International Journal of Scientific Research in Computer Science, Engineering and Information Technology
© 2019 IJSRCSEIT | Volume 5 | Issue 1 | ISSN : 2456-3307
DOI : https://doi.org/10.32628/CSEIT195128

Finite/Infinite Queueing Models Performance Analysis in Optical Switching Network Nodes

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ABSTRACT

In optical switching networks, optical information (packets/bursts) that are forwarded from an optical switch to another through the network could entering a queue of a certain length in each node and may be waiting inside this node before it will be transmitted to the next node. Various queueing models have been widely applied as the main tool in optical switching networks for modeling and performance evaluation analysis of the switching nodes. In this paper, studying the performance analysis of an optical switching node is discussed at Finite and Infinite queueing models to have the optimum queueing model for optical core node switch design. The waiting delay time, the average expected number of optical packets and the loss probability of packets in the optical switch are estimated at variable traffic loads and different wavelength channels.

Keywords : Queueing Models, Optical Switching Network, Finite Queue, Infinite Queue, Blocking Probability

I. INTRODUCTION

An optical information traffic access to the network with a given capacity is modeled in optical nodes as a queue with a certain distribution of traffic arrival times and a certain distribution of traffic service time.

Queueing in the network nodes are modeled in a variety of network techniques and principles [1, 2]. The Queueing model is a theoretical aspect of such the network node [3]. Typically, a queueing model represents the network node physical configuration by determining the number of optical packets in the switch and how fast that switch serves the optical packet traffic. Also, the queueing models give a statistical nature of the optical switch node, by specifying the variability in the arrival process to the switch and in the switch service process. In an optical switching, optical packets arrive at a system (switch) as random intervals and are served during a random time. In the switch if the wavelength channel is busy serving other packets, the arrivals are queued in the switch queueing buffer. Therefore, the model can determine the distribution of the number of packets in the system and their waiting time.

Queueing models in the optical switching networks have various application aspects. Queueing models with optical delay lines in optical packet switching networks are studied in [4]. The edge OBS node queueing is modelled in [5]. An analytical model optical delay line buffers in OBS networks using queueing theory are developed in [6].

In this paper, study the performance analysis of the optical switching network node is performed at different queueing models. Validating that the various queueing model parameters and the blocking probability are affected by the wavelength channels number and traffic loads.

For this, our work first presents some specific queueing models overview that can be used in optical switching networks, at section 2. The infinite and finite queueing models' numerical analysis is obtained in section 3. Finally, conclude in section 4.

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 [7]. A commonly used shorthand notation, called Kendall's notation [8], 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 m 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/m, and M/M/w/w systems [9]. 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. In addition, there is a finite queue system such as M/M/w/m, 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.

Table 1 represents the main differences between Finite and Infinite queueing models.

TABLE I

FINITE VS. INFINITE QUEUEING MODELS

Finite Queueing Model	Infinite Queueing Model
M/M/w/m	M/M/w
The arrival rate depends on the number of served and waiting packets in the system.	The arrival rate is not affected by the number of packets being served and waiting.
Limited buffer capacity.	Unlimited buffer capacity.
Faster and has lower average number of waiting packets in the system.	Packets waiting long times in the buffer.
There is a packet loss probability.	No packet loss probability.

III. Infinite/Finite Queueing Models Performance Analysis

In this section, a numerical performance analysis of infinite and finite queueing models in the optical switching node are represented. This analysis study aimed to determine the suitable queuing model for enhancement of an optical switch performance, 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. In our analysis taking in consideration the effect of the number of optical switch wavelength channels w whether at Infinite model M/M/w or Finite one M/M/w/m. The queueing models are used at suitable average arrival rate ρ

packet/sec and average service rate μ packets/sec 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 switch queueing delay time) W_s sec.
- The average time of optical packets waiting in the queue (the average waiting time to serviced) W_q sec.
- The blocking probability of optical packets P_B (at finite queueing models).

