

Dynamic Host Configuration, Time and Synchronization

Unit 15 - Hands-On Networking - 2018

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Recap

- **MAC addresses** identify hosts in **subnets**.
- **IP addresses** identify hosts in **networks**.
- DNS allows to **resolve names**.
- Certain application layer protocols are **time-sensitive**.

Dynamic Host Configuration

Bootstrap Network Communications

② Assume your device enters a new network. Which information do you need to participate in communication?

⚠ Answer:

- IP Address
- Subnet IP and Mask
- Default Router

② How can we get this information and configure the device?

- Configure manually (based on values from e.g. a network map).
→ **Static Configuration**
- Ask the network for it!
→ **Dynamic Configuration**

Automating Network Configuration

For small environments (e.g. home), configuration can be done manually.

👎 Drawbacks:

- Prone to errors (two hosts with same address hinder communication).
- Might be tricky to configure devices that are not network-accessible.
And might not even have a screen and input devices attached.
- Potentially still ressembles a lot of work for admins to configure hosts.

⚠️ For enterprise networks, this is infeasible! Automate and be consistent.

✓ Dynamic Host Configuration Protocol (DHCP) ([RFC2131](#))

Quiz

② Knowing nothing about the network you are physically connected to, how can you still communicate?

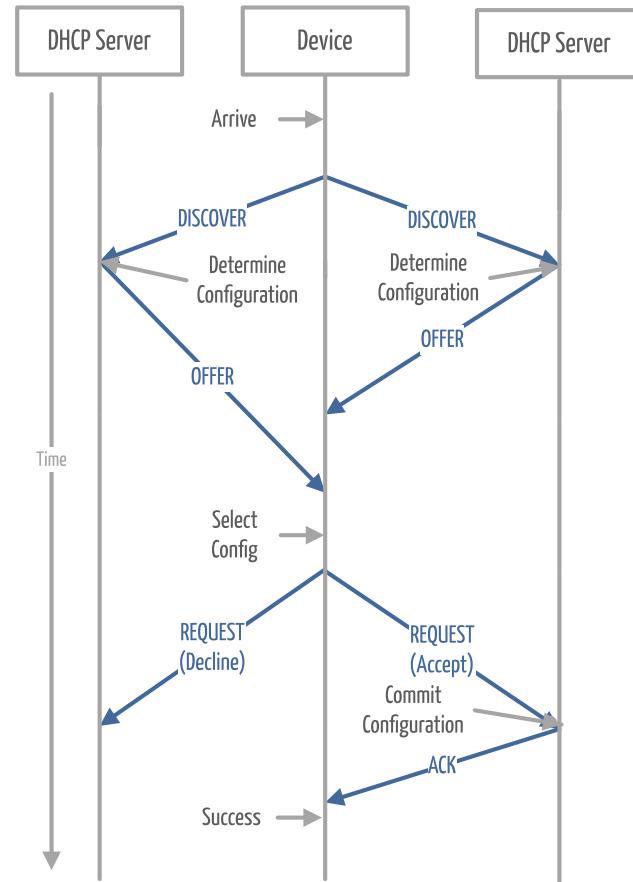
⚠ Answer:

Broadcast into the network, reaching all devices at the same time!

IP broadcast address of local network: 255.255.255.255

DHCP | Process

- Device enters network.
It has no configuration yet.
- **DISCOVER** message sent as a broadcast by device to local subnet.
Looking for a DHCP server.
- Server sends **OFFER** to device.
Includes configuration.
- Device sends **REQUEST** to server.
Sent configuration by server is taken.
- Server sends **ACK** to device.
Server ensures resource is allocated and acknowledges reservation for client.



DHCP | Configuration Parameters

Newly arriving device is **uniquely** identified by its **MAC address**.

Which it also uses for the subnet-local communication.

Provided configuration by the server includes:

Network Details

- IP Address
Must be allocated / reserved by the server.
- Subnet and Mask
So that the host can communicate with others in local subnet.
- Gateway Address
To know where to send packets that should be routed.

Meta Information

- Lease Time
Configuration expires after some time.

