Adaptive Modulation Regenerator and Distance Aware Algorithm for Dynamic Routing in Elastic Optical Networks

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***Abstract*—The Elastic Optical Network is a technology that offers versatile conversion of modulation format, allowing for more effective use of spectrum resources compared to the traditional fixed grid in WDM networks. Additionally, the content-oriented services offered by geographically distributed data centres raise a need for cost-effective and scalable data delivery. In this paper, we discuss Routing, Modulation and Spectrum Allocation (RMSA) in content-oriented networks, based on the Elastic Optical Network. We propose a new adaptive modulation, regenerator and distance-aware algorithm. Our findings discover an interesting trade-off between the request blocking and regenerator use.**

Keywords*—*elastic optical networks, dynamic routing, cloud computing, resource allocation, WAN

I. Introduction

Big data's phenomenon cannot be detached from the massive exchange of data through the Internet network. Since Facebook started in 2004, it was recorded that it has achieved a worldwide network of millions of active users. However, this brings a new challenge: extensive data transmission every millisecond in the network. Statistics show that the volume of network traffic per year increases by around 34 percent annually [1]. However, the current traditional wavelength division multiplexing (WDM) networks network can hardly allow sustaining such an increase [2]. The boom in data transfer is now inevitable, creating significant challenges for transport networks.

Thanks to the advanced technology of Elastic Optical Networks (EONs), optical society created a promising approach to effectively utilize the spectrum by allocating only adequate bandwidth to each request [3]. It is anticipated that the evolution of transport networks will lead to a mixed-line-rate Elastic Optical Network (MLR-EON) architectures or the Spectrally-Spatially Flexible Optical Networks (SS-FONs) [4]. As a result, the next-generation optical transport networks will make more effective use of network resources and, at the same time, provide flexible network access to bandwidth requirements.

A. Key Insight

This paper's main contribution is the design and implementation of two new approaches based on the Adaptive Modulation and Regenerator Aware (AMRA) algorithm [5] to solve the dynamic routing problem in optical network. The primary goal of the newly created Adaptive Modulation Regenerator and Distance Aware (AMRDA) algorithms (two versions) is to limit requests blocking in the network. To achieve the goal, we set up penalties for the candidate path based on the nodes' distances and the link lengths in the network. Two versions of AMRDA, namely AMRDA-L and AMRDA-P, are described later in this paper.

B. Key contribution

The main contributions of this paper are shown below:

- **Approach:** We study the dynamic Routing, Modulation and Spectrum Assignment problem in Elastic Optical Networks.
- **Implementation:** We implement two versions of the AMRDA algorithm, namely the AMRDA-P and AMRDA-L, to solve the problem mentioned above. The first technique is based on the system of penalties for every candidate path using the distance between the nodes and the second is based on the penalties allocated accordingly to the link lengths.
- **Evaluation:** We evaluate our algorithm by running in a CEONS simulator with two publicly available networks - Euro28 and US26 [6].

II. Related Work

Article [7] suggested a spectrum allocation scheme based on the first-last-exact fit allocation strategy for EONs to maximize the amount of available contiguous, aligned spaces, thus reducing the possibility of blocking in the network. This scheme distinguishes the disjoint and non-disjoint links by creating more balanced available slots using the first-last-exact match allocation strategy.

The paper [8] proposed a new Routing, Modulation Level and Spectrum Assignment (RMLSA) algorithm that considers the role of actual structures of EONs. The algorithm aims to reduce the possibility of circuit blocking induced by the deterioration of the communication efficiency in the development of new circuits. Overall, their algorithm obtained the highest results operating with First-Fit (FF) in terms of the possibility of blocking the circuit.

Next, the authors of [9], introduced a demand routing modulation standard and spectrum allocation (OD-RMSA). OD-RMSA leverages the design of nodes that enable both optical multicasting and collection of bandwidth variable spectrums. It increases bandwidth utilization by allocating spectrum to each network according to the intended downstream destination consumers of services of the network. Simulations demonstrate

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that the OD-RMSA approach will minimize bandwidth duplication and significantly decrease transceiver usage relative to the routing schemes.

