Estimation of Optimal Buffering parameters for dynamic traffic intensity and its Architectures.

Soumya Sen[1] *and V.K.Chaubey* [2]
[1] Student, Electronics and Instrumentation Engineering Department
[2]Assistant Professor, Electrical and Electronics Engineering Department
Birla Institute of Technology and Science, Pilani, Rajasthan 333 031, India.
E-mail: [1]Soumya_sen82@yahoo.com, {[2]f2001484, [3]vkc}@bits-pilani.ac.in

Abstract

In this paper, we have undertaken the mathematical formulation for determining the required buffering time based on the traffic intensity on an all-optical network. The effect of design parameters on optical network containing proper buffer and control circuitry has been evaluated. Some of the buffering architectures have been suggested to provide different buffering times as governed by the diurnal traffic requirements.

1. Introduction

In the present days a lot of research is being devoted towards the development of all optical networks with improved call-connection probability and better customer satisfaction by reducing lost-calls [1-4]. In order to provide better connection facilities, it has thus become imperative to provide buffering at busy nodes in order to prevent the calls from being dropped. Research efforts are being devoted to improve buffering facilities [5-6]. In the present paper we have developed a generic mathematical model for estimation of buffering time and we have integrated the concepts of queuing theory with the network parameters like the local and diurnal traffic requirements, number of wavelengths available at the node, the total number of buffers maintained at each node etc. The buffering based on the Acoustic wave generator structure will be highlighted along with some discussion about other alternative architectures.

2. Mathematical modeling

In a communication network with 'w' wavelengths at any node, let us have (m-w) buffers available to support the buffering of the calls. The call requests arrive with Poisson input with a rate 'λ'. In this network we assume that whenever a call comes at a particular wavelength to a node, the signal will be converted to some other wavelength which is free. If no wavelength is free at that time and a buffering space is available, then it is put into the buffer which provides the time delay corresponding to the calculated mean waiting time in the system and after the given buffering time delay, when a wavelength becomes free, then the buffered signal is converted to this free wavelength and the call proceeds. However, if no buffer space had been empty then the call would have been dropped, but the introduction of buffers will reduce the call drop rate. The model has been developed for all the buffers being 1:1 in nature i.e. it can buffer only one call at a time. This assumption is made since in a DWDM network the wavelength spacing is about 2 nm, hence if two such close wavelengths are buffered on the same link, then they might interact resulting in mixing up of signals. However if the wavelengths of the network had been spaced apart, then many wavelengths can be buffered with one buffer only and the model can be easily adjusted accordingly. The model also assumes that calls arrive at the node with a Poisson distribution and the service time of each wavelength (i.e. the mean call-duration time) has an exponential distribution. Another feature of this system will be that the incoming signals will be serviced or buffered based on first-come-first-serve (FCFS) basis. With these propositions we can model the system as a multiple server model with fixed number of servers (wavelengths) and fixed number of storage spaces (delay loops) and the equivalent Kendall's notation is given by: (M/M/s) : (FCFS/m/∞), with m>s, where s is the total number of servers i.e. the wavelengths (s=w) and (m-s) or 'm-w' is the total number of available buffers at the node. This remains as the basic formulation and we proceed towards the generalized calculation of mean delay time, call dropping probability, cost of set-up required and profit estimates. The mean time delay required for buffering can be statistically determined with preciseness by using standard methods like Monte-Carlo Simulation.

The 'w' servers (wavelengths) have service times, each exponentially distributed with parameter μ. Let ρ= λ/μ, be the ratio factor. The system will always be in steady state because if more than m calls arrive, only 'm' can be entertained (i.e. 'w' calls get connected and 'm-w' calls wait in buffers based on FCFS basis) while the remaining calls are dropped.

