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Network PDV accumulation study for frequency delivery with PTPv2

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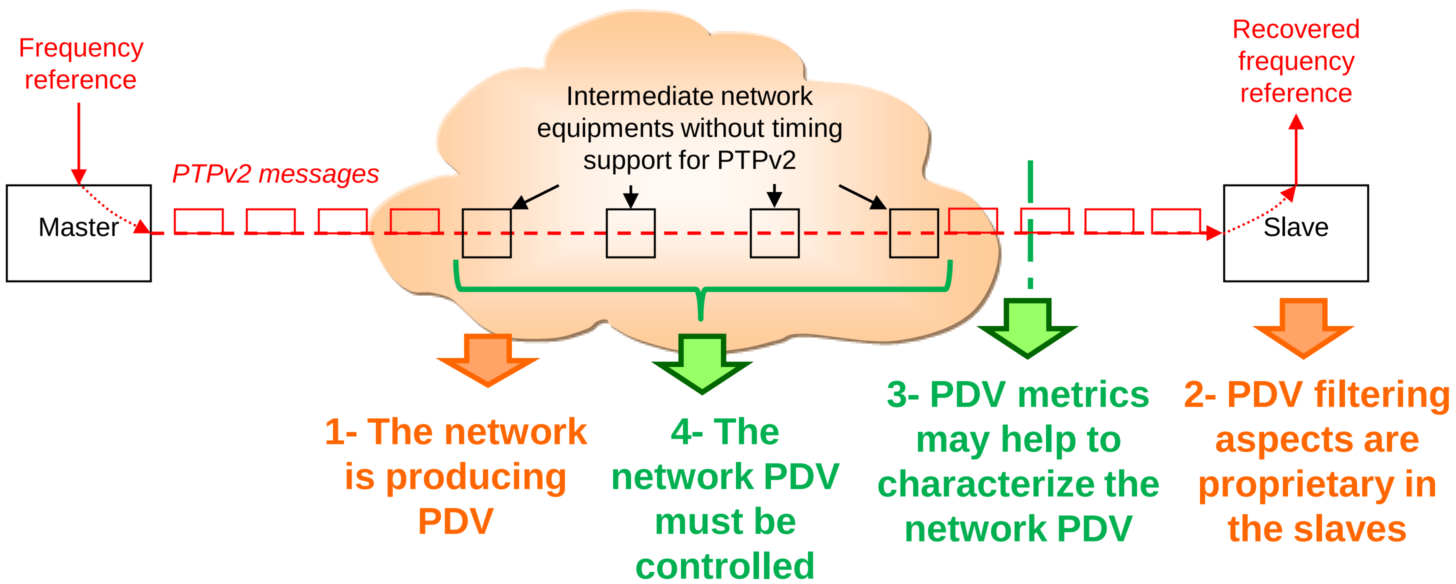
Agenda

Importance of network PDV accumulation and PDV metrics for an operator

Scope of the presentation

- Important efforts are on-going within standard bodies to study the **performance aspects of packet based methods**, such as IEEE1588v2
  - Short term need: **frequency distribution** over existing networks (i.e. no timing support from the network equipments) **=> focus of the presentation**
  - Longer term need: **phase/time distribution** over networks that may provide timing support from the network equipments (e.g. SyncE + BC or TC) in order to immune to PDV and asymmetry (likely to be necessary due to very stringent requirements)
- Key parameter impacting packet based methods performances when there is no timing support from the network nodes: **Packet Delay Variation (PDV)**
  - Essential to study the typical PDV that is seen over different telecom networks
  - Critical to develop engineering rules enabling a operator to deploy end-to-end packet based solutions for frequency with (almost) guaranteed performance
  - Important to standardize metrics characterizing PDV in an appropriate way, that do not corresponds to a specific implementation, and that enable building the network
- This paper introduces a model of **network PDV accumulation**, based on statistical analysis of the PDV generated by each network node

What are the challenges?



- 1- PDV generated by the network may lead to performance issues for the slave, and it is very difficult to predict it without studying the network equipments
  - The PDV that is observed today is not necessarily the PDV that will occur tomorrow
- 2- Different slaves may use different criteria to filter the PDV generated by the network
- 3- PDV metrics should enable to determine if the network PDV is acceptable for a slave in order to respect a certain performance objective
- 4- Appropriate methodology is required to build a network which meets the PDV tolerance of the filtering algorithms implemented in the slaves
  - Main question: how many nodes of different technologies can be cascaded?

Why defining appropriate PDV metrics is important?

- The use of **existing metrics (TIE/MTIE/TDEV) is still very important** in the packet environment, but not sufficient for end-to-end packet based methods
- **PDV generated by the network may evolve** as the network changes and grows
  - More data traffic to be carried, or new type of data traffic
  - New equipments/cards can be deployed in the network
- Importance to **monitor the PDV of the network**
  - During testing of PTP slaves (key parameter impacting performance)
  - Before and during field trials and deployment phases
  - After roll out, for troubleshooting (but only in case of problems, not all the time)
- Methodology for measuring PDV and analyzing the key components impacting the quality of the timing reference recovered by the PTP slaves is critical
  - PDV metrics / appropriate masks are expected to provide a **GO/NOGO information**
- Similar need for **new metrics is also foreseen for phase/time** for an operator (out of the scope of this presentation), but without specific PDV metrics consideration in case of timing support from the network equipments

