New Distance-Adaptive Modulation Scheme for Elastic Optical Networks

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Costa, Lucas R., and André C. Drummond. "New distance-adaptive modulation scheme for elastic optical networks." *IEEE Communications Letters* 21, no. 2 (2017): 282-285.

Goals

- ➢A key feature of EON is that modulation format and spectrum can be adaptive allocated and adjusted according to the distance and capacity requirements
- ➢A novel approach to address the routing, modulation level, and spectrum allocation **(RMLSA**) problem through the use of a **distance-adaptive modulation** scheme that enables the routing of traffic through **multiple hops in virtual topology**, enabling smoothing out the **spectrum continuity and transmission distance constraints.**

RMLSA

To further improve spectrum utilization efficiency, EON literature have incorporated quality of transmission (QoT) or transmission reach awareness into RSA solutions. This has turned the RSA problem into routing, modulation level and spectrum assignment (RMLSA) problem, which includes the attribution of the modulation format considering transmission distance

RMLSA problem into its sub-constituent problems, namely

(*i*) modulation format assignment; and

(*ii*) RSA algorithm execution, through multi-hop routing.

Adaptive Modulation Multi-hop Scheme (AMMS)

Aims to assign appropriate modulation levels associated with a suitable number of hops on accepting a connection request.

AMMS Implementation

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1. AMMS characterizes the network in reachability zones.
2. It implements the reachability zones through auxiliary graphs which represents the relative reach of each node for a particular modulation level.
3. Each edge in specific modulation topology is constructed using the shortest path between nodes and should also satisfy the modulation level reach to provides an acceptable QoT in network.

AMMS Implementation

1. Figure 1 shows virtual modulation topologies for a7-node sample physical topology.

2. BPSK and QPSK modulation formats were considered allowing maximum reaches of 8000 and 4000 km, respectively.

3. The edge weight is the shortest distance between nodes (the sum of edges weights which composes the shortest path).

4. For example, consider a connection request from P1 to the P4, you can accept the connection to only one optical path (*B*1→*B*4) in BPSK modulation, however it requires at least two optical paths (*Q*1→*Q*2→*Q*4) to meet the connection with the QPSK modulation.

