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# Queueing Models Performance Analysis in Optical Switching Network Nodes

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**Abstract-** In optical switching networks, queueing models are often used for modeling, analyzing, and evaluating the performance of switching nodes. These models determine the number of optical packets in the switch and how quickly the switch can serve the traffic. This paper examines the numerical performance of optical switching nodes under various queueing models and simulates a modeling system using the OPNET modeler simulation tool. The study estimates the expected average number of optical packets, the probability of packet loss, and the waiting delay time in an optical switch under different loads and wavelength channels.

## I. Introduction

At the optical network, optical information traffic with a given capacity is formed at the optical node as a queue with specific traffic arrival and service time distributions. The queue in the network nodes is designed according to different network technologies and principles [1, 2]. The queueing model is a statistical representation of a network node that represents the actual configuration of the node, specifying the number of optical packets in a switch and how fast that switch can serve packet-optical traffic [3]. Optical packets at an optical switching network arrive at a switching node with random intervals and are served for an unpredictable amount of time. If the wavelength channel is already occupied, the arrival packets will be held in a queueing buffer before being served. The queueing model determines the distribution of the number of packets in the system and their waiting time.

There are multiple application aspects to queueing models used in optical switching networks. Optical switching networks use queueing models for different applications. For instance, in [4], queueing models with optical delay lines in optical packet switching networks are studied. In [5], the queueing at the edge OBS node is modeled. An analytical model for optical delay line buffers in OBS networks using queueing theory is developed in [6]. Additionally, in [7], a burst rate-based dynamic IO Queue management scheme is presented. To analyze the performance of the OBS node, a proposed queue model is introduced and applied as a generalized Markovian node model in [8].

This paper analyzes the performance of optical switching network nodes using different queueing models. It confirms that the number of wavelength channels and traffic loads affect the parameters of the queueing models and the blocking probability. The behavior of the optical switching nodes is evaluated through numerical and simulation analysis of queueing delay and queueing size.

For this, our work first in section 2 presents an overview of some specific queueing models that can be used in optical switching networks. The queueing models' numerical analysis

is obtained in section 3. The work on OPNET modeler simulator for the queueing models is formulated in section 4. Finally, conclude in section 5.

## II. QUEUEING MODELS IN OPTICAL SWITCHES

At the optical switches, the arriving optical information traffic request some specific amount of resources such as; circuit, bandwidth, wavelength channel, etc. to be served. The most common queueing models assume that the optical information traffic inter-arrival and service times follow the exponential distribution or equivalently follow a Poisson distribution process with Markovian or memoryless properties [9]. A commonly used shorthand notation, called Kendall's notation [10], for such queue models describes the arrival process, service distribution, the number of servers and the buffer size (waiting line). The complete notation expressed as (a/b/c/d) where, *Arrival process/service distribution/ number of servers/waiting line*.

In optical switching networks the commonly used characters for the first two positions in the shorthand notations are M (Markovian – Poisson for the arrival or Exponential for the service time). The third positions used for the number of the output optical wavelength channels  $w$ . The fourth position indicates the switch queueing size  $k$  and it's usually not used in infinity waiting room buffers.

There are single server queueing models such as M/M/1 and M/M/1/ $w$ , and multiple server's systems such as M/M/ $w$ , M/M/ $w/k$ , and M/M/ $w/w$  systems [11]. There is an infinite queue system such as M/M/ $w$ , where the optical traffic arrivals are hold waiting for service and not affected by the number of packets already on the queue because there is unlimited buffer size. Also, there is a finite queue system such as M/M/ $w/k$ , which has a limited buffer capacity. In finite queue the optical arrivals that attempt to enter the full occupied system are denied entry or blocked.

## III. QUEUEING MODELS NUMERICAL ANALYSIS

In this section, a numerical performance analysis of different queueing models in the optical switching node are represented. This analysis study aimed to determine the suitable queueing model for enhancement of an optical switch performance. In which, queueing model has low loss probability, which one is faster and has lesser number of optical packets in the optical switch system serviced and waiting for service. A comparative numerical study of different queueing models is discussed taking in consideration the effect of the number of optical switch wavelength channels. In this analysis the queueing models M/M/1, M/M/ $w$ ,

M/M/1/ $k$ , M/M/ $w/k$ , and M/M/ $w/w$  are used at suitable average arrival rate  $\lambda$  packet/time unit and average service rate  $\mu$  packets/time unit values.

