (A.ROOT-SERVERS.NET), one of the 13 logical Internet Root name servers. Verisign cooperates with the eleven other Root Server Operators to provide authoritative data for the DNS Root Zone.

Verisign, a global leader in domain names and Internet security, enables Internet navigation for many of the world's most recognized domain names and provides protection for websites and enterprises around the world. Verisign ensures the security,

[37] See http://www.isi.edu/b-root/ (This is a version from USC/ISI.)
[38] See http://c.root-servers.org/
[39] See http://www.root-servers.org/.

stability and resiliency of key Internet infrastructure and services, including the .com and .net domains and two of the Internet's root servers, as well as performs the root-zone maintainer functions for the core of the Internet's Domain Name System (DNS). Verisign's Security Services include intelligence-driven Distributed Denial of Service Protection, iDefense Security Intelligence and Managed DNS.

Verisign views major obligations of being a Root Server Operator to be:

- Operate A-Root and J-Root in a manner that exceeds all RFCs and advice from related committees
- Serve the IANA root zone as distributed to Verisign from the root zone maintainer without modification
- Always serve up-to-date data on our root servers
- Meet ever-increasing demand by constantly improving performance, capacity, and resiliency.
- Target capacity capabilities to accommodate 10x, 100x, 1000x regular peak DoS attacks
- Worldwide deployment strategy to enable enough coverage and capacity to sustain worldwide demand when needed.

Significant events and milestones for A-Root include:

Prior to the development of the Domain Name System, domain names and IP addresses were allocated by the "Network Information Center" (NIC) at the SRI International. When DNS was initially proposed in the early 1980's, SRI International operated one of three initial root name servers. There were only four root name servers until late 1987.

In 1991, the Defense Information Systems Agency awarded the NIC contract to Government Systems, Inc. (GSI). GSI created a contract with Network Solutions, Inc. (NSI) to run the NIC.

In 1993, NSI added NS.INTERNIC.NET as a root name server, with IP address 198.41.0.4. That same year its network connection was upgraded from 56K to T1 (1.5 Mbps).

By late 1993 the number of root name servers had grown to an extent that the size of a "root hints" response was approaching the limit of 512 bytes. A plan was formed to rename all root servers under the ROOT-SERVERS.NET domain and NS.INTERNIC.NET was renamed to A.ROOT-SERVERS.NET in September 1995.

In 2000, Network Solutions, Inc. was acquired by Verisign.

In 2008, A-Root became a distributed service utilizing IP anycast.

In 2008, the IPv6 address 2001:503:ba3e::2:30 was added for A-Root.

3.2. B-Root

B-Root is operated by the University of Southern California, a research university with a long history of Internet development and operations. It is operated jointly by the USC/Information Sciences Institute and USC/Information Technology Services under the direction of the Computer Networks Division at USC/ISI.

USC has operated B-Root since the inception of the root service system, when Jon Postel selected USC as an initial site. At the time, USC was leading definition of DNS standards and was providing the IANA and RFC Editor functions; USC's operational participation accompanied those activities.

B-Root currently operates at a single site, providing root DNS service on the 192.228.79.201(IPv4) and 2001:500:84::b (IPv6), with load shared across multiple back-end computers. We operate with commodity load balancing and run Linux and BIND for our OS and server software. Through USC, B peers with a number of regional and national networks.

USC is expecting to bring up a second site by the end of 2016. It expects to continue to operate with a relatively few sites, with an operational focus on supporting research and educational networks.

As a Root Server Operator, B-Root is committed to serving the root zone reliably as one of the 12 organizations and participating in relevant coordination activities. In addition, as an academic organization, USC hopes that it˜s operation of B may foster collaboration between research and academia with operations.

3.3. C-Root

Cogent Communications operates C.ROOT-SERVERS.NET as a public service to the Internet. First operational in 1987, C.ROOT-SERVERS.NET was known as C.NYSER.NET and was established at the request of the Internet Assigned Numbers Authority (IANA).

In 1994, C.NYSER.NET became C.PSI.NET. PSINet, the first commercial ISP ever established, was operating the server when the root name server system started using the root-servers.net domain and thus became C.ROOT-SERVERS.NET.

In 2002, Cogent Communications acquired PSINet's major U.S assets, which included responsibility for operation of C.ROOT-SERVERS.NET. To promote the vital development of global social and economic infrastructure, Cogent Communications has committed to the safe, reliable and secure operation of the root server for the benefit of

the entire Internet. Instances of C.ROOT-SERVERS.NET are located in several locations throughout the United States and Europe.

3.4. D-Root

The D Root Server is operated by Advanced Cyber-Infrastructure Innovation Initiatives and Internet Global Services group at the University of Maryland, College Park, a public state university.

The University of Maryland was active in the early days of DNS. During the July 27-29, 1987 IETF, the Name Domain Planning working group met. From the Working Group Report of that meeting, the following was recorded:

> On the second day we held a one-hour meeting with a wider attendance to discuss root domain servers. In addition to the earlier attendees, we also had Steve Wolff (NSF), Marty Schoffstall (RPI) Hans-Werner Braun, and a few others. The impetus for this was the poor root nameserver service available on NSFNET and one goal of this meeting was to get some nameservers established that would provide good service to the NSFNET. We discussed and finally agreed on three new nameservers. Maryland and RPI were chosen fairly early on. Maryland was chosen in large part because it is in a position to service NSFNET, ARPANET, MILNET, and SURANET all equally well. After a bit more discussion we nominated NASA Ames and the third in absentia. Ames is an ideal location due to its connection to MILNET, ARPANET, NASA-Sci-Net, NSFNET?, and BARRNET?. Milo already had one of everything else, so he was happy to take on a root nameserver too. These three servers and the server at Gunter Adam are expected to be fully operation by the next IETF meeting.

