Timing Impairments and Clock Quality Metrics

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WSTS – 2013, San Jose, April 16-18, 2013

Presentation Outline

- Clock Metrics in Telecommunications
- Time Error for Physical Layer Clock Signals
  - MTIE/MRTIE and TDEV metrics
- Physical Layer Timing Impairments
  - Clock Recovery Jitter (data-dependent)
  - Slips in synchronous multiplexing schemes
  - Bit-stuffing-induced jitter/wander
- Time Error for Packet-based Timing Signals
  - MATIE/MAFE, xTDEV, Floor-population-metrics, etc.
- Packet Layer Timing Impairments
  - Packet Delay Variation
  - Asymmetry
  - Beating Effects

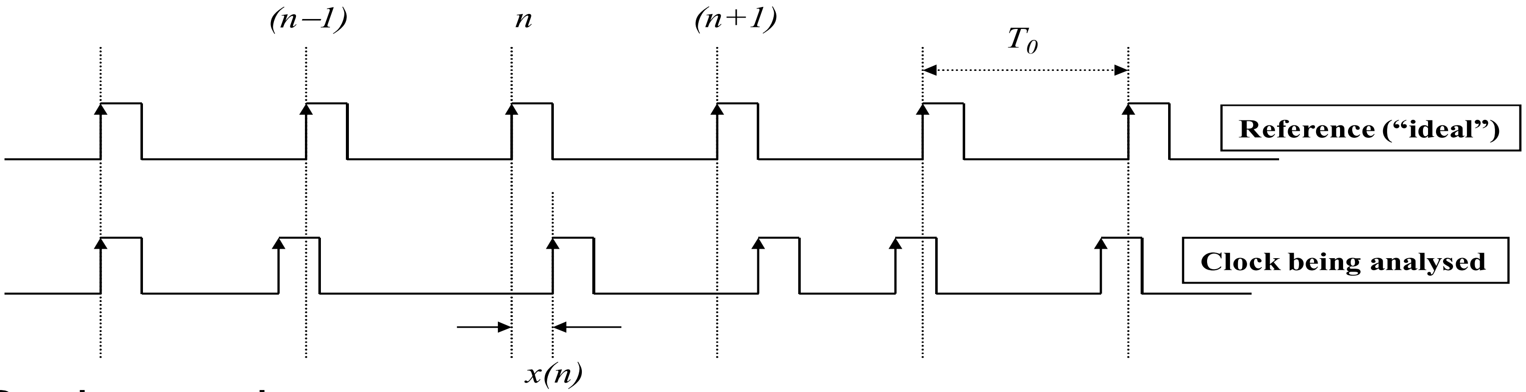
Note: Special thanks to Stefano Ruffini of Ericsson

Clock Metrics in Telecommunications

- Time-Division Multiplexing requires synchronization
  - e.g. all DS1/E1 bearers must be synchronized to line-clock
  - Poor synchronization results in slips (transmission errors)
- Real-time services as well as mobile technologies require synchronization
  - Physical layer (SDH/SyncE) or via packets (Circuit Emulation/IEEE1588)
  - Regardless of whether network is circuit-switched (TDM) or packet-switched (IP/ATM/etc.)
- Network equipment clocks must meet specifications
  - Clock output signal must meet prescribed MTIE and/or TDEV masks (clock “output” may be internal to NE)
  - Tolerance requirements are implied in TDM networks. Active area of study in packet networks
- Output verification:
  - Obtain time interval error (TIE) sequence by comparing clock output signal against (known) reference
  - Compute TDEV, MTIE (MRTIE) from TIE data and compare against prescribed mask

TE, MTIE and TDEV

Time Error



Basic premises:

- Both the reference and clock being analysed have the same *nominal* period
- This nominal period may require that one (or both) are divided down
- The *nominal* value for $x(n)$ is zero (or a constant)

The discrete-time signal $\{x(n)\}$ is the "Time Error" (TE), or phase error, and is the basis for quantifying the performance of the clock (relative to reference)

$\{x(n)\}$ can be viewed as the samples of a signal (analog), $x(t)$, taken every T_0 seconds (sampling rate = $f_0 = 1/T_0$)

Note: Time Interval Error (TIE): $TIE(n;k) = x(n+k) - x(n)$ represents a change in time error, characteristic of a "frequency" error.

TIE, MTIE and TDEV

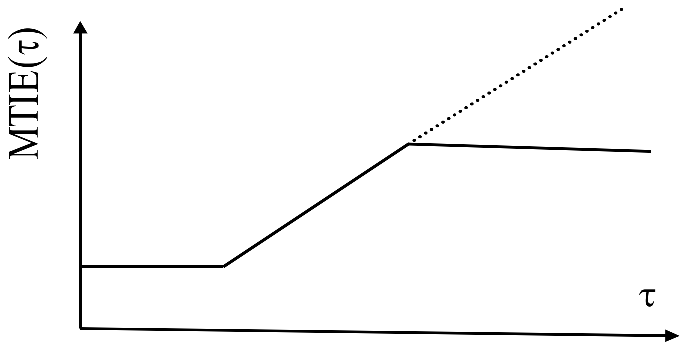
$$MTIE\ (\tau = n \cdot \tau_0) = \max_{i=0}^{N-n-1} \left\{ \max_{k=1}^{k=n} \left[\left| x(i+k) - x(i) \right| \right] \right\}$$

MTIE (MRTIE)

MTIE (MRTIE) is a useful indicator of the size of buffers, for predicting buffer overflows and underflows, and frequency offset.

Buffer size > MTIE(τ) implies that overflow/underflow unlikely in any interval < τ

Buffer size = MTIE(τ) implies that overflow/underflow could occur approx. every τ seconds



Observations:

- monotonically non-decreasing with t
- linear increase indicates freq. offset
- for very small τ, MTIE(τ) related to jitter
- for medium τ, MTIE(τ) related to wander
- for large τ, indicates whether “locked”

Note: If reference clock is “ideal” (i.e. in practical applications PRC/PRS) we use the term MTIE; otherwise we use the term MRTIE (see ITU-T Rec. G.810).

TIE, MTIE and TDEV

TDEV

- A measure of stability expected over a given observation interval, τ (τ is a parameter).
- Related to spectral distribution of clock noise power

Given a set of N observations $\{x_k;\ k=0,1,2,\ldots,(N-1)\}$ with underlying sampling interval τ_0, let $\tau = n\tau_0$ ("window" = n samples; $i = 1,2,\ldots,n$).

$$\sigma_x(\tau) = TDEV(\tau) = \sqrt{\frac{1}{6n^2(N-3n+1)} \sum_{j=0}^{N-3n} \left[\sum_{i=j}^{n+j-1} \left(x_{i+2n} - 2x_{i+n} + x_i \right) \right]^2}$$

$for\ n = 1,2,\ldots,\left\lfloor \frac{N}{3} \right\rfloor$

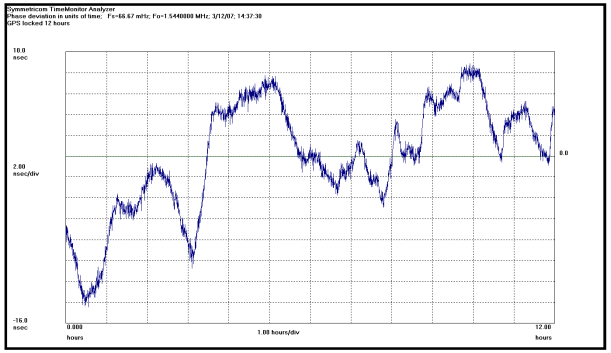
Note: $x(k) \Leftrightarrow x_k$

TVAR = square of TDEV

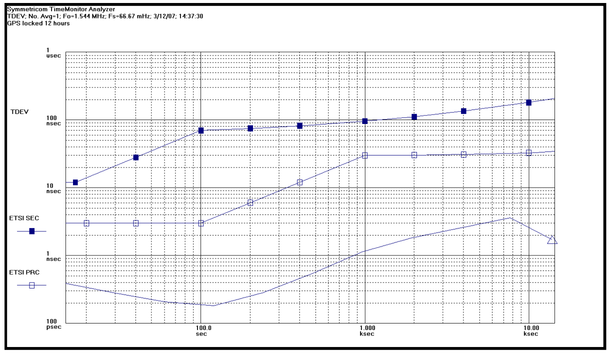
Modified Allan Variance (related to TDEV) : $\sigma_y(\tau) = \frac{\sqrt{3}}{\tau}\sigma_x(\tau)$

TDEV suppresses initial phase and frequency offset and quantifies the strength of the frequency drift and noise components

Example: Measuring Clock Performance

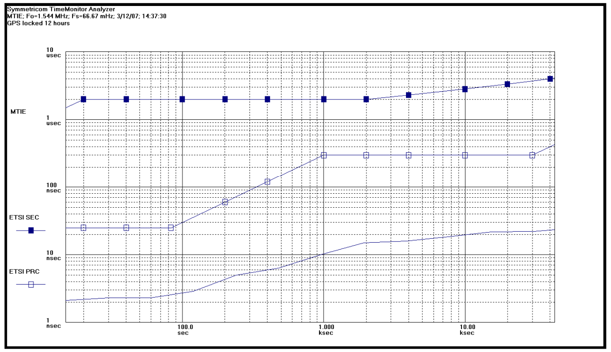


Time Error Sequence (measured)



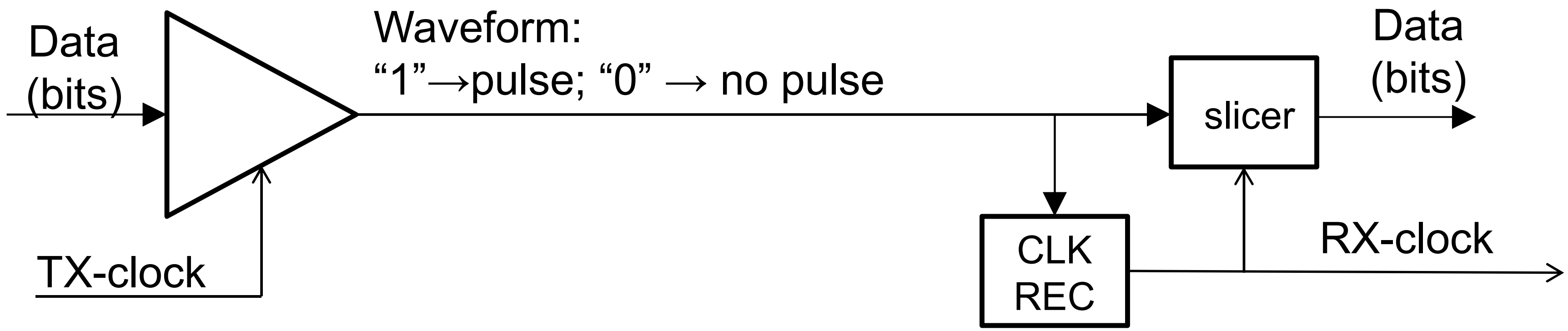
TDEV (calculated)

Also shown are masks for ETSI SEC and ETSI PRC



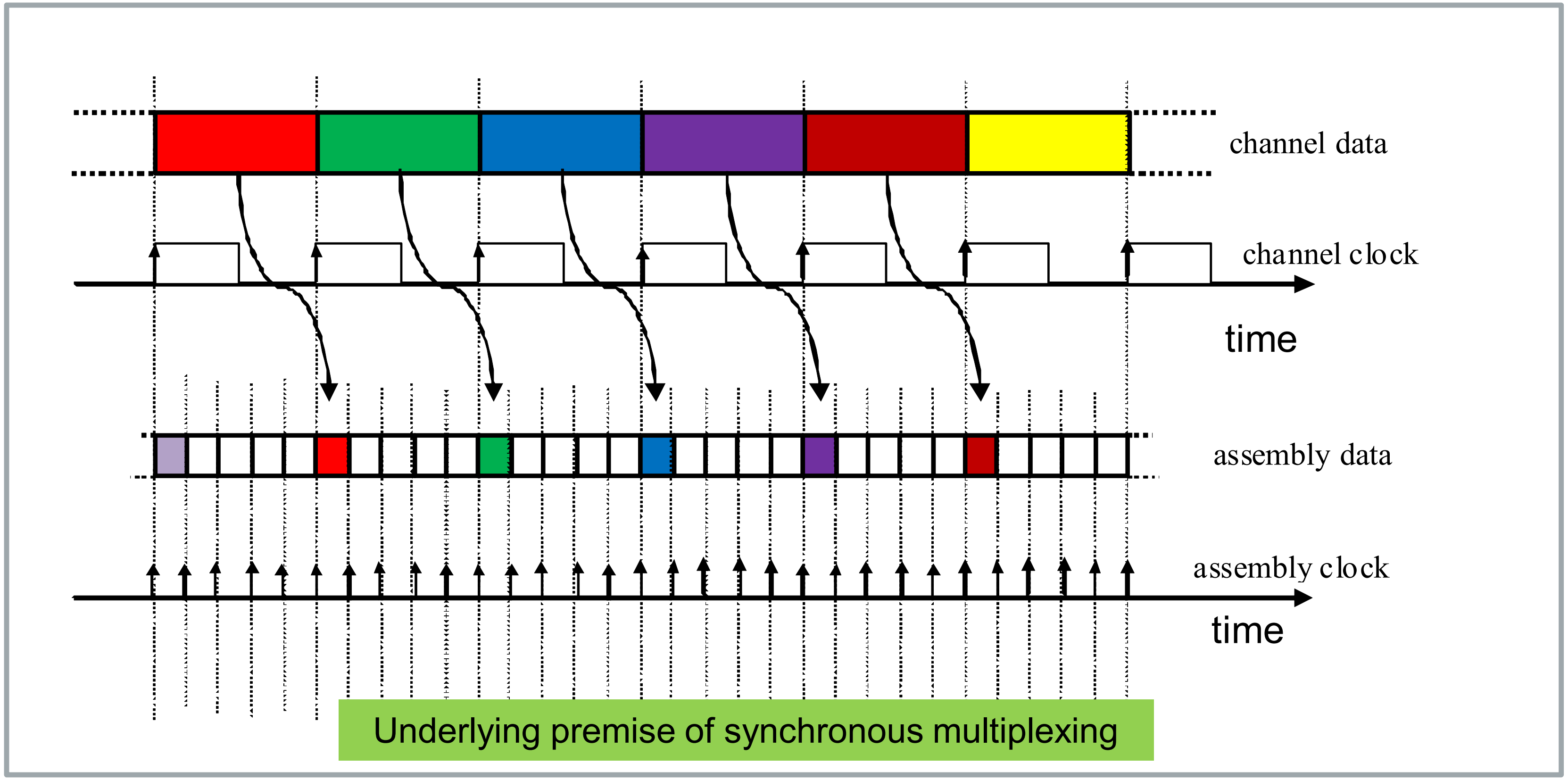
MTIE (calculated)

Physical Layer timing transfer



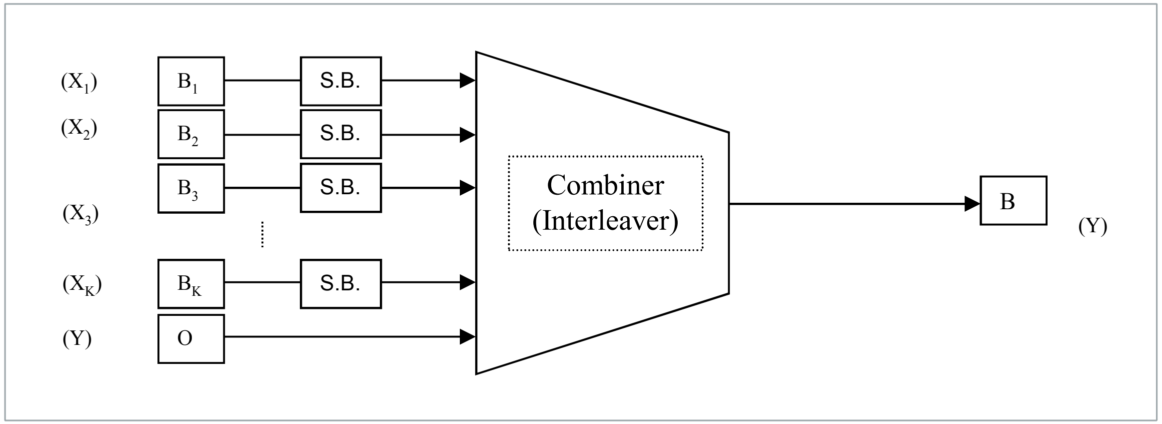
- Clock recovery necessary to extract data from received waveform
- Quality of recovered clock depends on density of transitions related to clock period
- Excessive "0"s results in jitter of the recovered clock
- If jitter is not filtered (e.g. PLL) then division can result in transfer of jitter power (high frequency) to wander (low frequency)…. aliasing

Synchronous Multiplexing



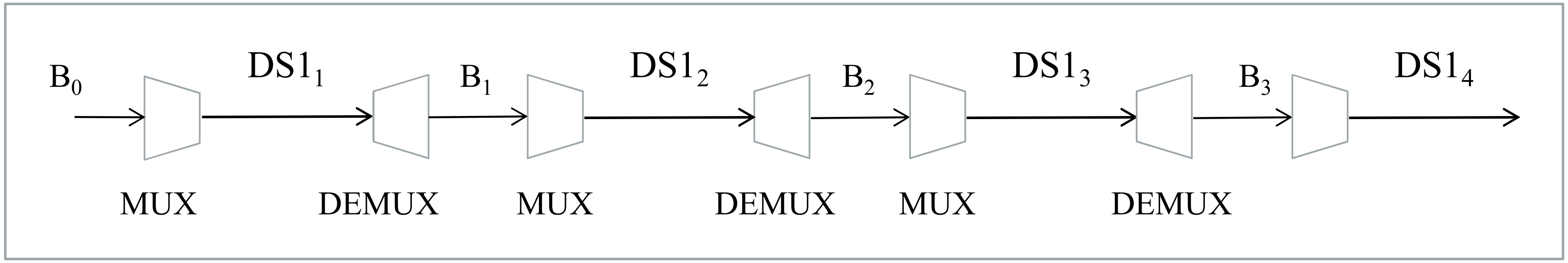
- Predetermined (rigid) ratio between channel clock and assembly clock
- 1-to-1 correspondence between channel bits and allowed bit positions
- Fractional frequency difference between channel and assembly clocks = 0

