High-Precision Capturing and Measuring of 2110 Streams Using Commodity IT Equipment

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IP Media Technology Architects

European Broadcasting Union

Essential measurements and compliance evaluation in SMPTE ST 2110 based facilities using commodity off-the-shelf IT hardware

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EBU
OPERATING EUROVISION AND EURORADIO

IP SHOWCASE™ THEATER

EBU – Live IP Software Toolkit

offline tool - open source project

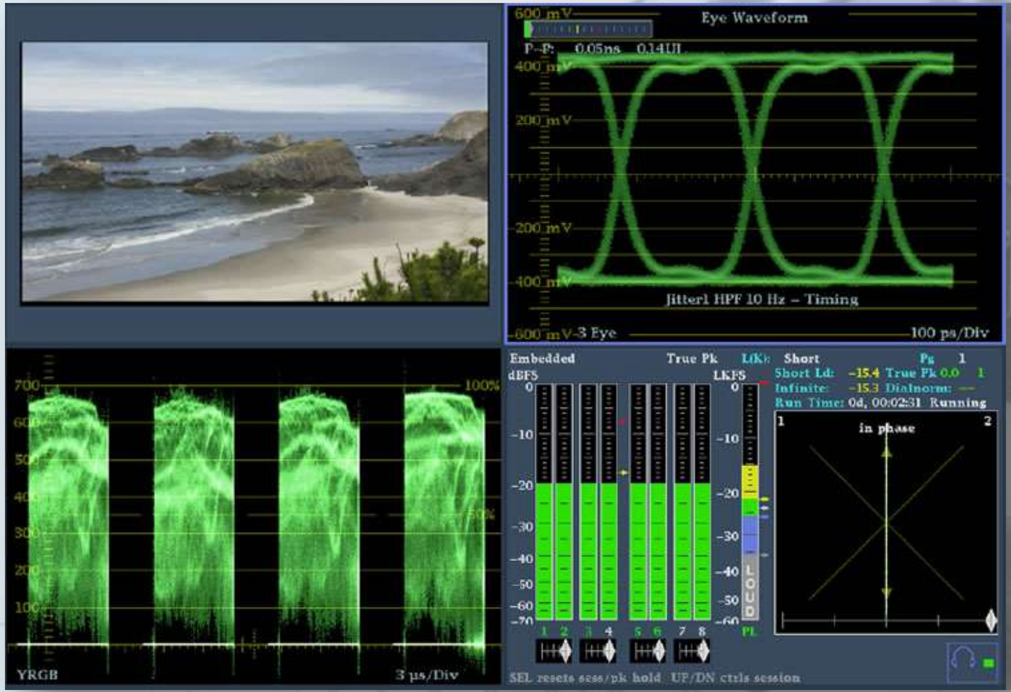
OPERATING EUROVISION AND EURORADIO

IP SHOWCASE™ THEATER

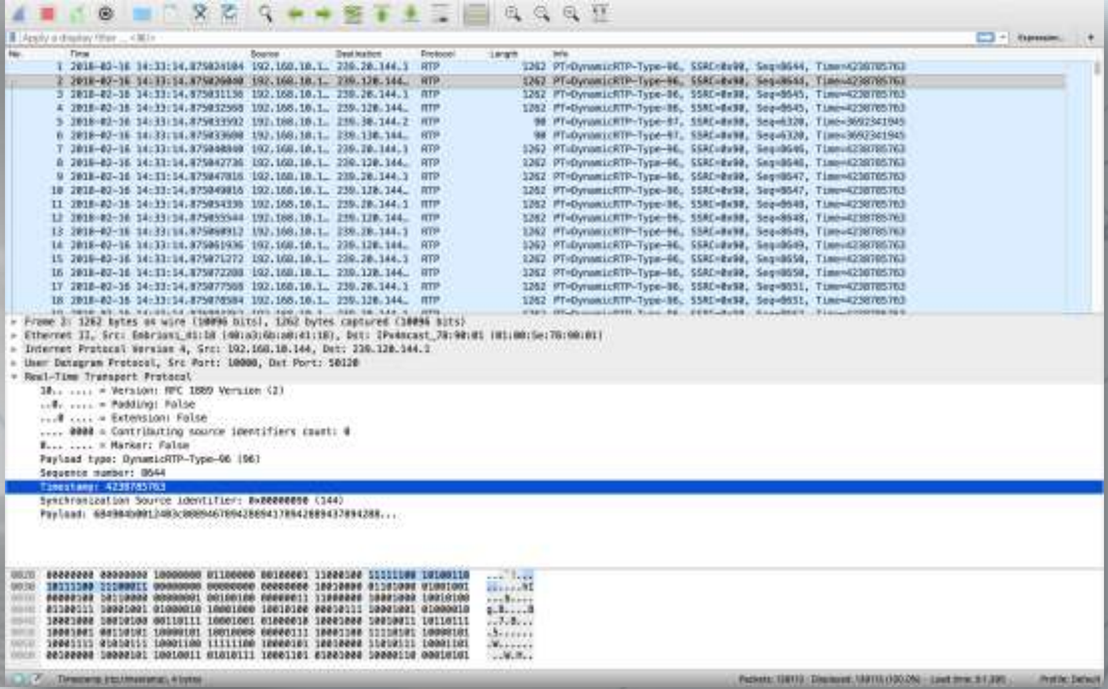
SKILLSET – BRIDGING THE GAP

Waveform Monitor

Packet Analyser



Eye Waveform
600 mV
P-P: 0.05ns 0.14UI
400 mV
200 mV
-200 mV
-400 mV
Jitter1 HPF 10 Hz – Timing
-600 mV 3 Eye
100 ps/Div
700
100%
YRGB
3 µs/Div
Embedded
dBFS
True Pk
LKFS
L(K): Short
Pg 1
Short Ld: -15.4 True Pk 0.0 1
Infinite: -15.3 Dialnorm: --
Run Time: 0d, 00:02:31 Running
in phase
LOUD
SEL resets sess/pk hold UP/DN ctrls session



```
No.  Time                          Source           Destination      Protocol  Length  Info
  1  2018-02-16 14:33:14.875024104 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8644, Time=4238785763
  2  2018-02-16 14:33:14.875026040 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8644, Time=4238785763
  3  2018-02-16 14:33:14.875031136 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8645, Time=4238785763
  4  2018-02-16 14:33:14.875032568 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8645, Time=4238785763
  5  2018-02-16 14:33:14.875033992 192.168.10.1…  239.30.144.2     RTP         98  PT=DynamicRTP-Type-97, SSRC=0x90, Seq=6320, Time=3692341945
  6  2018-02-16 14:33:14.875033600 192.168.10.1…  239.130.144…     RTP         98  PT=DynamicRTP-Type-97, SSRC=0x90, Seq=6320, Time=3692341945
  7  2018-02-16 14:33:14.875040040 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8646, Time=4238785763
  8  2018-02-16 14:33:14.875042736 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8646, Time=4238785763
  9  2018-02-16 14:33:14.875047016 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8647, Time=4238785763
 10  2018-02-16 14:33:14.875049016 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8647, Time=4238785763
 11  2018-02-16 14:33:14.875054336 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8648, Time=4238785763
 12  2018-02-16 14:33:14.875055544 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8648, Time=4238785763
 13  2018-02-16 14:33:14.875060912 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8649, Time=4238785763
 14  2018-02-16 14:33:14.875061936 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8649, Time=4238785763
 15  2018-02-16 14:33:14.875071272 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8650, Time=4238785763
 16  2018-02-16 14:33:14.875072208 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8650, Time=4238785763
 17  2018-02-16 14:33:14.875077568 192.168.10.1…  239.20.144.1     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8651, Time=4238785763
 18  2018-02-16 14:33:14.875078584 192.168.10.1…  239.120.144…     RTP       1262  PT=DynamicRTP-Type-96, SSRC=0x90, Seq=8651, Time=4238785763
```

```
▸ Frame 2: 1262 bytes on wire (10096 bits), 1262 bytes captured (10096 bits)
▸ Ethernet II, Src: Embrionix_41:18 (40:a3:6b:a0:41:18), Dst: IPv4mcast_78:90:01 (01:00:5e:78:90:01)
▸ Internet Protocol Version 4, Src: 192.168.10.144, Dst: 239.120.144.2
▸ User Datagram Protocol, Src Port: 10000, Dst Port: 50120
▾ Real-Time Transport Protocol
    10.. .... = Version: RFC 1889 Version (2)
    ..0. .... = Padding: False
    ...0 .... = Extension: False
    .... 0000 = Contributing source identifiers count: 0
    0... .... = Marker: False
    Payload type: DynamicRTP-Type-96 (96)
    Sequence number: 8644
    Timestamp: 4238785763
    Synchronization Source identifier: 0x00000090 (144)
    Payload: 684904b0012403c000946789428894178942889437894288...
```

```
0020  00000000 00000000 10000000 01100000 00100001 11000100 11111100 10100110
0030  10111100 11100011 00000000 00000000 00000000 10010000 01101000 01001001
```