Significant events and milestones for D root include:

On October 21, 2002, there was a massive DDOS attack on the Root name servers. Gerry Sneeringer of the University of Maryland co-authored an analysis report of that event with Paul Vixie (of ISC) and Mark Schleifer (of Cogent).[40]

In June 2011, D-Root started IPv6 support.

In January 2013, in anticipation of moving to anycasting, D-Root was transitioned from its original UMD local IP address 128.8.10.90 (also once known as TERP.UMD.EDU) to the current address 199.7.91.13.

On April 3, 2013, UMD partnered with Packet Clearing House (PCH) to provide expanded anycasting opportunities using server and network facilities in their various data centers around the world.

[40] See the Report at http://d.root-servers.org/october21.txt.

Current D-Root anycast the 199.7.91.13 address at 69 sites for a total number of 140 instances. The servers currently run BIND, but it is considering alternatives.

Over the years, D-Root's operation has been headed by:

1987-1993	Louie Mamakos
1993-2011	Gerry Sneeringer
2011-2014	Jason Castonguay
2014-	Bruce Crabill

Additional support has been provided by Karl Reuss (Senior DNS Advisor 1999-Present) and Robel Regassa (2011-2014).

D-Root has been involved with RSSAC with Gerry Sneeringer and Jason Castonguay attending the RSSAC meeting in 2011. From 2013-2014 our RSSAC representative was Tim Shortall. In 2014 Tripti Sinha took over the RSSAC representative role and Gerry Sneeringer was appointed the alternate representative.

3.5. E-Root

E-Root is operated by National Aeronautics and Space Administration (NASA) Ames Research Center (ARC). ARC, located in the heart of California's Silicon Valley, is one of ten NASA field enters. For more than 75 years, ARC has led NASA in conducting world-class research and development in aeronautics, exploration technology and science aligned with the center's core capabilities. Below are additional organizational details on the staff that manages and operates E-Root:

- NASA (US Federal Government Agency)
- Ames Research Center (located in Silicon Valley)
- Code I (Ames Chief Information Office)
- Code IO (IT Operations Division)

In the late 1980s, NASA ARC was involved in creating networks (e.g. NASA Science Internet, Space Physics Analysis Network) in national and international universities and research institutions. The root server expansion to eight root servers was driven by the fact the growth of NSFnet required more resources. In 1987, NASA received ns.nasa.gov primarily because it had direct connections to the universities, research institutions and other networks. Specifically, these included MILNET, ARPANET, NASA-SCINET, NSFNET and BARRNET. The Federal Internet eXchange West (FIX-WEST) was implemented during this time as well.

Milo Medin, Jon Postel and Elise Gerich discussed Ames's role in deploying the root name server as NASA Ames Research Center was developing and operating the NASA Science Internet (NSI) and the first Internet Exchange. NSI was a leader in IETF and

Milo was a major force behind the design and implementation of border gateway protocols.

Significant events and milestones for E-Root include:

1988 – The NASA Science Internet (NSI) program was established as a multivendor, integrated approach to building an internetworking infrastructure and services for the NASA Space Sciences community worldwide. The NSI program office was established at NASA ARC. This was a critical step forward in the evolution of networking as NSI lead the creation of the Internet with the development and operational support of the first Federal Internet Exchange (FIX, originally called FEBA).

1991 – The National Research and Education Network (NREN) led the charge in the development of high-speed networking in response the needs of the Federal supercomputing community. NASA ARC was the program office for NASA NREN.

1997 – NASA ARC leads the Federal Government Joint Engineering Team in developing the Next Generation Internet (NGI) technologies, speeds and applications in support of national goals and missions.

2011 – NASA establishes a non-reimbursable space act agreement with Packet Clearing House to enable anycasting of E-Root

2012 – NASA acquires an AS and IPv6 addresses for E-Root from ARIN.

2013-2014 – The three people that were the leads for supporting E-Root left the agency

2014-2015 – Three new leads for supporting E-Root were identified

Currently, E-Root operates at one core site with 91 anycast instances around the world. The servers are running BIND on FreeBSD. NASA ARC views its major obligation as a root server operator to be operating critical Internet infrastructure for the world. Specifically, adhering to the recently clearly defined guidance provided in the RSSAC documents (e.g. RSSAC001 and RSSAC002) and engaging in the Internet community.

3.6. F-Root

F-Root is operated by Internet Systems Consortium (ISC).[41]

Internet Systems Consortium (ISC) is a 501(c)3 public benefit corporation. Founded in 1994 under an initial grant from UUNET, ISC is governed today by a five-member Board of Directors. ISC software, of which BIND and ISC DHCP are the two best‐known

[41] In 1994 when ISC first began to run a root name server, the company name was Internet Software Consortium. it was later changed to Internet Systems Consortium.

examples, is open source. ISC is supported by donations from sponsors, by program membership fees, and by increasing revenues from DNSco, a for-profit subsidiary.[42]

ISC has operated F-Root for IANA since 1994. F-Root currently answers queries over IPv4 on 192.5.5.241, and over IPv6 on 2001:500:2f::f using a hierarchical anycast technique and BIND 9 software.

Significant events include:

In 2002, F-Root became the first root server to be anycasted internationally (Madrid was first outside of Palo Alto).[43] F-Root was also the first to use local area OSPF ECMP for load balancing across multiple physical servers.