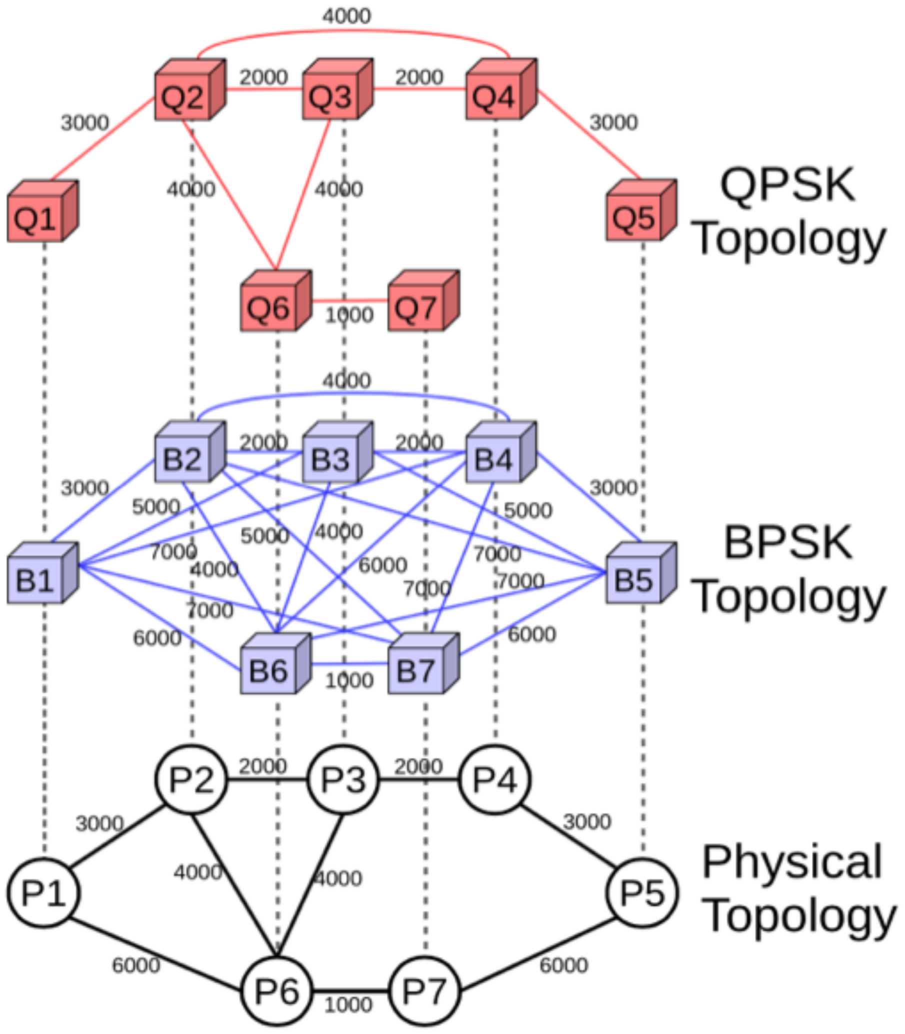

Fig. 1. Examples of virtual modulation topologies for a 7-node topology. Edge weights are set in kilometers.

Constraints to Consider

Limit on Number of Articulation Nodes

$\omega(s,d,k,m)$: returns a path composed by the source and destination nodes, *s* and *d*, and additional articulation nodes between them for a specific m modulation topology and k shortest path.

Each crossing in each articulation node represents a Optical-Electrical-Optical (O-E-O) conversion or, in other words, one hop in the virtual topology.

In order to choose the appropriate modulation level, a specific number of articulation nodes must be calculated, since many articulation nodes will bring up many virtual hops. To this end, we define a **multi-hop constraint factor (*MHC*).**

Constraints to Consider

- The *MHC* factor is a control mechanism to set the appropriate number of virtual hops in AMMS scheme. Moreover, *MHC* also provides the choice of the modulation level for the RMLSA solution.

$$MHC = \left\lceil \frac{dia \times 0.25}{Reach(max M)} \right\rceil + 1$$

where "*dia*" is the network diameter and "*Reach*(*maxM*)" represents the network reach of the best modulation format, which is defined here as the most spectrally efficient modulation available. the constant 0.25 was Empirically defined by simulation analysis considering several topologies and network scenarios.