Network PDV accumulation model

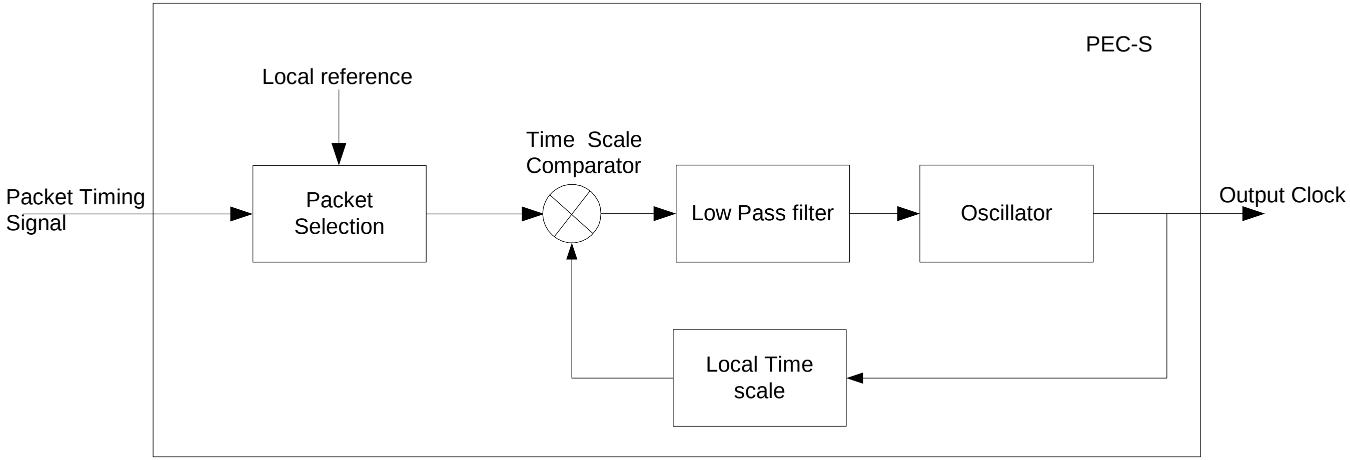
Objectives of the network PDV accumulation studies

- **Provide engineering rules regarding performance aspects for the deployment of PTPv2 technology for end-to-end frequency distribution** (using ITU-T G.8265.1 telecom profile) when the PTPv2 slave is embedded in the base station
  - Main question to be answered: how many transport nodes can be deployed between a PTPv2 master and a PTPv2 slave while maintaining the Packet Delay Variation (PDV) acceptable to achieve a given performance objective?
  - The number generally depends on the technology considered, but also on the specific hardware implementation of the transport nodes considered

- First step of the study: **check that the PDV accumulation can be correctly estimated** with suitable mathematical tools (e.g. convolution operation)
  - Results: the convolution operation estimation is quite correct for a hop-by-hop uncorrelated data traffic, but needs further investigation for end-to-end data traffic
- Second step of the study: perform **simulations based on convolution operation** applied on worst case PDV histograms obtained with PDV measurements to determine the theoretical maximum number of nodes which can be placed between the PTPv2 master and the PTPv2 slave (first results are given later)

Model of a packet slave clock

- <u>Model of a packet slave clock in ITU-T G.8263 latest draft</u>:

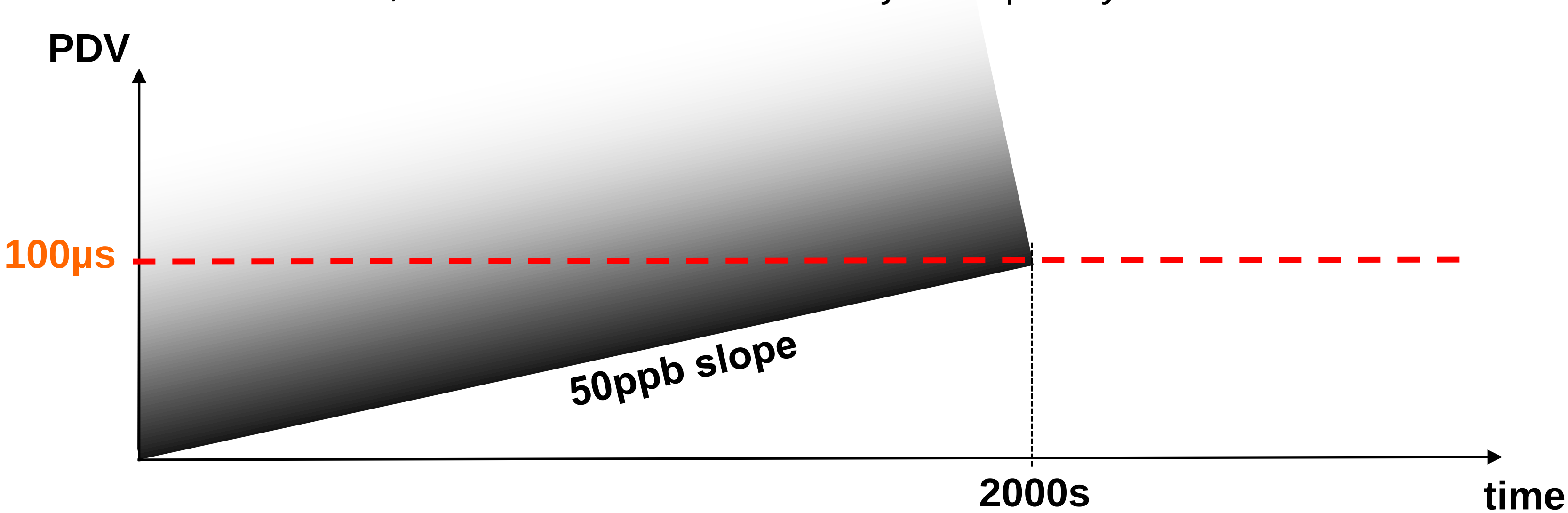


- PDV filtering algorithms are proprietary, however, common behaviors are seen:
  - **Packet pre-selection is almost always performed**: not all the PTP packets that are received are used for frequency recovery, only a subset
  - **Packets are selected in general according to their transit delay**: for instance, the packets located into a given delay window if their population is sufficient
- Therefore, if a network always offers, per design, a sufficient population of packets located in a given fixed delay window, then the slave performance should be improved (<u>it has been observed during testing</u>), and possibly almost guaranteed in some cases (e.g. slave targeting 50ppb)

