Novel analysis of blocking probability along with topologies of WDM Passive Optical Network

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Abstract. A novel analysis of blocking probability has been studied along with topologies. It has been shown that the algorithm proposed offers the minimum probability of blocking. The performance of wavelength division multiplexing passive optical network (WDM-PON) has been studied for different values of loads. To analyze the blocking probability, conventional algorithms have been used i.e. random and first-fit wavelength assignment using different number of wavelengths. It elaborates the proposed WDM-PON network in order to serve all ONUs providing the bandwidth as required by each ONU or end user. Performance of the system has been investigated using the quality parameters like signal-to-noise ratio (SNR), bit error rate (BER) and eye diagram. The result elaborates the performance of proposed algorithm which offers the least blocking probability. At last, study introduces different challenges and aspects of future needs in formulating an effective WDM PON system.

Keywords: Passive optical network, BER, SNR, Blocking probability, WDM-PON

1. INTRODUCTION

Major changes in technology have made up optical communication a future network to fulfill the tremendous demand for high speed data providing minimum latency for different types of applications. Wavelength division multiplexing passive optical network (WDM-PON) is basically a frequency division multiplexing (optical frequency domain) where in a single optical fiber, multiple channels exists at separate wavelengths [1-5]. WDM can provide large bandwidth using a single fiber (approx. terabits per second) using different WDM wavelengths. The optical fiber has very high bandwidth at low attenuation and it is about 1000 times of the total available radio bandwidth in world [6]. However, high data rates of is difficult to achieve since the access speed of the last mile electronic devices is low as compared with transmission media. Data requirement at the user side is shown in the figure 1.
Now, only video streaming uses 83% data and the rest is used by the other services like web, file sharing and gaming. To fulfill this demand a high speed network is required and the reliable solution for this is next generation passive optical network i.e. WDM-PON.

**FSAN Roadmap and ITU-T PON Standard:** Roadmap introduces by full service access network (FSAN) group is elaborated in figure 2. This depicts development of passive optical networking (PON) and its standards. It’s focus on two generations of PON i.e. before and beyond GPON 1. Next Generation PON (NG-PON) and 2. NG-PON2 respectively.

Guiding principles are given by this group for the deployment and design of ITU-T PON for future PON System. Firstly, roadmap conveys that the power splitter based PON system can be reused for a few years. NG-PON2 provides a very high-capacity access system to the end user. Further, point-to-point (PtP) WDM channels are defined to use Expanded Spectrum wavelength plan i.e. Channel Spacing below 50 GHz [17].

**Figure 1.** Usage at data center (user side)

**Figure 2.** FSAN Roadmap

**Figure 3.** Wavelength plans for U/S, upstream; D/S, downstream.

Different standardization of PON by international telecommunication Union-telecom (ITU-T), the roadmap for the PON has been delivered by the FSAN group as illustrated in figure3 The existence of
different PON architectures with its legacy are standardized by the ITU-T in its recommendation known as G.984.5 [13]. WDM optical networks installed between any two remote nodes (RN) or users are not completely optical. For all-optical networks, routing must be implemented in optical domain only. So passive optical communication is preferred transmission media for achieving the high capacity at the customer premises. WDM-PON has many advantages which can be summarized as:

- **High capacity**: In WDM PON, each user is assigned an individual wavelength which is not shared among other users. So each user can utilize the dedicated full capacity by using a single wavelength (which is larger than 100 Gb/s at present or more).
- **Security**: WDM PON provides high network security as each user operates on its own wavelength and there is no need to share it with other users.
- **Extended reach**: Unlike TDM PON, WDM PON does not suffer from large power-splitting loss. So the maximum reach can be extended without using remote optical amplifiers.
- **Simplified operation**: Each user in WDM PON has a virtual point-to-point connection to the central office (CO) and the medium access control (MAC) layer is also simple one.
- **Upgradability**: To increase the operating speed of a particular user in TDM PON, it is necessary to upgrade all the equipment attached to the network. However, in WDM PON, this speed can be increased on a needs basis by replacing only the equipment relevant to that particular user since each wavelength can be operated at a different speed and protocol.
- **Service transparency**: WDM PON can be used as a single platform for all services due to its high bit rate and protocol transparency.

