IEEE 1588-2008

Concepts

Why IEEE 1588?

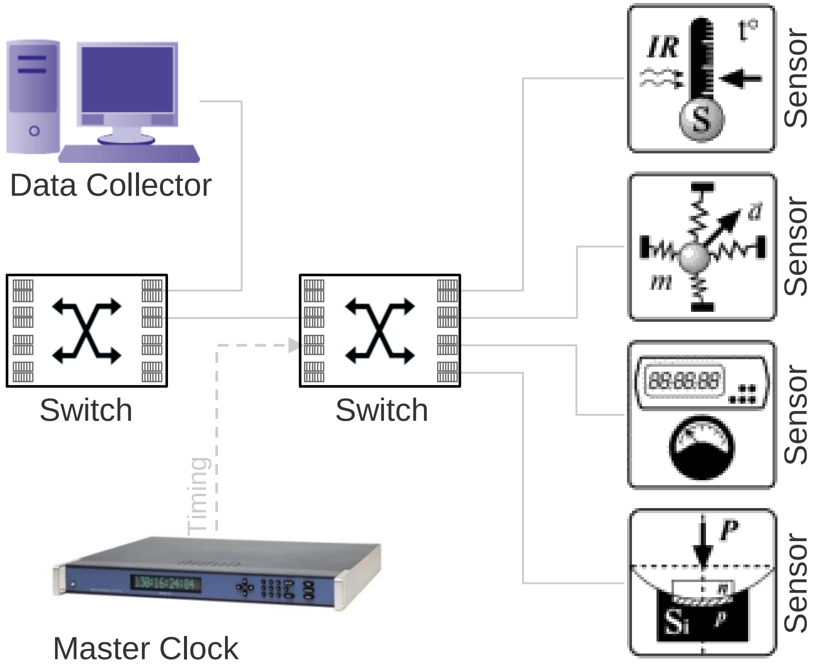
Image courtesy of National Instruments

F-18 Aircraft Static Fatigue Test System (Boeing)

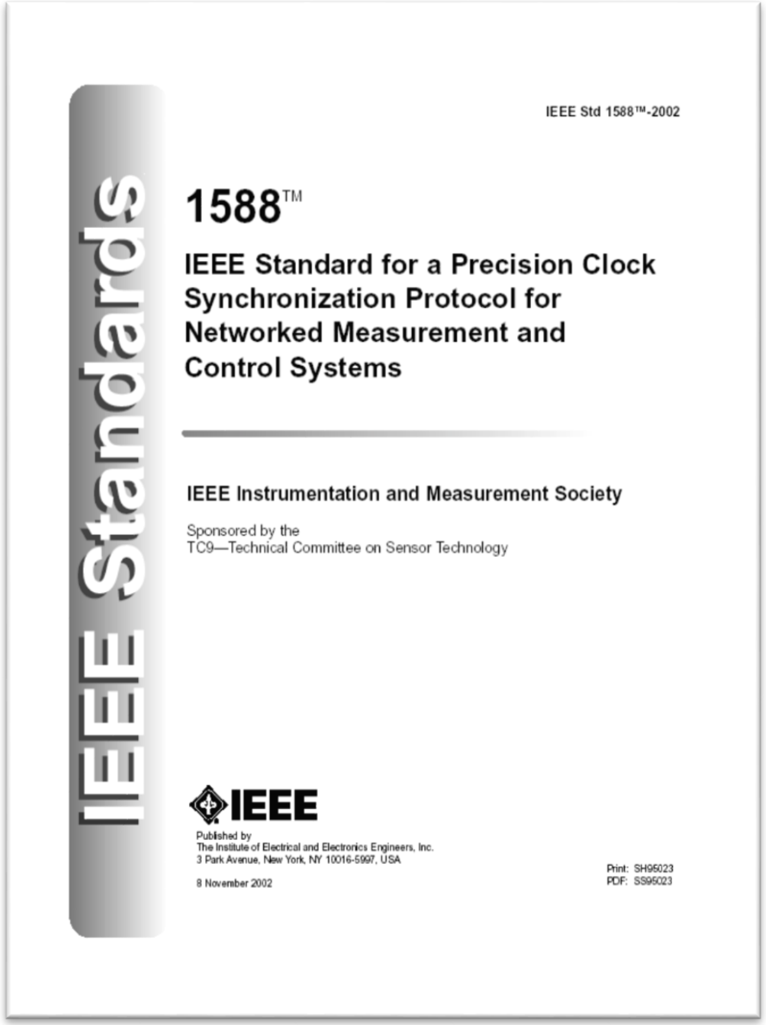
Why IEEE 1588?

Industry needed a means to deliver:

- Accurate timing at sensors, data collectors & recorders
- without the need for a point-to point parallel timing system (out of band)
- without a separate physical distribution system
- over the industrial Ethernet with the data (in-band)



IEEE 1588, The Standard



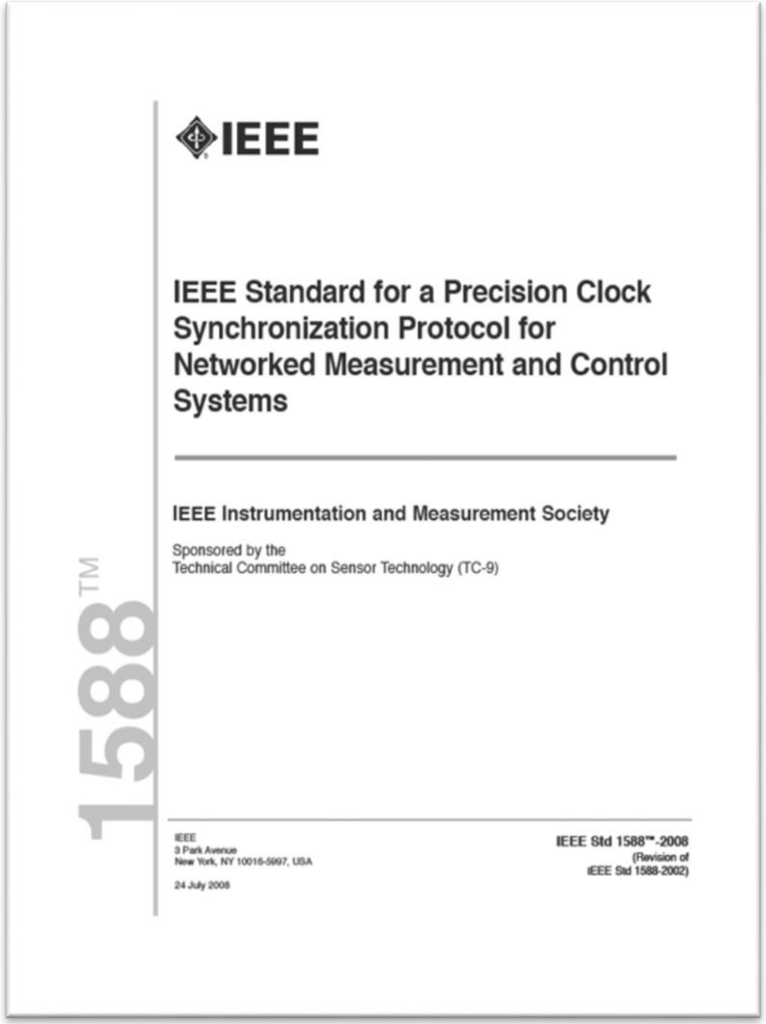
IEEE 1588 (-2002) version 1 …

- Is a protocol definition, not a product
- is known as Precision Time Protocol (PTP)
- is intended to synchronize independent clocks on separate nodes of a distributed system to a high degree of precision

Dominant Industry Application:

