Internet Engineering Task Force
Internet-Draft
Intended status: Best Current Practice
Expires: September 27, 2019

D. Reilly, Ed.
Orolia USA
H. Stenn
Network Time Foundation
D. Sibold
PTB

March 26, 2019

Network Time Protocol Best Current Practices
draft-ietf-ntp-bcp-13

Abstract

The Network Time Protocol (NTP) is one of the oldest protocols on the Internet and has been widely used since its initial publication. This document is a collection of Best Practices for general operation of NTP servers and clients on the Internet. It includes recommendations for stable, accurate and secure operation of NTP infrastructure. This document is targeted at NTP version 4 as described in RFC 5905.

Status of This Memo

This Internet-Draft will expire on September 27, 2019.

Copyright Notice

Table of Contents

1. Introduction

NTP version 4 (NTPv4) has been widely used since its publication as [RFC5905]. This document is a collection of best practices for the operation of NTP clients and servers.

The recommendations in this document are intended to help operators distribute time on their networks more accurately and more securely. It is intended to apply generally to a broad range of networks. Some specific networks may have higher accuracy requirements that require additional techniques beyond what is documented here.

Among the best practices covered are recommendations for general network security, time protocol specific security, and NTP server and client configuration. NTP operation in embedded devices is also covered.

This document also contains information for protocol implementors who want to develop their own implementations that are compliant to RFC 5905.

1.1. Requirements Language

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "NOT RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in BCP 14 [RFC2119] [RFC8174] when, and only when, they appear in all capitals, as shown here.

2. General Network Security Best Practices

2.1. BCP 38

Many network attacks rely on modifying the IP source address of a packet to point to a different IP address than the computer which originated it. UDP-based protocols such as NTP are generally more susceptible to spoofing attacks than connection-oriented protocols. NTP control messages can generate a lot of data in response to a small query, which makes it attractive as a vector for distributed denial-of-service attacks. (NTP Control messages are discussed further in Section 3.4). One documented instance of such an attack can be found here [1], and further discussion in [IMC14] and [NDSS14].

BCP 38 [RFC2827] was published in 2000 to to provide some level of remediation against address-spoofing attacks. BCP 38 calls for filtering outgoing and incoming traffic to make sure that the source and destination IP addresses are consistent with the expected flow of traffic on each network interface. It is RECOMMENDED that ISP's and large corporate networks implement ingress and egress filtering. More information is available at the BCP38 Info Web page [2] .

3. NTP Configuration Best Practices

This section provides Best Practices for NTP configuration and operation. Application of these best practices that are specific to the Network Time Foundation implementation, including example configuration directives valid at the time of this writing, are compiled in Appendix A.

3.1. Keeping NTP up to date

There are multiple versions of the NTP protocol in use, and multiple implementations, on many different platforms. The practices in this document are meant to apply generally to any implementation of [RFC5905]. NTP users should select an implementation that is actively maintained. Users should keep up to date on any known attacks on their selected implementation, and deploy updates containing security fixes as soon as practical.

3.2. Use enough time sources

An NTP implementation that is compliant with [RFC5905] takes the available sources of time and submits this timing data to sophisticated intersection, clustering, and combining algorithms to get the best estimate of the correct time. The description of these algorithms is beyond the scope of this document. Interested readers should read [RFC5905] or the detailed description of NTP in [MILLS2006].

o If there is only 1 source of time, the answer is obvious. It may not be a good source of time, but it's the only source of time that can be considered. Any issue with the time at the source will be passed on to the client.

o If there are 2 sources of time and they agree well enough, then the best time can be calculated easily. But if one source fails, then the solution degrades to the single-source solution outlined above. And if the two sources don't agree, it will be difficult to know which one is correct without making use of information from outside of the protocol.

- If there are 3 sources of time, there is more data available to converge on the best calculated time, and this time is more likely to be accurate. And the loss of one of the sources (by becoming unreachable or unusable) can be tolerated. But at that point, the solution degrades to the 2 source solution.

- 4 or more sources of time is better, as long as the sources are diverse (Section 3.3). If one of these sources develops a problem there are still at least 3 other time sources.

This analysis assumes that a majority of the servers used in the solution are honest, even if some may be inaccurate. Operators should be aware of the possibility that if an attacker is in control of the network, the time coming from all servers could be compromised.

Operators who are concerned with maintaining accurate time SHOULD use at least 4 independent, diverse sources of time. Four sources will provide sufficient backup in case one source goes down. If four sources are not available, operators MAY use fewer sources, subject to the risks outlined above.

But even with 4 or more sources of time, systemic problems can happen. One example involves the leap smearing concept detailed in Section 3.7.1. For several hours before and after the June 2015 leap second, several operators configured their NTP servers with leap smearing while others did not. Many NTP end nodes could not determine an accurate time source because 2 of their 4 sources of time gave them consistent UTC/POSIX time, while the other 2 gave them consistent leap-smeared time. This is just one of many potential causes of disagreement among time sources.

