SYNCHRONIZATION IN PACKET NETWORKS: TIMING METRICS AND MONITORING

Charles Barry and Srinivas Bangalore
Brilliant Telecommunications
307 Orchard City Drive,
San Jose, CA 95008, USA
E-mail: *srinivas@brillianttelecom.com*

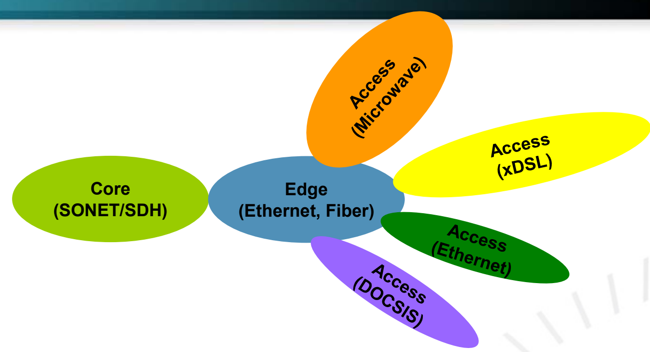
Abstract

Packet Delay Variation (PDV) is a major impediment to transferring timing from a source (Master/Server) to destination (Slave/Client) over a packet-switched network. PDV directly affects frequency alignment (syntonization) and asymmetry of PDV impacts time alignment (phase). There is considerable interest in the industry to establish a relationship between PDV and the ability to recover time/phase/frequency via a packet-based method (e.g., PTP, NTP). Recent developments in PDV analysis have indicated that it is feasible to build accurate models of network behavior under varying conditions of load, number of switches, forwarding algorithms, QoS implementation, and so on. It has also been shown that no single metric (e.g., TDEV, minTDEV) is sufficient to characterize PDV and that a suite of metrics is necessary. Study of PDV also develops intuition and permits heuristic approaches to be devised that use nonlinear processing to filtering of the PDV, greatly enhancing the performance of clock recovery compared to linear PLL methods.

In this presentation, Brilliant will provide experimental results and demonstrate that: (1) Practice does indeed have relationship to theory. Proper measurements are indeed consistent, repeatable, and significantly predictable; (2) Proper heuristics and multiple metrics provide high-quality clock recovery and knowledge of the transport layer (e.g., GigE, xDSL) can be applied to improve performance.

Implication of Network Evolution

brilliant



- Networks will be a hybrid of circuit-switched (i.e. legacy) segments and packet-switched segments
  - Circuit-switching good for real-time, delay-sensitive, low-bandwidth, continuous, 100%-duty-cycle traffic
  - Packet-switching good for non-real-time, delay-insensitive, high-bandwidth, bursty, low-duty-cycle traffic
- TDM streams (e.g. DS1/E1) will be transported over packet-switched networks introducing Circuit/Packet boundaries

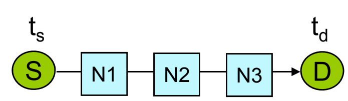
Networks are heterogenous; packet timing metrics must be flexible to account for different packet forwarding and media access

BRILLIANT PROPRIETARY 3

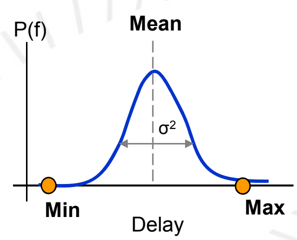
Packet Delay Variation Metrics

brilliant

- Metrics that characterize Packet Delay Variation (PDV) are computed from the sequence $\{x_k\}$ of delay measurements:
  - Probability density function (pdf) or cumulative distribution function (cdf) or histogram - all provide the same information related to amplitude, including:
    - Mean: x_{av} – Average of all values in the sequence x_k
    - Variance: $\sigma_x^2 = \langle x_k^2 \rangle - \langle x_k \rangle^2$ { < > is the average}
    - Standard deviation: square root of variance
    - Minimum, x_{min} : largest value such that $x_k > x_{min}$
    - Maximum-95 , x_{max} : smallest value such that $P[x_k < x_{max}] > 0.95$
  - Spectral metrics (e.g. TDEV) address temporal distribution
    - Implied sampling interval = t_0 (packet interval)
    - TDEV is a measure of stability of the mean
    - minTDEV estimates stability of the minima



