Analysis of the new ITU test patterns for packet based frequency synchronization

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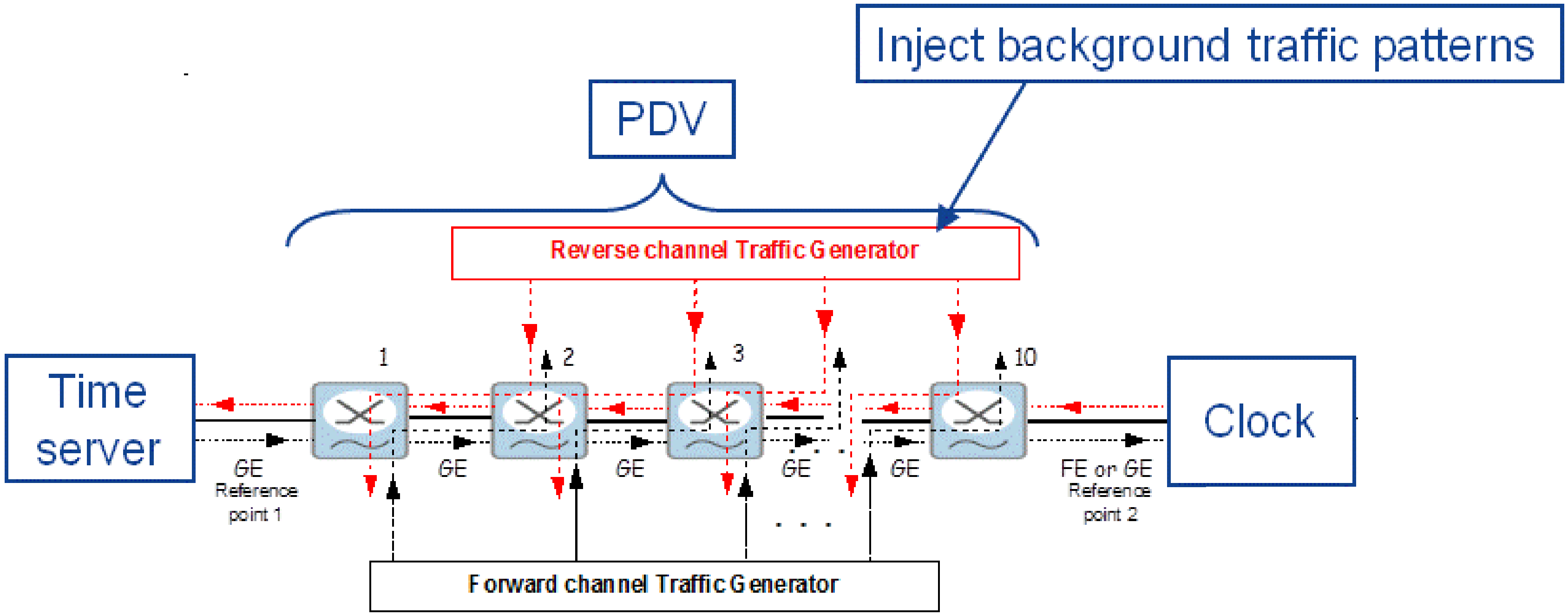
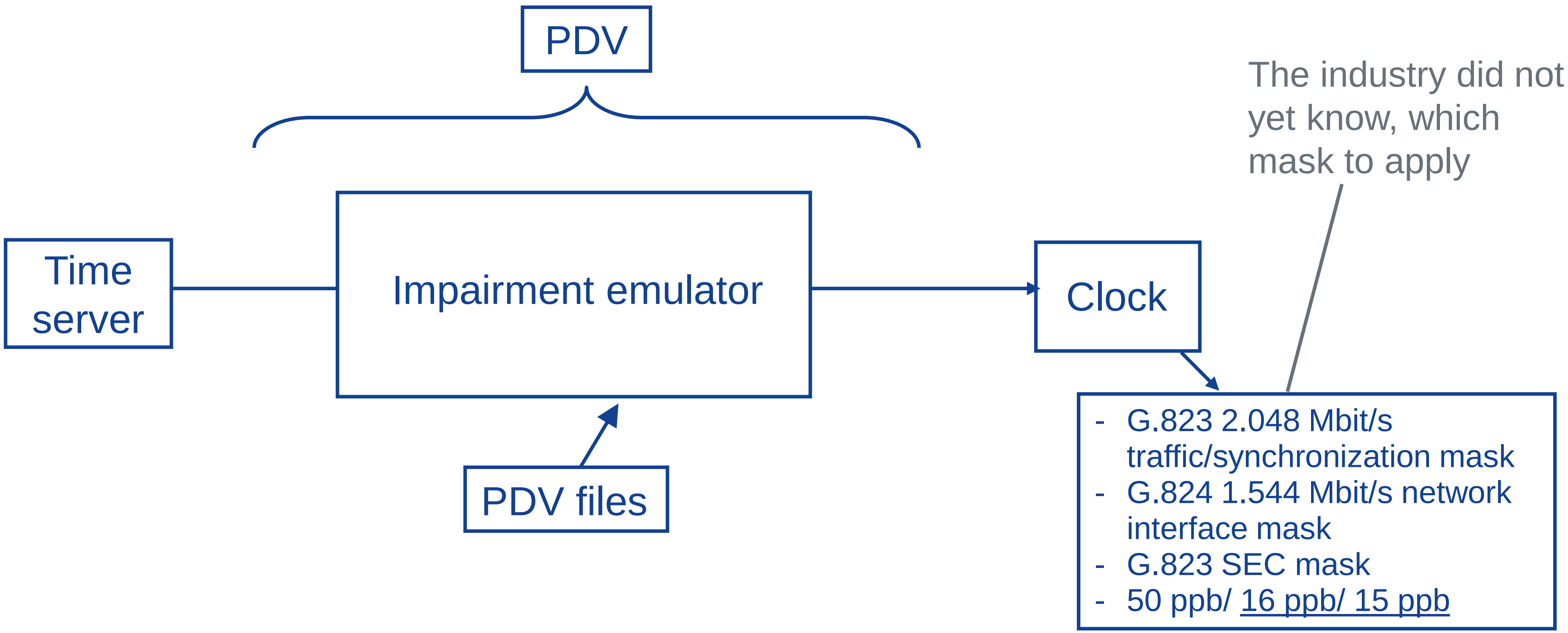
History of test patterns for frequency synchronization

- It was recognized at an early stage, around 2005, that reference models and packet delay variation (PDV) test patterns are needed for testing packet clocks.
- The first reference model and traffic patterns were introduced in Appendix VI of G.8261 during 2006-2007. The “ITU Test Cases” were created.
- All nodes loaded up to 80%.



Practical test setup

- Impairment emulator vendors developed delay files corresponding to the G.8261 test cases, 2009-2010.



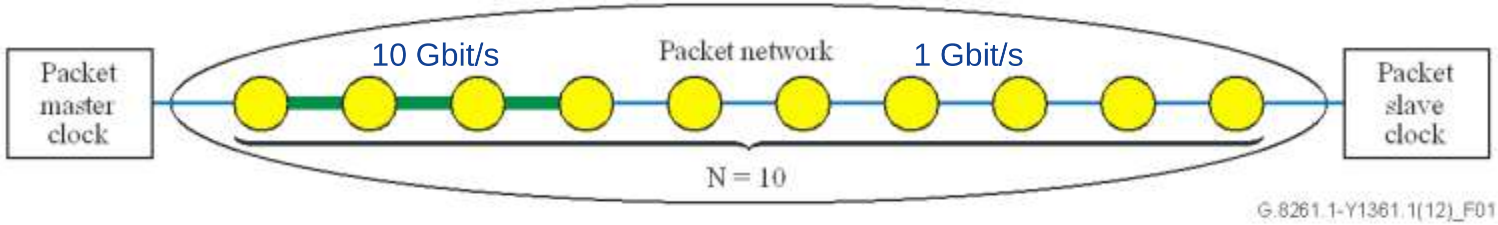
Metrics describing the magnitude of PDV – G.8260

- minTDEV (minimum time deviation) (2007)
- MAFE (maximum average frequency error) (2008), which Nokia (NSN) started to use as a proprietary network limit in 2008.
- pktfilteredMTIE (2010)
- FPP (floor packet percentage) (2011) tells how many percent of packets are within a delay range (cluster range) of the fastest packet in the measurement. A related metric Floor delay window was introduced in 2009

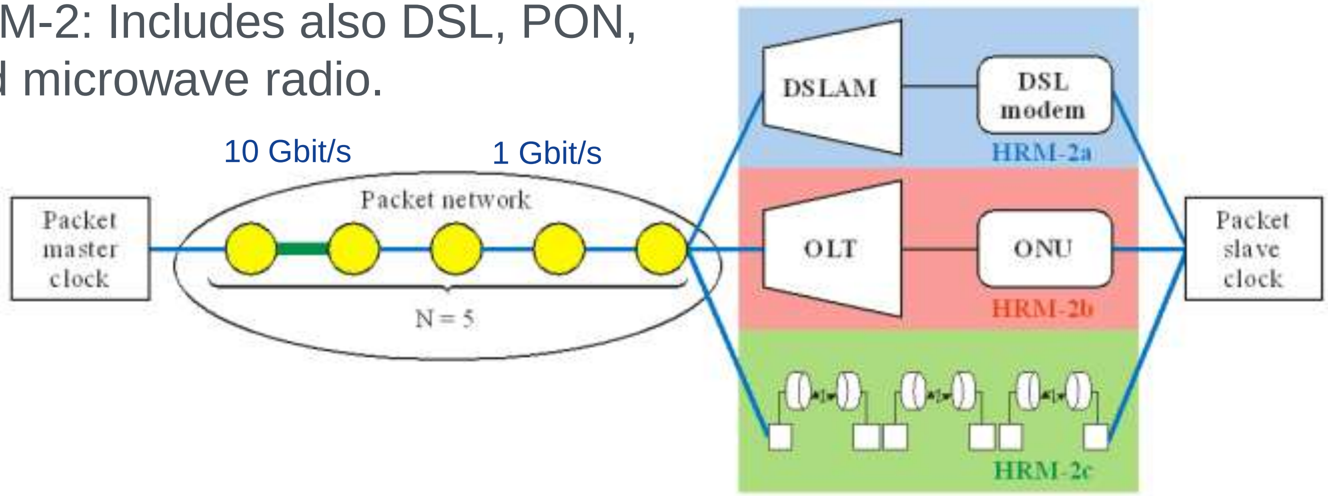
- Of these metrics, MAFE increases linearly with expected worst-case frequency error, so it is used in this presentation to compare the “challenge levels” of the test cases.

