Modelling Packet Delay in Ethernet and IP Networks

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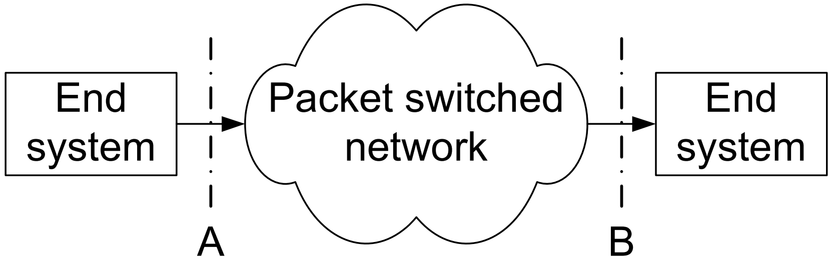
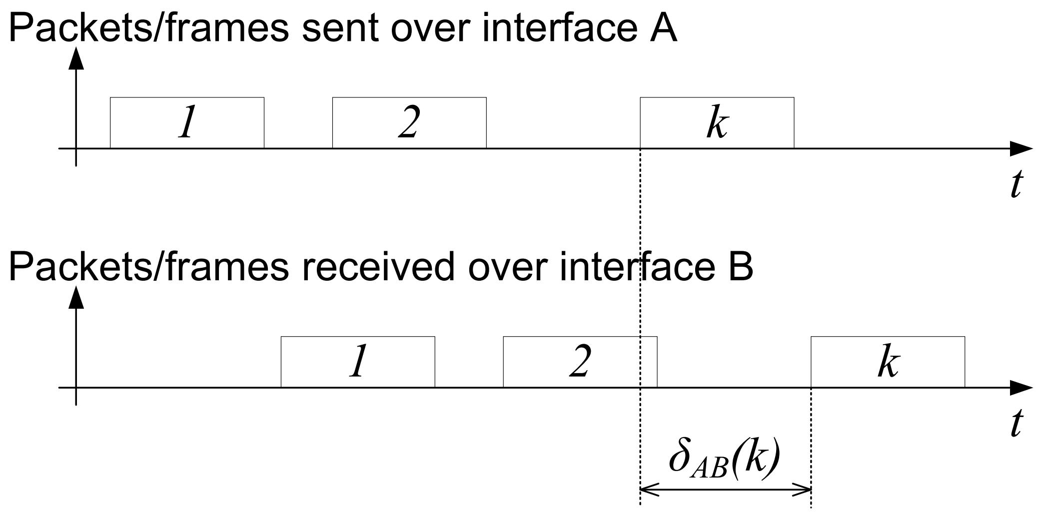
Introduction

- Is it possible to transfer time and frequency over packet switched networks with accuracies commonly required by telecom applications and equipment?
- If yes, under what conditions?
- Take as an example the ‘Precise Time Protocol’ (IEEE 1588)
- Use simulations to study packet propagation properties and predict performance
- Study the influence of traffic load
- Study the influence of protocol support in switching/routing nodes (e.g. Transparent Clocks)

Definition: Packet Delay $\delta_{AB}(k)$

Consider two interfaces A and B traversed by a given packet flow.



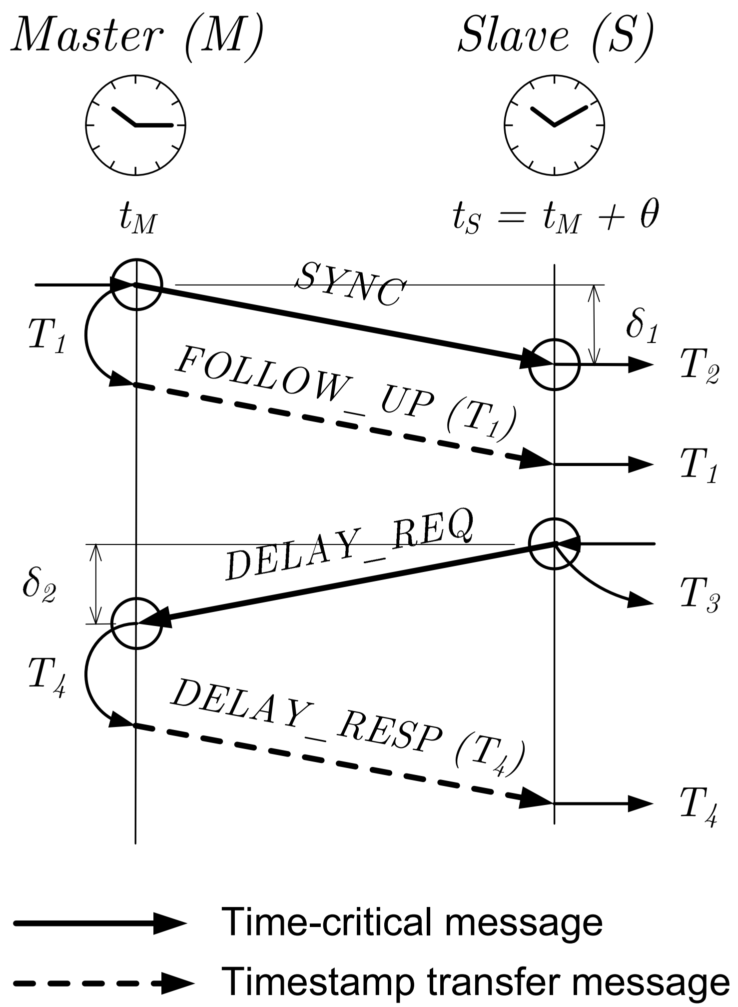


Definition: Packet Delay Asymmetry A(k)

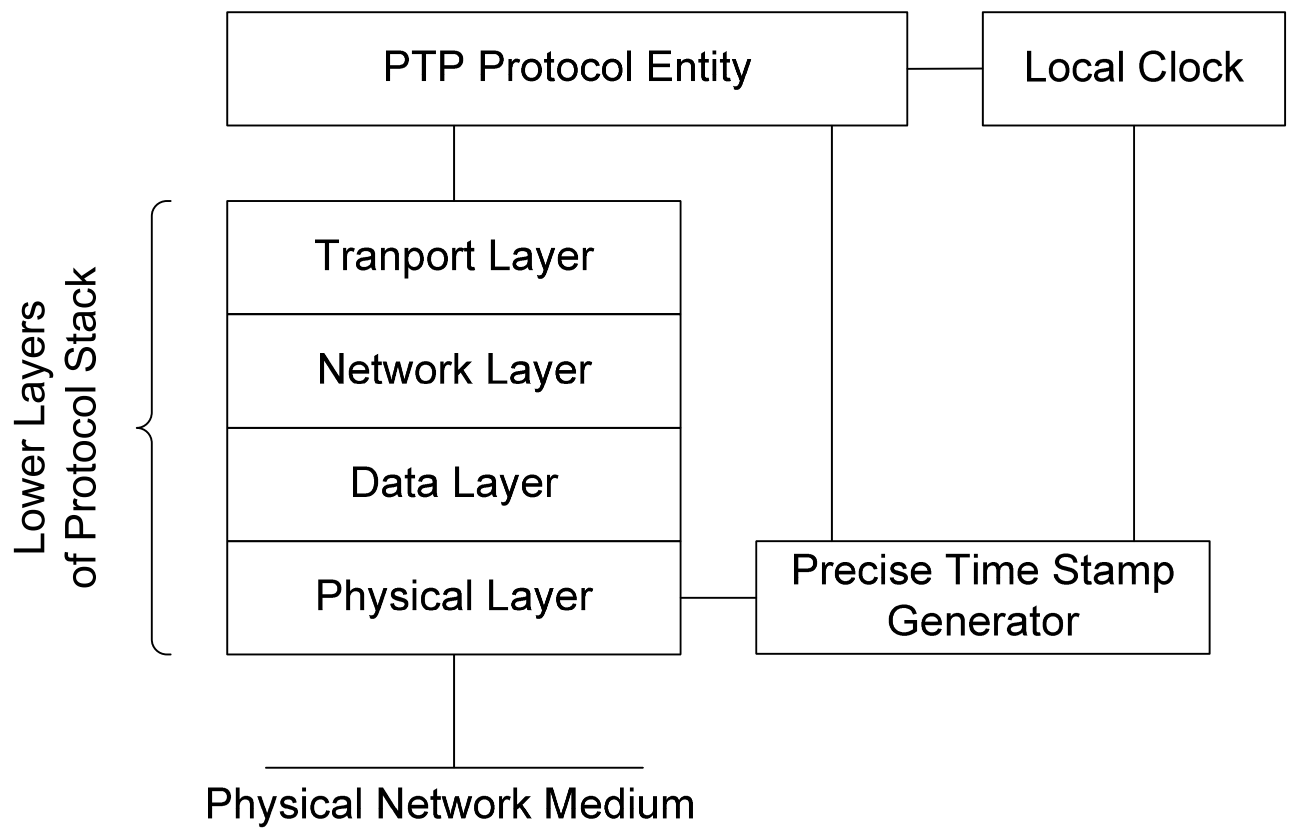
Consider two interfaces A and B traversed by bi-directional paired packet flows, where the k-th packet pair experiences the delay $\delta_{AB}(k)$ and $\delta_{BA}(k)$:

