Delay Histogram Analysis

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Introduction

- Worst-case delay has been discussed in IEEE 802 meetings [1-6]
  - Proposed rule of thumb for rough worst-case delay calculation [2]
  - Some formulas to obtain worst-case delay were presented, along with a mathematical proof given certain assumptions [1], [5]
  - A description was given on how worst-case delay can increase in bunching scenarios [5], [6]
  - Simulation results were presented [2], [3], [4]
- 2 ms is normally considered as acceptable delay bound
- The current presentation investigates the frequency of near-worst-case delay (including worst-case delay) and influential factors
  - Tools
    - Cumulative Distribution Function (CDF)
    - Histogram (using sample distribution)
  - Interesting points
    - Frequency (or probability) of near-worst-case delay
    - Factor that most influences near-worst-case delay

Purpose of Present Simulation Work

- Find the factor that most influences an increase in end-to-end delay
  - Utilization
  - Frame Size
  - Forwarding technique
  - Traffic pattern
  - Number of streams
  - Topology
- Compare the frequency (or probability) of Ethernet frame errors (obtained from link BER) and near-worst-case delay
- Compare delay bounds between conventional method and just forwarding method
  - Detailed description will be given in slide 13

BER Calculation in Ethernet Link

❑ Assumptions

- Ethernet BER (BER is in the range 1e-8 to 1e-12)
  - 1e-8 : 100BASE-T4 in 802.3 (Clause 23.1.2)
  - 1e-12: 1000BASE-X in 802.3 (Clause 36.1.2)
- Ethernet size (except preamble)
  - Minimum: 64 bytes (= 512 bits)
  - Maximum: 1518 bytes (= 12144 bits)
- Poisson error process
- Number of links from sender to receiver in a topology (at slide 6): 9 links

❑ Calculation (Maximum Ethernet size case)

- BER 1e-8
  - 1518byte Maximum size frame → 1e-3
  - 246Byte TS stream case → 1.7e-4
  - 56byte minimum frame→ 4e-5
- BER 1e-12
  - 1518byte Maximum size frame → 1e-7
  - 246byte TS stream case → 1.7e-8
  - 56byte minimum frame → 4e-9