Synchronous Multiplexing – Rate Adaptation



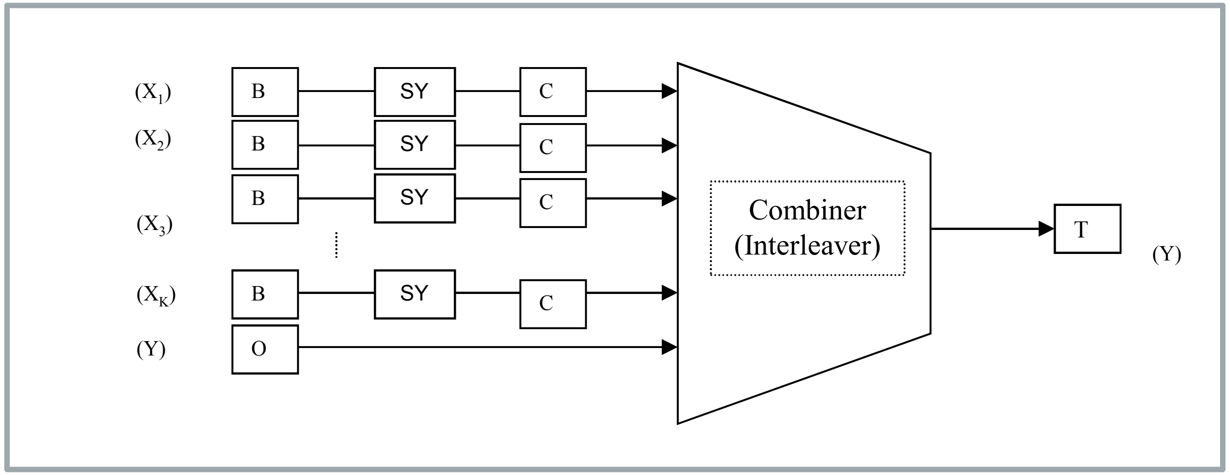
- Composite (assembly) (Y) comprised of individual channels (X_i) plus overhead
- Nominal bit rates: $B = B_1 + B_2 + \ldots + B_K + O$
- Frequency alignment achieved with a “slip buffer” (SB)
- Fractional frequency difference between channel and assembly results in data errors (slips)
- Nominal rates in DS1: B_i = 64 kbit/s; O = 8 kbit/s; B = 1544 kbit/sec; K = 24
- Nominal rates in E1: B_i = 64 kbit/s; O = 64 kbit/s; B = 2048 kbit/sec; K = 31
- Offset of Δf ppm results in (125/ Δf) slips per second
- 64 kbit/s channels can be combined to get Nx64 kbit/s channels

Accumulation of Slips



- Each cross-connection/switching node introduces a demultiplex-multiplex operation with slip-buffer
  - Channel clock replaced by assembly clock (service clock is not preserved)
- Slips occur if $f_i \neq f_{(i+1)}$ [end-points OK, slips in the middle!]
- ITU-T Rec. G.822 specifies that there should be less than 5 slips in a 24hr period (in an end-to-end 64 kbit/s hypothetical reference connection)
  - If only one slip buffer then Δf < ~5ppb
  - Basis for requiring G.811 (PRC) traceability [Δf < ~2x10^{-11}]
- Impact of slips more severe for voice-band data than human-human speech

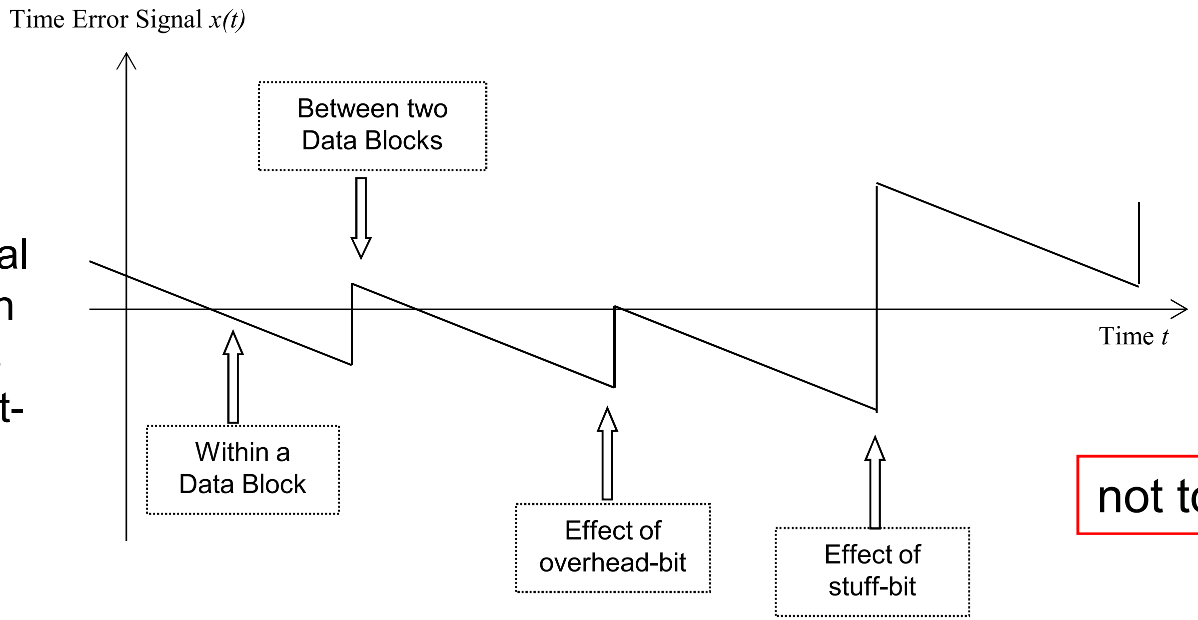
Asynchronous Multiplexing - Synchronizer



- Channel clock does not have to be "equal" (in FF sense) to the assembly clock
- Function of the "synchronizer" is to perform the necessary rate adaptation from B_x (channel clock) to C (bit-rate allocated in assembly) (with $C > B_x$)
- In one "frame" (N+1) bits allocated for a channel
  - (N+1) bits/frame corresponds to bit-rate of C (nominally uniform spacing)
  - In PDH (e.g. M12) B_x corresponds to $(N+\alpha)$ with $0 < \alpha < 1$
  - (N+1)-th bit is "data" in α (fraction) number of frames and a "stuff bit" in the remainder
  - Bit-rate is C in α frames and $C \cdot [N/(N+1)]$ in $(1-\alpha)$ frames

Asynchronous Multiplexing - Desynchronizer

Time error signal associated with asynchronous multiplexing (bit-stuffing)



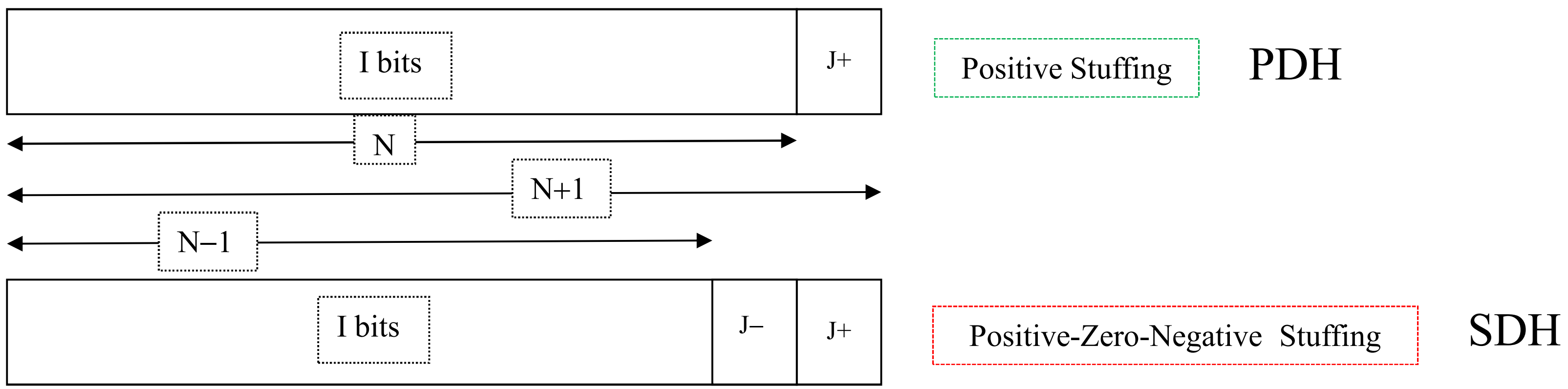
not to scale

- "Gapped Clock" : non-uniform signal based on assembly clock associated with valid channel bits in the assembly. Non-uniform because of over-head bit positions and stuff bits.
- Equal to channel clock "on the average"
- Goal: clock noise introduced by this non-uniformity is "high frequency" (i.e. jitter) and can be removed (filtered out) using a PLL (PDH bit-stuffing schemes are good)
- Channel clock noise = assembly clock noise + filtered version

SONET/SDH : SM & AM features

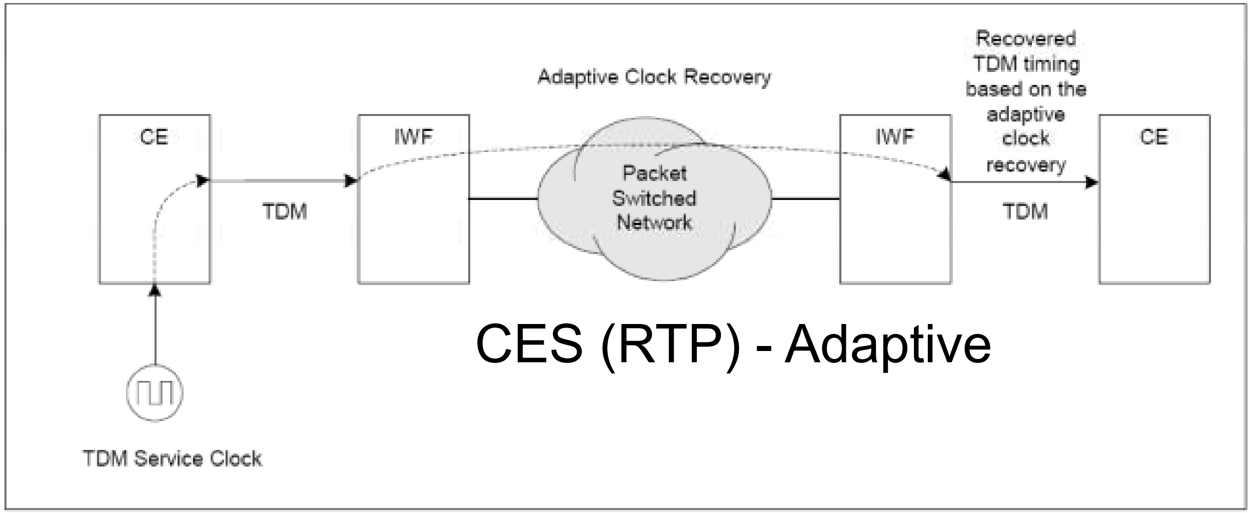
- STS-N created by interleaving N STS-1s; STM-N created by interleaving STM-1s
  - STS-1s (STM-1s) must be synchronized (zero frequency offset between constituent channels and assembly)
  - Constituents channels of STS-1 are synchronous to STS1 (“containers”)
- Bearer channels encapsulated into “containers”.
  - e.g. VT1.5 is a container for a DS1 (1.544 Mbit/s signal)
  - The synchronizer function for DS1 → VT1.5 employs “positive-zero-negative stuffing”
- Synchronizer function differences
  - PDH uses “positive stuffing”. Clock noise introduced is high-frequency (jitter) and can be filtered out
  - SONET/SDH use “positive-zero-negative” stuffing that can introduce low-frequency (wander) components
  - DS1-bearer in PDH can be used as a synchronization reference; DS1-bearer in SONET is not used as a synchronization reference

Justification Methods (Bit Stuffing)



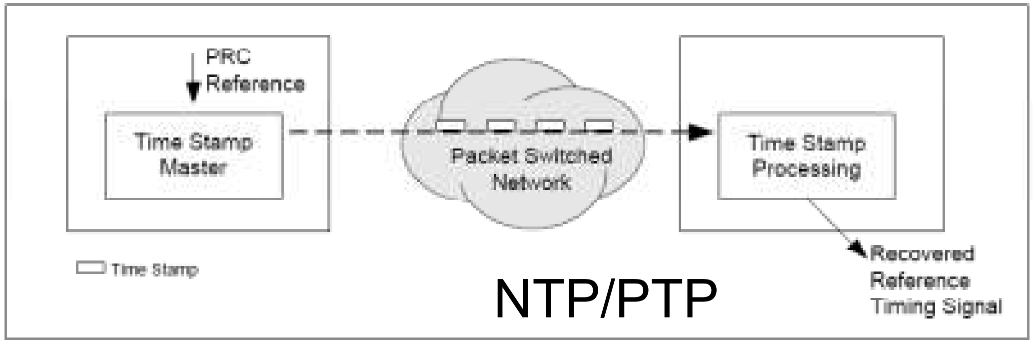
- The positive-stuffing method introduces a rapidly varying stuff pattern and hence the clock noise tends to be high frequency
- In positive-zero-negative stuffing the bearer channel rate corresponds to N (nominally) and thus it is possible that stuff events occur very infrequently resulting in low-frequency noise content (wander)
- Both methods preserve data (information)

Packet-Based Methods (Adaptive Methods)



From ITU-T G.8261

- Timing information contained in the arrival/departure time of the packets
- Timestamps carried by the packets can be used to support this operation
- Two-way or one-way protocols
- Timing recovery process based on filtering the PDV

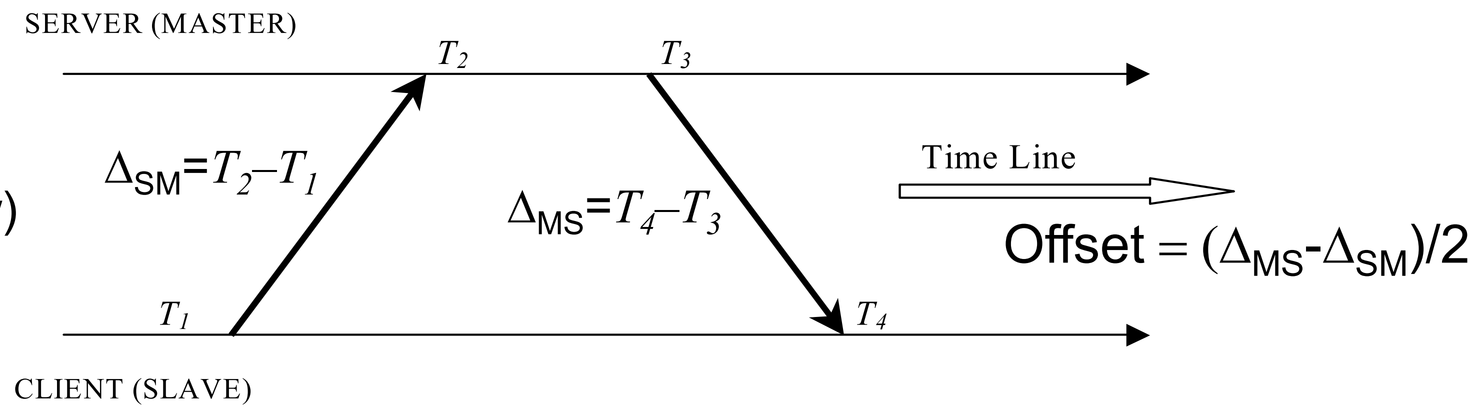


Applicable to CES-RTP and PTP/NTP

Time Synchronization using Packets

- The distribution of time via packets is based on the exchange of 4 time stamps between master and slave (T_1, T_2, T_3, T_4).
- Two main protocols: PTP (IEEE1588) and NTP/SNTP
- One-way [either (T_1,T_2) or (T_3,T_4)] can be used for frequency
- To obtain an unbiased time-offset estimate, the forward and reverse path delays must either be known or assumed equal (symmetric)

(NTP view)



Requirement: Symmetric Networks

Basics of Packet-based Methods

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- *It would be ideal if* each packet in a flow between source and destination experiences the same transit delay … but each packet can experience a different delay
- Consequently, we assume that:
  1. The transit delay is stochastically stationary
  2. The delay variation (i.e. PDV) has some desirable characteristics — stable minimum OR stable average OR stable mode OR stable…..(generally proprietary algorithm)
- Utilize this knowledge (assumption!) to establish a good control signal for disciplining oscillator, i.e. clock recovery (frequency)
- For time transfer (e.g. phase, time-of-day)
  - Need two-way packet flow with time-stamps
  - Estimate one-way delay (half-round-trip **if** symmetric)

