Joint IEEE-SA and ITU Workshop on Ethernet

IEEE 1588 Simulations – G.827x and 802.1AS

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Outline

- Introduction
- Applications and requirements
- PTP profiles and other requirements
- Focus of this presentation
- HRMs
- Budget components
- Simulation model parameters
- Simulation results – G.8275.1
- Simulation results – TSN
- Summary and conclusions

Introduction – 1

- Various applications that use timing transported by IEEE 1588 (PTP) profiles have respective timing requirements
  - Time accuracy
  - Jitter
  - Wander
- Network and equipment requirements must ensure that application requirements are met

Introduction – 2

- Approach
  - Develop HRM(s) based on use case(s)
  - Develop budget for each application requirement (time error, jitter, wander)
    - Generally have separate budget component for each impairment
  - Analyze accumulated time error, jitter, and/ or wander, for each budget component, using various models (analytical or simulation)
    - Analysis based on HRMs and possible equipment, protocol (PTP profile), and network parameters

Applications and Requirements – 1

- Telecom – cellular (backhaul)
  - Level 4 and below (see Table 1 of [1]
    - LTE-TDD, UTRA-TDD, CDMA-2000, WCDMA-TDD, WiMax-TDD (some configurations)
    - 1.5 μs max absolute value time error (max|TE|)
  - Level 5
    - WiMax-TDD (some configurations)
    - 1 μs max|TE|
  - Level 6
    - Location-based services, LTE-Advanced
    - <x ns max|TE| (x FFS)
  - MTIE and TDEV requirements FFS

Applications and Requirements – 2

- Time-sensitive networking (TSN; formerly Audio/Video bridging (AVB))
  - Consumer and professional Audio/Video (A/V)
    - 500 ns maximum absolute value time error (1 μs error between any two time-aware systems) over 7 hops (see Annex B of [2])
    - Also jitter/wander requirements; see backup slides
  - Industrial – maximum absolute value time error (see [3])
    - 100 μs over 128 hops for universal time (industrial automation)
    - 1 μs over 16 hops for universal time (energy automation)
    - 1 μs over 64 hops for working clock
  - Automotive – still being developed

PTP Profiles and Other Requirements – 1

- Telecom PTP profile, equipment, and network requirements
  - Being developed in G.827x series of Recommendations, in ITU-T Q13/15
  - Full timing support from the network (all nodes PTP-capable), G.8275.1 [20]
    - Frequency transport via synchronous Ethernet (SyncE) and time transport via PTP
    - Time and frequency transport via PTP
  - Partial timing support from the network (some nodes not PTP-capable), G.8275.2

PTP Profiles and Other Requirements – 2

- TSN (AVB) PTP profile, equipment, and network requirements
  - Gen 1 requirements in IEEE Std 802.1AS™ – 2011 [2] (developed in IEEE 802.1)
    - All nodes gPTP-capable (full timing support)
    - Time and frequency transport via PTP (for full-duplex Ethernet transport case)
      - Frequency transported by measuring nearest-neighbor frequency offsets on every link using Pdelay messages, and accumulating in Follow_Up TLV
    - Alternate BMCA that is very similar to default BMCA
    - Mainly for consumer and professional A/V

PTP Profiles and Other Requirements – 3

- TSN (AVB) PTP profile, equipment, and network requirements (Cont.)
  - Gen 2 will be in IEEE Std 802.1ASbt
  - Will contain extensions for industrial and automotive applications
  - Enhancements will allow better time accuracy, faster reconfiguration, and redundancy/fault-tolerance

Focus for this Presentation

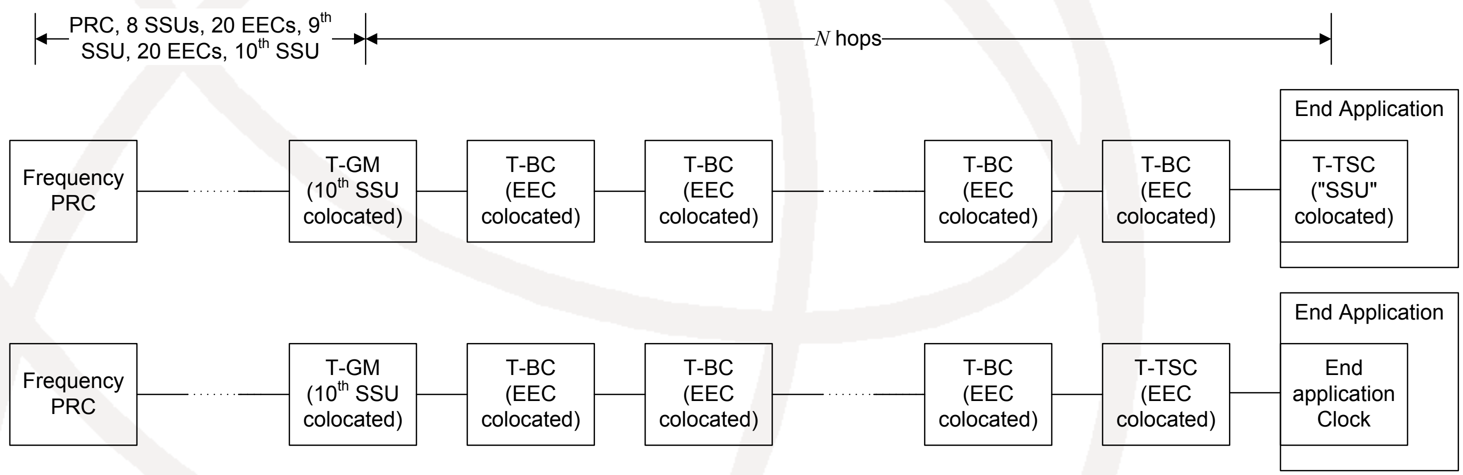
- Telecom applications
  - Full timing support with time transported via PTP and frequency via SyncE
  - Level 4 applications (1.5 μs maximum absolute value time error)
- TSN applications
  - IEEE Std 802.1AS – 2011 (Gen 1)
    - Consumer and professional A/V
    - 500 ns maximum absolute value time error
    - Jitter and wander requirements of slides 32 and 33

Hypothetical Reference Models (HRMs) – 1

- Telecom – Documented in Appendix II/ G.8271.1 [19] for case of full timing support from the network
  - Grandmaster (GM), *N* Telecom Boundary Clocks (T-BCs), and Telecom Slave Clock (T-TSC)
    - *N* = 10 (11 hops) and *N* = 20 (21 hops) have been simulated
  - SyncE may be
    - Congruent: SyncE chain follows chain of T-BCs
    - Non-congruent: multiple SyncE chains, with each chain providing a frequency reference to one T-BC or T-TSC

