So you want to build a deterministic networking system

A gentle introduction to Time Sensitive Networking

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$whoami

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- Kernel Developer at Pengutronix since 2022

- Embedded Linux consulting & support since 2001
- ~7600 patches in Linux kernel

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Agenda

- Application examples
- Application requirements
- Basic Building Blocks of TSN
- Linux Kernel and Userspace Components
- Hardware Requirements
- TL;DR

Application Examples

- Audio Video Bridging
- Machine Control
- Aerospace
- Automotive
- ...

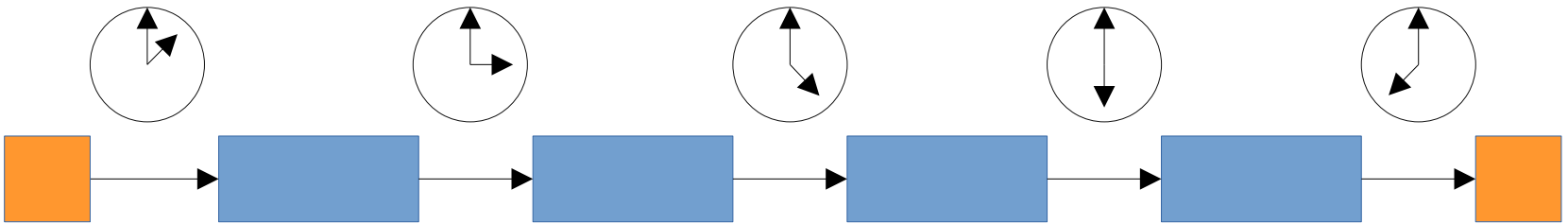
Application Requirements

- Time

  Synchronization

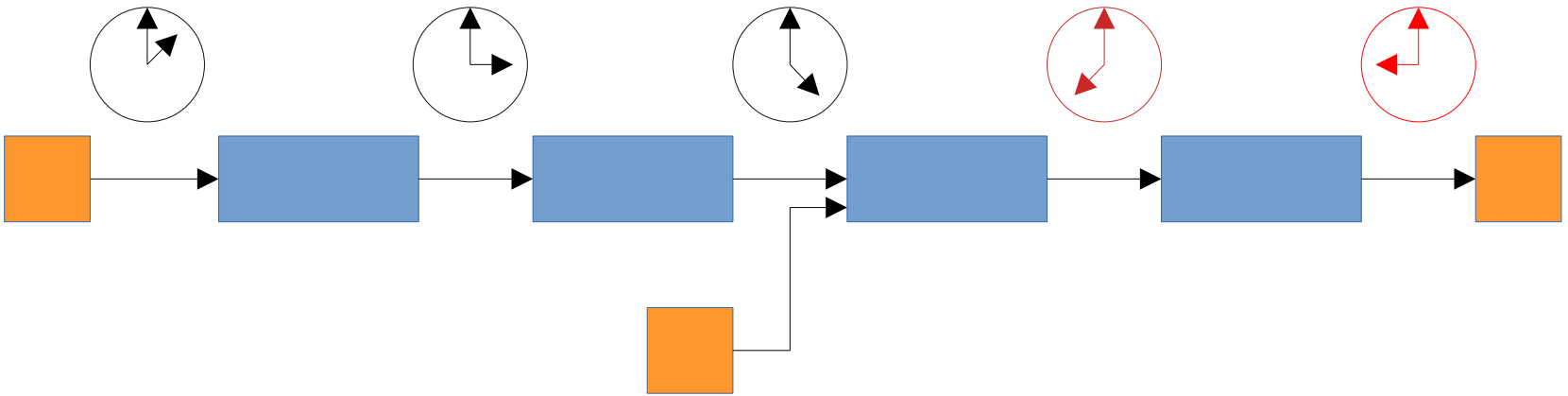
Application Requirements

- Time Synchronization
- Bounded Transmission Latency



Application Requirements

- Time Synchronization
- Bounded Transmission Latency

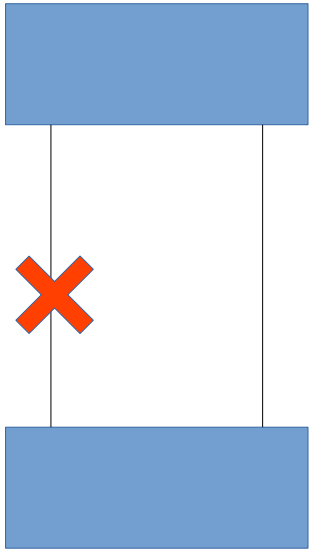