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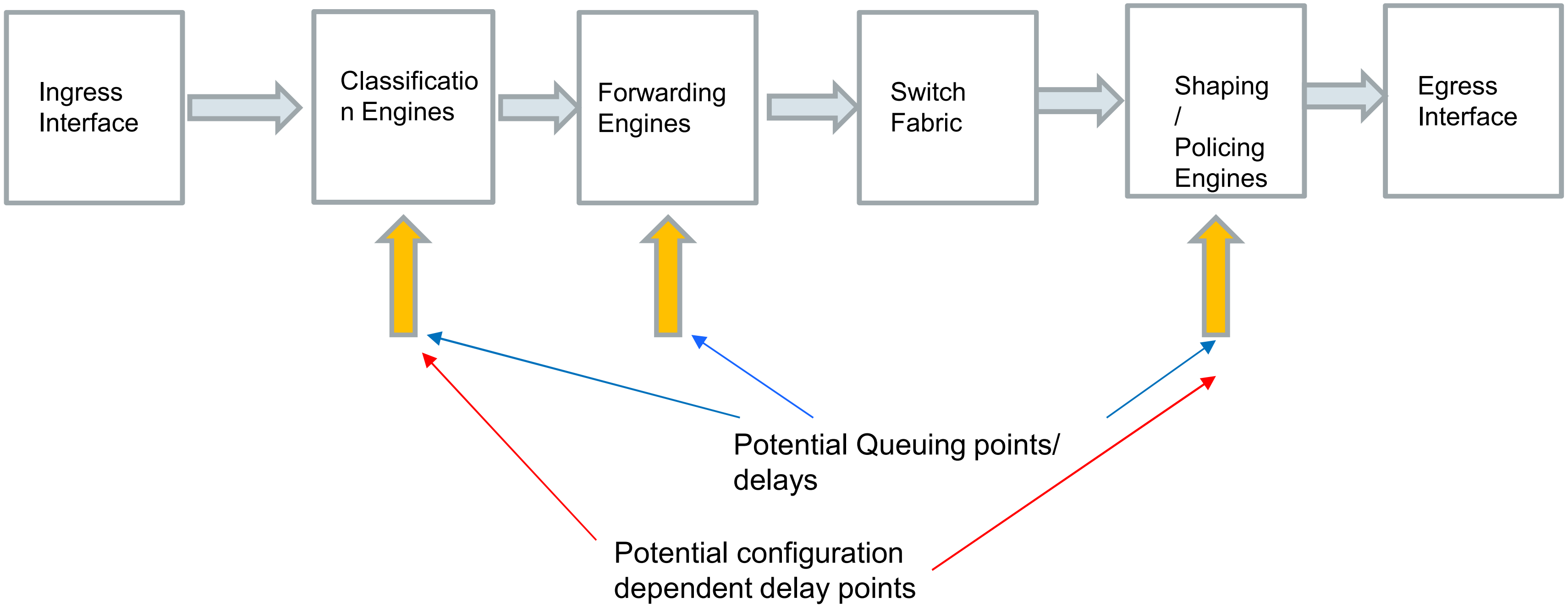
Impairments in Packet networks

- Typical Impairments in the packet networks
  - Packet delay variations [PDV]
    - Equipment design
    - Equipment configuration
  - Path dependent aspects
    - Physical path asymmetry
    - Path rerouting
  - Interactions between the packet streams

Packet delay variation (PDV)

- Queuing
- Equipment Configuration



Packet delay variation (PDV)

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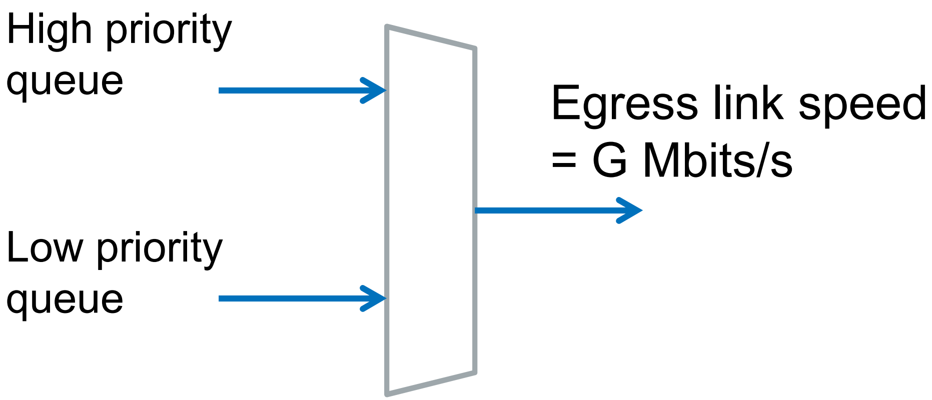
- Head of line blocking



MTU size M byte
Strict priority queue

$$\left(\Delta_{pp}\right)_{\max} \geq \left(\frac{M}{G}\right) \mu s$$

- A packet arrives in the HPQ, just when a packet from the LPQ has begun transmission
- The packet from HPQ is blocked till the LPQ packet is transmitted
- With more complex prioritization scheme the delay due to head of line blocking could vary significantly

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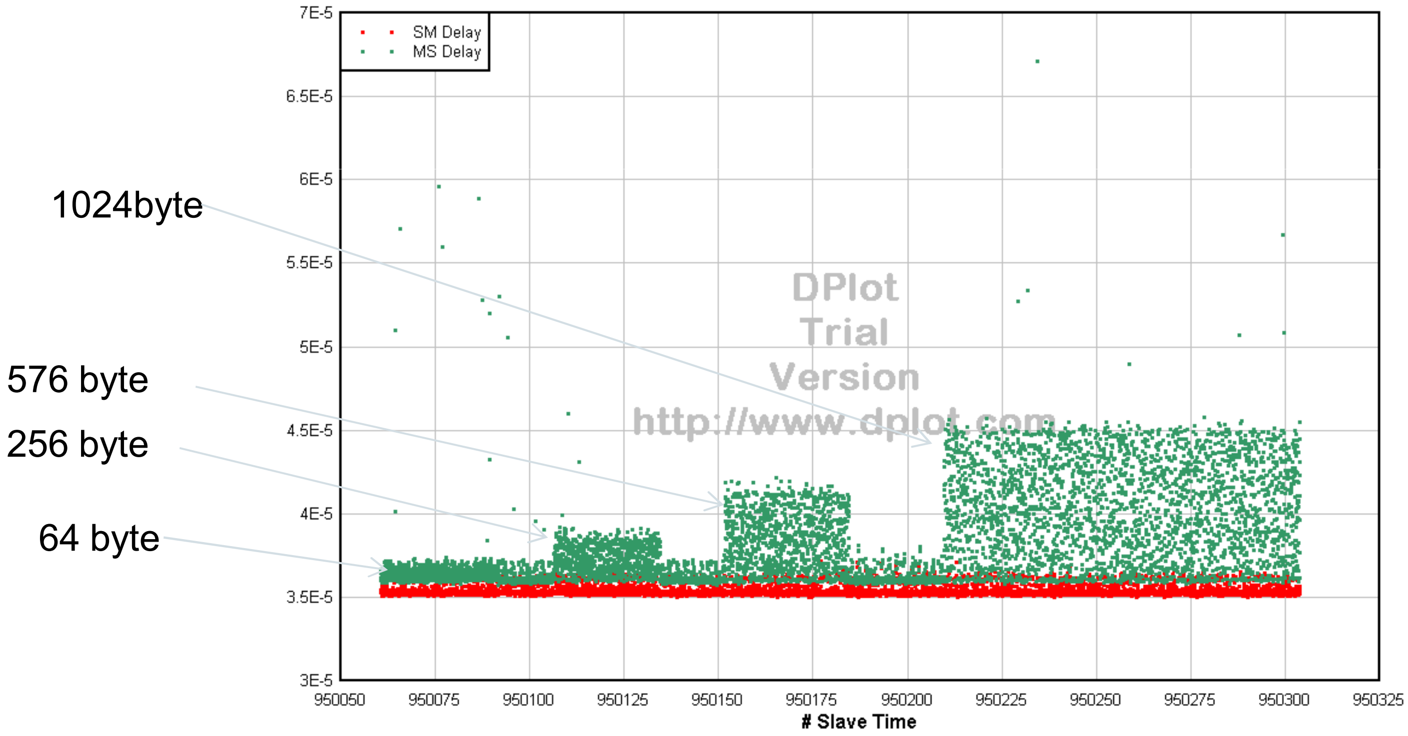
Packet delay variation (PDV)

Equipment implementation specifics
e.g. the Delay variation through a single piece of equipment, with packet sizes



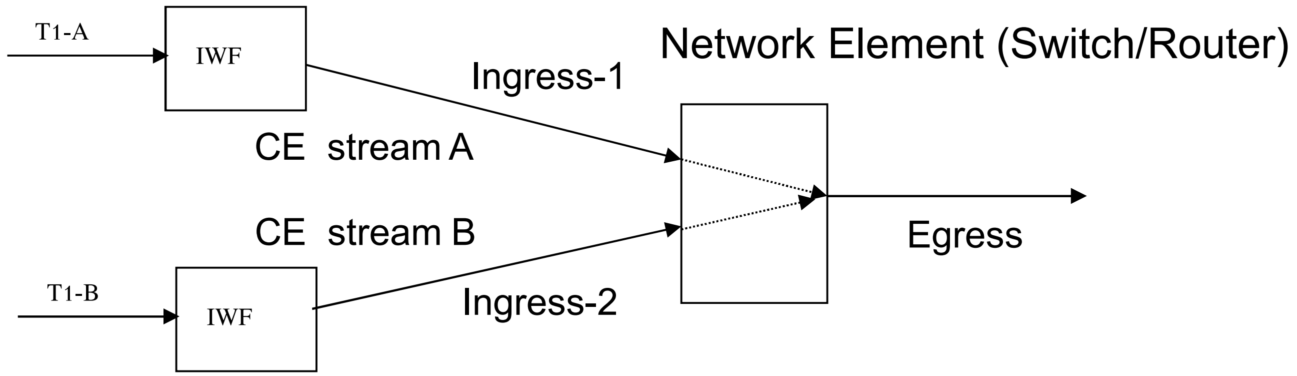
Path dependent impairments

- Asymmetry
  - Static Difference in paths between the forward and reverse paths. E.g difference in lengths of fiber
  - Forward and reverse paths pass through different node
- Rerouting
  - Leads change in path delays and can “confuse” the algorithms.

Interaction of flows

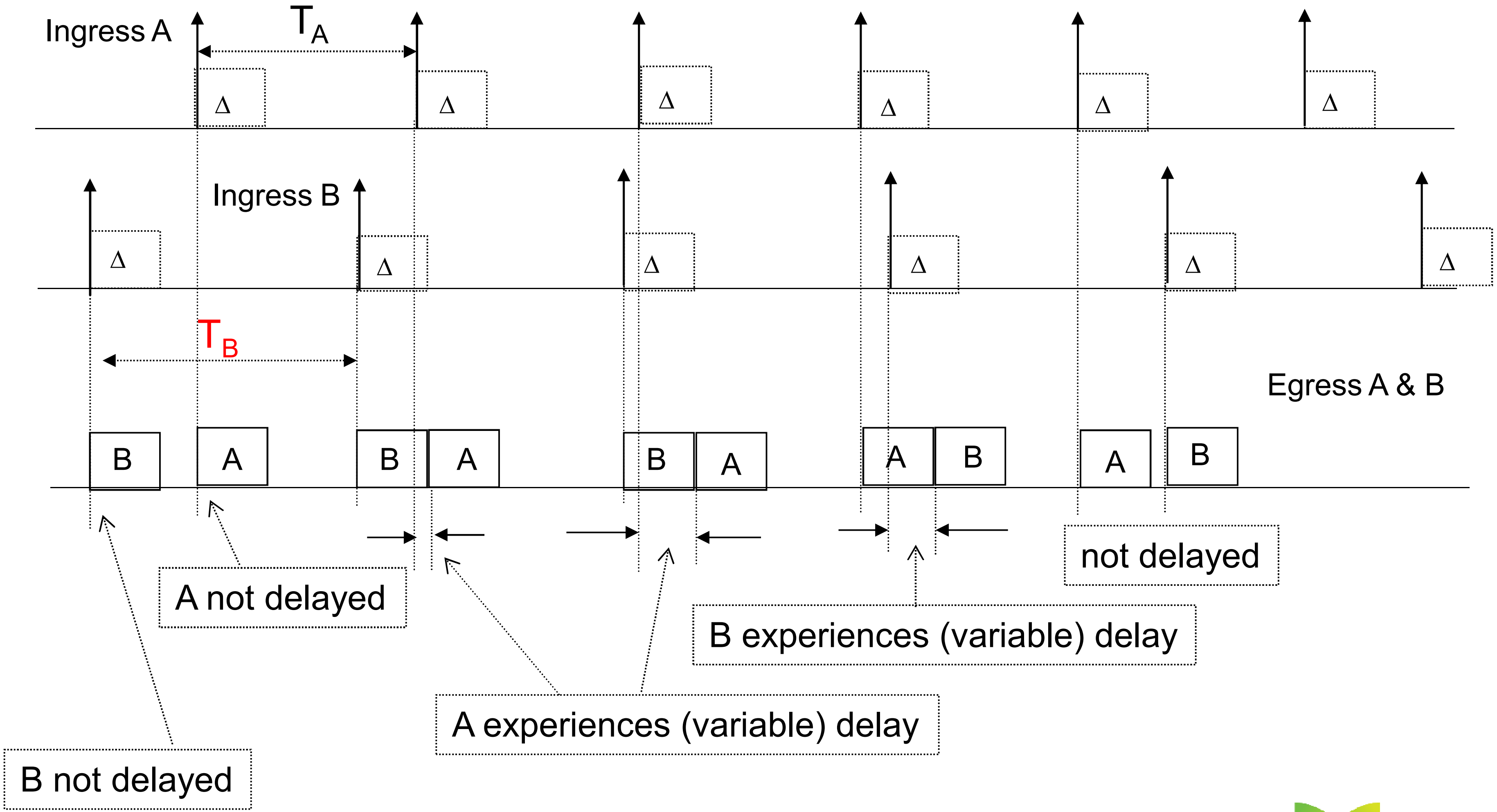
- This phenomenon occurs whenever two “non random” packets share a common path or transmission resource
  - Internal to system generating or terminating the flows
  - External the system: “Out there in the cloud”
- Two illustrative examples
  - 2 T1 streams converging on egress of CES Functions
  - The PTP Grandmaster & (Multiple slaves) (OCs) communicating over “unaware” networks
    - Could easily create “bottle necks” even on unloaded networks

Interaction of CBR streams

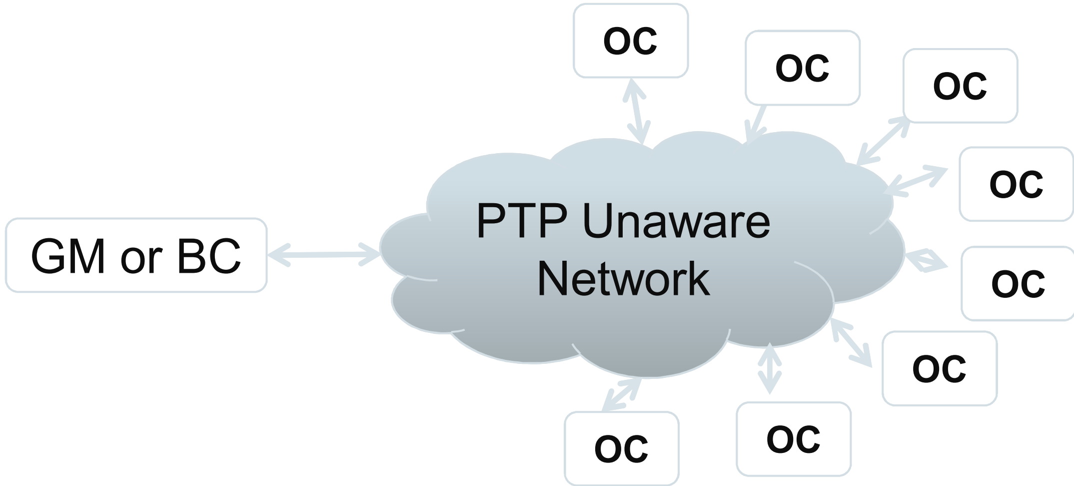


- Assumptions:
  - Streams A and B represent Circuit Emulation of T1 / E1-A and T1/ E1-B
  - Each packet is same size and the packet rates are nominally equal
  - The bandwidth of the egress is high (~ 1 Gbps) (NO bandwidth starvation). Each packet occupies ~ 2 μsec in the egress stream
- Stream A will experience a (variable) delay if it arrives when a stream B packet is being transmitted and viz.

Assumption: Streams A and B have same packet size and occupy Δ μsec on egress link



Ordinary Clock Beating Phenomenon



- Multiple Ordinary Clocks locked to Grandmaster (GM) or Boundary Clock (BC) over a PTP unaware network:
  - Ordinary Clocks (OC's) that generate Delay Requests at nominally same rates can result in queuing delays, even for lightly loaded or quiescent networks:
    - If the OC's are all about the same delay from the Master;
    - More likely as the number of OC's increases;
    - Worsens with better phase and frequency lock;
- Results in false floors of minimum delay and thus poor phase estimation at the slave.