The performance parameters that measured are:

- The average number of optical packets resident in the system  $L_s$  packets.
- The average number of optical packets waiting in the queue  $L_q$  packets.
- The average time of optical packets spend in the system (the average response time)  $W_s$  time unit.
- The average time of optical packets waiting in the queue (the average waiting time to serviced)  $W_q$  time unit.
- The blocking probability of optical packets  $P_B$  (at finite queueing models).

The values of respective parameters for each of the models were computed using the queueing model equations at [12] and tabulated as represented in Table I. For simplicity, assume that the average arrival rate  $\lambda = 2$  packets/time unit, the average service rate  $\mu = 3$  packets/time unit, and the corresponding queueing models are M/M/1, M/M/2, M/M/1/16, M/M/3/16, and M/M/16/16.

TABLE I  
QUEUEING MODELS NUMERICAL ANALYSIS – COMPARATIVE STUDY

Queue model	$L_q$ packets	$W_q$ Time unit	$L_s$ packets	$W_s$ Time unit	$P_B$
M/M/1	1.333	0.667	2	1	0
M/M/2	0.083	0.042	0.75	0.375	0
M/M/1/16	1.316	0.658	1.983	0.992	$6.88 \times 10^{-5}$
M/M/3/16	0.009	0.005	0.676	0.338	$1.85 \times 10^{-4}$
M/M/16/16	0	0	0.667	0.333	$1.7 \times 10^{-2}$

From the parameter values represented in Table I, it is clear that finite queueing faster and has lower average number of waiting packets in the optical system than infinite one, M/M/1/16 versus M/M/1. However, the M/M/1 queue has not loss probability due to infinite buffer capacity while M/M/1/16 has loss probability equal to  $6.88 \times 10^{-5}$ . Also it can be observed that the waiting time and the number of packets in the system (optical switch) are lowered as increasing the number of wavelength channels, M/M/1 against M/M/2 and M/M/1/16 against M/M/3/16 and M/M/16/16. At finite models, as wavelength channels increased at a fixed switch queueing size  $k = 16$ , the switch capacity ( $k - w$ ) decreases until it reaches to zero at M/M/16/16. Consequently, the blocking probability increased as the number of wavelengths increased with constant queueing size. A multi-server (multiple-wavelengths) finite queueing model M/M/16/16 has a lower average number of packets resident in the system  $L_s$  and lower average switch queueing delay  $W_s$ . However, it has more packet loss probability due to no buffer in the system, thus the waiting time in the queue  $W_q$  is zero and the time spent in the system is the service time  $1/\mu = 1/3$  time unit.

In general we can observe that the waiting time and the

number of packets in the switch are lowered as increasing the number of wavelength channels M/M/1 versus M/M/2 and M/M/1/16 against M/M/3/16. The finite queueing M/M/1/16 has good performance than infinite one M/M/1.

The following graphs Fig. 1 to 4 confirm these notes. These figures represent the average waiting time in the buffer  $W_q$ , the average waiting time in the system  $W_s$ , the average number of packets in the system  $L_s$  and the switch blocking probability  $P_B$ , respectively, versus the traffic load  $\rho$  (utilization factor) at the corresponding queueing models.

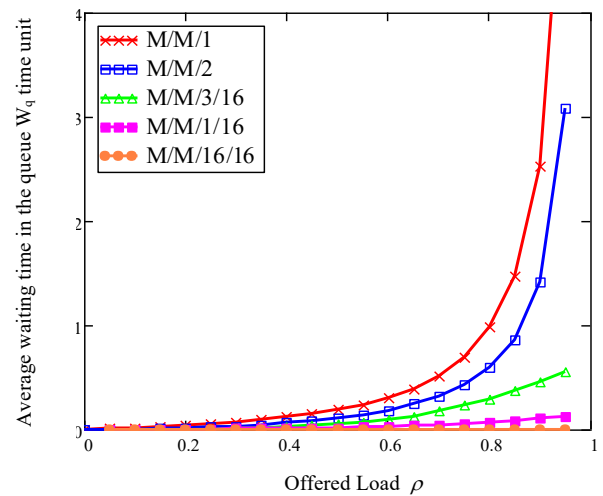


Fig. 1. Average waiting time in the queue vs. the offered load at different queueing models and service time  $1/\mu = 0.333$  time unit.

