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Allocation of Wavelengths in WDM Networks Considering Residual Dispersion under the Concept of Smart Cities

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Abstract

Internet traffic, given the applications of smart cities, is constantly growing and with it the applications of the type unicast/multicast with different requirements Quality of Service (QoS). S/G Light-tree is an architecture of nodes transport networks allowing optimal routing or traffic handling unicast/multicast using the concept of Traffic Grooming in an all-optical environment. The chromatic dispersion phenomenon deforms the transmitted pulses in an optical fiber and the effect depends on the wavelength used in the transmission and must be considered in allocation models wavelength. In this article, we propose a model and heuristic that allows assigning low dispersion wavelengths, maintaining greater available capacity, assigning the required quality of service and minimizing the amount of equipment required in each node of an all-optical network .

Keywords: Chromatic dispersion, traffic grooming, optimization, routing, smart cities, QoS.

INTRODUCTION

The concept of smart cities, requires traffic optimization in order to power according to the qualities of service (QoS) routing information minimizing energy consumption; this requires optical transport networks for transmission of information. Optical Transport Networks employ Wavelength Division Multiplexing (WDM) technology to transport as much information. WDM enables multiplexing different wavelengths on the same fiber, each conveying speeds around 10 Gbps and can reach speeds of terabit per second on a single fiber [1]. Traffic Grooming (TG) improves bandwidth utilization of optical transport networks, allowing multiplexing low-rate traffic in one wavelength [2].

Multicast traffic type (HDTV, IPTV, video conferencing, interactive games, etc.) is constantly growing [3]. Support for Multicast Traffic Grooming has proposed the concept of light-tree, where transport point-multipoint traffic is performed in a completely optical medium (without optoelectronic optical OEO conversions). This form of transmission is what is called transparent and may make using optical cross-connect (OXC) [4]. When co multiplexed unicast and multicast traffic, the light-tree consumes more bandwidth by routing sessions unicast to unwanted destinations, to avoid the OEO conversions, which are very costly from the standpoint of transparency in the transmission of information (bits).

In order to optimize the use of resources in an optical transport network, in an all-optical medium, it has been established Stop and Go architecture (S/G) Light-tree [5]. S/G Light-tree allows optimal routing unicast and multicast sessions (together). The S/G Light-tree architecture adds some power losses due to the use of detection systems, so it is essential to consider the physical transmission medium to implement routing algorithms and allocation of wavelengths. The architecture is shown in Figure 1, there are mostly observed: optical switches (OSW1, OSW2), multiplexers and demultiplexers (mux and demux), transmitters (Tx) and receivers (Rx), Splitter and Amplifier Bank (SAB) and the Detection System (DS), FSK demod, Contention Resolution, Bit Pattern Interpreter, and delay lines Idle detection part of the DS.

