LAB 2 [ECE 658]

Simulation based Evaluation of a Network Interface Card with Offload Capability

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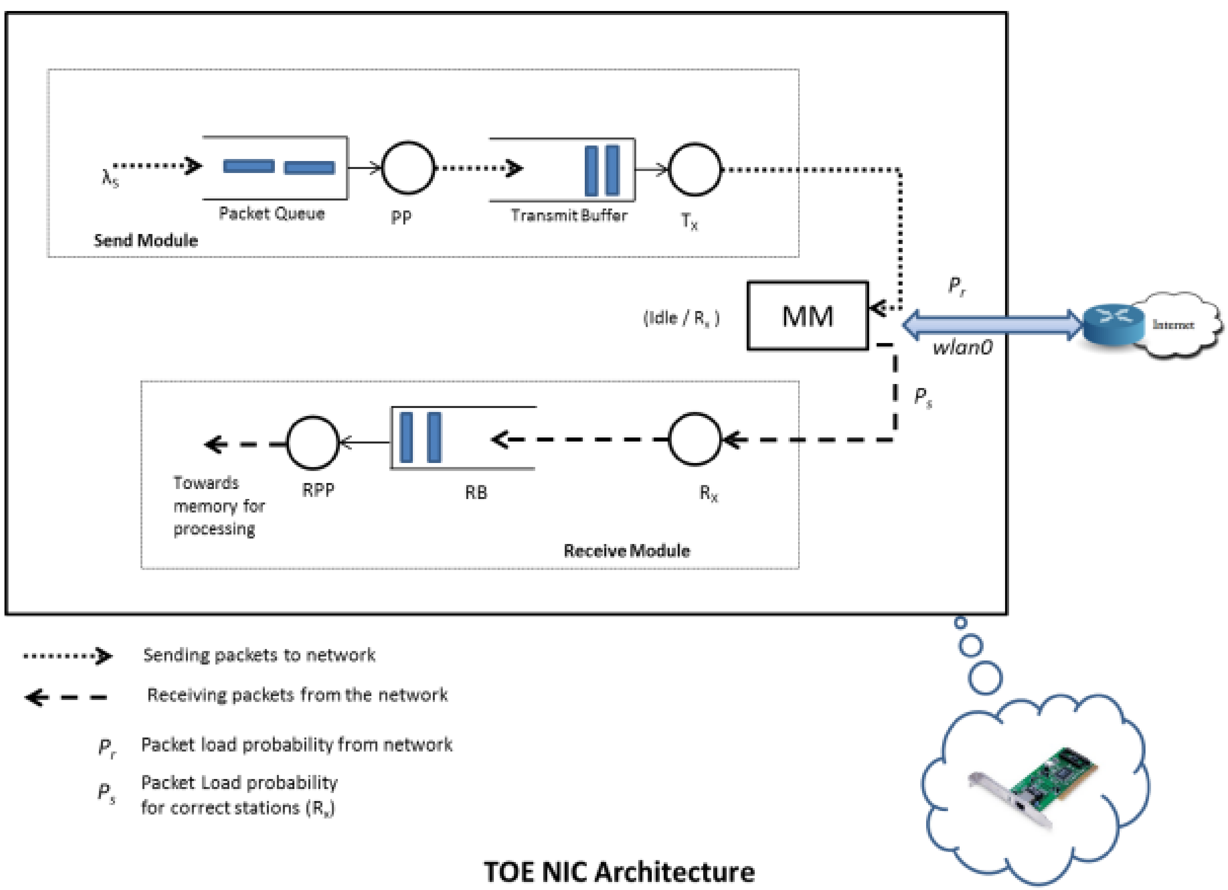
[Detailed Design Document and Report]

OBJECTIVE:

The main objective of this assignment is to design and implement an event-driven simulator to analyze the performance of the Network Interface Card (NIC).

NIC ARCHITECTURE (BLOCK DIAGRAM):



TOE NIC Architecture

The NIC allows the computers communicate over a local-area network and is both a physical layer and data link layer device and provides access to the transmission medium, and supports a MAC protocol and an addressing scheme. While sending a data packet it performs a series of operation before the packet is injected in the network and while receiving, it evaluates the incoming data packet for errors and checks whether it is the correct destination or not and performs the subsequent operations. It mainly consists of three modules: Send Module, Mac Module and the Receiver Module.

DESCRIPTION OF DESIGN:

We have initialized a clock which is set to '0' and incremented by a fixed value every cycle which will check for incoming messages at different arrival rates and inject them in the system.

