PTP* Introduction

- Part of workshop** on "HSR/PRP and PTP: Network Redundancy and Time Clock Synchronization" -

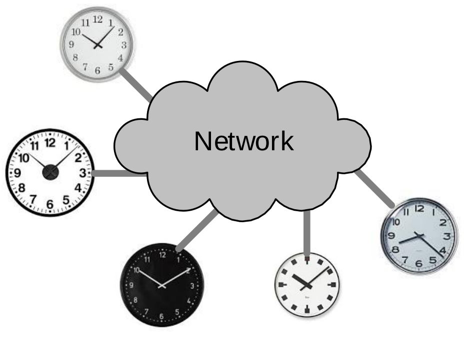
기안도
adki@future-ds.com

주최/주관: 한국통신학회 군통신연구회 / 명지대학교
장소: 숭실대학교 조만식기념관 427호
일자: 2019년6월7일

* PTP: Precision Time Protocol
** 이중화네트워크와 시각동기화 워크샵

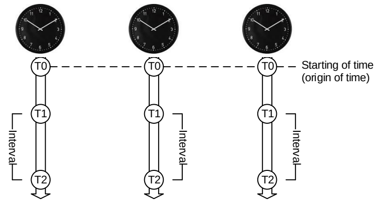
Table of Contents

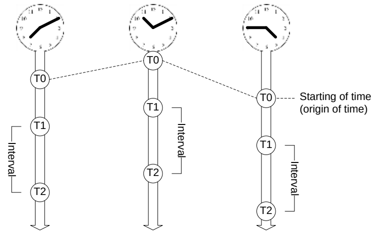
Clocks on the network



- Objective
  - Synchronize wall clocks, which are connected over packet-based network.
    - 패킷망에 연결된 시계들의 시간을 맞춘다
- Implications
  - '**Wall clock**' means real-time in nano/micro/milli second accuracy.
    - 실시간 정확도
  - '**Wall clocks over network**' mean a distributed system.
    - 분산시스템
  - '**Packet-based network**' means network delay varies.
    - 메시지(정보)를 주고 받음
    - 가변적 네트웍 지연

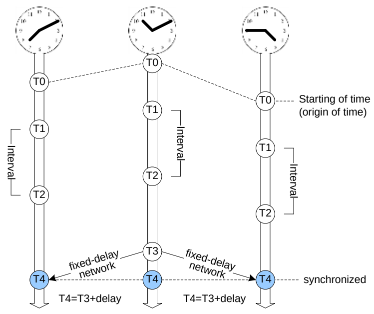
Distributed ideal clocks (1/2)





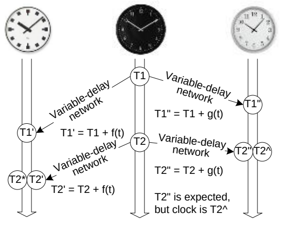
- Identical clocks with the same starting time.
  - There is nothing to do with synchronization.
    - 동일한 시작 시점을 갖는 '완전히 동일한 시계'들
      - 동기화가 필요치 않음
- Identical clock with different starting time.
  - There should be a mechanism to adjust offset.
    - One time synchronization is sufficient.
    - 시작 시점이 다른 '완전히 동일한 시계'들
      - 한 번만 시간을 맞추면 됨
        - 정확한 통신 지연 파악이 필요

Distributed ideal clocks (2/2)



- Distributed clock can be synchronized by communication.
  - For identical clocks with different starting time
  - Need something about communication.
    - What if communication delay is not deterministic? → Need mechanism to measure communication delay.
    - 시작 시점이 다른 '완전히 동일한 시계'들
      - 한 번만 시간을 맞추면 됨
        - 정확한 통신 지연 파악이 필요
- What if clocks are not the same?
  - Each clock has different frequency and starting point
  - 만약 각 시계가 동일하지 않다면?
    - 각 시계가 주파수와 시작 시점이 다르다면?

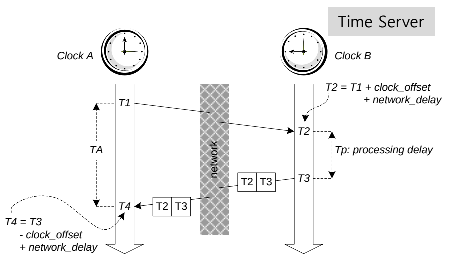
Distributed clocks with variable delay network



- Actual (i.e., non-ideal) clocks
  - Phases differ
  - Frequencies differ
  - 실제 시계들은 위상과 주파수가 다름
    - 위상: 24시간 중 몇 시; 서기 몇년 몇월
    - 주파수: 1초에 해당하는 시간

- Variable-delay network based clock synchronization
  - Due to temperature, acceleration, aging and so on
  - 온도, 가속, 노화 등으로 네트워 지연이 변함
- In addition to frequency calibration/correction of clocks, network-delay measurement is required.
  - 시계의 주파수 교정과 보정 뿐만 아니라 네트워크 지연도 측정해야 됨
- Delay and frequency should be measured periodically, since they are time-varying.
  - 네트워크 지연과 주파수는 주기적으로 측정하고 교정/보정 해야 됨

Clock synchronization algorithms (1/2)



- Cristian Algorithm
  - synchronization with a time server

Tdelay = (T4 – T1 – Tp) / 2
T2 = T1 + Toffset + Tdelay
T4 = T3 – Toffset + Tdelay
Toffset = [(T2 – T1) + (T3 – T4)] / 2
Tdelay = [(T4 – T1) – (T3 – T2)] / 2

F. Cristian, Probabilistic clock synchronization, Distributed Computing, Vol. 3, Issue 3, pp.146-158, Springer, 1989.

Clock synchronization algorithms (2/2)

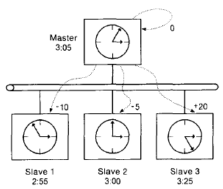


Fig. 1. The measurements.