Hypothetical Reference Models, G.8261.1 – 02/2012

- In the meanwhile, two HRMs were developed in G.8261.1 for defining PDV network limits. HRM-1 corresponds to almost the same network as defined in G.8261 "ITU test cases"
- Slave clock output limit, case 3: 16 ppb above the observation interval of 1125 s.
    - HRM-1: Fully optical network



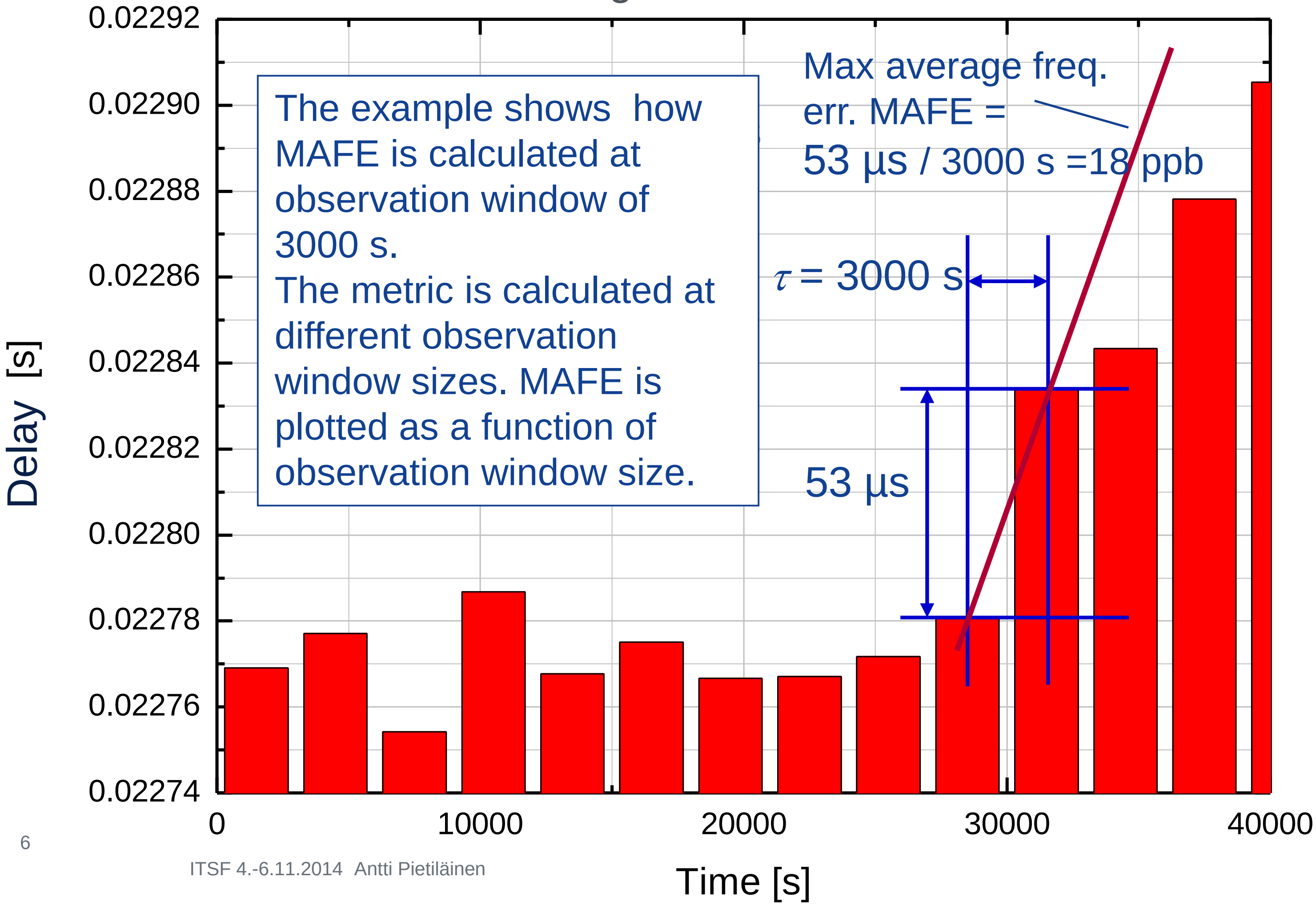
- HRM-2: Includes also DSL, PON, and microwave radio.



MAFE (maximum average/absolute frequency error)

- Introducing the metric used in the graphs

The delays of the fastest packets are averaged over observation windows and maximum change between two consecutive windows is determined. The slope of a line drawn between the averages is MAFE at observation interval τ.



The function estimates achievable worst-case stability over the whole PDV file as a function of the averaging time of the clock algorithm.

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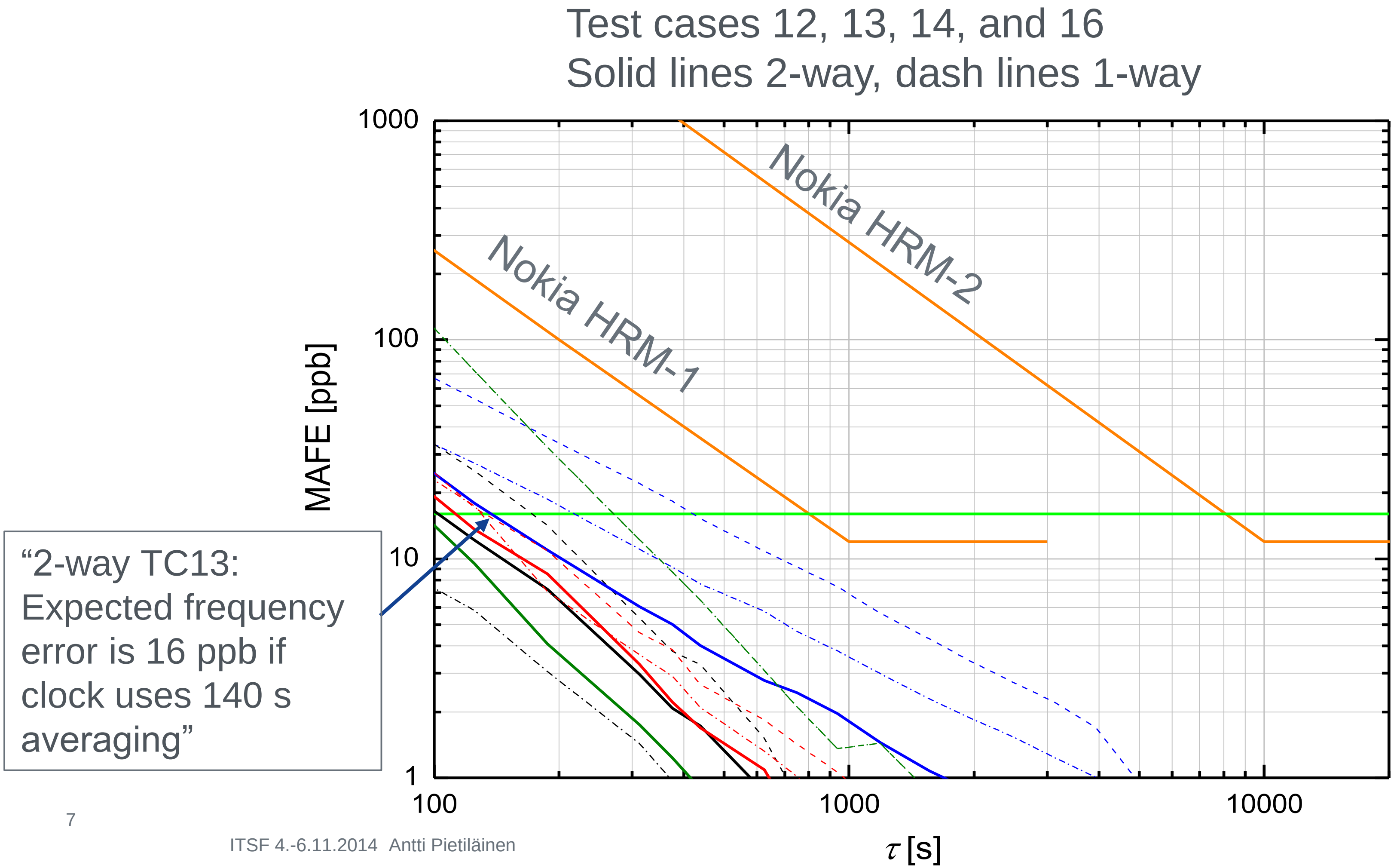
MAFE analysis of G.8261 test cases

- Vendor-A test patterns are well below Nokia's HRM-1 network limit.
- Further, G.8261 allows the slaves to stabilize first without any PDV.



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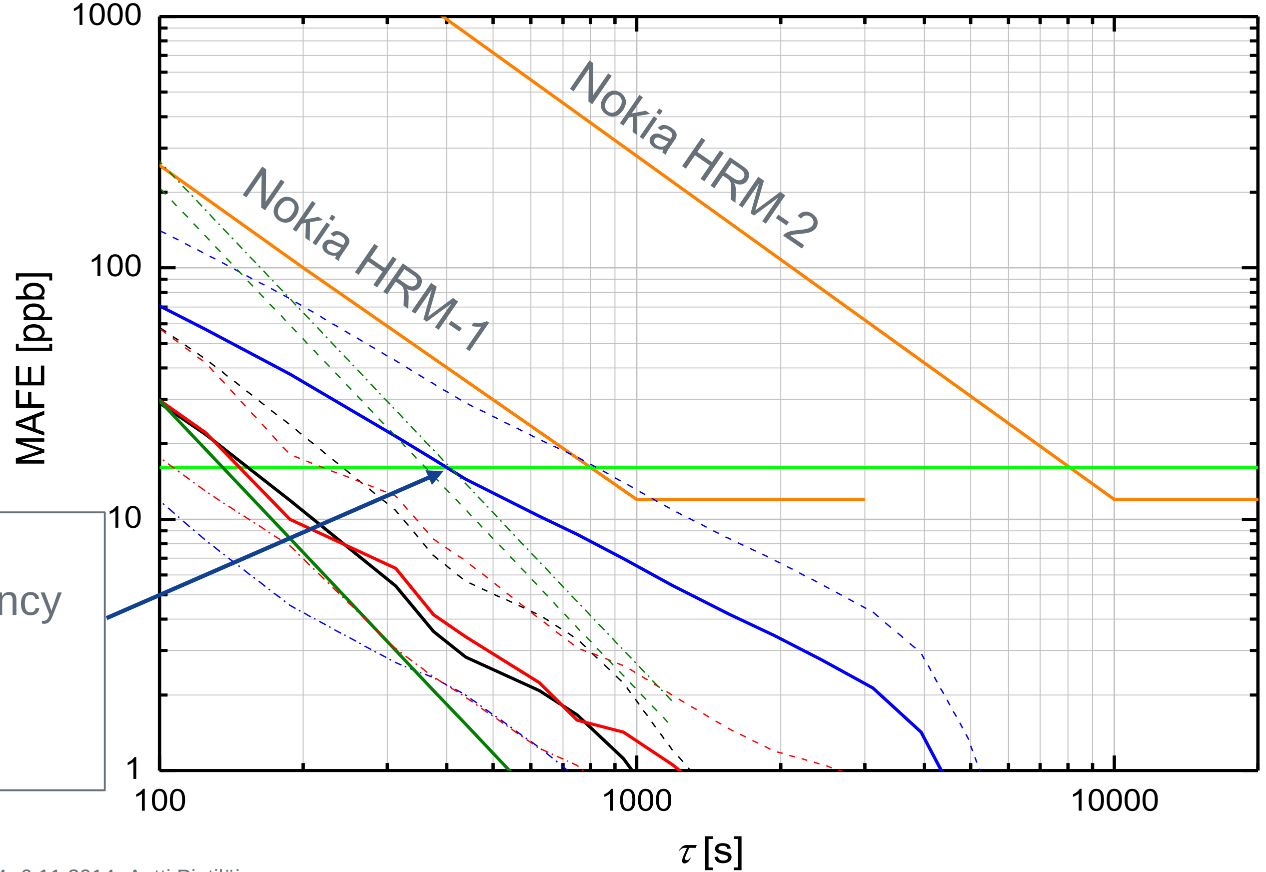
MAFE analysis of G.8261 test cases

- Also vendor-B patterns arebelow Nokia's HRM-1 network limit.