- **Message Arrival (Poisson's Distribution):** In the designed simulator, messages of random length (mean 32 KB) are generated (100~7000 messages), considering to be arriving at a random arrival rate following the Poisson's arrival distribution. It is the most common distribution used in Queuing theory as it states the random occurrence of events in a given interval.
- **Send Module (SM):**
  - Once the message enters the system in the given clock period, it will check if the Protocol Processor (PP) is busy. If it is free, the message will be sent to it for further processing else the message will be enqueued to the Packet Queue (PQ). If the message length exceeds 64KB, it is truncated to 64KB.
  - Once the PP receives a message, it will process the message into MAC frames of equal length (1526 bytes) and write them to the Transmit Queue (TQ) if it is not full. If the TQ is full, the PP will hold on to the current message and won't accept any new message unless it writes all the frames of the message to the TQ slots as they become free. The PP has a processing rate of 2ns/bit which does not include the waiting time for TQ to become free.
  - The lengths of the PQ and TQ can be changed as per the requirements to optimize the performance of the SM. Total of 512 KB is allocated between these two buffers. For lower arrival rate, the TQ size can be much higher than PQ. However, if the incoming traffic from the network is more, optimal parameters have to be chosen.
  - Once the frames are enqueued in the TQ, the transmitter (Tx) picks one frame at a time for transmission depending on the probability 'Pr' which determines the mode switching in the Mac Module (MM). The Tx module transmits frames, only one at a time (1526 bytes), and transmits it at a rate, B (1 Gbps) but requires a gap of Tg (time equivalent to transmit 74 bytes) between packets for sensing time and tolerance margin.
  - As soon as Tx picks up a frame from the TQ, the TQ writes the about the packet left with time stamp to the *SM-log* file hence keeping track of the frames transmitted.

- **Mac Module (MM):**
    - The Mac Module is the NIC controller for the system. It is a half-duplex link and acts as a transceiver switching between channel "busy/idle" mode.
    - The MM is either connected to the Send Module (SM) with probability Pr or the Receiver Module (RM) with probability (1 – Pr). This probability is determined depending on the traffic of either stations.
    - Once the MM switches the modes, it stays in that mode at least for one time-slot (time equivalent to transmit 1600 bytes).
    - When the MM is in the "channel idle" mode, it accepts a frame from the Tx of the SM in the given time slot and transmits it to the Internet. After that, depending on the traffic, the Pr switches again hence deciding the mode MM would be in.
    - In the "channel busy" mode, the MM module gets connected to the RM wherein it receives a frame from the Internet and transmits it to the receiver Rx.
    - The MM maintains a log of packets it transmitted to the Internet from the SM and the ones it received from Internet and sent to RM (with/without correct destination) in the *controller-log* file along with a time-stamp.

- **Receiver Module (RM):**
    - The receiver module has a receiver Rx which receives the frame from the MM in the given time slot when MM is in "channel busy" mode. Rx checks if a packet belongs to the correct address or not and drops the incorrect address packets with a probability S, in our case S = 0.5
    - Once the Rx decides that a frame belongs to the correct address, it queues the packet to a Receive Buffer(RB) of size 6000 bytes if space is available in the buffer or else it drops the packet.
    - Since RB is of fixed length (6000 bytes) and the packet size is assumed to be 1526 bytes every time, RB can accumulate a maximum of 3 frames only.
    - RPP waits until it can accumulate r frames (r is generated randomly between 1 - 3) from RB then combines the packets into a single larger file and send it to upper layers. RPP has a processing rate of 5ns/bit which does not include the waiting time to accumulate r frames.
    - The time RPP takes to process these frames depends on the total number of bits therein.

SIMULATION PARAMETERS:

- **Throughput:** Throughput or network throughput is the rate of successful message delivery over a communication channel. It is calculated by dividing the total number of packets transmitted (SM - Tx) or received (RM - Rx) divided by the elapsed time.

- **Delay introduced by NIC:** The delay introduced by the NIC is computed by calculating the difference between the time the message enters the PP or the PQ (if PP is busy) to the time the message leaves the Tx for the Send Module (SM). At the receiver module, the delay is calculated by computing the difference between time at packet entering MM to it leaving the RM at RPP.

- **Packet Loss:**
    - Packet Loss at Packet Queue: The packet loss in the SM occurs at the Packet Processor Queue when the queue gets full as PP is serving the current message or is waiting for the next TQ slot to become empty. Once PQ is full, the message generated at the time is dropped.
    - Packet Loss at the Receiver: There are two types of packet losses at the RM.
        - Packet loss at Rx: We have the Probability of dropping Ps = 0.5. Hence, 50% of the packets will be dropped (which don't belong to the destination).
        - Packet loss at Receive Buffer (RB): After Rx receives the packets, it writes those frames to the RB as per the slots availability. Once the RB gets full, it drops any of the packets after that.

- **Network Load:** The network load is the total number of messages entered and processed in the network. For the *SM-MM-Internet*, the network load is calculated by computing the difference between the total number of packets processed by the Protocol Processor. In the case of *Internet-MM-RM*, it is the total number of messages accepted by the MM in the given clock time.