Broadcast Engineer

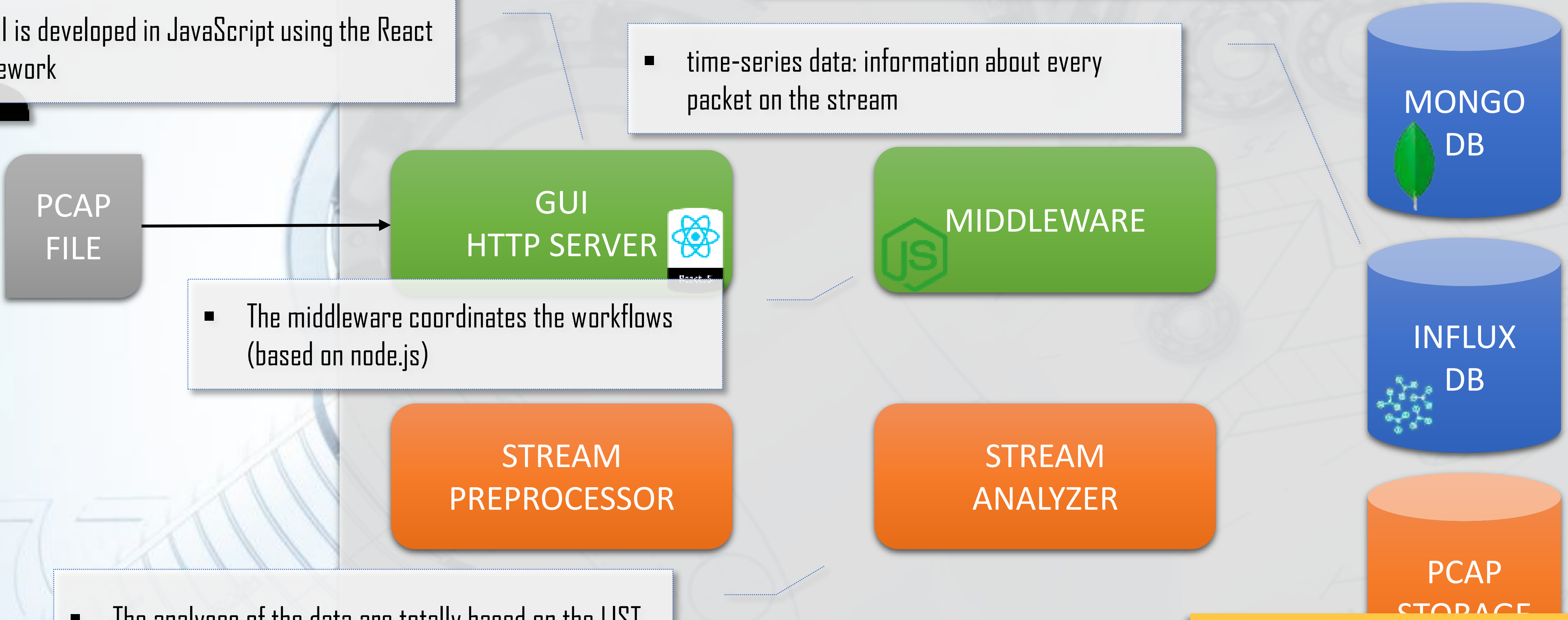
IT Engineer

ARCHITECTURE – OFFLINE

- non-time related data: user data static stream information, …

- The UI is developed in JavaScript using the React framework

- time-series data: information about every packet on the stream



- The middleware coordinates the workflows (based on node.js)

- The analyses of the data are totally based on the LIST Core libraries, which are developed in C++

- PCAP files are stored

The workflow can be accelerated if the PCAP capture process is included in LIST

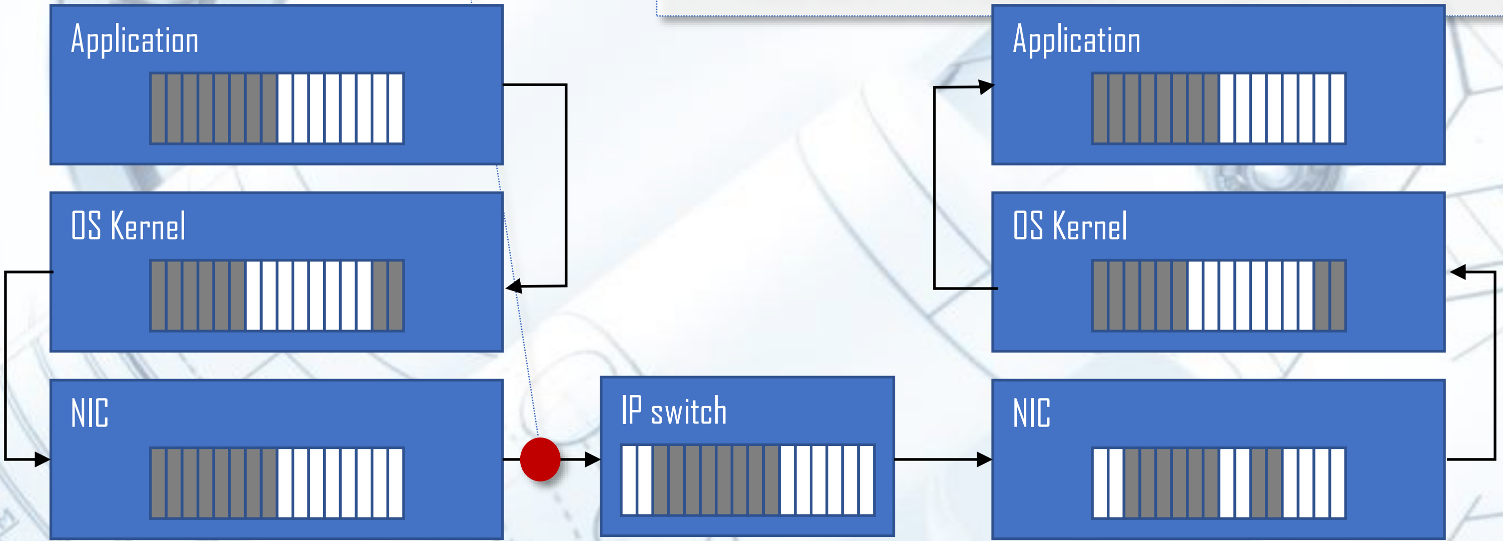
PREREQUISITE FOR VALID MEASUREMENT / CAPTURE

Critical success factor for the analysis:

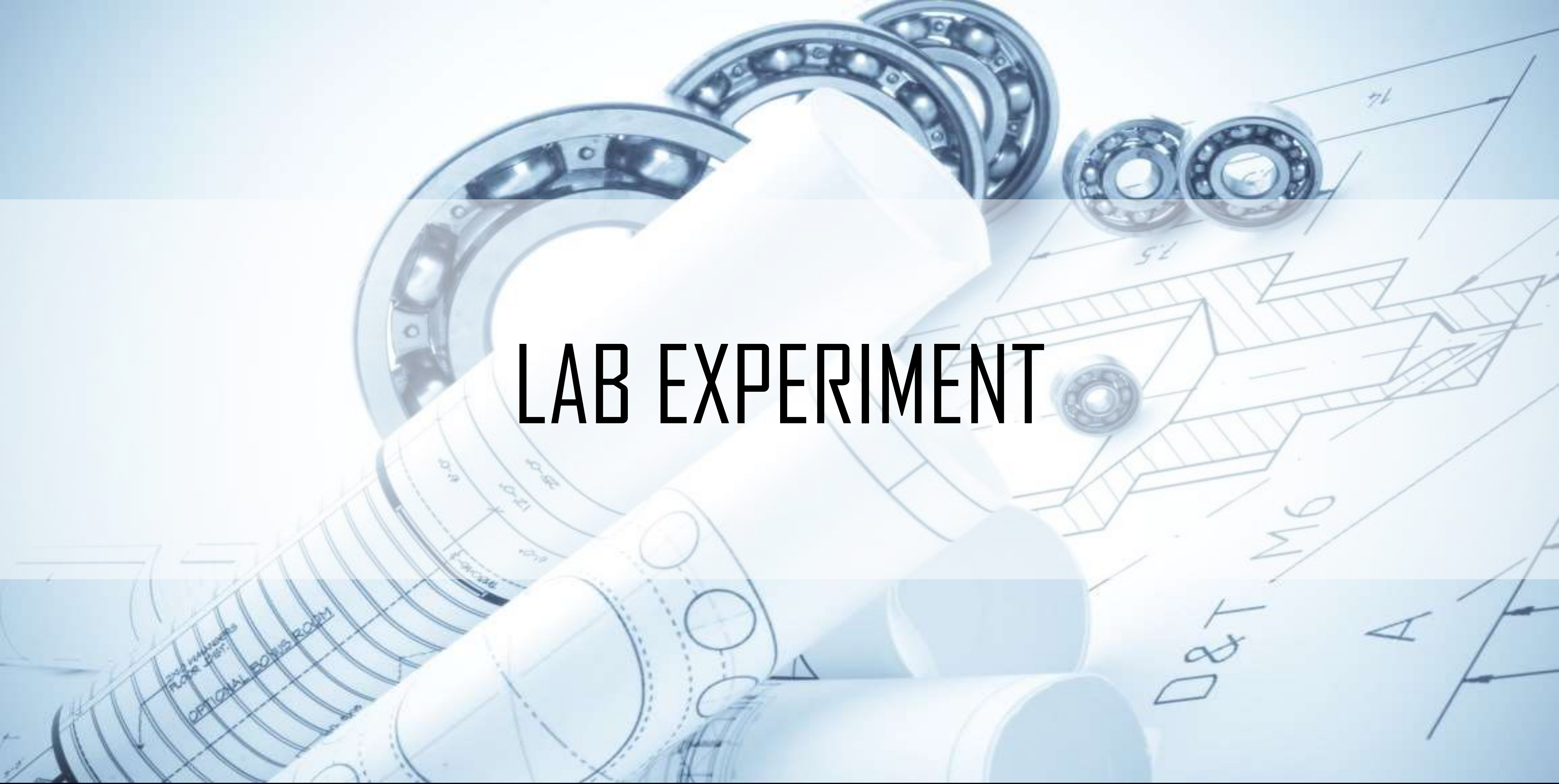
- Accuracy of IP Packet Timestamp
- Clock of capture device synchronized with PTP

SMPTE ST 2110-21 MEASURING THE BEHAVIOR OF A SENDER

- In order to measure the behavior of a sender,
  - Join the multicast stream as close to the sender
  - Port mirror
  - Use a network TAP, if not available use a switch port mirror
- Record the packet stream with a high precision capturing device
- Make sure PTP is available