$$A(k) = \delta_{AB}(k) - \delta_{BA}(k)$$

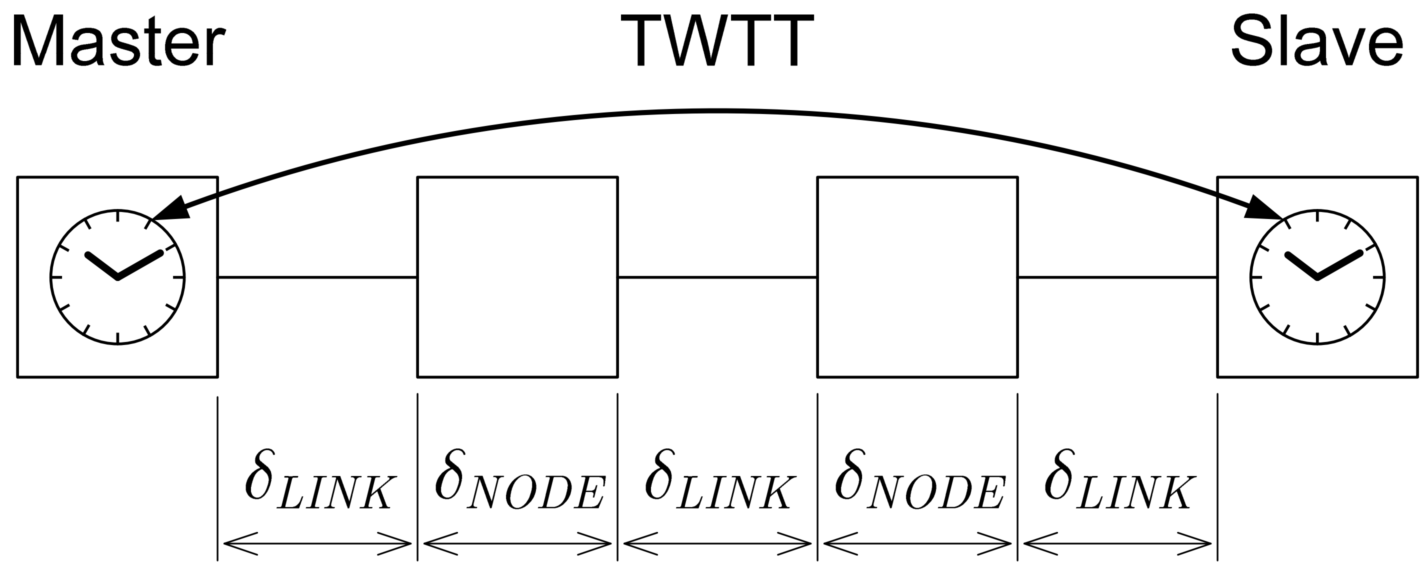
PTP IEEE 1588: TWTT



PTP IEEE 1588: Time-stamping



PTP IEEE 1588: Transparent Clocks



End-to-end Transparent Clock

$$\overline{\theta} = \frac{(T_2 - T_1) - (T_4 - T_3)}{2} = \theta + \frac{\delta_{M\to S} - \delta_{S\to M}}{2} = \theta - \frac{A}{2}$$

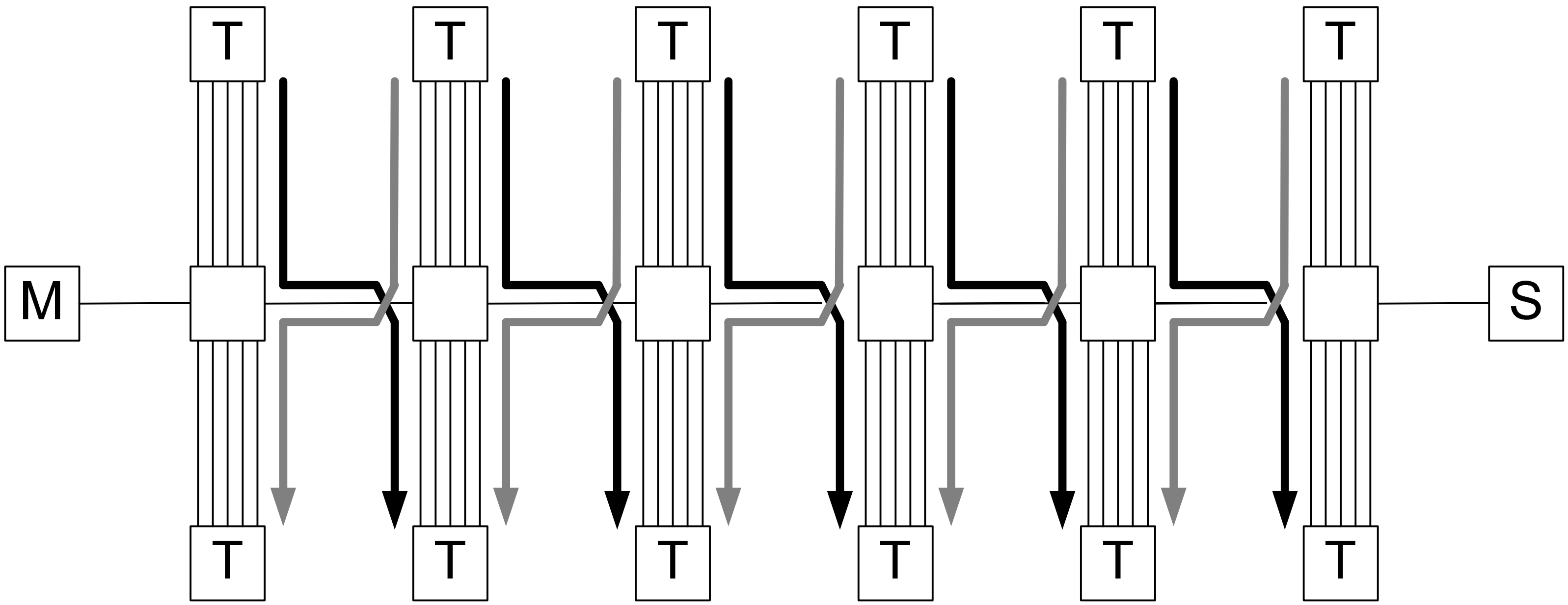
PTP with End-to-end Transparent Clocks:

$$\overline{\delta}_{M\to S} = \sum \overline{\delta}_{NODE,M\to S}$$

$$\overline{A} = \sum \overline{\delta}_{NODE,M\to S} - \sum \overline{\delta}_{NODE,S\to M}$$

$$\overline{\theta} = \frac{(T_4 - T_3) - (T_2 - T_1)}{2} - \frac{\overline{A}}{2}$$