V1 targeted at Industrial Ethernet applications

IEEE 1588-2008, The Standard


IEEE

IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

IEEE Instrumentation and Measurement Society

Sponsored by the
Technical Committee on Sensor Technology (TC-9)

1588™

IEEE
3 Park Avenue
New York, NY 10016-5997, USA

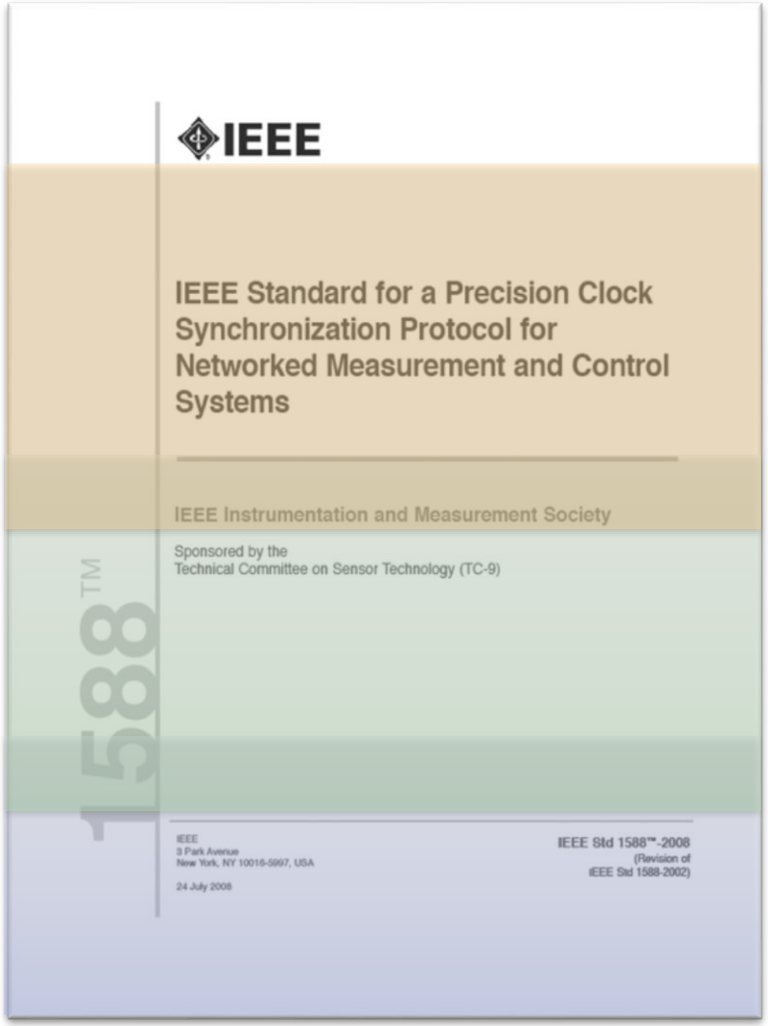
24 July 2008

IEEE Std 1588™-2008
(Revision of
IEEE Std 1588-2002)

IEEE 1588-2008 …

- -2008 is also referred to as version 2
- Changes in version 2 include:
  - Layer 3 transport option
  - Separate announce message (lower frequency)
  - Reduced sync message size & higher update rates (up to 128 Hz)
  - Unicast for the Telecom industry (with sync rate & duration negotiation)
  - Configuration mechanisms
  - Fault tolerance
- Boundary Clock switch introduction

IEEE 1588-2008 Profiles



IEEE 1588-2008 …

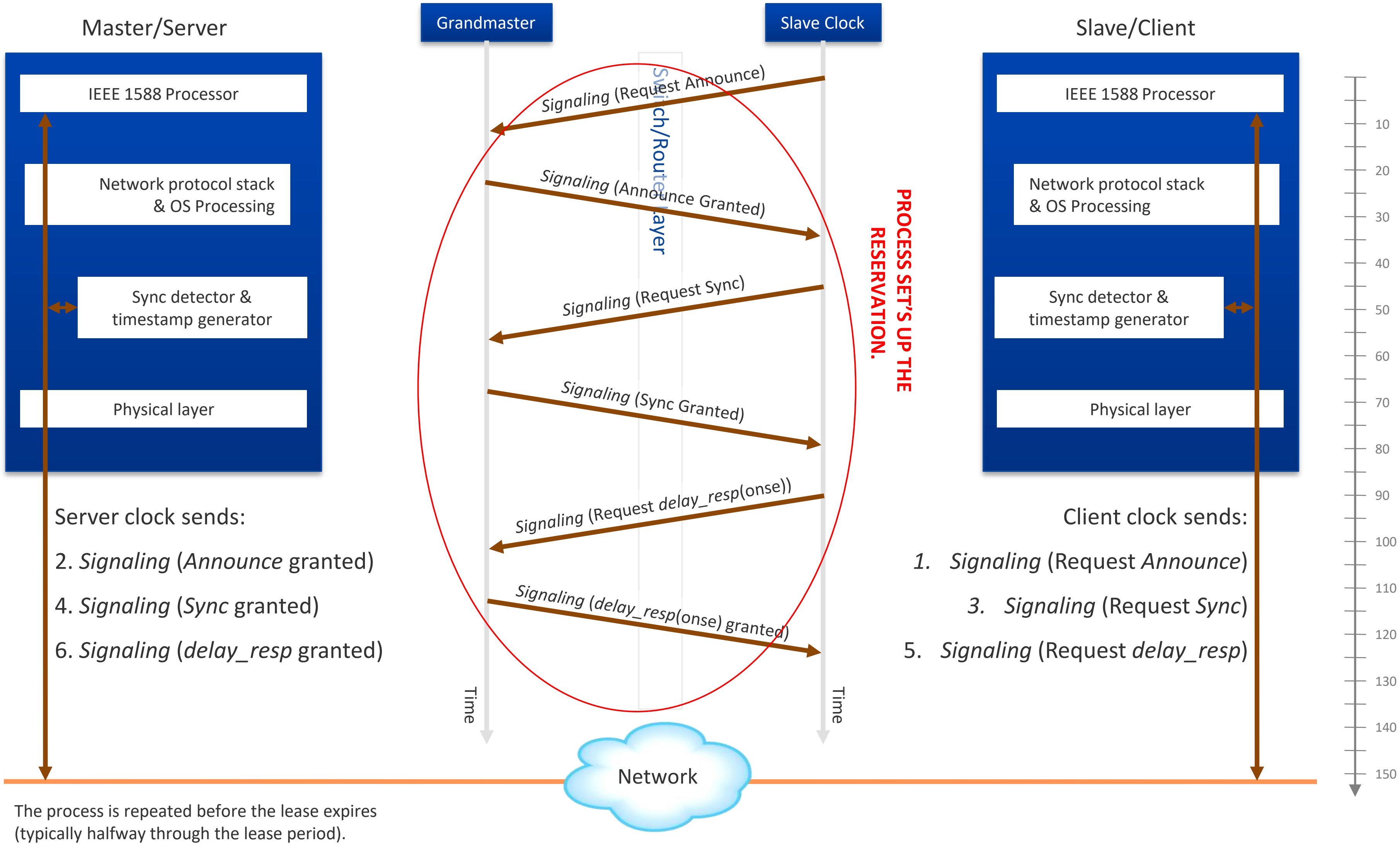
- -2008 defined for **all** applications … barrier to interoperability
- profiles define application related features from the full specification, enabling

Power Profiles
Defined by IEEE PSRC (C37.238)
Substation LAN Applications

Telecom Profiles
Defined by ITU-T
Telecom WAN Applications

Default Profile
Defined in Annex J. of 1588 specification
LAN/Industrial Automation Application (v1)

Unicast Startup Sequence



Server clock sends:

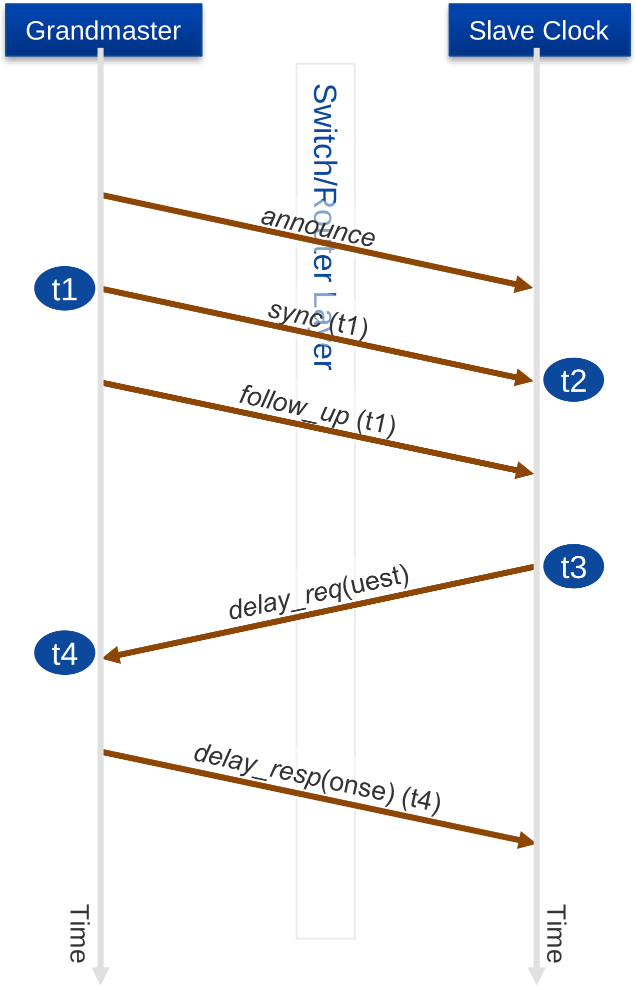
2. *Signaling* (*Announce* granted)
4. *Signaling* (*Sync* granted)
6. *Signaling* (*delay_resp* granted)

Client clock sends:

1. *Signaling* (Request *Announce*)
3. *Signaling* (Request *Sync*)
5. *Signaling* (Request *delay_resp*)

The process is repeated before the lease expires (typically halfway through the lease period).

Time Transfer Example



Data At Slave Clock

t1 = 100 seconds
t2 = 152 seconds (150+2)

t3 = 157 seconds (152+5)

t4 = 109 seconds (100+2+2+5)

The process is repeated up to 128 times per second.
(Announce rate is lower than Sync rate)

Assume at an instant in time:

- Master clock value = 100 seconds
- Slave clock value = 150 seconds
  - (the slave clock error = 50 seconds)
- One way path delay = 2 seconds

Sync message is sent at t = 100 seconds

For illustration, *Delay_Req* is sent 5 seconds after the *Sync* message is received:

Round Trip Delay

RTD = (t2 - t1) + (t4 - t3)
RTD = (152 - 100) + (109 - 157)
RTD = 4 seconds

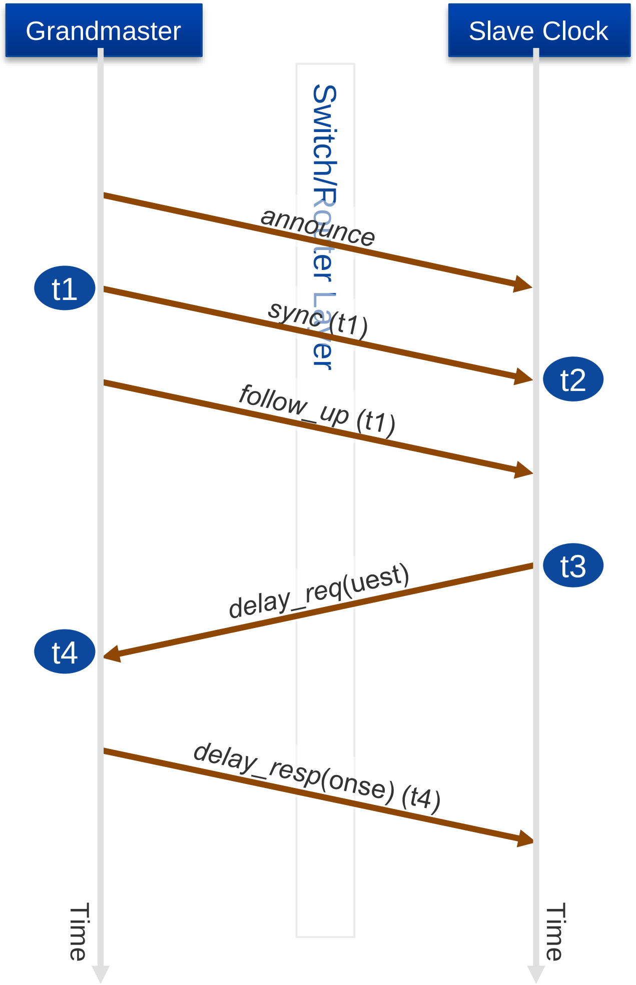
Round trip error eliminated

Slave Clock Error = (t2 - t1) - (RTD ÷ 2)
= (152 - 100) - (4 ÷ 2)
= 50 seconds

Slave clock error eliminated

If the slave clock is adjusted by -50 seconds, the Master & Slave will be synchronized

Announce Message

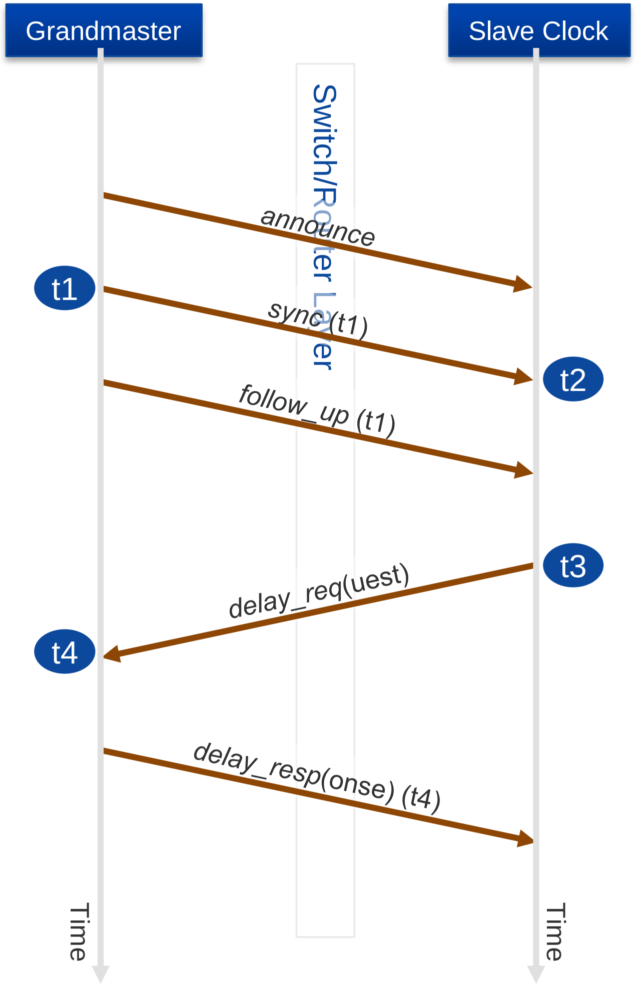


The *announce* message carries no Sync information.
It does transport the leap second offset