AMMS Scheme

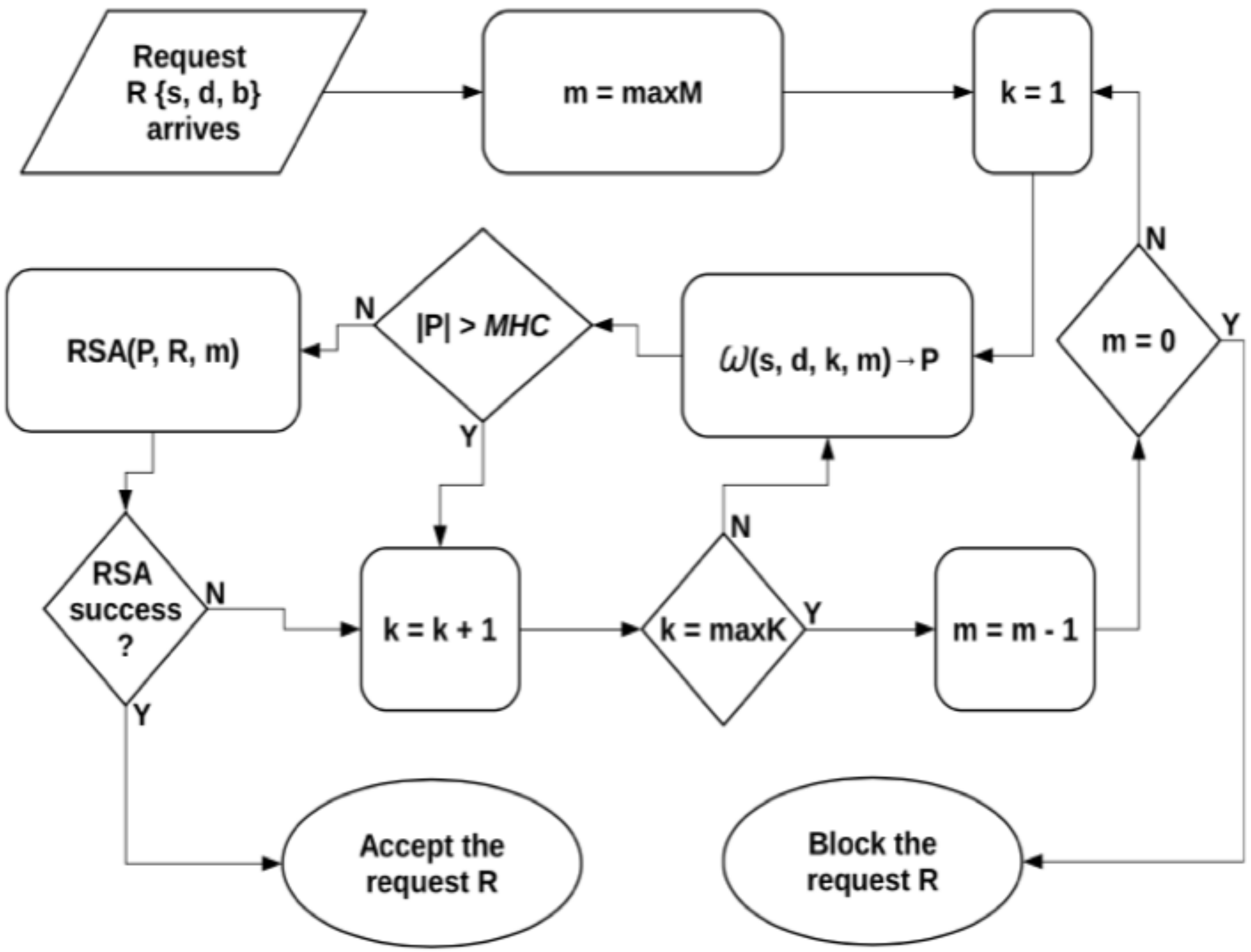

Fig. 2. Distance-adaptive modulation scheme - AMMS.

Performance Evaluation

- mAdap : *m Adaptive RSA algorithms*, called *mAdap*, which iterate through possible modulations, in decreasing order, applying the RSA algorithm until a solution is found.
- KSP using K-shortest paths routing, first-fit RSA algorithm,
- MSP is modified Dijkstra algorithm by introducing the spectrum intersection into the algorithm process
- SPV is a path vector tree with spectrum constraint to search the global optimal route.
- FPA uses disjoint shortest paths routing to uses the optical traffic grooming approach and K-shortest paths routing to establish new optical path.

Assumption and Parameters

- ONS network simulator
- Each simulation run involved 10^5 requests with 6 types of connection requests: 25 Gbps, 50 Gbps, 100 Gbps,200 Gbps, 300 Gbps, and 400 Gbps, with their proportion being 6:5:4:3:2:1, respectively.
- USANet topology, with 24 nodes and 43 bidirectional links was used in the simulation.
- The granularity of frequency slot is 12.5 GHz with a total of 320 slots in each fiber.
- Guardband of 2 slots

Assumption and Parameters

- Each node is the BV optical cross-connect (BV-OXC) equipped with sufficient BV-transponders, each with a maximum capacity of 32 slots.
- The modulation formats considered were BPSK,QPSK, 8QAM e 16QAM with 1, 2, 3, and 4 bits per symbol, respectively
- the maximal distances are 8000, 4000, 2000, and 1000 km, in the same order.

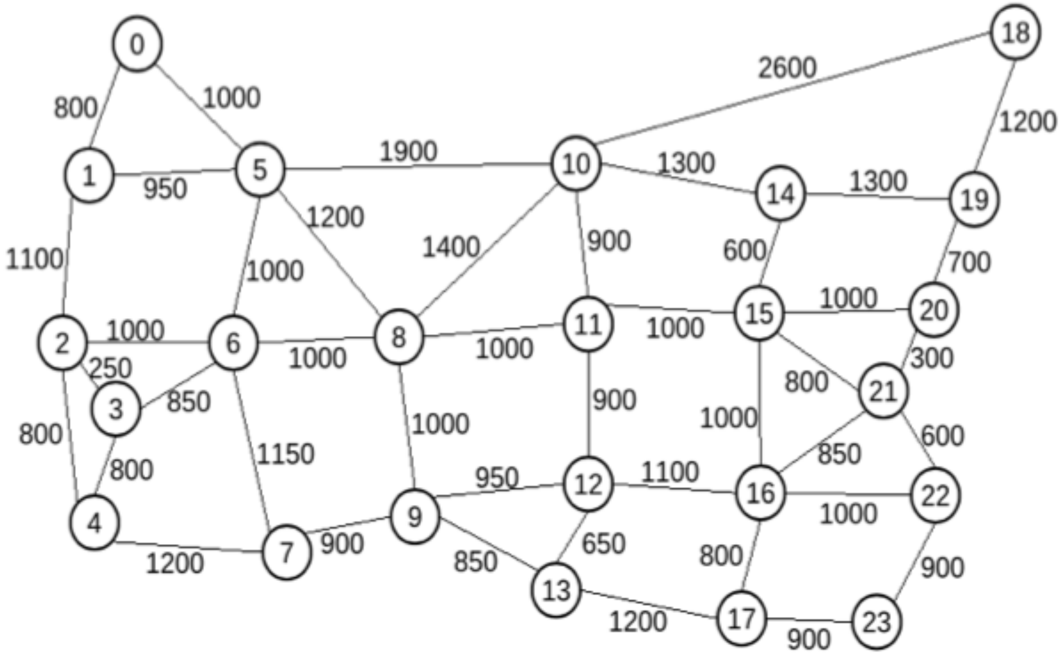

Fig. 3. USANet topology.

