Turning test results into traceability

Peter Lankford
Founder and Director, STAC

peter.lankford@STACresearch.com

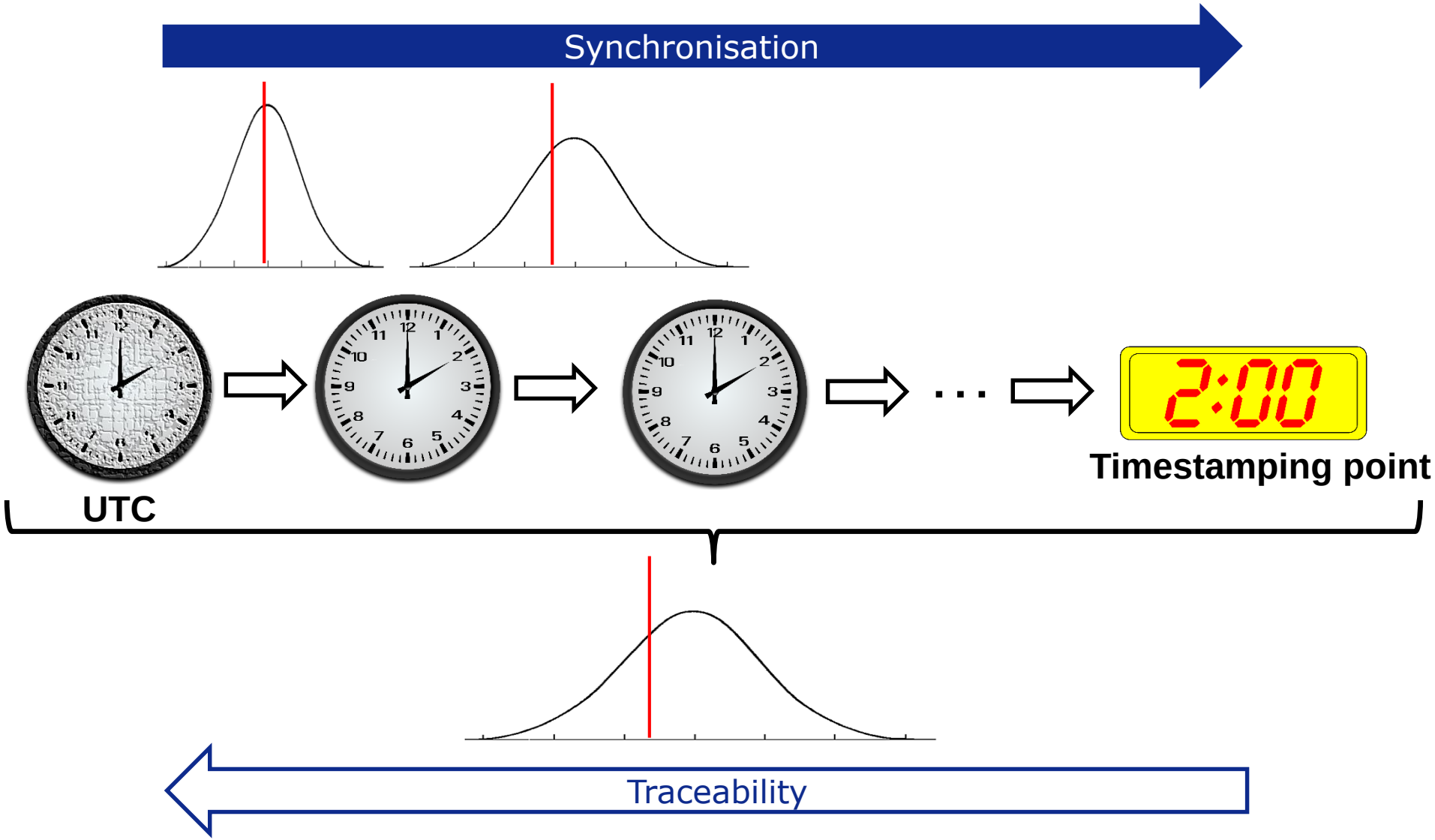
REVIEW: Business motivations

- Monitoring low-latency systems requires timestamps to be increasingly accurate relative to one another
- Monitoring low-latency markets requires timestamps to be increasingly accurate relative to a standard (UTC, NIST)
  - Regulations in EU and US
- W.r.t. regulations:
  - Firms must not only comply
  - They must demonstrate that they comply

REVIEW: Why is testing important for compliance?

- Can’t rely on monitoring
  - Rear-view mirror
- Can’t rely on manufacturer specifications
  - Can be wrong
  - Usually ambiguous
  - Many solutions have no manufacturer to turn to
- ESMA says so
  - “Relevant and proportionate testing of the system should be required…”

