On advantages of data driven traffic classification for dynamic routing in optical networks

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***Abstract*—In this paper, we concentrate on solving the dynamic routing problem with traffic classification using the Software Defined Elastic Optical Networks framework. We first define three categories of traffic based on the CISCO Traffic Reports. Then, we propose two algorithms to solve the Routing, Modulation and Spectrum Assignment problem with the support of traffic class recognition - the Split Spectrum and the Buffer. We evaluate our approach using representative network topologies and a wide range of simulations. The results clearly show that the Buffer algorithm provisions efficiently the incoming traffic in the network. In addition, we show the reduction of request blocking for the highest priority traffic that cannot be interrupted.**

***Index Terms*—elastic optical networks, data analytics, dynamic routing, traffic classification, big data**

I. Introduction

Traditional optical networks have been developed continuously to offer more flexible technology, complex algorithms, and new technologies, such as Elastic Optical Networks (EONs) [1] or Space Division Multiplexing (SDM) [2]. However, the recent trends, such as big data, Internet of Things (IoT) and 5G networks, demand not only high - capacity optical links but a compelling and programmable control over the network. To support efficient networking with the rapidly evolving data transfers, big data's features such as Velocity, Volume, Value, Variety, and Veracity should be accommodated by the optical networks [3]. Large-scale backbone networks require great capacity and that capacity can be increased by adding more resources, such as adding more spectrum (either by changing the technology or simply providing more fiber links). On the other hand, such an approach is not efficient both in terms of planning and cost-efficiency. Instead of adding more resources, one should ask the question of how we can use data analytics to make more efficient decisions. That leads us to a concept of cognitive networks [4].

A. Key Insight

In this paper, we focus on the reduction of the overall request blocking percentage (BP), defined as the ratio of the rejected to the offered traffic to the network. By introducing optical flows classification at the network controller level (e.g. Software Defined Networking - SDN), we can more efficiently use the existing resources. The rest of the paper is divided as follows. In Section II, we define our optimization problem. Furthermore, we introduce traffic classes support in our algorithm. In Section IV, we describe our algorithms, and then we discuss the simulation setup in Section V. Finally, section VI contains results, and conclusions follow it.

B. Contributions

The following are the main contributions of this paper.

- **Approach:** We study Routing, Modulation and Spectrum Assignment (RMSA) [5] problem in EONs using Software Defined Network controller that processes requests labelled with various traffic classes, similarly to work done in [6].
- **Implementation:** We implement two algorithms to solve RMSA problem with traffic classes - simple Shortest Path First and Distance Adaptive approach, with two novel variations - using a fixed spectrum limit for classes and using requests buffer. These two techniques are described in more detail in Section V. Our implementation has fast computation time, which means it can be easily deployed to real-time optical networks operations.
- **Evaluation:** We evaluate our algorithms by utilizing a pre-existing OMNeT++ simulator [7] with publicly available networks [8].

II. Optimization problem

In the EONs, the available optical spectrum is divided into narrow frequency slices of a given granularity (e.g. 6.25 GHz, 12.5 GHz, or 37.5 GHz). The width of a slice corresponds to the bandwidth of orthogonal frequency-division multiplexing (OFDM) subcarrier. To provide an optical connection between end nodes, optical resources are allocated along with links of an end-to-end path. In order to handle requests, the Routing, Modulation and Spectrum Assignment (RMSA) problem needs to be solved [9]–[11]. The goal is to find a route, assign a modulation format and allocate spectrum for each request such that the average blocking percentage is minimized. Moreover, searching for the best routing path, it has to be remembered that different modulations have different transmission ranges and spectral efficiency [12].

Let us explore this in more details using the following example (Fig. 1). We want to allocate a request between nodes A and G with a bit-rate of 400 Gb/s.

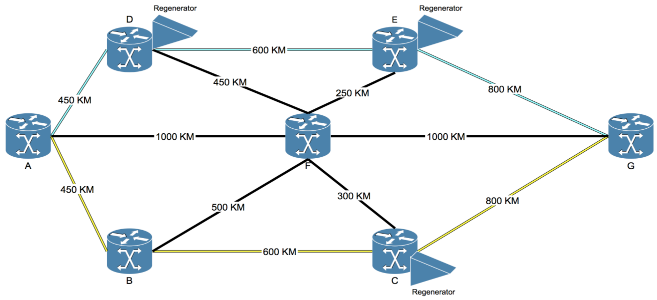

Fig. 1. An RMSA example

The procedure of dynamic RMSA is as follows. First, we want to find the best route to establish a connection. Searching for the best routing path, we have to remember about spectral efficiency, thus, transmission reach, of different modulations formats. In the Table I, we present an example that estimates the transmission reach of an optical signal in a function of the selected modulation format and transported bit-rate for 400 Gb/s request according to the physical model from [13]. Therefore, the designed RMSA algorithm must select a path and modulation format together in order to reduce BP.