First, we discuss the method to evaluate the profit at each node for the stated conditions. The profit calculation involves the inclusion of the terms like revenue, loss from blocked calls, loss from waiting calls and buffer usage cost, all considered on per hour basis. The expression obtained is given below:

Profit (per hour) = Revenue per hour – loss from blocked calls per hour – loss from waiting time of calls per hour – buffer usage (maintenance) cost per hour.

$$\text{Profit}= \lambda(1-P_m).C(\text{call})- \lambda \{\rho^m P_0 /(w!w^{m-w})\}. C(\text{call})- \{\rho^{w+1} /(w!w)\}.\{[1-(m-w+1)(\rho/w)^{m-w}+ (m-w)(\rho/w)^{m-w+1}]/(1-(\rho/w))^2\}P_0C(\text{buff/ hr.}) - (m-w).C(\text{setup or maintenance/hr.}) \quad (1)$$

where P_0=probability of no customer in the system and is given by,

$$P_0=1/[1+ \rho^w \{1- (\rho/w)^{m-w+1}\}/\{w!(1- \rho /w)\}+ \sum_{n=1}^{w-1} \rho^n/n!] \quad (2)$$

for ρ/w not equal to 1.

For ρ/w equal to 1, we have

$$\text{Profit} = \lambda(1-P_m).C(\text{call}) -\lambda \{\rho^m P_0 /(w!\, w^{m-w})\}. C(\text{call})- (w^w/w!)\{(m-w)(m-w+1)/2\}.P_0C(\text{buff}) - (m-w).C(\text{setup/maintenance}) \quad (3)$$

Where,

$$P_0=1/[1+ \{w^w (m-w+1)/w!\}+ \sum_{n=1}^{w-1} \rho^n /n!] \quad (4)$$

We assume that m>w for both the cases and (m-w) are the number of buffers used.
An estimation of the call-blocking probability also needs to be undertaken. This is given by the formula:
Blocking probability at each node is

$$P_m= \rho^m P_0/[w!w^{m-w}]. \quad (5)$$

It must be noted here that the call-blocking probabilities given throughout the discussion are not the blocking probabilities because of unavailability of wavelengths in the links lying ahead which leads to the destination node; rather it is the probability that a call will be blocked at a node due to the wavelengths on the immediate next link being busy and the unavailability of buffering slot at that node. The blocking probability drops as we increase the number of wavelengths.

For a fixed 'w' and 'm', we can also estimate the call-blocking probability against traffic density and thereby make a decision based on those result about the optimal number of buffers and the corresponding call-blocking probabilities.
The profit estimates will be inferred in the forth-coming discussions. The graphs shown below shows the call-blocking probabilities for links with six wavelengths, μ=6 and λ (referred as lam) varying from 19 to 25, for no buffers and two buffers respectively.

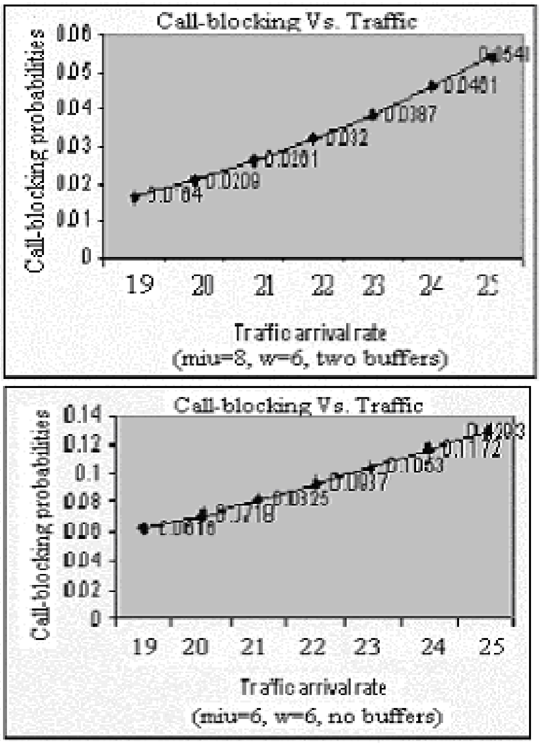
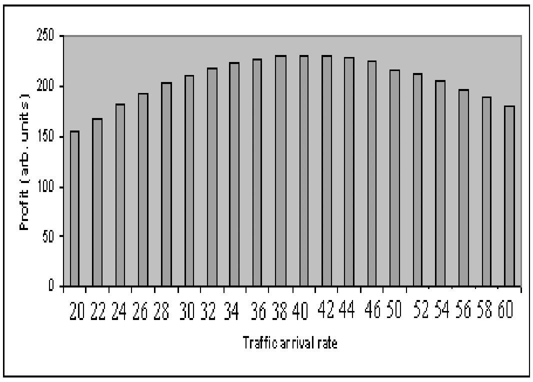