Since WDM PON has various advantages, so it is a most preferable solution for near future which is able to provide dedicated capacity to each user. However, it is still very expensive at the mass level deployment. But due to new advancement every day, cost will be decreasing on in near future. Other side, it becomes very important with the ever-increasing demand of the bandwidth at the customer end. Thus, it is necessary to improve the competitiveness of WDM-PON among other peers for its success in near future. Furthermore, it is still a challenge to increase reach ability and the operating speed of WDM PON. In WDM, every wavelength is capable to modulate the data in the optical window (1550 nm) of single mode fiber (SMF) with low value of attenuation. However, main concern here is how to assign these wavelengths to the end user effectively which faces the basically two problems which are wavelength assignment (WA) problem and blocking probability [7]. WA problem can be defined on a topology basis to find out the specific route and wavelength as per the need of the end user using few wavelengths. WA problem is one of the main problems of WDM PON optical networks. Several researches have been carried out to handle this problem [8]. Blocking probability for requesting a call is an important metrics of for the measurement of the quality of WDM-PON network. It depends on numerous conditions such as

- traffic load
- network topology
- algorithms
- method of wavelength conversion

To get the perfect WDM-PON solution, one has to deal carefully with these all problems. So blocking probability is the main concern here to predict the best quality of the WDM PON system. For getting the perfect solution designer have to consider all these parameters along with the choice of passive components.

2. RELATED WORK

A novel analysis for predicating the performance of a PON network is directly related with predication of probability of blocking a call request. It depends on the call acceptability. If calls are more than the number of light paths (wavelengths) available, probability of blocking will be more. This is completely based on availability of lines, trunks, light paths etc [6, 7]. Probability of blocking is defined as non-acceptance of a call request in the absence of resources in the network to the end user or ONU (optical network unit) [7]. So estimation of call blocking probabilities is necessary w.r.t. demand of the traffic. The evaluation of blocking probabilities has been studied by many authors as:
C. Chen et al. [1] presented a layered graph model for analysis and provided a solution of wavelength assignment problems in optical transmission networks. Author used virtual path between two nodes for the analysis of the wavelength assignment problem. Performance of the system has been predicated using probability of blocking with the variation of the wavelength.

Z. Rosberg et al. [3] introduced a new model for the estimation of blocking in OBS system. Some assumptions have made up for supporting the conversion of wavelengths.

A. Alyatama [4] evaluated probability of blocking without employing the wavelength conversion. This was totally based on different types of routing either fixed or random wavelength for the analysis of different layers to predict poison traffic overflow.

Mehmet Fatih Tuysuz et al. [7] focused on techniques for optimizing the transmitters section for the ultra-dense WDM (UD-WDM).

Anuj Singal et al. [10] defined an analytical form for the calculation of blocking in mesh network with different degrees of the conversion for the higher performance of the optical network.

Javier Mata et al. [15] elaborated the operation of transmitters using artificial intelligence techniques (AI) which facilitates modeling of individual optical components artistically. New modulation techniques introduced like 16 quadrature amplitude modulation (16QAM) and 64QAM or else for enhancing the capacity using high power carrier and phase. Phase noise is explained for lasers which are the important part.

Jawad Mirza et al. [19] focused on the study of neural networks for some applications in optical which includes different performance metrics like OSNR, eye-diagram and eye-histogram parameters etc.

J. Comellas et al. [20] presented a new method in optical burst switching (OBS) networks to minimize the probability of blocking a call. Some resources have been reserved for the avoiding the situation of blocking.

Different aspects of possible solutions have been presented by giving a new approach to estimate the probability of blocking accurately in any kind of optical topologies. The analysis of probabilities of blocking in each area is extracted using different approaches. It has been focused on to the AI techniques, OBS, Machine learning, different algorithms, probability of blocking, different topologies etc. for the wavelength assignment in WDM network.

The organization of the paper is summarized as: In section 1, basic roadmap provided by FSAN group along with ITU is elaborated including the data need and probability of blocking. In section 2, Literature survey is carried out. In section 3, probability of blocking and algorithms for evaluating, blocking probabilities have been elaborated. In section 4, novel dimension of the WDM-PON network has been introduced. In Section 5 simulation and results has been discussed. And in the last section 6, conclusion of the paper is concluded along with future aspects.