No.	Time	Source	Destination	Protocol	Info
36	3.260135	192.168.1.11	192.168.1.12	PTPv2	Announce Message
37	3.760126	192.168.1.11	192.168.1.12	PTPv2	Announce Message
38	3.791369	192.168.1.11	192.168.1.12	PTPv2	Sync Message
39	3.795499	192.168.1.8	192.168.1.5	TELNET	Telnet Data ...

```
⊞ Frame 37 (106 bytes on wire, 106 bytes captured)
⊞ Ethernet II, Src: Symmetri_01:31:b6 (00:b0:ae:01:31:b6), Dst: Symmetri_01:31:a5 (00:b0:a
⊞ Internet Protocol, Src: 192.168.1.11 (192.168.1.11), Dst: 192.168.1.12 (192.168.1.12)
⊞ User Datagram Protocol, Src Port: ptp-general (320), Dst Port: ptp-general (320)
⊟ Precision Time Protocol (IEEE1588)
  ⊞ 0000 .... = transportSpecific: 0x00
    .... 1011 = messageId: Announce Message (0x0b)
    .... 0010 = versionPTP: 2
    messageLength: 64
    subdomainNumber: 0
  ⊞ flags: 0x043c                                                   Flags
  ⊞ correction: 0.000000 nanoseconds
    ClockIdentity: 0x00b0aefffe000006
    SourcePortID: 1
    sequenceId: 1059
    control: Other Message (5)
    logMessagePeriod: -1
    originTimestamp (seconds): 1238433098
    originTimestamp (nanoseconds): 452974967
    originCurrentUTCOffset: 34                                      Leap Second Information
    priority1: 50
    grandmasterClockClass: 6                                        Grandmaster clockClass
    grandmasterClockAccuracy: The time is accurate to within 100 ns Grandmaster Accuracy
    grandmasterClockVariance: 25600
    priority2: 128
    grandmasterClockIdentity: 0x00b0aefffe000006
    localStepsRemoved: 0
    TimeSource: GPS (0x20)                                          Grandmaster Clock Type
```

Announce Message Flags

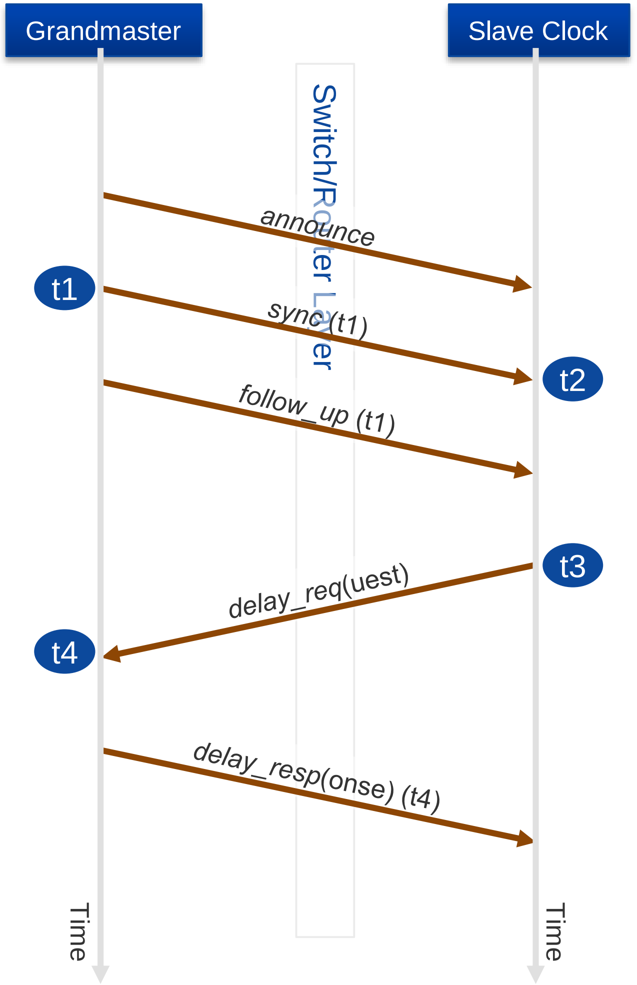


The flags are transported in all IEEE 1588 messages

No.	Time	Source	Destination	Protocol	Info
36	3.260135	192.168.1.11	192.168.1.12	PTPv2	Announce Message
37	3.760126	192.168.1.11	192.168.1.12	PTPv2	Announce Message
38	3.791369	192.168.1.11	192.168.1.12	PTPv2	Sync Message
39	3.795499	192.168.1.8	192.168.1.5	TELNET	Telnet Data ...

```
Frame 37 (106 bytes on wire, 106 bytes captured)
Ethernet II, Src: Symmetri_01:31:b6 (00:b0:ae:01:31:b6), Dst: Symmetri_01:31:a5 (00:b0:
Internet Protocol, Src: 192.168.1.11 (192.168.1.11), Dst: 192.168.1.12 (192.168.1.12)
User Datagram Protocol, Src Port: ptp-general (320), Dst Port: ptp-general (320)
Precision Time Protocol (IEEE1588)
  0000 .... = transportSpecific: 0x00
  .... 1011 = messageId: Announce Message (0x0b)
  .... 0010 = versionPTP: 2
  messageLength: 64
  subdomainNumber: 0
  flags: 0x043c
    0... .... .... .... = PTP_SECURITY: False
    .0.. .... .... .... = PTP profile Specific 2: False
    ..0. .... .... .... = PTP profile Specific 1: False
    .... .1.. .... .... = PTP_UNICAST: True              Unicast/Multicast
    .... ..0. .... .... = PTP_TWO_STEP: False            1-step or 2-step
    .... ...0 .... .... = PTP_ALTERNATE_MASTER: False
    .... .... ..1. .... = FREQUENCY_TRACEABLE: True
    .... .... ...1 .... = TIME_TRACEABLE: True
    .... .... .... 1... = PTP_TIMESCALE: True
    .... .... .... .1.. = PTP_UTC_REASONABLE: True
    .... .... .... ..0. = PTP_LI_59: False
    .... .... .... ...0 = PTP_LI_61: False
  correction: 0.000000 nanoseconds
  ClockIdentity: 0x00b0aefffe000006
  SourcePortID: 1
  sequenceId: 1059
  control: Other Message (5)
```