- **Frequency recovery only with PTP slave embedded in a base station**
- Packet slave clock requirement: 50ppb (3GPP requirement for air interface)
- Physical clock implemented in the packet slave clock: time constant of few thousands of seconds (e.g. 2000s) – in line with existing base stations
- Criteria used by the packet slave clock to filter PDV: fastest packets/floor delay
  - Note: the values above are arbitrary and may be slightly modified (e.g. 16ppb to leave margin to the base station, time constant higher than 2000s if a better oscillator is used, etc…)
  - Need to standardize these values in the future (e.g. in ITU-T G.8263)
- The key aspect leading to choose the floor delay criteria is that, in most of the PDV testing performed, prioritizing the packet timing flow (e.g. PTPv2 flow) enables to reduce the amplitude of the floor delay steps which occur when the network load increases, thus to optimize the packets close to the floor delay
  - Note: **the same model could be applied with delay window not located at the floor delay** (for instance, for technologies which do not offer a good population of packets close to the floor delay, e.g. DSL links) – point under study

How to determine a worst case frequency error?

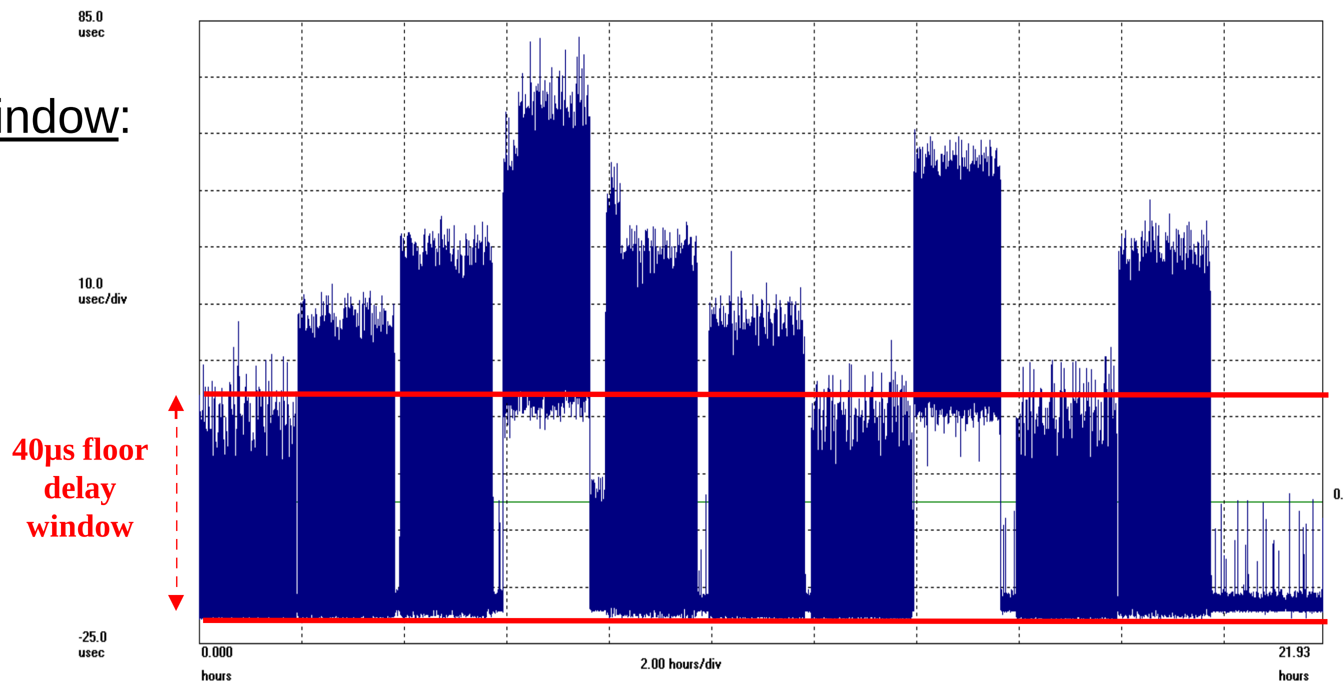
- Slow increase of data traffic load (e.g. over hours) may theoretically lead to slowly increase the delay transit of the fastest packets in the network
  - In this situation, the slave will be affected by a frequency error



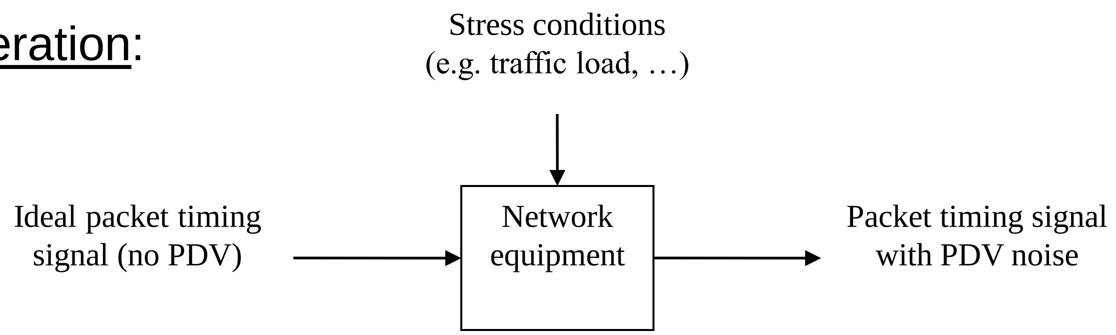
- Assuming that the fastest packets are pre-selected by the PTP slave, to ensure 50ppb accuracy, the maximum input noise after the selection of the "good" packets must be 100µs if the time constant is 2000s
  - Therefore, a 100µs floor delay window will be considered as a possible example
  - The size of the floor delay window is a tradeoff: a higher time constant can enable increasing the size of the floor delay window (>100µs), but a tighter accuracy objective (<50ppb) may lead to decrease the size of the floor delay window