Slide- Courtesy of Dr. Charles Barry

Ordinary Clock Beating Phenomenon

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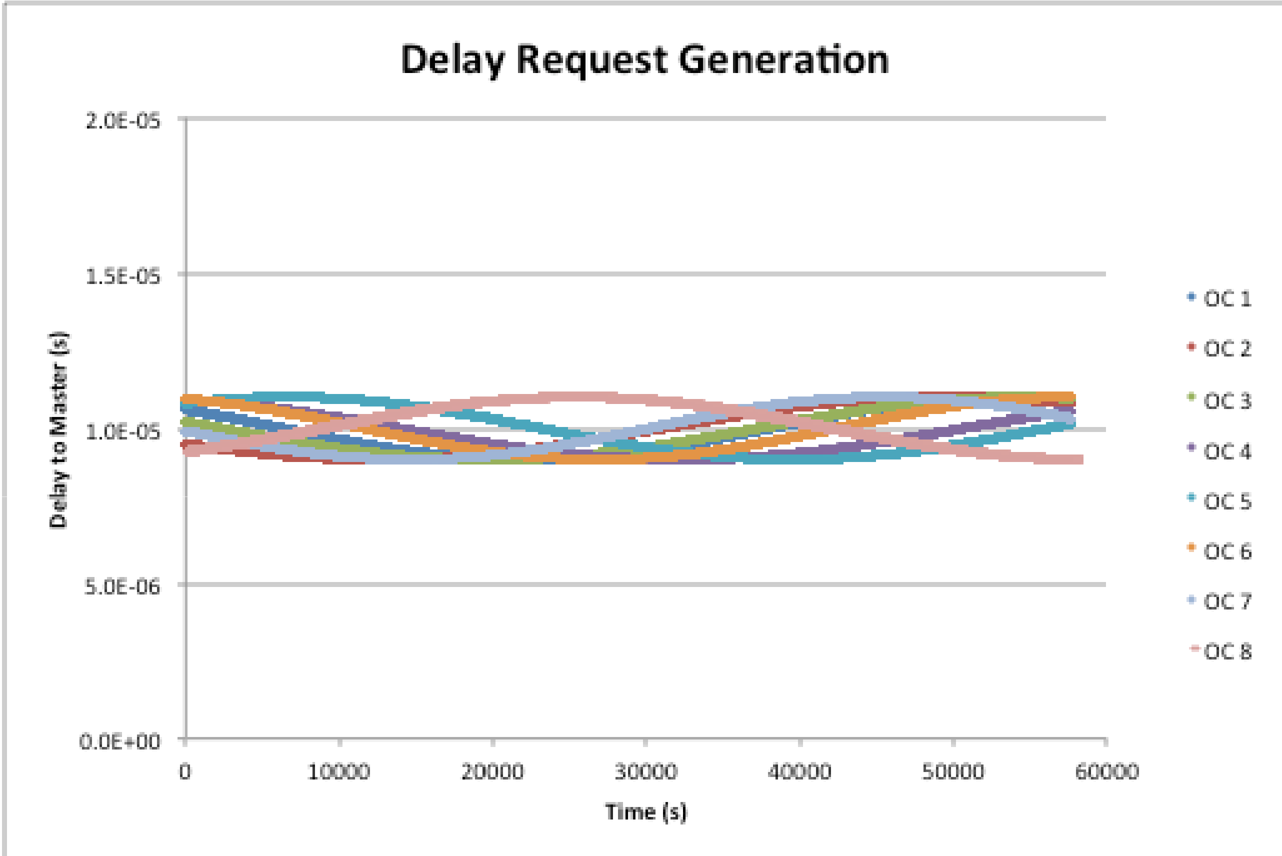

Delay Requests are generated at nearly the same time due to 1588v2 clock recovery and if the delay requests are at a regular interval, e.g., 32 requests/s shown.

(Simulated +/- 1.0us sinusoidal wander, random initial phase)

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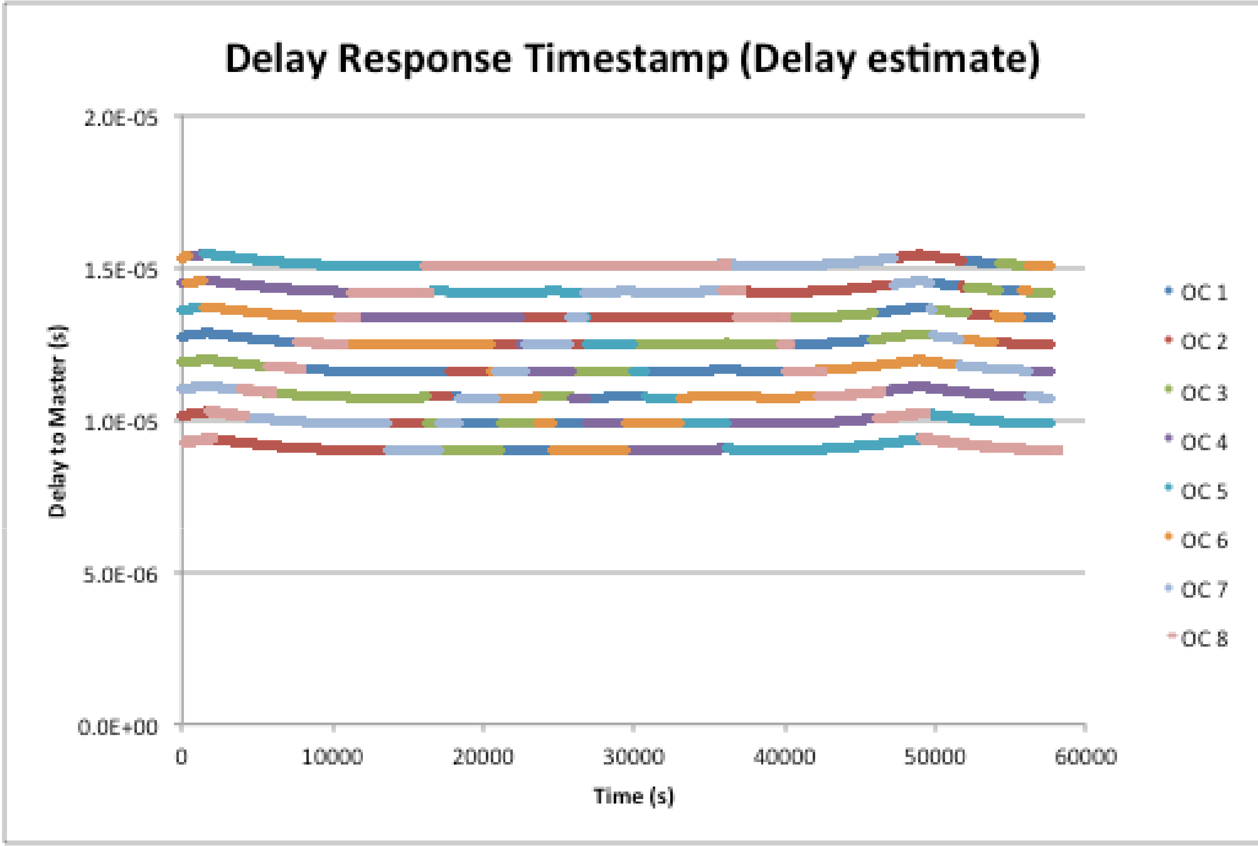
Ordinary Clock Beating Phenomenon



- Delay Responses from Master to Ordinary Clock are queued in the network before arriving at the master the slave resulting in:
- Large dispersion of the delay estimate and false floors for minimums for long durations;
- Floors are separated by the transmission delay of the packet at line rate e.g., 864ns for GbE

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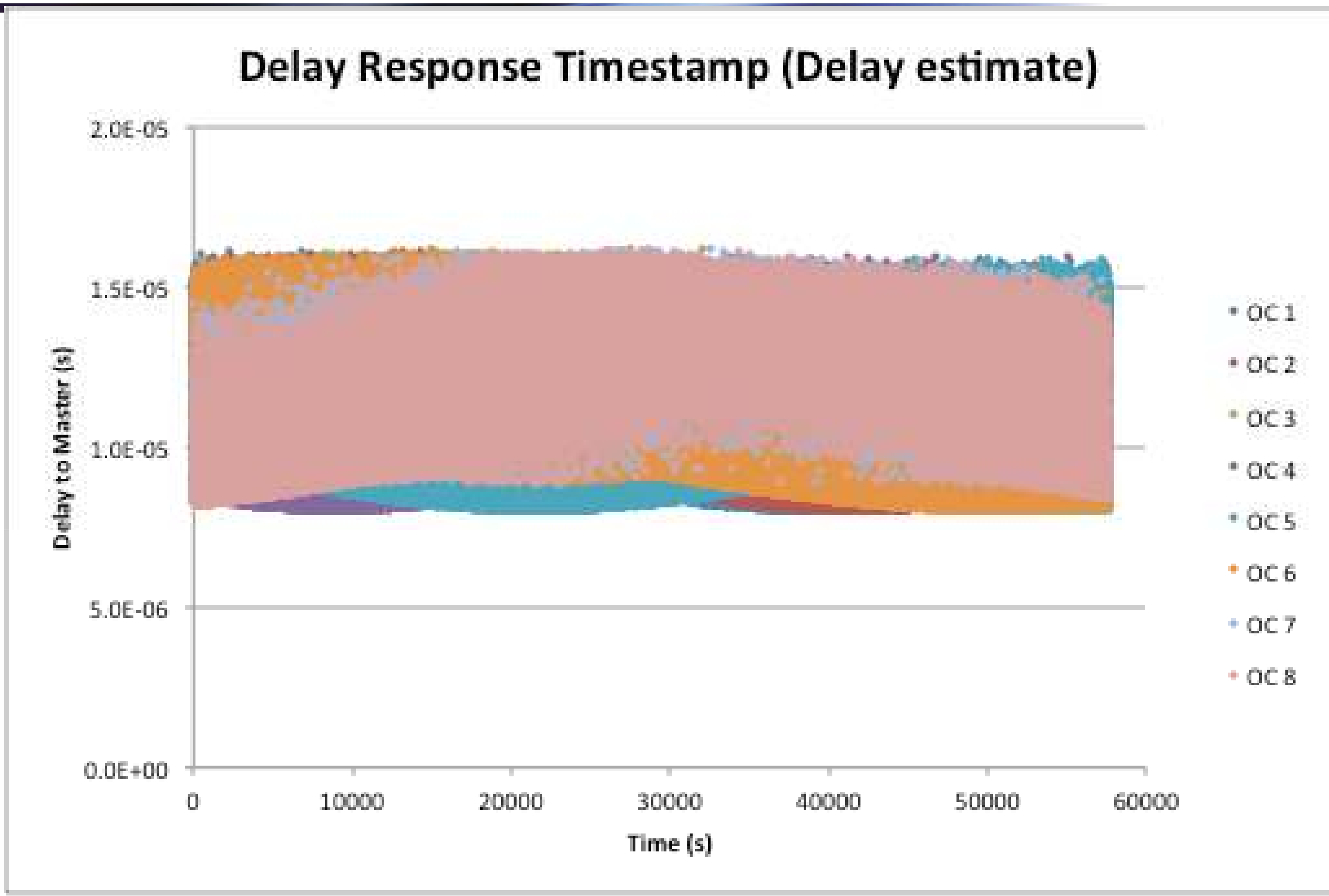
Ordinary Clock Beating Phenomenon



Mitigations:

Outside of the obvious, e.g., making the network PTP aware, reducing the number of OC's, varying the distance (delay) from OCs to master, it is possible to offset and/or dither the delay request generation of the OC's to reduce the likelihood and duration of the false floors.

Slide- Courtesy of Dr. Charles Barry

Key Aspects of Performance

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- Packet Delay Variation (PDV) is a major contributor to "clock noise"
  - Related to number of hops, congestion, line-bit-rate, queuing priority, etc. Time-stamp-error can be viewed as part of PDV
- Clock recovery involves low-pass-filter action on PDV
  - Oscillator characteristics determine degree of filtering capability (i.e. tolerance to PDV)
    - Higher performance oscillators allow for longer time-constants (narrower bandwidth == stronger filtering)
    - Lower performance (less expensive) oscillators may be used (may require algorithmic performance improvements)
- Performance improvements can be achieved by
  - Higher packet rate
  - Controlling PDV in network (e.g. network engineering, QoS)
  - Timing support from network (e.g. *boundary clocks* in PTP)
  - Packet selection and/or nonlinear processing

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Sync Metrics in Packet Networks

- Depending on the application the Network element clock output metrics (computed from TIE measurements) can be the same (MTIE/MRTIE/TDEV)
  - Clock <u>output</u> requirements are determined by existing masks
  - Some distinctions are required in case of packet clock integrated in the Base Station (no standardized output MTIE/TDEV)
- Metrics are needed to better characterize the behavior of packet networks (PDV) delivering the timing reference
  - E.g. a metrics that could associate PDV with FFO or phase variation
  - Tolerance masks will be useful for network operators and clock manufacturers
  - Packet selection methods can be justified
- No one single "magic" metric exists
  - May need to have a collection of metrics
  - All metrics are "useful" … a metric simply provides a quantitative description of some property of the PDV

Need for additional metrics

- Traditional IP networks utilize just peak-to-peak “jitter” as the sole time/timing related performance metric (e.g. 95% of delay variation samples <10 ms)
- This is generally not sufficient for the purpose of timing recovery as is seen in the following examples.
  - In all cases the synthetic PDV sequence has a peak-to-peak measure of approximately 10ms and packet rate of 10Hz
  - The PDV, pdf, and TDEV/minTDEV are shown in the following charts
  - One TDEV mask (ETSI SEC) is shown in the charts to provide a frame of reference
  - Exception: Stable oscillator (e.g. Stratum 2) and only frequency required
- Timing is generally recovered using selected “best” packets; this is not visible in the peak-to-peak measurements
  - Other variations include metrics derived from the distribution of the packet-arrival times (e.g. Mode, median, etc.)
- Suitable metric sets must include those that characterize amplitude distribution (including peak-to-peak) and spectral distribution.

Peak-to-peak jitter not sufficient

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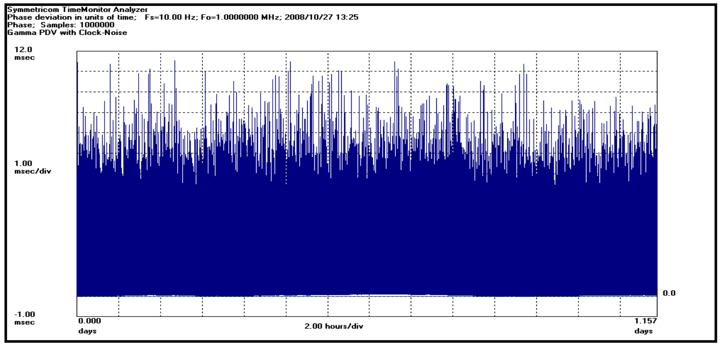
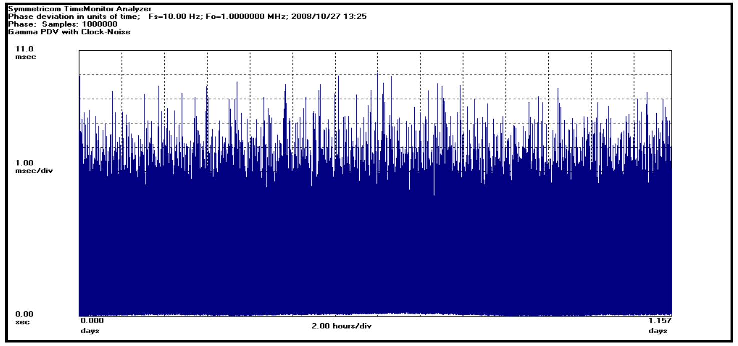
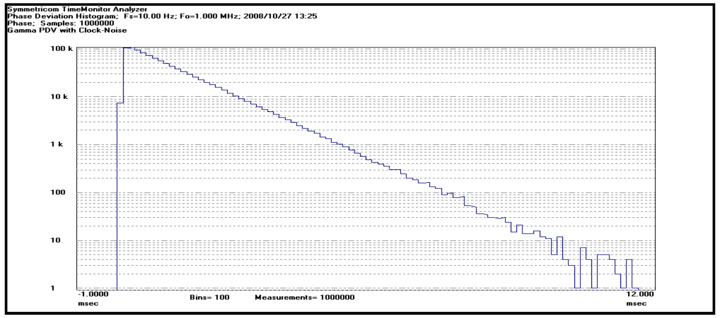
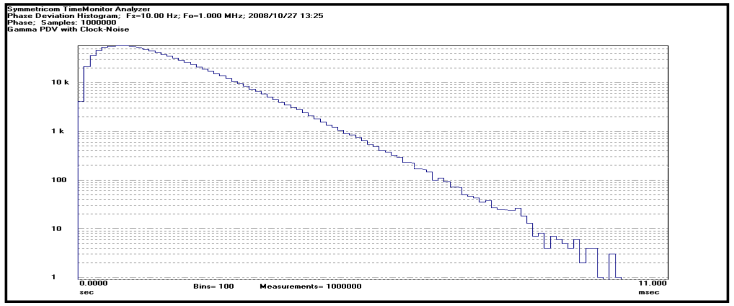