In the [10], authors focused on the problem of routing, modulation and spectrum allocation (RMSA) in EONs based on the process of awarding spectrum, amount of resources used R and distance-to-boundary I of the chosen set of spectra. They suggested three measures, R:I policy, I:R policy and R+I policy. Results of the simulation indicate that in nearly all situations, the R+I policy will work well, relative better to the R:I policy and I:R policy.

While all the papers introduced a different spectrum allocation procedure, our primary goal is to focus on the correct sorting and selection of candidate paths. By optimizing original AMRA, we introduce new selection strategies so that the spectrum allocation can be performed much more efficiently with the various spectrum and modulation approaches.

III. Problem Description

A. Notation

In this paper, we use the same model as described in [11]. We model the physical network as graph $G(V, E, B, L)$. The V stands for a set of nodes, the E stands for a set of fiber links, and every link could accommodate at most B frequency slices (slots). $L = [l(1), l(2), l(3), ..., l(E)]$ and each $l(e)$ represents the link length for every $e \in E$. We also assume that multiple modulation formats may be used in the networks, including BPSK, QPSK, and x-QAM, where x can be 8, 16, 32, and 64. In addition, the transmission distance cannot exceed the chosen modulation transmission range. Consequently, additional regenerators (which are very expensive) are not required in the network, while the spectrum consumption is kept on a low level. The number of all regenerators in the network is defined by variable $nregs$, whereas the number of required regenerators for the request d allocated on path p, using n slices, starting from the index b is defined by reg. The path distance $l(p)$ and maximum range $dist(m)$ of each modulation $m \in M$ is compared to find the assignment that minimizes the number of regenerators and maximizes the efficiency of the modulation format, accordingly to the transmission model presented in [12].

B. Dynamic Routing

The dynamic routing problem in EONs is a well-known problem discussed in the literature [13–17]. The network receives requests in a dynamic/live matter and the routes from the source to the destination of the requests are chosen based on the whole network status. During transmission, a lightpath is set up, resources are allocated and released after the request is torn down. The network state is determined based on all the current requests in the network, hence the network system needs to accommodate the network traffic in real-time. For example, in Figure 1, A is the source and D is the destination. The blue nodes C, F, G, I, J indicate nodes with the regenerators installed. Thus, there are three candidate paths from A to D with various distances and possible regeneration schemes. If we route using the $A - G - B - C - D$ path, we can use the regenerator in node G. It will then allow us to use the most spectrally efficient modulation format from A to G, which is 64-QAM. We can also use BPSK modulation from A to C without using a regenerator. Which candidate path to choose then? In dynamic traffic, the requests in the network would fragment the spectrum resources. So in highly loaded networks, it will result in the insufficient contiguous spectrum, which would cause the request blocking. This leads us to the main problem that we try to solve - the efficient candidate path selection. To remind, we do not focus on the spectrum allocation, assuming that this is done by the First-Fit method [18]. The main optimization goal is how we can evaluate candidate paths, using existing parameters, that the network resources are used more efficiently.

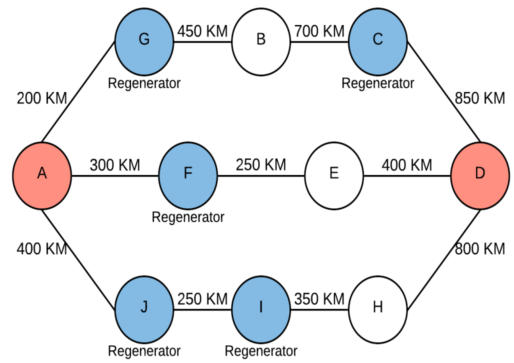

Fig. 1: Example network

IV. Algorithms

As discussed above, we modified the original AMRA algorithm [5] to include additional metrics. Those two, newly created approaches are discussed below.

