Performance Evaluation of Input and Virtual Output Queuing on Poisson and Self-Similar Traffic

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Abstract

The theoretical analysis of networks is generally carried out on the basis of exponential assumptions for analytical simplicity. This may lead to incorrect results since it had been proved that the network traffic is generally self similar rather than exponentially distributed [VPSF95].

The work on N x N switch with input and virtual output queue were done by Hluchyj [MKMG87] and McKeown [NMJW]. Their results of performance were based on the assumption that traffic is Poisson in nature. In this work we performed simulations using Poisson and Self Similar Traffic on a non-blocking 2 x 2 switch with both queue mechanisms.

The model we used here is same as used by Hluchyj and McKeown in their work. Our simulation results show that the throughput of 2 x 2 switch on Input and Virtual output queue on self similar traffic is around 100%.

1. Introduction

Several researchers performed the simulation of network traffic on the assumption that the traffic is Poisson in nature. However Verne Paxson and Sally Floyd showed in their work that the data on FTP, Internet and Telnet is self similar rather than Poisson [VPSF95]. This paper study the behavior of traffic on input and virtual output queued switches having 2 x 2 ports. Karol and Hluchyj in their paper studied the behavior on Input queued switches [MKMG87] whereas McKeown and Walrand studied the behavior of traffic on virtual output queue (VOQ) [NMJW]. However both study use the assumption that traffic is of Poisson nature. We, in this study, perform the simulation on both switches with the assumption that traffic is self similar. We first study the behavior of the two switches on Poisson traffic distribution and in order to simulate self similar nature, we used Pareto distribution. The model used is same as in [MKMG87] and [NMJW]. The data traffic is generated on NS 2. Results, however generated by our simulation are different from Hluchyj and McKeown's work. It shows that very few packets are dropped, and the throughput of Input queue and VOQ having Poisson distributed traffic is 99% and 100% respectively. For self similar traffic, our result shows that throughput is 100%.

The next section describes self similar traffic distribution. Section 4 and 5 presents the issues of Input and Virtual Output Queue respectively. Section 6 shows the assumptions we made in this research. Section 8 handles some implementation issues. Section 9 gives the various results we get in simulation. Section 10 shows the comparisons between Poisson and Self Similar traffic and the suggestion for further research.
3. Self-Similar Traffic

A self-similar phenomenon displays structural similarities across a wide range of timescales. Self-similarity is the property associated with "fractals," which are objects whose appearances are unchanged regardless of the scale at which they are viewed [CROV97]. In the case of stochastic objects like time series, self-similarity is used in the distributed sense. When viewed at varying timescales, the object's relational structure remains unchanged. As a result, such a time series exhibit bursts at a wide range of timescales [SHAI99]. Thus traffic that is bursty on many or all timescales can be described statistically using the notion of self-similarity.

In the work of [VPSF95], it has been pointed out, that self-similar network traffic can be generated with the help of ON-OFF sources. An ON-OFF source alternates between sending packets (ON) and being idle (OFF). If the durations of the ON and the OFF phases are described by heavy tailed probability distributions then the superposition of a large number of ON-OFF sources result in self-similar packet traffic [WTSW97]. Heavy tailed distributions have high or even infinite variance and therefore show extreme variability on all time scales.

The simplest type of heavy-tailed distribution is the Pareto distribution. Study done by many researches show that Ethernet, WWW and FTP data sessions follow Pareto distribution.

Research done by [CROV97] has revealed that the traffic generated by World Wide Web traffic shows self-similar characteristics. Comparing the distributions of ON and OFF times, they found that the ON time distribution was heavier-tailed than the OFF time distribution. The distribution of file sizes in the Web might be the primary determiner of Web traffic self-similarity.

Research done by [VPSF95], showed that in FTP data sessions have burstier arrival rates, and number of bytes in each burst has a heavy upper tail.

[WTSW97] showed that a Pareto heavy-tailed distribution reflects the actual behavior of an individual Ethernet source.

This study evaluates the performance of two switches that are separated on the placement of buffers (or queue). One of the designs proposes the buffer at input port and the other one also proposes at input port but the number of buffers depends on output port. Section 4 and 5 show the two architectures.

4. Input Queuing

In this type of queuing architecture, a separate buffer is placed on each input port of the switch. The input buffers operate in a First in First out (FIFO) fashion. This design however may lead to head-of-line (HOL) blocking. When 'n' cells at the heads of the queue compete for the same output, only one is allowed to pass through, and 'n-1' cells must wait for the next cycle. In the meantime, while one of the 'n-1' cells wait for its turn to get to the busy destination, other cells are queued in the FIFO, and blocked from reaching possibly idle output ports in the switch. In order to overcome HOL blocking, a solution of Virtual Output Queuing is proposed.

The model of input queue is made on the assumption that packet arrivals on the input will be independent and identical Bernoulli processes. Suppose that the probability that a packet will arrive on a particular input is p, then the probability of each packet handled by corresponding output is 1 /N. If several packets addressed to the same output port at a single time slot then one of the packet will be selected randomly.
5. Virtual Output Queuing

VOQ is implemented in switches by maintaining a dedicated FIFO at each input for each destination. Since the buffer is according to destination, one frame cannot be blocked by another frame for a different destination, hence eliminating HOL blocking completely.

