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Optical Communications Group

Solving Routing and Spectrum Allocation Related Optimization Problems

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ECOC 2013

Th.1.E.1

Outline

I. RSA Basics

II. Solving Techniques

III. Advanced RSA

IV. Off-line Network Planning

V. In-operation Network Planning

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Part I
RSA basics

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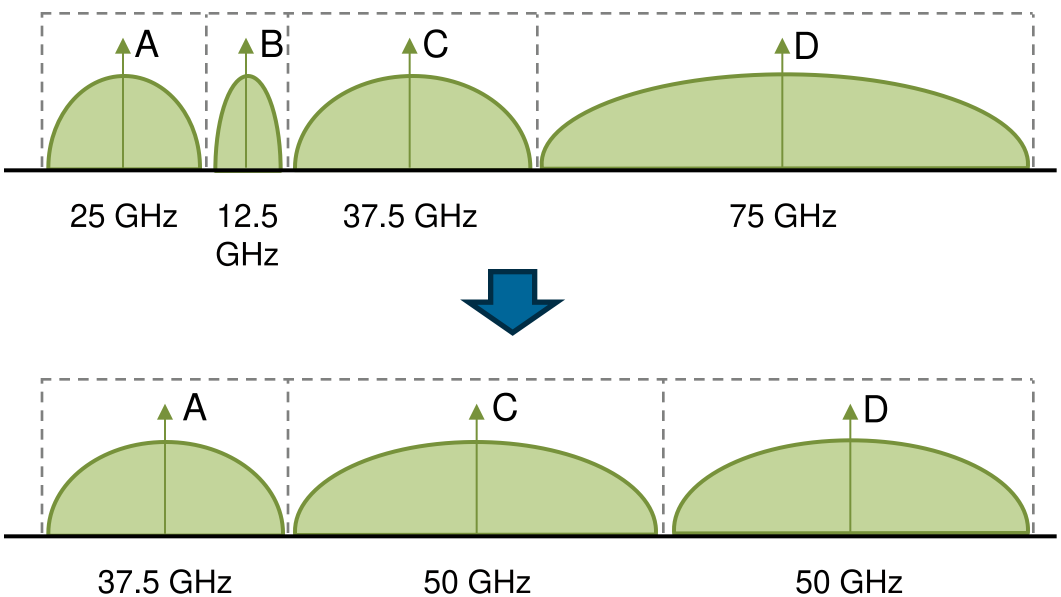
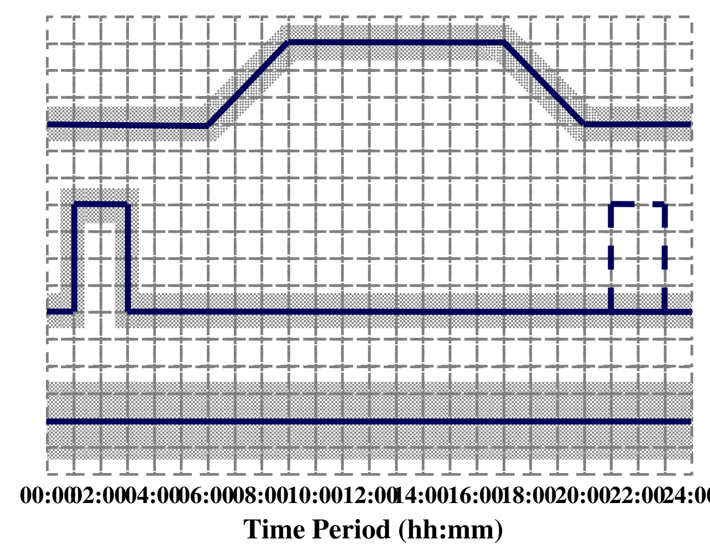
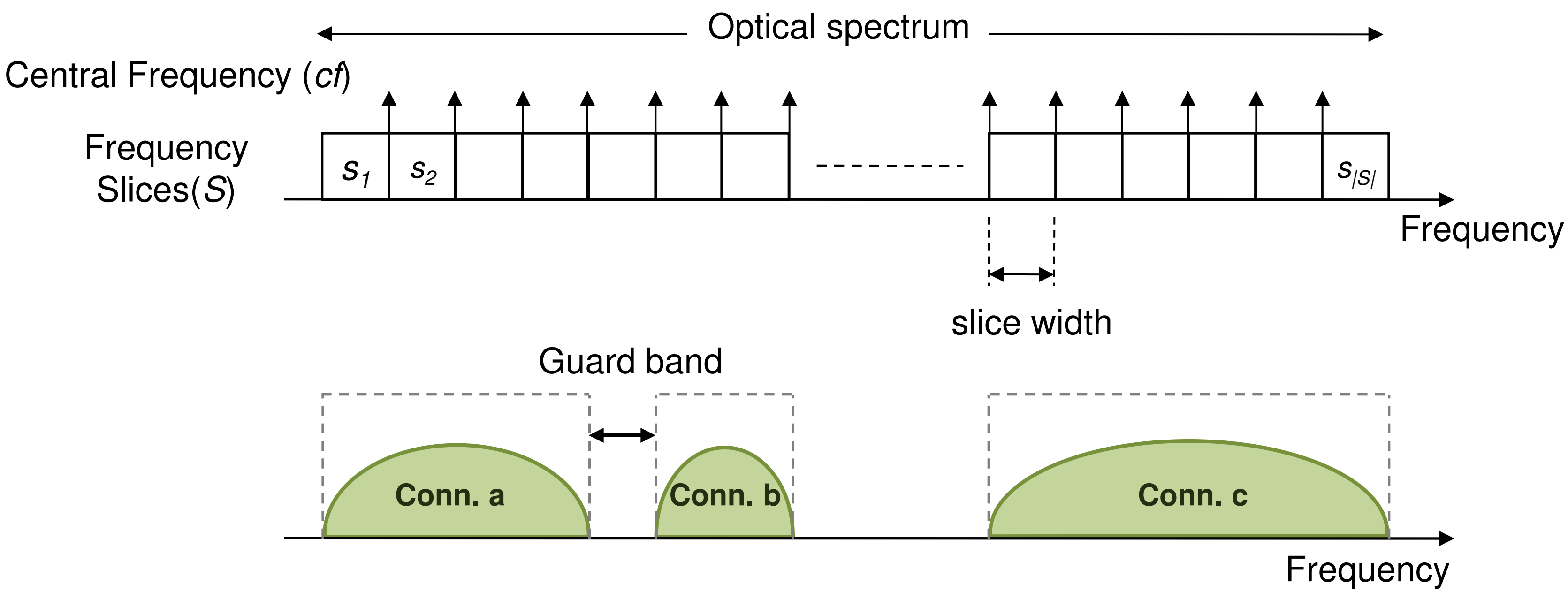
Flexgrid

- Flexgrid uses a finer spectrum granularity.
  - The optical spectrum is divided into frequency slices (e.g. 6.25GHz).
- It brings features that are not offered by the fixed grid networks, such as
  - **flexible** bandwidth allocation.
  - transporting optical connections with a capacity **beyond 100Gb/s**
  - **elasticity** against time-varying traffic.





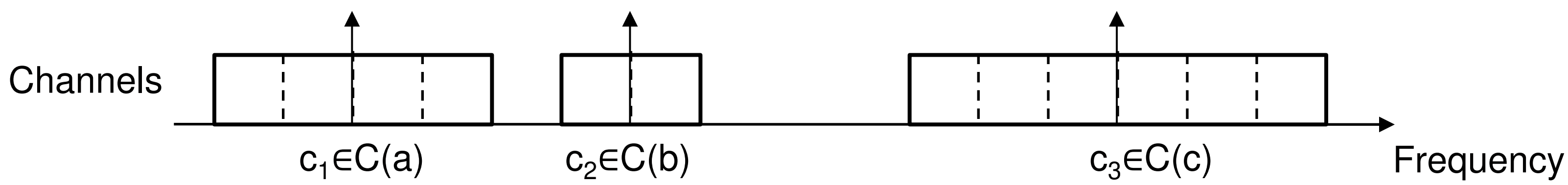
Spectrum allocation

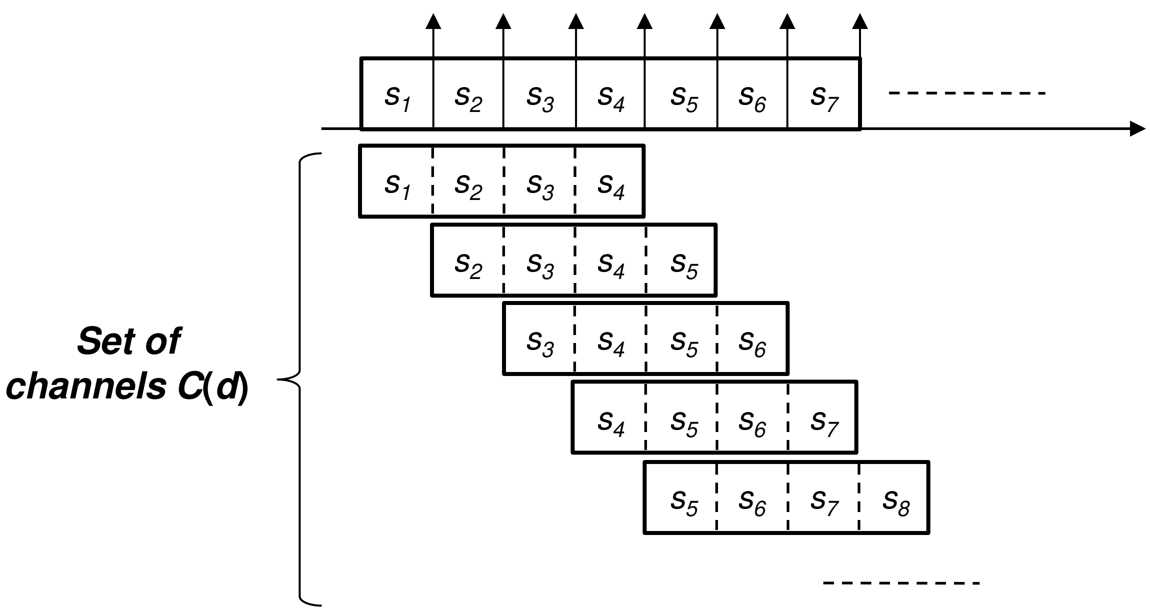


Spectrum allocation entail dealing with two constraints:

- **spectrum continuity** along the links of a given routing path: the same slices must be used in all links of the path,
- **spectrum contiguity**: the allocated slices must be contiguous in the spectrum.

Slices and Channels





C(*d*) pre-computation

INPUT S, d

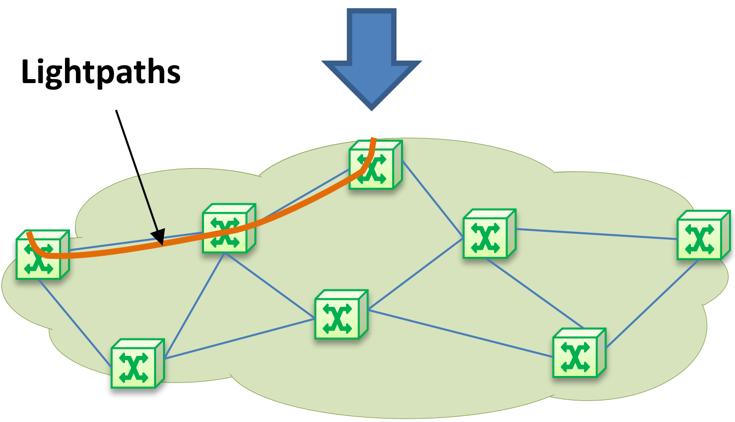
OUTPUT C(d)

```
Initialize: C(d) ← 0[|S|-nd+1 x |S|]
for each i in [0, |S|-n_d] do
    for each s in [i, i+n_d-1] do
        C(d)[s]=1
return C(d)
```

Basic RSA Problem Statement

Demand Matrix

From	To	BW



Flexgrid

- Given:
  1. a set *N* of locations and a set of optical fibers *E* connecting those locations;
  2. the characteristics of the optical spectrum (i.e., spectrum width, frequency slice width) and the set of modulation formats;
  3. a traffic matrix *D* with the amount of bitrate exchanged between each pair of locations in *N*;
- Output: the **Route and Spectrum Allocation** for each demand in *D*.
- Objective: one or more among:
  - Minimize the amount of bitrate blocked,
  - Minimize the total amount of used slices,
  - Minimize the total number of links used,
  - etc.

Link-path Channel Assignment Formulation

Pre-computed Parameters

$P(d)$	Set of predefined candidate paths for demand d.
$C(d)$	Set of channels for demand d.
δ_{pe}	Equal to 1 if path p uses link e, 0 otherwise.
γ_{cs}	Equal to 1 if channel c includes slice s, 0 otherwise.

