Network Time Synchronization

Network Time Synchronization

Segal's law

A man with a watch knows what time it is.

A man with two watches is never sure."

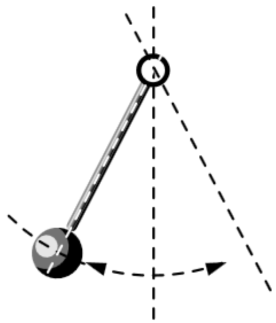
What is a Second?

13th General Conference of Weights and Measures (in 1967) CGPM [Conférence Générale des Poids et Mesures] Resolution 1…

- **“The second is the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the cesium-133 atom.”**
- **The current best accuracy for the realization of the second so defined is a value “y(t),” as defined above, of 3×10^{-15}.**
  - **This is equivalent to ±1 second in 10 million years.**

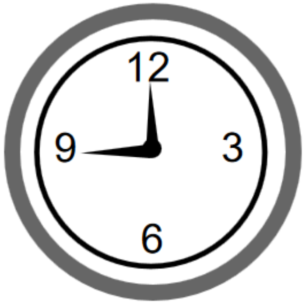
What is a Clock?

A clock is an Oscillator and a Counter

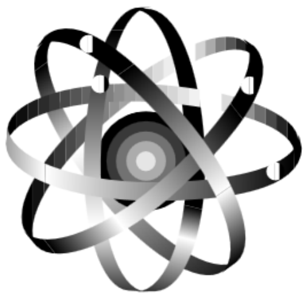


Oscillator
(Frequency Device)

+



Counter
(Counts Periodic Events)



Cs - 133 Atom

+

Fast Electronic Counter

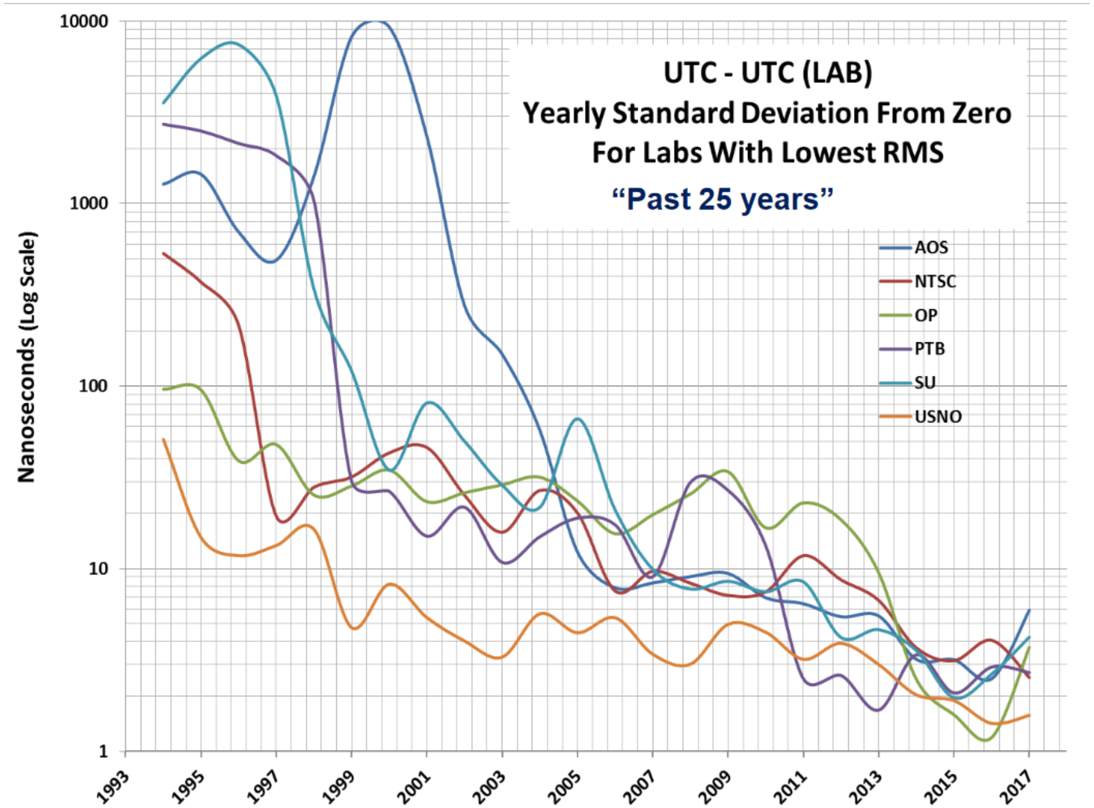
What Time Is It?

- **Sidereal Time**
  - **Determined by means of the apparent daily motion of the stars.**
- **Universal Time (UT)**
  - **Based on Sidereal Time, not SI seconds**
  - **UT0, UT1, UT1R, UT2, UT2R**
- **Universal Coordinated Time (UTC)**
  - **AKA Greenwich Mean Time (GMT)**
- **International Atomic Time (TAI) Time**
  - **International atomic time scale based on a continuous counting of the SI second.**
  - **TAI is currently ahead of UTC by 37 seconds.**
  - **TAI is always ahead of GPS by 19 seconds.**
- **GPS Time**
  - **GPS set to UTC time at 0h 6-Jan-1980**
  - **Not perturbed by leap seconds**
  - **GPS is now ahead of UTC by 18 seconds**

https://www.ucolick.org/~sla/leapsecs/timescales.html

UTC - Universal *Coordinated* Time

- **The C in UTC is "coordinated"**
- **UTC time adjustments are made after the fact from the average of world-wide clock references**



What Time Is It?

local	2020-02-07 15:14:00	Friday	day 038	timezone UTC-6
UTC	2020-02-07 21:14:00	Friday	day 038	MJD 58886.88472
GPS	2020-02-07 21:14:18	week 2091	508458 s	cycle 2 week 0043 day 5
Loran	2020-02-07 21:14:27	GRI 9940	444 s until	next TOC 21:21:24 UTC
TAI	2020-02-07 21:14:37	Friday	day 038	10 + 27 leap seconds = 37

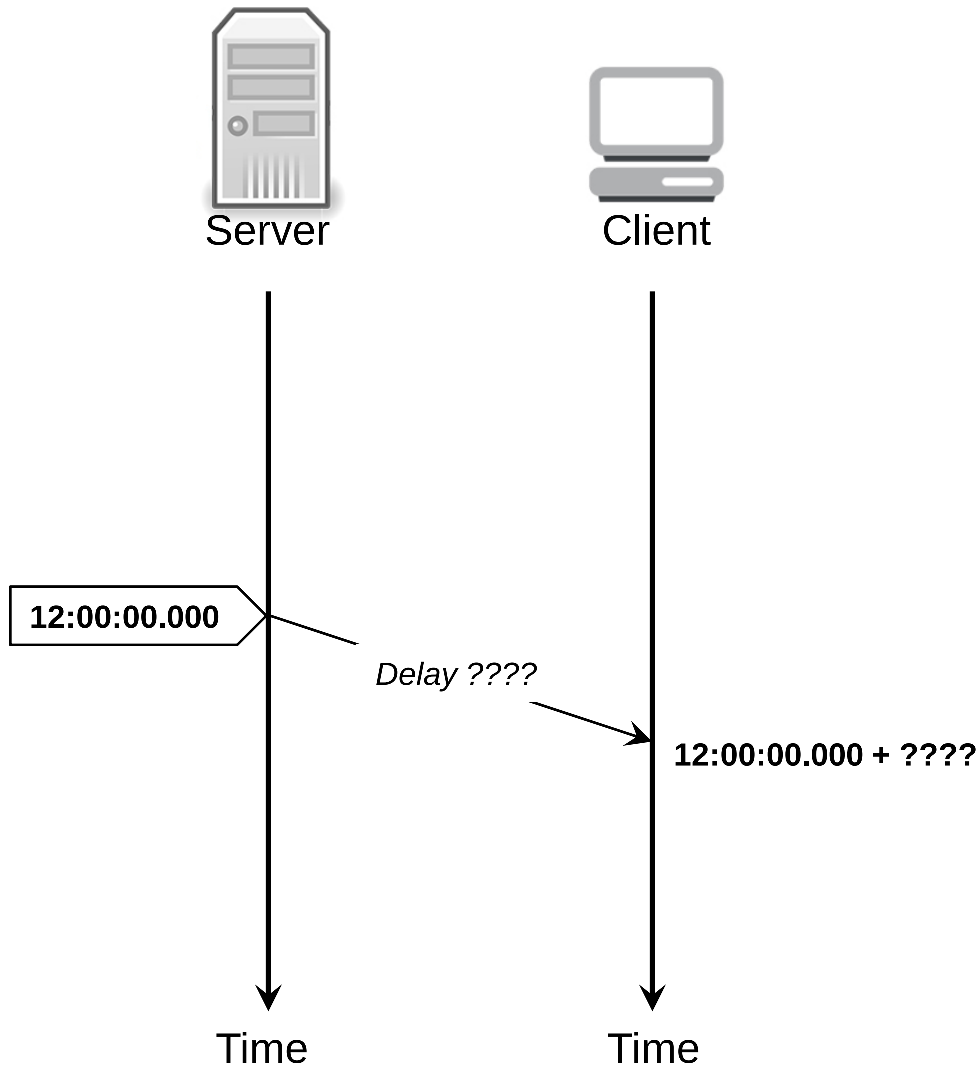
Beware of GPS Time!

GPS Time is very close to UTC

- Offset by a few seconds
- Looks very reasonable…. but probably not the time you are expecting

If someone says "GPS Time" ask if it really GPS Time or rather time supplied from a GPS (usually UTC)

The Network Time Synchronization Problem



- Simple Case - Server broadcast time information to all listeners
- Major error sources are the network and processing delays

Time delay is unknown!

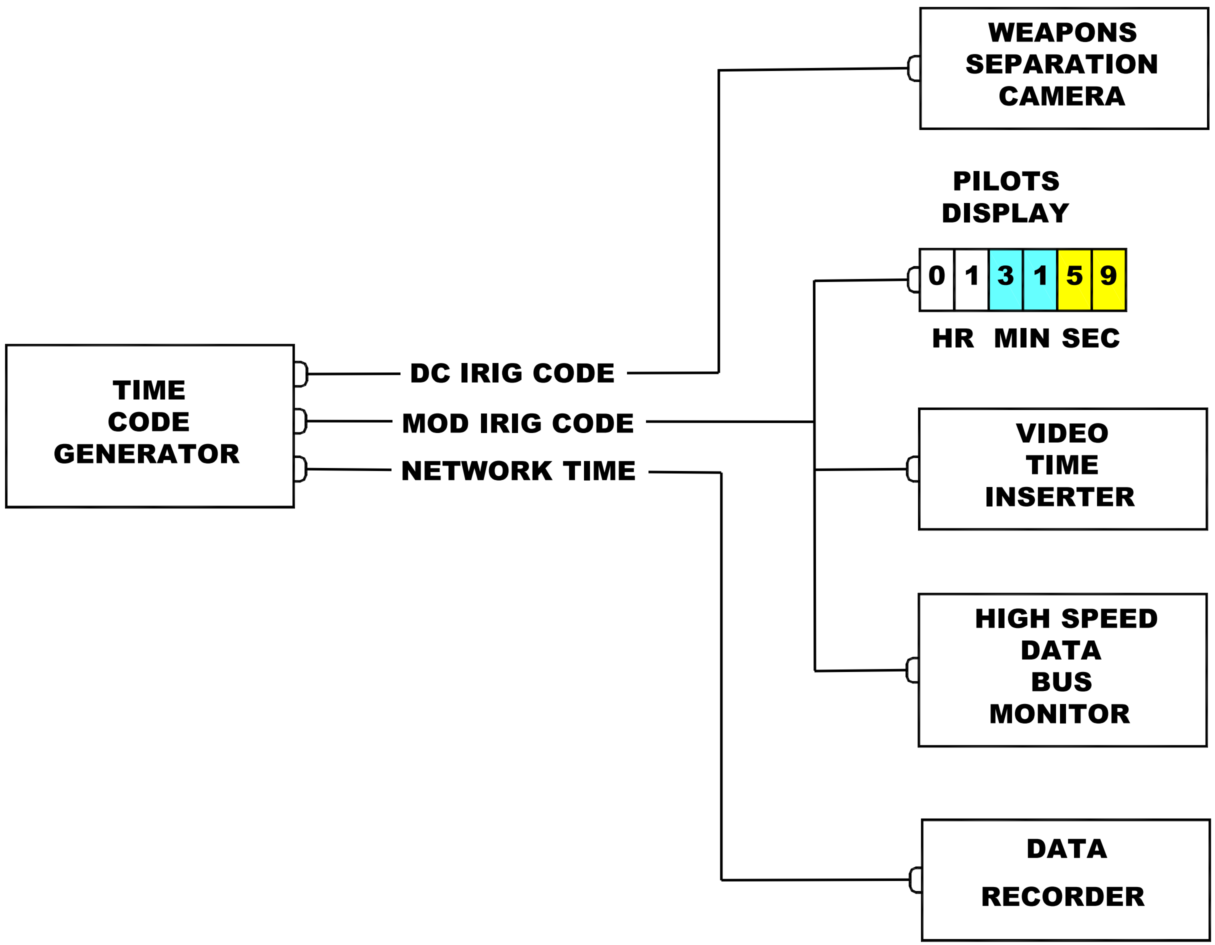
Overview

- **Synchronization protocols determines the time offset (i.e. network delay) of the server clock relative to the client clock**
- **Protocol measures the total round trip delay**
  - **One way propagation delay is half the roundtrip delay**
  - **Assumes the propagation delays are statistically equal in each direction**

History of Time Dissemination

- **HF Time (millisecond)**
  - **Navy Time broadcast started in 1902**
  - **Today NIST operates WWV, WWVB**
- **GOES (50 microsecond)**
  - **1972-2004**
- **Transit (10-25 microsecond)**
  - **1964 –1996**
- **VLF Omega (microsecond/day)**
  - **Off Sept 1997**
- **Loran-C (microsecond)**
  - **DoD end use mid-1990's with transfer to local governments and full system shutdown in 2010**
- **GPS (10-100 nanosecond)**
  - **1970's –Today**
- **TWSTT (1-5 nanosecond)**
  - **US Naval Observator Two-way Satellite Time Transfer program**
  - **TWSTT program starts in 1962 with Launch of Telestar1, to Today**
- **NTP (millisecond over IP networks)**
- **PTP (microsecond)**

Notional Distribution of Time



IRIG Time

- IRIG - Inter-Range Instrumentation Group

- IRIG 200 – Serial Time Code Formats
  - First published in 1960
  - Current version is IRIG 200-16 (i.e. 2016)

- Used to distribute time "one to many"

IRIG 200 Time Code Formats

- **IRIG B**
  - **1,000 hertz**
    - 1 second time data w/ 1000 microsecond (1 ms) calculated direct
- **IRIG A**
  - **10,000 hertz**
    - 0.1 second time data w/ 100 microsecond (0.1 ms) calculated direct
- **IRIG G**
  - **100,000 hertz**
  - 0.01 second time data w/ 10 microsecond (0.01 ms) calculated direct

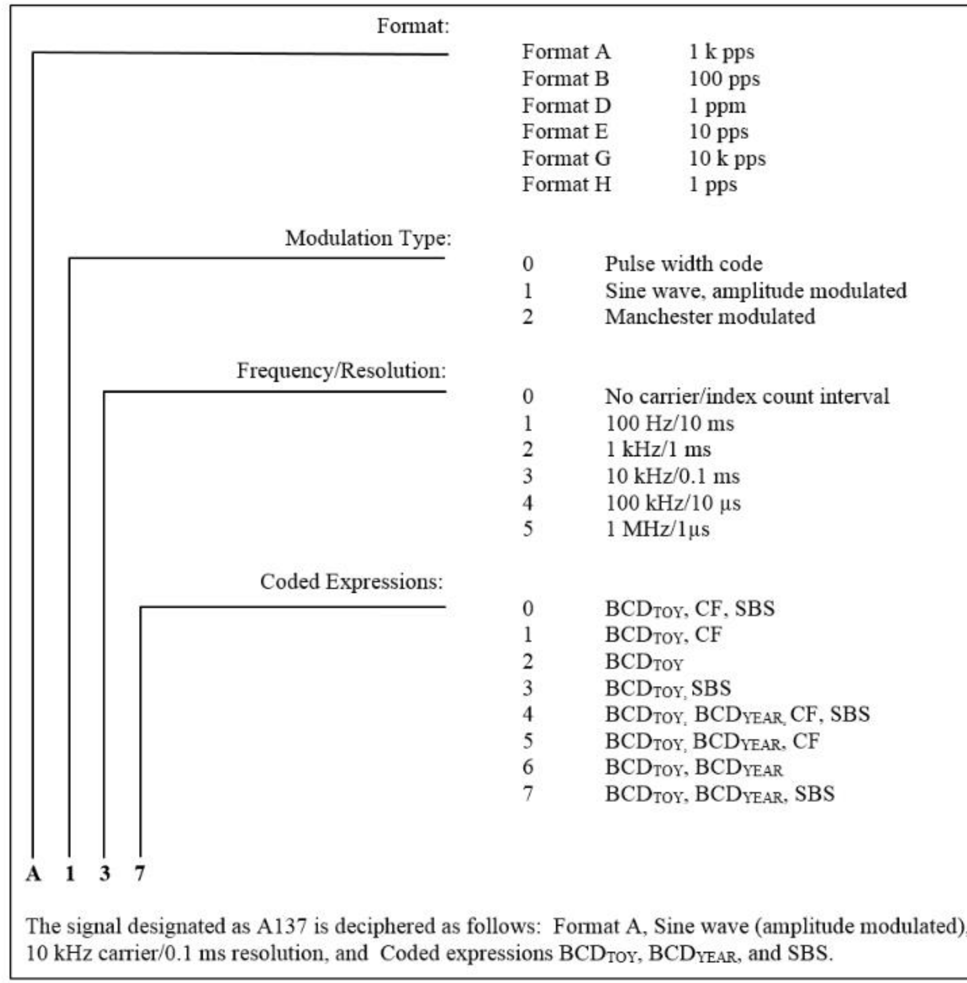
Time Code Formats

- IRIG Standard 200-16
- Must specify:
  - Signal Format
  - Modulation Type
  - Frequency
  - Data Format