Application Requirements

- Time Synchronization
- Bounded Transmission Latency
- Quality of Service

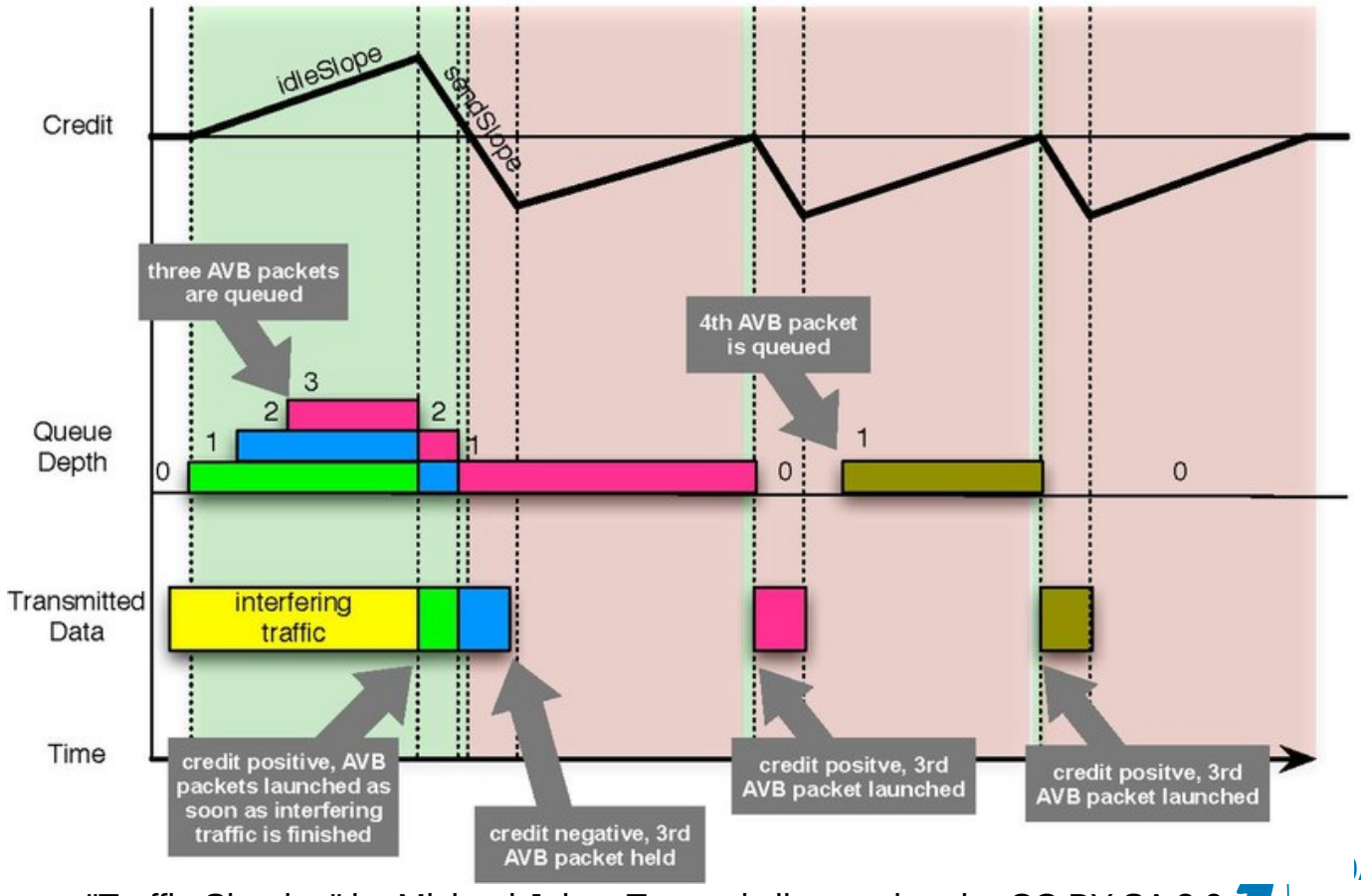
Application Requirements

- Time Synchronization
- Bounded Transmission Latency
- Quality of Service
- Link-Layer Redundancy
- …



Basic building blocks of TSN

- Set of IEEE standards (802.1QBA)
  - Time sync: gPTP (802.1as)
  - QoS: Traffic Shaping (802.1Qav, 802.1Qbv, 802.1Qch, 802.3br, 802.1Qbu. 802.1Qci)
  - Network Configuration: Stream Reservation (802.1Qat) or YANG/ Netconf (802.1Qcc)
  - Link Layer Redundancy: PCR (802.1Qca) and FRER (802.1CB)



Linux Kernel and Userspace Components (1)

- Time Synchronization: gPTP
  - Hardware: Timestamping Unit
  - Kernel: Hardware Timestamping, PTP hardware clock infrastructure
  - Userspace: linuxptp
- Traffic Shaping
  - Kernel: TC subsystem (some of the newer extensions WIP)
  - Userspace: netlink/iproute2
- Network Management
  - userspace only
    - SRP
    - YANG/Netconf

