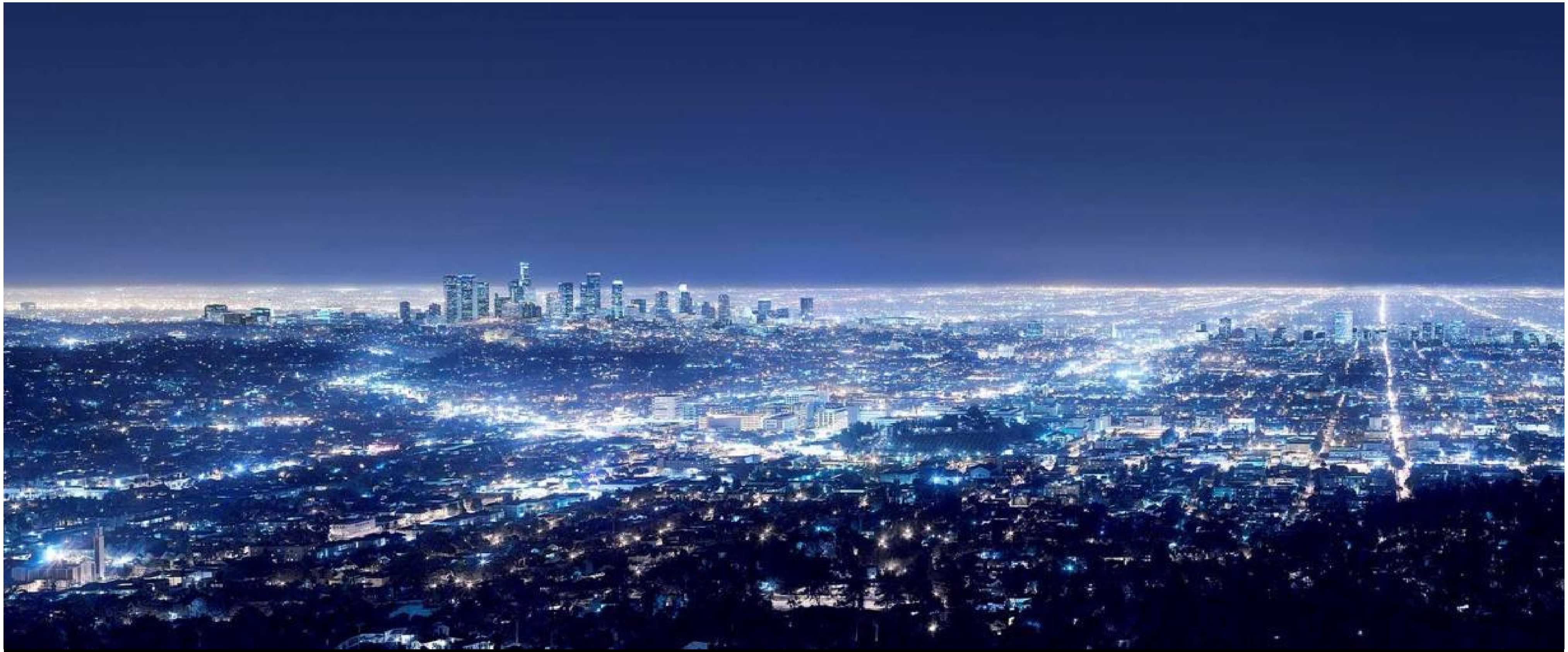

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Time Synchronization Challenges in Industrial Networks

Outline

- Time synchronization background
- Industrial requirements
- Current standards
- Challenges
- Time sync development efforts
- Outlook

Disclaimer: the following presentation does reflect my opinion which might not necessarily conincide with ABB's view or opinion in the given area.

Time synchronization background

- Why is time synchronization important?
- Applications and precision domains
- Time synchronization solutions
  - SNTP
  - IEEE 1588v2 -> working on v3
  - IEEE 802.1AS

Why is time synchronization important?