REVIEW: Traceability of each timestamp is a chain



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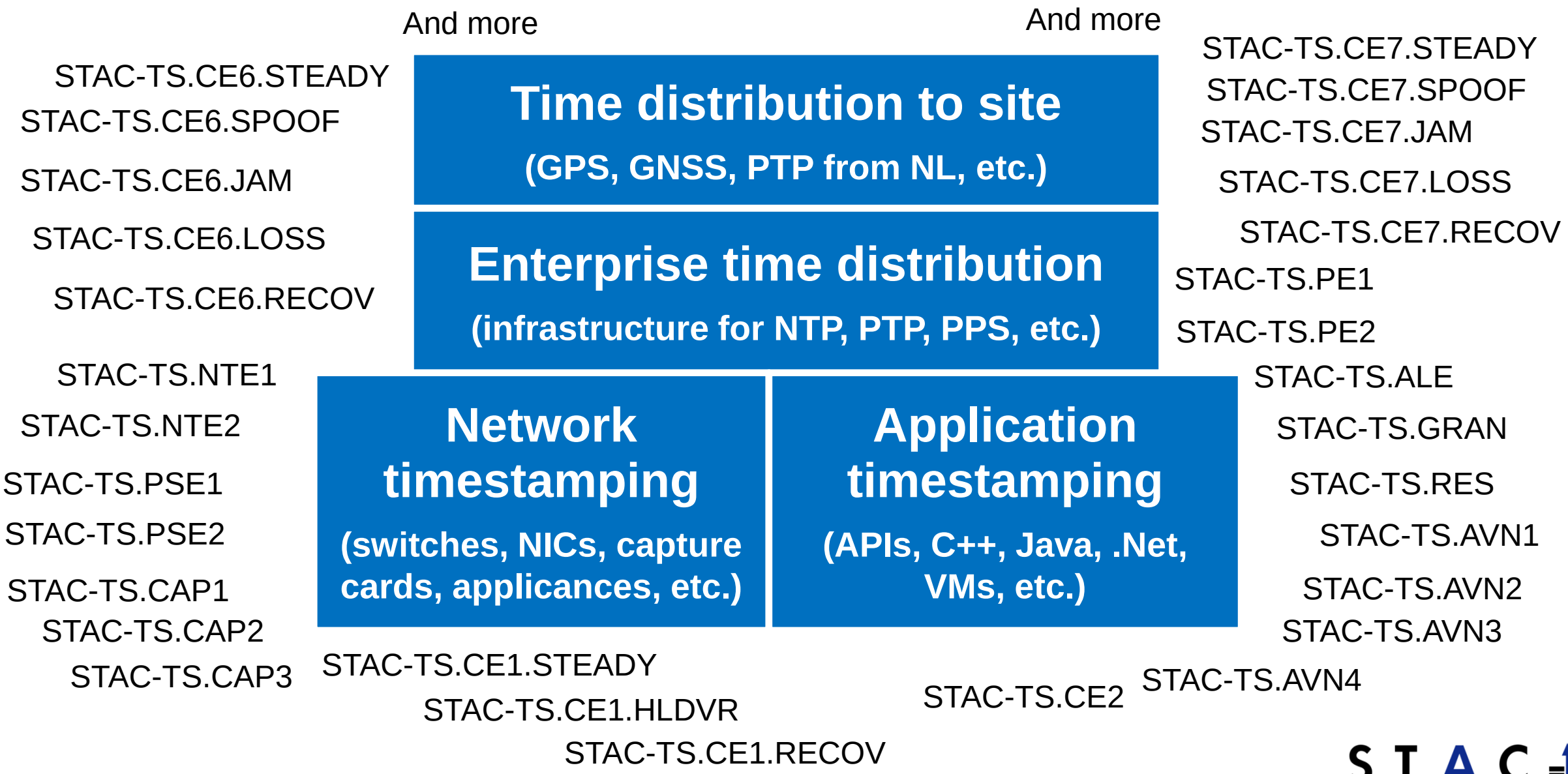
STAC-TS taxonomy for that chain



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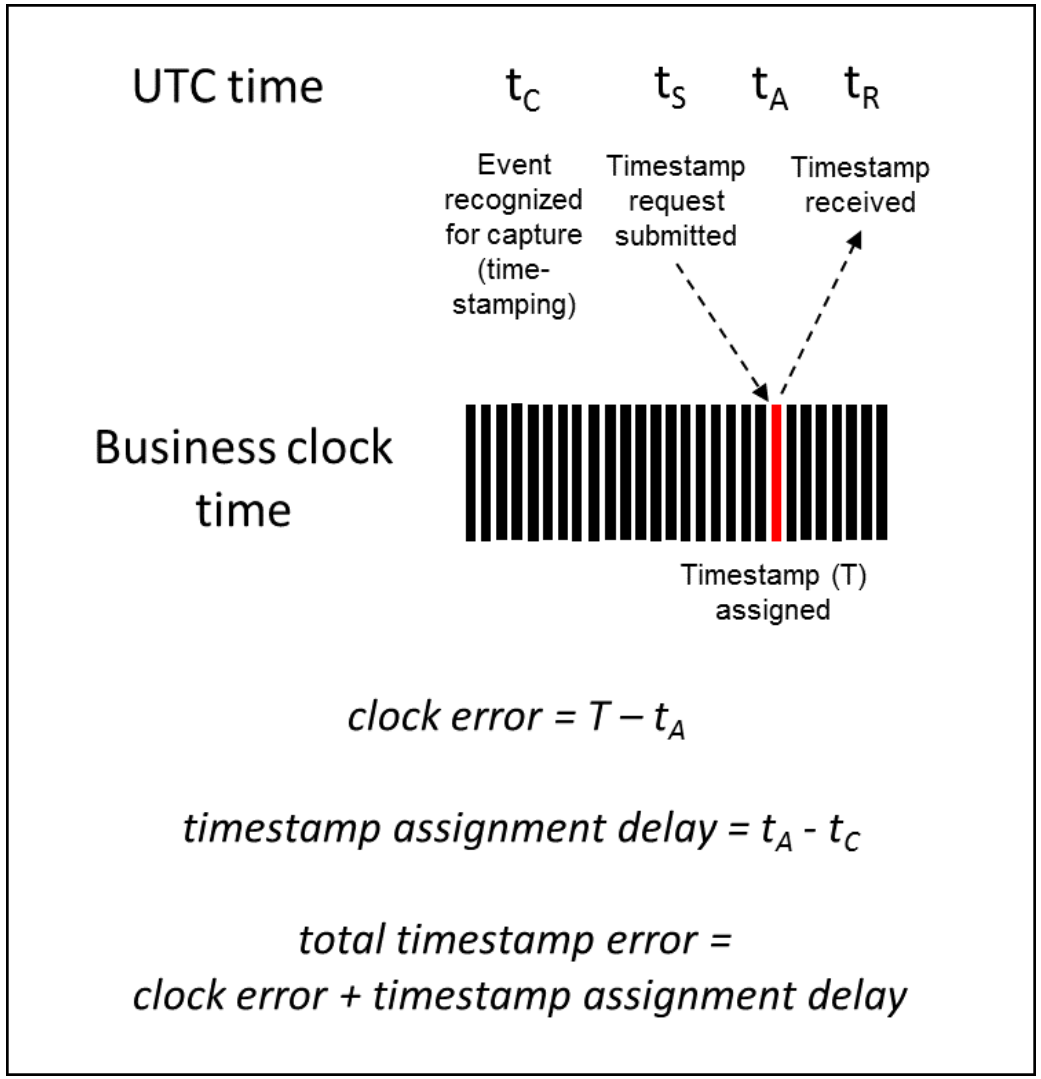
STAC-TS.ALE: Application-level error