Variables

x_d	Binary. Equal to 1 if demand d is rejected, 0 otherwise.
y_{pc}	Binary. Equal to 1 if channel c is assigned to path p and 0 otherwise

$$(LP-CA) \quad \min \sum_{d \in D} x_d \cdot b_d$$

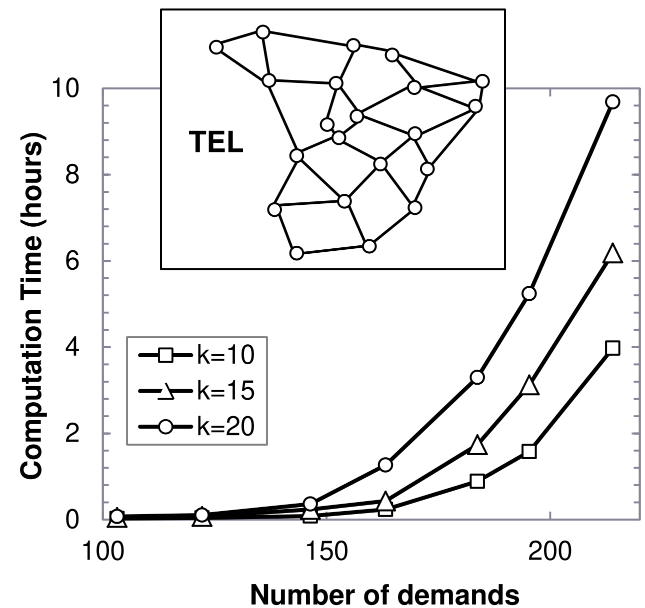
subject to:

$$\sum_{p \in P(d)} \sum_{c \in C(d)} y_{pc} + x_d = 1 \qquad \forall d \in D$$

$$\sum_{d \in D} \sum_{p \in P(d)} \sum_{c \in C(d)} \gamma_{cs} \cdot \delta_{pe} \cdot y_{pc} \le 1 \qquad \forall e \in E, s \in S$$

$O(|P(d)| \cdot |D| \cdot |C|)$ **variables**
$O(|D| + |E| \cdot |S|)$ **constraints**

Solved using CPLEX



* L. Velasco, et al., "Modeling the Routing and Spectrum Allocation Problem for Flexgrid Optical Networks," Springer Photonic Network Communications, 24, 177-186, 2012

Topology Design as a RSA Problem

- Given:

1. a connected graph G(N,E), where *N* is the set of locations and *E* the set of optical fibers;
2. the characteristics of the optical spectrum and modulation formats;
3. a traffic matrix *D*;

- Output:

1. The route and spectrum allocation for each demand in *D*.
2. **The links that need to be equipped;**

- Objective: **Minimize number of links to be equipped** to transport the given traffic matrix.

Node-link CA Formulation

Variables

w_{dec} Binary. Equal to 1 if demand *d* uses channel *c* in link *e*, 0 otherwise

z_e Binary. Equal to 1 if link *e* is opened, 0 otherwise

$$(NL-CA) \quad \min \sum_{e \in E} z_e$$

subject to:

$$\sum_{e \in E(v)} \sum_{c \in C(d)} w_{dec} = 1 \quad \forall d \in D, v \in \{s_d, t_d\}$$

$$\sum_{e \in E(v)} \sum_{c \in C(d)} w_{dec} \le 2 \quad \forall d \in D, v \notin \{s_d, t_d\}$$

$$\sum_{\substack{e' \in E(v) \\ e' \neq e}} w_{de'c} \ge w_{dec} \quad \forall d \in D, c \in C(d), v \notin \{s_d, t_d\}, e \in E(v)$$

$$\sum_{d \in D} \sum_{c \in C(d)} \gamma_{cs} \cdot w_{dec} \le 1 \quad \forall e \in E, s \in S$$

$$\sum_{d \in D} \sum_{c \in C(d)} w_{dec} \le |S| \cdot z_e \quad \forall e \in E$$

O(|D|·|E|·|C|) **variables**
O(|D|·|C|·|V|·|E|) **constraints**

* L. Velasco, et al., "Modeling the Routing and Spectrum Allocation Problem for Flexgrid Optical Networks," Springer Photonic Network Communications, 24, 177-186, 2012

Network Dimensioning as a RSA Problem

- Given:

1. a connected graph G(N,E), where *N* is the set of locations and *E* the set of optical fibers;
2. the characteristics of the optical spectrum and modulation formats;
3. a traffic matrix *D*;
4. **the cost of every component, such as optical cross-connects (OXC) and transponder (TP) types specifying its capacity and reach.**

- Output:

1. The route and spectrum allocation for each demand in *D*.
2. **Network dimensioning including the type of OXC and TPs in each location;**

- Objective: **Minimize the total cost** to transport the given traffic matrix.

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Part II
Solving Techniques

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Heuristics

- RSA problems are *NP-hard*, so there is little hope of ever finding efficient exact solution procedures for them.
- Un-tractability of MILP formulations appears when instances to be solved involve a large number of variables.
  - Tens of nodes x Tens of links x Hundreds of slots x Hundreds of demands = Millions of binary variables.
- Heuristics, i.e., **approximate solution techniques**, can be used to tackle RSA-based (combinatorial) problems.

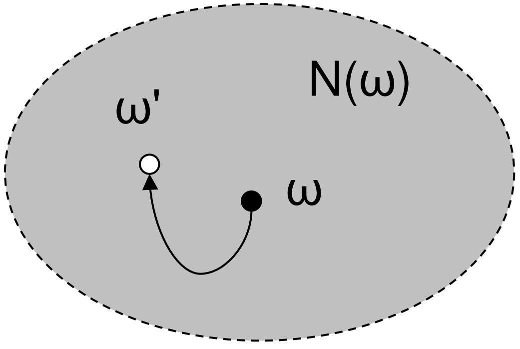
Ω	Solution space
$f: \Omega \rightarrow R$	Objective function defined on the solution space
goal:	find $\omega^* \in \Omega$, $f(\omega) \geq f(\omega^*)\ \forall\ \omega \in \Omega$

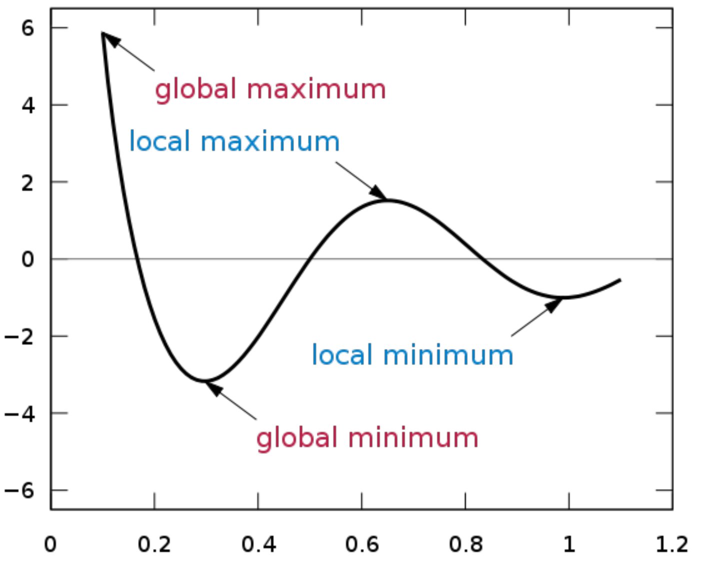
Heuristics

- Heuristic algorithms usually consists on two phases:
  - Constructive Phase, where a solution is built.
  - Local search, where the solution is improved.

- During the **Constructive phase**, greedy algorithms may be used.

- During the **local search** phase, exchanges among elements in the solution and not in the solution are done.



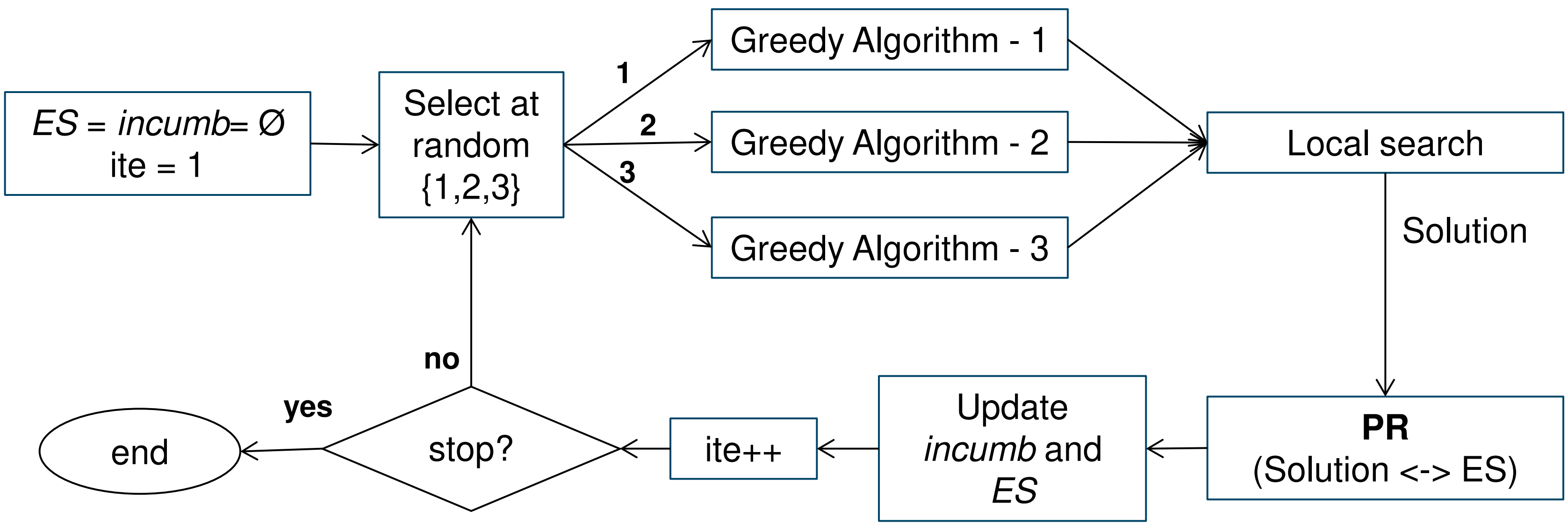


Meta-heuristics

- Meta-heuristics allow go beyond heuristics by:
  - adding variability (randomize)
  - allowing escaping from local optima, at risk of cycling
- Some well-known meta-heuristics are:
  - **GRASP** (Feo and Resende): a multi-start metaheuristic for combinatorial problems.
  - Evolutionary algorithms (genetics). **BRKGA** (M. Resende)
  - **Simulated Annealing**, probabilistic metaheuristic often used when the search space is discrete
  - **Tabu Search** (Fred W. Glover): Enhances the performance of Local search by using memory structures.
  - **Ant colony**: probabilistic technique (Marco Dorigo)
  - **Path relinking**: an *intensification* method.

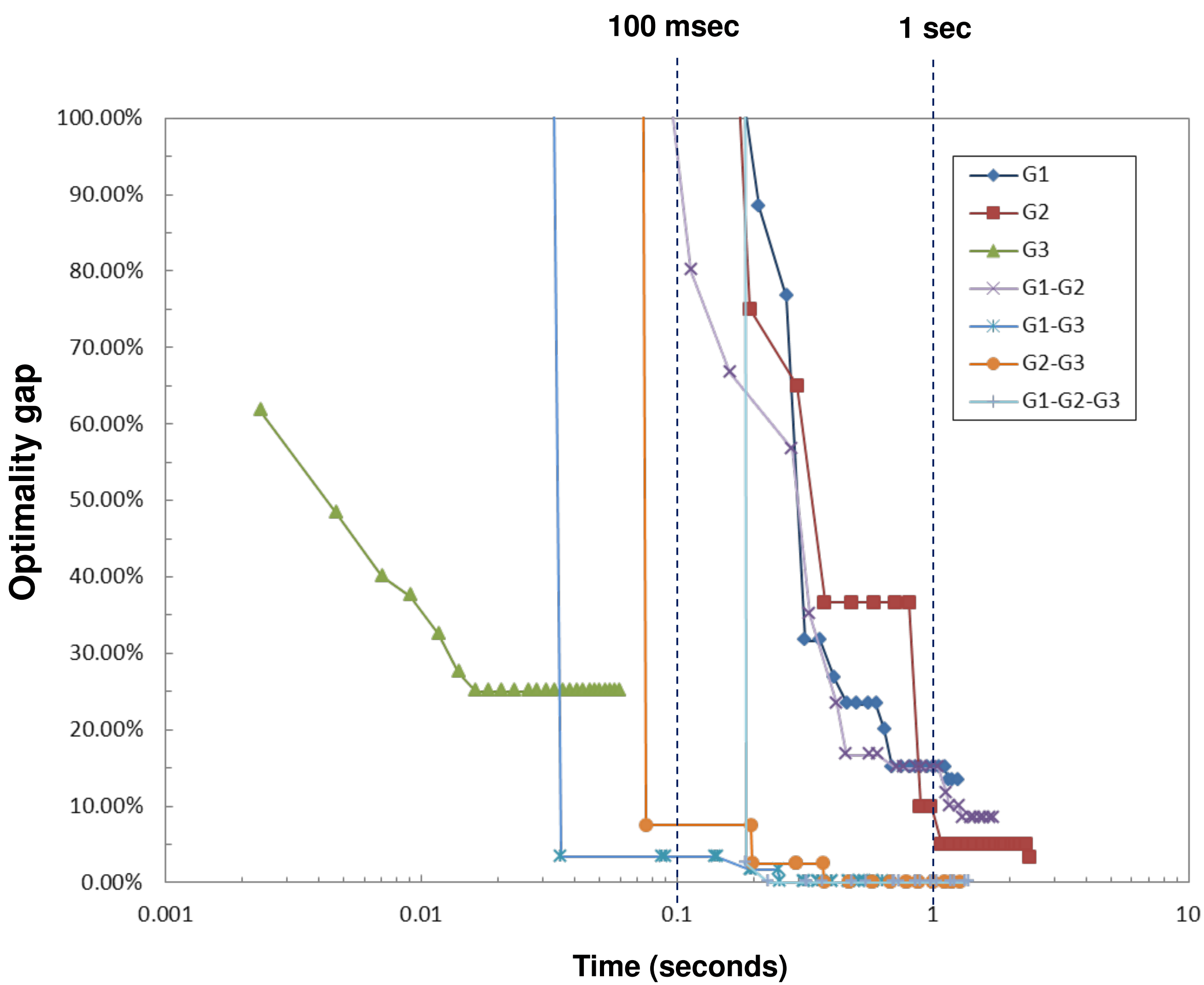
Hybrid meta-heuristics

- Heuristic hybridization: Combine several of the previous techniques.
  - GRASP + PR -> Diversification + Intensification
- Example: multi-greedy + PR
  - **Three different constructive** algorithms to provide diversification.
  - **Path Relinking** finds new solutions in the path connecting two solutions.