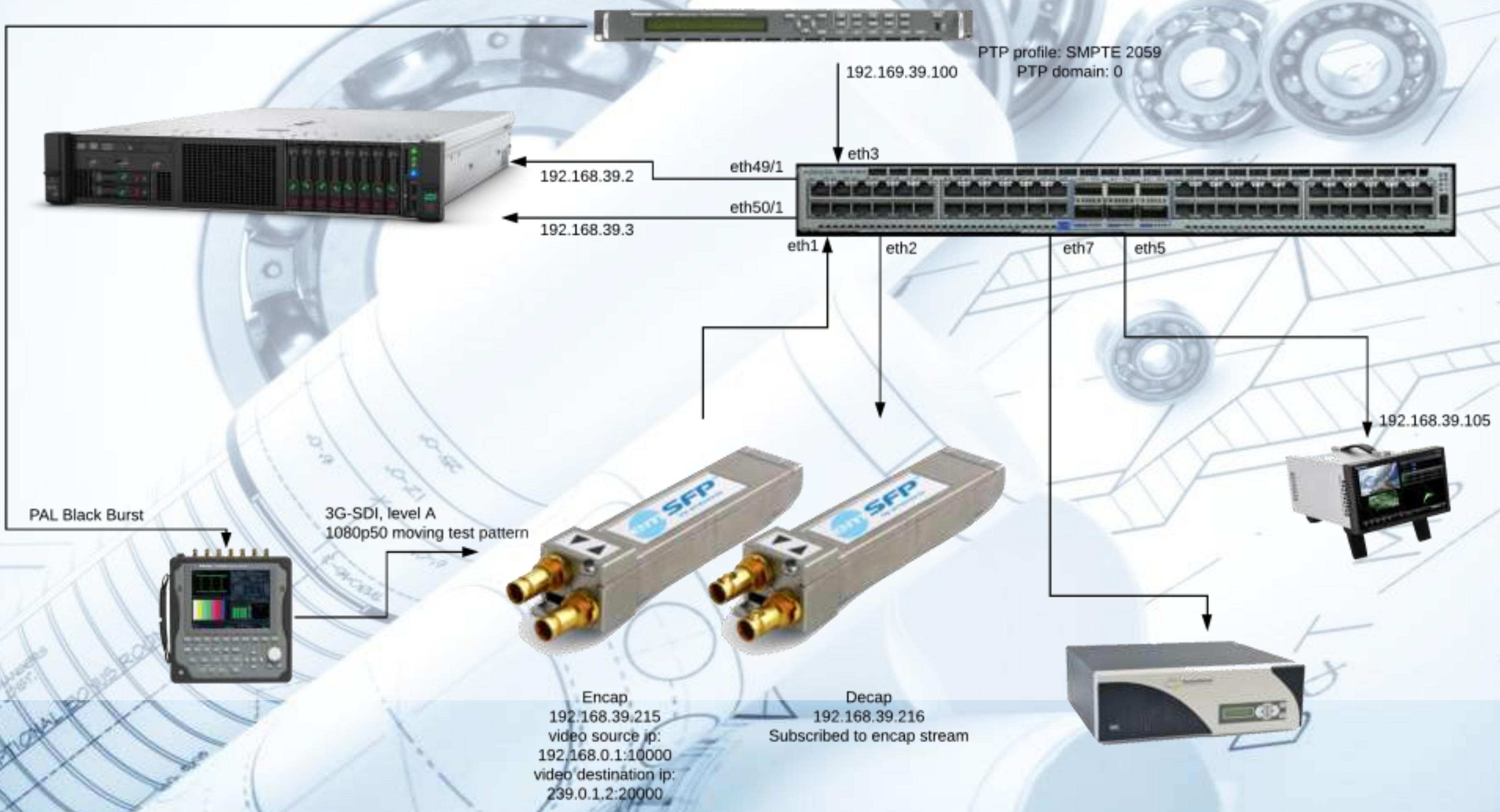


- Accurate timestamps
- Everything locked to PTP

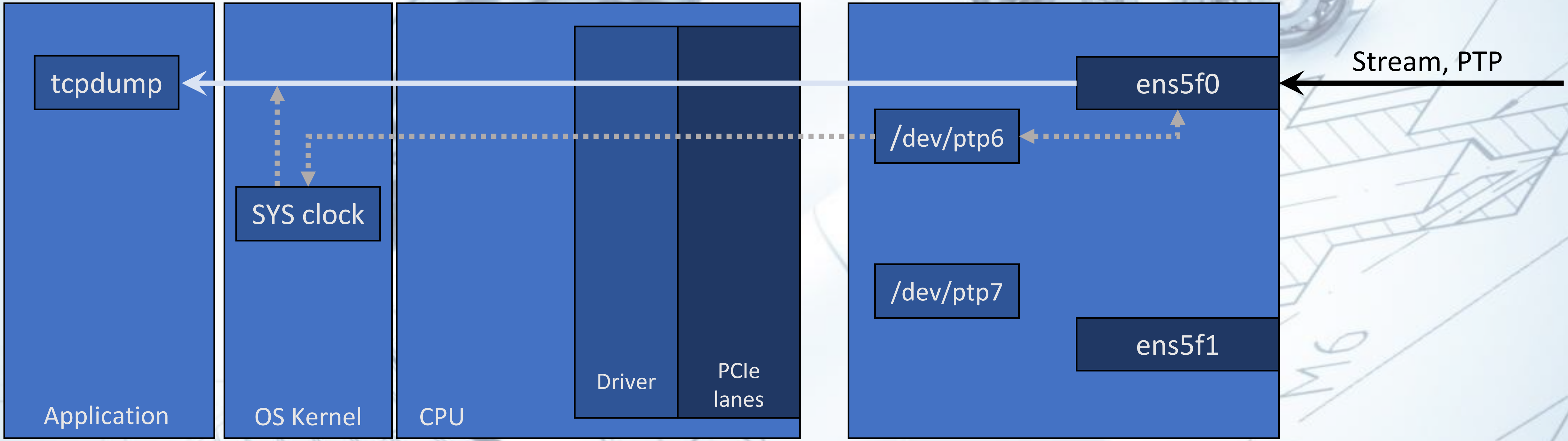


LAB EXPERIMENT

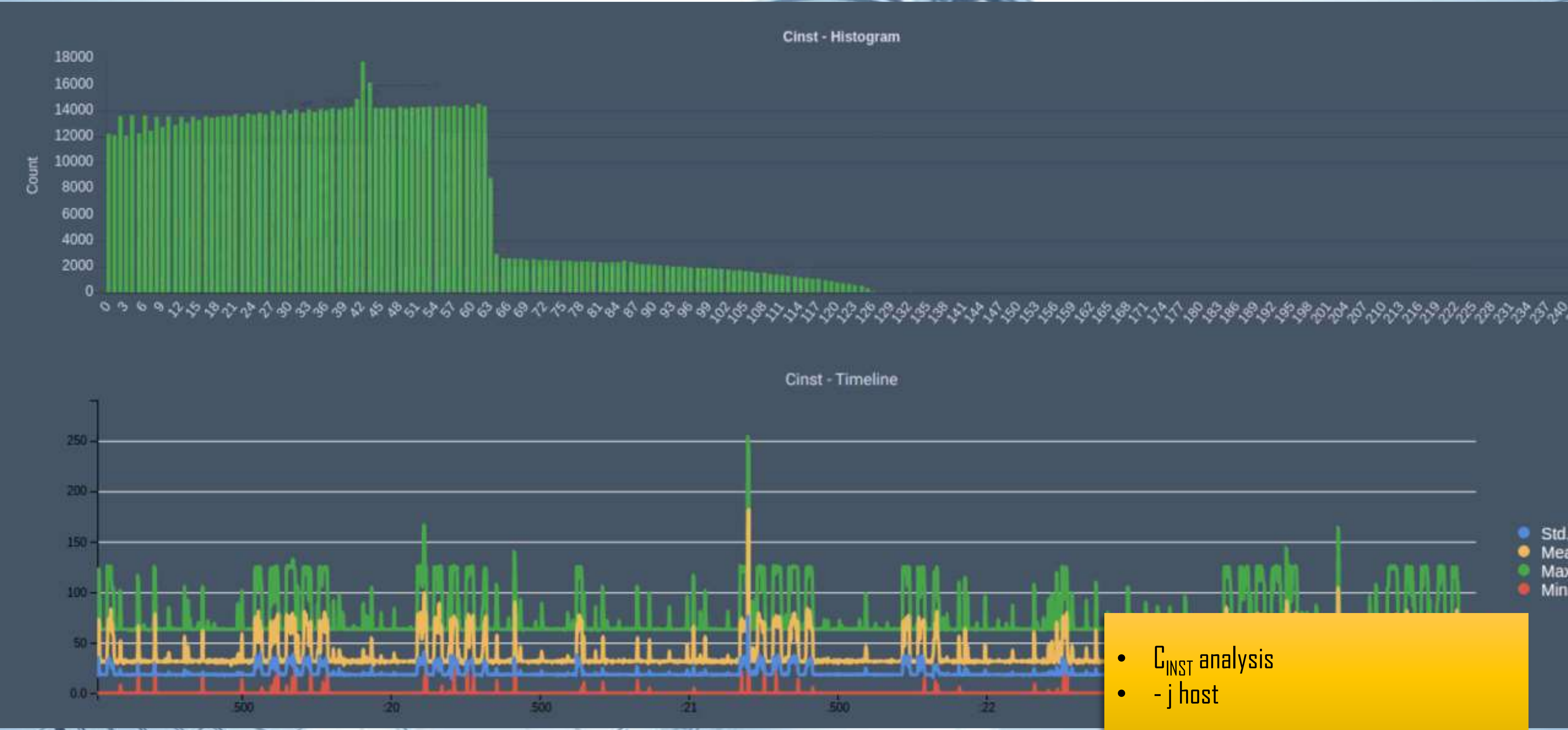
LAB EXPERIMENT: OUR TEST SETUP



NIC PIPELINE: STREAM JOIN, PTP INBAND

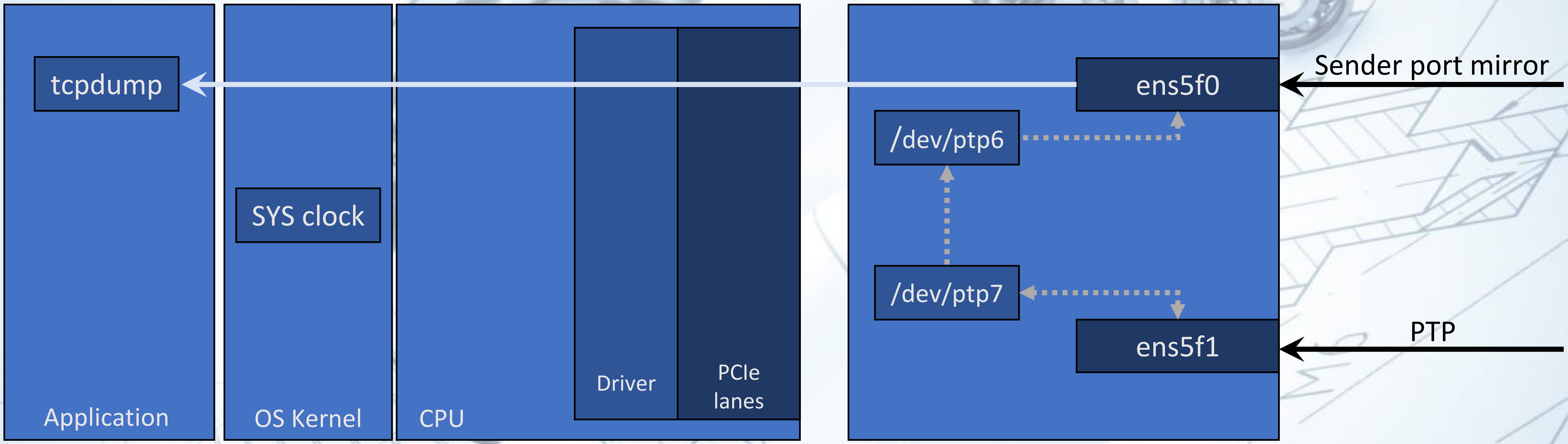


- -j host

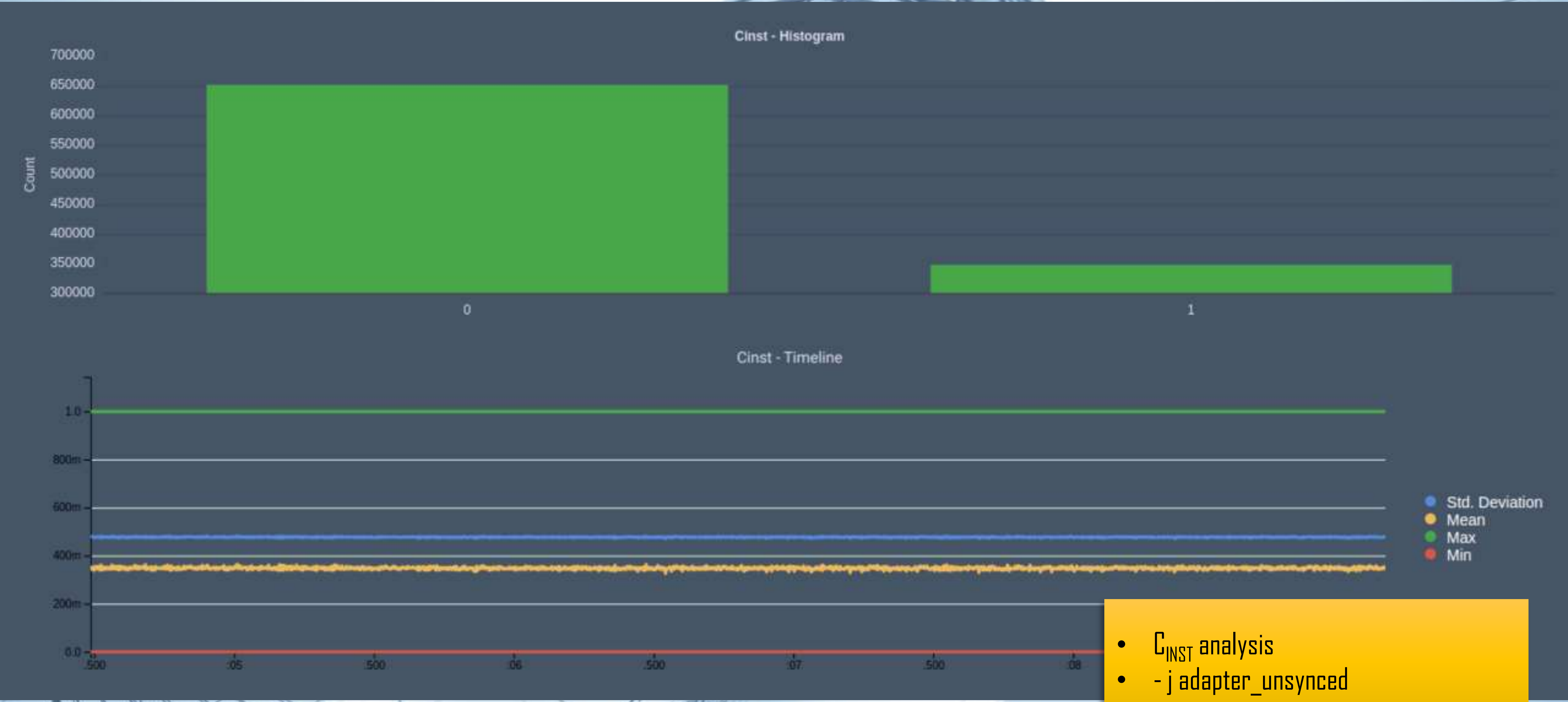


- C_{INST} analysis
- - j host

NIC PIPELINE: PORT MIRRORING, PTP OUTBAND

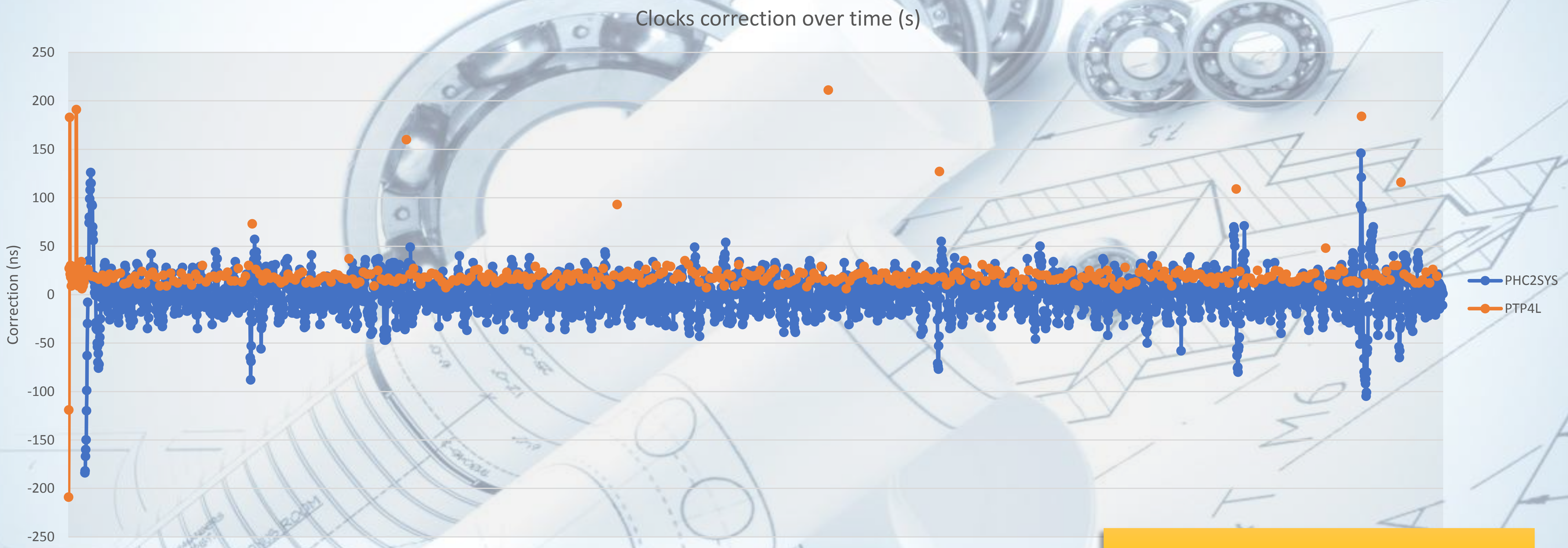


- - j adapter_unsynced



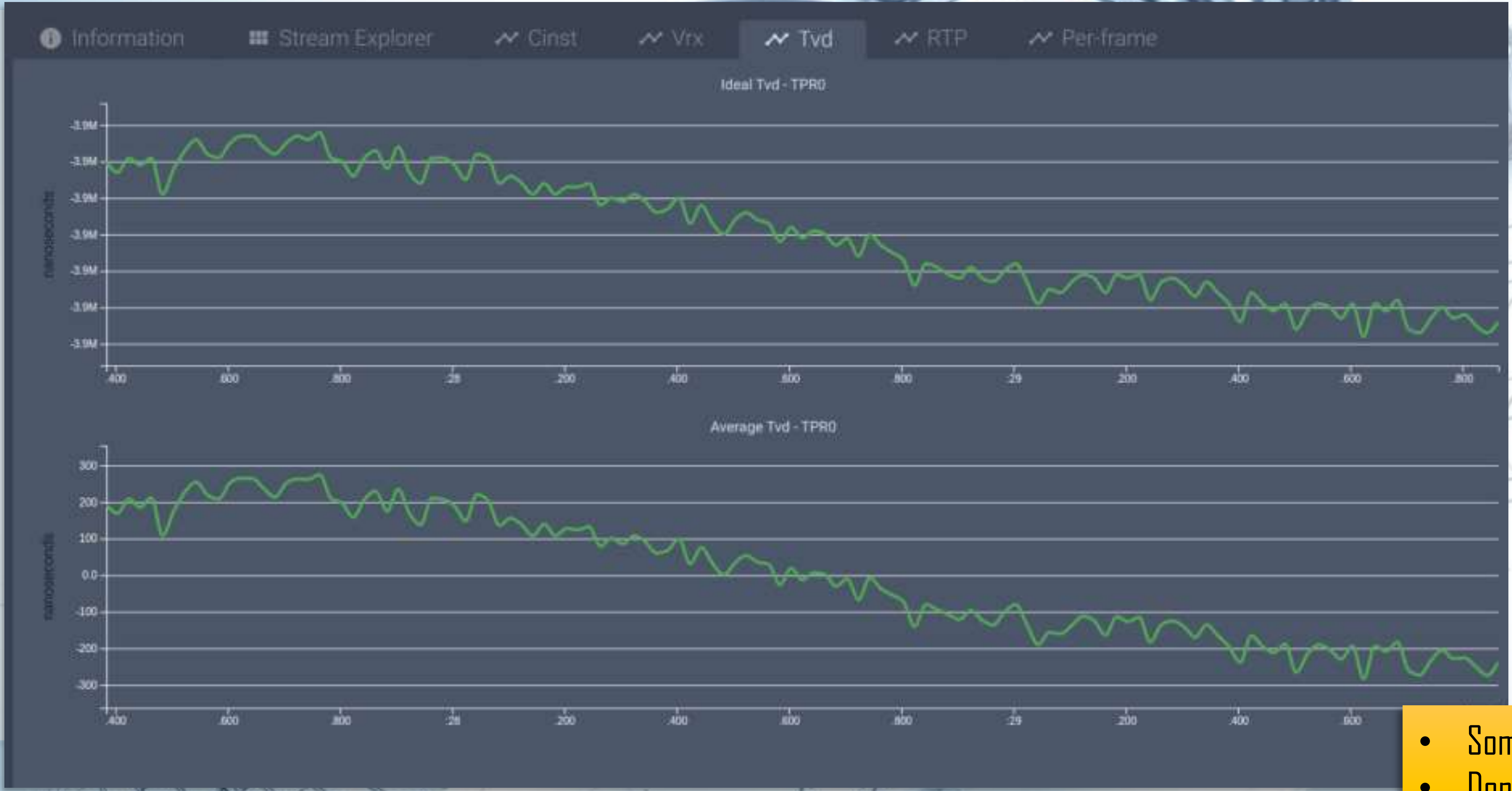
- C_{INST} analysis
- - j adapter_unsynced

PTP: CLOCK CORRECTION OVER TIME (ns)