- Application-level error is application timestamp error independent of clock error
- STAC Timestamper calls subject timestamping API with and without calls to reference timestamp (TSC)
- Multiple request patterns
- Multiple loading schemes
- Statistics drawn from worst case at each probability level



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A not uncommon profile of application-level error

Table 1 Timestamp Errors with Respect to Host Clock (STAC-TS.ALE1) - Worst Case Error Percentiles

Percentile	Error
Max	21,177.625
99.9999%	10,012.557
99.999%	32.836
99.99%	27.150
99.9%	21.833
99%	1.773
95%	1.640

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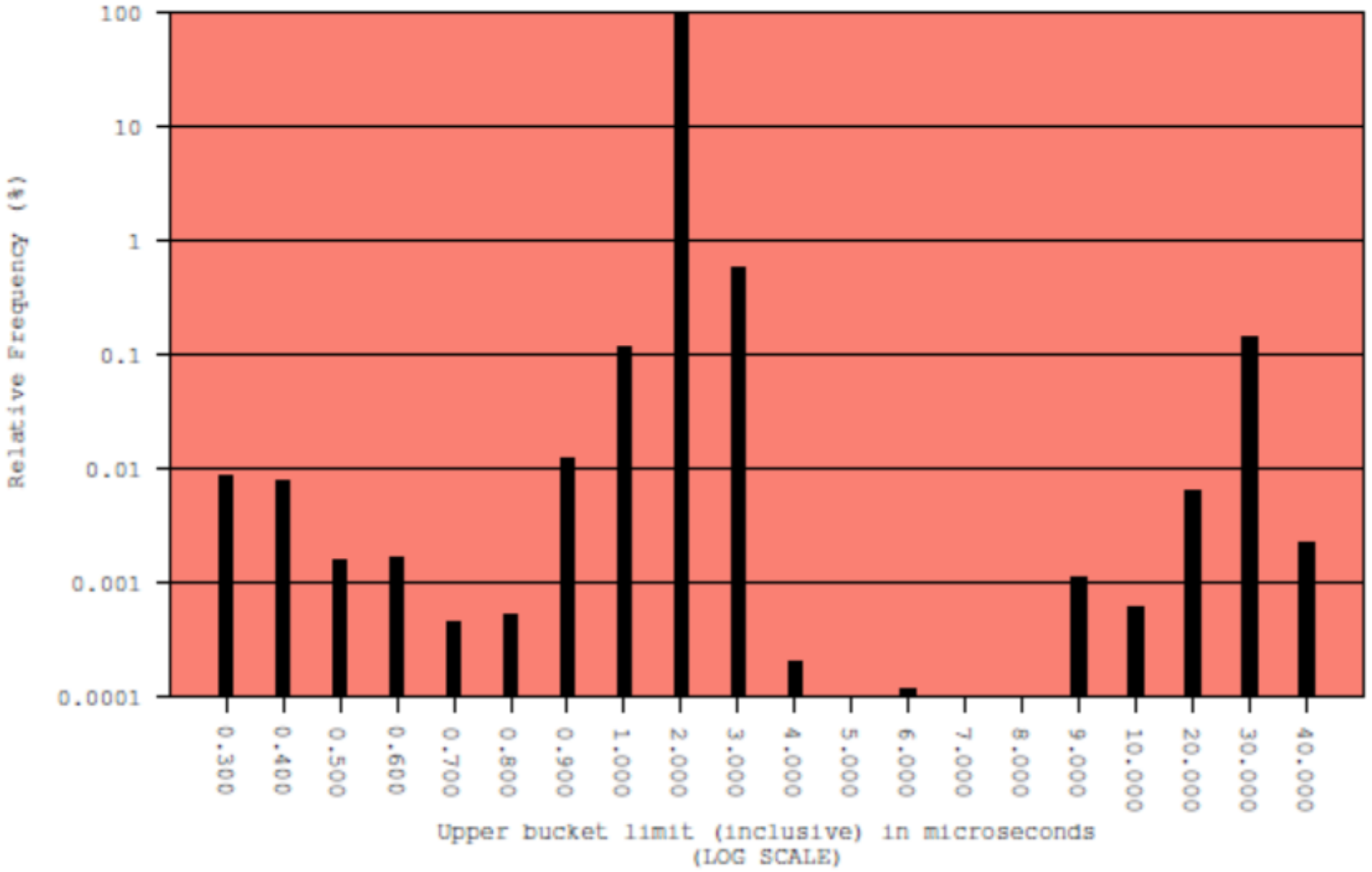
A not uncommon histogram of application-level error (log-log)