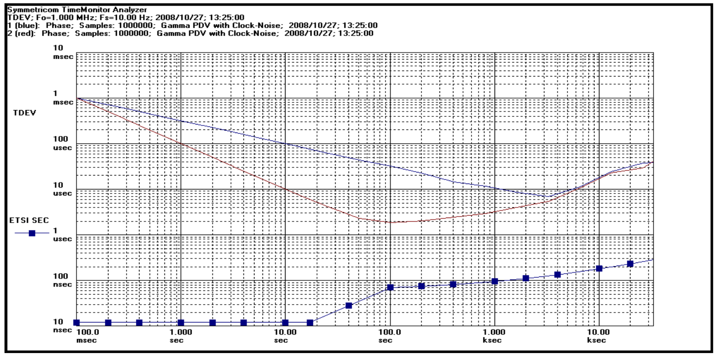
phase



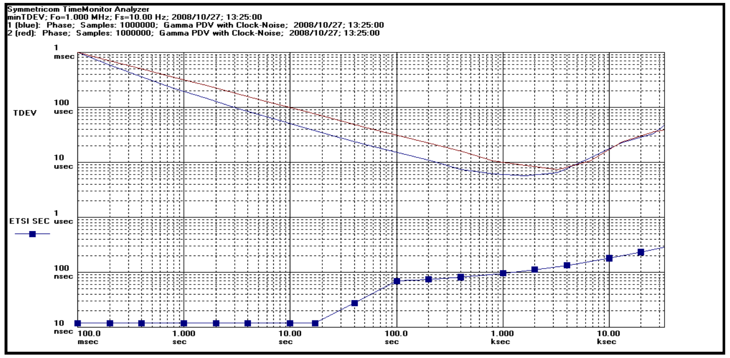


pdf





TDEV
and
minTDEV



Peak-to-peak jitter = 11.5ms

Peak-to-peak jitter = 10ms

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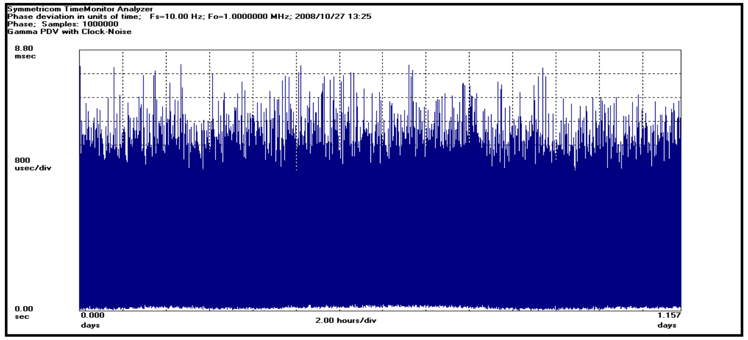
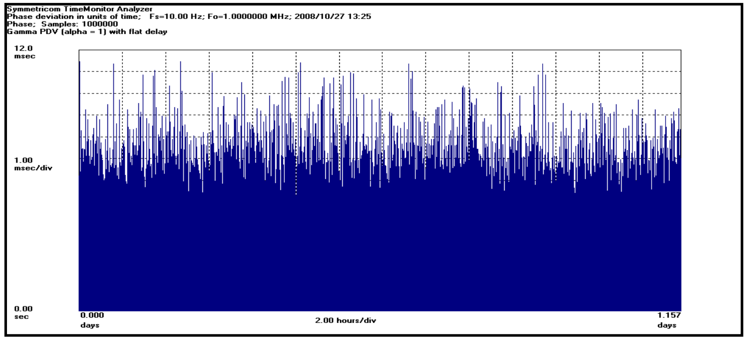
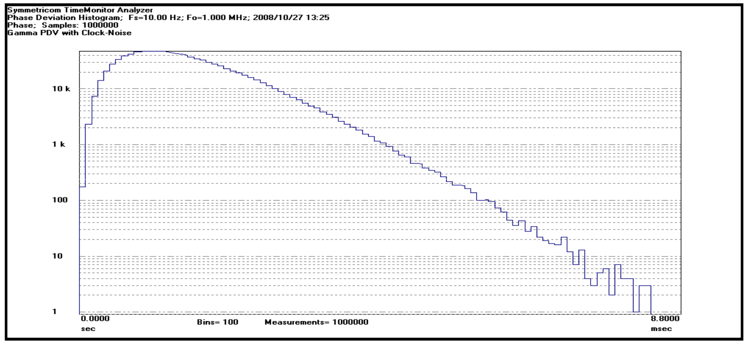
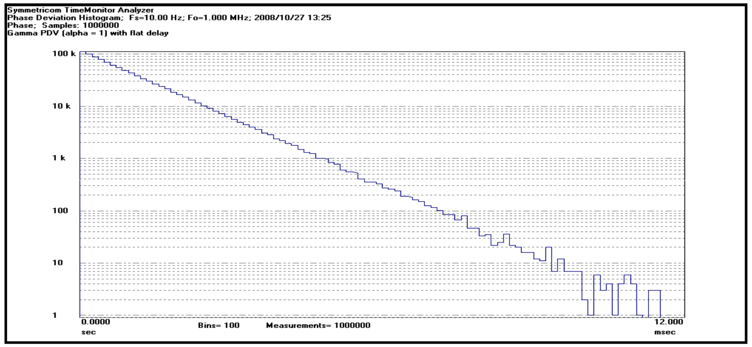
Peak-to-peak jitter not sufficient





phase





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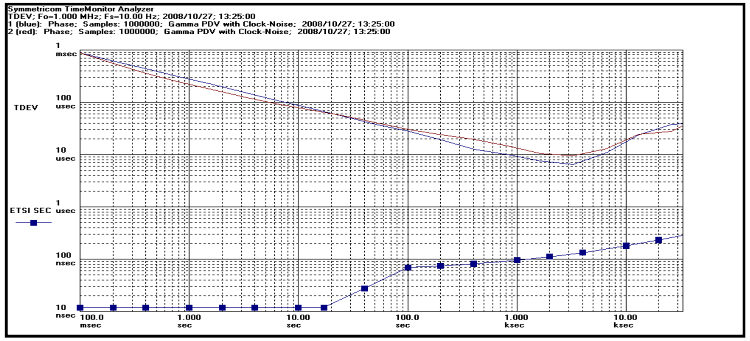
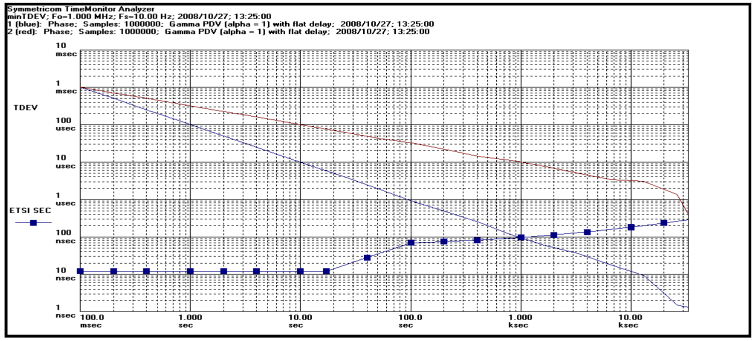




TDEV and minTDEV

Peak-to-peak jitter = 8.3ms

Peak-to-peak jitter = 11.5ms

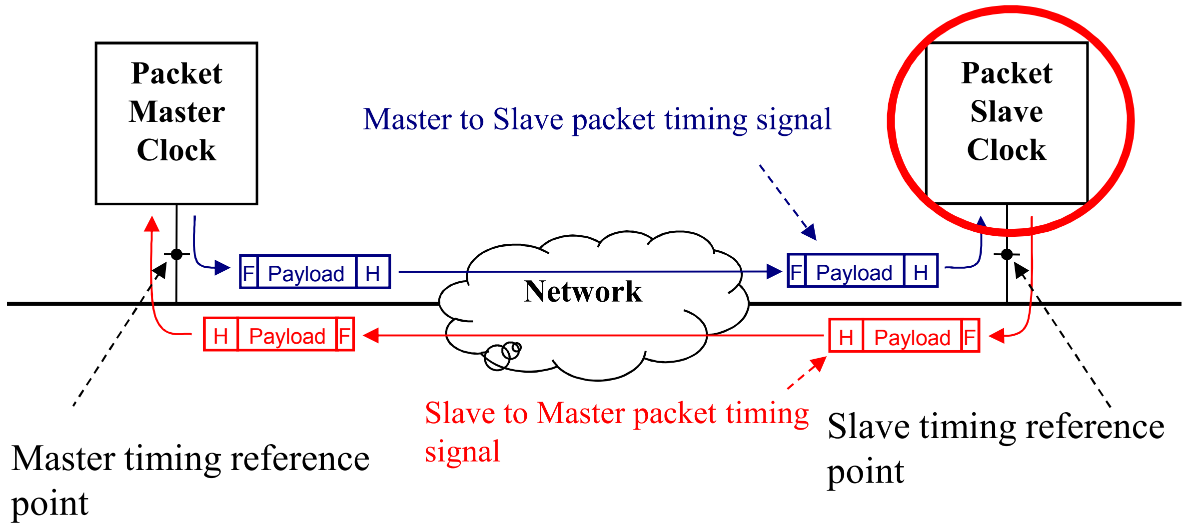
Thank You!

Questions?

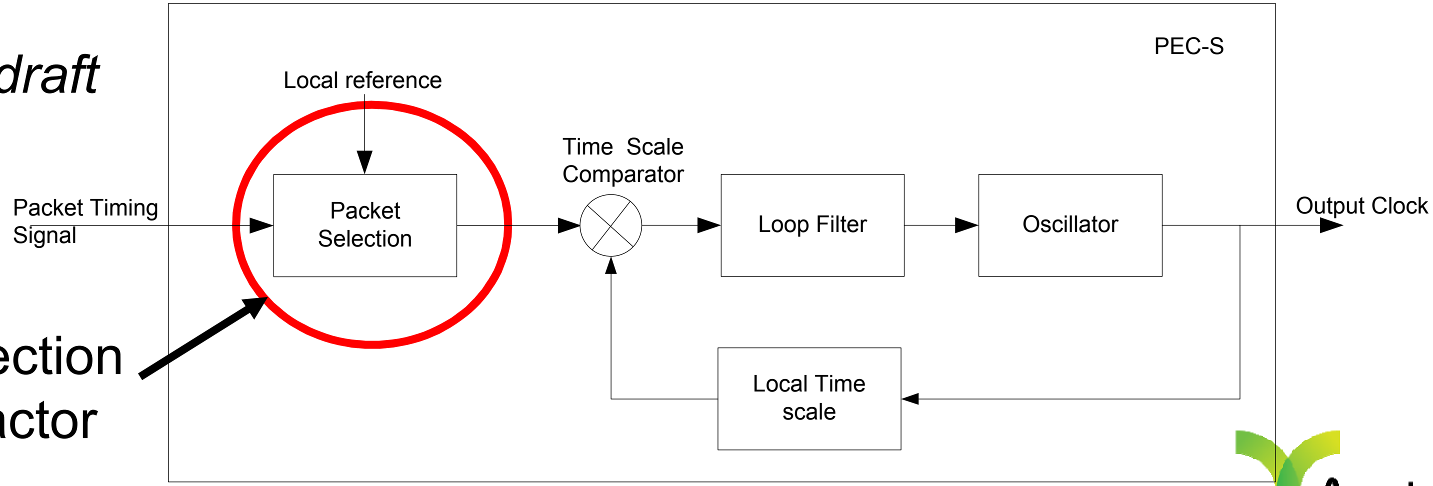
Packet Based Equipment Clocks

Clock Types	*Examples*
PEC-S	PTP Slave NTP Client
PEC-M	PTP Master NTP Server
PEC-B	PTP Boundary Clock NTP Stratum n Server (n>1)

PEC: Packet based Equipment Clock



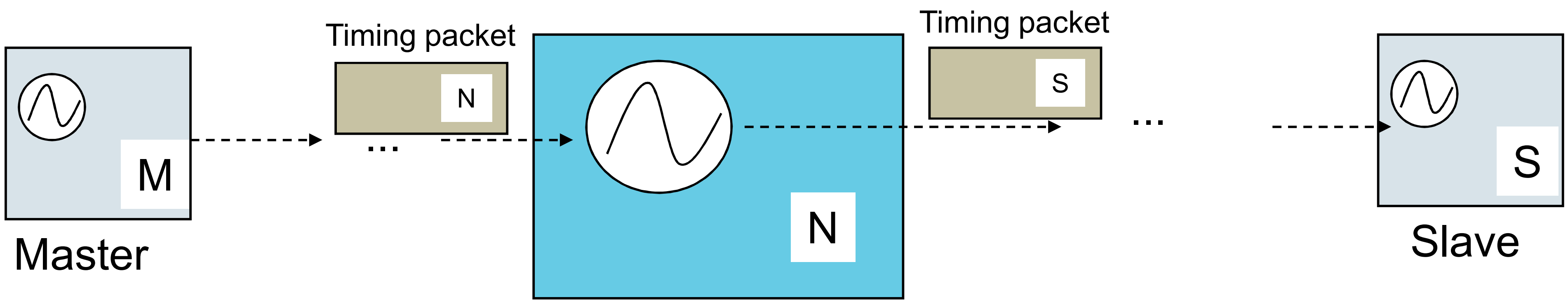
From G.8263 draft



Packet Selection is a key factor

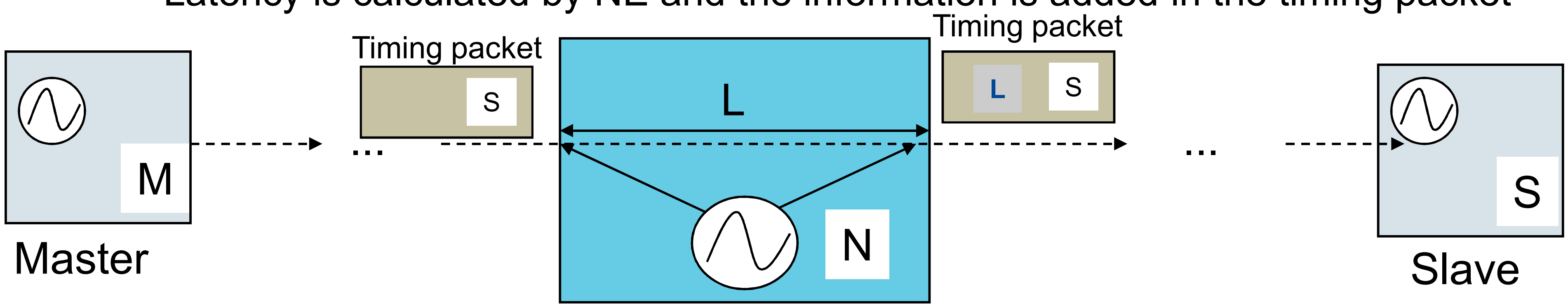
Examples of Timing Support

Timing packets are terminated and regenerated by N



e.g. IEEE1588 Boundary Clock, NTP Stratum Clock

Latency is calculated by NE and the information is added in the timing packet



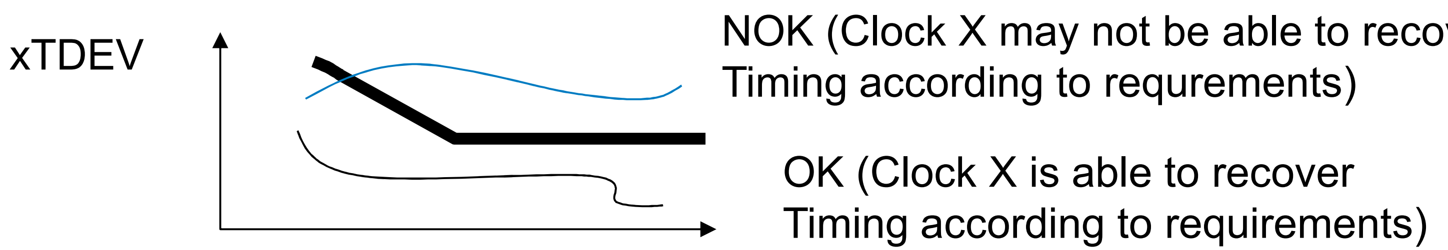
e.g. IEEE1588 Transparent Clock

General requirements for packet-based metrics

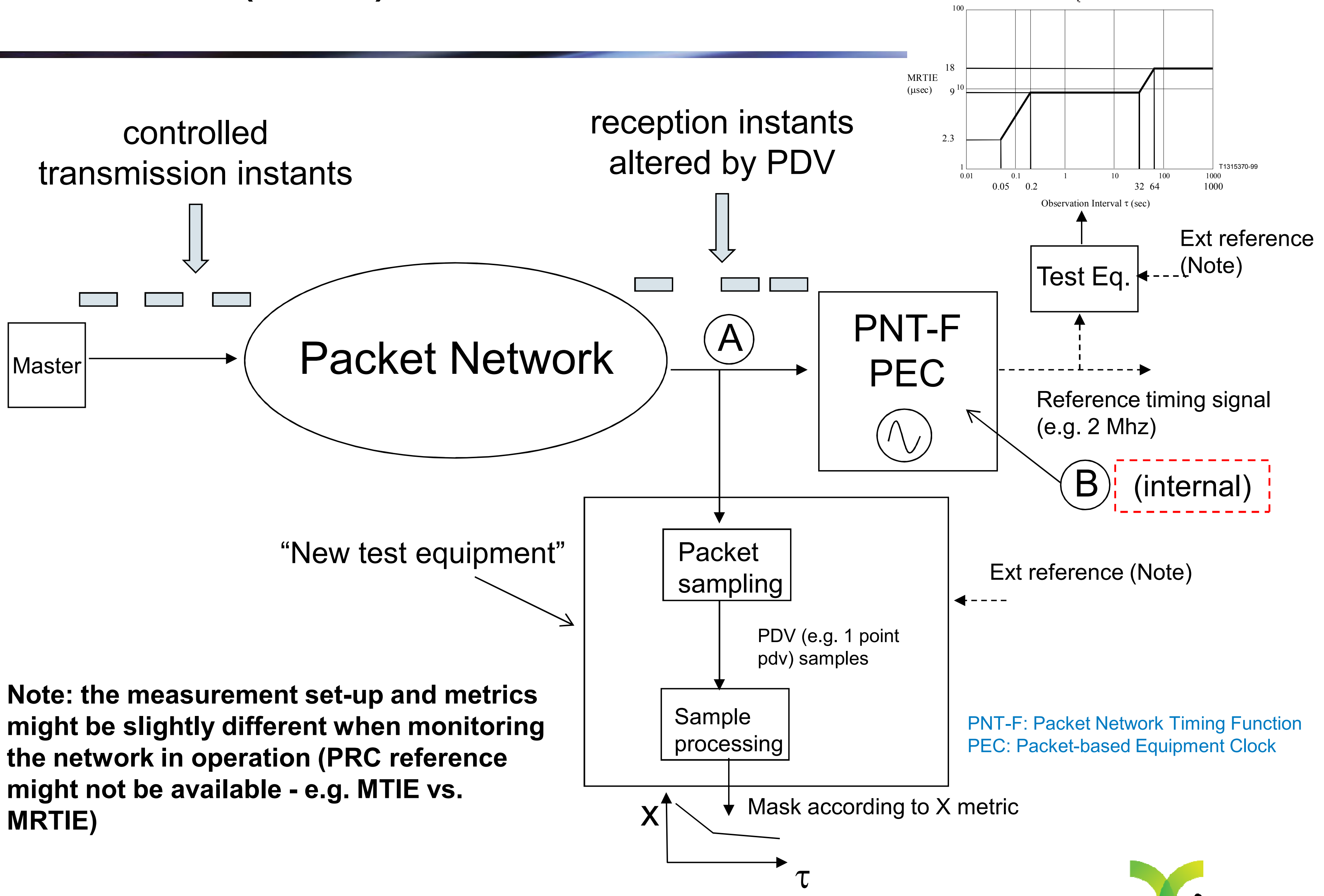
- The basic parameter is the packet delay variation (PDV)
- ITU-T Rec. Y.1540 provides definitions for packet delay variation
- Some processing of the PDV data is needed to get a proper interpretation of the packet network behaviour (metrics)
- Different metrics may be defined and these may have some relationship with hypothetical clock-recovery algorithms (e.g. packet selection)