Test cases 12, 13, 14, and 16
Solid lines 2-way, dash lines 1-way



"2-way TC13: Expected frequency error is 16 ppb if clock uses 400 s averaging"

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Defining network limit for HRM-1 in December 2011

- In each 200 s period, at least 1% of packets must be within a cluster range of 150 µs starting from the fastest packet of the measurement (corresponding to networks where almost all nodes can be overloaded) **or** 75 µs (highly loaded networks where about two nodes may be simultaneously overloaded).
- Network performance can be verified using FPP metric (floor packet percentage)
- The G.8261 test cases are becoming obsolete for testing slave clocks against the network limit because they are too “easy”:
  - 100% of packets are within the 150 µs limit (instead of only 1%).
  - Minimally, 50 % of packets are within the 75 µs limit (instead of 1 only %).

New test patterns for HRM-1 network limit in April 2014.

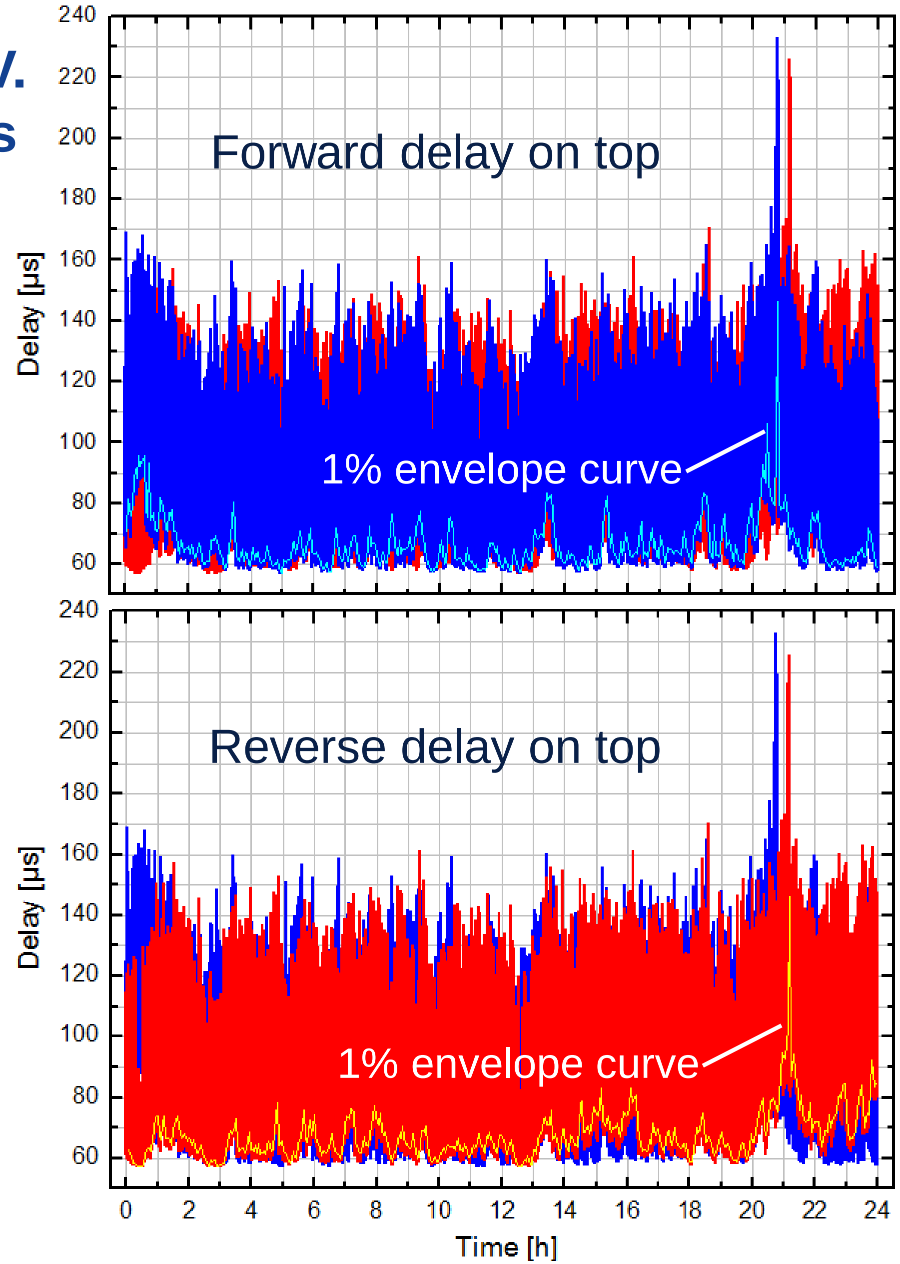
- New test patterns were developed in recommendation G.8263, which defines the slave clock requirements.
- Both network limits, 150 µs and 75 µs, are very conservative. Thus, the delay patterns are much more challenging than the G.8260 test cases.
- Further, in the new test cases, no stabilization period without PDV is allowed for the slave clock before starting the delay pattern.

New test patterns:

G.8263 1) Flicker Load Gamma PDV. One pattern suits both limits, 150 μs and 75 μs.

- Long-term delay variation is based on self similar flicker load pattern.
- Short-term packet delay variation (PDV) is based on gamma distribution where the weight is in the faster values. The short-term variation is based on similar principle also in the sinusoidal waveform cases.

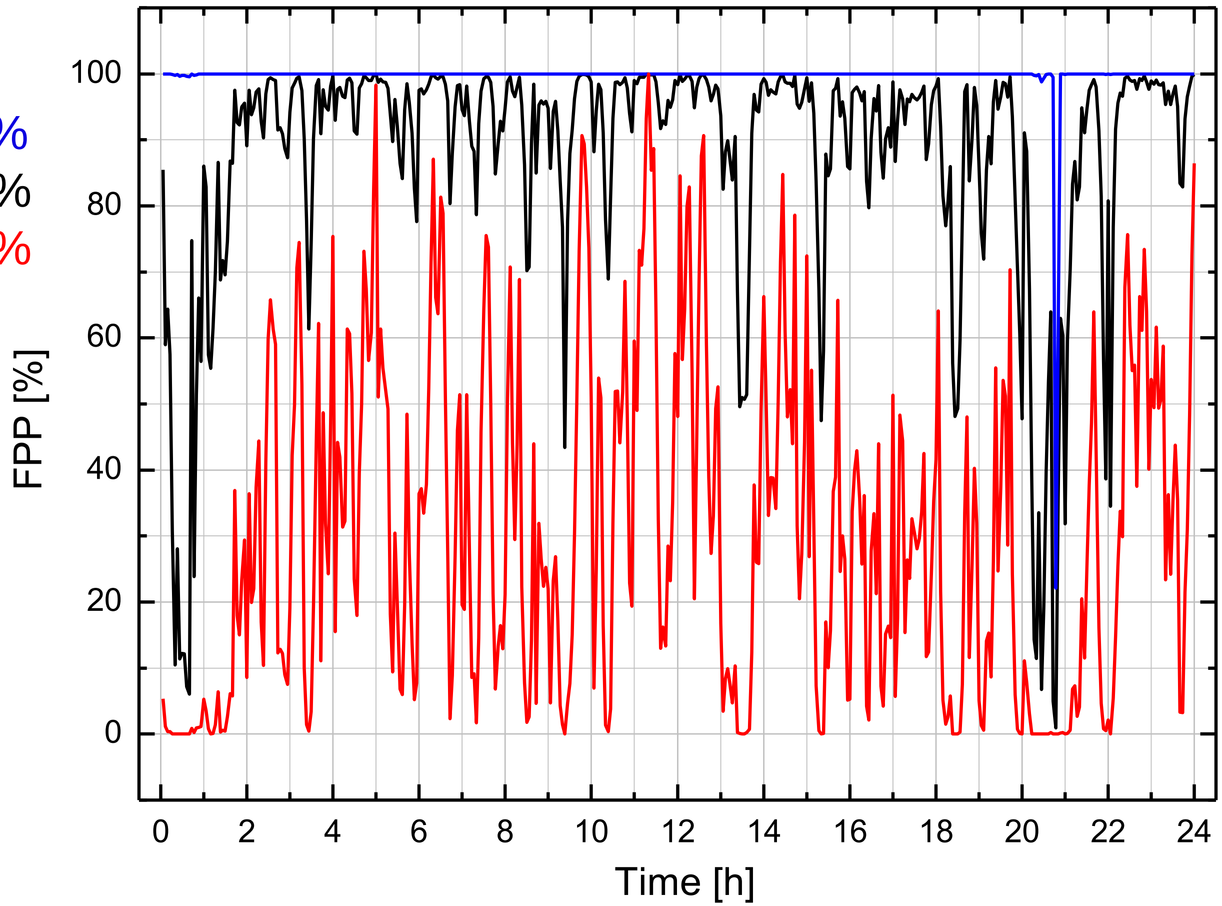
Pattern	Duration		
	Period	Total	Relevant
Flicker-Gamma	24 h	24 h	24 h



Ficker Load Gamma PDV – Floor Packet Percentage (FPP)