- Distribution of frequency and time
- In the Telecommunication Industry:
  - Is a requirement also from the telco side to allow use of e.g. carrier Ethernet instead of SDH
- In Broadcast or other Audio/Video applications:
  - synchronize audio and video streams
- In automation:
  - Synchronous operation of devices
  - Data logging and stamping
- Stock market

Industrial applications and precision domains

- 1 ms is relatively easy to reach, this is usually enough for SCADA data, time stamped data from protection relays (IEDs)
- 100 µs for tagging zero crossings
- 1 µs might be required be e.g. wave fault location, synchrophasor measurements
- Sub µs: synchronize a multi-axis drive system, logged data time stamping, telco network synchronization

- There are some exceptions: e.g. circuit breaking on a bus bar will happen if the message is received even if the time stamp is out of sync
- Clock synchronization requirements can be more strict as the network delay for transmitting the frame

What is challenging with time synchronization?

- On standard Ethernet efficiency, speed and delay were important metrics and not keeping synchronous operation (+-100 ppm clock difference)
  - More precise clock is needed or needs to be synced often (several Hz)
- With the exception of the physical layer (with the previously mentioned clock precision), entities have no connection to a real world clock from the network
  - Out of band time distribution: e.g. IRIG-B, direct GPS clock
  - Synchronous Ethernet
- Distance from the physical layer has a direct impact on the achievable precision

Time synchronization solutions

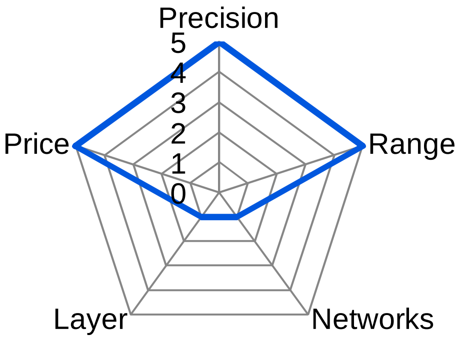
- SNTP:
  - L3 message exchange,
  - delay=half of (measured roundtrip delay minus processing at remote side).
  - In the ms range
- IEEE 1588 v2
  - Current industry standard
  - Sub µs with L2 stamping (optional, but often used)
  - Also for IEEE 1588: one-way transmission delay is one half of round-trip
- IEEE 802.1AS
  - Simplified and extended profile for IEEE 1588v2
  - First intended for AV applications

IEEE 1588 overview
The preferred technology for time synchronization

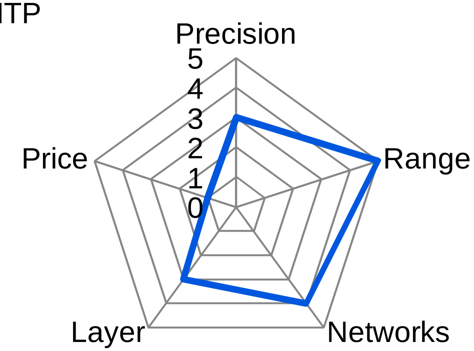
- IEEE 1588 ed. 2 from 2008 is rapidly emerging as the preferred time synchronization technology in most domains including automation
  - IEEE 1588 enables nodes on a network to synchronize their clocks to a clock master
    - IEEE 1588 packets are exchanged with timing and delay information
    - Used by the nodes to adjust their local clocks
  - Very accurate synchronization possible (1 µs or even better) when the infrastructure and end nodes have sufficient support IEEE 1588
    - Hardware timestamping of IEEE 1588 packets is needed for this level of accuracy
  - Many CPUs, MACs, PHYs, switch chips, switches and routers now support timestamping of IEEE 1588 packets