A. Adaptive Modulation Regenerator and Distance Aware - Link (AMRDA-L)

The first algorithm is named AMRDA-L. The main change is that we include a distance metric to evaluate candidate paths based on the link length relative to the shortest link length. The AMRDA-L algorithm's operation is presented as a flowchart in Figure 4.

The algorithm's first step is to update the available spectrum on each link and initialize all variables. In the next step, we calculate k candidate paths using Link Utilization Metric (LUM) described in [5]. Then, we proceed to the first loop. We merge all the path fragments (links between nodes) without regenerators and sum their lengths for each candidate path. For example, in Figure 2, node C does not have a regenerator, so it is being removed from the path and paths are merged as can be observed in Figure 3.

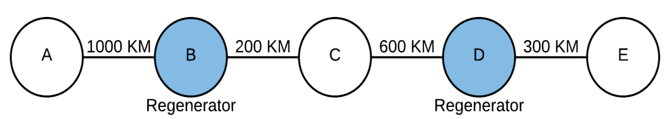

Fig. 2: Network before merging path fragments

Once paths are ready, we try to allocate the most spectrally efficient modulation format that supports the candidate path's length. E.g., in Figure 1, in order to establish the connection between A and D, using the following path fragments: $A - G$,

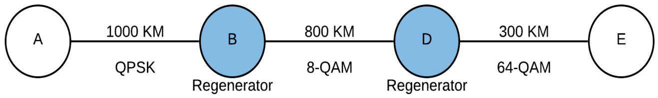

Fig. 3: Network after merging path fragments

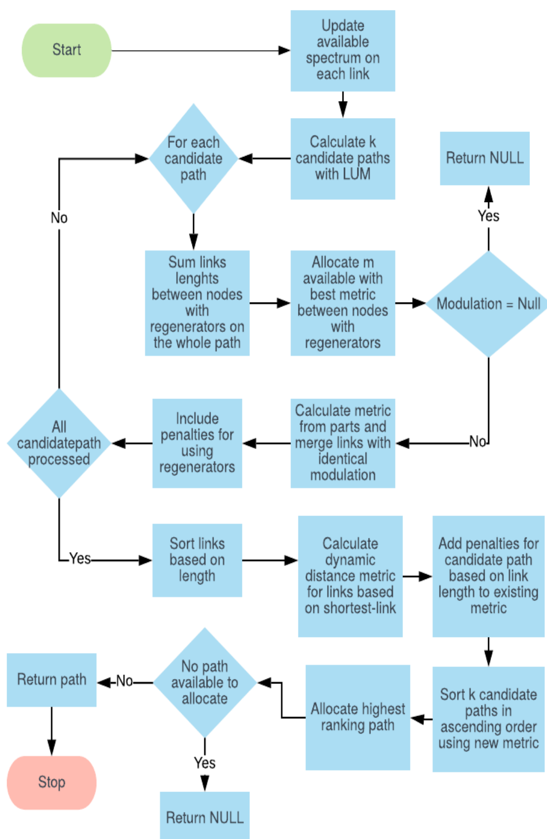

Fig. 4: AMRDA-L Algorithm

$G-C$ and $C-D$, we need to transmit for 200, 450 and 700 km, respectively. The request is rejected, if modulation does not support this requirement. Please note that the modulation can be changed in nodes with regenerators. Finally, we include the penalties for using the regenerators and proceed to link length metric calculation and candidate path sorting.

First, the candidate links are sorted based on their lengths. Formula 1 is used to calculate the distance metric for each link. While computing the distance penalty, the shortest link is given the lowest penalty and the penalty linearly increases with the link length in the path. Penalties for each candidate path are calculated based on the metric assigned to links in that particular candidate path and are added to the existing path ranking metric, calculated earlier. In the end, candidate paths are sorted in ascending order using the new metrics. If allocation fails on the path segments, we keep looking for the path which can be allocated, until k candidate paths are exhausted. In the final step, if the working path is not $null$, we return that path to establish a connection; otherwise, we return null and increase the request blocking percentage.