Concepts used in the PDV accumulation studies

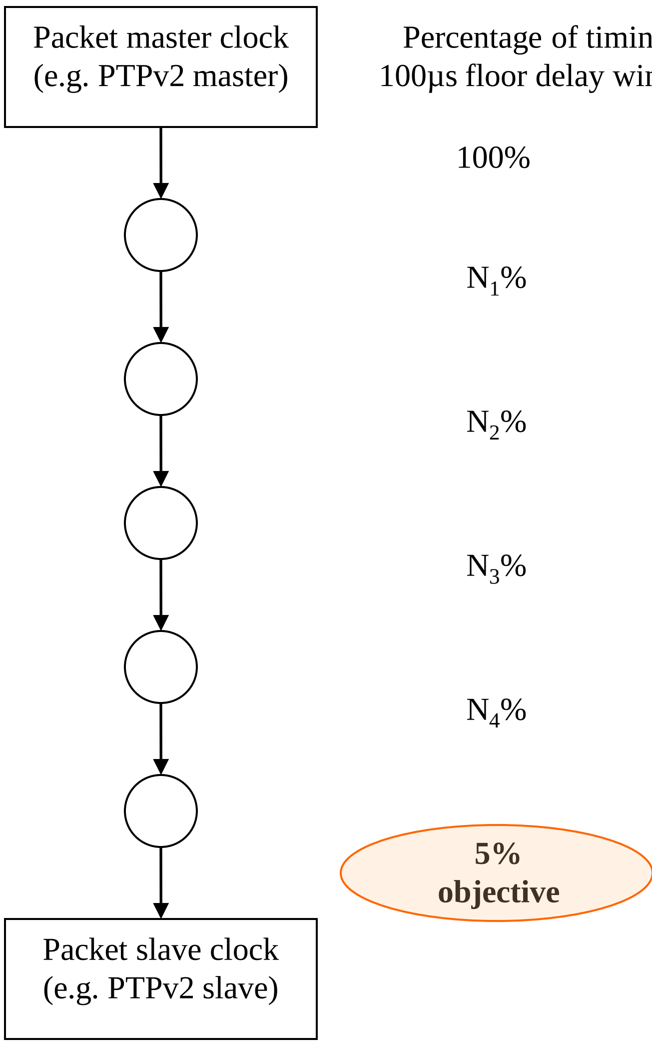
- Floor delay window:



- Equipment PDV generation:



Network PDV accumulation process

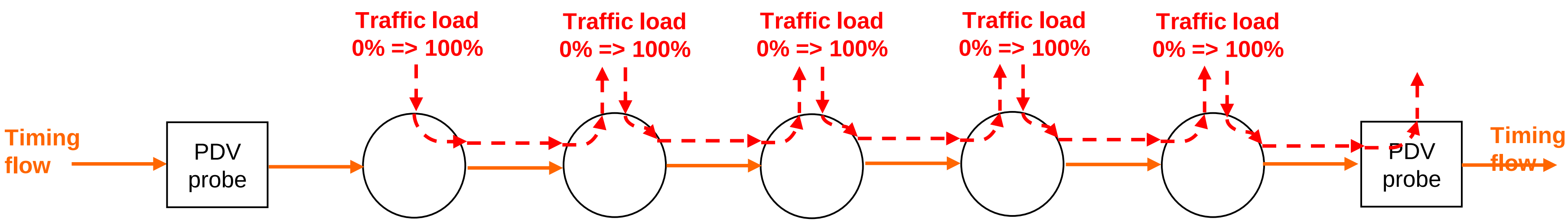


- Main objective: at the end of the chain, **enough packets must remain within the floor delay window** (e.g. 5% of the packets in a 50µs/100µs window)
- Each node "removes" a certain percentage of the packets from this floor delay window
- Each node is studied individually in order to determine the PDV it produces (equipment PDV generation testing)
- The PDV accumulation can be estimated using statistical analysis (e.g. based on convolution), based on the measurement of the PDV generated by each node

Comparison of the model with experimentations

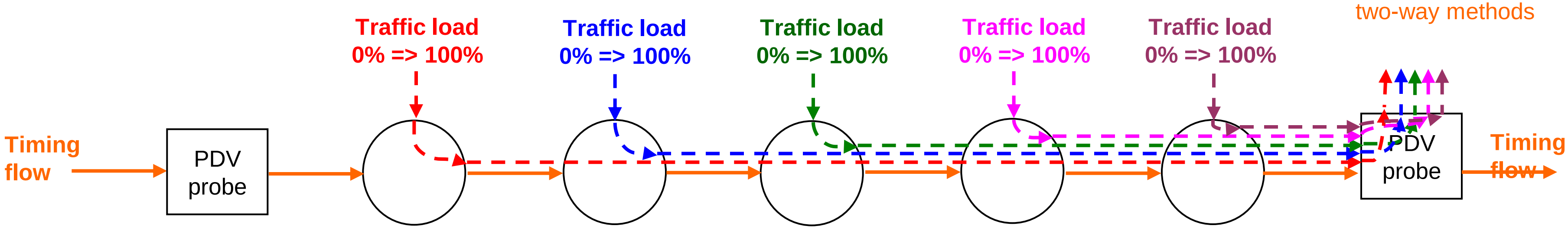
Types of traffic considered for PDV accumulation