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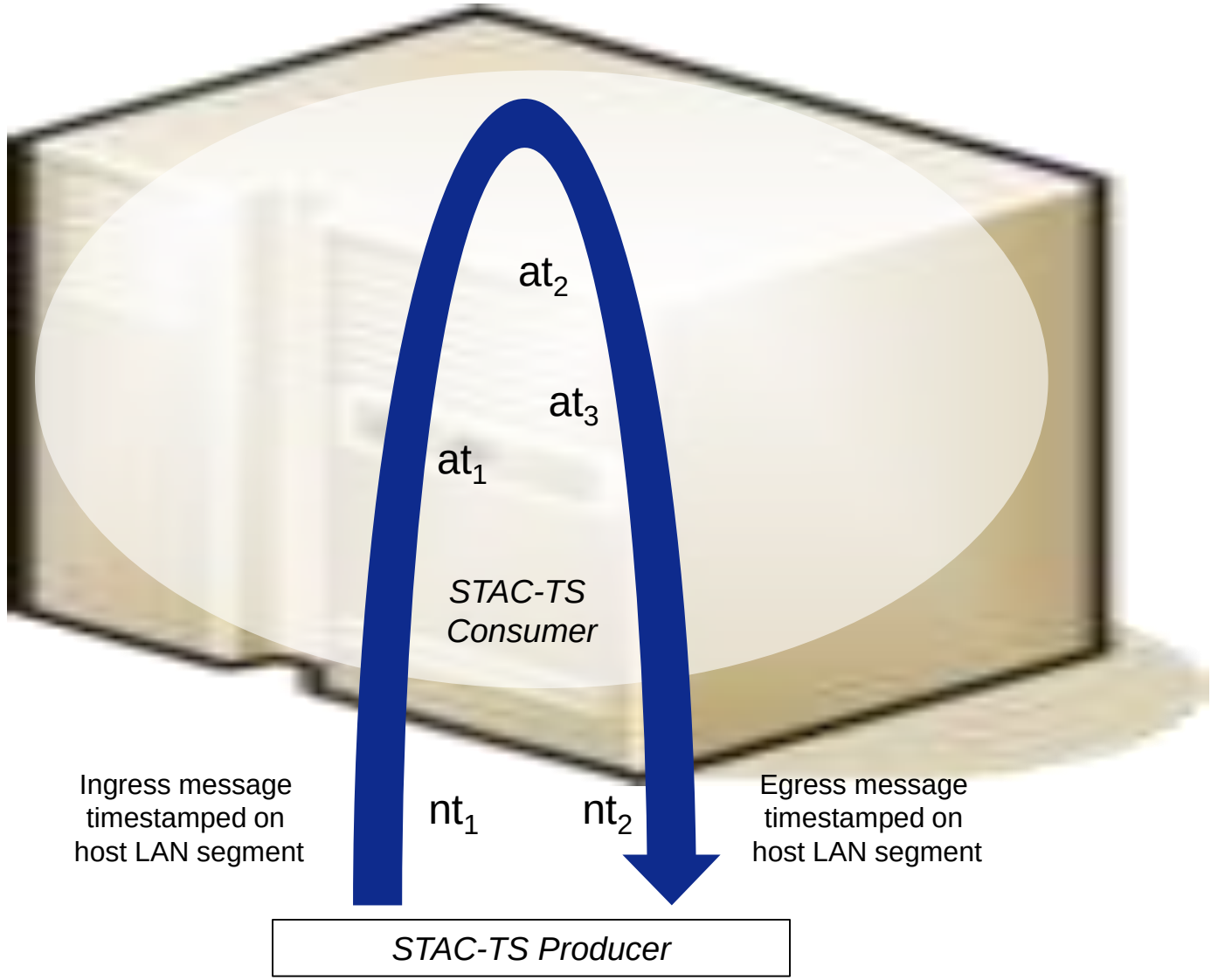
STAC-TS.AVN: Application versus network

- Measures total application timestamp error including host clock and application-level error
- Ingress events, egress events, application events
- Even inferred clock error
- Ideal for low-latency, low-jitter systems
- Include as much of the traceability chain as you like



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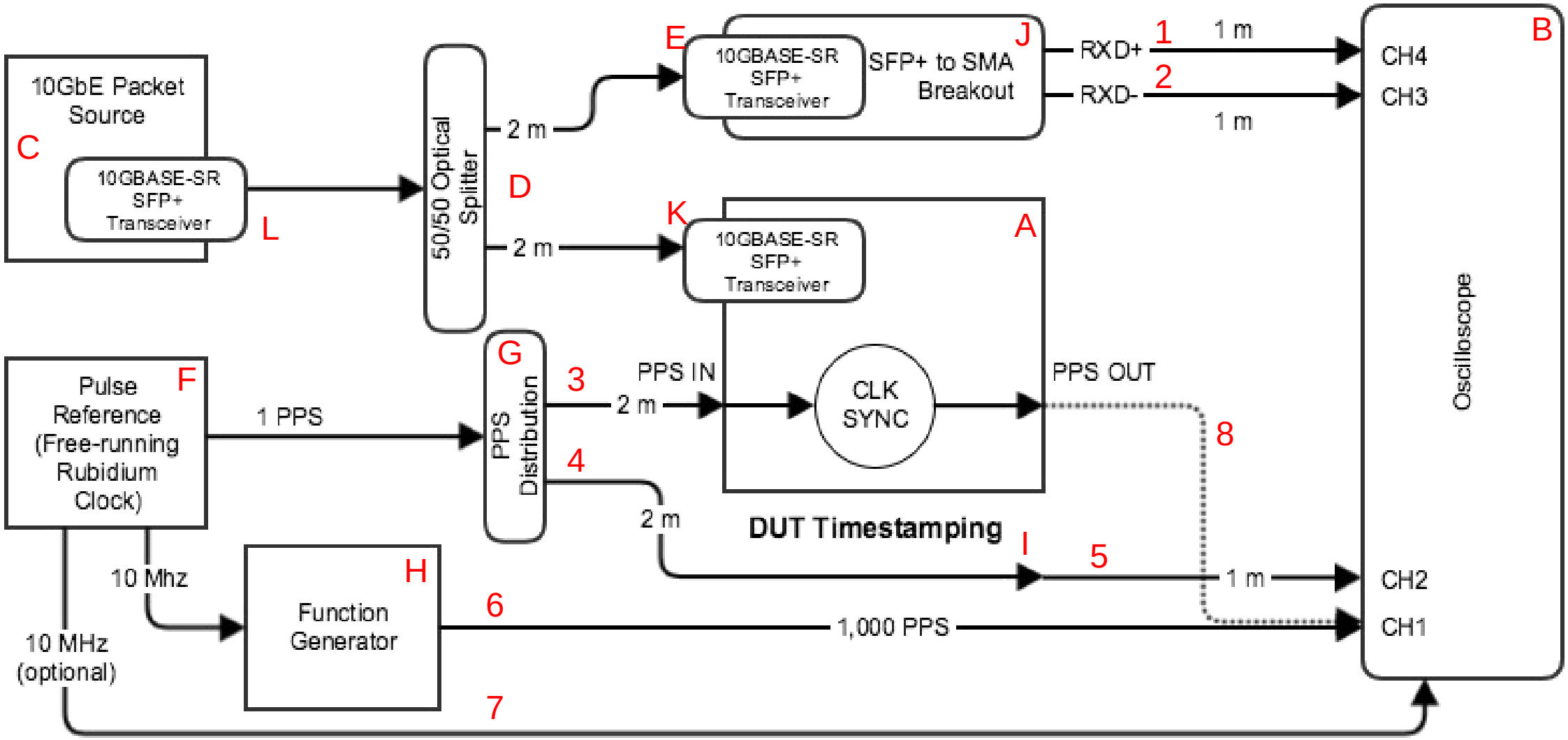
STAC-TS.NTE2: Absolute network-timestamp error vs high-freq scope