Formula 1:

$$DistanceMetric = \frac{LinkLength}{ShortestLinkLength}$$

B. Adaptive Modulation Regenerator and Distance Aware-Path (AMRDA-P)

In AMRDA-P, we have followed the same steps as in AMRDA-L, but we calculate the metric based on the total path length rather than path fragments, as seen in Formula 2.

Formula 2:

$$DistanceMetric = \frac{PathLength}{ShortestPathLength}$$

The flowchart presented in Figure 5 presents steps for the operation of AMRDA-P. As mentioned above, the main difference is that we sort the candidate paths based on their path lengths and we are computing the distance metric using Formula 2 for each of the candidate paths.

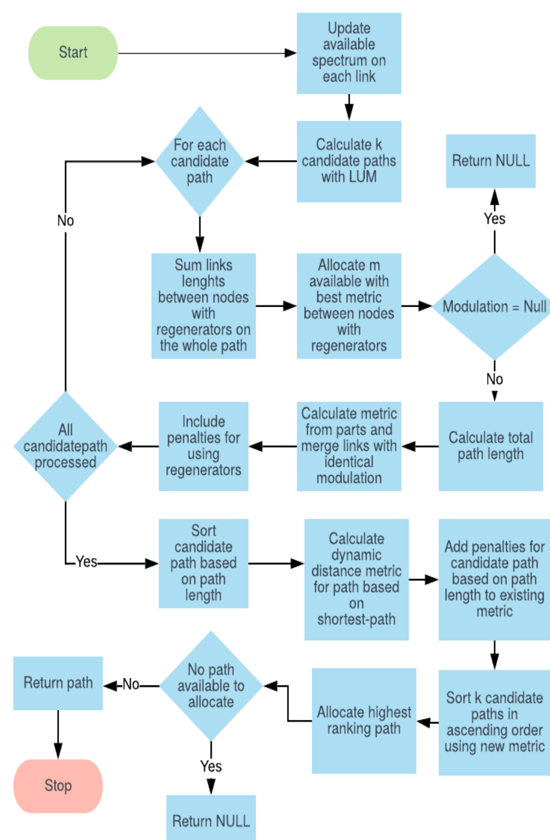

Fig. 5: AMRDA-P Algorithm

V. Simulation Setup

In the simulations, we use a pan-European Nobel-EU network comprising 28 nodes and 82 direct links (called Euro28), and a US regional backbone network consisting of 26 nodes and 84 direct links (called US26). Notice that for Euro28 and US26 networks, the link's average length is 610 km and 754 km, respectively. Each network has three points of interconnection to external networks used to transport international traffic, as seen in Figure 6 and Figure 7.

