Migration Towards Terascale Flexible-Grid Optical Networks

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Motivation

- With traffic growing at 40 percent annually, optical spectrum is becoming scarce, network architectures supporting channels operating at terabit per second becomes necessity.
- Traditionally, a fiber’s spectrum is divided using Wavelength-Division Multiplexing (WDM) into a fixed grid of equally-spaced optical channels at 50 or 100 GHz supporting fixed line rates (e.g., 40 or 100 Gbps).
- Conventional fixed grid is evolving towards a flexible grid, where an arbitrary number of smaller frequency slots (e.g., 12.5 GHz) can be assigned to serve traffic demands with as much spectral resources as requested.
- Our research will study the interoperability of fixed- and flex-grid, and develop novel migration and traffic grooming strategies from fixed-grid towards next-generation terascale flexible-grid optical networks.

Key Steps

1. **Brownfield Migration from Fixed-Grid to Flex-Grid Optical Networks**: We shall study inter-operability of fixed- and flex-grid technologies, as well as migration strategies from fixed to flex grid, addressing critical questions as follows: a) which node(s) should be upgraded first? b) should we create flex-grid island(s)? c) how many nodes should be upgraded for current network state? and d) should nodes be upgraded as a whole or starting from sub-components?

2. **Evolution of Traffic Grooming in Flex-Grid Networks**: We shall investigate how grooming (i.e., approaches for aggregation of lower-bit-rate flows in multi-Tbps flexible channel) would evolve with flexible-grid and elasticrate technologies, and during the migration. While traditional traffic grooming is essentially a combined routing and (fixed-size-)bin-packing problem, novel strategies are needed in flex-grid networks to efficiently aggregate traffic as container (bin) sizes vary in time.

Migration from Fixed to Flexible Grid

Main evolutionary steps that characterize the migration from fixed to flexible grid.

- **Mixed-Line-Rate (MLR) Networks**: In this case, the grid is still fixed but different line rates can be operated over different channels, typically featuring a mix of 10/40/100 Gbps. According to recent proposals, 400 Gbps and 1 Tbps transponders will require 75/100 GHz and 150/200 GHz of spectrum occupancy, respectively.

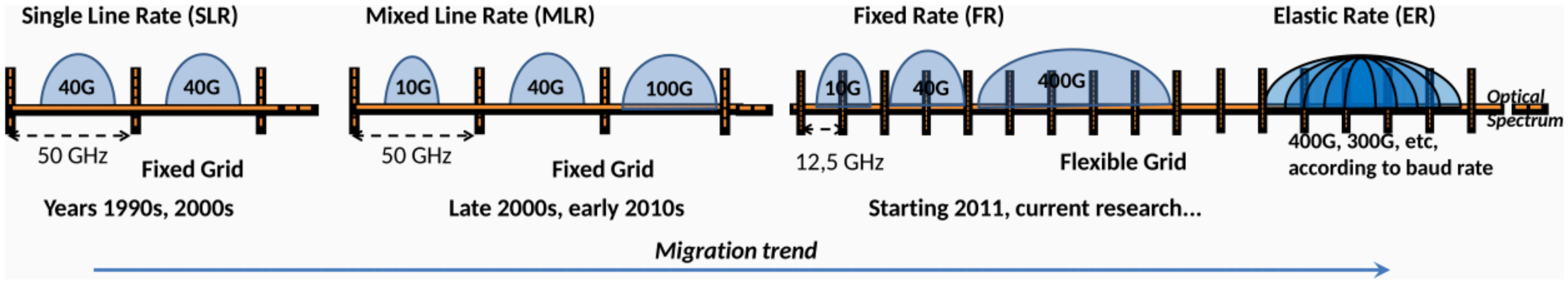


Figure 1: From Single Line Rate and Mixed Line Rate over fixed grid to Elastic Rate over flexible grid.

- **Elastic Rates (ER):** Innovative transponder technologies for dynamically tuning data rates according to the network state. These transponders are referred to as elastic or software-defined, and they enable flexible allocation of optical bandwidth based on current traffic demands.