* M. Ruiz, et al., "Ultra-fast meta-heuristic for the spectrum re-allocation problem in flexgrid optical networks", 25th European Conference on Operational Research (EURO XXV), 2012

Hybrid meta-heuristics: Solving Time



G3 provides feasible solutions in few miliseconds (20-50 msec)

G1 and G2 provide better solutions but at the expense of higher computation time

Multi-start with PR provides the best results:
(G1 + G3)
(G2 + G3)
(G1 + G2 + G3)

Large Scale Optimization (LSO)

- The objective of LSO methods is to extend the exact methodology (Branch & Bound) for MILP formulations.
- Among different methods, decomposition methods have been successfully used for solving communications network design problems
  - **Lagrangean relaxation** aims at improving lower bounds on the objective function, a decisive factor for the effectiveness of Branch & Bound.
  - **Column generation** consists in finding a reduced set of variables (columns) to solve the linear relaxation of the link-path MILP formulations, providing high quality integer solutions in an efficient way.
  - **Benders decomposition** is an iterative procedure based on projecting out a subset of variables from the original problem with the whole set of variables and creating new constraints (cuts) from the projected ones.

Lagrangian Relaxation

- Some (*difficult*) constraints are moved to the objective function and penalized by **Lagrange multipliers** (λ)

$$\begin{aligned}
&\min \sum_{d\in D} x_d \cdot b_d \\
&\text{s.t.} \\
&\sum_{p\in P(d)} \sum_{c\in C(d)} y_{pc} + x_d = 1 \quad \forall d \in D \\
&\boxed{\sum_{d\in D} \sum_{p\in P(d)} \sum_{c\in C(d)} \gamma_{cs} \cdot \delta_{pe} \cdot y_{pc} \le 1} \quad \forall e \in E, s \in S
\end{aligned}$$

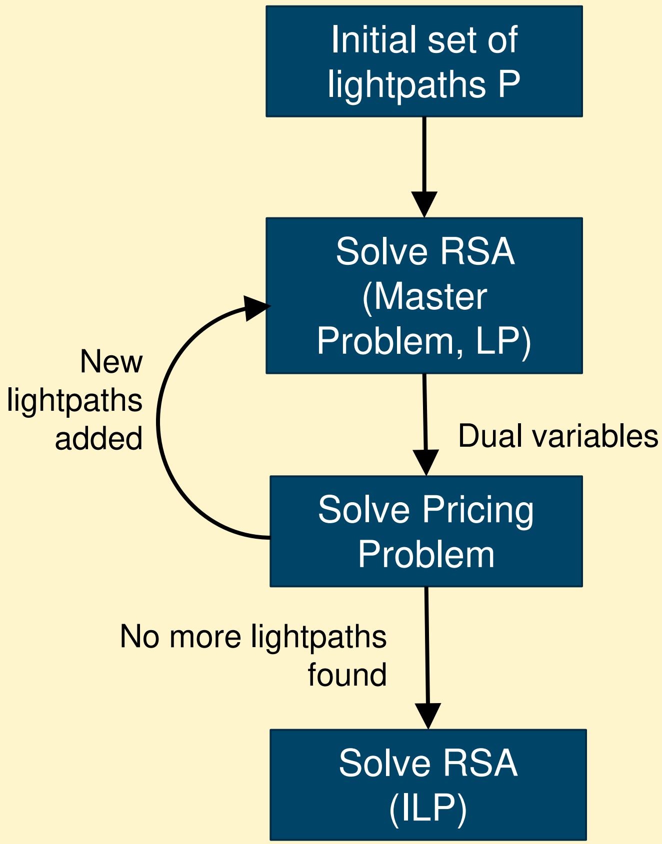
$\Rightarrow$

$$\begin{aligned}
&\min \sum_{d\in D} x_d \cdot b_d + \boxed{\sum_{e\in E} \sum_{s\in S} \lambda_{es} \cdot \left(\sum_{d\in D} \sum_{p\in P(d)} \sum_{c\in C(d)} \gamma_{cs} \cdot \delta_{pe} \cdot y_{pc} - 1 \right)} \\
&\text{s.t.} \\
&\sum_{p\in P(d)} \sum_{c\in C(d)} y_{pc} + x_d = 1 \quad \forall d \in D
\end{aligned}$$

- It allows obtaining **lower bounds** for the original problem for any positive Lagrange multipliers.
- Those Lagrange multipliers that provide the optimal solution of the original problem can be found by **solving the Lagrangian dual problem.**
  - Iterative methods such as **sub-gradient optimization** methods are commonly used for solving the Lagrangian dual problem.

Column Generation Algorithm

Main Algorithm



Lightpath set initialization

For each demand *d*:

1) Compute the shortest (hops) path in the network
2) Generate a lightpath with the shortest path and the first channel for demand *d*.

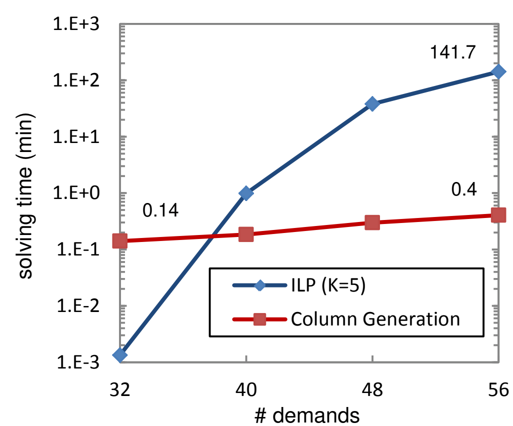
Pricing Problem

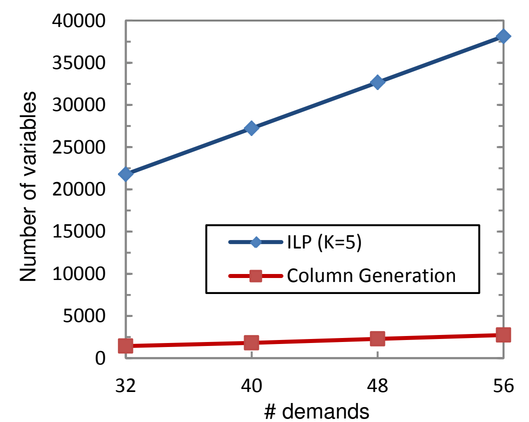
1) For each demand *d* and each channel in C_d, compute the shortest path in the network with link metrics:

$$f_e(c) = \sum_{s \in S(c)} \pi_{es} \qquad c \in C_d$$

2) Return those lightpaths (route + channel) with the highest positive reduced costs (if any)

Exhaustive search of channels optimized by means of Floyd-Warshall algorithm





* M. Ruiz, et al., “Column Generation Algorithm for RSA Problems in Flexgrid Optical Networks,” Springer Photonic Network Communications, 2013.

The Dijkstra's Shortest Path algorithm

```
Procedure Dijkstra (N, E, source)
begin
  S : = {source}, T = N − {source}
  d(source) = 0 and pred(source) = 0
  d(j) = ∞ for each j ≠ source
  update(source)
  while S ≠ N do
    let i ∈ T be a node for which
            d(i) = min {d(j) : j ∈ T}
    S = S ∪ {i}, T = T − {i}
    update(i)
end

Procedure Update (i)
 for each (i,j) ∈ E(i) do
    if d(j) > d(i) + c_ij then
        d(j) = d(i) + c_ij
        pred(j) = i
```

- Each node i is labeled with the aggregated metric $d(i)$ from the source node and with its predecessor $pred(i)$.
- the route $source\text{-}i$ (subset of links $E(source, i) \subseteq E$) can be computed visiting the predecessor node starting from i, until source node is reached.

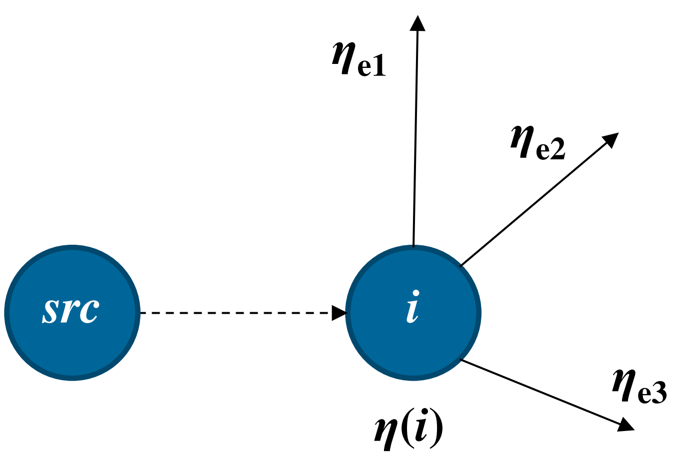
Dijkstra-based RSA (1/2)

```
Procedure Update (i)
 for each (i,j) ∈ E(i) do
    if [π(i,j)==1] and d(j) > d(i) + c_ij
    then
          d(j) = d(i) + c_ij
          pred(j) = i
```

- The label also contains $\eta_s(i)$, the aggregated state of frequency slice s

$$\eta_s(i) = \prod_{e \in E(source,i)} \eta_{es} \ \forall \ s \in S$$

- The downstream node j of node i updates the label only if at least one channel is available, computing:



$$\pi(e=(i,j)) = \begin{cases} 1 & \exists c \in C(d) : \eta_s(i) \cdot \eta_{es} = 1 \ \forall s \in S(c) \\ 0 & \text{otherwise} \end{cases}$$

Dijkstra-based RSA (2/2)

- Spectrum allocation can be done implementing any heuristic, such:
  - First Fit
  - Random
  - Least fragmented spectrum
  - etc.
- Modulation formats, reachability, etc, can be easily included.

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Part III
Advanced RSA

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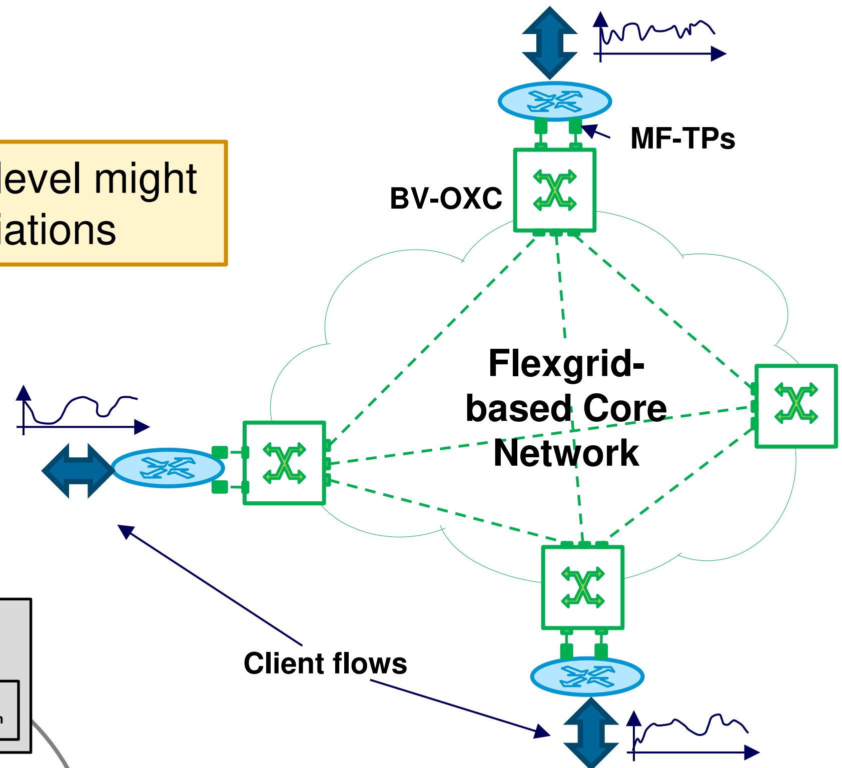
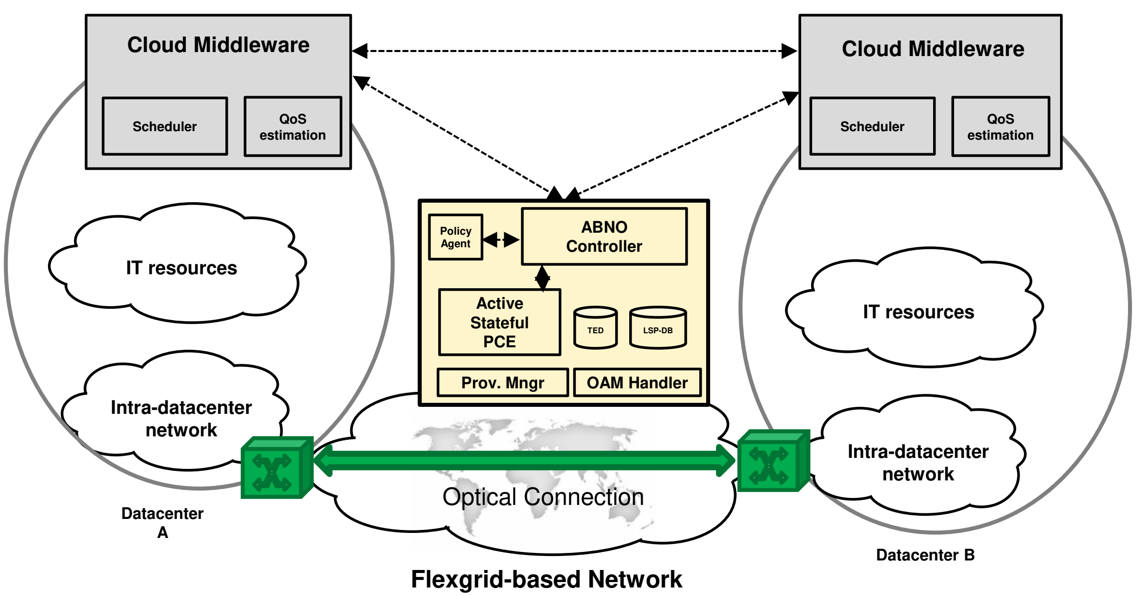
Source of traffic variations

