ANALYSIS AND COMPARISON OF FLEX GRID AND FIX GRID NETWORK SYSTEM

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Abstract: Core networks offer high capacities, thanks mainly to the optical technologies they utilize, but they consume a non-negligible amount of energy. The traffic volume in metro and core networks is forecast to grow at very high rates, exceeding 30% per year for the next five years, and if the corresponding energy requirements grow analogously, they will sooner rather than later form a bottleneck for network communications. Thus, energy efficiency in optical networks is mandatory for the sustainability of the future Internet. The objectives of the current work are to identifythe main causes of energy consumption for current fixedgridwavelength division multiplexing and future flex-gridoptical networks, and to propose and compare techniquesfor improving their energy efficiency. Wavelength Division Multiplexing (WDM) networks of the future are likely to use Flexgrid, providing operators withadditional flexibility when assigning spectrum compared totraditional WDM networks using the 50GHz ITU grid. Flexgridbreaks the spectrum up into small (typically 12.5GHz) slots, butits key feature is that contiguous slots can be joined together toform arbitrary sized blocks of spectrum. This additionalflexibility will allow faster transponders that utilise high spectralefficiency modulation techniques, but no longer fit within a50GHz slot due to their larger spectral width requirements, to becarried by the optical network. From the use of these newspectrum efficient modulation formats and finer control overspectrum allocations, a key benefit that Flexgrid offers networkoperators is that their WDM networks can carry more traffic.

I. GENERAL OVERVIEW

The Internet is continuously transforming our daily working reality and lifestyle, increasing productivity, and supporting economic development across the world. Between 1993 and 2013 the size of the data traffic increased by 113 GB/day to 13,888 GB/s, while Cisco predicts global IP traffic to nearly triple from 2013 to 2018 [1] (see Fig. 1). The global economic downturn seems unlikely slow the growth of Internet traffic, which leads to increased energy consumption for the infrastructures and devices needed to operate the Internet. ICT can of course help save energy through telecommuting, the introduction of smart grids, and many other ways, but the need for ICT to keep its own power consumption growth under control is also becoming increasingly evident [2]. It is estimated that the power consumption of the Internet is around 4% of the total energy consumption in broadband-enabled countries, and backbone net- work infrastructures (i.e., routers, transmission systems, optical switches) consume approximately 12% of total Inter-net energy consumption (estimated to increase to 20% in 2020) [3]. The continuing deployment and upgrade of network infrastructure drive up power consumption in a way that makes telecom operators worry that future power consumption levels may pose constraints on the growth of the Internet. Thus, it seems that an energy-aware approach is increasingly needed during the design, implementation, and operation of networks in general, and optical networks in particular, which carry more than 80% of the world's long-distance traffic. Two different approaches can be explored to reduce power consumption in optical networks: the improvement of the energy efficiency of the equipment and the energy awareness of the algorithms used.

II. FIXED-GRID AND FLEX-GRID OPTICAL NETWORKS

The current optical transport networks are based onwavelength division multiplexing (WDM) technology toconcurrently transport information on different wavelengths. In the past decades, research has focused on increasing network capacity by increasing the individualwavelength's capacity. Hence, WDM-based networks haveevolved from 1 to 2.5 to 10 to 40 GB/s, while 100 GB/s transceivers are just reaching the market. The next step is400 GB/s systems and then even higher rates. However,such transmissions would not fit in the 50 GHz wavelengthgrid of current WDM systems (initial designs of 400 GB/stransceivers are for 75 GHz). Going back to the 100 GHzgrid that was used in WDM systems in the past is not aviable solution. Moreover, WDM systems present an inefficiency problem due to the coarse granularity of the light-paths (as optical connections are typically referred to),which are allocated a whole wavelength. Traffic manipulation at lower capacity levels is performed at the electronic
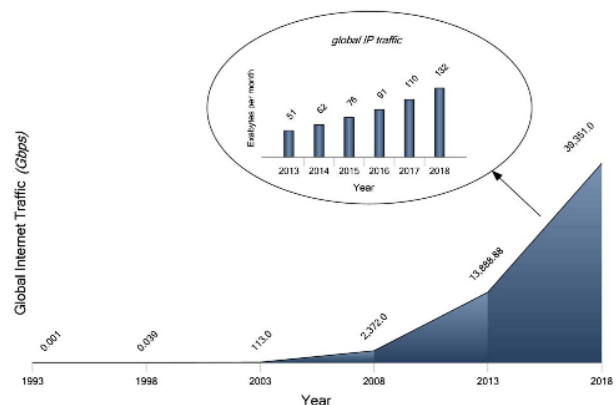