- Objective: verify if the theoretical network PDV accumulation based on convolution operations is observed also on a real platform
- PDV measurements have been performed in different scenarios
  1. G.8261-like traffic load ("link-by-link") **=> done**



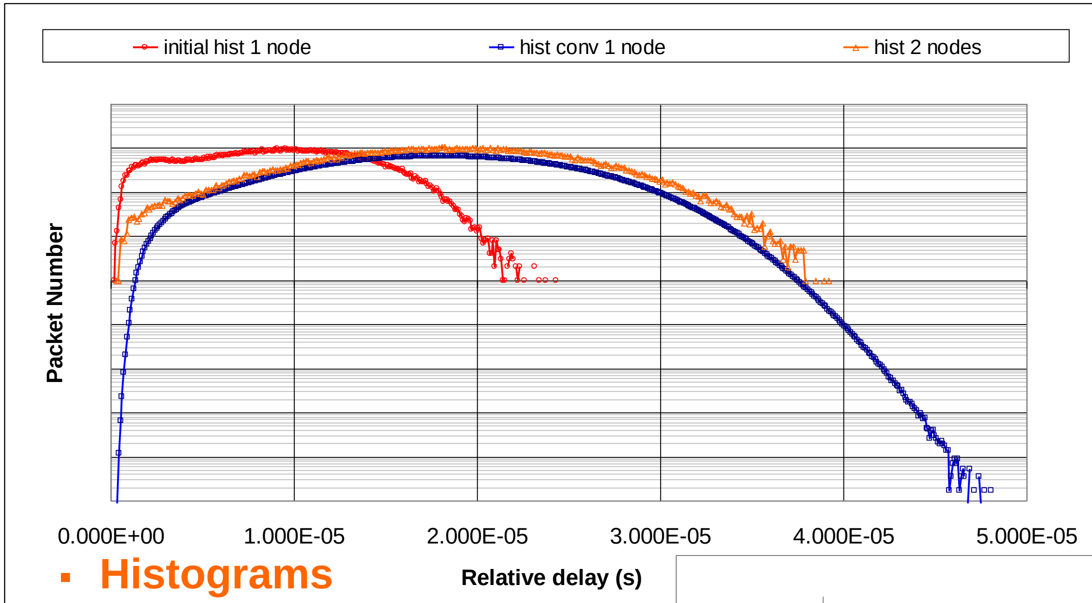
  2. Mobile backhaul-like traffic load ("end-to-end") **=> on-going**

Note: bi-directional traffic load have also been considered for two-way methods



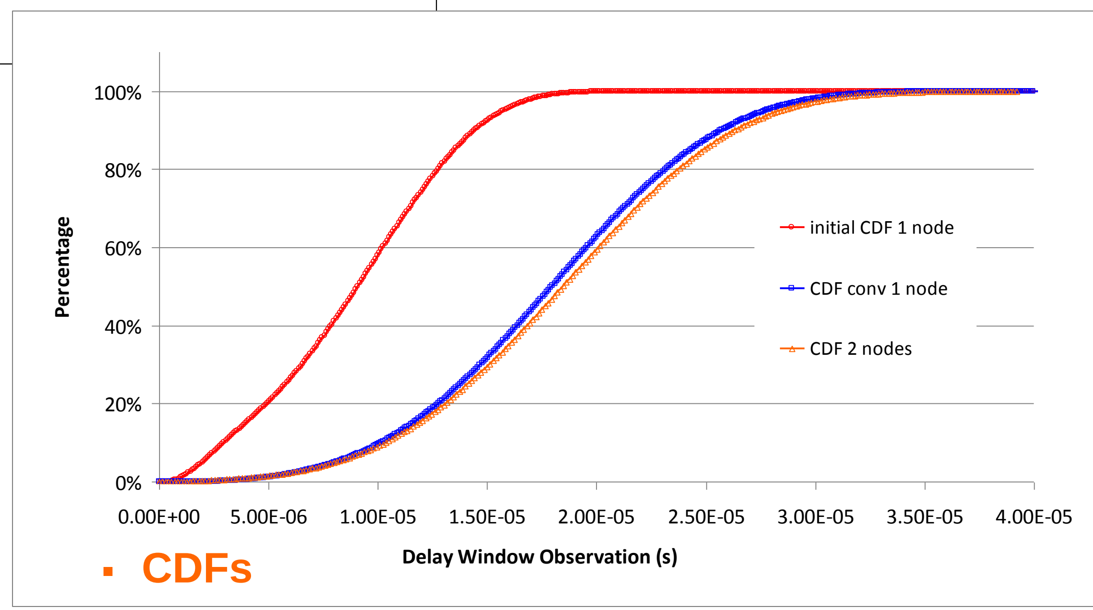
- Estimation of PDV accumulation using convolution has been found quite effective in the scenario 1, but requires further study in the scenario 2
  - Additional budget for delay steps may be required in the scenario 2

Convolution estimation comparison (scenario 1)



- **Histograms**

- Comparison of the histograms and CDFs of convolution estimation (blue curves) vs real measurement (orange curves) when 2 nodes are cascaded
- Red curves correspond to the measurement over 1 node