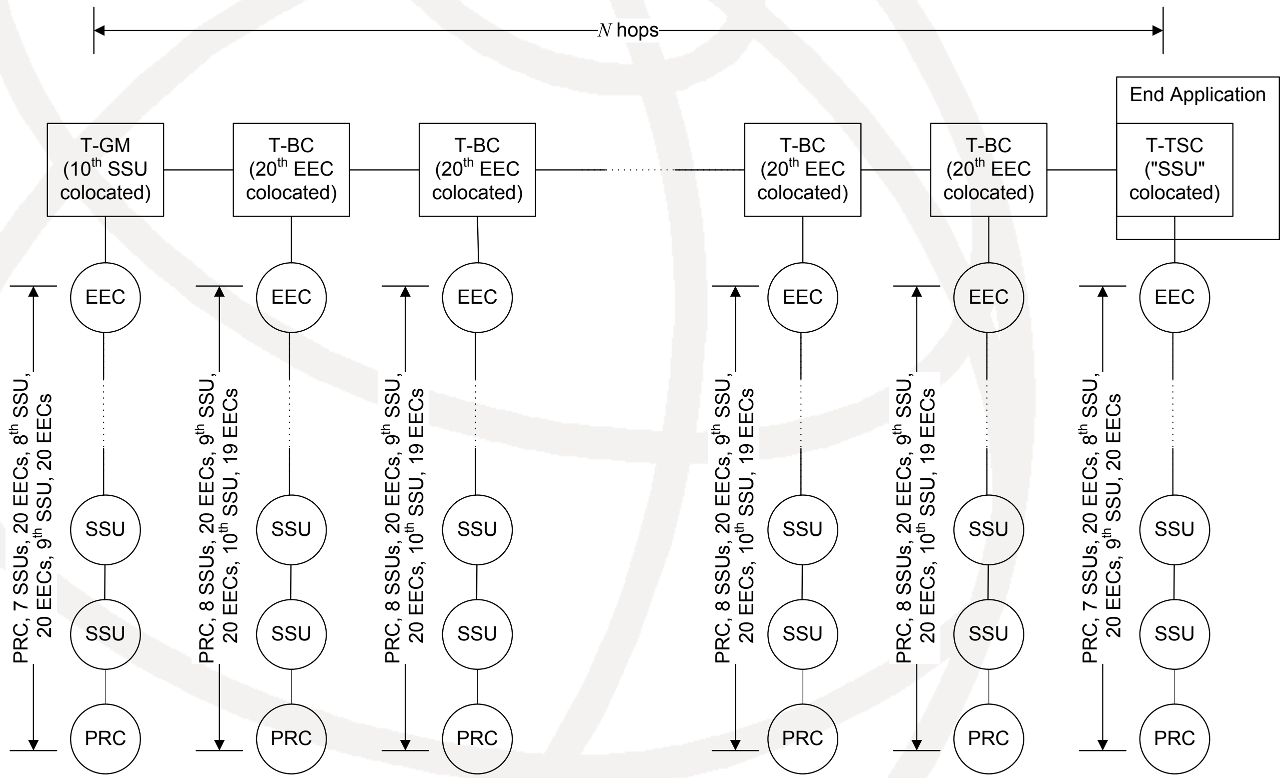
Hypothetical Reference Models (HRMs) – 2

- HRM for case of SyncE support – congruent scenario (from Figure II.2/G.8271.1)
- N = 11 (simulations performed for N up to 21)



Hypothetical Reference Models (HRMs) – 3

- HRM for case of SyncE support – non-congruent scenario, deployment case 1 (from Figure II.3/G. 8271.1, *N* as in previous slide)



Hypothetical Reference Models (HRMs) – 4

- TSN – Briefly described in Annex B.3 of IEEE Std 802.1AS
  - Refers to any two time-aware systems separated by six or fewer time-aware systems (7 hops)
  - The two time-aware systems may be bridges or end-stations, each synchronized by the same GM
  - The simulations considered a GM, followed by 6 time-aware bridges, followed by a time-aware end station

Budget Components Modeled in Simulations – 1

- Budget components in G.8271.1 include
  a) PRTC
  b) End application
  c) Holdover (time plane)
  d) Random and error due to SyncE rearrangements
  e) Node constant error, including intra-site
  f) Link asymmetries

Budget Components Modeled in Simulations – 2

- In TSN, only (d), (e), and (f) were relevant
- Simulations considered only (d)
  - Other components analyzed separately
- In G.8271.1, 200 ns is budgeted for (d)
- In TSN, a formal budget was not developed (not within scope of [2]), but simulations showed (d) was well within ±500 ns of GM

Simulation Model – Parameters - 1

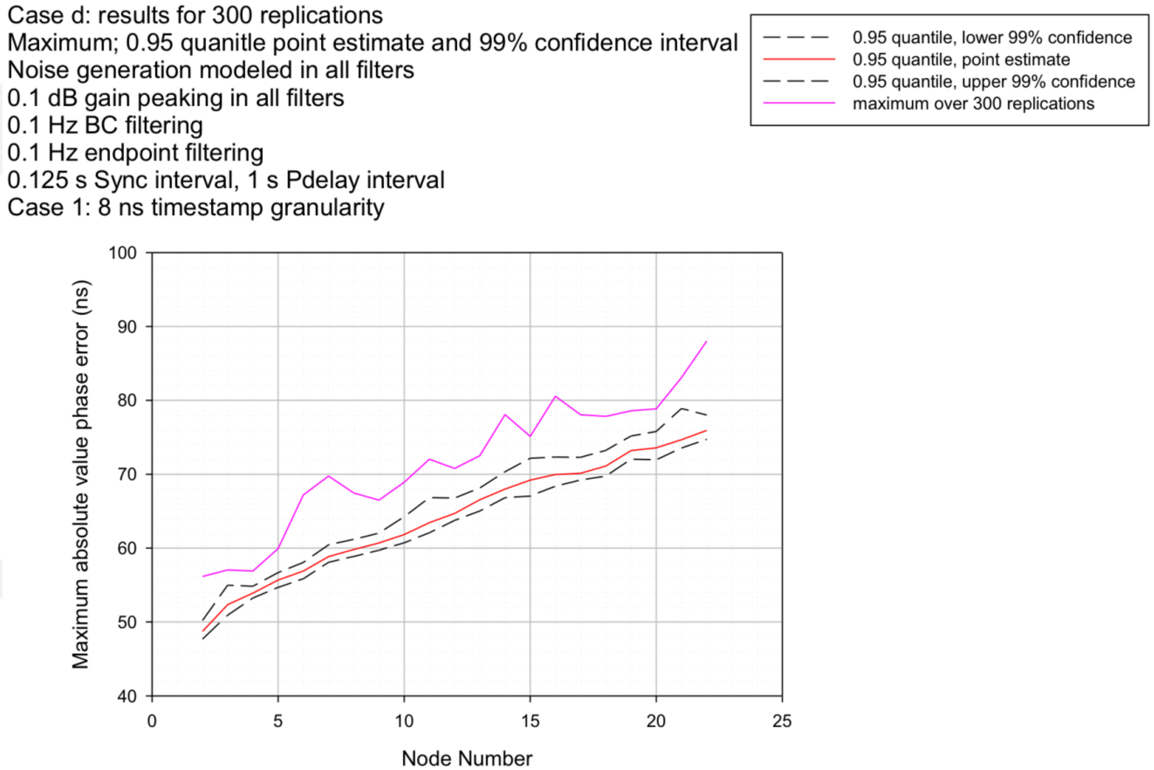
	ITU-T G.827x	IEEE 802.1 AS
HRM	SyncE+PTP (Congruent or non-Congruent)	Full-PTP
Hops	11, 21	7
Noise generation	SyncE network limit of ITU-T G.803 chain	Annex B.1.3.2 of 802.1 AS
Frequency accuracy	$\pm 10^{-11}$	$\pm 10^{-4}$
Asymmetry	0 (analyzed separately from simulations)	0 (analyzed separately from simulations)
Simulation time	11000 s	10010 s
Run replications	300	300
One-step/two-step	One-step	One-step for simulations
Delay mechanism	E2E (agreed by Q13) and P2P	P2P (agreed by 802.1 TSN TG)
Transmission of Sync, Delay_Req, and Pdelay_Req messages	Transmitted such that message intervals are within +/-30% of user-specified mean with 90% confidence	Sync transmitted such that residence-time requirement (see next slide) is met Pdelay_Req transmitted at nominal rate (see next slide)