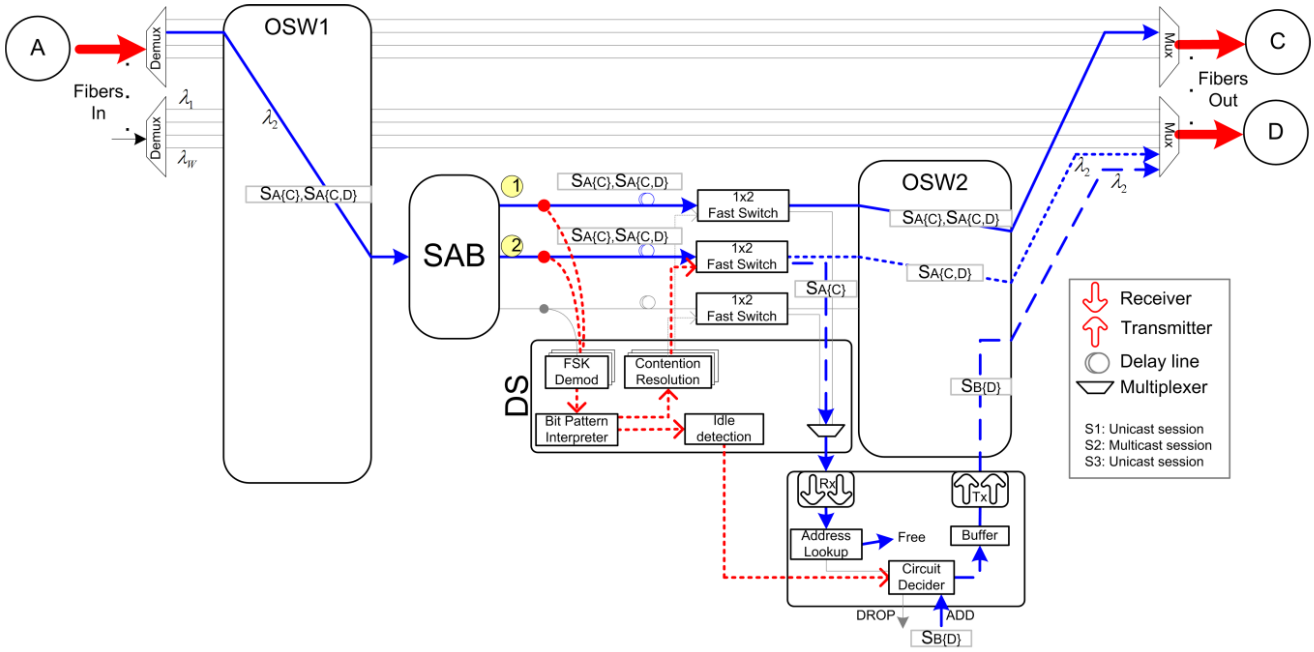

Figure 1. Architecture S/G Light-tree

Chromatic dispersion is a linear phenomenon that occurs in the optical fiber, which produces a bulge in the transmitted pulses. Widening produced depends largely on the wavelength and is relevant in optical transport networks. Currently, most routing algorithms and proposed allocation of lengths waves, do not consider the losses that may occur in the optical fiber, the main reason is the complexity of the algorithms as these are the type NP-Complete [6].

In this article, an allocation model of wavelengths that considers the physical medium (residual dispersion in the optical fiber) and types of services in different types of traffic used network is proposed. By employing classes of service for allocation is achieved lower the complexity of the algorithms, since the amount of search on the number of wavelengths is controlled.

MATERIALS AND METHODS

Traffic Grooming is the ability is given to a WDM network combining several low speed traffic (order of Mbps or few Gbps, eg OC-1, OC-3) into a high speed (OC-192 or other higher). TG is necessary to make the nodes possess some special features, even more if required for multicast traffic type. The problem of designing networks that efficiently support TG is not trivial and the solution can greatly impact on the cost of the network.

Dispersion in optical fibers and their implication in WDM networks

Most algorithms grooming, routing and wavelength assignment (GRWA) working with the assumption that all wavelengths in the optical medium have the same transmission characteristics bits without any bit error. However, the optical fiber has some phenomena unquestionably affects the transmission quality of light-trees. Phenomena that can occur in the fiber are:

- Linear: These phenomena are independent of the signal and affect each wavelength independently among them are: spontaneous amplification spontaneous emission (ASE), polarization mode dispersion (PMD), chromatic dispersion.
- Nonlinear: These phenomena generate not only dispersion in each channel but also crosstalk between channels. Some phenomena of this kind: Four-wave mixing (FWM), Selfphase modulation (SPM), cross-phase modulation (XPM), Stimulated Raman scattering (SRS).

Some work studying PMD, ASE, FWM applied to routing algorithms and allocation of wavelengths (without considering grooming), taking into account the effect of the power frequency, the set of wavelengths and the length of the connection [7]. The article proposed in this analysis takes into account the residual chromatic dispersion being relevant compared to other phenomena for assigning wavelengths in transmission systems employing optical fiber; it is also an optimal criterion for the assignment of wavelengths, especially above 10 Gbps speeds.

Classes of Service model allocation for traffic

Three (3) Classes of Service (CoS) for traffic or sessions that different network transport used are defined. The CoS are: Priority High (CoS_A), Medium priority (CoS_M) and Low priority (CoS_B). The CoS of each traffic circulate through the network depends on the type of protocol or traffic, for example, if video traffic type will require a better deal on the network, so their priority is high (CoS_A). In the case, for example of a data session priority will be low (CoS_B).

It defines Λ as the set of wavelengths available for allocation. Where $\Lambda = \lambda_\alpha, \lambda_\beta, \lambda_\gamma$. λ_α is the subset of wavelengths with low dispersion, λ_β the subset of wavelengths with average dispersion λ_γ the subset of wavelengths with high dispersion.