TABLE I
TRANSMISSION REACH OF A 400 GB/S REQUEST, USING VARIOUS MODULATION FORMATS.

Modulation Format	BPSK	QPSK	8-QAM	16-QAM	32-QAM	64-QAM
SE[b/s/[Hz]	1	2	3	4	5	6
# slices	34	18	14	10	10	8
Range [km]	1920	1200	989	779	569	359

In our simple scenario, we choose the A-D-E-G path. The total distance between the source and the destination node is equal to 1850 km. For the case without regenerators, we could only use the BPSK as the remaining modulation formats reach transmissions limitations. On the other hand, there are available regenerators in nodes C, D and E, which we may use to regenerate the signal. Therefore, the path from A to G is divided into the following segments: A-D, D-E and E-G, with distances of 450 km, 600 km and 800 km, respectively. If we decide to use regenerators, we would be able to choose 8-QAM or 16-QAM with higher spectral efficiency.

III. TRAFFIC CLASSES

We perform an automated traffic classification, using three categories of traffic:

- Class A includes requests of the highest priority that cannot be interrupted, e.g. Video on Demand and teleconferencing. Accordingly to CISCO reports, 60% of current traffic consist of these services [14]. Therefore, requests of class A are always processed with priority. We secure 60% of spectrum links to have a dedicated space for such requests.
- Class B consists of requests that cannot be interrupted; however, the quality of transmission can be lowered to decrease the size of the used spectrum. This approach follows from the fact that many network services may accept a temporary decrease in available bit-rate. For instance, it is possible to decrease the quality of a video transmission provided by services like YouTube. Another example is related to the fact that many applications are used to make calls over the Internet, such as Skype, Facebook, WhatsApp. In current technology, the moment of deterioration of a network connection (caused by a decrease in speed or a weaker signal), the application used to make calls switches to the inferior audio codec, this reduces a delay in the transmission or prevents a connection failure. In our case, we secure 40% of the spectrum for this class, but allocate it accordingly to two scenarios, described in the next sections.
- Class C embraces requests of the lowest priority that can be transmitted with delay (for example data backups or emails sent from the SMTP server). We implement two strategies for handling this class. In the first one, we try to allocate request immediately using 15% of the spectrum width. In case of multiple requests from class C that arrive at the same time, the ones that do not fit in the available spectrum are rejected. In the second approach, we implement a request buffer inside of the SDN controller, that can store up to 1 TB of traffic. We then allocate requests from class B and C using shared spectrum. If there is no spectrum available for class C, then we store requests in the buffer. For more details, please refer to the section on Algorithms.

Requests from the respective classes could be classified by the AI module inside the SDN controller [15]. Cooperation between SDN controllers in OpenFlow standard with EON was presented in [6], [16], [17]. In our case, it is used for assigning the traffic to the appropriate class, as seen in Fig. 2.

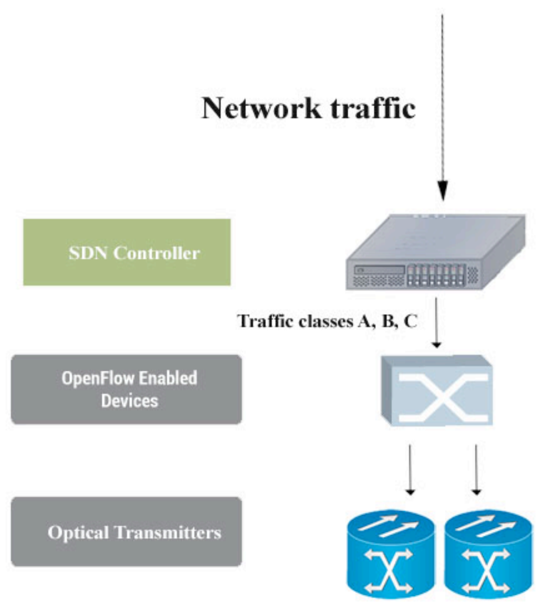

Fig. 2. Proposed requests classification.