Time synchronization landscape

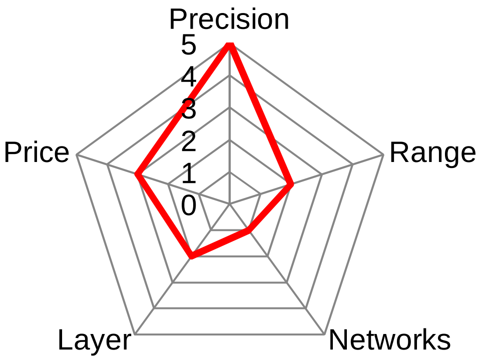
SDH



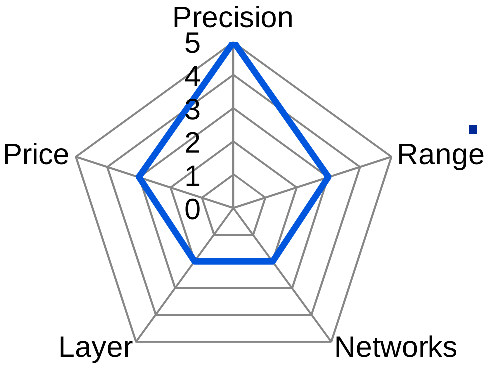
SNTP



IEEE 1588v2



- IEEE 802.1AS



- Need
  - Synchronous telecommunication networks are expensive and industry wants to use cheaper and more flexible links.
  - Industry needs higher precision than what is offered by the generic protocols
  - Distributed systems offer more flexibility for industry
  - E.g.: precision using SNTP on the application layer is several milliseconds, not adequate for motion control
- No
  - protocol for high precision sync over wireless sensor networks
  - protocol for precise sync over IP
  - routing for time synchronization
  - Support for asymmetric delays

IEEE 1588v2 Precision Time Protocol

- Current standard choice for time synchronization
- PTP can work over non-time aware infrastructure (then it uses filtering for variable delays)
- Can be deployed on existing infrastructure
- Current solution needs to be revised as
  - It is a hack
  - Transparent clocks break the IEEE bridge model by modifying frames on the fly without changing the Source Address
- Limited to Ethernet

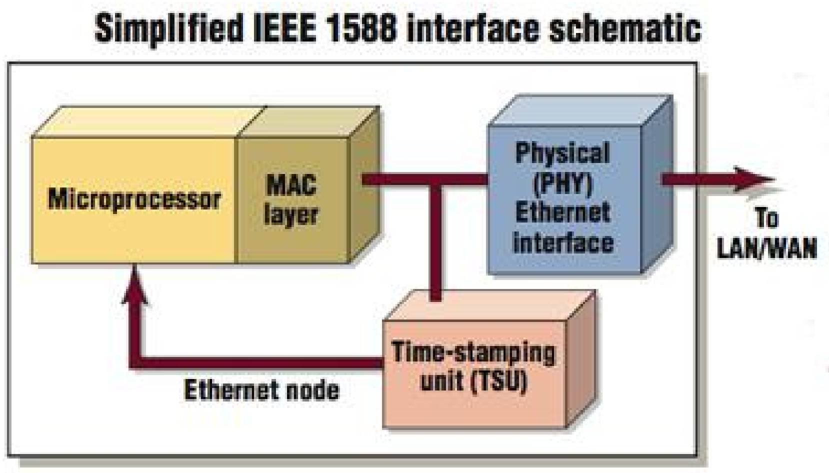
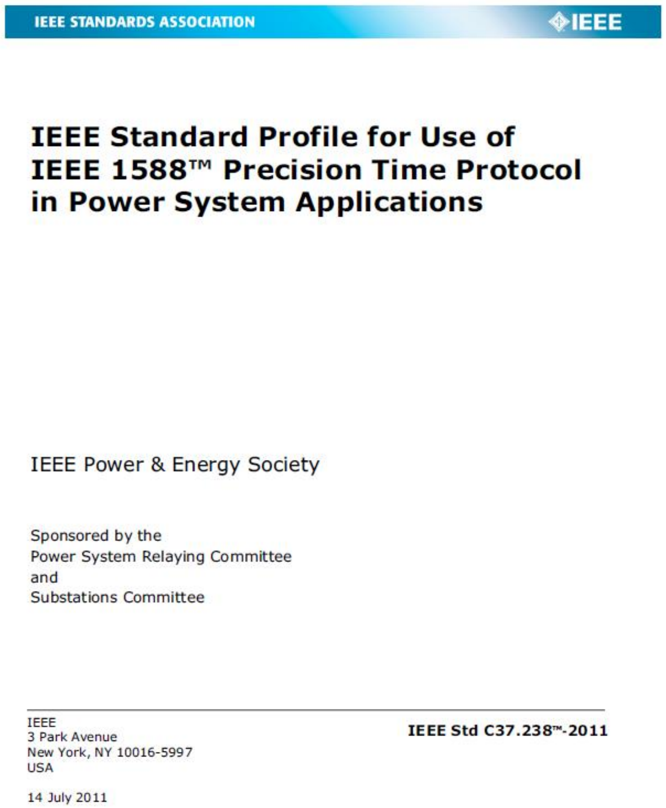


