A Network Emulator on the NetFPGA Platform

1st ASIA NetFPGA Developer's Wrokshop
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- A network emulator on the NetFPGA platform
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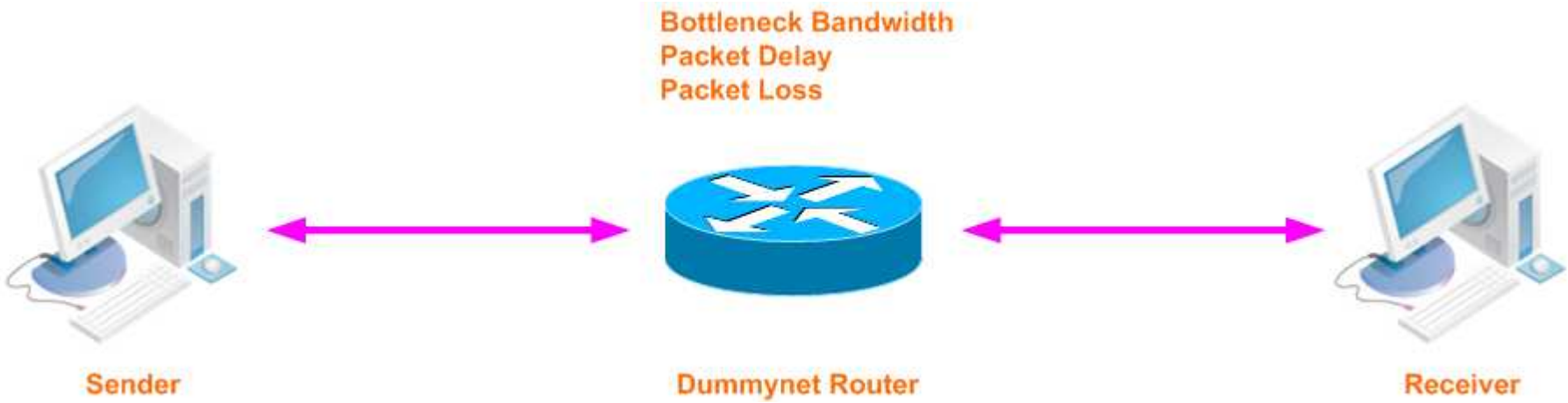
Network Emulation

- **Network Emulation is**
  - a technique where the properties of an existing, planned network are simulated in order to access performance, predict the impact of change, or otherwise optimize technology decision making.

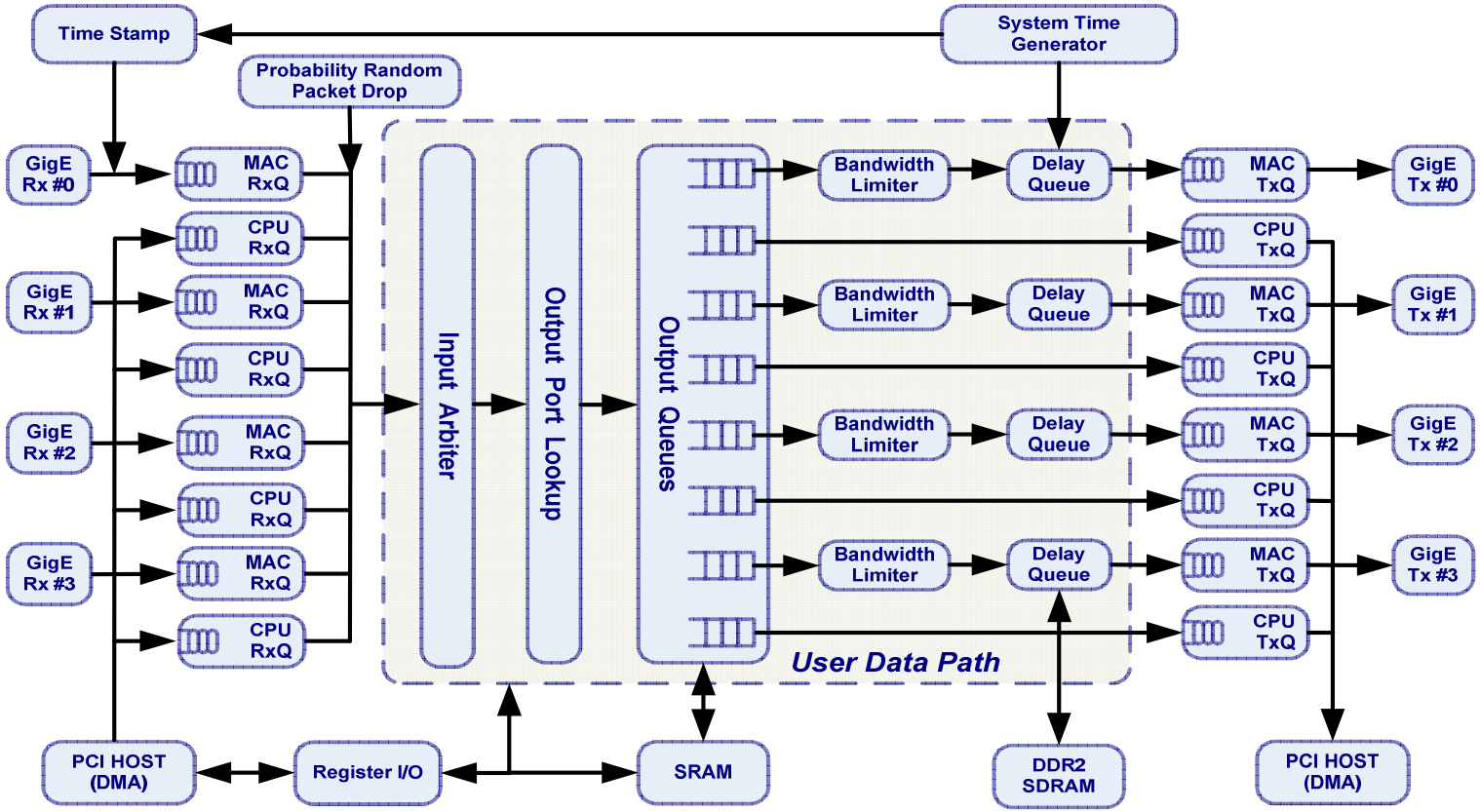


Widely Used Network Emulators

- **Dummynet & NISTnet**
  - Software-based network emulator
    - software packages running on PC
  - bottleneck bandwidth
    - bps ~ 1Gbps
  - probability random packet loss
    - 0~1 (floating point number)
  - packet delay
    - ms