Other Information

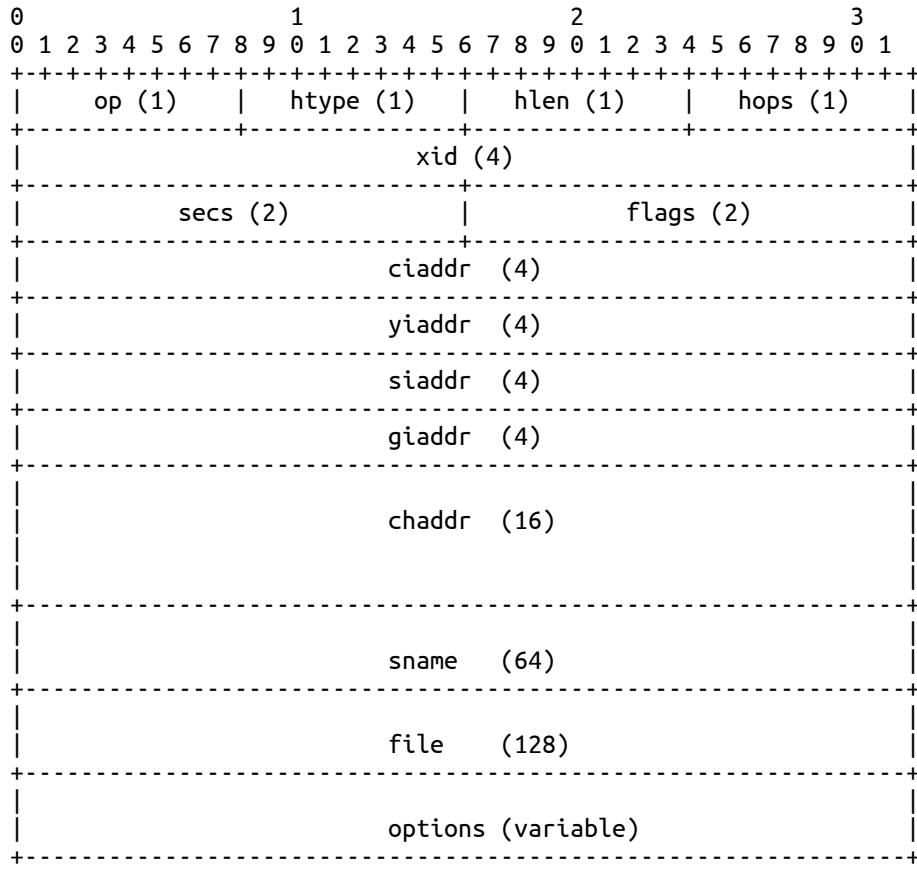
- DNS Server Address / DNS Suffix
Where can I resolve names? What is my domain?
- Boot files
Includes kernel / initial file system
etc

DHCP | Defining Configurations

- Network parameters are chosen by administrators when designing the network.
- IP addresses are associated with hosts manually.
- When the exact IP address is not important:
 - Define a pool of IP addresses (192.168.2.50 - 192.168.2.90).
 - Arriving hosts get an IP address from this range.
 - DHCP clients often try to renew allocations.
When querying again using the same MAC address, receiving the same configuration is very likely.

Stateful Configuration: DHCP requires the servers to keep state and devices to retrieve this information. A device cannot pick his configuration autonomously.

DHCP | Message Format



- **htype, hlen:** Hardware Type (e.g. Ethernet) and address length.
- **hops:** Used by relays.
- **xid:** Transaction ID, randomly chosen.
- **yiaddr:** Offered/assigned client IP.
- **chaddr:** Client hardware address.
- **giaddr:** Relay address if used.
- **file:** Boot file.

DHCP | Out of Stock

 Access networks (meeting rooms, ...) have a regular shortage of IP addresses.

 **Problem:** Hosts leaving the network typically don't actively return IP address.

⌚ What can we do about it?

- Decrease lease-time so that offline devices do not occupy an address for too long.
- Devices can renew leases while active in a network → use short lease times.
 - Active users do not recognize a difference.
 - Passive users are quickly removed from the lease list.
- Allows more devices to access a network than there are IP addresses.

 Number of devices accessing a subnet **concurrently** still limited by its size.

DHCP | Expanding Horizons

⚡ **Problem:** Hosts send DISCOVER only to subnet and not every subnet is equipped with a DHCP server. In enterprises, central servers keep configs consistent.