Image from: http://machinedesign.com/archive/industrial-networks-get-synced

IEEE 1588 ed. 2
Profiles for IEC 61850 and PROFINET

- IEC 61850 profile for PTP: IEEE C37.238-2011
- PROFINET profile for PTP: IEEE 802.1AS-2011
- These two profiles are different – what are the implications?



IEEE STANDARDS ASSOCIATION IEEE

IEEE Standard Profile for Use of IEEE 1588™ Precision Time Protocol in Power System Applications

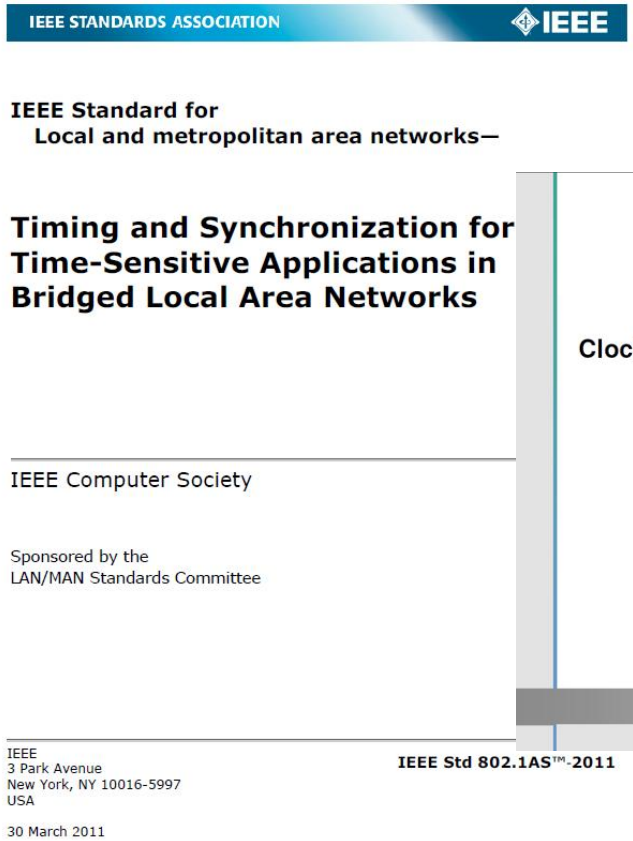
IEEE Power & Energy Society

Sponsored by the
Power System Relaying Committee
and
Substations Committee

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

14 July 2011

IEEE Std C37.238™-2011



IEEE STANDARDS ASSOCIATION IEEE

IEEE Standard for
Local and metropolitan area networks—

Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks

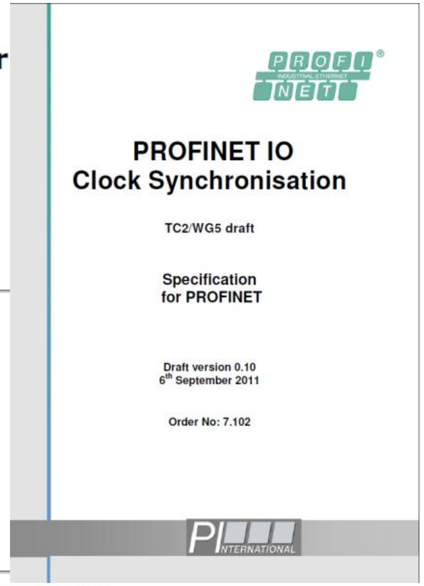
IEEE Computer Society

Sponsored by the
LAN/MAN Standards Committee

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

30 March 2011

IEEE Std 802.1AS™-2011



PROFINET IO
Clock Synchronisation

TC2/WG5 draft

Specification
for PROFINET

Draft version 0.10
6th September 2011

Order No: 7.102

Comparing the PTP variants

	IEEE 1588 ed. 2	IEEE C37.238	IEEE 802.1AS
Date of release	2008	2011	2011
Physical media	IEEE 802.3 Ethernet, some fieldbuses	IEEE 802.3 Ethernet	IEEE 802.3 Ethernet, IEEE 802.11 WLAN, IEEE 802.3 EPON, CSN (generic)
Node types supported	Boundary, ordinary, E2E transparent, P2P transparent, management	Boundary, ordinary, P2P transparent	Boundary, ordinary
Path delay	P2P and E2E	P2P	P2P
Time processing method	One-step and two-step	One-step and Two-step	Two-step
OSI layers supported	L2 and L3	L2	L2
Clock domains	Many	Many	One