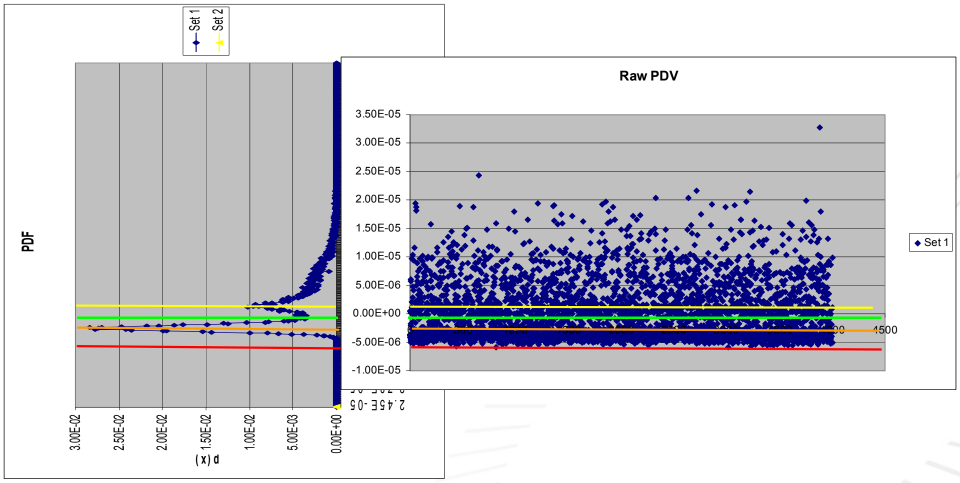
Delay = t_d - t_s



BRILLIANT PROPRIETARY 4

Interpreting Packet Delay Variation Charts

brilliant

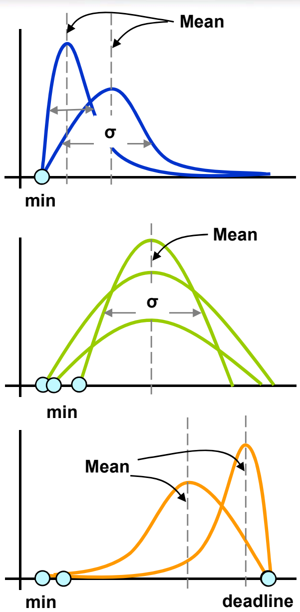


5 Switches 40% Load w/QoS – Multiple stable peaks in PDV pdf
min is always useful, but at high loads other metrics, if stable, may be used

BRILLIANT PROPRIETARY 5

The Need for Multiple Metrics

brilliant



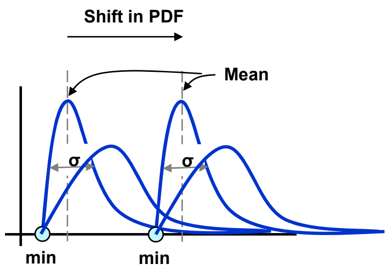
- Hardware-based routing/switching
- Forward packets as soon as possible
- *min* is a good measure for moderate loads and hop counts

- Point-to-point Media Access delays
- Media Access time variability is minimized
- *Mean* is a good metric, *min* is not

- Software-based forwarding
- Processes scheduled to meet real-time deadlines – “just in time” completion
- Deadline (*max*) may be a more stable metric than *min* at high loads