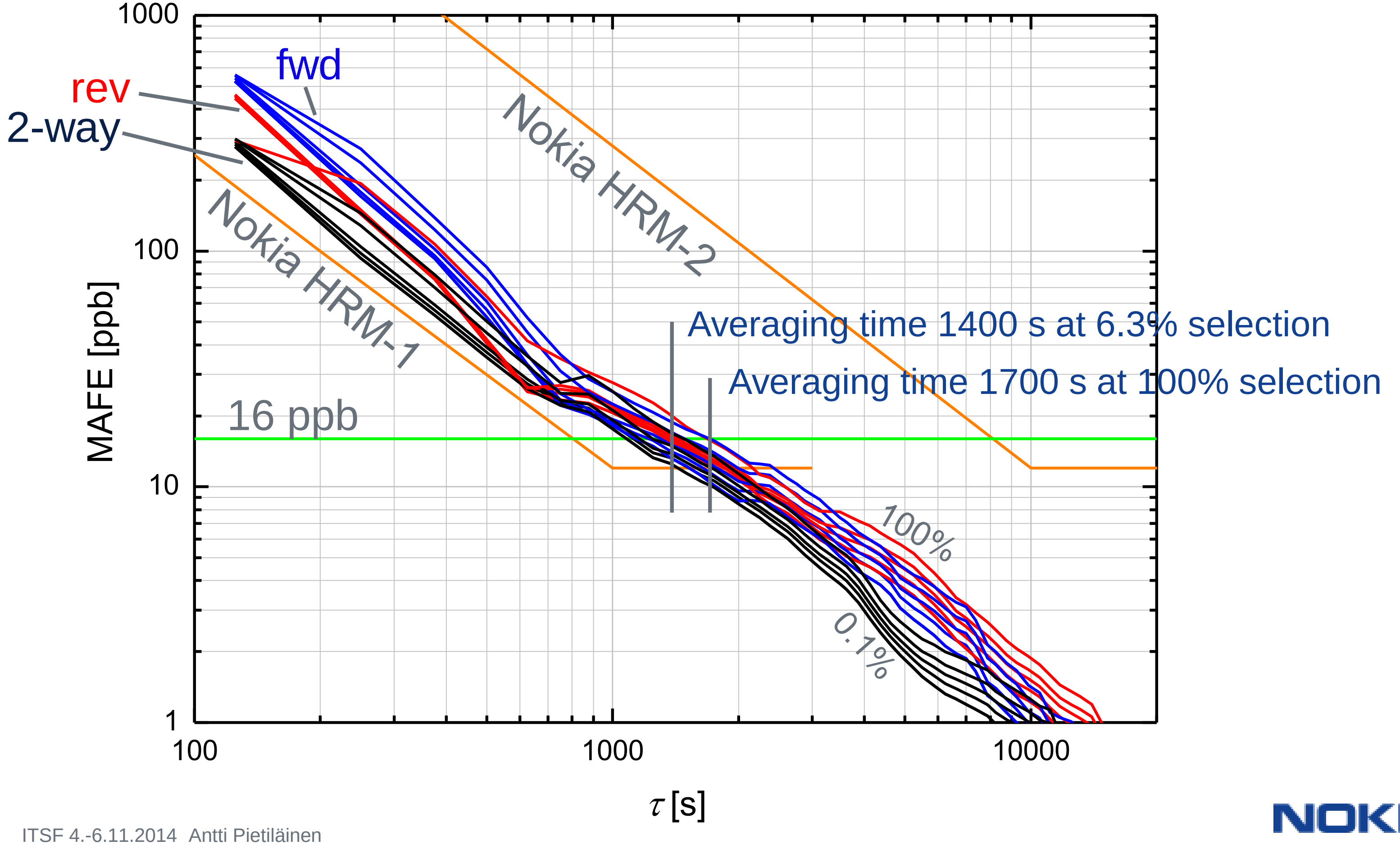
- FPP drops to 1% when cluster range is 102 µs

Window W - 200 s
Cluster range
δ = 150 µs, min FPP = 22%
δ = 102 µs, min FPP = 1%
δ = 75 µs, min FPP = 0%



Ficker Load Gamma PDV – MAFE analysis

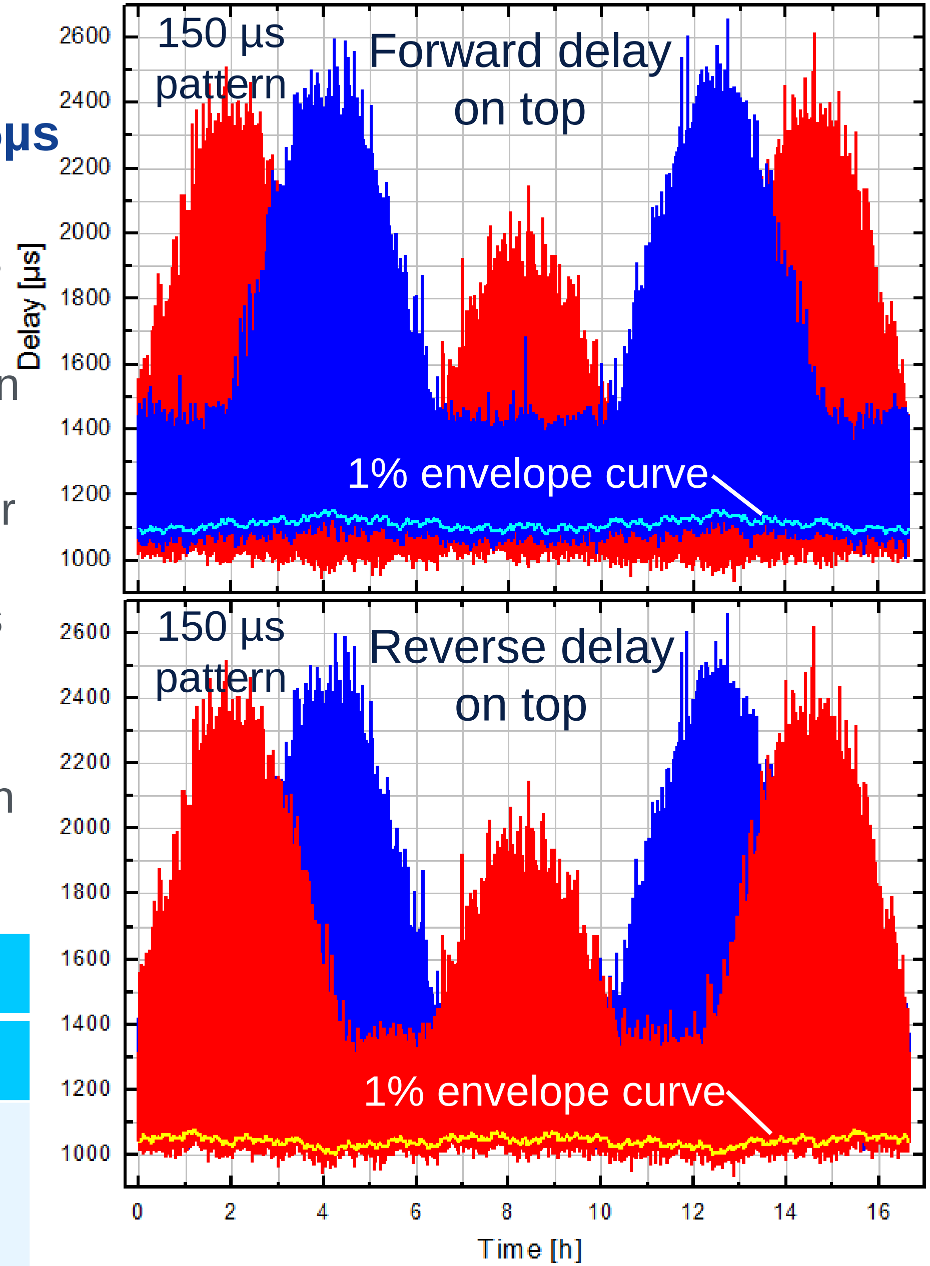
- Forward, reverse, and two-way algorithms experience similar challenges.
- Algorithm using fastest packets are slightly better off than algorithms using all packets.
- Oscillator stability requirement of **1400 s** obtained from the 16 ppb crossing of the 6.3% curve.



G.8263 2) Combined sinusoidal waveforms. Separately for 150 and 75µs

- Long-term PDV is based on sinusoidal waveforms with periods ranging from 50 s to 30000 s.
- Short-term PDV is based on noise function where smaller delays dominate.
- Some of the values are replaced by higher value delays so that clocks selecting only fastest packets perform better than clocks using all packets.
- The pattern is 30000 s long and repeated as a mirror image so that the delay pattern can be run in a continuous loop without creating delay jumps when starting over.

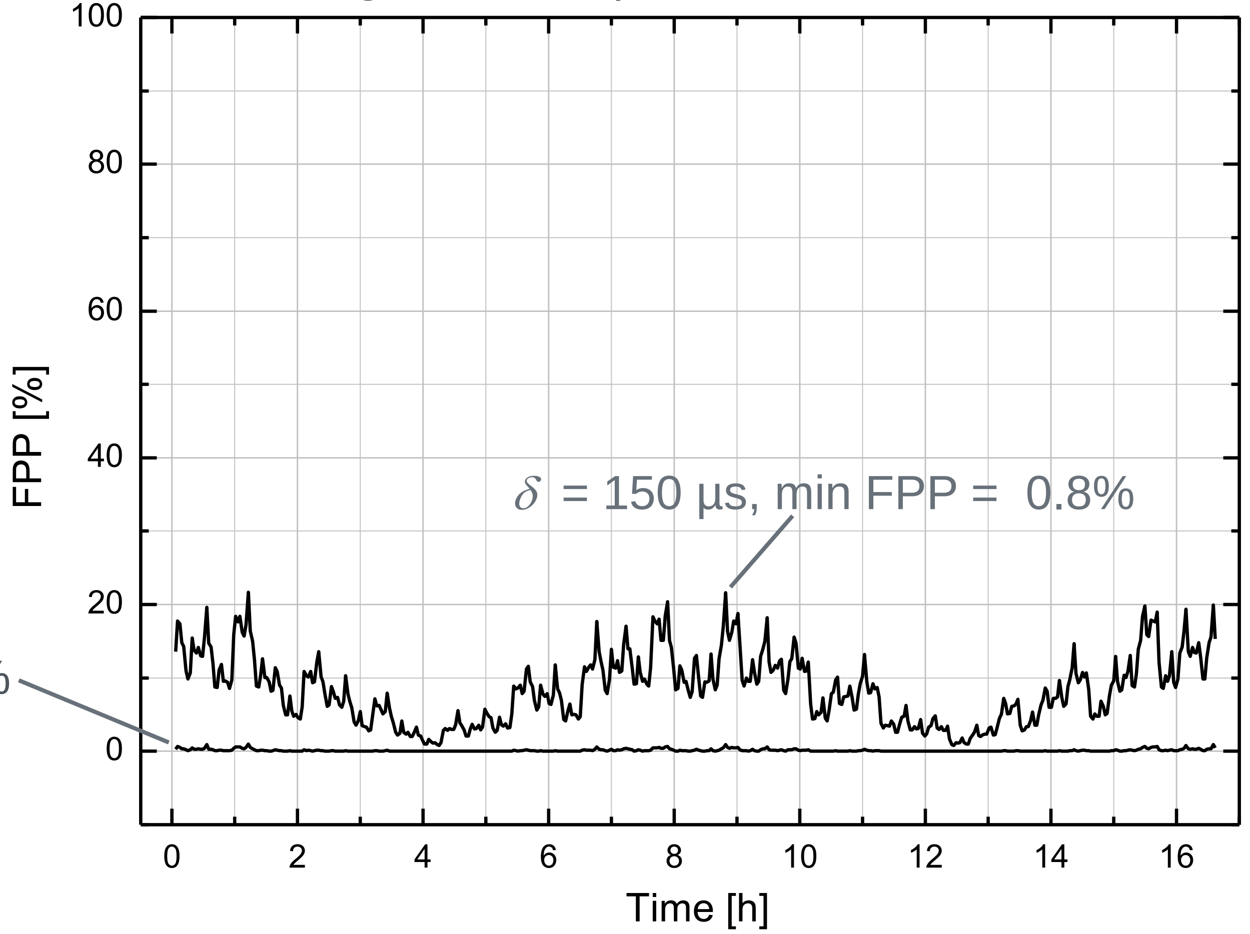
Pattern	Duration		
	Period	Total	Relevant
Combined sinus-oids 150 µs and 75 µs patterns.	8 h	17 h	11 h