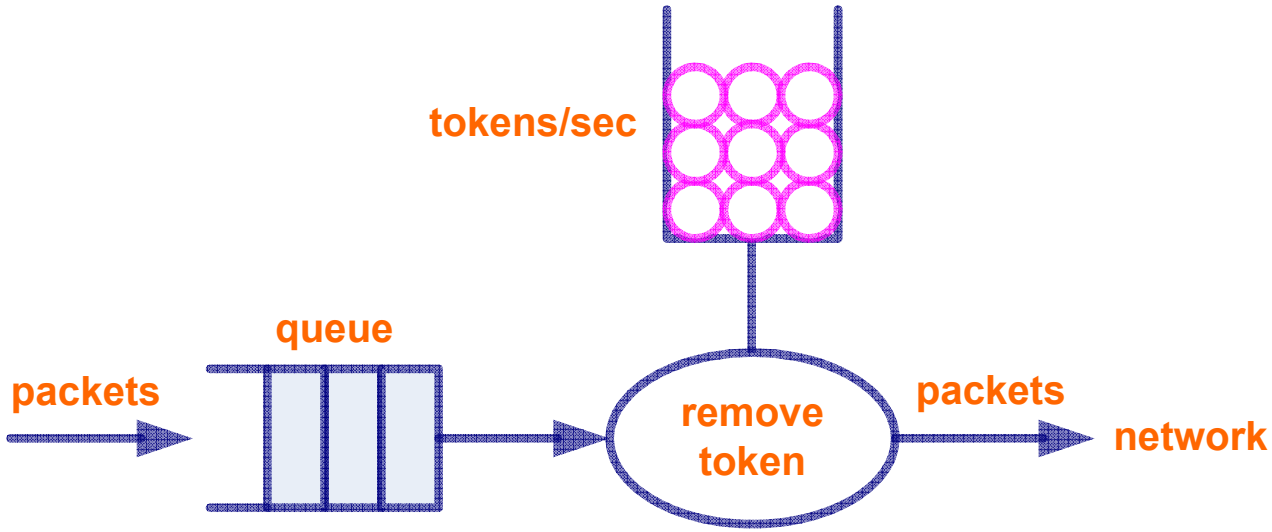
NetFPGA Network Emulator

- Overall Pipeline Architecture and features



NetFPGA Network Emulator (cont'd)

- **Bandwidth Limiter Module**
  - Traffic shapping with token bucket
  - Bottleneck bandwidth
    - 0 ~ 1Gbps

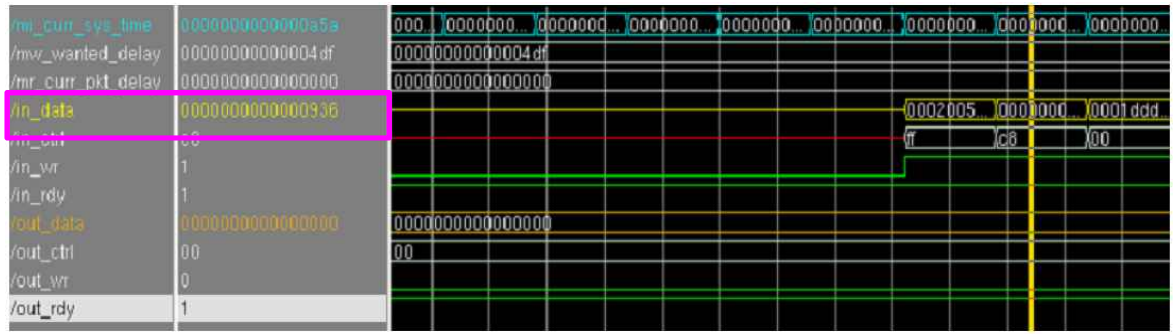


NetFPGA Network Emulator (cont'd)

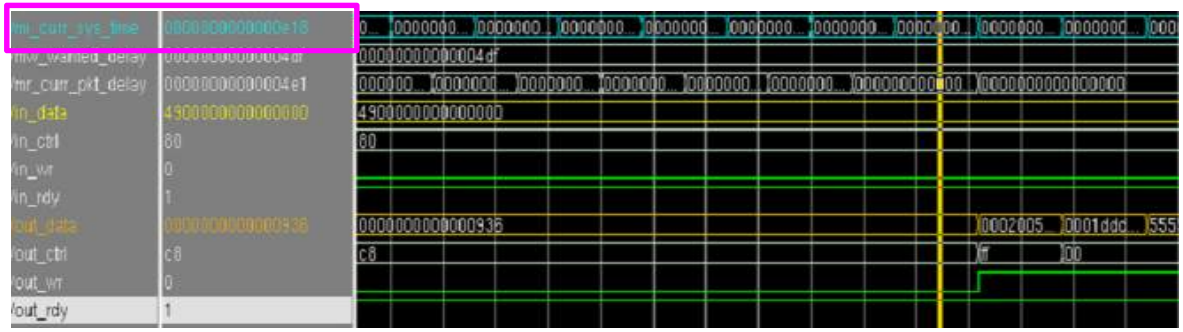
- **Packet Delay Module**
  - Time stamping for each ingress packet
  - Packet delay
    - 0ns ~ (2^{32} -1)ns (8ns step, 125MHz)

latency of packet
10ms = (0xe18 – 0x936) x 8ns

  - Ingress packet



  - Outgoing packet



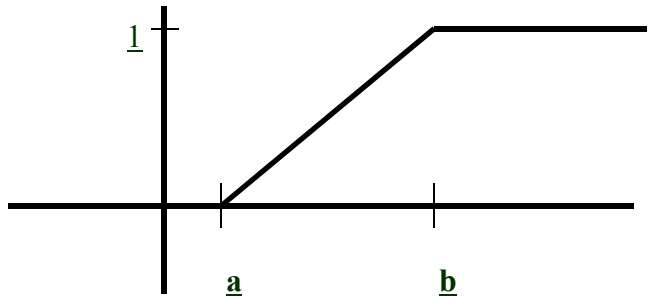
NetFPGA Network Emulator (cont'd)

