Assisted Partial Timing Support – Metrics

ITSF 2014, Budapest

Time in Distribution, Performance & Measurement

Kishan Shenoi (kshenoi@Qulsar.com)

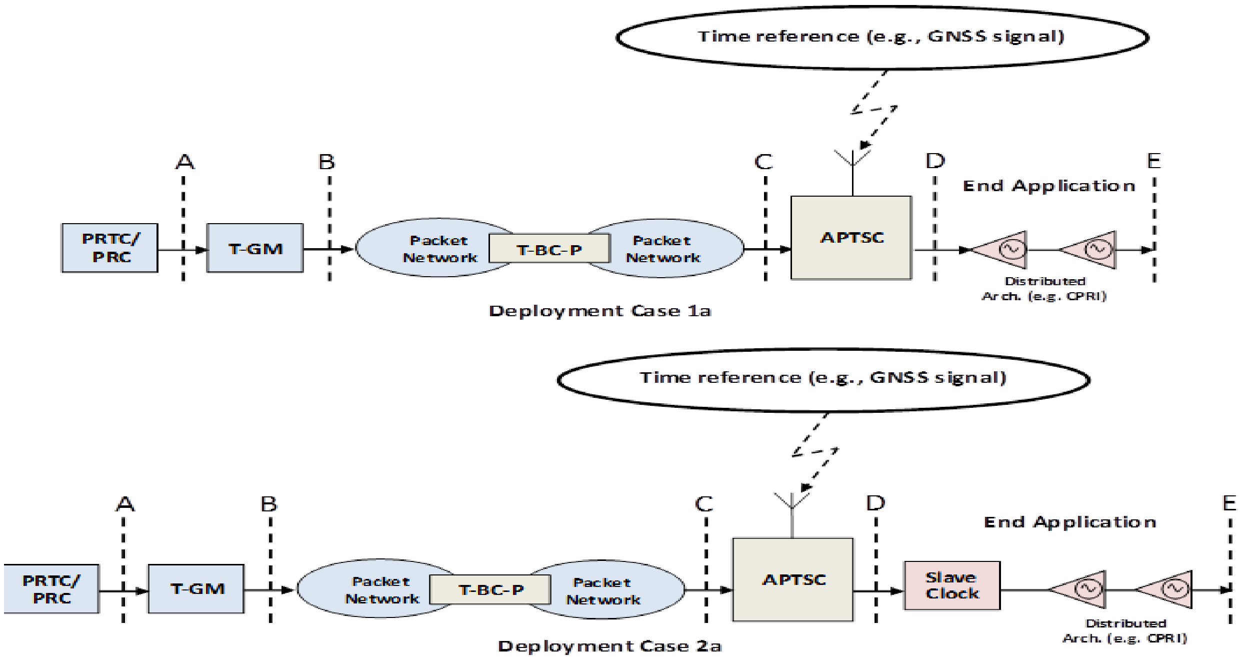
Qulsar, Inc., San Jose, California

Outline

- Principal concept of the Assisted "Partial-Support" approach for timing in a wireless (LTE) environment
  - Combination of GNSS and PTP approaches
- Mathematical principles underlying APTSC
  - Introduction to APTSC in companion presentation