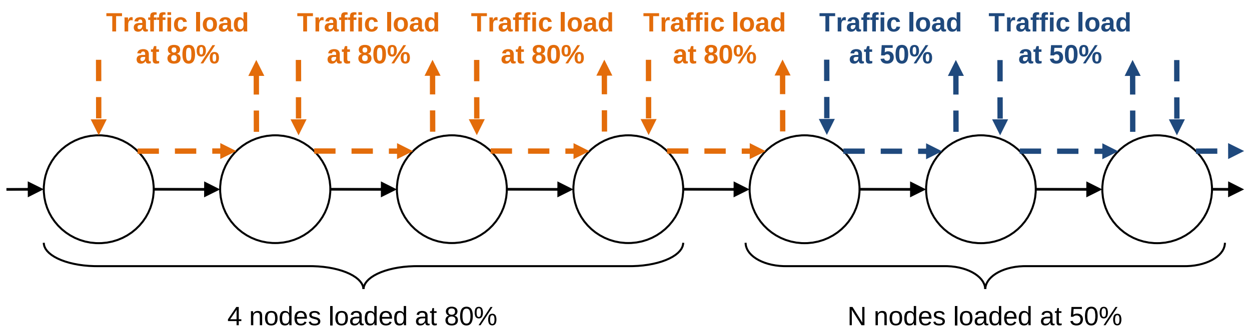
- **CDFs**

- <u>Additional observations:</u>
- These results are observed only when traffics are uncorrelated (assumed to be generally the case in the networks)
- The worst case PDV needs to be chosen carefully, in order to take into account all the possible sources of PDV noise

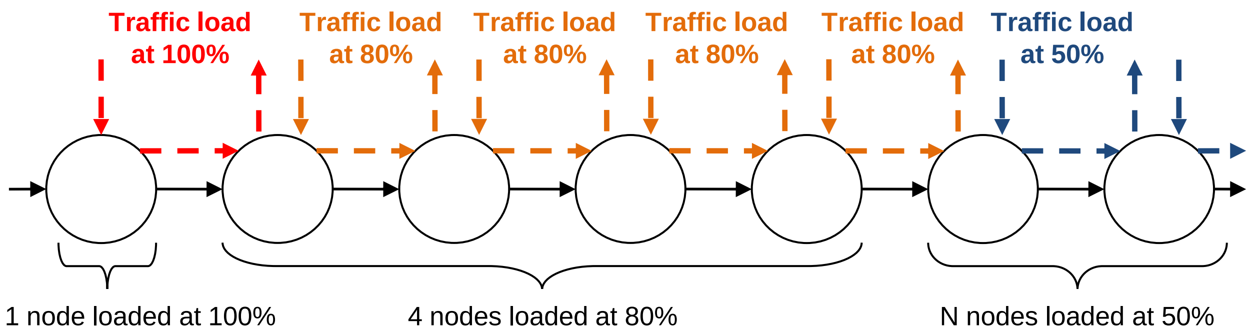
Simulations based on the model for building a network where PDV is controlled

Cases considered during the PDV simulations

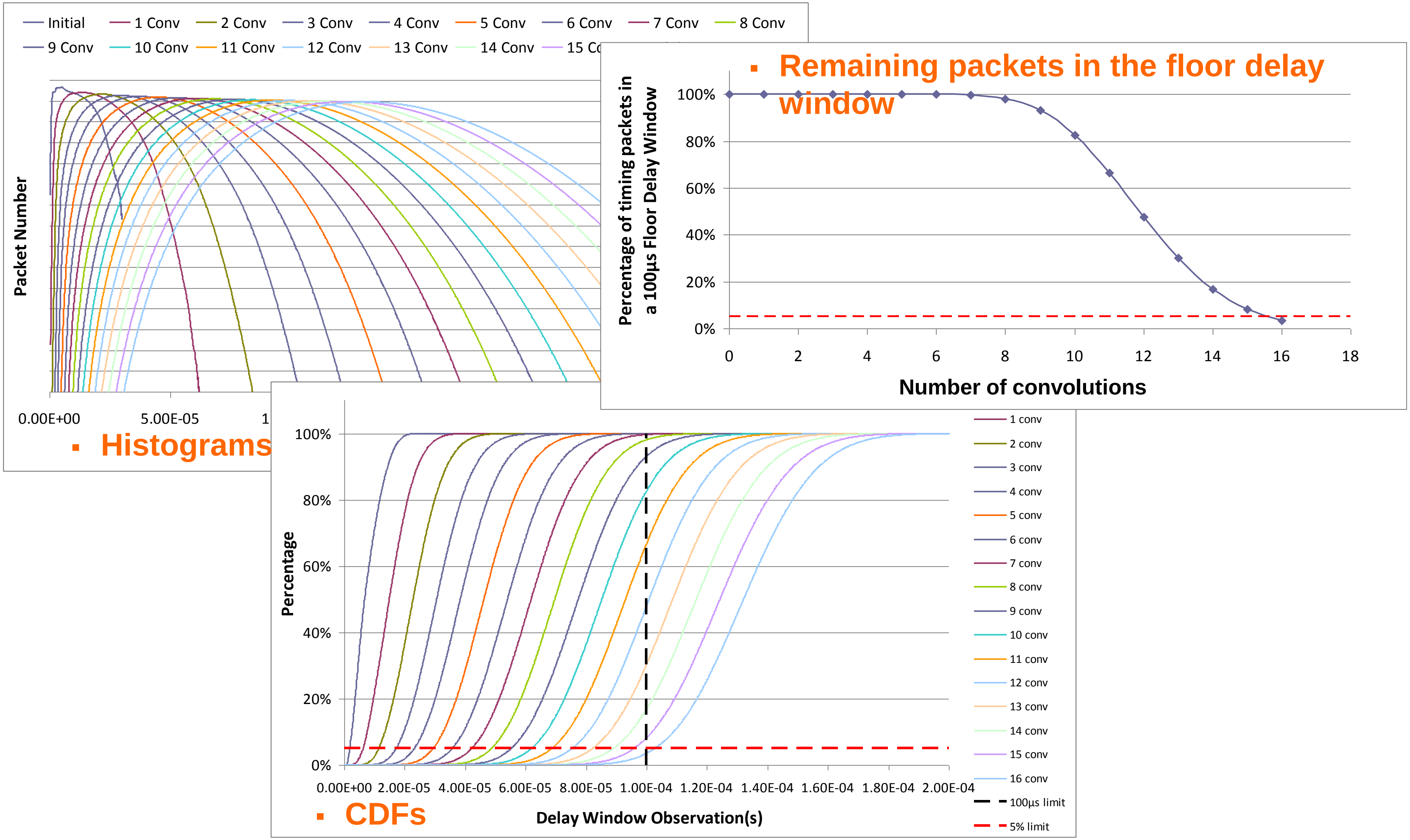
- 4 cases have been simulated:
  - Chain of nodes from supplier A loaded at 50%
  - Chain of nodes from supplier A loaded at 80%
  - Mixed chain 1 of nodes from supplier A (80% and 50%):