- **Packet Drop Module**
  - PRNG with 21-bits LFSR
  - Generation Polynomial of LFSR

$$P(x) = x^{21} + x^{20} + x + 1$$

  - Expectation and CDF of a Uniform Random Variable

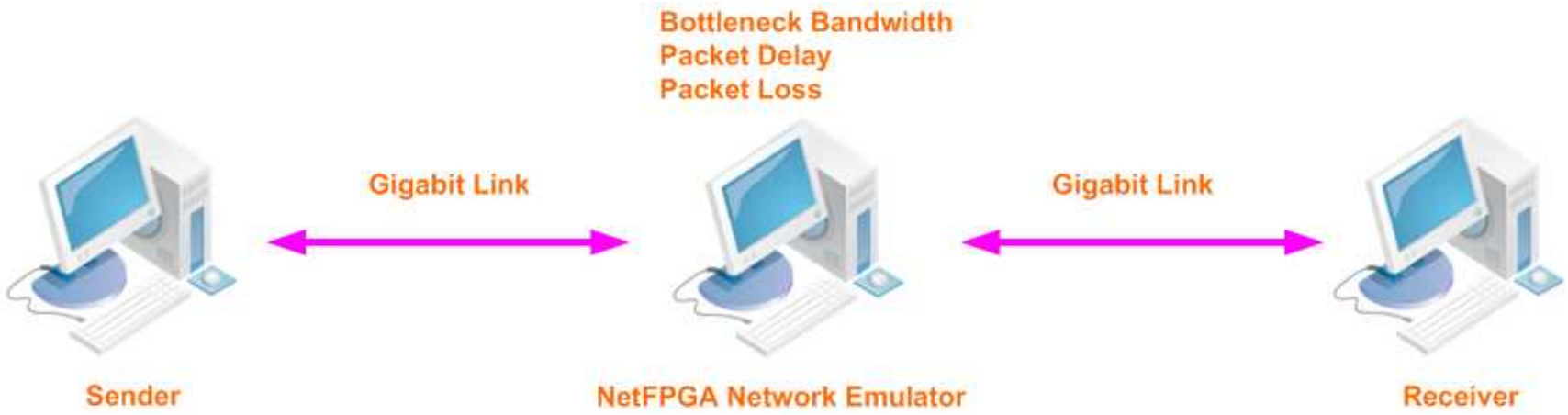
$$E[X] = \int_{\alpha}^{\beta} \frac{x}{\beta - \alpha} dx = \frac{\beta + \alpha}{2}$$