Fig. 1. Global Internet traffic growth and Cisco's VNI Global IP traffic growth forecasts (2013–2018)

Aggregation switches at the edges of the optical network and is, in most cases, done independently of and on different timescales than lightpath provisioning of the opticalWDM network. Therefore, to support future optical trans-missions and improve efficiency, a more flexible opticalnetwork with finer granularity is needed.

Recent research efforts on optical networks have focusedon architectures that support variable spectrum connections as a way to increase spectral efficiency, support futuretransmission rates, and reduce capital costs. Flex-grid(elastic or flexible are also terms used in the literatureand will be used in this paper interchangeably) optical net-works appear to be a promising technology for meeting therequirements of next-generation networks that will spanacross both the core and the metro segments. A flex-gridnetwork migrates from the fixed 50 GHz grid that traditional WDM networks utilize [4], and has granularityof 12.5 GHz, as standardized by the International Telecommunication Union (ITU-T) [5]. Moreover, flex-grid canalso combine spectrum units, referred to as slots, tocreate wider channels on an as-needed basis (Fig.2). Thistechnology enables a fine-granular, cost and power efficient network able to carry traffic that may vary in time,direction, and magnitude. Flex-grid networks [6] are built using bandwidth variable switches that are configured tocreate appropriately sized end-to-end optical paths of sufficient spectrum slots. Bandwidth variable switches operatein a transparent manner for transit (bypassing) traffic thatis switched while remaining in the optical domain.

In fixed-grid WDM networks and assuming a specifictype of transceiver, there is one way of serving a demand:the bit rate is fixed, the optical reach is fixed, and theoccupied spectrum is fixed (a single wavelength). Flexibletransceivers envisioned for flex-grid networks, alsoreferred to as bandwidth variable transponders (BVTs),allow multiple choices when serving a demand: they candecide some or all of the following: the modulation format,baud rate, spectrum, or even the forward error correction (FEC), and choose those that give sufficient performance toreach the required distance.

Fig. 1.2. Fixed WDM grid (with 50 GHz channel spacing) and flexible grid (with 12.5 GHz).

The problem of establishing connections in fixed-gridWDM networks is typically referred to as the routingand wavelength assignment (RWA) problem, which isknown to be an NP-hard problem. In the past, WDM systems were designed to use a single type of transponder,that is, they utilized a single-line rate (SLR). Recentadvances in transmission technologies and coherent reception have made possible the use of more than one type oftransponder simultaneously, exploiting trade-offs betweenreach and cost available in the different devices to improvethe efficiency and decrease the total network cost. Suchnetworks are typically referred to as mixed-line rate(MLR), as opposed to the SLR case discussed above. TheRWA problem for MLR WDM networks is more complicated than for SLR, since it involves making decisionsfor the type of transponder to use for each connection.

III. FIXED GRID TO FLEX GRID NETWORKS

Brown-Field Migration

Due to the increasing pressure on network operators to provide higher bandwidth with moreefficient resource utilization, replacing the legacyfixed-grid equipment with flexible-grid equipment in their transport networks is just a matterof time. However, the operator's decision tomigrate to flexible-grid technology will be influenced by key factors such as trade-off betweenbenefit and equipment cost, compatibility withlegacy systems, and complexity of network management. On one hand, the key enabling equipment (e.g., bandwidth variablewavelength-selective switches [BV-WSSs] supporting different grid definitions) has not yetreached a price point that allows massive deployment. It may not be economically viable to makea one-time complete upgrade to full flexible-gridtechnology for the entire network. On the otherhand, before the current optical transport net-work capacity is exhausted, the current fixed-gridnetwork could be kept maximally operationalduring the migration to preserve the already made investment.

Network Architecture

In practice, a likely scenario is that traffic loadson some nodes/links are significantly higher thanothers, so they become bottlenecks [10]. Forexample, a common scenario concerns nodesassociated with data centres, which tend to generate a large amount of traffic and can benefitfrom high-bandwidth super-channels interconnecting them. In these situations, the equipmentcausing the bottleneck could be replaced withflexible-grid equipment. As a result, brownfieldflexible-grid deployment on top of the existingfixed-grid network could happen as shown inFig. 1a.