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Example: MetaWatch 0.5.2 on MetaApp 32 A5A

- Absolute accuracy of a specific port (the “Anchor Port”) with respect to a free-running Rb reference
- Preliminary results only – further tests in progress

Error statistics (microseconds)						
Samples	Mean	Median	Std Dev	Minimum	Mid Point	Maximum
6e+04	-0.000	0.000	0.001	-0.003	-0.001	0.002

Table 1 Prediction Intervals

Probability	Interval (microseconds)
100%	-0.001 ± 0.003
99.9999%	-0.001 ± 0.003
99.999%	-0.001 ± 0.003
99.99%	0.000 ± 0.002
99.9%	0.000 ± 0.002
99%	-0.001 ± 0.002
95%	-0.001 ± 0.002

Table 2 Skew Adjusted Prediction Intervals

Probability	Interval (microseconds)
100%	0.0 ± 0.003
99.9999%	0.0 ± 0.003
99.999%	0.0 ± 0.003
99.99%	0.0 ± 0.002
99.9%	0.0 ± 0.002
99%	0.0 ± 0.002
95%	0.0 ± 0.002

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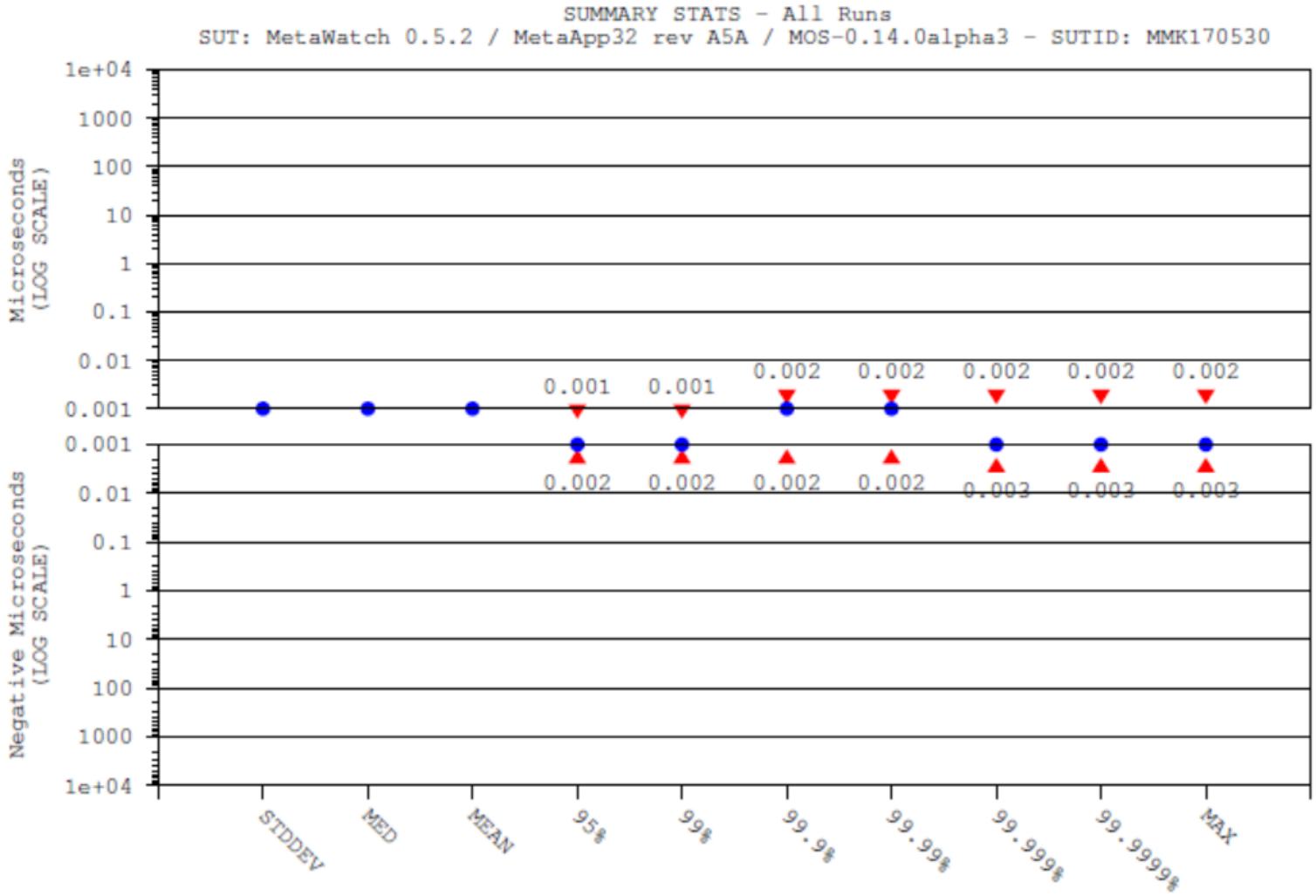
Example: MetaWatch 0.5.2 on MetaApp 32 A5A



