

The Role of Open-source Network Optimization Software in the SDN/NFV World

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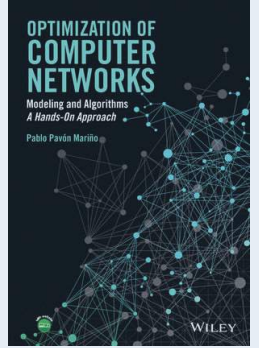


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15 years track in research
 in network optimization



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 open source network
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www.net2plan.com
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Co-founder of E-lighthouse
 Network Solutions



Multilayer network
 planning software

www.e-lighthouse.com

Networks 2018

**18th International Telecommunications Networks
Strategy and Planning Symposium**

10-12, September 2018, Los Alcázares (Spain)

networks2018.upct.es



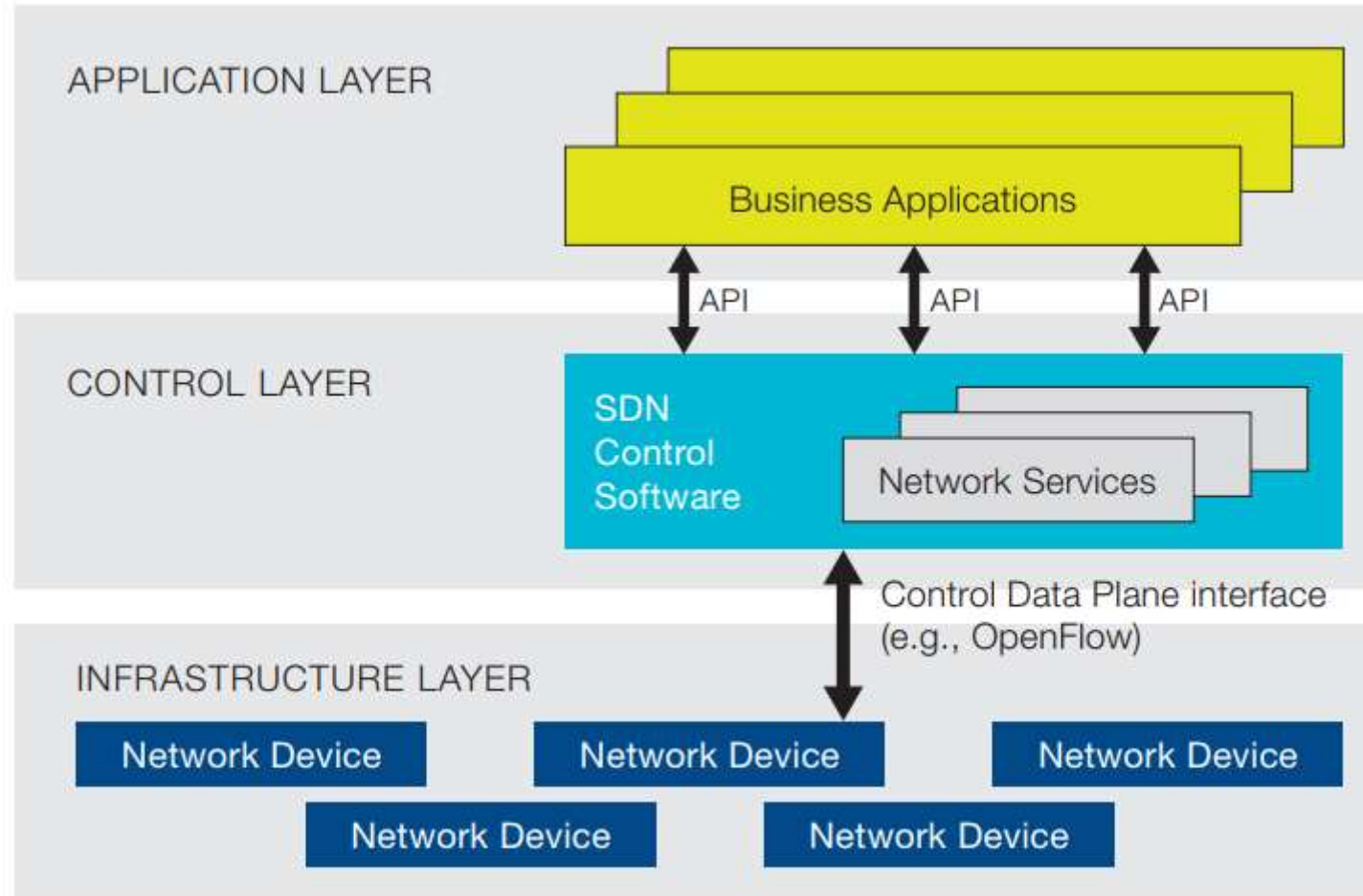
Agenda

1. Introduction
2. Use cases
3. Theoretical limits, heuristics, solvers
4. Network optimization software. Net2Plan
5. Wrap up

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- 1. Introduction**
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SDN / NFV introduction



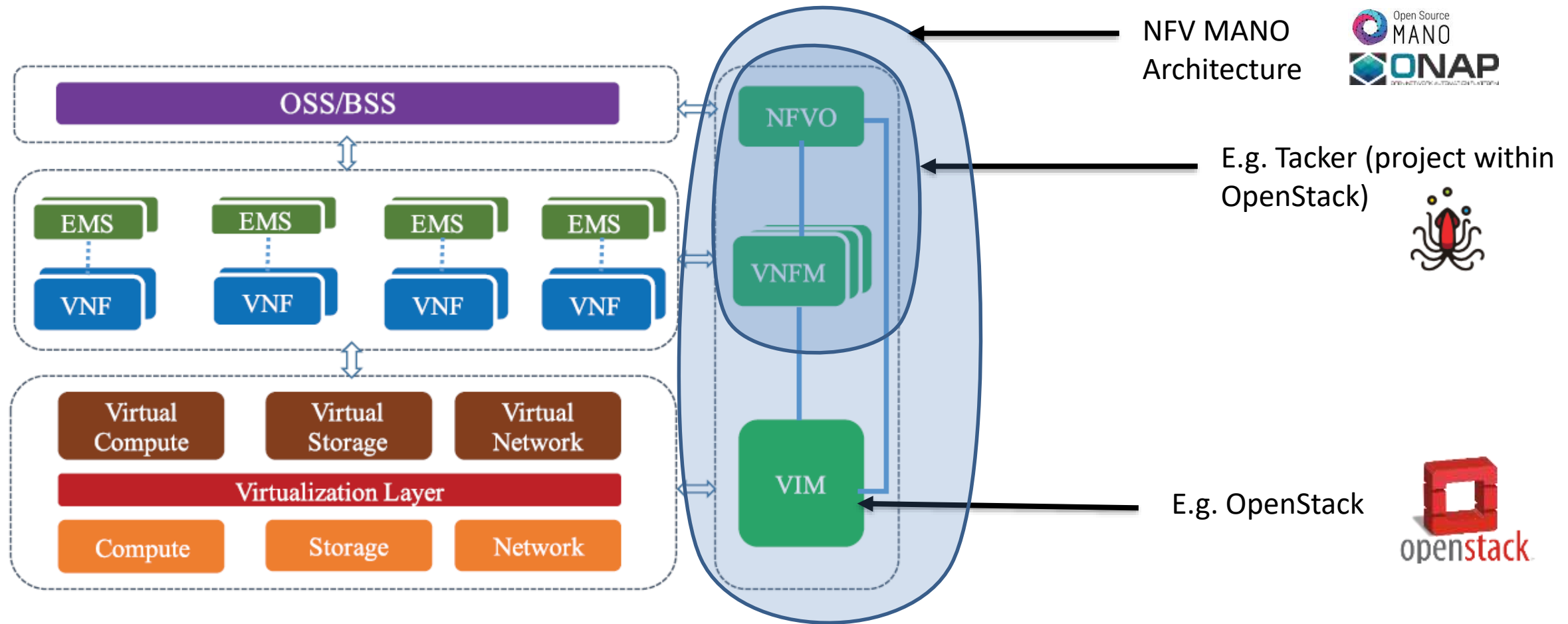
OaaS
Optimization-as-a-Service

As an SDN application

Source: ONF. Software-Defined Networking: The New Norm for Networks. White Paper April 13, 2012.

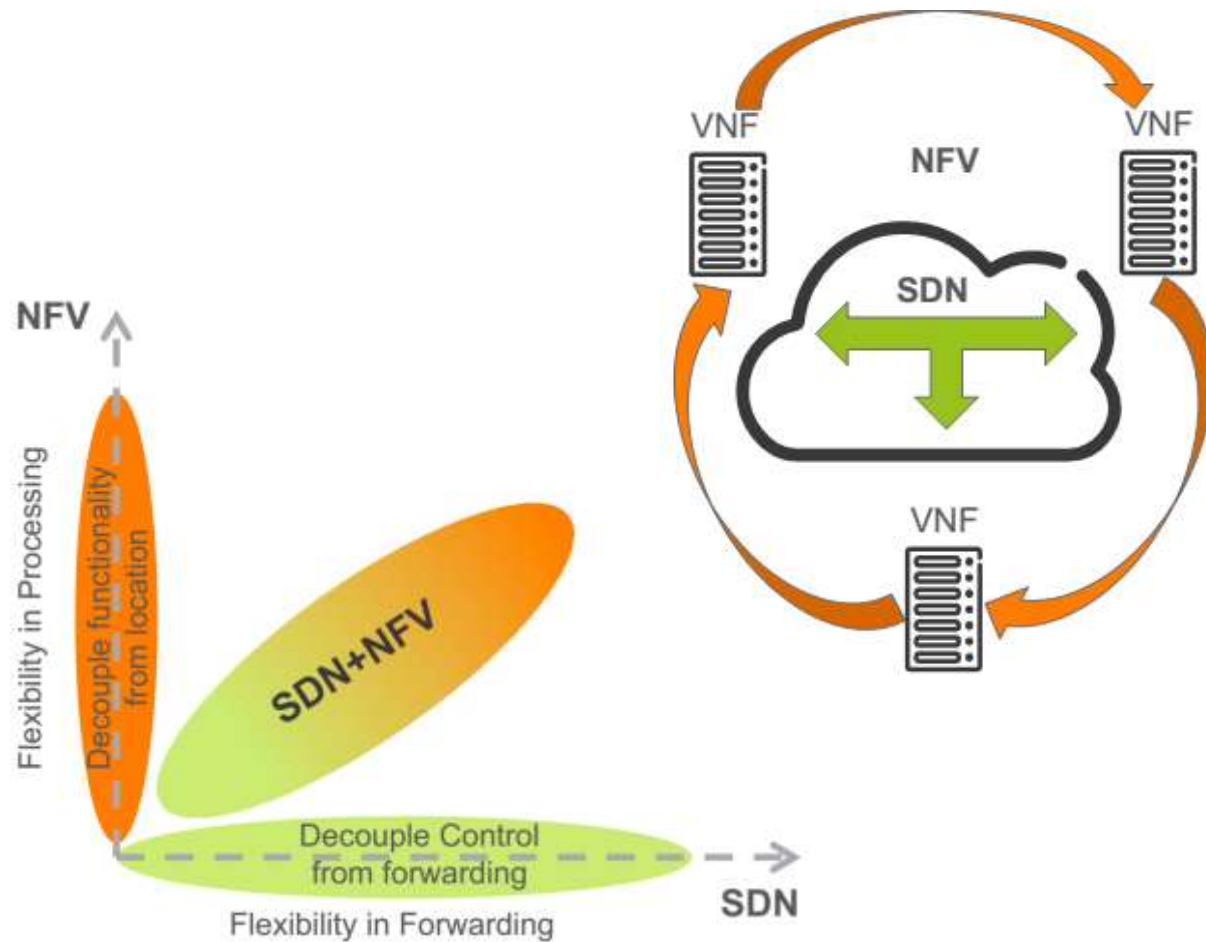
[<https://www.opennetworking.org/images/stories/downloads/sdn-resources/white-papers/wp-sdn-newnorm.pdf>]

SDN / NFV introduction



ETSI NFV ISG (NFV White Paper) Oct 2012. Image source: V. G. Nguyen, et al, "SDN/NFV-based mobile packet core network architectures: a survey," IEEE Comm. Surveys & Tutorials, 19(3), 1567-1602.

SDN / NFV introduction



PROGRAMMABLE NETWORK MEANS:

- NON-MANUAL DATA ACQUISITION
- NON-MANUAL NETWORK CONTROL

WE HAVE MULTIPLE NEW USE CASES FOR OPTIMIZATION IN PRODUCTION NETWORKS...

(that so far existed just in the papers)

Source: Ahmad Rostami (Ericsson Research)

[http://www.itc26.org/fileadmin/ITC26_files/ITC26-Tutorial-Rostami.pdf]

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- 2. Use cases**
3. Theoretical limits, heuristics, solvers
4. Network optimization software. Net2Plan
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Use cases: optimization in practical problems

Use cases:

1. Single VNF (VM), single OpenStack

- NOVA: Allocating VMs in computing resources, vertical scaling



2. VNF service chain, single OpenStack

- HEAT: Allocating NSs, optimizing horizontal autoscaling
- WATCHER: A project centralizing optimization decisions in an OpenStack



3. Network orchestration

- Optimization as a Service (OaaS)

4. Network service across multiple OpenStacks connected in a network

- OSM, TACKER, ONAP and others





USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack

Problem: Allocation of computing resources to VNFs

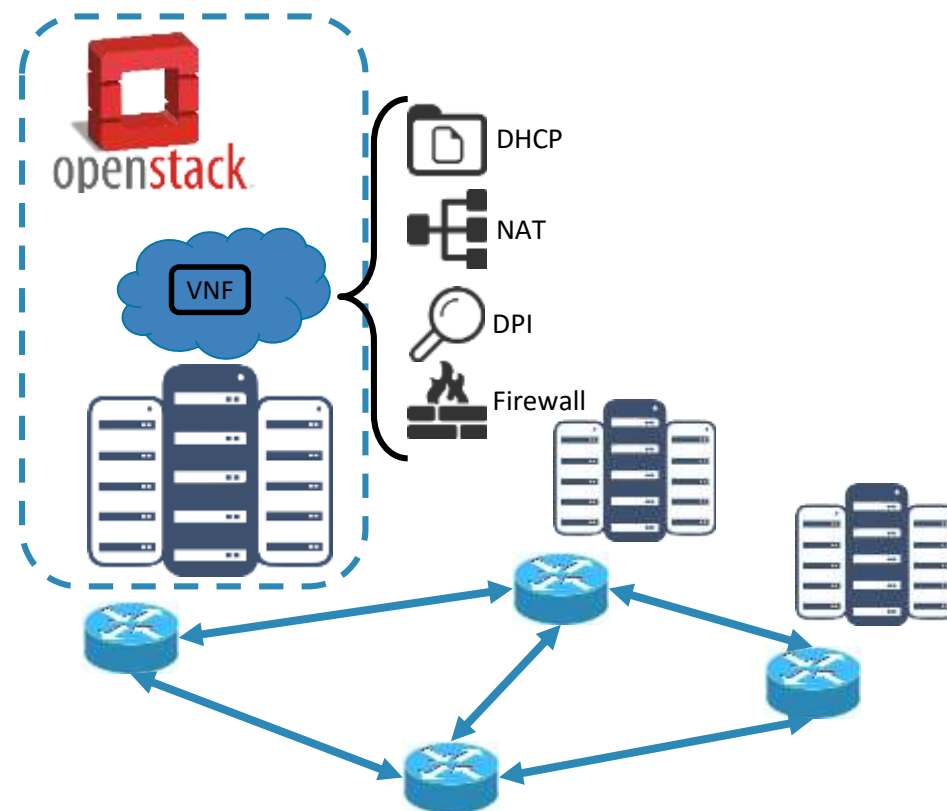
Input:

- VMs CPU, HD, RAM requisites & EPA info
- Servers: CPU, HD, RAM occup. & EPA info



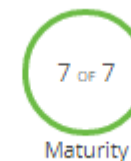
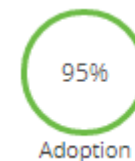
Output:

- Allocation of VMs in the servers



NOVA

Compute Service
[Wiki page](#)