Results

- We observe that the BBR performance of all algorithms in AMMS schema achieve better performance than *mAdap*, up to 82%, for all RSA algorithms considered. That is because the AMMS scheme, limited by the *M H C* factor, provides to the RSA algorithms more opportunities to accept requests.

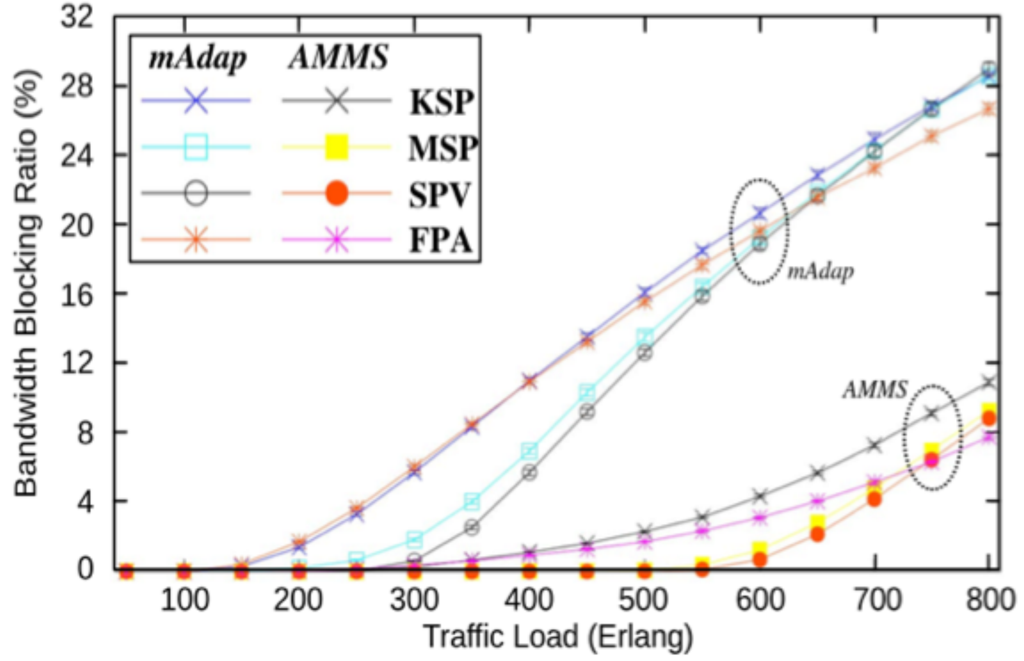

Fig. 4. Bandwidth blocking ratio (BBR).

Results

- The average number of virtual hops (Fig. 5) indicates how many Optical-Electrical-Optical conversions and electric processing are applied to connections. The algorithms under the *mAdap* scheme keeps in any traffic load an average of 1,since these algorithms, and *mAdap*, are single-hop. For the AMMS results, we observe roughly the same average of 1.75 virtual hops per request for all algorithms, regardless of the traffic load. This result evinces the capacity of the AMMS scheme to assure a solution with fewer hops, avoiding the allocation of paths with an excessive number of O-E-O conversions. This attests the efficacy of the *MHC* factor, which bounds the use of the multi-hop routing. Such capability contributes to lower the overall network latency.