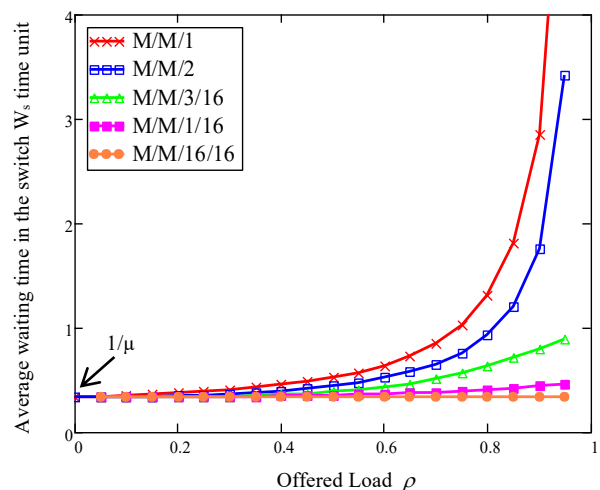


Fig. 2. Average waiting time in the system vs. the offered load at different queueing models and service time  $1/\mu = 0.333$  time unit.

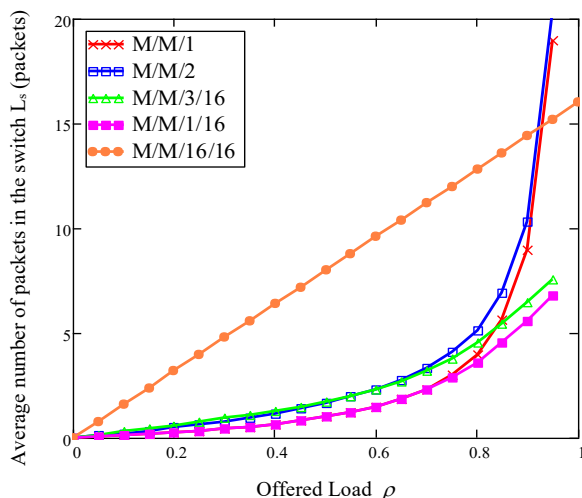


Fig. 3. Average number of packets in the system vs. the offered load at different queuing models and service time  $1/\mu = 0.333$  time unit.

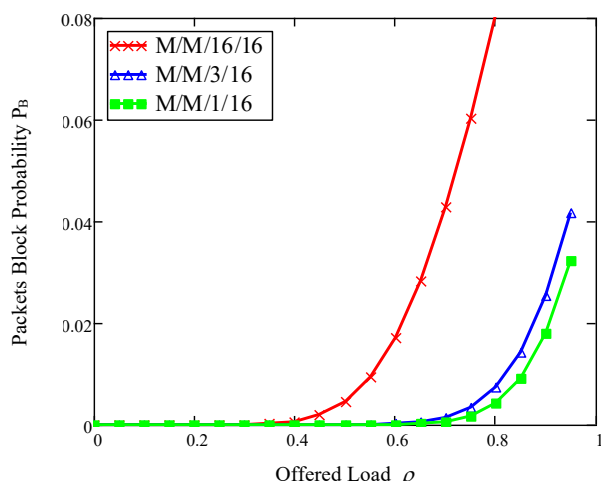


Fig. 4. Packets Block Probability  $P_B$  vs. the offered load at different queuing models and service time  $1/\mu = 0.333$  time unit.

The average time the packet spend in the switch is the average time waiting to serviced and the service time,  $W_s = W_q + 1/\mu$ . At low traffic, there is no packets waiting in the buffer,  $W_q = 0$ , Fig.1, where the traffic packets are serviced immediately. Therefore, the average waiting time in the system  $W_s$  depends only on the service time  $1/\mu$ , Fig.2. As the number of wavelength channels increased the expected number of packets in the system  $L_s$  increased where more packets are serviced, Fig.3. At high traffic values,  $\rho > 0.6$ , the waiting time in the queue  $W_q$  increased as offered load increased, depending on the queue model, and hence  $W_s$  is increased dependently. At M/M/1 and M/M/2 queues, the mean waiting time increased greatly that is due to the infinite buffer size. While at M/M/1/16 and M/M/3/16 queues, the mean waiting time in the system only has a slight increment. At M/M/16/16 queue, the mean waiting time in the system is fixed,  $1/\mu$  time unit, as no

queuing buffer exist. It is a loss system, there is no buffer  $W_q = 0$ , so  $W_s = 1/\mu$  and that is any traffic arrive over the wavelength number ( $w = 16$ ) the packets are blocked.

