Delay and Delay Variation Simulation Results for Additional Multi-hop Conventional Ethernet Cases with Bursting/Bunching

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Outline

- Introduction
- Case 1
- Case 2
- Case 3
- Conclusions

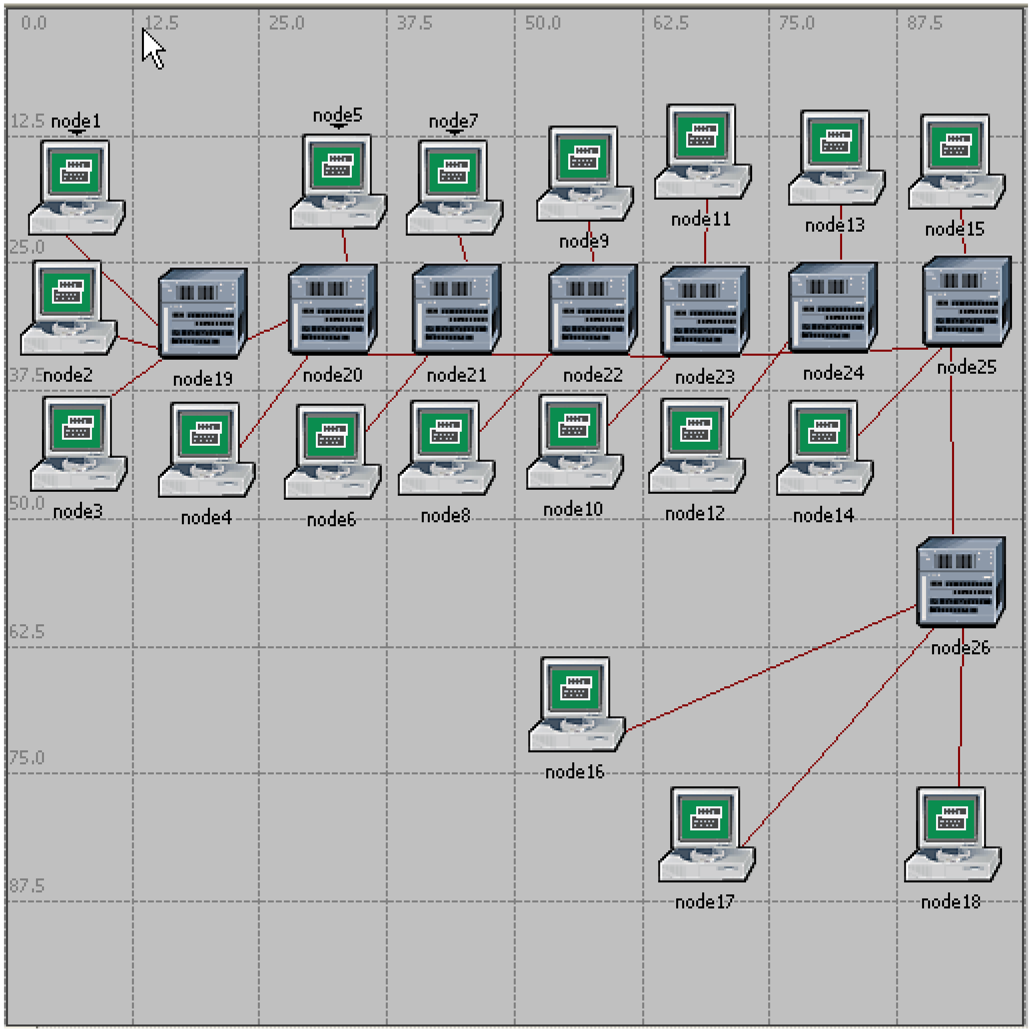
Simulation Case 1

- 7 switch to switch hops
- 100 Mbit/s
- 9 traffic sources
- All sources are time sensitive, CBR traffic with nominal rate of 1333.33 packets/s (nominal time between packets = 0.00075 s)
- Sources have various different frequency offsets that are all within ±100 ppm
- Maximum size packets (1500 bytes plus Ethernet overhead)
  - Switch to switch link utilization ≈ 50%
  - Packet service time (including ethernet overhead and inter-frame gap = $(1500+38)(8)(10^{-8})$ s = 0.12304 ms
- Network topology shown two slides following
  - 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 Case 1 (Cont.)

- Simulate for 2405 s, with traffic turned on at 5 s
  - Needed to add small amount of best-effort traffic in reverse direction to ensure each destination node would be in the forwarding database of each switch (otherwise get flooding and link utilizations that exceed 100%)