Sync Message



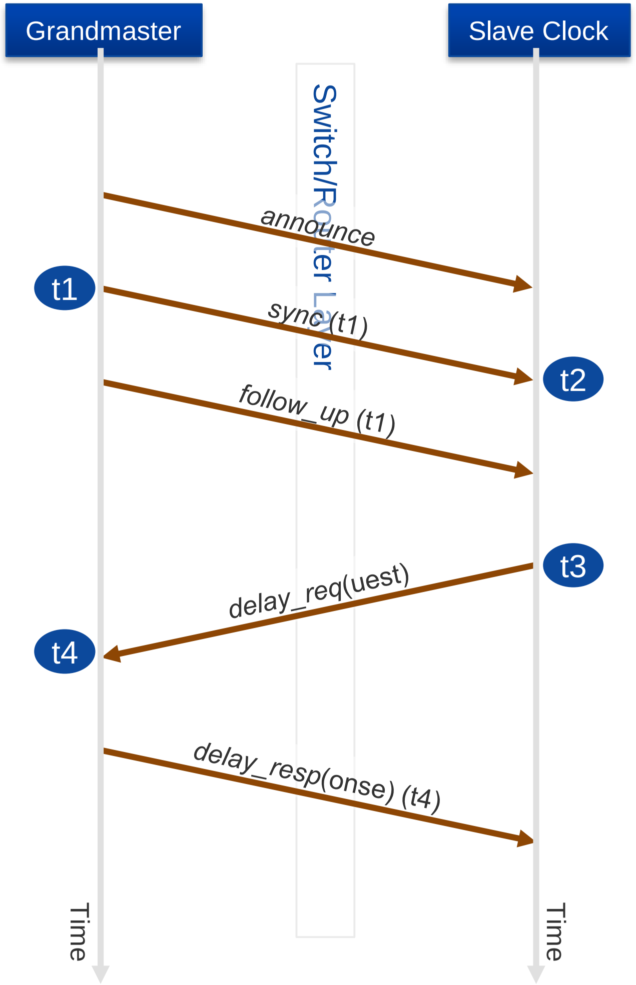
No.	Time	Source	Destination	Protocol	Info
4	0.015623	192.168.2.9	192.168.2.11	PTPv2	Delay_Req Message
5	0.015628	192.168.2.11	192.168.2.9	PTPv2	Delay_Resp Message
6	0.023074	192.168.2.11	192.168.2.9	PTPv2	Sync Message
7	0.031238	192.168.2.9	192.168.2.11	PTPv2	Delay_Req Message
8	0.031241	192.168.2.11	192.168.2.9	PTPv2	Delay_Resp Message

```
Frame 6 (86 bytes on wire, 86 bytes captured)
Ethernet II, Src: Symmetri_01:31:c3 (00:b0:ae:01:31:c3), Dst: Symmetri_01:32:0e (00:b0:ae:01
Internet Protocol, Src: 192.168.2.11 (192.168.2.11), Dst: 192.168.2.9 (192.168.2.9)
User Datagram Protocol, Src Port: ptp-event (319), Dst Port: ptp-event (319)
Precision Time Protocol (IEEE1588)
  0000 .... = transportSpecific: 0x00
  .... 0000 = messageId: Sync Message (0x00)
  .... 0010 = versionPTP: 2
  messageLength: 44
  subdomainNumber: 0
  flags: 0x043c
  correction: 0.000000 nanoseconds
  ClockIdentity: 0x00b0aefffe0131c3
  SourcePortID: 1
  sequenceId: 33668
  control: Sync Message (0)
  logMessagePeriod: -6
  originTimestamp (seconds): 1226970209
  originTimestamp (nanoseconds): 703365480
```

Flags (same as *announce*)

t1

Delay_Req(uest) Message



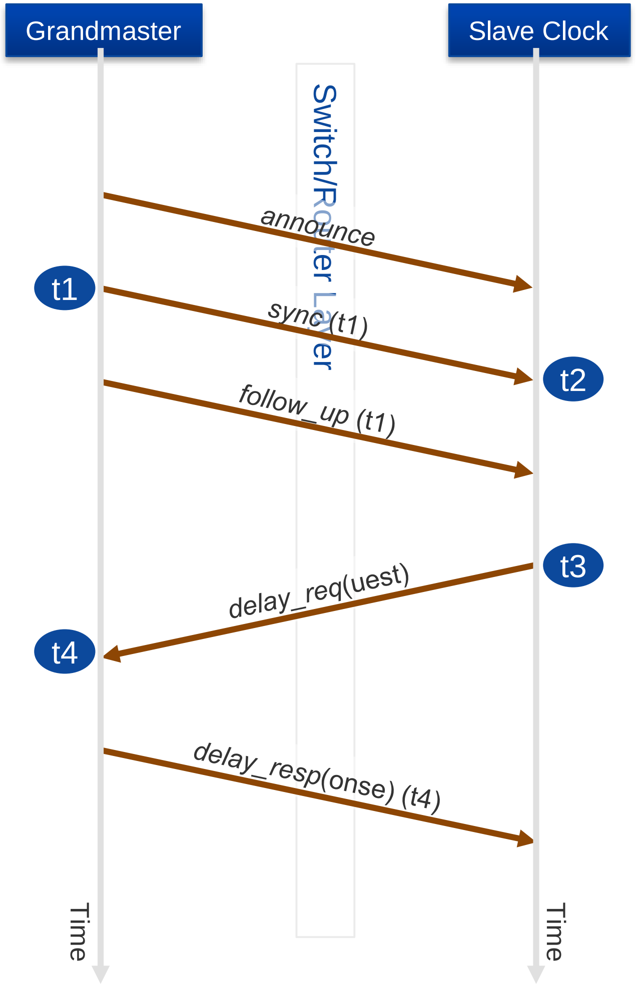
The *delay_req*(uest) message optionally carries timing information in the Timestamp field

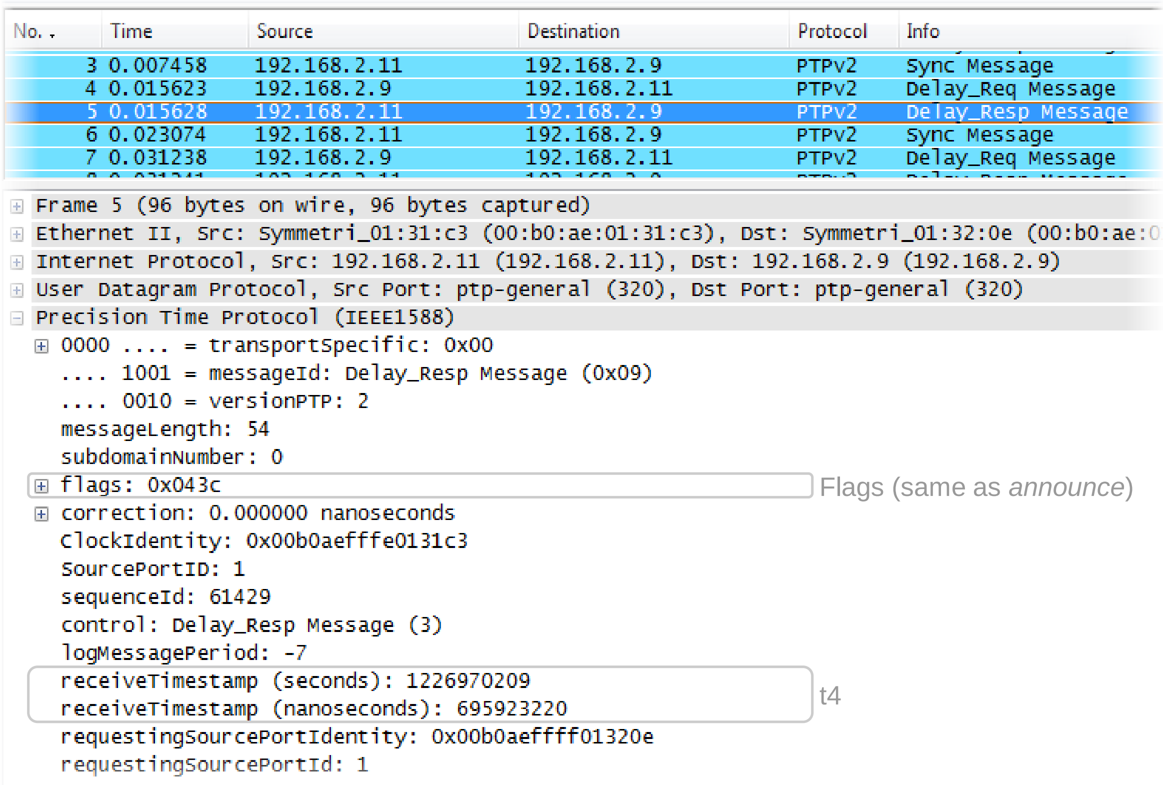
No.	Time	Source	Destination	Protocol	Info
2	0.000007	192.168.2.11	192.168.2.9	PTPv2	Delay_Resp Message
3	0.007458	192.168.2.11	192.168.2.9	PTPv2	Sync Message
4	0.015623	192.168.2.9	192.168.2.11	PTPv2	Delay_Req Message
5	0.015628	192.168.2.11	192.168.2.9	PTPv2	Delay_Resp Message
6	0.023074	192.168.2.11	192.168.2.9	PTPv2	Sync Message

```
⊞ Frame 4 (86 bytes on wire, 86 bytes captured)
⊞ Ethernet II, Src: Symmetri_01:32:0e (00:b0:ae:01:32:0e), Dst: Symmetri_01:31:c3 (00:b0:ae:01
⊞ Internet Protocol, Src: 192.168.2.9 (192.168.2.9), Dst: 192.168.2.11 (192.168.2.11)
⊞ User Datagram Protocol, Src Port: ptp-event (319), Dst Port: ptp-event (319)
⊟ Precision Time Protocol (IEEE1588)
  ⊞ 0000 .... = transportSpecific: 0x00
    .... 0001 = messageId: Delay_Req Message (0x01)
    .... 0010 = versionPTP: 2
    messageLength: 44
    subdomainNumber: 0
  ⊞ flags: 0x0400
  ⊞ correction: 0.000000 nanoseconds
    ClockIdentity: 0x00b0aeffff01320e
    SourcePortID: 1
    sequenceId: 61429
    control: Delay_Req Message (1)
    logMessagePeriod: -1
    originTimestamp (seconds): 0
    originTimestamp (nanoseconds): 0
```