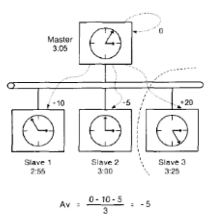


Fig. 2. The computation of the average.

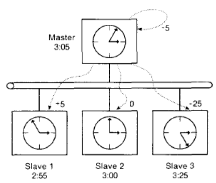


Fig. 3. The correction of the clocks.

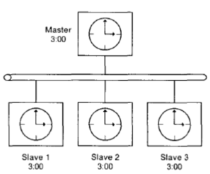
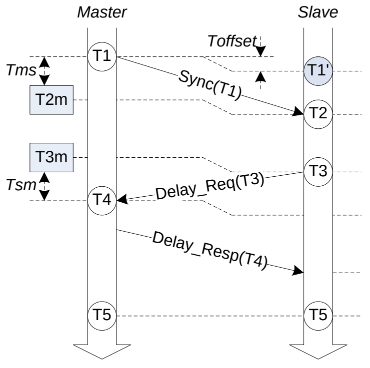


Fig. 4. Clocks are now synchronized.

- Berkeley Algorithm
  - synchronization without a time server

R. Gusella and S. Zatti, The accuracy of the clock synchronization achieved by TEMPO in Berkeley UNIX 4.3.BSD, IEEE Trans. on Software Engineering, Vol. 15, No. 7, pp.847-853, July 1989.

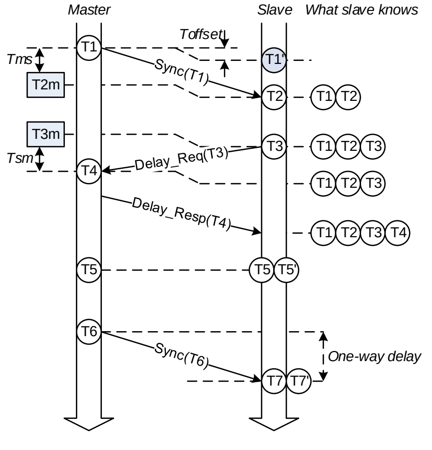
PTP in short (1/2)



Slave clock runs Toffset ahead

- 마스터와 슬레이브가 동일한 시계를 갖는다면 단순하게 통신지연만을 이용하여 동기 시킬 수 있다.
- 그러나 실제로는 시계가 차이가 나고, 이때 슬레이브 시계가 얼마나 빠른가를 Toffset이라 하며,
- Sync와 Delay_Req/Resp 패킷을 주고 받아서, 얻는 정보를 이용하여 통신지연과 Toffset을 유추해 낸다.
- 이때 통신지연은 양방향이 동일하다고 가정한다.
- 슬레이브 입장에서 T1’ (즉, T1 + Toffset) 시점에 Sync가 네트웍에 전송되고, 슬레이브 시간 T2에 도착한다.
- 슬레이브는 역방향 통신지연을 측정하기 위해, T3에 Delay_Req를 전송하고, 마스터 입장에서 T4에 받아
- T4 정보를 담아서 Delay_Resp를 보낸다.
- 이렇게 되면 T1, T2, T3, T4 정보를 슬레이브가 갖게 되므로, 이들을 이용하여 Toffset과 Tdelay를 계산한다.

PTP in short (2/2)



[offset] Toffset = Tslave - Tmaster	Eq.1
[ms_difference] ⊿Tms = T2 - T1	Eq.2
[sm_difference] ⊿Tsm = T4 - T3	Eq.3
[ms_delay] Tms = T2m - T1	Eq.4
[sm_delay] Tsm = T4 - T3m	Eq.5

T1' is T1+Toffset;
T2 is T2m+Toffset;
T3 is T3m+Toffset;

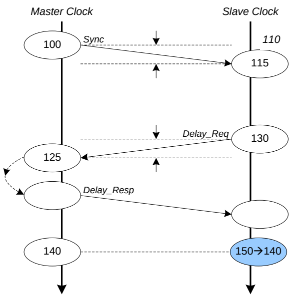
[ms_delay] Tms = T2m - T1 = T2 - Toffset - T1
= ⊿Tms - Toffset
[sm_delay] Tsm = T4 - T3m = T4 - (T3 - Toffset)
= ⊿Tsm + Toffset