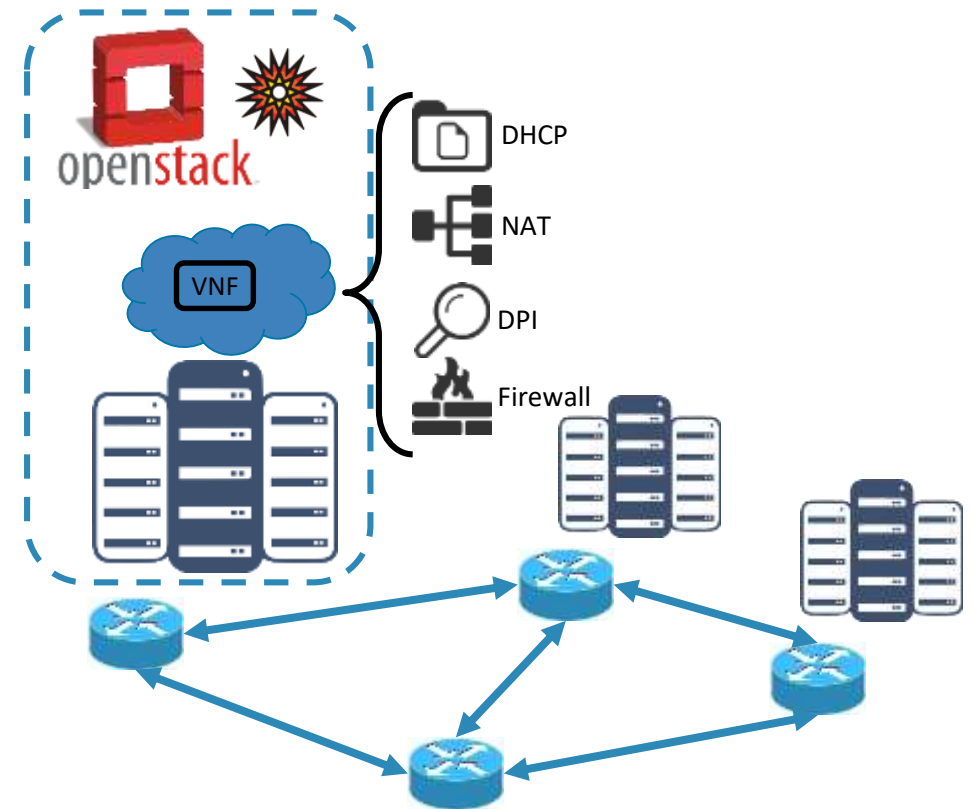
USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack

VM requisites: OpenStack flavors define the compute, memory, and storage capacity of nova computing instances.

```
$ openstack flavor list
```

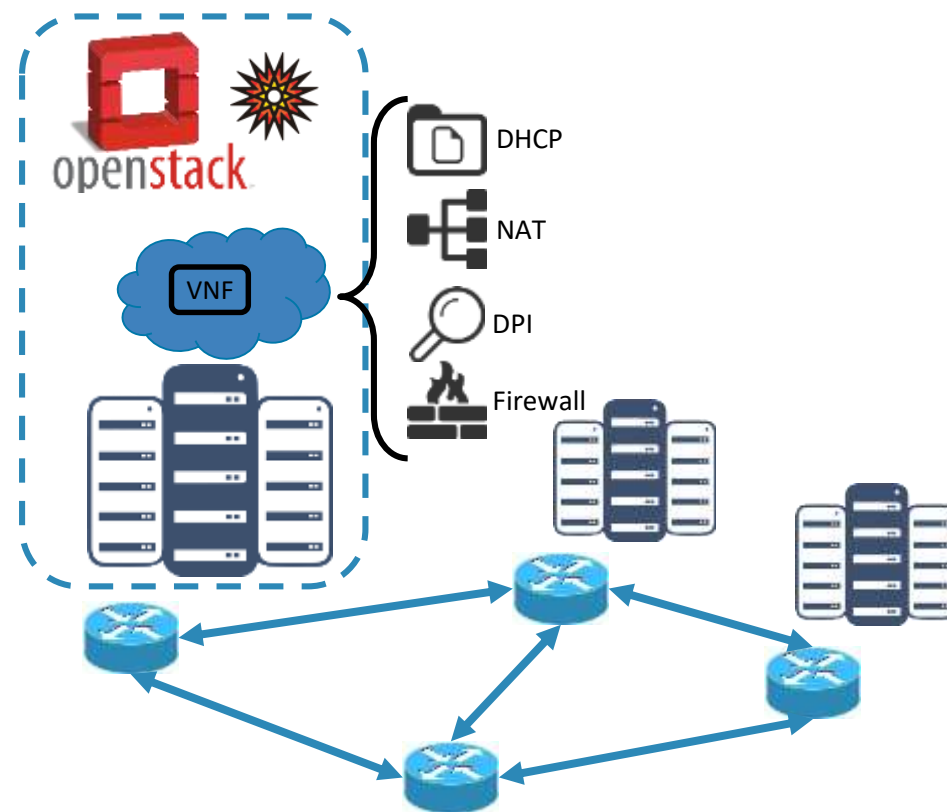
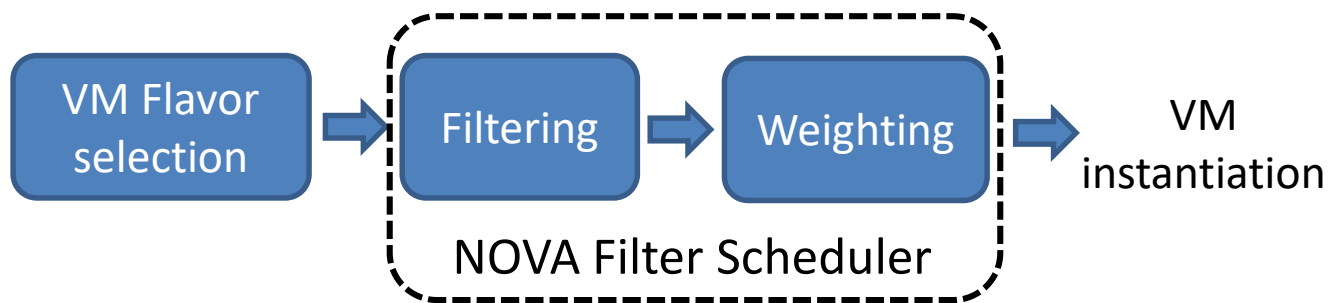
ID	Name	RAM	Disk	Ephemeral	VCPUs	Is_Public
1	m1.tiny	512	1	0	1	True
2	m1.small	2048	20	0	1	True
3	m1.medium	4096	40	0	2	True
4	m1.large	8192	80	0	4	True
5	m1.xlarge	16384	160	0	8	True



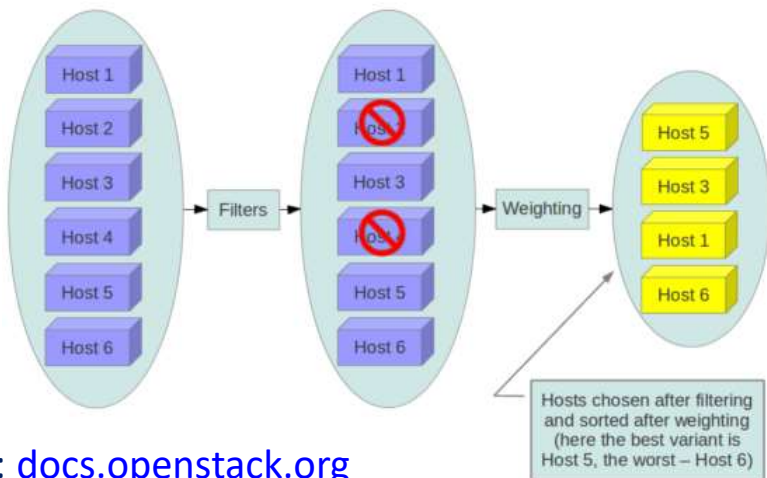


USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack



OpenStack mechanism for tuning the decision. Programmable filters & weighters



 Make your allocation algorithm and implement it as a new filter in OpenStack

Source: docs.openstack.org



USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack

Make your scheduler... things to play with

- **Availability zones** (NOVA and NEUTRON). A host can be tagged to be in one availability zone. E.g. Those connected to the same master power supply.

More info:

- <https://docs.openstack.org/nova/pike/user/aggregates.html>
- <https://docs.openstack.org/newton/networking-guide/config-az.html>



**Use the information for allocations
with enhanced availability**



USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack

Make your scheduler... things to play with

NUMA topology (visible through the hypervisor)

The system memory is divided into cells or nodes that are associated with a particular CPU.

CPU pinning

An instance's vCPU is assigned (pinned) to a particular host CPU.

EPA. Enhanced Platform Awareness

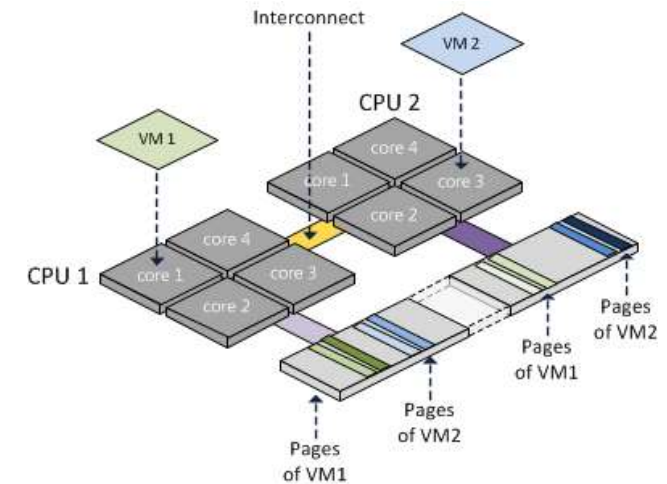
TOSCA VNFD* templates allow specifying VNF requirements such as NUMA topology, SR-IOV, Huge pages and CPU pinning.

Source:

<https://docs.openstack.org/nova/pike/admin/cpu-topologies.html>

<https://www.stratoscale.com/blog/openstack/cpu-pinning-and-numa-awareness/>

https://docs.openstack.org/tacker/latest/user/enhanced_placement_awareness_usage_guide.html



**Optimized allocations:
latency & performance**



USE CASES: Optimization problems in SDN/NFV (1/4)

1. Single VNF (VM), single OpenStack

M. Scharf, M. Stein, T. Voith, and V. Hilt, “**Network-aware instance scheduling in OpenStack,**” IEEE International Conference on Computer Communication and Networks (ICCCN), 2015:

- Extension of the OpenStack scheduler that enables a network-aware placement of instances by taking into account bandwidth constraints between nodes and exterior
- External resource tracker can monitor the allocation of bandwidth

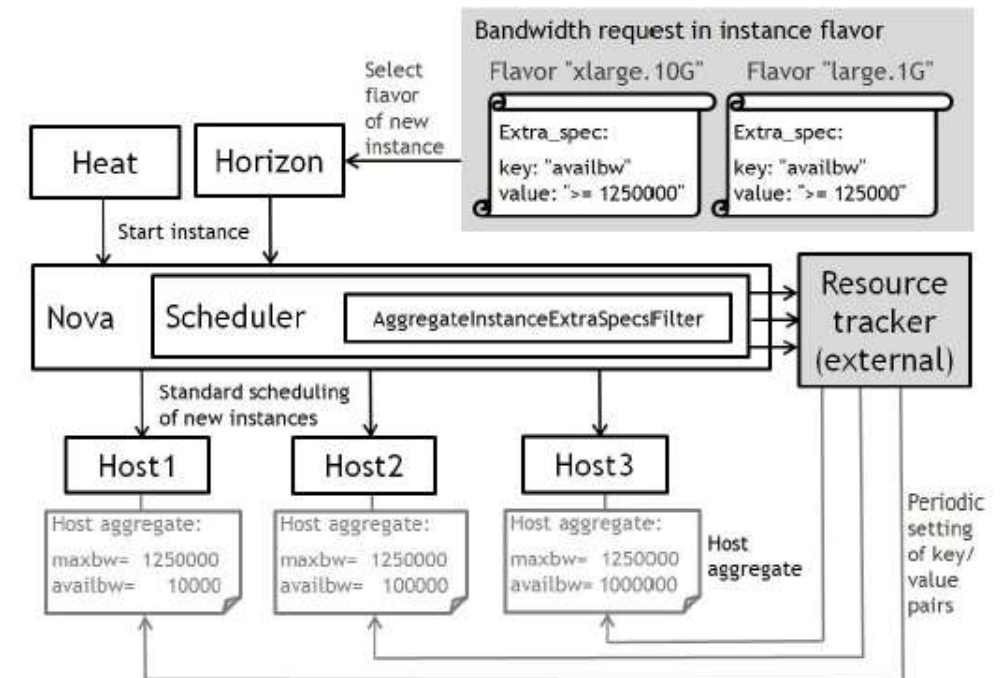


Fig. 4: Design of the host bandwidth awareness prototype



USE CASES: Optimization problems in SDN/NFV (2/4)

2. VNF service chain, single OpenStack

Problem: Allocation of network service

Input:

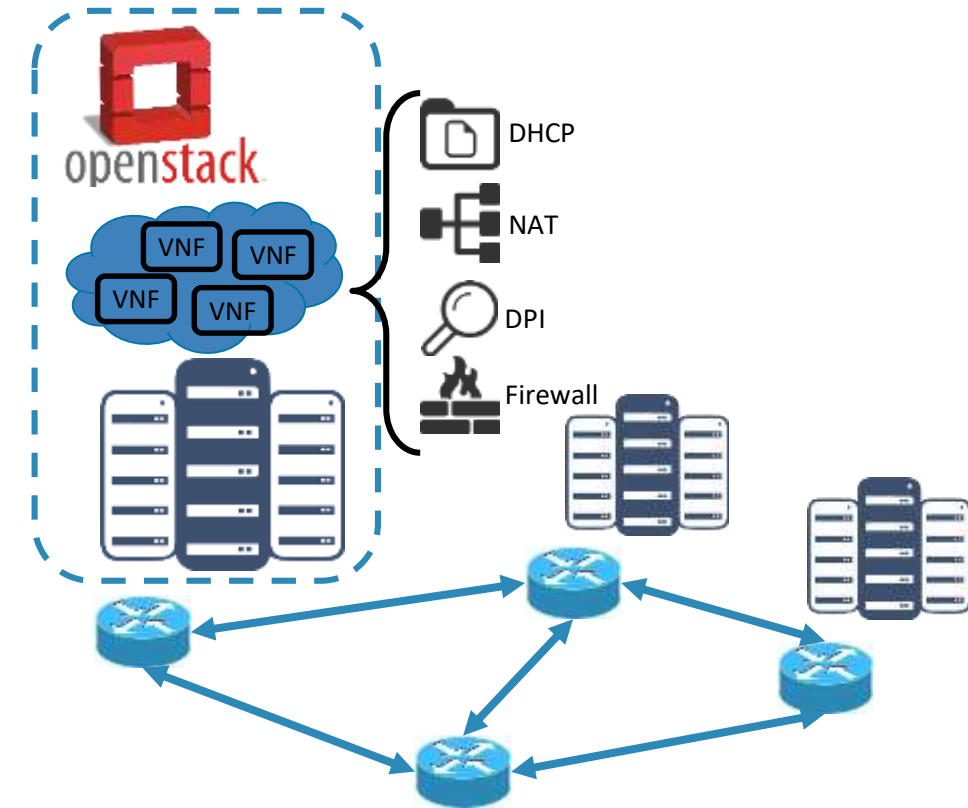
- Template (e.g. AWS-style, HOT) with set of VNFs, virtual connections and metadata



Output:

- Allocation of VMs in the servers
- Configuration of the virtual links between them

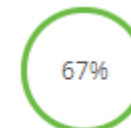
Heat: orchestrates the allocation of **network services** defined in templates (HOT templates), to underlying computing & networking infrastructure



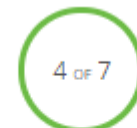
HEAT

Orchestrator

[Wiki page](#)



Adoption



Maturity



Age



USE CASES: Optimization problems in SDN/NFV (2/4)

2. VNF service chain, single OpenStack

Input: HOT template

```
heat_template_version: 2015-04-30

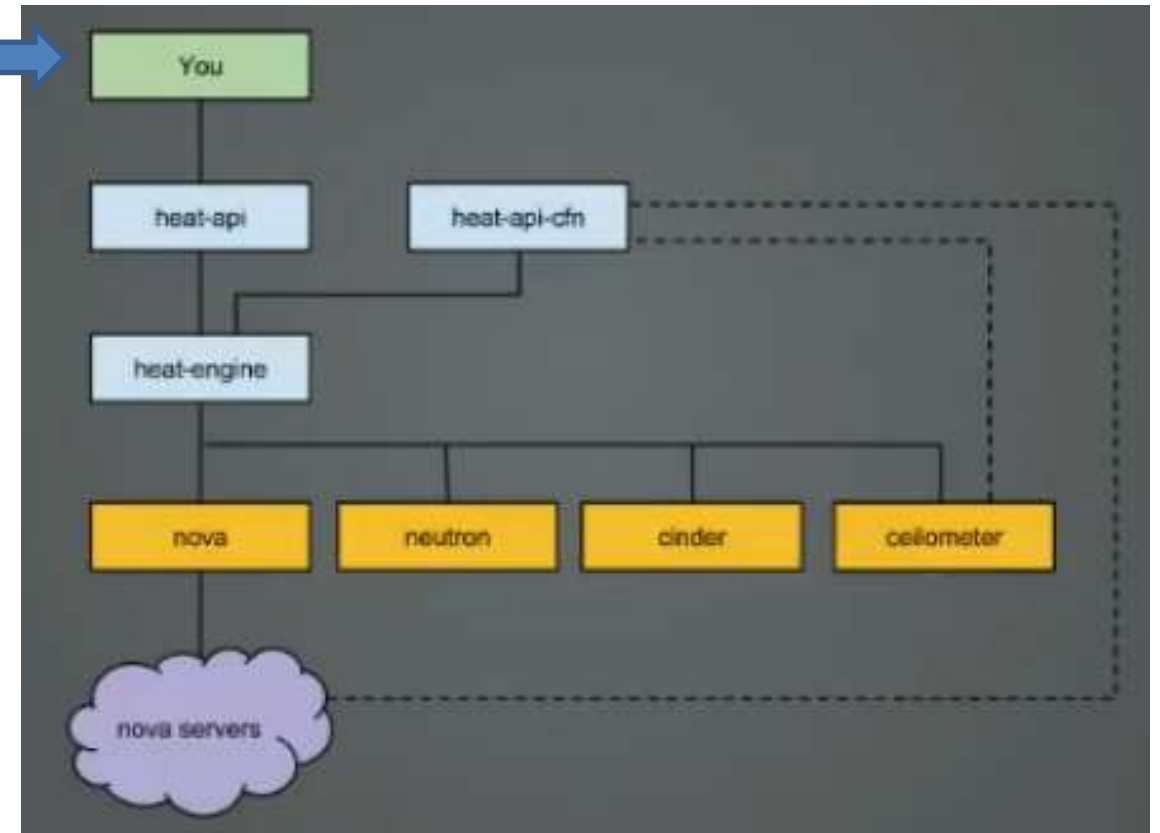
description: Simple template to deploy a single compute instance

resources:
  my_instance:
    type: OS::Nova::Server
    properties:
      key_name: my_key
      image: ubuntu-trusty-x86_64
      flavor: m1.small
```

Heat Orchestration Template (HOT) structure

- Version
- Description
- Parameters
- (Stack of) Resources
- Output

Heat architecture components



Source: L. Kellog-Stedman, "Deploying with heat", Sept. 2014.