Simulation: network structure



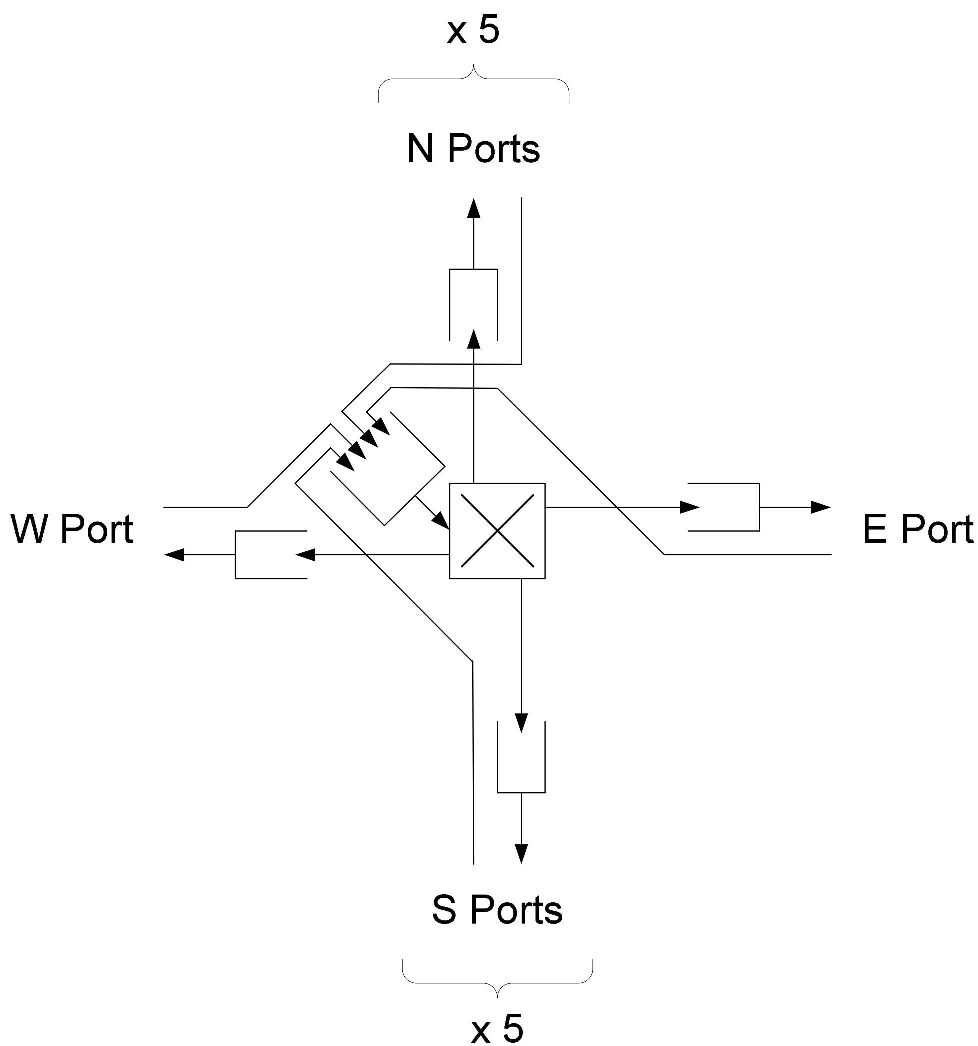
M	= PTP Master		= Switch or Router
S	= PTP Slave	T	= Traffic Source & Sink

Traffic sources

- Each source bloc shown in the diagram represents 5 independent smaller sources with the same stochastic properties
- Packet interarrival times process: « walker held by an elastic leash »
- Packet sizes:

Packet size [octet]	1518	506	126
Probability	0.6	0.3	0.1

Simulation: node structure



Simulation scenarios

Run no.	Traffic load λ	N_N	X = non-PTP-capable node O = PTP-capable node
1	0.16	2	- O - X - X - O - O - O -
2		4	- O - X - X - X - X - O -
3		6	- X - X - X - X - X - X -
4	0.43	2	- O - X - X - O - O - O -
5		4	- O - X - X - X - X - O -
6		6	- X - X - X - X - X - X -

Traffic load λ = (avg. data rate / link capacity) on a longitudinal link

N_N = number on non-PTP-capable nodes

Simulation parameters and output

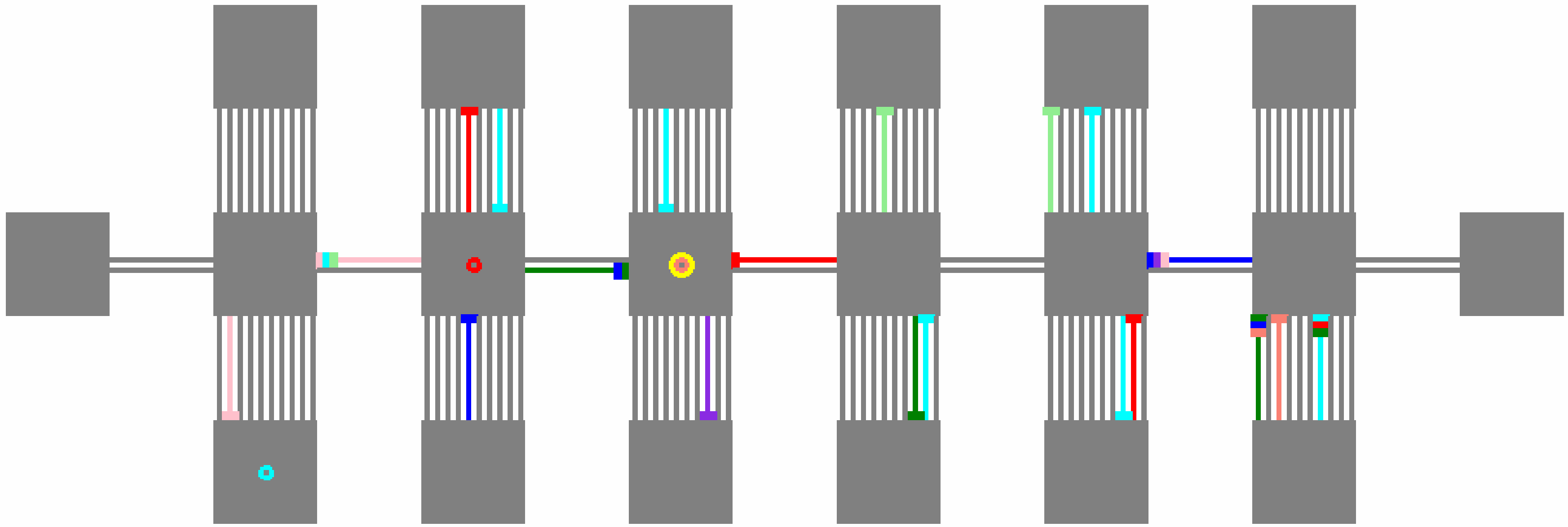
Simulation parameters:

- Link capacity C = 100 Mbit/s
- Input queues = 150,000 octets
- Output queues = 150,000 octets
- TWTT interogation rate = 100 s^{-1} (SYNC & DELAY_REQ)
- Sampling period T_S = 10 µs
- Simulation length = 30,000 s
- (=> 400 mio. samples on 68 sources and nodes!)