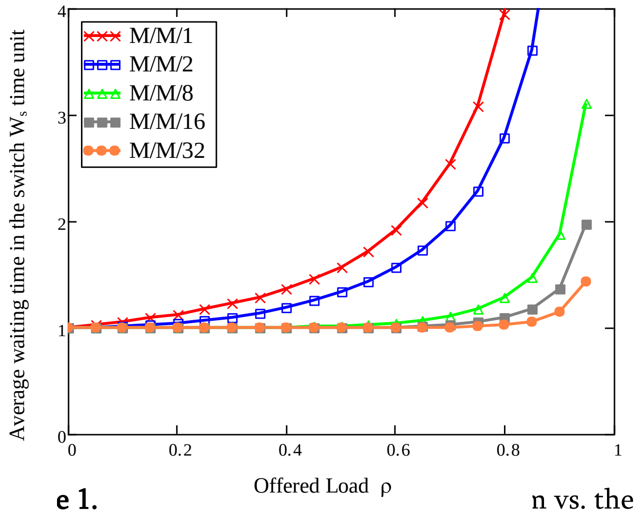
In this analysis, the waiting time in the system W_s established at two different cases [10]. First, if it is considered that the service rate per channel is constant $\mu = 1$ packet/sec, which gives $\rho = \lambda/w$. Later, the total service rate in the switch is kept constant $w\mu = 1$, which gives $\rho = \lambda$ becomes independent on w. At Infinite model we will study the influence of the wavelength channel numbers at the different two analysis cases. At Finite model the effect of the switch queueing size and the number of wavelength channels are illustrated on the optical switch performance taking in consideration the second analysis case.

A. Infinite Queueing Models

With infinite queuing systems M/M/w, where w is the number of servers or optical wavelength channels, the queue buffer size is infinite. The system filling L_s and the waiting times W_q and W_s, in the queue and the optical switch respectively, establish the main optical switch characteristics.

In figures from 1 to 4, the optical switch performance is studied at an infinite queueing models. W_s, W_q and L_s parameters are represented at different number of wavelengths (servers), $w = 1, 2, 8, 16, 32$. In Fig. 1, the service rate per channel is constant $\mu = 1$ packet/time unit. While at figures 2 to 4, the entire switching capacity $w\mu$ is kept constant by $\mu = 1/w$ packets/time unit, which gives $\rho = \lambda$ becomes independent on w.

From Fig. 1 it is clear that for a lower offered load, the mean time in the system is very low and equal to $1/\mu = 1$ time unit. As the load increases, in the M/M/1 queue, the mean total time in the optical switch increases greatly and increased slightly as the number of wavelengths w increased. At the M/M/32 queue, the mean total time in the system only has a slightly increment. Therefore, as the number of wavelengths increased the queue has a superior performance than M/M/1 queue.



e 1. n vs. the offered load of M/M/w with different number of wavelength channels and $\mu = 1$ packet/time unit per channel

If the switching capacity is constant, figures 2 to 4 are illustrated. Obviously, at low loads, less than 80% load or $\rho < 0.8$, the Waiting time in the optical switch (mean flow time), $W_s = W_q + 1/\mu$, shown is ruled by the increased holding time, $1/\mu = w$, which results from decreasing the service rate for increased wavelength numbers w in order to keep the switching capacity constant.

At high loads the mean time in the optical switch increases significantly because the waiting time in the queue component W_q becomes dominant. This increase in queueing waiting time also causes the increase in the system filling (Number of packets in the system) L_s shown in Fig. 3. However, this only results from the longer serving interval required per server and not from an increase in the mean waiting queueing time W_q. Figure 4 shows the mean waiting time in the switch queue W_q. It is decreased dramatically with increasing wavelength numbers w, and the service rate per channel be slower. So, in this case, it is clear that a single wavelength queueing model is preferred over a multi-wavelength model because it has less average number of packets resident in the system and lower mean time in the system.

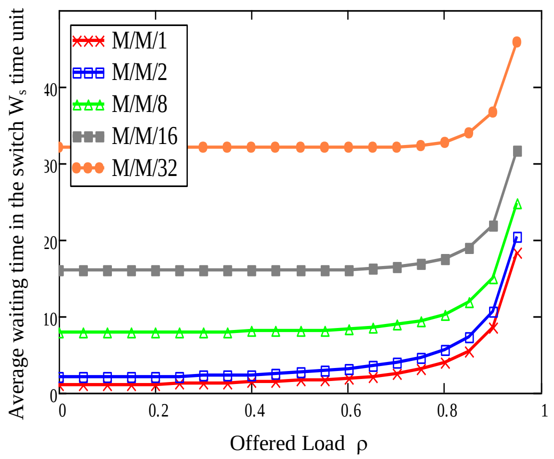


Figure 2. Average waiting time in the system vs. the offered load of M/M/w with different number of wavelength channels and normalized to equal system load $\rho = \lambda$ by setting $\mu = 1/w$ packet/time unit per channel