While the sparse deployment of flexible-gridnodes can cost-effectively increase the capacityof only selected nodes/links, one challenge wewill face is in the operational issues due to thecoexistence of fixed-grid and flexible-grid technologies. Fixed- and flexible-grid nodes requiredifferent technologies. In particular, reconfigurable optical add/drop multiplexers (ROADM)are the key equipment to perform wavelengthswitching at intermediate nodes. Fixed-gridROADMs follow the traditional rigid ITU-Telecommunication Standardization Sector(ITU-T)-defined
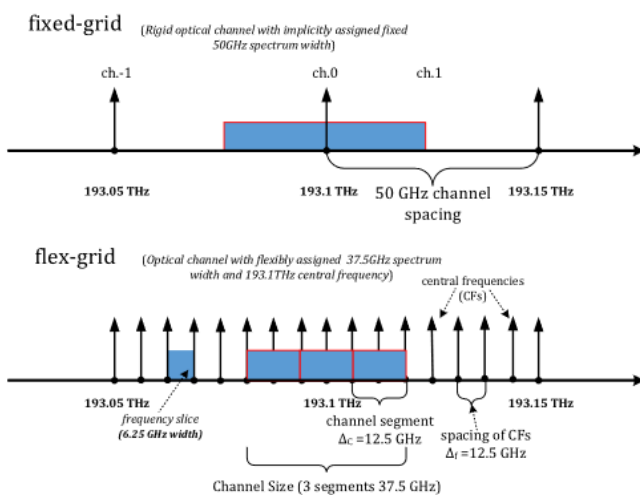
central frequencies and spectrum grids (e.g., 50 or 100 GHz) regardless ofthe actual bit rate carried by each individualchannel. Network devices (e.g., optical switches,multiplexers, and transponders) have to complywith this grid, as shown in Fig. 1b.

The flexible grid ROADM is different, as shown in Fig. 1c.Embedded wavelength-selective switches (WSSs)in flexible-grid ROADM do not need to strictlyfollow the ITU-T fixed grid, and can switch multiple concatenated slices as a single entity, whereeach slice may be 6.25 or 12.5 GHz.

These fixed-grid and flexible-grid nodeswould need to interoperate before all nodes areupgraded to flexible grid. So a question is: howcan newly added flexible-grid nodes be operatedin a network with other legacy fixed-grid nodes?Below, we discuss the relevant challenges interms of light path routing, wavelength assignment, and spectrum allocation.
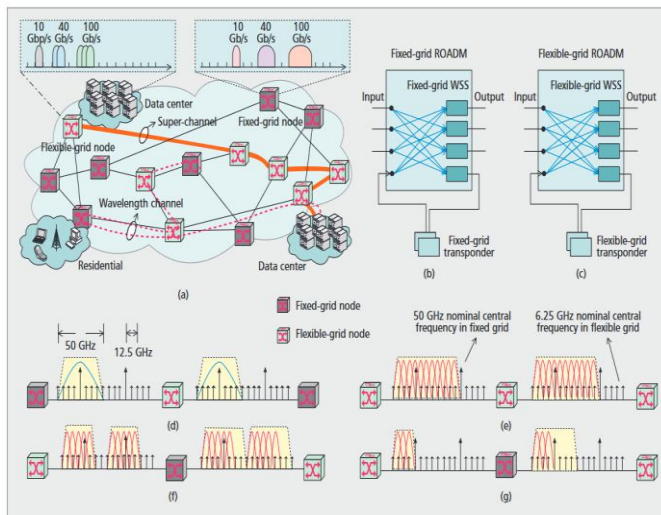

Figure 2.1 Optical network with co-existing fixed-grid and flexible-grid technologies: a) network architecture; b) fixed-grid ROADM; c) flexible-grid ROADM; d) wavelength channel; e) 200-Gb/s super-channel; f) two 100-Gb/s channels; g) 40-Gb/s sub channel

IV. INTEROPERATION BETWEENFIXED-GRID ANDFLEX-GRIDNODES

When a request arrives, we need to establish anoptical path between its source and destinationby determining a route through the network, andassigning/allocating a wavelength/frequency slotfor this path. Here, a frequency slot is a spectrum allocation dedicated to a certain connection, and is specified by its nominal centralfrequency and slot width. Suppose a route isselected for a lightpath in an optical networkwith both fixed-grid and flexible-grid technologies, so there are several situations for wave-length assignment (WA)/spectrum allocation(SA):

• When the source is a fixed-grid node, wehave the traditional WA problem. If thetraffic demand is larger than 100 GB/s, itcan be served by several lightpaths, eachaccommodating 100 GB/s or less (all following the same path, if possible).