  - Mixed chain 2 of nodes from supplier A (100%, 80% and 50%):



Example of PDV simulations outputs



First simulations results for nodes from supplier A

		Criteria to be met:	
		Minimum 5% of timing packets in a 50µs floor delay window	Minimum 5% of timing packets in a 100µs floor delay window
Nodes loaded at 50%	Theoretical maximum number of cascaded nodes loaded at 50% or less with fixed packet size of 1518 bytes	**7 nodes** - 9.25% remaining (only 2.80% remaining after 8 nodes)	**13 nodes** - 6.87% remaining (only 2.74% remaining after 14 nodes)
	Theoretical maximum number of cascaded nodes loaded at 50% or less with variable packet size	**9 nodes** – 6.15% remaining (only 1.80% remaining after 10 nodes)	**16 nodes** - 8.06% remaining (only 3.46% remaining after 17 nodes)
Nodes loaded at 80%	Theoretical maximum number of cascaded nodes loaded at 80% or less with fixed packet size of 1518 bytes	**4 nodes** – 6.45% remaining (only 1.01% remaining after 5 nodes)	**7 nodes** – 15.86% remaining (only 1.43% remaining after 8 nodes)
	Theoretical maximum number of cascaded nodes loaded at 80% or less with variable packet size	**5 nodes** – 24.5% remaining (only 4.5% remaining after 6 nodes)	**10 nodes** – 16.16% remaining (only 4.2% remaining after 10 nodes)
Mixed chain 1	Theoretical maximum number of cascaded nodes with mixed configuration 1 (4 nodes loaded at 80% + N nodes loaded at 50% or less) with fixed packet size of 1518 bytes	**0 node** (only 1.08% remaining after 1 node)	**6 nodes** – 7.32% remaining (only 2.42% remaining after 7 nodes)
	Theoretical maximum number of cascaded nodes with mixed configuration 1 (4 nodes loaded at 80% + N nodes loaded at 50% or less) with variable packet size	**3 nodes** – 5.09% remaining (only 1.33% remaining after 4 nodes)	**10 nodes** – 7.71% remaining (only 3.15% remaining after 11 nodes)
Mixed chain 2	Theoretical maximum number of cascaded nodes with mixed configuration 2 (1 node in congestion + 4 nodes loaded at 80% + N nodes loaded at 50% or less) with fixed packet size of 1518 bytes	**0 node**	**3 nodes** – 6.74% remaining (only 1.88% remaining after 4 nodes)
	Theoretical maximum number of cascaded nodes with mixed configuration 2 (1 node in congestion + 4 nodes loaded at 80% + N nodes loaded at 50% or less) with variable packet size	**0 node** (only 0.45% remaining after 1 node)	**7 nodes** – 6.06% remaining (only 2.15% remaining after 8 nodes)

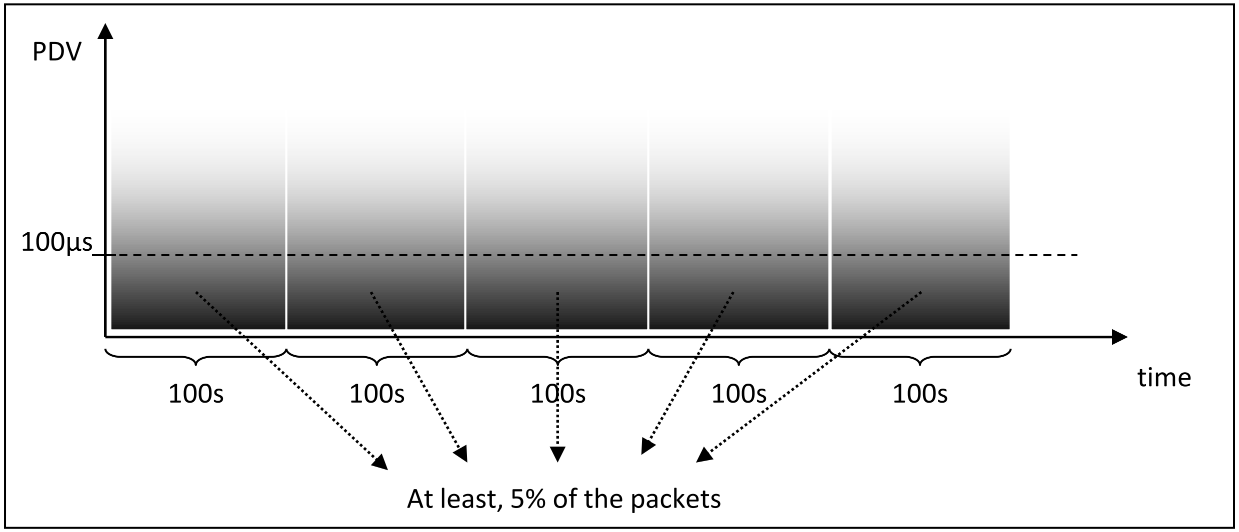
Links with MATIE/MAFE PDV metrics

Reminder on MATIE/MAFE

- PDV metrics introduced by NSN (e.g. ITU-T, ITSF 2008, ITSF 2009)
- **Pre-selection of packets is outside MATIE/MAFE calculation**
  - Different criteria are possible (e.g. floor delay, etc…)
- MATIE calculation: use of 2 sliding windows, average of the samples in each window
- Calculation of MAFE is based on MATIE (MAFE = MATIE / Tau)
- MAFE mask has been proposed by NSN
  - The **notion of "corner point"** is clear: it corresponds to the time constant of the packet slave clock
  - The other points of the mask for Tau values higher or lower than the corner point require further clarifications
- MATIE/MAFE could be useful for a slave targeting only a maximum frequency error objective (e.g. 50ppb), but not necessarily for a slave targeting a maximum phase error accumulation objective (e.g. MTIE mask)
  - **MATIE/MAFE could be the only PDV metric necessary for a slave embedded in a base station targeting 50ppb** (xTDEV PDV metrics should not be needed)