On January 4th, 2008, ISC became the first root server operator to sign a Mutual Responsibilities Agreement[44] with ICANN.

In 2008, ISC F-Root's ipv6 address was changed, about three months after it first started using an ipv6 address, due to the need for a shorter BGP prefix.

3.7. G-Root

G-Root is operated by the US Department of Defense Network Information Center (NIC). Based in Columbus, Ohio, DISA IE72 assumed control of the DoD NIC mission in 2005. This mission includes managing the G-Root, serving as the Internet registry for DoD, and providing .mil registry/registrar services.

The DoD NIC provides 24x7 support and consists of 23 civilian government employees, and one government contractor. Its major focus as a root server operator is to provide consistently reliable access and 100% availability to the G-Root anycast system, which serves the IANA authorized root zone.

Significant events and milestones for G-Root include:

Mid-1980s - G-Root can be traced back to an SRI-NIC server at address 26.0.0.73.

1990 - Service at 26.0.0.73 ends, and is replaced by a server at 192.67.67.53 (called ns.nic.ddn.mil)

1991 - Root server ns.nic.ddn.mil changed address to 192.112.36.4; in conjunction with transferring the DDN NIC management contract from SRI International to GSI.

1995 - Changed name to G.ROOT-SERVERS.NET

[42] For further information, please visit https://www.isc.org/supportisc.
[43] See https://www.nanog.org/meetings/nanog27/presentations/suzanne.pdf
[44] See http://archive.icann.org/en/froot/ICANN-ISC-MRA-26dec07.pdf.

1995 - DDN NIC changed name to DoD NIC

Mid-1990s - contract to manage the DoD NIC (which includes the G-Root) is transferred from GSI to SAIC

2005 - DoD NIC operations and management transferred from SAIC to a DISA civilian-staffed government office in Columbus, Ohio

2006 - The .mil zone is removed from the root servers that had been providing authoritative support (A, B, E, F, G, and H).

2008 - Anycast implemented for G-Root at six locations.

3.8. H-Root

The United States Army Research Laboratory (ARL), formerly known as the Ballistics Research Laboratory (BRL), has a long history of being a leader in the computing and networking arenas. BRL was the home of the world's first electronic digital computer, ENIAC, and one of the first 50 sites to have a web server on the Internet. Many BRL/ARL researchers were involved in the early development of UNIX, the Internet, and TCP/IP protocols (including DNS). BRL was one of the first and one of the most well connected nodes on the ARPANET/MILNET back in the late 70s and early 80s. As such, BRL volunteered to host one of the original root servers—both to assist in the further development of DNS and to provide a root server for the MILNET in the event that MILNET had to be disconnected from the Internet. Currently, ARL is home to one of the world's largest supercomputing facilities and resides on the high-speed Defense Research and Engineering Network (DREN), which ARL scientists helped design. To this day, ARL continues to operate a root name server as a service to the Internet community.

Notes of interest:

BRL sponsored the development and was the home of the ENIAC. Until May 23, 2013, the H-Root server was located in the same building as ENIAC.

Mike Muuss,[45] author of the ping utility, and Doug Kingston, both BRL employees, were involved in early BIND development.[46] They were instrumental in establishing a root server at BRL/ARL and were two of the original operators.

Today, ARL operates one of the five U.S. Department of Defense supercomputing centers (http://www.arl.hpc.mil).

Significant events and milestones for H-Root include:

[45] See https://en.wikipedia.org/wiki/Mike_Muuss.
[46] See http://web.archive.org/web/20081118071434/https://www.isc.org/software/bind/history.

1985 - BRL-AOS (aos.brl.mil) added as one of the first four root servers and the first one to be running BIND (released on April 1, 1985). It was a VAX-11/780 (5 MHz) and its IP addresses were 192.5.25.82 and 128.20.1.2.

Before November 1991 - 26.3.0.29 address added to AOS

Before November 1991 - 128.63.4.82 address added to AOS

After November 1992, before May 1994 - 128.20.1.2 address removed from AOS

After March 1993, before May 1994 - 26.3.0.29 address removed from AOS

1992 - U.S. Army's Ballistic Research Laboratory (BRL) incorporated into the newly established Army Research Laboratory (ARL), BRL is dissolved

1994, 3 April - aos.brl.mil renamed to aos.arl.army.mil

1995 – AOS (VAX-11/780) replaced with a Sun Sparc 5 (70/85/110 MHz)

1995, 18 August - aos.arl.army.mil renamed to H.ROOT-SERVERS.NET. IP changed from 128.63.4.82/192.5.25.82 to 128.63.2.53.

1998, August - H transitions from Sun Sparc5 to 168-MHz Sun Ultra-2

~2000 - .com, .net, and .org zones removed from H

2001, 10 June - H transitions from 168-MHz Sun Sparc5 running Solaris to a 1.2 GHz Intel system running Linux

2002, 9 December - IPv6 support added to H at address 2001:500:1::803f:235 (no AAAA's added to root zone until 2008)

2002, 9 December - H load balanced across multiple nodes (IPv4 only)

2003, 10 November - One instance of H converted from BIND to NSD

2004 - All instances of H converted to NSD

2006, 31 October - .mil zone removed from H

2008, 4 February - IPv6 AAAA record for H (along with 5 other root servers) added to the root zone

2010, 14 March - H begins serving DNSSEC signed .arpa zone

2010, 14 April - H begins serving unvalidatable DNSSEC signed root zone

2010, 15 July - all root servers begin serving valid DNSSEC signed root zone

2010, 16 December – hot spare instance brought online at SPAWAR in San Diego

2011, 28 February - H stops serving in-addr.arpa zone

2011, 17 March - IPv6 added to load balancing

2015, 1 December - IP addresses changed to 198.97.190.53 and 2001:500:1::53 in the root and root-servers.net zones.