• When the source is a flexible-grid node,there are two cases:

–If the nodes on the path are flexible nodes,we have the SA problem, where a single-carrier channel or a super-channel

withmultiple subcarriers can be set up to accommodate the demands.

–If there are both fixed- and flexible-gridnodes on the path, the spectrum is sharedas common resources between fixed-andflexible-grid technologies, and the corresponding WA and SA problem becomescomplex, different from WA in fixed gridand SA in flexible grid. On the path fromthe flexible-grid node to the fixed-gridnode, we have the SA problem; but fromthe fixed-grid node to the flexible-gridnode, we have the WA problem. If the traf-fic demand is larger than 100 GB/s, we setup several lightpaths, each offering up to100 GB/s rate.

Figures 1d–1g illustrate four possible cases innetworks with fixed-/flexible-grid coexistence.We consider the spectral granularity of fixed grid nodes to be 50 GHz and that of flexible-gridnodes to be 12.5 GHz. Figure 1d shows the spectrum utilization of links for a 100-Gb/s lightpaththat originates from a fixed-grid node and goesthrough a flexible-grid node. It occupies 50 GHzon both a fixed-grid link (i.e., a link originatingfrom a fixed-grid node) and a flexible-grid link(i.e., a link originating from a flexible-grid node);Fig. 1e shows a 200-Gb/s light path that originates from a flexible-grid node and then goesthrough a flexible-grid node. Since we can set upa super-channel that comprises six 12.5 GHzslots, only 75 GHz of spectrum will be usedinstead of two 50 GHz channels in a fixed-gridnetwork. However, when the path of a 200 GB/sdemand originates from a flexible-grid node butgoes through a fixed-grid node, as shown in Fig.1f, two lightpaths are set up, with each offeringup to 100 Gb/s. Figure 1g shows a 40-Gb/s light path originating from a flexible-grid node andgoing through a fixed-grid node. Here, 25 GHzspectrum will be assigned to the optical path onthe flexible-grid link, and 50 GHz will beassigned on the fixed-grid link, since the switching granularity of the fixed node cannot be smaller than 50 GHz.
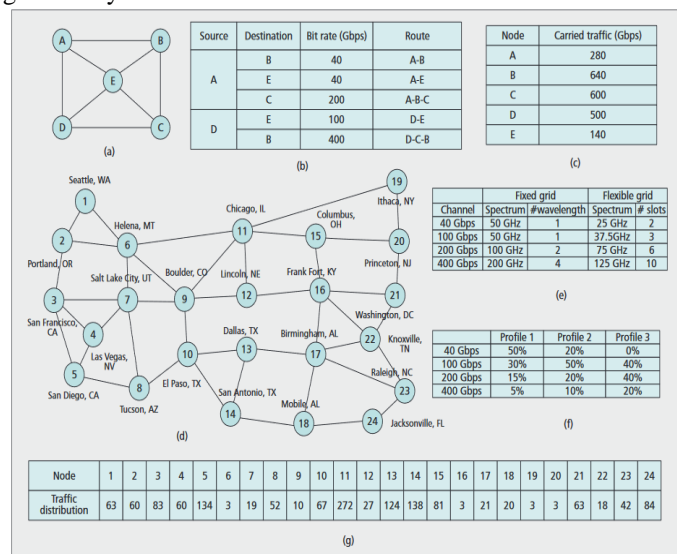

Figure 2.2 a) 5-node topology; b) traffic matrix; c) carried traffic by each node; d) U.S. network topology; e)optical channels in fixed-grid and flexible-grid technologies; f) connection demand ratios in different traffic profiles; g) traffic distribution In the non-uniform case.