Combined sinusoidal waveforms, 150-µs test pattern – Floor Packet Percentage (FPP)

- Minimum FPP = 0.8 % when cluster range δ is 150 µs.

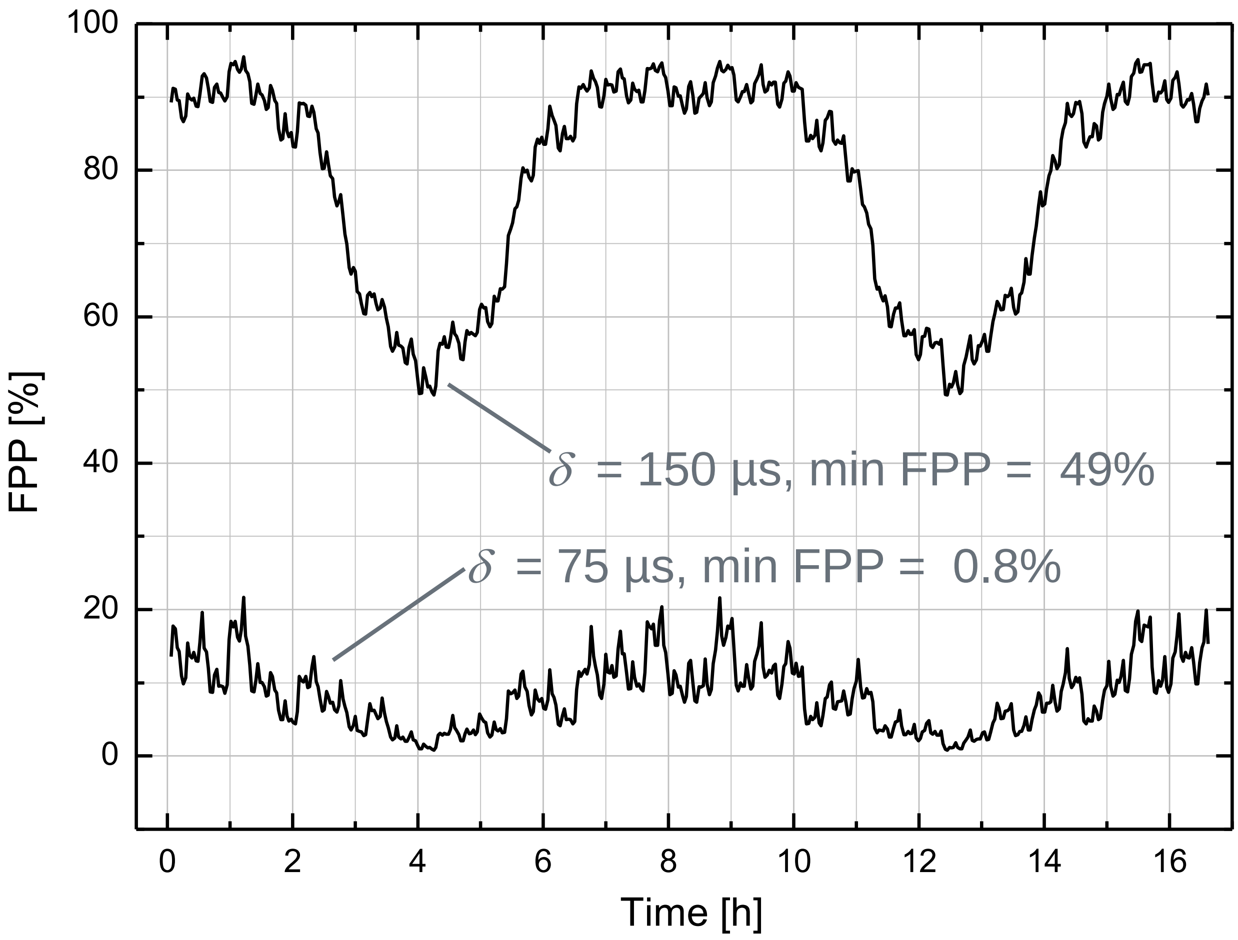
Window W: 200 s
Cluster range δ:
75 µ and 150 µs



Combined sinusoidal waveforms, 75-µs test pattern – Floor Packet Percentage (FPP)

- Minimum FPP = 0.8 % when cluster range δ is 75 µs.

Window W: 200 s
Cluster range δ:
75 µ and 150 µs



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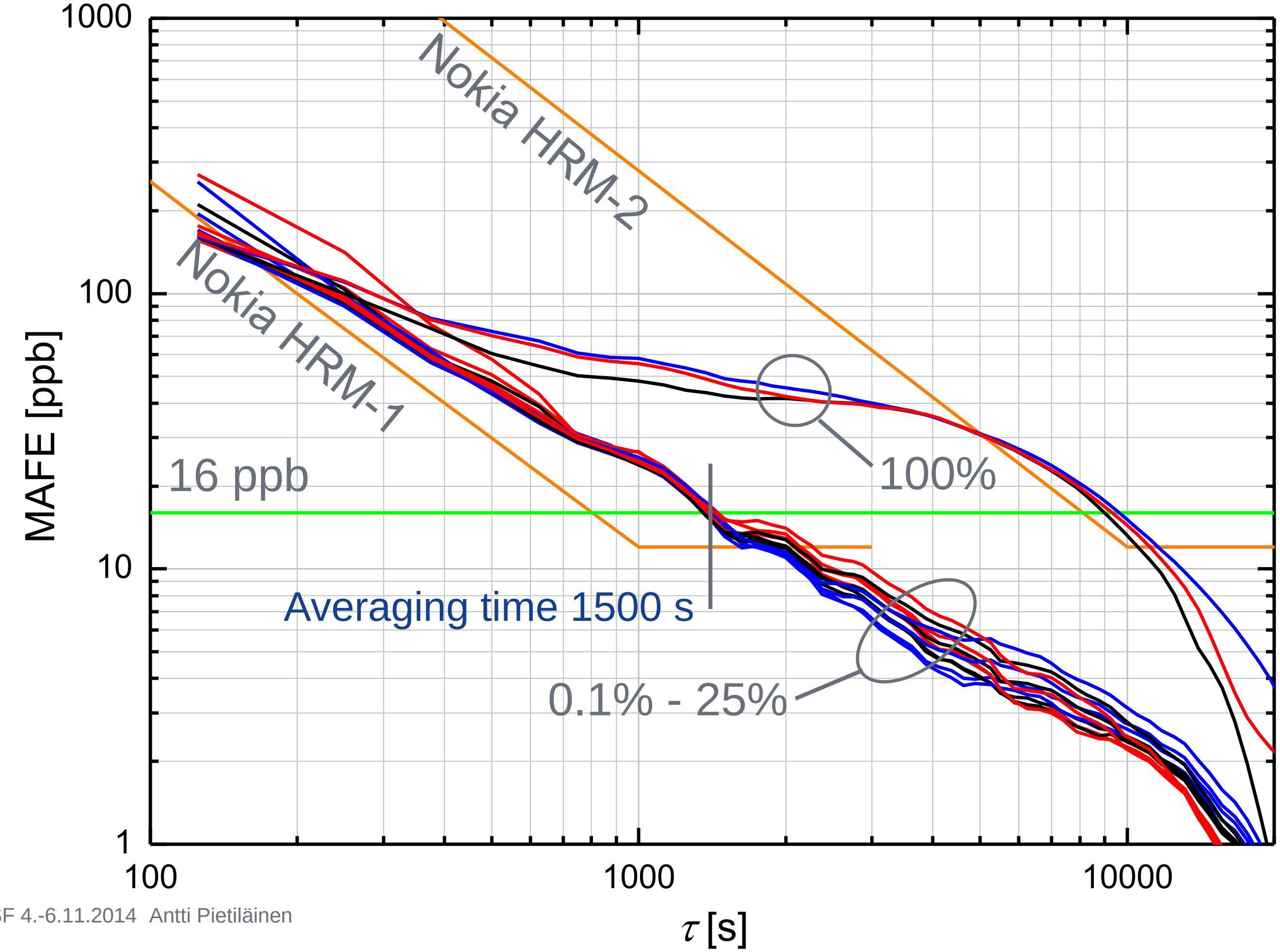
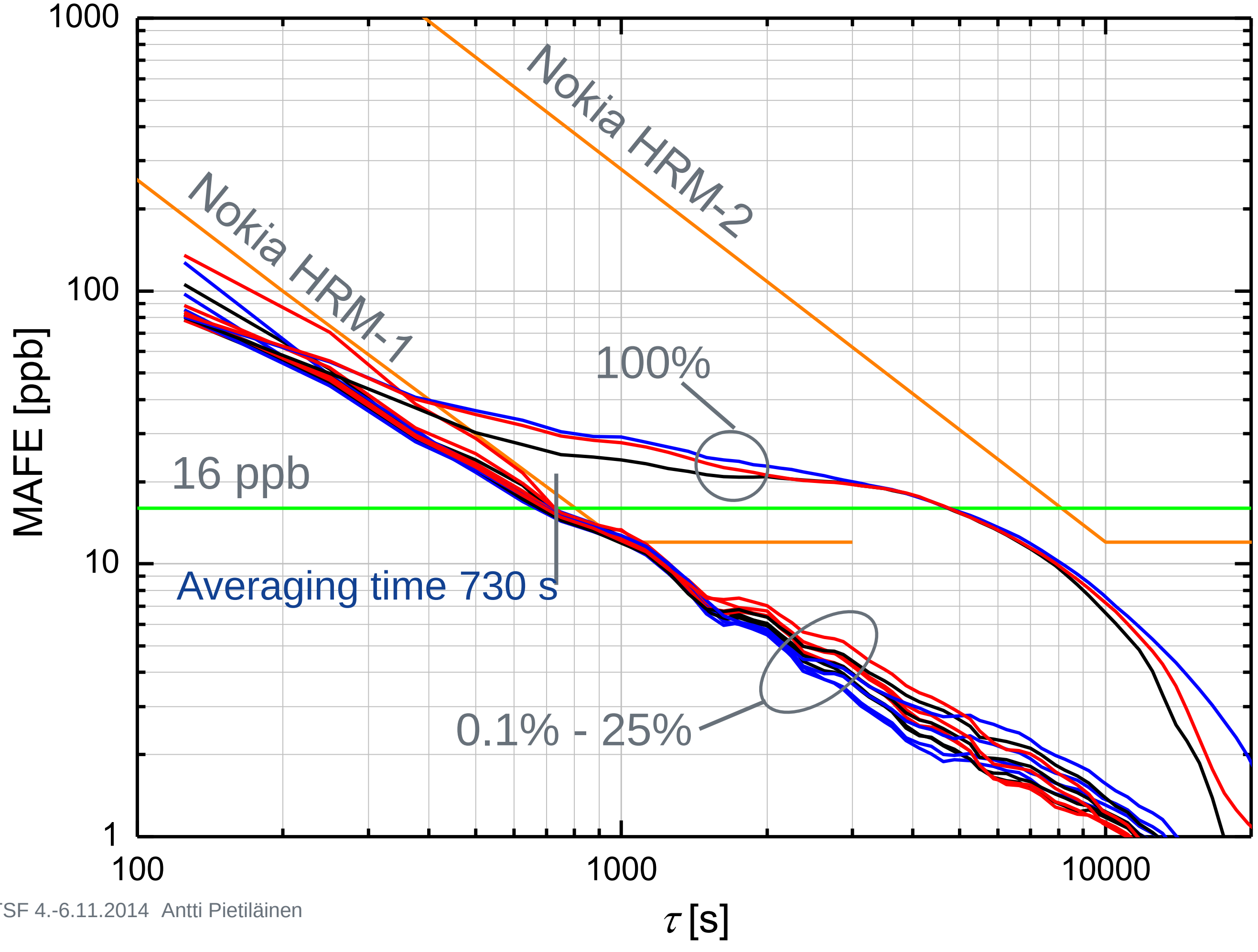
Combined sinusoidal waveforms, 150-µs test pattern – MAFE analysis

