OCP - Time Appliances Project

Introduction to PTP

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Agenda

PTP overview

Overview of PTP

Protocol Introduction

Types of timestamping

PTP on Linux

Kernel interfaces

- Ptp sysfs
- ethtool

Linuxptp

- ptp4l
- ts2phc
- phc2sys
- ptm

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Protocol introduction

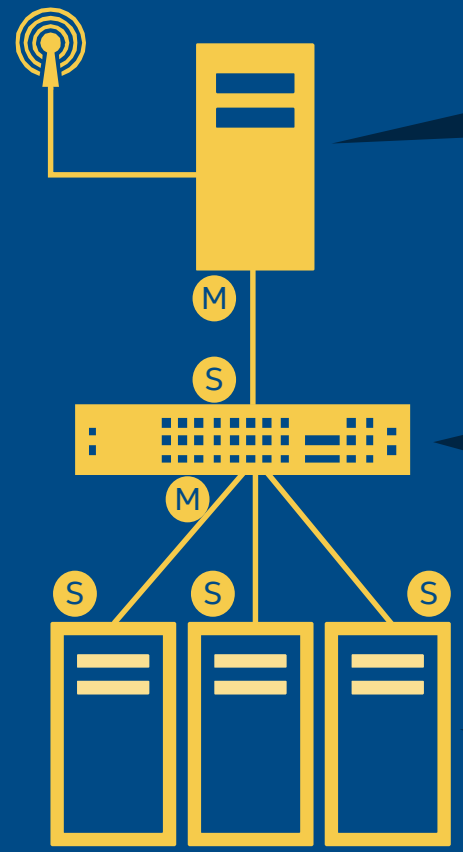
- PTP – Precision Time Protocol
- IEEE 1588 standard
- Synchronize timers to sub-microsecond accuracy
- Hierarchical M-S architecture for clock distribution
- Administration-free operation
- For both high-end devices and low-end devices

Definitions

- grandmaster clock
- ordinary clock
- boundary clock

- master clock
- slave (subordinate) clock
- PHC

Sample PTP network

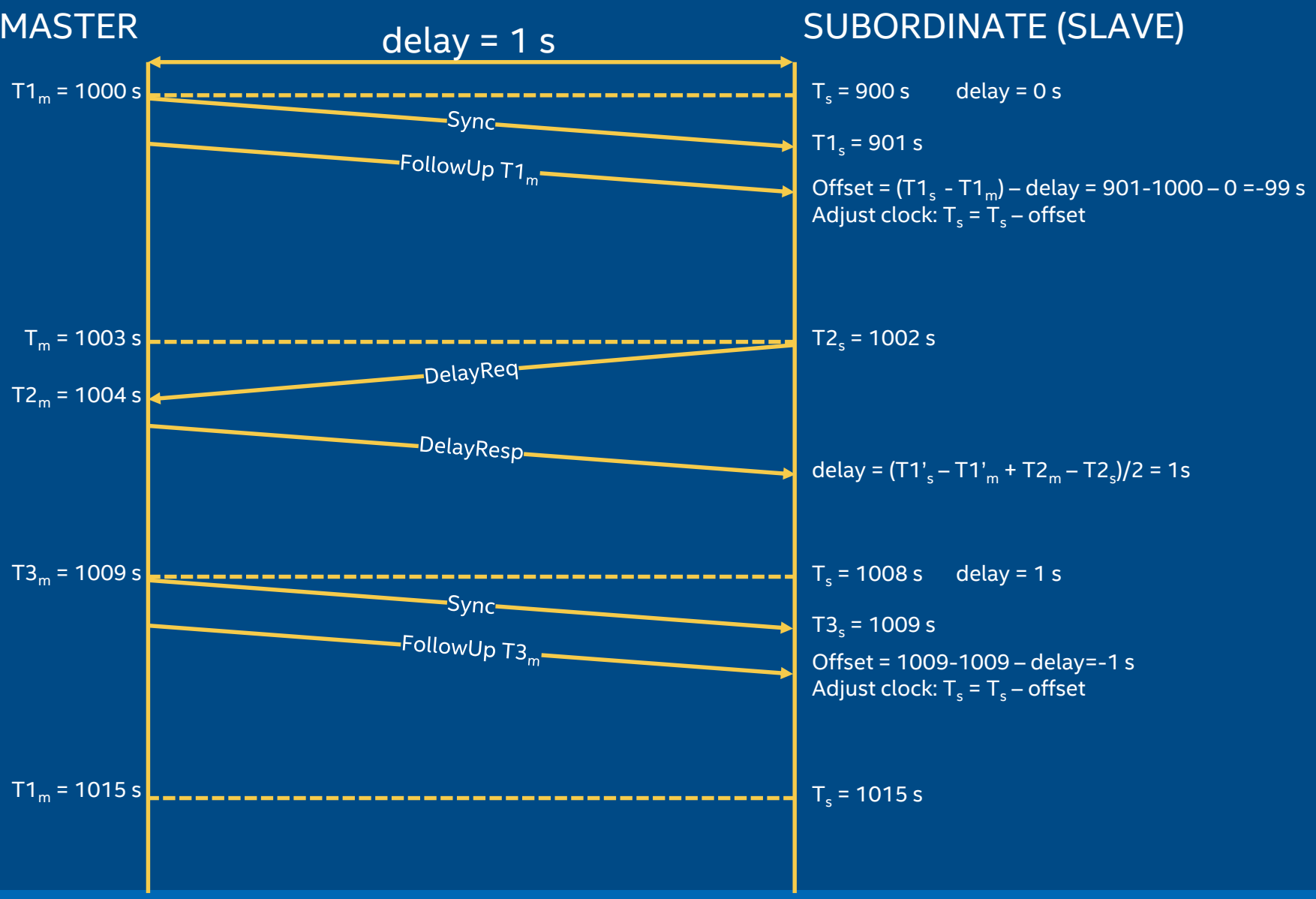


Grandmaster Clock
- Ordinary time source for the PTP network
- Typically synchronized to a very precise source (like a GPS)

Boundary Clock
- Multiple network connections
- Synchronized to a master
- Can synchronize network segment
- When Grandmaster clock is lost it may become a Grandmaster