  - Probability Random Packet Loss
    - 0.001% ~ 100%

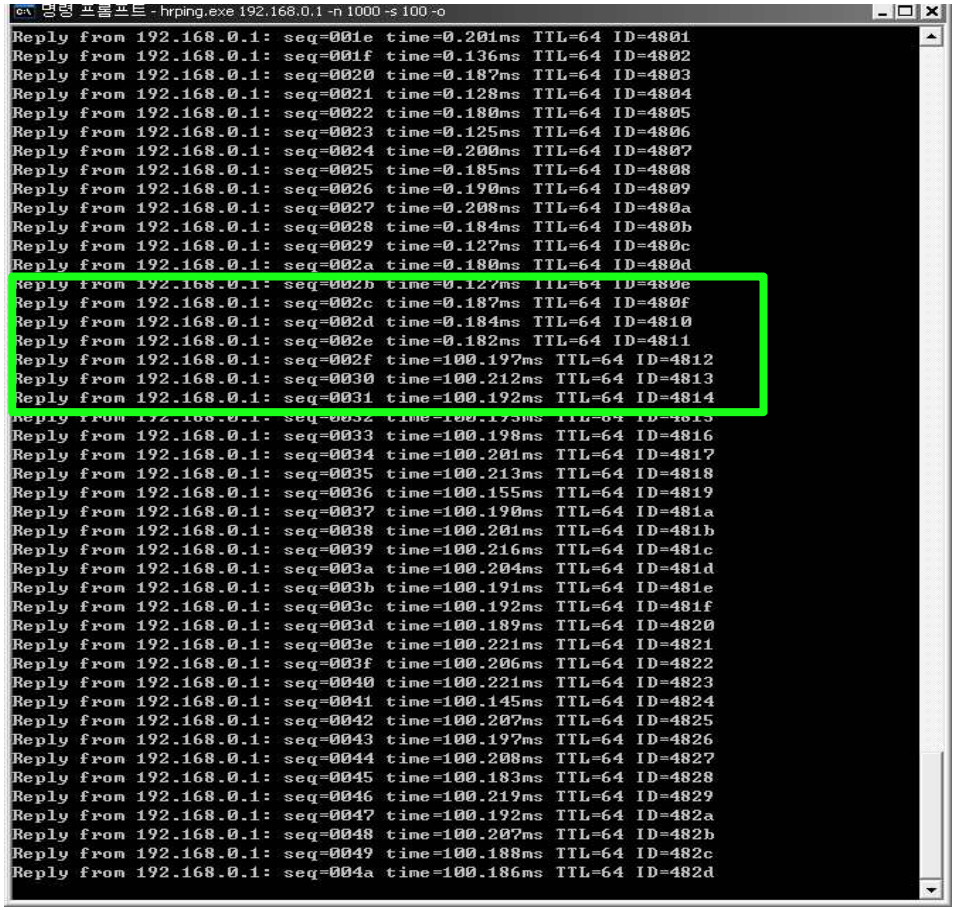
Experimental Setup

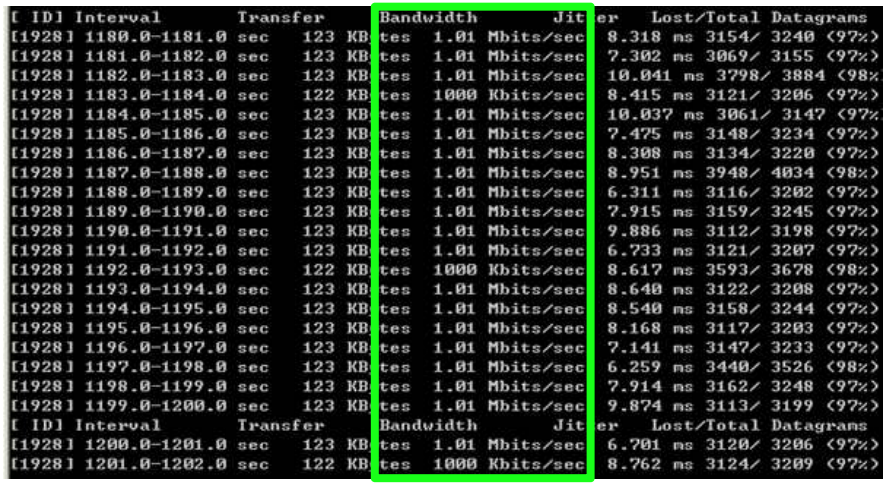
- **Dummynet PC**
  - OS: FreeBSD 8.0
  - CPU: Intel Quad-Core i5, 2.8 GHz
  - Memory: 4 Gbytes
  - NIC: Gigabit Ethernet
- **Sender, Receiver and NetFPGA PCs**
  - OS: CentOS 5.2
  - CPU: Intel Dual-Core E8400, 3.0GHz
  - Memory: 4 Gbytes
  - NIC: Gigabit Ethernet