Operators are advised to monitor all time sources that are in use. If time sources do not generally agree, operators are encouraged to investigate the cause of this and either correct the problems or stop using defective servers. See Section 3.5 for more information.

3.3. Use a diversity of Reference Clocks

When using servers with attached hardware reference clocks, it is suggested that different types of reference clocks be used. Having a diversity of sources with independent implementations means that any one issue is less likely to cause a service interruption.

Are all clocks on a network from the same vendor? They may have the same bugs. Even devices from different vendors may not be truly independent if they share common elements. Are they using the same base chipset? Are they all running the same version of firmware? Chipset and firmware bugs can happen, but they can be more difficult to diagnose than application software bugs. When having the correct time is of critical importance, it's ultimately up to operators to ensure that their sources are sufficiently independent, even if they are not under the operator's control.

A systemic problem with time from any satellite navigation service is possible and has happened. Sunspot activity can render satellite or radio-based time source unusable. Depending on the application requirements, operators may need to consider backup scenarios in the rare circumstance when the satellite system is faulty or unavailable.

3.4. Control Messages

Some implementations of NTPv4 provide the NTP Control Messages (also known as Mode 6 messages) that were originally specified in Appendix B of [RFC1305] which defined NTPv3. These messages were never included the NTPv4 specification, but they are still used. At the time of this writing, work is being done to formally document the structure of these control messages in [I-D.ietf-ntp-mode-6-cmds].

The NTP Control Messages are designed to permit monitoring and optionally authenticated control of NTP and its configuration. Used properly, these facilities provide vital debugging and performance information and control. But these facilities can be a vector for amplification attacks when abused. For this reason, it is RECOMMENDED that publicly-facing NTP servers should block NTP Control Message queries from outside their organization.

The ability to use NTP Control Messages beyond their basic monitoring capabilities SHOULD be limited to authenticated sessions that provide a 'controlkey'. It can also be limited through mechanisms outside of the NTP specification, such as Access Control Lists, that only allow access from approved IP addresses.

The NTP Control Messages responses are much larger than the corresponding queries. Thus, they can be abused in high-bandwidth DDoS attacks. Section 2.1 gives more information on how to provide protection for this abuse by implementing BCP 38.

3.5. Monitoring

Operators SHOULD use their NTP implementation's remote monitoring capabilities to quickly identify servers which are out of sync, and ensure correctness of the service. Operators SHOULD also monitor system logs for messages so problems and abuse attempts can be quickly identified.

If a system starts to receive NTP Reply packets from a remote time server that do not correspond to any requests sent by the system, that can be an indication that an attacker is forging that system's IP address in requests to the remote time server. The goal of this attack is to adversely impact the availability of time to the targeted system whose address is being forged. Based on these forged packets, the remote time server might decide to throttle or rate limit packets, or even stop sending packets to the targeted system.

If a system is a broadcast client and its system log shows that it is receiving early time messages from its server, that is an indication that somebody may be forging packets from a broadcast server. (Broadcast client and server modes are defined in Section 3 of [RFC5905])

If a server's system log shows messages that indicates it is receiving NTP timestamps that are much earlier than the current system time, then either the system clock is unusually fast or somebody is trying to launch a replay attack against that server.

3.6. Using Pool Servers

It only takes a small amount of bandwidth and system resources to synchronize one NTP client, but NTP servers that can service tens of thousands of clients take more resources to run. Network operators and advanced users who want to synchronize their computers MUST only synchronize to servers that they have permission to use.

The NTP Pool Project is a group of volunteers who have donated their computing and bandwidth resources to freely distribute time from primary time sources to others on the Internet. The time is generally of good quality but comes with no guarantee whatsoever. If you are interested in using this pool, please review their instructions at http://www.pool.ntp.org/en/use.html [3].

Vendors can obtain their own subdomain that is part of the NTP Pool Project. This offers vendors the ability to safely make use of the time distributed by the pool for their devices. Details are available at http://www.pool.ntp.org/en/vendors.html [4] .

If there is a need to synchronize many computers, an operator may want to run local NTP servers that are synchronized to the NTP Pool Project. NTP users on that operator's networks can then be synchronized to local NTP servers.

3.7. Leap Second Handling

UTC is kept in agreement with the astronomical time UT1 [5] to within +/- 0.9 seconds by the insertion (or possibly a deletion) of a leap second. UTC is an atomic time scale whereas UT1 is based on the rotational rate of the earth. Leap seconds are not introduced at a fixed rate. They are announced by the International Earth Rotation and Reference Systems Service (IERS) in its Bulletin C [6] when necessary to keep UTC and UT1 aligned.

NTP time is based on the UTC timescale, and the protocol has the capability to broadcast leap second information. Some Global Navigation Satellite Systems (like GPS) or radio transmitters (like DCF77) broadcast leap second information. If an NTP client is synced to an NTP server that provides leap second notification, the client will get advance notification of impending leap seconds automatically.

Since the length of the UT1 day is generally slowly increasing [7], all leap seconds that have been introduced since the practice started in 1972 have been positive leap seconds, where a second is added to UTC. NTP also supports a negative leap second, where a second is removed from UTC, if that ever becomes necessary.