USE CASES: Optimization problems in SDN/NFV (2/4)

2. VNF service chain, single OpenStack

Heat: we can define an **Autoscaling Group** to create a desired count of similar resources (defined with the resource property in HOT format).

```
heat_template_version: 2015-04-30
...
resources:
  ...
  the_resource:
    type: OS::Heat::AutoScalingGroup
    properties:
      cooldown: Integer
      desired_capacity: Integer
      max_size: Integer
      min_size: Integer
      resource: {...}
      rolling_updates: {"pause_time": Number, "max_batch_size": Integer, "min_in_service": Integer}
```



Dynamically tune the autoscaling thresholds to e.g. avoid unproductive short-lived re-scalings

Source: https://docs.openstack.org/heat/pike/template_guide/openstack.html#OS::Heat::AutoScalingGroup



USE CASES: Optimization problems in SDN/NFV (2/4)

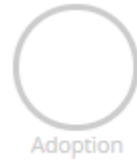
2. VNF service chain, single OpenStack



WATCHER

Optimization Service

[Wiki page](#)



Adoption

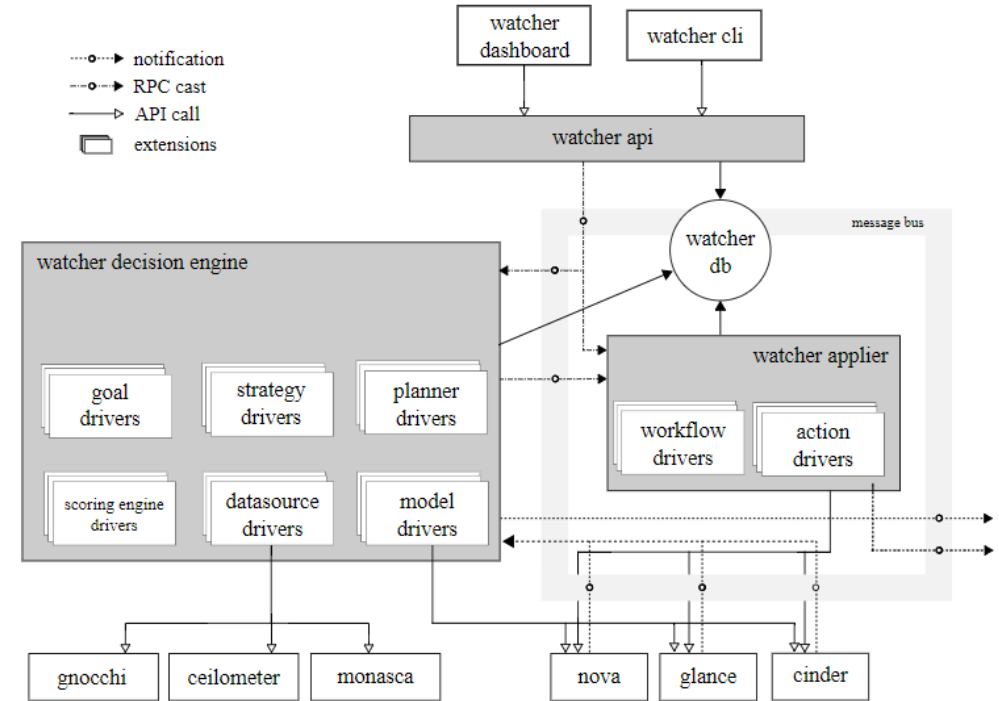


Maturity



Age

- **Watcher: A project to ease a complete optimization of the OpenStack**
 - Reads monitoring information e.g. from Ceilometer service (e.g., # of vcpus, CPU utilization %, memory used)
 - Permits plugging in optimization algorithms using it



Source: <https://docs.openstack.org/watcher/pike/architecture.html>



Watcher looks like a good place for capacity planning of computing/network resources in the DC & periodic application of reoptimization algorithms

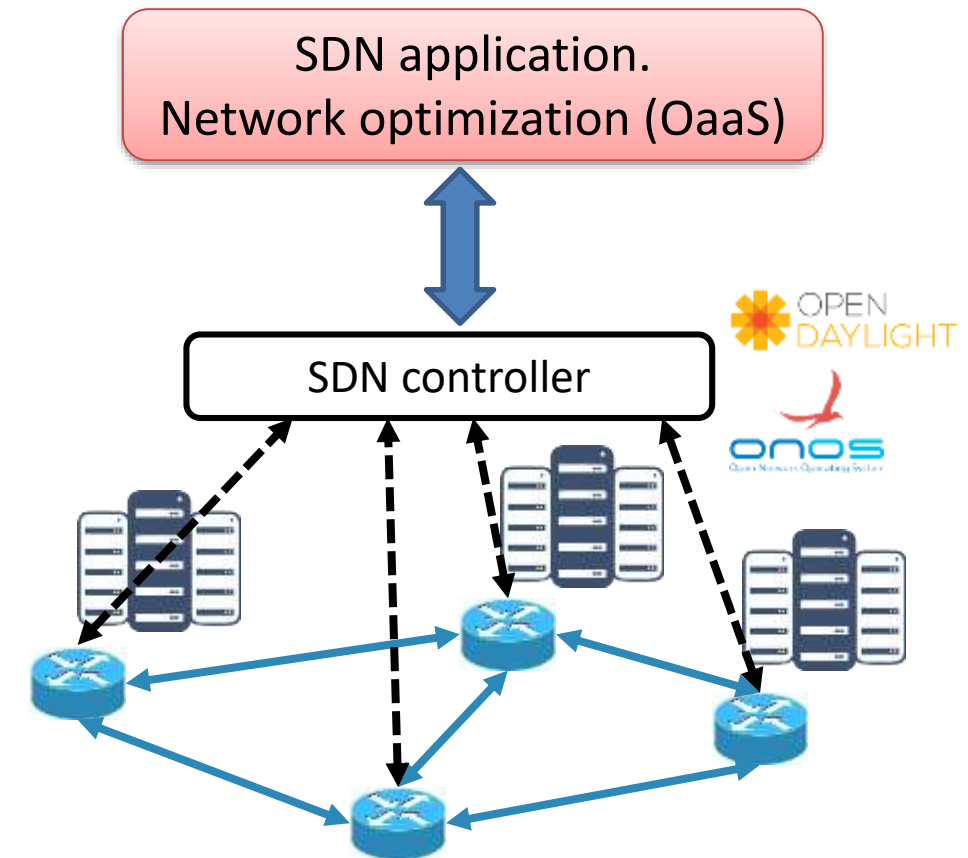
USE CASES: Optimization problems in SDN/NFV (3/4)

3. Optimization of network resources

- **Classical SDN use cases for network optimization:**
 - Periodic reoptimization
 - PCE-like path computation for provisioning
- **More options in the scope of OaaS:**
 - Capacity planning & long term network planning



Optimization-as-a-Service naturally fits as a NBI application.





USE CASES: Optimization problems in SDN/NFV (4/4)

1. Network service across multiple OpenStacks connected in a network

Problem: Provision network service across multiple-VIMs: **network & computing resources are JOINTLY allocated**

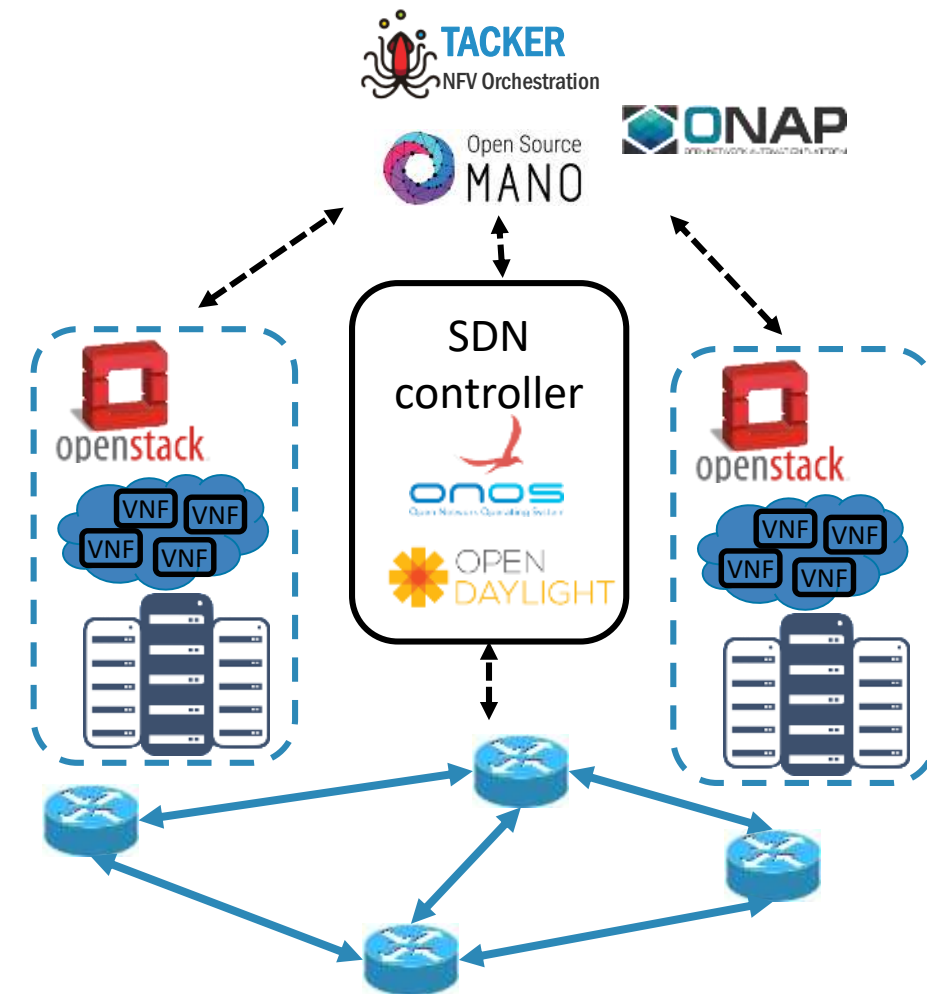
Input:

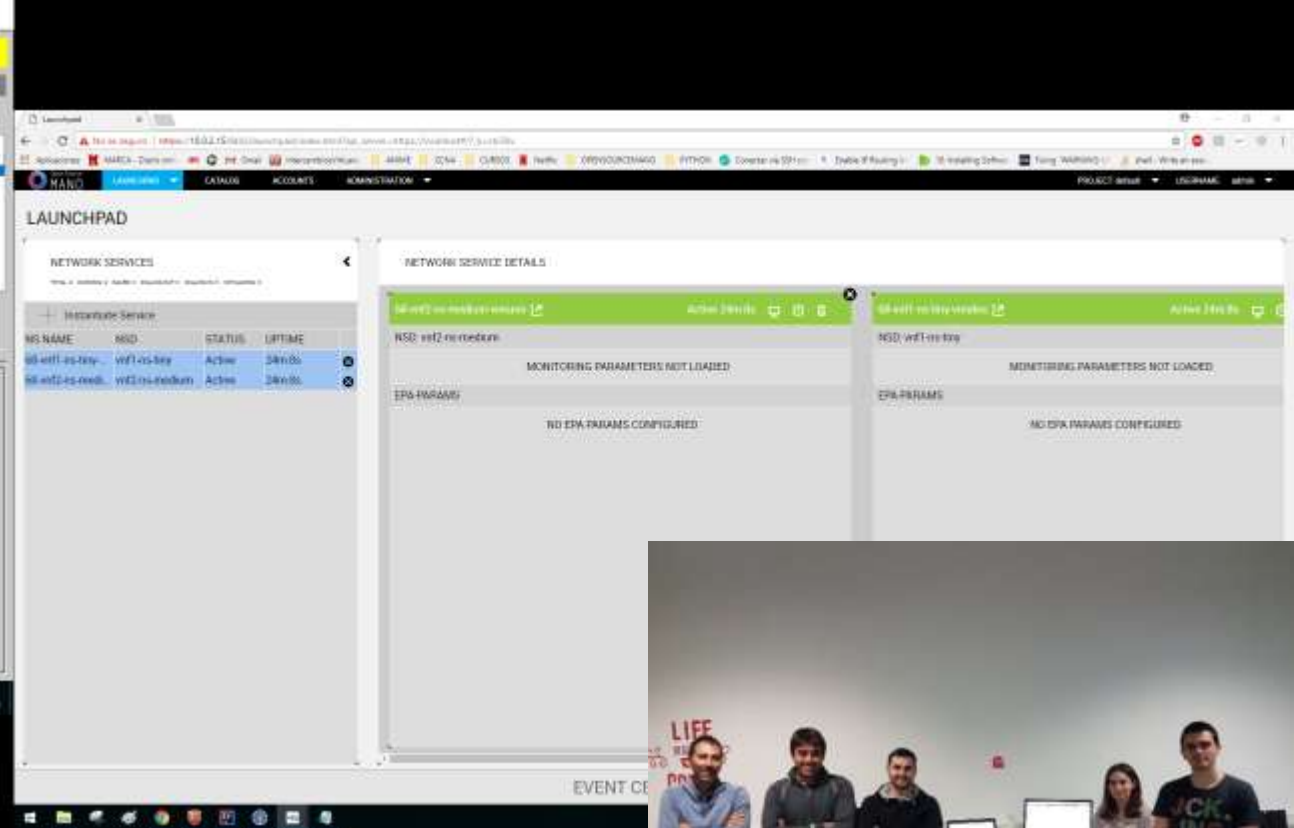
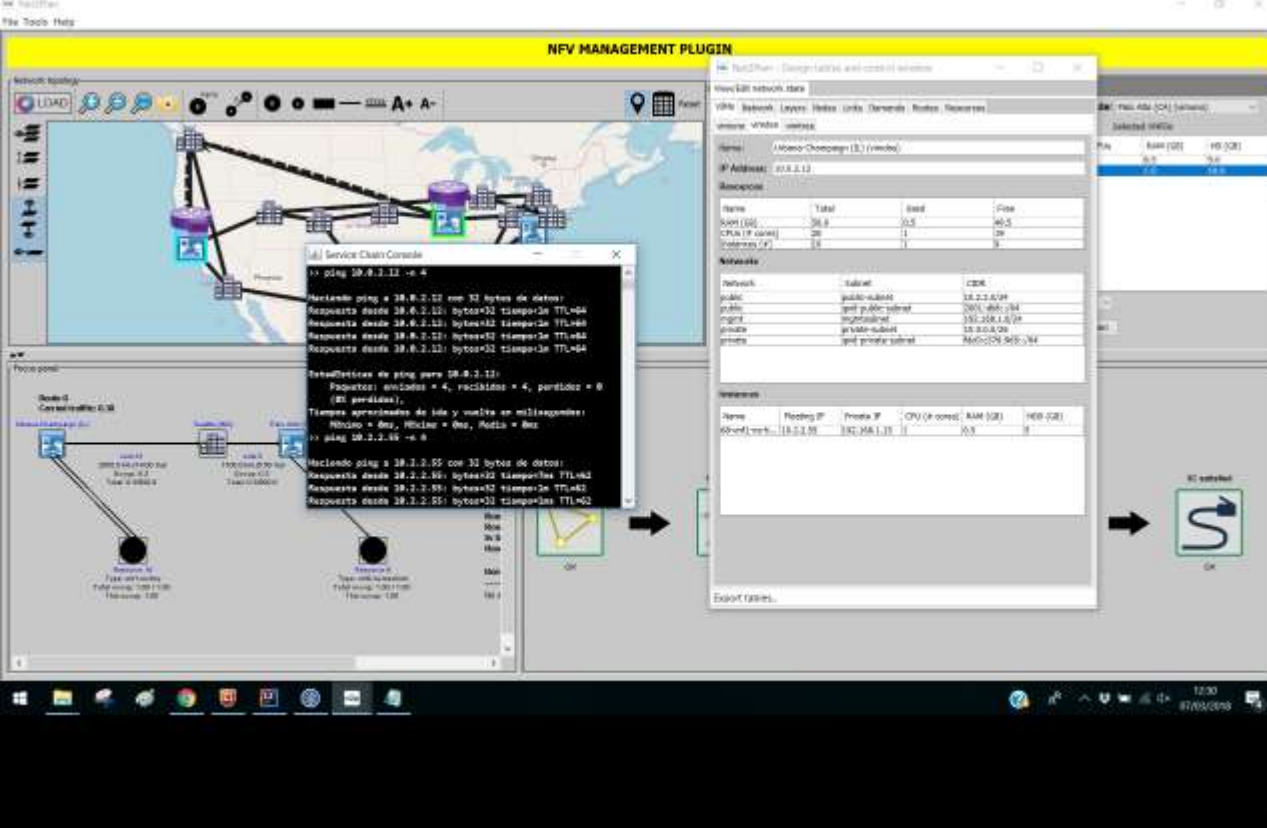
- Template (e.g. AWS-style, HOT) with set of VNFs, virtual connections and metadata