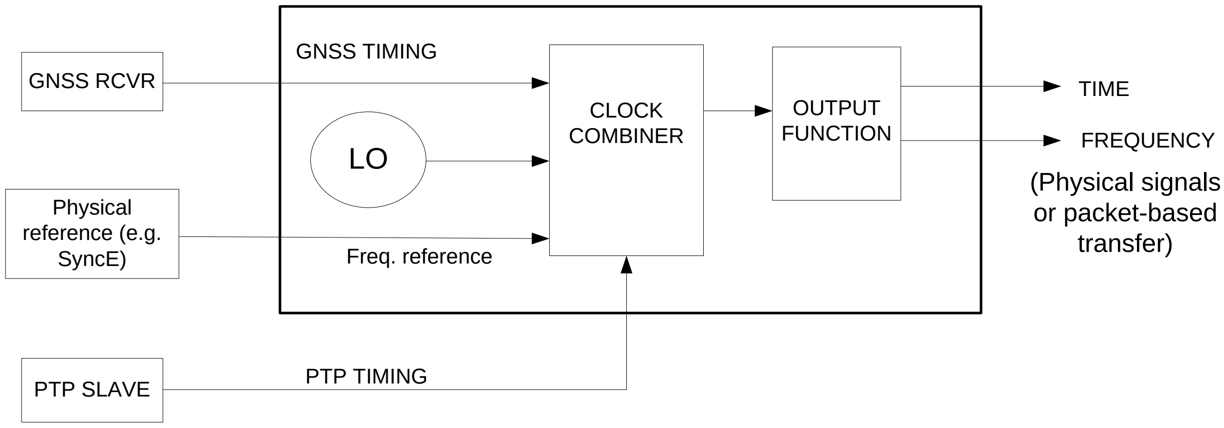
Conceptual View of Assisted Partial-Support

(From ITU-T Contribution WD11-Copenhagen)



- The PRTC function is GNSS based (e.g. GPS)
- The packet network between device and upstream master (GM or T-BC) may not be full on-path support (hence “partial-support”)
- Primary reference for APTSC (and T-GM) is GNSS
- PTP provides time-holdover when GNSS becomes unavailable

Conceptual View of APTSC



- Output function provides the output timing signal
  - PTP Master and/or 1PPS+ToD and/or frequency(e.g. 1544/2048)
- Clock Combiner considers all sources to generate the composite time/frequency to drive the output function
  - Primary reference GNSS
- Holdover (when GNSS is unavailable) using one or more of the other sources available
  - Physical references (e.g. SyncE may not be available)
- Not indicated: Ability to coordinate references (especially PTP and/or SyncE and/or GNSS working in concert)

Operational Principles

Primary Reference : GNSS

- While GNSS is active ("valid"):
  - Generate output clock (time/frequency) – time error < 100ns
    - Output time-clock absolute error should be < 100ns
  - Measure packet-delay variation (PDV) for PTP packets
  - Compute metrics that enable prediction of time-holdover when PTP used to generate output
  - Monitor performance of local oscillator and other references (if available)

Secondary Reference : PTP

- When GNSS is lost ("invalid"):
  - Use PTP timing (frequency) to control progression of time-clock (case considered here)
    - Possible Alternative: use PTP time-clock (assuming asymmetry calibration)

- Tertiary Reference : LO / other Reference
    - Frequency reference/local-oscillator fallback if PTP timing is inadequate

Mathematical Basis

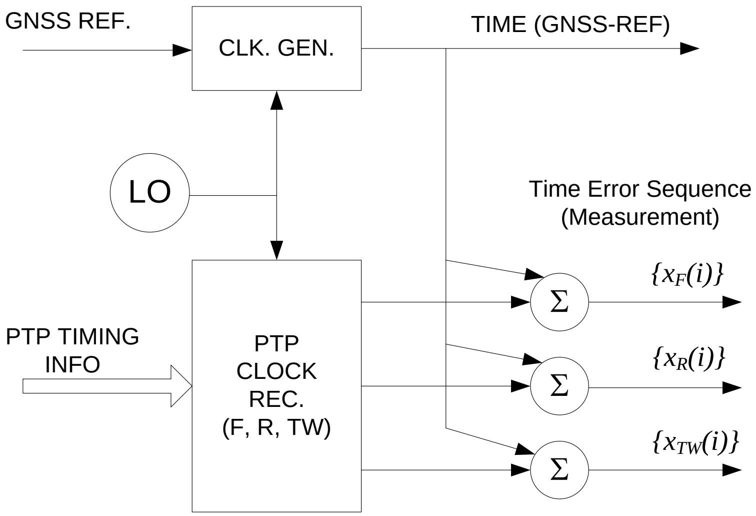
QULSAR

- Let t = 0 be the point that GNSS declared invalid. The time error of the "holdover clock" modeled as:

$$x(t) = x_0 + y_0 \cdot t + \underbrace{\int_0^t \gamma(\tau)d\tau + \varphi(t)}_{\text{Holdover error}}$$