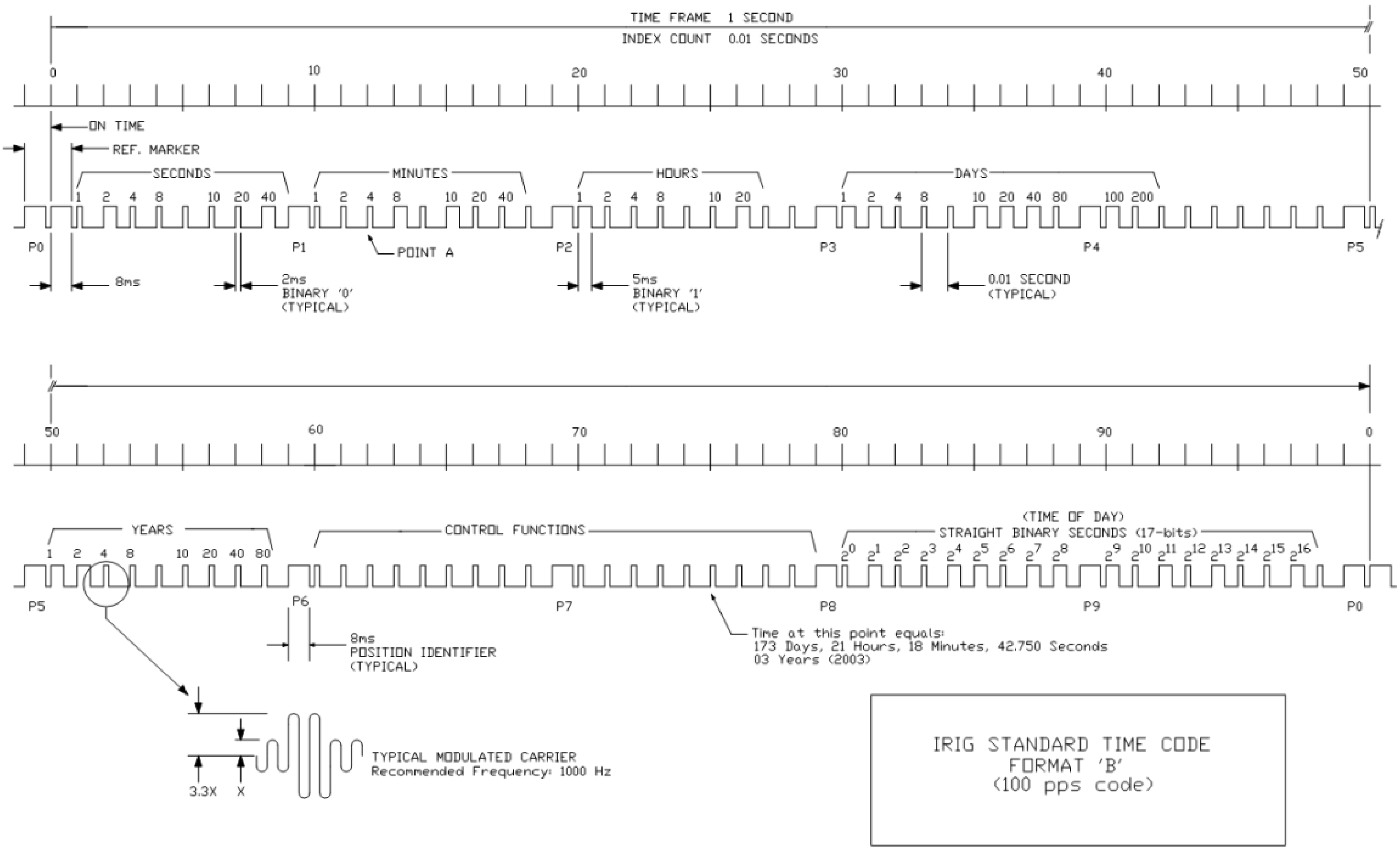
CF - Control Function

SBS - Straight Binary Seconds

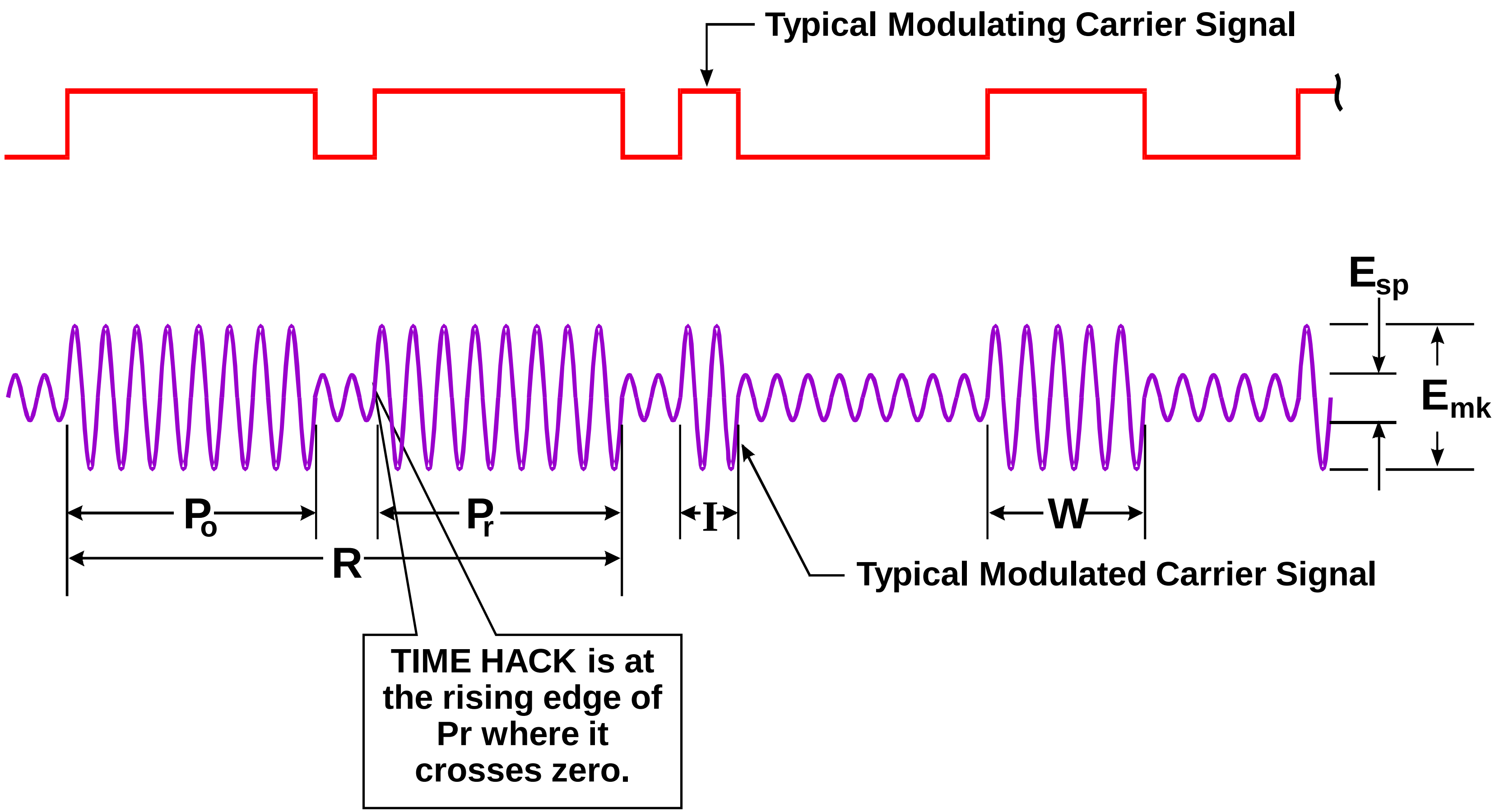
TOY - Time of Year



Time Format IRIG B
(Reference)



Typical Time Codes



Time Format IRIG B Examples

- **Common AM modulated format**

B122 **1 = Sine wave, amplitude modulated**
2 = 1 kHz/1 ms
2 = BCD_{TOY}

- **Common baseband (unmodulated) format**

B022 **0 = DC Level Shift**
2 = 1 kHz/1 ms
2 = BCD_{TOY}

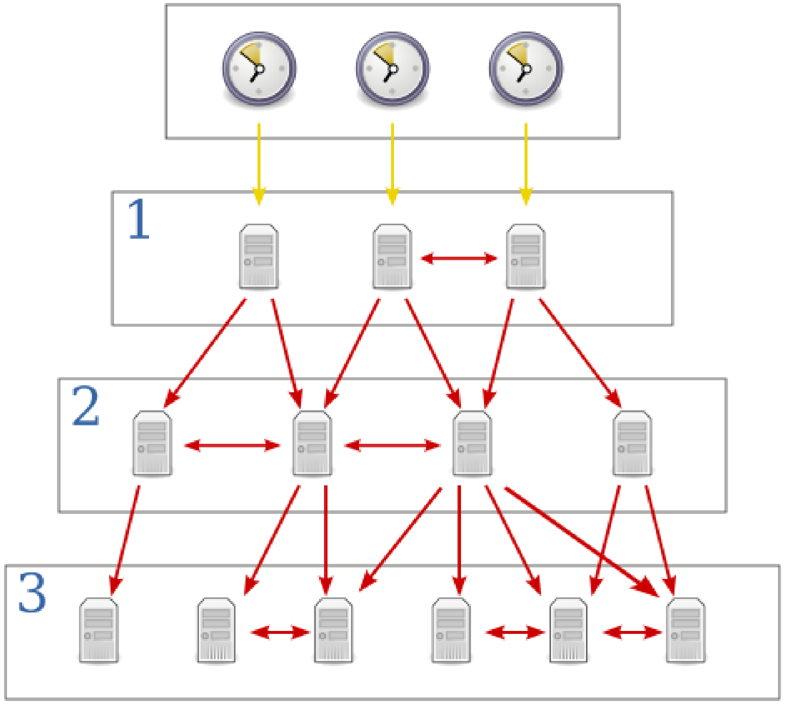
- **AM modulated including year**

B126 **1 = Sine wave, amplitude modulated**
2 = 1 kHz/1 ms
6 = BCD_{TOY}, BCD_{YEAR}

Network Time Synchronization Protocols

Network Time Protocol (NTP)	**RFC 5905**
Simple Network Time Protocol (SNTP)	**RFC 4330**
Precision Time Protocol V1 (PTPv1)	**IEEE1588-2002**
Precision Time Protocol V2 (PTPv2)	**IEEE1588-2008**

Time Protocols



- **Hierarchy of clocks**
- **One measure of “goodness” is the distance (i.e. hops) from the master clock**

Network Time Protocol (NTP)

- **Granddaddy of time protocols**
  - In operation since before 1985
  - One of the oldest Internet protocols in current use.
  - **Current version is NTPv4**

- **Software only implementation**
- **No special network equipment necessary**
- **Native support**
  - **Windows**
  - **MacOS**
  - **Linux**
  - **Lots of others**
- **Still in us on many DoD ranges**

NTP Implementation

- **NTP Standard defines:**
  - **Data packet format**
  - **On-wire exchange protocol**
  - **Peer process operation**
  - **System server process operation**
  - **Clock adjust process operation**
  - **Poll process operation**
  - **Others (modes, security, etc.)**

NTP Packet Format

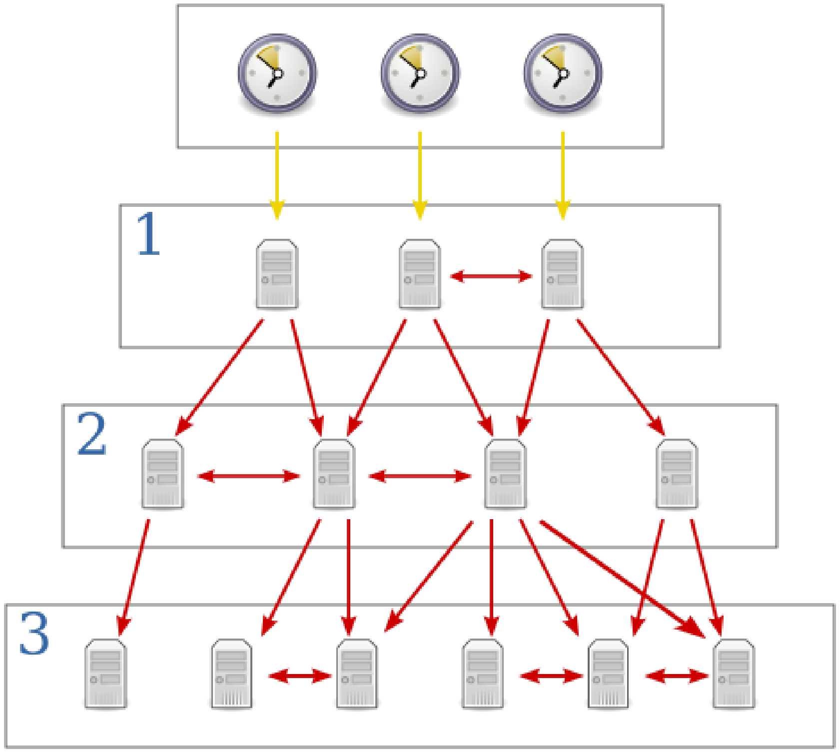
LI	VN	Mode	Strat	Poll	Prec
Root delay					
Root dispersion					
Reference ID					
Reference timestamp (64)					
Origin timestamp (64)					
Receive timestamp (64)					
Transmit timestamp (64)					
Extension field (optional)					
Extension field (optional)					
Key identifier					
Message digest (128)					

Name	Formula	Description
leap	leap	leap indicator (LI)
version	version	version number (VN)
mode	mode	mode
stratum	stratum	stratum
poll	poll	poll exponent
precision	rho	precision exponent
rootdelay	delta_r	root delay
rootdisp	epsilon_r	root dispersion
refid	refid	reference ID
reftime	reftime	reference timestamp
org	T1	origin timestamp
rec	T2	receive timestamp
xmt	T3	transmit timestamp
dst	T4	destination timestamp
keyid	keyid	key ID
dgst	dgst	message digest