2016, 1 June - 128.63.2.53 address scheduled to be removed from service.

Currently, H-Root is operated in two sites, primary in Aberdeen Proving Ground, MD and hot spare in San Diego, CA. Each site is load balanced across multiple nodes. All nodes run NSD and support both IPv4 and IPv6.

3.9. I-Root

In a coordinated effort in 1995, all root servers were renamed into one and the same domain. NIC.NORDU.NET's was renamed to i.root-servers.net.

As time progressed, the European Internet was developed. One such step was the advent of Internet exchange points (IXs). One of the first European IXs was established by the networking staff at the KTH in Stockholm.

Networking in the 1990s was infected by hindering traffic policies. NORDUnet, despite having an extremely open traffic policy, ran the risk of being accused of prohibiting traffic to the root name server, and decided to move it, from inside NORDUnet, to its own service provider connected directly to the IX in Stockholm. That way, an independent and totally open peering policy could be set for I-root.

The exchange point was eventually spun off from the KTH to a separate corporate structure created for the purpose, with a foundation (TU-stiftelsen) owning a limited not-for-profit company (Netnod[47]) that operates the service. In the year 2000, Netnod created a subsidiary called Autonomica for the purpose of tying specialist DNS staff closer to the company, and NORDUnet and Autonomica operated in close cooperation to provide the service.

The Internet continued to shift from academic to commercial, and with NORDUnet being focused on its work on the academic side it made sense to shift responsibilities. In 2004 NORDUnet and Autonomica made an agreement, which shifted all practical

[47] Formally, Netnod Internet Exchange i Sverige AB, http://www.netnod.se/

responsibilities to Autonomica, to facilitate administration and financial support for the service. According to the agreement, NORDUnet remains as a last resort, guaranteeing the service in the event of Netnod's demise and inability to provide it.

Eventually Autonomica and Netnod were merged into one and the same company, retaining the Netnod organisation and name. Netnod assumed all responsibilities of Autonomica's, which included the NORDUnet agreement and the operations of I-root.

In an open letter to ICANN in 2009, Netnod-Autonomica affirmed the mutual commitment to coordination of DNS root name service operations, acknowledging that a single, unique DNS root is paramount to the stable operations of the Internet and to ensuring global reachability.[48]

On the technical side, I-Root started back in 1991 as a single Sun 3/50 machine with 4 MB of RAM. It evolved through the 1990s with single server Sun Sparc systems, until, in 1998, PC clones were employed for a few years, shifting over to Digital Equipment Alpha servers, with one operating machine and one hot spare. Eventually Netnod shifted back to PCs in 2002. To further improve robustness and availability of the service, Netnod started to make use of the anycast model in 2003, where servers are deployed at different sites across the entire Internet, still using one and the same IP address. Today (as of November 2015) Netnod operates a worldwide system of more than 50 sites, with local routers, support servers, and traffic analyzers at each site.

Netnod manages a robust constellation of servers around the globe, and intends to further expand the I.ROOT-SERVERS.NET server footprint in the coming years.

Netnod commits to serving complete and unmodified DNS data (including DNSSEC signatures) from the global root zone, exactly as received from the root zone maintainer, to the global Internet community.

3.10. J-Root

Verisign operates J-Root (J.ROOT-SERVERS.NET), one of the thirteen logical Internet Root name servers. Verisign cooperates with the eleven other Root Server Operators to provide authoritative data for the DNS Root Zone.

J-Root receives DNS queries over IPv4 at 192.58.128.30 and over IPv6 at 2001:503:c27::2:30. J-Root uses IP Anycast to provide service from a large number of locations throughout the world, which may change from time to time.

Significant events and milestones for J-Root include:

[48] See http://www.netnod.se/joint-rootserver-statement-icann

In 1997, J.ROOT-SERVERS.NET was added as the 10th root name server. Operated by Network Solutions, it was initially co-located with A-Root and used the IP address 198.41.0.10.

In 2000, Network Solutions, Inc. was acquired by Verisign.

In 2002, J-Root was renumbered to 192.58.128.30, thus allowing it to be anycasted.

In 2008, the IPv6 address 2001:503:c27::2:30 was added for J-Root.

3.11. K-Root

The RIPE NCC operates K.ROOT-SERVERS.NET, one of the 13 Internet root name servers. The K-Root service is provided by a set of distributed nodes using IPv4 and IPv6 anycast. Each node announces prefixes from 193.0.14.0/23 in AS25152. Additionally, some nodes announce prefixes from 2001:7fd::/32 in AS25152. A K-Root node consists of one or more servers running BIND, Knot or NSD.

The RIPE NCC is a not-for-profit membership association under Dutch law. Its membership consists mainly of Internet service providers, telecommunication organizations, and large corporations. Currently there are more than 12,000 members from more than 100 countries. It is governed by its general assembly and Executive Board, and is guided by the RIPE community.

The RIPE NCC has provided root service reliably since 1997, at its members' expense and for the benefit of the Internet as a whole. The RIPE NCC recognizes that a single, unique DNS root is vital to the stable operations of the Internet and to ensure global reachability. We fully share the views expressed by the Internet Architecture Board in RFC 2826.

ICANN establishes global consensus about the content of the root zone, compiles and maintains it, and makes it available to the RIPE NCC and other DNS root name server operators, all in accordance with its governance processes. Through K.ROOT-SERVERS.NET, the RIPE NCC publishes the DNS root zone to Internet users in a non-discriminatory fashion, following the relevant technical standards and best practices, and in accordance with RIPE NCC governance processes.