Output:

- Allocation of VMs in the servers
- Configuration of the virtual links between them
- Allocation of network resources





F.J. Moreno-Muro, C. San-Nicolas-Martinez, E. Martin-Seoane, M. Garrich, P. Pavon-Marino, O. Gonzalez de Dios, V. López, “Joint Optimal Service Chain Allocation, VNF instantiation and Metro Network Resource Management Demonstration”, OFC 2018 (SDN/NFV Demo Zone)



- **Net2Plan and SDN/NFV**
 - **OFC 2018 SDN/NFV Demo zone.** Connection of Net2Plan to **OpenStack & OSM** for making optimized allocations of service chains in multi-VIM environment
 - **Demonstrating joint allocation of IT (CPU, RAM, HD) and network resources**

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Theoretical limits to algorithm performances



Message: There are theoretical limits to algorithm performances
Most problems in this context are proven to be **INAPPROXIMABLE** (Assuming $\mathcal{P} \neq \mathcal{NP}$)

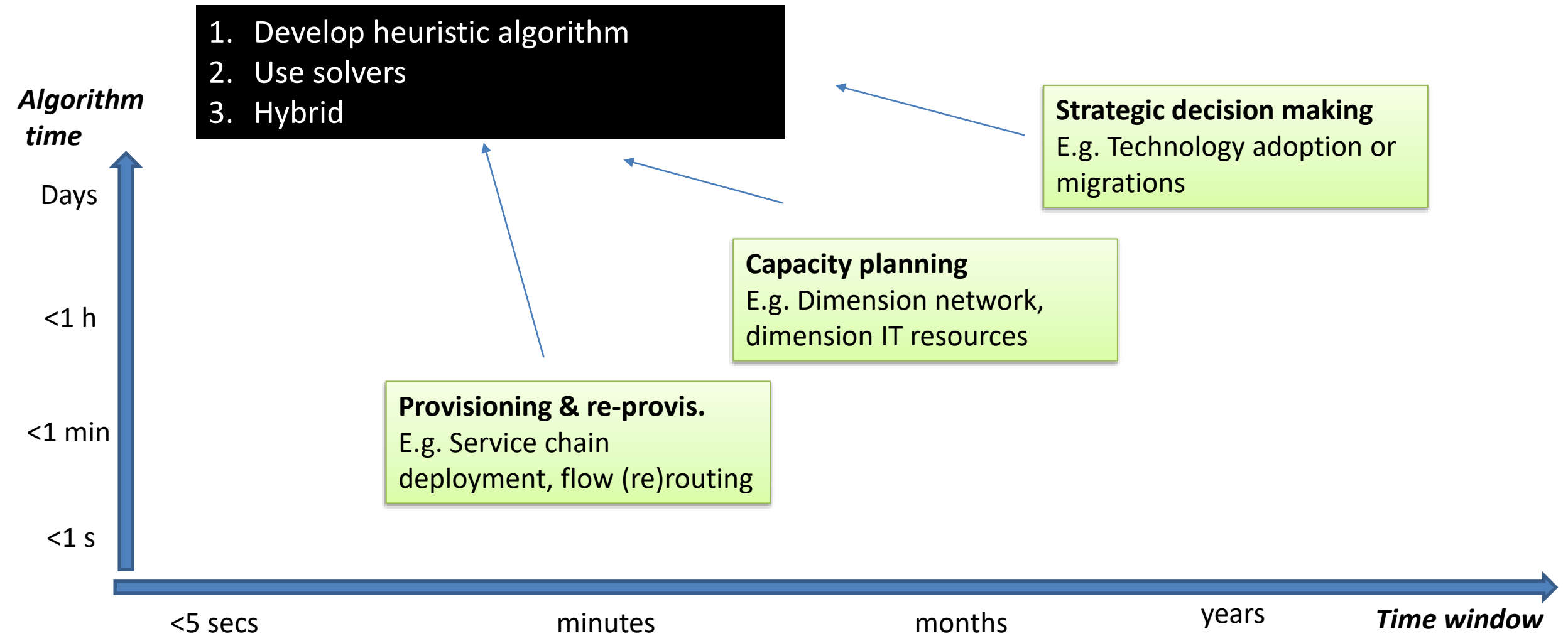
Table C.2 Complexity of some optimization problems of interest in network design.

Name	Description	Complexity
Conv	General convex programs	Polynomial (\mathcal{P})
ILP	General integer linear programs	\mathcal{NPO} -complete
BLP	General binary linear programs	\mathcal{NPO} -complete
Min-kMST	k -minimum cost spanning trees	Polynomial (\mathcal{P})
Min-kSP	k -minimum cost paths	Polynomial (\mathcal{P})
Min-kSP	k -minimum cost paths	Polynomial (\mathcal{P})
Min-Ste	Min cost multicast tree (Steiner tree)	0.55-approx., \mathcal{APX} -complete
Max-Clique	Maximum size clique	\mathcal{NPO} -complete
Min-TSP	Min cost ring	\mathcal{NPO} -complete
Min-NonBif	Min congestion non-bifurcated routing	2.23-approx., \mathcal{APX} -complete
Max-IntegralFlow	Max integral k multicommodity flow on trees	1-approx., \mathcal{APX} -complete
Min-NodeLocation	Min cost node location, no connectivity limit	1.4-approx., \mathcal{APX} -complete

Source: P. Pavon, "Optimization of computer networks. Modeling and algorithms. A hands-on approach", Wiley 2016.

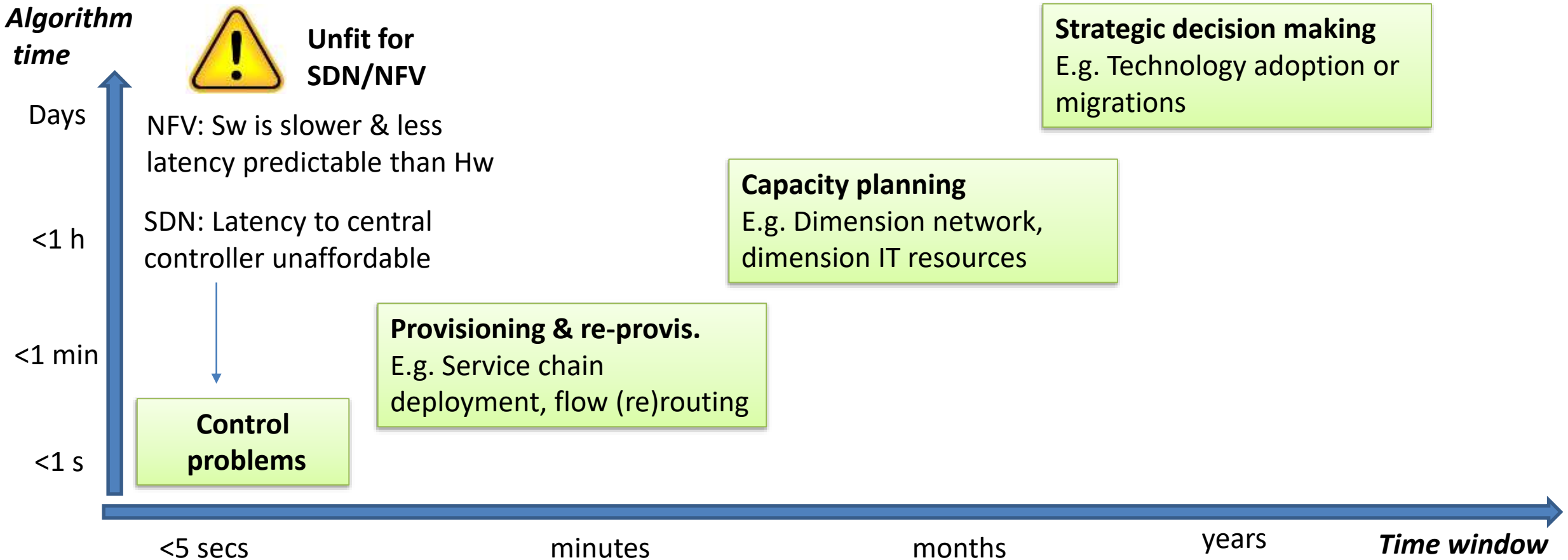
E.g. \mathcal{NPO} -complete = No **POLYNOMIAL** algorithm exists that guarantees giving a solution at most X% worse than the optimum (for any "X")

Choose the right optimization technique



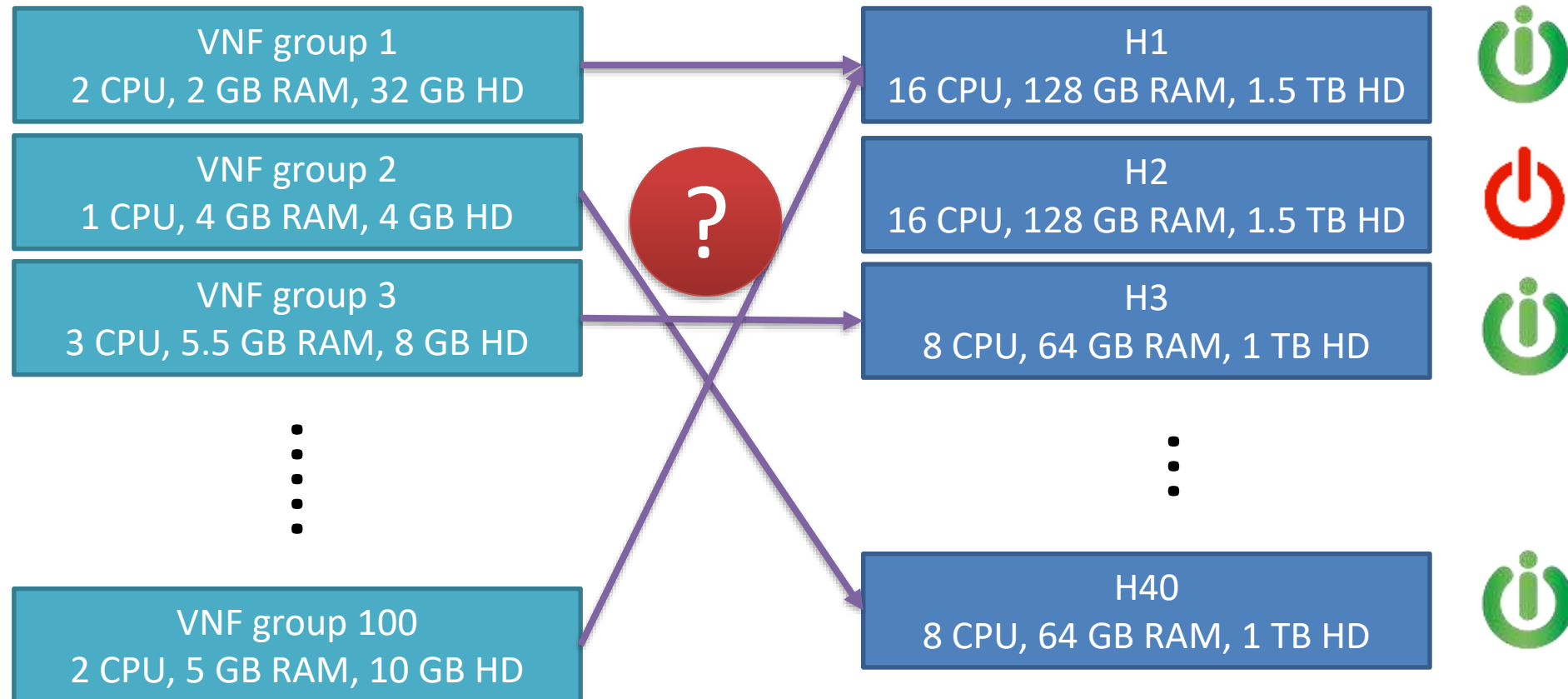
Choose the right optimization technique

Message: SDN & NFV. Choose the right optimization technique



Example

Example: Reoptimize VNF grouping assignments to servers in the DC, minimizing **energy costs** and **avoiding excessive migrations**



Example

Example: Reoptimize VNF grouping assignments to servers in the DC, minimizing **energy costs** and **avoiding excessive migrations**

$$\begin{aligned} \min \quad & \sum_h a_h + \alpha \sum_{vh} c_{vh} x_{vh} \quad \text{subject to:} \quad \longrightarrow \quad \text{Minimize number of switched on hosts + weighted migration costs} \\ & \sum_v CPU(v) x_{vh} \leq CPU(h) a_h, \quad \forall h \in \mathcal{H} \quad \longrightarrow \quad \text{Limit to the CPUs in the hosts} \\ & \sum_v RAM(v) x_{vh} \leq RAM(h) a_h, \quad \forall h \in \mathcal{H} \quad \longrightarrow \quad \text{Limit to the RAM in the hosts} \\ & \sum_v HD(v) x_{vh} \leq HD(h) a_h, \quad \forall h \in \mathcal{H} \quad \longrightarrow \quad \text{Limit to the HD in the hosts} \\ & \sum_h x_{vh} = 1, \quad \forall v \in \mathcal{V} \quad \longrightarrow \quad \text{All VNF groups are allocated} \\ & a_h \geq x_{vh}, \quad \forall v \in \mathcal{V}, h \in \mathcal{H} \quad \longrightarrow \quad \text{A host with at least one VNF should be switched on} \end{aligned}$$

Example. Heuristic vs formulation

Algorithmic options

Heuristic algorithms

- Ad-hoc developed algorithms for a purpose, no approximation guarantees
- Creative combination of different meta-heuristic techniques, e.g. genetic algorithms, tabu, greedy approaches, ...