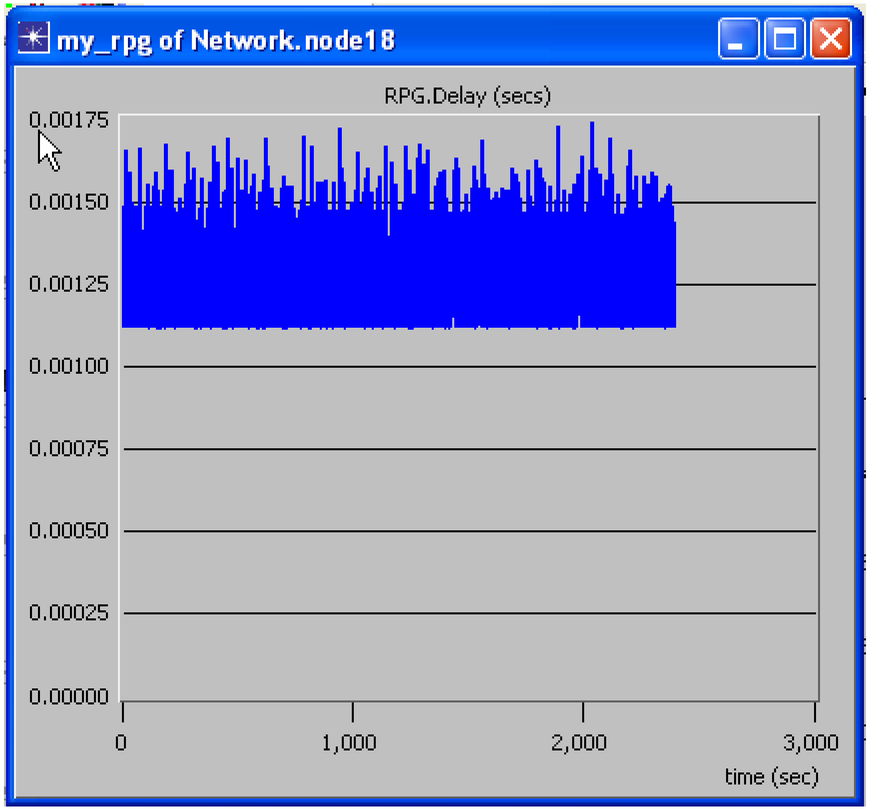
Simulation Case 1



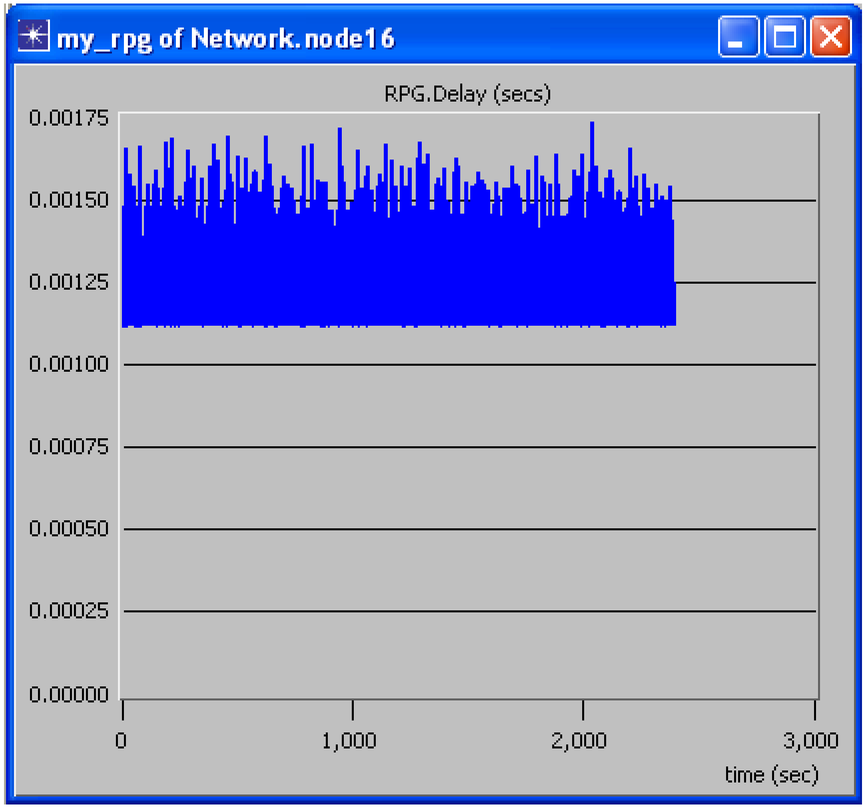
Switch to Switch link utilization = 50%

Case 1 - Results for through traffic streams

Node 1 – 18

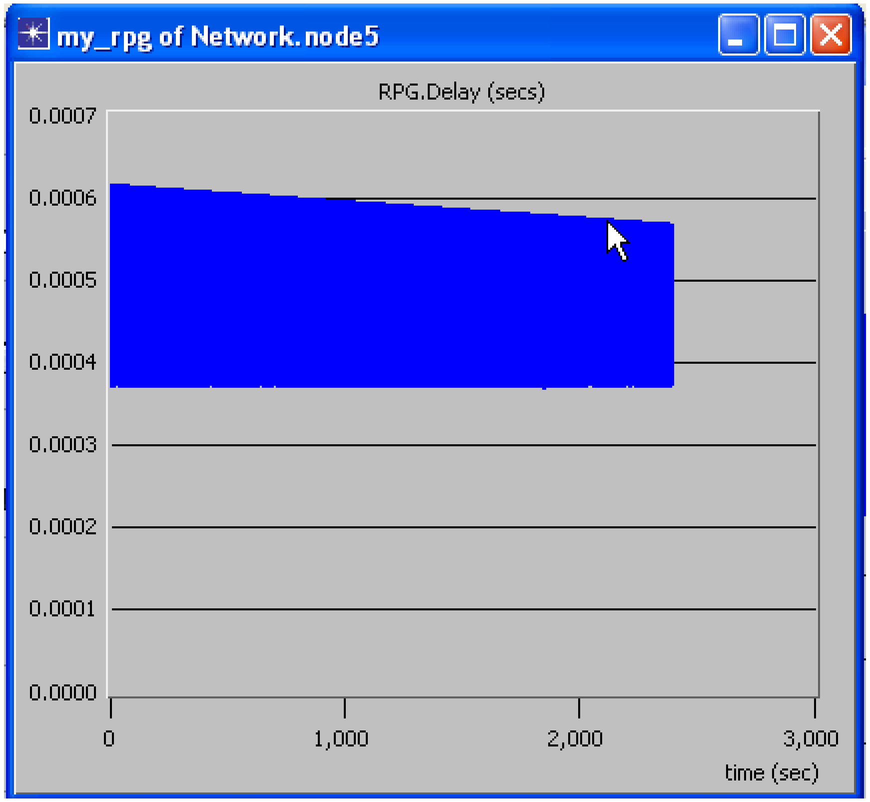


Node 2 – 16

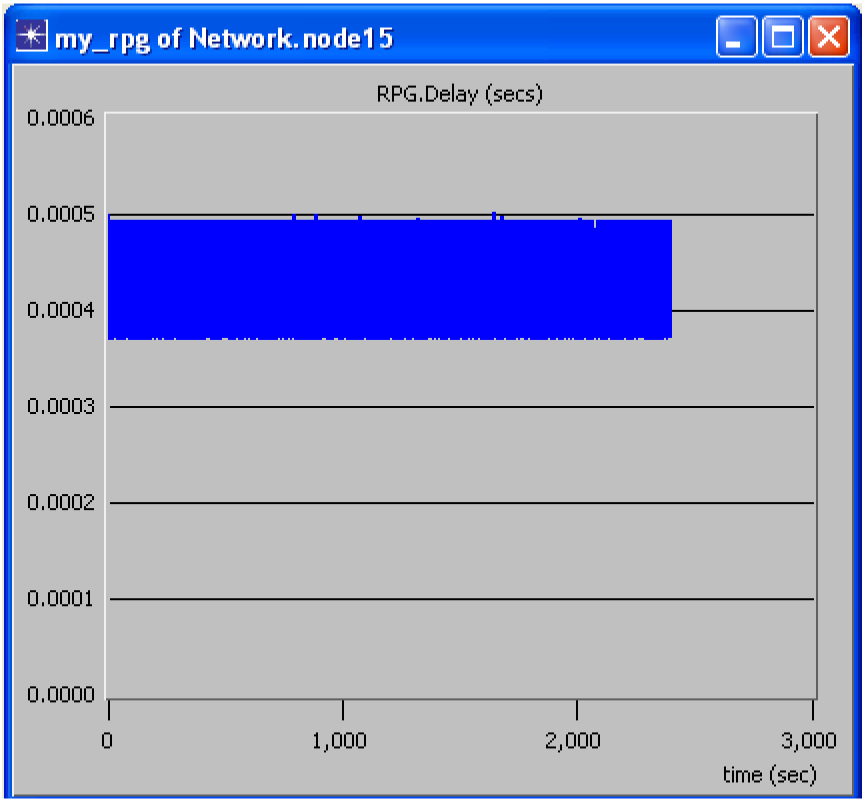


Case 1 - Results for 1-hop streams

Node 3 – 5



Node 12 – 15



Case 1 Results

- Minimum delay for through streams = 1.1 ms
  - Approximately 9(packet service time) = 9(0.12304) ms as expected (7 interswitch hops plus 2 access hops)
- Maximum delay over 2400 s for through streams is approximately 1.75 ms
  - This is less than would be predicted by rule of thumb
  - Total of 8 contending streams
    - Rule of thumb would give (9+8)(0.12304 ms) = 2.09 ms
  - Other simulations with through stream from node 2 going to various intermediate nodes showed that maximum delay predicted by rule of thumb was not reached when number of contending streams reached 5 or 6
- Minimum delay for 1-hop streams = 0.37 ms (consistent with 3 hops)
- Maximum delay for Node 12-15 1-hop stream = 0.49 ms (consistent with 1 contending stream)
- Maximum delay for Node 3-5 1-hop stream = 0.63 ms
  - Roughly consistent with 2 contending streams, but not clear from figure if steady state has been reached