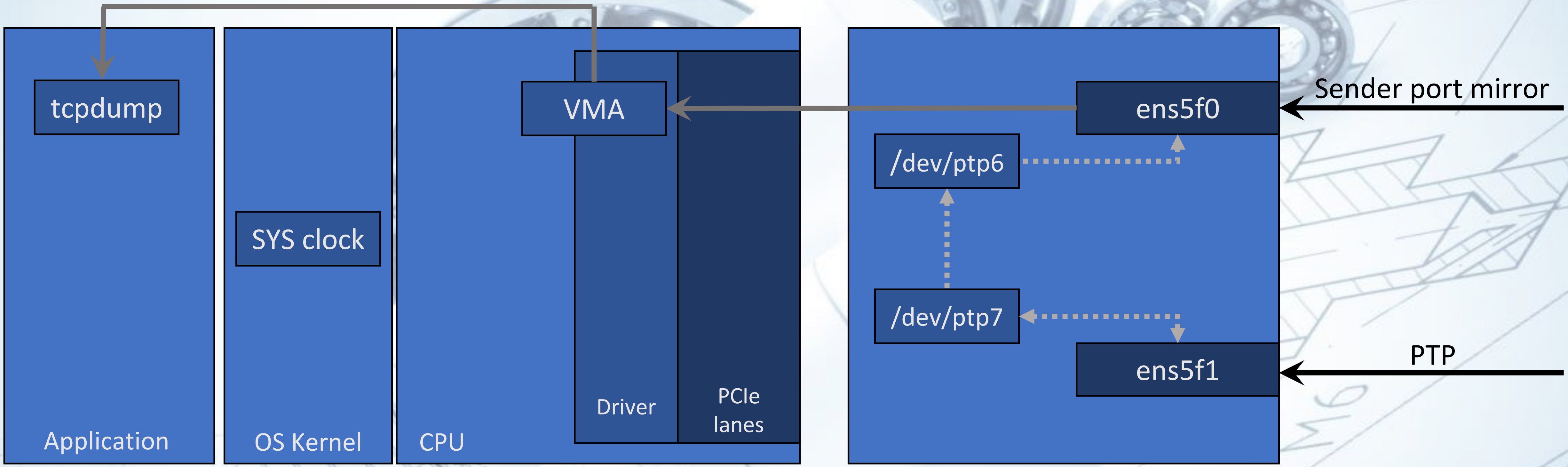
- PTP4L drives PHC2SYS

LOOKING AT THE FIRST RESULTS



- Something is wrong!
- Don't forget to lock your SDI source to the reference

NIC PIPELINE: PORT MIRRORING, PTP OUTBAND + KERNEL OFFLOAD



- PTP4L drives PHC2SYS

WE STARTED WITH...

- Our first implementation
- DL 380 G10

WE MINIATURIZED ...

+

- Mini PC
- Thunderbolt-PCIe Enclosure

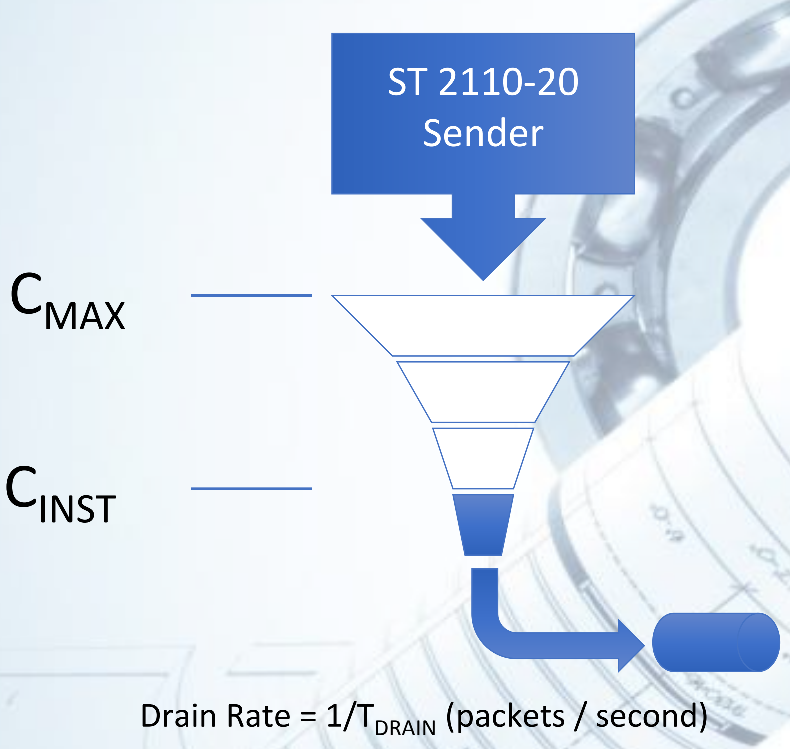
SMPTE ST 2110-21

Traffic Shaping and Delivery Timing for Video

SMPTE ST 2110-21 – TRAFFIC SHAPING AND DELIVERY TIMING FOR VIDEO

- Describes a virtual test for the network (**C_{MAX}**)
  - Constrains the packet delay variation of a sender