The model of VOQ consists of a switch with 2 inputs and 2 outputs. The arrival process is assumed to be stationary and ergodic. The set of all arrival processes is considered “Admissible” if no input or output is oversubscribed otherwise it is “Inadmissible”. An edge joining non-empty input queues with the destined output queues makes a bipartite graph.

The FIFO queues are served with scheduling algorithms that selects a match/matching M between the input and outputs by solving the graph. There are two types of matching algorithms available.

- Maximum Size Matching Algorithm (finds the match containing the maximum number of edges/packet-transfer).
- Maximum Weight Matching Algorithm (finds the maximum weight, consider only integer-valued weights equaling the occupancy of each queue).

We are using maximum size matching algorithm in our simulation. In this algorithm, packets are addressed in a fashion to serve as many queues as possible.

6. Network Simulator

The traces of network traffic are generated on NS 2. Network Simulator (NS 2) is an object-oriented, discrete event driven network simulator. It is useful in the simulation of networks based on LAN and WAN by using protocols such as TCP and UDP. The traffic source behavior can be based on FTP, Telnet, Web, CBR and VBR. The scheduling algorithms for queue in NS are Drop Tail, RED and CBQ. NS also implements multicasting and some of the MAC layer protocols for LAN simulations.

7. Simulation Model

The evaluations of input and virtual output queuing are made on the same model as used in [MKMG87] and [NMJW], for both Poisson and Self-Similar traffic. The main difference is in probability distribution for inter arrival times. For Poisson distribution we generated traffic with “Exponential ON/OFF” distribution, and for self-similar traffic (heavy-tailed) we used Pareto ON/OFF distribution.

The simulation model consists of following assumptions.

\(2 \times 2\) Non-Blocking Switches

We took the case of only non-blocking switch having 2 x 2 input-output ports that allows establishment of connection at any time between any pair of idle input-output ports. Crossbar switch is an example, with \(N^2\) inter-connections of switch fabric.
**Fixed-Length Packet**

Switch operates synchronously with fixed-length packets.

**Packet Scheduling**

During any time slot, packet may arrive at any input port which will then be destined to any output port. As we are maintaining queues at the input ports, switch fabric will operate at the same speed as the input/output ports. During each time slot only one packet may be accepted for any given output and remaining packets will be queued at the input queue.

8. **Implementation**

The project requires the simulation on two traffic generators: Poisson and Pareto (Self Similar) distribution. In simulating both traffic distribution on VOQ and input queued switch we used a single 2 x 2 switch having the bandwidth of 10 Mb and delay of 10 ms. The scheduling policy for queue is Drop-Tail. Traffic source is UDP. The UDP sources are connected wi

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Traffic</th>
<th>Packet Size (Bytes)</th>
<th>Burst Time (ms)</th>
<th>Idle Time (ms)</th>
<th>Rate (bps)</th>
<th>Shape</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson</td>
<td>1000</td>
<td>0</td>
<td>0</td>
<td>1000000M</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Pareto</td>
<td>200</td>
<td>50</td>
<td>50</td>
<td>164 K</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>

9. **Results**

This section shows various results we got after performing simulations. It first shows the result generated on input queue and then the results of VOQ on both distributions. Section 9.1 and 9.2 give the results of Poisson and Self Similar traffic on Input queue. Section 9.3 and 9.4 give the result of both traffic on VOQ.

9.1. **Input Queue (Poisson Distribution)**

The traffic pattern used here is created by Poisson generator. The queue packet drop policy is Drop-Tail. Table 1 shows the total number of packets dropped at various queue sizes. At link bandwidth of 10 Mbps and the delay of 10 ms, the arrival rate of each packet of size 1000 byte is 0.0008s. The data is taken at buffer sizes 1, 2 and 5.
Table 1: Total number of packets dropped at various queue sizes

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Queue</th>
<th>Queue Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0008</td>
<td>Q1</td>
<td>(60007)</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>(59939)</td>
</tr>
</tbody>
</table>

Table 2 shows the throughput of N x N input queued switch when N = 2. The buffer sizes at which data is taken are 1, 2 and 5. It shows that at buffer size of 5, and link bandwidth is 10 Mbps with the delay of 10ms the throughput is approximately 99.99%.

<table>
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<td>(60007)</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>(59939)</td>
</tr>
</tbody>
</table>

Table 2: Throughput of 2 x 2 input queued switch at various queue sizes

Mean waiting time of the packet is the time packet waits in switch. Figure 1 shows the time when queue size is 5. For both the queues of 2 x 2 switch mean waiting time is 0.0016.

Figure 1 Graph of Waiting Time Utilization

9.2 Input Queue (Pareto Distribution)

Table 3 shows the dropping of packets at time interval 0.0008s. It shows that all the packets generated are served and no packets are dropped.