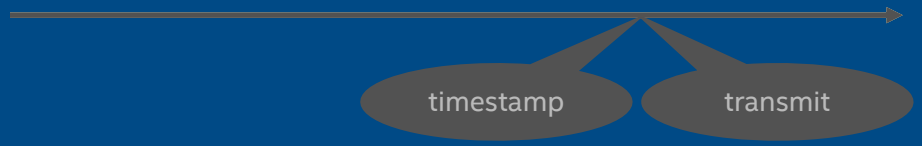
Subordinate Clock
- Ordinary clock
- Synchronizes to the master (grandmaster or boundary clock)
- May become Grandmaster if other Grandmasters are not available

IEEE 1588

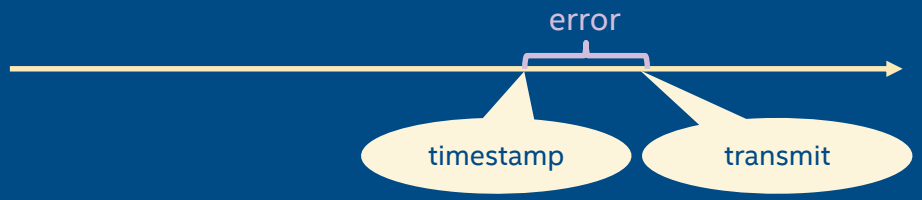

MASTER
SUBORDINATE (SLAVE)
delay = 1 s
T1m = 1000 s
Ts = 900 s
delay = 0 s
Sync
T1s = 901 s
FollowUp T1m
Offset = (T1s - T1m) – delay = 901-1000 – 0 =-99 s
Adjust clock: Ts = Ts – offset
Tm = 1003 s
T2s = 1002 s
DelayReq
T2m = 1004 s
DelayResp
delay = (T1's – T1'm + T2m – T2s)/2 = 1s
T3m = 1009 s
Ts = 1008 s
delay = 1 s
Sync
T3s = 1009 s
FollowUp T3m
Offset = 1009-1009 – delay=-1 s
Adjust clock: Ts = Ts – offset
T1m = 1015 s
Ts = 1015 s

Timing of the timestamp

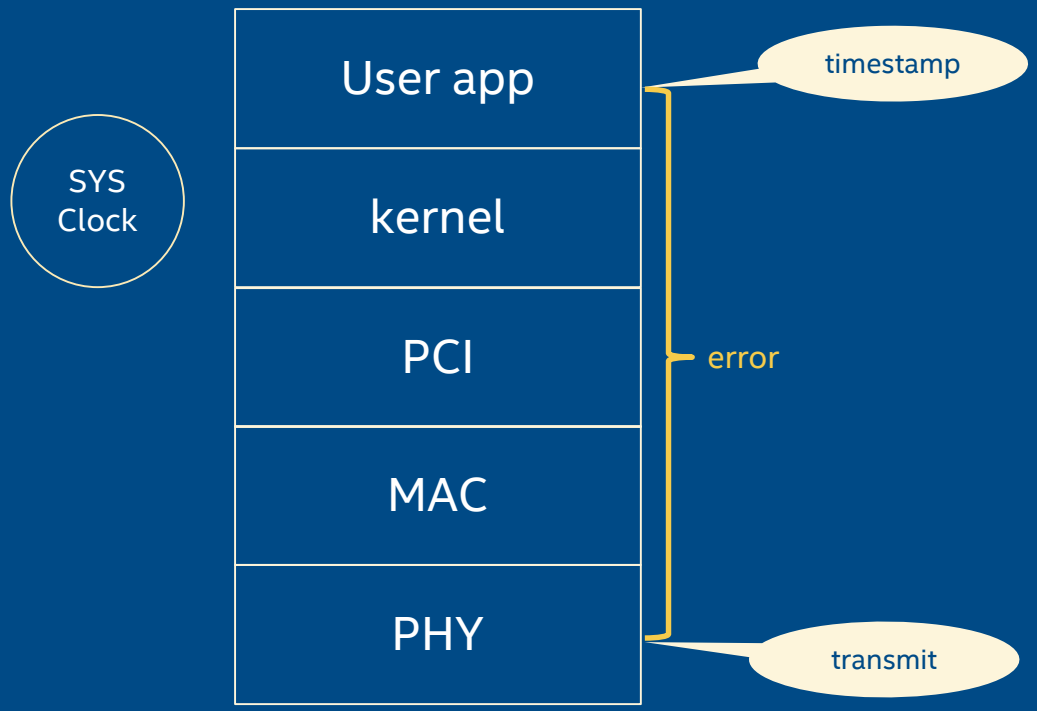
- Ideal timestamp timing:



- Real timestamp timing:



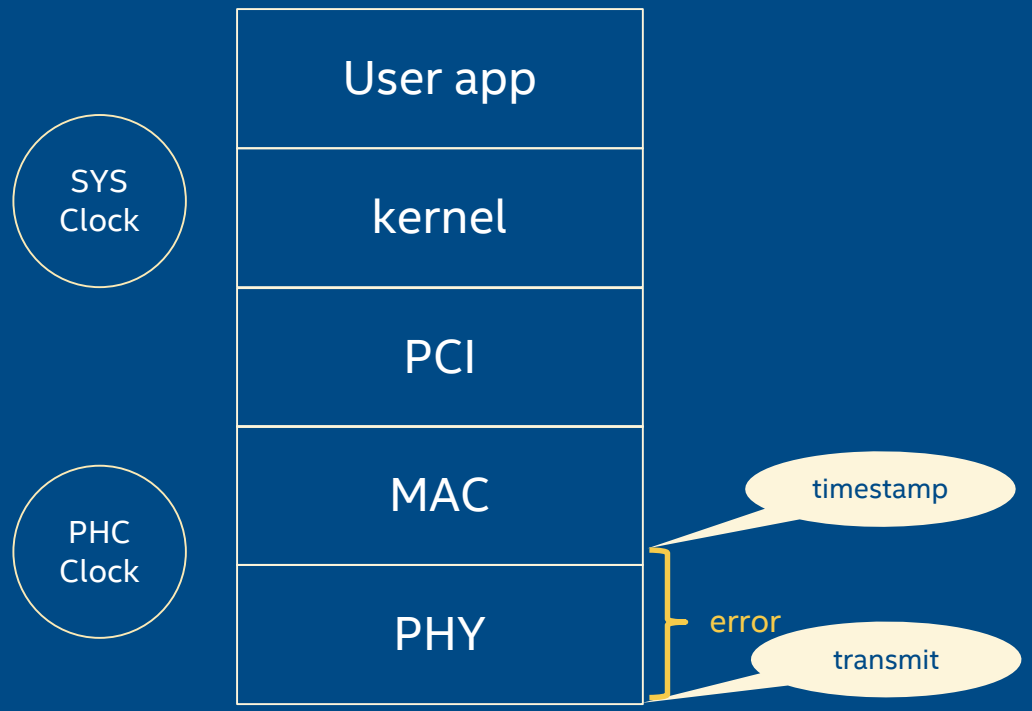
Software timestamping



1. Read system clock
2. Timestamp the packet
3. Send the packet through the stack

- Relatively BIG error.