(Mixed) Integer formulations

- The formulation is built using a MODELER, passed then to an external SOLVER
- Solver is configured with a MAXIMUM RUNNING TIME
- Fancy callbacks can be used to drive the solver

Program logic

1. Receive the input data
2. Apply the heuristic
3. Return the results to the business logic

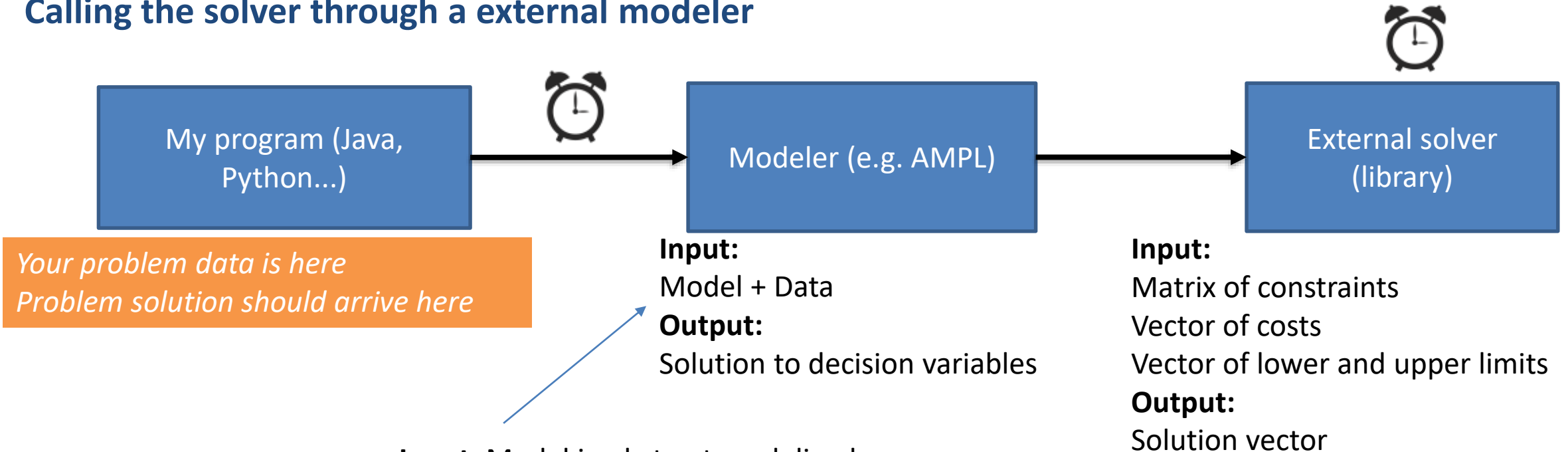
Program logic

1. Receive the input data
2. Build the model
3. Call the external solver, and wait for answer
4. Build the response to return



Optimization tools. Solvers

Calling the solver through a external modeler



$$\begin{aligned} \min \quad & \sum_h a_h + \alpha \sum_{vh} c_{vh} x_{vh} \quad \text{subject to:} \\ & \sum_v CPU(v) x_{vh} \leq CPU(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v RAM(v) x_{vh} \leq RAM(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v HD(v) x_{vh} \leq HD(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_h x_{vh} = 1, \quad \forall v \in \mathcal{V} \\ & a_h \geq x_{vh}, \forall v \in \mathcal{V}, h \in \mathcal{H} \end{aligned}$$

Input: Model in abstract modeling language

```
## Example Two - Model with sets
set P;

param t;
param p{i in P};
param r{i in P};
param m{i in P};

var paint{i in P};

maximize profit: sum{i in P} p[i]*paint[i];
subject to time: sum{i in P} (1/r[i])*paint[i] <= t;
subject to capacity{i in P}: 0 <= paint[i] <= m[i];
```

Optimization tools. Modelers

External modelers – Specific modeling languages

- 😊 Provide easy interaction with the most popular solvers
- 😞 Proprietary front-ends, interaction with your program not always easy nor fast

```
## Example Two - Model with sets
```

```
set P;
```

```
param t;  
param p{i in P};  
param r{i in P};  
param m{i in P};
```

```
var paint{i in P};
```

```
maximize profit: sum{i in P} p[i]*paint[i];  
subject to time: sum{i in P} (1/r[i])*paint[i] <= t;  
subject to capacity{i in P}: 0 <= paint[i] <= m[i];
```

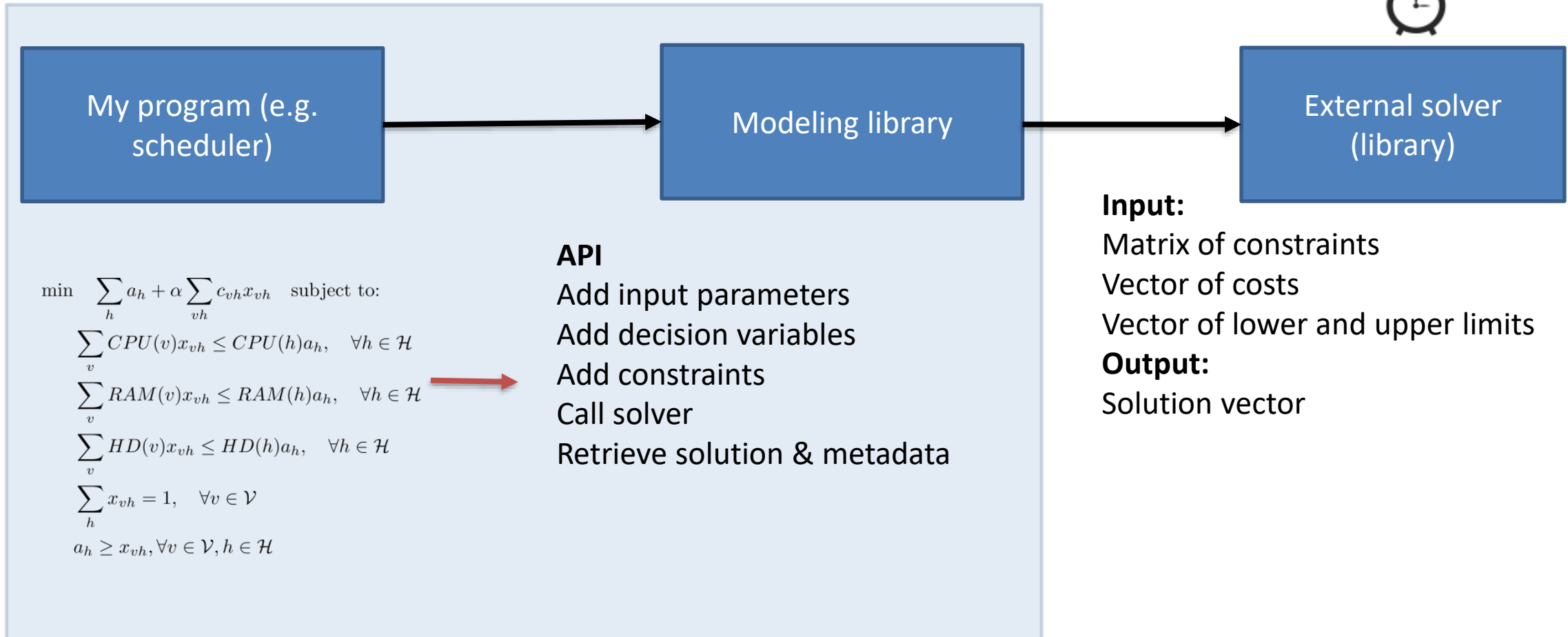


	http://www.ampl.com	Commercial
	http://www.gams.com/	Commercial
	http://www.aimms.com	Commercial
LINGO	http://www.lindo.com	Commercial
MPL	http://www.maximalsoftware.com	Commercial
	http://www.tomopt.com/	Commercial

Other front-ends (some free): CMPL (COIN-OR modeling language), GMPL (open-source AMPL clone), R (RSymphony plugin), CVX (from Stanford spinoff, for Matlab), ...

Optimization tools. Solvers

Language-integrated modeling options



Optimization tools. Modelers

Language-integrated modeling options (free)

▶ Python

- Pyomo. <http://www.pyomo.org/>
- PuLP. <https://pythonhosted.org/PuLP/>
- CyLP. <https://github.com/coin-or/CyLP>
- yaposib. <https://github.com/coin-or/yaposib>

▶ C++:

- FLOPC++. <https://projects.coin-or.org/FlopC++>

▶ Java



JOM (Java Optimization Modeler). <http://www.net2plan.com/jom> ,
<https://github.com/girtel/JOM>

Optimization tools. Solvers

Solvers

- ☺ Typically, commercial solvers incorporate libraries for calling from Java, C++, Python...
- ☹ Free solvers not always do that... rely on external modelers... or not model at all...
- ⚠ Watch out! Not all the suites solve all the problem types

Name	Type
CPLEX (IBM)	Commercial
GUROBI	Commercial
XPRESS	Commercial
MOSEK	Commercial
LGO	Commercial
KNITRO	Commercial
SCIP	Free
Google Optimization tools	Free
COIN-OR (IPOPT, CLP...)	Free
GLPK	Free
SNOPT	Free
MINOS	Free
LP_SOLVE	Free
MIPCL	Free

MIP: Great grade in the tests!

(<http://plato.asu.edu/ftp/milpc.html>)

→ Around 6 times worse than commercial solvers

An example with JOM

Step 1. Initialization

Create the optimization problem object

Set the values of the input parameters (already in your program)

Set the decision variables, integer or not, minimum and maximum value



Parameters, variables, and constraints can be N-dimensional arrays, dense or sparse

$$\begin{aligned} \min \quad & \sum_h a_h + \alpha \sum_{vh} c_{vh} x_{vh} \quad \text{subject to:} \\ & \sum_v CPU(v) x_{vh} \leq CPU(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v RAM(v) x_{vh} \leq RAM(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v HD(v) x_{vh} \leq HD(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_h x_{vh} = 1, \quad \forall v \in \mathcal{V} \\ & a_h \geq x_{vh}, \forall v \in \mathcal{V}, h \in \mathcal{H} \end{aligned}$$

```
/* Create the optimization problem object */
OptimizationProblem op = new OptimizationProblem();

/* Introduce in the model the values of the input parameters */
op.setInputParameter("c_vh", c_vh);
op.setInputParameter("cpu_v", cpu_v , "row");
op.setInputParameter("ram_v", ram_v , "row");
op.setInputParameter("hd_v", hd_v , "row");
op.setInputParameter("cpu_h", cpu_h , "row");
op.setInputParameter("ram_h", ram_h , "row");
op.setInputParameter("hd_h", hd_h , "row");

/* Add the decision variables to the problem */
op.addDecisionVariable("a_h", true, new int[] { 1 , H }, 0, 1);
op.addDecisionVariable("x_vh", true, new int[] { V , H }, 0, 1);
```

An example with JOM

Step 2. Set objective function and constraints

N-dim array representation eases constraint creation

$\min \sum_h a_h + \alpha \sum_{vh} c_{vh} x_{vh}$ subject to:

$$\sum_v CPU(v)x_{vh} \leq CPU(h)a_h, \quad \forall h \in \mathcal{H}$$

$$\sum_v RAM(v)x_{vh} \leq RAM(h)a_h, \quad \forall h \in \mathcal{H}$$

$$\sum_v HD(v)x_{vh} \leq HD(h)a_h, \quad \forall h \in \mathcal{H}$$

$$\sum_h x_{vh} = 1, \quad \forall v \in \mathcal{V}$$

$$a_h \geq x_{vh}, \quad \forall v \in \mathcal{V}, h \in \mathcal{H}$$

`/* Sets the objective function */`

```
op.setObjectiveFunction("minimize", "sum(a_h) + 0.001 * sum(c_vh .* x_vh)");
```

`/* Add the constraints */`

```
op.addConstraint("cpu_v * x_vh <= cpu_h .* a_h");
```

```
op.addConstraint("ram_v * x_vh <= ram_h .* a_h");
```

```
op.addConstraint("hd_v * x_vh <= hd_h .* a_h");
```

```
op.addConstraint("sum(x_vh,2) == 1");
```

```
op.addConstraint("ones([V;1]) * a_h >= x_vh");
```

An example with JOM

Step 3. Call the solver, wait, and get the results

Solvers supported: GLPK (MILP, free), IPOPT (nonlinear, free), CPLEX (MILP, commercial), XPRESS (MILP, commercial)

Maximum solver time & solver library location are parameters

In non integer problems, gives access to Lagrange multipliers

$$\begin{aligned} \min \quad & \sum_h a_h + \alpha \sum_{vh} c_{vh} x_{vh} \quad \text{subject to:} \\ & \sum_v CPU(v) x_{vh} \leq CPU(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v RAM(v) x_{vh} \leq RAM(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_v HD(v) x_{vh} \leq HD(h) a_h, \quad \forall h \in \mathcal{H} \\ & \sum_h x_{vh} = 1, \quad \forall v \in \mathcal{V} \\ & a_h \geq x_{vh}, \forall v \in \mathcal{V}, h \in \mathcal{H} \end{aligned}$$

```
/* Call the solver to solve the problem */
op.solve("glpk" , "maxSolverTimeInSeconds" , 5.0);
if (op.feasibleSolutionDoesNotExist())
    throw new RuntimeException ("A feasible solution does not exist");

/* Print the solution */
final double [] sol_ah = op.getPrimalSolution("a_h").to1DArray();
final double [][] sol_xvh = op.getPrimalSolution("x_vh").view2D().toArray();

/* Your code continues here */
//
//
```

Heuristic & solver combination

Idea: A heuristic iterative method guides the global optimization, solving “Mini”-MILPs in each iteration with time limits

- 😊 Heuristic in the outer loop smartly diversifies the search
- 😊 Solvers are extremely effective and fast in medium-small problems
- ⚠️ We need modelers building the problem also fast! JOM can do that! 😊

Table 12.1 Case study results.

Description	1+1 protection	Shared protection	Restoration	No recovery
Total cost (K\$ / year)	29506.5	28808.7	27710.7	15358.7
Link costs (K\$ / year)	26046.5	25928.7	25928.7	13612.7
Transponder costs (K\$ / year)	3348.0	2772.0	1674.0	1674.0
OADM costs (K\$ / year)	112	108	108	72
Num. links	62	58	58	32
Num. transponders (bid)	1116	924	558	558
Num. degree 2 OADMs	0	1	1	1
Num. degree >2 OADMs	14	13	13	13
Num. GRASP iterations	11	21	21	92
Num. solver calls	1981	9421	9421	16698
Av. solver time (s)	0.241	0.194	0.194	0.052
Av. JOM modeling time (s)	1.55	0.182	0.182	0.159

SUBSECOND building + solving time for each mini-ILP*

*"Mini" means 1000s of variables and constraints

Source: P. Pavon, "Optimization of computer networks. Modeling and algorithms. A hands-on approach", Wiley 2016.

Agenda

1. Introduction
2. Use cases
3. Theoretical limits, heuristics, solvers
- 4. Network optimization software. Net2Plan**
5. Wrap up

Network optimization/planning tools

What we do NOT mean with network optimization/planning tools

- Event-driven simulators, suitable for simulating network protocols at the PACKET level
- Network emulators



This screenshot shows the main content area of the ns-3 website. It includes a descriptive paragraph about ns-3 as a discrete-event network simulator, a 'Recent Posts' section with three entries from November, October, and July 2017, and two sidebars. The left sidebar has 'Get ns-3:' and 'Get involved:' sections with links to code, documentation, and mailing lists. The right sidebar contains a 'Downloads' section with a 'DOWNLOAD' button and a 'Publications' bar chart showing an increasing trend from 2001 to 2013.

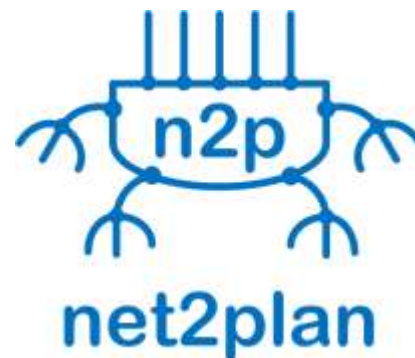


This screenshot shows the main content area of the OMNeT++ website. It features a large blue header with the text 'OMNeT++ Discrete Event Simulator' and a description of the framework. Below this is a 'Featured Projects' section with logos for INET, INETMANET, SIMeTe, veins, CoRE, and RINASim. A 'Downloads' section with a 'DOWNLOAD' button is on the right. Below the main content is a 'Tips for New Users' section with links to tutorials and documentation.