NTP Time Stamps

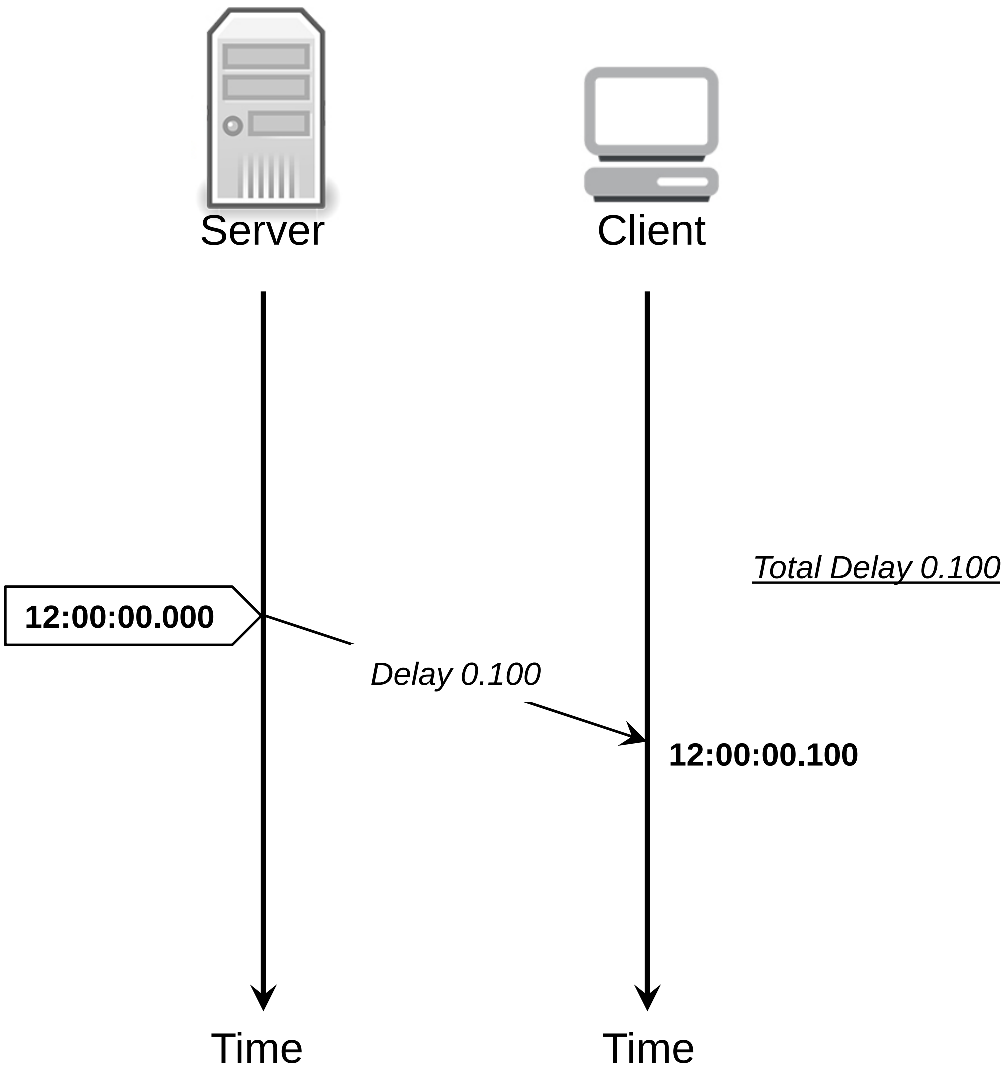
- **NTP time is a 64 bit quantity**
  - 32-bit part for seconds
    - Seconds since Midnight Jan 1st, 1900
    - Roll over every 136 years
  - 32-bit part for fractional second
    - "Fractional Seconds" are expressed decimal point to the left of bit 32
      - That means the left most bit represents ½ second, next bit to the right represents ¼ second, and so on
    - Least significant bit is 2^{-32} seconds (233 picoseconds)

NTP Clocks



- **Hierarchy of clocks**
  - **“Stratum”**
- **Accuracy**
  - Tens of milliseconds over the public Internet
  - Better than one millisecond accuracy in local area networks under ideal conditions.
  - Asymmetric routes and network congestion can cause errors of 100 ms or more

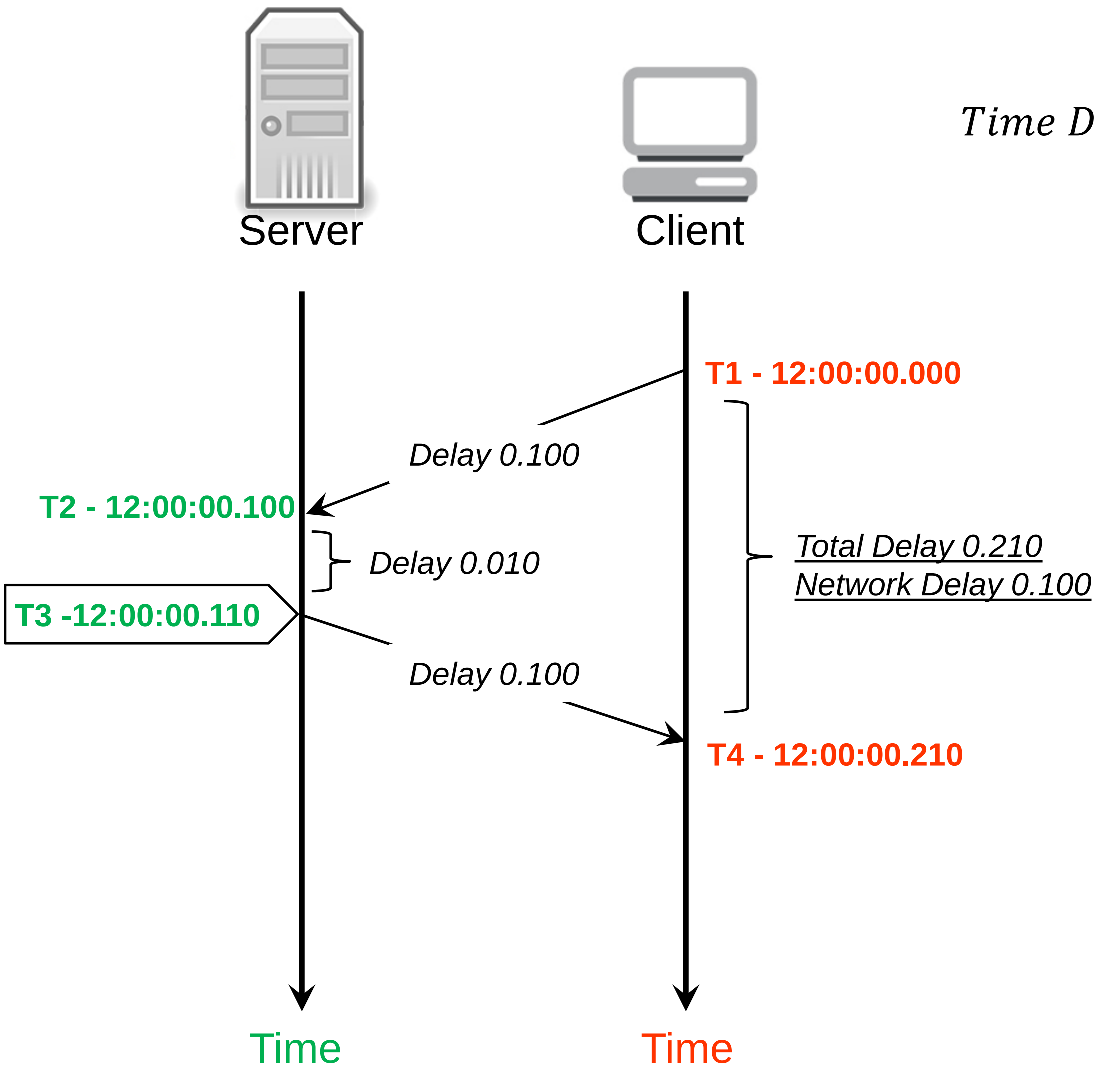
NTP Time Synchronization



- Server broadcast time information to all listeners
- Major error sources are the network and processing delays

- Simplest Implementation
- Support One-to-Many

NTP Time Synchronization

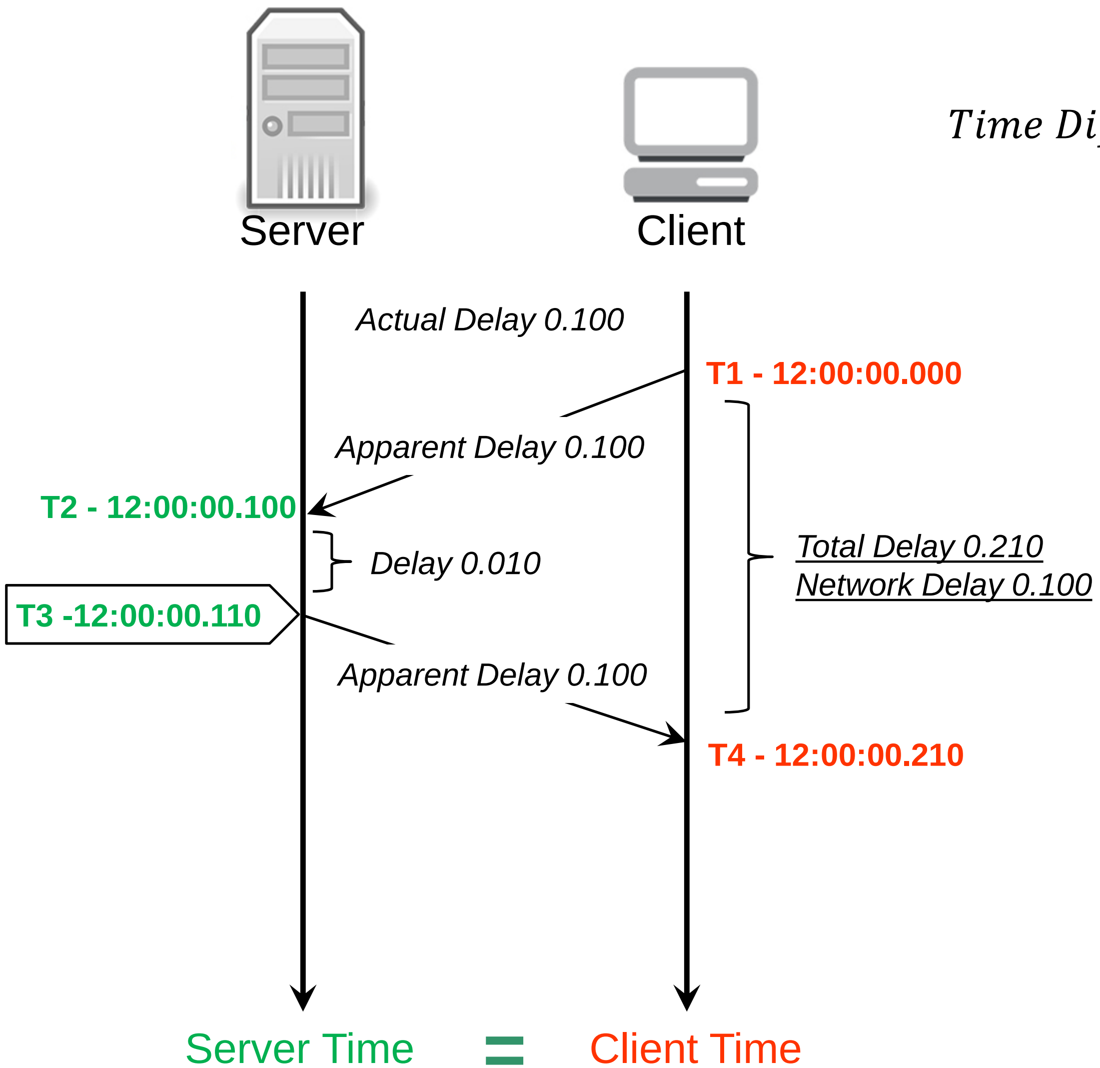


$$Time\ Diff = \frac{(T2 - T1) + (T3 - T4)}{2}$$

- Client requests time
- Server responds
- Time request/response contain all time stamps

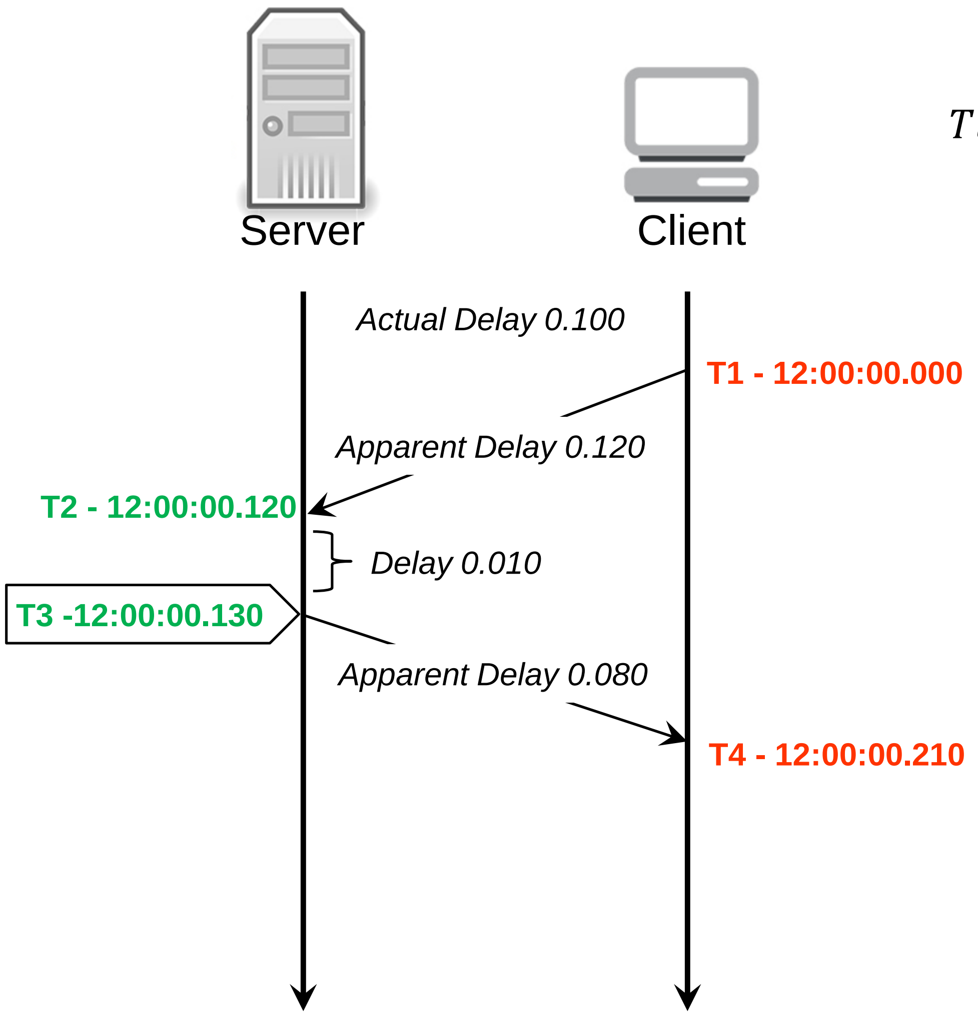
- “Software-only” solution
- Calculate clock offset and network delay
- Adjust time and frequency

NTP Time Synchronization
Example 1 - Synchronized



$$
\begin{aligned}
Time\ Diff &= \frac{(T2 - T1) + (T3 - T4)}{2} \\
&= \frac{(0.100 - 0.000) + (0.110 - 0.210)}{2} \\
&= \frac{0.100 + (-0.100)}{2} \\
&= 0.000\ sec
\end{aligned}
$$

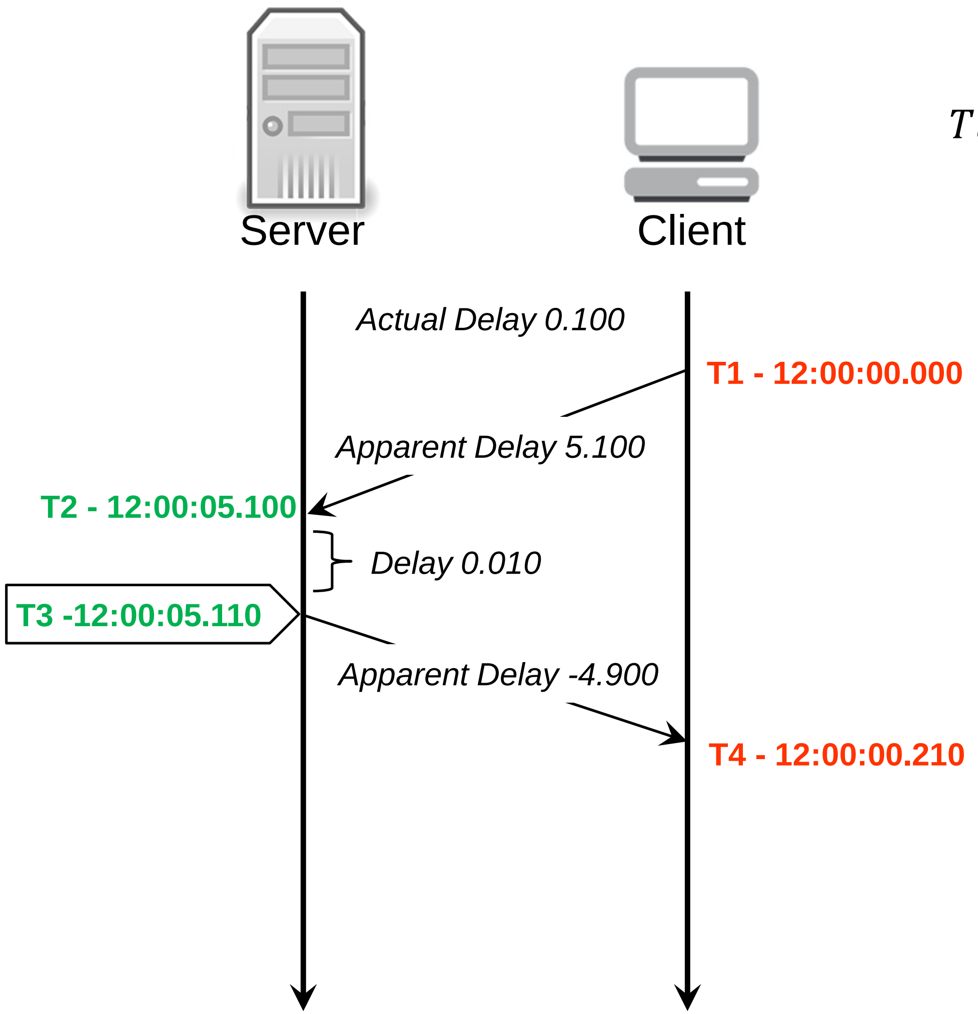
NTP Time Synchronization
Example 2 – Small Error



$$
\begin{aligned}
Time\ Diff &= \frac{(T2 - T1) + (T3 - T4)}{2} \\
&= \frac{(0.120 - 0.000) + (0.130 - 0.210)}{2} \\
&= \frac{0.120 + (-0.080)}{2} \\
&= 0.020\ sec
\end{aligned}
$$