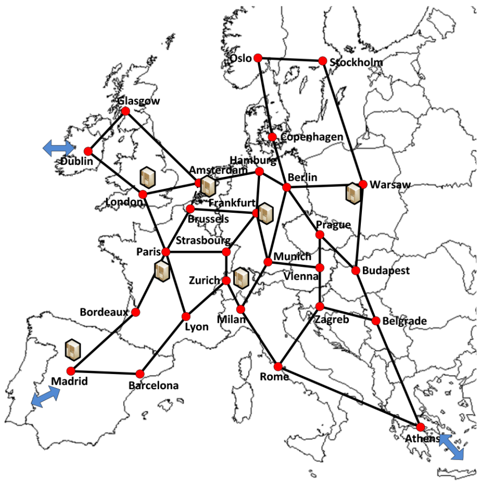

Fig. 6: The Euro28 network topology

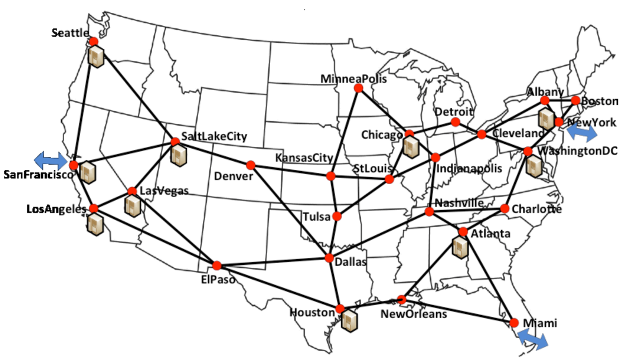

Fig. 7: The US26 network topology

The regenerator location is set upon simulation initiation and is equal to 100 regenerators per node. Data centers are allocated in the nodes marked with the server icon. The entire spectrum of 4 Thz is divided into 320 slices. The model is created under the predictions in the reports of the "Cisco Visual Networking Index" and "Cisco Global Cloud Index"; it shares the traffic forecasts from 2020 [1]. We assume the requests will have some lifetime, after which they will be torn down. The requests arrive one by one, using a Poisson cycle with an average time-unit arrival rate of λ requests. Every request's lifespan follows a negative exponential distribution with an average of $1/\mu$. Accordingly, the load of traffic is λ/μ Erlangs (ER). In the dynamic scenario, the number of requests is 200,000. We remove the first 5000 requests from the assessment, as the network is not in a steady-state. Finally, there are four types of requests generated:

- City – City (CC) (7.1 percent of all traffic, 10-100 Gbps of requested bit-rate)
- City – Data Center (51.8 percent of all traffic, 10-200 Gbps)
- Data Center – Data Center (DD) (21.1 percent of all traffic, 40-400 Gbps)
- International (IN) traffic – (20 percent of all traffic, 10-100 Gbps)

VI. Results

The experiments' primary objective is to evaluate algorithm efficiency for the Routing, Modulation and Spectrum Assignment (RMSA) problem in EONs. First, in Figures 8 and 9, we are comparing baseline algorithms, such as Shortest Path First (SPF) and AMRA and two newly developed AMRDA-L and AMRDA-P in terms of Request Blocking Percentage (BP) for the Euro28 and US26 network topologies. It is observed from both Figures that the AMRDA-L and AMRDA-P outperform the baseline solution, which is SPF. The first instance of request blocking is detected around 800 ER, which is already considered a high traffic load scenario.

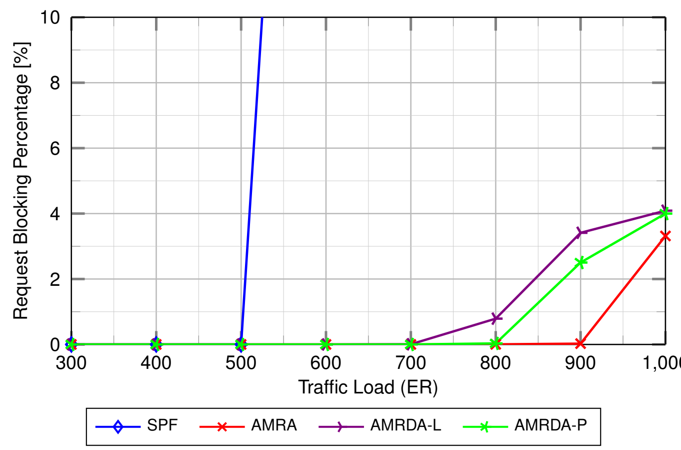

Fig. 8: Blocking percentage for the Euro28 network

The trends for US26 are similar (presented in Figure 9). The reason behind them is that SPF chooses the shortest path possible with no regard to regenerator usage, which leads to blockage of regenerators. On the other hand, all three AMRA versions achieve the lowest BP as they choose the best trade-off between distance and regenerator usage with particular modulation selection.