General requirements for packet-based metrics (contd)

- Requirements for the (network) metrics include:
  - Measurable
  - Characterize real (typical) packet networks behaviour
  - it shall be possible to state (e.g. 99% of the time) that "*if network meets mask A then a type X clock can meet some defined output timing mask B*"
  - It should be possible to design packet networks and clocks that can fulfill these masks
  - Metric is likely to be some form of statistical average (e.g. a variation of TDEV)



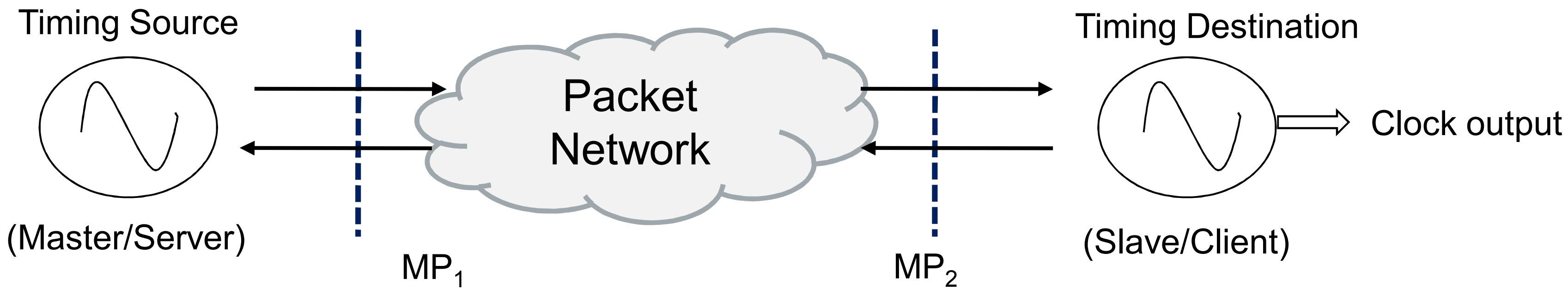
General (Test) Scenario



Note: the measurement set-up and metrics might be slightly different when monitoring the network in operation (PRC reference might not be available - e.g. MTIE vs. MRTIE)

PNT-F: Packet Network Timing Function
PEC: Packet-based Equipment Clock

Packet Delay Variation (Y.1540)



- IP Packet Transfer Delay (IPTD): $x_k = t_2(k) - t_1(k)$
  - $t_m(k)$ = time that packet "*k*" traverses MP
- Reference delay: $d_{1,2}$ (something "fixed"):
  - x_0 (first packet)
  - *average over "recent" past*
  - *minimum over "recent" past*
  - other (affects just the mean value, not variance or spectrum)

Commonly used for sync discussions

- 2-point IP Packet Delay Variation : $v_k = x_k - d_{1,2}$
- 1-point PDV(at MP_2) : $y_k = t_2(k) - T_2(k)$
  - $T_2(k)$ = expected time of arrival of k^{th} packet, e.g. based on periodicity
  - $T_2(k)$ = time-stamp in k^{th} packet (essentially ignoring $d_{1,2}$)
  - Well-suited for CES and other packet-based (frequency) methods

Y.1540 and IEEE1588 in G.826x

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- The Time Error ("x") in the packet timing context
  - 1–point PDV as per Y.1540 in case of periodic packets (e.g. CES)
  - extended definition of the 1-point PDV in case of (non-necessarily periodic) packet timing signal carrying timestamps (e.g. time error calculated comparing the timestamp of the packet with a reference time generated at the output of the packet network) .
  - Alternatively a modified definition of the 2-Point PDV could be used.
- The required accuracy of the reference time in case of non-synchronized clock configurations is under study.
- The definition of time-instant for establishing time-of-arrival and time-of-departure of packets based on the *Event message timestamp point* as defined in IEEE1588
  - the above definition is specified for PTP packets but could be used for other packet protocols unless other definitions are specifically specified.

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Additional Metrics

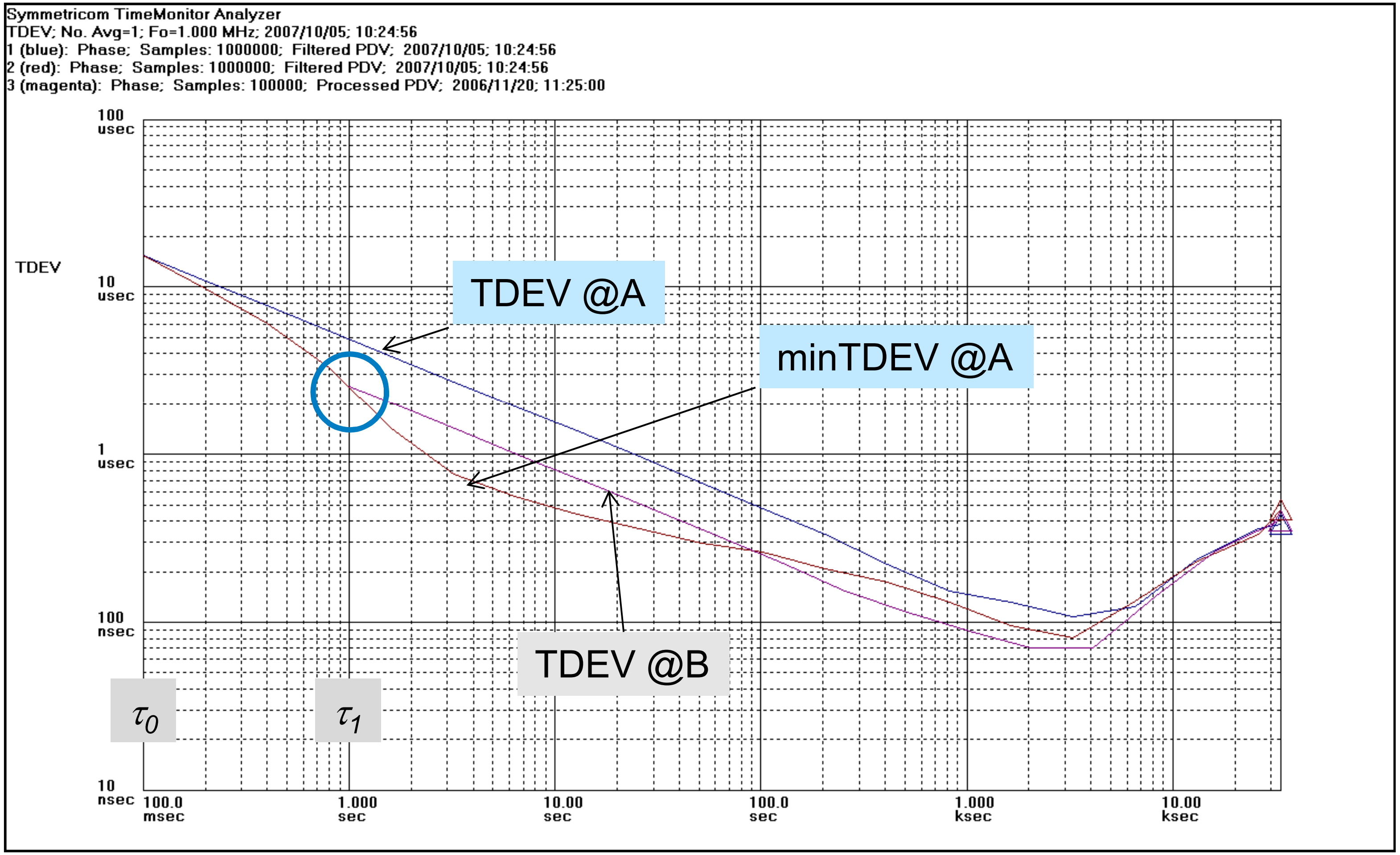
- Several metrics addressing distribution of timing are being studied and planned to be included in ITU-T Recc. G.8260.
  - minTDEV and MATIE are considered to illustrate fundamental principles
- minTDEV and percentileTDEV are analogous to TDEV
  - TDEV utilizes the average over windows
  - minTDEV utilizes the minimum over windows
  - percentileTDEV utilizes the average over the x% least delay packets
  - Computed at “A” (and/or “B”)
- MATIE is related to MTIE
  - MTIE computed directly on the time error sequences $\{x_k\}$ or $\{y_k\}$ is not that meaningful because of large “jitter” (PDV)
  - MATIE is computed on the sequence following the pre-filtering (packet-selection) and emulates the low-pass nature of the traditional clock model (bandwidth / time-constant). MAFE is a variation of MATIE
  - Computed at “B” (input to PLL function)
- When the application involves distribution of time-of-day, additional metrics for quantifying network asymmetry are needed

minTDEV

$$\left[\min TDEV(\tau)\right]^2 = \frac{1}{6(N-3n+1)} \sum_{j=0}^{N-3n} \begin{bmatrix} \min\{(x_{i+2n}); j \le i \le (n+j-1)\} - \\ 2\min\{(x_{i+n}); j \le i \le (n+j-1)\} + \\ \min\{(x_i); j \le i \le (n+j-1)\} \end{bmatrix}^2$$

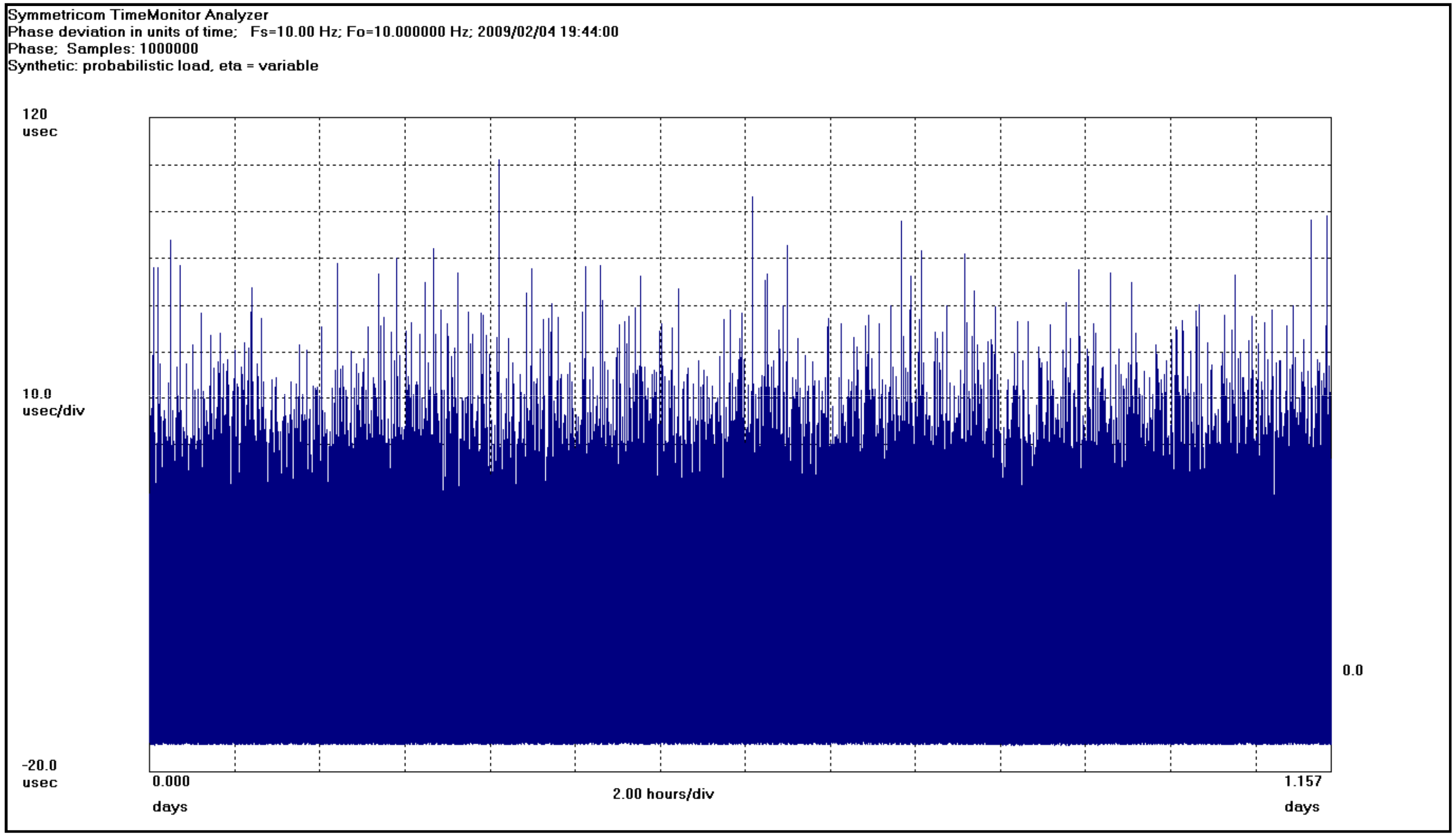
- Evaluating minTDEV for $\tau = n \cdot \tau_0$ involves taking the minimum value over the window of width n samples (τ units of time)
- One property of minTDEV that is appropriate:
  - Consider the case where the TE sequence is under-sampled by a factor of N by retaining the packet corresponding to the minimum TE in each window of N packets (samples)
  - The TDEV of the resulting signal for "n = 1" (i.e. at the new sampling interval $\tau = \tau_1 = N \cdot \tau_0$) matches the minTDEV computed on the original TE

minTDEV and TDEV



Under-sampling by factor of N = 10 : $\tau_1 = 10 \cdot \tau_0$

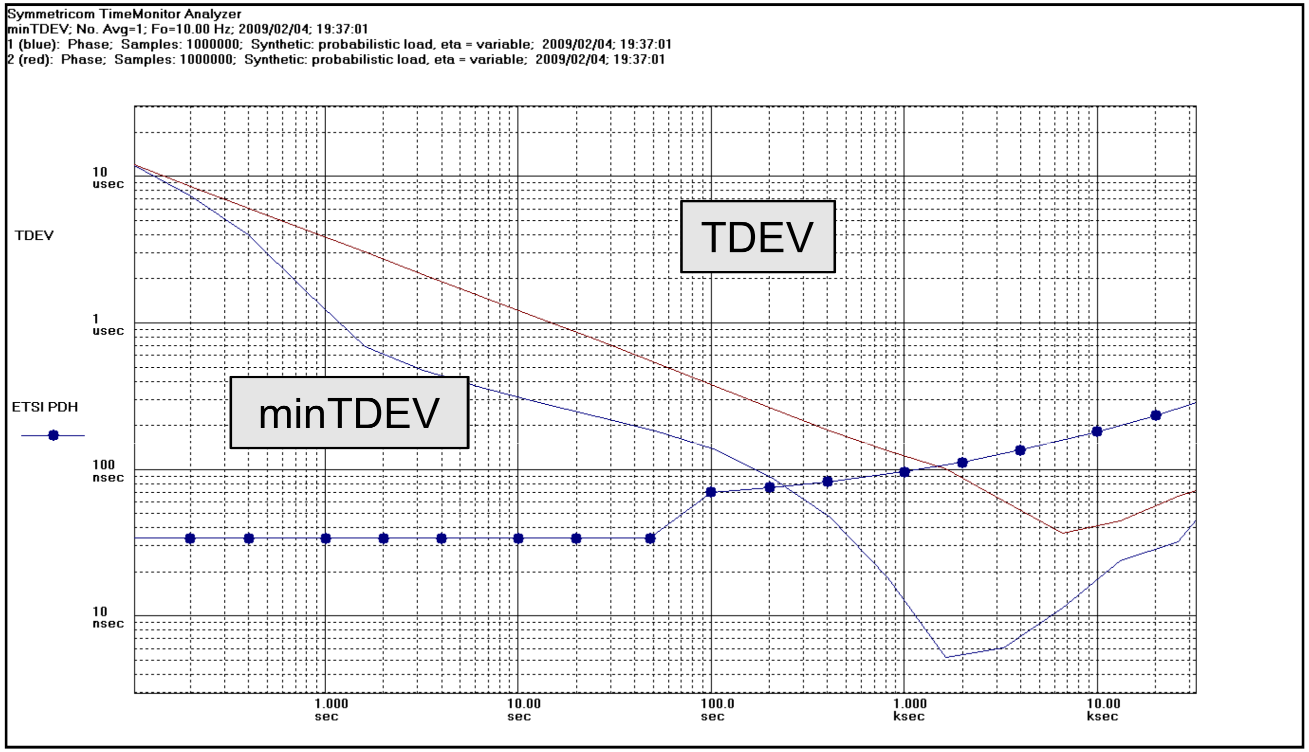
PDV Processing example



Simulated PDV $\{y_k\}$; nominal packet rate = 10 Hz (τ_0=0.1s)
[as seen at "A"]

PDV Processing example

QULSAR



- TDEV and minTDEV [at point A]
- Mask shown is ETSI PDH (for example)