Migration from Fixed to Flexible Grid

- **Fixed Grid to Flex Grid :** Standard ITU 50-GHz grid is evolving to a finer-grained spectrum with frequency slots of 12.5 GHz. Switching equipments need to also evolve to support flex-grid network operation. Novel **BandwidthVariable Reconfigurable Optical Add-Drop Multiplexer (BV-ROADM)** are being developed to switch channels with almost arbitrary channel spacing. BV-ROADM can be realized using several interconnected Flexible Wavelength Selective Switches (Flex-WSS).

Proposed Research

- **Brownfield Migration :** Traffic loads on some nodes/links are significantly higher than others, so they become bottlenecks. A common scenario are datacenter nodes, as they tend to generate larger amount of traffic, and they will be most likely the first to require an upgrade to flex-grid.
- A brownfield flex-grid deployment on top of the existing fixed-grid network could happen as shown in Fig. 2, where some nodes (mostly those closer to datacenters) have been already upgraded, but other nodes in the network still remain fixed-grid nodes.

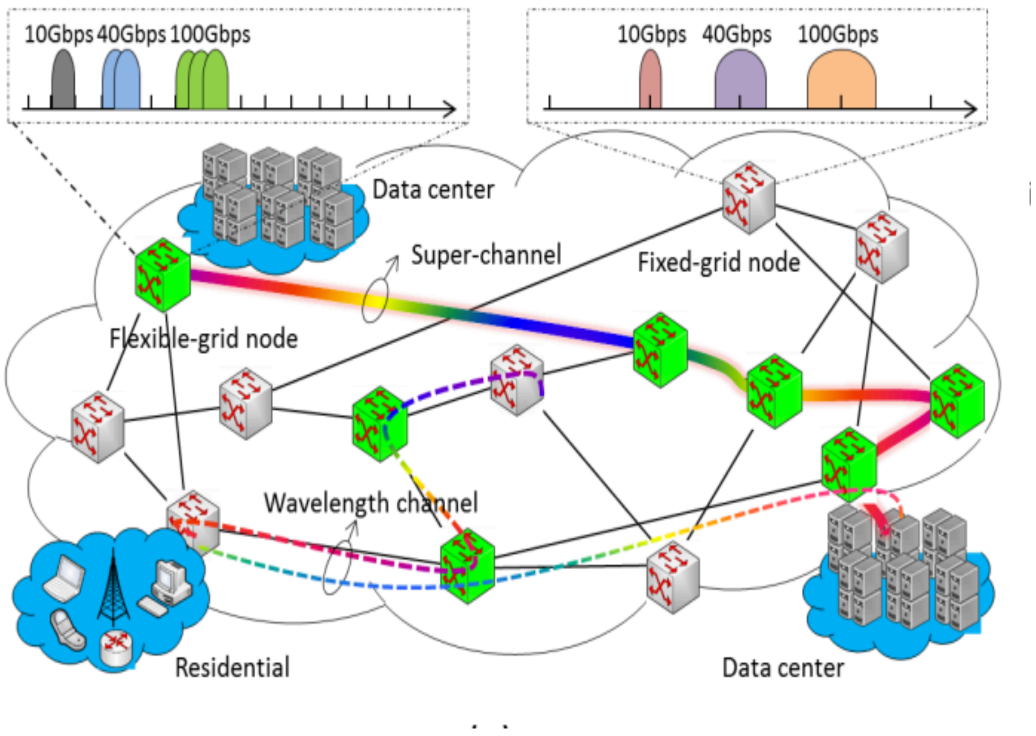


Fig. 2 Optical network with co-existing fixed-grid and flexi-grid technologies.

Proposed Research

- **Challenges:** A flex-grid ROADM is different, Wavelength-selective switches (WSSs) in a flex-grid ROADM need not strictly follow the ITU-T grid, and can switch contiguous spectrum slices as a single entity, where each slice may be, e.g., a multiple of 12.5 GHz. These fixed-grid and flex-grid nodes need to interoperate during the migration to flex-grid.