Reducing aggregation level might increase traffic variations

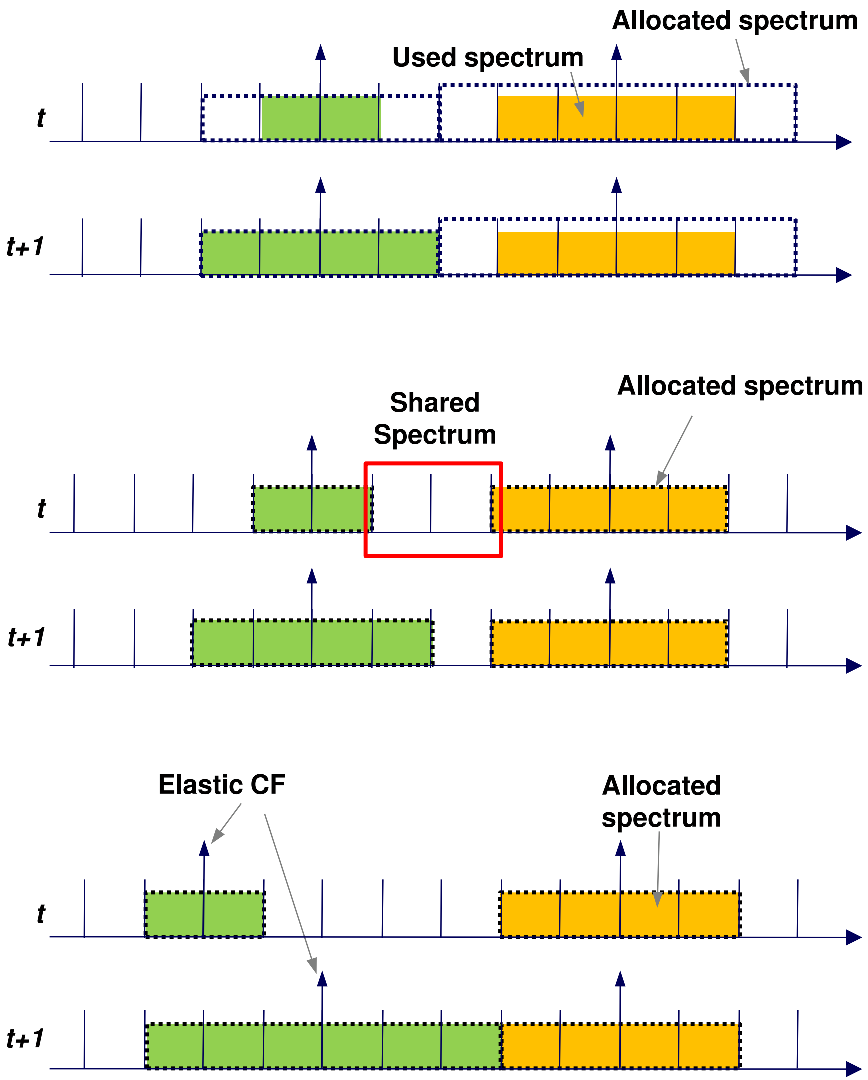


Datacenter interconnection to transfer bulk data



* L. Velasco, et al., "Cross-Stratum Orchestration and Flexgrid Optical Networks for Datacenter Federations," accepted in IEEE Network Magazine, 2013.

Elastic Spectrum Allocation Policies



Fixed: both the assigned CF and spectrum width do not change in time.

Semi-Elastic: the assigned CF is fixed but the allocated spectrum may vary.

- At each time interval, the allocated spectrum corresponds to the utilized spectrum.
- Spectrum increments/decrements are achieved by allocating/releasing frequency slices.
- The frequency slices can be shared between neighboring demands, but used by, at most, one demand in a time interval.

Elastic: both the assigned CF and the spectrum width can be subject to change in each time interval.

* M. Klinkowski, et al., "Elastic Spectrum Allocation for Time-Varying Traffic in Flexgrid Optical Networks," IEEE Journal on Selected Areas in Communications (JSAC), vol. 31, pp. 26-38, 2013

Multi-period RSA

- Find, for each demand in *D:*
  - a route and
  - **a SA for each time period in *T*,** constraining SA changes to a certain policy.
- Complexity depends on SA policy
  - SA between consecutive time periods is constrained by the chosen policy

RSA

$$\sum_{p \in P(d)} \sum_{c \in C(d)} y_{pc} + x_d = 1 \qquad \forall d \in D$$

$$\sum_{d \in D} \sum_{p \in P(d)} \sum_{c \in C(d)} \gamma_{cs} \cdot \delta_{pe} \cdot y_{pc} \le 1 \qquad \forall e \in E, s \in S$$

MP-RSA

$$\sum_{p \in P(d)} x_p + x_d = 1 \qquad \forall d \in D$$

$$\sum_{d \in D} \sum_{p \in P(d)} \sum_{c \in C(d)} \gamma_{cs} \cdot \delta_{pe} \cdot y_{pc}^{t} \le 1 \qquad \forall t \in T, e \in E, s \in S$$

Dynamic lightpath adaptation

- *Given*:
  - a core network topology represented by a graph G(N, E);
  - a set S of available slices of a given spectral width for every link in E;
  - a set L of lightpaths already established on the network; each lightpath l is defined by the tuple $\{R_l, f_l, s_l\}$, where the ordered set $R_l \subseteq E$ represents its physical route, f_l its central frequency and s_l the amount of frequency slices.
  - a lightpath $p \in L$ for which spectrum adaptation request arrives and the required number of frequency slices, $(s_p)^{req}$.
- *Output:*
  - the new values for the spectrum allocation of the given lightpath p: $\{R_p, f_p, (s_p)'\}$ and $\{R_p, (f_p)', (s_p)'\}$, respectively, if the *Semi-Elastic* and *Elastic* policy is used.
- *Objective*: maximize the amount of bit-rate served.

On-line Algorithms for Elastic SA

Algorithm for the *semi-elastic* policy

INPUT: $G(N,E)$, S, L, p, $(s_p)^{req}$
OUTPUT: $(s_p)'$

1: **if** $(s_p)^{req} \le s_p$ **then** $(s_p)' \leftarrow (s_p)^{req}$
2: **else**
3: $L^+ \leftarrow \emptyset$, $L^- \leftarrow \emptyset$
4: **for each** $e \in R_p$ **do**
5: $L^- \leftarrow L^- \cup \{l \in L: e \in R_l\text{, adjacents}(l, p)\text{, } f_l<f_p\}$
6: $L^+ \leftarrow L^+ \cup \{l \in L: e \in R_l\text{, adjacents}(l, p)\text{, } f_l>f_p\}$
7: $s_{max} \leftarrow 2*\min\{\min\{f_p - f_l - s_l, l \in L^-\}, \min\{f_l - f_p - s_l, l \in L^+\}\}$
8: $(s_p)' \leftarrow \min\{s_{max}, (s_p)^{req}\}$
9: **return** $(s_p)'$

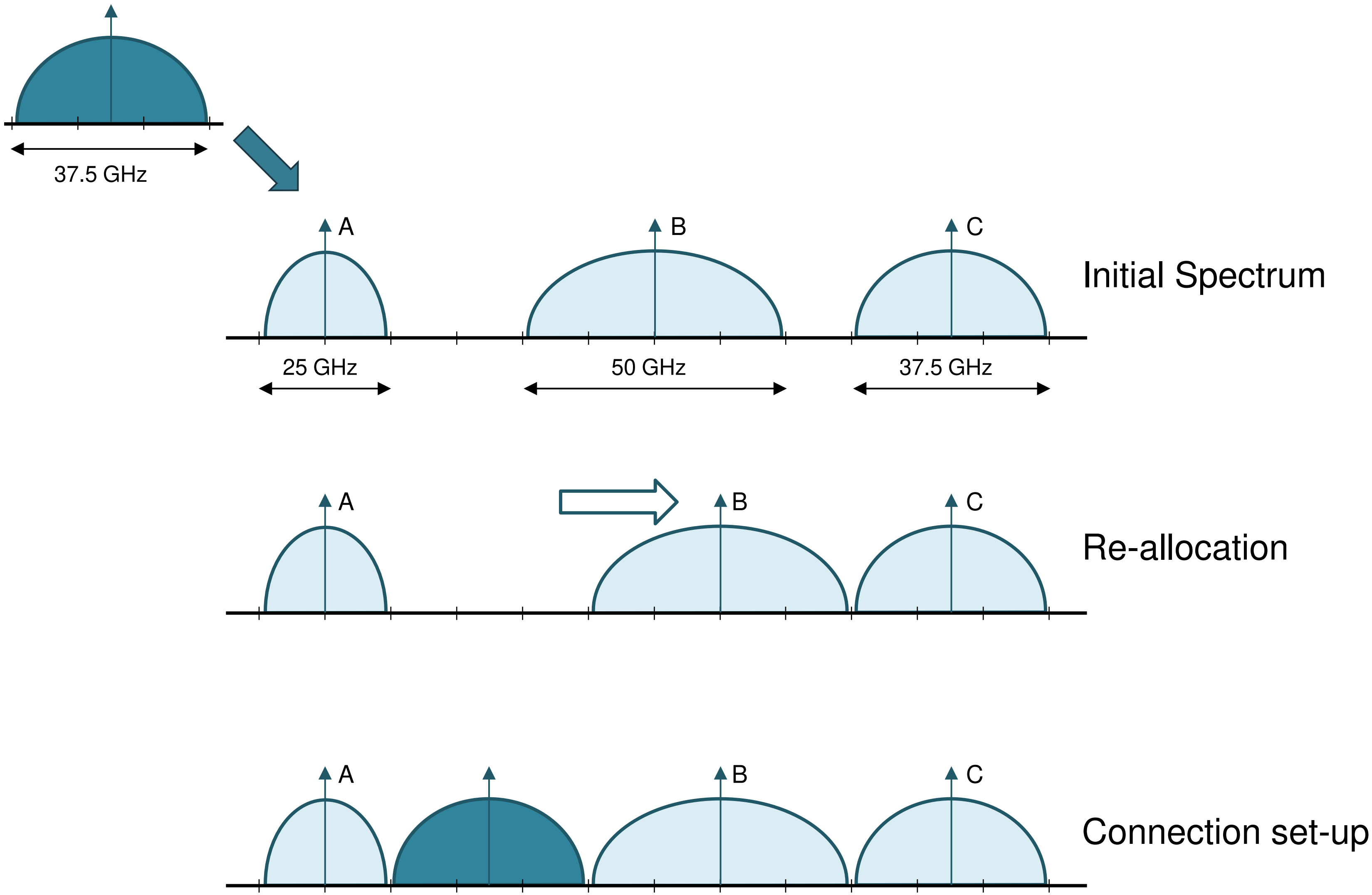
Algorithm for the *elastic* policy

INPUT: $G(N,E)$, S, L, p, $(s_p)^{req}$
OUTPUT: $(f_p)'$, $(s_p)'$

1: **if** $(s_p)^{req} \le s_p$ **then** $(s_p)' \leftarrow (s_p)^{req}$; $(f_p)' \leftarrow f_p$
2: **else**
3: $L^+ \leftarrow \emptyset$, $L^- \leftarrow \emptyset$
4: **for each** $e \in R_p$ **do**
5: $L^- \leftarrow L^- \cup \{l \in L: e \in R_l\text{, adjacents}(l, p)\text{, } f_l<f_p\}$
6: $L^+ \leftarrow L^+ \cup \{l \in L: e \in R_l\text{, adjacents}(l, p)\text{, } f_l>f_p\}$
7: $s_{max} \leftarrow \min\{f_p - f_l - s_l, l \in L^-\} + \min\{f_l - f_p - s_l, l \in L^+\}$
8: $(s_p)' \leftarrow \min\{s_{max}, (s_p)^{req}\}$
9: $(f_p)' \leftarrow$ *findSA_MinCFShifting* $(p, (s_p)', L^+, L^-)$
10: **return** $\{(f_p)', (s_p)'\}$

* A. Asensio, et al., "Impact of Aggregation Level on the Performance of Dynamic Lightpath Adaptation under Time-Varying Traffic," in Proc. IEEE International Conference on Optical Network Design and Modeling (ONDM), 2013.

Example of Re-optimisation (Defragmentation)



Spectrum Reallocation (SPRESSO)

Parameters

Pm subset of *P* with the candidate paths, including *newP*. $Pm = P(newP) \cup \{newP\}$.

Variables

x_{pc} binary, 1 if channel *c* is assigned to path *p*, 0 otherwise.

y_p binary, 1 if path *p* is reallocated, 0 otherwise.

r integer with the number of already established paths to reallocate.