DHCP Relays

DHCP | Keep it Static

 Some services require static IPs (e.g. printers) and might not support DHCP.

 **Problem:** Can lead to duplicate IP addresses, when DHCP assigns this IP.

② What options do we have?

A) Exclude IP:

- IP pools can be configured on the server.
- Ensure that this specific IP is not in the pool.
 - Blacklist it.
 - Choose pools in a way that parts of the subnet are not assigned.

B) Assign IP:

- Enter the printers MAC in the DHCP server's association table.
- The printer might not support DHCP, but by this the IP is excluded from being assigned to others.

DHCP | Servers

- Enterprise networks require DHCP servers to be present.
- There should be only one DHCP server per zone (single point of truth).

Dedicated Server

- Software solutions for all major operating systems are available.
- Benefits:
 - Easier to coordinate for multiple zones and instances.
- Examples:
 - [dnsmasq](#) ()
 - [dhcpserver](#) ()
 - Microsoft DHCP Server ()

part of Windows Server

Built-In Network Hardware

- Routers come with DHCP facilities, including configurable mappings.
- Benefits:
 - No need to run a dedicated server.
- Drawbacks:
 - Puts more burden on networking hardware.

Zero Configuration (RFC3927)

Sometimes you want hosts to communicate with each other **without local servers for DHCP or DNS** (ad-hoc or isolated scenarios).

- Choose a link-local IP address (only valid on the same physical or logical link).
- IP addresses are picked randomly out of the subnet **169.254/16** (169.254.1.0 to 169.254.254.255) seeded with the MAC address.
Hosts should try keeping an address to provide stability.
- Conflicts are avoided by using e.g. ARP probes.
Check who has the picked IP. Source IP set to 0.0.0.0 to avoid confusions.
- Hosts will defend their configuration.
Taking action when they detect ARP requests or responses for their IP address.

Stateless Configuration: The devices can decide on their own, don't have to keep state or find out about the state of the network from somewhere else.

Time and Synchronization

The only reason for time is so everything
does not happen at once.

(Albert Einstein)

When god made time, he made plenty of it.

(Irish Saying)

It's About Time...

... to ask oneself: What is ?

Definition Attempt: Indefinite continued progress of existence and events that occur in apparently irreversible succession.

Unit: Second

Reference: Defined by electronic transition frequency of caesium atoms.

Purpose: Measure used to...

- sequence events.
- compare event durations.
- compare intervals between events.
- quantify rates of change.
- have a fourth dimension together with the three spatial ones.



Very important measure that has to be calculated properly.

Clocks

Hardware Clock

- Clock running independently of any control program.
- Even runs when the machine is powered off.
- Other names: RTC (Real-time clock), bios clock, CMOS clock.