- **TPP Processing Rate:** The TPP processing rate is the processing rate for the Protocol Processor – 2ns/bit. It is calculated by dividing the total time PP is actively serving in the SM (Service time) by the total number of packets processed.

- **RPP Processing Rate:** The RPP processing rate is the processing rate for the Receive Protocol Processor (RPP) – 5ns/bit. It is calculated by dividing the total time RPP is actively serving divided by the total number of packets processed.

- **Buffer sizes:** As per the performance requirements, the buffer sizes of the Packet Queue and the Transmit Queue are allocated. They share a total space of 512 KB. The size of the Receive Buffer (RB) however stays constant at 6 KB (it can hold max of 3 frames at time).

SIMULATION RESULTS:

The simulation time is kept constant = 10s

1. ARRIVAL RATE = 7000 messages/s PACKETS FROM INTERNET = 7000

Buffer Size = 64 KB Rpp processing rate: 11.7644519282 ns/bit Tpp processing rate: 1.87950695269 ns/bit Tx throughput: 532.036697081 Mbps Rx throughput: 85.0010528264 Mbps Packet loss at Receiver: 0.379386658236 % Message loss at PQ: 44.4671428571 % Average delay in NIC for each message processed in send module is: 3866.40354696 microseconds Average delay in NIC for each packet processed in RM is: 18.85046594 microseconds	Buffer Size = 128 KB Rpp processing rate: 11.7080325946 ns/bit Tpp processing rate: 1.87914245569 ns/bit Tx throughput: 532.151351448 Mbps Rx throughput: 85.4117027803 Mbps Packet loss at Receiver: 0.38985237208 % Message loss at PQ: 44.6442857143 % Average delay in NIC for each message processed in send module is: 3869.7092103 microseconds Average delay in NIC for each packet processed in RM is: 18.945063166 microseconds
Buffer Size = 256 KB Rpp processing rate: 11.7002586118 ns/bit Tpp processing rate: 1.87985651476 ns/bit Tx throughput: 531.951716588 Mbps Rx throughput: 85.4642216644 Mbps Packet loss at Receiver: 0.395560614684 % Message loss at PQ: 44.1685714286 % Average delay in NIC for each message processed in send module is: 3869.95984444 microseconds Average delay in NIC for each packet processed in RM is: 18.7662066784 microseconds	Buffer Size = 512 KB Rpp processing rate: 11.7002586118 ns/bit Tpp processing rate: 1.87985651476 ns/bit Tx throughput: 531.951716588 Mbps Rx throughput: 85.4642216644 Mbps Packet loss at Receiver: 0.395560614684 % Message loss at PQ: 44.1685714286 % Average delay in NIC for each message processed in send module is: 3869.95984444 microseconds Average delay in NIC for each packet processed in RM is: 18.7662066784 microseconds

2. ARRIVAL RATE = 100 messages/s PACKETS FROM INTERNET = 600

Buffer Size = 64 KB Rpp processing rate: 138.096160665 ns/bit Tpp processing rate: 35.4874120682 ns/bit Tx throughput: 28.1781384938 Mbps Rx throughput: 7.24119043938 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 338.427000014 microseconds Average delay in NIC for each packet processed in RM is: 2.61644758996 microseconds	Buffer Size = 128 KB Rpp processing rate: 136.01759774 ns/bit Tpp processing rate: 34.9734217439 ns/bit Tx throughput: 28.5924938341 Mbps Rx throughput: 7.35020377481 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 346.901000018 microseconds Average delay in NIC for each packet processed in RM is: 2.67645118716 microseconds
Buffer Size = 256 KB Rpp processing rate: 134.354753705 ns/bit Tpp processing rate: 37.1452471553 ns/bit Tx throughput: 26.9200420747 Mbps Rx throughput: 7.4414582532 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 348.312473946 microseconds Average delay in NIC for each packet processed in RM is: 2.52902374652 microseconds	Buffer Size = 512 KB Rpp processing rate: 138.026456158 ns/bit Tpp processing rate: 39.0052174866 ns/bit Tx throughput: 25.6370821818 Mbps Rx throughput: 7.24323900437 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 325.519000049 microseconds Average delay in NIC for each packet processed in RM is: 2.51316239303 microseconds