Hardware timestamping



1. Set appropriate flags in the descriptor
2. MAC reads the PHC (PTP Hardware Clock), stamps and sends the packet

- Relatively small error.

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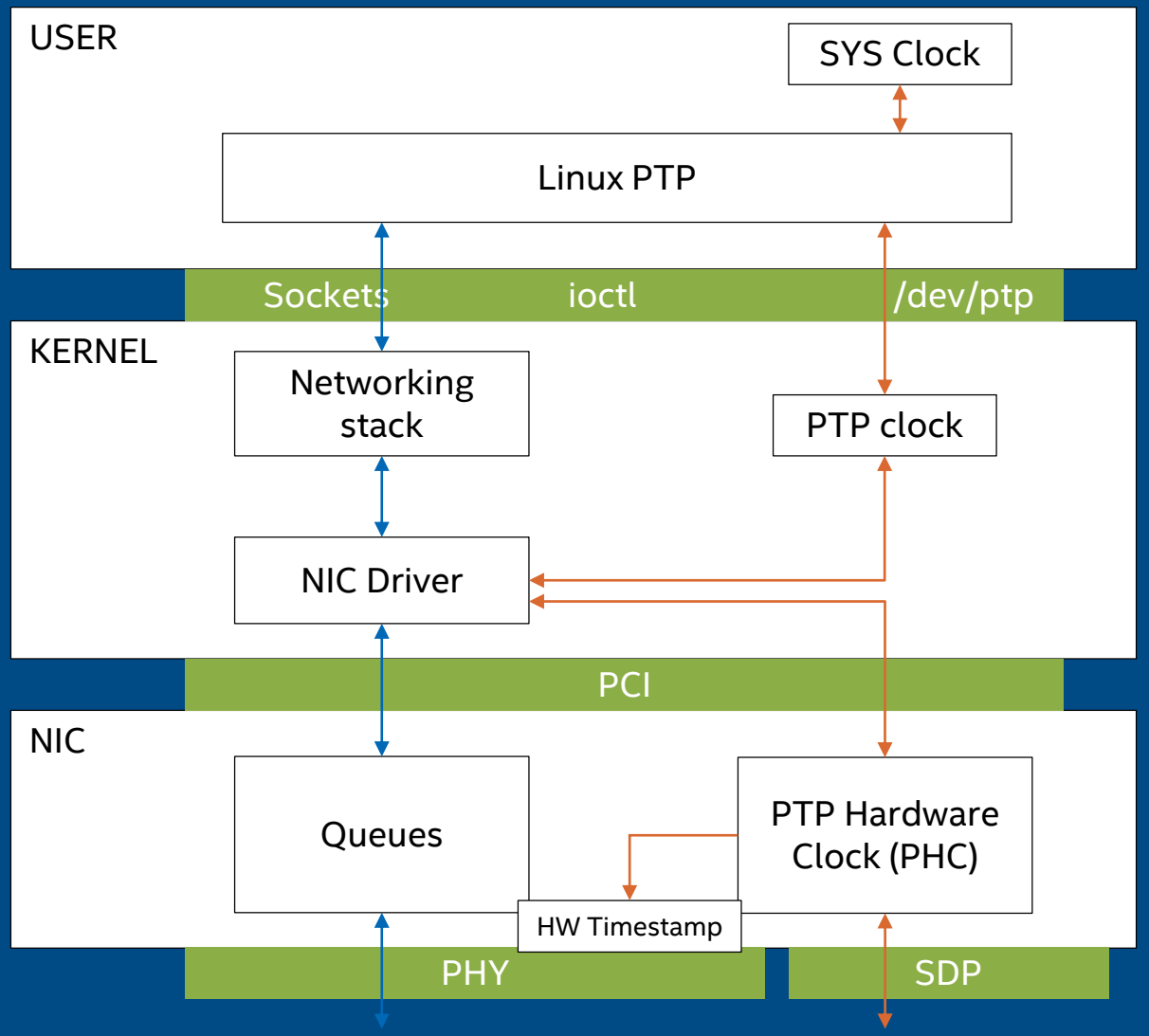
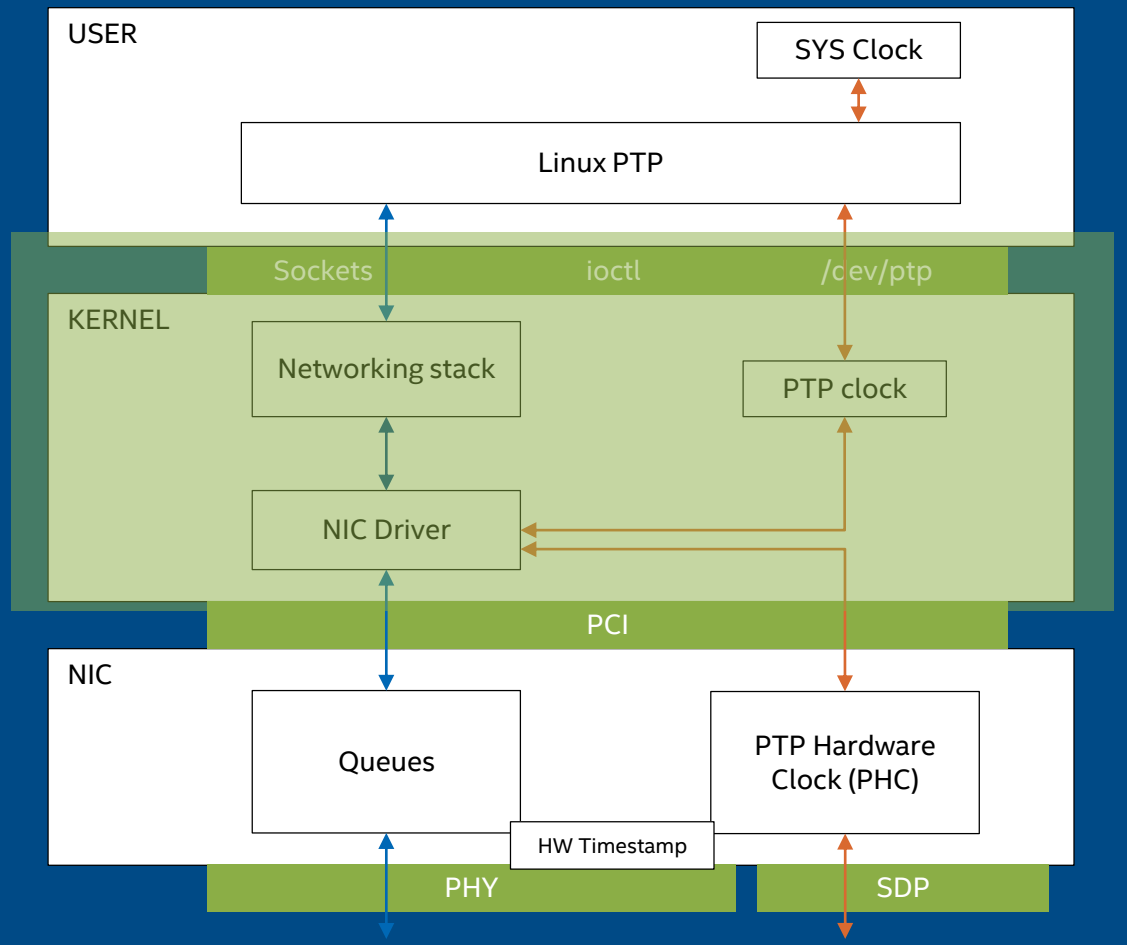
PTP on Linux