Assume that Tms == Tsm,

One-way delay Tdelay = [(T2 - T1) + (T4 - T3)] / 2

Toffset = [(T2 - T1) - (T4 - T3)] / 2 = (T2 - T1) - Tdelay

PTP examples



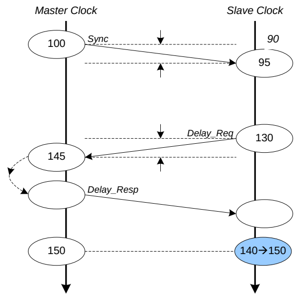
Delay = [(T2-T1)+(T4-T3)]/2
= [(115-100)+(125-130)] / 2
= [15 - 5] / 2 = 5

Offset = [(T2-T1)-(T4-T3)]/2
= [15 + 5] / 2 = 10

Slave has positive offset

Offset = 10

Delay = 5



Delay = [(T2-T1)+(T4-T3)]/2
= [(95-100)+(145-130)] / 2
= [-5 + 15] / 2 = 5

Offset = [(T2-T1)-(T4-T3)]/2
= [-5 - 15] / 2 = -10

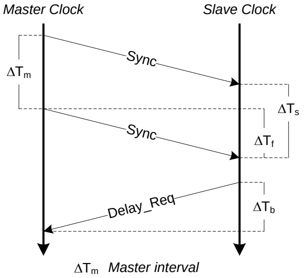
Slave has negative offset

Offset = -10

Delay = 5

Offset: Slave clock runs ahead of the master.

PTP mathematics



ΔT_m *Master interval*
ΔT_s *Slave interval*
ΔT_f *Forward delay*
ΔT_b *Backward delay*

$$\text{Delay } (T_d) = \frac{\Delta T_f + \Delta T_b}{2}$$

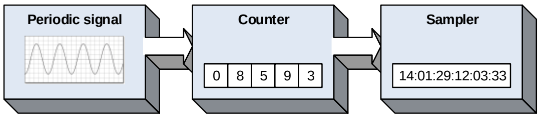
$$\text{Offset } (T_o) = \frac{\Delta T_f - \Delta T_b}{2} = \Delta T_f - T_d$$

$$\text{Drift } (\lambda) = \frac{\Delta T_m - \Delta T_s}{\Delta T_s}$$

- Offset: clock shift
  - 두 시계의 시점이 얼마나 다른가 (12시 ← →12시1분)
- Drift: clock period difference
  - 시계가 빠르고 느린 정도
- Slave clock is ahead of the master clock by the Offset (To).
  - decrease To
- Slave clock is slower than the master clock by the Drift (λ) per second
  - 슬레이브 클럭이 마스트 클럭보다 얼마만큼 느린가 (초당 몇 초 느린가)

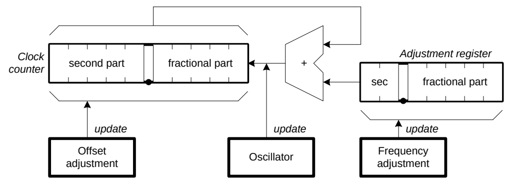
Clock

- Clock is a counter of periodic events.



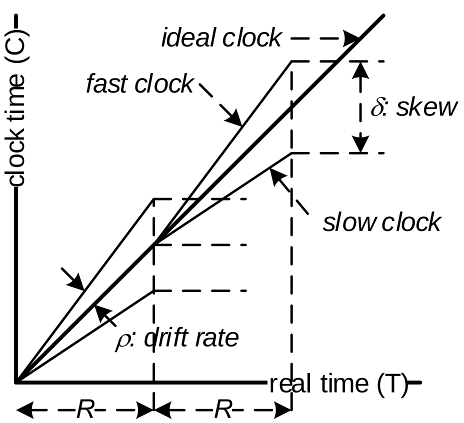
- VCO-based (Voltage Controlled Oscillator)
  - Rare implementation

- Counter-based clock



- Offset/phase can be adjusted by updating value of counter
  - 오프셋/위상은 카운트의 값을 변화시켜서 조정 가능
- Drifting/frequency can be adjusted by varying the amount of increment.
  - 드리프팅/주파수는 증가하는 값을 변화시켜 서 조정가능

Terminologies



R: Resynchronization interval

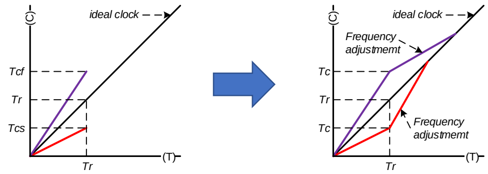
- Terminologies
  - Resynchronization interval R
  - Drift rate ρ
    - Clock drift: Count at different rates. (Different frequency of the oscillator.)

      $$1-\rho \le \frac{dC}{dt} \le 1+\rho$$

    - Ideal clock: drifting rate 0
  - Clock skew δ
    - Clock skew (offset): Difference between time on two clocks.