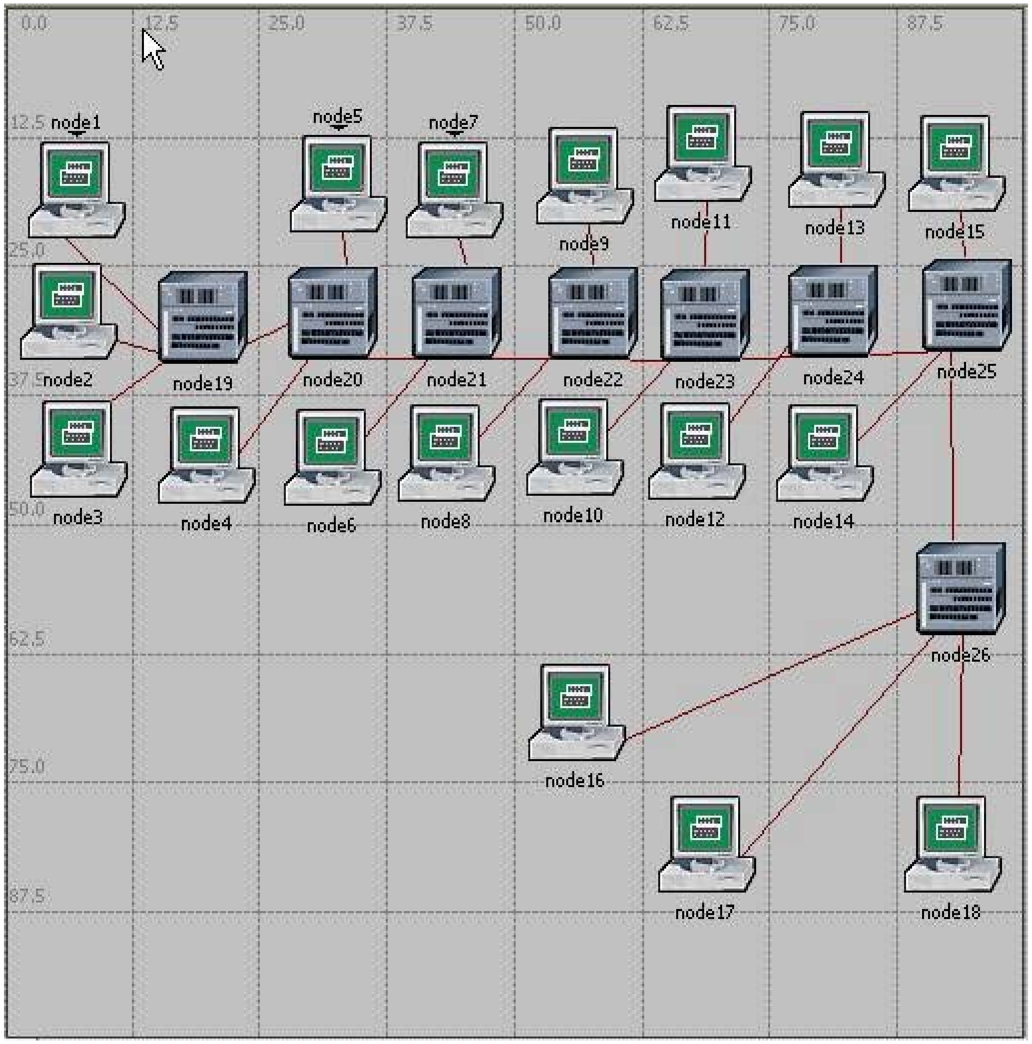
Simulation Scenarios

- All sources are time sensitive, CBR traffic with nominal rates set to produce desired link utilization
- Sources have various different frequency offsets that are all within ± 100ppm
- 7 switch to switch hops
- 100 Mbps link bandwidth
- 9 traffic sources
- Packet size (1526 bytes/ 763 bytes/ 382 bytes/ 191 bytes including Ethernet header and FCS)
  - Switch to switch link utilization ≈ 30%, 50%, 70%, 100%
  - Ethernet Inter-Frame Gap (IFG) (i.e. 12 bytes) is applied to link utilization calculation
  - Exact description of 100% utilization: 99.76%/ 99.99%/ 99.53%/ 99.93% for each
- Source start time of each source is ideally configured to show worst case delay
- Description of network topology 1
  - 3 sources at first switch (nodes 1 – 3)
  - Traffic from 2 of these sources go to final switch (nodes 16 and 18)
  - Traffic from 3rd source (node 3) is dropped at 2nd switch
  - At switches 2 – 7 (nodes 20 – 25 in figure), traffic added from single CBR source, carried 1 hop, and dropped

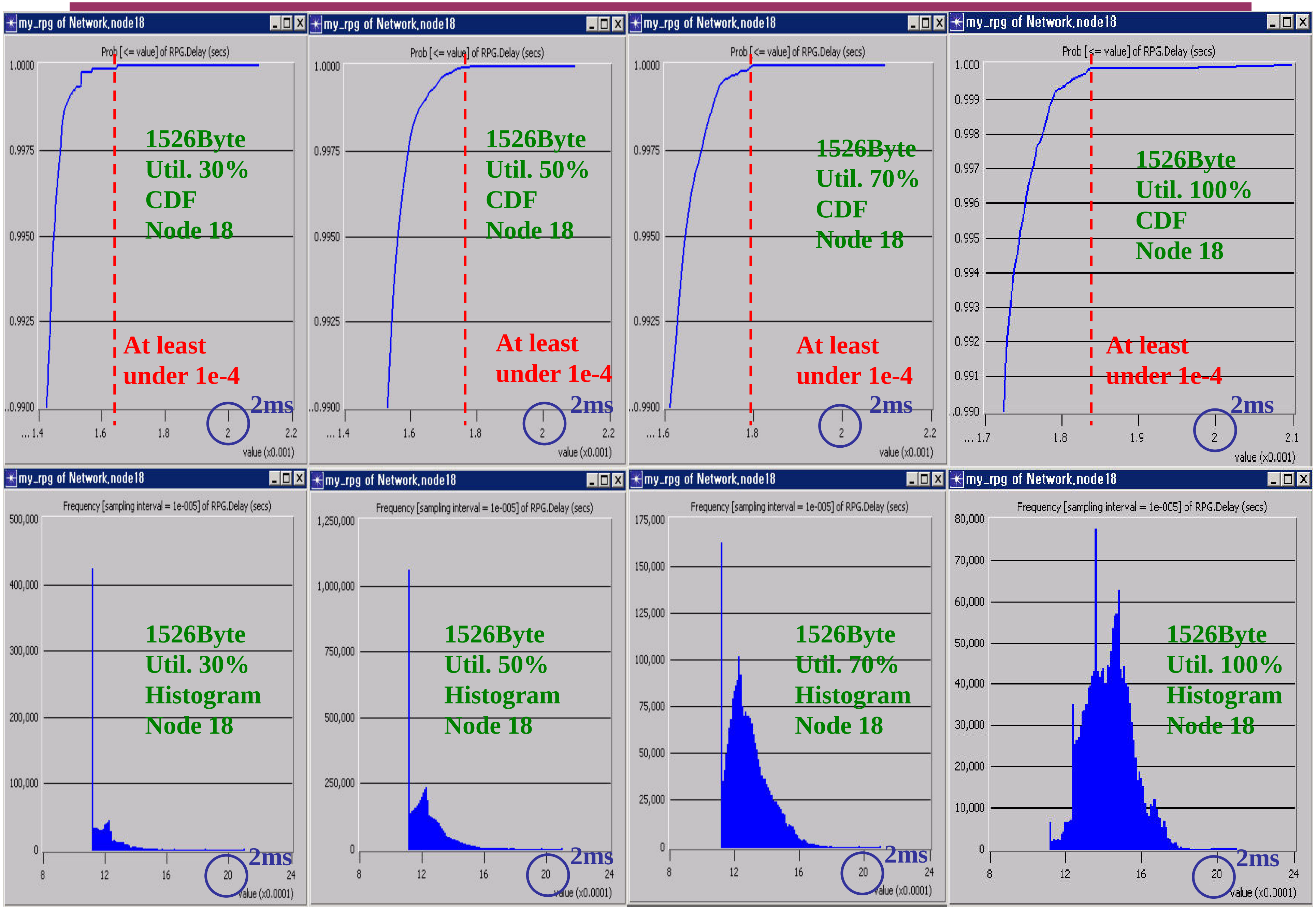
Simulation Scenarios (Cont.)