  - x_0 is the initial error (GNSS error + transient effect) (reduces holdover budget)
  - y_0 is the initial frequency error (generally ≈ 0)
  - $\gamma(\ )$ is the frequency error due to temperature changes and aging
  - $\varphi(\ )$ represents the random noise component
  - Performance metrics computed on "holdover error" while GNSS valid to develop KPIs

Measurement basis

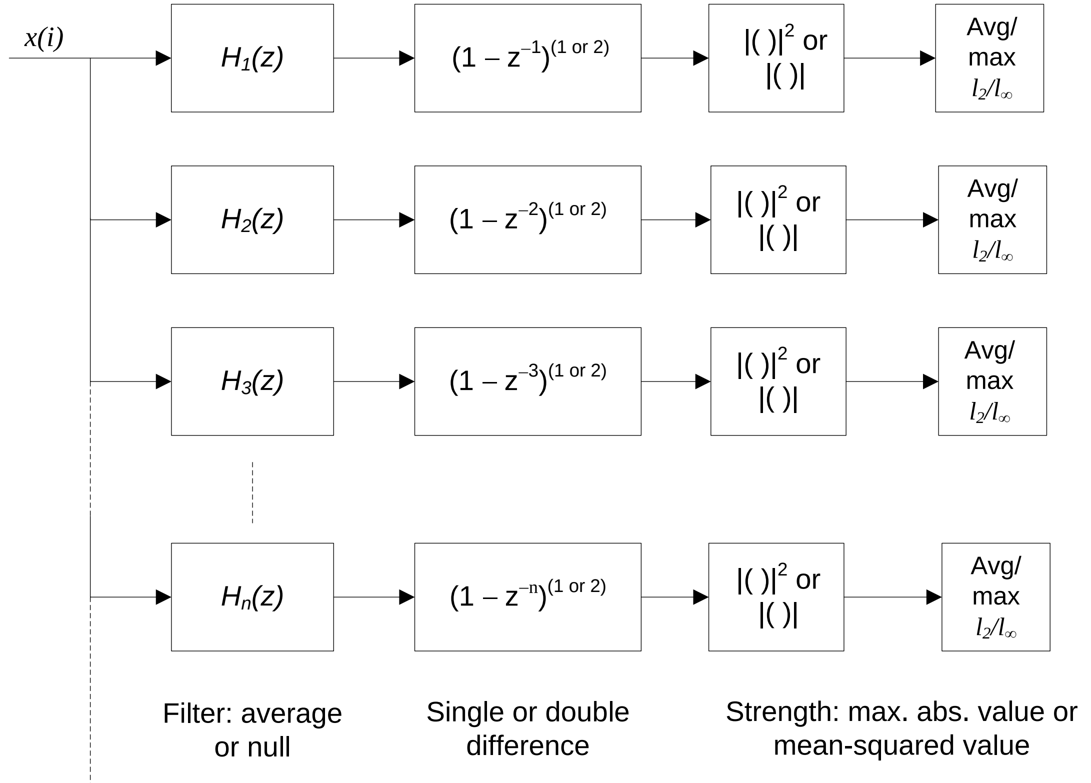


- PTP clock recovery could be based on one-way (F or R) or two-way
- The recovered PTP clock could be a physical signal or “paper clock”
- The PTP “clock recovery” processing block must include any non-linear operations such as packet selection
- The PTP “clock recovery” processing block may include linear-time-invariant operations such as low-pass filtering

Metrics - Computation

- Metrics are computed on time error sequence $\{x(k)\}$; implied sampling interval = τ_0
- Intent is to see how much dispersion could occur in an interval (*aka* observation interval) $\tau = n\tau_0$
- *First difference* : $\{x(k+n) - x(k)\}$ removes constant time error x_0
- Double difference : $\{x(k+2n) - 2x(k+n) + x(k)\}$ removes x_0 as well as frequency offset y_0
- Smoothing function (optional) : Average over *n* consecutive values
- Strength calculation: maximum-absolute value or mean-square value (variance) (square-root gives rms or standard deviation)