ICANN and the RIPE NCC have affirmed their mutual commitment to coordination of DNS root name service operations through an open exchange of letters in 2009, acknowledging that a single, unique DNS root is paramount to the stable operations of the Internet and to ensuring global reachability.[49]

RIPE NCC remains committed to these principles, and will continue working to operationalize them, independent of changes to the IANA stewardship.

[49] See https://ripe.net/s/kr2h.

The quality of service of K-Root, and other root name servers, is continuously monitored from thousands of RIPE Atlas probes deployed around the Internet. The RIPE DNSMON service provides analyses of this monitoring for name server operators. All these measurements and analyses are available to the general public.

The RIPE NCC continuously evaluates and evolves the technical implementation of K root in order to provide high quality service to all Internet users with some emphasis on the RIPE region. The service is continuously augmented to meet peak loads and provide continuous service while under attack.

Resources:

General information about the RIPE NCC and its governance: http://www.ripe.net
General information about K-Root: http://k.root-servers.org/
RIPE NCC's current expansion plan is available at: http://k.root-servers.org/hosting.html.
Monitoring: https://dnsmon.ripe.net/ https://atlas.ripe.net/

Significant events and milestones for K-Root include:

K-Root went live on May 19, 1997 from servers located at the LINX operated by the RIPE NCC. A hot-standby set of servers was deployed at the AMS-IX shortly afterwards.

In early 2000s, there were increasing concerns about the lack of diversity in name server software. The RIPE NCC partnered with NLnet Labs to design and develop an authoritative name server (NSD)[50] from scratch. The RIPE NCC contributed requirements, input to the design and lab testing to the initial development of NSD. NSD was deployed on K-Root in 2003.

In 2003, K-Root deployed anycast based on the hot-standby in Amsterdam.[51]

On February 4th 2008 K-Root service became available on IPv6.

3.12. L-Root

The L-Root Server is currently operated by Internet Corporation For Assigned Names and Numbers (ICANN). ICANN is a not-for-profit public-benefit corporation with participants from all over the world dedicated to keeping the Internet secure, stable and interoperable. It promotes competition and develops policy on the Internet's unique identifiers. Through its coordination role of the Internet's naming system, it does have an important impact on the expansion and evolution of the Internet.

[50] See http://www.nlnetlabs.nl/projects/nsd/
[51] See https://www.ripe.net/publications/docs/ripe-268.

ICANN sees that the major obligations of being the L-Root server operator is to transparently provide global service of root zone resolution from L-Root in the face of all operational and political concerns.

In 2000, ICANN became operator of L-Root in 2000 with John Crain as ICANN CTO and commenced plans to anycast L-Root.

Significant events and milestones for L-Root include:

In November 2007, L-Root changed its IPv4 address from 198.32.64.12 to 199.7.83.42 in zone serial 2007110201.

In December 2008, L-Root added its IPv6 address (2001:500:3::42) to the root zone in zone serial 2008121201.

In 2009, Joe Abley joined ICANN in 2009 to lead an expansion of L-Root's anycast cloud.

In 2013, Terry Manderson took over Management of the DNS Operations Department.

In 2014, The DNS Operations Department was moved into the ICANN IT Function and renamed DNS Engineering.

The expansion of L-Root along with the incremental improvements in engineering practices continues.

The L-Root system currently operates at the IPv4 199.7.83.42 with the range 199.7.83.0/24 and the IPv6 address 2001:500:3::42 with the range 2001:500:3::/48 both ranges are announced from AS20144. L-Root is currently anycasted at over 145 locations on both IPv4 and IPv6. L-Root runs both Name Server Daemon (NSD) from NLnet Labs and Knot software platforms on both Linux and BSD.

3.13. M-Root

M-Root is jointly operated by WIDE Project and Japan Registry Services (JPRS). WIDE Project is a research project based in Japan, working for the networking and distributed technologies. JPRS is the ccTLD registry operator of .jp, as well as roles in gTLD registry and registrar operation.

The discussion of distribution of the root servers was made on the IEPG meetings around 1995 and 1996. Japan was proposed as one of the additional locations with WIDE Project as its operator. The note from June 1996 IEPG meeting is as below.

> "The IEPG proposed to draft an IEPG Operational Note, proposing to IANA an experimental deployment of 2 additional name servers, with proposed locations in

> the UK (Linx) and Japan (WIDE Project) and proposed timing, duration and objectives of the experiment to be documented (Action: Bill Manning)."[52]

After further discussion, Jun Murai (Founder of WIDE Project) received an appointment to operate a root server in Tokyo, Japan at the December 1996 IEPG meeting.

In December 2005, JPRS joined the operation of M-Root by the request from WIDE Project to provide more operational and financial stability.[53]

Significant events and milestones for M-Root include:

1997	WIDE Project started M-Root operation in Tokyo, Japan
2001	redundant operation using "Anycast in Rack" started
2001	backup site in Osaka, Japan launched
2004	Anycast deployment started in Seoul, Korea and Paris, France,[54] and San Francisco, USA
2005	JPRS joined for the operation
2008	IPv6 address added in the root zone and root-servers.net zone
2009	letter exchange about M-Root operation between ICANN and WIDE Project[55]

Currently, the IP addresses for M-Root are: (IPv4) 202.12.27.33 and (IPv6) 2001:dc3::35. M-Root is anycasted at the following locations: Tokyo, JP (including 3 sites); Osaka, JP; Paris, FR; San Francisco, US; and Seoul, KR. Each location provides both IPv4 and IPv6 transport.