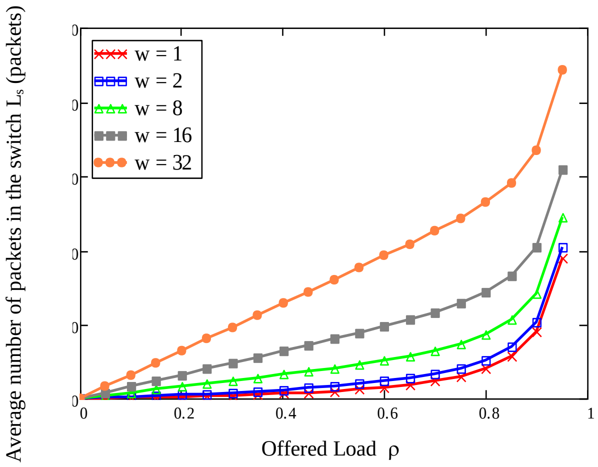


Figure 3. Average number of packets in the system vs. the offered load of M/M/w with different number of wavelength channels and normalized to equal system load $\rho = \lambda$ by setting $\mu = 1/w$ packet/time unit

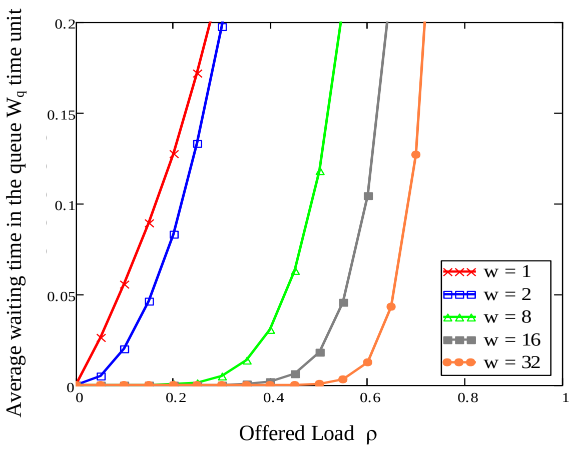


Figure 4. Average waiting time in the queue vs. the offered load of M/M/w with different number of wavelength channels and normalized to equal system load $\rho = \lambda$ by setting $\mu = 1/w$ packet/time unit

In a realistic view, if we consider that the switching capacity is constant, the best service is provided for the lower number of wavelengths possible. While, if the service rate per channel is constant, increasing a system wavelength channels is preferred.

Consequently, if the costs of using more wavelengths switch less, constant service rate per channel is more preferred choice. However, constant switching capacity is better at lower wavelengths number. An optical switch with an adequately chosen number of wavelengths is the better choice.

B. Finite Queueing Models

In finite queueing model systems M/M/w/m, an arriving optical packet may be admitted to the free wavelength channel immediately. It may be placed in the queue until a wavelength channel is available, or it may be blocked due to all wavelengths are busy and all buffer places are occupied.

Figures from 5 to 8 illustrate how the finite queueing M/M/w/m performance depends on the system size m. These figures show the mean time in the optical switch W_s, the mean waiting time in the switch queue W_q, the mean optical packet number in the switch L_s and the blocking probability P_B all over the increasing system load ρ of M/M/w/m queueing systems. The analysis is using eight wavelengths, w = 8, and the switch buffer size m = (8, 16, 32, 64). Impact of the system size m on the optical switch declared at high traffic loads ρ > 1. As the system buffer size increases, with a constant wavelength number, the more load can be buffered and that may increase the mean optical packets number in the system (switch filling) L_s, Fig. 5. Therefore, it is increasing the waiting time in the queue and in the system W_q and W_s, figures 6 and 7 respectively.