3. ARRIVAL RATE = 500 messages/s PACKETS FROM INTERNET = 7000

Buffer Size = 64 KB Rpp processing rate: 11.6993856479 ns/bit Tpp processing rate: 7.75710536228 ns/bit Tx throughput: 128.913460078 Mbps Rx throughput: 85.4752319334 Mbps Packet loss at Receiver: 0.43791495974 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 473.978999996 microseconds Average delay in NIC for each packet processed in RM is: 13.9391884213 microseconds	Buffer Size = 128 KB Rpp processing rate: 11.7433290547 ns/bit Tpp processing rate: 7.85701345528 ns/bit Tx throughput: 127.268604568 Mbps Rx throughput: 85.1547287266 Mbps Packet loss at Receiver: 0.395937338612 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 459.633675531 microseconds Average delay in NIC for each packet processed in RM is: 13.708030878 microseconds
Buffer Size = 256 KB Rpp processing rate: 11.665927494 ns/bit Tpp processing rate: 7.77597688523 ns/bit Tx throughput: 128.597109213 Mbps Rx throughput: 85.718899872 Mbps Packet loss at Receiver: 0.336738770618 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 457.702800026 microseconds Average delay in NIC for each packet processed in RM is: 13.6653590644 microseconds	Buffer Size = 512 KB Rpp processing rate: 11.7392236046 ns/bit Tpp processing rate: 7.94427162162 ns/bit Tx throughput: 125.871423318 Mbps Rx throughput: 85.179082836 Mbps Packet loss at Receiver: 0.360896177388 % Message loss at PQ: 0.0 % Average delay in NIC for each message processed in send module is: 455.026422684 microseconds Average delay in NIC for each packet processed in RM is: 13.3698820657 microseconds

4. ARRIVAL RATE = 1000 messages/s PACKETS FROM INTERNET = 600

Buffer Size = 64 KB Rpp processing rate: 137.935391766 ns/bit Tpp processing rate: 4.07723737553 ns/bit Tx throughput: 245.263620382 Mbps Rx throughput: 7.24896962349 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.02 % Average delay in NIC for each message processed in send module is: 648.833404178 microseconds Average delay in NIC for each packet processed in RM is: 3.43521367486 microseconds	Buffer Size = 128 KB Rpp processing rate: 138.220534119 ns/bit Tpp processing rate: 3.98465793457 ns/bit Tx throughput: 250.956808936 Mbps Rx throughput: 7.22358770586 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.08 % Average delay in NIC for each message processed in send module is: 652.991353089 microseconds Average delay in NIC for each packet processed in RM is: 3.41493351489 microseconds
Buffer Size = 256 KB Rpp processing rate: 135.270737759 ns/bit Tpp processing rate: 3.96815515077 ns/bit Tx throughput: 251.991280444 Mbps Rx throughput: 7.38946521055 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.07 % Average delay in NIC for each message processed in send module is: 688.728535528 microseconds Average delay in NIC for each packet processed in RM is: 3.28838451251 microseconds	Buffer Size = 512 KB Rpp processing rate: 136.508252478 ns/bit Tpp processing rate: 3.99842232973 ns/bit Tx throughput: 250.093366057 Mbps Rx throughput: 7.32394413593 Mbps Packet loss at Receiver: 0.0 % Message loss at PQ: 0.02 % Average delay in NIC for each message processed in send module is: 670.167647043 microseconds Average delay in NIC for each packet processed in RM is: 3.19911953916 microseconds

5. ARRIVAL RATE = 3000 messages/s PACKETS FROM INTERNET = 7000

Buffer Size = 64 KB Rpp processing rate: 11.7124555943 ns/bit Tpp processing rate: 1.92600457624 ns/bit Tx throughput: 519.192379134 Mbps Rx throughput: 85.3776641011 Mbps	Buffer Size = 128 KB Rpp processing rate: 11.7381630178 ns/bit Tpp processing rate: 1.92485876589 ns/bit Tx throughput: 519.514583398 Mbps Rx throughput: 85.1918309807 Mbps