The model is based on the residual dispersion (RD), which is defined as the total dispersion in an optical fiber transmission considering compensation fibers. The model takes into account a normalized section (Figure 2) containing the following elements:

- *Single Mode Fiber* (SMF): optical fiber designed to carry a single light beam. It may contain different wavelengths. It is used in DWDM.
- *Dispersion Compensating Fiber* (DCF): control the chromatic dispersion. It works by preventing excessive temporary widening of the light pulses and signal distortion. Offset the cumulative distortion in the SMF.
- SMF length (LSMF)
- DCF length (LDCF)
- EDFAs

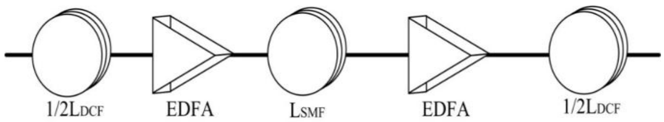

Figure 2. Section Normalized

With the model is to find the percentage of wavelengths with low (λ_α), half (λ_β) and high dispersion (λ_γ), Comparing the value of RD with a threshold. The model is defined as follows:

INPUTS:

B: Compensation Factor (Slope Dispersion) [ps / nm2km].

Λ: Set of wavelengths available for allocation. $\Lambda = \lambda_1, \lambda_2, \lambda_w$. Where w is the number of wavelengths.

λ_{ref} : Reference wavelength [nm]. It depends on the bandwidth of the channels. The parameters are available in the Rec G.694.1.

Threshold: Acceptance threshold. [Ps / nm]. Threshold = $\pm$ 1000ps / nm for 10 Gbps.

DSMF: Dispersion coefficient in the SMF to the reference wavelength [ps / nm.Km].

DDCF: Dispersion coefficient in the DCF for the reference wavelength [ps / nm.Km].

LSMF: SMF length [km].

LDCF: DCF length [km].

OUTPUTS:

$$\Delta\lambda_w = \lambda_w - \lambda_{ref} \quad (1)$$

$$\Delta D_w = \Delta\lambda_w \times B \quad (2)$$

$$D_w = D_{\lambda ref} + \Delta D_w \quad (3)$$

The above equations help to obtain the parameters of RD:

$$RD_w = D_w(DMS) \times L_{SMF} + D_w(DCF) \times L_{DCF} \quad \forall w \quad (4)$$

As mentioned above, the RD parameter shall be used to the allocation of wavelengths. The proposal seeks wavelengths less RD sessions with higher priority (CoS_A) are assigned. Here it was described as the process for the allocation algorithm.

Consider a test network as NSFnet (14 nodes, 21 bidirectional links), which has an average length of links d = 1299km. By performing different tests found that for a spacing of 25 GHz and w = 64 (w: number of wavelengths), the lower values for RD are in approximately 15% of the first wavelength available to assign. To determine the cost function was used proposed [7] (Threshold = 1000, other parameters were taken from [8]:

$$d_{ij} \times RD_w \le Umbral \quad (5)$$

Given the analyzes, the following allocation model wavelengths is proposed:

Sessions with CoS_A have the highest probability of being assigned a wavelength less value RD (within 15% of the first wavelength). Sessions with CoS_B have a chance of access to a wavelength of the intermediate window RD (from 15% to 75%) and finally, have sessions with CoS_C have high probability to access wavelengths with highest value RD (last 25%).

ALLOCATION MODEL PROPOSED

Problem Specifications

The WDM network is modeled by a directed graph G connected (V, E) where V is the set of network nodes with $N = |V|$ nodes. E is the set of network links. Each physical link between nodes m and n is associated with a weight L_{mn}, which may represent the cost of fiber length, the number of transceivers, the number of detection systems or other. The total cost to route unicast/multicast sessions in the physical topology is given by Equation 6:

$$Total\ cost = \sum_{k}\sum_{W}\sum_{N} L_{mn} \cdot f_i \cdot \chi_{mn}^{iw} \quad (6)$$

Where:

N: Number of nodes in the network.

W: Maximum number of wavelengths per fiber.

bw_i: Bandwidth required per session unicast / multicast i.

c_w: Capacity of each channel or wavelength. For example, c_w = OC-192 or OC-48.

f_i: Fraction of the ability of a wavelength used by the session i. $f_i = \frac{bw_i}{c_w}$.

k: Unicast or multicast group sessions.