- The MAFE curves are similar to the ones in Flicker-Gamma
- When all packets are selected the MAFE curve is much higher, being clearly more challenging for the clock recovery algorithm.



Combined sinusoidal waveforms, 75-µs test pattern – MAFE analysis

- The 75 µs patterns satisfy Nokia's HRM-1 limit except the 100 % curve.
- Oscillator stability requirement is 730 s.



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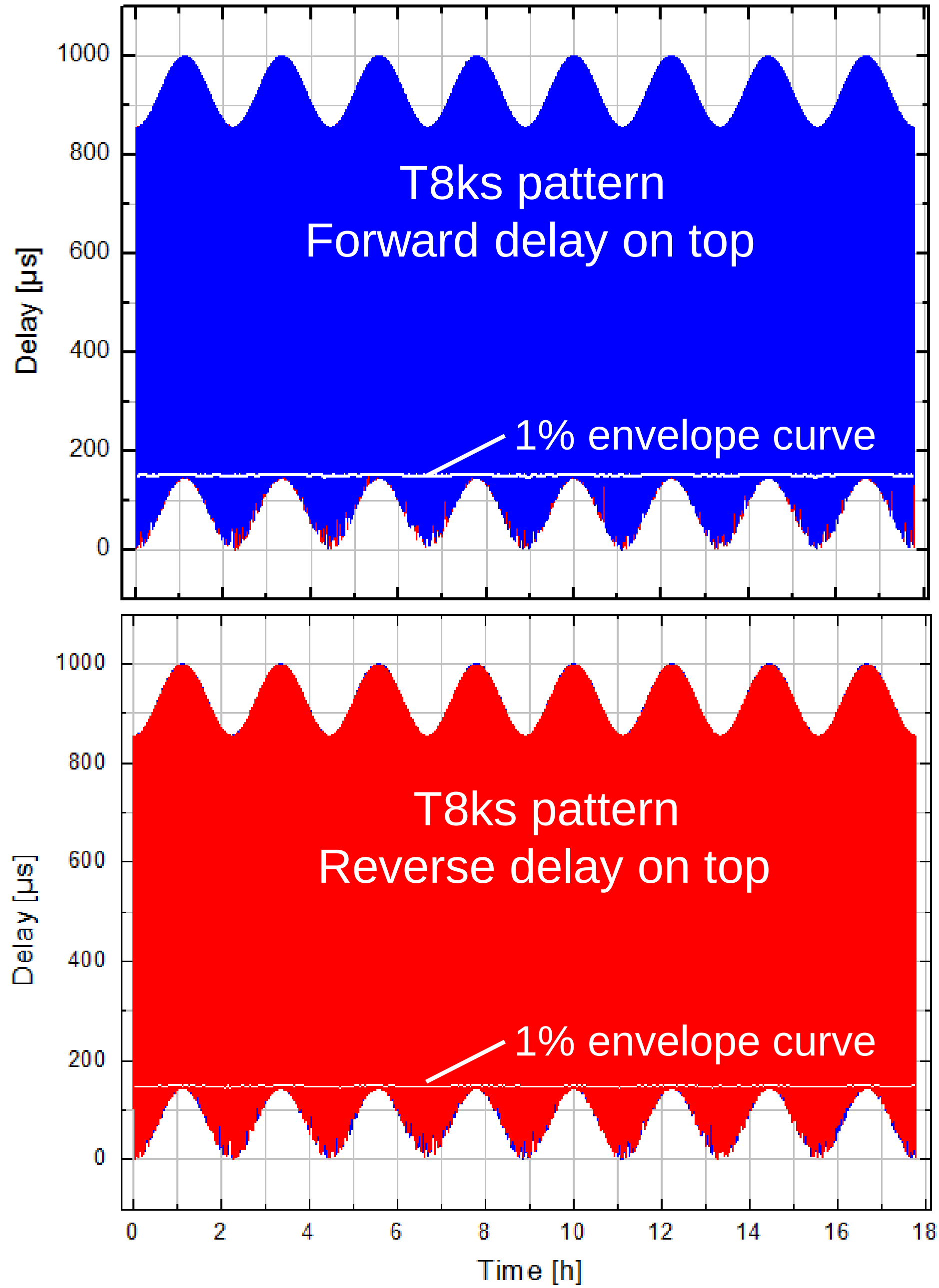
G.8263 3) Single sinusoidal waveforms – Optional test case

- 8 sinusoidal patterns for 150 µs limit. Forward and reverse patterns similar in shape
- Total duration 6 days.
- Relevant duration estimate 50 h.

Pattern	Duration		
	Period	Total	Relevant
T200s	200 s	18 h	3 h
T500s	500 s	18 h	3 h
T1ks	1000 s	18 h	3 h
T2ks	2000 s	18 h	3 h
T4ks	4000 s	18 h	3 h
T8ks	8000 s	18 h	5 h
T16ks	16000 s	18 h	7 h
T86400s	86400 s	24 h	24 h