While earlier versions of NTP contained some ambiguity regarding when a leap second that is broadcast by a server should be applied by a client, RFC 5905 is clear that leap seconds are only applied on the last day of a month. However, because some older clients may apply it at the end of the current day, it is RECOMMENDED that NTP servers wait until the last day of the month before broadcasting leap seconds. Doing this will prevent older clients from applying a leap second at the wrong time. When implementing this recommendation, operators should ensure that clients are not configured to use polling intervals greater than 24 hours, so the leap second notification is not missed.

In circumstances where an NTP server is not receiving leap second information from an automated source, certain organizations maintain files which are updated every time a new leap second is announced:

NIST: ftp://time.nist.gov/pub/leap-seconds.list

US Navy (maintains GPS Time): ftp://tycho.usno.navy.mil/pub/ntp/leap-seconds.list

IERS (announces leap seconds):
https://hpiers.obspm.fr/iers/bul/bulc/ntp/leap-seconds.list

3.7.1. Leap Smearing

Some NTP installations make use of a technique called Leap Smearing. With this method, instead of introducing an extra second (or eliminating a second) on a leap second event, NTP time will be slewed in small increments over a comparably large window of time (called the smear interval) around the leap second event. The smear interval should be large enough to make the rate that the time is slewed small, so that clients will follow the smeared time without objecting. Periods ranging from 2 to 24 hours have been used successfully. During the adjustment window, all the NTP clients' times may be offset from UTC by as much as a full second, depending on the implementation. But at least all clients will generally agree on what time they think it is.

The purpose of Leap Smearing is to enable systems that don't deal with the leap second event properly to function consistently, at the expense of fidelity to UTC during the smear window. During a standard leap second event, that minute will have 61 (or possibly 59) seconds in it, and some applications (and even some OS's) are known to have problems with that.

Operators who have legal obligations or other strong requirements to be synchronized with UTC or civil time SHOULD NOT use leap smearing, because the distributed time cannot be guaranteed to be traceable to UTC during the smear interval.

Clients that are connected to leap smearing servers MUST NOT apply the standard NTP leap second handling. These clients must never have a leap second file loaded, and the smearing servers must never advertise to clients that a leap second is pending.

Any use of leap smearing servers should be limited to within a single, well-controlled environment. Leap Smearing MUST NOT be used for public-facing NTP servers, as they will disagree with non-smearing servers (as well as UTC) during the leap smear interval, and there is no standardized way for a client to detect that a server is using leap smearing. However, be aware that some public-facing servers may be configured this way anyway in spite of this guidance.

System Administrators are advised to be aware of impending leap seconds and how the servers (inside and outside their organization) they are using deal with them. Individual clients MUST NOT be configured to use a mixture of smeared and non-smeared servers. If a client uses smeared servers, the servers it uses must all have the same leap smear configuration.

4. NTP Security Mechanisms

In the standard configuration NTP packets are exchanged unprotected between client and server. An adversary that is able to become a Man-In-The-Middle is therefore able to drop, replay or modify the content of the NTP packet, which leads to degradation of the time synchronization or the transmission of false time information. A threat analysis for time synchronization protocols is given in [RFC7384]. NTP provides two internal security mechanisms to protect authenticity and integrity of the NTP packets. Both measures protect the NTP packet by means of a Message Authentication Code (MAC). Neither of them encrypts the NTP's payload, because this payload information is not considered to be confidential.

4.1. Pre-Shared Key Approach

This approach applies a symmetric key for the calculation of the MAC, which protects authenticity and integrity of the exchanged packets for an association. NTP does not provide a mechanism for the exchange of the keys between the associated nodes. Therefore, for each association, keys MUST be exchanged securely by external means, and they MUST be protected from disclosure. It is RECOMMENDED that each association be protected by its own unique key. It is RECOMMENDED that participants agree to refresh keys periodically. However, NTP does not provide a mechanism to assist in doing so. Each communication partner will need to keep track of its keys in its own local key storage.

[RFC5905] specifies using the MD5 hash algorithm for calculation of the MAC, but other algorithms may be supported as well. The MD5 hash is now considered to be too weak and unsuitable for cryptographic usage. [RFC6151] has more information on the algorithm's weaknesses. Implementations will soon be available based on AES-128-CMAC [I-D.ietf-ntp-mac], and users SHOULD use that when it is available.

Some implementations store the key in clear text. Therefore it MUST only be readable by the NTP process.

An NTP client has to be able to link a key to a particular server in order to establish a protected association. This linkage is implementation specific. Once applied, a key will be trusted until the link is removed.

4.2. Autokey

[RFC5906] specifies the Autokey protocol. It was published in 2010 to provide automated key management and authentication of NTP servers. However, security researchers have identified vulnerabilities [8] in the Autokey protocol.

Autokey SHOULD NOT be used.

4.3. Network Time Security

Work is in progress on an enhanced replacement for Autokey. Refer to [I-D.ietf-ntp-using-nts-for-ntp] for more information.