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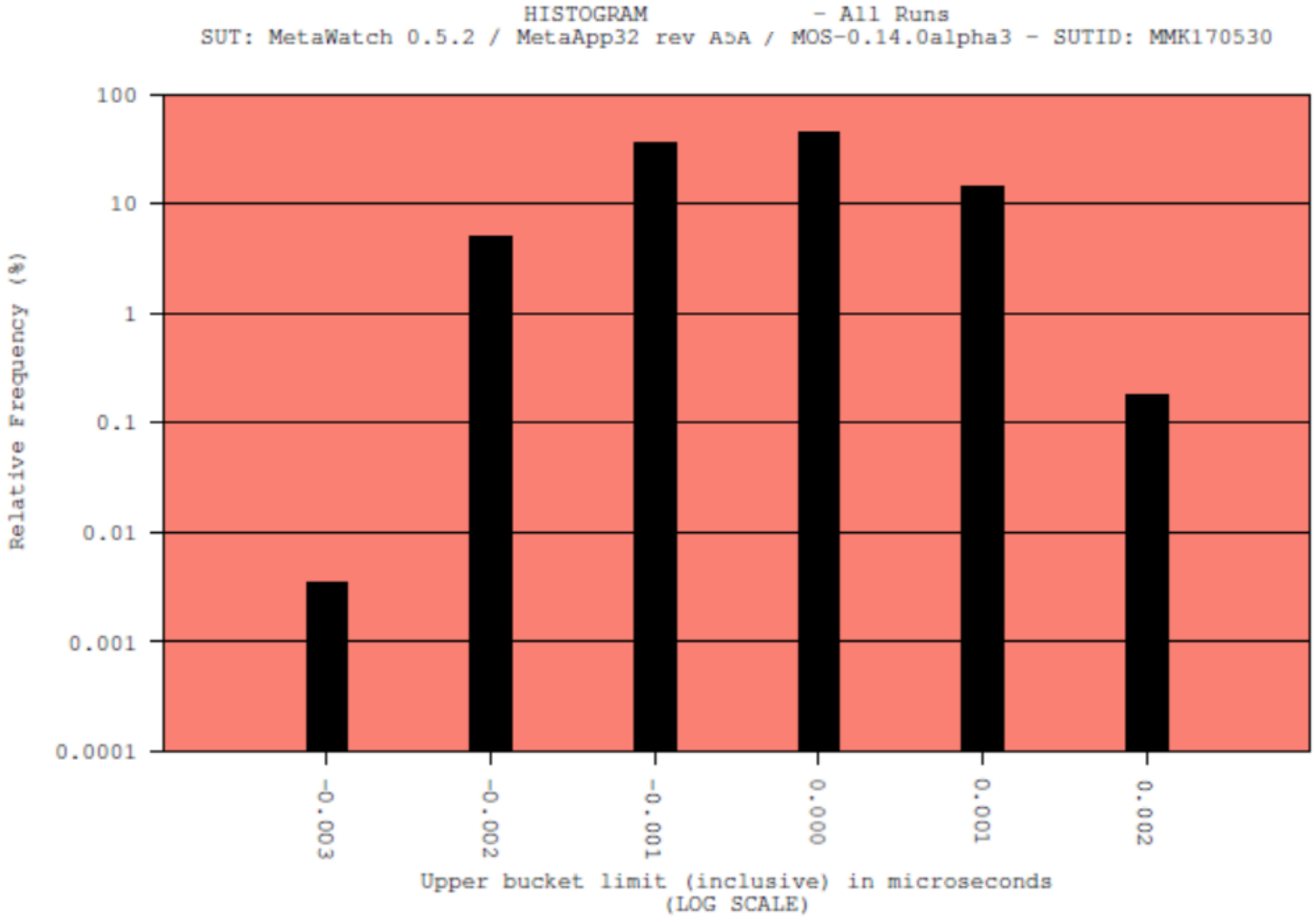

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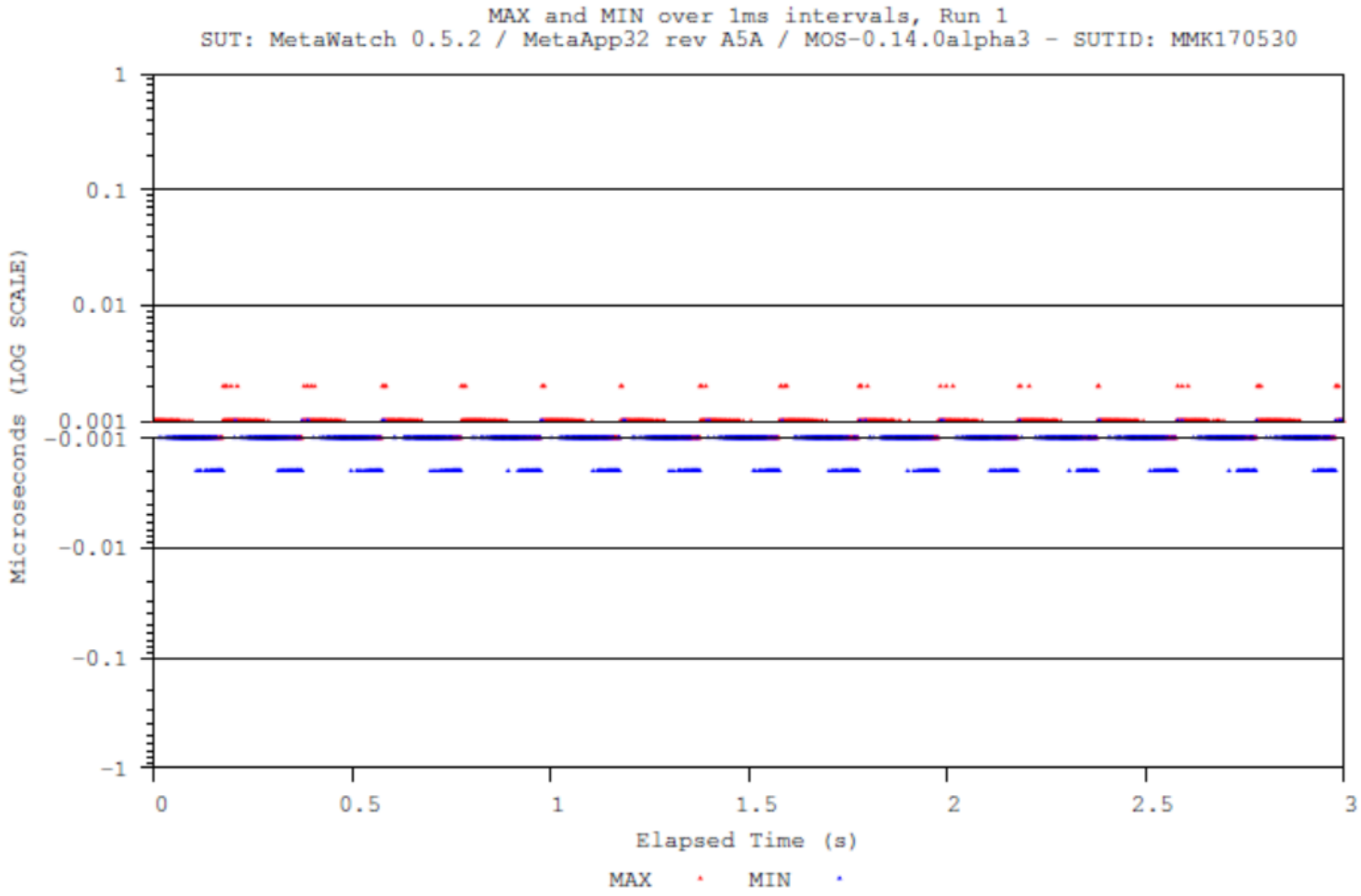