Simulation Model – Parameters - 2

	ITU-T G.827x	IEEE 802.1 AS
Nominal message rate	8 Hz for Sync and 1 Hz for Delay_Req (or Pdelay_Req for respective simulation cases)	8 Hz for Sync and 1 Hz for Pdelay_Req
Turnaround time	Simulated 10ms, 100ms, 162.5ms, 500ms, 1000ms, and case of no turnaround time requirement	10 ms (single replications of 1 ms and 50 ms also simulated)
Residence time	No requirement	10 ms (single replications of 1 ms and 50 ms also simulated)
Link propagation time	0.1ms	500 ns
Timestamp granularity	8ns (agreed by Q13) and 40ns	40ns (agreed by 802.1 TSN TG); 8ns also simulated
Filter	0.1hz bandwidth for BC and OC slave, 0.1 dB gain peaking	No filtering in BCs (time-aware bridges) 10 Hz, 1 Hz, 0.1 Hz, 0.01 Hz, 100 mHz, with 0.1 dB gain peaking, simulated for OCs (time-aware end-stations)

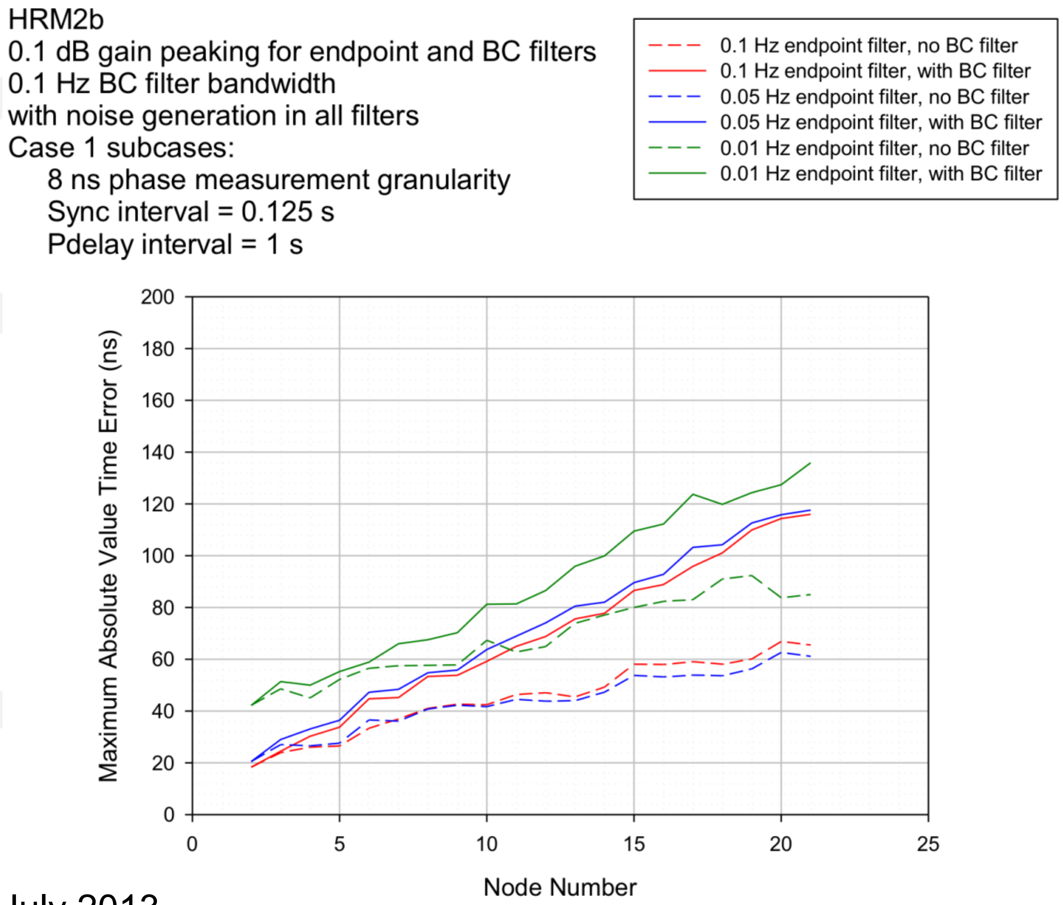
Simulation Results – G.8275.1 – 1

- Non-congruent case (HRM3), no SyncE rearrangements (see [10])