- Achieved simulation results
  - delay CDF and histogram (using sample distribution)
  - results given for node 18
  - dashed line in each CDF corresponds to 10^{-4} exceedance probability (i.e., 99.99 percentile)

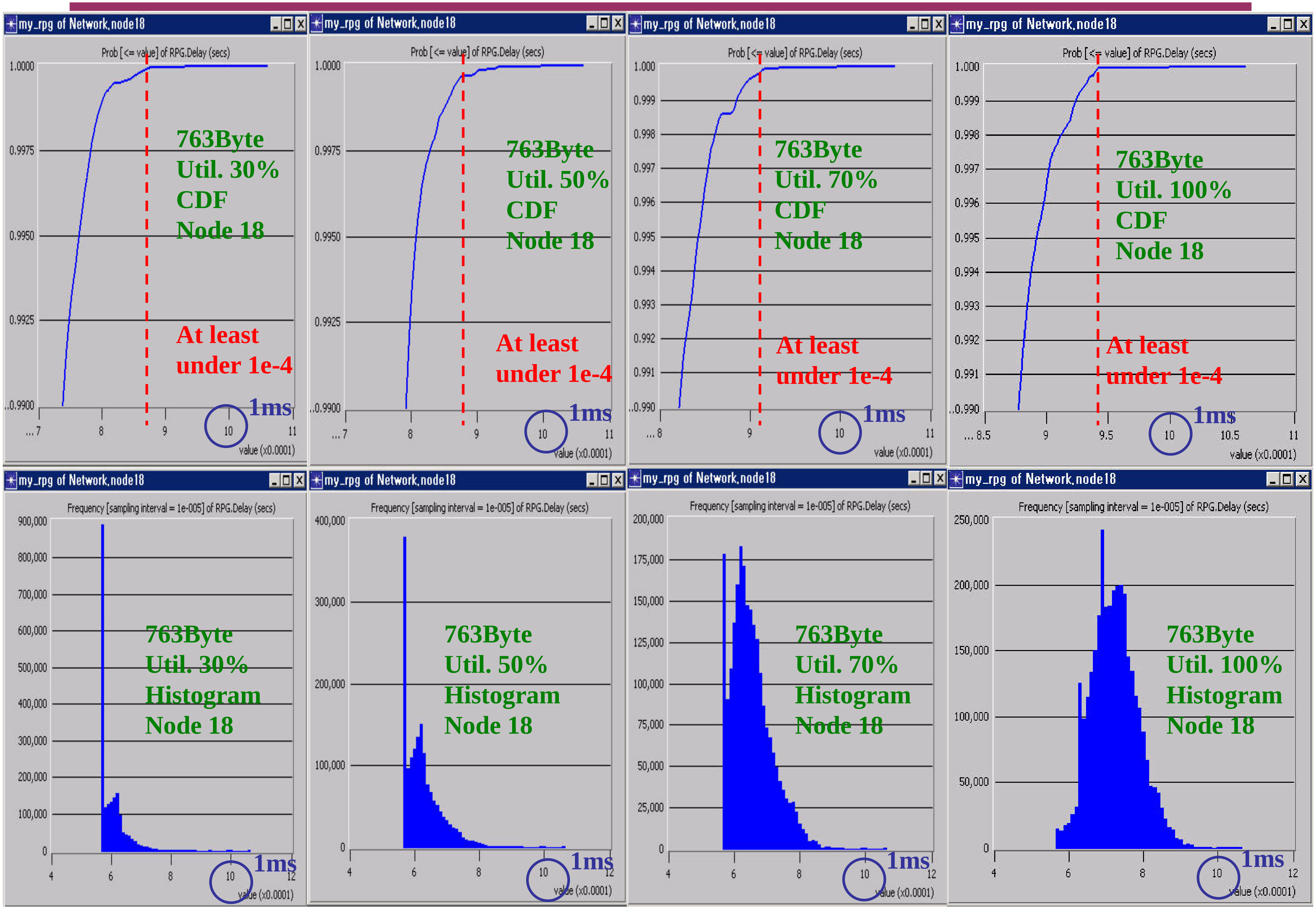
Topology


0.0
12.5
25.0
37.5
50.0
62.5
75.0
87.5
node1
node2
node3
node4
node5
node6
node7
node8
node9
node10
node11
node12
node13
node14
node15
node16
node17
node18
node19
node20
node21
node22
node23
node24
node25
node26