Main simulation output:

- Residual Packet Delay $\delta_{R,M\rightarrow S} = \delta_{M\rightarrow S} - \overline{\delta}_{M\rightarrow S}$
- Residual Packet Delay Asymmetry $A_R = A - A$

Simulator State Display



MinTDEV and 'Min'TDEV

MinTDEV of residual delay δ_R:

$$\text{MinTDEV}(\tau) = \sqrt{\tfrac{1}{6}\left\langle\left[\delta_{R,\min}(i+2n) - 2\delta_{R,\min}(i+n) + \delta_{R,\min}(i)\right]^2\right\rangle}$$

where

$\tau = n\tau_0$, $\tau_0 =$ sampling period

$\delta_{R,\min}(i) = \min\left[\delta_R(j)\right]$ for $\forall j : i <= j <= i+n$

'Min'TDEV of residual asymmetry A_R:

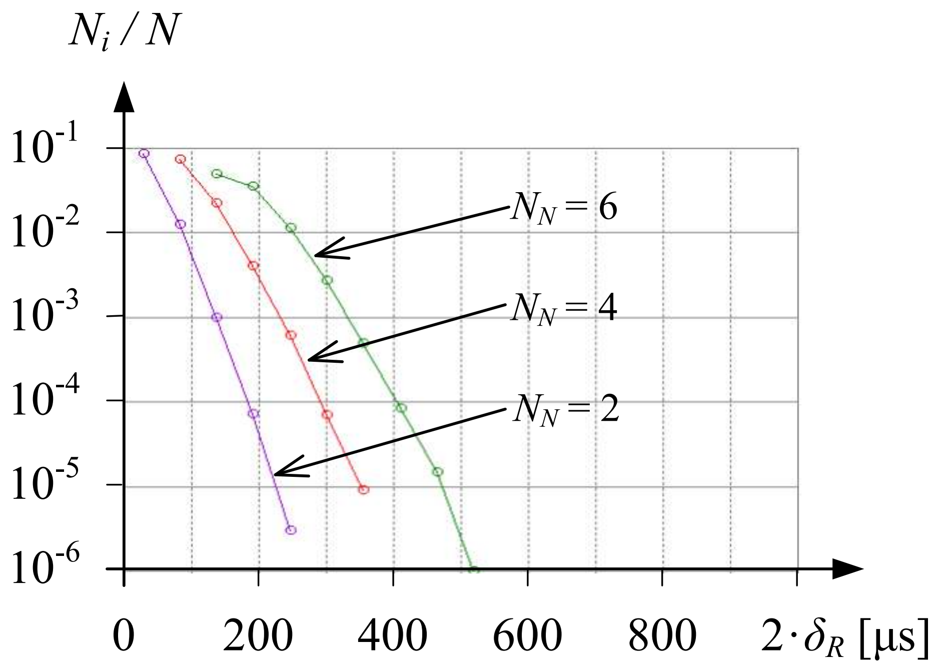
$$\text{'Min'TDEV}(\tau) = \sqrt{\tfrac{1}{6}\left\langle\left[A_{R,\min}(i+2n) - 2A_{R,\min}(i+n) + A_{R,\min}(i)\right]^2\right\rangle}$$

where

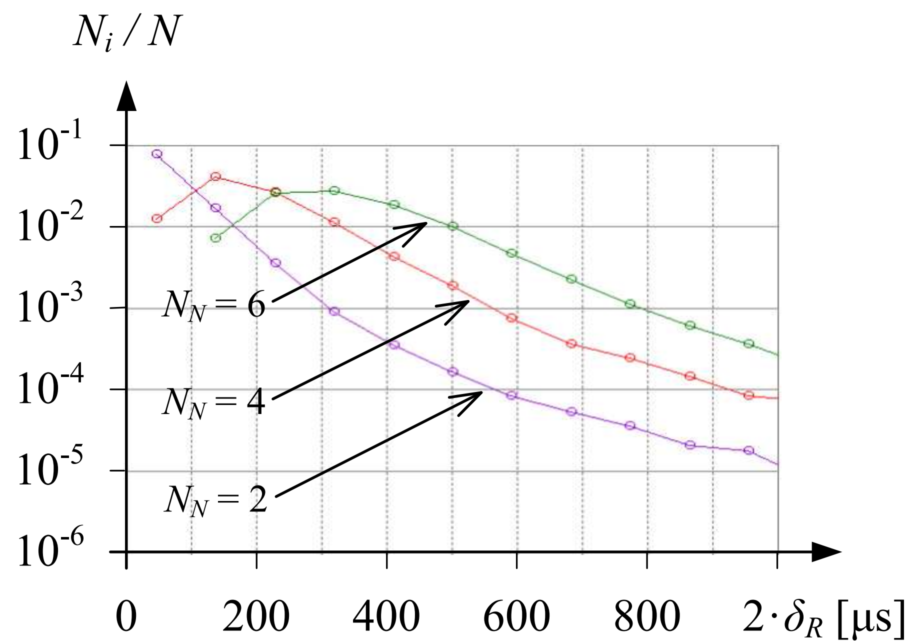
$\tau = n\tau_0$, $\tau_0 =$ sampling period

$A_{R,\min}(i) = \min\left[\delta_{R,M\to S}(j)\right] - \min\left[\delta_{R,S\to M}(j)\right]$ for $\forall j : i <= j <= i+n$