- Appears that must simulate for much longer to see full delay predicted by rule of thumb

Case 1 Results (Cont.)

- Nominal time between packets = 0.75 ms
- Packet service time = 0.12304 ms
  - Packet service time is 16% of interpacket interval for 1 stream
- To get worst-case delay predicted by rule of thumb, packets on all 8 contending streams must arrive at approximately same time
  - E.g., if they arrive within a time window equal to 5% of the packet time, the amount the actual delay will be less than the worst case delay will be at most 8(0.05 packet times) = 0.4 packet times
  - This means they must all arrive within a window of approximately (0.16)(0.4) inter-packet times = 0.064 inter-packet times
  - Due to the frequency offsets of the CBR streams, the packets of different streams are gaining/receding relative to each other
  - If we assume that, over a long time, the packet arrivals of any stream fall in all possible locations within the interpacket time of any other stream, and also assume that at any given time the location is random, then the probability that the packets of 8 streams all line up within 0.4 packet times is (0.064)^8 = 2.8×10^{-10}
  - Nominal number of packets observed for 1 stream over 2400 s = 2400/0.00075 = 3.2×10^{6}

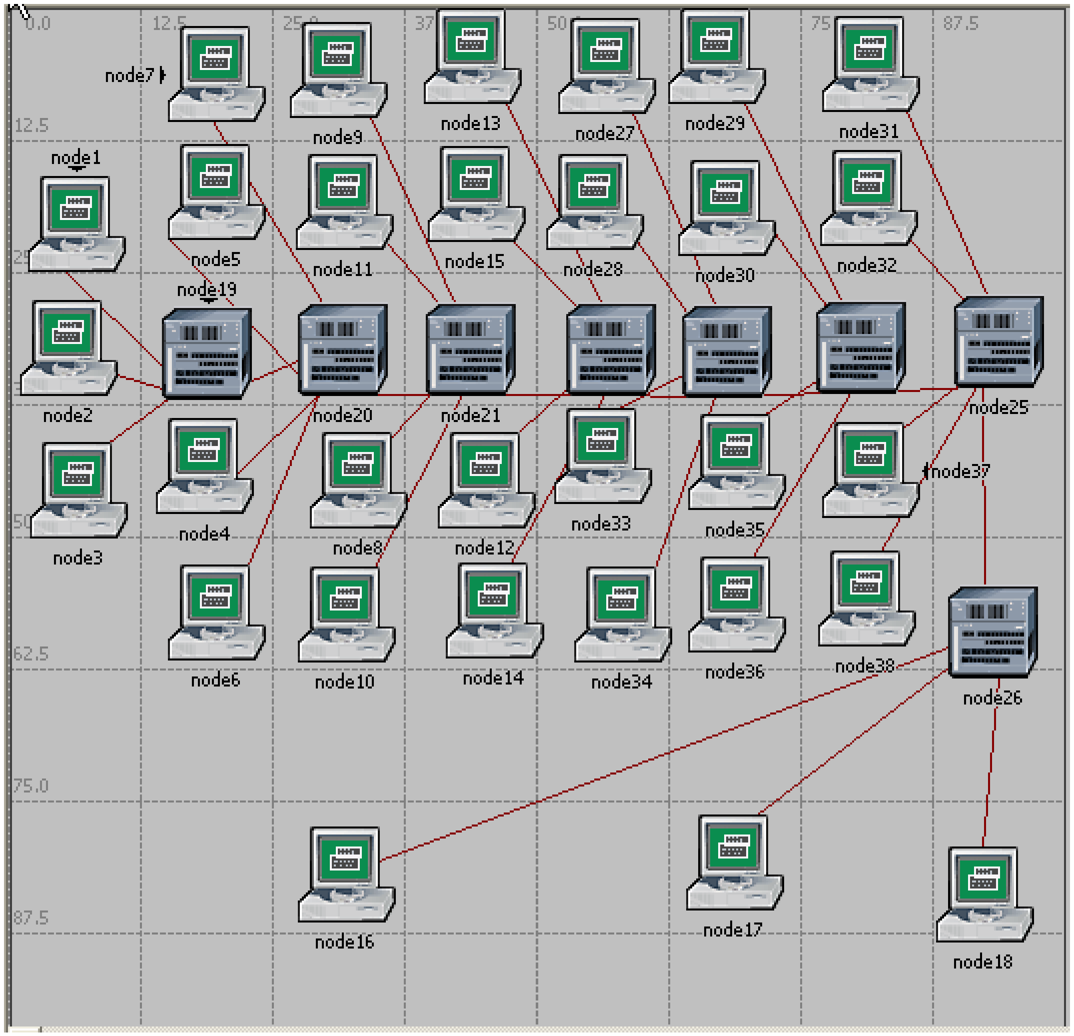
Case 1 Results (Cont.)