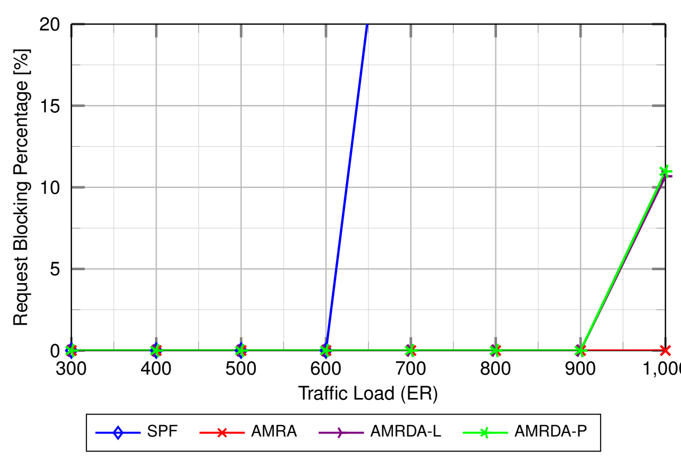

Fig. 9: Blocking percentage for the US26 network

As our approaches' performance is similar to the AMRA, we want to learn more about how algorithms use the existing resources. First, we compare the average modulation usage for all algorithms, in Figures 10 to 16. First, let us focus on the SPF method. We can see that SPF chooses the shortest path available without the focus on modulation - it always selects QPSK throughout different traffic loads. It explains higher BP as QPSK provides a larger transmission range but lower spectral efficiency and as a result, we need more spectrum and regenerator resources. Please note that the results for SPF using the Euro28 and US26 networks were the same, thus, we present only the ones for Euro28.

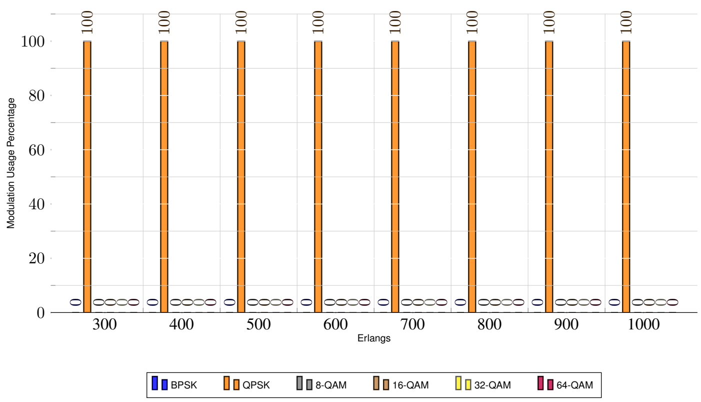

Fig. 10: Modulation usage using SPF algorithm - Euro28

Next, we focus on the AMRA method (Figures 11 and 12). From the graph, we can deduct that the usage of BPSK is gradually decreasing with the increase in traffic load, whereas 8-QAM and 16-QAM usage is increasing with the increase in traffic load. This behaviour is understandable as traffic increases the demand for more bandwidth, thus, makes the usage of more spectrally efficient modulations suitable for such transmission.

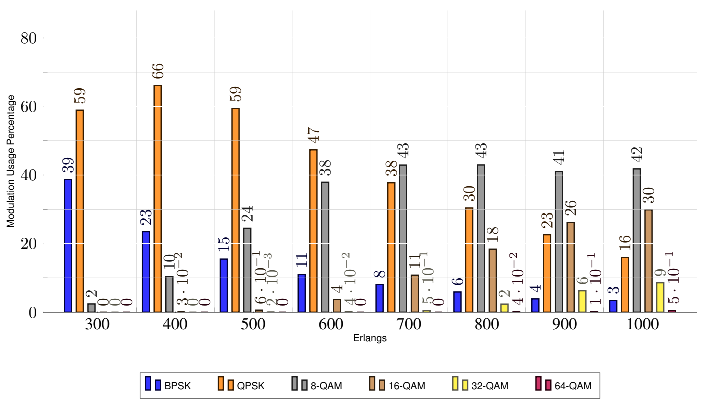

Fig. 11: Modulation usage using AMRA algorithm - Euro28

We also compare the average modulation usage percentage for different modulations using AMRDA-L and AMRDA-P algorithm. The usage of modulation is similar to that of AMRA, though it uses more spectrally efficient modulations, such as 16-QAM and 32-QAM more often than standard AMRA, which benefits routing.