  - Narrow senders
  - Wide senders
- Describes a virtual test for the receive buffer (**VRX_{FULL}**)
  - Narrow receivers (not capable of receiving wide senders)
  - Wide receivers (universal)
- Describes Packet Read Schedules

SMPTE ST 2110-21 LEAKY BUCKET I: THE NETWORK COMPATIBILITY MODEL

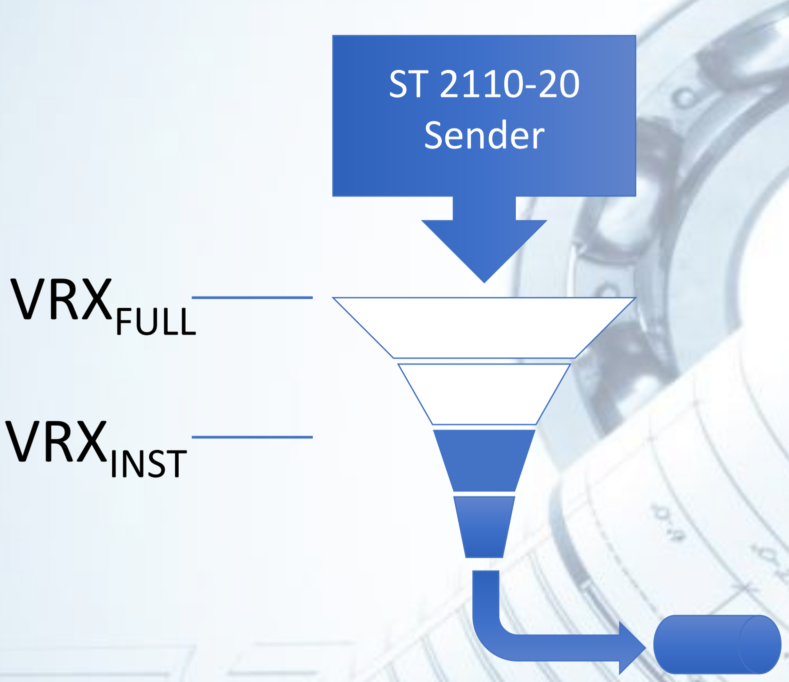


Drain Rate = $1/T_{DRAIN}$ (packets / second)

- Tested at the output of the sender
- Measures PDV introduced by a sender
- C_{MAX} is the maximum amount of packets allowed in the "leaky bucket"
- If $C_{INST} > C_{MAX}$ -> packets might get dropped in the network

- We just said, don't drop any packet??