Flags (same as *announce*)

Delay_Resp(onse) Message





No.	Time	Source	Destination	Protocol	Info
3	0.007458	192.168.2.11	192.168.2.9	PTPv2	Sync Message
4	0.015623	192.168.2.9	192.168.2.11	PTPv2	Delay_Req Message
5	0.015628	192.168.2.11	192.168.2.9	PTPv2	Delay_Resp Message
6	0.023074	192.168.2.11	192.168.2.9	PTPv2	Sync Message
7	0.031238	192.168.2.9	192.168.2.11	PTPv2	Delay_Req Message

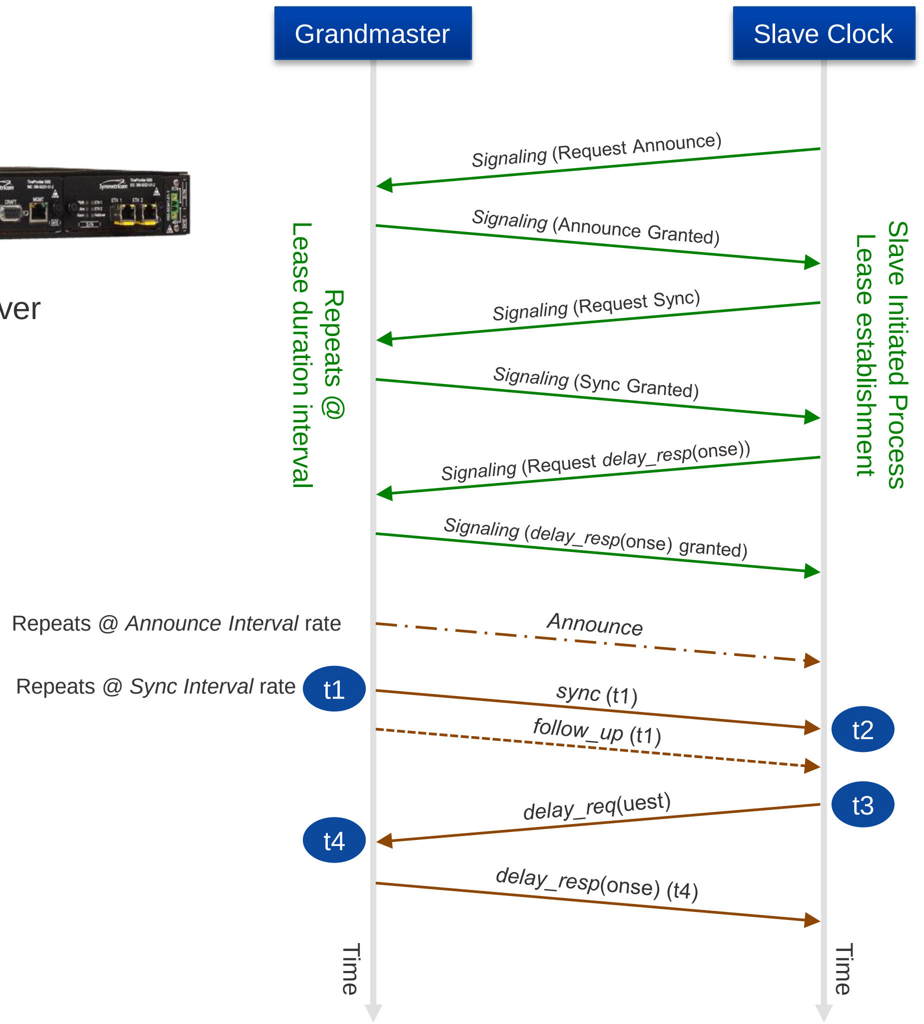
```
Frame 5 (96 bytes on wire, 96 bytes captured)
Ethernet II, Src: Symmetri_01:31:c3 (00:b0:ae:01:31:c3), Dst: Symmetri_01:32:0e (00:b0:ae:0
Internet Protocol, Src: 192.168.2.11 (192.168.2.11), Dst: 192.168.2.9 (192.168.2.9)
User Datagram Protocol, Src Port: ptp-general (320), Dst Port: ptp-general (320)
Precision Time Protocol (IEEE1588)
  0000 .... = transportSpecific: 0x00
  .... 1001 = messageId: Delay_Resp Message (0x09)
  .... 0010 = versionPTP: 2
  messageLength: 54
  subdomainNumber: 0
  flags: 0x043c
  correction: 0.000000 nanoseconds
  ClockIdentity: 0x00b0aefffe0131c3
  SourcePortID: 1
  sequenceId: 61429
  control: Delay_Resp Message (3)
  logMessagePeriod: -7
  receiveTimestamp (seconds): 1226970209
  receiveTimestamp (nanoseconds): 695923220
  requestingSourcePortIdentity: 0x00b0aeffff01320e
  requestingSourcePortId: 1
```

Flags (same as *announce*)

t4

Time Transfer (Unicast)