Server Time **>** Client Time by a small (0.020 sec) amount

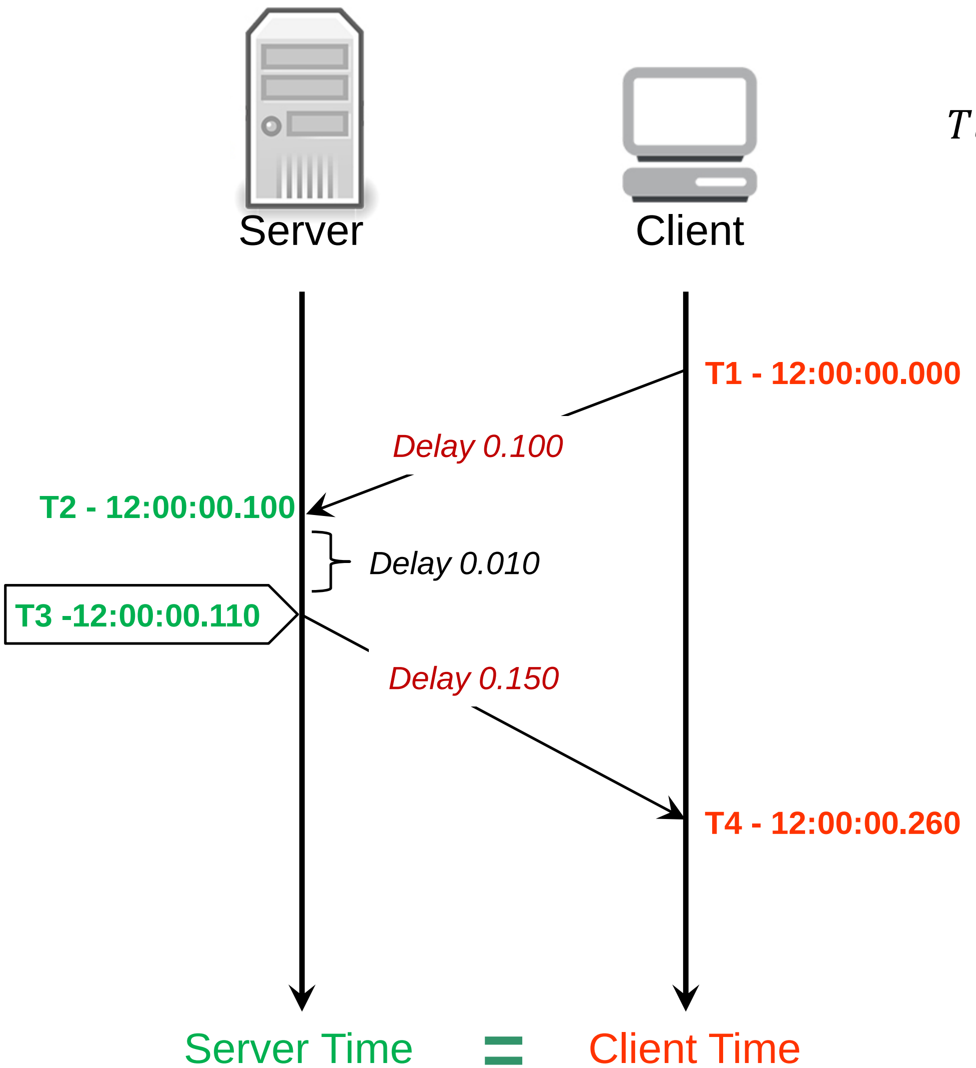
NTP Time Synchronization
Example 3 – Large Error



$$
\begin{aligned}
Time\ Diff &= \frac{(T2 - T1) + (T3 - T4)}{2} \\
&= \frac{(5.100 - 0.000) + (5.110 - 0.210)}{2} \\
&= \frac{5.100 + 4.900}{2} \\
&= 5.000\ sec
\end{aligned}
$$

Server Time > Client Time by a large (5.000 sec) amount

NTP Time Synchronization
Example 4 – Asymmetric Delay



$$
\begin{aligned}
Time\ Diff &= \frac{(T2 - T1) + (T3 - T4)}{2} \\
&= \frac{(0.100 - 0.000) + (0.110 - 0.260)}{2} \\
&= \frac{0.100 + (-0.150)}{2} \\
&= -0.050\ sec
\end{aligned}
$$

Wrong!
Should be 0.000 sec

NTP IANA Considerations

IANA – Internet Assigned Number Authority

- **UDP/TCP Port 123**
- **IPv4 multicast group address 224.0.1.1**
- **IPv6 multicast address ending :101**
- **IANA registry for:**
  - **NTP extension fields**
  - **NTP Reference Identifier codes**
  - **NTP Kiss-o'-Death codes**

Time Clock Disciplining

- **Both Time and Frequency adjustment**
- **Time jumps are bad**
- **Time backup is worse!**
- **Once synchronized system clocks are "disciplined"**
  - **Time is slowly sped up or slowed down to adjust**
  - **The system clock frequency is adjusted to minimize drift**
- **For "large" time errors time must jump**
  - **Linux adjusts the time with a rate of 0.5ms per second**

NTP Leap Seconds

- **A leap second is a one-second adjustment to UTC**
  - **Accommodate the difference between precise time (as measured by atomic clocks) and imprecise observed solar time**
  - **Inserted about every 20 months, on average**
- **NPT is notified on the day of the leap second**
- **Leap second is inserted with the sequence 23:59:59, 23:59:60, 00:00:00**
- **Negative leap second should ever become necessary, it would be deleted with the sequence 23:59:58, 00:00:00, skipping 23:59:59**

NTP vs SNTP

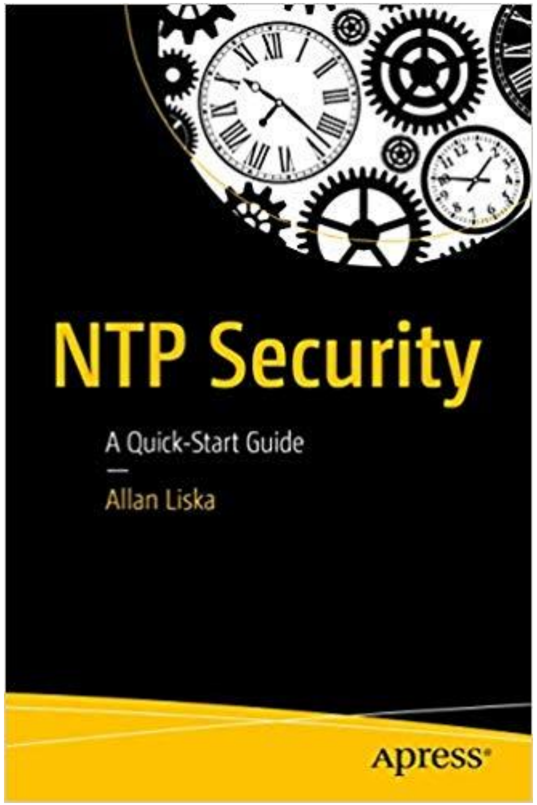
- **SNTP is a simpler subset of NTP**
- **No complicated error mitigation algorithms**
- **SNTP intended for**
  - **Servers with a single reference clock**
  - **Clients with a single upstream server and no dependent clients**
- **NTP and SNTP servers and clients are completely interoperable**
- **Can be intermixed in NTP subnets**

- **Which to use? NTP!**

Security

- **1992 - NTP added authentication based on secret MD5 hashed keys**
  - **MD5 is not considered secure anymore**
  - **Secret key cryptography is difficult to implement on a wide scale**
- **2003 – NTP added authentication based on “Autokey” public key encryption**
  - **Effective at the time but is now considered weak**
- **2007 - Work began on the Network Time Security**
  - **Still working on it!**

NTP Security Book



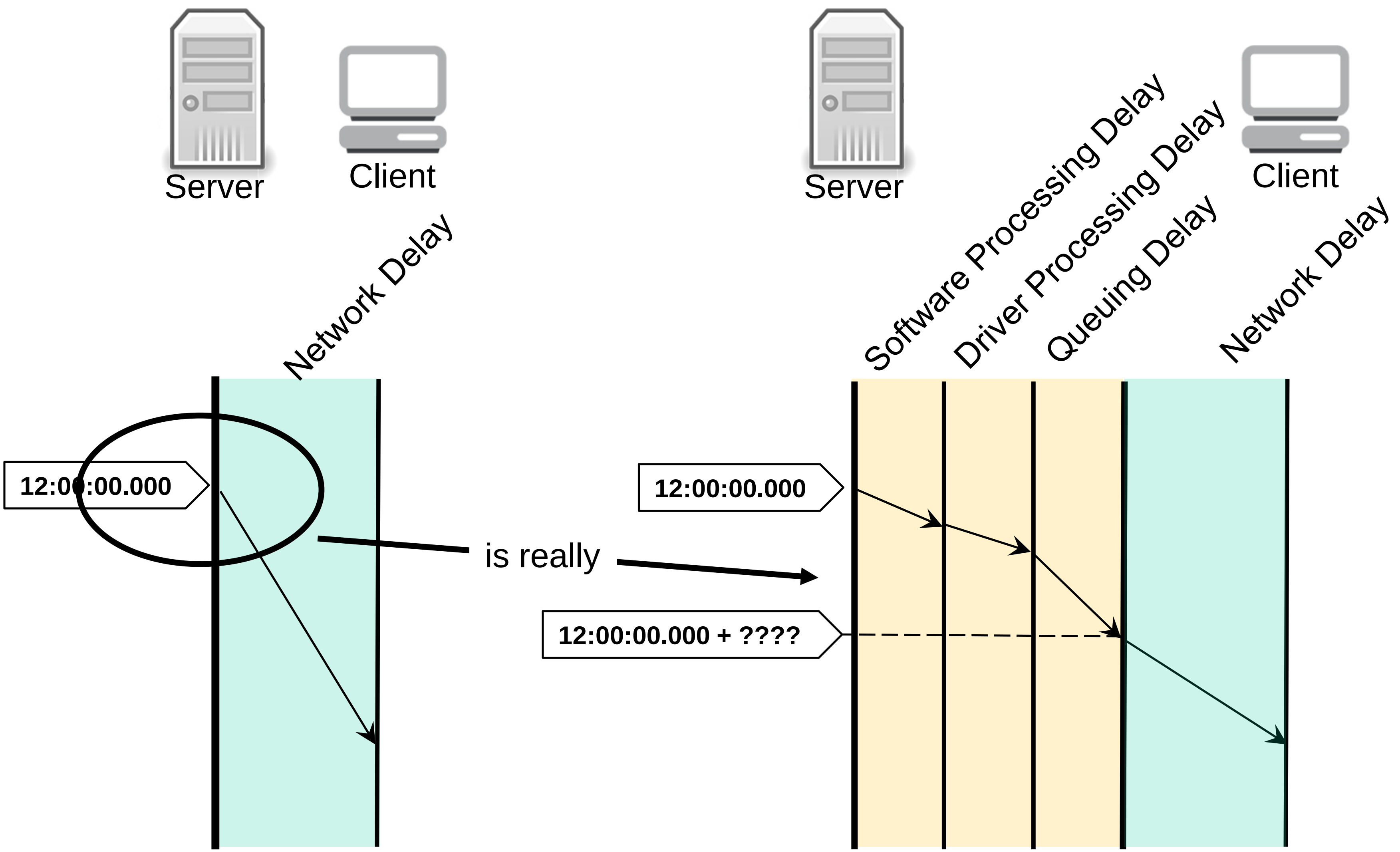
- **Paperback:** 108 pages
- **Publisher:** Apress; 1st ed. edition (December 12, 2016)
- **Language:** English
- **ISBN-10:** 9781484224113
- **ISBN-13:** 978-1484224113
- **ASIN:** 1484224116

Windows NTP Time Accuracy

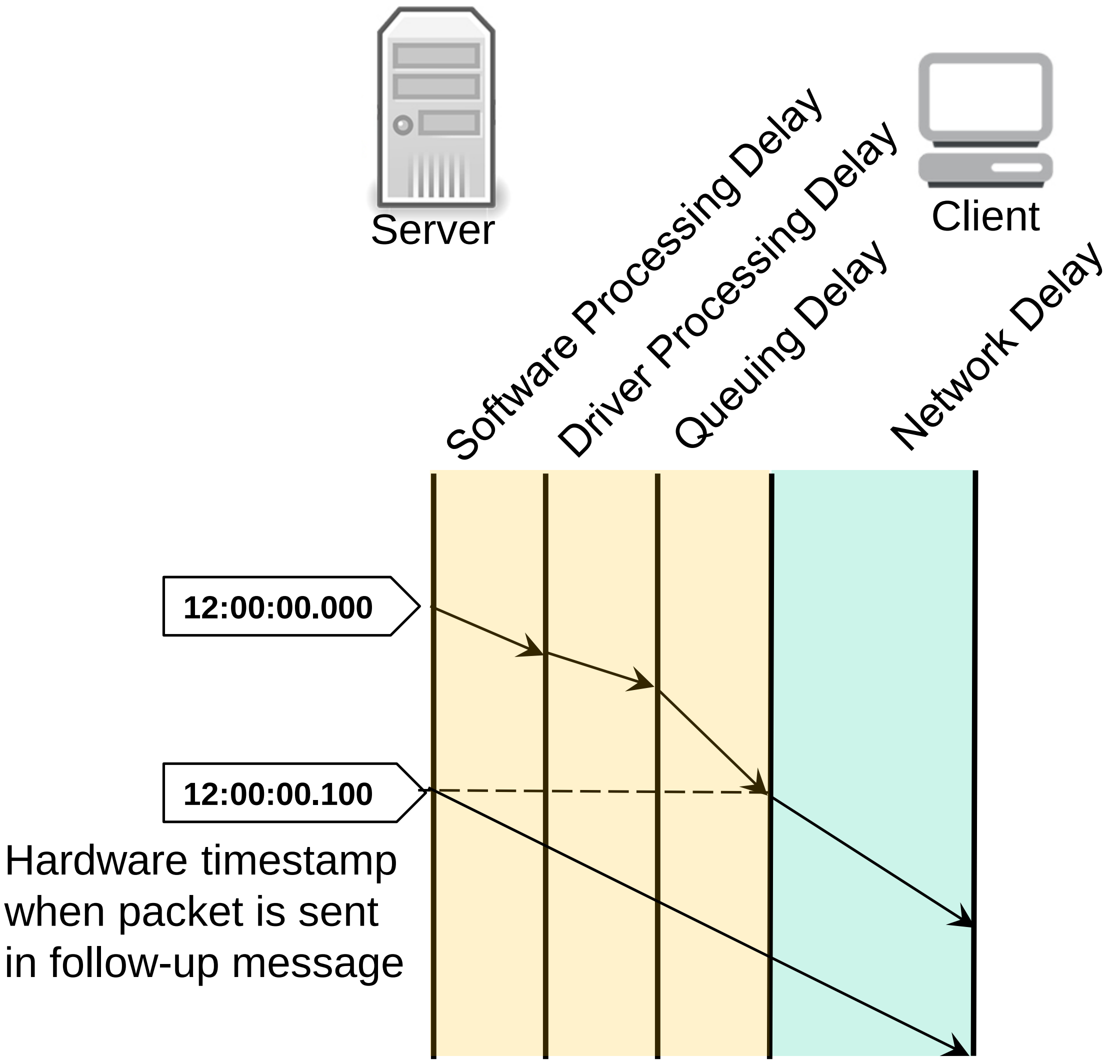
- **Windows 2000 and Windows XP only implements SNTP, and violates several aspects of the NTP version 3 standard**
- **Windows Server 2003 and Windows Vista implement a compliant implementation of NTP**
  - **Microsoft states that W32Time cannot reliably maintain time synchronization with one second accuracy**
- **Windows 10 / Windows Server 2016 and newer accuracy**
  - **1 second**
  - **50ms**
  - **1ms**

https://docs.microsoft.com/en-us/windows-server/networking/windows-time-service/support-boundary

The NTP Software-Only Problem



The Hardware Solution



Precision Time Protocol IEEE1588

- **The Precision Time Protocol is a protocol used to synchronize clocks over a computer network.**

- **Accuracy better than 100 nanoseconds can be reached.**

PTP V1 vs V2

IEEE1588-2002 (aka PTP version 1)