χ_{mn}^{iw}: Boolean variable, which is equal to one if the link between nodes m and n is occupied by the session i in the wavelength w. If not $\chi_{mn}^{iw} = 0$.

k sessions unicast/multicast are considered denoted $r_i(s_i, D_i, \Delta_i) \mid i = 1,2,...,k$. Each session r_i is composed of a source node if node or set of nodes D_i destination and class of service parameter associated $\Delta_i = \{CoS_A, CoS_M, CoS\_B\}$. Δ_i It will be determined by a model presented in the arrival and duration of sessions modeling section.

Be $T_i(s_i, D_i, \Delta_i, \lambda_i)$ the routing tree for session r_i in the wavelength λ_i. When r_i is the multicast type, the message source if D_i along the tree T_i is divided (split) on different nodes to route through the different branches of the tree until all nodes Di. The S/G Light-tree architecture allows this operation. Regarding the degree of the node it is assumed in the article that is unlimited (bank splitter of the S/G unlimited architecture). In addition conversions are not considered wavelength, ie the session occupies the same wavelength throughout the tree. Conversions wavelengths in a completely optical medium are expensive and still are under development.

The goal of the algorithm grooming, routing and mapping is to minimize the cost of the tree considering the dispersions present in the wavelengths. That is to say, the network has a set $\Lambda = \lambda_1, \lambda_2, ... = \{\lambda_\alpha, \lambda_\beta, \lambda_\gamma\}$ wavelength of which: the set of wavelengths low dispersion, is the set wavelength dispersion medium and the set of wavelengths of high scattering. It is obtained as the first 15%, 15 to 75% and the last 25% of the lengths of approximately waves. The wavelength that is assigned to certain r_i depend on the class of service $\lambda_\alpha \lambda_\beta\ \lambda_\gamma\ \Delta_i$ required for that session. The main objective is given by the equation:

$$\text{Minimize} \sum_{i \in k}\sum_{w \in W}\sum_{(m,n) \in N} L_{mn} \cdot f_i \cdot \chi_{mn}^{iw} \quad (7)$$

The problem of routing unicast/multicast is basically a minimum Steiner tree problem, which is NP-hard. Article arises heuristics to find the routing tree having for QoS (through CoS) and dispersions in the set of wavelengths. Another feature of heuristics is trying to maintain higher available capacity on the wavelengths with low dispersion for the sessions are most likely to access this resource $r_i\Delta_i = CoS\_A$.

Modeling arrival and duration of sessions

In order to get as close to reality results, we chose to get a session arrival model the optical transport network as well as the duration of these. Traces of available data were used in ACM SIGCOMM [9] which contain completed in the transport network lasting 30 days between the Lawrence Berkeley Laboratory, California and the rest of world traffic. The data have information on the time, duration, protocol, bytes transmitted and others. Data were processed and analyzed in order to obtain the model that will then to model allocation and routing sessions in WDM optical transport network correctly.

Given the CoS, the average duration of each session was modeled similarly. The average duration times were also analyzed and validated to be represented by an exponential function, with the following averages: $\mu_A = 229.8$, $\mu_B = 183.06$, $and\ \mu_C = 177.06$ seconds.

Heuristics proposal

It has been shown that traffic grooming is a NP-Complete[10] problem and proposed different techniques for optimal routing information. The ILP (ILP) has been used to model the different networks employing traffic grooming. However, when traffic grooming problem NP-complete, the ILP techniques are not scalable and therefore can only be applied to small networks (small number of nodes, 8 approx.). It can be used where the heuristic approaches, which seek to optimize network resources as the number of wavelengths, equipment, throughput, other; and have considerable execution time.

This article uses a heuristic agent that deals with the optimal routing, allocating wavelengths and grooming, taking into account quality of service of the different sessions and the effects of dispersion in the lengths of available waves to assign.

The heuristic aims probabilistically assign wavelengths with less dispersion sessions with higher priorities. The algorithm is called Grooming-QoS and shown in Figure 3. The algorithm uses AsignaGrooming function which is shown in Figure 4. The input parameters of the algorithm are:

N is the number of nodes in the network.

X: set of sessions, $k = |X|$ the number of sessions. $k = 1,2, ... i$.

Set $\Lambda = \lambda_1, \lambda_2, ... = \{\lambda_\alpha, \lambda_\beta, \lambda_\gamma\}$ of wavelengths which: λ_α the set of wavelengths low dispersion, λ_β is the set wavelength dispersion medium and λ_γ the set of wavelengths of high scattering. W =|Λ| the number of lengths available.