SMPTE ST 2110-21 LEAKY BUCKET II: THE VIRTUAL RECEIVE BUFFER

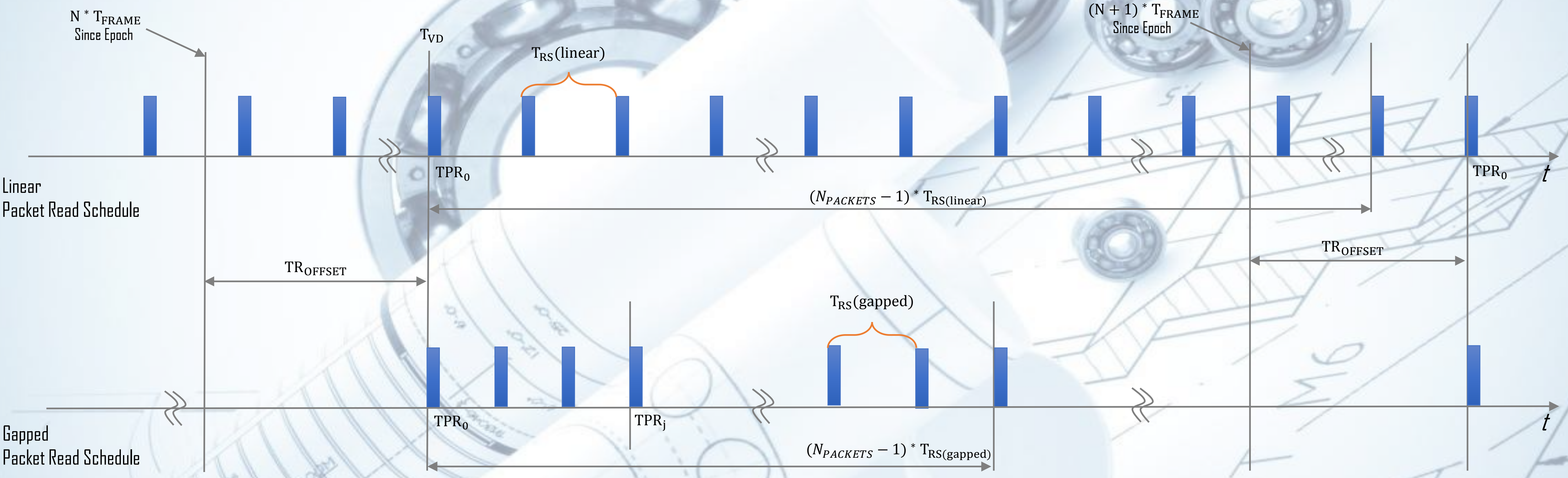


Packet J drains at Time TPR_J

- Tested at the output of the sender
- The VRX buffer is drained as a function of the packet read schedule
- VRX_{FULL} is the maximum amount of packets allowed in the "leaky bucket"
- If $VRX_{INST} > VRX_{FULL}$ -> packet might get dropped at receiving end

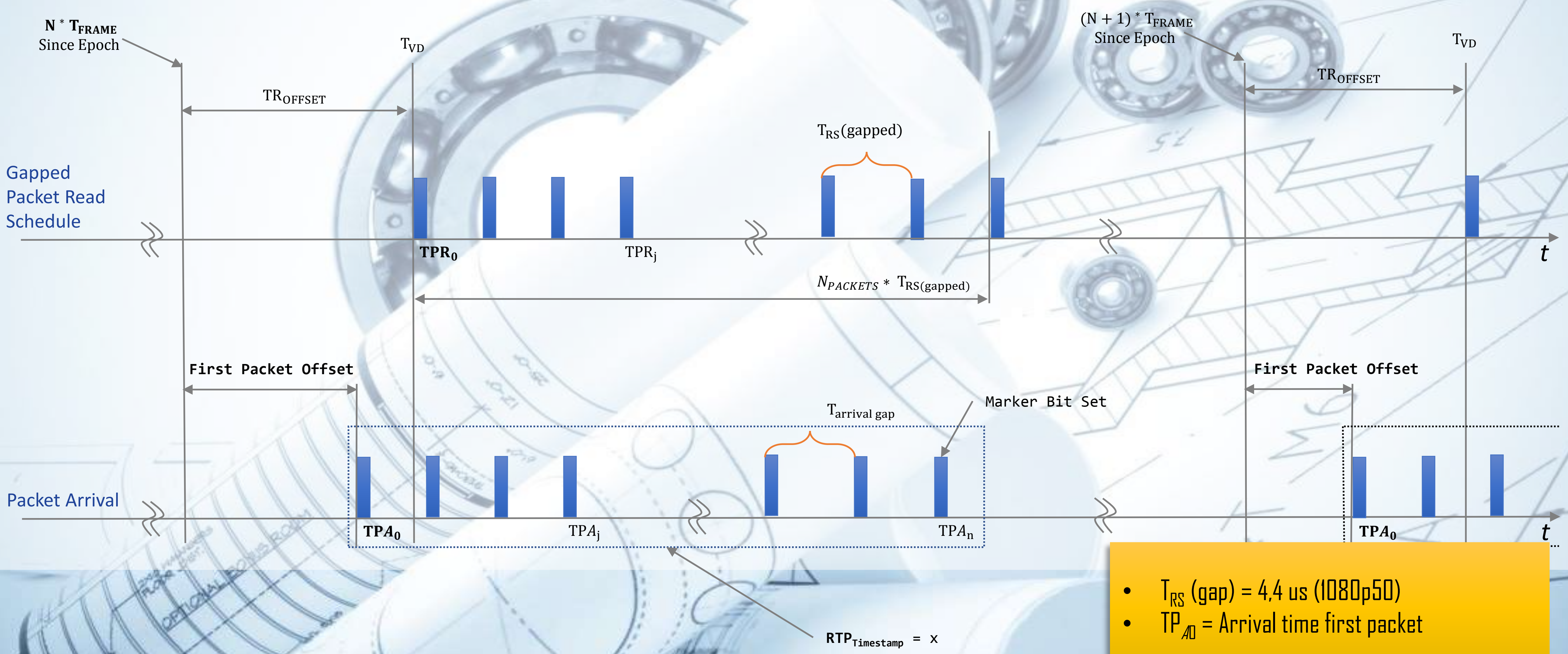
- We just said, don't drop any packet??

SMPTE ST 2110-21 PACKET READ SCHEDULES

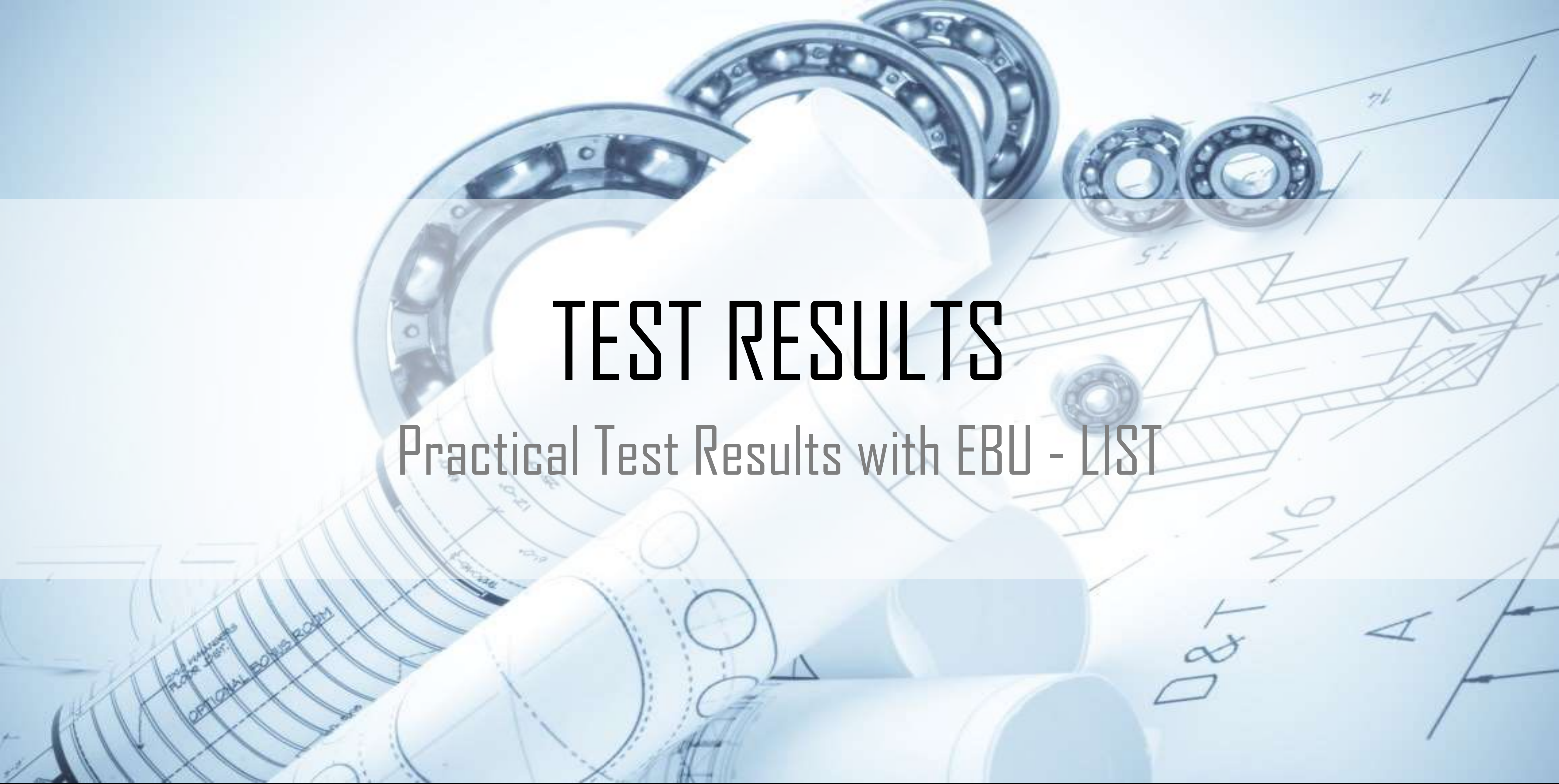


N * T_FRAME Since Epoch
T_VD
T_RS(linear)
(N + 1) * T_FRAME Since Epoch
TPR_0
TPR_0
t
Linear Packet Read Schedule
(N_PACKETS − 1) * T_RS(linear)
TR_OFFSET
TR_OFFSET
T_RS(gapped)
TPR_0
TPR_j
t
Gapped Packet Read Schedule
(N_PACKETS − 1) * T_RS(gapped)