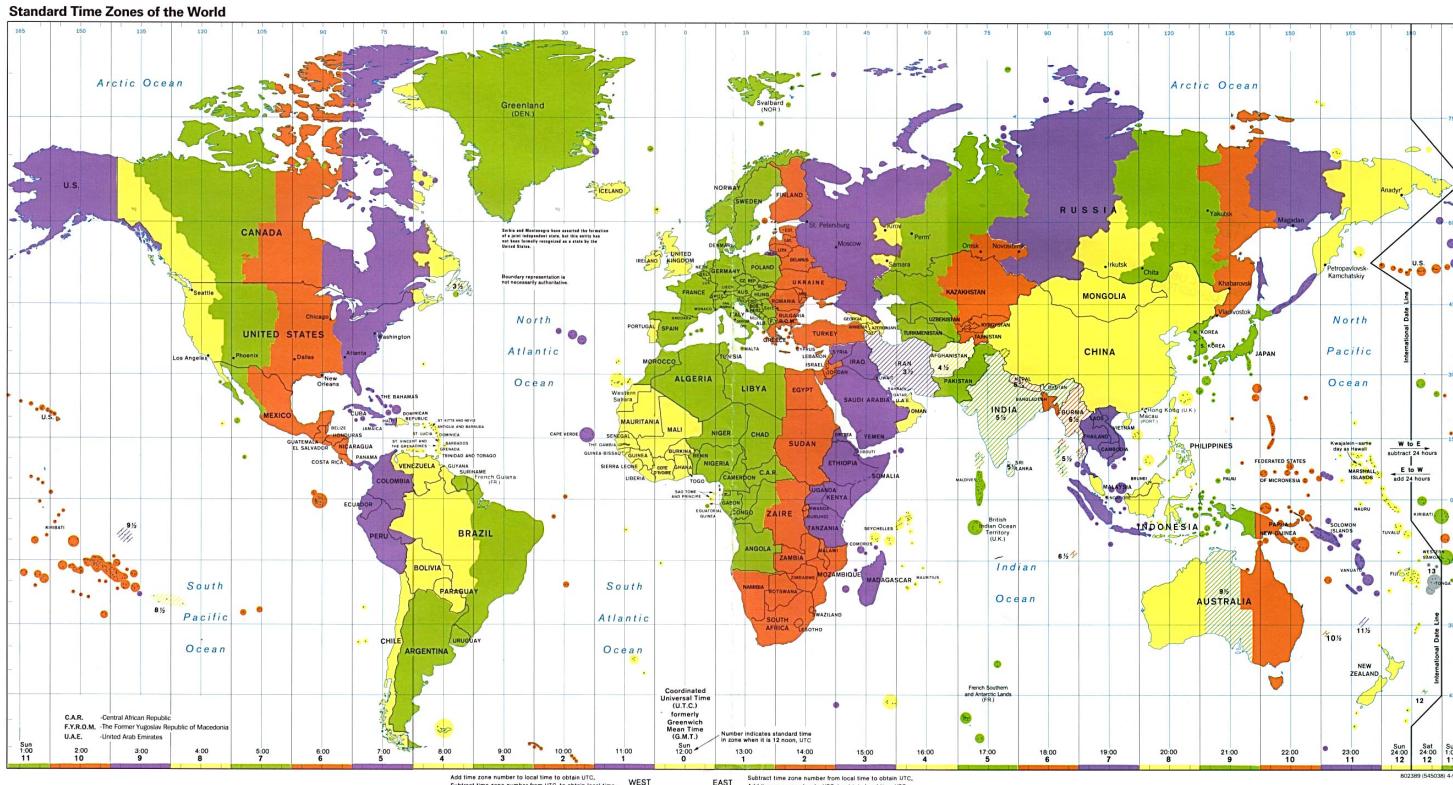
System Clock

- Clock running in the kernel.
- Triggered by an interrupt.
- Counts in seconds since 00:00:00 January 1, 1970 UTC.



If you ever want to update clocks in whatever direction (System-to-Hardware or Hardware-to-System) use `hwclock` (syscall and cmdline tool).

World Time Zones



Look Before You Leap... and Code!

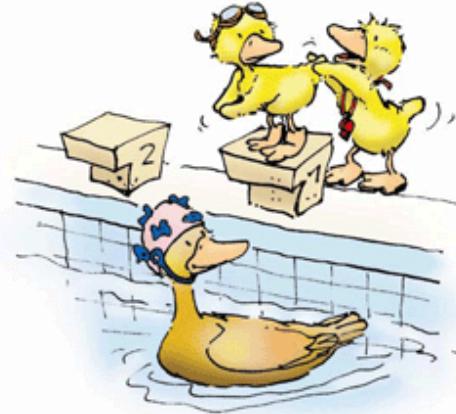
Due to the world not working in decimal means there are:

- **Leap Years**

Seasonal and astronomical events do not repeat in integer multiples of days.

- **Leap Seconds**

Earth rotates at irregular rates.



Optimistic programmers (using only two digits to represent a year) caused the [Y2K problem](#) (or check out the [Y2K38 problem](#)).

- Consider leap-somethings when developing time-critical software.
- Be optimistic about your software's lifetime. It might be longer than you think!

Back to the Train Station

Assume you want to do a coordinated flashmob:
At 12:00 everyone should throw toy animals into the air!

But: As the animals are so big and heavy, everyone forgot to bring watches, so they have to ask random people for the time.

② What is necessary for your flashmob to provide the proper "experience"?

- Everyone should ask the same person for the time or ...
- All "time providers" should have the same notion of time.

Synchronization

⌚ Goal: Systems have **and** .

⚡ Problem: Clock Drift.

No two clocks proceed at same speed due to imprecisions with manufacturing.