PTP frames used	Announce, Sync, Management, PdelayReq, PdelayResp (Follow_Up, PdelayReq_Follow_up)	Announce, Sync,, Pdelay_Req, Pdelay_Resp (Follow_Up, PdelayReq_Follow_Up), No Management message defined	Announce, Sync, Follow_Up, Pdelay_Req, Pdelay_Resp, Pdelay_Resp_Follow_Up,Signaling, No Management message defined
VLAN tagging of PTP frames	Optional	Mandatory, untagged frames accepted	Not allowed
EtherType	0x88F7	0x88F7	0x88F7
TLV	Optional. Unknown TLVs are ignored.	Mandatory TLVs: Announce. Unknown TLVs are ignored	Mandatory TLVs: Announce, Follow_Up. Unknown TLVs are ignored.
Announce period	$2^{-124}\ldots2^{123}$ s	1s (no range allowed)	Default: 1 s (All PTP values allowed)
Sync period	$2^{-124}\ldots2^{123}$ s	1s (no range allowed)	Default: 125 ms (All PTP values allowed)
Time format	48 bit second 32 bit nanosecond	48 bit second 32 bit nanosecond	48 bit second 32 bit nanosecond
Precision	Implementation dependant (typically sub microseconds)	Implementation dependant (typically sub microseconds)	Implementation dependant (typically sub microseconds)
BMCA	Standard PTP BMCA	Standard PTP BMCA	Simplified PTP BMCA
Local clock precision	Not specified	50 ns jitter (TC), 0.2 µs jitter (GMC)	100 ppm
Syntonization	Optional	Optional?	Mandatory
Time base	TAI	TAI	TAI
Leap seconds	Indirectly handled	Indirectly handled	Indirectly handled
Holdover time	Not specified	Within 2 µs for 5s	Sync timeout default value: 1s
Signaling	Optional	Not used	Mandatory
Management	Optional	Different from IEEE 1588	Mandatory?
Backup master	Via BMCA	Via BMCA	Via BMCA (simplified)
MIB	Optional	Specified, mandatory for grandmaster capable devices	Specified
GrandmasterID	Mandatory?	Mandatory	Mandatory?