USER
SYS Clock
Linux PTP
Sockets
ioctl
/dev/ptp
KERNEL
Networking stack
PTP clock
NIC Driver
PCI
NIC
Queues
PTP Hardware Clock (PHC)
HW Timestamp
PHY
SDP

Linux Kernel

- External sync pins
  - standard sysfs interface
  - external timestamping input
  - periodic output
- Socket options
  - Control hardware timestamping
  - Receive timestamps
- POSIX Clock API
  - IOCTLs



PTP Pins interface

```
# echo <function> <channel> > pins/GPIO_4
```

function – desired pin function:

- 0 – none
- 1 – ext_ts
- 2- perout

channel - channel index

https://www.kernel.org/doc/Documentation/ABI/testing/sysfs-ptp

```
[root@localhost /sys/class/ptp/ptp4]# tree
.
├── clock_name
├── dev
├── device -> ../../../0000:af:00.0
├── extts_enable
├── fifo
├── max_adjustment
├── n_alarms
├── n_external_timestamps
├── n_periodic_outputs
├── n_programmable_pins
├── period
├── pins
│   ├── GPIO_4
│   ├── SDP3_2
│   └── SDP3_3
├── power
│   ├── autosuspend_delay_ms
│   ├── control
│   ├── runtime_active_time
│   ├── runtime_status
│   └── runtime_suspended_time
├── pps_available
├── pps_enable
├── subsystem -> ../../../../../../class/ptp
└── uevent
```

PTP sysfs interface

```
# echo <channel> <enable> > extts_enable
```

channel - channel index
enable – set to 1 to enable or 0 to disable

```
# echo <channel> <st_s> <st_ns> <per_s> <per_ns> > period
```

channel - channel index
st_s - start time seconds
st_ns - start time nanoseconds
per_s - period seconds
per_ns - period nanoseconds

https://www.kernel.org/doc/Documentation/ABI/testing/sysfs-ptp

```
[root@localhost /sys/class/ptp/ptp4]# tree
.
├── clock_name
├── dev
├── device -> ../../../0000:af:00.0
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├── n_periodic_outputs
├── n_programmable_pins
├── period
├── pins
│   ├── GPIO_4
│   ├── SDP3_2
│   └── SDP3_3
├── power
│   ├── autosuspend_delay_ms
│   ├── control
│   ├── runtime_active_time
│   ├── runtime_status
│   └── runtime_suspended_time
├── pps_available
├── pps_enable
├── subsystem -> ../../../../../../class/ptp
└── uevent
```

POSIX Clock API

- Every POSIX clock is represented by a character device (/dev/ptpX)
- clock_adjtime: Adjust the clock
  - Adjfreq (adjfine)
  - adjtime
- clock_gettime: Read the current time
- clock_settime: Set the current time
- ioctl: Optional IOCTL methods

ethtool

```
# ethtool -T ens260f0
Time stamping parameters for ens260f0:
Capabilities:
        hardware-transmit     (SOF_TIMESTAMPING_TX_HARDWARE)
        software-transmit     (SOF_TIMESTAMPING_TX_SOFTWARE)
        hardware-receive      (SOF_TIMESTAMPING_RX_HARDWARE)
        software-receive      (SOF_TIMESTAMPING_RX_SOFTWARE)
        software-system-clock (SOF_TIMESTAMPING_SOFTWARE)
        hardware-raw-clock    (SOF_TIMESTAMPING_RAW_HARDWARE)
PTP Hardware Clock: 4
Hardware Transmit Timestamp Modes:
        off                   (HWTSTAMP_TX_OFF)
        on                    (HWTSTAMP_TX_ON)
Hardware Receive Filter Modes:
        none                  (HWTSTAMP_FILTER_NONE)
        ptpv1-l4-sync         (HWTSTAMP_FILTER_PTP_V1_L4_SYNC)
        ptpv1-l4-delay-req    (HWTSTAMP_FILTER_PTP_V1_L4_DELAY_REQ)
        ptpv2-l4-event        (HWTSTAMP_FILTER_PTP_V2_L4_EVENT)
        ptpv2-l4-sync         (HWTSTAMP_FILTER_PTP_V2_L4_SYNC)
        ptpv2-l4-delay-req    (HWTSTAMP_FILTER_PTP_V2_L4_DELAY_REQ)
        ptpv2-l2-event        (HWTSTAMP_FILTER_PTP_V2_L2_EVENT)
        ptpv2-l2-sync         (HWTSTAMP_FILTER_PTP_V2_L2_SYNC)
        ptpv2-l2-delay-req    (HWTSTAMP_FILTER_PTP_V2_L2_DELAY_REQ)
        ptpv2-event           (HWTSTAMP_FILTER_PTP_V2_EVENT)
        ptpv2-sync            (HWTSTAMP_FILTER_PTP_V2_SYNC)
        ptpv2-delay-req
```