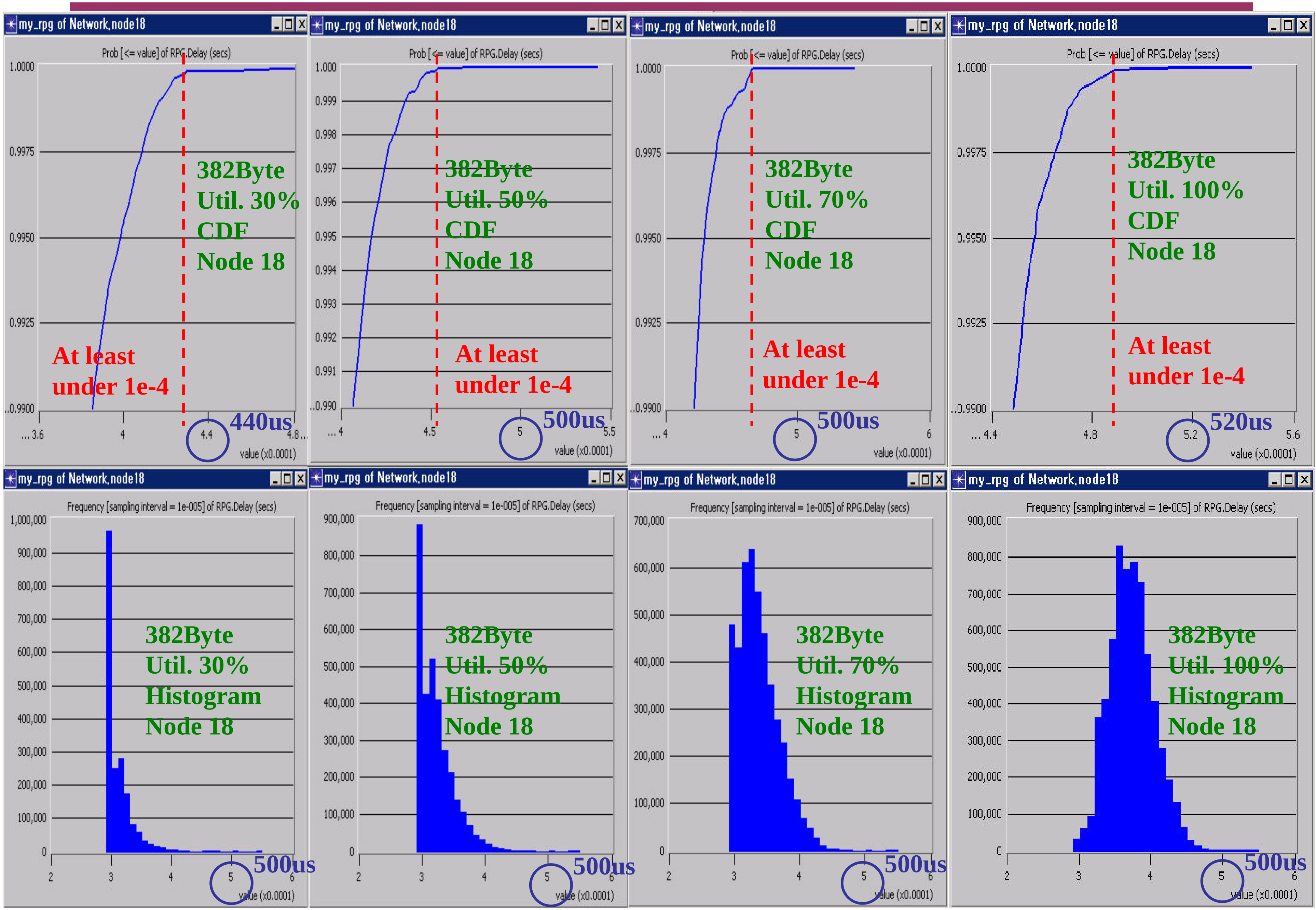
Scenario 1 – 1526 bytes



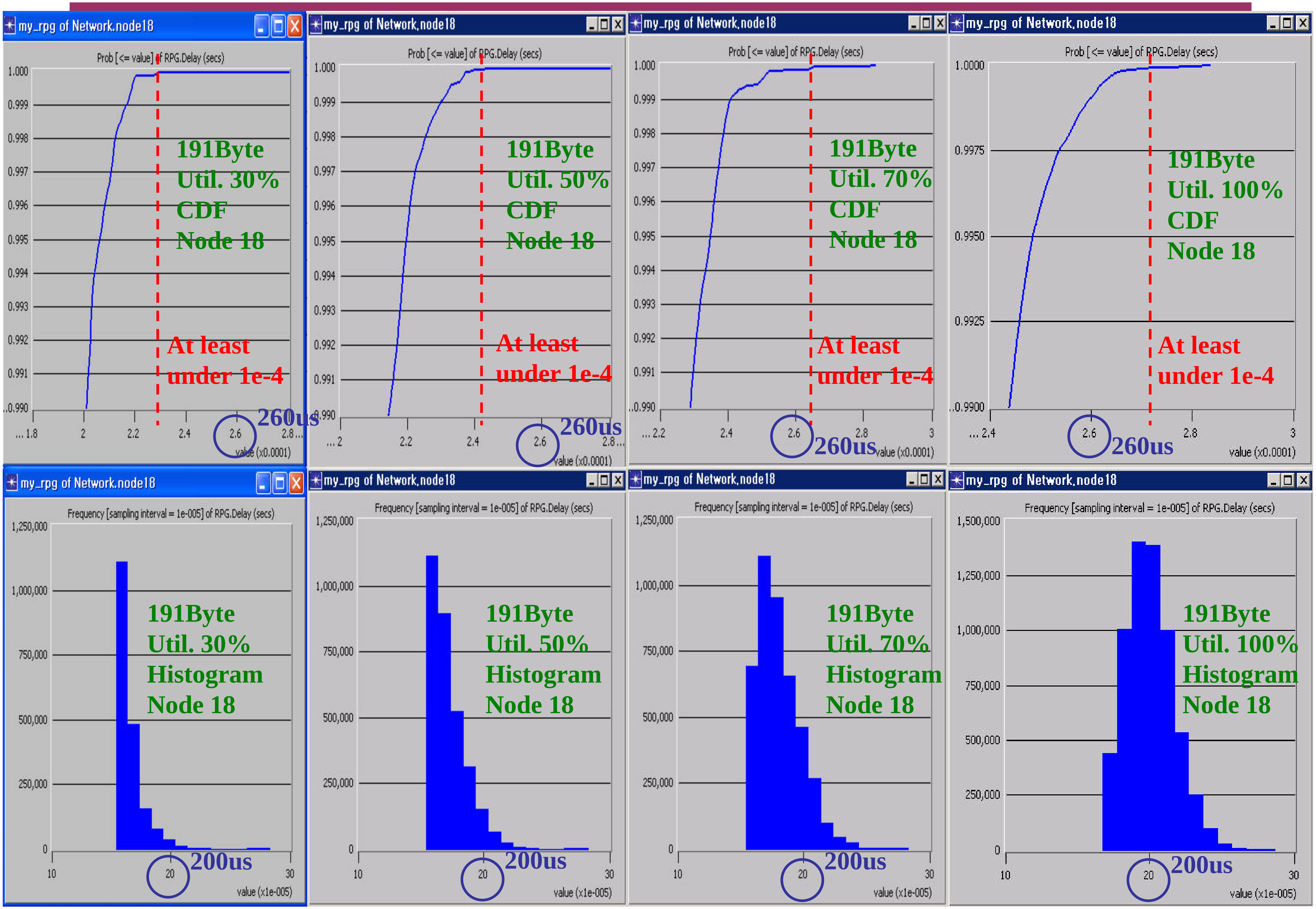
Scenario 2 - 763 bytes



Scenario 3 – 382 bytes



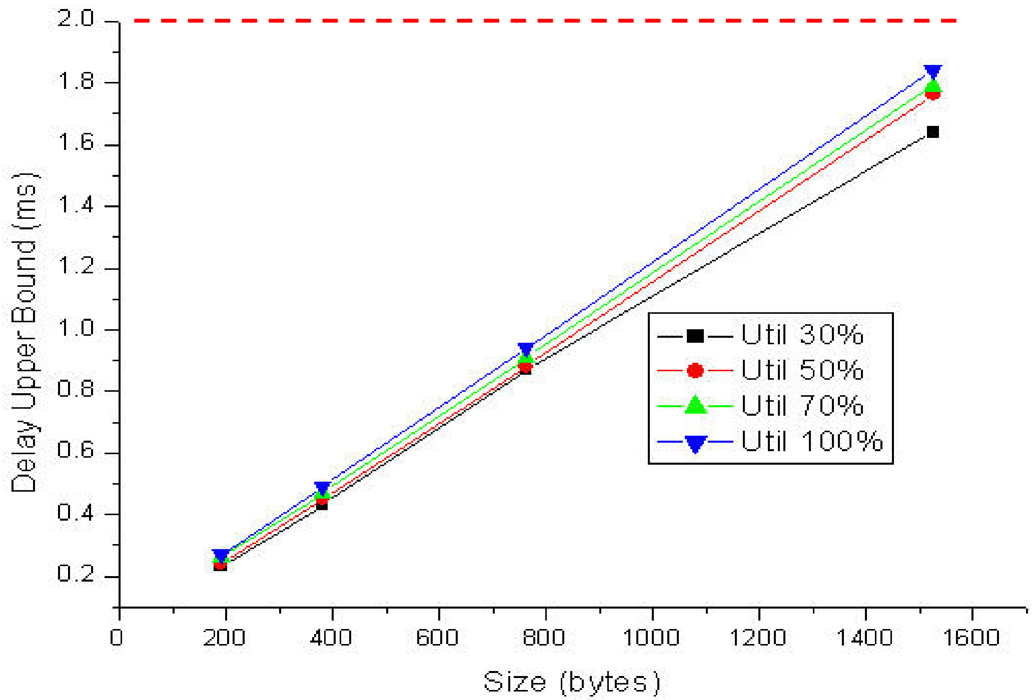
Scenario 4 – 191 bytes



Delay Upper Bound

- Delay upper bound (10^{-4} exceedance probability, i.e., 99.99 percentile)