V. FIX GRID AND FLEX GRID NETWORK

The inflation of data transfer is inevitable and brings significant challenges for transport networks. To meet the increasing requirements of users, new technology has to be deployed in backbone networks [1]. Elastic Optical Networks (EONs), based on optical-orthogonal frequency division multiplexing (OFDM) is able to accommodate high bandwidth demand applications. The basic concept of EONs is to fragment the available spectral resources into tight, width-constant spectral slices (optical channels represented in frequency domain) that correspond to different optical wavelengths. The slices are allocated over an optical lightpath, according to source, destination and capacity of a demand [2]. In this paper, we focus on showing the minimum requirements for EONs resources in order to achieve the best trade-off between the CAPEX/OPEX network costs and obtaining the various thresholdsof Service Level Agreement (SLA).

In addition, the EONs technology is a next step in the evolution of optical networks, therefore we will present a comparison of network resource usage in current technology (Wavelength Division Multiplexing – WDM) and EONs. Methods of migration from WDM to EONs are presented in [3]. Comparisons of the performance of WDM and EONs in dynamic routing are presented in [4-5] The main novelty presented in this paper is consideration of forecasted traffic volumes for the next few years, as well as consideration of path protection (PP) methods. Moreover, we take into account anycast and unicast traffic. Any casting – defined as one-to-one-of-manytransmission – is a useful way to serve network services provisioned in data centres including popular cloud computing and content-oriented services.

We investigate two different scenarios for dynamic routing in EONs, i.e., requests are notprovided with any protection and requests are protected by PP methods. Both scenarios are introduced and compared in section 3, preceded by a description of the network model inSection 2. In section 4, we provide and analyse results of extensive simulation experiments which run on two representative network topologies. We examine the performance of both scenarios in terms of two important metrics: spectrum and regenerators usage. Finally, the last section concludes this work.

Network Model

In this section, we describenetwork model used in our simulations. We also present the differences between WDM and EONs technologies.

Optical networks evolution

Over the last decade, optical networks have gone through a rapid evolution, starting with 16 wavelengths of 2.5 GB/s in late 1990s to 80 wavelengths of 100GB/s in 2012 [6-7]. Today, the term of optical networks denote high-capacity telecommunications networks based on optical technologies and components that can provide capacity, provisioning, routing, grooming,or restoration at the wavelength level. With estimated exponential traffic growths, future networks have to boost their capacity. The channel capacity will need to be increased beyond 100 GB/s per channel or higher, together with an increase of spectral efficiency. Currently used optical technology networks are Wavelength Division Multiplexing (WDM). The main idea underlying the concept of WDM networks is to communicate end-users in optical layer via all-optical WDM channels, which are referred to as lightpaths [8].

A connection in a wavelength-routed WDM network is supported by lightpath which may span multiple fibre links. In addition, when there are no wavelength converters, a lightpath must occupy the same wavelength on all the fibre links through which it traverses due to the wavelength-continuity constraint.

Despite all benefits of conventional WDM networks, their biggest problem is a low bandwidth efficiency due to fixed large granularity. Full wavelength capacity has to be dedicated for establishing a connection between end-nodes, even when the traffic between the nodes does not need to fill the full spectrum. It causes the poor utilization of the residual bandwidth of wavelength. Flexible-grid technologies can alleviate these limitations for demand provisioning. These technologies represent promising candidates for future optical networks supporting transmissionsof 100-Gb/s and beyond. In this case, several wavelengths are aggregated and allocated according to the request. On the other hand, it is easy to perform segmentation of large requests in flexible-grid networks.

Notation

We use similar notations as in [9]. The physical network is modelled as graph $G(V, E, B, L)$ where Vdenotes a set of nodes, Eis a set of fibre links, each fibre link can accommodate Bfrequency slices (slots) at most, and $L= [l(1),l(2),...,l(|E|)]$ represents link lengths for each $e \in E$. We assume that Rdata centres are already located at some nodes of the network. In addition, we assume that data centres (DCs) are equally connected to network nodes, to which are connected to, which means that we do not take the physical connection between the server and the backbone network node. Furthermore, we assume that each anycast request can be assigned to each DC, because DCs provide the same service of content.

Network Scenarios

In the simulations, we use a pan-European Nobel-EU network that contains 28 nodes and 82 directed links, and a US national backbone network consisting of 26 nodes and 84 directed links with 7 DCs located in each network. The networks have three points thatare interconnected to other networks, which are used to carry international traffic. The data provided by [10] determines the location of DCs and interconnection points. We take into consideration the physical impairment of links (fiber attenuation, component insertion loss) and we use regenerators to regenerate the signal on paths that – due to using higher modulation formats (MFs) – exceed the transmission range of a particular MF.