Figure1:Call-blocking probability against Traffic

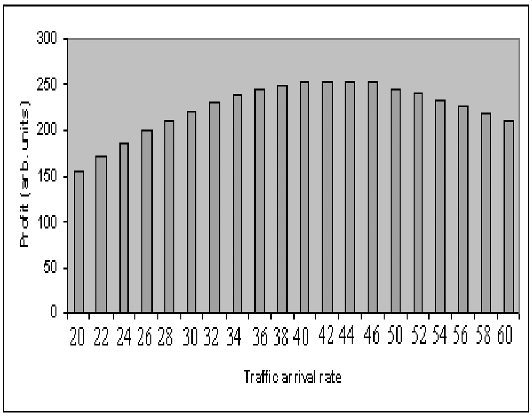
For a fixed w, we also vary 'm' and find the profit for various combinations of traffic intensity and number of buffers. Intuitively it can be said that increase in number of buffers will improve profit, but the restriction is imposed by the number of buffers allowable at each node.

Here we take a look at the graphs obtained with varying number of buffers used (no buffer for the first graph, one buffer for the second and three for the third graph respectively), under different traffic intensities. The mean service rate for all these graphs has been kept as 8 calls per unit time. The graphs for profit estimates obtained for the stated values are shown next:

It is clearly evident from the graphs of Fig. 2, that the initial increase in profit with in creasing value of λ, is due to the fact that more customers are arriving, hence profit increases, but soon the profit starts falling sharply because the contribution from the loss due to increase in blocking probability and increased delay time becomes progressively dominant.



m=7, one buffer , w=6, mu=8, ccall=8, cbuff=2.5, cset=1



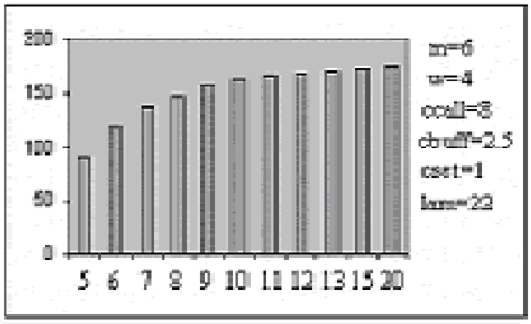
m=8, two buffers, w=6, mu=8, ccall=8, cbuff=2.5, cset=1

Figure2:Nonuniform Profit variation with Traffic

The above plots have been drawn with some chosen values of the parameter, but it must be emphasized that the nature of the plot and the steepness in drop in profit amount is dependent on these parameter values, so similar plots can be undertaken with proper cost values for real-life analysis. However a general trend can thus be forecasted from the above graphs.

In a similar way, we need to undertake an estimation of the variation in profit by varying the number of buffers used and for different values of service rate μ, while the value of traffic intensity is kept constant. Thus from the graphs obtained so far, we can correlate between different parameters to arrive at the optimal decision. The call-blocking probability graphs can be used to find the required number of buffers to be used in order to achieve the desired service efficiency. Then for those values of service rate and traffic arrival rate, we can find the profit estimate.