Planning Interoperable Fixed- and Flex-Grid Networks:

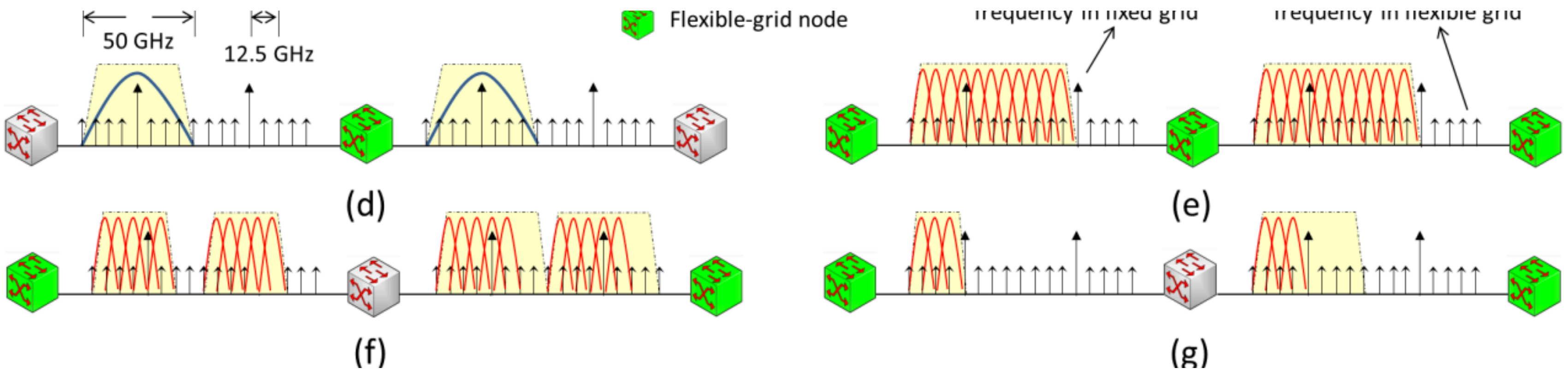


Fig. 3 d) wavelength channel; e) 200-Gbps super-channel; f) two 100-Gbps channels; and g) 40-Gbps sub-channel.

Scalable algorithms for static interoperable RSA/RWA problem. ILP can give a solution to this problem. However, ILPs have scalability limits, and today there are no scalable algorithms for this problem. While finding a feasible solution for the problem is not hard, avoiding spectrum wastage will require scalable and practical approaches.

Migration Strategies

Question 1: Which node should be upgraded first?

- *Highest Degree First (HDF): Nodes with the highest nodal degree should be upgraded first.*
- *Highest Generated Traffic First (HGTF): Nodes generating the most traffic should be upgraded first.*
- *Highest Carried Traffic First (HCTF): Nodes which carry the most traffic should be upgraded first.*

Migration Strategies

- Question 2: Should we create “flexible island(s)”?

“flex-grid” island as a set of nodes where every node supports flex-grid technology.

Enlarging a single island: We start by upgrading the first node according to, e.g., HCTF, and then choose as the second node the one with highest HCTF, but only among the adjacent nodes to those already upgraded. This leads to the formation of an island which will keep growing during the migration.

Enlarging multiple islands: Since a traffic pattern in the network may have several “hot spots” (e.g., the east and west coasts of US may have higher traffic volumes than other places), a further improvement would be to have multiple islands growing independently. An idea is to choose nodes to be upgraded using metrics which can capture “the locality of traffic”.

Migration Strategies

- Question 3: How many nodes should be upgraded?

While the ultimate goal is to migrate the entire network to support flex-grid technology, upgrading only a subset of the nodes might be enough to overcome current network bottlenecks. This may lead to different numbers of nodes to be upgraded under a given scenario with a predetermined objective.

Migration Strategies

Question 4: Should nodes be upgraded as a whole or starting from sub-components?

Fixed-grid WSS follows traditional rigid ITU-T-defined central frequencies and spectrum grids (e.g., 50 GHz), while flex-WSS does not need to strictly follow the fixed frequency grid, and can switch spectral bandwidth as an integer multiple of finer-granularity slices (e.g., 12.5 GHz or even 6.25 GHz). Operators can benefit from upgrading the WSSs from fixed to flexible grid, even only a subset of them in a ROADM.