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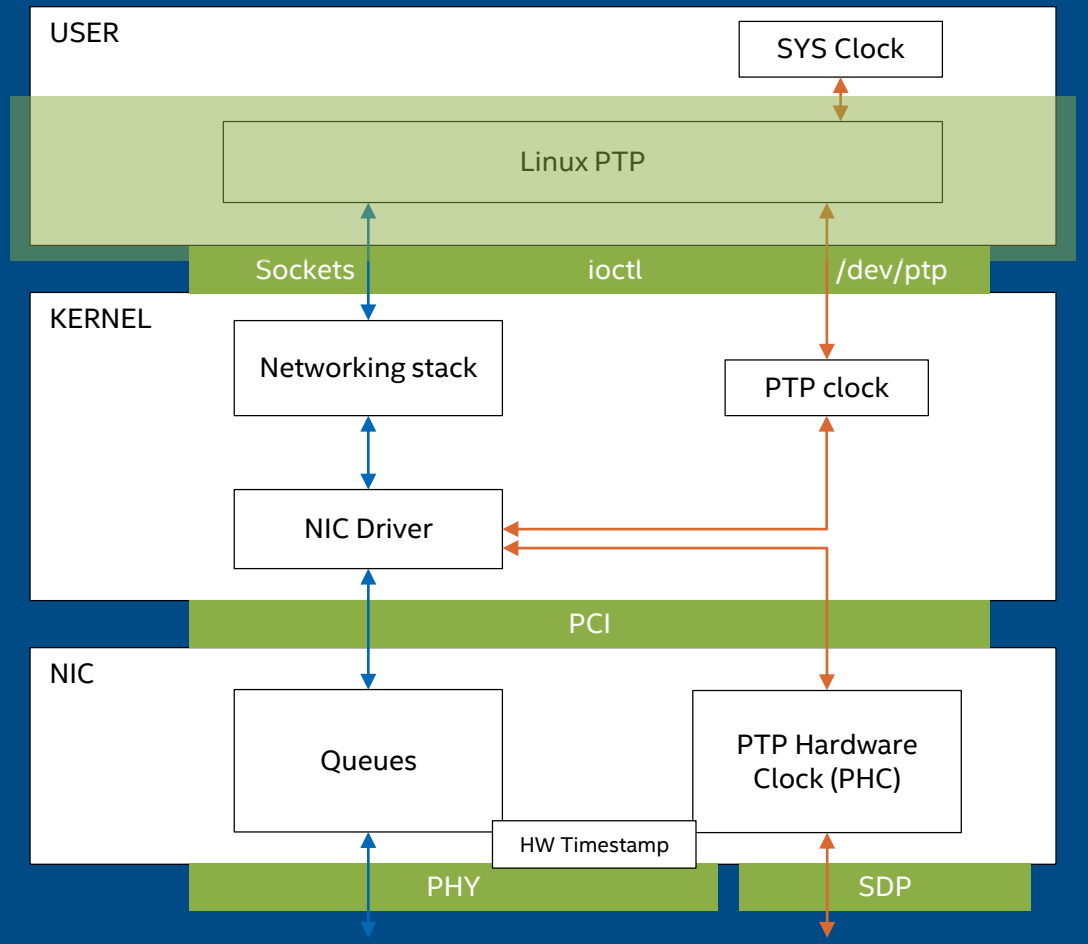
Linux PTP project

- Set of userspace tools
- Implement PTP (IEEE 1588)
- Use standard kernel APIs to synchronize and manage the clocks
- Supports HW and SW time stamping
  - Best precision w/ HW time stamping
- http://linuxptp.sourceforge.net/