Histogram of 2 x Residual Delay

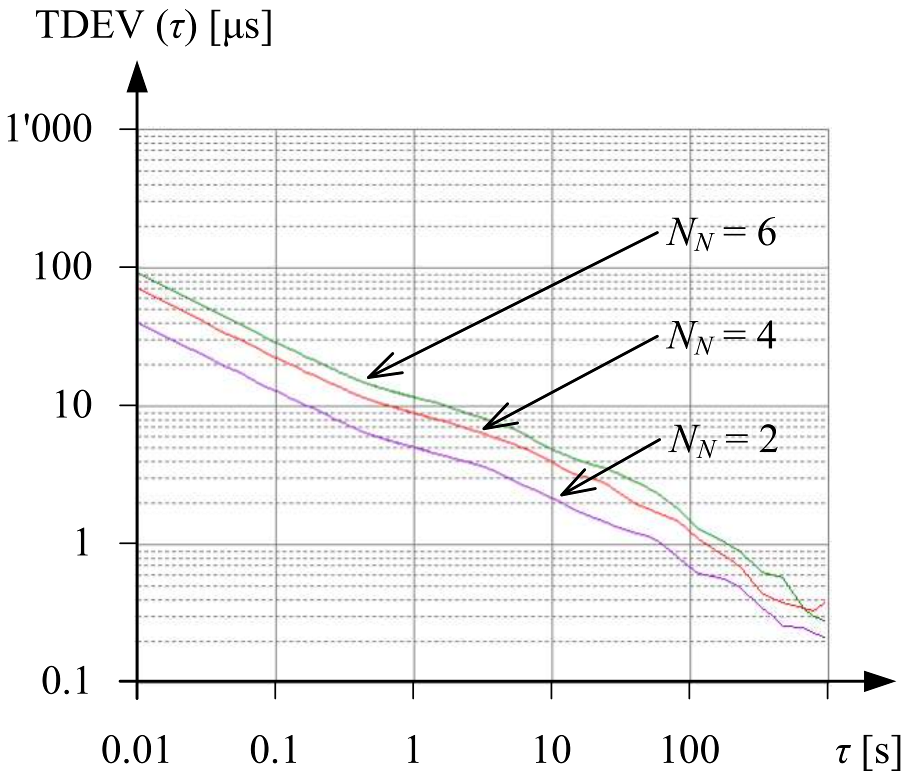


$\lambda = 0.16$



$\lambda = 0.43$

TDEV of 2 x Residual Delay



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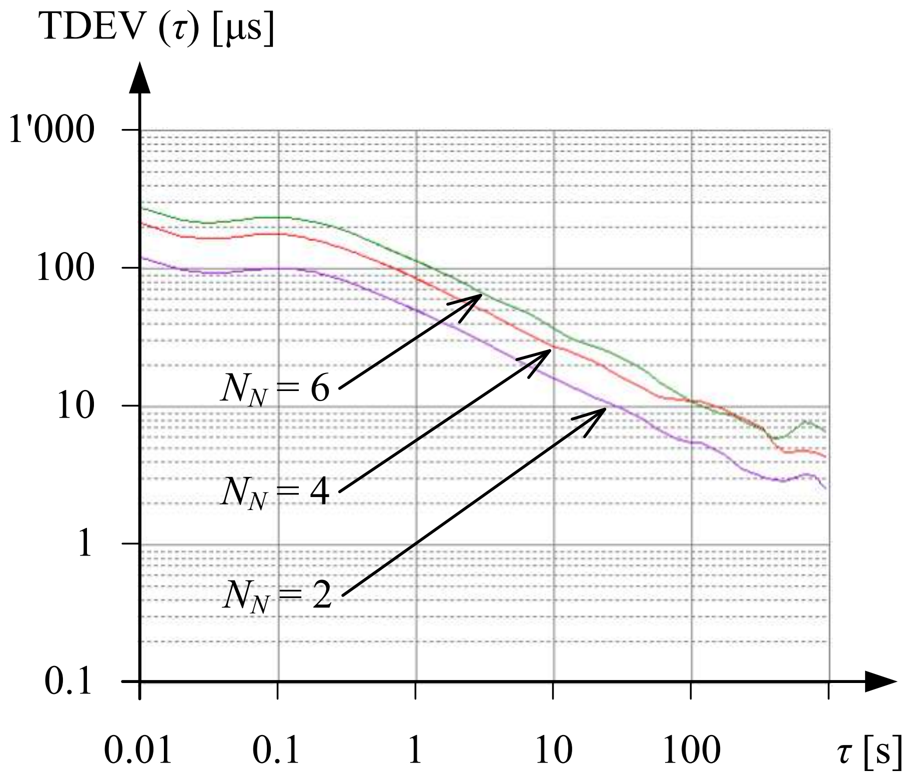
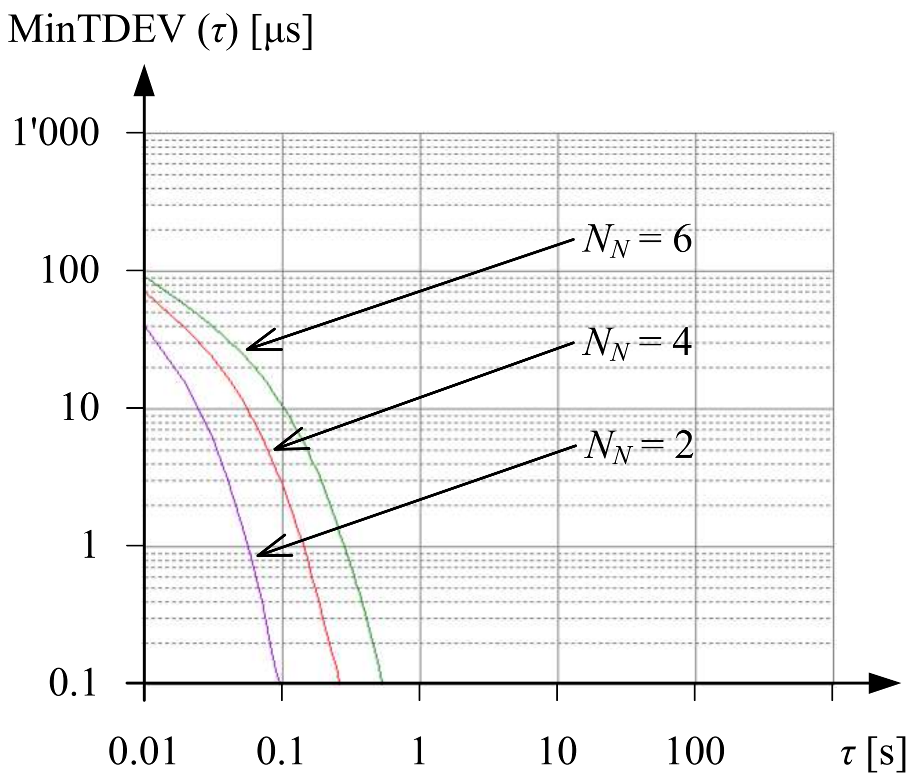


$\lambda = 0.43$

MinTDEV of Residual Delay



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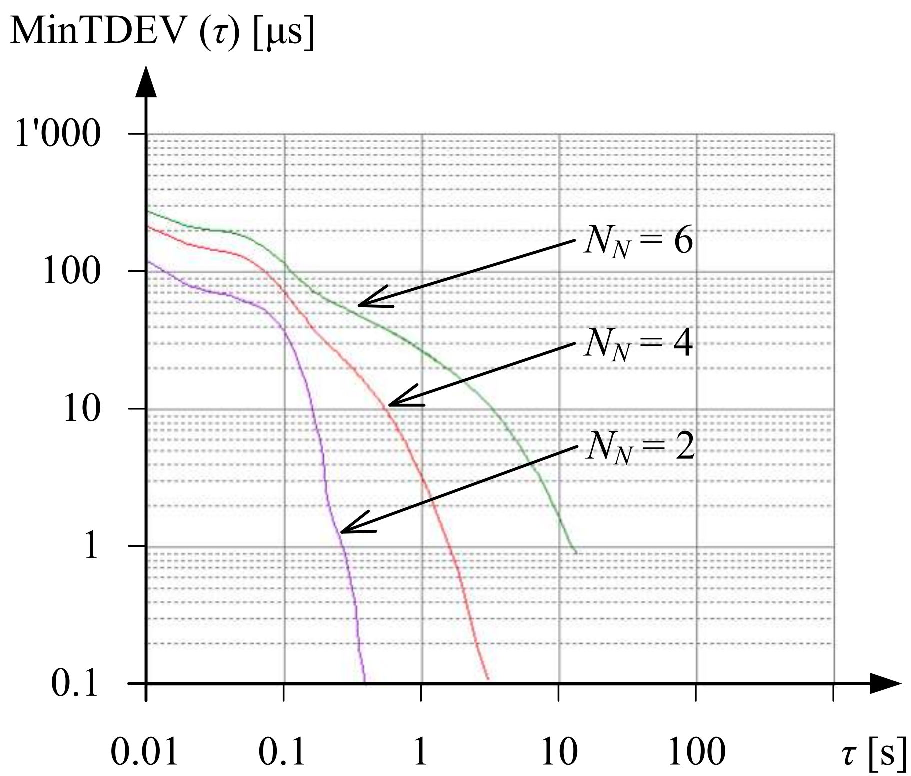