Linux Kernel and Userspace Components (2)

- Payload Packetization and Transmission
  - Mostly Userspace
  - Kernel: Earliest TxTime First (ETF) Qdisc, XDP, ...
  - highly application-specific (gstreamer avtp-plugin, open62651, ...)
- PCR/FRER
  - Hardware: requires HW offloading
  - Kernel: WIP (TC match, flower)
  - Userspace: mostly proprietary at the moment

Hardware Requirements

- Endpoints
  - gPTP: Hardware Timestamping for Layer2 1588
    - Measurement Precision and Accuracy
  - Traffic Shaping: HW Offloading reduces CPU load significantly
  - PCR/FRER: requires HW offloading
- Bridges (a.k.a. network switches)
  - Need to implement gPTP (IEEE802.1as)
  - Need to implement bandwidth reservation
  - For „AVB-style“-TSN: need to implement SRP

TL;DR

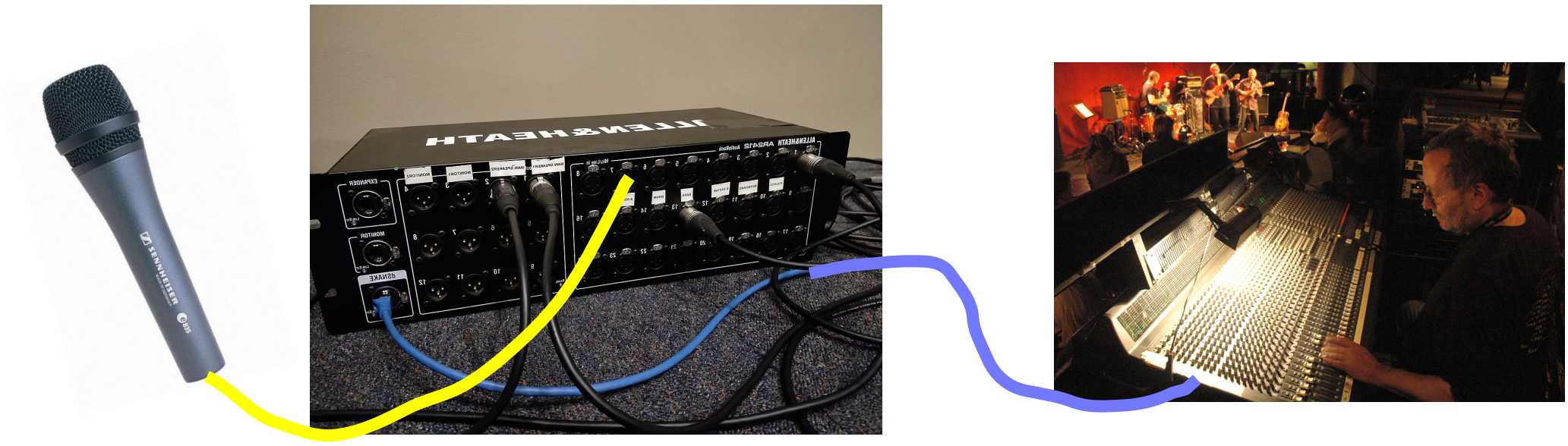
- The „hard“ stuff is already implemented and readily available*
- gPTP and Traffic Shaping offloading require HW support
- Network Gear (Switches) need explicit support for gPTP, Traffic Shaping
- Configuration can be tricky, see projects in the bonus slides for reference

*for endpoints, most parts for bridges available as well

Thank you for your attention

Are there any Questions?

Bonus Slides: Let’s build a simple stagebox (1)



Bonus Slides: Let's build a simple stagebox (2)

- gPTP (Time Synchronization) → ptp4l
- Traffic Shaping → Traffic Control (TC): VLANs, mqprio qdisc with CBS qdisc in its subqueues
- Audio Input → ALSA
- Data Paketization: gstreamer avtpaafpay + avtpsink
- Connection Management: AVDECC, use https://gitlab.freedesktop.org/wtaymans/pipewire/-/tree/avb
- SRP: implemented and hooked up to AVDECC in above pipewire branch

Further Reading, Code, Presentations

- https://tsn.readthedocs.io/
- https://gitlab.freedesktop.org/wtaymans/pipewire/-/tree/avb
- https://github.com/vladimiroltean/isochron
- https://github.com/open62541/open62541/tree/master/examples/pubsub_realtime
- https://github.com/christophe-calmejane/Hive
- https://github.com/audioscience/avdecc-lib
- https://youtu.be/z3J5LCsMzOM
- https://youtu.be/Hs7oRukMuak