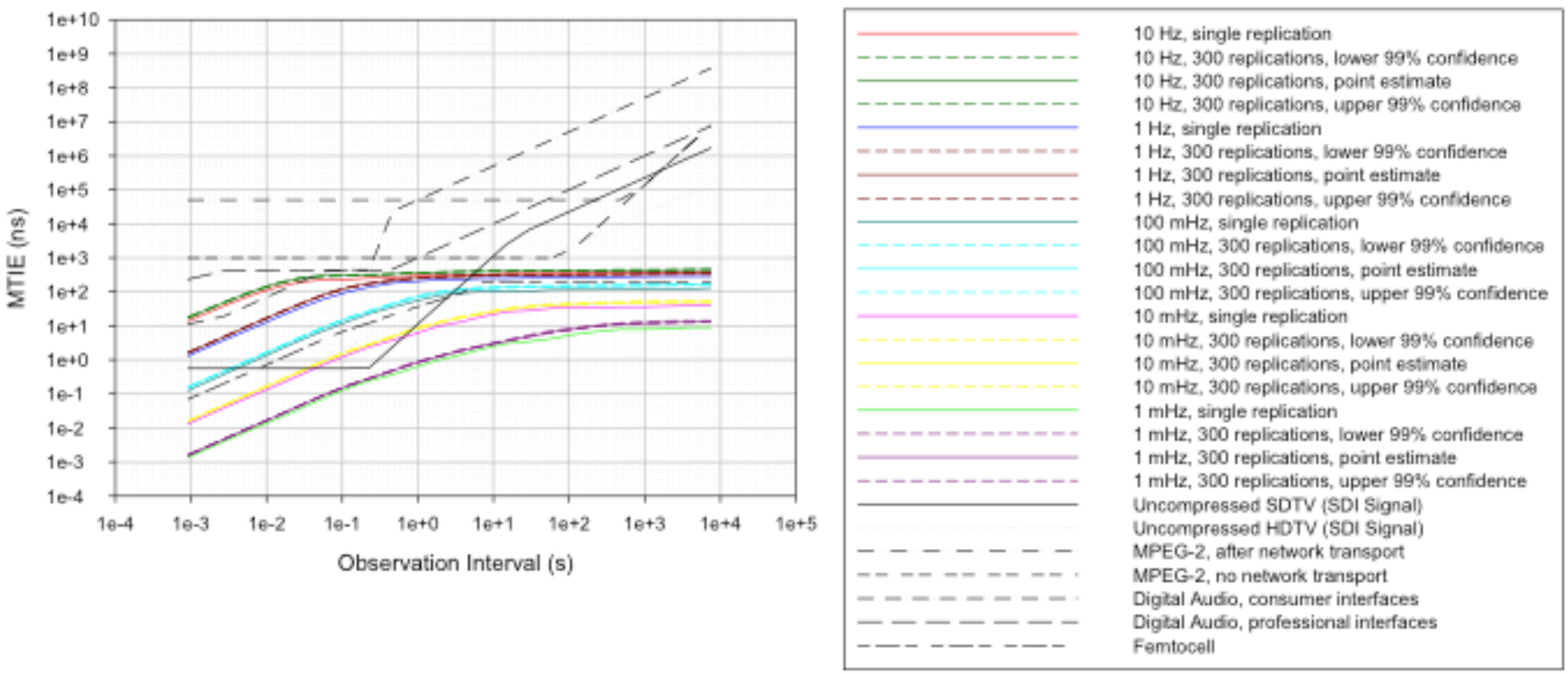
Simulation Results – G.8275.1 – 2

- Congruent case (HRM2), no SyncE rearrangements (see [11])



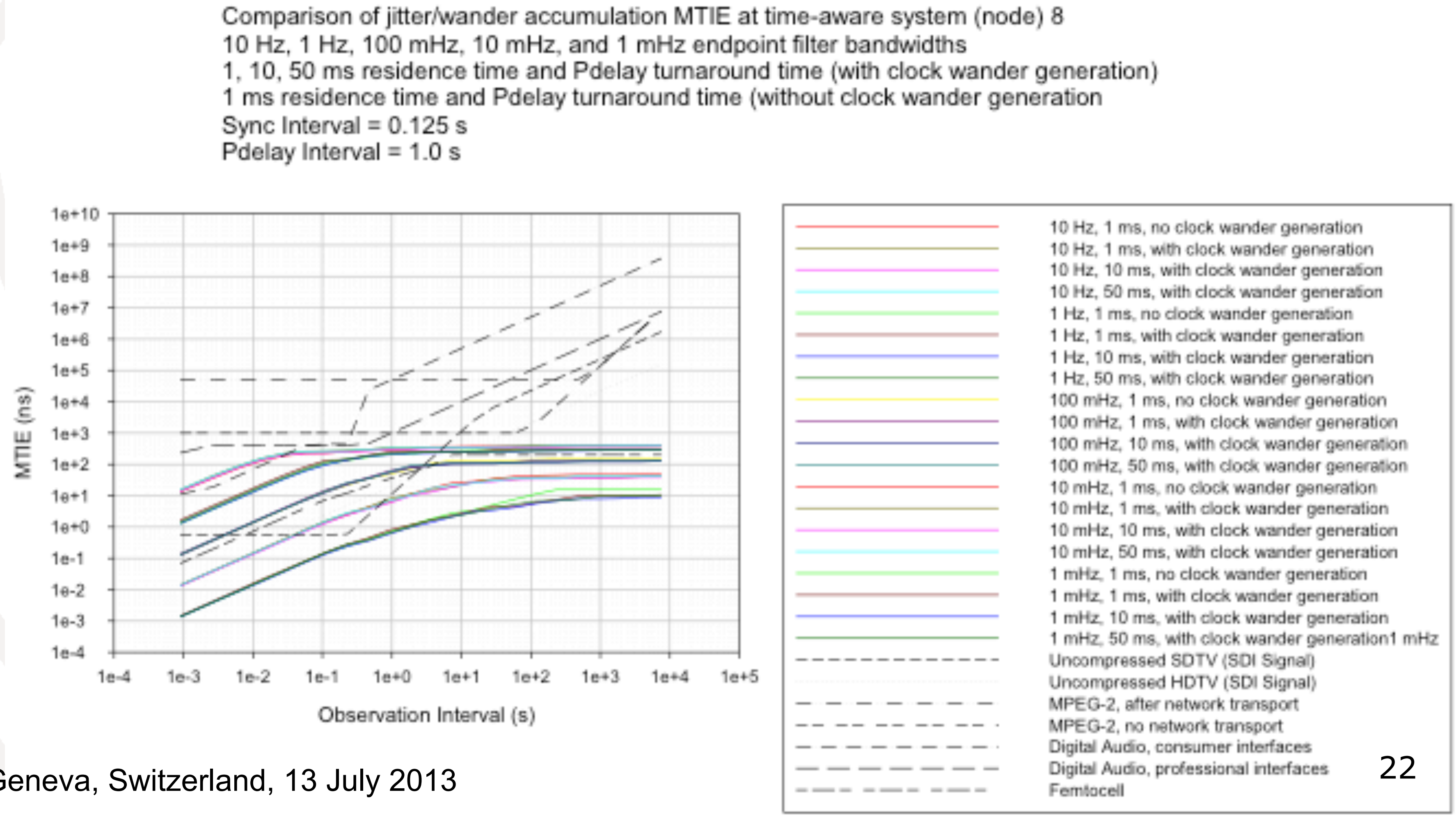
Simulation Results – TSN – 1

Time-aware system (node) 8
Comparison of jitter/wander accumulation MTIE results for single replication and 300 independent replications of simulation
10 Hz, 1 Hz, 100 mHz, 10 mHz, and 1 mHz endpoint filter bandwidths
10 ms residence time and Pdelay turnaround time, with clock wander generation
Sync Interval = 0.125 s
Pdelay Interval = 1.0 s



Simulation Results – TSN – 2

- MTIE results, node 8, single replication, comparison for various residence and turnaround times (node frequency offsets given in backup slide)



Summary and Conclusions – 1

- For G.8275.1 telecom time profile, max|TE| is kept to within 200 ns budget component for
  - 21 hops without SyncE rearrangements (118 ns for congruent case and 88 ns for non-congruent cases)
  - 21 hops with SyncE rearrangements (180 ns for non-congruent case, see backup slides)