- Then approximate probability of observing the packets of 8 streams lining up after 2400 s = $(3.2 \times 10^6)(2.8 \times 10^{-10}) = 8.96 \times 10^{-4}$
- Would need to simulate for a time on the order of 2400 s/8.96×10^{-4} = 2.68×10^6 s = 31 days to have a reasonable chance of observing such an event
- **Note:**
  - Previous results, for bursting and bunching case, also had 8 contending streams (2 contending streams at each of 4 switches)
    - Simulated delay (1.6 ms) was slightly less than theoretical maximum predicted by rule of thumb (1.72 ms)
    - Simulated peak-to-peak delay variation (850 μs) was slightly less than theoretical maximum predicted by rule of thumb (980 μs)
    - Previous simulated results for 3 hops (6 contending streams) were also slightly less than theoretical maximum predicted by rule of thumb
      - 1.1 ms (note: this was incorrectly listed as 1.5 ms in previous VGs) versus 1.35 ms for delay
      - 510 μs versus 738 μs for delay variation

Simulation Case 2

- 7 switch to switch hops
- 100 Mbit/s
- 15 traffic sources
- All sources are time sensitive, CBR traffic with nominal rate of 1333.33 packets/s (nominal time between packets = 0.00075 s)
- Sources have various different frequency offsets that are all within ±100 ppm
- Maximum size packets (1500 bytes plus Ethernet overhead)
  - Switch to switch link utilization ≈ 50%
  - Packet service time (including Ethernet overhead and inter-frame gap = $(1500+38)(8)(10^{-8})$ s = 0.12304 ms
- Network topology shown two slides following
  - 3 sources at first switch (nodes 1 – 3)
  - Traffic from 1 of these sources (node 1) goes to final switch (node18)
  - Traffic from 2^{nd} and 3^{rd} source (nodes 2 and 3) is dropped at 2^{nd} switch (nodes 5 and 7)
  - At switches 2 – 7 (nodes 20 – 25 in figure), traffic added from 2 CBR sources, carried 1 hop, and dropped
- Simulate for 605 s, with traffic turned on at 5 s