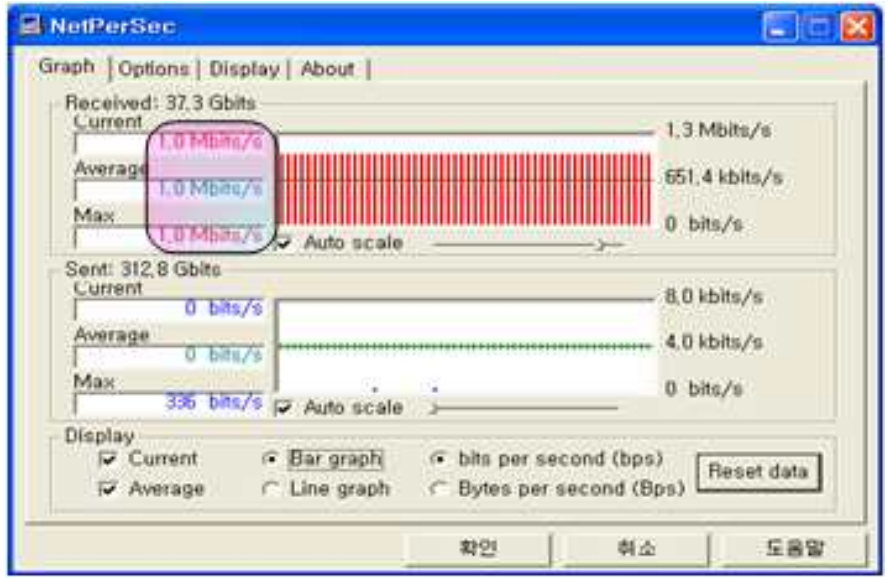


Experimental Results

- **Bottleneck bandwidth & Delay**

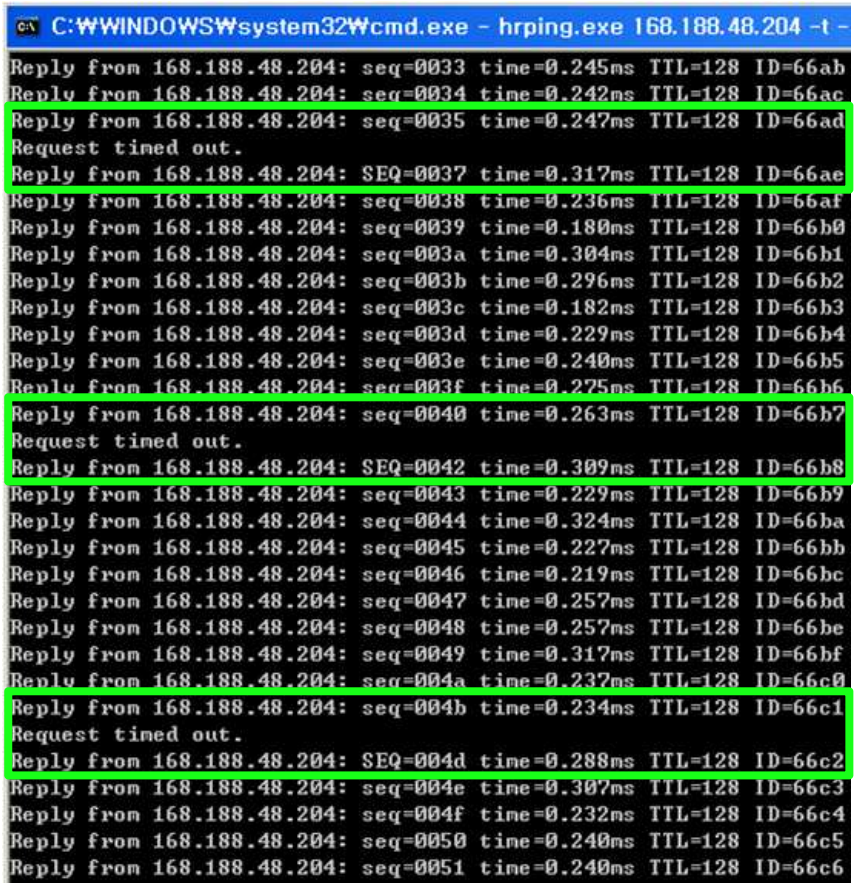


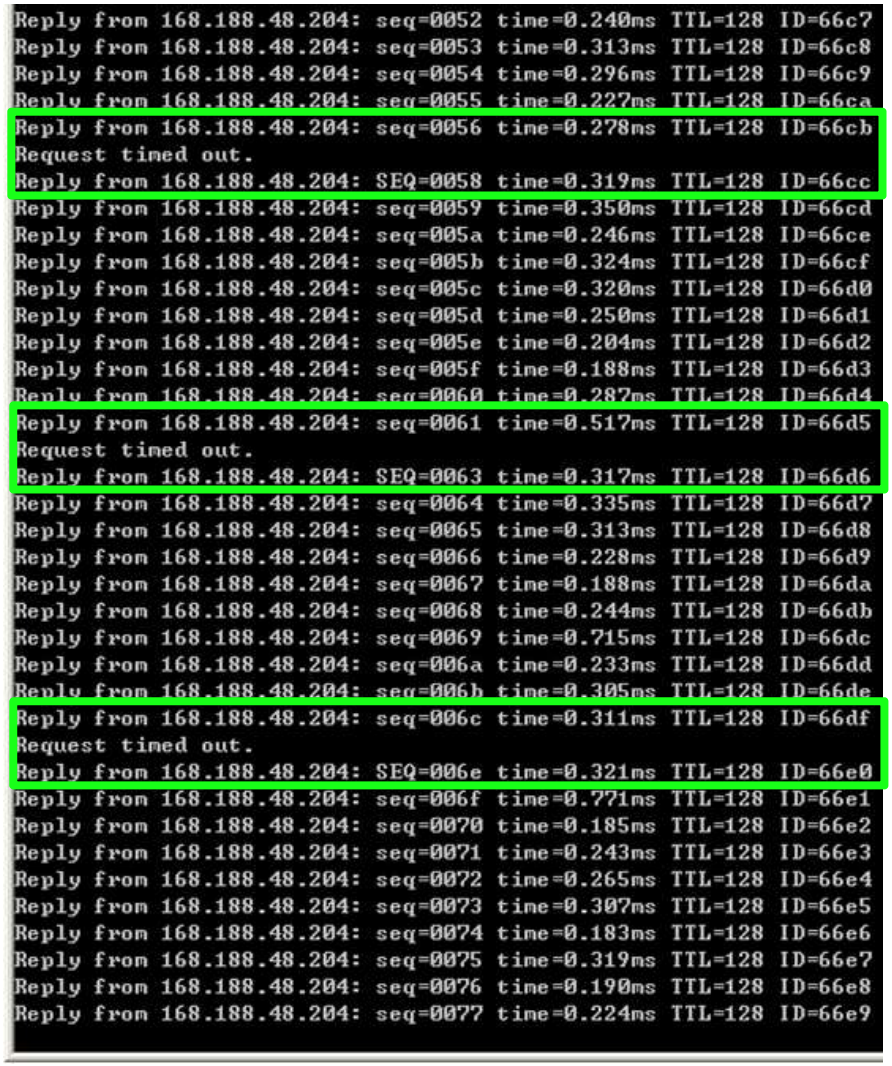




Experimental Results (cont'd)

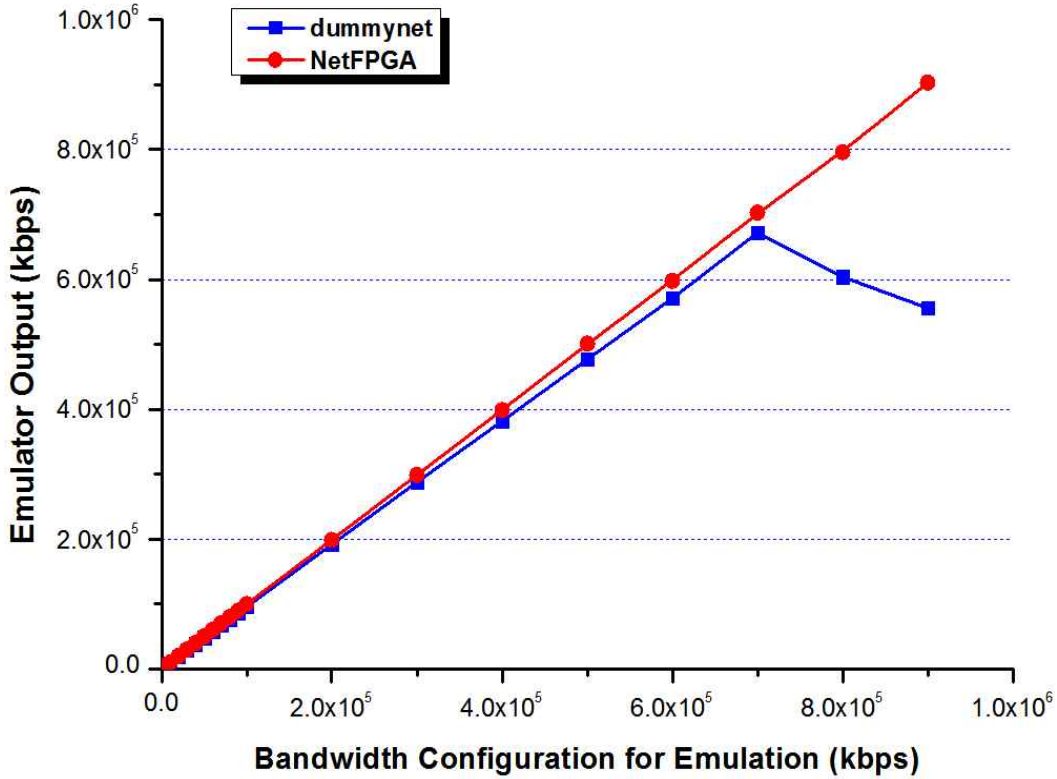
- **Packet Loss**
  - every 11th packet drop





