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EPI 25 Time Reference in ACN Systems Using SNTP and NTP

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Table of Contents

ACN EPIs

ANSI E1.17-2006 is the “ESTA Architecture for Control Networks” standard [ACN]. It specifies an architecture — including a suite of protocols and languages which may be configured and combined with other standard protocols in a number of ways to form flexible networked control systems.

E1.17 Profiles for Interoperability (EPIs) are standards documents which specify how conforming implementations are to operate in a particular environment or situation in order to guarantee interoperability. They may specify a single technique, set of parameters or requirement for the various ACN components. They may also specify how other standards (including other EPIs) either defined within ACN or externally are to be used to ensure interoperability.

Foreword

This EPI specifies restrictions and guidelines for establishment of a common time reference across components within an ACN system using SNTP (Simple Network Time Protocol) and optionally NTP (Network Time Protocol). This EPI does not define a control synchronization model, but the network wide time reference it establishes can form the basis of a number of different models.

1 Introductory Discussion

Within the control of entertainment lighting and effects time synchronization is very important. In a typical system this can require that hundreds or thousands of individual and autonomous components are required to behave in a coordinated manner to achieve a desired effect, and the coordination needs to remain the same night after night.

The variation in synchronization must therefore be imperceptible or at least unobtrusive to an audience.

Historically, connection between a controller and a piece of controlled equipment has taken the form of a direct linkage by wire and in most cases a single controller has been the main or only source of commands. In this model, synchronization is down to the performance of the controller and to the well known characteristics of the wire connection. Delays within the system of tens of milliseconds can easily be compensated if they are nearly constant - and are anyway often imperceptible when the object of control is an incandescent lamp with a filament time constant which ranges into hundreds of milliseconds.

With control of an ever widening array of equipment controlled in entertainment technology and the inclusion of equipment with very short time constants such as LED based or video effects, much smaller time discrepancies become perceptible — especially when sound, lighting and other effects are combined.

Within an ACN system the linking factor for control of all these components is the network - they cannot be relied upon to have any other linkage. However, delays and variation within the network infrastructure can mean that there is much more variability - even where total delays are no greater - than with the historical model described above.

2 Definitions

accuracy: Refers to how well a clock's frequency and time compare to international standards. See [NTPv3].

component: An ACN communications endpoint. Defined in [Arch].

drift: The variation in skew over time (the second derivative of offset with time). See [NTPv3].

host: A single node on the network. The term is used in the sense commonly used in networking.

offset: The difference in time between two clocks. See [NTPv3].

precision: A measure of the error (or lack of it). See [NTPv3].

skew: The difference in frequency between two clocks (the first derivative of offset with time). See [NTPv3].

stability: Refers to how well a clock can maintain a constant frequency. See [NTPv3].

3 Synchronization Models

3.1 Synchronizing Control vs. Time Reference

There is a difference between synchronization of control and synchronization of time reference. Synchronization of control means that separate controlled devices which are intended to act in a time coordinated way, do so with acceptably small variation from instance to instance. Synchronization of time reference simply means that all components within the system, which operate with a concept of time, use and are synchronized to the same agreed time reference to within acceptable limits.

One way to achieve synchronization of control is to connect a controller to all the devices using a dedicated known-latency connection. Provided the devices respond to control signals in a short or known time, synchronization is entirely up to the controller. This is the implicit model of many historical control methods as described above.

In a system where the link between the controller and the controlled device introduces a significant and unknown or variable delay, this simple model does not work. There are a number of solutions to the issue, and a large number of them rely on all devices within the system sharing a common sense of time. This enables actions to be associated with time such that coordination is maintained despite network delays and variations.

It is important to recognize that time synchronization in itself does not ensure coordinated action. However it a common component of many strategies to achieve control synchronization and is therefore an enabling method.

3.2 Control Techniques Based on Synchronized Time

Specific techniques are not within the scope of this document and this section is purely informative. Given an accurate common time reference a number of strategies for control synchronization are possible including:

• Structuring commands with both an action and a future execution time.

• Executing all commands at constant "tick" times.

• Timestamping all commands so receivers know when they were sent and can compensate for delays.

The last is the approach taken by Real Time Protocol [RTP] and which has achieved success on the Internet. If required it can be refined by configuring all equipment to execute commands at a fixed latency after they were sent — since both sender and receiver know the latency, know the time of the command and have the same time reference, the effect is entirely predictable even where multiple controllers are operating together.

3.3 Time and Synchronization Model: Introduction to NTP and SNTP

This standard is based on [NTPv3], which is described in simplified form here. The model assumes that a master time reference exists and is disseminated across the network in a stratified hierarchy. The lowest stratum contains hosts that are directly connected to the most accurate references of the master reference. On the Internet these are specialist time servers, which attach directly to atomic clocks that are a part of international time keeping standards. At higher strata, hosts can act as clients that synchronize to servers in the stratum below. They can also act as servers to synchronize hosts in the stratum above. This structure is similar to a tree with time disseminating from the root towards the branches.