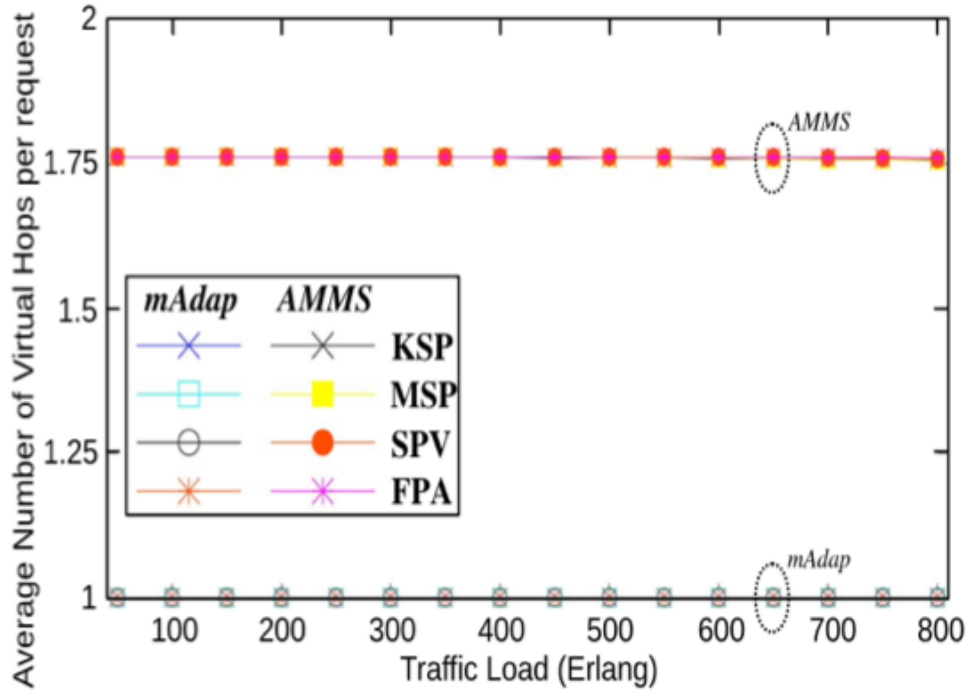

Fig. 5. Average number of hops in the virtual topology per request.

Results

- The spectrum availability ratio (Fig. 6) reflects the usage of spectral resources in the network, higher values mean more spectrum is available to handle increasing traffic(in the future). It is clear that AMMS schema has from 2% to7% less spectral usage than the *mAdap* schema throughout the evaluated traffic loads. This is because AMMS takes advantage of the modulation levels available in the network providing the use of best modulation level without increasing the number of virtual hops.

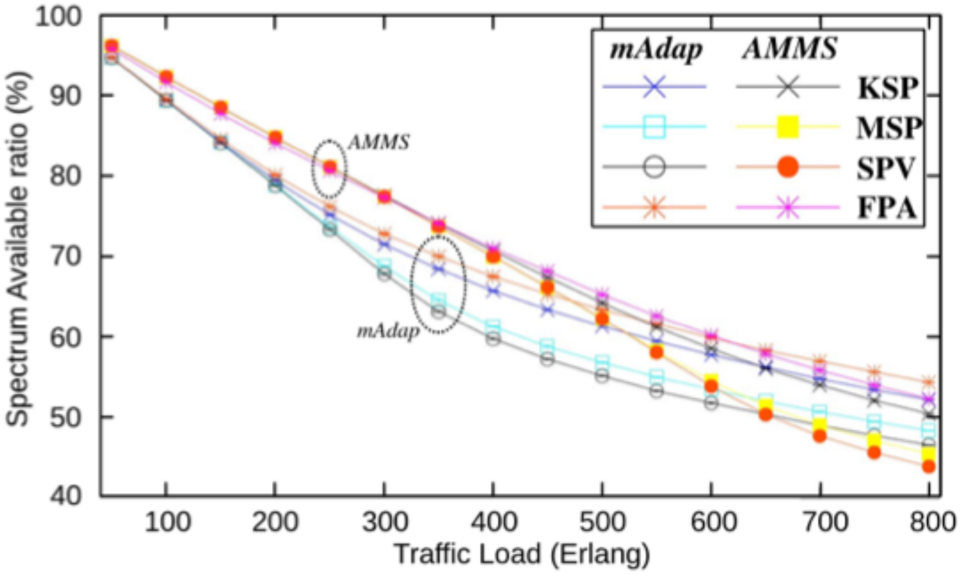

Fig. 6. Spectrum available ratio.

Analysis

TABLE I

AVERAGE RATE OF MODULATION USED (%)

	Modulation	KSP	MSP	SPV	FPA
mAdap	*BPSK*	23,45	24,88	25,62	23,08
	QPSK	42,34	41,39	40,99	41,22
	8QAM	21,72	21,40	21,17	22,98
	16QAM	12,49	12,33	12,22	12,72
AMMS	*BPSK*	0,11	0,14	0,01	0,04
	QPSK	35,90	36,41	36,60	36,26
	8QAM	41,33	41,01	41,00	41,21
	16QAM	22,66	22,44	22,39	22,49

Conclusion

Simulation results demonstrated that the use of the adaptive modulation scheme proposed provides a gain up to 82% in the bandwidth blocking rate using 7% less spectral resources in the network