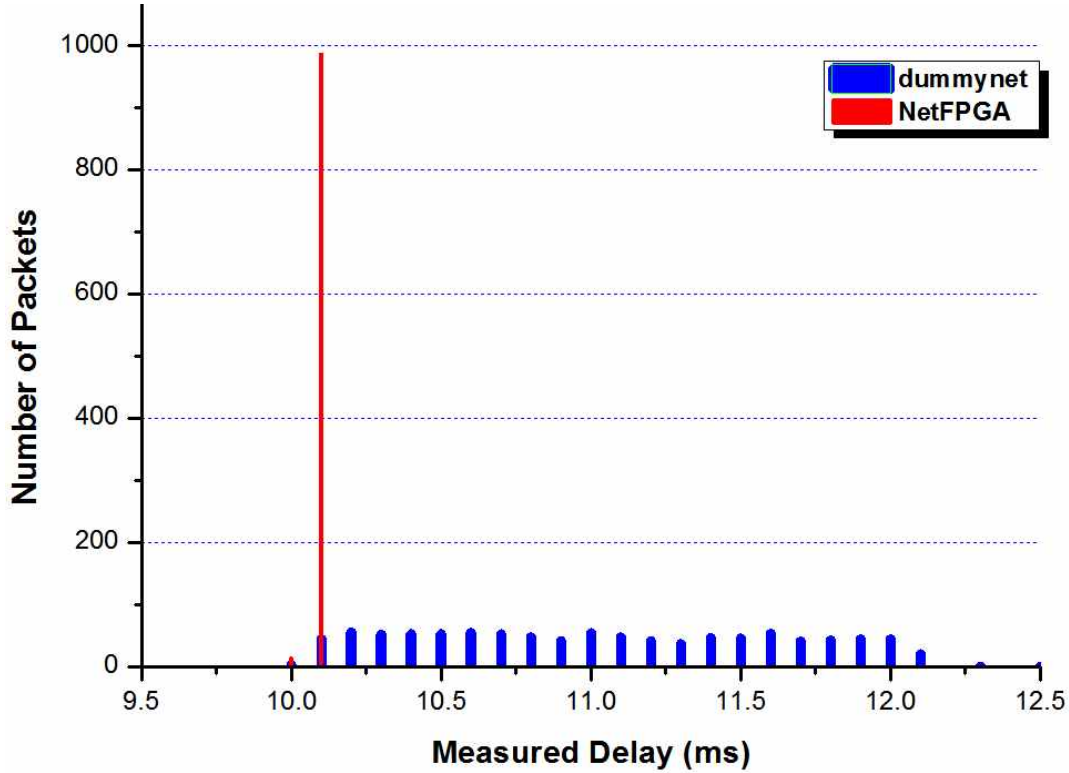
NetFPGA vs. Dummynet

- **Emulation of Bottleneck Bandwidth**
  - The NetFPGA emulator can emit exact throughput almost up to 1 Gbps, but the output of the Dummynet is saturated around 700 or 800 Mbps.



NetFPGA vs. Dummynet (cont'd)

- **Emulation of Packet Delay**
  - NetFPGA emulator is very accurate according to the configured value, but the Dummynet has more diverse variation. (10 ms, 1000 ping packets)



NetFPGA vs. Dummynet (cont'd)

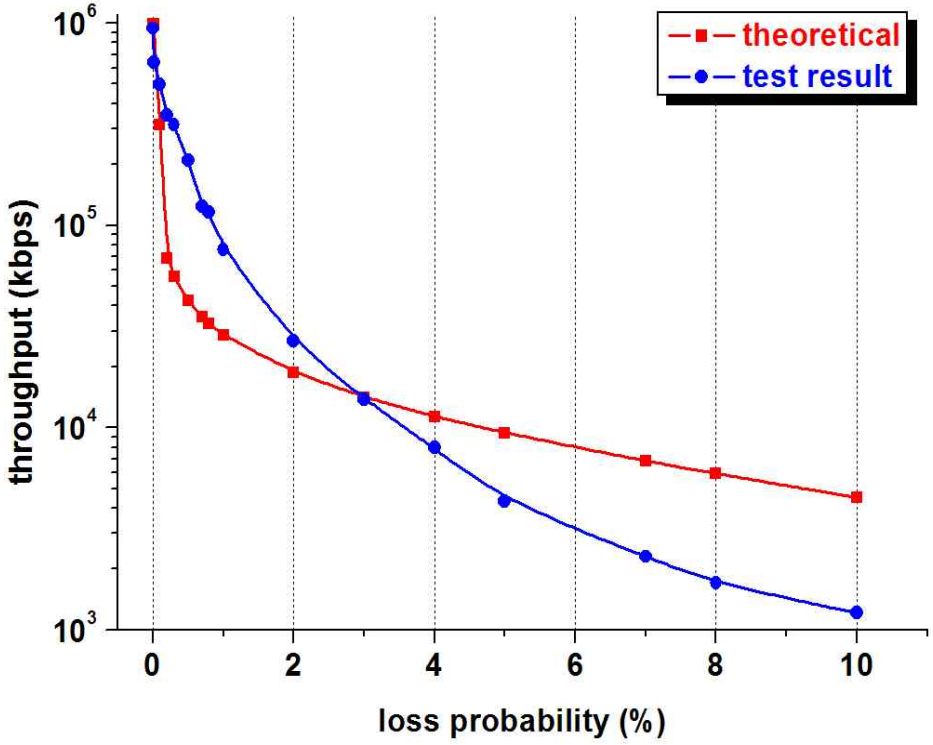
- **Emulation of Packet loss**
  - NetFPGA emulator can control more exactly
  - Exact mean value and very small variance of loss probability