Summary and Conclusions – 2

- 11 hops with SyncE rearrangements (440 ns for congruent case and no additional scheme for mitigation, see backup slides)
- 11 hops with SyncE rearrangements
  - (200 ns with SyncE transient rejected, and phase changes on rejecting and reacquiring SyncE limited to 30 ns and 60 ns; 135ns with T-BC filter turned off during SyncE transient and initialized when turned back on with state it would have if not turned off; see backup slides)

Summary and Conclusions – 3

- For TSN, satisfying jitter/wander requirements requires suitable filtering at endpoint
  - 10 Hz needed for professional audio and compressed video (MPEG-2)
  - 1 Hz needed for consumer audio
  - For SDI video, very narrow bandwidths are needed (see backup), but mainly to meet stringent requirements on wide-band jitter and frequency drift
  - MTIE results suggest that max|TE| for dynamic component of time error will be well within ±500 ns for endpoint filter bandwidth of 0.1 Hz or less

References – 1

1. ITU-T Rec. G.8271/Y.1366, *Time and phase synchronization aspects of packet networks*, Geneva, February 2012.
2. IEEE Std 802.1AS™ – 2011, *IEEE Standard for Local and metropolitan area networks - Timing and Synchronization for Time-Sensitive Applications in Bridged Local Area Networks*, 30 March 2011.
3. Franz-Josef Goetz, *Two Time Scales @ IEEE 802.1ASbt (Gen 2)*, Siemens presentation to IEEE 802.1 TSN TG, 14 January 2013.
4. Geoffrey M. Garner, *Description of ResE Video Applications and Requirements*, Samsung presentation to IEEE 802.3 Residential Ethernet SG, May 16, 2005.
5. Geoffrey M. Garner, *Description of ResE Audio Applications and Requirements*, Samsung presentation to IEEE 802.3 Residential Ethernet SG, May 16, 2005.

References – 2

6. Geoffrey M. Garner, *End-to-End Jitter and Wander Requirements for ResE Applications*, Samsung presentation to IEEE 802.3 Residential Ethernet SG, May 16, 2005.
7. Geoffrey M. Garner and Wei Jianying, *Further Simulation Results for syncE and STM-1 Jitter and Wander Accumulation over Networks of OTN Islands*, Huawei contribution to ITU-T SG 15, Q13, Geneva, May 2010, COM 15 – C 965 – E.
8. G. H. Manhoudt, *Comparison Between ETSI and ANSI Requirements Concerning SDH Clock Bandwidths*, AT&T NS Netherlands BV contribution to ITU-T SG 13, Q21, Geneva, March 7 – 18, 1994, D.360.
9. IEEE Std 1588™ – 2008, IEEE Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems, 24 July 2008.

References – 3

10. Geoffrey M. Garner, Lv Jingfei, Sebastien Jobert, and Michel Ouellette, *Initial Multiple Replication Simulation Results for Transport of Time over the HRM3 chain of Boundary Clocks*, Huawei, France Télécom, and Iometrix contribution to ITU-T Q13/15, York, 26 – 30 September 2011, WD53.
11. Geoffrey M. Garner, Lv Jingfei, Sebastien Jobert, and Michel Ouellette, *Initial Simulation Results for Transport of Time over the HRM2b chain of Boundary Clocks*, Huawei, France Télécom, and Iometrix contribution to ITU-T SG 15, Q13, Geneva, November, 2011, COM 15 – C 1729 – E.
12. Geoffrey M. Garner, *Multiple Replication Simulation Results for 802.1AS Synchronization Transport with Clock Wander Generation and Updated Residence and Pdelay Turnaround Times*, Samsung presentation to IEEE 802.1 AVB TG, September 13, 2010.

References – 4

13. Geoffrey M. Garner, *Simulation Results for 802.1AS Synchronization Transport with Clock Wander Generation and Updated Residence and Pdelay Turnaround Times*, Samsung presentation to IEEE 802.1 AVB TG, July 12, 2010.
14. Geoffrey M. Garner, Lv Jingfei, Sebastien Jobert, and Michel Ouellette, *Initial Simulation Results for Transport of Time over the HRM3 chain of Boundary Clocks, with SyncE Reference Chain Rearrangements*, Huawei, France Télécom, and Iometrix contribution to ITU-T SG 15, Q13, Geneva, November, 2011, COM 15 – C 1725 – E.
15. Geoffrey M. Garner, Lv Jingfei, Sebastien Jobert, Michel Ouellette, and Han Li, *Potential Mitigation of the HRM2b Transient*, Huawei, France Télécom, Iometrix, and China Mobile Communications Corporation contribution to ITU-T Q13/15, Helsinki, 4 – 8 June 2012, WD71.

References – 5

16. Geoffrey M. Garner, Lv Jingfei, Sebastien Jobert, Michel Ouellette, Han Li, Liuyan Han, and Lei Wang, *New Analysis and Proposal for Solution for Mitigation of the HRM2 SyncE Rearrangement Transient*, Huawei, France Télécom, Iometrix, and China Mobile Communications Corporation contribution to ITU-T Q13/15, San Jose, 8 – 12 April 2013, WD39.
17. ITU-T Rec. G.810, *Definitions and terminology for synchronization networks*, Geneva, August 1996.
18. Athanasios Papoulis, *Probability, Random Variables, and Stochastic Processes*, Third Edition, McGraw-Hill, 1991.
19. ITU-T Draft New Rec. G.8271.1, Network Limits for Time Synchronization in Packet Networks, New Latest Draft, San Jose, 8 – 12 April 2013, WD8271.1ND.
20. ITU-T Draft New Rec. G.8275.1, Precision time protocol telecom profile for phase/time synchronization, New Latest Draft, San Jose, 8 – 12 April 2013, WD8275-1NLD.