Network optimization/planning tools

What we DO mean with network optimization & planning open-source tools

- ▶ Open API for developing and plugging-in your own optimization algorithms (planning / provisioning)
- ▶ Open source, accessible in usual repositories (e.g. github)
- ▶ Some external academic and/or non-academic adoption & development maturity
- ▶ Provides CLI and/or GUI for network visualization and manipulation of the data

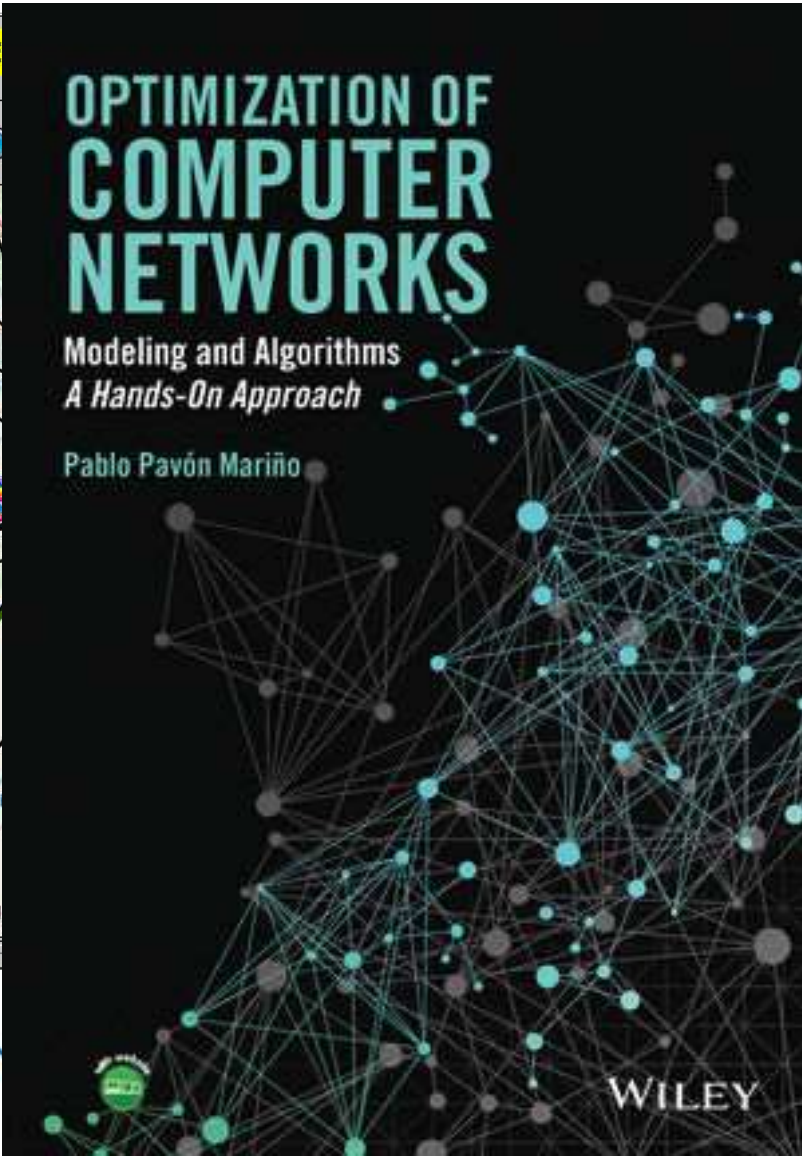


<http://www.net2plan.com>

<http://github.com/girtel/net2plan>

The screenshot shows the Net2Plan software interface. On the left, there's a map-based network topology view with various nodes and links. On the right, a data table displays network entry details. A large blue rounded rectangle is overlaid on the right side, containing logos for Metro H2020, 5G X Crosshaul, and ACINO.

Unique id...	Index	Show/Hide	Origin no...	Destinati...	State	Capacity	Carried t...	Occupati...	Utilization	Is bottlen...	Length (k...	Prop
34829	0	<input checked="" type="checkbox"/>	270 (Mála...	82 (Córdo...	<input checked="" type="checkbox"/>	40	20	2	0.05		133.388	
34860	31	<input checked="" type="checkbox"/>	414 (Zara...	1397 (Ma...	<input checked="" type="checkbox"/>	40	190	19	0.475		274.01	
34861	32	<input checked="" type="checkbox"/>	1397 (Ma...	428 (Gijón...	<input checked="" type="checkbox"/>	40	290	29	0.725		383.781	
34862	33	<input checked="" type="checkbox"/>	428 (Gijón...	1397 (Ma...	<input checked="" type="checkbox"/>	40	280	28	0.7		383.781	
34863	34	<input checked="" type="checkbox"/>	1474 (Mur...	82 (Córdo...	<input checked="" type="checkbox"/>	40	220	22	0.55		320.213	



Planning tool (started in 2011)
 technology agnostic
 (10K nodes)

- State-of-the-art optimization algorithms. Open API for adding your own algorithms
- Used in a number of academic and industry projects (e.g. > 150 students/year in UPCT)


www.net2plan.com
github.com/girtel/net2plan

Net2Plan

File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Network Layers Nodes Links Demands Multicast demands Routes Multicast trees Resources Shared-risk groups

Number of entries: 130 Reset VFs

Unique id...	Index	Demand	Ingress n...	Egress n...	Demand ...	Carried t...	Occupied...	Sequenc...	Sequenc...	Number ...
259	104	104	3 (Sevilla)	5 (Málaga)	100	100	1.0	L9	N3,N5	1
266	111	111	3 (Sevilla)	2 (Valencia)	100	100	1.0	L8,L0	N3,N0,N2	2
273	118	118	3 (Sevilla)	4 (Zarago...	100	100	1.0	L8,L2	N3,N0,N4	2
279	124	124	3 (Sevilla)	6 (Murcia)	100	100	1.0	L9,L13	N3,N5,N6	2
186	31	31	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
194	39	39	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
202	47	47	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
212	57	57	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
224	69	69	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
232	77	77	4 (Zarago...	1 (Barcelo...	100	100	1.0	L11	N4,N1	1
240	85	85	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
250	95	95	4 (Zarago...	2 (Valencia)	100	100	1.0	L10,L0	N4,N0,N2	2
252	97	97	4 (Zarago...	1 (Barcelo...	100	100	1.0	L11	N4,N1	1
272	117	117	4 (Zarago...	0 (Madrid)	100	100	1.0	L10	N4,N0	1
274	119	119	4 (Zarago...	3 (Sevilla)	100	100	1.0	L10,L1	N4,N0,N3	2
275	120	120	4 (Zarago...	6 (Murcia)	100	100	1.0	L10,L0,L7	N4,N0,N2,N6	3
277	122	122	4 (Zarago...	5 (Málaga)	100	100	1.0	L10,L1,L9	N4,N0,N3,N5	3
206	51	51	5 (Málaga)	0 (Madrid)	100	100	1.0	L12,L8	N5,N3,N0	2
216	61	61	5 (Málaga)	0 (Madrid)	100	100	1.0	L12,L8	N5,N3,N0	2
230	75	75	5 (Málaga)	0 (Madrid)	100	100	1.0	L12,L8	N5,N3,N0	2
248	93	93	5 (Málaga)	0 (Madrid)	100	100	1.0	L12,L8	N5,N3,N0	2
256	101	101	5 (Málaga)	1 (Barcelo...	100	100	1.0	L13,L14,L6	N5,N6,N2,N1	3
260	105	105	5 (Málaga)	3 (Sevilla)	100	100	1.0	L12	N5,N3	1
268	113	113	5 (Málaga)	2 (Valencia)	100	100	1.0	L13,L14	N5,N6,N2	2
278	123	123	5 (Málaga)	4 (Zarago...	100	100	1.0	L12,L8,L2	N5,N3,N0,N4	3
281	126	126	5 (Málaga)	6 (Murcia)	100	100	1.0	L13	N5,N6	1
220	65	65	6 (Murcia)	0 (Madrid)	100	100	1.0	L14,L5	N6,N2,N0	2
236	81	81	6 (Murcia)	0 (Madrid)	100	100	1.0	L14,L5	N6,N2,N0	2
254	99	99	6 (Murcia)	1 (Barcelo...	100	100	1.0	L14,L6	N6,N2,N1	2
262	107	107	6 (Murcia)	2 (Valencia)	100	100	1.0	L14	N6,N2	1
264	109	109	6 (Murcia)	0 (Madrid)	100	100	1.0	L14,L5	N6,N2,N0	2
276	121	121	6 (Murcia)	4 (Zarago...	100	100	1.0	L14,L6,L4	N6,N2,N1,N4	3
280	125	125	6 (Murcia)	3 (Sevilla)	100	100	1.0	L15,L12	N6,N5,N3	2
282	127	127	6 (Murcia)	5 (Málaga)	100	100	1.0	L15	N6,N5	1
---	---	---	---	---	13000.00	13000.00	130.00	---	---	3.00

Export tables...



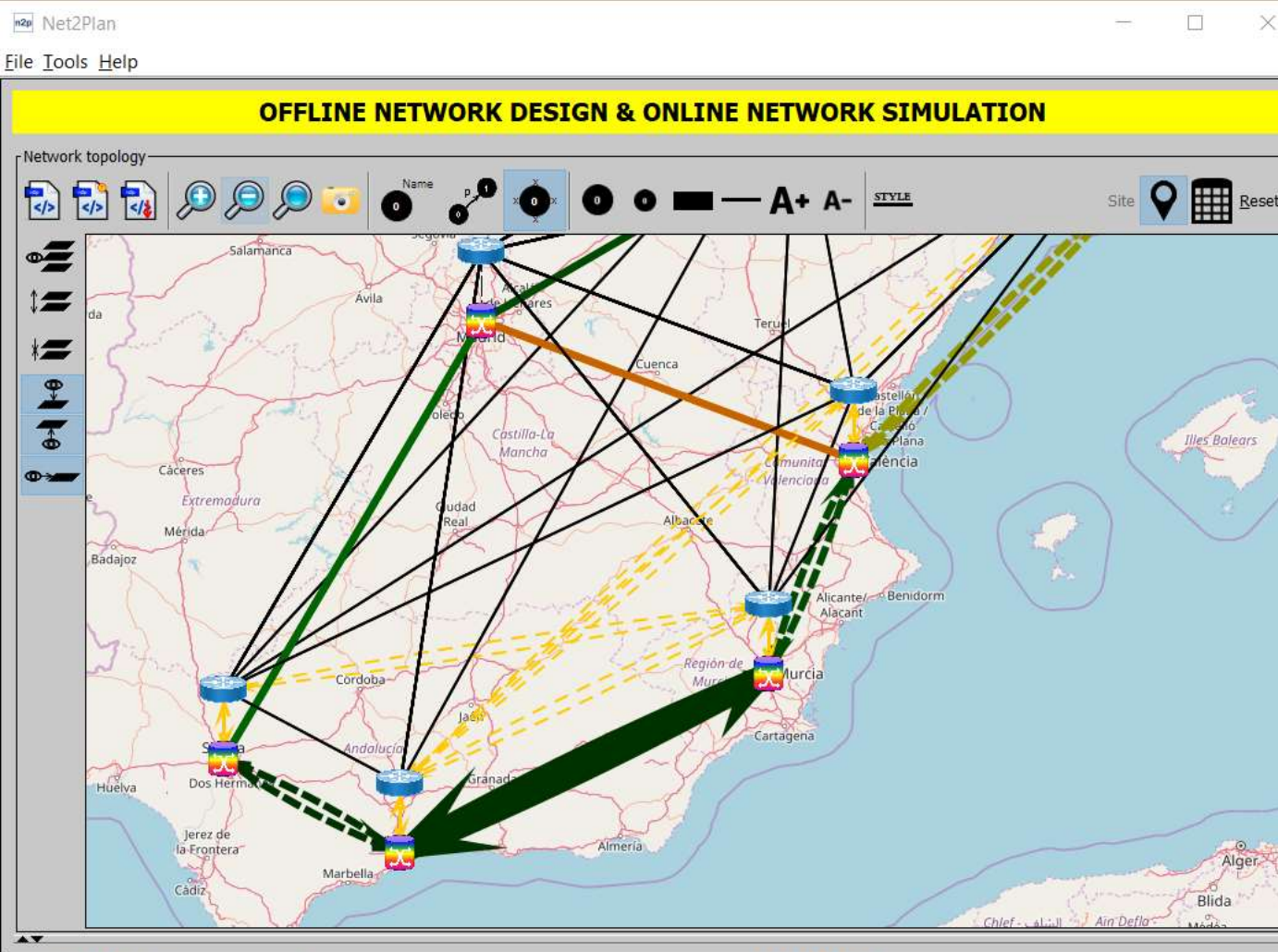
net2plan

www.net2plan.com

github.com/girtel/net2plan

- Multilayer visualization

- Abstract **MULTILAYER** model: Layer, Node, Link, Demand, Multicast demand, Route, SRG...
- Tables full of **technology-agnostic statistics** (loads, utilizations, latencies...)
- **Technology-related information** can be added as ATTRIBUTES, transparent to Net2Plan, but that algorithms can process to create technology-related behaviors



Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Network Layers Nodes Links Demands Multicast demands Routes Multicast trees Resources Shared-risk groups

Number of entries: 8 Reset VFs

Unique id...	Index	MTTF (d...	MTTR (d...	Availability	Nodes	Links	Links (ot...	# Affecte...	# Affecte...	# Affecte...	Ta
458	0	635.772	0.5	0.999	none	0, 5	0, 5	66	0	0	0
459	1	490.273	0.5	0.999	none	1, 8	1, 8	28	0	0	0
460	2	704.628	0.5	0.999	none	2, 10	2, 10	22	0	0	0
461	3	632.753	0.5	0.999	none	3, 6	3, 6	50	0	0	0
462	4	748.412	0.5	0.999	none	4, 11	4, 11	6	0	0	0
463	5	1083.697	0.5	1	none	7, 14	7, 14	16	0	0	0
464	6	1218.756	0.5	1	none	9, 12	9, 12	14	0	0	0
465	7	594.359	0.5	0.999	none	13, 15	13, 15	8	0	0	0
---	---	---	---	---	0.00	16.00	16.00	210.00	0.00	0.00	---

Export tables...

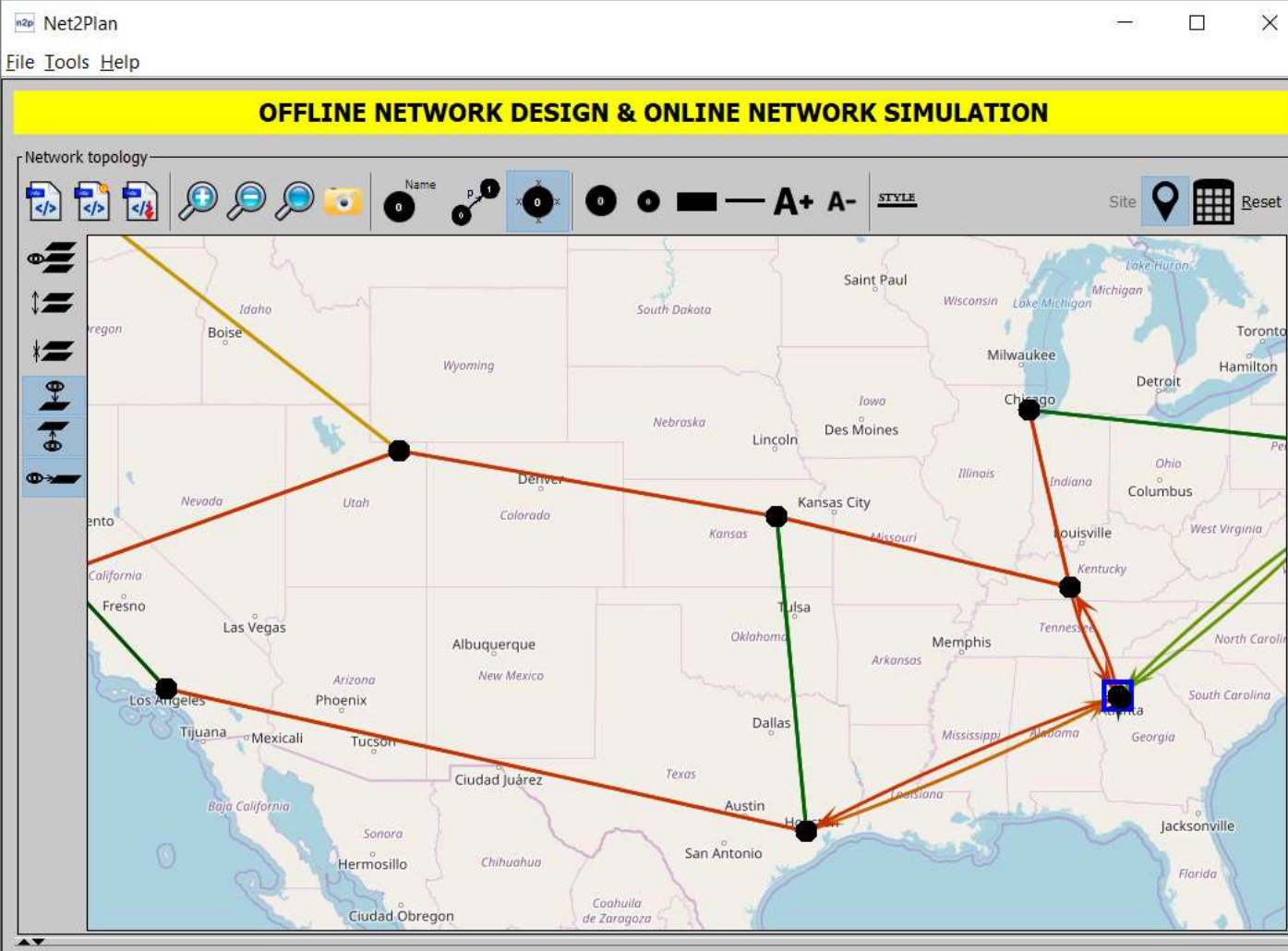


net2plan

www.net2plan.com

github.com/girtel/net2plan

- **Failure model:** shared-risk-group (SRG) definition
 - SRG: arbitrary set of nodes and/or links that can simultaneously fail
 - Represents a vulnerability (e.g. duct cut)
 - Algorithms can typically try to create designs tolerant to all single-SRG failures