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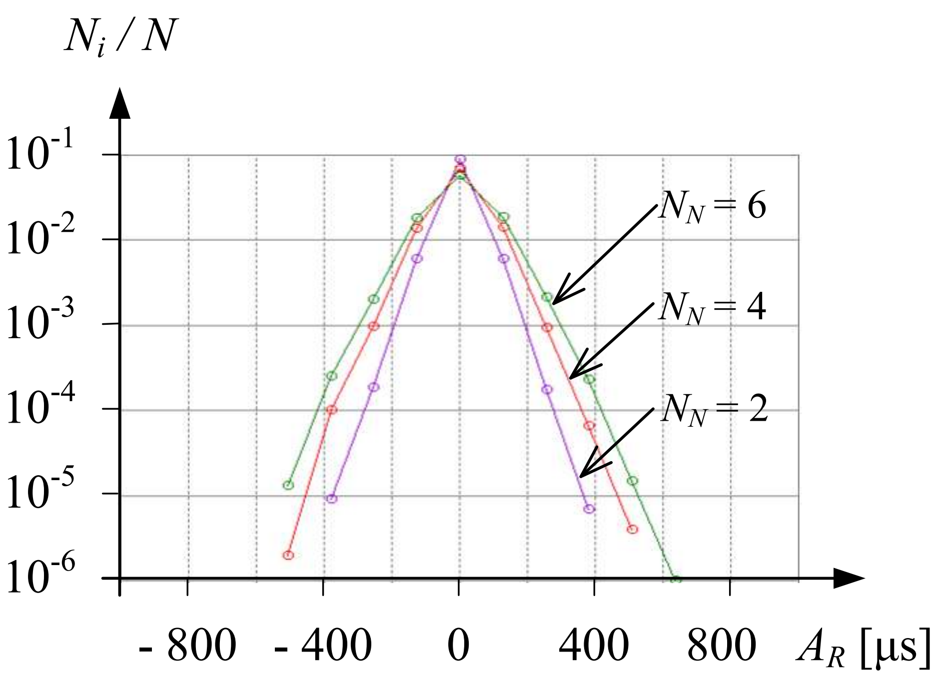
Histogram of Residual Asymmetry



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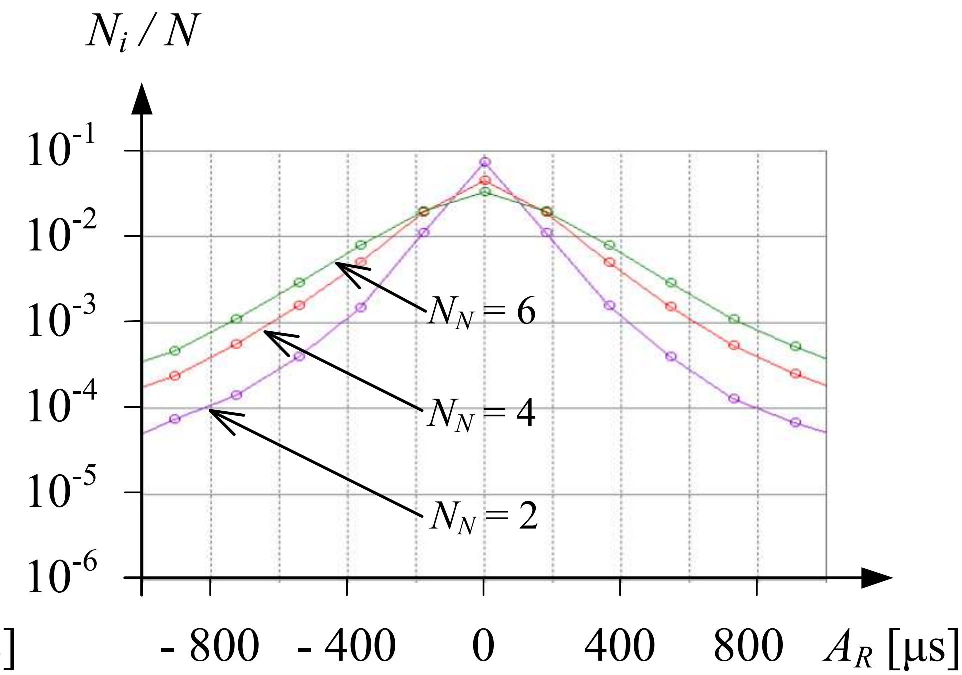

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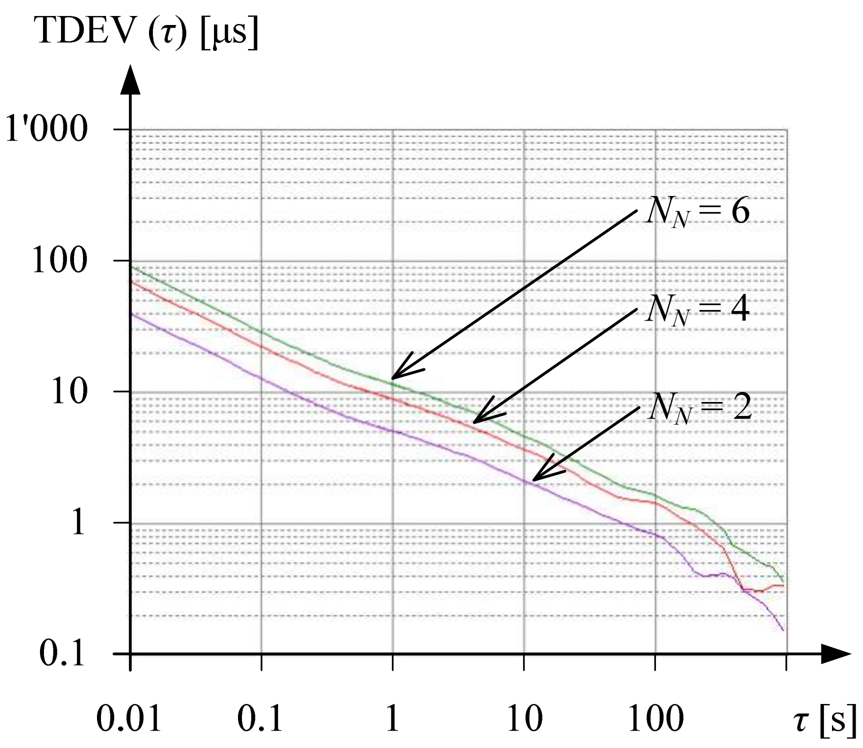
TDEV of Residual Asymmetry