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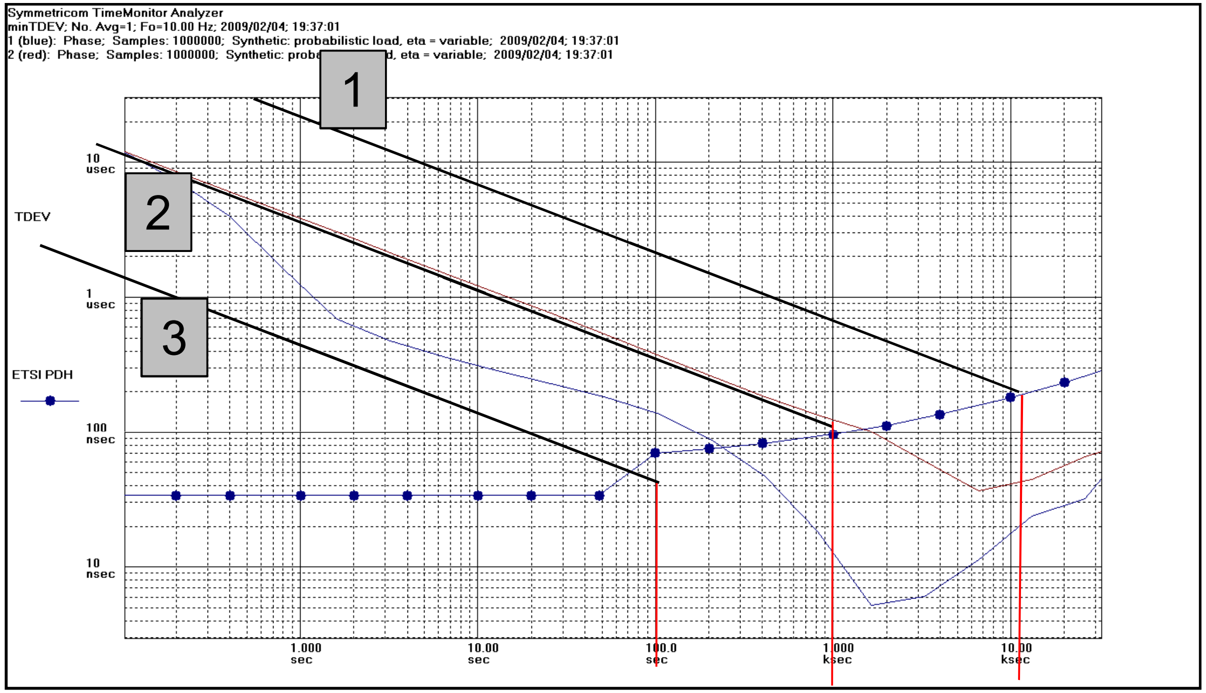
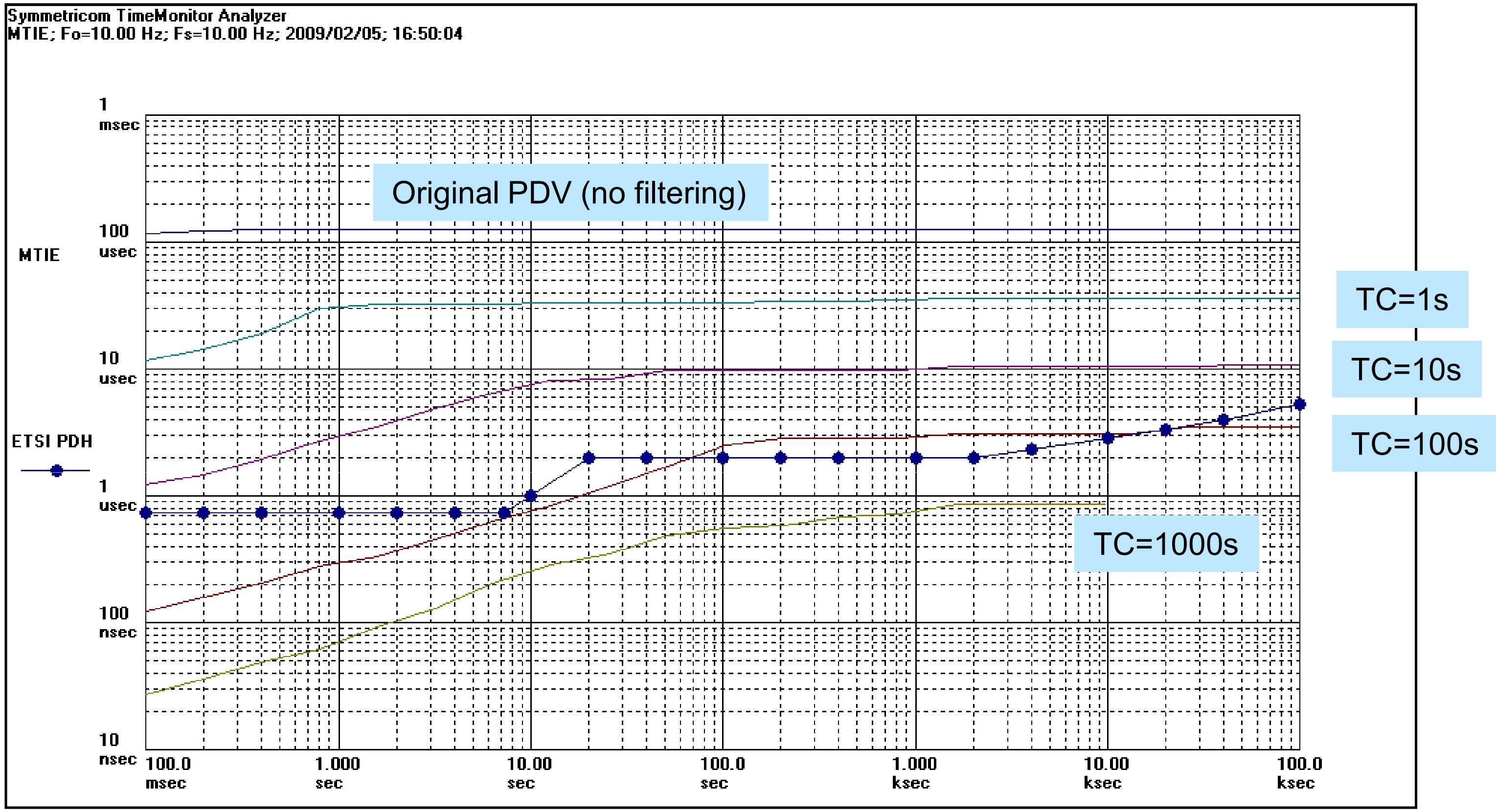
PDV Processing example



- (Mask , time-constant): (1,1000s); (2,400s); (3,50s) applies at point “B”
- No pre-filtering required if time-constant > 1000s
- With time-constant = 400s, averaging is inadequate but minimum picking over a window > 10samples will meet mask
- Neither averaging nor minimum picking works if time-constant ≤ 50s

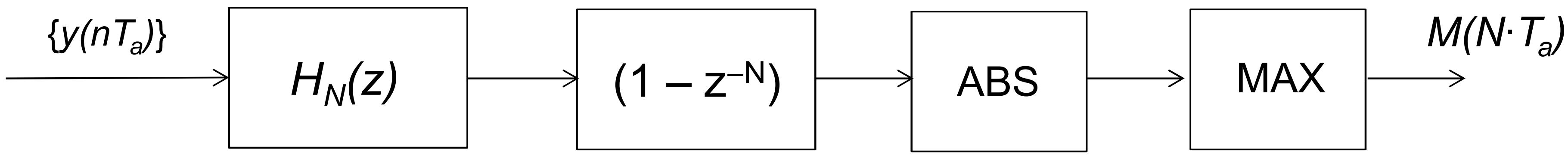
MTIE/MRTIE – impact of low-pass filtering



- MTIE after filtering the PDV [at point "A"] implying no pre-filtering
- 1000s time-constant achieved in two-steps (convenience)
- The reduction in the overall MTIE (MRTIE) with low-pass filtering is basis for MATIE (ZTIE)

MATIE (ZTIE) and MAFE

- Generally applied at point "B" (simulate packet selection if necessary) where sampling interval = T_a
- Can be viewed an a bank of low-pass filters with varying time-constant ("observation interval")
  - $H_N(z) = (1/N)(1 + z^{-1} + z^{-2} + \ldots + z^{-(N-1)})$
- Utilizes the notion of MTIE being a (maximum) peak-to-peak measure
- $\text{MAFE}(\tau) = \text{MATIE}(\tau)/\tau$



(repeat with N = 1, 2, 3, …); $\tau = N \cdot T_a$

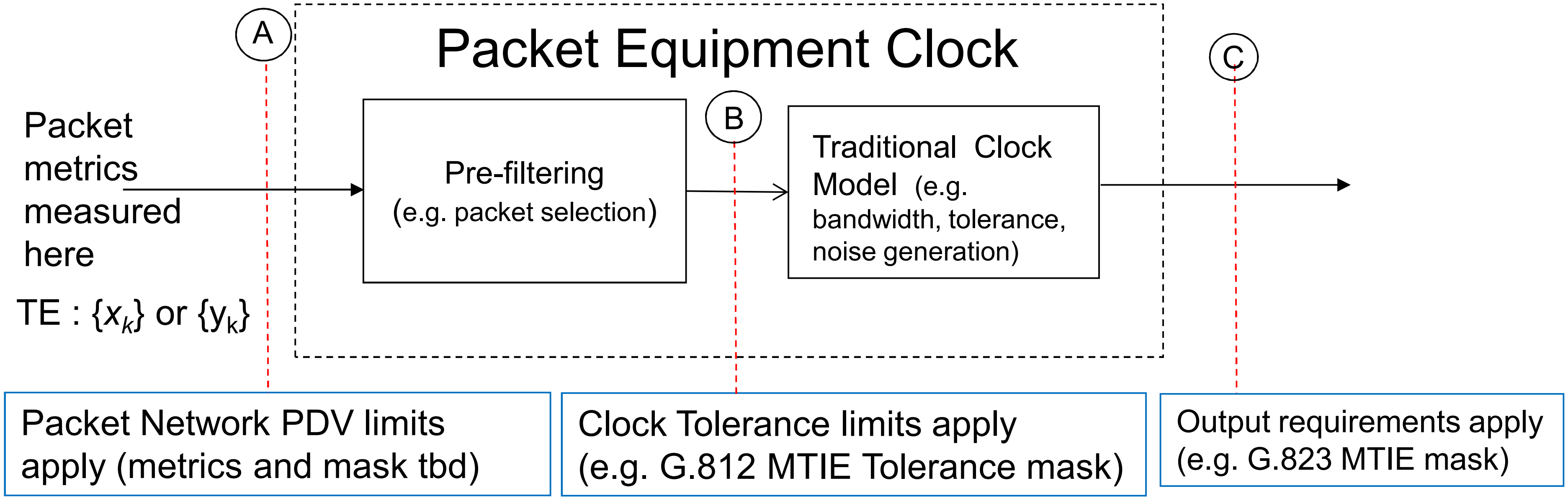
Ongoing Discussions in ITU-T on the different metrics

Metrics family	Metrics	Characteristics	Potential Use	Open Issues
TDEV	**TDEV**	- no packet selection - useful for networks where packet delay distributions has not with a well-populated mode somewhere in the packet delay distribution - sensitive to systematic effects - no sensitive to frequency offsets - no sensitive to a small number of outliers	- Provides information on network packet delay noise processes . - To specify tolerance and network limits in case of 1,5 Mbit/s or 2 Mbit/s clock recovery (e.g. according to G.823 masks) - It is not optimal for frequency offset characterization. - The different metrics in this family could be used in combination depending on the characteristics of the delay distribution (i.e. optimum packet selection)	Definition of the related mask.
	minTDEV	- packet selection incorporated into the calculation - useful for networks where it is possible to identify a suitable set of packets with packet delay variation close to a minimum delay - sensitive to systematic effects - sensitive to a small number of outliers - sensitive to frequency offsets		
	Perc.TDEV	- in some circumstances, noise is reduced - packet selection incorporated into the calculation - sensitive to systematic effects - sensitive to a small number of outliers - sensitive to frequency offsets		
	BandTDEV	- additional complexity - effective for packet delay distributions with a well-populated mode somewhere in the packet delay distribution		

Ongoing Discussions in ITU-T on the different metrics, cntd

Metrics family	Metrics	Characteristics	Potential Use	Open Issues
MTIE	**MATIE**	-packet selection pre-processing prior to the calculation -predicts the performance of a first order filter	- optimal for frequency offset characterization in the time domain. - not suited for the study of noise processes	Packet Selection mechanism still unclear. Definition of the related mask (only corner frequency is relevant?).
	MAFE (min Selection)	-packet selection pre-processing prior to the calculation -predicts the performance of a first order filter -sensitive to a small number of low-lying outlier	- optimal for frequency offset characterization in the frequency domain. - not suited for the study of noise processes - The different packet selection approaches could be used in combination depending on the characteristics of the delay distribution	
	MAFE (band selection)	-packet selection pre-processing prior to the calculation -additional complexity -effective for packet delay distributions with a well-populated mode somewhere in the packet delay distribution		

Hypothetical Reference Model for a Packet-based Clock



Packet based Equipment Clock modeling:

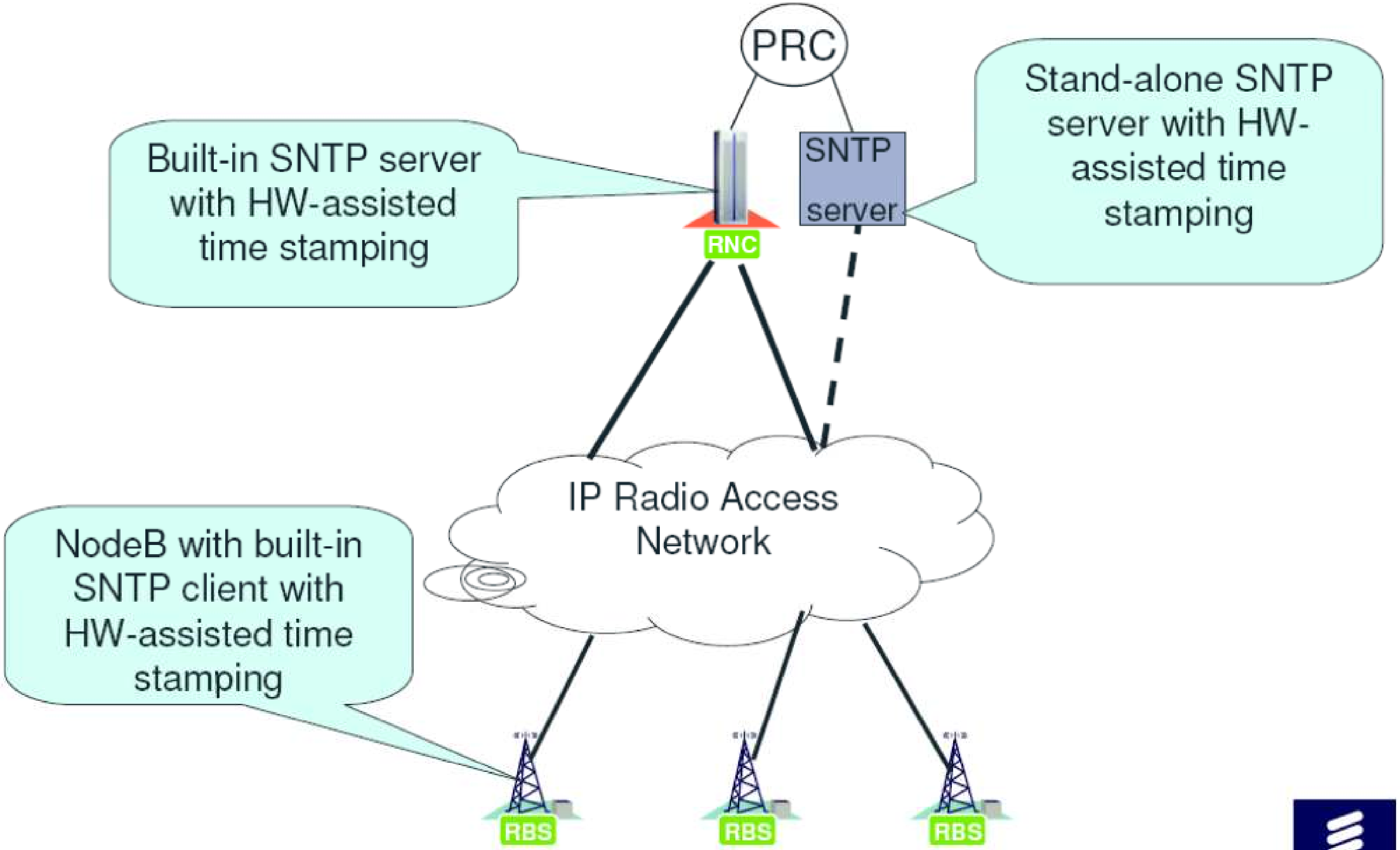
- partitioned into a traditional "TDM" based clock and a prefiltering block
- pre-filtering (e.g. Packet selection) strictly related to the relevant metrics
  - minimum (delay) in "window"
  - average (delay) in "window"
  - any proprietary algorithm should do as well or better

two simple choices

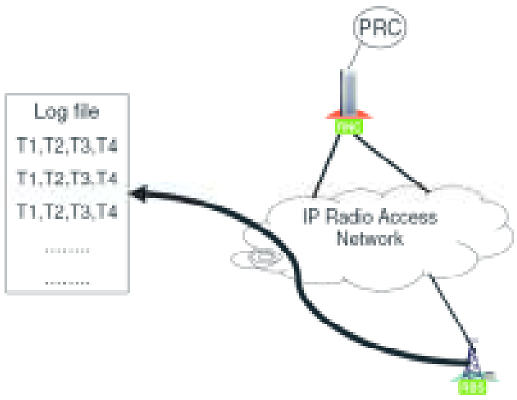
PDV Metrics and Packet Based Clocks

- The definition of Packet Based Clock is a priority item in standardization bodies (e.g. ITU-T SG15/Q13 – G.8263) (see slide 11).
  - Despite some clear differences with the clock traditionally used in TDM networks, there are important similarities
- The approach currently agreed upon is to model the clock with a pre-filtering function (i.e. packet selection function).
  - With this model the PDV metric (mask) would apply at the input of the pre-filtering (in case of the MAFE some selection mechanism shall be assumed))
  - If (traditional) MTIE/TDEV masks can be defined at the output of the pre-filtering, the remaining part of the clock can be defined according to the traditional (TDM-style) specifications
  - New masks (extensions of existing masks) may be required (e.g. in case of packet based clock integrated in a Base Station there is no MTIE mask currently standardized; requirements on the radio interface is only specified in terms of frequency, e.g. 50 ppb)
- The following experiments provide justification that multiple metrics might be needed in combination...
  - i.e. even if one metric provides a negative indication, it might still be OK!