4.4. External Security Protocols

If applicable, external security protocols such as IPsec and MACsec can be applied to enhance integrity and authenticity protection of NTP time synchronization packets. Usage of such external security protocols can decrease time synchronization performance [RFC7384]. Therefore, operators are advised to carefully evaluate if the decreased time synchronization performance meets their specific timing requirements.

Note that none of the security measures described in Section 4 can prevent packet delay manipulation attacks on NTP. Such delay attacks can target time synchronization packets sent as clear-text or even within an encrypted tunnel. These attacks are described further in Section 3.2.6 of [RFC7384].

5. NTP Security Best Practices

This section lists some general NTP security practices, but these issues may (or may not) have been mitigated in particular versions of particular implementations. Contact the maintainers of the relevant implementation for more information.

5.1. Minimizing Information Leakage

The base NTP packet leaks important information (including reference ID and reference time) that may be used in attacks [NDSS16], [CVE-2015-8138], [CVE-2016-1548]. A remote attacker can learn this information by sending mode 3 queries to a target system and inspecting the fields in the mode 4 response packet. NTP control queries also leak important information (including reference ID, expected origin timestamp, etc.) that may be used in attacks [CVE-2015-8139]. A remote attacker can learn this information by sending control queries to a target system and inspecting the leaked information in the response.

As such, mechanisms outside of the NTP protocol, such as Access Control Lists, SHOULD be used to limit the exposure of this information to allowed IP addresses, and keep it from remote attackers not on the list. Hosts SHOULD only respond to NTP control queries from authorized parties.

An NTP client that does not provide time on the network can additionally log and drop incoming mode 3 timing queries from unexpected sources. Note well that the easiest way to monitor the status of an NTP instance is to send it a mode 3 query, so it may not be desirable to drop all mode 3 queries. As an alternative, operators SHOULD either filter mode 3 queries from outside their networks, or make sure mode 3 queries are allowed only from trusted systems or networks.

A "leaf-node host" is a host that is using NTP solely for the purpose of adjusting its own system time. Such a host is not expected to provide time to other hosts, and relies exclusively on NTP’s basic mode to take time from a set of servers. (That is, the host sends mode 3 queries to its servers and receives mode 4 responses from these servers containing timing information.) To minimize information leakage, leaf-node hosts SHOULD drop all incoming NTP packets except mode 4 response packets that come from known sources. An exception to this can be made if a leaf-node host is being actively monitored, in which case incoming packets from the monitoring server can be allowed.

Please refer to [I-D.ietf-ntp-data-minimization] for more information.

5.2. Avoiding Daemon Restart Attacks

[RFC5905] says NTP clients should not accept time shifts greater than the panic threshold. Specifically, RFC 5905 says "PANIC means the offset is greater than the panic threshold PANICT (1000 s) and SHOULD cause the program to exit with a diagnostic message to the system log."

However, this behavior can be exploited by attackers as described in [NDSS16], when the following two conditions hold:

1. The operating system automatically restarts the NTP client when it quits. (Modern *NIX operating systems are replacing traditional init systems with process supervisors, such as systemd, which can be configured to automatically restart any

daemons that quit. This behavior is the default in CoreOS and Arch Linux. As of the time of this writing, it appears likely to become the default behavior in other systems as they migrate legacy init scripts to process supervisors such as systemd.)

2. The NTP client is configured to ignore the panic threshold on all restarts.

In such cases, if the attacker can send the target an offset that exceeds the panic threshold, the client will quit. Then, when it restarts, it ignores the panic threshold and accepts the attacker's large offset.

Operators need to be aware that when operating with the above two conditions, the panic threshold offers no protection from attacks. The natural solution is not to run hosts with these conditions. Specifically, operators SHOULD NOT ignore the panic threshold in all cold-start situations unless sufficient oversight and checking is in place to make sure that this type of attack cannot happen.

As an alternative, the following steps MAY be taken by operators to mitigate the risk of attack:

- Monitor the NTP system log to detect when the NTP daemon has quit due to a panic event, as this could be a sign of an attack.

- Request manual intervention when a timestep larger than the panic threshold is detected.

- Configure the ntp client to only ignore the panic threshold in a cold start situation.

- Increase the minimum number of servers required before the NTP client adjusts the system clock. This will make the NTP client wait until enough trusted sources of time agree before declaring the time to be correct.

In addition, the following steps SHOULD be taken by those who implement the NTP protocol:

- Prevent the NTP daemon from taking time steps that set the clock to a time earlier than the compile date of the NTP daemon.

- Prevent the NTP daemon from putting 'INIT' in the reference ID of its NTP packets upon initializing. This will make it more difficult for attackers to know when the daemon reboots.

5.3. Detection of Attacks Through Monitoring

Operators SHOULD monitor their NTP instances to detect attacks. Many known attacks on NTP have particular signatures. Common attack signatures include:

1. Bogus packets - A packet whose origin timestamp does not match the value that expected by the client.

2. Zero origin packet - A packet with an origin timestamp set to zero [CVE-2015-8138].

3. A packet with an invalid cryptographic MAC [CCR16].

The observation of many such packets could indicate that the client is under attack.