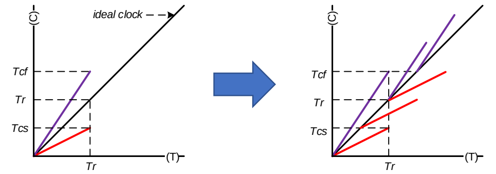
Adjustment

■ Frequency adjustment



- Syntonization
  - Frequency synchronization
    - different time, but keeping a constant time difference

■ Offset adjustment



- Synchronization
  - Phase synchronization
    - keep the same time

Time transfer technologies

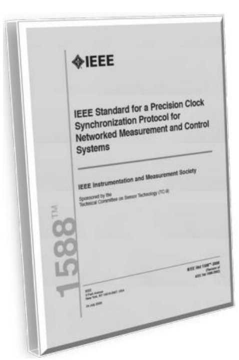
	IRIG-B	(S)NTP	PTP	GPS
Accuracy (typical)	1-10μs	1ms – 10 ms	100ns-1μs	10ns
Transport media	Dedicated cables	Ethernet cable	Ethernet cables	Wireless
Protocol style	Master-slave	Client-server	Master-slave	
Built in latency correction	No	Yes	Yes	
Set-up	Configured	Configured	Self-organizing, or configured	
Update intervals	1 second	Minutes	1 second	
Specialized hardware	Required	No	Required	Required

IRIG: Inter-Range Instrumentation Group; (S)NTP: Simple Network Time Protocol; GPS: Global Positioning System

PTP related standards

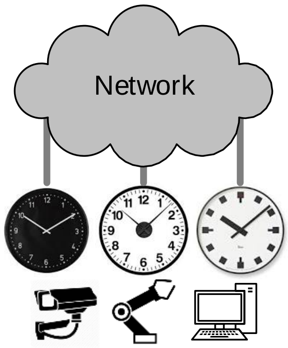
- IEEE 1588-2008
  - IEC 61588 Ed.2
    - IEC - International Electrotechnical Commission
  - Sub-microsecond synchronization
  - Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems
- IEEE 802.1AS
  - Standard for transport of precise timing and synchronization in Audio/Video Bridging (AVB) networks (AVB) networks.
  - It is based on IEEE 1588 V2, and includes a PTP profile.
  - It is also known as General Precision Time Protocol (gPTP).
- White Rabbit project
  - Sub-nanosecond synchronization
  - Utilizes Synchronous Ethernet (SyncE) to achieve syntonization and IEEE 1588 (1588) Precision Time Protocol (PTP) to communicate time
- (Not clear year)
  - IEEE 1588-2018 (?), PTPv2.1, PTPv3
    - Compatible with PTPv2
    - Security extensions
    - Sub-nanosecond accuracy

Table of Contents



IEEE 1588 PTP

- IEEE 1588
  - (commonly known as Precision Time Protocol, PTP)
  - v1: 2002
  - v2: 2008 (IEC 61588 Ed.2)
- IEEE 1588 specifies "*A protocol to synchronize independent clocks running on separate nodes of a distributed measurement or control system to a high accuracy and precision*".
- IEEE 1588 is a protocol designed to synchronize real-time clocks in the nodes of a distributed system that communicate using a network.
  - IEEE 1588은 네트웍을 통해 통신하는 분산 시스템의 각 노드에 있는 시계를 동기시키는 프로토콜



Precision Time Protocol (PTP) is a protocol to synchronize clocks throughout a network and it achieves clock accuracy in the sub-microsecond range on a local area network.

PTP는 네트웍을 통한 시간동기화 프로토콜이며, 로컬네트웍에서 마이크로초 (10^{-6}sec)이내의 정확도로 시간을 맞춘다.

PTP v1 & v2

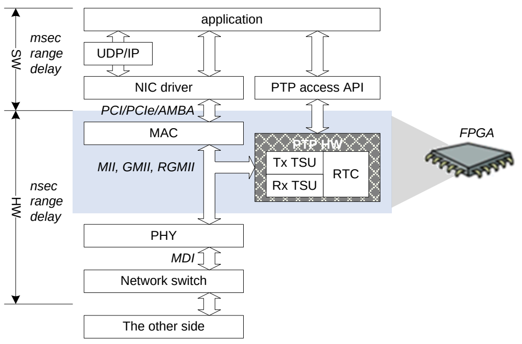
Criteria	PTPv1	PTPv2
clock types	Ordinary Clock (OC) Boundary Clock (BC)	Ordinary Clock (OC) Boundary Clock (BC) end-to-end Transparent Clock (e2e TC) peer-to-peer Transparent Clock (p2p TC) Management Node
time representation	epoc number (16 bit) seconds (32 bit) nanoseconds (32 bit)	seconds (48 bit) nanoseconds (32 bit)
time interval resolution	1 ns	2^{-16} ns (15.26 fs)
message types	Sync Follow_Up	Announce Sync Follow_Up
	Delay_Req Delay_Resp	Delay_Req Delay_Resp
	Management	Management
		Pdelay_Req Pdelay_Resp Pdelay_Resp_Follow_Up
		Signaling
message rates	small choice	bigger range and selectable per message type
addressing	multicast	multicast unicast
mappings	UDP/IPv4 over IEEE 802.3	UDP/IPv4 over IEEE 802.3 UDP/IPv6 over IEEE 802.3 directly over IEEE 802.3 PROFINET DeviceNet/ControlNet
extensions	none	by Type/Length/Value (TLV)
redundancy	BMC	BMC, Alternate Master, Master Cluster
	no	yes
multiple domains	by 4 multicast addresses	by Domain Number (8 bit)
What else?		profiles
		unicast message negotiation
		security protocol (experimental)

- V1 and V2 cannot directly synchronize to each other because they use different message format.
- V2
  - Transparent clock
  - More accurate clock (48-bit sec & 32-bit nsec)
    - Starts 1970.Jan.1: echo == 0
    - 48-bit second: up to 8_925_512 years
  - Peer-to-peer messages
  - UDP/IPv6 (layer 3) & Raw Ethernet (layer 2) packet
- Standard protocol only, but nothing about how to correct the slave.