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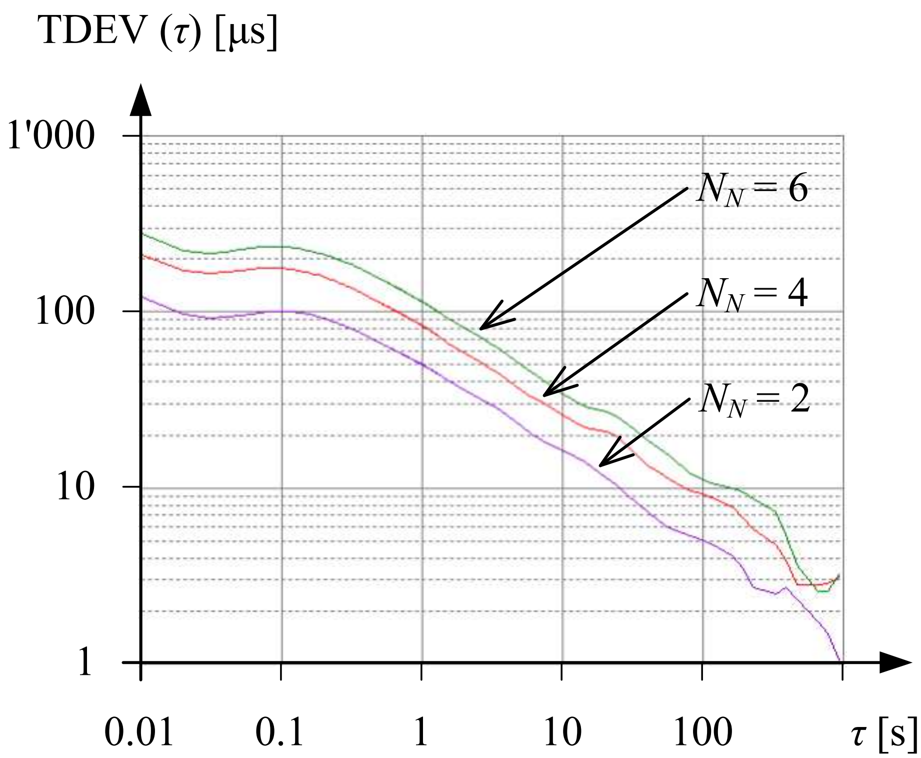
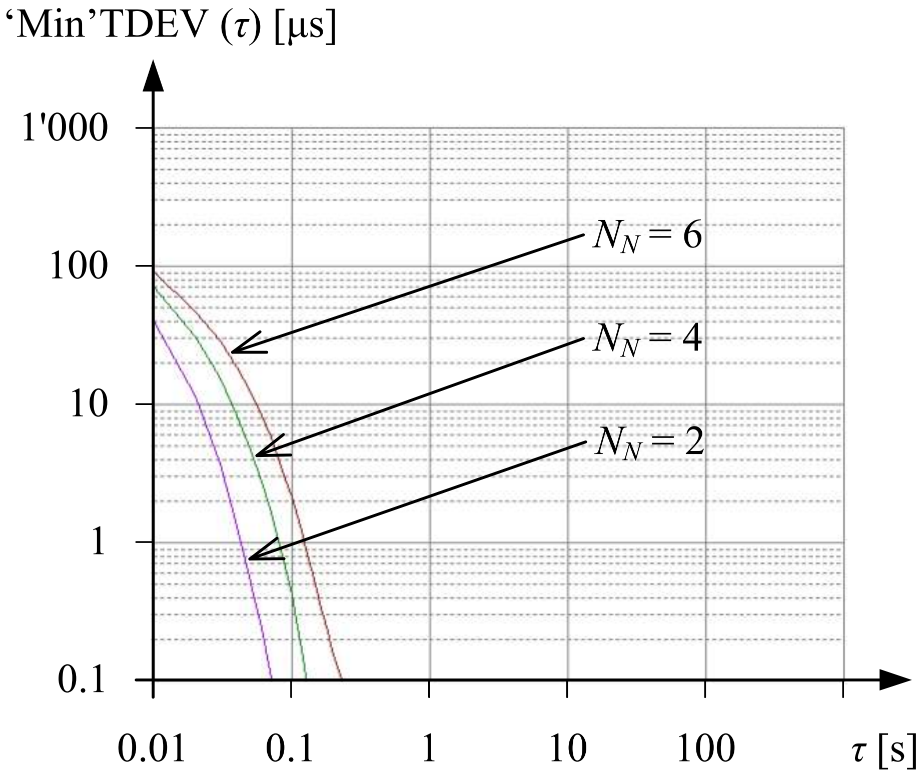
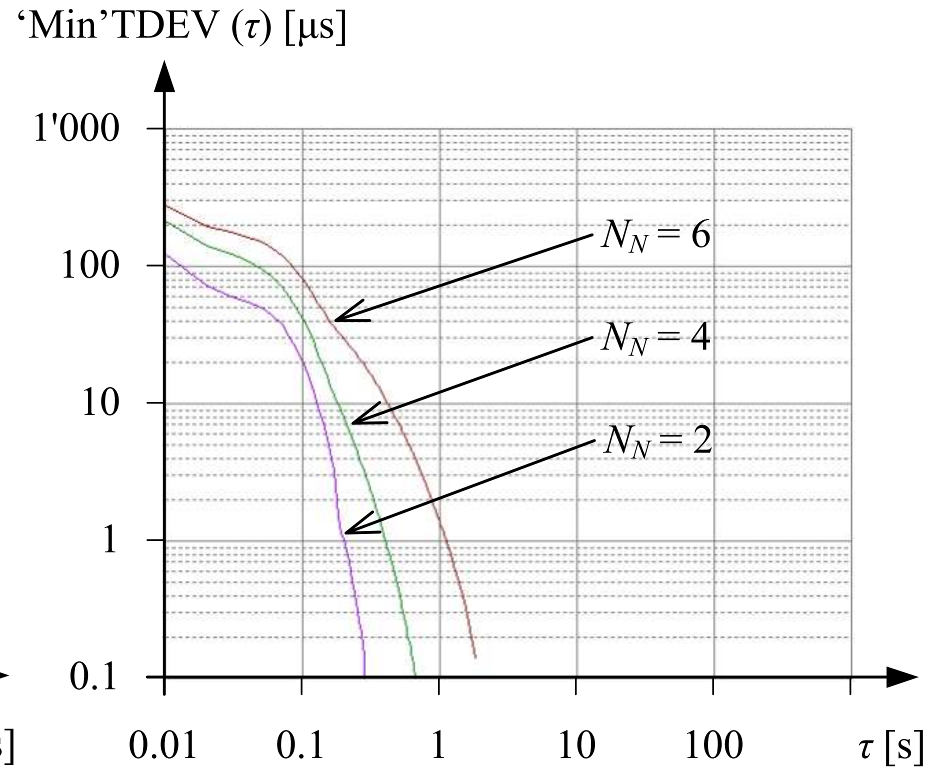