$T_i(s_i, D_i, \Delta_i, \lambda_i)$ It is the routing tree for the session r_i on the wavelength λ_i

Class of Service (CoS) associated $\Delta_i = \{Cos\_A, CoS\_M, CoS\_B\}$

P_{mn}: Physical topology, where P_{mn} = 1 indicates a direct fiber optic link between the nodes m and n. If no fiber link between nodes m and n then P_{mn} = 0.

Each link between nodes m and n is associated a weight L_{mn}.

C: Capacity of each wavelength. This article assumes C = OC-48.

s_i: Source node for the session i

D_i: Set of destination nodes for each session. D_i includes unicast and multicast traffic.

bwi: Bandwidth required for each session.

```
GroomingQoS function(N, s, D) bw,Λ,Δ
    lambda= Determine set lengths which can be assigned
    ()Λ,Δ
    If Lambda ∈ λ_α
        T =AsignaciónyGrooming (n, s, D, bw,
        lambda);T
        If he could not assign
          | Blocking
        end

    elseif Lambda ∈ λ_β
        T =AsignaGrooming  (n,  s,  D,  bw,
        lambda);T
        If he could not assign
          | Blocking
        end

    If Lambda ∈ λ_γ
        T =AsignaGrooming (n, s, D, bw, lambda);T
        If he could not assign
          | Blocking
        end
    end
```

Figure 3. Algorithm GroomingQoS

```
AsignaGrooming function(N, s, D,)); bw,Λ,Δ
  t = numero de longitudes disponibles para asignar
  == false && While Asigno t > 0
     T_temporal =Search tree set of lambdas available (used Steiner
     tree minimun)
     If there is capacity available for the whole tree  bw ≤
     cap disponible

        Generates the routing tree in particular lambda
        Available capacity decreases lambda: cap disponible − bw
                                T = T_temprotal

        Assigned = true
     else
      | Assigned = false
     End
     t--;
  End
```

Figure 4. Function AsignaGrooming

The algorithm initially Grooming QoS with session r_i information determines the service class (Δ) and the set of lengths (λ ∈ Δ) in which can be routed session (including grooming). With this information we proceed to apply the routing algorithm, allocation and grooming shown in Figure 4. The allocation algorithm and is based on grooming minimun known Steiner tree to determine the routing tree. Once the tree routing is determined (in this case the time) it is found that the wavelength being tested has available capacity for the session can access that resource. In case there is available capacity is assigned that wavelength to the session and included in T. If it is not possible to assign this wavelength is tested in the following, to find available capacity or until the wavelengths are exhausted. If it is not possible to assign any wavelength, it proceeds to delete that session and marked as blocked traffic. The advantage of the algorithm is that by using the CoS search cycles are decreased when looking for that wavelength can be assigned

RESULTS

In order to determine the performance of the proposed software simulation discrete event Network Simulator 3 (NS3) algorithm was employed, where the WDM system is emulated with different sources and quality of service parameters. Simulations are performed using the transport network NSFnet, in which the physical topology consists of 14 nodes with 21 bidirectional links.

The proposed allocation model is compared to the case when given the same treatment to the different sessions (regardless of their QoS). Article blocking probability (blocking), the available capacity of each wavelength and the bank number of splitters (BS) maximum required S/G Light-tree architecture to efficiently route the sessions are compared unicast/multicast. The most expensive section of the architecture is given by these components, in [10] there is a detailed analysis. The analysis is done taking into account the following simulation parameters:

- Number of wavelengths: 10
- Wavelengths capacity: OC-12
- Possible bandwidth: generated with a uniform distribution. $bw = \{\mathrm{OC}-1, \mathrm{OC}-3, \mathrm{OC}-12\} OC-1: OC-3: OC-12 = 1:1:1$
- Maximum number of sessions: 10.000
- Group wavelengths with low dispersion λ_α= [1: 2].
- Group wavelengths with low dispersion λ_β = [3: 7].
- Group wavelengths high dispersion λ_γ= [8:10].

Arrival rat session (λ) and the duration (μ) of these were modeled as indicated above. However, to determine the probability of blocking the session length was left fixed. The load is defined as Erlangs $Load(Erlang) = bw \times \lambda/\mu$.

In Figure 5 a plot of load vs Erlangs Blocking Probability for traffic with CoS_A, CoS_M and CoS_B in cases shown when the proposed model (GroomingQoS) is used without. It is observed that for high priority traffic (CoS_A) the blocking probability is much lower compared to other traffic (about 14% improvement). Traffic blocking probability have a very similar (62% approx.) When not taken into account the priority for assignment. However, it is clear that the proposed model, it is possible that traffic with high and medium priority have a lower probability. Low priority traffic in the model does not receive good service going from 70% to 75% probability.