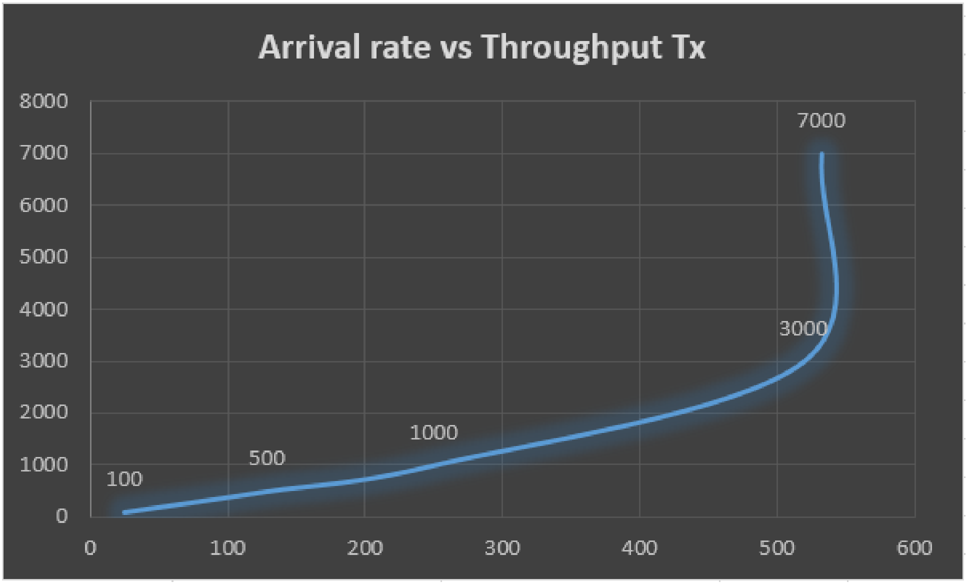
Packet loss at Receiver: 0.663396932498 % Message loss at PQ: 14.78 % Average delay in NIC for each message processed in send module is: 3034.35595321 microseconds Average delay in NIC for each packet processed in RM is: 22.0664421471 microseconds	Packet loss at Receiver: 0.635544915641 % Message loss at Packet Queue: 15.223333333 % Average delay in NIC for each message processed in send module is: 3058.91773716 microseconds Average delay in NIC for each packet processed in RM is: 21.9156747437 microseconds
Buffer Size = 256 KB Rpp processing rate: 11.6341040995 ns/bit Tpp processing rate: 1.92656547662 ns/bit Tx throughput: 519.025963791 Mbps Rx throughput: 85.9524614231 Mbps Packet loss at Receiver: 0.643306481455 % Message loss at Packet Queue: 15.12 % Average delay in NIC for each message processed in send module is: 3033.44088503 microseconds Average delay in NIC for each packet processed in RM is: 22.4579000127 microseconds	Buffer Size = 512 KB Rpp processing rate: 11.6330731597 ns/bit Tpp processing rate: 1.92394698843 ns/bit Tx throughput: 519.734052279 Mbps Rx throughput: 85.9522193587 Mbps Packet loss at Receiver: 0.662595067988 % Message loss at Packet Queue: 15.616666667 % Average delay in NIC for each message processed in send module is: 3048.5584039 microseconds Average delay in NIC for each packet processed in RM is: 21.9582100791 microseconds

Analysis of the simulation results:

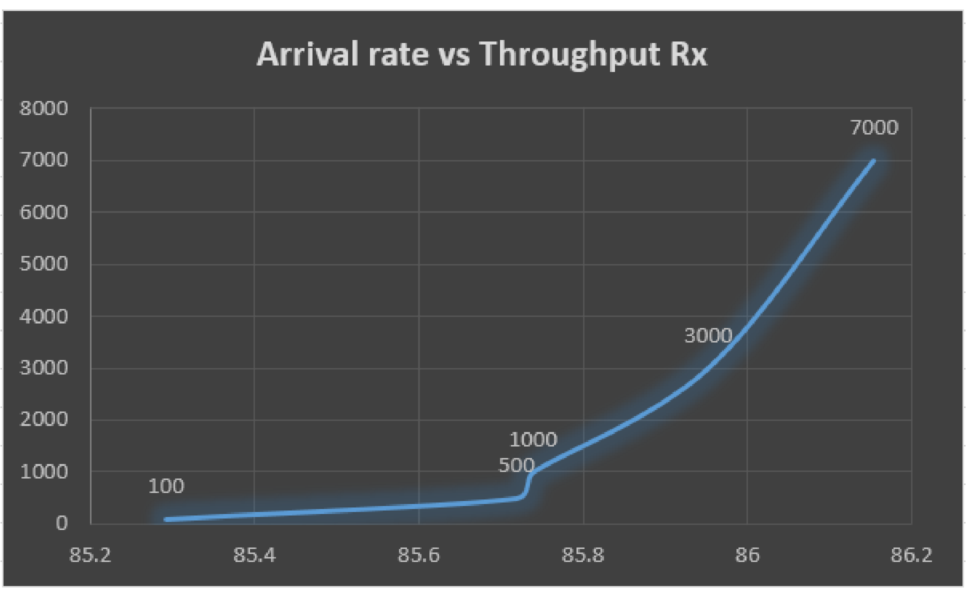
From the above generated results, it can be observed that there is an obvious trade-off between the buffer sizes for Packet Queue (PQ)/ the Transmit Buffer Queue (TB) and the message loss at Packet Queue. With increase in the buffer size of PQ, the message dropping probability is reduced. The message dropping probability is also dependent on the arrival rate (number of messages). Higher the arrival rate, higher is the dropping probability for a given PQ buffer size. The boundary conditions and some intermediate conditions for arrival rates are considered.

For the receiver module, the packet loss depends upon the slot availability of the receive buffer (RB) which is fixed to 1600 bytes. The delay by the NIC changes as per the arrival rate, packets from the Internet and buffer size. Depending on the number of packets generated by the Internet, the probability Pr will switch the MM between channel idle and channel busy mode. This will in turn determine the delay introduced by the NIC.