Size \ Util	30%	50%	70%	100%
1526 Byte	1.64 ms	1.76 ms	1.79 ms	1.84 ms
763 Byte	0.87 ms	0.88 ms	0.91 ms	0.94 ms
382 Byte	0.43 ms	0.45 ms	0.47 ms	0.49 ms
191 Byte	0.23 ms	0.24 ms	0.26 ms	0.27 ms

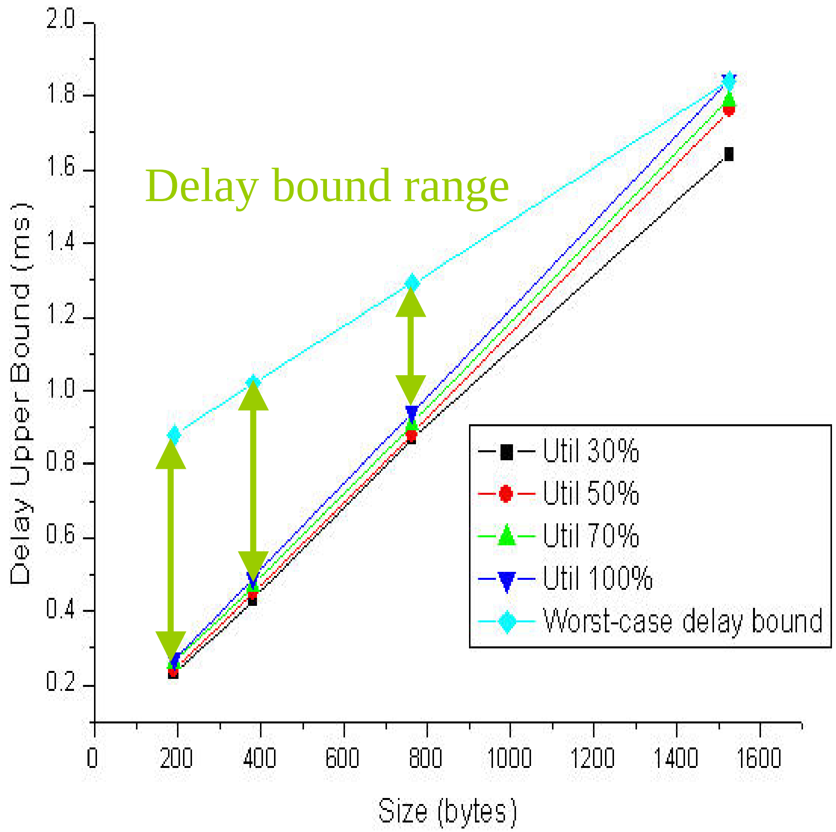


- **Frame size has significant impact on delay upper bound**
  - **Utilization has much less impact**