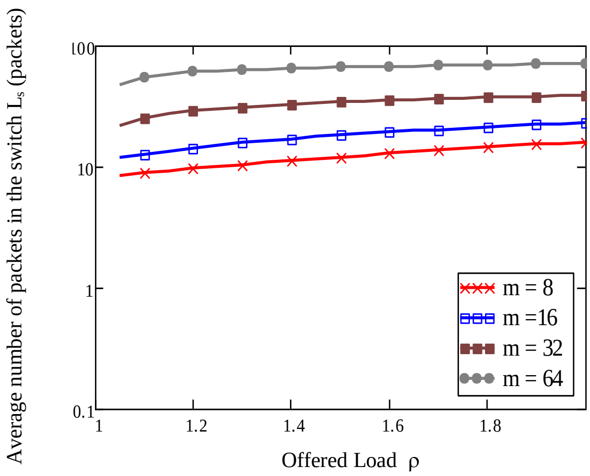


Figure 5. Average number of packets in the system vs. the offered load of M/M/w/m with different switch buffer size m and w = 8 wavelengths

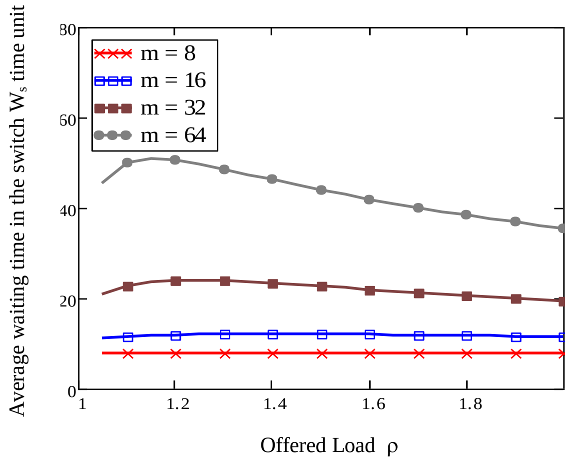


Figure 6. Average waiting time in the switch vs. the offered load of M/M/w/m with different switch buffer size m and w = 8 wavelengths

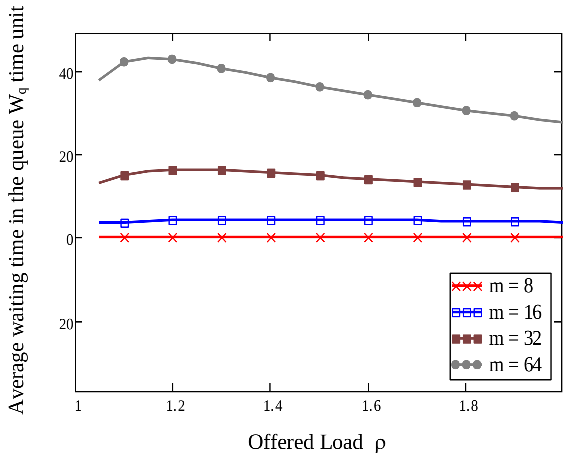


Figure 7. Average waiting time in the queue vs. the offered load of M/M/w/m with different switch buffer size m and w = 8 wavelengths

However, this cause a heavily decreases in the switching blocking probability P_B as in Fig. 8.

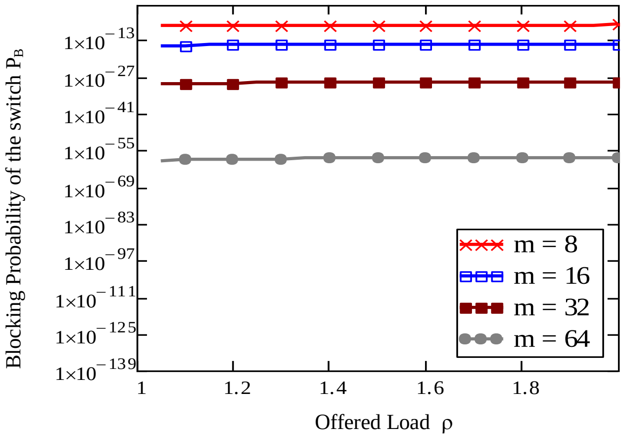


Figure 8. Packets blocking probability P_B in the system vs. the offered load of M/M/*w*/*m* with different switch buffer size *m* and $w = 8$ wavelengths

For the special case $m = w$ at queue model M/M/*w*/*w*, no loads can wait for service, such that no waiting time in the queue, $W_q = 0$. In this case, all loads that cannot be served immediately become blocked, and consequently, these systems are commonly called loss systems.