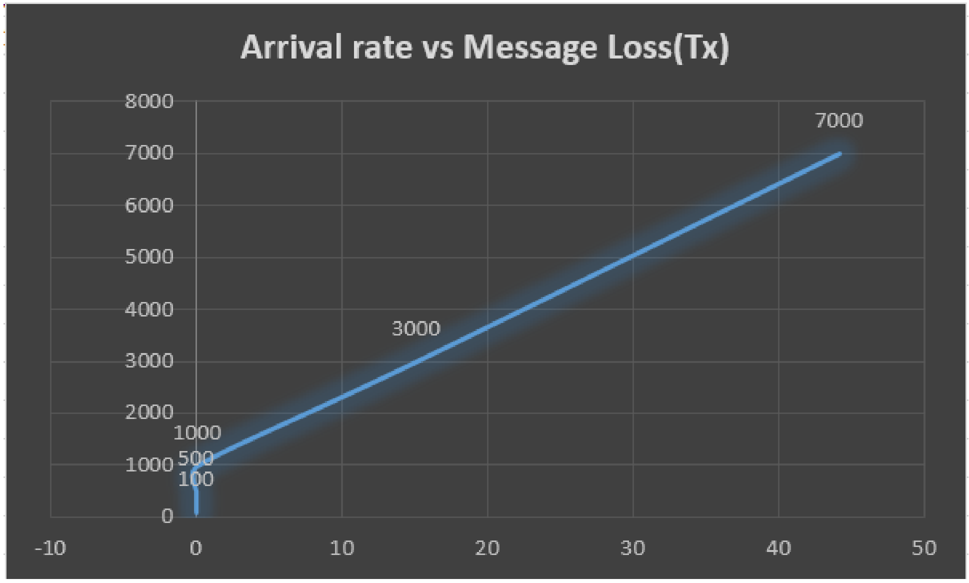
PLOTS:



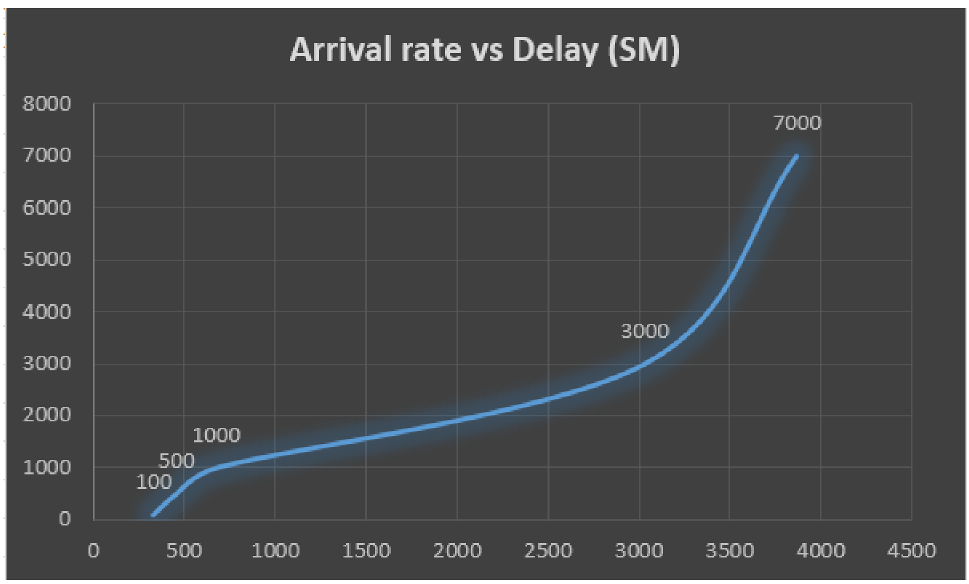
This graph plots the Arrival rate vs Throughput Tx for a constant buffer size of 256KB. It shows increase in the throughput with increase in arrival rate.