We estimate the number of regenerators in each node required to obtain particular SLA in terms of dynamic routing. For each network, the number of available spectrum in each link is set either to 2 THz or to 4 THz. We use a similar traffic model to [9]. The traffic model is created under the forecast in "Cisco Visual Networking Index: Forecast and Methodology, 2014-2019 White Paper". For Euro28 traffic in 2015 is set to 50 Tb/s and for the US26 it

equals 60 Tb/s. It increases over the years accordingly to Cisco reports.

The simulations are made for dynamic traffic, using reference algorithm from the literature - AMRA [11]. For WDM we use Least Loaded (LL) algorithm [12-13]. In this paper, we assume a WDM network with spectrum of 2 and 4 THz and bands of 50 GHz, each allowing to transmit 100 GB/s and EONs with two configurations – 2 and 4 THz with 6.25 GHz bands allowing to transmit up to 400 GB/s. In one scenario, we check the need for regenerators and the spectrum without PP methods, while in the second scenario, we check the same requirements with PP. Moreover, we test two methods to ensure the network survivability, i.e., one that uses more resources and gives 100%protection and a second, which is more efficient in terms of spectrum and regenerator usage, but does not provide 100%protection. Note that the main performance metric is Bandwidth Blocking Probability (BBP) defined as the volume of rejected traffic divided by the volume of all traffic offered tothe network. Note that the request blocking can occur due to two reasons: lack of spectrum resources and/or lack of regenerators required to regenerate long distant requests. For more details on this issue see [11].

Description of Algorithms
In this section we outline the algorithms we used in ourstudies for minimizing the energy consumption when planning SLR and MLR fixed-grid WDM and flex-grid opticalnetworks. In particular, the algorithms are referred to asEA-RWA for the MLR and SLR fixed-grid WDM networksand EA-RSA for the flex-grid network.We start by giving a general definition of the networkplanning problem that is common in all cases, and thenwe focus on the differences among the algorithms. The switch architectures,inwhich the only difference between the fixed- and flex-gridcases is the use of bandwidth-variable WSSs in the lattercase. Finally, we assume that, in the case of fixed-grid networks (SLR andMLR), the system supportsWwavelengths, while in theflex-grid case, the network supportsSspectrum slots.The objective is to serve all traffic and minimize theenergy consumed in the corresponding fixed-grid WDMand flex-grid optical networks. To do so, we reduce thenumber of power consuming components, such as transponders, regenerators, add/drop terminals, and amplifiers, which leads to the reduction of the energyconsumed in the whole network. Especially for the caseof MLR networks, minimizing the energy consumption ofthe transponders is achieved by choosing the right typeof transponder for each connection. In flex-grid networks,assuming the use of a single type but tunable transponder,the main issue is to choose the right configuration of thetransponder for each connection.

Since the related planning problems are NP-hard and weare considering realistic problem instances with networksof many nodes/links and heavy traffic, we decided to useheuristic algorithms, since searching for absolute optimums for several scenarios would be time consuming. Inparticular, the heuristic algorithms we used for the different cases follow a similar logic. They serve all the demandsdefined in the static traffic matrix one-by-one

according toa specific ordering, remembering the choices made forprevious served requests so that we can avoid wavelengthcontention, and incrementally calculate the energy consumption of the whole network. Note that the energy consumption (but also the spectrum and other networkperformance metrics) depends significantly on the orderingin which demands are served. This is because choices madefor one connection, e.g., to serve it over a specific path thatplaces regenerators at specific nodes so as to avoid addingadd/drop terminals or utilizing a network interface over an-other path, could differ later when the chosen path becomescongested and requires adding more add/drop terminals,while the avoided path turns out to be relatively empty.Since the ordering plays an important role, our algorithmsuse a simulating annealing (SA) metaheuristic to searchamong different orderings.