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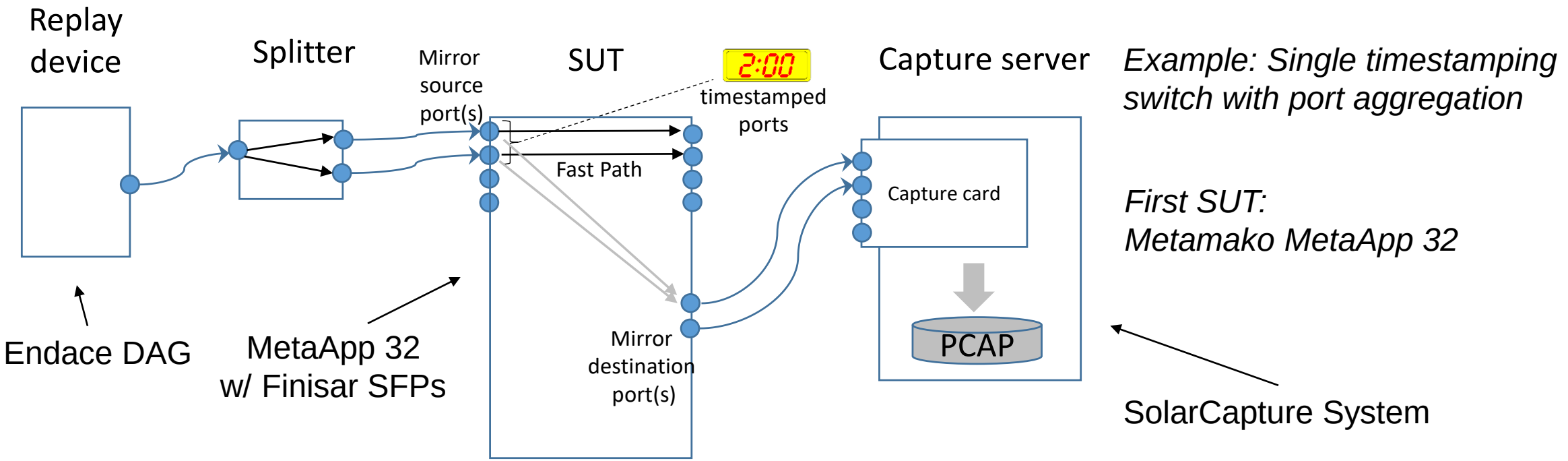
STAC-TS.PSE: Port-sync error



Example: Single timestamping switch with port aggregation

First SUT: Metamako MetaApp 32

- Cards, multiple cards, switches, multiple switches
- Simultaneous (or known skew) arrival of packets at two ports
- Measure each port against a single port (Anchor Port) and extrapolate
- Extrapolate all-to-all via transitivity property
- No measurement uncertainty

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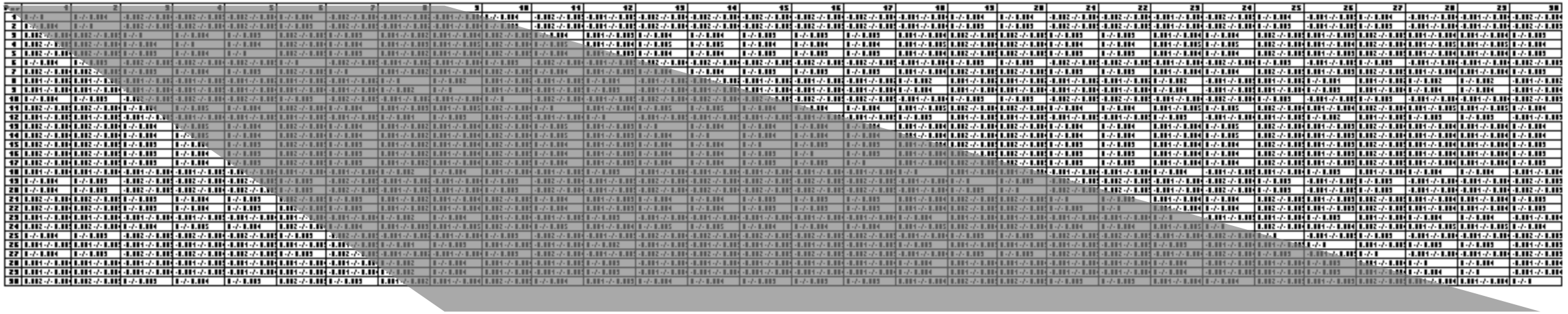
Port-sync error matrix (30 ports to each other)