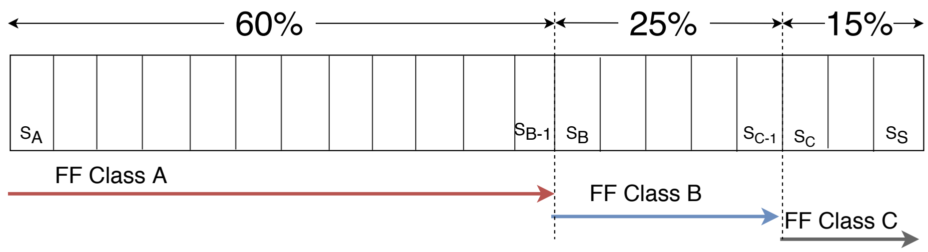

Fig. 3. Spectrum allocation for the SS algorithm; $s_A, \ldots, s_S$- indexed slices.

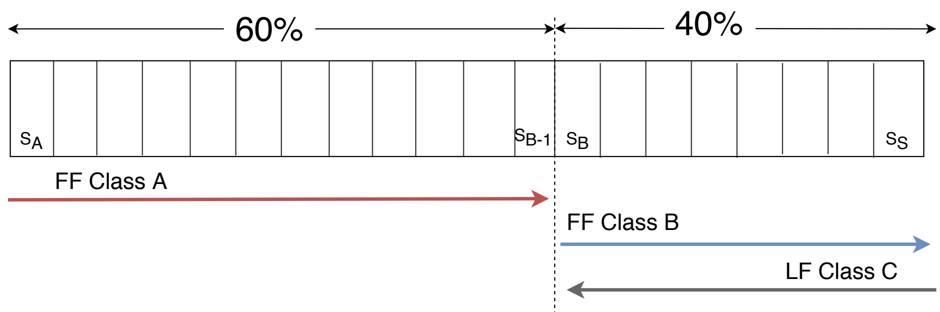

Fig. 4. Spectrum allocation for buffer algorithm; $s_A, \ldots, s_S$- indexed slices.

IV. Algorithms

We propose two algorithms with the ability to process traffic classes presented in the previous section. The goal is to make adaptive decisions on how to solve the Routing, Modulation and Spectrum Allocation problem.

To solve the dynamic routing problem with traffic classes the connection is established using one of two RMSA algorithms: Distance-Adaptive Transmission (DAT) or Shortest Path First (SPF) using two allocation strategies, Split Spectrum (SS) or Buffer (BFF). The allocation strategies are visualized in Figs. 3 and 4. Let us assume dedicated partitions of contiguous slices created for the three different classes. The class A can allocate the spectrum in range $(s_A : s_{B-1})$, class B - $(s_B : s_{C-1})$, class C - $(s_C : s_S)$. Class A is allocated using the First Fit (FF) approach in both strategies, always using the first 60% of the spectrum. Then class B is allocated using the FF approach, either on 25% of the spectrum (SS) or on the last 40% of the spectrum, sharing resources with class C (BFF).

Finally, class C is allocated using FF and the last 15% of the spectrum (SS), or using Last Fit (LF) approach on the shared 40% of the spectrum, if no requests from class B are allocated there. We also buffer requests if they cannot be allocated (up to 1 TB). We reject requests if the buffer is above 1 TB. The proposed concept can be easily implemented in SDN-based networks analogously to our previous works.

V. Simulation setup

For this study, we utilize a pre-existing OMNeT++ simulator [7]. The network topologies that we use are NSF15 (see Fig. 5) and UBN24 (see Fig. 6), which consist of 15 nodes and 46 directed links, 24 nodes and 86 directed links, respectively, and can be found in [8].

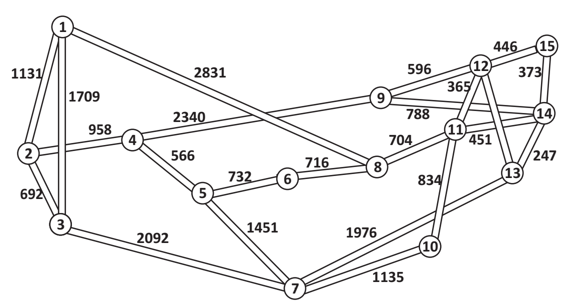

Fig. 5. NSF15 topology

For the experiment purpose, the entire band of 4 THz spectrum is divided into 320 frequency slots, each having width of 12.5 GHz. We consider the physical impairment of links and use regenerators for signals that require higher modulation formats. We use transmission model from [13]. Finally, the number of regenerators is 1000 per node in both networks. To simplify calculations, we assumed pre-computed k-shortest paths in the initialization phase, equal to 10.