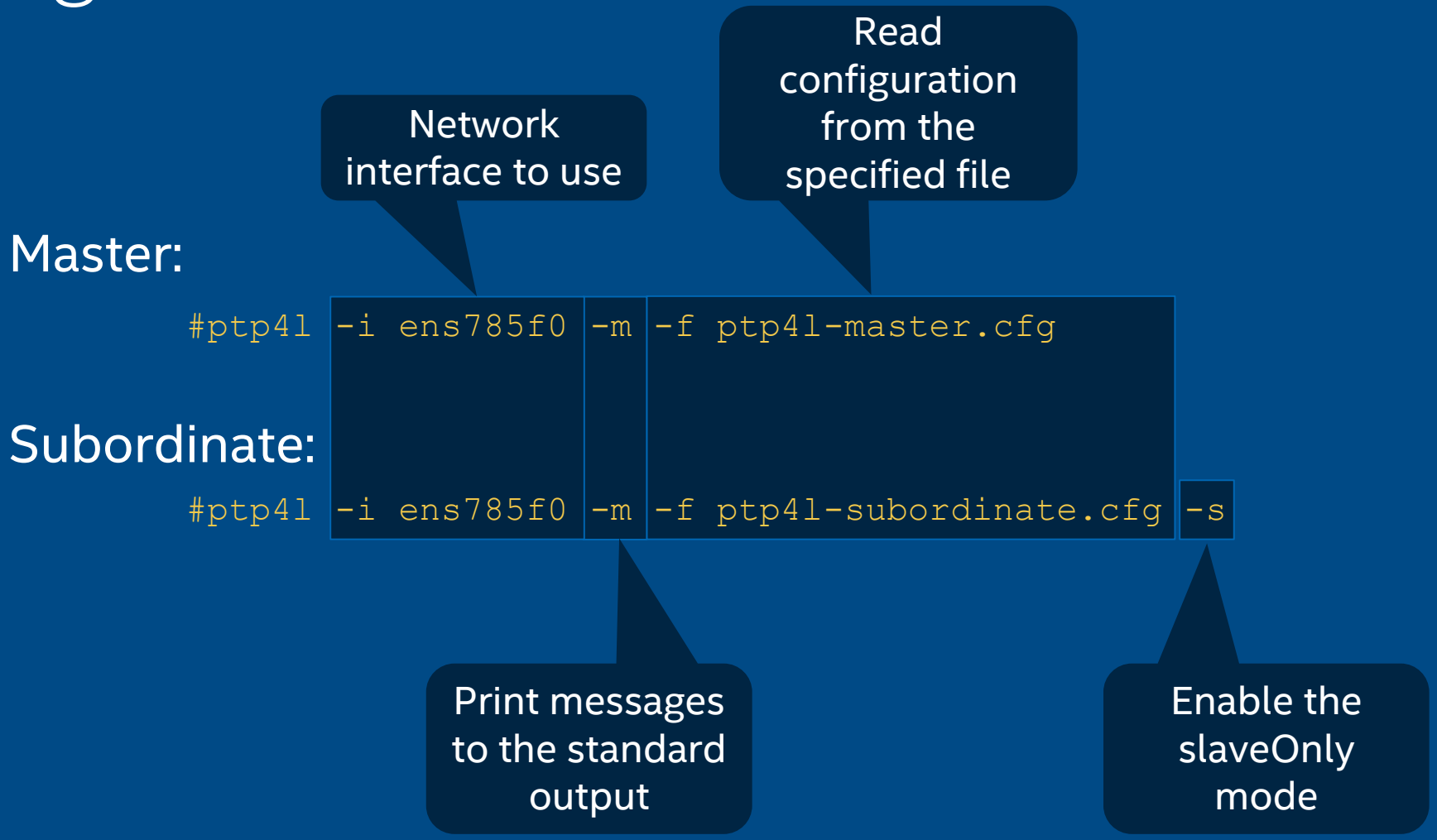
Linux PTP project

- ptp4l
  - Synchronize 2 PHCs using the PTP protocol (IEEE 1588)
- ts2phc (new tool)
  - Synchronize PHCs to external time stamp signal (1PPS signals).
- phc2sys
  - synchronize two (or more) POSIX clocks
  - Can synchronize PHC and SYS
- pmc
  - PTP management client

ptp4l

- Implements the PTP boundary clock and ordinary clock
- Synchronizes the PTP hardware clock to the master clock
- Can run as:
  - Standalone tool
  - Service
    - Options are specified in the /etc/sysconfig/ptp4l
    - Can be started using # systemctl start ptp4l
- Use PI servo to slew frequency of PHC
- https://www.mankier.com/8/ptp4l

Starting the Master and the Subordinate



ptp4l - master

```
#ptp4l -i ens785f0 -m -f ptp4l-master.cfg
ptp4l[212068.052]: selected /dev/ptp4 as PTP clock
ptp4l[212068.053]: port 1: INITIALIZING to LISTENING on INIT_COMPLETE
ptp4l[212068.054]: port 0: INITIALIZING to LISTENING on INIT_COMPLETE
ptp4l[212075.790]: port 1: LISTENING to MASTER on ANNOUNCE_RECEIPT_TIMEOUT_EXPIR
ptp4l[212075.790]: selected local clock b49691.fffe.5cea1c as best master
ptp4l[212075.790]: assuming the grand master role
```

We're the grandmaster

ptp4l - subordinate

```
#ptp4l -i ens785f0 -m -f ptp4l-subordinate.cfg -s
ptp4l[4605984.309]: selected /dev/ptp4 as PTP clock
ptp4l[4605984.311]: port 1: INITIALIZING to LISTENING on INIT_COMPLETE
ptp4l[4605984.312]: port 0: INITIALIZING to LISTENING on INIT_COMPLETE
```

Initialization

```
ptp4l[4605985.875]: port 1: new foreign master b49691.fffe.5cea1c-1
ptp4l[4605987.443]: selected local clock b49691.fffe.5ce960 as best master
ptp4l[4605989.875]: selected best master clock b49691.fffe.5cea1c
ptp4l[4605989.875]: port 1: LISTENING to UNCALIBRATED on RS_SLAVE
ptp4l[4605989.971]: port 1: minimum delay request interval 2^0
```

Finding the master

```
ptp4l[4654022.546]: master offset     -23628 s0 freq   -5470 path delay      1074
ptp4l[4654023.546]: master offset     -23636 s1 freq   -5478 path delay      1074
ptp4l[4654024.546]: master offset      -1695 s2 freq   -7173 path delay      1074
ptp4l[4654024.546]: port 1: UNCALIBRATED to SLAVE on MASTER_CLOCK_SELECTED
ptp4l[4654025.546]: master offset          5 s2 freq   -5981 path delay      1074
```

Synchronizing the PHC

ptp4l - subordinate

Synchronization state:
- s0 – servo unlocked
- s1 – clock step
- s2 – servo locked

Delay of the path

```
ptp4l[466010.881]: master offset         -5 s2 freq      -5 path delay      1073
ptp4l[466011.881]: master offset          0 s2 freq      -1 path delay      1073
ptp4l[466012.881]: master offset          2 s2 freq      +1 path delay      1073
ptp4l[466013.881]: master offset          0 s2 freq      -1 path delay      1073
ptp4l[466014.881]: master offset          0 s2 freq      -1 path delay      1073
ptp4l[466015.881]: master offset         -1 s2 freq      -2 path delay      1073
ptp4l[466016.881]: master offset         -7 s2 freq      -8 path delay      1074
ptp4l[466017.881]: master offset          6 s2 freq      +3 path delay      1074
ptp4l[466018.881]: master offset          0 s2 freq      -1 path delay      1074
ptp4l[466019.881]: master offset          1 s2 freq      -0 path delay      1074
ptp4l[466020.881]: master offset          0 s2 freq      -1 path delay      1074
ptp4l[466021.881]: master offset          0 s2 freq      -1 path delay      1074
```

Offset to the master clock (in ns)