As the root server operator, WIDE and JPRS sees it obligation to support the operational stability of the Root Servers for all Internet users.

4. Conclusions

The root server system began at Information Science Institute in 1984, at the time it was used to develop the domain name system and to test the DNS software. As the software matured, network information centers (e.g. SRI International, Network Solutions) started to host root servers. The development of the root server system was also to meet the needs of the growing interconnected networks, from ARPANET, MILNET, NSFNET, to the general Internet around the world.

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[52] See http://www.iepg.org/june1996/index.html

[53] See http://www.wide.ad.jp/news/press/20051220-RootDNS-e.html and http://jprs.co.jp/press/2005/051220.html (Japanese)

[54] See http://www.wide.ad.jp/news/press/20040929-dns-e.html.

[55] See https://www.icann.org/en/system/files/files/murai-to-twomey-06may09-en.pdf.

Today, the DNS root (name) servers make the DNS root zone available to all DNS users on the Internet. The servers are operated by 12 independent organizations. As operators, they publish the authoritative root zone without modification.

Dr. Jon Postel chose the organizations based on technical expertise, Internet connectivity, and diversity in both their organizations and operating practices. Today, entities that operate root servers include government network information centers, laboratories, universities, for profit organizations, and not for profit service associations. There is great diversity in the operational history and approaches of root servers, as well as hardware and software. This diversity in aspects such as geography, organizations and operations has enabled the root server system to deal with local challenges, avoid capture by any single party, and provide reliable service to the Internet community.

The system has always provided reliable service to the Internet community. The root server system has evolved over more than three decades in all aspects, such as the number and diversity of the operators, the capacity and connectivity of the servers, diversity of DNS software, IPv6 capability, and last but not least anycast.

5. Appendixes

5.1. Current Root Server name, IP Address and Operator

Hostname	IP Addresses	Operator
A.ROOT-SERVERS.NET	198.41.0.4, 2001:503:ba3e::2:30	Verisign, Inc.
B.ROOT-SERVERS.NET	192.228.79.201, 2001:500:84::b	University of Southern California (ISI)
C.ROOT-SERVERS.NET	192.33.4.12, 2001:500:2::c	Cogent Communications
D.ROOT-SERVERS.NET	199.7.91.13, 2001:500:2d::d	University of Maryland
E.ROOT-SERVERS.NET	192.203.230.10	NASA Ames Research Center
F.ROOT-SERVERS.NET	192.5.5.241, 2001:500:2f::f	Internet Systems Consortium, Inc.
G.ROOT-SERVERS.NET	192.112.36.4	US Department of Defense (NIC)
H.ROOT-SERVERS.NET	198.97.190.53, 2001:500:1::53	US Army (Research Lab)
I.ROOT-SERVERS.NET	192.36.148.17, 2001:7fe::53	Netnod
J.ROOT-SERVERS.NET	192.58.128.30, 2001:503:c27::2:30	VeriSign, Inc.
K.ROOT-SERVERS.NET	193.0.14.129, 2001:7fd::1	RIPE NCC
L.ROOT-SERVERS.NET	199.7.83.42, 2001:500:3::42	ICANN
M.ROOT-SERVERS.NET	202.12.27.33, 2001:dc3::35	WIDE Project

5.2. Historical Copies of Root Hint File or Root Cache File

Operators who manage a DNS recursive resolver typically need to configure a *"root hints file"*. This file contains the names and IP addresses of the root zone, so the software can bootstrap the DNS resolution process. For many pieces of software, this list comes built into the software.

5.2.1. June 1993

Source: https://github.com/sergev/4.4BSD-Lite2/blob/master/etc/namedb/root.cache

```
;       @(#)root.cache  8.1 (Berkeley) 6/9/93
```

```
; Initial cache data for root domain servers.
.                   IN    NS    NS.NIC.DDN.MIL.
                    IN    NS    A.ISI.EDU.
                    IN    NS    AOS.BRL.MIL.
                    IN    NS    C.NYSER.NET.
                    IN    NS    GUNTER-ADAM.AF.MIL.
                    IN    NS    NS.NASA.GOV.
                    IN    NS    TERP.UMD.EDU.

; Prep the cache (hotwire the addresses).  Order does not matter.
NS.NIC.DDN.MIL      IN    A     192.67.67.53
A.ISI.EDU           IN    A     26.3.0.103
                    IN    A     128.9.0.107
AOS.BRL.MIL         IN    A     128.20.1.2
                    IN    A     192.5.25.82
C.NYSER.NET.        IN    A     192.33.4.12
GUNTER-ADAM.AF.MIL.       IN    A     26.1.0.13
NS.NASA.GOV.        IN    A     128.102.16.10
                    IN    A     192.52.195.10
TERP.UMD.EDU.       IN    A     128.8.10.90
```