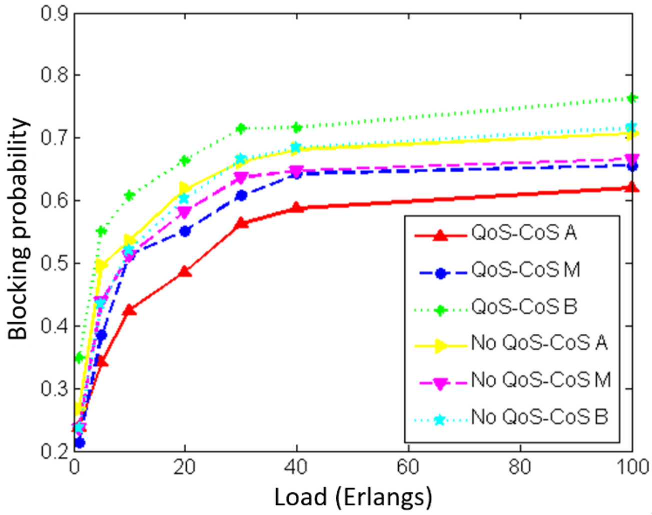

Figure 5. Blocking Probability

Regarding the available capacity on the wavelengths, shown in Figure 6 with the model wavelengths low dispersion, kept greater available capacity, improved by 14%. This enables sessions with QoS requirements can more easily access the resource.

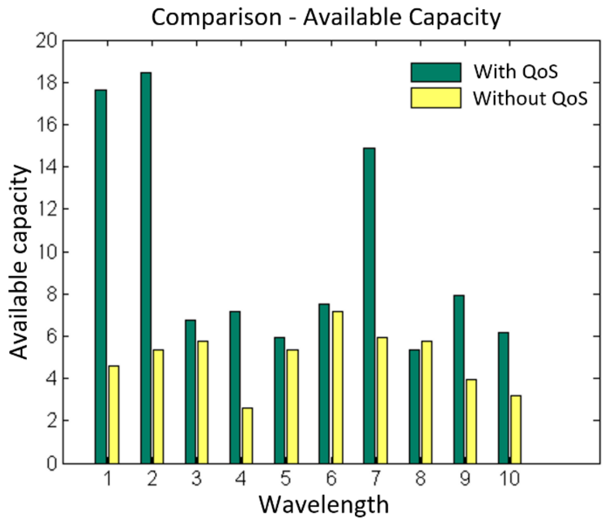

Figure 6. Percent Capacity Available

The number of Bank Splitter (BS) using the model shows a slight improvement as shown in Figure 7. On average BS requires less compared to the case when assigned not taking into account the quality of service.

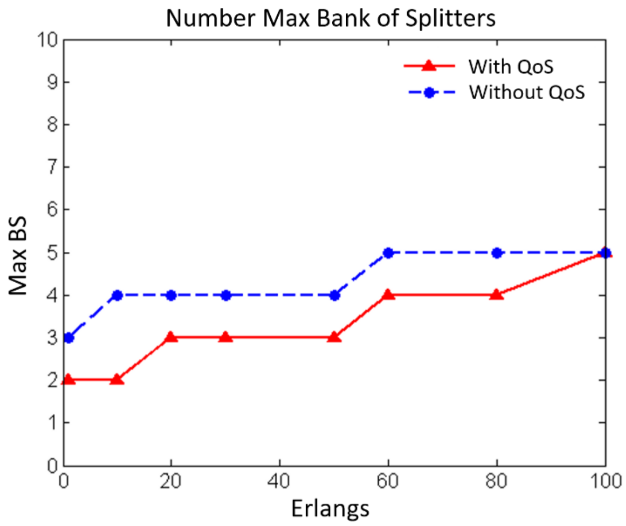

Figure 7. Maximum number Splitters Bank

CONCLUSIONS

In this article an allocation model, routing and grooming which takes account of phenomena present in the optical fiber as well as parameters of quality of service in unicast traffic and multicast type is proposed. The routing model, allocation and grooming that considers fiber dispersions and quality parameters of service (QoS) greatly improves blocking probability for traffic with medium and high priority. Furthermore, the model keeps most available capacity on the wavelengths with low dispersion, which will allow traffic with high quality requirements may be more likely to access good resources.

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