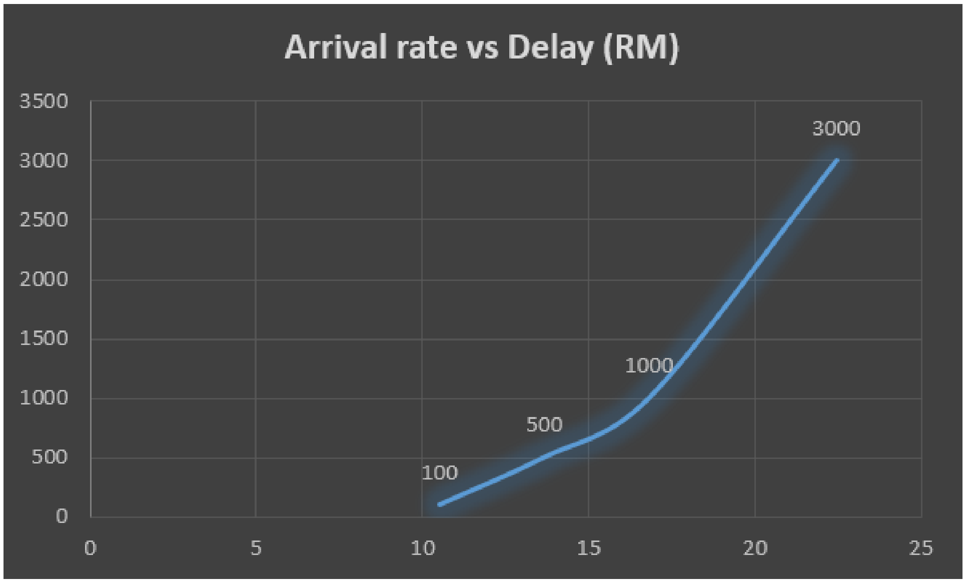
This graph shows the same result for Receiver Module (Rx).



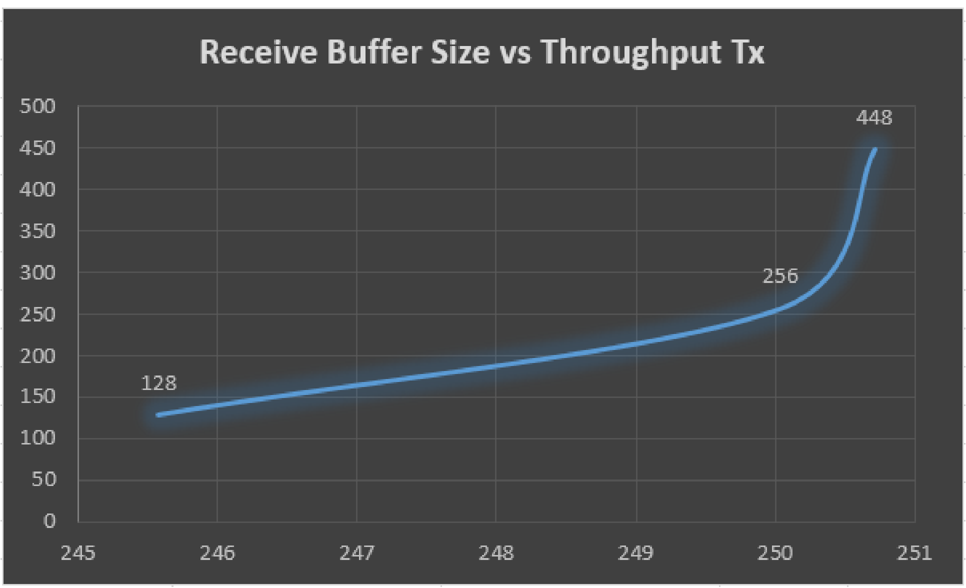
This graph shows the increase in the Message loss with increase in the arrival rate for a constant buffer size (RB)



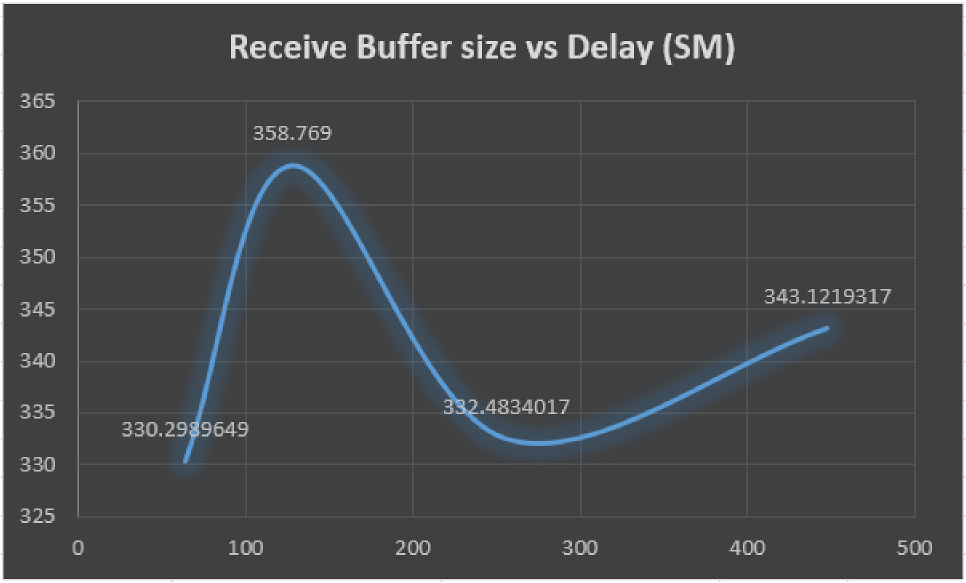
The graph depicts the increase in the delay introduced by NIC at SM with increase in the arrival rate for a constant buffer size