3. BLOCKING PROBABILITY AND ALGORITHMS

The prime objective is to minimize the probability of blocking in optical system. The multiplexing of the signals identifies applicability of Erlang model for estimating traffic in telecommunication network. The calls will arrive as according to poison process generally. The main feature of this model is its insensitivity. It depicts the independency of the probability of blocking [5]. The traffic is defined by a unique parameter which is estimated by arrival rate of a call and it’s holding time. The insensitivity feature of Erlang method is also fulfilled by the Engset method calculation. Engset formula estimates a less probability of blocking as comparison to Erlang formula when traffic intensities are equal. So, the Erlang and the Engset methods may be combined for production of any traffic conditions. The probability of blocking here depends on the intensity of traffic. For better predication of probability of blocking, wavelengths must be assigned in best way. So this is the main challenge in WDM PON to enhance the bandwidth for the end user effectively and this can be achieved by minimizing the probability of blocking [10]. Till now, two techniques have been explored for the proper assignment of the wavelength. These are as:

- Random wavelength assignment: This methodology assigns random wavelengths to the ONU or end user from the group of available one in WDM PON System and assign accordingly.
- First-Fit wavelength assignment (FFWA): In this, wavelengths are assigned in a fixed manner. A few light path (wavelength) requests will not be entertained (blocked) because of
unavailability of the wavelengths. So, it estimates the probabilities of blocking of a call based on the unexpected demands of bandwidth in the system. Various techniques have been used by the researchers to find the probabilities of blocking of a request for assigning the wavelength [6].

In proposed algorithm, number of wavelength will be assigned based on the availability of the wavelength (W). First, it will collect the request a user (R) and then it will compare it with 'W'. If R < W, then it will assign the wavelength to the user otherwise it will move to the other wavelength. It has been shown in proposed algorithm as in figure 4.

![Proposed Wavelength Assignment Algorithm](image)

**Figure 4.** Proposed Wavelength Assignment Algorithm

Different tools have been used for the analysis of probability of blocking for assigning the wavelength. In proposed algorithm when a end user demands for the bandwidth then the role of this algorithm starts. It will check whether bandwidth is available or not and allocate accordingly. It will also check the remaining resources availability. If bandwidth is available, then it assigns to the request but if bandwidth is not available then it will move to the next wavelength. In this manner assignment of the bandwidth is carried out. Here, Poisson traffic will estimate the path blocking. The overflow of the traffic will also include predicting the best route with minimum probability of blocking.

3.1. Cost analysis

Cost analysis has been conducted by using different locations using different number of output ports as shown in Table 1 for the placement of the passive components like splitter or AWG. Table I contains the cost ($) of the equipment [15] along with attenuation (dB) parameters which is directly related with output ports of the splitter or AWG. Here, cost analysis of splitters and AWG (Arrayed Waveguide Grating) is being carried out.

**Table 1 [Ref: 15]**

| Output Ports | AWG | Splitter |
|--------------|-----|----------|
|              | Attenuation (dB) | Cost ($) | Attenuation (dB) | Cost ($) |
| 2            | 3   | 950      | 3   | 800      |
| 4            | 3   | 1100     | 6   | 900      |
| 8            | 3   | 1400     | 9   | 1100     |
| 16           | 5   | 2000     | 12  | 1500     |
| 32           | 5   | 3200     | 15  | 2300     |
| 64           | 5   | 3700     | 18  | 5600     |
It has been noticed that the cost of the AWG is going on increasing with the number of output ports as compared with splitters. It has almost same cost at the initial stage but almost double as the number of output ports is more than 64. This can be predicated on the basis of the Table I. But it is also clear that attenuation of the AWG is constant as moving in upward direction while it is increasing in the case of splitters. So there is a tradeoff between the cost and attenuation of the AWG and splitter respectively. Cost of the overall network can be minimized by proper deployment of OLT and the ONUs while fulfilling the demands and by selecting passive optical components based on the need of the bandwidth of the end user.