Finally, we checked the utilization of another resource available in the network - regenerators, shown in Figures 17 and 18. We can observe that AMRDA-L and AMRDA-P algorithms are outperforming AMRA and SPF by utilizing the regenerators better. We can also observe that AMRDA-P shows the best

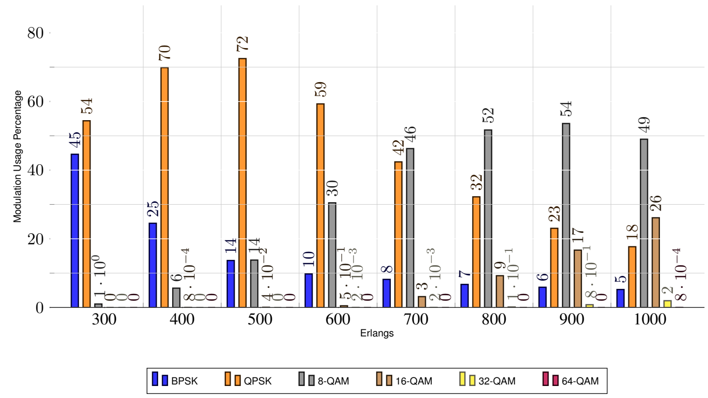

Fig. 12: Modulation usage using AMRA algorithm - US26

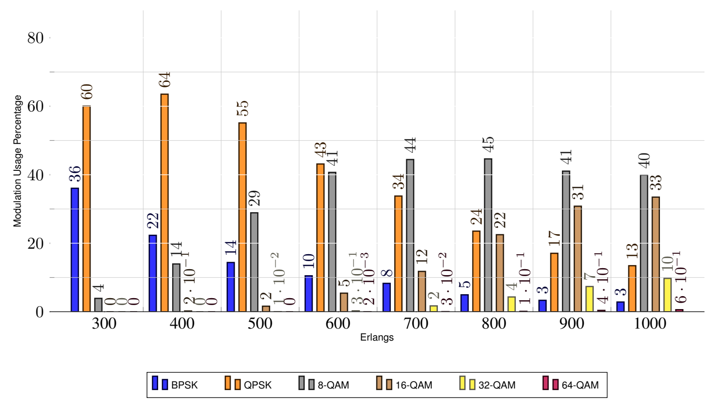

Fig. 13: Modulation usage using AMRDA-L algorithm - Euro28

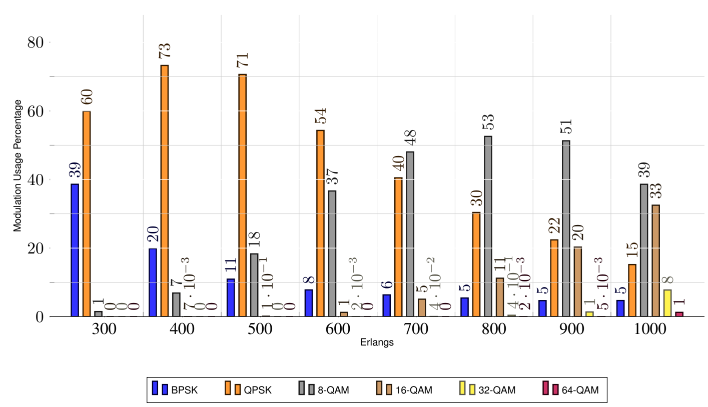

Fig. 14: Modulation usage using AMRDA-L algorithm - US26

utilization of regenerators when traffic reaches 1000 Erlang, which means that this approach is highly suitable for highly congested networks.

VII. Conclusion

In this paper, we applied various techniques to solve the dynamic routing problem in Elastic Optical Networks. Our methods aim to avoid request blocking and we developed two algorithms to achieve that. Both techniques that we developed were able to solve the dynamic routing problem for EONs efficiently and keep the blocking percentage on a low level.