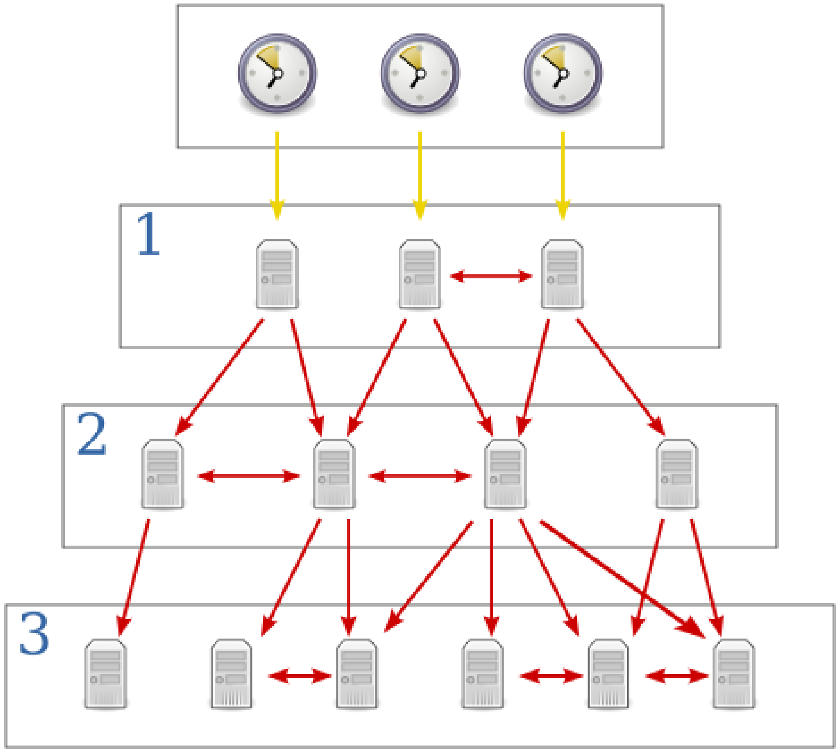
IEEE1588-2008 (aka PTP version 2)

- **PTPv1**
  - **Introduces hardware timestamps and follow up messages**
  - **Defines functions of “PTP-aware” switches and routers**
- **PTPv2 offers:**
  - **Higher effective resolution when communicating time stamps**
  - **Additional flexibility in communication, by introducing unicast messaging and more flexible sync message rates.**
  - **Adds transparent clock functionality for better synchronization across networks.**
- **PTPv2 does not interoperate with PTPv1**

PTP Time Stamps

- **PTP time is a 64 bit quantity**
  - 32-bit part for seconds
    - Typically seconds since Midnight Jan 1st, 1970
      - Based on International Atomic Time (TAI) not UTC
      - Grandmaster communicates the current offset between UTC and TAI
    - Roll over every 136 years
  - 32-bit part for fractional second
    - “Fractional Seconds” are expressed integer nanoseconds
    - Least significant bit is 1 nanosecond

PTP Clocks

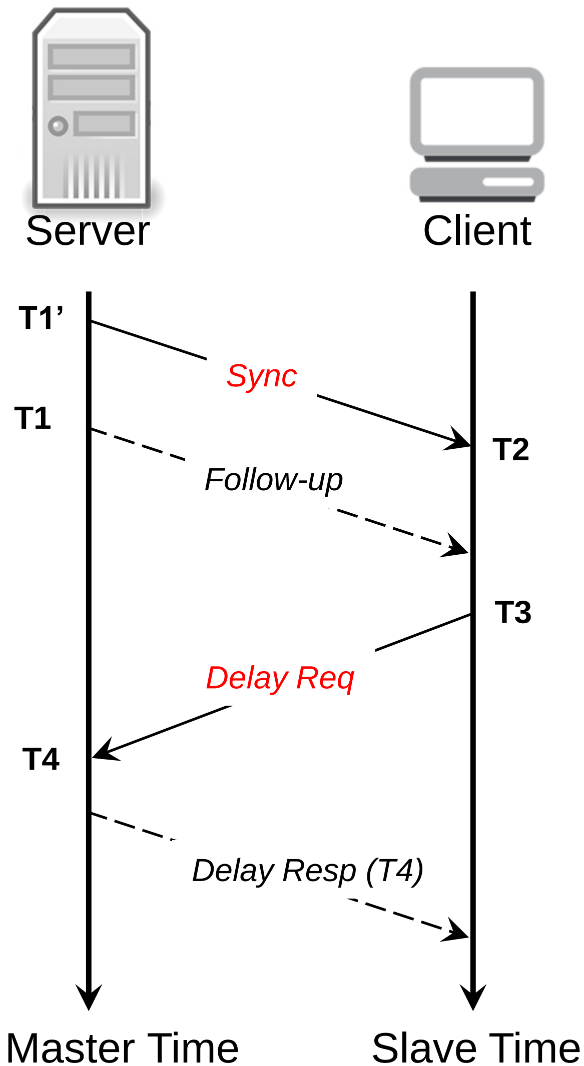


- **Hierarchy of clocks**
  - **“Stratum”**
- **Accuracy**
  - Tens of milliseconds over the public Internet
  - Better than one millisecond accuracy in local area networks under ideal conditions.
  - Asymmetric routes and network congestion can cause errors of 100 ms or more

PTP Message Types

- ***Sync*, *Follow_Up*, *Delay_Req* and *Delay_Resp***
  - **Used by *ordinary* and *boundary* clocks and communicate time-related information used to synchronize clocks across the network**
- ***Pdelay_Req*, *Pdelay_Resp* and *Pdelay_Resp_Follow_Up***
  - **Used by *transparent (PTPv2 only)* clocks to measure delays across the communications medium so that they can be compensated for by the system**
- ***Announce* messages**
  - **Used by the Best Master Clock Algorithm *(PTPv2 only)* to build a clock hierarchy and select the *grandmaster***
- ***Management* messages**
  - **Used by network management to monitor, configure and maintain a PTP system.**
- ***Signaling* messages**
  - **Used for non-time-critical communications *(PTPv2 only)* between clocks**

PTP Sync - Delay Request - Response



Master / Slave Configuration

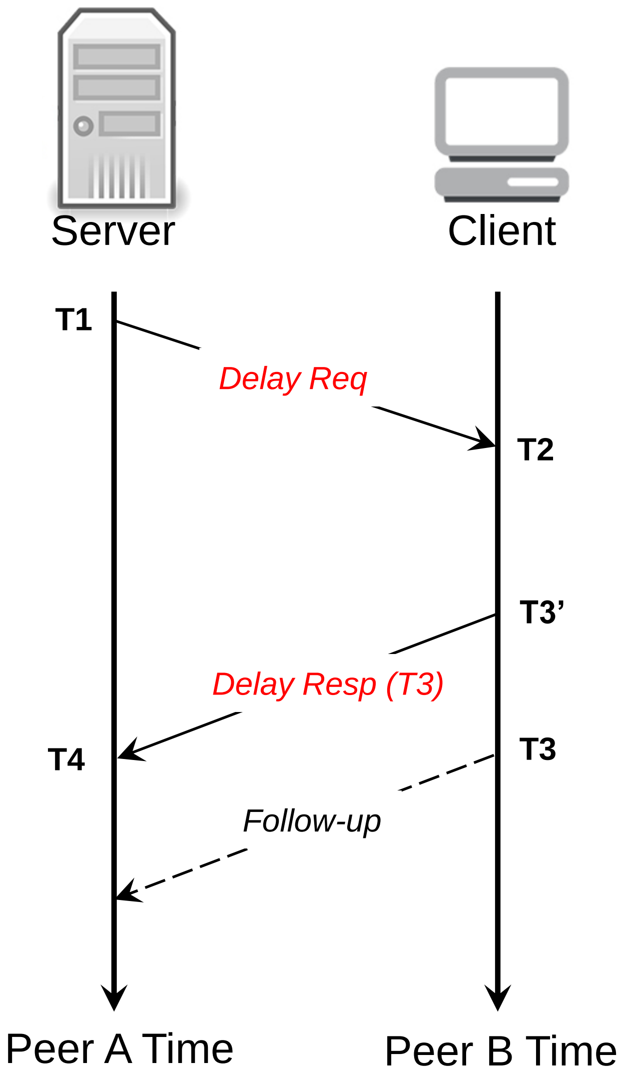
Delay Request - Response mechanism

- Server sends time
- Server sends corrected follow-up time
- Client requests delay calculation
- Server sends delay response

- Message in RED are PTP Time Critical messages
- All other PTP message are General messages

$$Time\ Diff = \frac{(T2 - T1) + (T3 - T4)}{2}$$

PTP Sync – Peer Delay



Peer to Peer Configuration

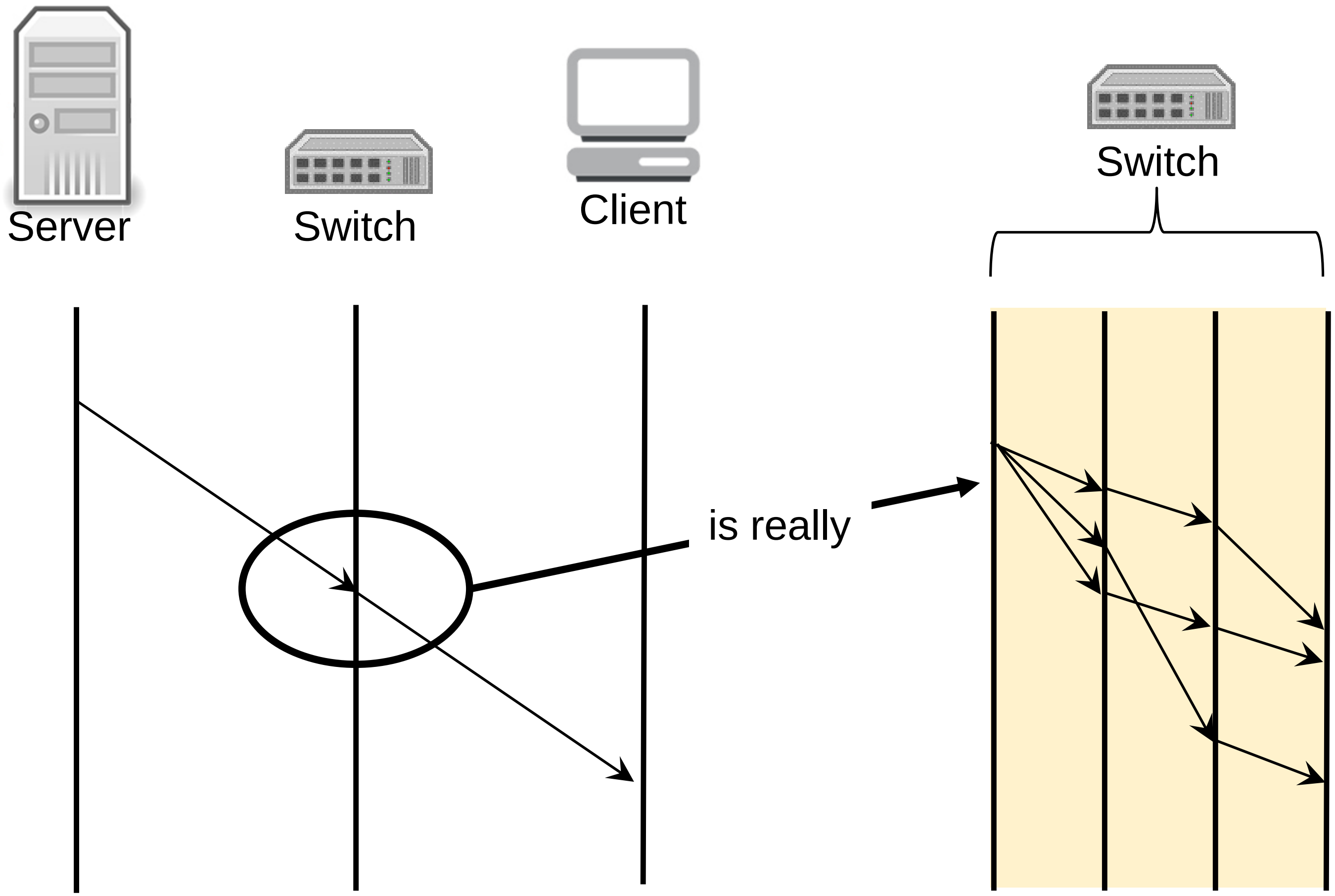
- Server sends time
- Server sends corrected follow-up time
- Client requests delay calculation
- Server sends delay response

PTP IANA Considerations

IANA – Internet Assigned Number Authority

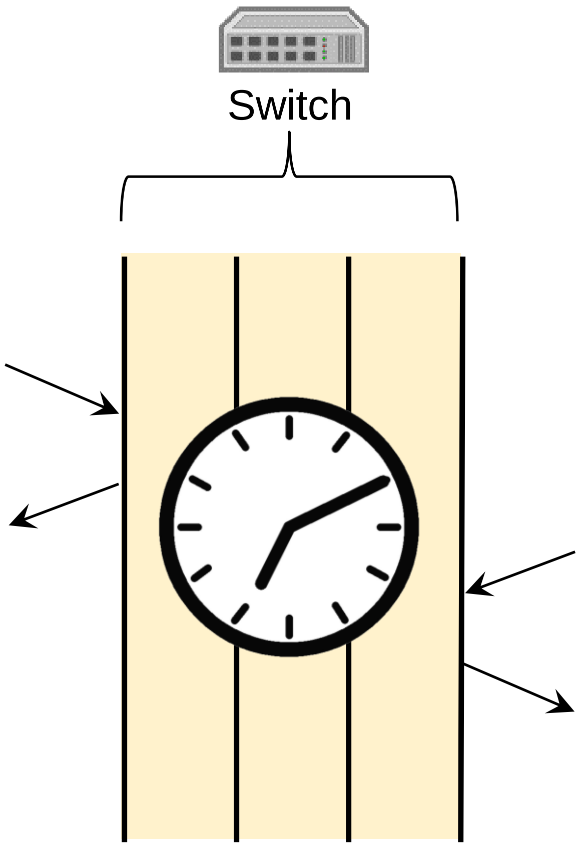
- **UDP Only**
- **Time-critical *Event* messages (Sync, Delay_Req, Pdelay_Req and Pdelay_Resp) use UDP Port 319.**
- ***General* messages (Announce, Follow_Up, Delay_Resp, Pdelay_Resp_Follow_Up, management and signaling) use UDP port 320**
- **Implementations are also available for bare IEEE802.3 Ethernet, Device Net, Control Net and Profinet**

The Switch / Router Problem



The Switch / Router Solution #1

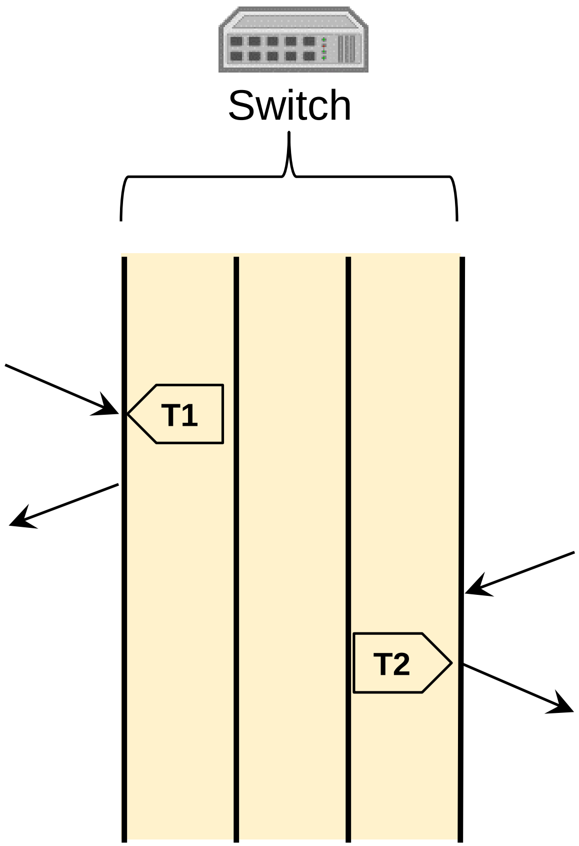
PTP Boundary Clock



- **PTP aware switch / router has internal PTP clock**
- **Defined in PTPv1 and PTPv2**

The Switch / Router Solution #2

PTP Transparent Clock



- PTP aware switch / router timestamps incoming and outgoing PTP packets
- PTPv2 Only
- Adds Times T1 and T2
- Defined in PTPv2
- Two Types
  - End to End Transparent Clock
  - Peer to Peer Transparent Clock

PTP Transparent Clocks

- **End to End Transparent Clock**
  - **More versatile, because it can handle ordinary switches and routers**
- **Peer to Peer Transparent Clock**
  - **Each device manages keeping track of link delays**
  - **Works well when every switch is either a transparent clock or a boundary clock.**