The profit graphs for different number of buffers and varying service rate from 5 to 20 calls/unit time, but with fixed traffic arrival rate are given in Fig. 3.



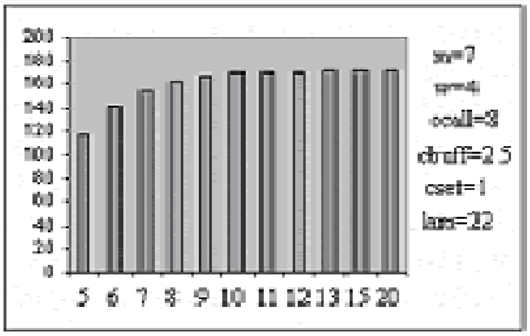


Figure 3: Profit variation with Service Time.

The following plot shows the variation in probabilities with the changing values of mean call time (service rate), μ. It is observed that with increasing values of μ, for fixed value of λ (=20 in this case), the result is that the call-blocking probability i.e. P_m (where 'm-w' buffers are present) decreases. This can also be seen intuitively from the fact that a larger value of μ (or 'miu') means more number of customer calls being serviced per unit time i.e. service rate is higher, or correspondingly mean call duration is lower, hence the blocking probability is also low. As the value of μ decreases, the call-duration increases, hence blocking probability goes up as shown in the following graph:

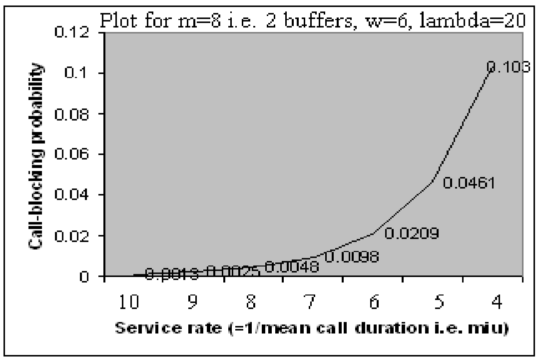


Figure 4: Call-connection Vs. Service Rate.

The mean waiting time i.e. delay required (buffering time) is given by: $W_q=L_q/\lambda'$, where $\lambda'=(1-P_m)\,\lambda$, where $\lambda'=\lambda[1-(\rho^m)/(w!)w^{m-w}]$. (6)
The graph below shows the variation in delay required as 'λ' varies.

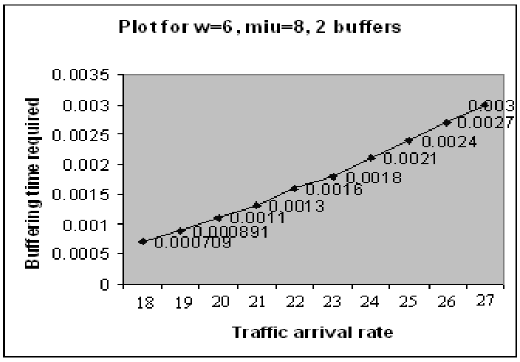


Figure 5: Required Buffering time Vs. Traffic.

If W_q is the delay that has to be introduced in the buffer loop and L be the loop length required to introduce a delay of T units of time, then the length of the fiber required for buffering = Wq.L/T.

Cost of fiber implementation per unit length=C(fiber).

So, cost of buffering for each loop= C(setup cost/hr.)=Wq.L.C(fiber)/T (7)

Thus, the Cost of buffering for each loop is equal to the cost C(setup/maintenance)

Utilization factor of each wavelength is N/w where N=(Number of busy servers) and is given by,

$$N=\sum_{n=0}^{w} n\,P_n + w\sum_{n=w+1}^{m} P_n \qquad (8)$$

Therefore,

$$N=\sum_{n=0}^{w}(n/n!)\,\rho^n P_0 + w\sum_{n=w+1}^{m} \rho^n P_0/(w!w^{n-w}) \qquad (9)$$

3. Architecture to achieve Buffering:

In this model we have a buffer made up of several links which can provide different time delay as and when required. In the model discussed here, we have considered only 1:1 buffering i.e. each loop can accommodate and provide delay to one signal at a time. The idea can be simply extended to loops accommodating more than one signal at different wavelengths.