Links between floor delay window and MAFE (1/2)

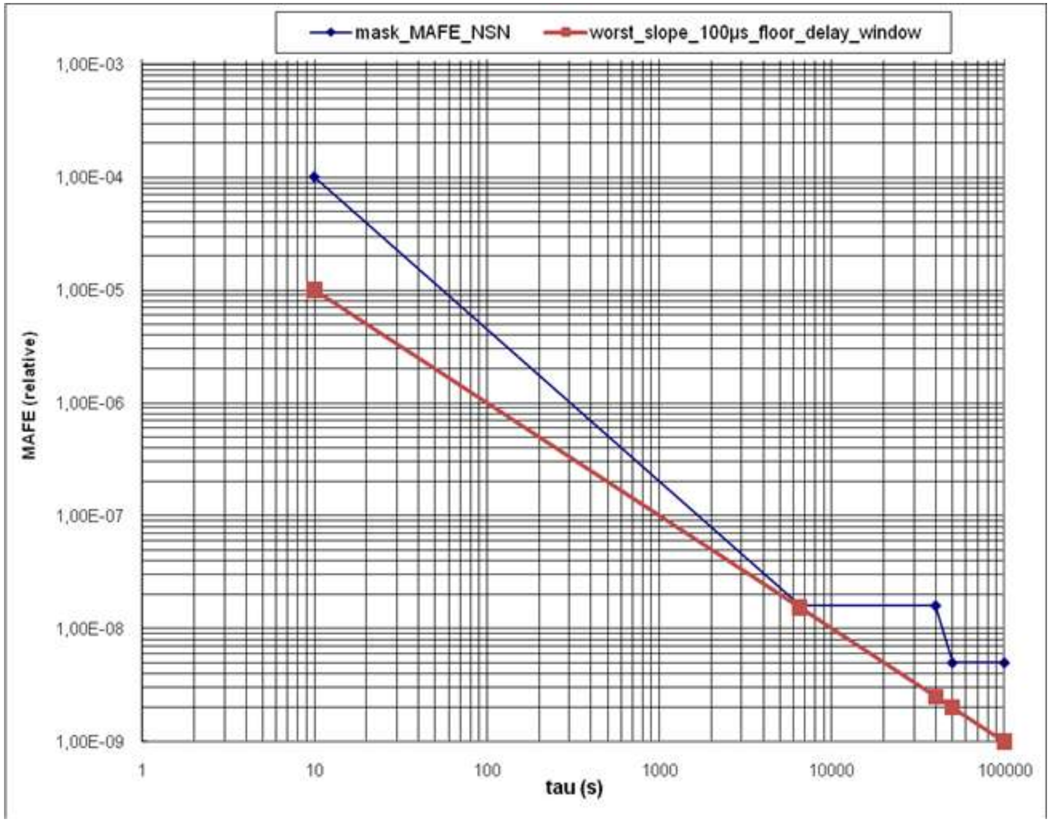
- Let’s assume a PDV measurement for which, for every 100s observation window, a minimum of 5% of packets is located in a 100µs floor delay window



- Let’s consider that before applying the MAFE calculation, the 5% of fastest packets for each 100s window are pre-selected => all the pre-selected packets are necessarily included in the 100µs floor delay window
- The maximum error which can be found between two consecutive windows in MATIE calculation is 100µs. Since MAFE = MATIE / Tau, the worst case MAFE curve can be expressed as a function of Tau, based on the 100µs maximum value
  - For instance, over a Tau value of 6500s, it corresponds to:
    100.10-6 / 6500 = 15.38ppb (approximately 16ppb)

Links between floor delay window and MAFE (2/2)

- Assuming a MAFE mask with a corner point at 6500s for a 16ppb objective, for any PDV which experiences for every 100s observation window a minimum of 5% of packets in a 100µs floor delay window, the corner point will be respected (as well as the rest of the mask proposed by NSN for other Tau values):



- **<u>Conclusion:</u> building a network using the model presented in this paper should permit to respect a PDV network limit expressed in terms of the MAFE PDV metric**

Conclusion

Conclusion and next steps

- This study on PDV accumulation shows that it might be **possible to control the network PDV for timing applications** if the purpose is to ensure that a minimum population of packets is located in a given fixed delay window
- However, the **theoretical estimations presented earlier are only valid for the specific equipment which has been tested** and for which worst case histograms have been derived (supplier A), in the specific hardware configuration which has been tested, and in case of "hop-by-hop" uncorrelated data traffic
- Other equipments or hardware versions of this node might produce more or less PDV, the maximum number of nodes that can be cascaded can be different
  - **PDV testing on a case-by-case basis is needed** (define PDV generation categories?)
  - Clarification of the input tolerance of a packet slave clock is also necessary (G.8263)
- Next steps:
  - Continue the studies for the end-to-end data traffic case
  - Extend the studies to other pre-selection criterias than the floor delay (e.g. for technologies like DSL, MW…)

thank you