5.4. Kiss-o'-Death Packets

The "Kiss-o'-Death" (KoD) packet includes a rate management mechanism where a server can tell a misbehaving client to reduce its query rate. KoD packets in general (and the RATE packet in particular) are defined in Section 7.4 of [RFC5905]. It is RECOMMENDED that all NTP devices respect these packets and back off when asked to do so by a server. It is even more important for an embedded device, which may not have an exposed control interface for NTP.

That said, a client MUST only accept a KoD packet if it has a valid origin timestamp. Once a RATE packet is accepted, the client should increase its poll interval value (thus decreasing its polling rate) up to a reasonable maximum. This maximum can vary by implementation but should not exceed a poll interval value of 13 (2 hours). The mechanism to determine how much to increase the poll interval value is undefined in [RFC5905]. If the client uses the poll interval value sent by the server in the RATE packet, it MUST NOT simply accept any value. Using large interval values may open a vector for a denial-of-service attack that causes the client to stop querying its server [NDSS16].

The KoD rate management mechanism relies on clients behaving properly in order to be effective. Some clients ignore the RATE packet entirely, and other poorly-implemented clients might unintentionally increase their poll rate and simulate a denial of service attack. Server administrators are advised to be prepared for this and take measures outside of the NTP protocol to drop packets from misbehaving clients when these clients are detected.

Kiss-o'-Death (KoD) packets can be used in denial of service attacks. Thus, the observation of even just one RATE packet with a high poll value could be sign that the client is under attack. And KoD packets are commonly accepted even when not cryptographically authenticated, which increases the risk of denial of service attacks.

5.5. Broadcast Mode Should Only Be Used On Trusted Networks

Per [RFC5905], NTP's broadcast mode is authenticated using symmetric key cryptography. The broadcast server and all its broadcast clients share a symmetric cryptographic key, and the broadcast server uses this key to append a message authentication code (MAC) to the broadcast packets it sends.

Importantly, all broadcast clients that listen to this server have to know the cryptographic key. This mean that any client can use this key to send valid broadcast messages that look like they come from the broadcast server. Thus, a rogue broadcast client can use its knowledge of this key to attack the other broadcast clients.

For this reason, an NTP broadcast server and all its clients have to trust each other. Broadcast mode SHOULD only be run from within a trusted network.

5.6. Symmetric Mode Should Only Be Used With Trusted Peers

In symmetric mode, two peers Alice and Bob can both push and pull synchronization to and from each other using either ephemeral symmetric passive (mode 2) or persistent symmetric active (NTP mode 1) packets. The persistent association is preconfigured and initiated at the active peer but not preconfigured at the passive peer (Bob). Upon receipt of a mode 1 NTP packet from Alice, Bob mobilizes a new ephemeral association if he does not have one already. This is a security risk for Bob because an arbitrary attacker can attempt to change Bob's time by asking Bob to become its symmetric passive peer.

For this reason, a host SHOULD only allow symmetric passive associations to be established with trusted peers. Specifically, a host SHOULD require each of its symmetric passive association to be cryptographically authenticated. Each symmetric passive association SHOULD be authenticated under a different cryptographic key.

6. NTP in Embedded Devices

As computing becomes more ubiquitous, there will be many small embedded devices that require accurate time. These devices may not have a persistent battery-backed clock, so using NTP to set the correct time on power-up may be critical for proper operation. These devices may not have a traditional user interface, but if they connect to the Internet they will be subject to the same security threats as traditional deployments.

6.1. Updating Embedded Devices

Vendors of embedded devices are advised to pay attention to the current state of protocol security issues and bugs in their chosen implementation, because their customers don't have the ability to update their NTP implementation on their own. Those devices may have a single firmware upgrade, provided by the manufacturer, that updates all capabilities at once. This means that the vendor assumes the responsibility of making sure their devices have an up-to-date and secure NTP implementation.

Vendors of embedded devices SHOULD include the ability to update the list of NTP servers used by the device.

There is a catalog of NTP server abuse incidents, some of which involve embedded devices, on the Wikipedia page for NTP Server Misuse and Abuse [9].

6.2. Server configuration

Vendors of embedded devices with preconfigured NTP servers need to carefully consider which servers to use. There are several public-facing NTP servers available, but they may not be prepared to service requests from thousands of new devices on the Internet. Vendors MUST only preconfigure NTP servers that they have permission to use.

Vendors are encouraged to invest resources into providing their own time servers for their devices to connect to. This may be done through the NTP Pool Project, as documented in Section 3.6.

Vendors should read [RFC4085], which advises against embedding globally-routable IP addresses in products, and offers several better alternatives.

7. NTP over Anycast

Anycast is described in BCP 126 [RFC4786]. (Also see [RFC7094]). With anycast, a single IP address is assigned to multiple servers, and routers direct packets to the closest active server.