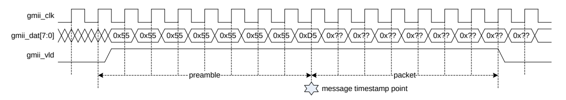
Hans Weibel, Technology Update on IEEE 1599: The Second Edition of the High Precision Clock Synchronization Protocol, 2009.

PTP implementation (example)

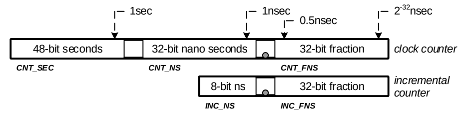
- PTP components
  - RTC: real-time clock
  - TSU: time-stamp unit
  - PTP API



- TSU takes time-stamp at the network side as close as possible in order to minimize time-varying.
  - Message time stamping at the end of preamble.



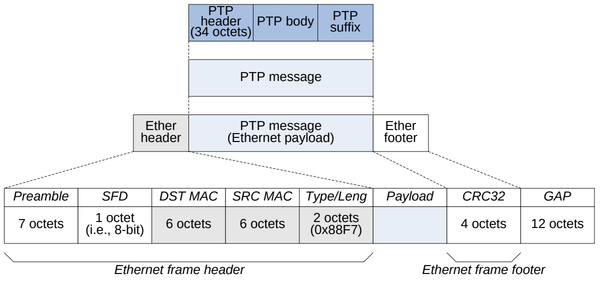
- RTC maintains two groups of counters; one is 'clock counter' and the other is 'incremental counter'



PTPv2 messages (1/3)

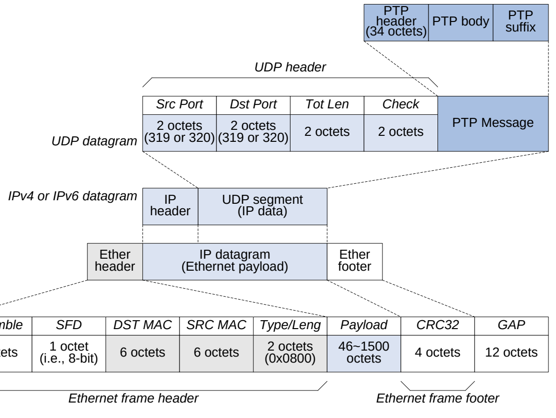
Message type	Message	Note
Event message	Sync	master to slave (to adjust offset)
	Delay_Req	slave to master (to measure propagation delay)
	Pdelay_Req	port to port (to measure link delay)
	Pdelay_Resp	port to port (to measure link delay)
General message	Announce	
	Follow_Up	master to slave (to adjust offset)
	Delay_Resp	master to slave (to measure propagation delay)
	Pdelay_Resp_Follow_Up	port to port (to measure link delay)
	Management	
	Signaling	

PTPv2 messages (2/3)



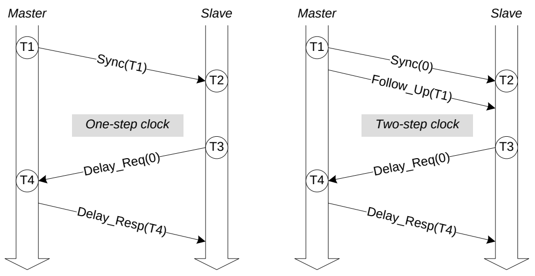
- Raw Ethernet
  - Ref: IEEE 1588-2008 Annex F
  - Ethernet type field: 0x88F7.
  - Destination MAC address
    - 01-1B-19-00-00-00 (delay message)
      - Sync, Announce
    - 01-80-C2-00-00-0E (peer delay message)
      - Pdelay_Req

PTPv2 messages (3/3)



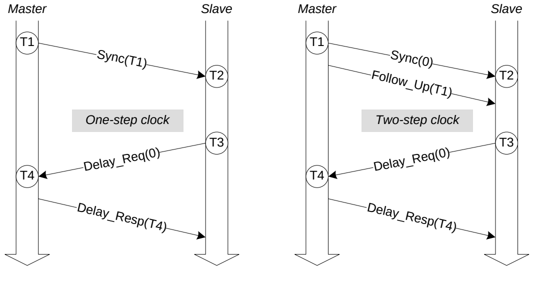
- UDP/IP over Ethernet
  - Ref: IEEE 1588-2008 Annex D and E
  - Ethernet type field: 0x0800 (IP)
  - UDP port: 319 or 320
    - 319 for even messages: Sync, Delay_Req
    - 320 for general message: Follow_Up, Delay_Resp
  - Destination IP address (multicast)
    - IPv4
      - 224.0.1.129 (delay message) 0xE0.00.01.81
        - MAC: 01-00-5E-00-01-81
      - 224.0.0.107 (peer delay message) 0xE0.00.00.6B
        - MAC: 01-00-5E-00-00-6B
    - IPv6
      - FF0x::181 (delay message)
      - FF02::6B (peer delay message)

