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Routing and spectrum assignment in flexible optical networks using hybrid transponders

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ABSTRACT: The continuous growth of IP traffic in combination with other emerging high rate applications, such as high definition TV, video on demand, cloud computing and grid applications require more scalable and cost-effective networking infrastructure. To cope with this ever increasing bandwidth demand, we are moving towards more sophisticated communication systems, advanced modulation schemes, resources flexibility and more intelligent devices. While moving toward more agile networks flexible resources have clear edge on static resources in terms of reconfigure ability without manual intervention but this solution is not cost effective though. However high cost of flexible and intelligent resources has drawn attention toward hybrid environment where flexible resources join already existing infrastructure to meet bandwidth demands. This study is supported by simulative results derived from a sample optical network. The results give an insight of the spectrum resources utilization and efficiency benefits that can be obtained using hybrid transponder schemes in optical networks.

KEYWORDS: 400G systems, RAMAN, EDFA, Frequency Slots, Resource utilization, QAM, Simulations, Network Planning.

1 INTRODUCTION

Networks today must support a variety of traffic types, including legacy traffic based on regional SONET ring structures that require multiple traffic adds/drops (that is, voice, asynchronous transfer mode [ATM], frame relay) but must also support high-speed Internet backbones that are typically express lanes that require little add/drop multiplexing. Deploying the hybrid Raman amplifier and erbium-doped fibre amplifier (EDFA) amplification application in the L-band enables extended long-haul reach for this express Internet traffic, while still allowing deployment of the C-band as traditional long haul for legacy-type traffic, a deployment that requires multiple traffic add/drop sites. This mix of traditional long haul in the C-band and extended long haul in the L-band allows for better network flexibility. The ongoing advances in photonic technologies, such as optical multilevel modulation, optical orthogonal frequency-division multiplexing (OFDM) [2], and the seamlessly bandwidth-variable wavelength selective switch (WSS) [5] make it possible to treat optical fibre as a sharable continuous resource pool. Taking advantage of these concepts, a highly efficient spectrum resource allocation scheme adaptive to the client data rate in SLICE has been realized using the concepts of sub wavelength, super wavelength, and multiple-rate accommodation including future novel bit rates. In addition, spectrum resource allocation adaptive to the available spectral resources on the route is highly appreciated and enables flexibility in a network.

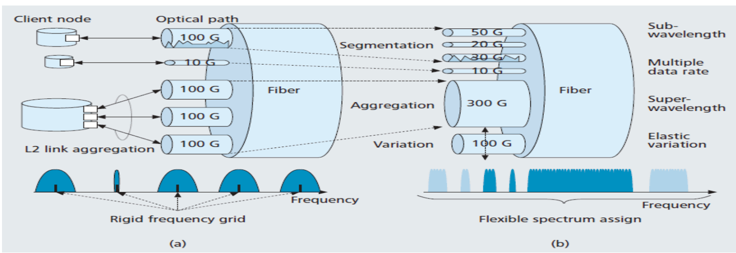

Figure 1.1 Static vs. Flexible spectrum assignment

In this work, we have evaluated how the performance of a transponder (i.e. its optical reach at a given data rate) influences the number of required spectrum resources in a realistic network scenario using different routing algorithms. Introducing 1+1 protection in the network even increases the margin of dynamic data rate DWDM compared with static data rate DWDM. We have presented a cost comparison for adaptive data rate transponders and traditional static data rate transponders which show a remarkable cost reduction capability of nearly 50% for adaptive flexible transponders.

2 EXPERIMENTAL SETUP

100 G systems are in market to fulfill the increasing demand of new services and 400 G systems are seeking their way to market. They are supposed to improve the economics and performance of 100G systems - broadening and accelerating 100G market adoptions. As 400 G innovation is seen as the gateway to a long, successful future. In this proposed study we are focusing on 400 G systems.

2.1 NETWORK MODEL

Network model considered is consisting of 30 nodes connected with each other in a unidirectional orientation. Each link between two pairs consists of 80 frequency slots. Number of slots assigned during connection setup is based on QAM flavour. Two different amplification scenarios (EDFA and RAMAN (+EDFA)) are considered, guaranteeing different optical reach.