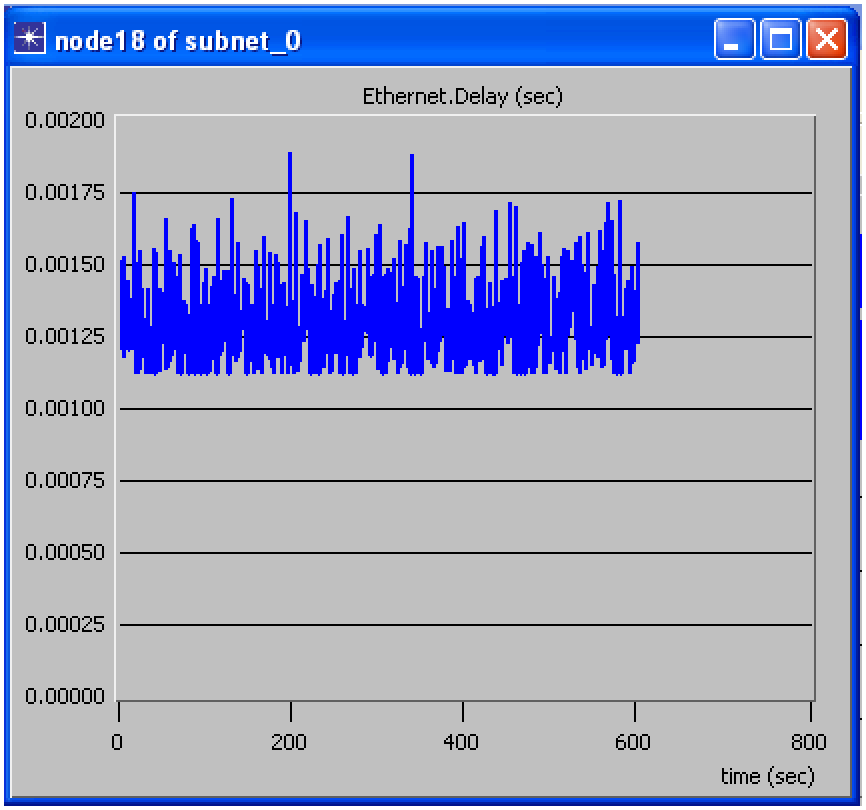
Simulation Case 2



Switch to Switch link utilization = 50%

Case 2 - Results for through traffic stream

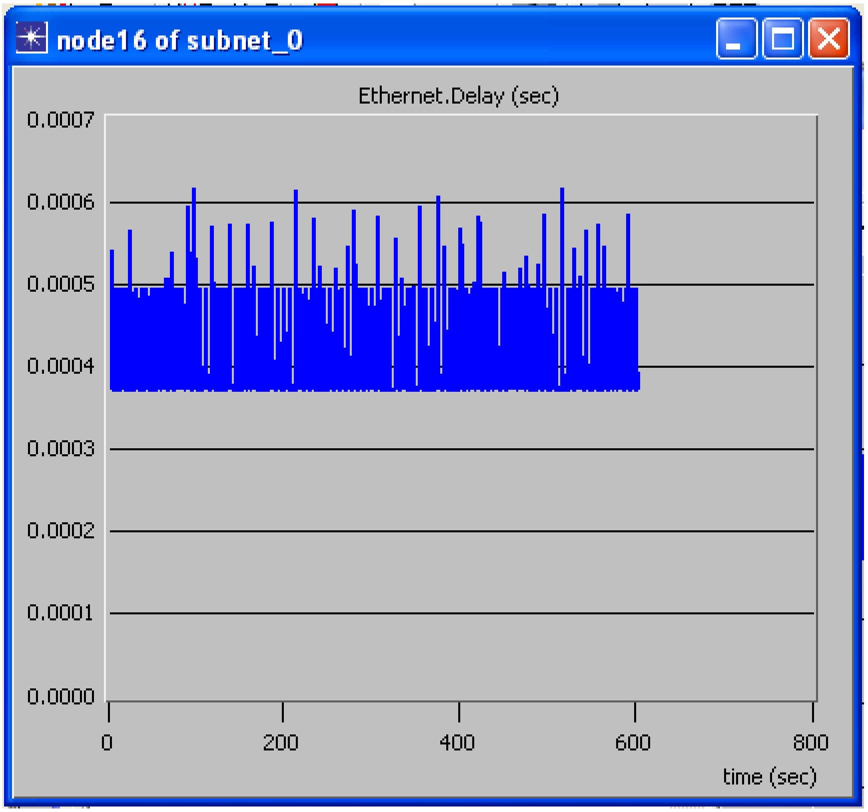
Node 1 – 18

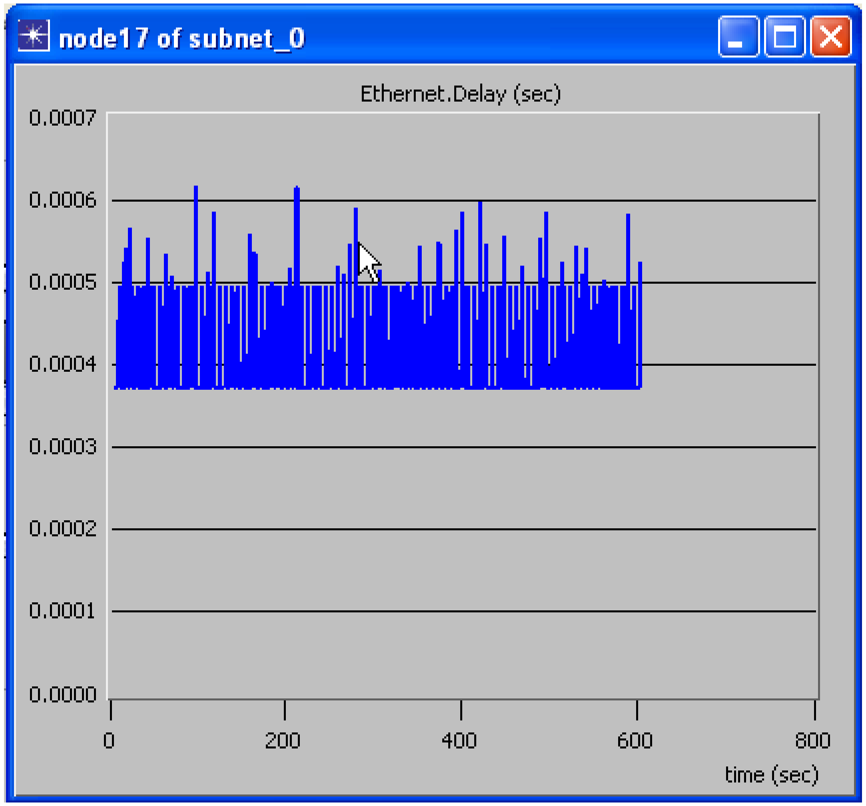


Case 2 - Results for 1-hop streams

Node 37 – 16

Node 38 – 17





Case 2 Results

- Minimum delay for through streams = 1.1 ms
  - Approximately 9(1.2304) ms as expected (7 interswitch hops plus 2 access hops)
- Maximum delay over 600 s for through streams is approximately 1.89 ms
  - This is less than would be predicted by rule of thumb
  - Total of 14 contending streams
    - Rule of thumb would give (9+14)(1.2304 ms) = 2.8 ms
  - Note that this does exceed maximum delay for Case 1 (and for 2400 s there), which had two contending streams per switch instead of three
- Minimum delay for 1-hop streams = 0.37 ms (consistent with 3 hops)
- Maximum delay for Node 12-15 1-hop stream = 0.62 ms (consistent with 2 contending streams)
- Appears that must simulate for much longer to see full delay predicted by rule of thumb