- STAC-TS.PSE1 assesses the worst case
- But also allows you to be selective if you want

Port	1	2	3	4	5	6	7	8	
1	0 +/- 0	0 +/- 0.004	-0.002 +/- 0.004	-0.002 +/- 0.005	-0.002 +/- 0.004	0 +/- 0.004	-0.002 +/- 0.004	-0.001 +/- 0.002	-0.001 +/- 0.0
2	0 +/- 0.004	0 +/- 0	-0.002 +/- 0.003	-0.002 +/- 0.004	-0.002 +/- 0.003	0 +/- 0.003	-0.002 +/- 0.003	-0.001 +/- 0.002	-0.001 +/- 0.0
3	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0	0 +/- 0.004	0 +/- 0.003	0.002 +/- 0.003	0 +/- 0.003	0.001 +/- 0.002	0.001 +/- 0.0
4	0.002 +/- 0.005	0.002 +/- 0.004	0 +/- 0.004	0 +/- 0	0 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0.001 +/- 0.003	0.001 +/- 0.0
5	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0.003	0 +/- 0.004	0 +/- 0	0.002 +/- 0.003	0 +/- 0.003	0.001 +/- 0.002	0.001 +/- 0.0
6	0 +/- 0.004	0 +/- 0.003	-0.002 +/- 0.003	-0.002 +/- 0.004	-0.002 +/- 0.003	0 +/- 0	-0.002 +/- 0.003	-0.001 +/- 0.002	-0.001 +/- 0.0
7	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0.003	0 +/- 0.004	0 +/- 0.003	0.002 +/- 0.003	0 +/- 0	0.001 +/- 0.002	0.001 +/- 0.0
8	0.001 +/- 0.002	0.001 +/- 0.002	-0.001 +/- 0.002	-0.001 +/- 0.003	-0.001 +/- 0.002	0.001 +/- 0.002	-0.001 +/- 0.002	0 +/- 0	0 +/- 0.002
9	0.001 +/- 0.004	0.001 +/- 0.004	-0.001 +/- 0.004	-0.001 +/- 0.005	-0.001 +/- 0.004	0.001 +/- 0.004	-0.001 +/- 0.004	0 +/- 0.002	0 +/- 0
10	0 +/- 0.004	0 +/- 0.003	-0.002 +/- 0.003	-0.002 +/- 0.004	-0.002 +/- 0.003	0 +/- 0.003	-0.002 +/- 0.003	-0.001 +/- 0.002	-0.001 +/- 0.0
11	0.002 +/- 0.005	0.002 +/- 0.004	0 +/- 0.004	0 +/- 0.005	0 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0.001 +/- 0.003	0.001 +/- 0.0
12	0.001 +/- 0.003	0.001 +/- 0.003	-0.001 +/- 0.003	-0.001 +/- 0.004	-0.001 +/- 0.003	0.001 +/- 0.003	-0.001 +/- 0.003	0 +/- 0.001	0 +/- 0.003
13	0.002 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0 +/- 0.005	0 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0.001 +/- 0.002	0.001 +/- 0.0
14	0.002 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0 +/- 0.005	0 +/- 0.004	0.002 +/- 0.004	0 +/- 0.004	0.001 +/- 0.002	0.001 +/- 0.0
15	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0.003	0 +/- 0.004	0 +/- 0.003	0.002 +/- 0.003	0 +/- 0.003	0.001 +/- 0.002	0.001 +/- 0.0
16	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0.003	0 +/- 0.004	0 +/- 0.003	0.002 +/- 0.003	0 +/- 0.003	0.001 +/- 0.002	0.001 +/- 0.0
17	0.002 +/- 0.004	0.002 +/- 0.003	0 +/- 0.003	0 +/- 0.004	0 +/- 0.003	0.002 +/- 0.003	0 +/- 0.003	0.001 +/- 0.002	0.001 +/- 0.0
18	0.001 +/- 0.004	0.001 +/- 0.004	-0.001 +/- 0.004	-0.001 +/- 0.005	-0.001 +/- 0.004	0.001 +/- 0.004	-0.001 +/- 0.004	0 +/- 0.002	0 +/- 0.004

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Putting it together

Port-timestamp accuracy (microseconds)

	Skew	Uncertainty	Notes
STAC-TS.NTE2	-0.001	+/- 0.003	Worst case accuracy of any port. Measurement uncertainty of +/- 50 picoseconds (ignored).
STAC-TS.PSE1	0	+/- 0.007	Worst case port-sync error within a single device. There is no measurement uncertainty.

- Absolute & relative accuracy across all ports on the device
- NOTE: These results are still preliminary, subject to final analysis.

So you have all these tests results…

Now what?

What must a regulated firm demonstrate?

- Which test results relate to which production components?
- Why are those the relevant tests?
- Which components affect which timestamps?
- What do the component-level tests mean for end-to-end timestamp accuracy?

For firms with simple architectures, documenting this may be straightforward.

For larger firms, it is not.

STAC Traceability Report (in development)

- Reports the accuracy and granularity of timestamps based on a traceability chain
- For any given instance of a timestamping component in a firm's architecture
- Non-trivial problem to construct valid prediction intervals (probabilities like percentiles)
- Draw from internal STAC-TS results and results on STAC site
- Usage:
  - Point-in-time analysis
  - Vulnerability analysis
  - Compliance survey – event driven or periodic (at least annual)

Assumptions (based on input so far)

- No need for STAC to supply a traceability database
- Firms will use existing config mgmt databases and timeseries databases to construct the state of the system at any given point in time and feed the relationship info to the STAC tools creating the STAC Traceability Report

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