Metrics - Computation



$$H_n(z) = \frac{1}{n} \cdot \sum_{k=0}^{n-1} z^{-k}$$

(average over n consecutive values)

- MTIE calculation does not fit neatly into this model
- Boundary points need to be handled with care when data set is finite

Important Metrics

Metric	Strength calc.	Filter	Difference level	Comments
MATIE (MAFE)	maximum	averaging	First difference	Identifies frequency offset
TIE_{rms}	(root) mean-square	none	First difference	Power of time error
TEDEV (TEVAR)	(root) mean-square	averaging	First difference	Power of time error
TDEV (TVAR)	(root) mean-square	averaging	Second difference	Power of time error
ADEV (AVAR)	(root) mean-square	none	Second difference	Power of time error (indirect)
MDEV (MVAR)	(root) mean-square	averaging	Second difference	Power of time error (indirect)

optimum prediction of time dispersion is proportional to ADEV:

$$\Delta t(\tau) = constant \cdot \tau \cdot \sigma_y(\tau)$$

Example of Performance Estimation

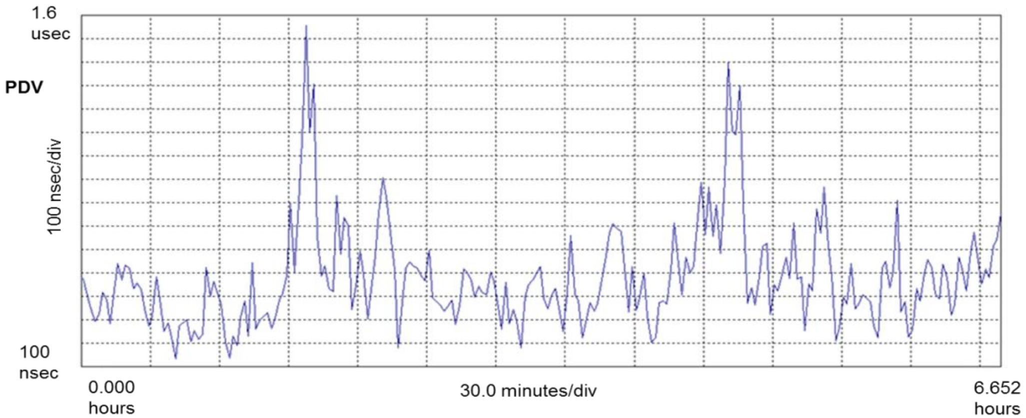
QULSAR

- Assume:
  - Overall time-holdover requirement: 1.5μs
  - Budget for GNSS error and switching transient: 500ns
  - Holdover using PTP frequency recovery using master-slave direction (*sync_messages*)
    - Packet rate: 32 pps
    - Selection mechanism: 1% over 100s windows
    - Filtering bandwidth: 1mHz
- One possible metric: MTIE
  - Requirement: MTIE(τ) < 1000ns
- Simulation:
  - 5 GigE switches
  - Load : mean load = 60% ; standard deviation = 20%