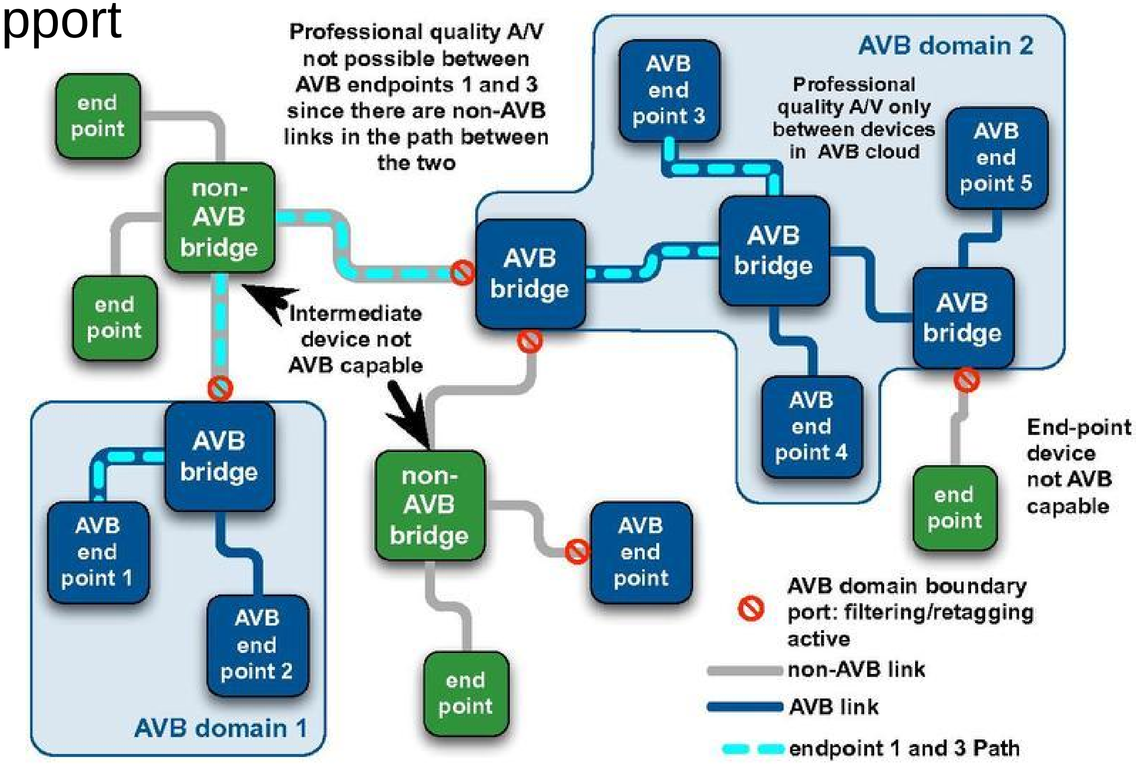
Address usage by PTP profiles
Several inconsistencies

Frame type	IEEE 1588 ed. 2 Destination address	IEEE 802.1AS Destination address	C37.238 Destination address
Sync frames	01-1B-19-00-00-00	01-80-C2-00-00-0E	01-1B-19-00-00-00
Follow_Up	01-1B-19-00-00-00	01-80-C2-00-00-0E	01-1B-19-00-00-00
Pdelay_Req	01-80-C2-00-00-0E	01-80-C2-00-00-0E	01-80-C2-00-00-0E
Pdelay_Resp	01-80-C2-00-00-0E	01-80-C2-00-00-0E	01-80-C2-00-00-0E
Pdelay_Resp_Follow_Up	01-80-C2-00-00-0E	01-80-C2-00-00-0E	01-80-C2-00-00-0E
Announce frames	01-1B-19-00-00-00	01-80-C2-00-00-0E	01-1B-19-00-00-00
Signaling frames	01-1B-19-00-00-00	01-80-C2-00-00-0E	Not used