QAM Flavour	EDFA Reach ability	Raman Amplifier Reach ability	No. of Slots
64 QAM	263 km	300km	3 slots
16 QAM	590 km	700km	5 slots
4 QAM	1457 km	1800km	9 slots

Listing 2.1 Statistics for 400 G with QAM Flavours, EFDA and RAMAN based amplification

Following topology is used in this research activity. This is layout of Spanish national backbone network and is named as Spanish topology.

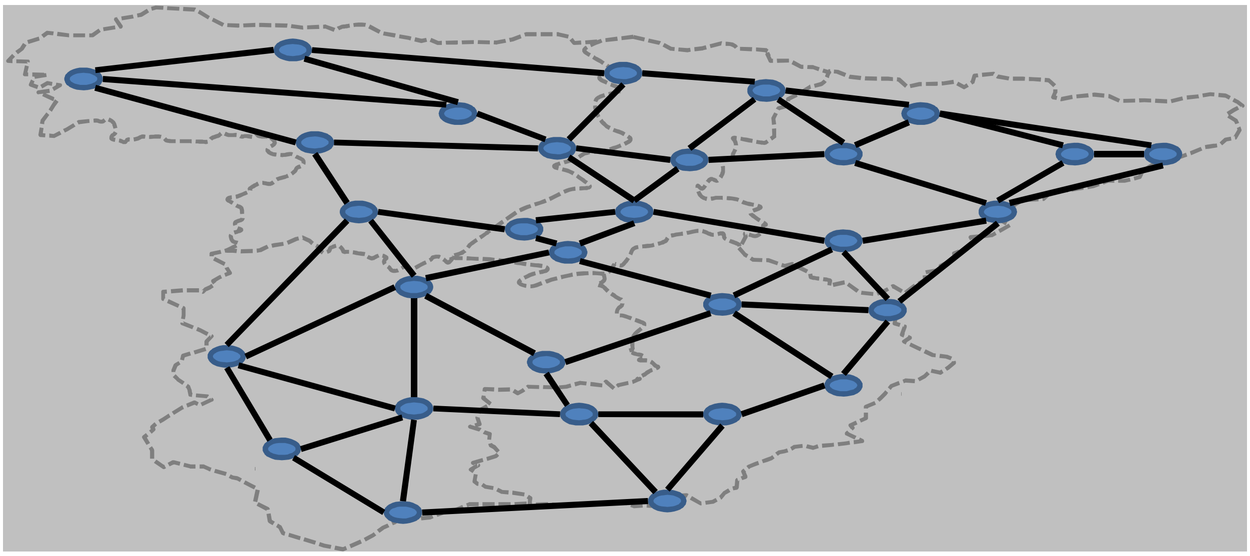

Figure 2.1 Prototype Topology

Based on reach estimations provided in Table (2.1) the RWA decides which flavour to use and how many slots to occupy. As light path is established for both primary and backup paths we have to make a decision about transponder type. If path length of backup path and primary exists in different QAM flavours we have two choices either to choose static transponder or flexible one. The first choice is cost-effective but expensive in terms of resource utilization while the second choice is optimum in terms of resource utilization but with increased budgeting due to higher complexity of flexible technologies.

RWA scheme is applied to identify the resources guaranteeing the adequate signal quality while solving the wavelength/slot contention issue. Results show that the number of resources required for the flexible network is much less than compared to the network with static transponders.

2.2 ROUTING AND WAVELENGTH ASSIGNMENT STRATEGIES

For each simulation a random traffic matrix is generated on the above topology. This helped us to collect very diverse statistics. Different routing schemes have been considered. In each of the following routing scheme we used First Fit (FF) strategy for resource allocation.

1. Shortest Path first (OSPF)(primary path)
2. Shortest (+1) path first (Backup path)
3. Shortest distance first
4. Longest distance first

However this study is based on single data rate system. We are using 400 G system to analyze resource utilization considering EDFA and RAMAN (+EDFA) amplifications. We are focusing on performance evaluation of static and flexible transponders.

3 RESULTS AND DISCUSSION

Here we are giving statistics calculated during this study and research activity using EDFA and RAMAN Amplifiers. Based on the reach ability constraints, if active and backup paths can be accomplished using same number of slots we will use a static transponder otherwise a flexible transponder would be used. But this is purely based on network model. So every time we use a different network model we will have different listings.