$\lambda = 0.43$

‘Min’TDEV(1) of Residual Asymmetry



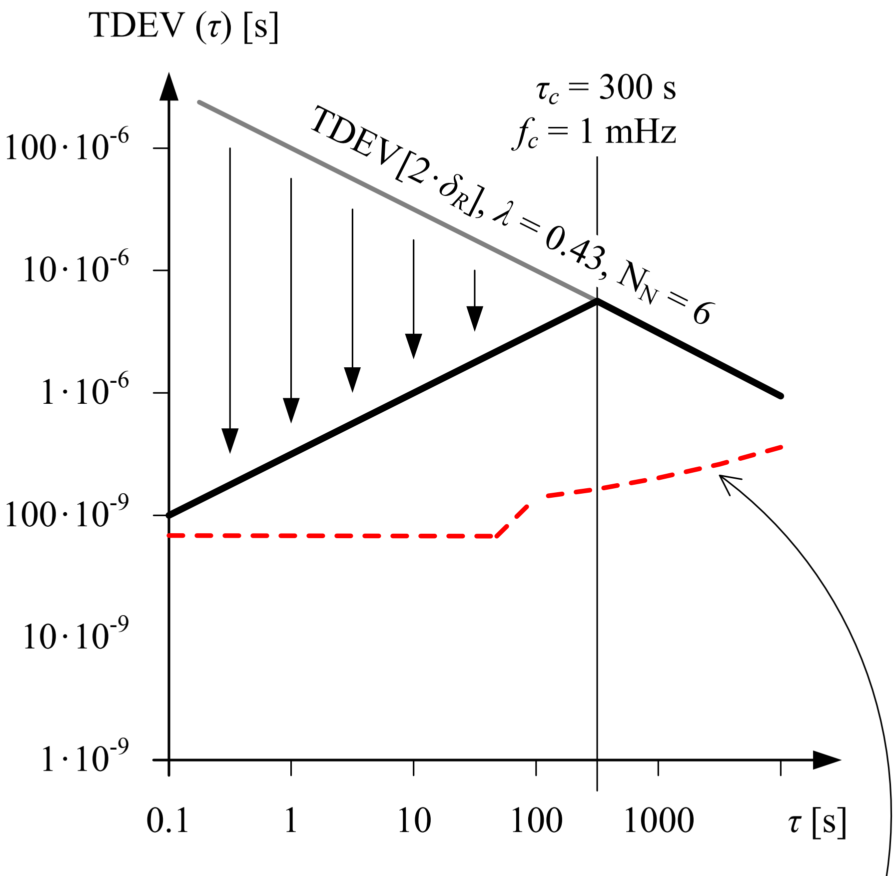
$\lambda = 0.16$



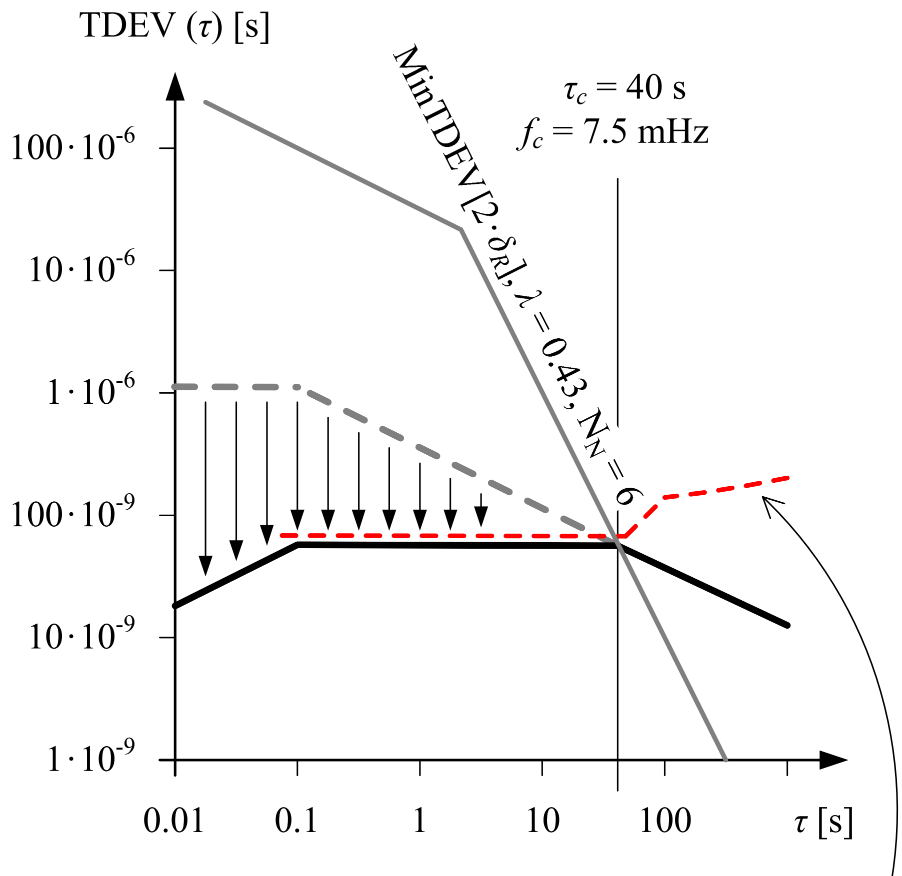
$\lambda = 0.43$

1: In the $\mathrm{MinTDEV}$ definition, replace $x_{\min}$ by $\min\left[\delta_{M\to S}\right] - \min\left[\delta_{S\to M}\right]$

Filtering Residual Delay

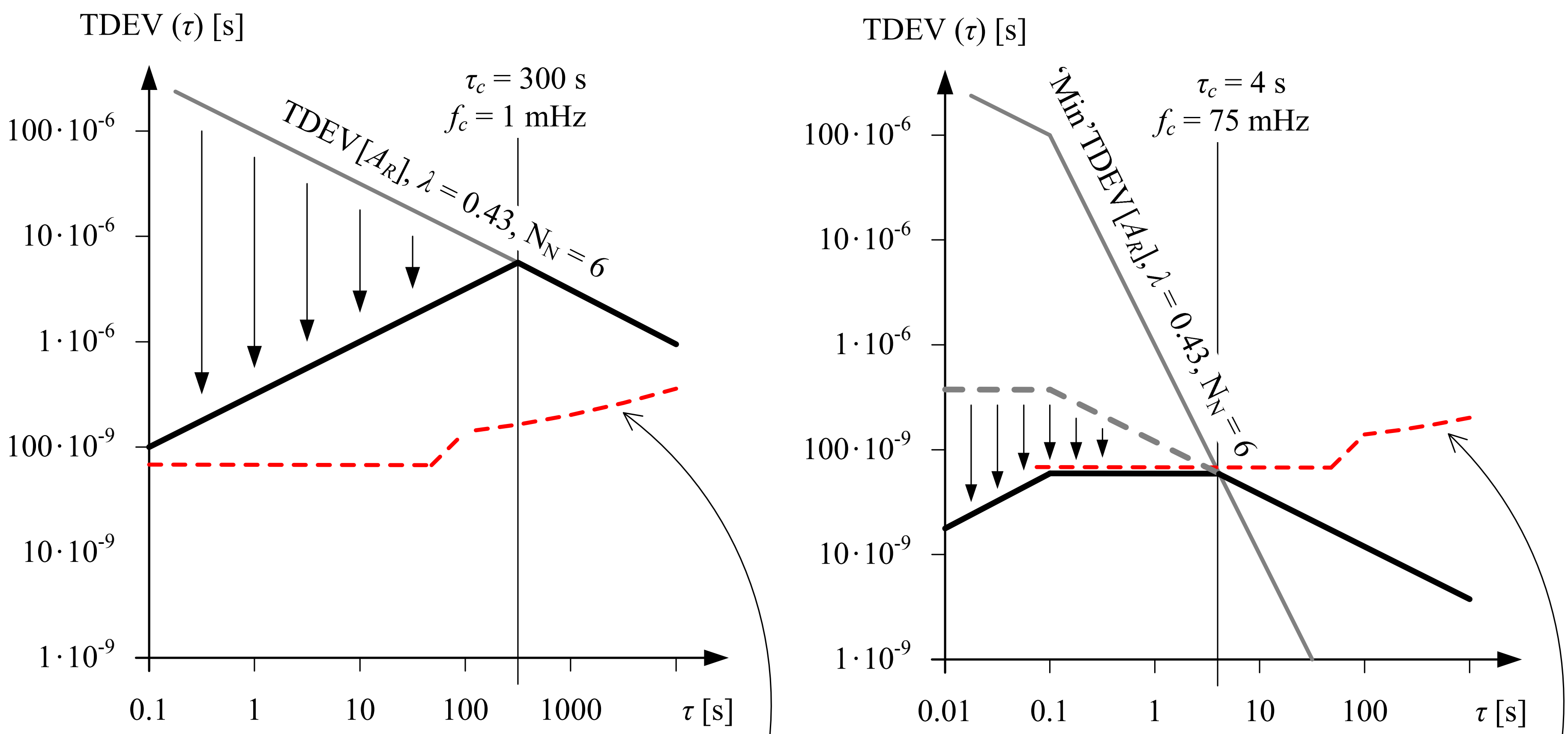


2 x Network Limit for PDH distribution output, ITU-T Rec. G.823



2 x Network Limit for PDH distribution output, ITU-T Rec. G.823

Filtering Residual Asymmetry



2 x Network Limit for PDH distribution output, ITU-T Rec. G.823

2 x Network Limit for PDH distribution output, ITU-T Rec. G.823

Conclusions

- With PTP IEEE 1588 telecom performance level is achievable over moderate size networks
- If traffic load is controlled, performance objectives are attained even in PTP networks without PTP-capable nodes
- High traffic loads deteriorate performance in PTP networks without PTP-capable nodes
- PTP suitable for the distribution of time and frequency in network types such as Metro Area Networks, base-station backhaul networks, access aggregation networks, etc.

Thank you