In NTP though, hosts can not only synchronize to servers in the stratum below, but can synchronize in both directions with other hosts in the same stratum. The algorithms used mean that all the hosts within a stratum will converge on a common consensus of time in an elegant way. Furthermore, even without a reference from a lower stratum, NTP hosts can synchronize to each other to ensure a common concept of time across their own stratum and those above although the resulting reference does not relate to any external timeframe.

4 Scope and Applicability

The methods specified in this EPI are designed to synchronize the internal clocks of hosts within the system together using fairly infrequent exchanges (minutes or even hours apart). Between exchanges, the internal clocks free run. These methods will therefore not work well if an internal clock's reference changes by significant amounts in an unpredictable way between exchanges. In practical terms, this means that a clock running from a quartz crystal will typically not have a significant effect on overall accuracy but clocks based on RC oscillators or even on ceramic resonators may not be acceptable - depending on the precise algorithms applied.

The SNTP protocol does not use the advanced averaging and compensation methods of full NTP and is therefore more susceptible to network latency effects and routing variations. Where all hosts are on a simple Ethernet network without excessive loading, accuracy will be good enough for nearly all entertainment synchronization requirements, however, where hosts are separated by many routers and complex network infrastructure with unknown traffic (e.g. the Internet), accuracy may be inadequate. More discussion of accuracy and methods for mitigation are given below.

> It is strongly recommended that SNTP be used only at the extremities of the synchronization subnet ... and in configurations where no NTP or SNTP client is dependent on another SNTP client for synchronization.

—SNTP Version 4

The use of NTP and SNTP for synchronization is not suited to applications where very rapid synchronization to a reference which might change rapidly, pause, skip or move backwards such as for example, a video source. In these circumstances synchronization using a timecode method such as SMPTE LTC or MIDI Time Code is more appropriate.

The techniques used here all express time as calendar time or "time of day". The actual values used relate to the epoch that began at midnight (00:00) on January 1st 1900.

5 NTP and SNTP: an Informative Description

This section is informative only. Implementers must read the original standards as necessary.

The synchronization model used by [NTPv3] and [SNTPv4] is described above. The basis of both protocols is a simple message that is passed between hosts and contains three timestamps of interest: originator timestamp, receive timestamp, and transmit timestamp. The transmit timestamp is always filled in by a host (from its own clock) immediately before sending a packet.

In the common client/server exchange, the client fills in the transmit timestamp and sends a message to the server. The server fills in the receive timestamp with its own time when it receives the message. It then copies the transmit timestamp to the originator time field and returns the message to the client, filling in the transmit timestamp with its own time at the time it sends the message. On receipt of the reply, the client records its time of arrival giving four times:

t1 in Originator Timestamp field
    The time the message left the client (in client's time).

t2 in Receive Timestamp field
    The time the message arrived at the server (in server's time).

t3 in Transmit Timestamp field
    The time the reply left the server (in server's time).

t4 recorded when reply arrived at client
    The time the reply arrived at the client (in client's time).

From these four times it is possible to calculate the difference between the client's time and the server's time (the offset) and also the round-trip delay between the client and the server.

$$offset = ((t_2 - t_1) + (t_3 - t_4)) / 2$$

$$delay = ((t_4 - t_1) - (t_3 - t_2))$$

Although this is described as a client/server interaction, there is no reason that a host has to always behave as one or the other and this allows peer to peer convergence of clocks across groups of hosts — any host can act as a client in order to discover the round-trip delay and clock offset to another host.

5.1 Difference Between SNTP and NTP

Both NTP and SNTP provide algorithms based on this simple exchange which enable client and server to adjust their clocks to synchronize them together.

Both NTP and SNTP use the same packet format[1] and require similar behavior in terms of how hosts should respond to messages. In most cases a host cannot tell whether another host they communicate with is actually implementing NTP or SNTP.

[1] SNTP does provide some format extensions but these are mostly concerned with applying the protocol over other transports than IPv4 and for anycast addressing.

5.1.1 NTP

NTP uses the information from the above exchange (together with some information in other fields related to accuracy and strata) over many exchanges with a number of peers and/or with servers at the lower stratum. It specifies how hosts should not only adjust their own clocks towards the common reference but also how they know statistically what the error limits on that reference are. Clock adjustment is a gradual process and NTP hosts are careful to adjust their clocks in a manner that does not cause it to change abruptly (which can give rise to missed times or times which seemingly occur twice).

5.1.2 SNTP

SNTP recognizes that for many hosts the above is overkill. An SNTP client is configured to interact with a single server and can adjust its own clock on the basis of a single successful exchange with that server. An SNTP server simply passes its own time reference (however obtained) onto its clients and does not operate (in the context of SNTP) within a stratum of peers. However, because of the interoperability at the protocol level, a host running full NTP can act as a server for an SNTP client with no modification necessary.

SNTP also allows for a multicast synchronization method where clients are entirely passive and synchronize to periodic multicast messages from a server. However, this method provides no automatic compensation at all for network latencies and is disallowed by this EPI.

5.2 SNTP Servers

Time accuracy within an SNTP system can be no better than the accuracy of the server. SNTP servers are not required to use any specific reference but the time reference generated by the internal clock of a computer is not likely to be accurate over a long period. An external time reference (such as a radio clock or GPS reference) is therefore preferred.