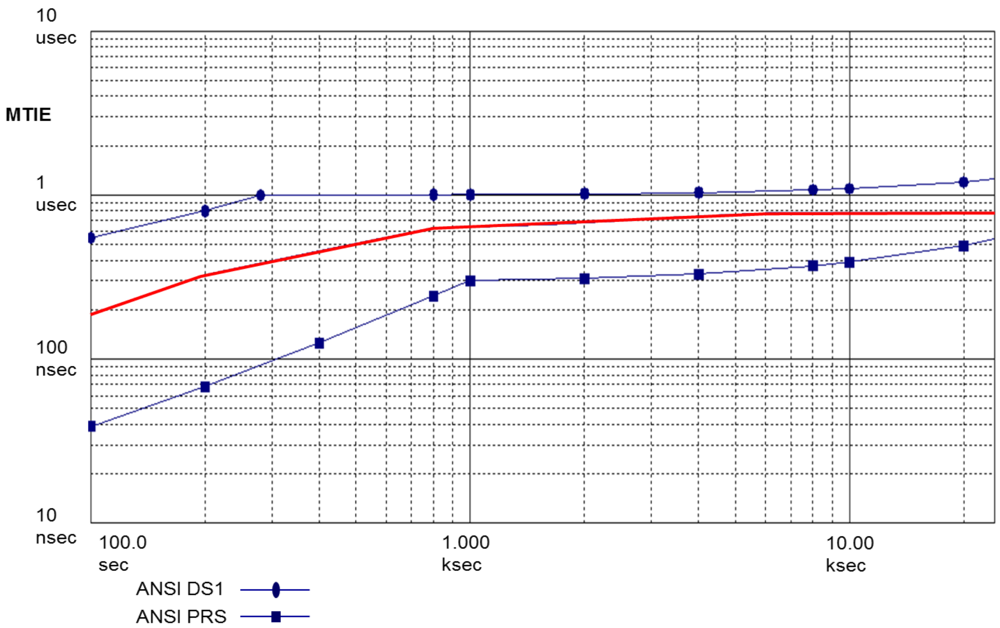
Simulation Example

- Assumption:
  - Overall time-holdover requirement: 1.5μs
  - Budget for GNSS error and switching transient: 500ns
  - Holdover using PTP frequency recovery using master-slave direction (*sync_messages*)
    - Packet rate: 32 pps
    - Selection mechanism: 1% over 100s windows
    - Filtering bandwidth: 1mHz
- Simulation model:
  - PTP packet is “highest priority”
  - Loading follows a flicker model, changing every 250ms
  - Packet rate: 32pps
  - PDV introduced in switch by “head-of-line blocking”
  - Network has 5 GigE switches
  - Interfering traffic… 90% is “large” packets (1.5kbyte)
  - Load : mean load = 60% ; standard deviation = 20%

Simulation Example



Packet-delay-variation (PDV) based on:
– “floor”
– 1-percentile
– 100s window
– representative transit delay equal 1-percentile average