SMPTE ST 2110-21 GAPPED PACKET ARRIVAL

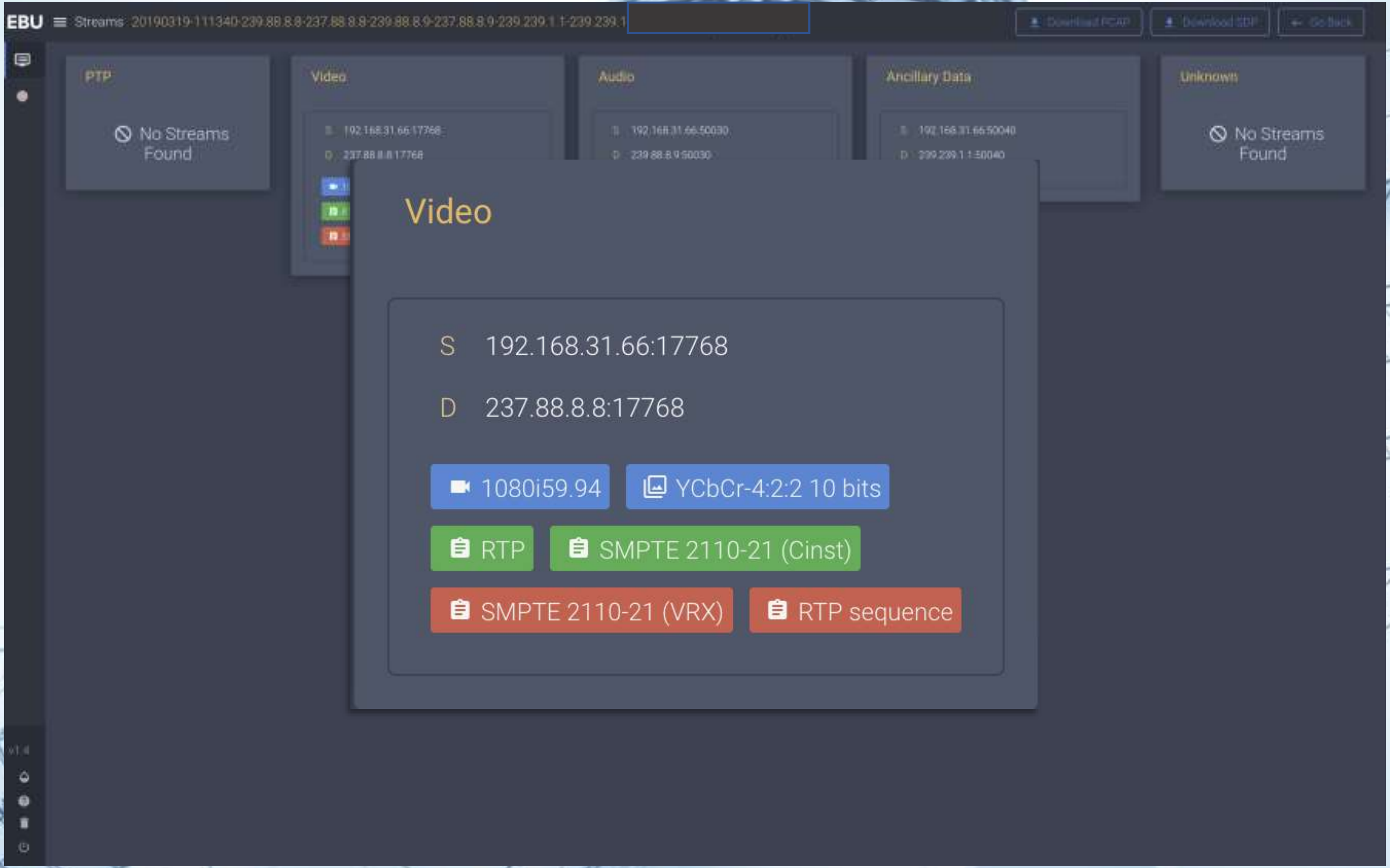


- T_{RS} (gap) = 4,4 us (1080p50)
- TP_{A0} = Arrival time first packet



TEST RESULTS

Practical Test Results with EBU - LIST



Video

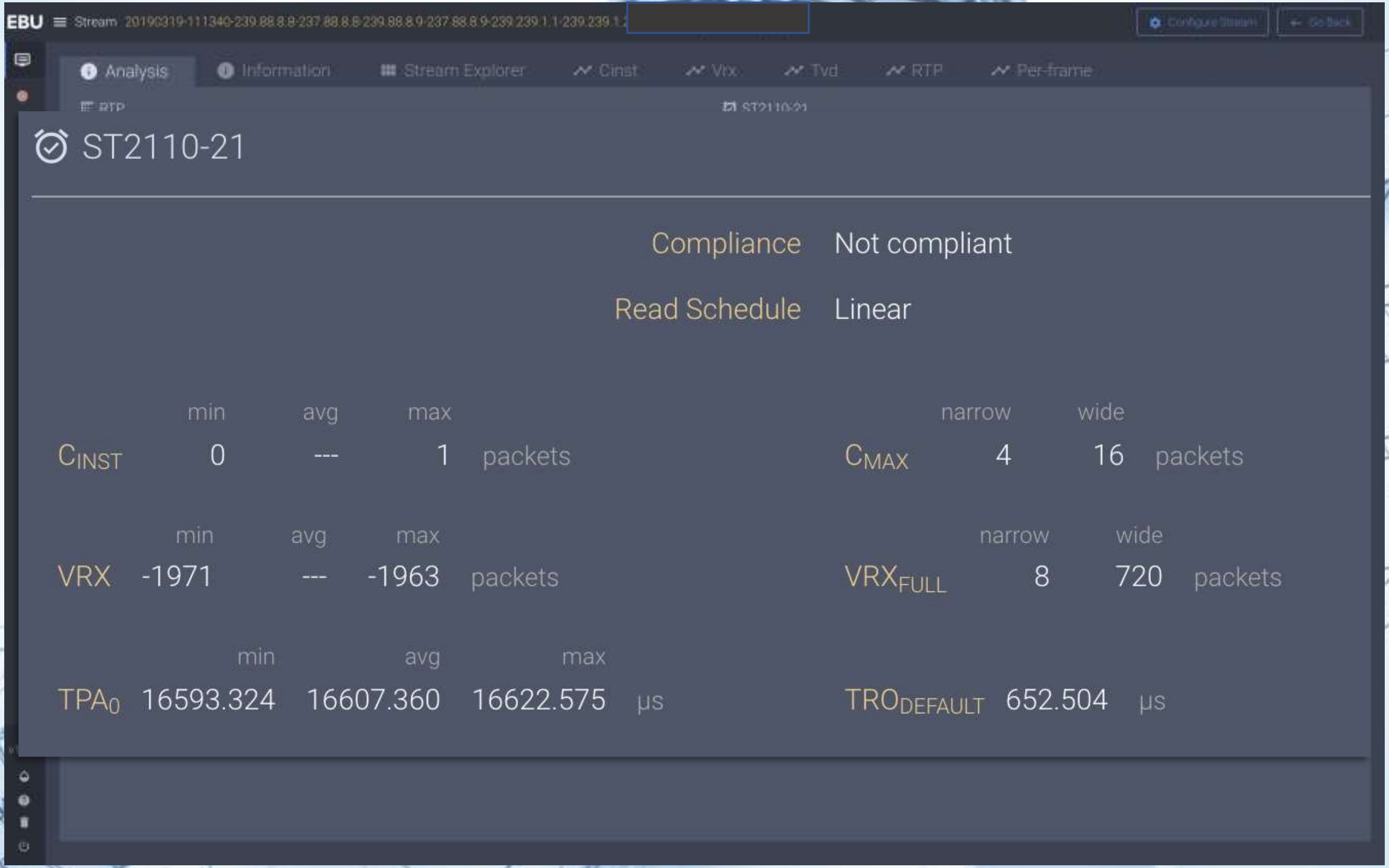
S 192.168.31.66:17768

D 237.88.8.8:17768

1080i59.94 | YCbCr-4:2:2 10 bits

RTP | SMPTE 2110-21 (Cinst)

SMPTE 2110-21 (VRX) | RTP sequence



Stream 20190319-111340-239.88.8.8-237.88.8.8-239.88.8.9-237.88.8.9-239.239.1.1-239.239.1.[redacted]