Anycast is often used for Internet services at known IP addresses, such as DNS. Anycast can also be used in large organizations to simplify configuration of many NTP clients. Each client can be configured with the same NTP server IP address, and a pool of anycast servers can be deployed to service those requests. New servers can be added to or taken from the pool, and other than a temporary loss of service while a server is taken down, these additions can be transparent to the clients.

Note well that using a single anycast address for NTP presents its own potential issues. It means each client will likely use a single time server source. A key element of a robust NTP deployment is each client using multiple sources of time. With multiple time sources, a client will analyze the various time sources, selecting good ones, and disregarding poor ones. If a single Anycast address is used, this analysis will not happen. This can be mitigated by creating multiple, separate anycast pools so clients can have multiple sources of time while still gaining the configuration benefits of the anycast pools.

If clients are connected to an NTP server via anycast, the client does not know which particular server they are connected to. As anycast servers enter and leave the network, or the network topology changes, the server a particular client is connected to may change. This may cause a small shift in time from the perspective of the client when the server it is connected to changes. In extreme cases where the network topology is changing rapidly, this could cause the server seen by a client to rapidly change as well, which can lead to larger time inaccuracies. It is RECOMMENDED that network operators only deploy anycast NTP in environments where operators know these small shifts can be tolerated by the applications running on the clients being synchronized in this manner.

Configuration of an anycast interface is independent of NTP. Clients will always connect to the closest server, even if that server is having NTP issues. It is RECOMMENDED that anycast NTP implementations have an independent method of monitoring the performance of NTP on a server. If the server is not performing to specification, it should remove itself from the Anycast network. It is also RECOMMENDED that each Anycast NTP server have an alternative method of access, such as an alternate Unicast IP address, so its performance can be checked independently of the anycast routing scheme.

One useful application in large networks is to use a hybrid unicast/anycast approach. Stratum 1 NTP servers can be deployed with unicast interfaces at several sites. Each site may have several Stratum 2 servers with two ethernet interfaces, or a single interface which can support multiple addresses. One interface has a unique unicast IP address. The second has an anycast IP interface (with a shared IP address per location). The unicast interfaces can be used to obtain time from the Stratum 1 servers globally (and perhaps peer with the other Stratum 2 servers at their site). Clients at each site can be configured to use the shared anycast address for their site, simplifying their configuration. Keeping the anycast routing restricted on a per-site basis will minimize the disruption at the client if its closest anycast server changes. Each Stratum 2 server can be uniquely identified on their unicast interface, to make monitoring easier.

8. Acknowledgments

The authors wish to acknowledge the contributions of Sue Graves, Samuel Weiler, Lisa Perdue, Karen O'Donoghue, David Malone, Sharon Goldberg, Martin Burnicki, Miroslav Lichvar, Daniel Fox Franke, Robert Nagy, and Brian Haberman.

9. IANA Considerations

This memo includes no request to IANA.

10. Security Considerations

Time is a fundamental component of security on the internet. The absence of a reliable source of current time subverts many common web authentication schemes, e.g., by allowing the use of expired credentials or by allowing for replay of messages only intended to be processed once.

Much of this document directly addresses how to secure NTP servers. In particular, see Section 2, Section 4, and Section 5.

There are several general threats to time synchronization protocols which are discussed in [RFC7384].

[I-D.ietf-ntp-using-nts-for-ntp] specifies the Network Time Security (NTS) mechanism and applies it to NTP. Readers are encouraged to check the status of the draft, and make use of the methods it describes.

11. References

11.1. Normative References

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, DOI 10.17487/RFC2119, March 1997, <https://www.rfc-editor.org/info/rfc2119>.

[RFC2827] Ferguson, P. and D. Senie, "Network Ingress Filtering: Defeating Denial of Service Attacks which employ IP Source Address Spoofing", BCP 38, RFC 2827, DOI 10.17487/RFC2827, May 2000, <https://www.rfc-editor.org/info/rfc2827>.

[RFC4085] Plonka, D., "Embedding Globally-Routable Internet Addresses Considered Harmful", BCP 105, RFC 4085, DOI 10.17487/RFC4085, June 2005, <https://www.rfc-editor.org/info/rfc4085>.

[RFC4786] Abley, J. and K. Lindqvist, "Operation of Anycast Services", BCP 126, RFC 4786, DOI 10.17487/RFC4786, December 2006, <https://www.rfc-editor.org/info/rfc4786>.

[RFC5905] Mills, D., Martin, J., Ed., Burbank, J., and W. Kasch, "Network Time Protocol Version 4: Protocol and Algorithms Specification", RFC 5905, DOI 10.17487/RFC5905, June 2010, <https://www.rfc-editor.org/info/rfc5905>.

[RFC8174] Leiba, B., "Ambiguity of Uppercase vs Lowercase in RFC 2119 Key Words", BCP 14, RFC 8174, DOI 10.17487/RFC8174, May 2017, <https://www.rfc-editor.org/info/rfc8174>.

11.2. Informative References

[CCR16] Malhotra, A. and S. Goldberg, "Attacking NTP's Authenticated Broadcast Mode", SIGCOMM Computer Communications Review (CCR) , 2016.