Different types of clocks

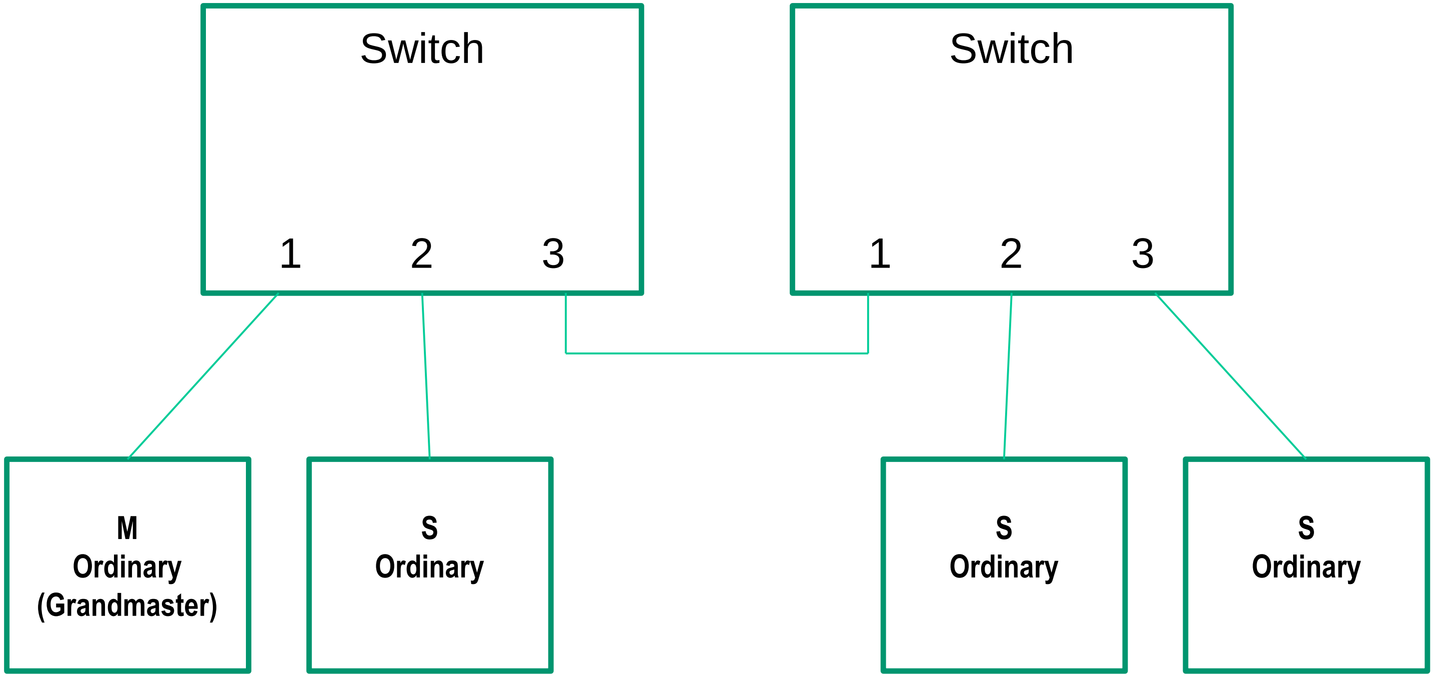
- A **Grand Master Clock** is the root timing reference which transmits synchronizing information for all other clocks in the PTP network.

- An **Ordinary Clock** is a device that uses a single network connection for time synchronization. It can act as a master or a slave clock.

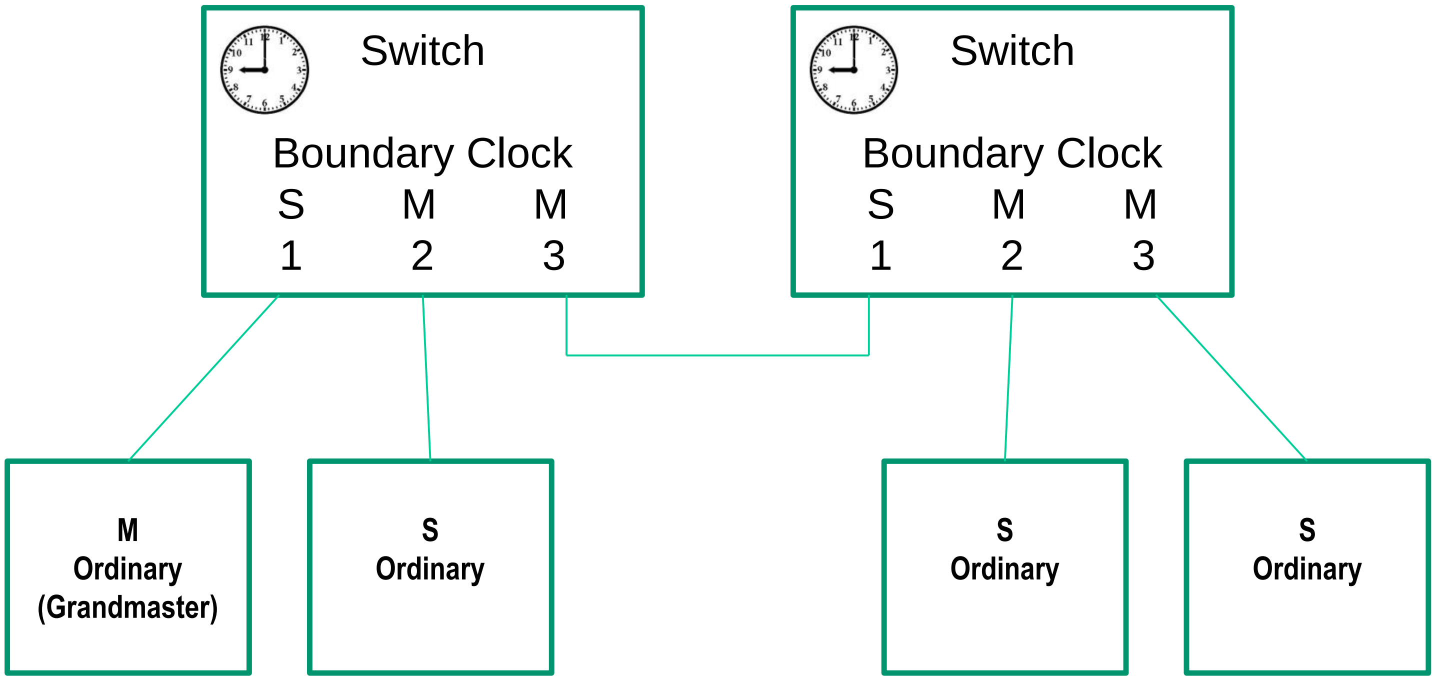
- A **Boundary Clock** uses multiple network connections and can synchronize network segments.

- A **Transparent Clock** (PTPv2 only). It conveys PTP messages and modifies the time information with the time slice the message spent passing through the network equipment. => Better compensation of message delays.

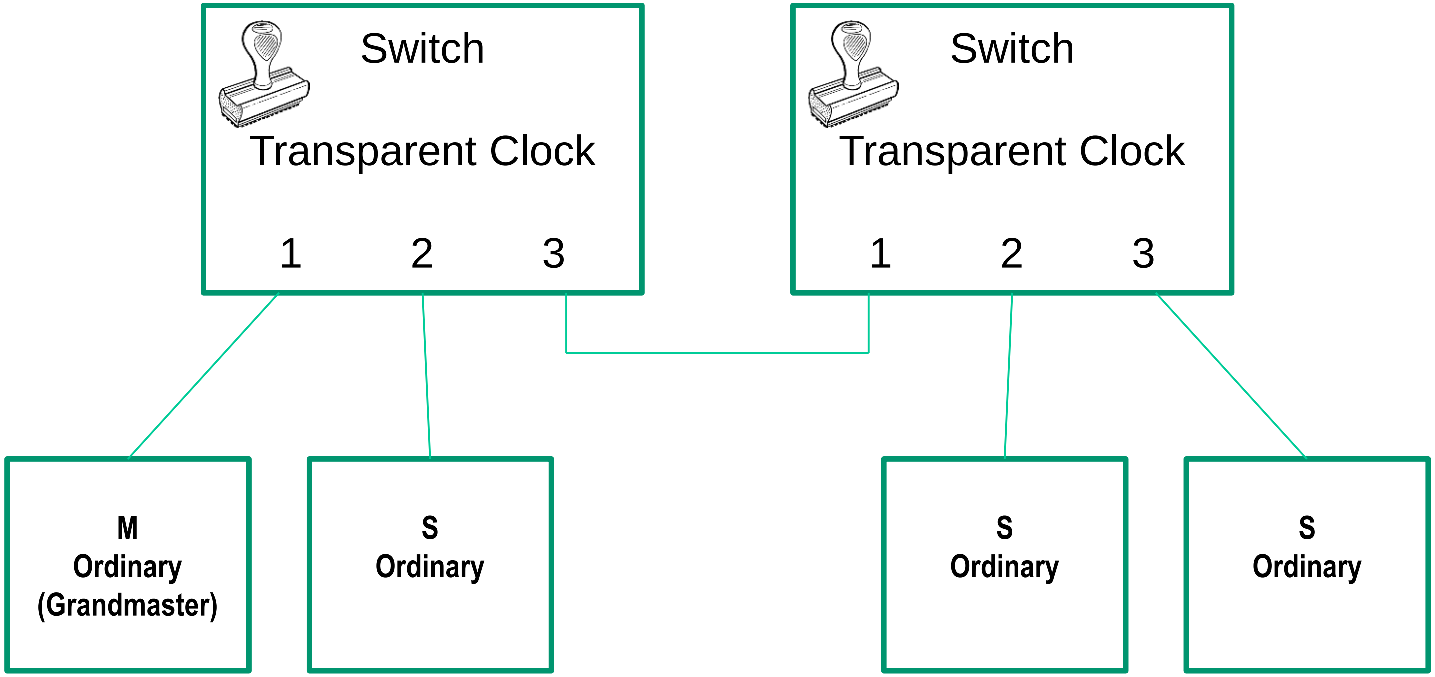
Clock Network
Switch / Router



Clock Network
PTP Aware Switch



Clock Network
PTP Aware Switch



Best Master Clock Algorithm

- **Selection of the best master reference clock in the network**
  - **Uses the "Best Master Clock Algorithm" (BMCA)**
- **Criteria for selection:**
  - **Unique identifier: MAC Address of network card**
  - **Quality: *Expected* timing deviation, clock accuracy**
  - **Priority: Stratum, priority 1 and priority 2, administratively set.**
  - **Variance: Stability based of observation against reference clock**
- **Also static selection of time sources available using pre-defined configuration variables**

Network Time in Recorders

- **Use of the IRIG serial time code standard (IRIG 200-16) is largely being replaced by network based time**
- **PTP accuracy is as good as or better than IRIG 200**
- **Wiring is more convenient**

Hardware Design Considerations from IRIG 200-16

Table C-1. Time Code Generator Hardware Minimum Design Considerations			
Code	**Level (dc) Pulse Rise Time Between the 10 and 90% Amplitude Points**	**Jitter Modulated at Carrier Frequency**	**Jitter Level (dc) Pulse-to-Pulse**
Format A	≤200 ns	≤1%	≤100 ns
Format B	≤1 μs	≤1%	≤200 ns
Format D	≤1 μs	≤1%	≤200 ns
Format E	≤1 μs	≤1%	≤200 ns
Format G	≤20 ns	≤1%	≤20 ns
Format H	≤1 μs	≤1%	≤200 ns

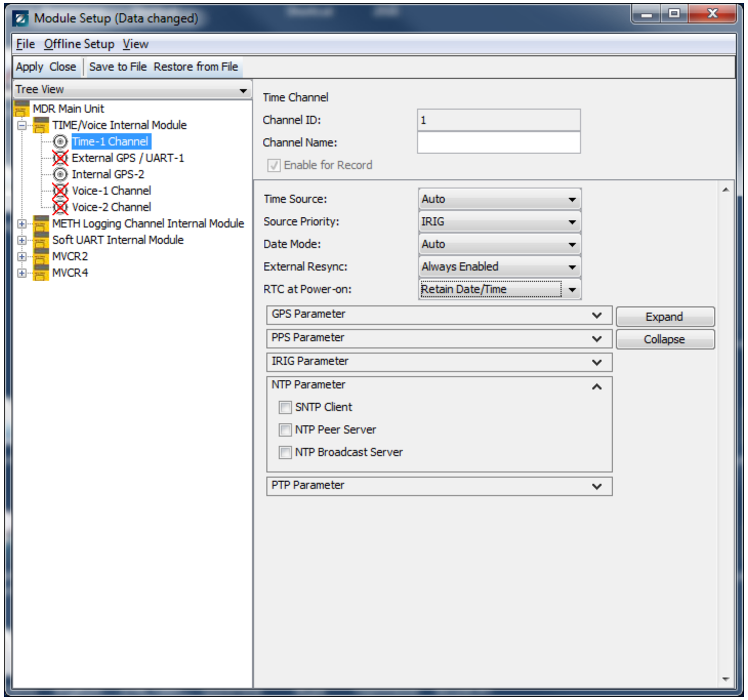
Is Accuracy Important?

- **Maybe!**
  - **If you have data recorded at two different locations and you want to "glue" the data sets together to make one complete and total mission, timing accuracy may be important.**
- **Maybe Not!**
  - **If you are interested in a sequence of events and the timing relationship between those events, then timing accuracy may not be important.**
- **Absolute versus Relative Timing**
  - **Absolute timing means being aligned to the world**
  - **Relative timing means being aligned to itself**

Zodiac G/MDR and XMA

Zodiac G/MDR and XMA

- **Supports**
  - **SNTP client**
  - **NTP client**
  - **NTP Peer Server**
  - **NTP Broadcast Server**
  - **PTPv1 client and server**
  - **PTPv2 client and server**
- **Configured with setup**
  - **D4Recorder**
  - **Various manual offsets and corrections**



Zodiac G/MDR and XMA

Accuracy of MDR Time Sync via PTP

- **Devices with legacy controller:**
  - **1PPS offset between 2 MDR_HS is better than 1µs.**
- **Devices with new controller and without high precision oscillator reference time counter tuning enabled:**
  - **1PPS offset between 2 MDR_HS is better than +-400ns.**
- **Devices with new controller and with high precision oscillator reference time counter tuning enabled:**
  - **1PPS offset between 2 MDR_HS devices is even better than 10ns.**

Accuracy of XMA Time Sync via PTP

- **Accuracy typically < 150 nsec**

TTC

- Support PTPv1 and PTPv2
- *Sub-microsecond* error using hardware time-stamping
- Dynamic selection of redundant time sources (Grand Master election) using the “Best Master Clock Algorithm” (BMCA)
- Static selection of time sources using pre-defined configuration variables
- TAI Time scale with the standard POSIX epoch
  - Seconds since January 1st 1970

TTC – PTP Versions

- **IEEE 1588-2002 (PTPv1)**
  - **Original PTP protocol**
  - **Supported by most CW-TTC network products**
    - HSC, nMGR, nGWY

- **IEEE 1588-2008 (PTPv2)**
  - **Most recent PTP protocol version**
  - **Supported by select CW-TTC network products (all new products support PTPv2 & PTPv1)**
    - NSW-12GT-1, NSW-5GT-TGE, ADSR,MnACQ-2600, nDAU-26XX

- **Comparison**
  - **PTPv2 more widely adopted**
    - TTC was an early adopter of PTPv1 and thus still offers a wide variety of PTPv1 products
      - All TTC PTPv2 capable products are backwards compatible with PTPv1
  - **PTPv2 supports faster (>1Hz) message rates**
  - **Message format differences (incompatible)**
  - **Synchronization performance is the same between versions**
    - Time stamping is performed the same way; no performance hit from running in PTPv1 mode

TTC – Managed Switches

- **TTC offers managed switches:**
  - **NSW-5GT-TGE**
  - **NSW-12GT**
- **Latency behavior for each family different**
  - **Second generation: ASIC**

NSW-12GT

- **A transparent clock forwards PTP traffic and provides corrections for the network time as it switches data**
- **As a boundary clock, the NSW-12 terminates all PTP traffic and relay frames.**
- **In boundary mode, the switch searches the network for grandmaster switches, and if it has a superior external time source, becomes the grandmaster. If it does not, it remains a boundary or slave switch.**

Ampex

- NTP
  - RFC 958/1119/1305/5905
- PTP
  - IEEE 1588
    - v1 / v2?