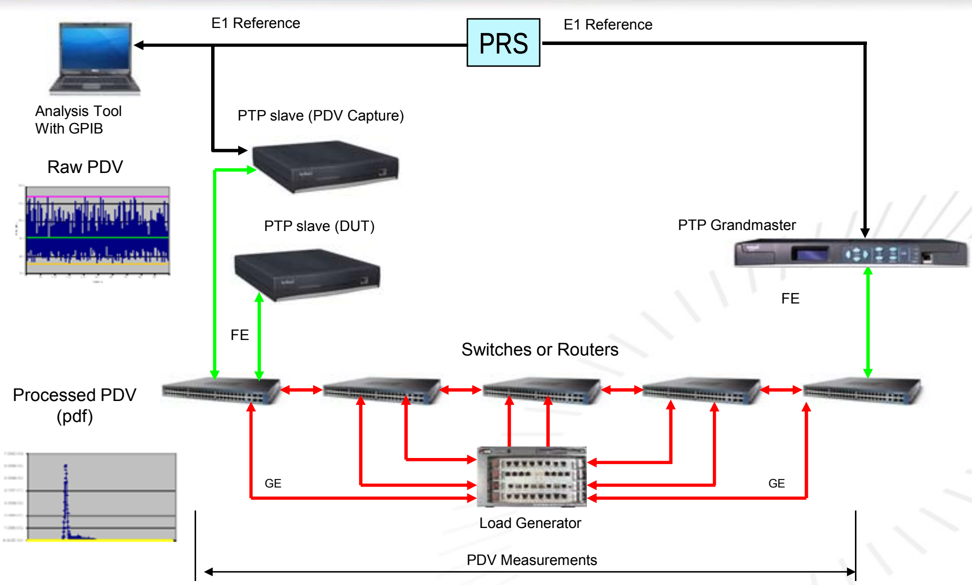
BRILLIANT PROPRIETARY 6

The Need for Multiple Metrics



- Network Reconfiguration Detection
- Discontinuity in *min* and *mean* is useful to detect network rearrangements
  - Network protection switching
  - Network additions/deletions/outages
- *Variance* can be used to provide a measure of confidence of the detection
- End-point Frequency and Phase must remain stable during revertive and non-revertive rearrangement scenarios

G.8261 Test Setup – PDV Analysis



PDV Measurement Tool

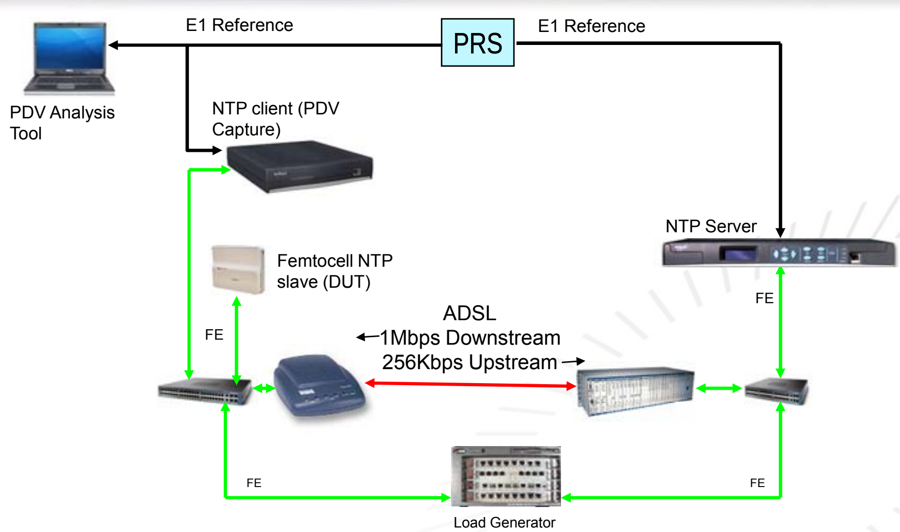
brilliant

- Measures PDV to 16ns resolution
- Uses NTP or PTP
- Logs PDV in Real Time
- Off-line analysis and modeling
  - Provides ability to improve understanding of network behavior
  - Impact of load, Hop-Count, QoS and forwarding algorithms on network performance
- Provides insight into the improvement of the time sync algorithms
  - Multiple Metrics – min, mean, max, variance