In the following model, we have sets of main links, all capable of providing equal delay, but each main link has many inner links with different loop lengths and the entry of the light signal into this loop is controlled with a switch (switched-loop selector arrangement), which in turn is controlled by the control word generated by a computer in order to provide the required time delay. The incoming signal is diverted to an empty buffering space by means of Bragg diffraction caused by the generation of an Acoustic wave having a proper period to diffract the light in the required direction into an empty link the architecture is represented below:

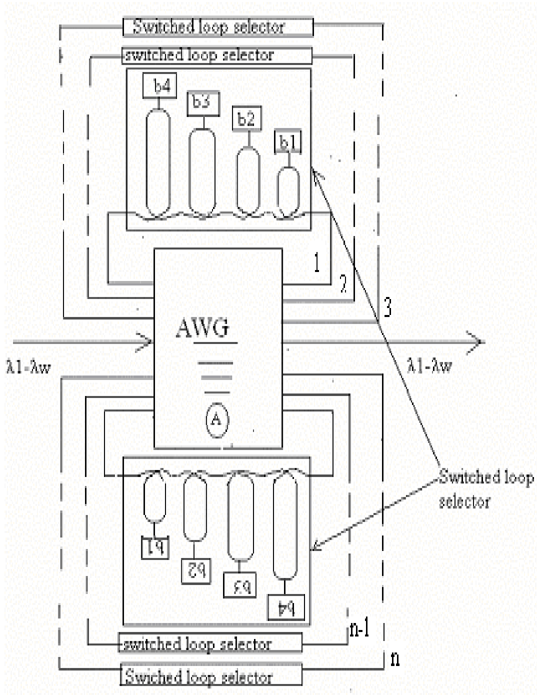


Fig.: Acoustic Wave Generator based buffering.

From the above discussion it is clear that when a signal at a particular wavelength needs to be buffered, then the most important parameter that comes into picture is the delay required i.e. the buffering time needed. We would like to deliberate on few other aspects before entering into further discussions.

It must be mentioned here that the traffic arrival rate varies over the day, the morning may traffic rate may be lower than the mid-day and again the traffic might increase in the night and then decrease in the late night. Thus we can expect to have to have four to five values of mean traffic arrival rate, λ, over different times of the day, with slight variation around these mean values.

The buffering block shown above can be used to account for such an application. The lengths of the delay loops shown can be dynamically changed over the day by controlling the opening of the switches which are placed at the entry of the inner loops (each inner loop having a different length to provide different time delay). When a signal arrives for buffering, a main loop (numbered from 1 to 'n' in the above figure) which is free (i.e. doesn't contain a buffered signal already at that instant) is chosen. The light signal thus needs to be directed into the corresponding loop. It is evident that the signal needs to be directed at some particular angle in order to place them in the selected loop by a system on chip.

The following figure shows the arrangement, where one signal converted to a particular wavelength travels a greater distance inside the buffer to get greater delay, whereas in the other case another signal at a different wavelength gets reflected at a previous position where it satisfies the Bragg condition. Thus variable delays can be given to the signals by converting them to proper wavelengths such that the condition for reflection is satisfied at different distances inside the grating. This architecture can be thought of to produce buffers. The calculations for the delay time required and the wavelength into which the incoming signal can be converted can be efficiently done by a processor.