Delay upper bound is under 2ms

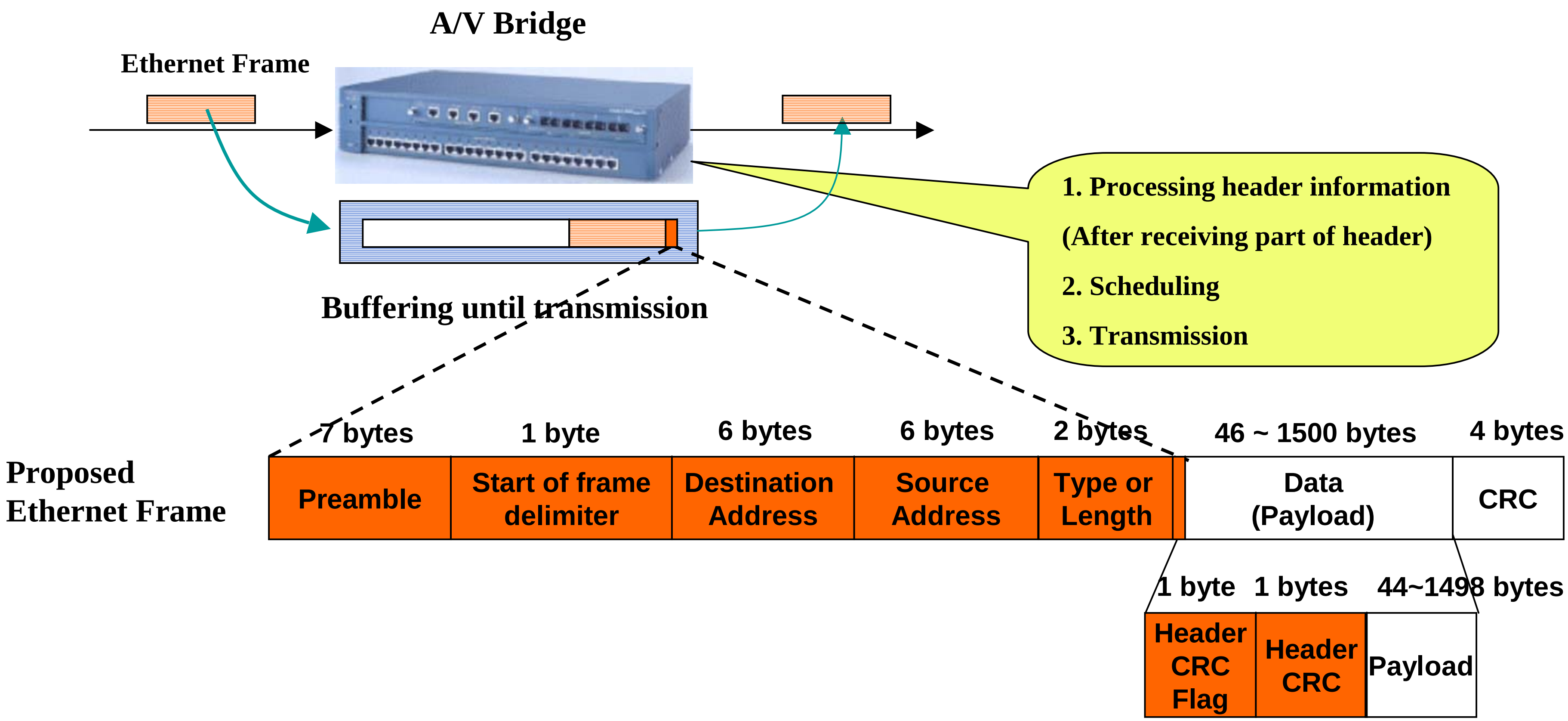
Delay Upper Bound (cont.)

- Worst-case delay bound (of ranged area under 1e-4 probability) when small and big size frames are simultaneously transmitted to switches
  - Necessary delay of maximum size frame (i.e. 1526 bytes) when it pass over 7 hop switches: 122.08 us (tx_delay) + (122.08 us + 2 us (proc_delay)) * 8 = 1.11 ms
  - Additional delay (i.e. delay by buffering) of maximum size frame at 100% utilization: 1.84 ms – 1.11 ms = 0.73 ms
  - 191 bytes case: necessary delay is 0.15 ms, so worst-case delay bound is 0.15 ms + 0.73 ms = 0.88 ms
  - 382 bytes case: necessary delay is 0.29 ms, so worst-case delay bound is 0.29 ms + 0.73 ms = 1.02 ms
  - 763 bytes case: necessary delay is 0.56 ms, so worst-case delay bound is 0.56 ms + 0.73 ms = 1.29 ms
  - 1526 bytes case: worst-case delay bound is the same as 1.84 ms



For the AV stream and real-time applications

- We may not need to perform a CRC check on the whole frame since an errored frame need not be retransmitted.