⌚ Absolute Time Synchronization

- Two systems are simultaneously at the same instant of time.
- Example: Both systems say that 1515422939 seconds have passed since 1st January 1970 00:00:00 UTC.

⌚ Clock Synchronization

- Frequency Synchronization
Clocks tick in same interval.
- Phase Synchronization
Clocks tick at the same moment within the interval.

Network Time Protocol (NTP) ([RFC5905](#))

◎ Goals

- Synchronize over networks that...
 - are packet-switched and
 - have variable latency.
- Precision:
 - Public Internet: $\approx 10ms$.
 - LAN: $< 1ms$.

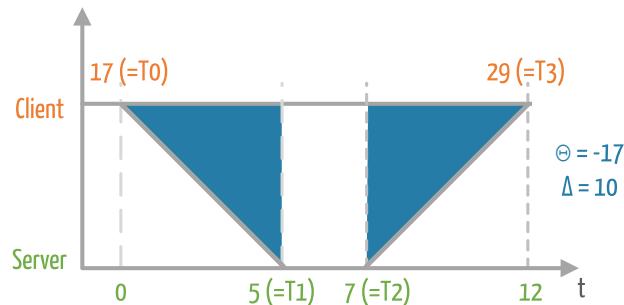
👎 Weaknesses

Precision reduces due to multiple factors:

- Asymmetric Routes
Latency from A to B is different than from B to A.
- Network Congestion
Packets are slower than normal, have random delays or might get lost altogether.

NTP | Algorithm

Protocol



Process

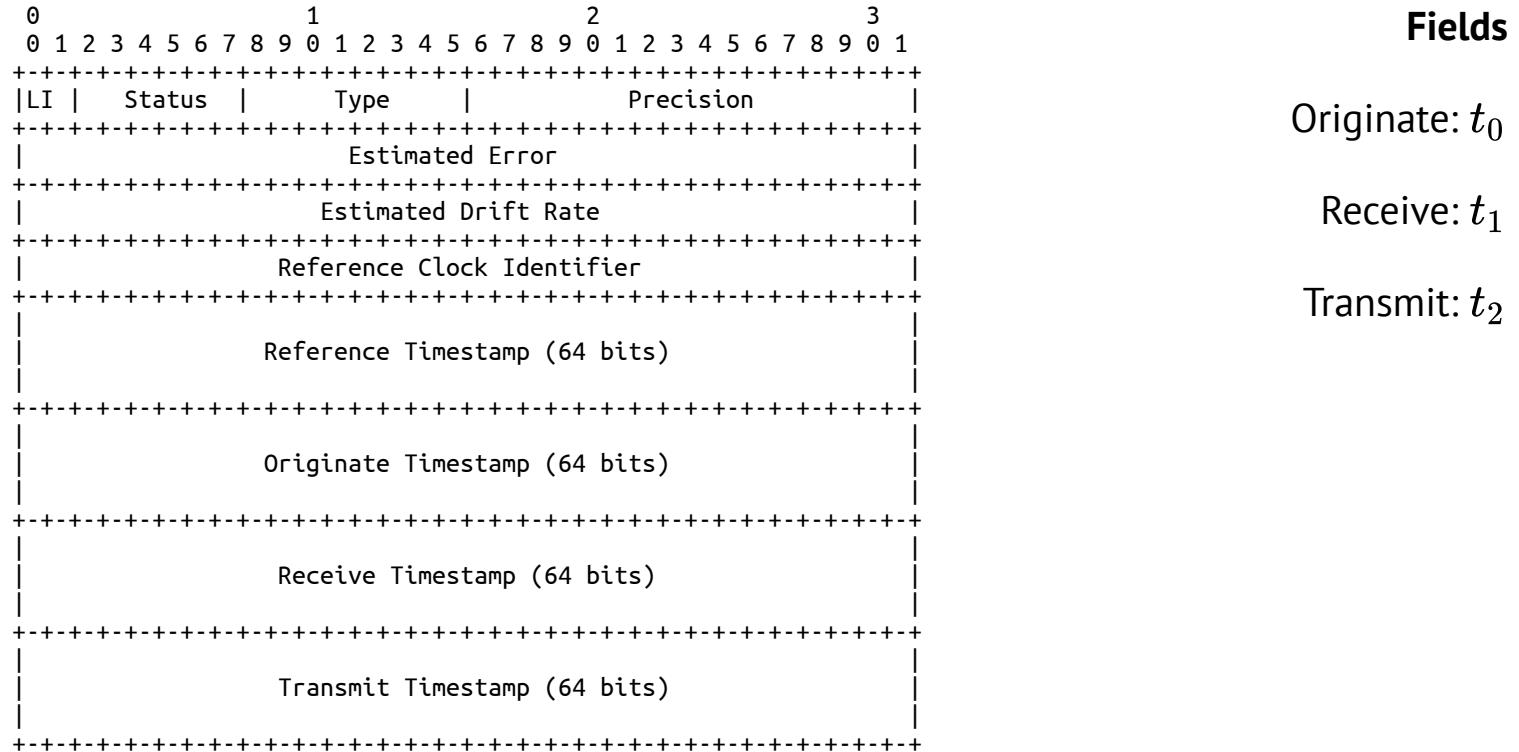
- Poll three or more servers at the same time.
- Filtering and statistical analysis are applied on θ and Δ , outliers are discarded.
- Derive time from best three samples.
- θ and Δ are adjusted to reduce the offset.
This creates a feedback loop.
- Bellman-Ford shortest path spanning tree used to minimize accumulated RTT to best time servers.