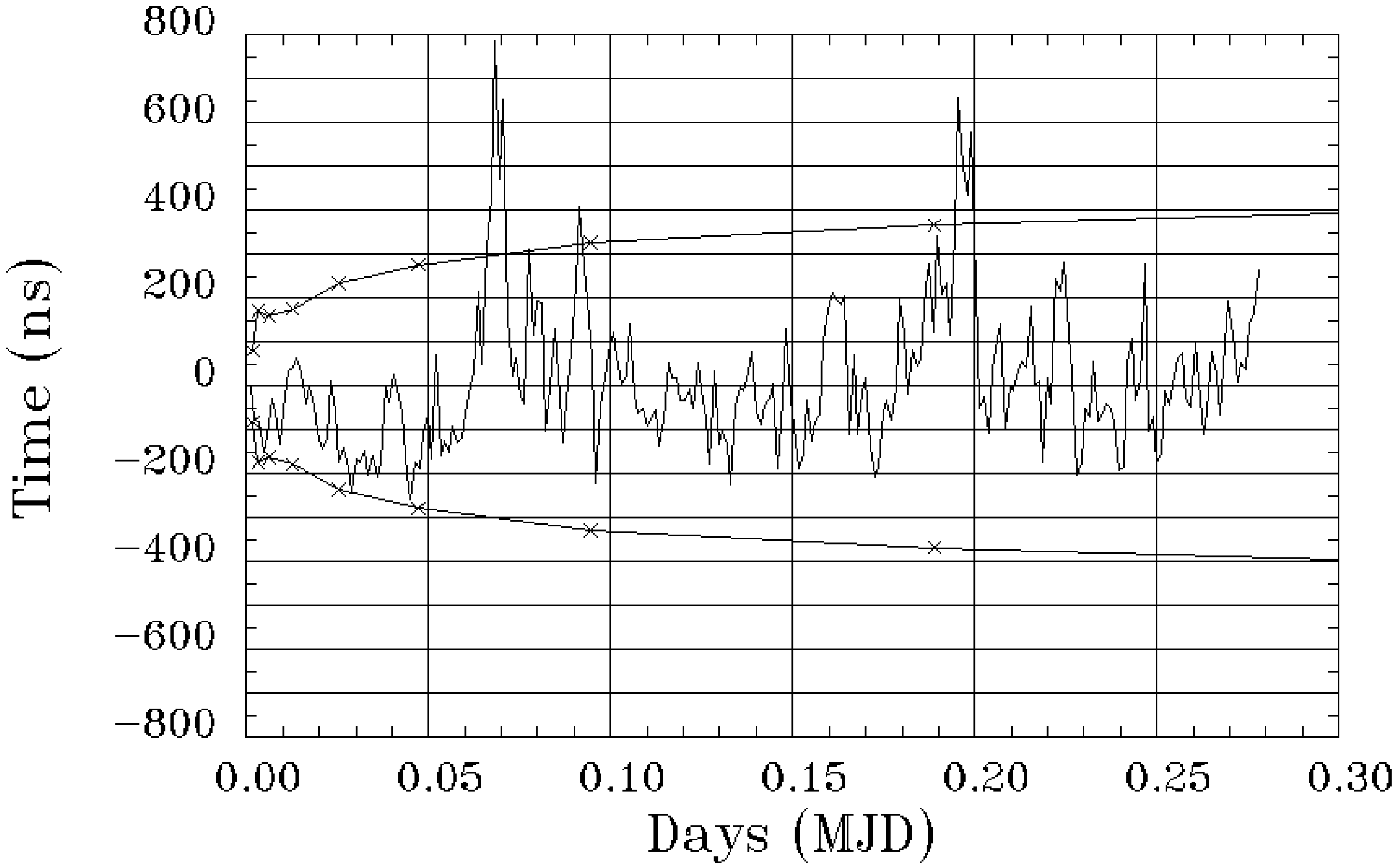


MTIE :
– 1mHz filter
– $<1\mu s$

Conclusion:
– With this network PDV, PTP (one-way-frequency) can support time-holdover indefinitely
– “Alarm” condition: GREEN

Simulation Example

Expected Dispersion based on simulated PDV



Taken from earlier presentations by Dr. Marc Weiss

Concluding Remarks

- Time holdover using PTP can be predicted
- When GNSS is active the network PDV can be measured and quantified
  - Metrics are computed on measured PDV and not necessarily related to network configuration (such as number of switches)
- Metrics (e.g. MTIE, TDEV, etc.) quantify strength of noise process and estimates of (future) time dispersion if in holdover
- Companion presentation provides an introduction to the principles underlying Assisted Partial-Support