BRILLIANT PROPRIETARY 9

ADSL/Femtocell Test Setup

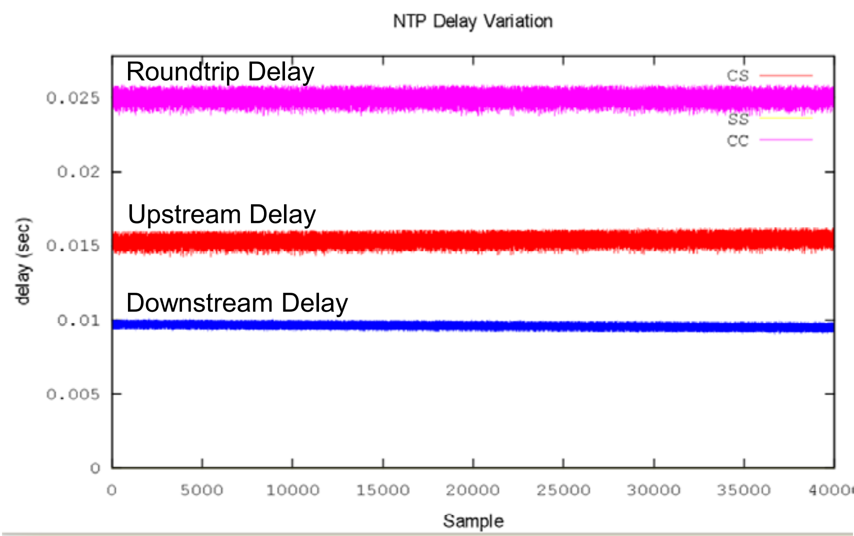
brilliant



Maintain Femtocell Frequency (and Phase) accuracy over Asymmetric DSL

BRILLIANT PROPRIETARY 10

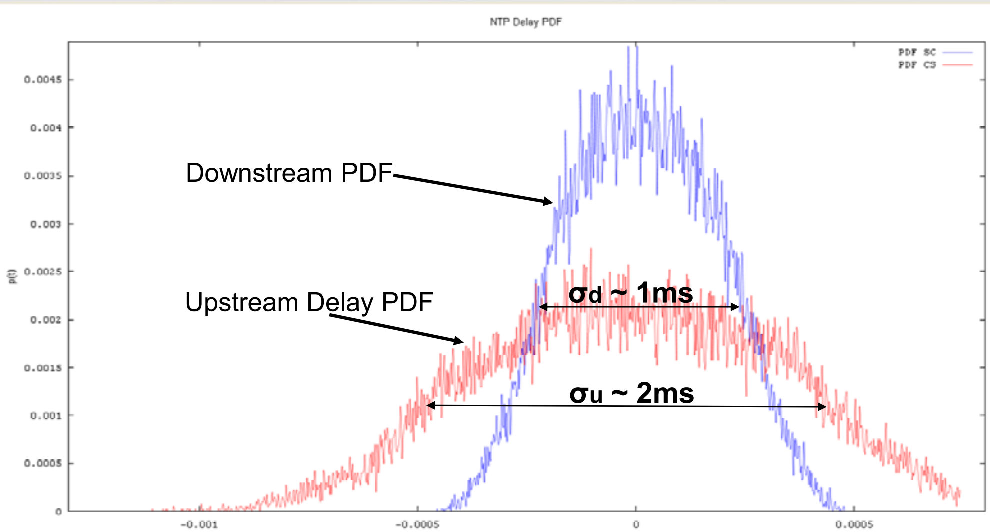
ADSL/Femtocell – Delay Variation



Highly Asymmetric Delay; Jitter order of magnitude greater than GbE: 1-2ms vs. 100μs

BRILLIANT PROPRIETARY 11

ADSL Test Setup – PDF Analysis



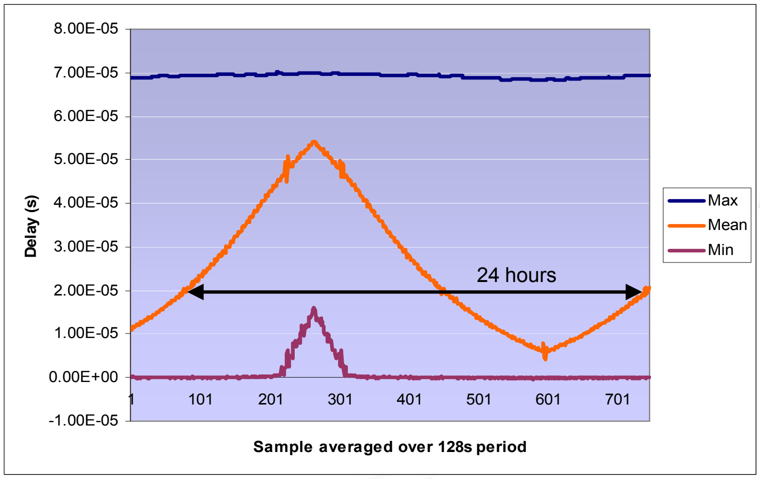
ADSL: Highly asymmetric PDF, downstream is more stable (less variance) than upstream

BRILLIANT PROPRIETARY 12

Deadline-based Software Delay

brilliant

5 Hops, G.8261 Test Case 3 – 24 Hour Cycle 20% to 80% Load



Mean metric is unusable for timing analysis
Min metric is extremely stable at low to moderate loads
However, *Max* in this case is a stable metric for timing at high loads

Concluding Remarks

brilliant

» PDV monitoring in Next Generation Networks provides clock distribution assurance

» Monitoring achieved using timing client/server communications with existing protocols (e.g., PTP, NTP)
  – IEEE1588v2/PTP is suitable for Mobile Backhaul networks
  – NTP is suitable for Femtocell timing over Layer 3 IP Access

» Multiple PDV metrics may be appropriate for synchronization
  – min is a very useful metric in most, but not all cases
  – min, mean, max and variance have important roles
  – Packet timing must gracefully accommodate heterogeneous networks, media access and network rearrangement scenarios