Mechanisms to measure offset



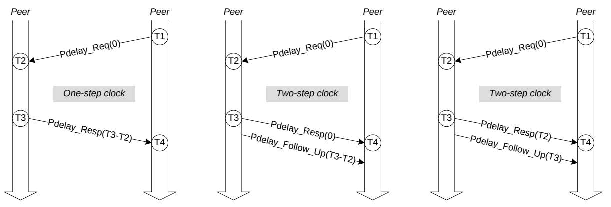
- Under the assumption of symmetric link
  - propagation time from master to slave equals to the propagation time from slave to master
  - offset = (Slave Time) – (Master Time) = [(T2-T1)-(T4-T3)]/2
- For **one-step**, the 'Sync' message carries time-stamp, while 'Follow_Up' carries time-stamp for **two-step**.

Mechanisms to measure delay (1/2)



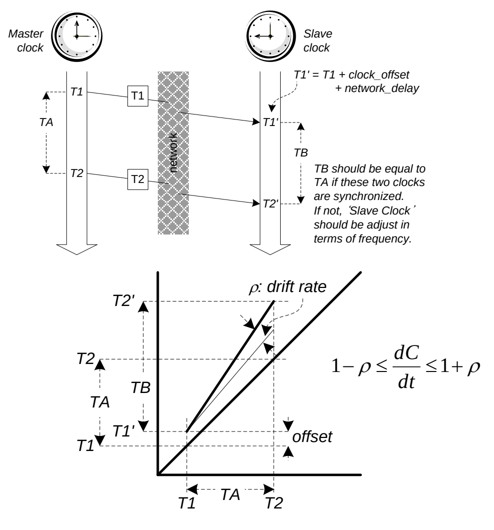
- Delay request-response mechanism
  - to generate and communicate the timing information needed to synchronize ordinary and boundary clocks
  - 1-step clock
    - Sync, Delay_Req, Delay_Resp
    - [(T2-T1)+(T4-T3)]/2
  - 2-step clock
    - Sync, ***Follow_Up***, Delay_Req, Delay_Resp
- For **one-step**, the 'Sync' message carries time-stamp, while 'Follow_Up' carries time-stamp for **two-step**.

Mechanisms to measure delay (2/2)



- Peer delay mechanism
  - to <u>measure the link delay between two clock ports</u>
  - 1-step clock
    - Pdelay_Req, Pdelay_Resp
    - [(T4-T1)-(T3-T2)]/2
  - 2-step clock
    - Pdelay_Req, Pdelay_Resp, ***<u>Pdelay_Resp_Follow_Up</u>***
    - [(T2-T1)+(T4-T3)]/2

Mechanisms to measure drift

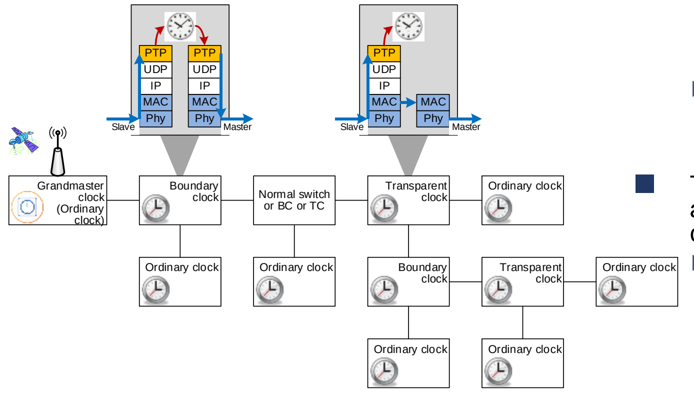


- Drift_Rate
  - [(T2'-T1')/(T2-T1)] – 1
  - TB/TA – 1 = (TB – TA) / TA
- If Slave clock increments its frequency with Fs, it should be adjusted as follows.
  - Fs' = Fs – (Fs * Drift_Rate)

PTP clocks (1/2)

PTP devices (clock and node)	Remark
OC: Ordinary clock	A **single port device** that can be a Master or Slave clock.
GMC: grandmaster clock	
SC: Slave clock	
CC: Connection clock	A **multi port device**
BC: Boundary clock	A **multi port device** that can be a Master or Slave clock. It has a **built-in Slave** clock that recovers a clock. This clock is then used to drive the **built-in Master**, which supplies the clock to the next node.
TC: Transparent clock	A multi-port device that is not a master or slave clock but a bridge between the two.
E2E TC: End-to-End TC	**Forwards and modifies all PTP Messages** to compensate for residence time. Compensation is achieved by addition of the bridge residence time into a correction field within the header of the message.
P2P TC: Peer-to-Peer TC	**Forwards and modifies Sync and Follow_Up messages** only to compensate for residence time. Compensation is achieved by addition of the bridge residence time + the peer-to-peer link delay, into a correction field within the header of the message.
Management node	A device that configures and monitors clocks.