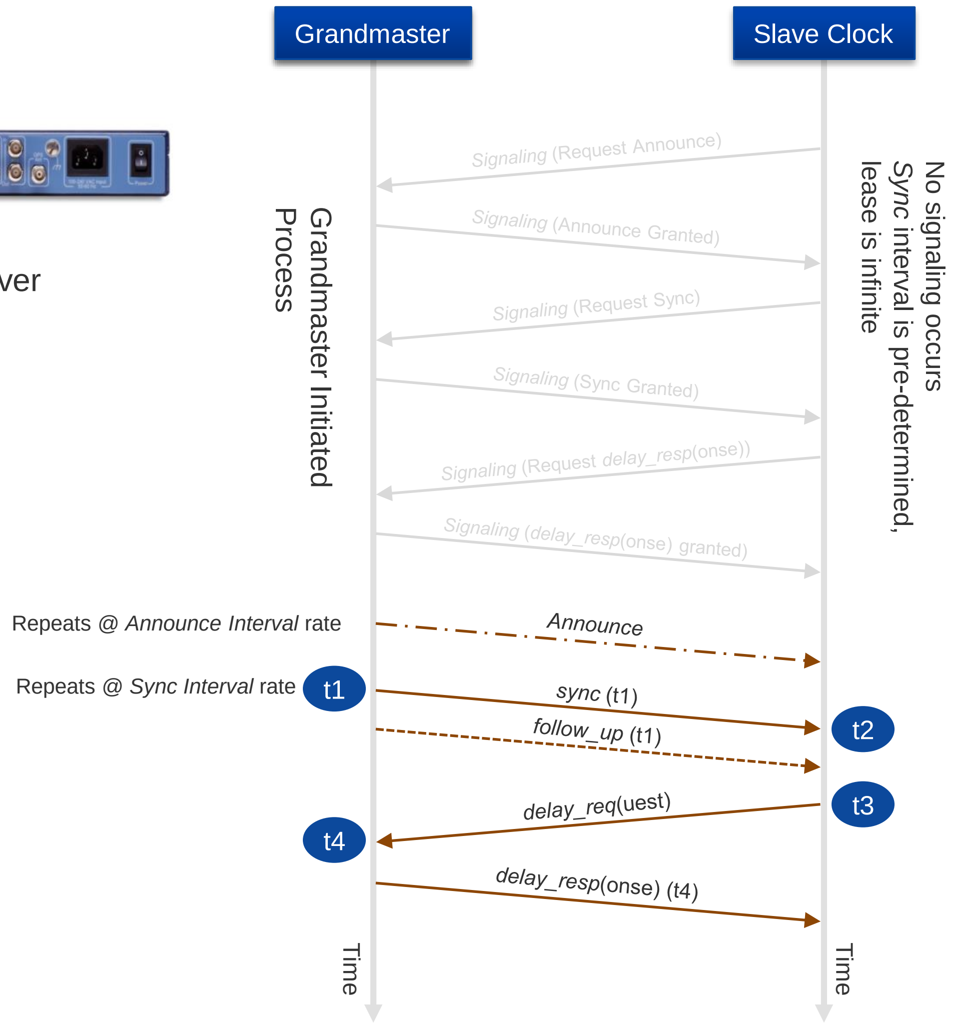
Grandmaster/Server



Slave/Client

Time Transfer (Multicast)

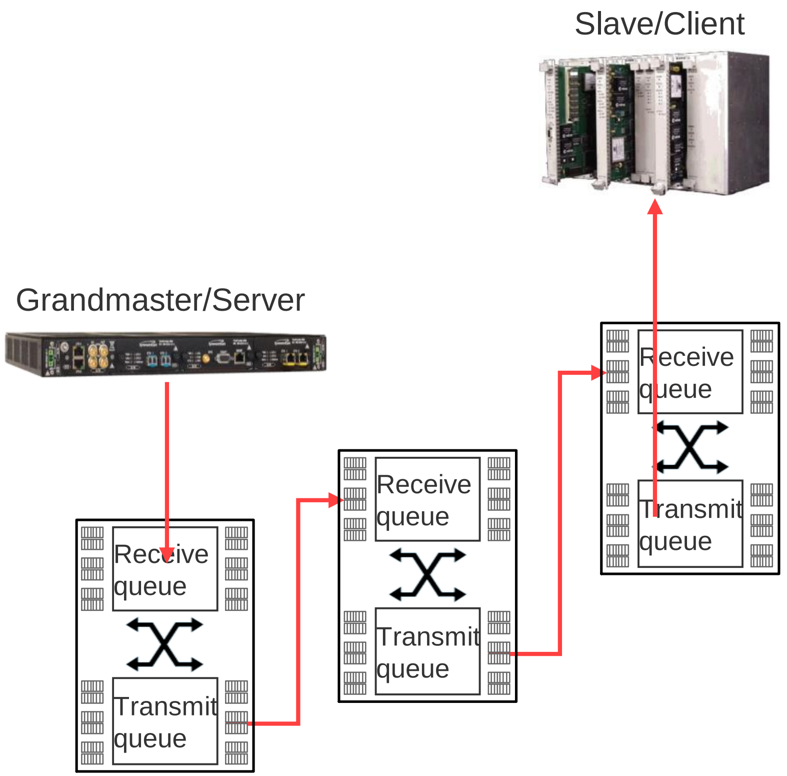
Grandmaster/Server



Slave/Client

Influences on IEEE 1588 Accuracy

- Network asymmetry
  - Forward path & return path not same
- Packet Delay Variation (PDV)
  - Packet delay variation (jitter)
  - Increases with number of network elements and traffic load
  - Causes include queuing delays, routing changes, congestion, switches versus routers, etc.
- Prolonged Packet Loss (Outage)
  - Causes slave to enter holdover
- Local oscillator quality (part of the filtering process)
- Packet Delay, Packet Loss, and Packet Errors are not an issue for packet timing protocols



Introducing IEEE 1588 Elements

- Ordinary Clocks (consisting of the Grandmaster & Slave)

- Boundary Clock
  Regenerates PTP message, (Switch with a built-in clock)
- Transparent Clock
  Adjusts the *correction field* in the *sync* and *delay_req* event messages (Switch with ability to measure packet residence time)
- Management Node
  Human/programmatic interface to PTP management messages

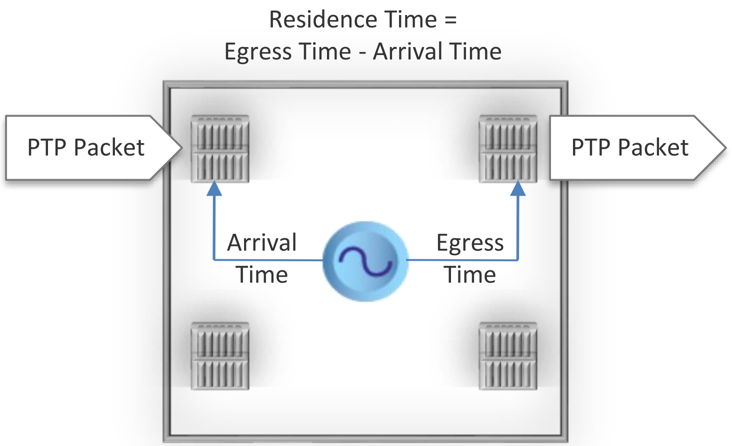
On Path Support Elements

Transparent Clock

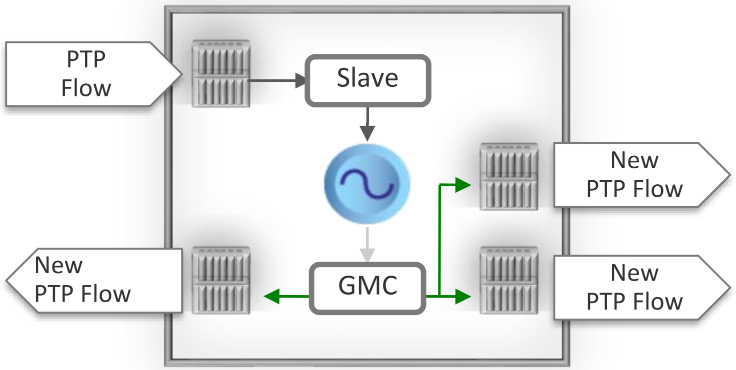
- Switch, not a Clock
- Measures 1588 packet delay inside the switch (“residence time”)
- *Modifies (adds)* residence time to the *correction field* in the 1588 message
- Limited to non-encrypted networks
- *Correction field* must be accurate

Boundary Clock

- **Switch with built-in clock – internal oscillator**
- Internal clock synchronized via 1588 to the upstream master
- Slave on 1 port, master on other ports
- **Interrupts the Grandmaster sync flow**
- Regenerates 1588 messages
- **Essentially a client one side being used to discipline a GM on the other**