(SPRESSO) minimize r

subject to:

$$r = \sum_{p \in Pm \setminus \{\text{newP}\}} y_p$$

$$\sum_{c \in C(p)} x_{pc} = 1 \quad \forall p \in Pm$$

$$x_{pc} - \omega_{pc} \le y_p \quad \forall p \in Pm, c \in C(p)$$

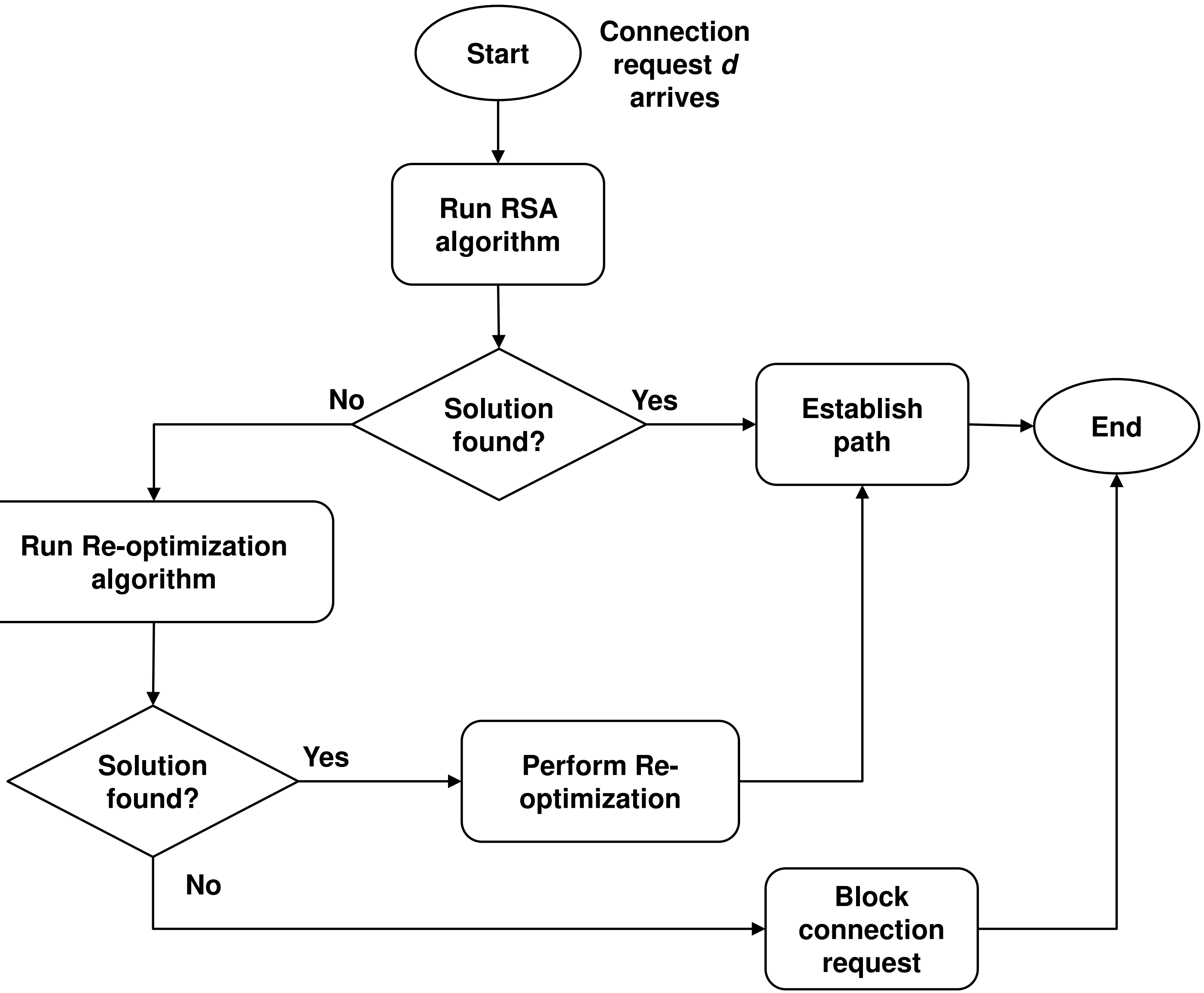
$$\sum_{p \in P(e)} \sum_{c \in C(p)} \delta_{cs} \cdot x_{pc} \le \eta_{es} \quad \forall e \in E, s \in S$$

$$r \le \text{maxR}$$

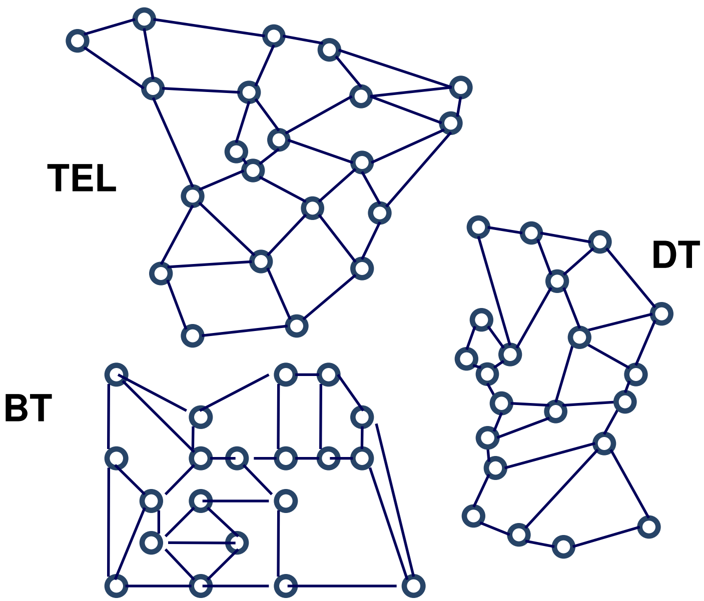
$O(|Pm| \cdot |C|)$ **variables**
$O(|Pm| \cdot |C| + |E| \cdot |S|)$ **constraints**

* A. Castro, et al., "Dynamic Routing and Spectrum (Re)Allocation in Future Flexgrid Optical Networks," Elsevier Computers Networks, vol. 56, pp. 2869-2883, 2012.

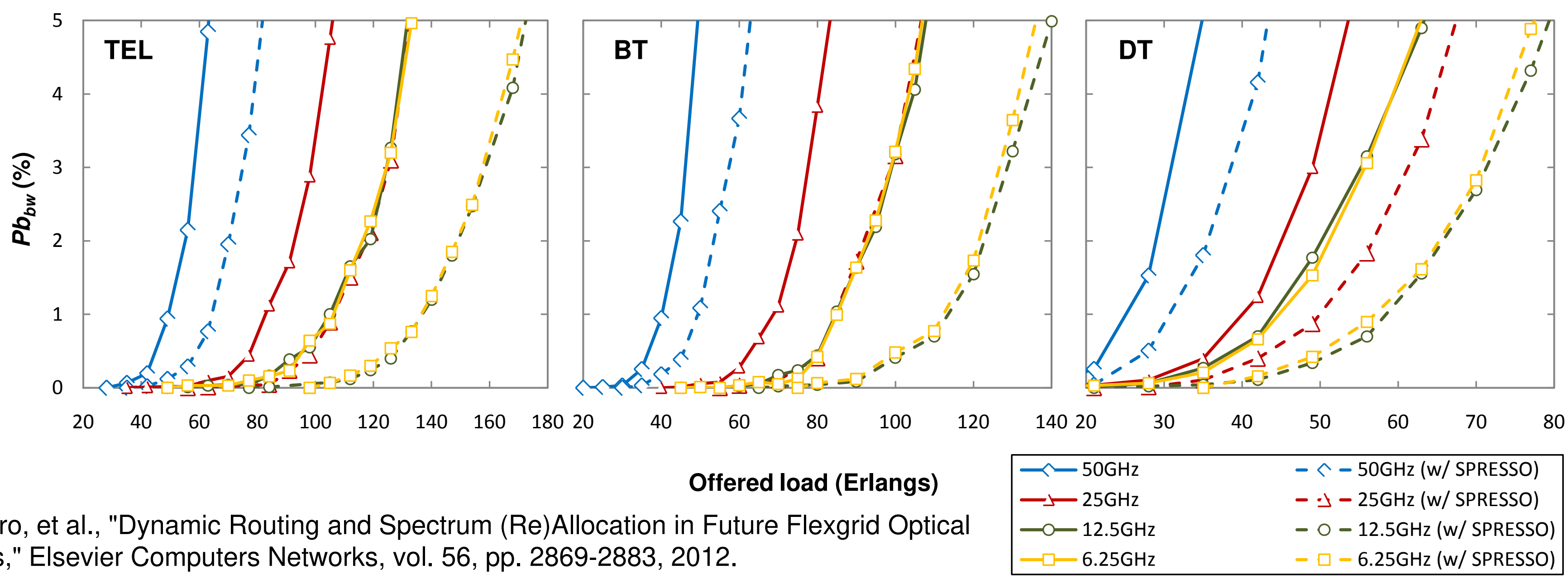
Provisioning-triggered re-optimization



Gains of Using SPRESSO



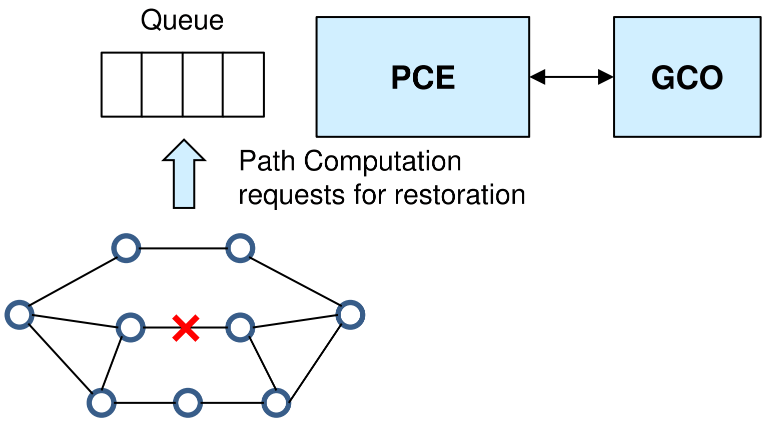
Network	25 GHz	12.5 GHz	6.25 GHz
TEL	30,4%	28,4%	30,3%
BT	22,9%	23,0%	34,1%
DT	22,2%	24,8%	33,0%



* A. Castro, et al., "Dynamic Routing and Spectrum (Re)Allocation in Future Flexgrid Optical Networks," Elsevier Computers Networks, vol. 56, pp. 2869-2883, 2012.

Bulk path computation

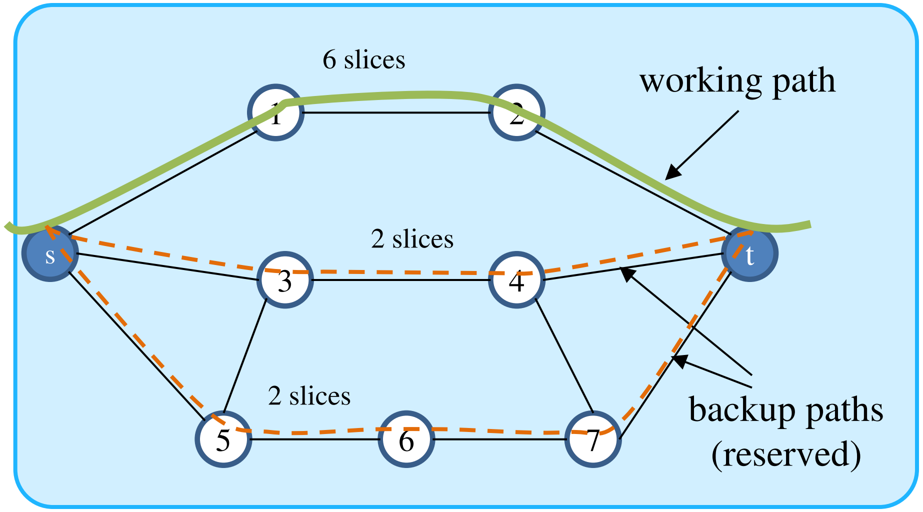
- Path computation for a set of connection requests.
  - the bulk of path requests is computed attaining the optimal solution for the whole set.
  - Increases optimality but increases also provisioning time.
- Bulk path computation can be used for restoration.
  - Reduces resource contention.
  - Increases resource utilization, specially in MLN.
  - Stringent computation times require heuristic algorithms.

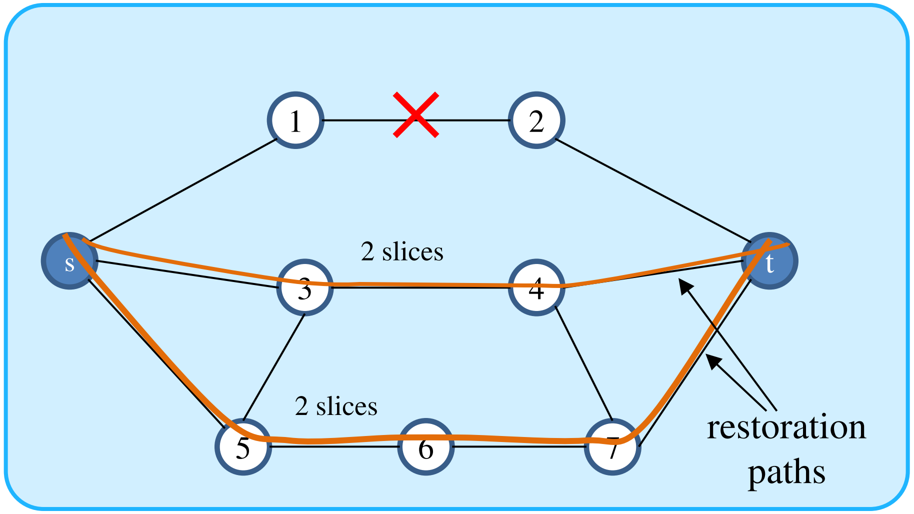


* R. Martínez, et al., "Experimental Validation of Dynamic Restoration in GMPLS-controlled Multi-layer Networks using PCE-based Global Concurrent Optimization," in Proc. IEEE/OSA Optical Fiber Communication Conference (OFC), 2013.

Bitrate Squeezed and Multi-path Recovery

Path Recovery	Description
Protection	Protection routes are known in advance: • Dedicated Protection • Shared Protection
Restoration	Restoration routes are found adaptively based on the failure and the state of the network at the time of failure.