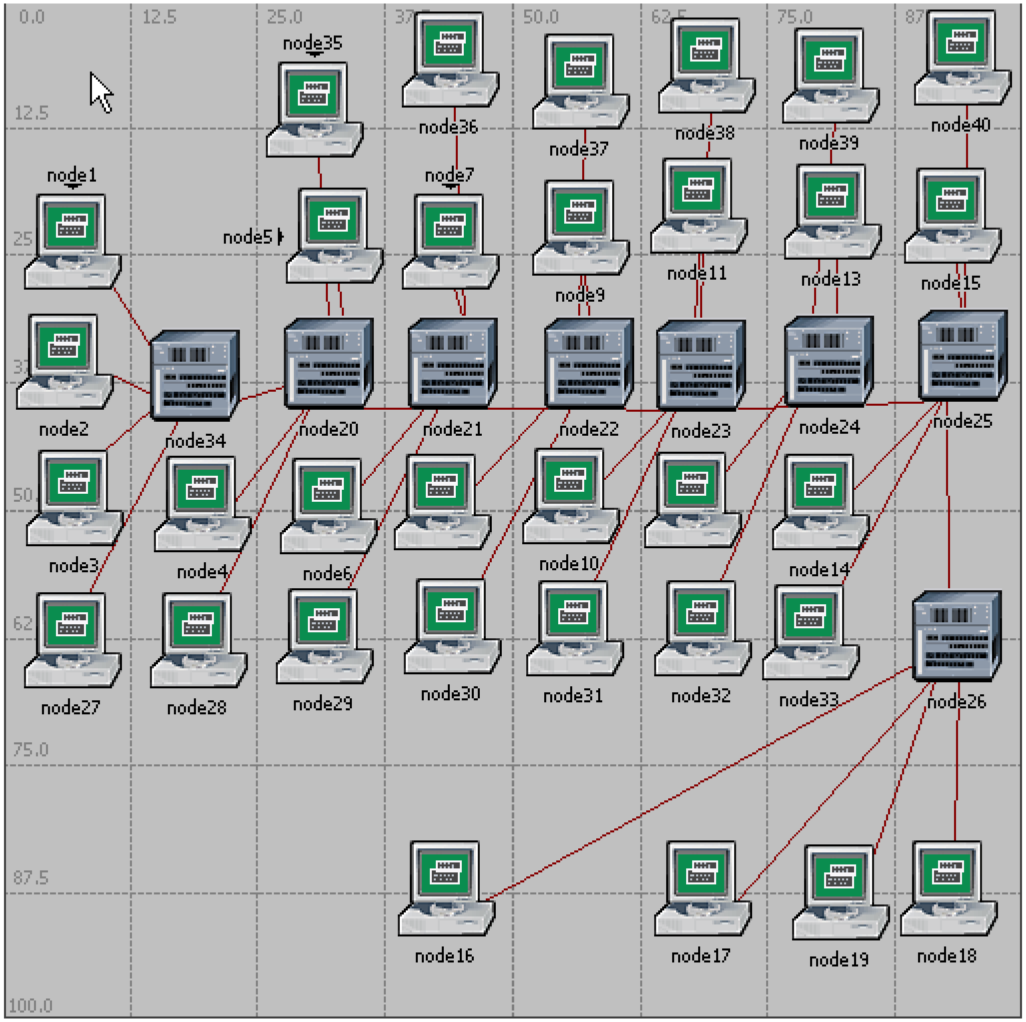
Simulation Case 3

- 7 switch to switch hops
- 100 Mbit/s
- 9 time sensitive, CBR traffic sources, with nominal rate of 1333.33 packets/s (nominal time between packets = 0.00075 s)
- 6 best effort (Poisson) traffic sources with average rate of 2083.33 packets/s (mean time between packets = 0.00048 s)
- CBR sources have various different frequency offsets that are all within ±100 ppm
- Maximum size packets (1500 bytes plus Ethernet overhead)
  - Switch to switch link utilization ≈ 75%
    - 50% for time-sensitive; 25% for best-effort
  - Packet service time (including Ethernet overhead and inter-frame gap = $(1500+38)(8)(10^{-8})$ s = 0.12304 ms

Simulation Case 3 (Cont.)

- Network topology shown two slides following
  - 3 time-sensitive (nodes 1-3) and 1 best effort source (node 27) at first switch (node 34)
  - Traffic from 2 of these time-sensitive sources (nodes 1 and 2) go to final switch (nodes16 and 18)
  - Traffic from 3rd time-sensitive source (node 3) is dropped at 2nd switch (node 5)
  - Traffic from best effort source is dropped at 2nd switch (node 35)
  - At switches 2 – 7 (nodes 20 – 25 in figure), traffic added from 1 time-sensitive and 1 best effort source, carried 1 hop, and dropped
- Simulate for 305 s, with traffic turned on at 5 s