To study the influence of the number of wavelength channels on the queueing model performance, figures from 9 to 12 show the performance of M/M/*w*/*m* switching system over the number of provided wavelengths *w*. This study at high load $\rho = 2$, at different system size *m* values ($m = 8, 16, 32, 64$), and constant system capacity $w\mu = 1$.

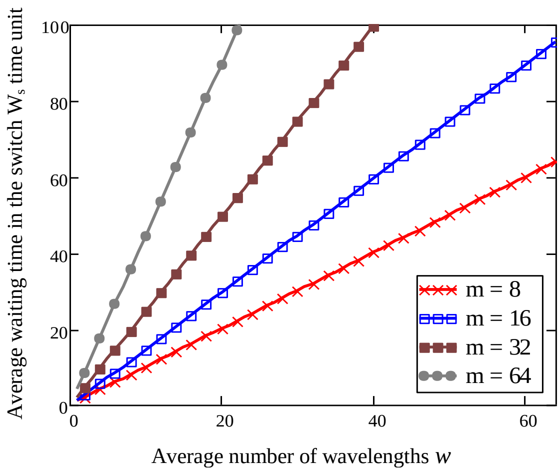


Figure 9. Average waiting time in the switch vs. Average number of wavelengths for M/M/*w*/*m* with different switch buffer size *m* at $\rho = \lambda$

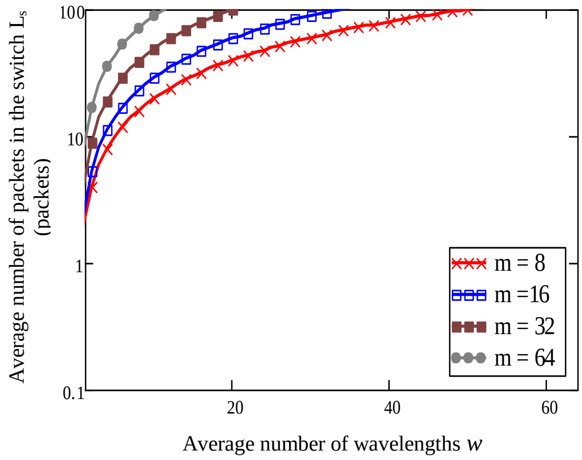


Figure 10. Average number of packets in the switch vs. Average number of wavelengths for M/M/*w*/*m* with different switch buffer size *m* at $\rho = \lambda$

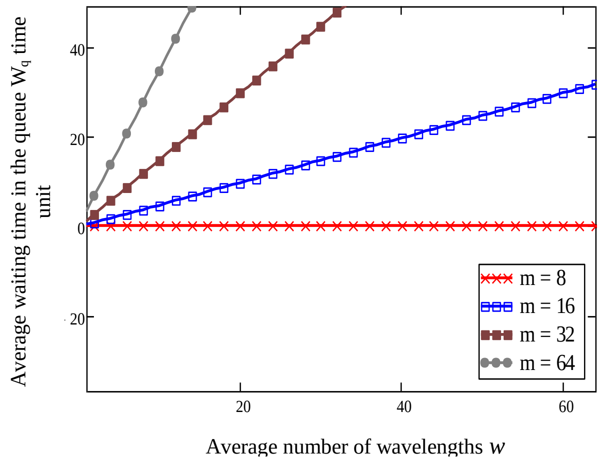


Figure 11. Average waiting time in the queue vs. Average number of wavelengths for M/M/*w*/*m* with different switch buffer size *m* at $\rho = \lambda$