5.2.2. December 1993

The oldest BIND source code available is for version 4.9.2, dating back to around December 1993. In this package is found the following "conf/root.cache" file:

```
;; QUESTIONS:
;;   ., type = NS, class = IN
;; ANSWERS:
.    518400    NS   NS.INTERNIC.NET.
.    518400    NS   AOS.ARL.ARMY.MIL.
.    518400    NS   KAVA.NISC.SRI.COM.
.    518400    NS   C.NYSER.NET.
.    518400    NS   TERP.UMD.EDU.
.    518400    NS   NS.NASA.GOV.
.    518400    NS   NIC.NORDU.NET.
.    518400    NS   NS.NIC.DDN.MIL.

;; ADDITIONAL RECORDS:
NS.INTERNIC.NET. 518400   A    198.41.0.4
AOS.ARL.ARMY.MIL.    518400    A    128.63.4.82
AOS.ARL.ARMY.MIL.    518400    A    192.5.25.82
KAVA.NISC.SRI.COM.   518400    A    192.33.33.24
C.NYSER.NET.   518400    A    192.33.4.12
TERP.UMD.EDU.  518400    A    128.8.10.90
NS.NASA.GOV.   86400 A   128.102.16.10
NS.NASA.GOV.   86400 A   192.52.195.10
NIC.NORDU.NET.   518400   A    192.36.148.17
NS.NIC.DDN.MIL.  518400   A    192.112.36.4
;; FROM: gw.home.vix.com to SERVER: ns.nasa.gov  128.102.16.10
;; WHEN: Sun Dec 19 13:42:51 1993
;; MSG SIZE  sent: 17  rcvd: 402
```

5.2.3. Nov 1995

Source: http://uw714doc.sco.com/en/man/html.4tcp/root.cache.4tcp.html

```
;       This file holds the information on root name servers needed to
;       initialize cache of Internet domain name servers
;       (e.g. reference this file in the "cache  .  <file>"
;       configuration file of BIND domain name servers).
;
;       This file is made available by InterNIC registration services
;       under anonymous FTP as
;           file                /domain/named.root
;           on server           FTP.RS.INTERNIC.NET
;       -OR- under Gopher at    RS.INTERNIC.NET
;           under menu          InterNIC Registration Services (NSI)
;              submenu          InterNIC Registration Archives
;           file                named.root
;
;       last update:    Nov 8, 1995
;       related version of root zone:   1995110800
;
;
; formerly NS.INTERNIC.NET
;
.                        3600000  IN  NS    A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.      3600000      A     198.41.0.4
;
; formerly NS1.ISI.EDU
;
.                        3600000      NS    B.ROOT-SERVERS.NET.
B.ROOT-SERVERS.NET.      3600000      A     128.9.0.107
;
; formerly C.PSI.NET
;
.                        3600000      NS    C.ROOT-SERVERS.NET.
C.ROOT-SERVERS.NET.      3600000      A     192.33.4.12
;
; formerly TERP.UMD.EDU
;
.                        3600000      NS    D.ROOT-SERVERS.NET.
D.ROOT-SERVERS.NET.      3600000      A     128.8.10.90
;
; formerly NS.NASA.GOV
;
.                        3600000      NS    E.ROOT-SERVERS.NET.
E.ROOT-SERVERS.NET.      3600000      A     192.203.230.10
;
; formerly NS.ISC.ORG
;
.                        3600000      NS    F.ROOT-SERVERS.NET.
F.ROOT-SERVERS.NET.      3600000      A     192.5.5.241
;
; formerly NS.NIC.DDN.MIL
;
.                        3600000      NS    G.ROOT-SERVERS.NET.
G.ROOT-SERVERS.NET.      3600000      A     192.112.36.4
;
; formerly AOS.ARL.ARMY.MIL
;
.                        3600000      NS    H.ROOT-SERVERS.NET.
```

```
H.ROOT-SERVERS.NET.      3600000      A     128.63.2.53
;
; formerly NIC.NORDU.NET
;
.                        3600000      NS    I.ROOT-SERVERS.NET.
I.ROOT-SERVERS.NET.      3600000      A     192.36.148.17
; End of File
```

5.2.4. Feb 1997

Source: http://marc.info/?l=namedroppers&m=95837845327369&w=2

```
;       This file holds the information on root name servers needed to
;       initialize cache of Internet domain name servers
;       (e.g. reference this file in the "cache  .  <file>"
;       configuration file of BIND domain name servers).
;
;       This file is made available by InterNIC
;       under anonymous FTP as
;           file                /domain/named.root
;           on server           FTP.RS.INTERNIC.NET
;       -OR- under Gopher at    RS.INTERNIC.NET
;           under menu          InterNIC Registration Services (NSI)
;              submenu          InterNIC Registration Archives
;           file                named.root
;
;       last update:    Feb 28, 1997
;       related version of root zone:   1997022800
;
; formerly NS.INTERNIC.NET
;
.                        3600000      NS    A.ROOT-SERVERS.NET.
A.ROOT-SERVERS.NET.      3600000      A     198.41.0.4
;
; FORMERLY NS1.ISI.EDU
;
.                        3600000      NS    B.ROOT-SERVERS.NET.
B.ROOT-SERVERS.NET.      3600000      A     128.9.0.107
;
; FORMERLY C.PSI.NET
;
.                        3600000      NS    C.ROOT-SERVERS.NET.
C.ROOT-SERVERS.NET.      3600000      A     192.33.4.12
;
; FORMERLY TERP.UMD.EDU
;
.                        3600000      NS    D.ROOT-SERVERS.NET.
D.ROOT-SERVERS.NET.      3600000      A     128.8.10.90
;
; FORMERLY NS.NASA.GOV
;
.                        3600000      NS    E.ROOT-SERVERS.NET.
E.ROOT-SERVERS.NET.      3600000      A     192.203.230.10
;
; FORMERLY NS.ISC.ORG
;
.                        3600000      NS    F.ROOT-SERVERS.NET.
```

```
F.ROOT-SERVERS.NET.      3600000      A     192.5.5.241
;
; FORMERLY NS.NIC.DDN.MIL
;
.                        3600000      NS    G.ROOT-SERVERS.NET.
G.ROOT-SERVERS.NET.      3600000      A     192.112.36.4
;
; FORMERLY AOS.ARL.ARMY.MIL
;
.                        3600000      NS    H.ROOT-SERVERS.NET.
H.ROOT-SERVERS.NET.      3600000      A     128.63.2.53
;
; FORMERLY NIC.NORDU.NET
;
.                        3600000      NS    I.ROOT-SERVERS.NET.
I.ROOT-SERVERS.NET.      3600000      A     192.36.148.17
;
; temporarily housed at NSI (InterNIC)
;
.                        3600000      NS    J.ROOT-SERVERS.NET.
J.ROOT-SERVERS.NET.      3600000      A     192.41.0.10
;
; temporarily housed at NSI (InterNic)
;
.                        3600000      NS    K.ROOT-SERVERS.NET.
K.ROOT-SERVERS.NET.      3600000      A     198.41.0.11
;
; temporarily housed at ISI (IANA)
;
.                        3600000      NS    L.ROOT-SERVERS.NET.
L.ROOT-SERVERS.NET.      3600000      A     198.32.64.12
;
; temporarily housed at ISI (IANA)
;
.                        3600000      NS    M.ROOT-SERVERS.NET.
M.ROOT-SERVERS.NET.      3600000      A     198.32.65.12
; End of file
```