- 01-80-C2-00-00-0E is also used by LLDP
  - Needs to be handled properly in nodes with support for both PTP and LLDP – not enough to discriminate by MAC address in driver layer (use EtherType)

IEEE 802.1AS

- Originally from Audio Video Bridging now Time Sensitive Networking (TSN) WG
- Requires time-aware infrastructure
- Is a well-defined restricted profile for IEEE 1588v2
- Implements proper separation of protocol elements: abstraction of the physical network
- It also extends network support



Challenges - Asymmetric delay

- Measurement and averaging in both IEEE 802.1 AS and IEEE 1588 is based on the assumption of symmetric delays
- Typically no problem on LANs, problem on WAN
- Per hop forwarding decision
- How to provide end-to-end quarantees

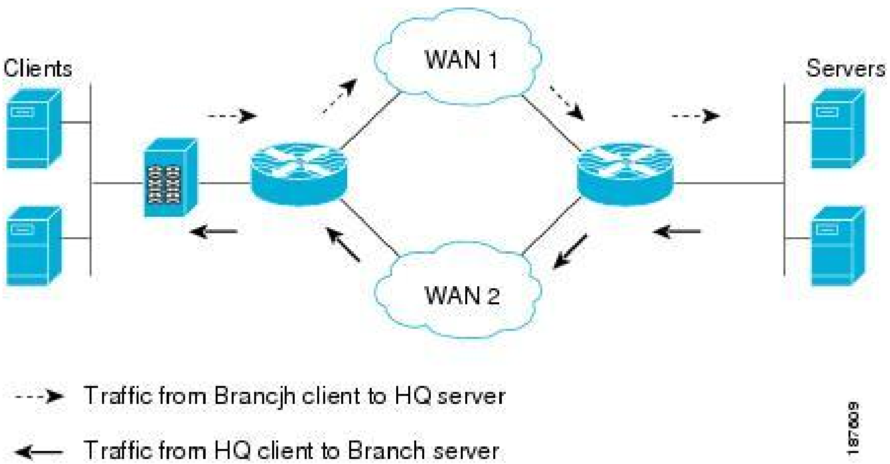


Figure from Cisco

Challenges

- Support for heterogenous networks
- Inclusion the time sync into quality of service parameters
- Bandwidth reservation e.g. using RSVP
- Synchronization in wireless sensor networks
- Using Transparent Clocks is an elegant solution but breaks the bridge model by modifying frames on the fly without updating source field

IEEE 1588 vs. IEEE 802.1Q
Compliance with the Ethernet switching standad

- IEEE 1588 (ed. 2) is not 100% compliant with IEEE 802.1Q
  - 1-step transparent clocks:
    - Sync frames are updated on the fly by a compliant node
    - The source address of the packet is not updated
      - Thus: a node generates a packet with the source MAC address of some other node
  - 2-step transparent clocks:
    - Sync frames and Follow_Up frames are updated by a compliant node
    - The source address of the packet is not updated
      - Thus: a node generates two packets with the source MAC address of some other node
  - This issue is currently being discussed by a IEEE 802.1 working group
    - IEEE 1588 behavior most likely allowed but could create problems
      - Note: transparent clock has to be implemented as a higher layer entity – not just as a MAC relay entity (switch)
      - The issue is not solved by updating the source address, as then the recipient will have no knowledge on the sender

Protocol develompent

- 802.1ASbt
  - Explicit support for one-step processing
    - Backwards compatible to two-step
  - Hot standby for backup grand master clocks
  - Multiple paths for clock propagation
  - Clock path quality metric
- 1588v3
  - Have a proper protocol split
  - WAN sync: provide end-to-end quality information
  - Find a solution for the TC layer violation

Outlook

- Importance grows
- Coverage for heterogenous networks, including wireless sensors
- Wide range of possible usage areas, including smart grid, distributed SCADA environments or in general, for services using a packet switched bearer network
- Find a solution on the use of transparent clocks

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