ST2110-21

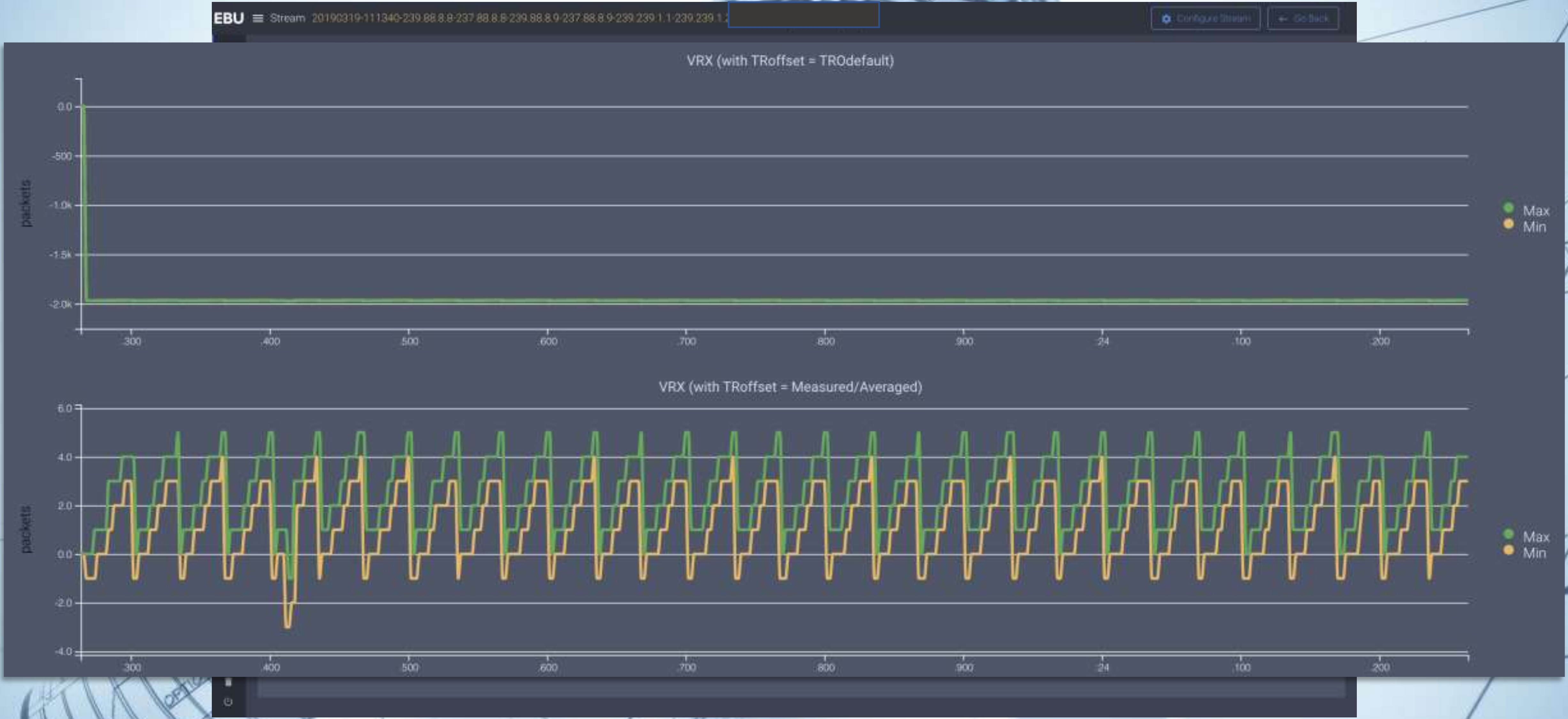
Compliance Not compliant

Read Schedule Linear

	min	avg	max	
C_{INST}	0	---	1	packets
VRX	-1971	---	-1963	packets
TPA_0	16593.324	16607.360	16622.575	µs

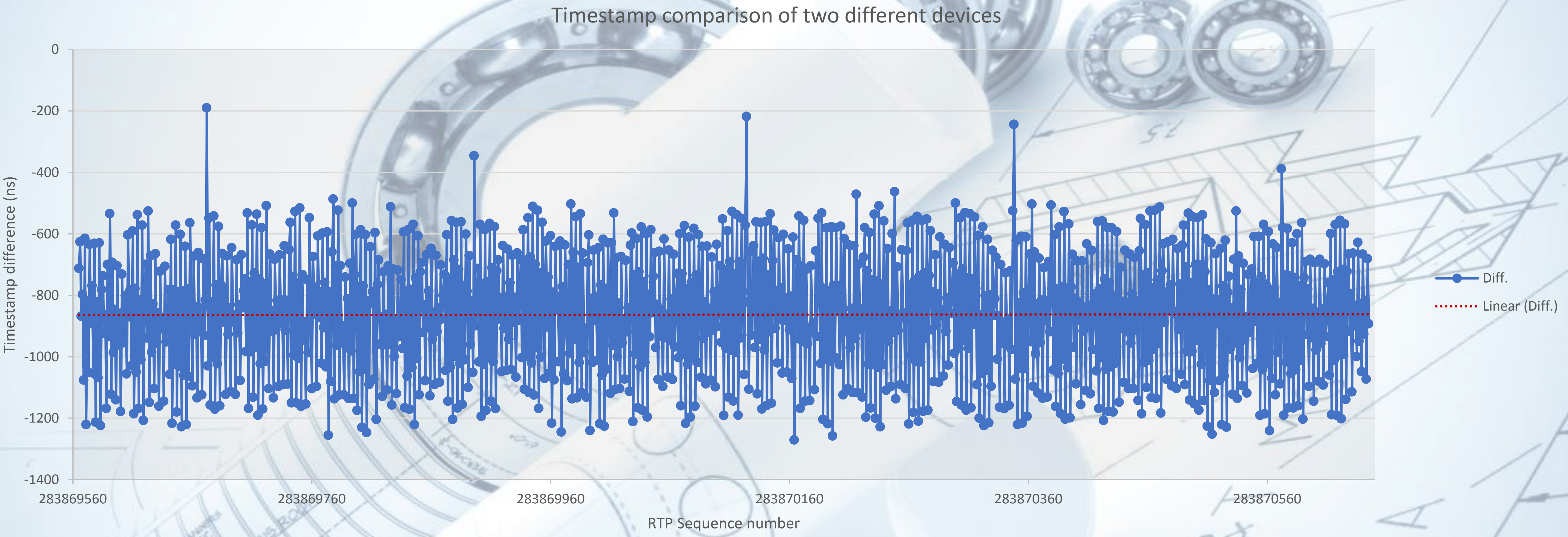
	narrow	wide	
C_{MAX}	4	16	packets
VRX_{FULL}	8	720	packets

$TRO_{DEFAULT}$ 652.504 µs



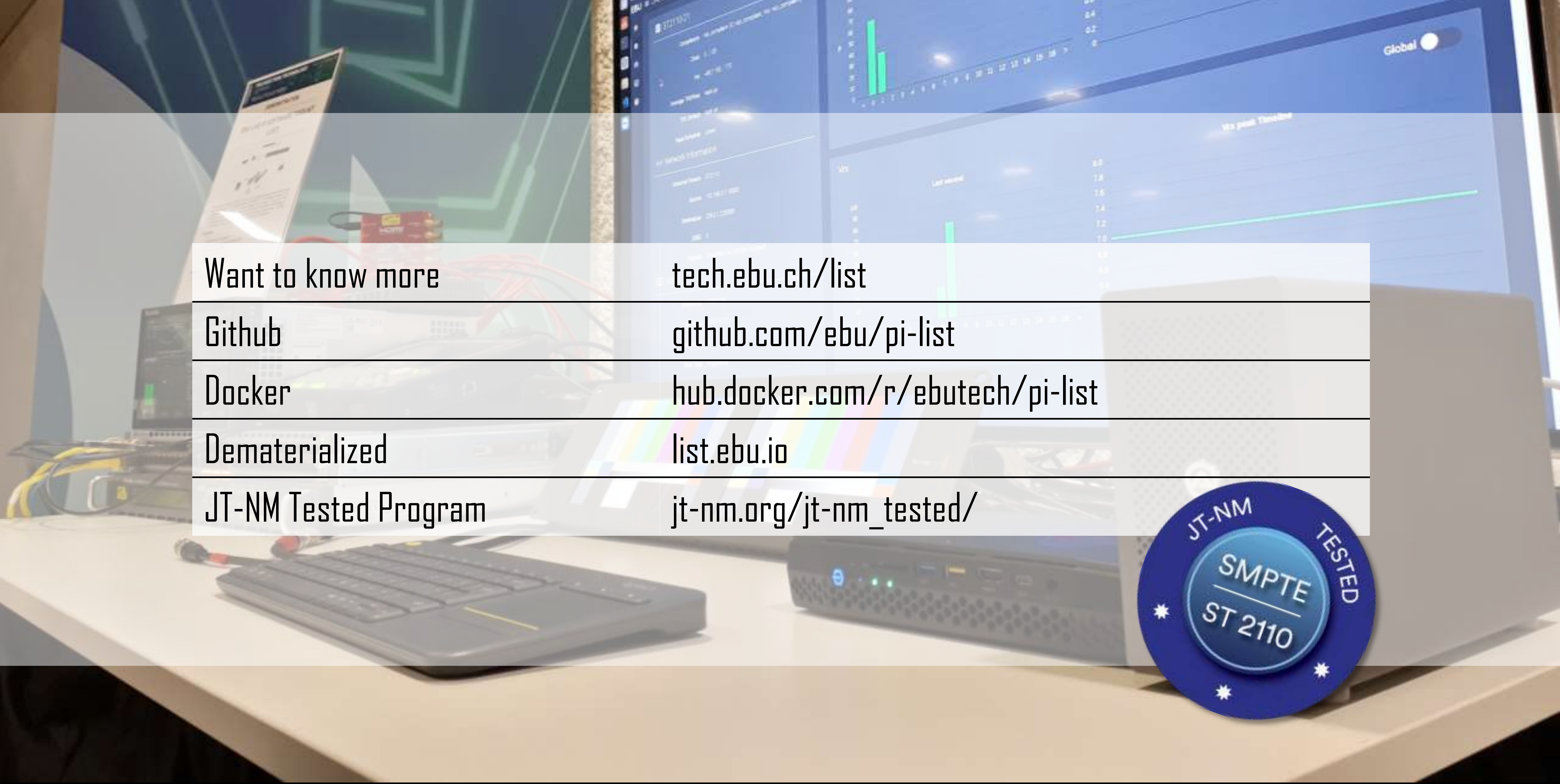
EBU ≡ Stream 20190319-111340-239.88.8.8-237.88.8.8-239.88.8.9-237.88.8.9-239.239.1.1-239.239.1.2

TIMESTAMP COMPARISON OF TWO DIFFERENT CAPTURE DEVICES



CONCLUSION

- Avoid any bottlenecks in the capturing pipeline:
  - Use a NIC capable of handling the bandwidth
  - Use kernel bypass to avoid packet drops by the OS
  - Check storage performance - enough to store the capture in real time
- Frequency and Phase lock
  - Use a NIC with hardware clocking / timestamp support
  - Synchronize the NIC to PTP
- It is possible to perform accurate captures with COTS equipment



Want to know more	tech.ebu.ch/list
Github	github.com/ebu/pi-list
Docker	hub.docker.com/r/ebutech/pi-list
Dematerialized	list.ebu.io
JT-NM Tested Program	jt-nm.org/jt-nm_tested/

Thank you!

Any Questions?