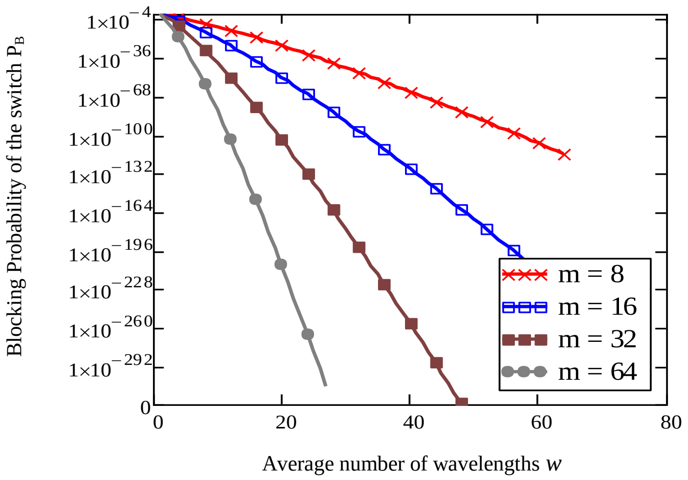


Figure 12. Packets blocking probability P_B in the system vs. average number of wavelengths w of M/M/w/m with different switch buffer size m at $\rho = \lambda$

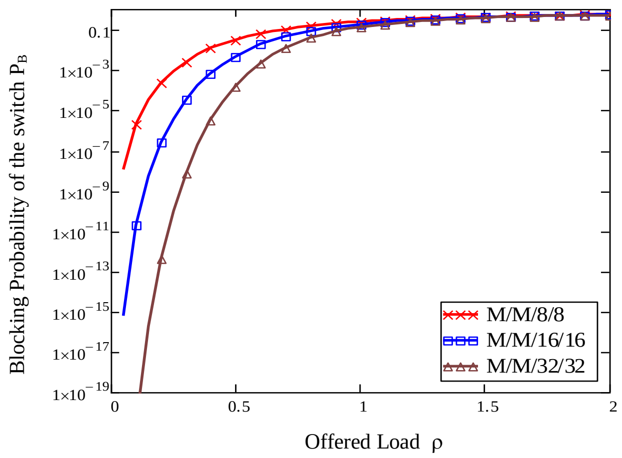


Figure 13. Packet blocking probability P_B in the system vs. the offered load of M/M/w/w at different servers and $\rho = \lambda$

Again, for $m = w$ no waiting space exists, and thus, the waiting time in the queue W_q equal zero in case of M/M/8/8. In addition that the queue M/M/8/8 gives the better performance, less average number of packets and low waiting time in the system. However, the strong reduction of the blocking probability P_B is gained from the implicit queue size increase.

Then, on finite queueing optical switches, the blocking probability decreases at increasing the number of wavelengths (servers).

Finally, Fig. 13 investigates the switch blocking probability P_B for the M/M/w/w model at different number of wavelength channels w = 8, 16, 32. The switch performance illustrated at different traffic loads ρ = 0 to 2.

It is clear that as the load increases, the blocking probability also increases at low traffic and saturated at high traffic. However, as the number of wavelength channels increases, the blocking probability decreases because the incoming traffic has a more chance to be serviced.

IV.CONCLUSION

Optical switching network node performance analysis was done with Finite and Infinite queueing models to indicate the optimum model at optical switch design. Queue delay time, expected number of packets in the system and blocking probability are the main parameters in the analysis to demonstrate the optical switch performance. At Infinite queueing model, two different analysis cases were used to represent the wavelength channel number impact on the optical switch node performance. First analysis was considered a constant service rate per channel which is preferred if the costs of using more wavelengths switch less. However, fixed switching capacity analysis is better at lower wavelength number. For Finite queueing model, impact of the system size on the optical switch declared at high traffic loads. As the system buffer size increases, with a constant wavelength number, the more load can be buffered and that may increase the mean optical packets number in the system. Therefore, it is increasing the waiting time in the queue and in the system. Also, the switching blocking probability P_B is heavily decreases.

As the number of wavelength channels increased with fixed queue buffer size, the blocking probability increased due to the switch buffer capacity lowered until it reaches zero at M/M/w/w queueing system. 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. At this model, 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 queueing system can be modelled well at optical switching nodes under a certain predefined number of wavelengths to lower the blocking probability problem.

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Cite this article as :

Waleed M. Gaballah, "Finite/Infinite Queueing Models Performance Analysis in Optical Switching Network Nodes", International Journal of Scientific Research in Computer Science, Engineering and Information Technology (IJSRCSEIT), ISSN : 2456-3307, Volume 5 Issue 1, pp. 163-170, January-February 2019. Available at doi : https://doi.org/10.32628/CSEIT195128

Journal URL : http://ijsrcseit.com/CSEIT195128