For the SLR-RWA algorithm we used the heuristicalgorithm presented in [26]. This algorithm precalculatesk-shortest paths for each demand. Then for each path,given the transmission reach of the specific SLR transponder, the algorithm allocates a regenerator at the previousnode of the link that, when added, makes the path longerthan the given transmission reach. The algorithm takesinto account the optical switch architecture, the add/dropterminal NIs utilized up to that point, and the regenerationpoints of each of thek-paths. It selects the path that minimizes the incremental energy consumption of serving thedemand at hand and continues serving the next demand.

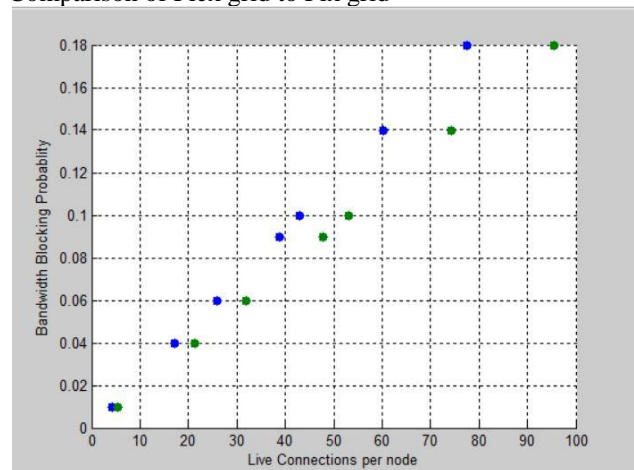# VI. MODELLING AND SIMULATION
Comparison of Flex grid to Fix grid

Figure 5.1Comparison of Flex grid to Fixed Grid

Above shown figure is comparison of Flex grid to fix grid, where we have used Poison process & Negative exponential algorithms for creating a flex grid scenario. Here, we have used a frequency slot of 12.5 GHz ranging for 1 to 12 for flex grid service. For fix grid we have kept the frequency slot a constant of number 8. At the same time we have used 12.5 GHz slot even in Fix grid which helps us comparing both grid network methods easily. The option of 50 GHz is discarded by us, because it won't be a modern approach wherein we are trying to use a frequency slot of only 12.5 GHz. As can be seen from above figure Green dots are of

Flex grid network which shows that we are able to provide more live connections using flex grid method. Parameters for Load on network are some as Inter-arrival time, Holding time, live connections & other random parameters that comes with a use of grid network. Comparison shows us that Flex grid better utilizes provided frequency slots.

VII. CONCLUSION

Increasing the energy and spectral efficiency of opticaltransport networks has emerged as one of the most challenging tasks for telecom operators and industry. Optical transport networks are required to provide high resilience levels toguarantee an appropriate quality of service. Recently, EON hasbeen presented as a promising solution to enable flexible andhigh-capacity transmission by means of its elastic bandwidthusage. Simulation results showed EON as an energy andspectral efficient solution, which allows for the transmissionof more bits per GHz per Joule (energy efficiency perGHz) thanany other WDM approach for all the protection schemes(dedicated and shared path ones).

Despite the potential advantages of energy and spectralefficiency showed by EON, cost is one of the main drivers todetermine whether EON will be finally adopted by theoperators. In this regard, the traffic conditions and the net-work topology will be decisive for the cost efficiency of EON,which is strongly dependent on its main cost contributor, theBVT. As shown in the presented results, the manner in whichthe bandwidth of this transponder is utilized has a significantimpact on the final cost. Thus, even if the cost per bit of a BVTcould be initially higher than that of a current WDM transponder, EON can be a cost-efficient solution if the transpondercapacity is shared between multiple demands. Accordingly, inmany circumstances, the data that can be transmitted per GHzwithasinglecostunit(cost efficiency perGHz) is higher inEON than in any other WDM network approach.

The higher spectral efficiency of EON results in lowerblocking, which permits to accommodate more traffic in asingle fiber. This fact has a relevant impact on both costand energy efficiency, as the number of additional fibresand energy-consuming devices can be reduced for a giventraffic load. Furthermore, there are some other potentialfactors that can turn this technology into a more cost efficient solution, such as the possibility of deploying asingle transponder model in the network. Among the protection schemes, SPwas shown as the most energy and cost-efficient, thanks to its lower power consumption and spectrum usage, andDP1þ1astheleastenergy- and cost-efficient due to its duplicated transmission, despite offering the highest availability and fastest recovery. In general, migrating from dedicated to shared protection schemes may significantly improve the cost and energy efficiency of the network.

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