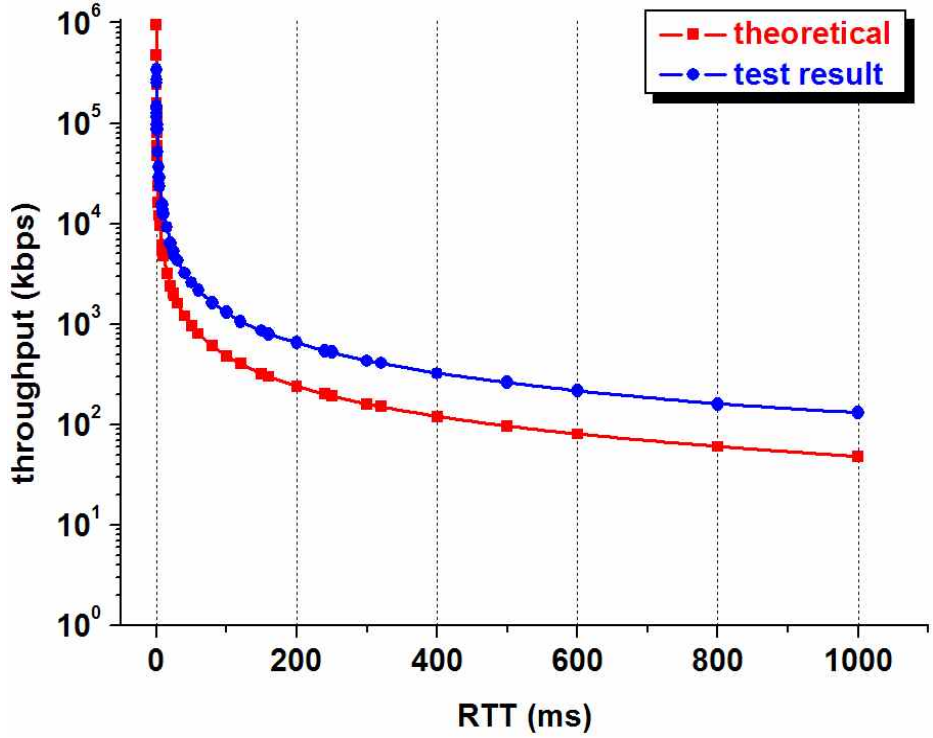
Loss Probability Configuration		0.1%	1%	5%	10%
NetFPGA Result	mean	0.100062	1.00111	5.004734	10.11184
	variance	4.26e-11	2.39e-10	7.63e-10	2.22e-09
Dummynet Result	mean	0.099667	0.997294	4.939374	9.754387
	variance	9.72e-11	2.96e-10	2.21e-09	6.93e-09

Application to TCP throughput performance

- **Measurement of the Throughput Performance**

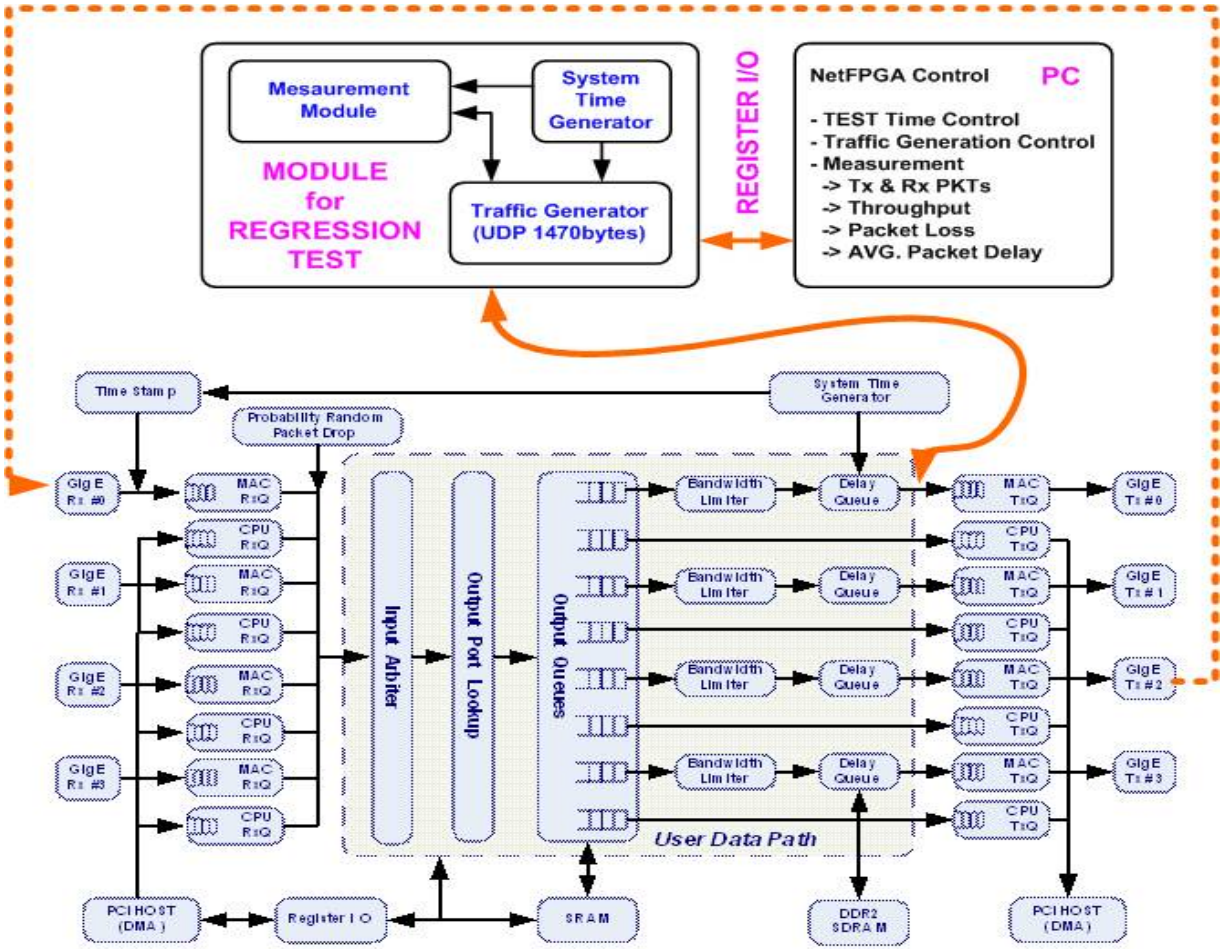
$$Throughput(TCP/Reno) = \frac{1}{RTT}\sqrt{\frac{3}{2p}}$$