* A. Castro et al., "Single-path Provisioning with Multi-path Recovery in Flexgrid Optical Networks," International Workshop on Reliable Networks Design and Modeling (RNDM), 2012

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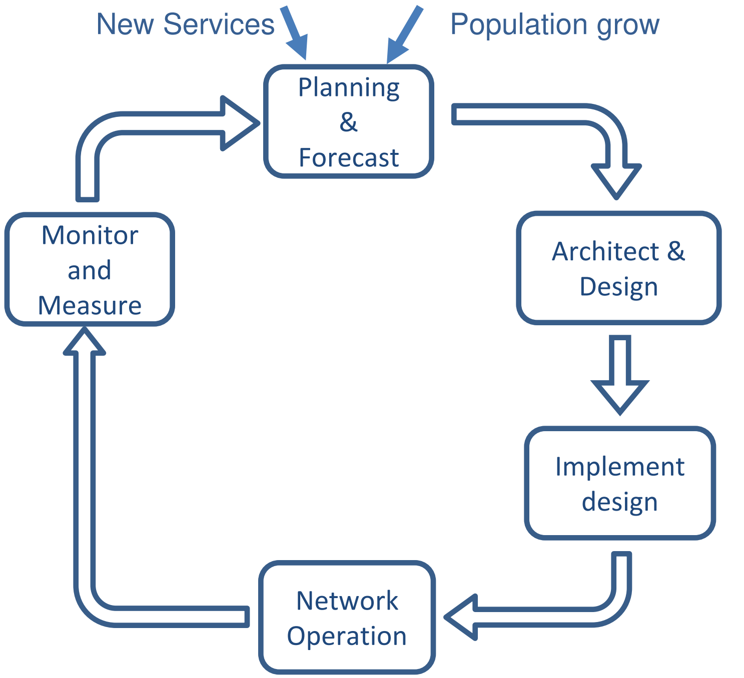
Part IV
Off-line Network Planning

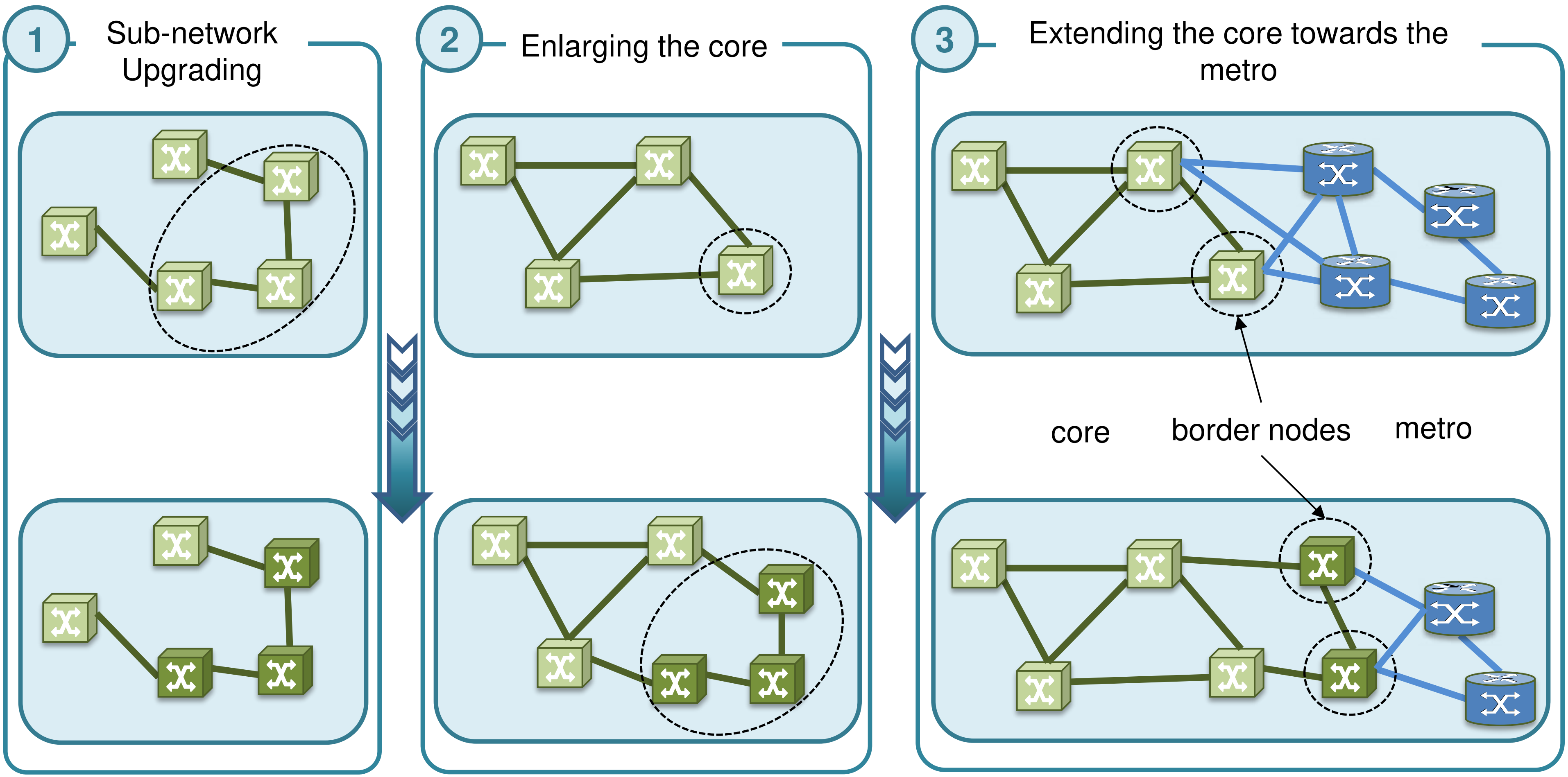
Luis Velasco

Network Life Cycle

- Network planning is performed periodically:
  - **Capacity** is installed to guarantee that the network can support the forecast traffic.
  - **Long planning cycles** are used to upgrade the network and prepare it for the next planning period.
  - Results from network capacity planning are **manually deployed** in the network.



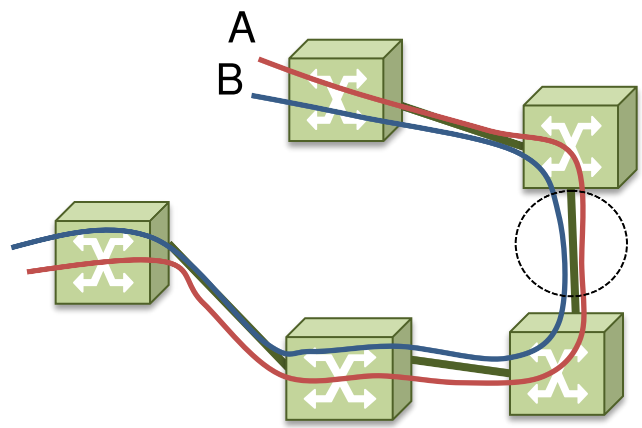
Migrating Towards Flexgrid Technology

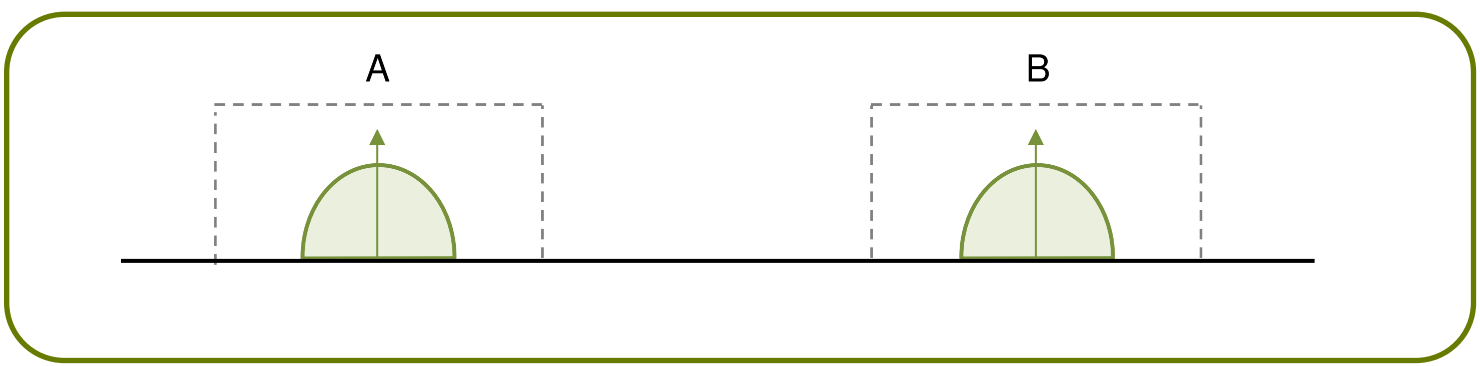


* M. Ruiz, et al, "Planning Fixed to Flexgrid Gradual Migration: Drivers and Open Issues," submitted to IEEE Communications Magazine, 2014.

Migrating connections (1/4)

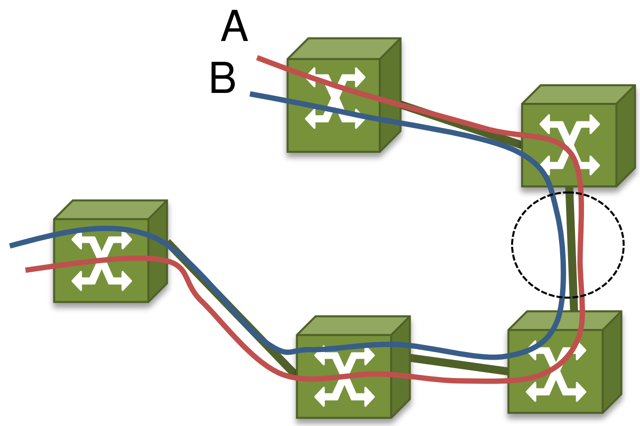
Fixed grid

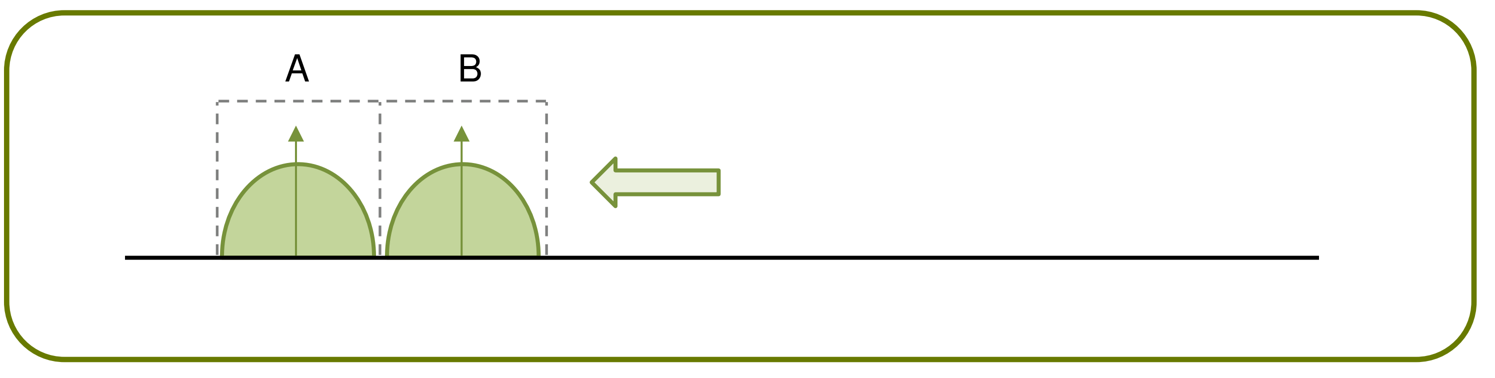




Migrating connections (2/4)

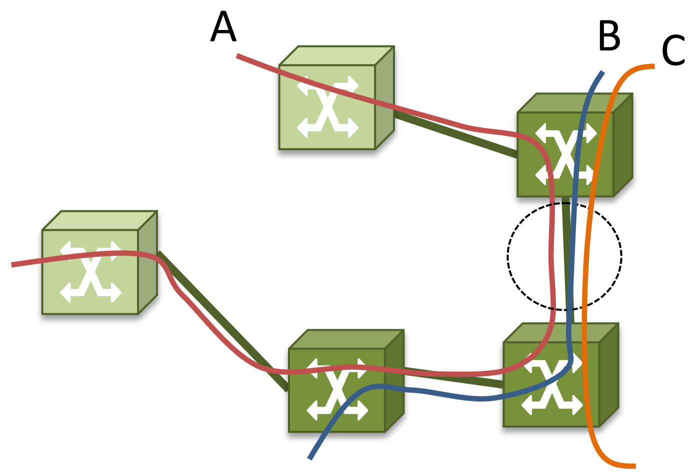
Flexgrid

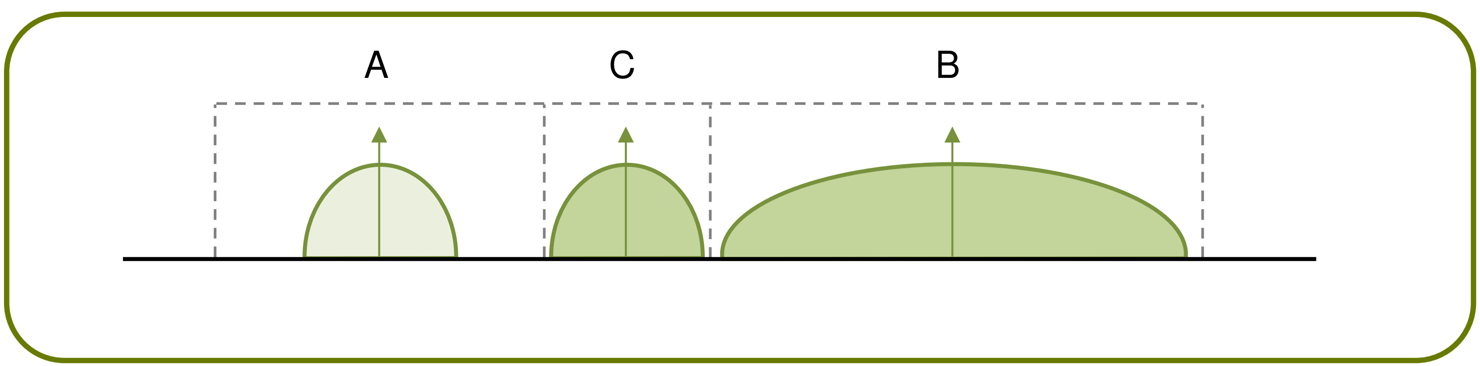




Migrating connections (3/4)