3.1 TRAFFIC MATRIX GENERATION AND RESOURCE ALLOCATION

For resource utilization statistics each simulation is done for dynamic traffic matrix and thousands of connection establishment requests. Here each simulation consists of 5000X 50 requests. So there are 250,000 requests to be established. A request is established using static transponder if resource allocation needs equal number of spectrum resources for both active and backup path, otherwise we use flexible transponder. Following results indicates the resource utilization for 10 simulations which are averaged for 50 requests. As we are using two types of amplifiers EDFA and RAMAN amplifiers in this study and their reach-ability is different from each other. So we calculate their statistics separately for static transponders and hybrid transponders scheme (static + flexible). Following listing shows results of 10 simulations each consisting of averaged 50 requests.

No. of Static Transponders	Hybrid Orientation Static | Flexible		Resource used with all static transponders	Resource used with hybrid transponders
50	37	13	5921	3192
50	31	19	5116	2070
50	30	20	5099	1839
50	34	16	5912	2307
50	32	18	4838	2124
50	30	20	4851	1780
50	27	23	5913	1904
50	33	17	4705	2074
50	32	18	4772	3102
50	31	19	5968	2909

Listing 3.1 Resource utilization using EDFA

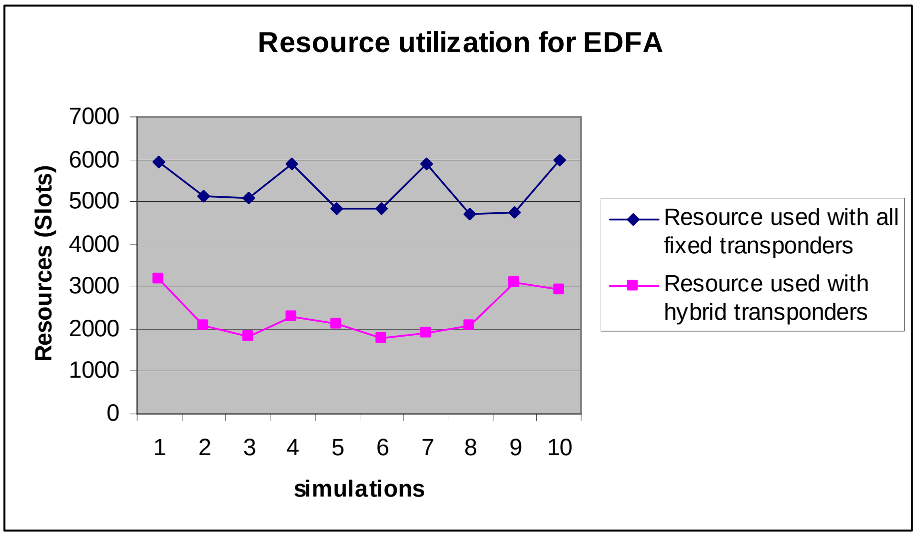

Figure 3.1 (EDFA) Resource utilization graph

Following listing shows overall resource utilization using static and hybrid transponders with RAMAN amplification scheme.

No. of Static Transponders	Hybrid Orientation Static |	Flexible	Resource used with all static transponders	Resource used with hybrid transponders
50	32	18	5848	2631
50	35	15	5324	2328
50	31	19	5907	2588
50	34	16	4009	1679
50	33	17	5595	2416
50	32	18	4879	2165
50	34	16	6390	2766
50	33	17	3856	1701
50	32	18	5477	2320
50	33	17	5143	2018