[CVE-2015-8138] Van Gundy, M. and J. Gardner, "NETWORK TIME PROTOCOL ORIGIN TIMESTAMP CHECK IMPERSONATION VULNERABILITY", 2016, <http://www.talosintel.com/reports/TALOS-2016-0077>.

[CVE-2015-8139] Van Gundy, M., "NETWORK TIME PROTOCOL NTPQ AND NTPDC ORIGIN TIMESTAMP DISCLOSURE VULNERABILITY", 2016, <http://www.talosintel.com/reports/TALOS-2016-0078>.

[CVE-2016-1548] Gardner, J. and M. Lichvar, "Xleave Pivot: NTP Basic Mode to Interleaved", 2016, <http://blog.talosintel.com/2016/04/vulnerability-spotlight-further-ntpd_27.html>.

[I-D.ietf-ntp-data-minimization]
Franke, D. and A. Malhotra, "NTP Client Data Minimization", draft-ietf-ntp-data-minimization-04 (work in progress), March 2019.

[I-D.ietf-ntp-mac]
Malhotra, A. and S. Goldberg, "Message Authentication Code for the Network Time Protocol", draft-ietf-ntp-mac-06 (work in progress), January 2019.

[I-D.ietf-ntp-mode-6-cmds]
Haberman, B., "Control Messages Protocol for Use with Network Time Protocol Version 4", draft-ietf-ntp-mode-6-cmds-06 (work in progress), September 2018.

[I-D.ietf-ntp-using-nts-for-ntp]
Franke, D., Sibold, D., Teichel, K., Dansarie, M., and R. Sundblad, "Network Time Security for the Network Time Protocol", draft-ietf-ntp-using-nts-for-ntp-17 (work in progress), February 2019.

[IMC14] Czyz, J., Kallitsis, M., Gharaibeh, M., Papadopoulos, C., Bailey, M., and M. Karir, "Taming the 800 Pound Gorilla: The Rise and Decline of NTP DDoS Attacks", Internet Measurement Conference , 2014.

[MILLS2006]
Mills, D., "Computer network time synchronization: the Network Time Protocol", CRC Press , 2006.

[NDSS14] Rossow, C., "Amplification Hell: Revisiting Network Protocols for DDoS Abuse", NDSS’14, San Diego, CA. , 2014.

[NDSS16] Malhotra, A., Cohen, I., Brakke, E., and S. Goldberg, "Attacking the Network Time Protocol", NDSS’16, San Diego, CA. , 2016, <https://eprint.iacr.org/2015/1020.pdf>.

[RFC1305] Mills, D., "Network Time Protocol (Version 3) Specification, Implementation and Analysis", RFC 1305, DOI 10.17487/RFC1305, March 1992, <https://www.rfc-editor.org/info/rfc1305>.

[RFC5906] Haberman, B., Ed. and D. Mills, "Network Time Protocol Version 4: Autokey Specification", RFC 5906, DOI 10.17487/RFC5906, June 2010, <https://www.rfc-editor.org/info/rfc5906>.

[RFC6151] Turner, S. and L. Chen, "Updated Security Considerations for the MD5 Message-Digest and the HMAC-MD5 Algorithms", RFC 6151, DOI 10.17487/RFC6151, March 2011, <https://www.rfc-editor.org/info/rfc6151>.

[RFC7094] McPherson, D., Oran, D., Thaler, D., and E. Osterweil, "Architectural Considerations of IP Anycast", RFC 7094, DOI 10.17487/RFC7094, January 2014, <https://www.rfc-editor.org/info/rfc7094>.

[RFC7384] Mizrahi, T., "Security Requirements of Time Protocols in Packet Switched Networks", RFC 7384, DOI 10.17487/RFC7384, October 2014, <https://www.rfc-editor.org/info/rfc7384>.

11.3. URIs

[1] https://blog.cloudflare.com/technical-details-behind-a-400gbps-ntp-amplification-ddos-attack/

[2] http://www.bcp38.info

[3] http://www.pool.ntp.org/en/use.html

[4] http://www.pool.ntp.org/en/vendors.html

[5] https://en.wikipedia.org/wiki/Solar_time#Mean_solar_time

[6] https://www.iers.org/IERS/EN/Publications/Bulletins/bulletins.html

[7] https://en.wikipedia.org/wiki/Solar_time#Mean_solar_time

[8] https://lists.ntp.org/pipermail/ntpwg/2011-August/001714.html

[9] https://en.wikipedia.org/wiki/NTP_server_misuse_and_abuse

[10] http://www.ntp.org/downloads.html

[11] http://bk1.ntp.org/ntp-stable/README.leapsmear?PAGE=anno

[12] https://support.ntp.org/bin/view/Support/ConfiguringNTP

Appendix A. Best Practices specific to the Network Time Foundation implementation

The Network Time Foundation (NTF) provides a widely used implementation of NTP, known as ntpd [10]. It is an evolution of the first NTP implementations developed by David Mills at the University of Delaware. This appendix contains additional recommendations specific to this implementation that are valid at the time of this writing.