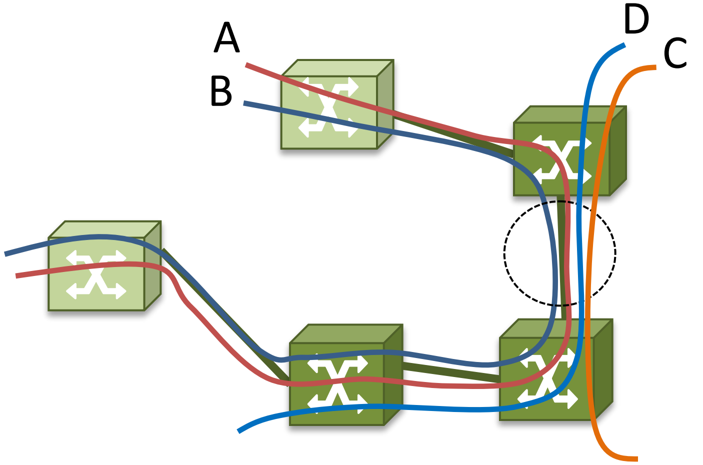
Mixed grid

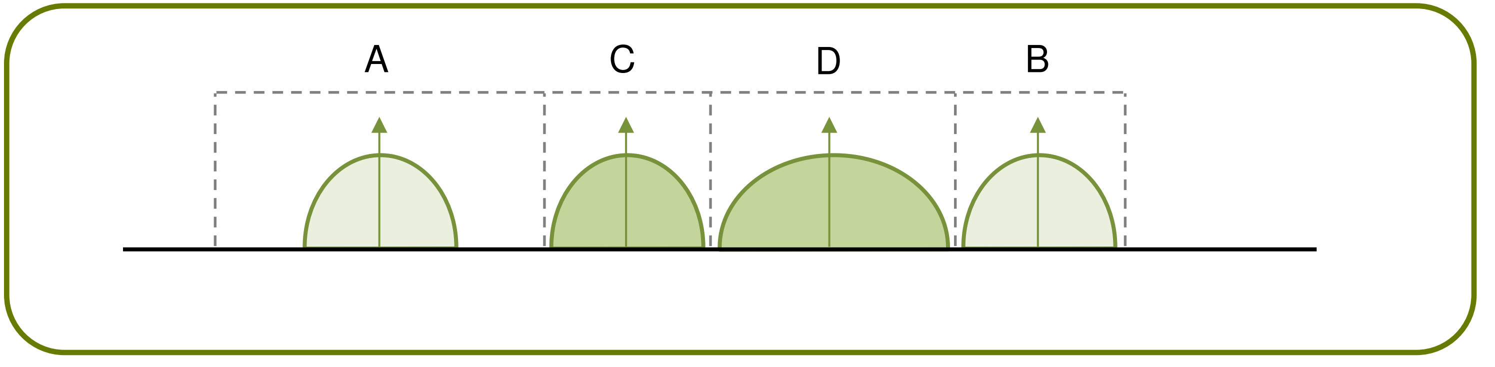




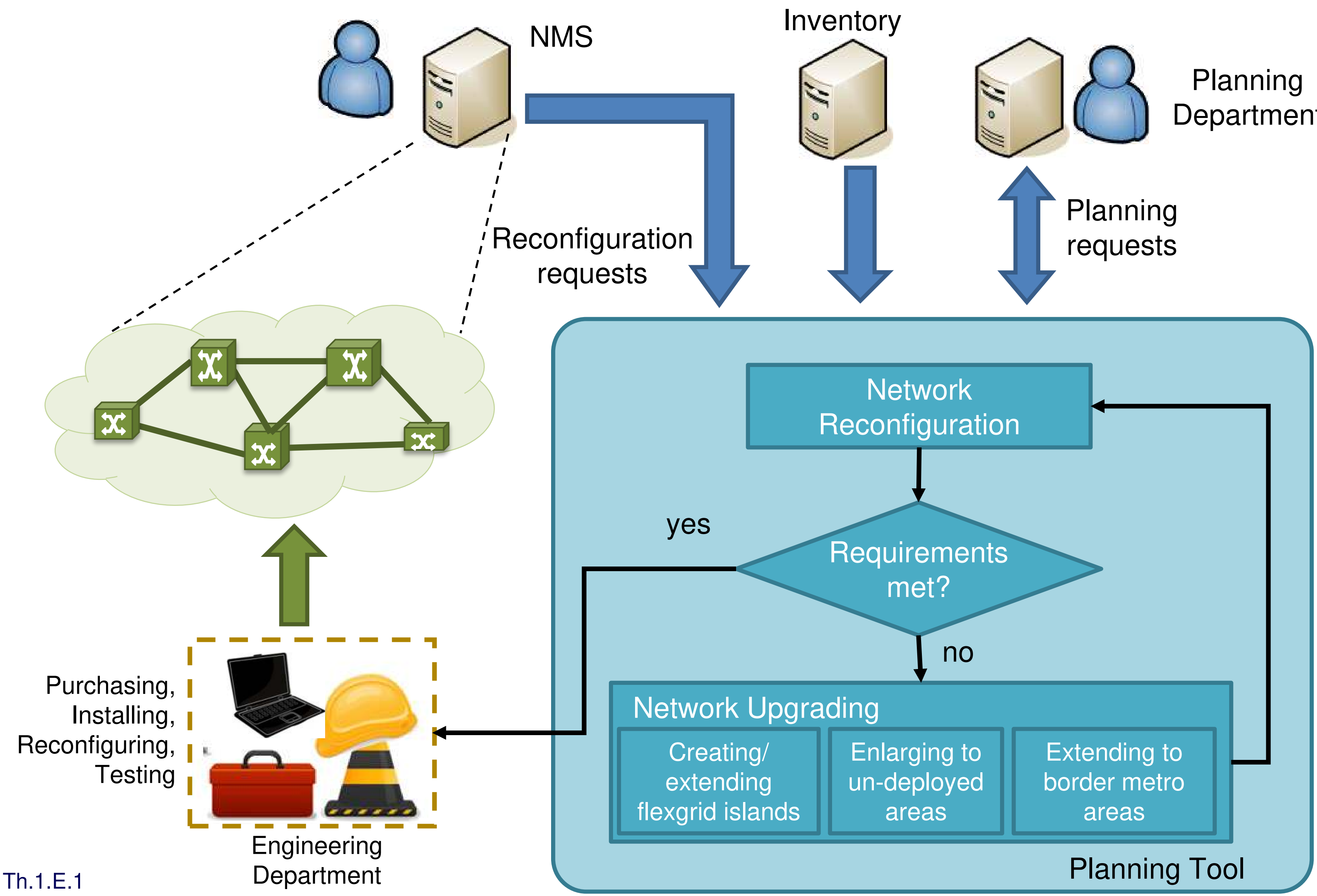
Migrating connections (4/4)

Mixed grid





Migration flow chart



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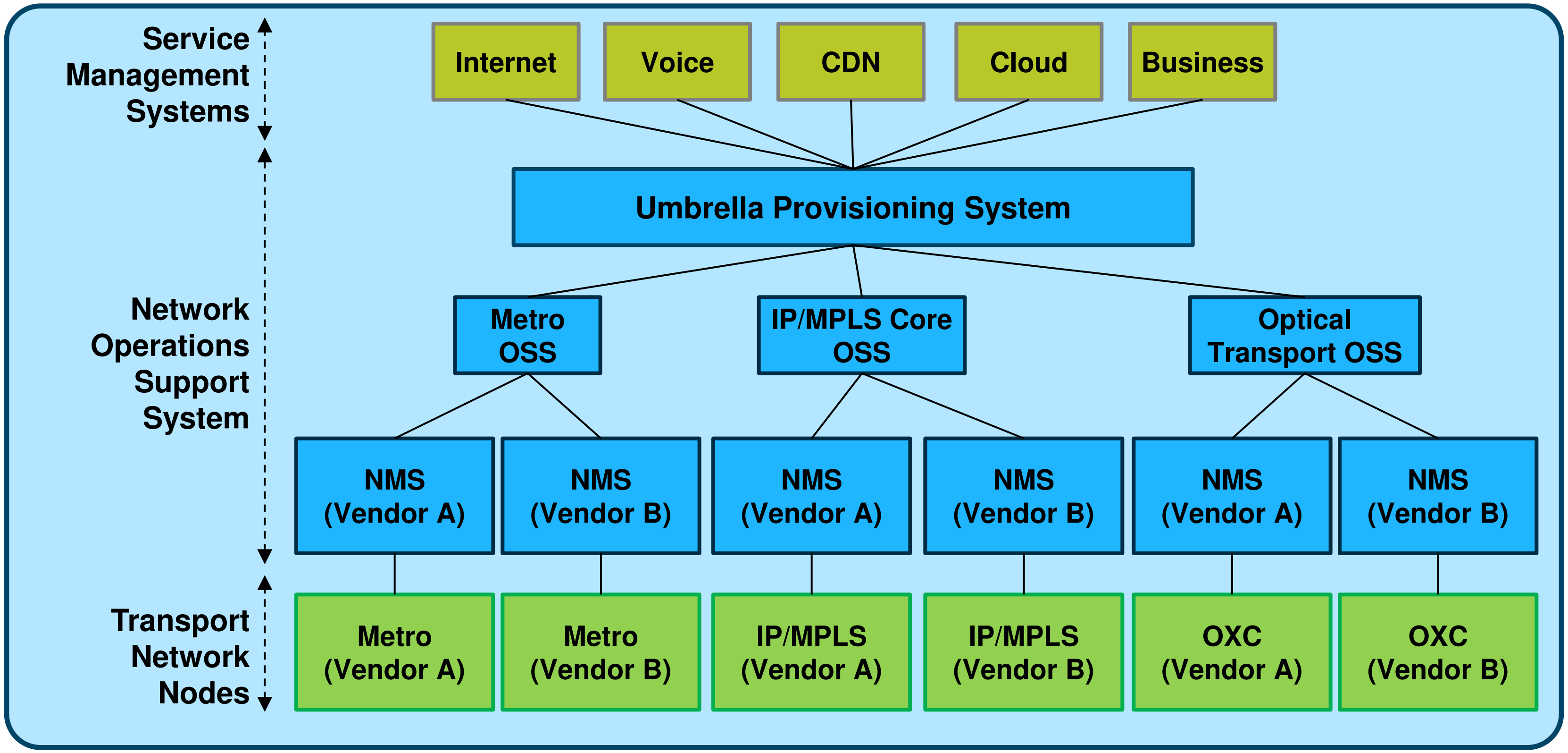
Part V
In-operation Network Planning

Luis Velasco

Static Network Operation



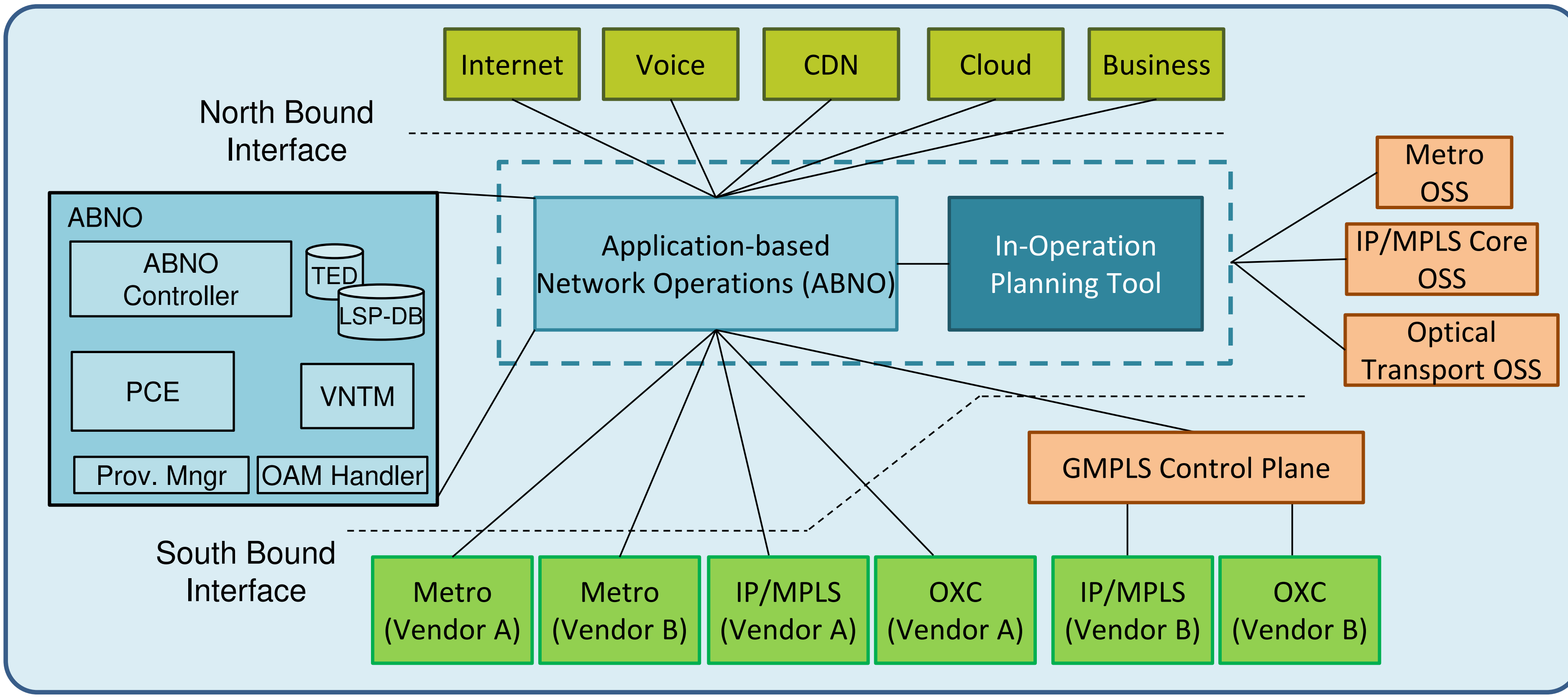
IETF architectures supporting in-operation Planning (1/2)

Architecture	Strengths	Weaknesses
Stateless PCE	• **Path computation** can be off-loaded onto a dedicated entity capable of complex computations with tailored algorithms and functions. • Has a **standard** and **mature** interface and protocol. • Supports **simple optimisation**, such as bulk path computation.	• Is **unaware of existing LSPs** and has no view of the current network resource utilisation and key choke points. • **Cannot configure** by itself any **LSP** in the network. • Delays need to be introduced to sequence LSP set-up.
Stateful PCE	• Maintains a **database of LSPs** that are active in the network, i.e. so that new requests can be more efficiently placed optimising network resources. • **Supports optimization** involving already established LSPs.	• **More complex** than a stateless PCE, requires additional database and synchronization. • **No existing LSPs can be modified**, e.g. for network re-configuration purposes.