Demonstration

❖ **Scheme of the Regression Test**



Demonstration (cont'd)

- Regression Test
  - Scenario #1
    - Verifying the Regression Test Module
  - Scenario #2
    - Verifying the Bandwidth Limiter Module
  - Scenario #3
    - Verifying the Packet Delay Module
  - Scenario #4
    - Verifying the Packet Drop Module

Scenario #1

❖ Verifying the Regression Test Module

- Without packet loss, packet delay and bottleneck bandwidth.
- Regression test is working correctly?

```
            Regresstion Test for Network Emulator (rev 0.90)

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********************************************************************************

-> This test will Verify the regression test module ...

-> If you don't want, press Ctrl-C to exit ...

-> Test Set-up Start ...

        Register Reset ........................... OK !!!

-> Test Set-up Status ...

        Packet Loss Probability ................... 0.000 %
        Bottleneck Bandwidth ......................     1 Gbps
        Packet Delay .............................. 0.000 us
```

```
-> Test Start ...

        Last packet scheduled for transmission within 180.000 sec

        Sending packets........................... Elapsed 180.000 sec


-> Tx & Rx statistics ...

        PKT Gen Time : 180.000 sec
        PKT Size     : 1512 bytes (MAC, UDP: 1470 bytes)
        Tx PKTs      : 14648682
        Rx PKTs      : 14648682
        Drop PKTs    : 0


-> Final Reports ...

        0] Test Time         : 180.000 sec
        1] Generated Traffic : 938.789 Mbps
        2] Throughput        : 938.789 Mbps
        3] Loss Ratio        : 0.000 %
        4] Avg. Delay        : 0.001 msec


-> Test Finish ...

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Scenario #2

❖ Verifying the Bandwidth Limiter Module

- Only with bottleneck bandwidth (without packet loss and delay)

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********************************************************************************
                Regresstion Test for Network Emulator (rev 0.90)

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********************************************************************************


-> This test will Verify the bandwidth limiter module ...


-> If you don't want, press Ctrl-C to exit ...


-> Test Set-up Start ...


        Register Reset ............................. OK !!!


-> Test Set-up Status ...

        Packet Loss Probability .................... 0.000 %
        Bottleneck Bandwidth ....................... 1.000 Mbps
        Packet Delay ............................... 0.000 us
```

```
-> Test Start ...

        Last packet scheduled for transmission within 180.000 sec

        Sending packets............................. Elapsed 180.000 sec



-> Tx & Rx statistics ...

        PKT Gen Time : 180.000 sec
        PKT Size     : 1512 bytes (MAC, UDP: 1470 bytes)
        Tx PKTs      : 14648682
        Rx PKTs      : 15475
        Drop PKTs    : 14633207


-> Final Reports ...

        0] Test Time         : 180.000 sec
        1] Generated Traffic : 938.789 Mbps
        2] Throughput        : 0.992 Mbps
        3] Loss Ratio        : 99.894 %
        4] Avg. Delay        : 1.730 msec


-> Test Finish ...

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Scenario #3

❖ Verifying the Packet Drop Module

- Only with packet drop (without packet delay and bottle bandwidth)

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                Regresstion Test for Network Emulator (rev 0.90)

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-> If you don't want, press Ctrl-C to exit ...

-> Test Set-up Start ...


        Register Reset ............................ OK !!!


-> Test Set-up Status ...

        Packet Loss Probability ..................... 5.000 %
        Bottleneck Bandwidth .......................     1 Gbps
        Packet Delay ............................... 0.000 us
```

```
-> Test Start ...

        Last packet scheduled for transmission within 180.000 sec

        Sending packets............................ Elapsed 180.000 sec



-> Tx & Rx statistics ...

        PKT Gen Time : 180.000 sec
        PKT Size     : 1512 bytes (MAC, UDP: 1470 bytes)
        Tx PKTs      : 14648682
        Rx PKTs      : 13915242
        Drop PKTs    : 733440


-> Final Reports ...

        0] Test Time         : 180.000 sec
        1] Generated Traffic : 938.789 Mbps
        2] Throughput        : 891.785 Mbps
        3] Loss Ratio        : 5.007 %
        4] Avg. Delay        : 0.001 msec


-> Test Finish ...

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```

Scenario #4

❖ Verifying the Packet Delay Module

- Only with packet delay (without packet loss and bottleneck bandwidth)
- Ping test between sender and receiver through the NetFPGA network emulator
- Ping 10.10.10.10 –i 0.001 (1ms)

References

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- NISTNet, http://www-x.antd.nist.gov/nistnet.
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- Matthew Mathis, Jeffery Semke, Jamshid Mahdavi, Teunis Ott, "The Macroscopic Behavior of the TCP Congestion Avoidance Algorithm", ACM SIGCOMM, vol 27, no 3, July 1997.

Thank you

for your attention !!!