View/Edit network state | Offline algorithms | Online simulation | What-if analysis | View reports

Network | Layers | Nodes | Links | Demands | Multicast demands | Routes | Multicast trees | Resources | Shared-risk groups

List view | Traffic matrix view

	ATLAM5	ATLAng	CHINng	DNVRng	HSTNng	IPLSng	KSCYng	LOSAng	NYCMng	SNVAng	S
ATLAM5	0	0.029	0.078	0.01	0.044	0.02	0.016	0.025	0.029	0.006	
ATLAng	0.054	0	0.154	0.084	1.402	0.227	0.061	1.725	0.22	0.054	
CHINng	0.069	0.918	0	0.784	8.242	0.362	0.843	9.65	0.597	0.09	
DNVRng	0.041	0.086	0.35	0	0.191	0.192	0.104	0.191	0.154	0.551	
HSTNng	0.021	0.652	0.323	0.036	0	0.083	0.051	0.411	0.171	0.016	
IPLSng	0.05	0.2	0.68	0.269	0.368	0	0.121	0.559	0.467	0.052	
KSCYng	0.019	0.05	0.195	0.099	0.072	0.095	0	0.07	0.096	0.03	
LOSAng	0.033	1.112	10.624	0.161	4.04	0.298	0.069	0	0.299	0.573	
NYCMng	0.027	0.45	3.058	0.292	0.825	0.219	0.172	0.854	0	0.129	
SNVAng	0.016	0.024	0.174	0.128	0.072	0.083	0.05	0.24	0.136	0	
STTLng	0.023	1.033	0.609	0.187	0.194	0.739	0.338	0.912	0.322	0.654	
WASHng	0.05	0.638	0.865	0.402	0.669	0.251	0.253	1.103	1.002	0.155	
Total	0.403	5.192	17.111	2.453	16.118	2.57	2.078	15.74	3.493	2.311	

Filters

Filter out nodes without links at this layer

Consider only demands between nodes tagged by... [NO FILTER]

Consider only demands tagged by... [NO FILTER]

Traffic matrix synthesis

Select a method for synthesizing a matrix [] Apply

Traffic normalization and adjustments

Select a method [] Apply

Export tables...



net2plan
www.net2plan.com
github.com/girtel/net2plan

- Traffic matrix synthesis, manipulation, normalization

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Network Layers Nodes Links Demands Multicast demands Routes Multicast trees Resources Shared-risk groups

Number of entries: 12 Reset VFs

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Focus panel

Tree index/id:
Layer:
Tree demand:
M. Demand offered traffic:
M. Demand carried traffic:
Tree carried traffic:
Is up?:
Worst link utilization:
E2E num. hops (av / max):
E2E length in km (av / max):
E2E length in ms (av / max):

User-defined attributes

No attributes defined

Unique id...	Index	Multicast...	Ingress n...	Egress n...	Demand ...	Carried t...	Occupied...	Set of links	Number ...	Set of no...	W
2960	0	0 0 (ATLAM5)	n8 (id 10)...		4	4	4	9	5	4926.432	
2961	1	1 1 (ATLang)	n9 (id 11)...		1.3	1.3	1.3	9	4	4776.955	
2962	2	2 2 (CHINng)	n8 (id 10)...		1	1	1	8	4	4465.336	
2963	3	3 3 (DNVRng)	n8 (id 10)...		1.3	1.3	1.3	8	4	3919.019	
2964	4	4 4 (HSTNng)	n6 (id 8)(...		1.3	1.3	1.3	8	3	4050.666	
2965	5	5 5 (IPLSng)	n6 (id 8)(...		23	23	23	8	3	4392.751	
2966	6	6 6 (KSCYng)	n8 (id 10)...		1.3	1.3	1.3	8	3	3022.271	
2967	7	7 7 (LOSAng)	n6 (id 8)(...		0.9	0.9	0.9	7	4	5261.624	
2968	8	8 8 (NYCMng)	n6 (id 8)(...		1.9	1.9	1.9	7	5	5986.605	
2969	9	9 9 (SNVAng)	n6 (id 8)(...		1.3	1.3	1.3	9	5	5821.451	
2970	10	10 10 (STTLng)	n8 (id 10)...		3.4	3.4	3.4	9	5	5986.605	
2971	11	11 11 (WASH...)	n1 (id 3)(...		7	7	7	6	5	5837.733	
---	---	---	---	---	47.70	47.70	47.70	---	5.00	5986.61	

Export tables...



www.net2plan.com
github.com/girtel/net2plan

- **Multicast traffic**
 - Includes algorithms for solving the k minimum cost multicast problem

Net2Plan

File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Toggle What-If Mode

The what-if analysis tool permits visualizing the changes produced in the network under some events triggered in the user interface.

The events that can be tested are:

- Setting failures/repairs in nodes and links. This can be done in the Nodes table, Links table and Shared-risk group tables.
- Modifying the offered traffic of demands (only those not coupled to any upper layer link).

In the what-if analysis, the user modifications in the previous tables will trigger appropriate events sent to the (built-in or user-developed) plug-in.

File: C:\Users\Pablo\Desktop\Net2Plan-0.5.3-SNAPSHOT\workspace\BuiltinExamples.jar Load

Online_evProc_ipOverWdm (com.net2plan.examples.general.onlineSim)

Description: Implements the reactions of an IP over WDM multilayer network, where the IP traffic is carried over fixed rate lightpaths, routed over a topology of fiber links with a fixed wavelength grid

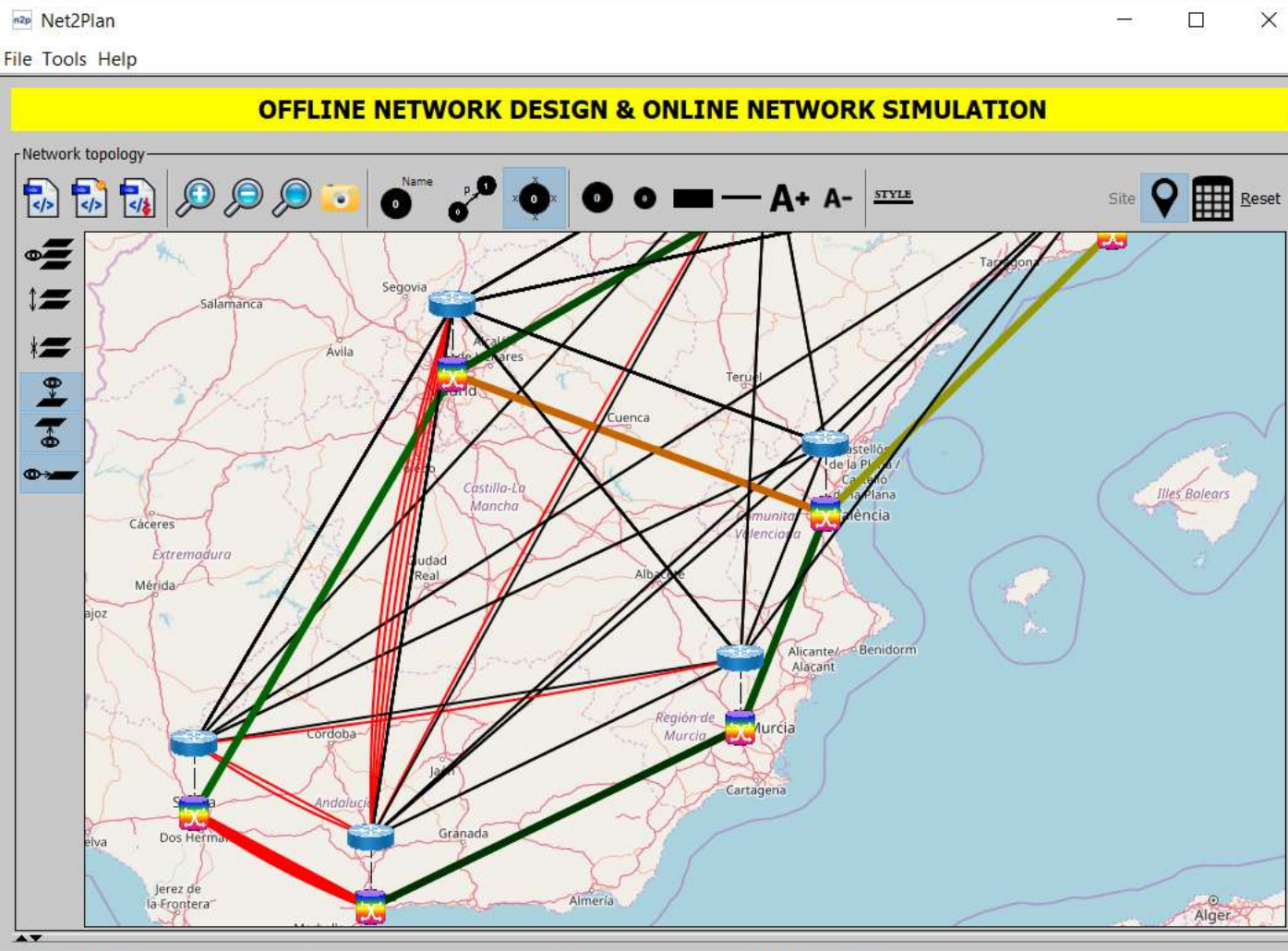
Parameters

Parameter	Value	Description
ipMaximumE2ELatencyMs	-1.0	Maximum end-to-end latency of the traffic of ...
wdmDefaultAndNewRouteRecoveryType	none	New lightpaths are not protected, or are prot...
wdmK	2	Maximum number of admissible paths per de...
wdmMaxLightpathNumHops	-1	A lightpath cannot have more than this numb...
wdmNumFrequencySlotsPerFiber	40	Set the number of frequency slots per fiber. I...
wdmRandomSeed	1	Seed for the random generator (-1 means ra...
wdmRemovePreviousLightpaths		If true, previous lightpaths are removed from ...
wdmRwaType	srg-disjointness-aware-route-first-fit	Criteria to decide the route of a connection a...
wdmTransponderTypesInfo	10 1 1 9600 1	Transponder types separated by ";". Each typ...



www.net2plan.com
github.com/girtel/net2plan

- Multilayer analysis tracking **traffic anomalies** and **failure propagation across layers**
 - Plug in your **network behavior algorithm** (or use a built-in one) coding how the network reacts to failures and traffic



Net2Plan - Design tables and control window

View/Edit network state | Offline algorithms | Online simulation | What-if analysis | View reports

Network | Layers | Nodes | Links | Demands | Multicast demands | Routes | Multicast trees | Resources | Shared-risk groups

Number of entries: 16 Reset VFs

Unique id...	Index	Show/Hide	Origin no...	Destinati...	State	Capacity	Carried t...	Occupati...	Utilization	Is bottlen...	Le...
9	0	<input type="checkbox"/>	0 (Madrid)	2 (Valencia)	<input type="checkbox"/>	40	3300	33	0.825	<input checked="" type="checkbox"/>	
10	1	<input type="checkbox"/>	0 (Madrid)	3 (Sevilla)	<input type="checkbox"/>	40	900	9	0.225	<input type="checkbox"/>	
11	2	<input type="checkbox"/>	0 (Madrid)	4 (Zarago...	<input type="checkbox"/>	40	1100	11	0.275	<input type="checkbox"/>	
12	3	<input type="checkbox"/>	1 (Barcelo...	2 (Valencia)	<input type="checkbox"/>	40	2500	25	0.625	<input type="checkbox"/>	
13	4	<input type="checkbox"/>	1 (Barcelo...	4 (Zarago...	<input type="checkbox"/>	40	300	3	0.075	<input type="checkbox"/>	
14	5	<input type="checkbox"/>	2 (Valencia)	0 (Madrid)	<input type="checkbox"/>	40	3300	33	0.825	<input checked="" type="checkbox"/>	
15	6	<input type="checkbox"/>	2 (Valencia)	1 (Barcelo...	<input type="checkbox"/>	40	2500	25	0.625	<input type="checkbox"/>	
16	7	<input type="checkbox"/>	2 (Valencia)	6 (Murcia)	<input type="checkbox"/>	40	800	8	0.2	<input type="checkbox"/>	
17	8	<input type="checkbox"/>	3 (Sevilla)	0 (Madrid)	<input type="checkbox"/>	40	1400	14	0.35	<input type="checkbox"/>	
18	9	<input type="checkbox"/>	3 (Sevilla)	5 (Málaga)	<input type="checkbox"/>	40	0	0	0	<input type="checkbox"/>	
19	10	<input type="checkbox"/>	4 (Zarago...	0 (Madrid)	<input type="checkbox"/>	40	1000	10	0.25	<input type="checkbox"/>	
20	11	<input type="checkbox"/>	4 (Zarago...	1 (Barcelo...	<input type="checkbox"/>	40	300	3	0.075	<input type="checkbox"/>	
21	12	<input type="checkbox"/>	5 (Málaga)	3 (Sevilla)	<input type="checkbox"/>	40	700	7	0.175	<input type="checkbox"/>	
22	13	<input type="checkbox"/>	5 (Málaga)	6 (Murcia)	<input type="checkbox"/>	40	300	3	0.075	<input type="checkbox"/>	
23	14	<input type="checkbox"/>	6 (Murcia)	2 (Valencia)	<input type="checkbox"/>	40	800	8	0.2	<input type="checkbox"/>	
24	15	<input type="checkbox"/>	6 (Murcia)	5 (Málaga)	<input type="checkbox"/>	40	400	4	0.1	<input type="checkbox"/>	
---	---	---	---	---	---	640.00	19600.00	196.00	---	---	

Export tables...



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- Multilayer analysis tracking **traffic anomalies** and **failure propagation across layers**
 - Plug in your **network behavior algorithm** (or use a built-in one) coding how the network reacts to failures and traffic
 - **WHAT-IF:** Then, manually create failures/repairs and/or traffic shifts, and see the network reaction in all the layers

Net2Plan

File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Algorithm: C:\Users\Pablo\Desktop\Net2Plan-0.5.3-SNAPSHOT\workspace\BuiltInExamples.jar Load

Offline_fa_ospfWeightOptimization_tabuSearch (com.net2plan.examples.ocnbook.offline)

Description: Given a set of nodes, links and offered traffic, this algorithm assumes that the nodes are IP routers running the OSPF protocol (applying ECMP rules) for routing it. The algorithm searches for the set of link weights that optimize the routing. In particular, the target is minimizing a congestion metric computed as a function of both the worst-case link utilization and the average link utilization. The algorithm is based on applying a tabu search heuristic approach.

Parameters

Parameter	Value	Description
algorithm_maxExecutionTimeInSeconds	60.0	Algorithm maximum running time in seconds
algorithm_outputFileNameRoot	ospfWeghtOptimization_tabu	Root of the file name to be used in the output...
algorithm_randomSeed	1	Seed of the random number generator
ospf_maxLinkWeight	16	OSPF link weights are constrained to be integ...
ospf_weightOfMaxUtilizationInObjectiveFunction	0.9	Objective function is this factor multiplied by ...
ts_aspirationCriterion	<input checked="" type="checkbox"/>	Apply aspiration criterion in tabu search
ts_differenceInWeightToBeNeighbors	1	Two solutions where all the links have the sa...
ts_initializationType	random	The type of initialization of the OSPF link weig...
ts_maxNumIterations	50000	Maximum number of iterations
ts_maxNumIterationsNonImprovingIncumbent...	15	Num iterations non improving the incumbent ...
ts_tabuListSizeAsFractionOfLinks	0.5	Size of the tabe list, given as a fraction of the...

Execute



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- **Offline algorithms (e.g. for capacity planning)**

- Plug in your algorithm (or use a built-in one) that makes network redesigns
- Check the repository of algorithms in the Javadoc!!