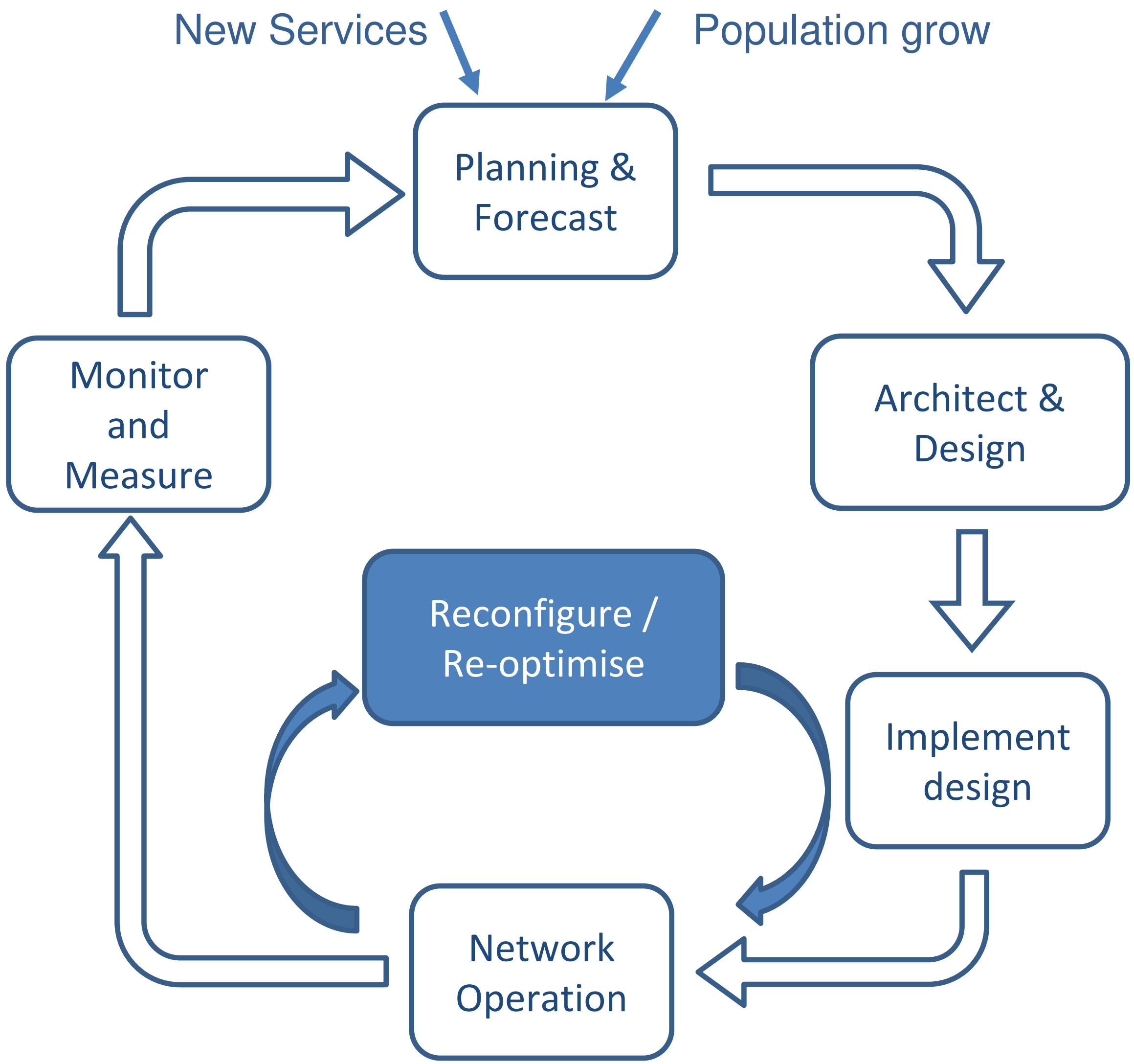
IETF architectures supporting in-operation Planning (2/2)

Architecture	Strengths	Weaknesses
Active Stateful PCE	• **Capable of responding to changes** in network resource availability and predicted demands and reroute existing LSPs for increased network resource efficiency. • Supports **complex reconfiguration and re-optimization**, even in multilayer networks.	• **No new LSPs can be created**, e.g. for VNT re-optimisation purposes. • Requires **protocol extensions** to modify and/or instantiate (if the capability is available) LSPs.
ABNO	• Provides a **network control system** for coordinating OSS and NMS requests to compute paths, enforce policies, and manage network resources for the benefit of the applications that use the network. • New **LSPs can be created** for in-operation planning. VNTM in charge of VNT re-configuration. • Supports deployment of solutions in **multi-technology scenarios** (NetConf, OpenFlow, control plane, etc.)	• Requires **implementation of a number of key components** in addition to the PCE function. • Some **interfaces** still need to be defined and **standardized**.

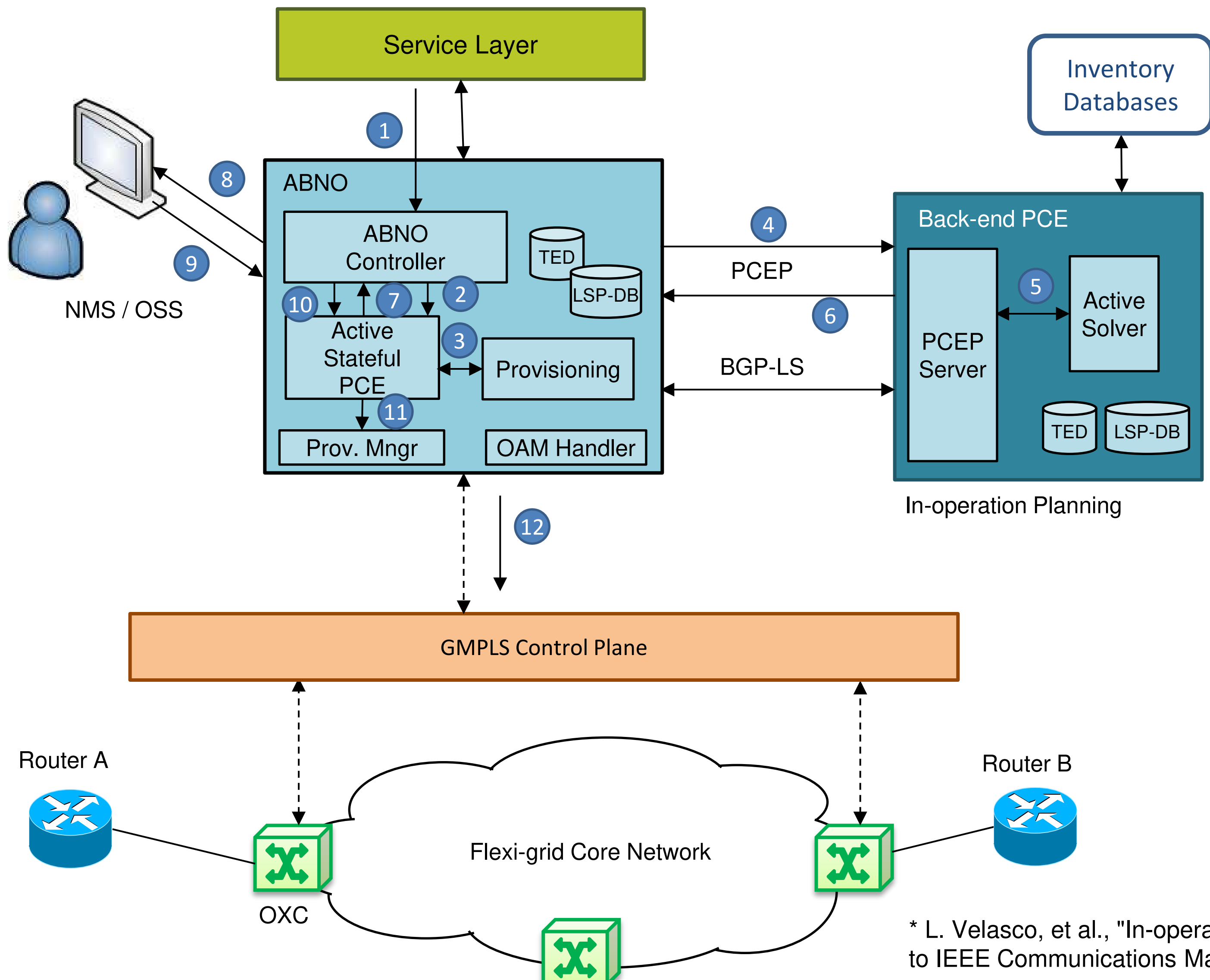
Migration towards in-operation network planning



Extended Networks Life Cycle

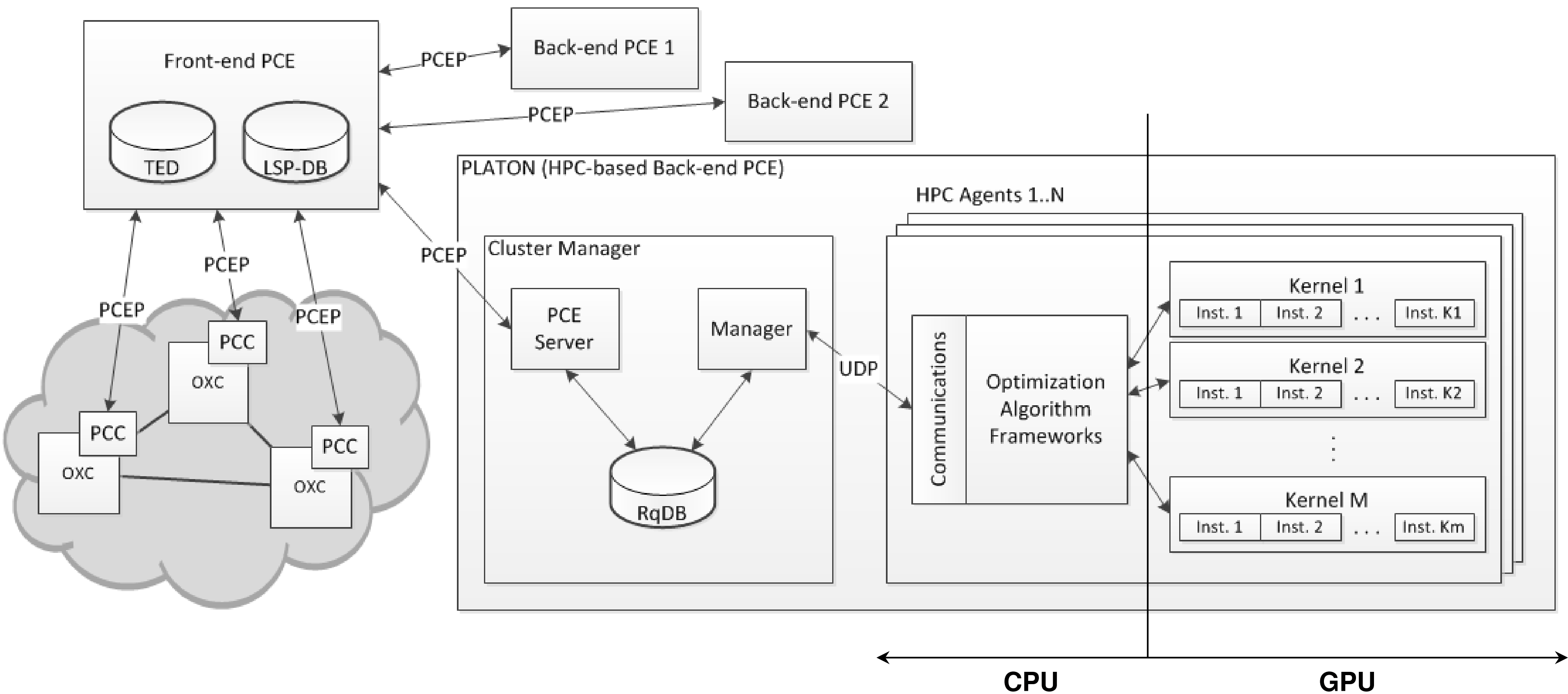


Re-optimisation Process



* L. Velasco, et al., "In-operation Network Planning ," submitted to IEEE Communications Magazine, 2014.

In-Operation Planning Tool: PLATON



* L. Gifre, et al. “Architecture of a Specialized Back-end High Performance Computing-based PCE for Flexgrid Networks," in Proc. IEEE International Conference on Transparent Optical Networks (ICTON), 2013.

Conclusions

- **Basic RSA algorithms have been reviewed**
- **Elastic SA**: Semi-elastic and Elastic policies
- **Off-line planning**: and example for gradual migration process from fixed to Flexgrid has been presented.
- **Re-optimization** can be performed to increase network performance.
- A control and management architecture to support **in-operation planning**.
  - The architecture allows dynamic network operation and to reconfigure and re-optimise the network near real-time in response to changes.
  - Networks life cycle is extended achieving better resource utilization.
  - Process automation reduces manual interventions and, consequently, OPEX.
- **PLATON**: an In-Operation Planning Tool has been presented.

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Thank you for your attention!

Solving Routing and Spectrum Allocation Related Optimization Problems

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