The delay enhancement with that approach

- Performance expectation
  - Assumption: In a single switch/ No buffered frame
  - Major factors influencing at switch
    - Transmission delay: depends on frame size
    - Processing delay: under 2 usec
  - Minimum size cases (of Fast Ethernet); 64 byte
    - Store and forward: 2 usec + 5.12 usec = 7.12 usec

      / Transmit only correct frame
    - Cut-through (based on having to buffer 22 bytes): 1.76 usec + 2 usec = 3.76 usec

      / Transmit all frames without checking error
    - Check the header error case (based on having to buffer 24 bytes): 1.92 usec + 2 usec = 3.92 usec

      / Transmit only frames with correct header

      (44% delay reduction compared to store and forward method)
  - Maximum size cases (of Fast Ethernet); 1526 byte
    - Store and forward : 122.08 usec + 2 usec = 124.08 usec
    - Cut-through: 1.76 usec + 2 usec = 3.76 usec
    - Check the header error case: 1.92 usec + 2 usec = 3.92 usec

      (97% delay reduction per hop compared to store and forward method)

Simulation Scenarios

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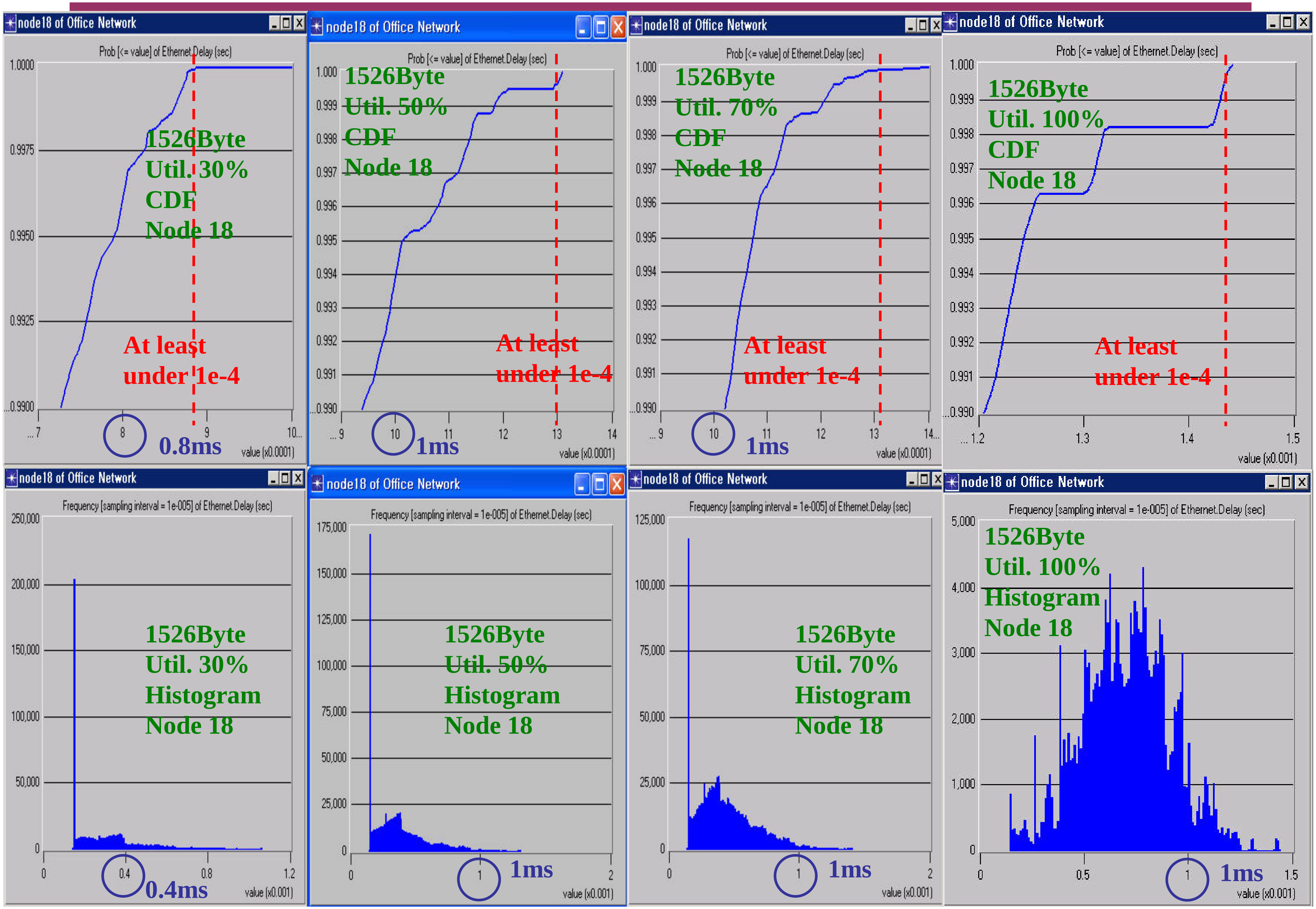
Scenario – 1526 bytes