Backup Slides

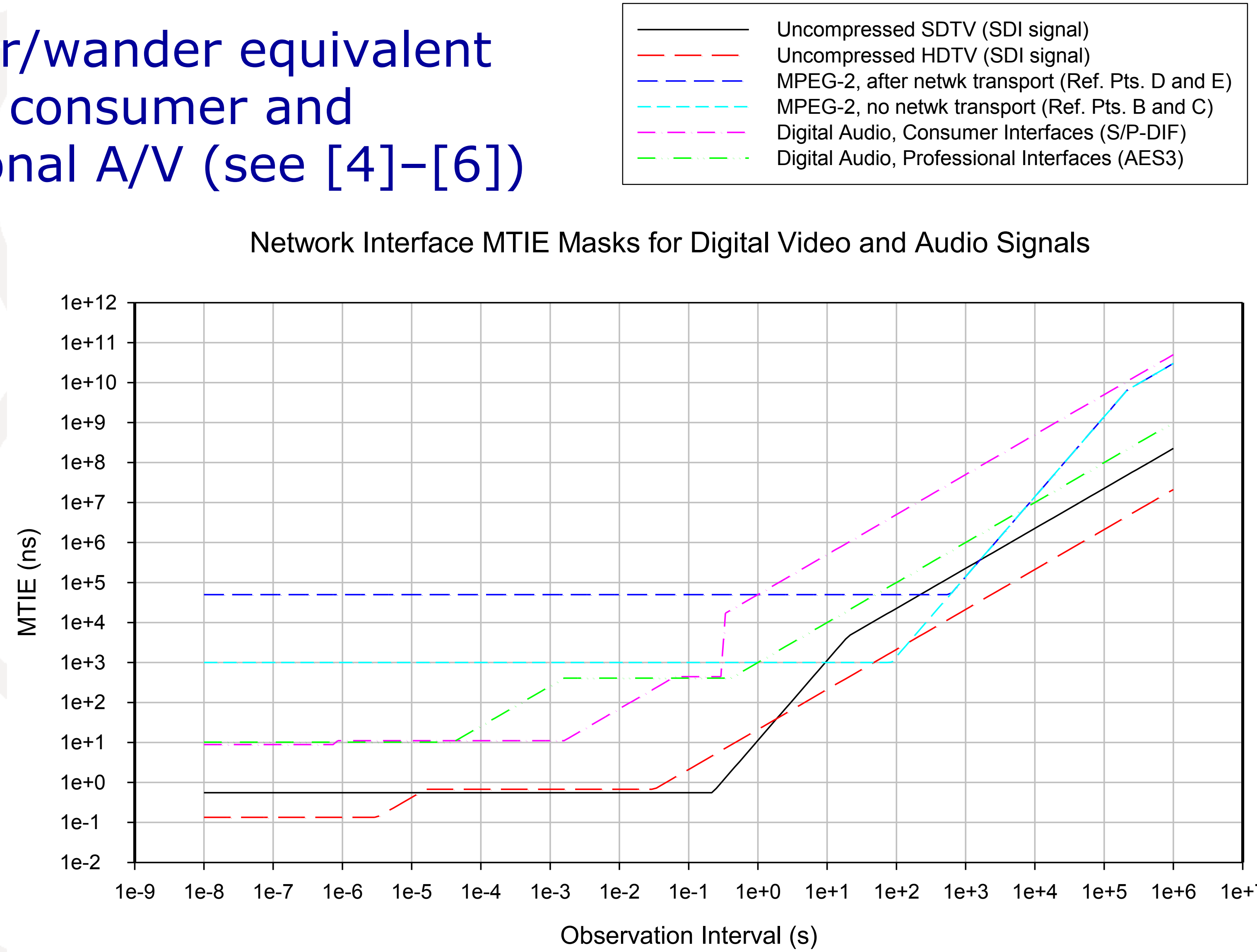
Jitter/Wander Requirements for TSN – 1

TSN jitter/wander requirements for consumer and professional A/V (see [4]–[6])

Requirement	Uncompressed SDTV	Uncompressed HDTV	MPEG-2, with network transport	MPEG-2, no network transport	Digital audio, consumer interface	Digital audio, professional interface
Wide-band jitter (UIpp)	0.2	1.0	50 µs peak-to-peak phase variation requirement (no measurement filter specified)	1000 ns peak-to-peak phase variation requirement (no measurement filter specified)	0.25	0.25
Wide-band jitter meas filt (Hz)	10	10			200	8000
High-band jitter (UIpp)	0.2	0.2			0.2	No requirement
High-band jitter meas filt (kHz)	1	100			400 (approx)	No requirement
Frequency offset (ppm)	±2.79365 (NTSC) ±0.225549 (PAL)	±10	±30	±30	±50 (Level 1) ±1000 (Level 2)	±1 (Grade 1) ±10 (Grade 2)
Frequency drift rate (ppm/s)	0.027937 (NTSC) 0.0225549 (PAL)	No requirement	0.000278	0.000278	No requirement	No requirement

Jitter/Wander Requirements for TSN – 1

TSN jitter/wander equivalent MTIE for consumer and professional A/V (see [4]–[6])



Simulation Model – General – 1

- Model is combination of discrete-event and discretization of continuous time
  - PTP Messages use discrete-event model
    - Messages modeled include Sync, Pdelay_Req, Pdelay_Resp, Delay_Req, and Delay_Resp
  - Filters in PTP clocks are modeled as discretization of second-order phase-locked loop (PLL) with 20 dB/decade roll-off and specified bandwidth and gain peaking

Simulation Model – General – 2

- An event list is maintained, and the simulation scheduler function gets the next event off this list
  - An event would be transmission or reception of a message
- An event-handler function is invoked, to perform all the necessary operations implied by the event
  - For example, if the current event is the transmission of a Sync message, the event handler would, among other things, compute the fields of the message

Simulation Model – General – 3

- Any new events resulting from the current event are added to the event list
  - For example, if the current event is receipt of Pdelay_Req, transmission of Pdelay_Resp would be scheduled on completion of the current event
- For simplicity, clocks are modeled as one-step (use of one-step versus two-step clocks has small impact on performance)

Simulation Model – General – 3

- Discrete events
  - Transmission of Sync on a master port
  - Reception of Sync on a slave port
  - Transmission of Pdelay_Req on a slave port
  - Reception of Pdelay_Req on a master port
  - Transmission of Pdelay_Resp on a master port
  - Reception of Pdelay_Resp on a slave port
  - Transmission of Delay_Req on a slave port
  - Reception of Delay_Req on a master port
  - Transmission of Delay_Resp on a master port
  - Reception of Delay_Resp on a slave port

Simulation Model – General – 4

- Pdelay mechanism requires specification of Pdelay turnaround time (interval between receipt of Pdelay_Req and sending of Pdelay_Resp)
- With Delay Request/Resp mechanism, Delay_Req is sent independently of the receipt of Sync (so turnaround time can be as large as one Sync interval)

Simulation Model – General – 5

- Note that a simulation case uses either Pdelay or Delay Request/Resp
  - IEEE Std 1588™ – 2008 [9] specifies that the two mechanisms are not mixed
- The earlier G.8275.1 [20] simulations used the Pdelay mechanism, and later simulations used Delay Request/Resp (after Q13/15 decided on the latter for G. 8275.1)
- The TSN simulations used only the Pdelay mechanism, as this is specified in IEEE Std 802.1AS - 2011

Simulation Model – G.8275.1 – 1

- Only the case of SyncE support for frequency has been simulated so far
- Use of SyncE results in time error due to
  - Random phase noise accumulation in the SyncE reference chain
    - Results of previous models and simulations, developed for SDH and OTN, used for this (see [7])
  - SyncE rearrangements
    - Previous model, develop for SDH, used (see [8])

Simulation Model – G.8275.1 – 2

- Sync interval and Sync message transmission
  - Complies with 7.7.2.1 of [9]
  - 90% of inter-message times are within ±30% of mean Sync interval
    - Inter-message times selected from Gamma distribution, but also limited by twice the mean
- Timestamp granularity is 8 ns (40 ns also simulated in earlier cases)

Simulation Model – TSN – 1

- Node local clocks are free-running, with frequency offset chosen randomly within ±100 ppm
- Node noise generation complies with TDEV mask of B.1.3.2 of [2]
- Timestamp granularity is 40 ns (8 ns also simulated)
- Sync transmitted within 10 ms of receipt of previous Sync (residence time)(50 ms also simulated)
- Pdelay turnaround time is 10 ms (50 ms also simulated)