Formulas

- Time Offset: $\theta = \frac{(t_1 - t_0) + (t_2 - t_3)}{2}$
- Round-Trip Delay:

$$\Delta = (t_3 - t_0) - (t_2 - t_1)$$

NTP | Header



NTP | Clock Strata

Definition

- Stratum \equiv Layer of "accuracy".
- Relative (not absolute) scale for quality and reliability of time information.
- System X sync to other system with stratum $n \rightarrow$ stratum of X is $n + 1$.
- Prevents cyclical dependencies.

Stratum 0 (*reference clocks*)

- High precision devices.
Atomic clocks, GPS or radio.
- Generate an accurate pulse per second (PPS) signal.

Stratum 1 (*primary time servers*)

- Sync-Quality: few microseconds.
- May peer with other stratum 1 servers for sanity check and backup.

Stratum 2

- Often query multiple servers and chose best (peering possible).

Stratum 3 - 15

- Further layers similar to strat. 2.

Stratum 16 (*unsynchronized*)

NTP | Security Sidenote



DDoS Attacks

- As mentioned before: Many hosts produce load on a server with the goal of crashing it.
- **Amplification Attacks:** Generating traffic by sending small requests that cause large responses to be sent to the victim.
- Possible using many protocols, given that you can spoof your IP address.

Case Study

- Prof. Christian Rossow had discovered this.
(System Security Group @ CISPA)
- Published a paper on it.
["Exit from hell" \(Usenix Sec. 2014\)](#)
- Caused a number of ISPs to block these types of packets and informed server owners about the vulnerability.

NTP `monlist` Vulnerability

- With NTP it is possible to achieve an amplification factor of: 4670.
- Messages with 44kB UDP payload.

Precision Time Protocol (PTP) (IEEE 1588)

◎ Goal: Highly accurate time over local area networks.

Context

- Desired: Sub-microsecond accuracy.
- Use Cases / Application Domains:
 - Measurement Systems.
 - Control Systems.

Releases

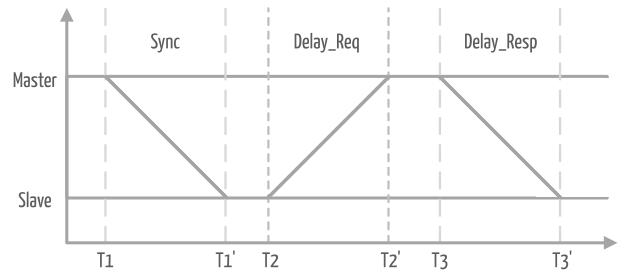
- Version 1 (2002).
- Version 2 (2008).
- No backward compatibility.

Implementation

- Master-Slave architecture.
- Master-clock regularly broadcasts current time.
- Slave-clocks calculate and compensate for their offset.
- PTP is payload to IP or Ethernet.
- Uses IPv6 multicast if available.