3.2 Topologies

Different topologies have been used for making the best architecture of the WDM-PON. This includes mainly linear topology, ring topology, mesh topology and dual ring topology. But out of all these the preferred solution for the least blocking, better availability and the best routing is dual ring topology. The probability of blocking of the network is directly related with availability bandwidth (light paths) in ring topology [13].

Figure 5. Dual Ring Topology

So on enhancing the wavelength availability, probability of blocking decreases in given topology and vice-versa. It has been considered in WDM network as shown in Fig.5. It is different from the simple ring topology, in this inner ring is used for the receiver (Rx) and the outer one is used for the transmission (Tx) as shown in figure 5. At point A and B, loop back is done to avoid the failure of the topology in the crisis [9].

4. NOVEL DIMENSIONING OF NETWORK

Performance monitoring of a network is the essential part to maintain the quality of service (QoS) So one have to take care of these various performance metrics like OSNR, SNR, BER and Q-factor respectively in optical domain like WDM-PON network. It provides accurate estimation on of fairness in power in the termination network along with AWG or Splitter. Estimation and acquisition of these metrics of allow well diagnosis of the optical system to take timely actions of repairing damages or rerouting traffic before any crisis takes place [6-8, 20]. This is an essential metric that is mainly calculated by two different strategies. Firstly, It is estimated by counting the error bit in the received signal as compared with input signal. But for minimum value of BER, this process requires a more number of bits for the simulation. Secondly, Q-factor (quality) is used to estimate the quality of the signal whereas BER is used to calculate standard deviation and average values at high or low levels. The Q-factor is used in systems which have additive noise. Generally the electrical components create the noise within the system [9, 14]. So if numbers of active components are reduced then noise can be minimized up to a very much extent. WDM-PON utilizes the passive components, so minimum level of noise will be there. Further, Q-factor is fairly associated with both the performance metrics i.e. BER, SNR. Relationship between various metrics can be shown as
Here “erfc” is the error function.

However BER is the useful metric, but it is not more useful for the noisy environment. So another metric is used which is noise figure i.e. NF. It measures the degradation of SNR when noise is present in a system. So, NF can be calculated as:

\[ NF \ (dB) = 10 \log_{10} \left( \frac{SNR_{in}}{SNR_{out}} \right) \]  \hspace{1cm} (3)

where \( SNR_{in} \) and \( SNR_{out} \) are the SNR at the input and output level respectively.

Availability of the network is the main concern of the service provider. It depends totally on the basis of the need of an individual customer. WDM have various advantages and abundant amount of bandwidth is available. So it is the best suited PON technology for the near future for the customer [17-19]. Selection of the passive components in network depends on the type of service needed by the customer. For PtP communication, AWG is used while for multicasting splitter is the best choice as shown in figure 6.

Maintenance cost of the passive components is very less as comparison to active components. So beauty of the PON network is to minimize the cost of deployment by utilizing the passive components.

5. SIMULATION AND RESULTS

The probability of blocking of the network fluctuates according to the situations of the demand of the end user. It depends on available wavelengths, number of nodes and load at a particular time frame. Here variation in the number of nodes is carried out w.r.t. load as 25 Erlangs and 30 Erlangs respectively for the simulations as in figure 7(a) and figure 7(b) respectively [4-6]. In comparison to the conventional algorithms, it introduces the least blocking with the variation of the load.
The simulation shows the probability of blocking with variation in wavelength and load. With increase in number of channels or wavelengths the probability of blocking reduces in all algorithms but the proposed one reduces more as in figure 7. Here from the simulation, it is very clear that result of the second one is far better than the first one. So it can be concluded that as we increase the number of users inversely to the available light paths, probability of blocking will also increases and vice-versa [20]. This has been analyzed that it introduces the least blocking as compared with other.

6. CONCLUSION

A novel analysis has been carried out using different performance metrics. Essential part has the estimation of the blocking of a call as per bandwidth requirement by the end user or ONU. The blocking performance of the WDM PON network analyzed with variation in available wavelength. It has been concluded that with increase in number of wavelength, probability of blocking decreases and reverse of this is also applicable. Selection along with suitability of the passive components like splitter and AWG is also presented. In optical transmission, it is expected that AI and machine learning will make dramatic change in the future PON technologies. Furthermore, security enhancement can be having a great advancement using AI and machine learning.
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