In the context of entertainment control it is often the case that accurate synchronization of devices is much more important than absolute time — low offset is much more important than good accuracy. However, there are applications where accuracy is important, particularly in the world of architectural lighting or in environments such as theme parks where hosts run timed events over very long periods. Stability is also often an important criterion — simple quartz oscillators for example often change frequency significantly with temperature changes.

In a system with multiple servers, particularly where anycast addressing is used (allowing a single client to synchronize to an arbitrary one of multiple servers), it is vital that the servers are well synchronized. SNTP provides no explicit mechanism for synchronization of SNTP servers so they must be synchronized externally (e.g. to the same radio time signal using similar hardware).

5.3 Use of NTP Servers

A full NTP host with an Internet connection will achieve good accuracy and can be used as an SNTP server for a network of SNTP clients (the server cannot easily distinguish whether clients are SNTP or NTP). In cases where multiple servers are required, full NTP can also ensure good synchronization of those multiple servers.

Use of full NTP hosts as SNTP servers is therefore strongly recommended for systems where there are multiple servers and no common external reference.

6 EPI Requirements

All compliant equipment shall comply fully with SNTP and may comply with NTP. Additional requirements are specified here.

While NTP hosts are permitted and can bring benefits to a synchronized system as defined here, details of configuration of those NTP hosts is beyond the scope of this document.

6.1 System and Server Configuration

6.1.1 Choice of Time Reference

A system as established by this EPI, consists of multiple hosts connected by a network which are all synchronized to a single time reference (referred to as “system time”). Permissible time references in order of preference are:

1. UTC (Universal coordinated time) as imported to the system, either by one or more hosts with full NTP synchronization over the internet, or by non-network inputs to one or more hosts (e.g. radiocode clocks), or by a combination of these methods.

2. An alternative stable external reference which is relevant to the particular system and is imported in a similar way to 1. This allows, for example, use of an accurate studio wide reference if available, or, in special cases, synchronization to a program source such as music or video.

3. An internal reference established by one or more hosts on the network. Where the reference is established by multiple hosts, they shall be synchronized together using NTP to establish a “consensus” time.

6.1.2 SNTP Servers
Systems shall contain one or more servers able to service SNTP clients in unicast mode.

Where a system includes more than one SNTP server, those servers shall all be synchronized together, either by full NTP or by an external method which ensures equivalent accuracy. This means that in a system which uses nothing but SNTP, there can only be one server.

6.1.3 Client-Server Hierarchy
No SNTP client shall act as a time server for other clients in the system. This means that hosts which synchronize themselves using SNTP must be leaf nodes of the synchronization tree.

As a special case, an exception may be made to the forgoing rule where a single SNTP server for the ACN system synchronizes itself to a source outside of the system using SNTP. This case is permitted in recognition of the wide availability of implementations of this kind, but should be avoided wherever possible because of the possibility for abrupt changes in time reference.

6.1.4 Server Modes
SNTP servers shall respond to unicast mode synchronization messages from clients.

SNTP servers should respond to anycast mode synchronization messages from clients.

SNTP servers should not transmit multicast synchronization messages.

6.1.5 Precautions for Use of Anycast Mode
The anycast mode of SNTP provides a simple method for clients to discover a server in a zeroconfiguration environment. However, an anycast client synchronizes to the first server from which it receives a reply, so the only way to ensure good synchronization by this method is for the system to be configured so that there is only one SNTP server which will respond or if there are multiple servers, that they are all well synchronized with each other.

Furthermore, in many systems, particularly on mixed use or wireless networks, there is the possibility of a response from an SNTP server which had not been considered to be a part of the ACN system. When configuring a system using anycast mode, it is essential that the user be aware of this issue.

Manufacturers of ACN equipment that provides SNTP server capability shall provide the means to configure the server off.

Manufacturers of ACN equipment incorporating SNTP servers that respond to anycast messages shall provide the means to disable anycast responses.

6.2 Client Configuration
All hosts within the system requiring synchronization shall be synchronized to system time using one of the following methods:

• SNTP

• NTP

• External synchronization to the common system reference (e.g. using a GPS receiver).

SNTP clients shall synchronize using the unicast operating mode of SNTP.

SNTP clients may initiate communication using the anycast mode subject to server discovery rules below.

SNTP clients shall not synchronize to multicast mode packets.

6.3 Server Discovery for SNTP Clients
SNTP clients shall allow configuration of their server using DHCP option 042 (NTP server).

SNTP clients should support configuration of their server using the anycast method defined in SNTP.

SNTP clients may support static configuration of a server.

In the case that more than one of these configuration methods are available and working, the client shall pick a server based on the following priority order:

1. Configuration received from DHCP server.

2. SNTP anycast

3. Static configuration

7 Suggestions and Recommendations
On power-up or reset, it is strongly recommended that hosts commence operation before synchronization to avoid long power-up delays and to ensure that equipment can operate even when no time server is present. Controllers that rely on time synchronization to coordinate control must be aware of this, and may choose not to operate until they know that the devices under control are synchronized.

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