Simulation Model – TSN – 2

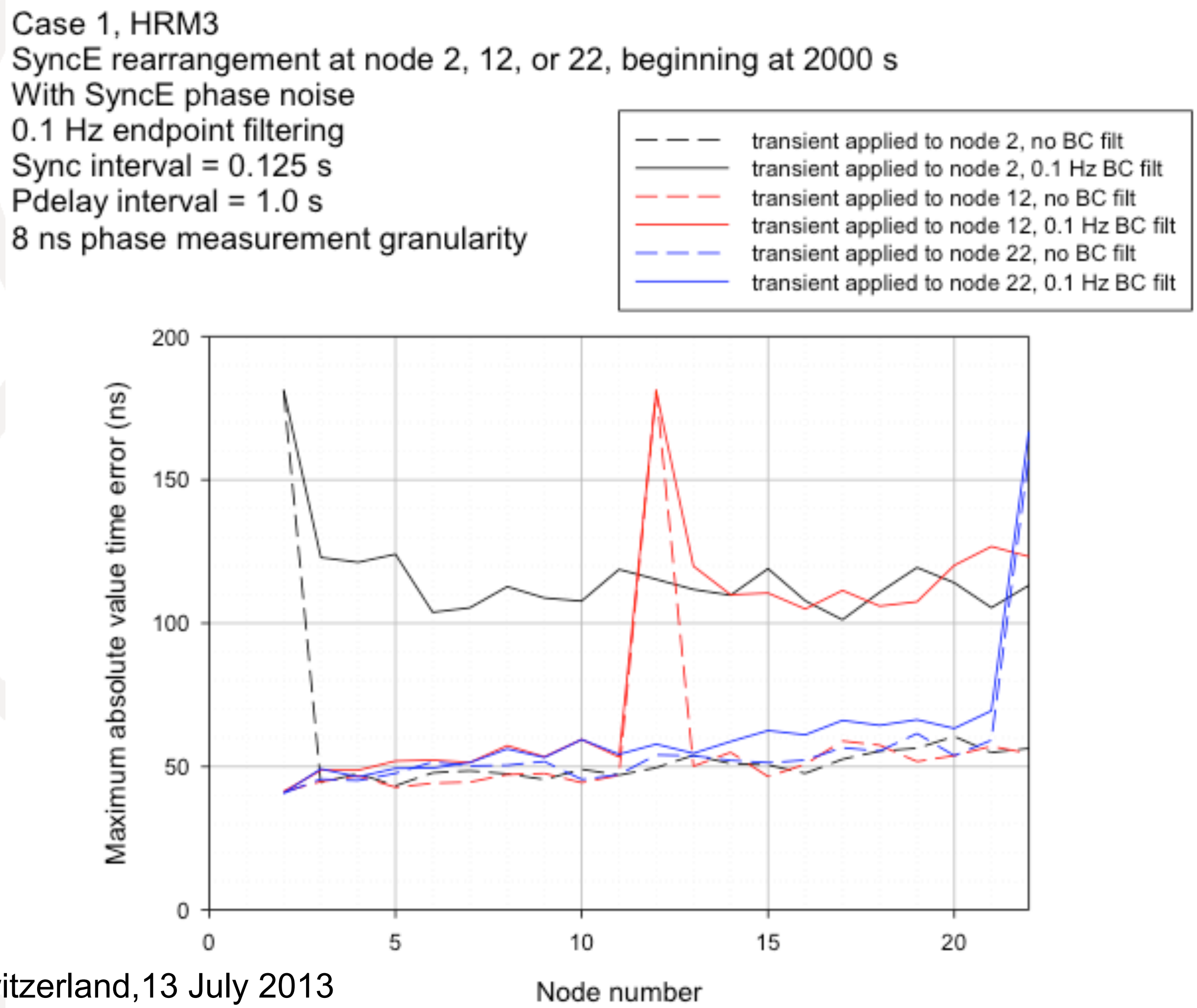
- No PLL filtering in time-aware bridges
  - All filtering is at end devices
- Simulations with 50 ms residence and turnaround times showed small difference compared to 10 ms
  - In 802.1AS-Cor-1, the 10 ms requirements are changed to recommendations
- Frequency transported using PTP, as specified in [2]
  - Nearest-neighbor frequency offsets computed on each link using Pdelay messages
  - Frequency offset relative to GM accumulated in TLV attached to Follow_Up message

Statistics for Simulation Results

- For cases without SyncE rearrangements, 99% confidence interval for the 0.95 quantile of MTIE or max|TE| was obtained by running 300 independent replications
  - Results (for MTIE, this was done separately for each observation interval) were place in ascending order
  - Desired confidence interval was bounded by the 75th and 94th smallest values (see II.5 of [17] or 9-2 of [18])