Requests arrive one by one in the Poisson process with arrival rate λ and a negative exponential distributed holding time with $1/\mu$. Therefore, traffic load could be defined as λ/μ

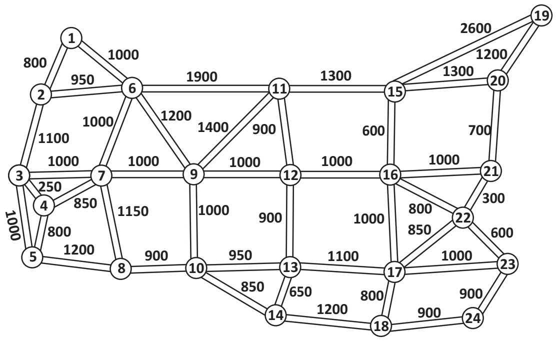

Fig. 6. UBN24 topology

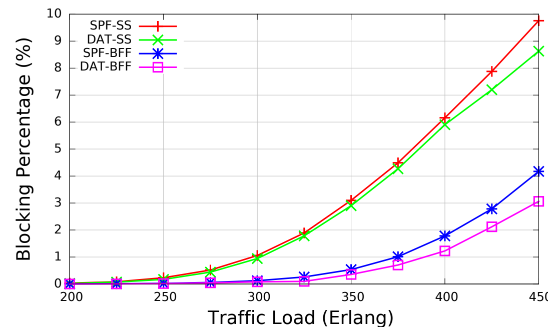

Fig. 8. Simulation results for the UBN24 network.

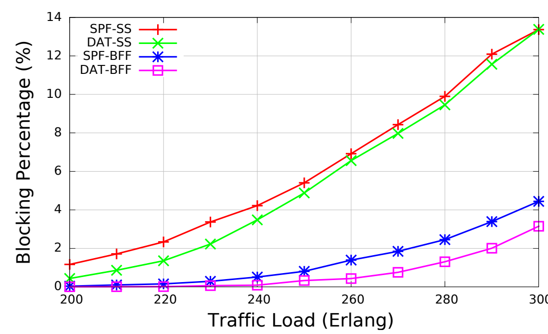

Fig. 9. Simulation results for the NSF15 network, class A only.

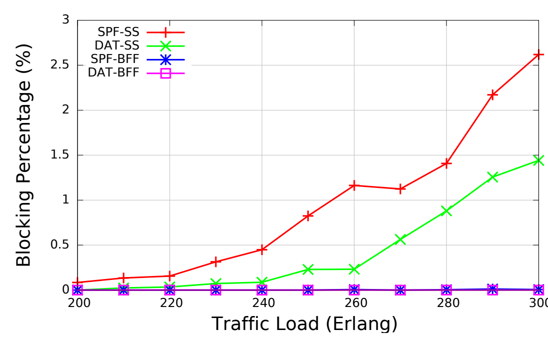

Fig. 10. Simulation results for the NSF15 network, class B only.

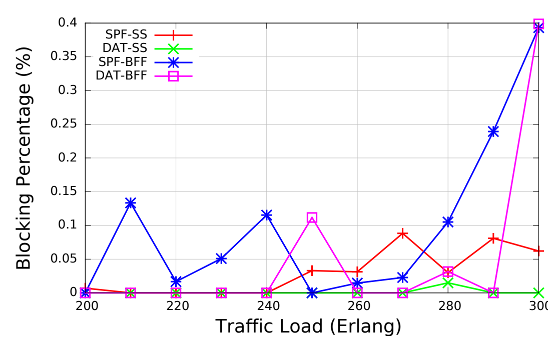

Fig. 11. Simulation results for the NSF15 network, class C only.

Erlangs. For each value of traffic load, first 5000 requests were not considered, due to the network not being in steady-state. After that, next 10^6 requests were evaluated.

There are tree types of generated requests: Class A (60% of all traffic) - 40-400 Gbps of requested bit-rate; Class B (25% of all traffic) and class C (15% of all traffic) - 10-200 Gbps of requested bit-rate, accordingly to the CISCO traffic report for the 2019 [14]. The spectrum is divided in the following way: $s_A = 0$, $s_{B-1} = 191$, $s_B = 192$, $s_{C-1} = 271$, $s_C = 272$, $s_S = 319$.