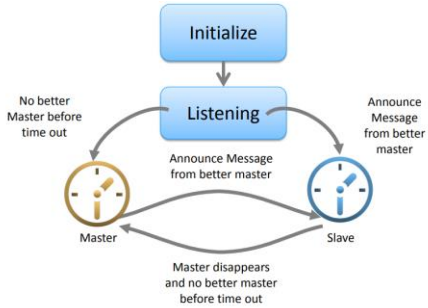
PTP clocks (2/2)



- BC (Boundary Clock) extends synchronization across an intermediate network element
  - A boundary clock contains more than one PTP port:
    - a slave port that is synchronized with a remote master, and
    - a master port that synchronizes other slaves downstream
  - Synchronization messages are terminated at each port and not forwarded
- TC (Transparent Clock) is a switch that adjusts a PTP message's timestamp to compensate for its own queuing delays
  - Timestamp in incoming message is modified before sending the message out
    - Creates security issues, since original crypto checksum is not valid anymore

PTP best master clock algorithm

- The *best master clock* (BMC) algorithm performs a distributed selection of the best candidate clock based on the clock properties.
  - Any ordinary clock can be grand master clock.
- Clock properties are broadcasted via ‘Sync’ (PTPv1) or ‘Announce’ (PTPv2) message. (lower has higher priority)
  - 1. priority (0-255): user configurable
  - 2. class (0-255): got GPS
  - 3. accuracy: 100ns
  - 4. variance: frequency stability
  - 5. priority (0-255): user configurable
  - 6. unique identifier (clock id)

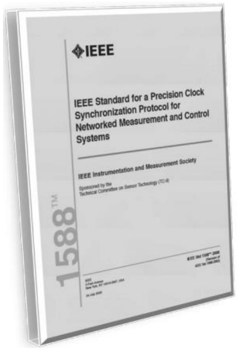


PTP profiles

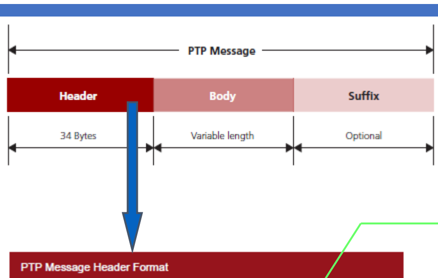
- The set of allowed PTP features applicable to a device. (more restrictive set of rules for specific application)
  - Specifies
    - Required options
    - Allowed options
    - Forbidden options
    - Network topology limitations
    - Performance requirements
- Default profile
  - Defined by IEEE 1588 (it only defines this default profile)
- Power plant profile
  - IEEE C37.238-2011/2017 Standard
- Telecom profile for frequency transfer
  - ITU-T G.8265, G.8275
- Audio & video application profile
  - IEEE 802.1AS
- Enterprise profile

Profiles are a set of rules which place restrictions on PTP, intended to meet the needs of a specific application or set of similar applications.

Table of Contents



PTPv2 message

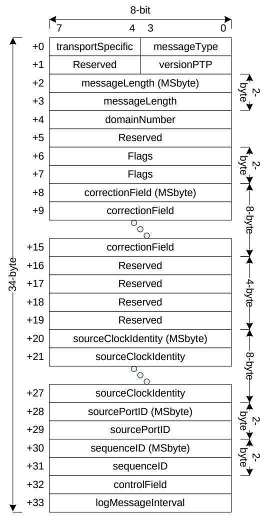


Bits								Octets	Offset
7	6	5	4	3	2	1	0		
transportSpecific				messageType				1	0
Reserved				versionPTP				1	1
messageLength								2	2
domainNumber								1	4
Reserved								1	5
Flags								2	6
correctionField								8	8
Reserved								4	16
sourcePortIdentity								10	20
sequenceID								2	30
controlField								1	32
logMessageInterval								1	33

- All PTP message consists of
  - header (34-byte)
    - common to all PTP message
  - body (variable length)
  - suffix (optional)

Type	code	Message
Event message	0x0	Sync
	0x1	Delay_Req
	0x2	Pdelay_Req
	0x3	Pdelay_Resp
General message	0x8	Follow_Up
	0x9	Delay_Resp
	0xA	Pdelay_Resp_Follow_Up
	0xB	Announce
	0xC	Signaling
	0xD	Management

PTPv2 message header



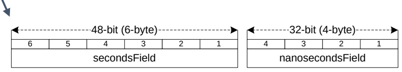
- The header (34-byte) is common to all PTP message. (note that big-endian style for multi-byte data)
  - transportSpecific: '0' or '1' depending on UDP payload 124-byte requirement
    - 1 for IEEE 802.1AS and 0 by default
  - messageType: Sync, Delay_Req, …
  - versionPTP: PTP version of the originating node
    - 2 for PTPv2
  - messageLength: full length including header, body and suffix, but excluding any padding
  - domainNumber: domain this message belongs to
    - domain: logical group of clocks to be synchronized
  - flags: status information
  - correctionField: correction value in nano-second
  - souceClockIdentity
  - sourcePortIdentity: originating port for this message
  - sequenceID: sequence number of each message types
  - controlField: backward compatibility
  - logMessageInterval: depends on type of message

Announce message

- Indicates the capabilities of a clock to the other clocks on the same domain.