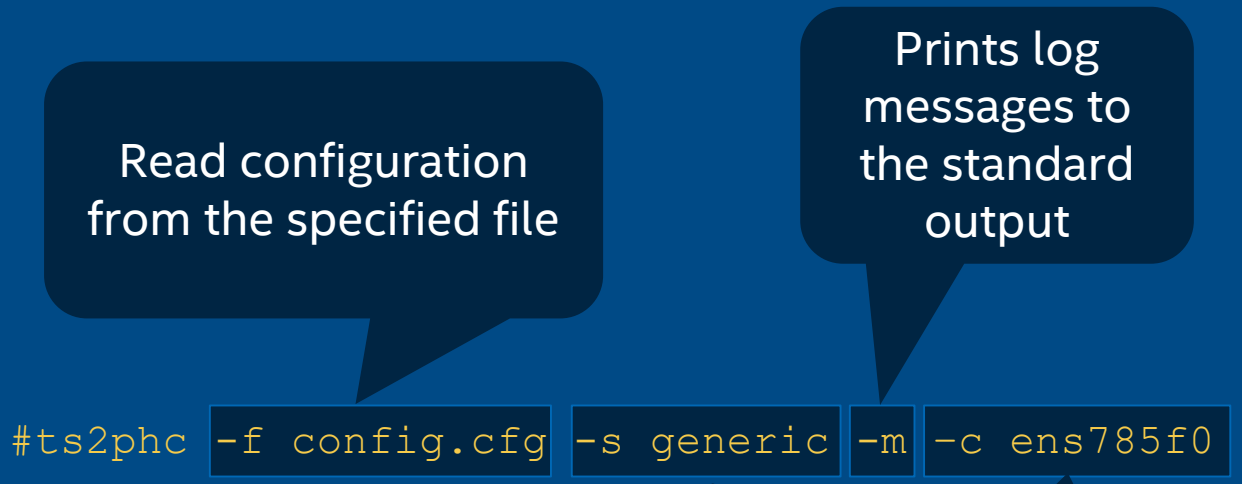
Frequency difference to the master clock (in ppb)

ts2phc

- New tool in linuxptp-3.0
- Synchronizes one or more PHC using external time stamps.
- Can sync PHC to 1pps
- New option – sync to NMEA GPS output (GPRMC)

- https://www.mankier.com/8/ts2phc

ts2phc – command line



phc2sys

- Synchronizes the system clock to the PHC on the NIC
- Can run as:
  - Standalone tool
  - Service
    - options are specified in the /etc/sysconfig/phc2sys
    - Can be started using # systemctl start phc2sys

- https://www.mankier.com/8/phc2sys

phc2sys – command line

Specify the master clock by:
- device (e.g. /dev/ptp0)
- interface (e.g. eth0)
- by name (e.g. CLOCK_REALTIME for the system clock)

Wait until ptp4l is in a synchronized state

```
#phc2sys -s ens260f0 -c CLOCK_REALTIME -w -m
```

Specify the subordinate clock by:
- device (e.g. /dev/ptp1)
- interface (e.g. eth1)
- Name

The default is CLOCK_REALTIME

Print messages to the standard output

phc2sys - output

Synchronization state:
- s0 – servo unlocked
- s1 – clock step
- s2 – servo locked

Delay of the path

```
phc2sys[4649082.619]: CLOCK_REALTIME phc offset  -4717525 s0 freq      +0 delay   1274
phc2sys[4649083.619]: CLOCK_REALTIME phc offset  -4728162 s1 freq  -10632 delay   1273
phc2sys[4649084.620]: CLOCK_REALTIME phc offset        40 s2 freq  -10592 delay   1278
phc2sys[4649085.620]: CLOCK_REALTIME phc offset         7 s2 freq  -10613 delay   1276
phc2sys[4649086.620]: CLOCK_REALTIME phc offset        -5 s2 freq  -10623 delay   1280
phc2sys[4649087.620]: CLOCK_REALTIME phc offset        13 s2 freq  -10606 delay   1277
phc2sys[4649088.621]: CLOCK_REALTIME phc offset       -13 s2 freq  -10628 delay   1278
phc2sys[4649089.621]: CLOCK_REALTIME phc offset        -5 s2 freq  -10624 delay   1290
phc2sys[4649090.621]: CLOCK_REALTIME phc offset         5 s2 freq  -10616 delay   1277
phc2sys[4649091.621]: CLOCK_REALTIME phc offset       -18 s2 freq  -10637 delay   1294
phc2sys[4649092.622]: CLOCK_REALTIME phc offset         7 s2 freq  -10618 delay   1288
phc2sys[4649093.622]: CLOCK_REALTIME phc offset        12 s2 freq  -10611 delay   1286
```