5.2.5. May 2015

```
;       This file holds the information on root name servers needed to
;       initialize cache of Internet domain name servers
;       (e.g. reference this file in the "cache  .  <file>"
;       configuration file of BIND domain name servers).
;
;       This file is made available by InterNIC
;       under anonymous FTP as
;           file                /domain/named.cache
;           on server           FTP.INTERNIC.NET
;       -OR-                    RS.INTERNIC.NET
;
;       last update:    May 23, 2015
;       related version of root zone:   2015052300
;
; formerly NS.INTERNIC.NET
;
.                        3600000      NS    A.ROOT-SERVERS.NET.
```

```
A.ROOT-SERVERS.NET.      3600000      A     198.41.0.4
A.ROOT-SERVERS.NET.      3600000      AAAA  2001:503:ba3e::2:30
;
; FORMERLY NS1.ISI.EDU
;
.                        3600000      NS    B.ROOT-SERVERS.NET.
B.ROOT-SERVERS.NET.      3600000      A     192.228.79.201
B.ROOT-SERVERS.NET.      3600000      AAAA  2001:500:84::b
;
; FORMERLY C.PSI.NET
;
.                        3600000      NS    C.ROOT-SERVERS.NET.
C.ROOT-SERVERS.NET.      3600000      A     192.33.4.12
C.ROOT-SERVERS.NET.      3600000      AAAA  2001:500:2::c
;
; FORMERLY TERP.UMD.EDU
;
.                        3600000      NS    D.ROOT-SERVERS.NET.
D.ROOT-SERVERS.NET.      3600000      A     199.7.91.13
D.ROOT-SERVERS.NET.      3600000      AAAA  2001:500:2d::d
;
; FORMERLY NS.NASA.GOV
;
.                        3600000      NS    E.ROOT-SERVERS.NET.
E.ROOT-SERVERS.NET.      3600000      A     192.203.230.10
;
; FORMERLY NS.ISC.ORG
;
.                        3600000      NS    F.ROOT-SERVERS.NET.
F.ROOT-SERVERS.NET.      3600000      A     192.5.5.241
F.ROOT-SERVERS.NET.      3600000      AAAA  2001:500:2f::f
;
; FORMERLY NS.NIC.DDN.MIL
;
.                        3600000      NS    G.ROOT-SERVERS.NET.
G.ROOT-SERVERS.NET.      3600000      A     192.112.36.4
;
; FORMERLY AOS.ARL.ARMY.MIL
;
.                        3600000      NS    H.ROOT-SERVERS.NET.
H.ROOT-SERVERS.NET.      3600000      A     128.63.2.53
H.ROOT-SERVERS.NET.      3600000      AAAA  2001:500:1::803f:235
;
; FORMERLY NIC.NORDU.NET
;
.                        3600000      NS    I.ROOT-SERVERS.NET.
I.ROOT-SERVERS.NET.      3600000      A     192.36.148.17
I.ROOT-SERVERS.NET.      3600000      AAAA  2001:7fe::53
;
; OPERATED BY VERISIGN, INC.
;
.                        3600000      NS    J.ROOT-SERVERS.NET.
J.ROOT-SERVERS.NET.      3600000      A     192.58.128.30
J.ROOT-SERVERS.NET.      3600000      AAAA  2001:503:c27::2:30
;
; OPERATED BY RIPE NCC
;
```

```
.                       3600000      NS    K.ROOT-SERVERS.NET.
K.ROOT-SERVERS.NET.     3600000      A     193.0.14.129
K.ROOT-SERVERS.NET.     3600000      AAAA  2001:7fd::1
;
; OPERATED BY ICANN
;
.                       3600000      NS    L.ROOT-SERVERS.NET.
L.ROOT-SERVERS.NET.     3600000      A     199.7.83.42
L.ROOT-SERVERS.NET.     3600000      AAAA  2001:500:3::42
;
; OPERATED BY WIDE
;
.                       3600000      NS    M.ROOT-SERVERS.NET.
M.ROOT-SERVERS.NET.     3600000      A     202.12.27.33
M.ROOT-SERVERS.NET.     3600000      AAAA  2001:dc3::35
; End of file
```

6. Acknowledgments

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K-root RIPE NCC
L-root ICANN
M-root WIDE/JPRS

Expert Interviews
David Conrad
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Mark Kosters
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