Calculex

- **No information on Calculex capabilities**

Wideband Systems

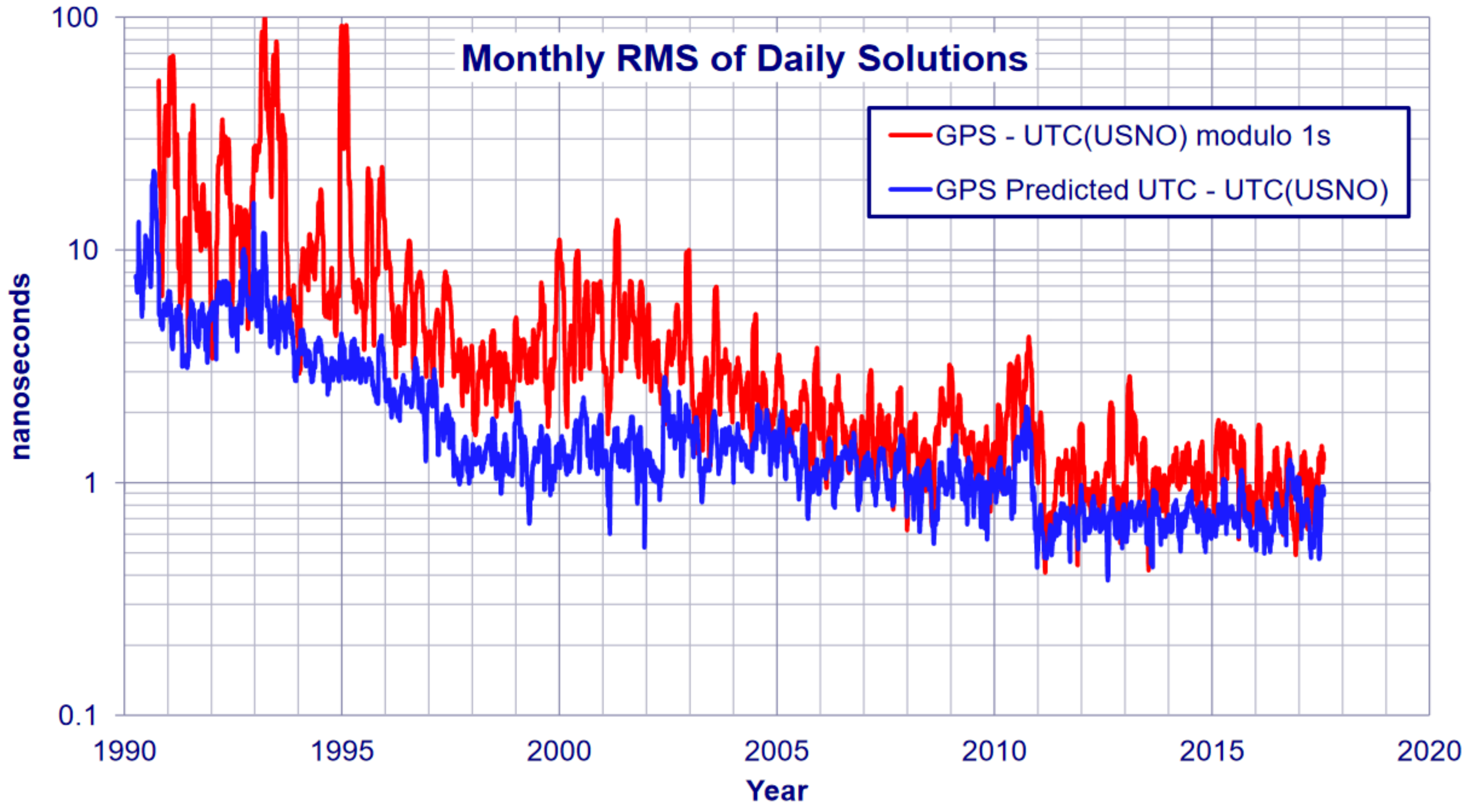
- **No network time**
- **IRIG 200 only**

GPS as a Time Source

- **GPS Time is slowly adjusted to maintain alignment with UTC**
  - **No leap seconds though**

- **GPS time accuracy is related to GPS position accuracy**
  - **GPS calculates 4 unknowns… X, Y, Z, and time**
  - **GPS signals travel at the speed of light**
    - 1 foot per nanosecond
  - **If GPS position error is 100 feet then time error may be on the order of 100 nanoseconds**

GPS Time Stability

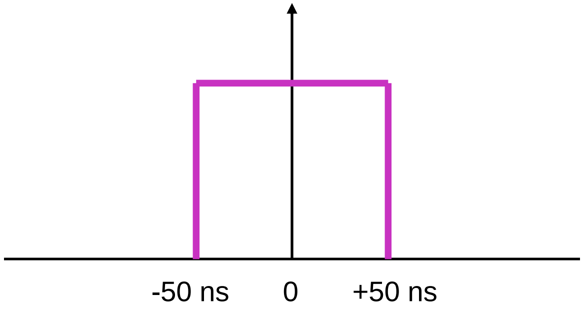


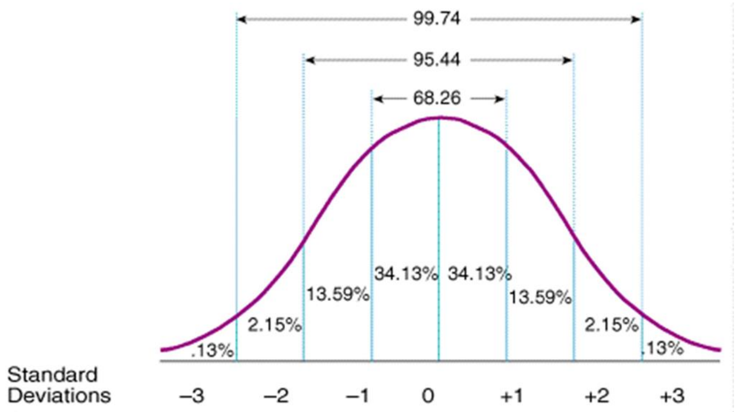
GPS as a Time Source

- **How accurate is GPS time from a GPS receiver?**
- **Just about every quoted accuracy figure is WRONG!**
- **GPS receiver time error, like GPS position error, is not bounded**
  - **Error is probabilistic and needs to be quoted as such**

WRONG
GPS Time Error < 50 nSec

RIGHT
GPS Time Error < 50 nSec 95% of the time





GPS Accuracy Specs

Masterclock

RECEIVER OPTIONS

	GPS Option	GPS+GNSS Option
Satellites	12-channel, up to 12 satellites simultaneously, parallel	32-channel, up to 24 satellites simultaneously, parallel
Frequency	L1, 1575 MHz	L1, 1575 MHz and 1598-1606 MHz
Antenna Connector	SMA female	SMA female
RF Bias to Antenna	5 V DC, center pin	5 V DC, center pin
PPS	50 ms, TTL level, on-time leading edge	50 ms, TTL level, on-time leading edge
Accuracy	±60 ns of UTC	±15 ns of UTC

Brandywine Communications

- IEEE 1588-2008 (v2) Time protocol
- Distributes frequency, phase and time-of-day to ren
- Advanced hardware-generated timestamps
- GPS input source
- ±100 ns timing accuracy when locked to GPS
- Highly stable internal oscillator maintain accurate sy
- Auxiliary outputs include 1PPS, 10MHz, 2.048 MHz,
- 19 inch 1U high rack mountable chassis

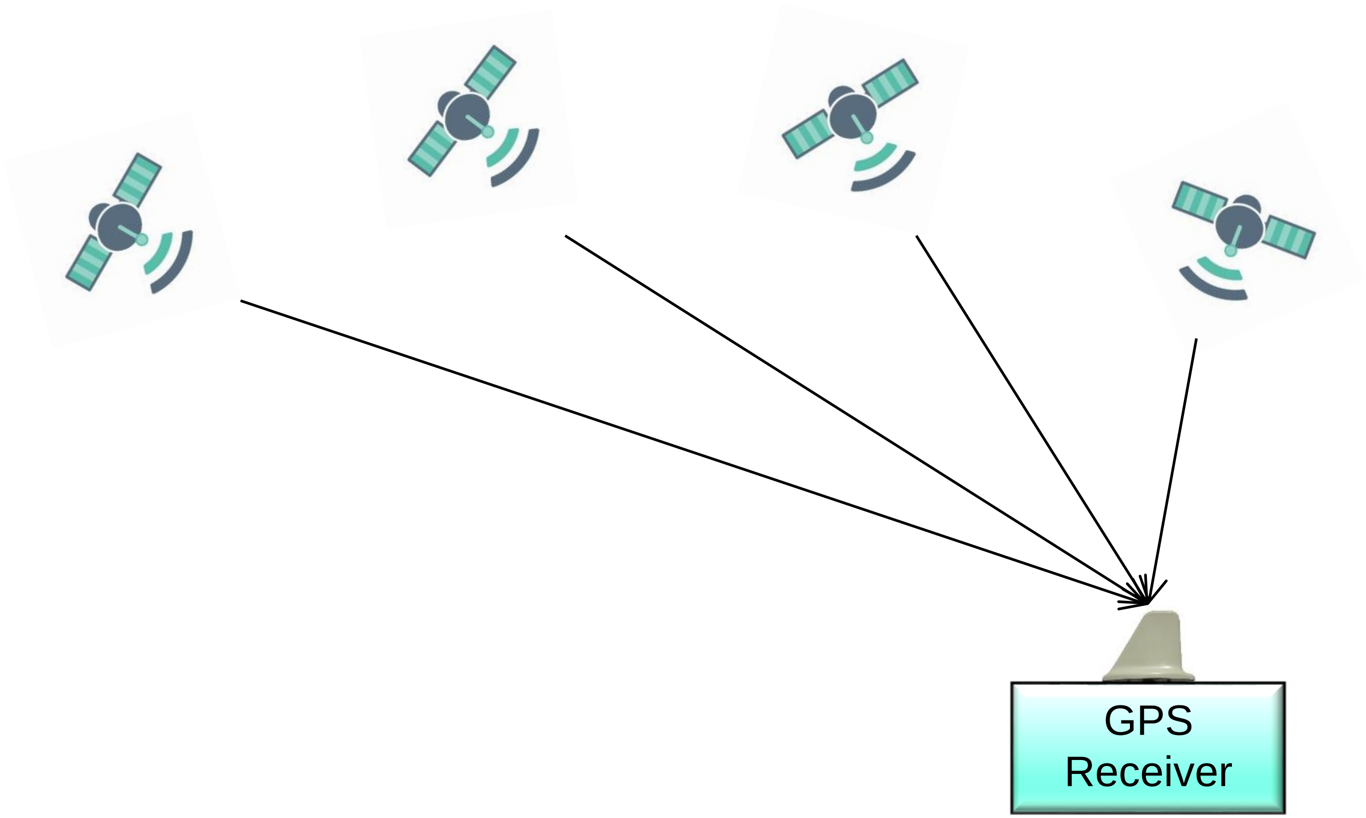
Meinberg

Pulse outputs	Pulse Per Second (PPS) via BNC connector (TT
Accuracy of pulse outputs	< ±100ns (OCXO HQ, OCXO DHQ, Rubidium)
Interface	Two independent serial RS232-interfaces, me

The Science of Timekeeping HP Application Note 1289

Currently, GPS can be used to obtain an estimate of the UTC(USNO MC) clock. If the time output of a good multi-channel Clear Access (C/A) code GPS receiver is averaged for one day against a sufficiently stable local clock, such as a cesium standard, the resulting estimate of UTC(USNO MC) will be within 20 ns 95 percent of the time. Since UTC(USNO MC) is steered to be within 20 ns of UTC at least 95 percent of the time, we can expect that the GPS broadcast correction will be within 30 ns of UTC 95 percent of the time. The frequency

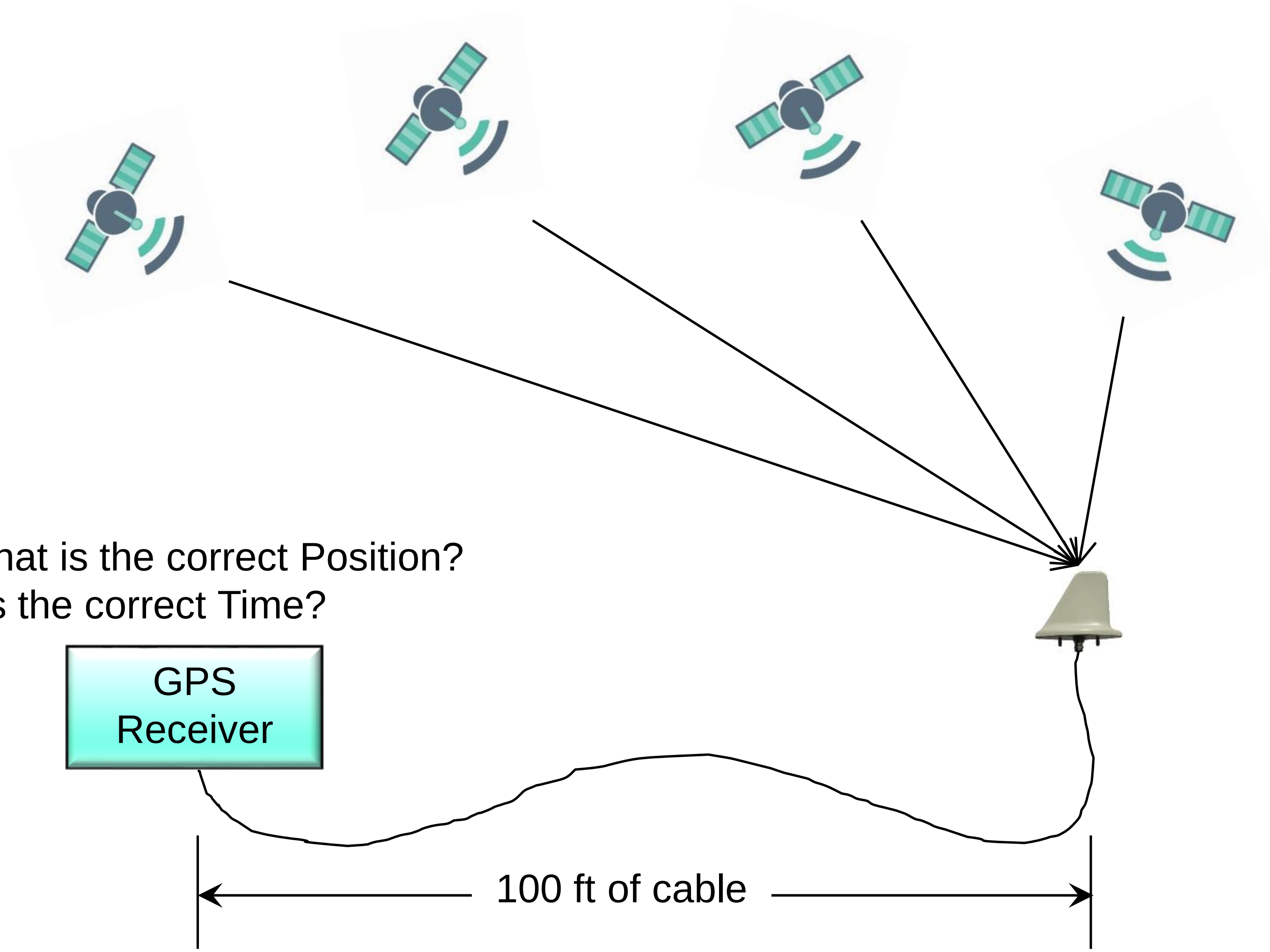
The GPS Antenna Cable Problem



Accurate Position and Time

The GPS Antenna Cable Problem

Now what is the correct Position?
What is the correct Time?