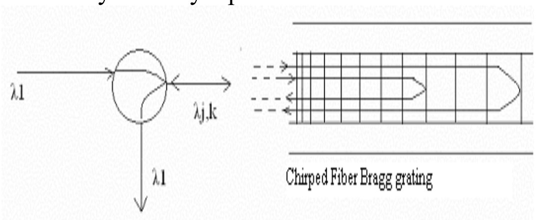


Figure 5: Chirped Fiber Bragg Grating Buffer.

Another possible modeling that can be thought of is also based on similar lines. In this case, instead of converting the incoming signal to a suitable wavelength to satisfy the reflectivity criteria, if we can vary the grating period dynamically by producing chirped stationary Acoustic wave, such that the grating period becomes 'Λ_1' at a distance 'L' inside the grating, thereby providing the required time delay and also satisfying the Bragg condition for the incoming wavelength λ1.

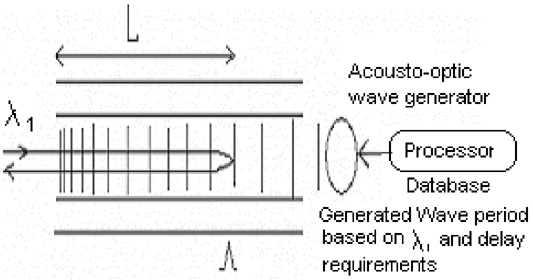


Figure 6: Dynamically varying Chirped Grating for Buffer architecture.

From the above figure it is seen that the delay time required is same in both the cases, so the reflection must occur after the signals have traveled a distance 'L' inside the grating. However, the two incoming signals were at different wavelengths. Hence to satisfy the Bragg condition for reflection, the values of the wave-period at the required distance 'L' should be different. This necessitates the generation of chirped stationary Acoustic wave for proper buffering. These ideas can be explored further for implementation as buffers. However, the estimations and mathematical modeling for any buffering design, profit estimates, delay required etc. remains the same and can be thought as a Queuing system model as discussed elaborately.

4. Conclusions

The paper discusses the mathematical modeling for mean buffering time based on various design consideration parameters like mean traffic arrival rate, mean call-duration, number of wavelengths at a node and the number of buffers available. The approach adopts Queuing System formulations and provides insight into the inter-relation among the design parameters and the system profitability, leading to a compromised solution for optimal buffering design at the node. Ideas for hardware implementation have also been undertaken. A detailed analysis for switched-loop selector based buffer architecture has been presented along with some scope of conventional buffers. The paper, in general, focuses on the modeling and designing aspects for buffering by highlighting on the correlation between network parameters and design parameters. This can help the designers and the management to determine an acceptable solution for profitability and reduced call-blocking probability in the buffering of signals in optical networks.

References

[1] Byrav Ramamurthy and B.Mukherjee, 'Wavelength conversion in WDM networking', IEEE J SAC, pp.1061-1073., Sept.1998

[2] A.Mukherjee, S.P.Singh, V.K.Chaubey, 'Wavelength Conversion Algorithm in an intelligent WDM network', Optical Communications, Elsevier, pp.59-65. 2004.

[3] Michael Frey, T. Ndousse, 'Wavelength Conversion and Call Connection Probability in WDM networks', IEEE Transactions on communication, vol.49, pp. 1780-1787, Oct. 2001.

[4] Satinder Pal Singh, Abhisek Mukherjee and V K Chaubey " Wavelength conversion algorithm in an intelligent optical network from a multilayered approach' Journal of Optical Network (OSA) vol.3 pp.354-362,2004.

[5] Juan Diao, Pak. L. Chu, 'Analysis of Partially Shared Buffering for WDM Optical Packet Switching', IEEE JLT, vol.17, no.12, pp 2461-2469, Dec. 1999.

[6] B. Vidal, J.L.Corral et al., ' Optical Delay Line based on Arrayed waveguide Gratings' Spectral Periodicity and Dispersive Media for Antenna Beamforming applications, IEEE Journal of Selected Topics in Quantum Electronics, vol. 8, no.6, Nov/Dec 2003.