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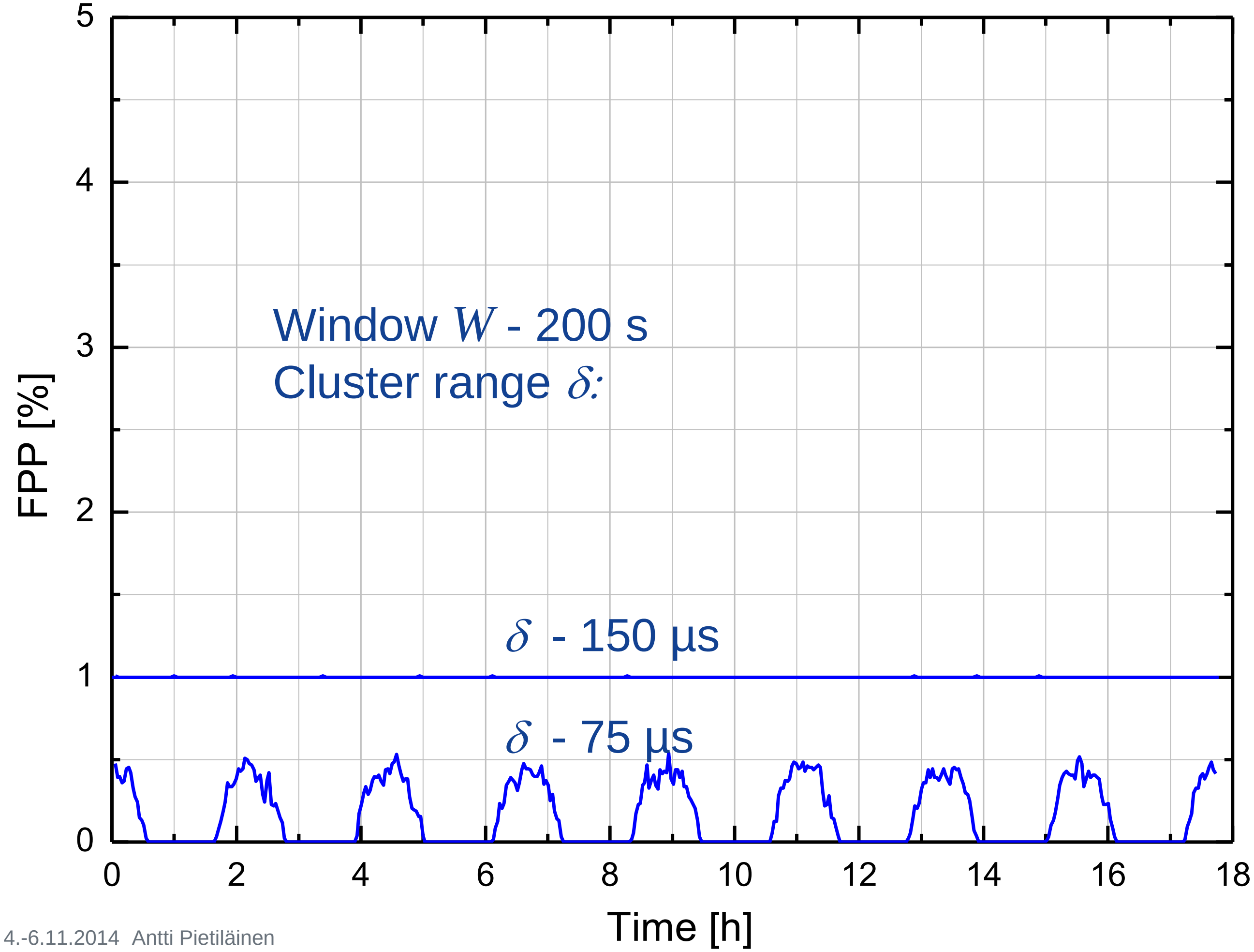
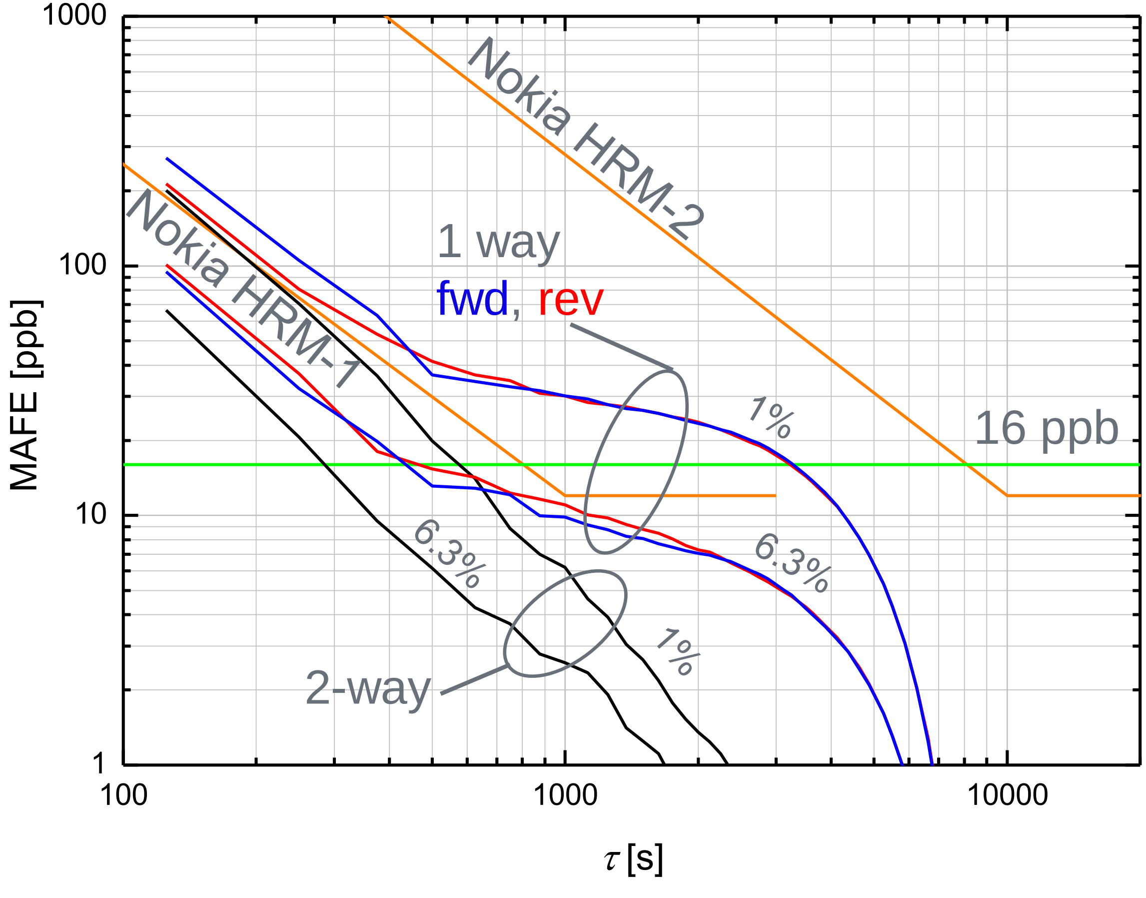
Single sinusoidal waveforms – Floor Packet Percentage (FPP)

- The delay floor varies by 145 µs.
- Exactly 1% of packets in any 200 s window is within 150 µs of the fastest packet in the delay file.



Single sinusoidal waveforms – MAFE analysis

- Example: T8ks delay pattern (sinusoidal pattern, 8000 s period)
- The position of the curves is heavily affected by the selection percentage and whether 1-way or 2-way algorithm is used.



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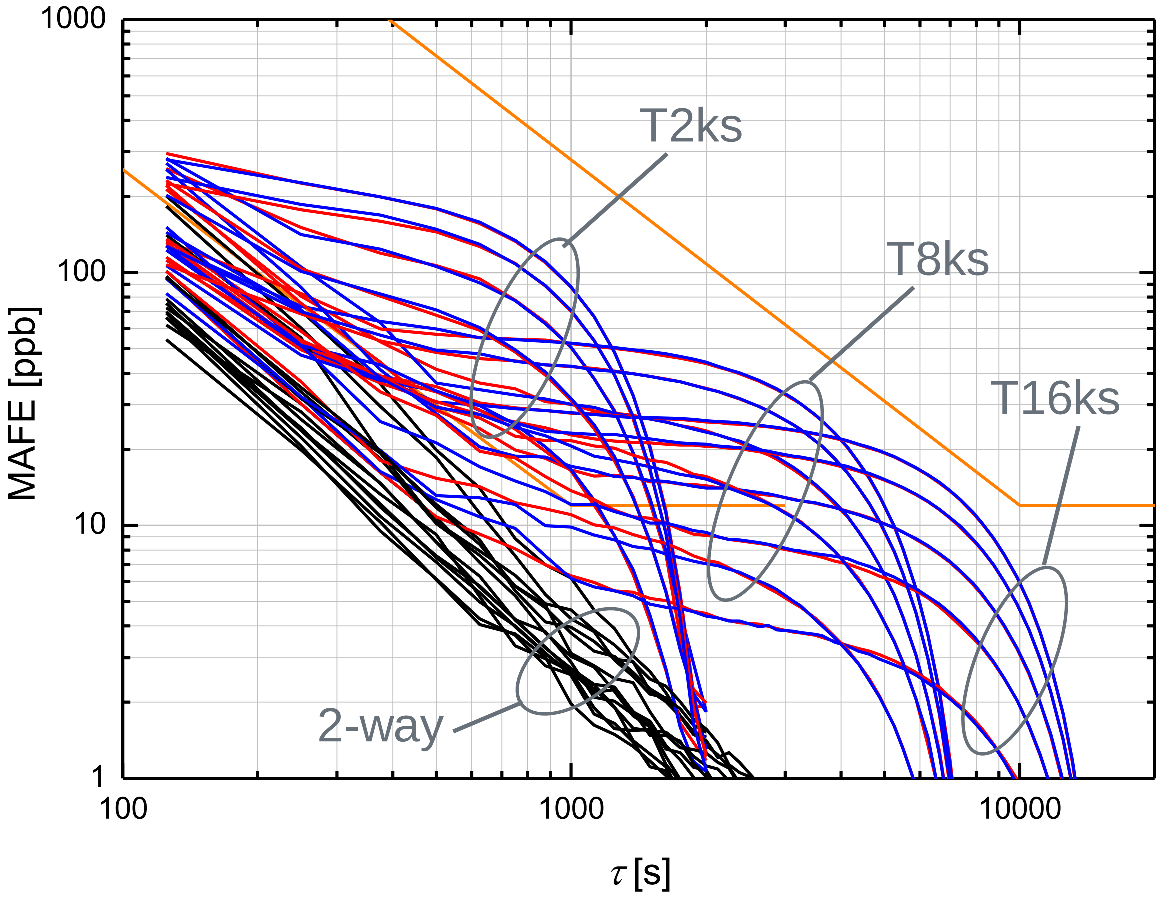
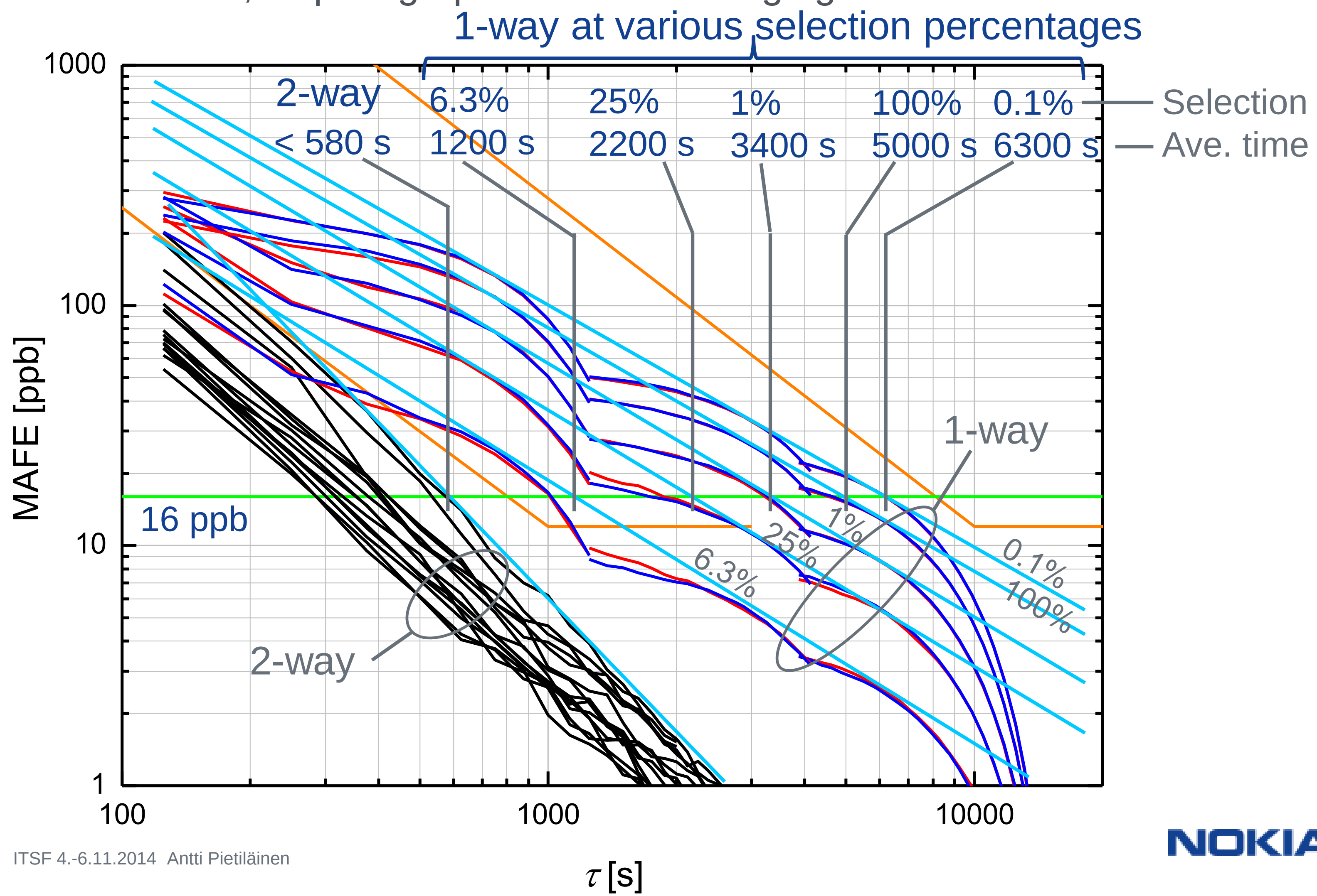
Single sinusoidal waveforms – MAFE analysis