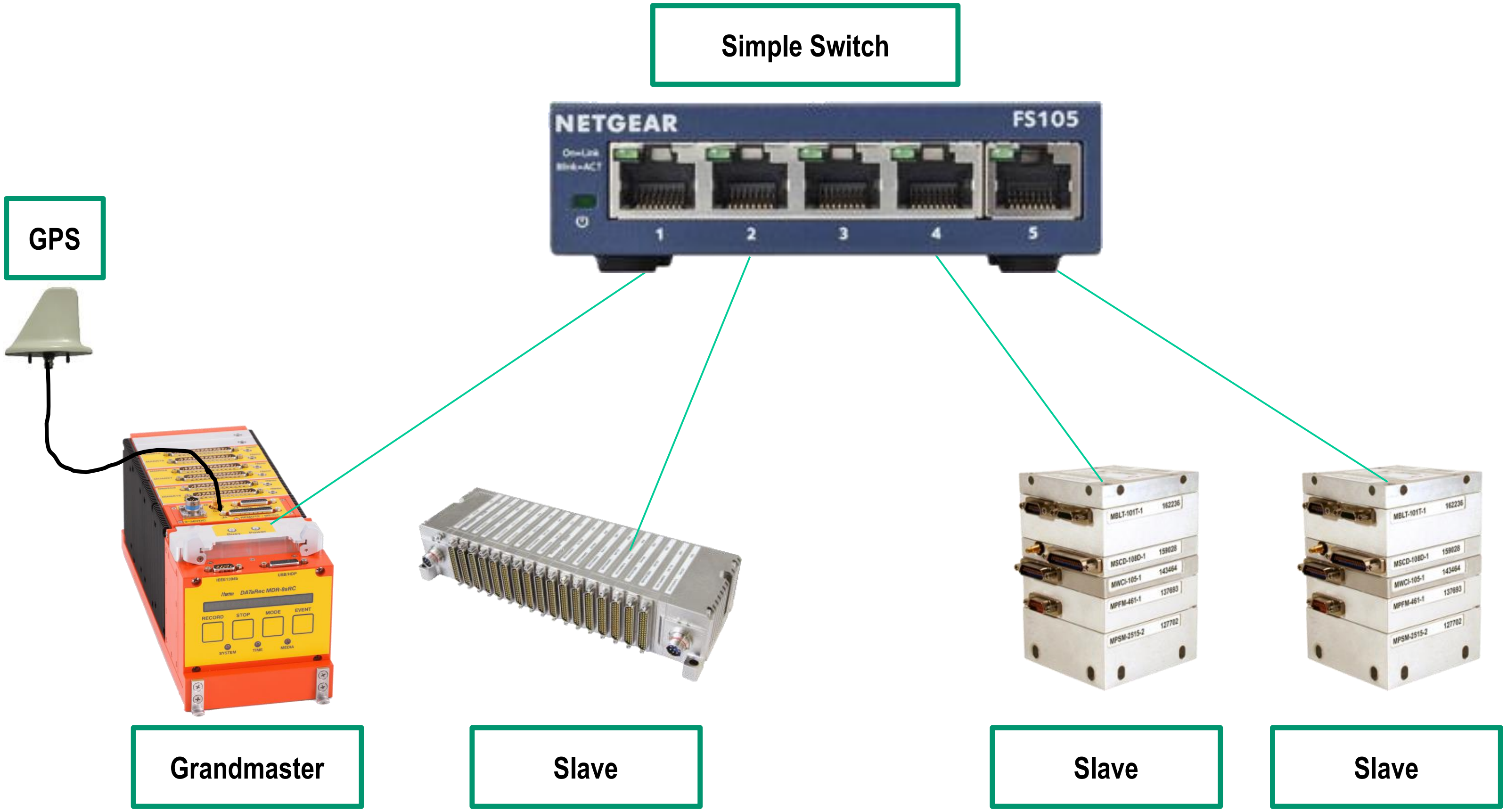


Hold Over Clocks

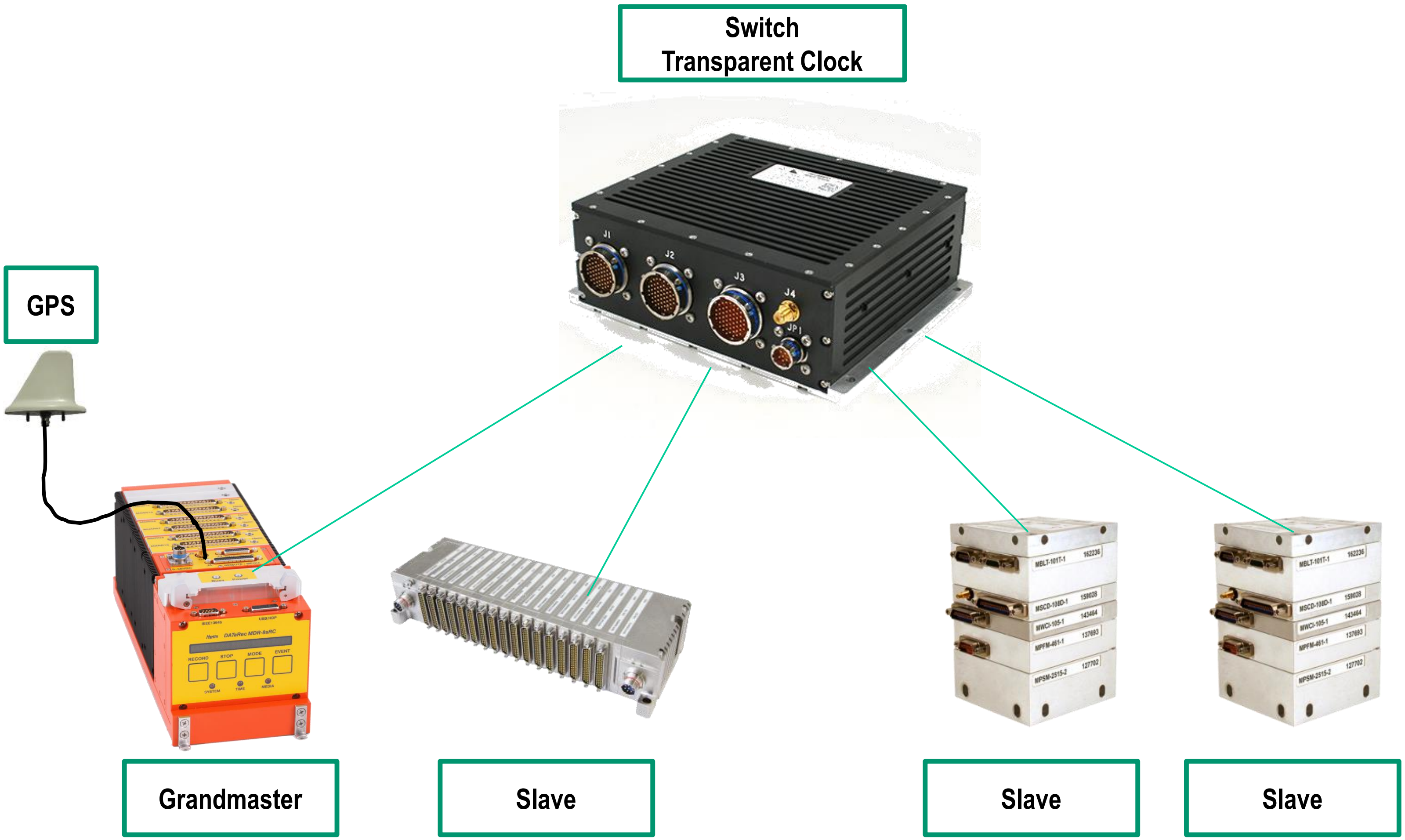
- **Commercial Cesium clocks provide stratum 1, frequency accuracy directly without external referencing**
- **Rubidium clocks can provide microsecond holdover for up to one week**
- **Chip scale atomic clocks are presently available that enable microsecond timing level hold over for many hours with relatively low Size, Weight, and Power**

Some Practical Examples

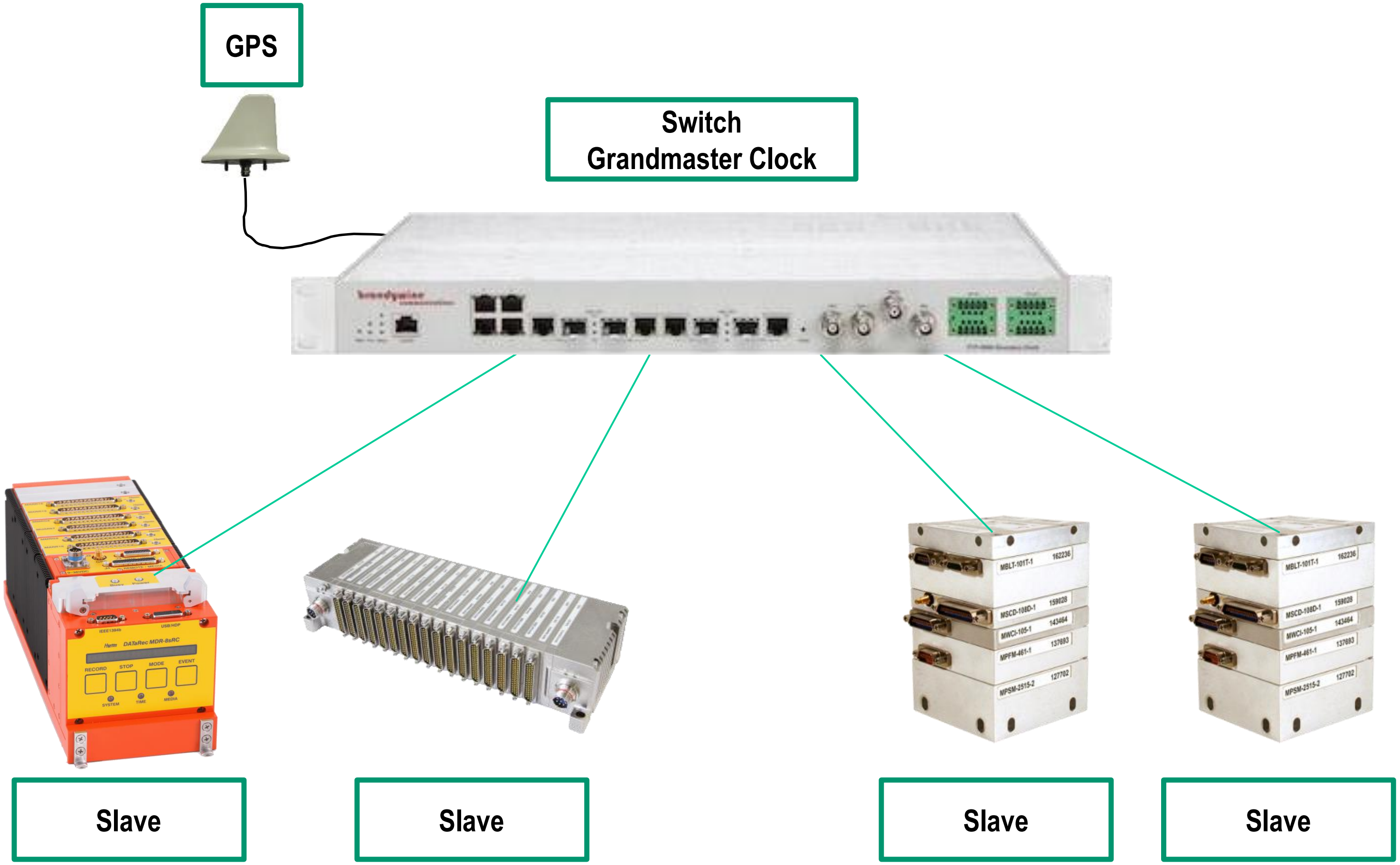
Instrumentation Network



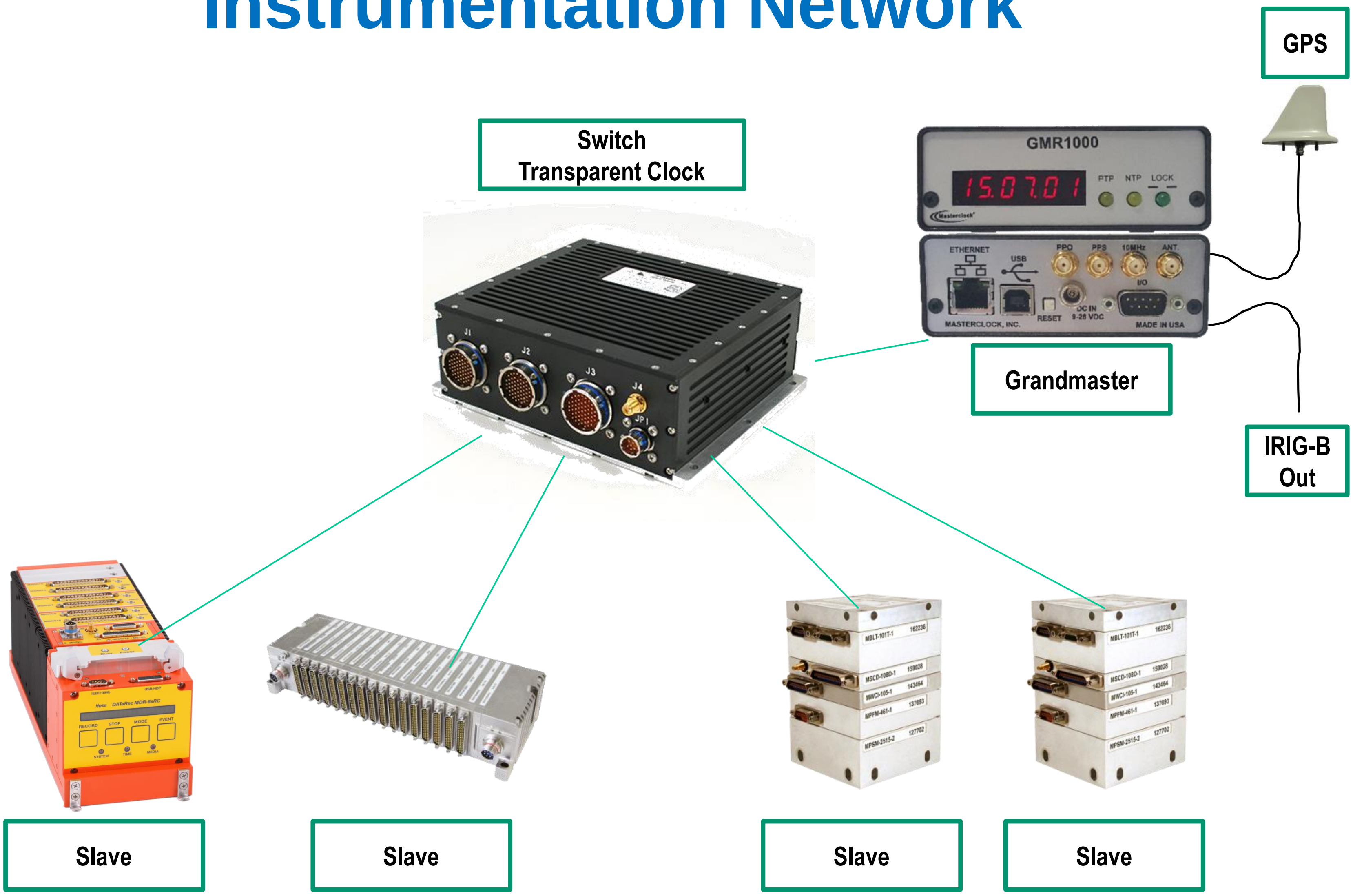
Instrumentation Network



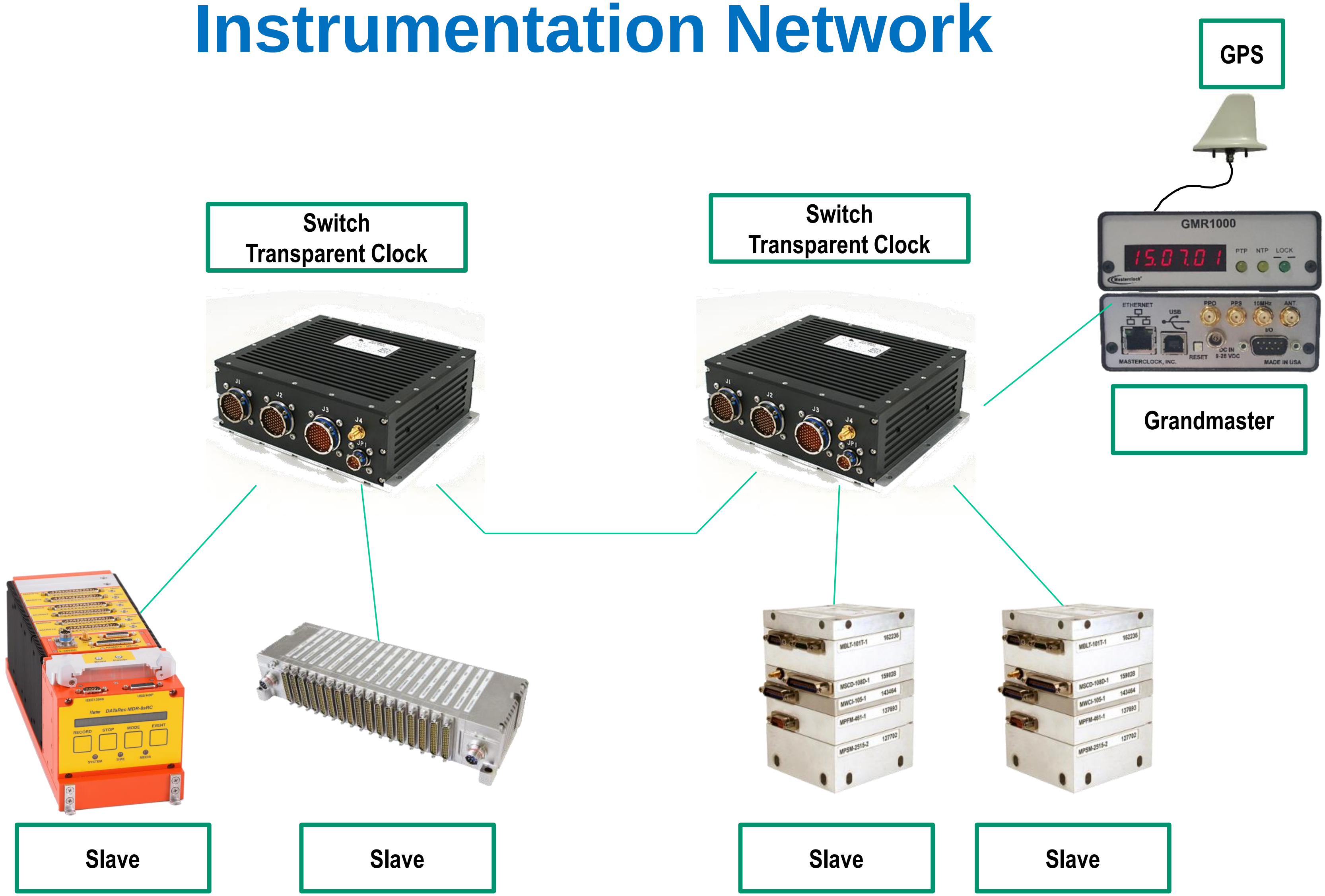
Instrumentation Network



Instrumentation Network



Instrumentation Network



Instrumentation Network