Also, the average number of packets in the system  $L_s$  increased significantly at infinite queues due to unlimited queue size. It is clear in Fig.4 that the blocking probability  $P_B$  increased as increasing in the offered load. The blocking probability begins early and has higher value as the switch capacity ( $k - w$ ) decreases.

Consequently, it is observed that as the number of wavelength channels increase, the system will be faster and has lower number of packets waiting for serving. While the loss probability is increased.

#### IV. QUEUEING MODELS SIMULATION ANALYSIS

A simulation tool is performed to analyze the queuing modeling systems using an OPNET modeler simulation tool [13].

The performance of a queuing system depends on the following parameters:

- Packet arrival rate  $\lambda$ .
- Packet size (service requirement)  $1/\mu$ .
- Service capacity  $m$ .

Thus, the queue simulation model requires a means of generating, queuing, and serving packets, all of which can be done with existing node modules provided in the Node Editor. A queueing node Model is illustrated at Fig. 5, the main model objects in the Node Editor are one **queue** and two **processors**. The **source module** generates packets and the **sink module** is used to dispose of the packets generated by the source. The **queue** represents the buffer and the server. **Packet streams** are used to connect each of the modules in the Node Editor.



Fig. 5. The queueing system simulation node model

Some source and queue attributes are declared in Figs. 6 and 7 respectively.

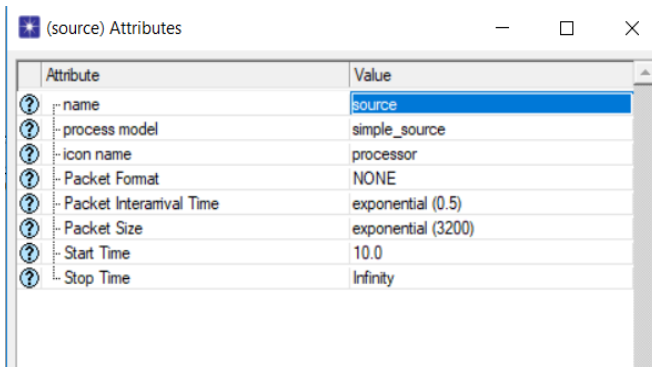


Fig. 6. The queueing system source attributes

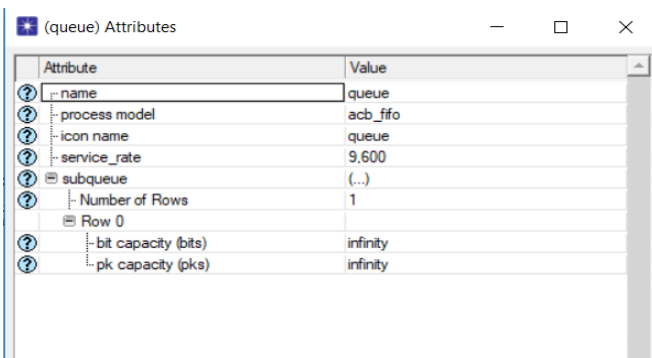


Fig.7. The queueing system queue attributes for M/M/1

The source attributes doesn't change from one queueing model to another, while the queue model can be changed as the following table, Table II, according to the queue model type. (i.e. **acb\_fifo** in OPNET process model is active, concentrating, bit-oriented first-in first-out queueing process model. While **acb\_fifo\_ms** is active, concentrating, bit-oriented, multi-server first-in first-out queueing process model.)

TABLE II  
SOME QUEUE MODEL ATTRIBUTES

Queue Model	Process model	<i>m</i> capacity (packets)
M/M/1	acb_fifo	infinity
M/M/2	acb_fifo_ms	infinity
M/M/1/16	acb_fifo	16
M/M/3/16	acb_fifo_ms	16
M/M/16/16	acb_fifo_ms	16

The statistics that should be calculated are,  
 - The average packet delay time in the switch (queue delay, in seconds)  $W_s$ .  
 - The average packets number that are in the switch (queue size, in packets)  $L_s$ .