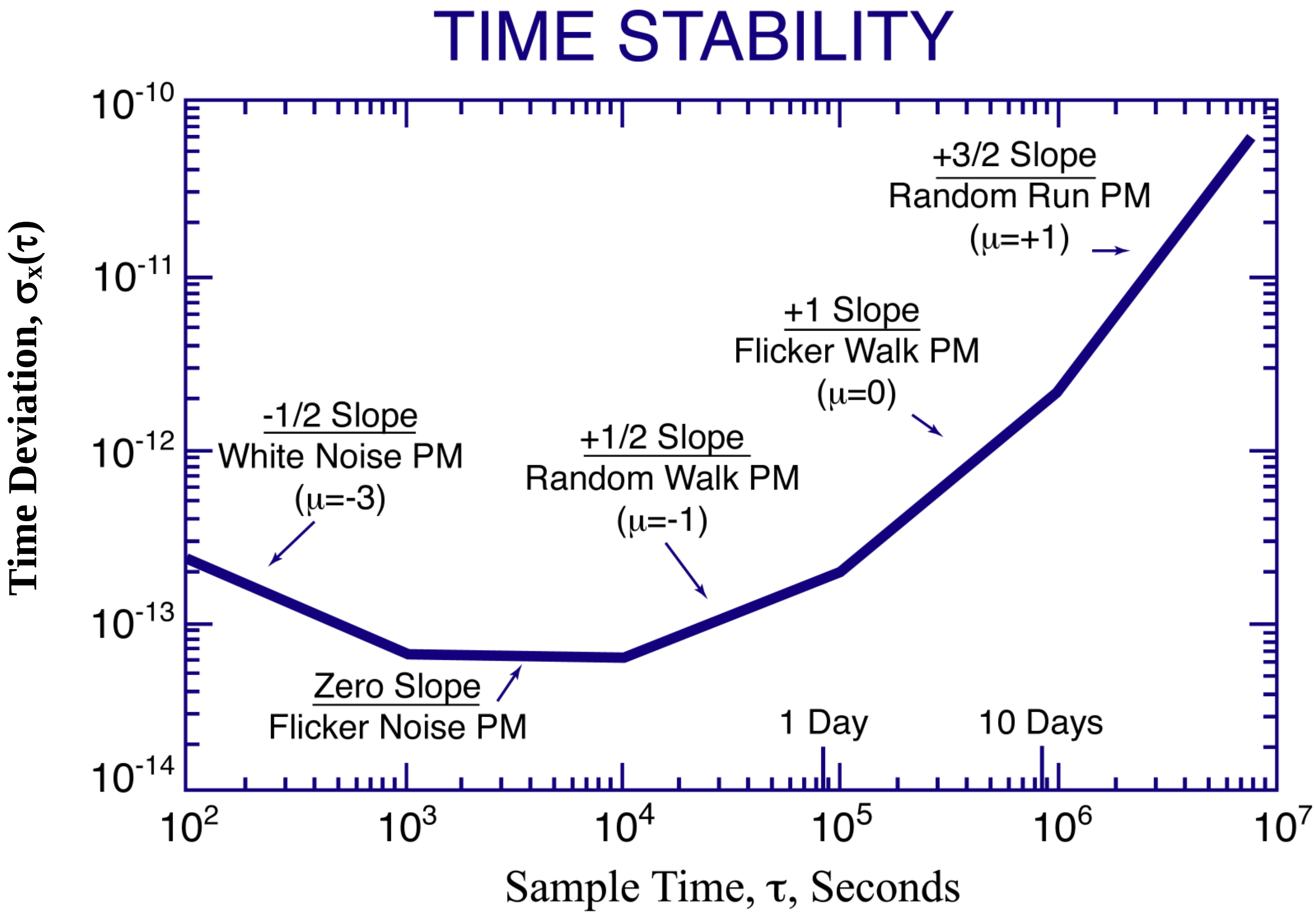
Thank You!

Questions?

Kishan Shenoi (kshenoi@Qulsar.com)

BACKUP SLIDES

TDEV Reveals the Noise Type



Taken from earlier presentations by Dr. Marc Weiss

Estimating Time Dispersion

Optimum Prediction is Based on Noise Types

α	Typical Noise Types Name	Optimum Prediction $x(\tau_p)$ rms[a]	Time Error: Asymptotic Form
2	white-noise PM	$\tau_p \cdot \sigma_y(\tau_p)/\sqrt{3}$	constant
1	flicker-noise PM	$\sim \tau_p \cdot \sigma_y(\tau_p)\sqrt{\ln \tau_p / 2 \ln \tau_0}$	$\sqrt{\ln \tau_p}$
0	white-noise FM	$\tau_p \cdot \sigma_y(\tau_p)$	$\tau_p^{1/2}$
−1	flicker-noise FM	$\tau_p \cdot \sigma_y(\tau_p)/\sqrt{\ln 2}$	τ_p
−2	random-walk FM	$\tau_p \cdot \sigma_y(\tau_p)$	$\tau_p^{3/2}$

[a] τ_p is the prediction interval.

These expressions are in terms of the Allan Deviation

Taken from earlier presentations by Dr. Marc Weiss