Offset to the master clock

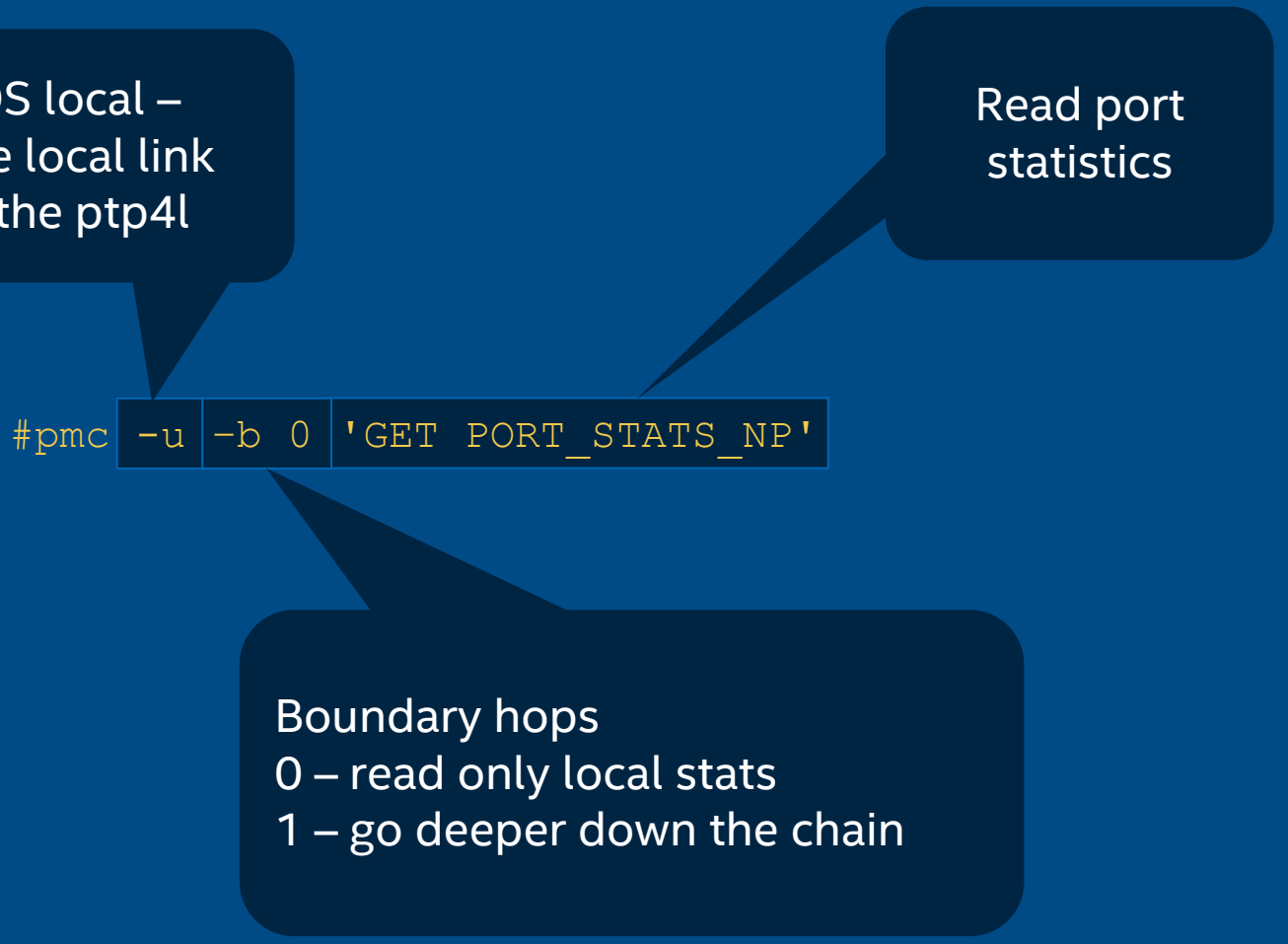
Frequency difference to the master clock (in ppb)

pmc

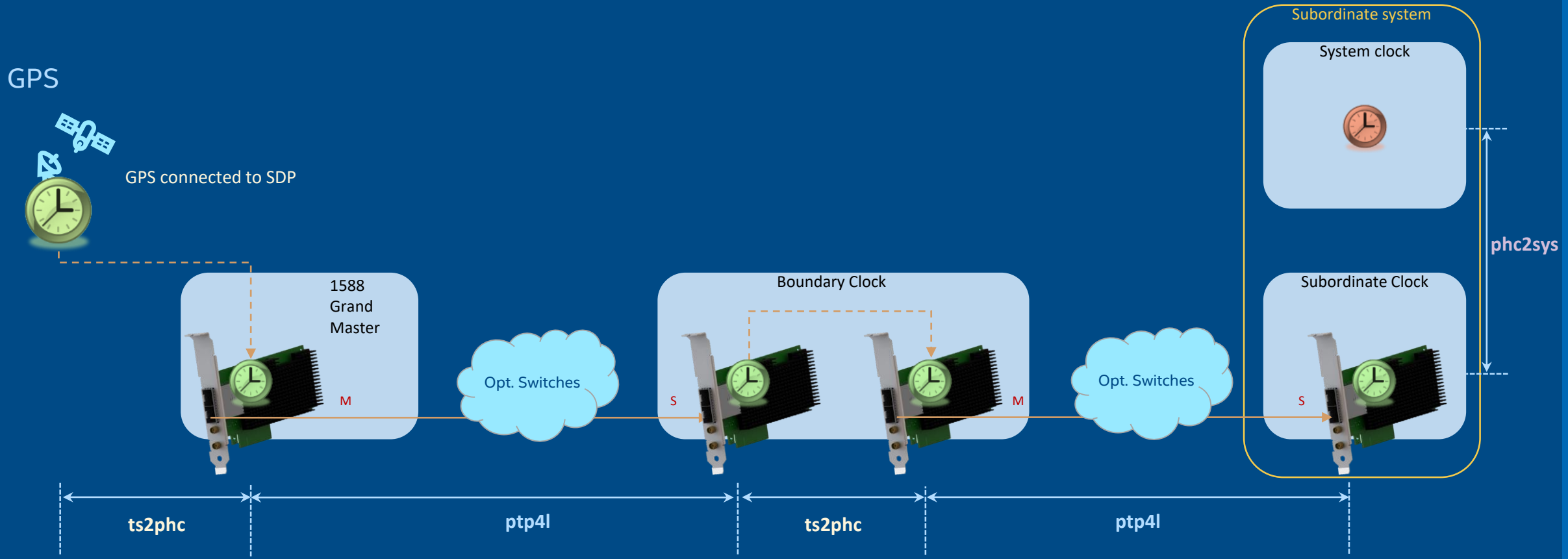
- Management client
- Can obtain additional information from a running ptp4l

- https://www.mankier.com/8/pmc

pmc – command line



Putting it all together



Putting it all together

- MASTER

Config the hw pins (via /sys/class/ptp/ptpX)

```
echo 1 0 > /sys/class/ptp/ptp4/pins/SDP3_2
echo 0 1 > /sys/class/ptp/ptp4/extts_enable
```

```
# ts2phc -f config.cfg -s generic –m –c ens260f0
```

```
# ptp4l -f ptp4l-master.cfg -i ens260f0 -m
ptp4l[254799.658]: assuming the grand master role
```

- SUBORDINATE

```
# ptp4l -f ptp4l-subordinate.cfg -i ens260f0 -m -s
```

```
# phc2sys -s ens260f0 -c CLOCK_REALTIME -w -m
```


intel

Useful links

- https://docs.fedoraproject.org/en-US/fedora/rawhide/system-administrators-guide/servers/Configuring_PTP_Using_ptp4l/
- https://tsn.readthedocs.io/timesync.html
- https://www.mankier.com/8/phc_ctl