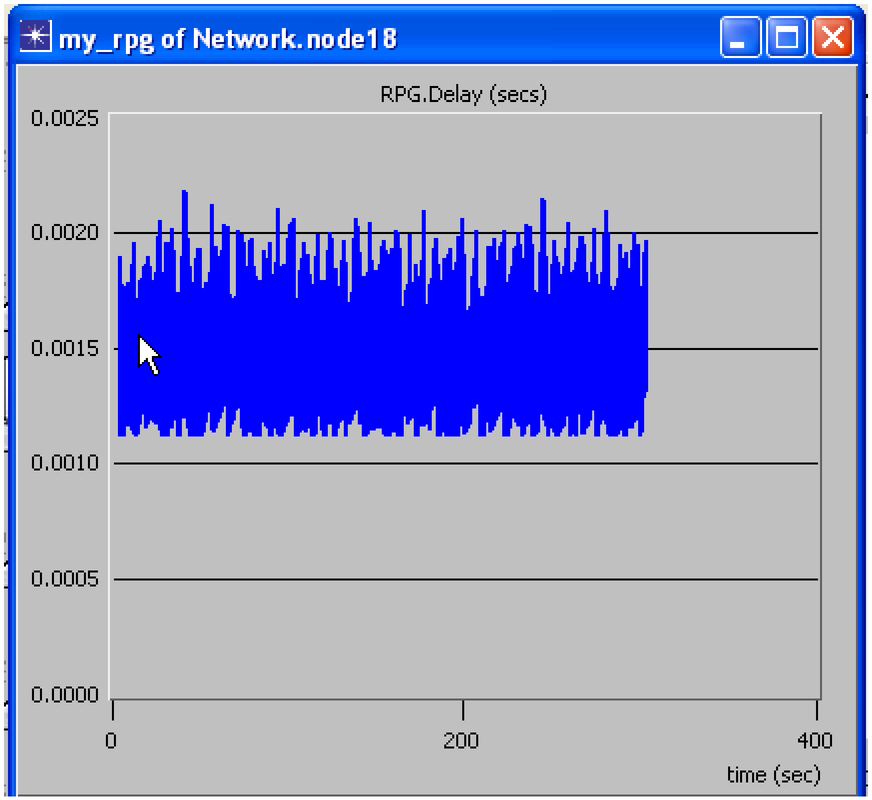
Simulation Case 3



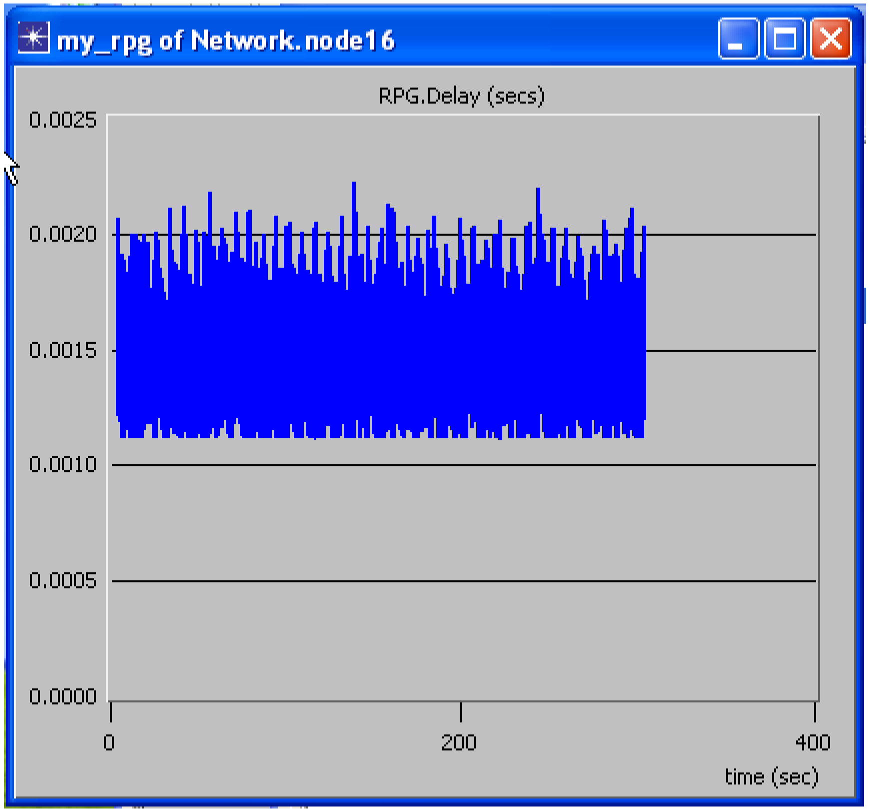
Switch to Switch link utilization = 75%

Case 3 - Results for through CBR traffic streams

Node 1 – 18

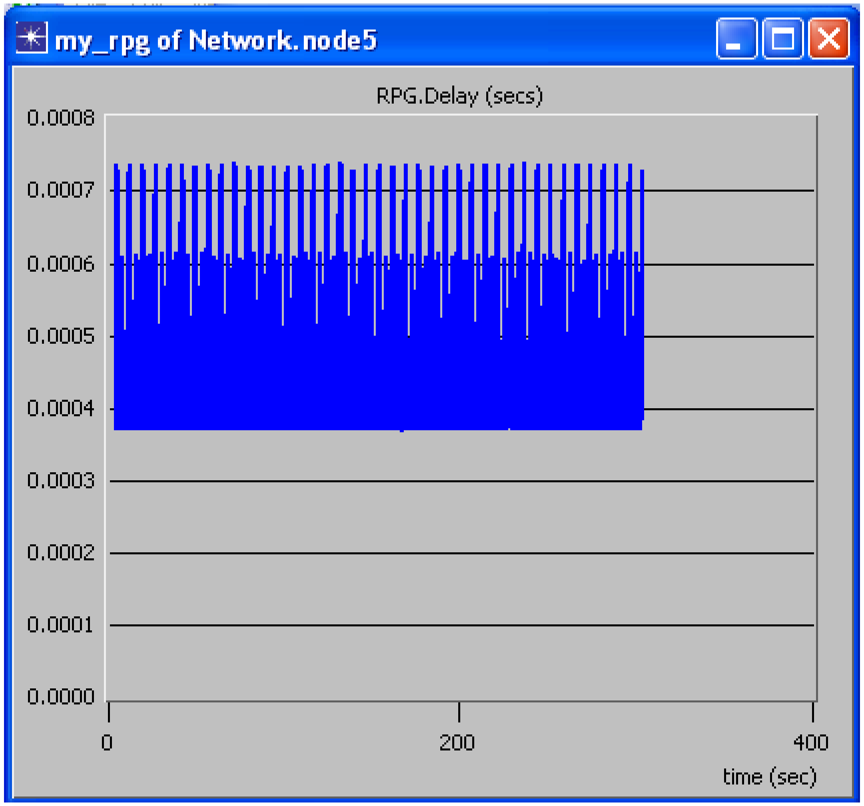


Node 2 – 16

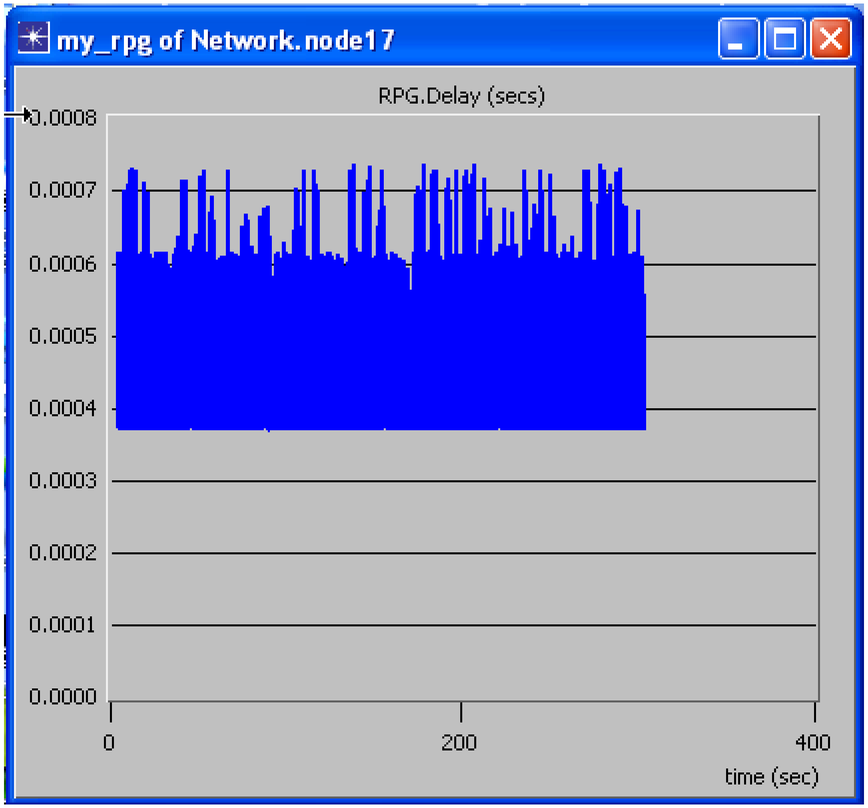


Case 3 - Results for 1-hop CBR traffic streams

Node 3 – 5

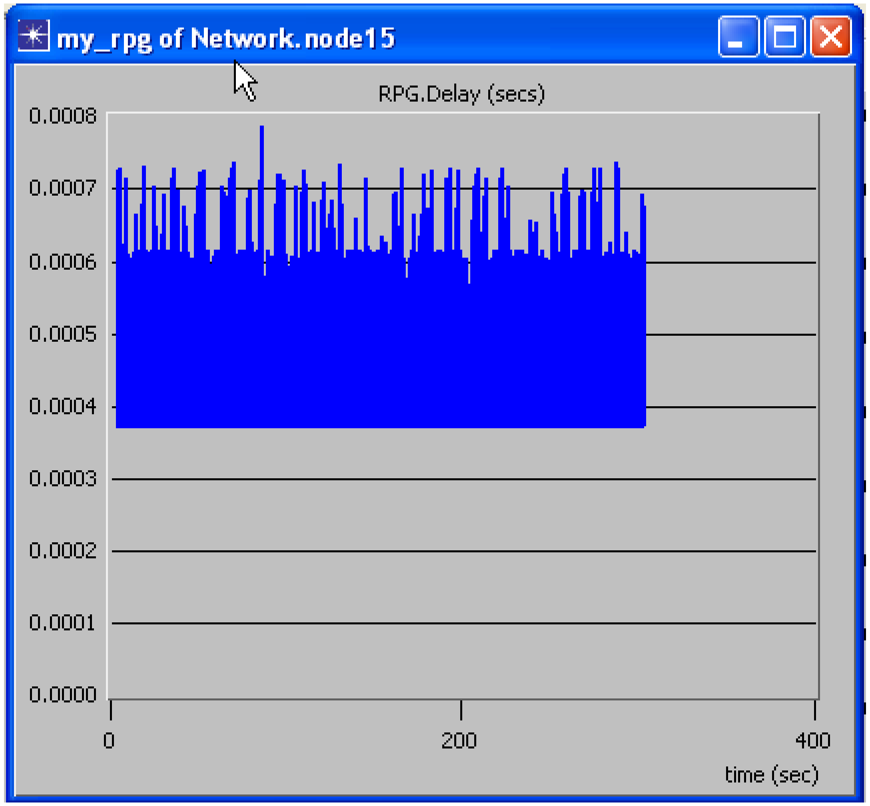


Node 14 – 17



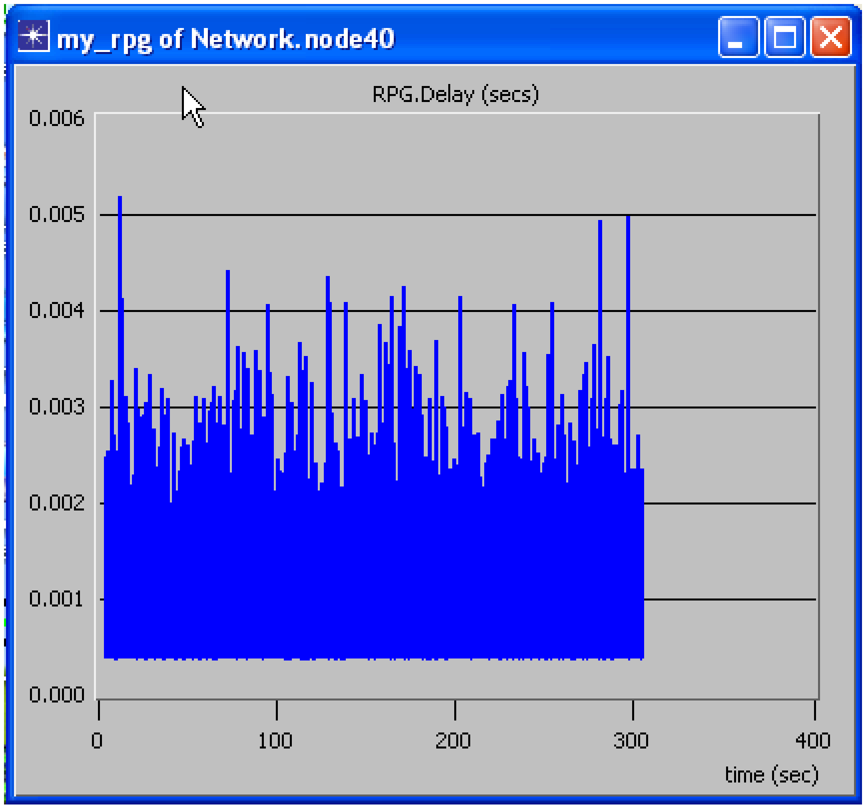
Case 3 - Results for 1-hop CBR traffic streams (Cont.)

Node 23 – 15



Case 3 - Results for 1-hop VBR traffic streams

Node 32 – 40



Case 3 Results

- Minimum delay for through CBR streams = 1.1 ms
  - Approximately 9(1.2304) ms as expected (7 interswitch hops plus 2 access hops)
- Maximum delay over 300 s for through streams is approximately 2.2 ms
  - This is less than would be predicted by rule of thumb
  - Total of 15 contending streams
    - Rule of thumb would give (9+15)(1.2304 ms) = 2.95 ms
  - Note that this does exceed the 2 ms limit for end-to-end delay
  - Maximum delay for Node 23-15 1-hop stream = 0.62 ms (consistent with 2 contending streams)
- Appears that must simulate for much longer to see full delay predicted by rule of thumb

Conclusions

- Rules of thumb give worst-case delay and delay variation
  - Apply to cases with only time-sensitive (CBR) traffic, and cases with both CBR and best-effort traffic
- For link utilizations of 50 – 75%, worst-case delay and delay variation are reached after reasonable simulation time (e.g., up to a few hundred seconds) for a relatively small number of contending traffic streams (e.g., 5 or fewer)
  - For a larger number of contending traffic streams, it apparently takes a much longer simulation time to reach the theoretical maximum delay and delay variation predicted by the rules of thumb