VI. Results

In this section, we present the simulation results. The main objective is to show the improvement of transmission efficiency with the use of a buffer, resulting in a decrease of the BP. In the beginning, we evaluate the performance of SS and BFF algorithms using the NSF15 network, as shown in Fig. 7. Then we proceed with simulations using the UBN24 network, as shown in Fig. 8.

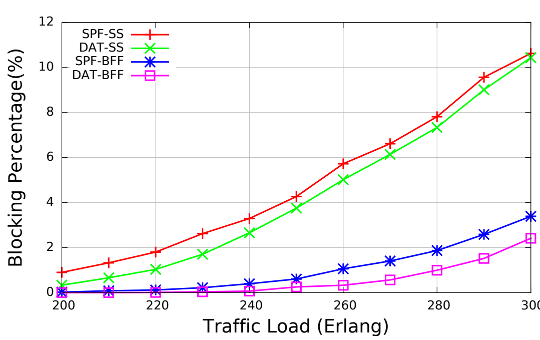

Fig. 7. Simulation results for the NSF15 network.

Based on the Figs. 7 and 8 the following conclusions can be drawn. SPF-SS provides the worst performance in terms of BP when compared to DAT-BFF and DAT-SS algorithms. Buffer mechanisms provide lower BP compared to SS for both networks. In order to understand why this is happening, we include the results for each class, in Figs. 9-11 for NSF15.

As we can see, class A is handled well in both scenarios, using SPF and DAT algorithms (see Fig. 9). The main advantage of using buffer is when we start process requests from class B and C. The buffer strategy allows to achieve almost 0% of BP for class B, while in SPF-SS and DAT-SS, we get around

2-3% of rejections (as seen in Fig. 10). Finally, requests from class C are allocated in a similar manner. Here, we observe higher fluctuations for the buffer, but this is still under 1% of BP (see Fig. 11).

Similar trends are observed when analyzing BP for each class separately for the UBN24, shown in Figs. 12-14.

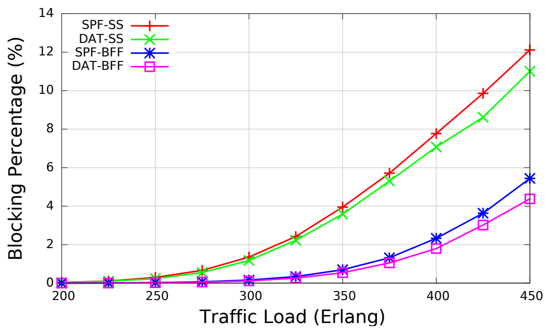

Fig. 12. Simulation results for the UBN network, class A only.

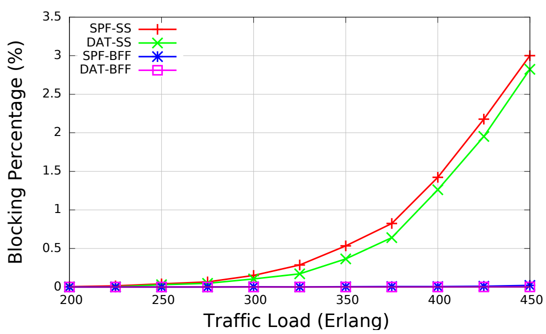

Fig. 13. Simulation results for the UBN network, class B only.

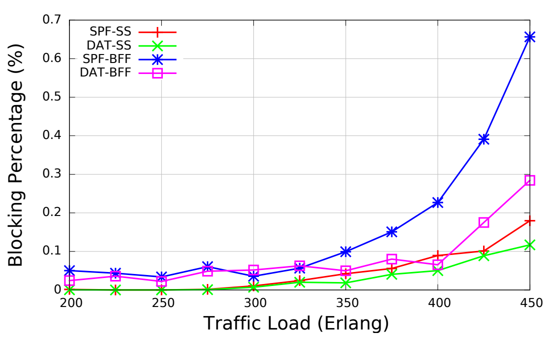

Fig. 14. Simulation results for the UBN network, class C only.

VII. Conclusions

We investigated the performance of the various algorithms to provision multi-class traffic. Presented methods have been evaluated by means of numerical simulations using the Poisson traffic model and two different network topologies.

The obtained simulation results have separately verified the performance of routing methods in terms of effective reduction of the request blocking percentage. The buffer strategy allowed to best BP for all classes of traffic.

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