General Structure of Experiment

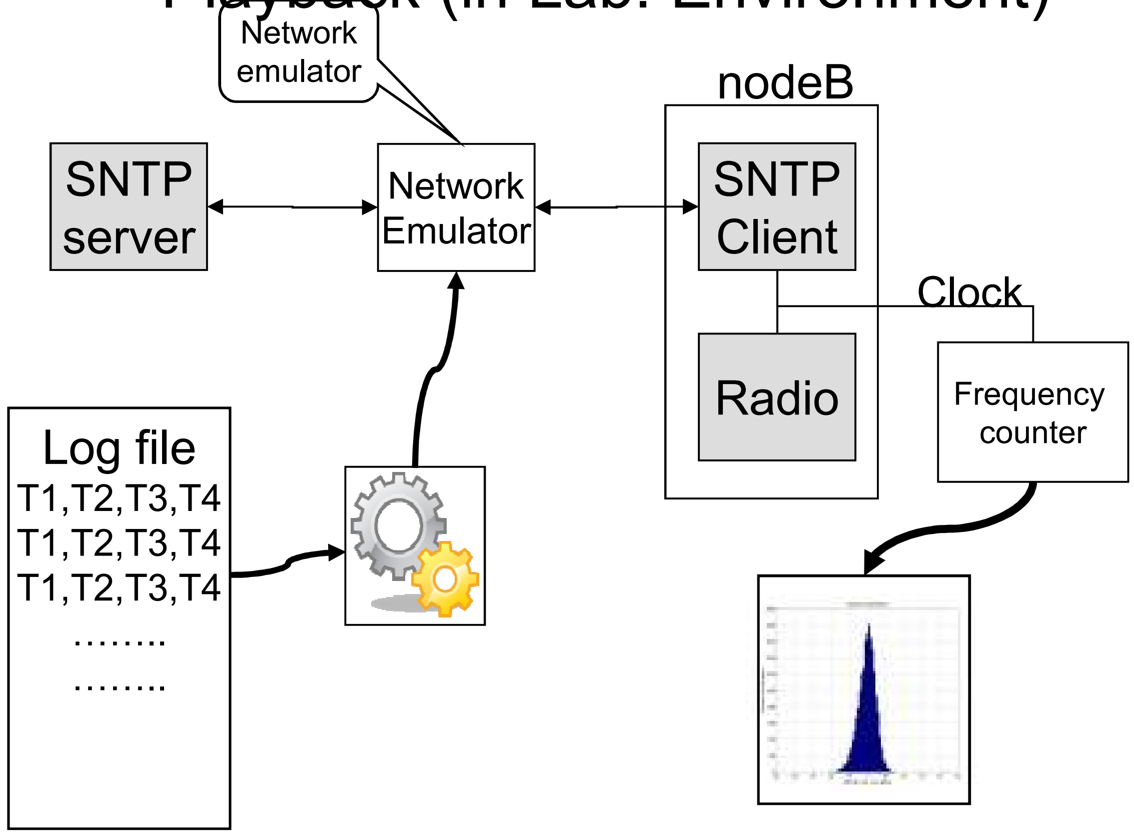


Data Collection and Playback



Collection (in field)

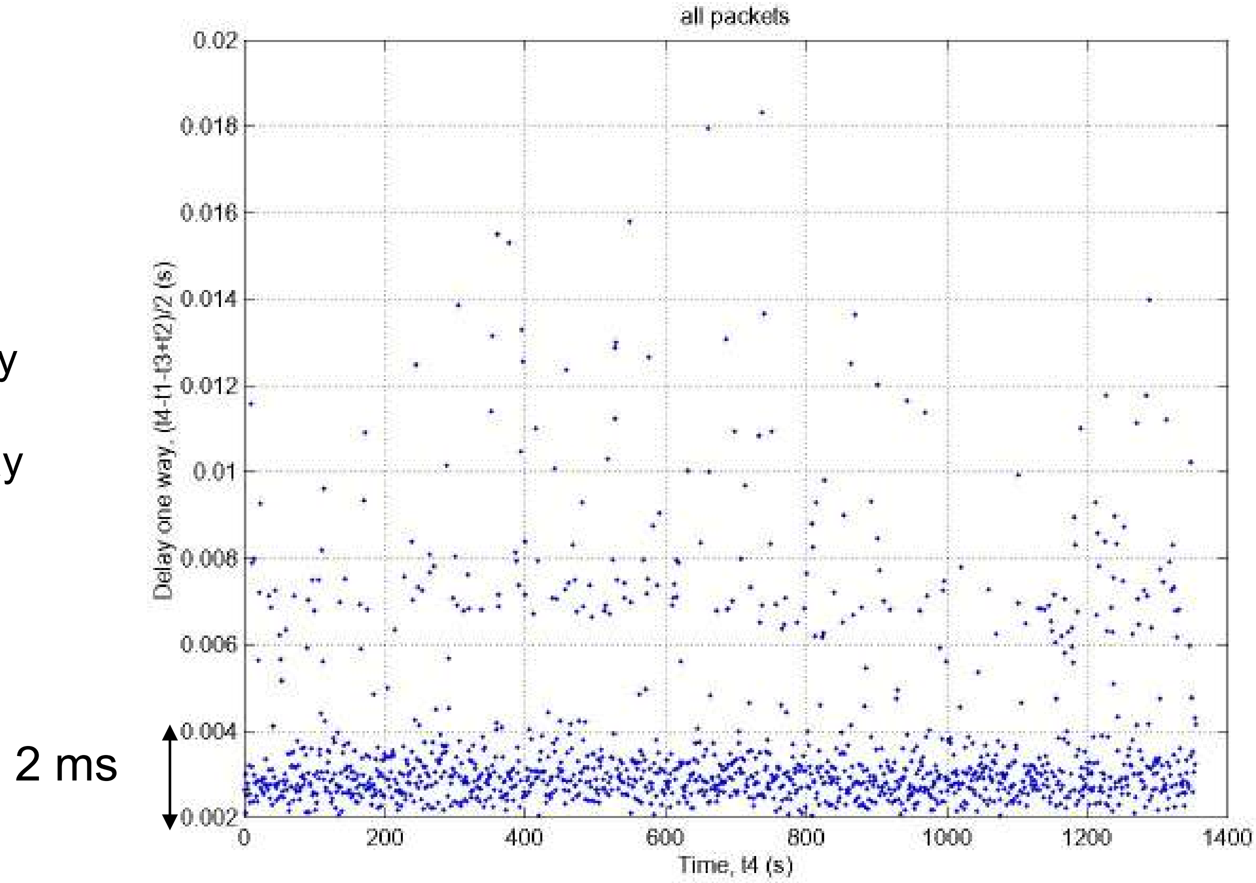
Playback (in Lab. Environment)



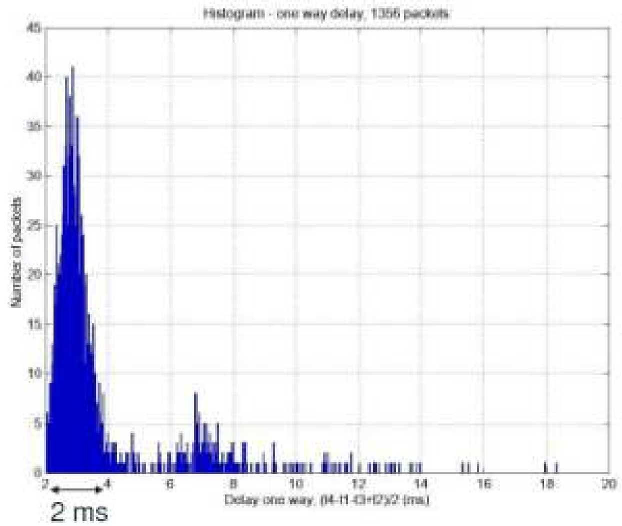
Measured delay — example #1

Network particulars not known. Meets the 3GPP expectation that 98% packets have < 10ms delay

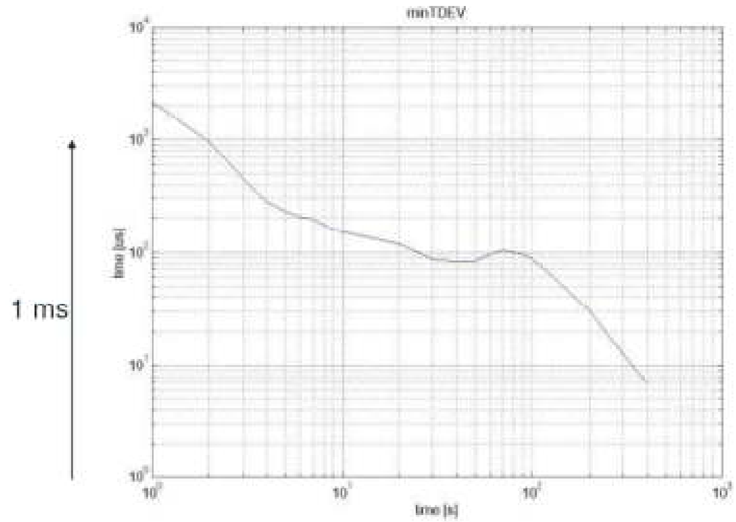
One-way delay
= one-half of
round-trip delay



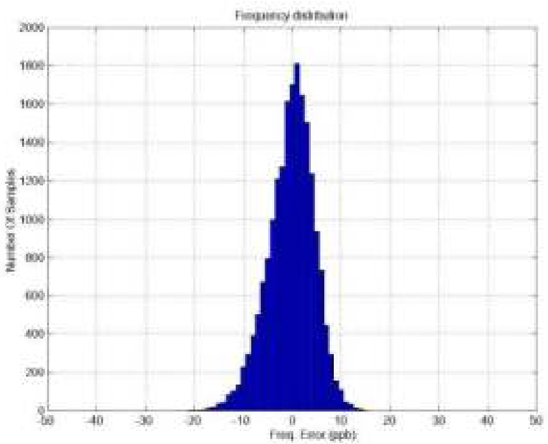
Analysis of delay – example #1



Probability Distribution of delay



minTDEV computed on delay sequence



Short-term fractional frequency offset histogram. Note that frequency deviation has mean 0 and extremes less than ~20ppb.

Note also that minTDEV behavior indicates that (near-)minimum packet selection will be effective (below 30 microseconds in tau=200s).

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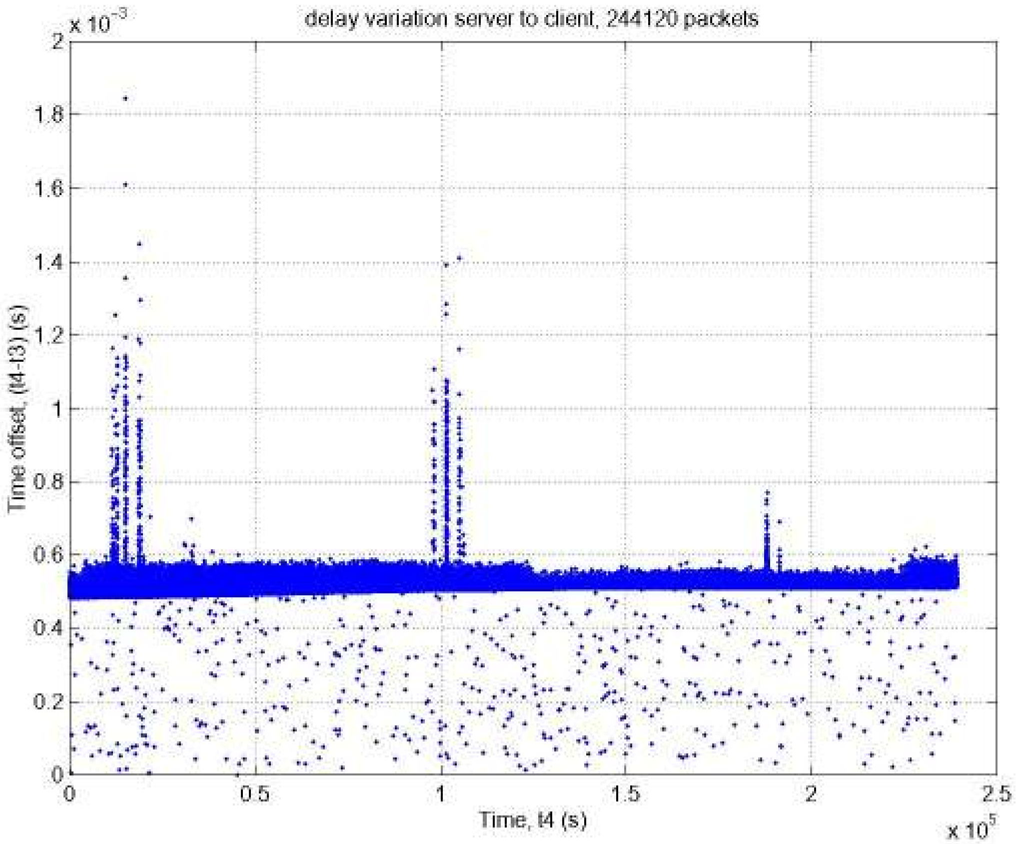
Measured delay – example #2

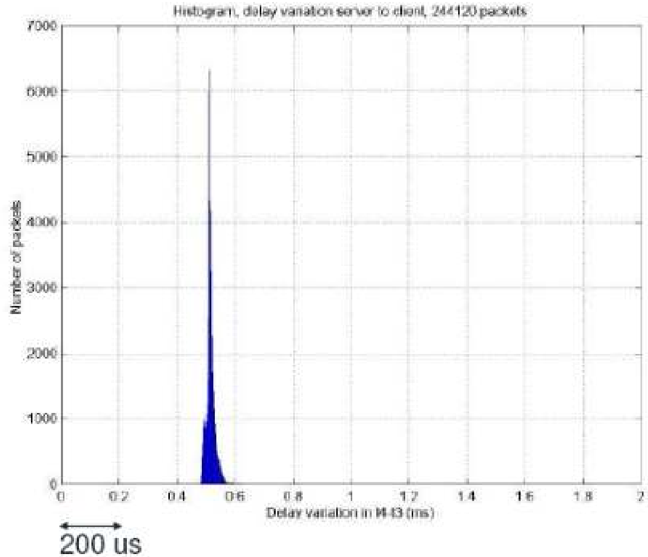
One-way delay meets the expectation that 98% packets have < 10ms delay; minimum delay difficult to quantify

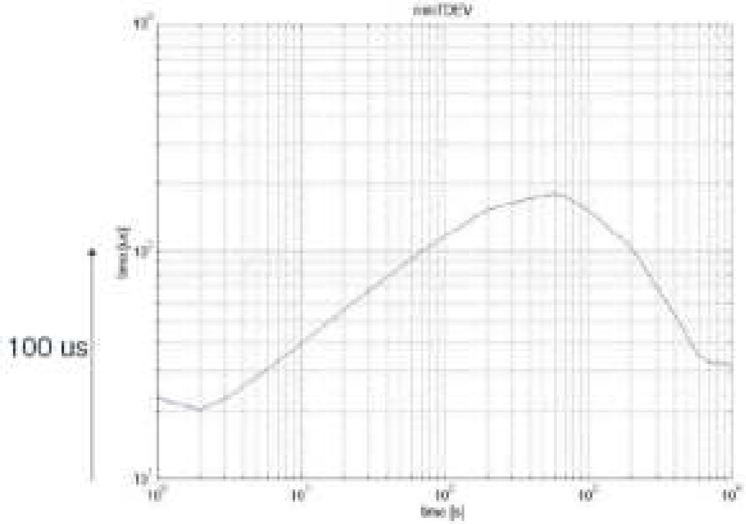
One-way delay
(estimate)

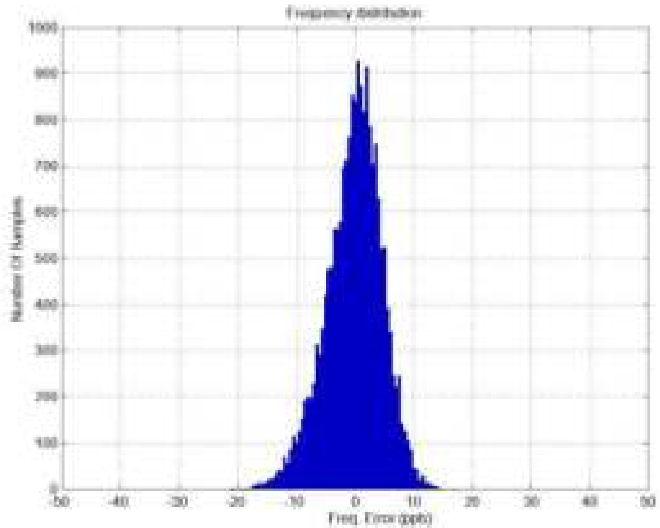
200 us



Analysis of delay – example #2







Short-term fractional frequency offset histogram. Note that frequency deviation has mean 0 and extremes less than ~20ppb. The clock entered lock condition in less than 10 min

Note however that minTDEV behavior indicates that the use of minimum delayed packets might not be efficient (100 microseconds noise at tau=2000 s)