Evolution of Traffic Grooming in Flex-Grid Networks

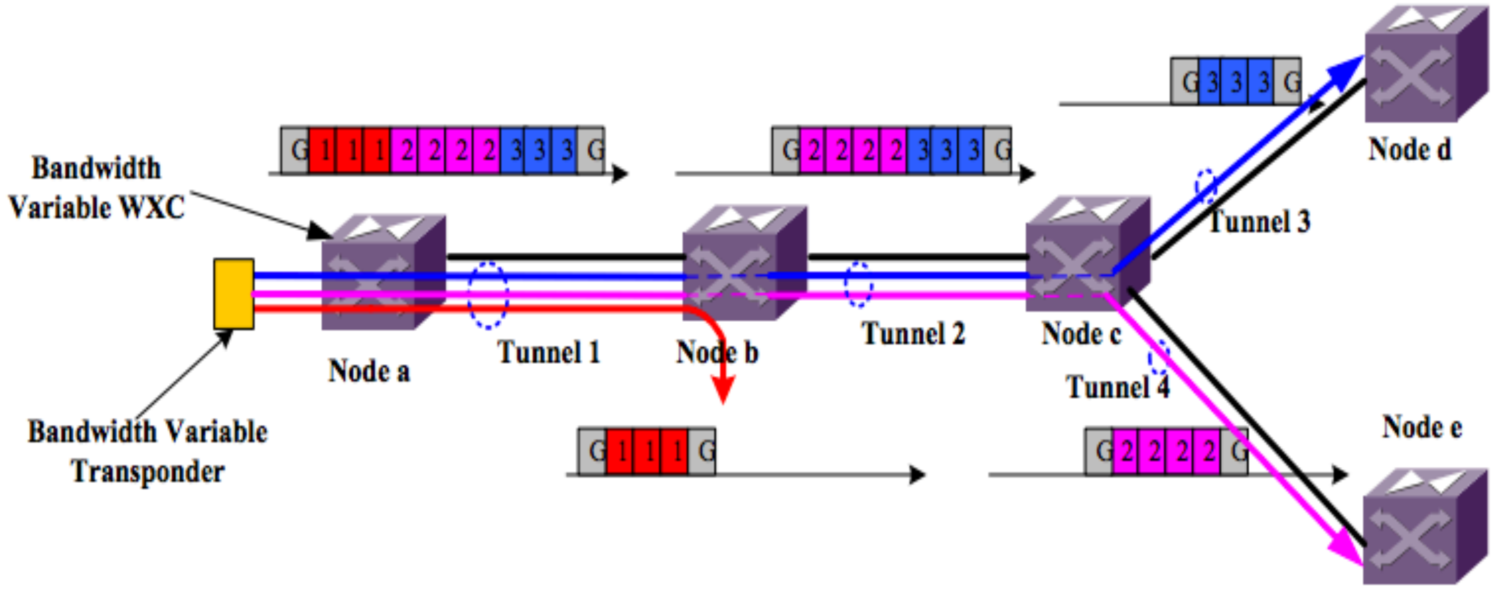
- Current IP tributary flows are on the order of a few Gbps (1, 5, 10, etc.) while a frequency slice of 12.5 GHz is expected to accommodate approx. 25 Gbps. Moreover, since optical channels must be separated by guard bands, provisioning each low-speed traffic flow with a separate optical channel can lead to high spectrum wastage due to guard bands.

Therefore Traffic grooming is necessary !

Grooming in Spectral Domain

- We have proposed a novel grooming technique, performed directly at the optical layer, which can decrease the number of OEO conversions.
- We exploit orthogonality properties of OFDM signal, which is composed of adjacent sub-carriers that must be, in principle, switched as a whole ("optical tunnel"). As most current ROADM architectures employ a broadcast-and-select structure which replicates the signal over multiple ports, then, for each replica, a different subset of the sub-carriers could be dropped or switched optically in the intermediate nodes, without employing OEO conversion and electronic switching.

Grooming in Spectral Domain



Optical Grooming in OFDM network

Thank You !