Using the same queueing parameters, the average arrival rate  $\lambda = 2$  packets/s and the average service rate  $\mu = 3$  packets/s at the corresponding queueing models M/M/1, M/M/2, M/M/1/16, M/M/3/16 and M/M/16/16, the results of the simulation project have expected values as obtained from the analytical analysis, Table I, which is in accord with each other. Figure 8 represents the simulation results of the queue delay in the system for the different queueing models at the time during the traffic sent in bytes. It is clear that the M/M/16/16 queueing model has the minimum queueing delay (approximately 0.333 sec.). Figure 9 represents the simulation results of the queue size in the system for the different queueing models at the time during the traffic sent in bytes. The M/M/16/16 queueing model has the minimum queueing size (approximately 0.667 packets).

That indicates that the M/M/*w*/*w* queueing model has better performance values that can be modeled well at optical switching nodes.

The large change early in the simulation reflects the sensitivity of averages to the relatively small number of samples collected. Towards the end of the simulation, the average stabilizes.

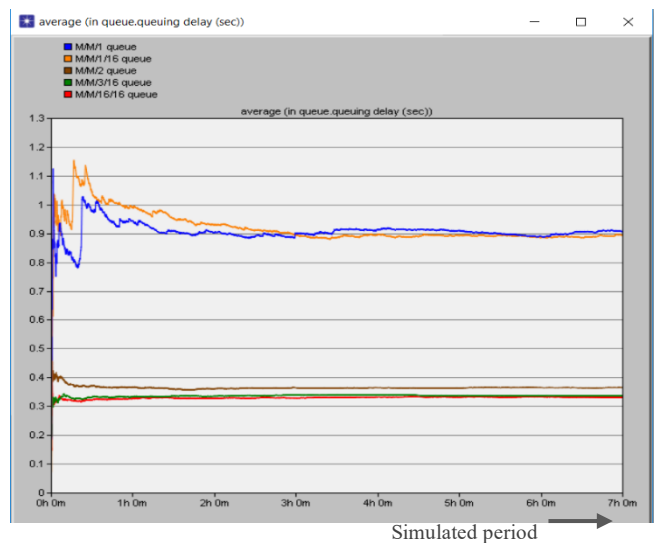


Fig. 8. The average queueing delay simulation results



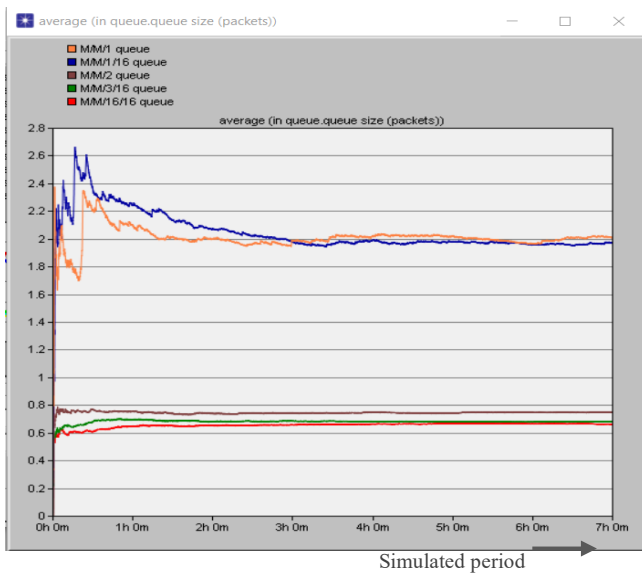


Fig. 9. The average queuing size simulation results

### Conclusions

Optical switching network node performance analysis is done with different queuing models. Using finite, infinite, single-server and multi-server queuing models to indicate which model is more suitable at optical switch design. Queue delay time, expected number of packets and blocking probability are the main parameters in numerical and simulation analysis to demonstrate the optical switch performance. Number of wavelength channels impact is studied at different queuing models and at suitable arrival and service rate values. The simulation results are accorded with the analytical analysis. The results show that, finite queuing M/M/w/k is faster and has lower expected waiting packets in the switch than infinite queue M/M/w. However, the finite queuing have loss probability. As the number of wavelength channels increase, the system is faster and has low waiting time in the switch. At M/M/w/w queue system, it is faster and has less waiting packets in the switch, while it has high blocking probability due to no queue buffer. Also as the number of wavelength channels increases, the blocking probability decreases due to that the incoming traffic has a more chance to serviced. Therefore, using M/M/w/w queuing system can be modeled well at optical switching nodes under a certain predefined number of wavelengths to lower the blocking probability problem.

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