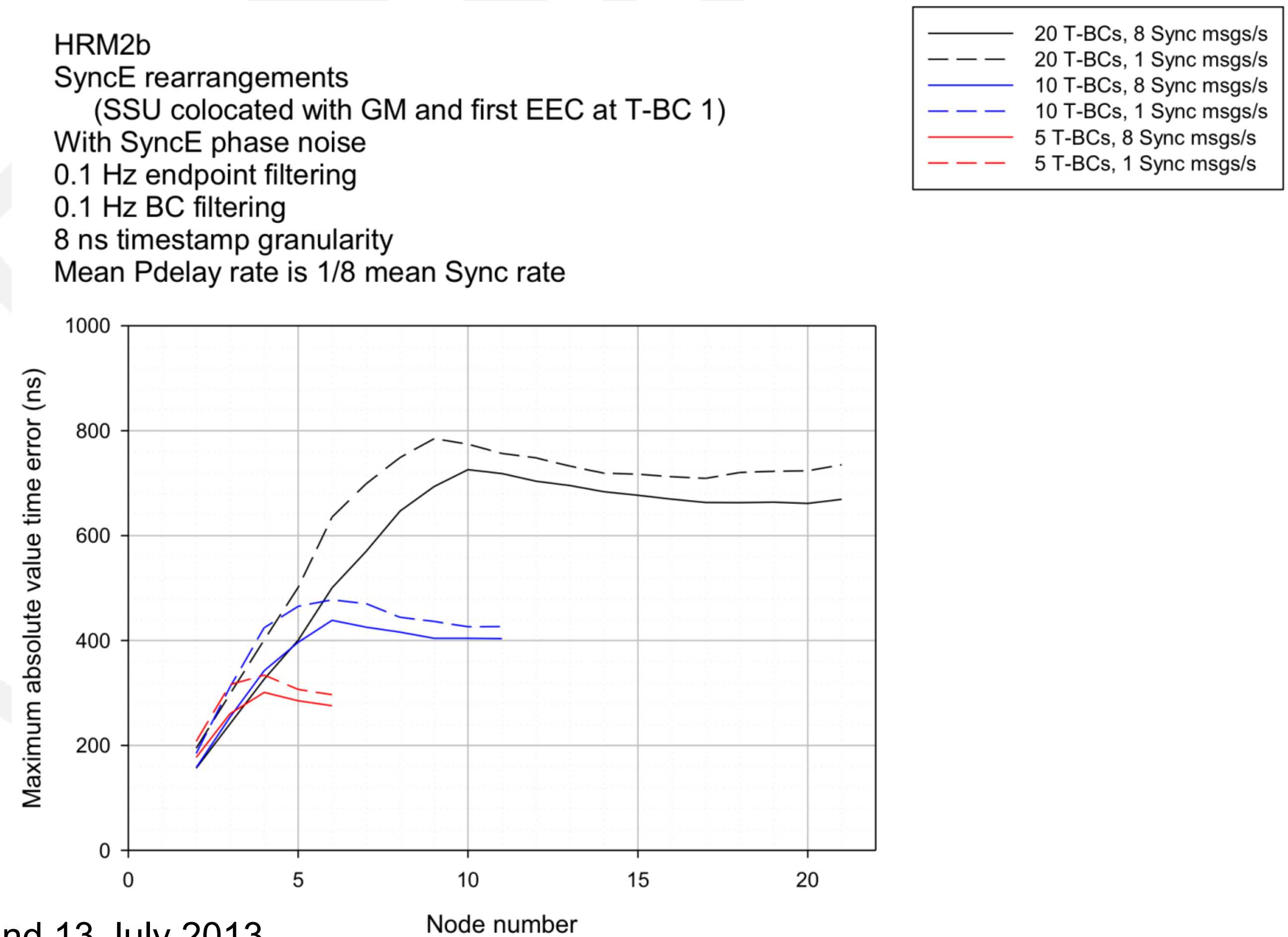
Simulation results – G.8275.1

- Non-congruent case (HRM3), with SyncE rearrangements



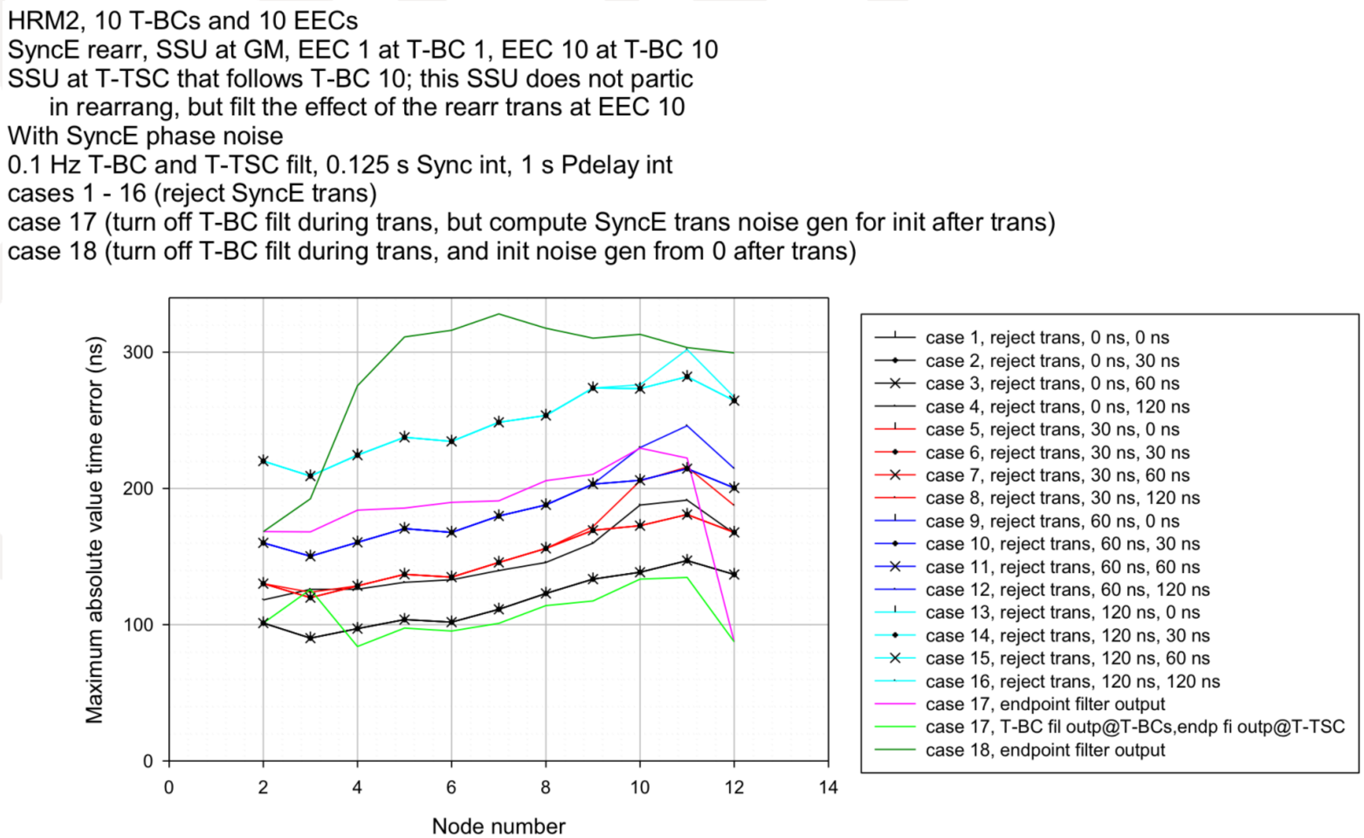
Simulation results – G.8275.1

- Congruent case (HRM2), with SyncE rearrangements and no additional mitigation schemes (see [15])



Simulation results – G.8275.1

- Congruent case (HRM2), with SyncE rearrangements and mitigation of effect of rearrangement by rejecting the SyncE transient or turning off the T-BC filter during the transient (see [16]) (assumptions on next two slides)



Simulation results – G.8275.1

- Phase jumps on rejecting and reacquiring SyncE, for cases 1 – 16 of previous slide

Case	$\Delta\phi_1$ (ns)	$\Delta\phi_2$ (ns)	Case	$\Delta\phi_1$ (ns)	$\Delta\phi_2$ (ns)
1	0	0	9	60	0
2	0	30	10	60	30
3	0	60	11	60	60
4	0	120	12	60	120
5	30	0	13	120	0
6	30	30	14	120	30
7	30	60	15	120	60
8	30	120	16	120	120

Simulation results – G.8275.1

- Assumptions for cases 17 and 18 – turning T-BC filter off during SyncE transient
  - In both cases, turn filter off on detection of transient (via SSM)
  - In both cases, turn filter on 10 s after SSM indicates SyncE is again traceable to PRC
  - Case 17: Initial conditions are those that would exist if the filter had not been turned off
  - Case 18: Zero initial conditions

Simulation Results – TSN

- Frequency offsets for single-replication results on slide 29

Node	Frequency offset (ppm)
1	0 (GM)
2	6.4276
3	-55.714
4	32.295
5	-53.950
6	38.774
7	64.124
8	-83.231