Listing 3.2 Resource utilization using RAMAN Amplifiers

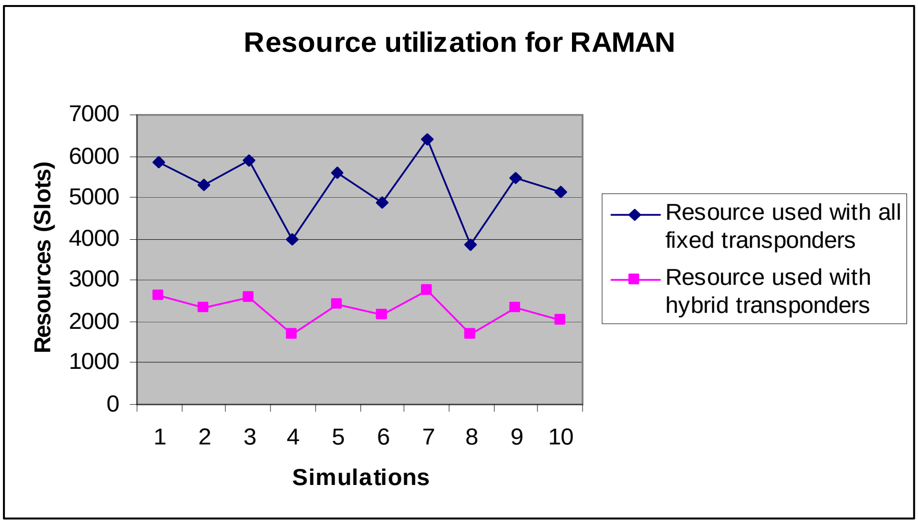

Figure3.2 (RAMAN) Resource utilization graph

Resource utilization trends shown by graph for the above mentioned simulations.

Using EDFA Amplifications

On average:

Resources used per simulation for all static transponder scenario = 5310

Resources used per simulation for hybrid transponder scenario = 2330

So all static transponders uses about 2.27 times more resources compared to the hybrid environment.

Using Raman Amplifications:

On average:

Resources used per simulation for all static transponder scenario = 5242

Resources used per simulation for hybrid transponder scenario = 2261

So all static transponders uses about 2.3 times more resources compared to the hybrid environment.

Static and flexible transponder utilization ratio

For the given network model using OSPF algorithm we computed number of static and flexible transponders for 10 simulations each consisting of 5000X 50 requests. So in total we have 250,000 requests and we got following statistics.

@ EDFA:

Requests established using static transponders= 161380

Requests established using hybrid transponders= 88620

Out of 50 Requests established using static transponders=
161380 / 250000 X 50 = 32.2= 32 approx.

Out of 50 Requests established using hybrid transponders=
88620 / 250000 X 50 = 17.8 = 18 approx.

On average, out of 50 requests, 32 are established using static transponders while 18 are established using hybrid transponders for this specific network model. This result is similar to that shown in listing 4.3 where 10 simulations are done with each having 50 requests and hybrid and static scenarios are compared. So taking averages of these 5000 simulations for static and hybrid transponders we get following listing.

Static transponders	Hybrid Transponders
34.532	15.468
31.725	18.275
30.2	19.8
33.463	16.537
32.125	17.875
30.092	19.908
28.639	21.361
33.567	16.433
32.563	17.437
31.879	18.121

Listing 3.3

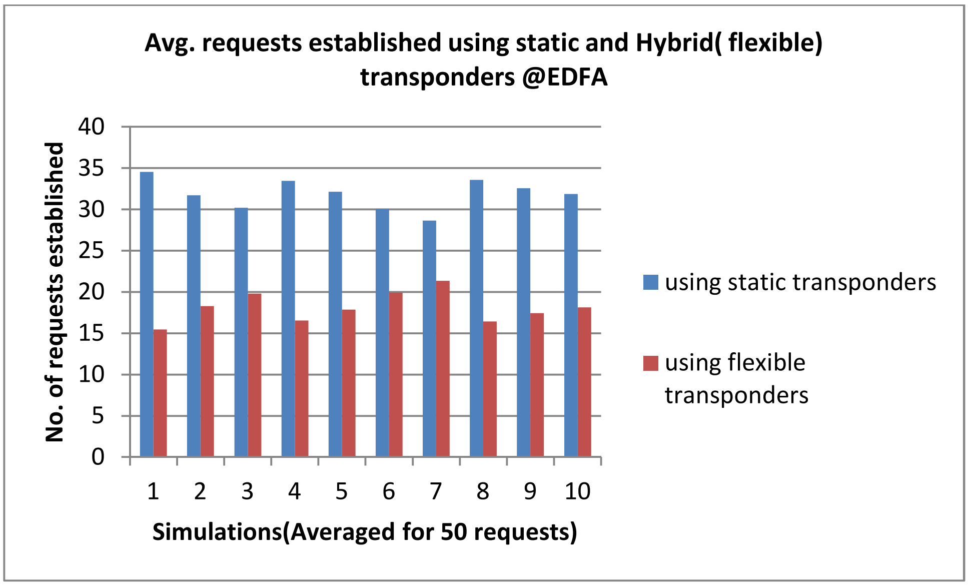

Figure 3.3

@ RAMAN:

Requests established using static transponders= 152100

Requests established using hybrid transponders= 97900

Total connection requests= 250000

Out of 50 Requests established using static transponders=
152100/250000 X 50 = 30.42= 30 approx.