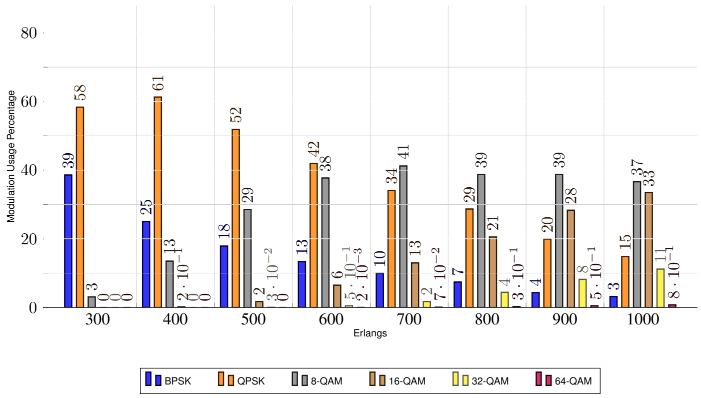

Fig. 15: Modulation usage using AMRDA-P algorithm - Euro28

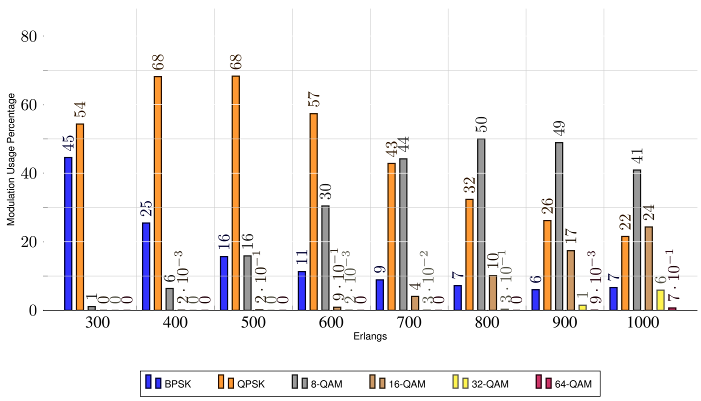

Fig. 16: Modulation usage using AMRDA-P algorithm - US26

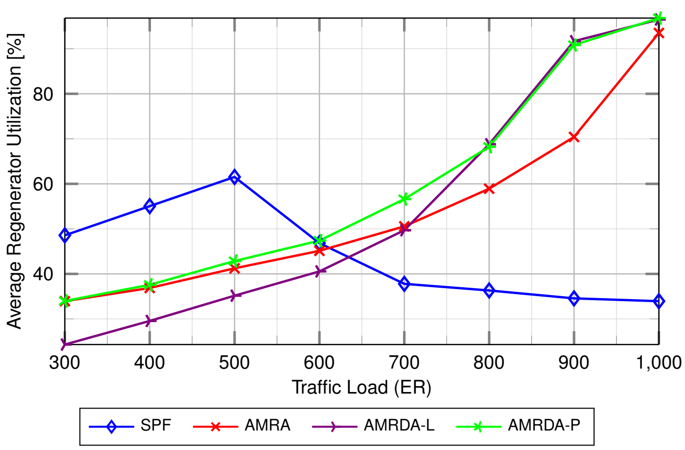

Fig. 17: Regenerator Usage for Euro28 network.

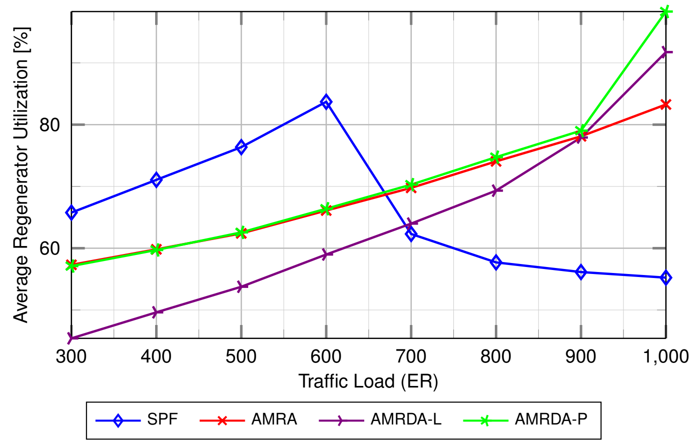

Fig. 18: Regenerator Usage for US26 network.

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