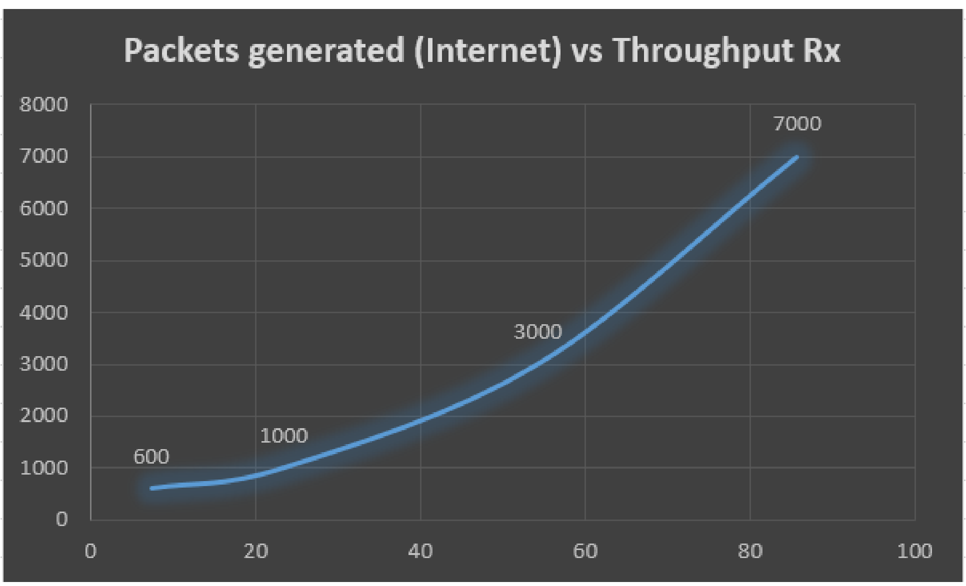
An increase in delay by NIC at RM with increase in arrival rate of packets by Internet is shown here.



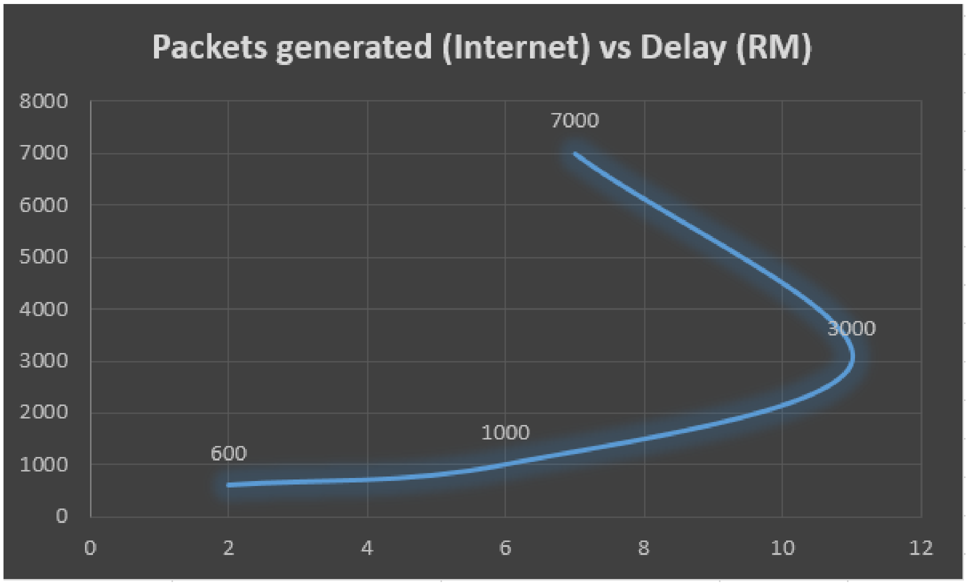
Here for a constant arrival rate, the increase in the Throughput Tx by SM with increase in buffer size RB is shown



This graph shows the fluctuations in delay with increase in buffer size. However, over a longer interval, the value becomes consistent for a constant arrival rate.



For a constant arrival rate at SM greater than the arrival rate from the Internet, the graph of Packets generated via Internet vs Throughput Rx at RM follows a linear graph.



For a constant arrival rate at SM, this graph plots the Packets generated at Internet vs the Delay introduced by NIC at RM. This should be an exponentially increasing value. However, not that the arrival rate at SM is not greater than the one at Internet here.

Arrival rate at SM = 1000 msgs/s

Hence, whenever the number of packets generated at the Internet becomes larger than the ones from SM, there is more probability of MM going in “channel busy” mode releasing the *Internet-MM-RM* path. Hence, the delay introduced by the network shows a sudden reduced spike.