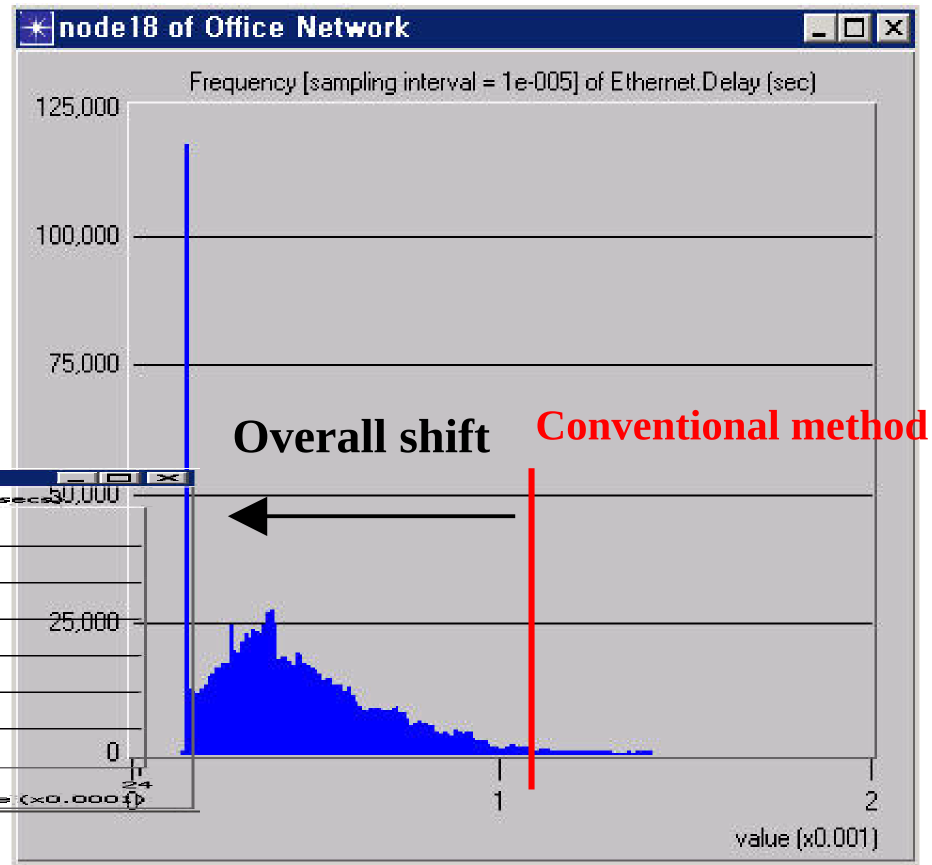
Transition of Delay Distribution Shape

- Case: Size 1526 bytes and utilization 70%

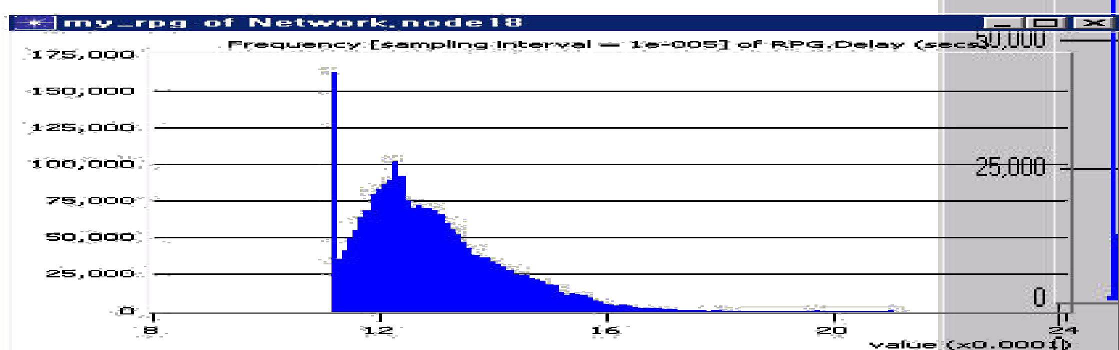
Util (%)	Conventional	Just forwarding
30	1.64 ms	0.88 ms
50	1.76 ms	1.30 ms
70	1.79 ms	1.31 ms
100	1.84 ms	1.44 ms

In the just forwarding case, the 99.99 percentile was reduced by 0.4 – 0.8 ms

Just forwarding case



Conventional case



Conclusion

- Frame error rate in end-to-end links with given assumptions are
  - 1e-3; when Ethernet link BER is 1e-8
  - 1e-7; when Ethernet link BER is 1e-12
- Simulation results of scenario 1 to 4 show that every case within acceptable delay bound range (equal or bigger than 1 - 1e-4 probability) do not exceed 2ms, acceptable delay bound
  - Probability (or area) of delay longer than 1.84 ms is less than 1e-4 even in the case of 1526 byte and 100% utilization (which is worst scenario)
- If we just forward Ethernet frame not having header error, we may reduce end-to-end link delay by 0.4 – 0.8 ms
- Most influential factors are frame size and forwarding method in this study environment
- Studying impact of traffic pattern, number of stream and topology change can be future works

Reference

[1] Max Azarov, “Worst-case Ethernet network latency for shaped sources”, IEEE 802.1 Audio/Video Bridge Task Group, Jan. 2006

[2] G. M. Garner, “Delay and delay variation simulation results for additional multi-hop conventional Ethernet cases with bursting/bunching”, IEEE 802.3 Residential Ethernet SG, Sep. 2005

[3] Felix, F. Feng, G.M. Garner, “Meeting ResE Requirements: A simulation study”, IEEE 802.3 Residential Ethernet SG, Sep. 2005

[4] Felix, F. Feng, “Simulation results on 802.1p and pacing approach”, IEEE 802.3 Residential Ethernet SG, Sep. 2005

[5] Max Azarov, “Worst-case Ethernet network latency for shaped sources”, IEEE 802.3 Residential Ethernet SG, Nov. 2005

[6] David James, “Burst and bunching considerations”, IEEE 802.3 Residential Ethernet SG, Nov. 2005