Announce Message Format

Bits (7 6 5 4 3 2 1 0)	Octets	Offset
header (13.3)	34	0
originTimestamp	10	34
currentUtcOffset	2	44
Reserved	1	46
grandmasterPriority1	1	47
grandmasterClockQuality	4	48
grandmasterPriority2	1	52
grandmasterIdentity	8	53
stepsRemoved	2	61
timeSource	1	63



Sync & Follow_Up messages

Sync Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
originTimestamp								10	34

48-bit (6-byte)					
6	5	4	3	2	1
secondsField					

32-bit (4-byte)			
4	3	2	1
nanosecondsField			

- The 'Sync' message is sent by a master clock and contains the master time
  - If the master clock is a two-step, this timestamp will be zero value. Actual timestamp value will be sent afterwards in the associated 'Follow_Up' message.

Follow_Up Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
preciseOriginTimestamp								10	34

48-bit (6-byte)					
6	5	4	3	2	1
secondsField					

32-bit (4-byte)			
4	3	2	1
nanosecondsField			

- The 'Follow_Up' message is sent by master clock and contains the master time
  - It is used when the master clock is a two-step.

Delay_Req & Delay_Resp messages

Delay_Req Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
originTimestamp								10	34

48-bit (6-byte)					
6	5	4	3	2	1
secondsField					

32-bit (4-byte)			
4	3	2	1
nanosecondsField			

- The 'Delay_Req' message is sent by a slave clock and contains the slave time
  - It is only used in the delay request-response mechanism.

Delay_Resp Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
receiveTimestamp								10	34
requestingPortIdentity								10	44

48-bit (6-byte)					
6	5	4	3	2	1
secondsField					

32-bit (4-byte)			
4	3	2	1
nanosecondsField			

- The 'Delay_Resp' message is sent by the master clock and contains the master time when the 'Delay_Req' message was received.
  - It is only used in the delay request-response mechanism.
  - 'requestingPortIdentity' contains the value of 'sourcePortIdentity' field of the associated 'Delay_Req' message.

Pdelay_Req & Pdelay_Resp messages

Pdelay_Req Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
originTimestamp								10	34
reserved								10	44

48-bit (6-byte)					
6	5	4	3	2	1
secondsField					

32-bit (4-byte)			
4	3	2	1
nanosecondsField			

- The ‘Pdelay_Req’ message is sent by ‘delay requester’ peer-to-peer clock and contains the ‘delay requester’ peer-to-peer clock time.
  - It is sent only in the peer delay mechanism.
  - ‘reserved’ filed is used to make the message length the same as the ‘Pdelay_Resp’ message.

Pdelay_Req & Pdelay_Resp messages

Pdelay_Resp Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
receiveReceiptTimestamp								10	34
requestingPortIdentity								10	44

Pdelay_Resp_Follow_Up Message Format

Bits								Octets	Offset
7	6	5	4	3	2	1	0		
header (13.3)								34	0
responseOriginTimestamp								10	34
requestingPortIdentity								10	44

- The ‘Pdelay_Resp’ message is sent by ‘delay responder’ peer-to-peer clock and contains the ‘delay responder’ peer-to-peer clock time.
  - It is sent only in the peer delay mechanism.
  - ‘requestingPortIdentity’ contains the value of ‘sourcePortIdentity’ field of the associated ‘Pdelay_Req’ message.
  - If the clock is a two-step, this timestamp will be zero value. Actual timestamp value will be sent afterwards in the associated ‘Pdelay_Resp_Follow_Up’ message.
- The ‘Pdelay_Resp_Follow_Up’ message is sent by ‘delay responder’ peer-to-peer clock.

Signaling and management messages

Signalling Message Format

Bits (7 6 5 4 3 2 1 0)	Octets	Offset
header (13.3)	34	0
targetPortIdentity	10	34
One or more TLVs	N	44

Management Message Format

Bits (7 6 5 4 3 2 1 0)	Octets	Offset
header (13.3)	34	0
targetPortIdentity	10	34
startingBoundaryHops	1	44
boundaryHops	1	45
Reserved / actionField	1	46
Reserved	1	47
managementTLV	M	48

Bits (7 6 5 4 3 2 1 0)	Octets	TVL Offset
tlvType	2	0
lengthField	2	2
managementID	2	4
dataField	N	6

- Signaling message
  - Send TLV (Type Length Value)
    - REQUEST_UNICAST_TRANSMISSION
    - GRANT_UNICAST_TRANSMISSION
    - CANCEL_UNICAST_TRANSMISSION
    - ...
- Management message
  - to transmit information from a clock to a node manager and from a node manager to one or more clocks.

References

- IEEE 1588-2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems.
- RFC 5905, Network Time Protocol Version 4: Protocol and Algorithms Specification, 2010.6.
- RFC 2030, Simple Network Time Protocol (SNTP) Version 4 for IPv4, IPv6 and OSI, 1996.10.
- J.C. Eidson, Measurement, Control and Communication Using IEEE 1588, Springer, 2010.
- D.L. Mills, Computer Network Time Synchronization, 2nd Edition, CRC Press, 2010.

㈜퓨쳐디자인시스템
34051 대전광역시 유성구 문지로 193, KAIST 문지캠퍼스, F723호
(042) 864-0211~0212 / contact@future-ds.com / www.future-ds.com

Future Design Systems, Inc.
Faculty Wing F723, KAIST Munji Campus, 193 Munji-ro, Yuseong-gu, Daejeon 34051, Korea
+82-042-864-0211~0212 / contact@future-ds.com / www.future-ds.com

FUTURE
Design Systems