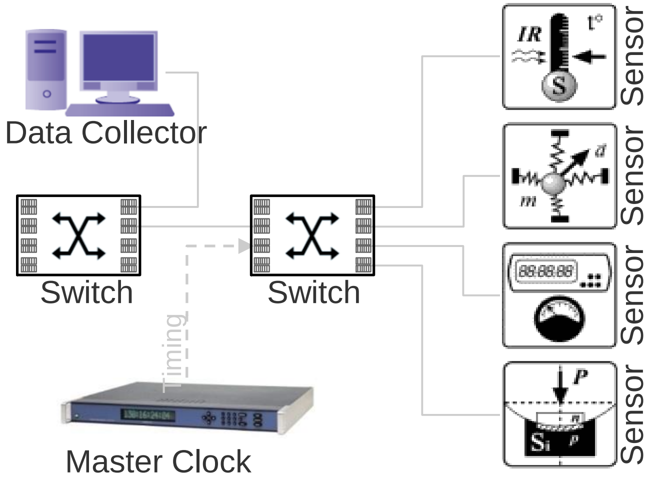
Transparent Clock



Boundary Clock

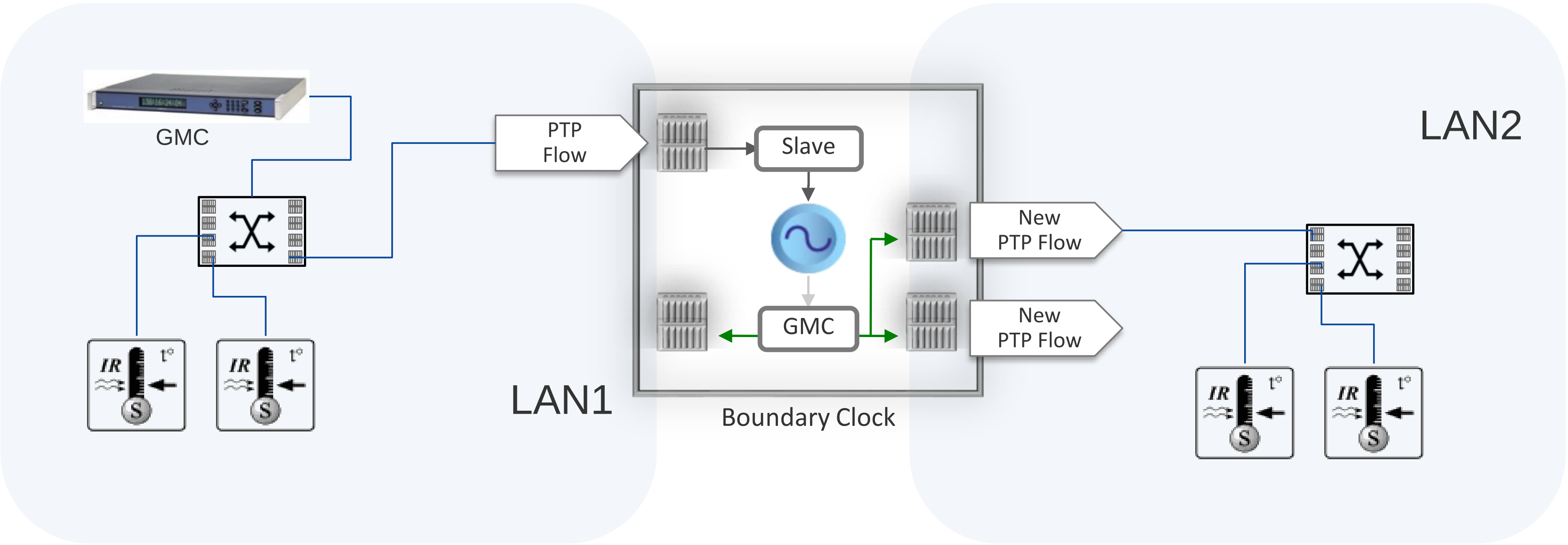
Boundary Clock – initial use

- We have to go back to IEEE 1588 – 2002 (1588v1)
  - PTP was just designed to work in a **LAN**
  - PTP packets will pass through only ONE/TWO switches
  - PTP packet rate: 0.5, 1, 2 pps
  - Precision needed: in the order of µsecs
  - PTP was (is) used to recover time



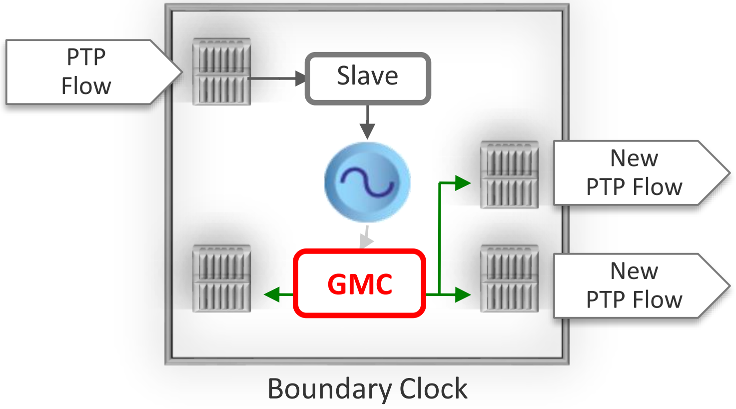
Boundary Clock – initial use

- **What if we needed to pass PTP to another network?**
  - Some switches would be able to receive PTP as slaves and internally use it as a reference to create another PTP domain and act as new GMC for the other network. They were not meant to filter or "clean" the PTP packets
  - These switches would act as BOUNDARY CLOCKS between two LANs



Boundary Clock

- **The reference of this new GMC (inside the BC) uses whatever the slave algorithm of the switch has received and translated. So the frequency and phase quality will depend on how good this algorithm is, and how good the Oscillator is**



1588 clockClass (Stratum)

Yet another definition for Clock Accuracy

Telecom Definition		Timing Definition		IEEE 1588 Definitions	
A measure of the frequency accuracy of the oscillator or clock being described.		A measure of the distance from the UTC traceable source (number of steps)		clockClass (called stratum model in v1) represents the quality of the clock.	
Stratum 1	G.811	Stratum 0	UTC source	Version 1	Version 2
Stratum 2	G.812	Stratum 1	Gets Time from	0	6
Stratum 3EG.812			Stratum 0 source	1	9
Stratum 3	G.813	Stratum 3	Timed from	2	10
Stratum 4	G.813		Stratum 2 source	3	248
		Stratum 4	Timed from	4	251
			Stratum 3 source	255	255

```
priority1: 50
grandmasterClockClass: 6
grandmasterClockAccuracy: The time is accurate to within 100 ns (0x21)
grandmasterClockVariance: 25600
priority2: 128
```

1588 clockClass (Stratum)

clockClass	Definition
0	Reserved to enable compatibility with future versions
1-5	Reserved
6	Clock synchronized to a Primary Reference time source
7	Clock previously in clockClass 6 but is in holdover within holdover specs.
8-12	Reserved
13	Clock synchronized to the application time of source. Time scale is arbitrary.
14	Clock previously in clockClass 13 but is in holdover within holdover specs
15-186	Reserved or use by alternate PTP profiles
187	Clock previously in clockClass 7 but not within holdover specs. May be slave to another clock
188-192	Reserved
193	Clock previously in clockClass 14 but not within holdover specs. May be slave to another clock
194-254	Reserved for alternate PTP Profiles
255	Slave only clock

IEEE Std 1588-2008, Table 5

Microsemi, a wholly owned subsidiary of Microchip Technology Inc. (Nasdaq: MCHP), offers a comprehensive portfolio of semiconductor and system solutions for aerospace & defense, communications, data center and industrial markets. Products include high-performance and radiation-hardened analog mixed-signal integrated circuits, FPGAs, SoCs and ASICs; power management products; timing and synchronization devices and precise time solutions, setting the world's standard for time; voice processing devices; RF solutions; discrete components; enterprise storage and communication solutions, security technologies and scalable anti-tamper products; Ethernet solutions; Power-over-Ethernet ICs and midspans; as well as custom design capabilities and services. Learn more at www.microsemi.com.

Microsemi Headquarters
One Enterprise, Aliso Viejo, CA 92656 USA
Within the USA: +1 (800) 713-4113
Outside the USA: +1 (949) 380-6100
Sales: +1 (949) 380-6136
Fax: +1 (949) 215-4996
email: sales.support@microsemi.com
www.microsemi.com