A.1. Use enough time sources

In addition to the recommendation given in Section 3.2 the ntpd implementation provides the 'pool' directive. Starting with ntp-4.2.6, using this directive in the ntp.conf file will spin up enough associations to provide robust time service, and will disconnect poor servers and add in new servers as-needed. The 'minclock' and 'maxclock' options of the 'tos' command may be used to override the default values of how many servers are discovered through the 'pool' directive.

A.2. NTP Control and Facility Messages

In addition to NTP Control Messages the ntpd implementation also offers the Mode 7 commands for monitoring and configuration.

If Mode 7 has been explicitly enabled to be used for more than basic monitoring it should be limited to authenticated sessions that provide a 'requestkey'.

As mentioned above, there are two general ways to use Mode 6 and Mode 7 requests. One way is to query ntpd for information, and this mode can be disabled with:

```
restrict ... noquery
```

The second way to use Mode 6 and Mode 7 requests is to modify ntpd's behavior. Modification of ntpd's configuration requires an authenticated session by default. If no authentication keys have been specified no modifications can be made. For additional protection, the ability to perform these modifications can be controlled with:

```
restrict ... nomodify
```

Users can prevent their NTP servers from considering query/configuration traffic by default by adding the following to their ntp.conf file:

```
restrict default -4 nomodify notrap nopeer noquery

restrict default -6 nomodify notrap nopeer noquery

restrict source nomodify notrap noquery
```

A.3. Monitoring

The ntpd implementation allows remote monitoring. Access to this service is generally controlled by the "noquery" directive in NTP's configuration file (ntp.conf) via a "restrict" statement. The syntax reads:

```
restrict address mask address_mask noquery
```

If a system is using broadcast mode and is running ntp-4.2.8p6 or later, use the 4th field of the ntp.keys file to specify the IPs of machines that are allowed to serve time to the group.

A.4. Leap Second File

The use of leap second files requires ntpd 4.2.6 or later. After fetching the leap seconds file onto the server, add this line to ntpd.conf to apply and use the file, substituting the proper path:

```
leapfile "/path/to/leap-file"
```

There may need to restart ntpd to apply this change.

ntpd servers with a manually configured leap second file will ignore leap second information broadcast from upstream NTP servers until the leap second file expires. If no valid leap second file is available then a leap second notification from an attached reference clock is always accepted by ntpd.

If no valid leap second file is available, a leap second notification may be accepted from upstream NTP servers. As of ntp-4.2.6, a majority of servers must provide the notification before it is accepted. Before 4.2.6, a leap second notification would be accepted if a single upstream server of a group of configured servers provided a leap second notification. This would lead to misbehavior if single NTP servers sent an invalid leap second warning, e.g. due to a faulty GPS receiver in one server, but this behavior was once chosen because in the "early days" there was a greater chance that leap second information would be available from a very limited number of sources.

A.5. Leap Smearing

Leap Smearing was introduced in ntpd versions 4.2.8.p3 and 4.3.47, in response to client requests. Support for leap smearing is not configured by default and must be added at compile time. In addition, no leap smearing will occur unless a leap smear interval is specified in ntpd.conf . For more information, refer to http://bk.ntp.org/ntp-stable/README.leapsmear?PAGE=anno [11].

A.6. Configuring ntpd

See https://support.ntp.org/bin/view/Support/ConfiguringNTP [12] for additional information on configuring ntpd.

A.7. Pre-Shared Keys

Each communication partner must add the key information to their key file in the form:

```
keyid type key
```

where "keyid" is a number between 1 and 65534, inclusive, "type" is an ASCII character which defines the key format, and "key" is the key itself.

An ntpd client establishes a protected association by appending the option "key keyid" to the server statement in ntp.conf:

```
server address key keyid
```

substituting the server address in the "address" field and the numerical keyid to use with that server in the "keyid" field.

A key is deemed trusted when its keyid is added to the list of trusted keys by the "trustedkey" statement in ntp.conf.

```
trustedkey keyid_1 keyid_2 ... keyid_n
```

Starting with ntp-4.2.8p7 the ntp.keys file accepts an optional 4th column, a comma-separated list of IPs that are allowed to serve time. Use this feature. Note, however, that an adversarial client that knows the symmetric broadcast key could still easily spoof its source IP to an IP that is allowed to serve time. (This is easy to do because the origin timestamp on broadcast mode packets is not validated by the client. By contrast, client/server and symmetric modes do require origin timestamp validation, making it more difficult to spoof packets [CCR16]).

Authors' Addresses

Denis Reilly (editor)
Orolia USA
1565 Jefferson Road, Suite 460
Rochester, NY 14623
US

Email: denis.reilly@orolia.com

Harlan Stenn
Network Time Foundation
P.O. Box 918
Talent, OR 97540
US

Email: stenn@nwtime.org

Dieter Sibold
Physikalisch-Technische Bundesanstalt
Bundesallee 100
Braunschweig D-38116
Germany

Phone: +49-(0)531-592-8420
Fax: +49-531-592-698420
Email: dieter.sibold@ptb.de