Out of 50 Requests established using hybrid transponders=
97900/250000 X 50 = 19.58 = 20 approx.

On average out of 50 requests 30 are established using static transponders while 20 are established using hybrid transponders for this specific network model. This result is similar to that shown in listing 4.4 where 10 simulations are done with each having averaged 50 requests and hybrid and static scenarios are compared. So taking averages of these 5000 simulations for static and hybrid transponders we get following listing.

Static transponders	Hybrid Transponders
28.54	21.46
31.72	18.28
30.6	19.4
31.46	18.54
29.12	20.88
30.09	19.91
28.64	21.36
30.56	19.44
32.56	17.44
31.879	18.121

Listing 3.4

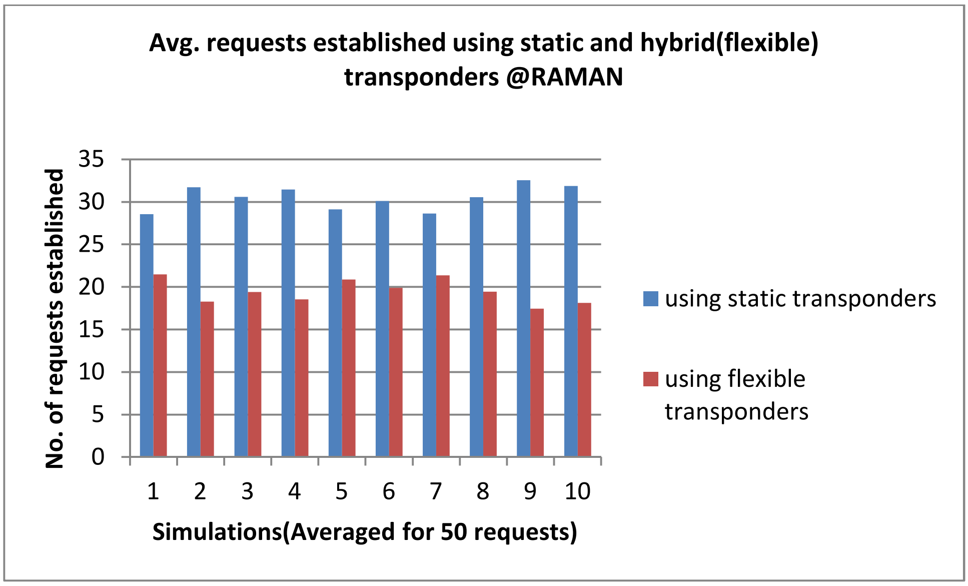

Figure 3.4

4 CONCLUSIONS

Adaptive hybrid transponders in optical networks provide high data rates while utilizing minimum spectrum resources. Hybrid transponders can be used to increase the total network capacity on the expenses of a potential increase in the network cost due to the higher complexity of adaptive technologies. In this work, we have evaluated how the performance of a transponder (i.e. its optical reach at a given data rate) influences the number of required spectrum resources in a realistic network scenario using different routing algorithms. Using flexible transponders has remarkable advantage as it is possible to increase the reach by reducing the capacity while changing the modulation format. Therefore, for longer links, it is still possible to find a feasible routing with worse performing adaptive data rate transponders than with static data rate transponders. Considering this, it might be cost effective for an ISP to deploy more transponders with a lower optical reach, but still keeping the logistical convenience to only deal with a single type of transponder for spares, upgrades, etc. Introducing 1+1 protection in the network even increases the margin of dynamic data rate DWDM compared with static data rate DWDM. We have presented a cost comparison for adaptive data rate transponders and traditional static data rate transponders which show a remarkable cost reduction capability of nearly 50% for adaptive flexible transponders. Furthermore, the ability of flexible transponders to extend the reach by decreasing the data rate shows significant benefits, as adaptive flexible transponder allows feasible planning solutions even for much shorter reference distances.

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