- T2ks, T8ks, and T16ks waveforms, forward, reverse, and two-way
- Selection percentages of 0.1%, 1%, 6.3%, 25%, and 100%
- See next page for analysis



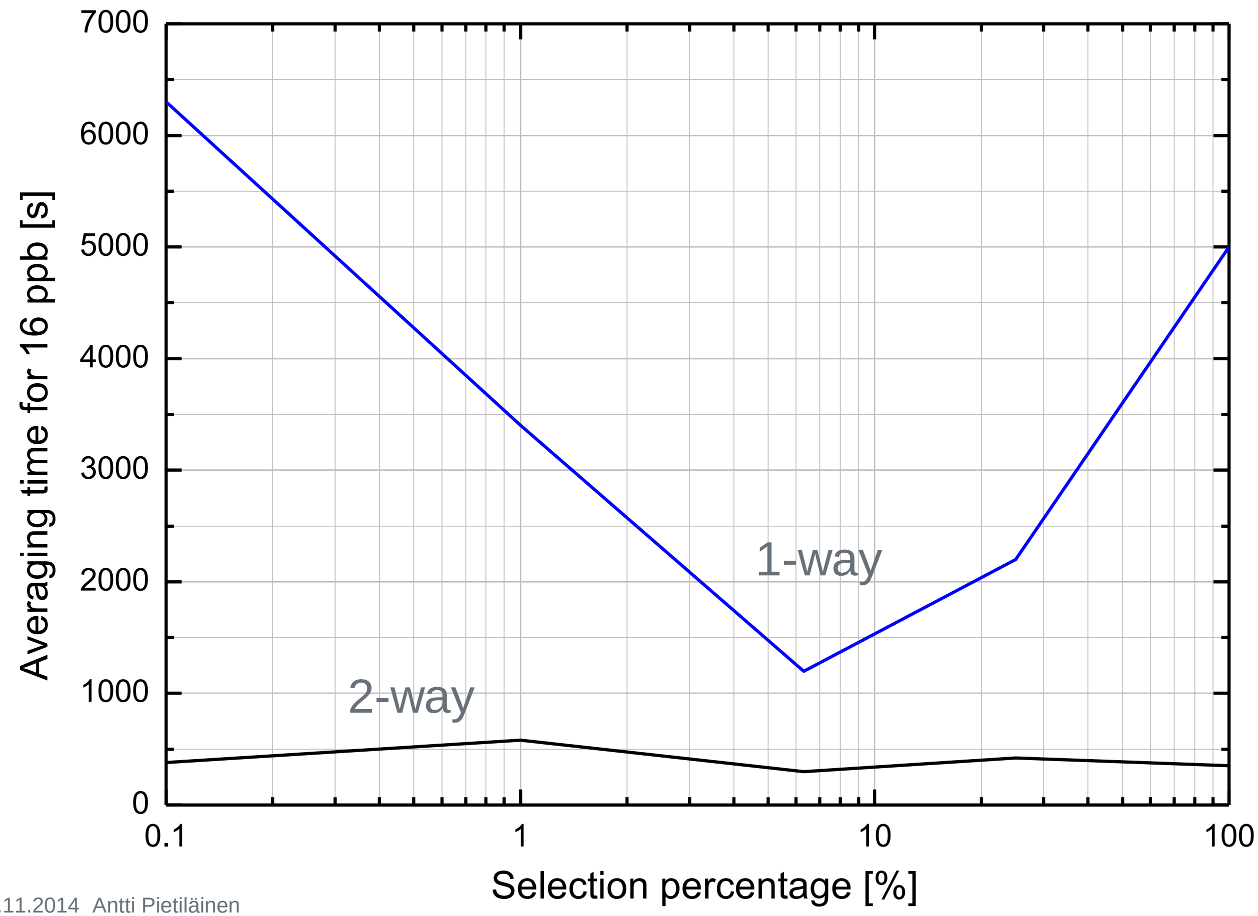
Estimated averaging time to achieve < 16 ppb frequency error

- For 2-way algorithms the patterns are lenient, less than 600 s averaging required.
- For 1-way algorithms with very low or very high selection percentage the test patterns are severe, requiring up to 6300 s averaging.



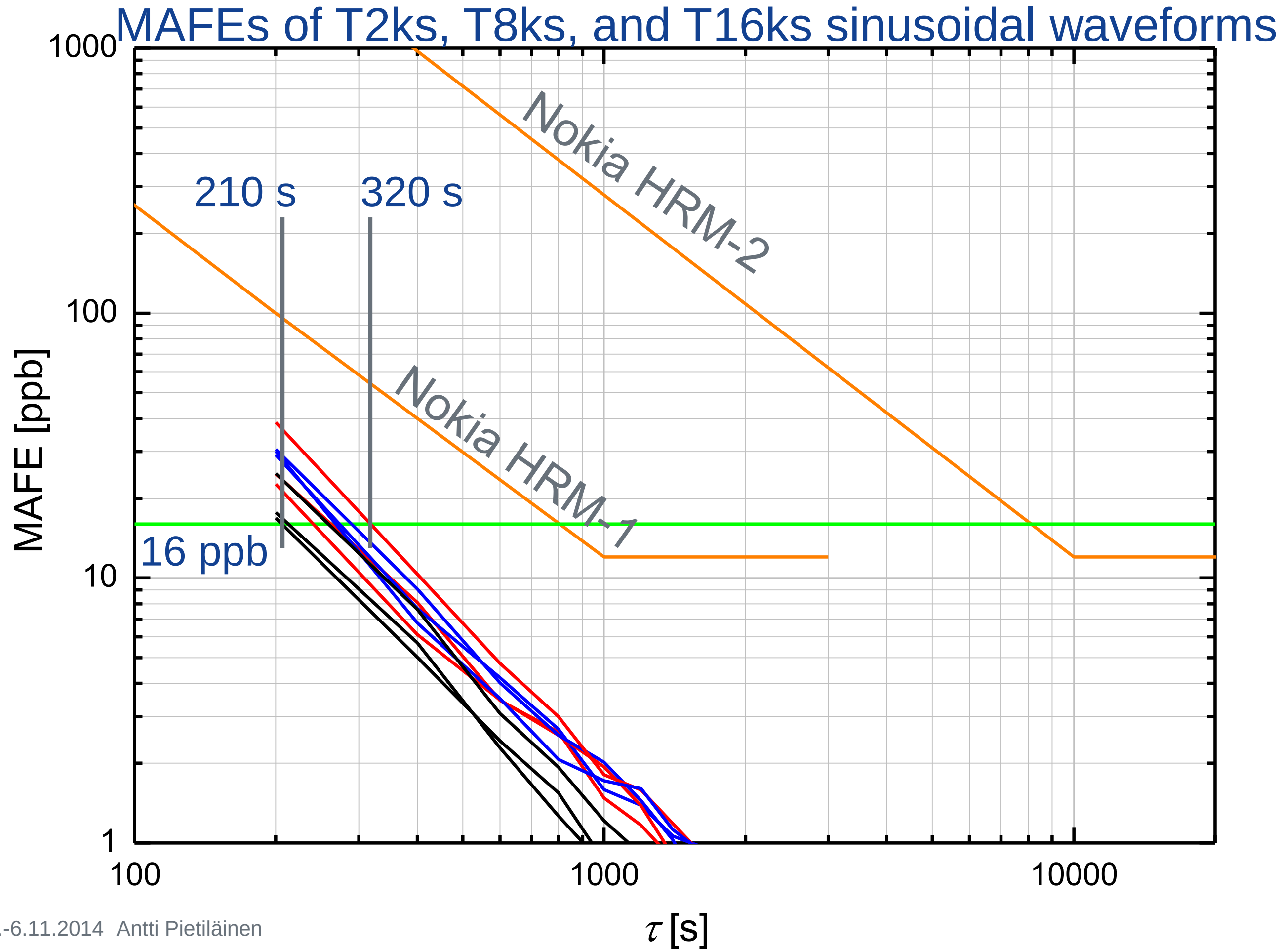
Estimated averaging time to achieve < 16 ppb frequency error

- The 16-ppb-line-crossing values from previous slide are represented as curves below.
- Shortest averaging time is reached if the selection percentage of the clock is about 6.3%.



Single sinusoidal waveforms – special case – 200 s, 1% envelope selection

By taking advantage of the design principle where 1% of packets selected from 200 s windows is located below a straight horizontal line, i.e. by using 1% envelope selection from 200 s windows, 210-270 s averaging would be adequate to reach 16 ppb performance – resembling the challenge level of G.8261 test cases.



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Minimum FPP and estimated averaging time to reach 16 ppb

Delay pattern

Metric	Flicker-Gamma	Combined sinusoids 150 µs	Combined sinusoids 75 µs	Single sinusoids
minFPP150µs	22%	0.8%	49%	1%
minFPP75µs	0%	0%	0.8%	0%
MAFE16ppb 0.1-6.3% min	1100 s	1400 s	660 s	280 s
MAFE16ppb 0.1-6.3% Max	1300 s	1500 s	730 s	6300 s

Summary of test patterns

HRM-1

- ITU test cases G.8261 – Considered not challenging enough for HRM-1 frequency synchronized slaves, born 2006-2007, retiring 2014.

1) Flicker load – Gamma delay G.8263 (Symmetricom/Microsemi) – Suitable for HRM-1 testing.
2) Combined sinusoidal waveforms G.8263 (NSN/Nokia) – Suitable for HRM-1 testing
3) Single sinusoids G.8263 (France Télécom/Orange) – Optional test case. On one hand, very challenging to one-way algorithms, but on the other hand quite lenient to two-way algorithms. Easy also for certain one-way algorithms using specific packet selection criteria. – For HRM-1 testing with reservations

HRM-2

- Work has not started in ITU