PTP | Protocol and Algorithm

Protocol



A) Sync Message (with T_1) sent by master.
Slave notes T_1' when receiving.

B) Slave at T_2 sends Delay_Req to master
(reaching at T_2').

C) Master sends Delay_Resp so that the slave can learn T_2' .

Algorithm

- Slave offset: $o(t) = s(t) - m(t)$.
- With the learned timestamps:

$$o(t) = (T_1' - T_1 - T_2' + T_2)/2$$
- Note: Precision heavily depends on symmetry of RTT.

Optional Additional Step

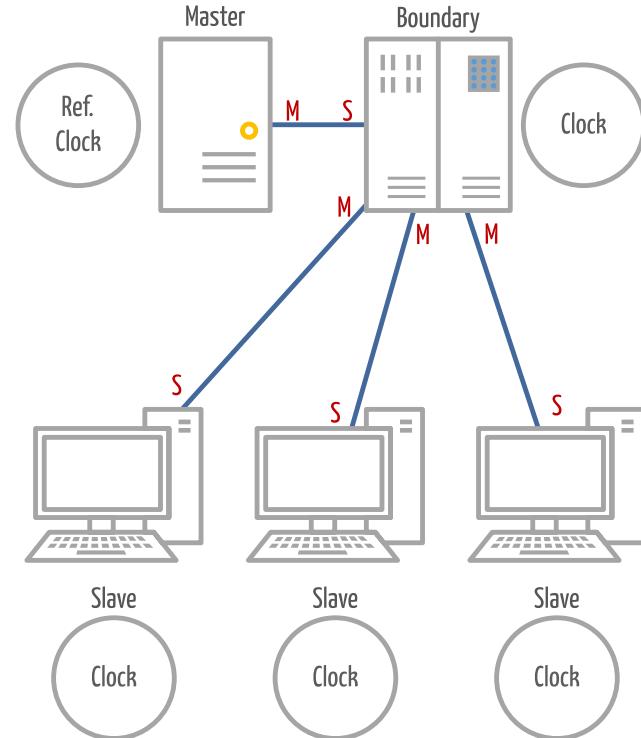
*) Follow_Up messages are used for masters that cannot include the proper timestamp in Sync.

PTP | Architecture

Type: Hierarchical master-slave.

Clocks

- **Ordinary:** Devices with single network connection (source or destination of sync reference).
- **Boundary:** Device with multiple network connections (syncs between segments).
- **Transparent:** Knows about processing delay of packets inside the device and correct for it.
- **Master:** Selected for each segment in the system.
- **Grandmaster:** Reference clock. Elected among all clocks.



PTP | Master Clock Selection Algorithm

Uses **Announce** messages.

Selection Criteria

- : Usually MAC address.
- : Estimated by device. Stratum concept similar to NTP.
- : Administratively configured (two 8 bit priority fields).
- : Clocks estimate of stability based on observation of its performance against the PTP reference.

Selection Algorithm

- Priority 1: Static priority to set order by design.
- Class: Clocks are part of classes (which are prioritized).
- Accuracy: Precision between clock and UTC in ns.
- Variance: Clock variability.
- Priority 2: Backup priority if others don't work.
- Unique Identifier (tie breaker).

Other Synchronization Mechanisms

Synchronous Ethernet (SyncE)

- ITU-T standard for clock signal transfer on Ethernet layer.
- Signal should be traceable to external clock.
- Applications:
 - Cellular networks.
 - IPTV or VoIP.
- When combined with PTP: **Sub-Nanosecond** synchronization accuracy can be achieved.

Global Positioning System (GPS)

- Global Navigation Satellite System (GNSS).
- Satellites broadcast location information.
- Connection to at least four satellites allows trilateration, hence getting your current location.
- GPS further broadcasts time information.
- Precision in order of **+ - 10ns** can be achieved.

Wrap-Up

Questions?

🏡 Take-Home Messages

- DHCP is used to **automatically configure arriving hosts** in a network.
- DHCP can configure **network and boot details**.
- **Time** is an important measure in networking.
- **Synchronization** can be done in **absolute** and **relative** terms.
- NTP, PTP and other systems provide different **granularities of precision**.

📘 Further Reading (Optional)

- [RFC5905](#) (NTP)
- IEEE 1588 (PTP)