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Queue</th>
<th>Queue Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0008</td>
<td>Q1</td>
<td>(10258)</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>(9769)</td>
</tr>
</tbody>
</table>
Therefore, the throughput of switch on self similar traffic is 100%. The link bandwidth and delay are same as used in the study of Poisson traffic. Table 4 shows the simulated results.

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Throughput %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue</td>
<td>Queue Size</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Q1 (10258)</td>
<td>100</td>
</tr>
<tr>
<td>Q2 (9769)</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 4: Throughput of switch at various queue sizes

Performance of mean waiting time utilization of input queued switch is shown in figure 4. The simulations show that for both the queues of 2 x 2 switch mean waiting time is 0.073.

9.3 **Virtual Output Queue (Poisson Distribution)**

This result is obtained on VOQueued switch. The queue packet drop policy is Drop-Tail as used in Input queue. Table 5 shows the total number of packets dropped at various queue sizes. At link bandwidth of 10 Mbps and the delay of 10 ms, the arrival rate of each packet of size 1000 byte is 0.0008s. The data is taken at buffer sizes 1, 2 and 5.
Table 5 Total number of packets dropped at various queue sizes

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Queue</th>
<th>1</th>
<th>2</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0008</td>
<td>Q1</td>
<td>5</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>6</td>
<td>5</td>
<td>2</td>
</tr>
</tbody>
</table>

Table 6 shows the throughput of N x N input queued switch when N = 2. The buffer sizes are 1, 2 and 5. It shows that at link bandwidth, 10 Mbps and the delay of 10ms, the throughput is approximately 99.99%.

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Queue</th>
<th>Throughput</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0008</td>
<td>Q1</td>
<td>0.999916676</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>0.999899898</td>
</tr>
</tbody>
</table>

Table 6 Throughput of 2 x 2 input queued switch at various queue sizes

Mean waiting time of the packet is the time packet waits in switch. Figure 2 shows the time when queue size is 5. For both the queues of 2 x 2 switch mean waiting time is 0.0016.

9.3. Virtual Output Queue (Pareto Distribution)

Table 7 shows the dropping of packets at time interval 0.0008s. It shows that all the packets generated are served and no packets are dropped.
Table 7: Packets dropped at various queue sizes having self similar distribution

Therefore, the throughput of switch on self similar traffic is 100%. Table 4 shows the simulated results.

Table 8: Throughput of switch at various queue sizes

<table>
<thead>
<tr>
<th>Time Slot</th>
<th>Throughput %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Queue</td>
<td>Queue Size 1</td>
</tr>
<tr>
<td>Q1</td>
<td>100</td>
</tr>
<tr>
<td>Q2</td>
<td>100</td>
</tr>
</tbody>
</table>

Performance of mean waiting time utilization of input queued switch is shown in figure 4. Our simulations show that for both the queues of 2 x 2 switch mean waiting time is 0.067.

Figure 4: Mean Waiting Time Utilization

The results shown here are based on simulations performed on NS 2. Improvements are still needed to improve the results.

10. Conclusion

Self Similarity is a phenomenon that displays structural similarities across a wide range of timescales. We covered this issue in great detail and studied this pattern on a 2 x 2 switch. The results on Poisson traffic are however different to the works of Hluchyj for input queue [MKMG 87] and McKeown for VOQ [NMJW].
The results on self similar traffic show that no packet has been dropped. The input queue results show that throughput of traffic based on Poisson distribution is 99%, whereas on Self Similar traffic, it is 100%. The mean waiting time of packet in both queuing techniques on Poisson traffic is 0.0016. However, in self similar traffic, input queue performs at 0.073 and VOQ performs at 0.067.

More efforts are still required to study this behavior. This research is done using 2 x 2 switch. For good and reliable results, the study should be carried out on N x N switch, where N is a very large number.

11. References


[NMJW] Nick McKeown and Jean Walrand, “Achieving 100% Throughput in Input Queued Switch”.


6. Appendix

Independent Process/Random Variable

When the probability of occurring one event is independent of the occurrence of other event then these event are know as independent events.
**Bernoulli Random Variable/Processes**

A R.V or process is known to be a “Bernoulli” if there are only two possible outcomes either success or failure. We can also represent these values as 0/1 or ON/OFF.

**Stochastic Process**

Stochastic process is a random variable that is a function of time.

**Stationary Stochastic Process**

In which probability characteristics of process do not vary as a function of time. Here, the expected value is a constant and its autocorrelation function depends only on the time difference.

**Ergodic Process**

Stationary stochastic process is called ergodic if its

Time average = ensemble average

Because \( E[X(t)] \) is constant for stationary process

\[ E[M_t] = E[X(t)] = \mu \]

For a ergodic process

\[ \lim_{T \to 0} \text{Var}[M_t] = 0; \]

**Ensemble averages of SP**

In random variable set of all possible outcomes is called ensemble and have mean and variance for this called ensemble averages.

**Time averages**

We consider only a single outcome of \( X(t) \), random variable of expected values.