Overview (Net2Plan 0.5.0 x

net2plan.com/documentation/current/javadoc/examples/

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All Classes

Packages

com.net2plan.examples.general.offline
com.net2plan.examples.general.offline.nfv
com.net2plan.examples.general.onlineSim
com.net2plan.examples.general.reports
com.net2plan.examples.ocnbook.offline

All Classes


Offline_ba_numFormulations
Offline_ca_wirelessCsmaWindowSize
Offline_ca_wirelessPersistenceProbability
Offline_ca_wirelessTransmissionPower
Offline_cba_congControlLinkBwSplitTwoQoS
Offline_cba_wirelessCongControlTransmissionF
Offline_cfa_modularCapacitiesAndRoutingDual
Offline_cfa_xpMultiperiodModularCapacities
Offline_Example_Algorithm
Offline_fa_ospfWeightOptimization_ACO
Offline_fa_ospfWeightOptimization_EA
Offline_fa_ospfWeightOptimization_GRASP
Offline_fa_ospfWeightOptimization_greedy
Offline_fa_ospfWeightOptimization_localSearch
Offline_fa_ospfWeightOptimization_SAN
Offline_fa_ospfWeightOptimization_tabuSearch
Offline_fa_xde11PathProtection

com.net2plan.examples.general.reports	Several example reports
com.net2plan.examples.ocnbook.offline	Examples of offline network design algorithms, corresponding to case studies in this book .
com.net2plan.examples.ocnbook.onlineSim	Examples of online event processors and event generators corresponding for event-driven simulation, corresponding to case studies in this book .
com.net2plan.examples.ocnbook.reports	Examples of reports corresponding to different methods described in this book .

This page gives access to the Javadoc documentation of the Net2Plan built-in examples, contained in the file JAR workspace/BuiltInExamples.jar.

- Link here for searching in the examples using a set of keywords.
- Link here for searching in the examples used in the book:

Pablo Pavón Mariño, *Optimization of computer networks. Modeling and algorithms. A hands-on approach*, Wiley 2016.



OVERVIEW PACKAGE CLASS USE TREE INDEX HELP

PREV NEXT FRAMES NO FRAMES

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- **Offline algorithms (e.g. for capacity planning)**

- Plug in your algorithm (or use a built-in one) that makes network redesigns
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Offline_cba_wirelessCongControlTransmissionF
Offline_cfa_modularCapacitiesAndRoutingDual
Offline_cfa_xpMultiperiodModularCapacities
Offline_Example_Algorithm
Offline_fa_ospfWeightOptimization_ACO
Offline_fa_ospfWeightOptimization_EA
Offline_fa_ospfWeightOptimization_GRASP
Offline_fa_ospfWeightOptimization_greedy
Offline_fa_ospfWeightOptimization_localSearch
Offline_fa_ospfWeightOptimization_SAN
Offline_fa_ospfWeightOptimization_tabuSearch
Offline_fa_xde11PathProtection

OVERVIEW PACKAGE CLASS USE TREE INDEX HELP

PREV NEXT FRAMES NO FRAMES

Keywords

Keyword	Description
Ant Colony Optimization (ACO)	An example where a heuristic using an ant colony optimization (ACO) algorithmic approach is used
Backpressure routing	An example where the traffic routing is performed using a backpressure approach.
Bandwidth assignment (BA)	An example where the volume of traffic to be carried by each demand, is an algorithm output (that includes congestion control algorithms).
CAC (Connection-Admission-Control)	An example where an algorithm performing the admission control to incoming connection requests is involved.
CSMA	An example where the wireless links are coordinated using a CSMA MAC.
Capacity assignment (CA)	An example where the capacities in the links are algorithm outputs.
Destination-based routing	An example related to a problem where the traffic routing is destination-based (i.e. like in IP)
Destination-link formulation	An example where a destination-link formulation of the routing is involved.
Distributed algorithm	An example where a distributed algorithm (different agents operating more or less independently, coordinated by an implicit or explicit signaling) is involved.



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- **Offline algorithms (e.g. for capacity planning)**
 - Plug in your algorithm (or use a built-in one) that makes network redesigns
 - Check the repository of algorithms in the Javadoc!!
 - Includes indexing by keyword to search for algorithms

Overview (Net2Plan 0.5.0 x

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com.net2plan.examples.general.offline

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Offline_cba_wirelessCongControlTransmissionF
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Offline_cfa_xpMultiperiodModularCapacities
Offline_Example_Algorithm
Offline_fa_ospfWeightOptimization_ACO
Offline_fa_ospfWeightOptimization_EA
Offline_fa_ospfWeightOptimization_GRASP
Offline_fa_ospfWeightOptimization_greedy
Offline_fa_ospfWeightOptimization_localSearch
Offline_fa_ospfWeightOptimization_SAN
Offline_fa_ospfWeightOptimization_tabuSearch
Offline_fa_xde11PathProtection

Exercise 3.8

- **Online_evGen_generalGenerator**: Generates events to a technology-agnostic network, consisting of connection requests/releases and failures and repairs.
- **Online_evProc_generalProcessor**: Implements the reactions of a technology-agnostic network to connection requests under various CAC options, and reactions to failures and repairs under different recovery schemes.

Chapter 4

Routing Problems

Section 4.2

- **Offline_fa_xp11PathProtection**: Solves several variants of unicast routing problems with 1+1 protection, with flow-path formulations
- **Offline_fa_xpFormulations**: Solves several variants of unicast routing problems, with flow-path formulations

Section 4.3

- **Offline_fa_xde11PathProtection**: Solves several variants of unicast routing problems with 1+1 protection, with flow-link formulations
- **Offline_fa_xdeFormulations**: Solves several variants of unicast routing problems, with flow-link formulations
- **Offline_fa_xdeSharedRestoration**: Solves several variants of unicast routing problems with flow-link formulations, so that designs are fault tolerant to a set of failure states, using shared restoration

Section 4.4

- **Offline_fa_xteFormulations**: Solves several variants of routing problems in the form of destination-link formulations.



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- **Offline algorithms (e.g. for capacity planning)**
 - Plug in your algorithm (or use a built-in one) that makes network redesigns
 - Check the repository of algorithms in the Javadoc!!
 - Includes indexing by keyword to search for algorithms
 - For book readers: includes links to sections describing the maths behind

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File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Simulation input parameters Simulation control Simulation report

Simulation execution

Simulation parameters

Parameter	Value	Description
disableStatistics	<input type="checkbox"/>	Disable compilation of simulation statistics (on...
refreshTime	10	Refresh time (in seconds)
simEvents	-1	Total simulation events (including transitory p...
simTime	-1	Total simulation time (in seconds, including tr...
transitoryEvents	-1	Number of events for transitory period (-1 me...
transitoryTime	-1	Transitory time (in seconds) (-1 means no tra...

Event generator Provisioning algorithm

File: Load

Online_evGen_ipOverWdm (com.net2plan.examples.general.onlineSim)

Description: Generates events for an IP over WDM multilayer network, with an IP/OSPF layer on top of a WDM layer where lightpaths are carried in a fixed grid of wavelengths

Parameters

Parameter	Value	Description
ipOverWdmFailureStatisticalPattern	exponential-iid	Type of failure and repair statistical pattern
ipOverWdmFailureDefaultMTTFInHours	10.0	Default value for Mean Time To Fail (hours...
ipOverWdmFailureDefaultMTTRInHours	12.0	Default value for Mean Time To Repair (ho...
ipOverWdmFailureModel	perBidirectionalLinkBundle	Failure model selection: SRGfromNetPlan, ...
ipTFFastFluctuationCoefficientOfVariation	1.0	Average time between two changes of dem...
ipTFFastFluctuationType	none	
ipTFFastMaximumFluctuationRelativeFactor	1.0	The fluctuation of a demand cannot exceed...
ipTFFastTimeBetweenDemandFluctuations...	0.1	Average time between two changes of dem...
ipTFSlowDefaultTimezone	0	Default timezone with respect to UTC (in ra...



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- **Online (provisioning) algorithms for event-driven network simulation**
 - Plug in your event generation algorithm (or use a built-in one) that produces traffic shifts, failures and repairs etc.

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File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

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Event generator Provisioning algorithm

File: C:\Users\Pablo\Desktop\Net2Plan-0.5.3-SNAPSHOT\workspace\BuiltInExamples.jar

Online_evProc_ipOverWdm (com.net2plan.examples.general.onlineSim)

Description: Implements the reactions of an IP over WDM multilayer network, where the IP traffic is carried over fixed rate lightpaths, routed over a topology of fiber links with a fixed wavelength grid

Parameters

Parameter	Value	Description
ipMaximumE2ELatencyMs	-1.0	Maximum end-to-end latency of the traffic of...
wdmDefaultAndNewRouteRecoveryType	none	New lightpaths are not protected, or are pro...
wdmK	2	Maximum number of admissible paths per d...
wdmMaxLightpathNumHops	-1	A lightpath cannot have more than this num...
wdmNumFrequencySlotsPerFiber	40	Set the number of frequency slots per fiber. ...
wdmRandomSeed	1	Seed for the random generator (-1 means r...
wdmRemovePreviousLightpaths	<input type="checkbox"/>	If true, previous lightpaths are removed fro...
wdmRwaType	srg-disjointness-aware-route-first-fit	Criteria to decide the route of a connection a...
wdmTransponderTypesInfo	10 1 1 9600 1	Transponder types separated by ";". Each ty...

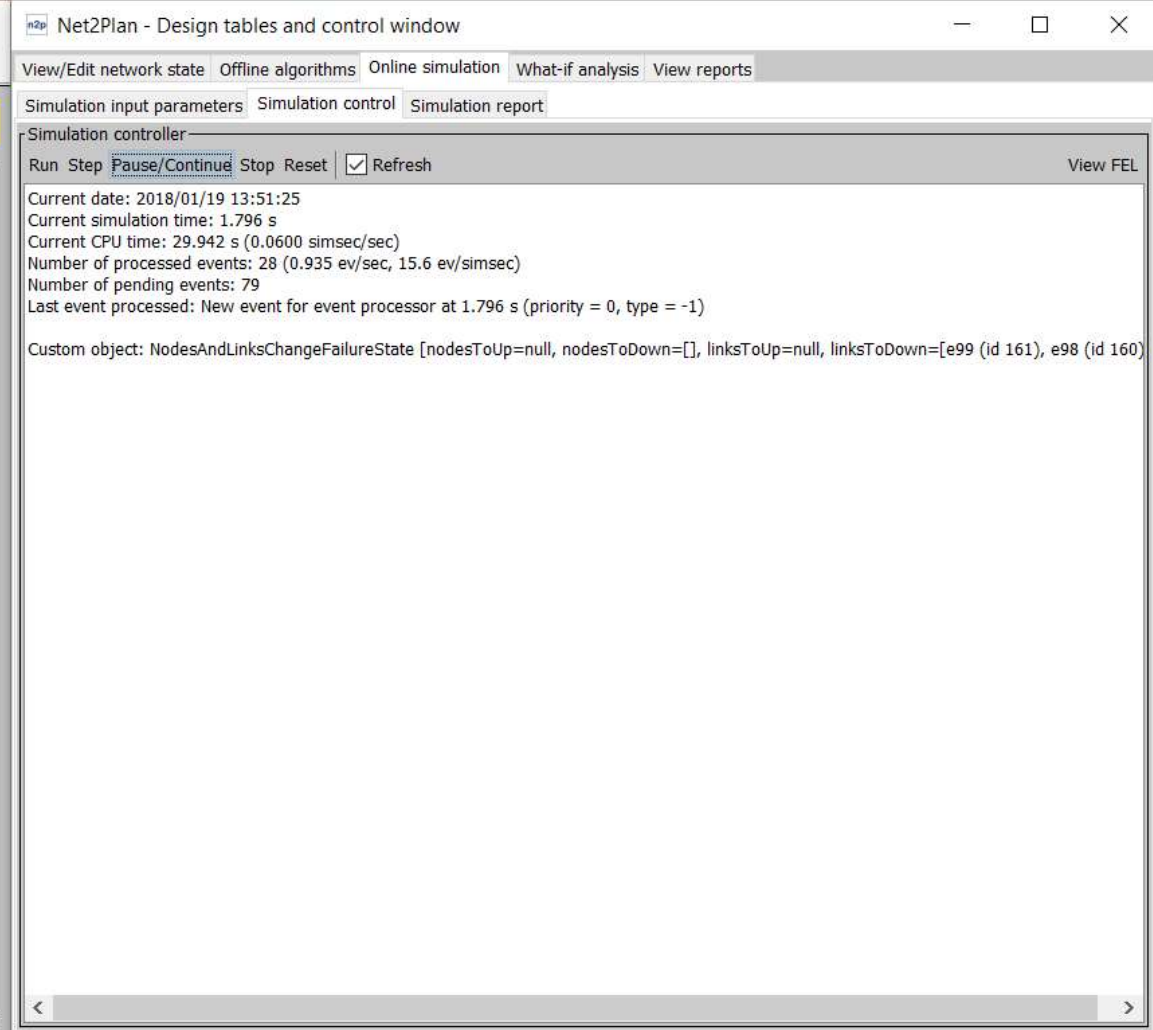
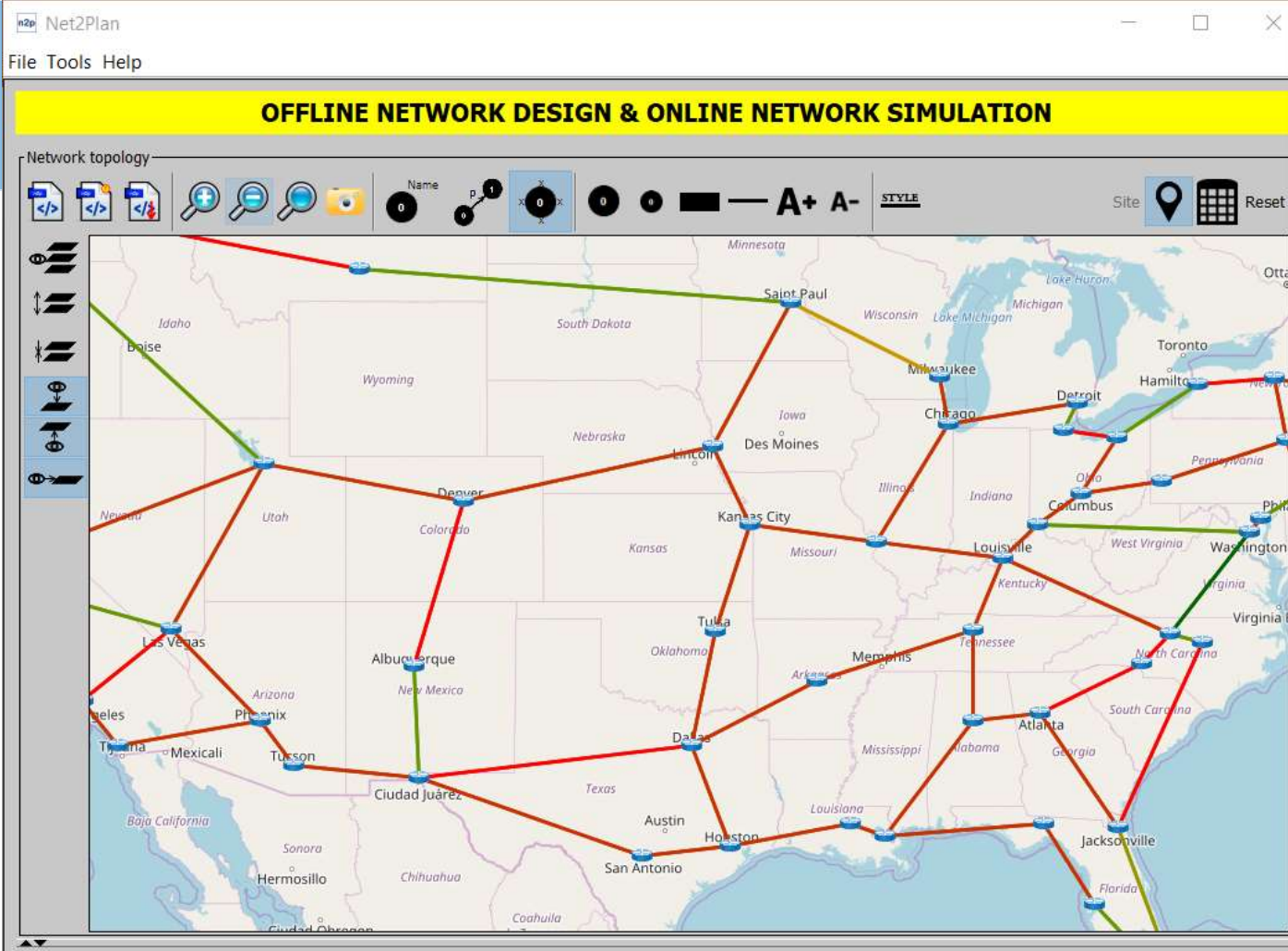


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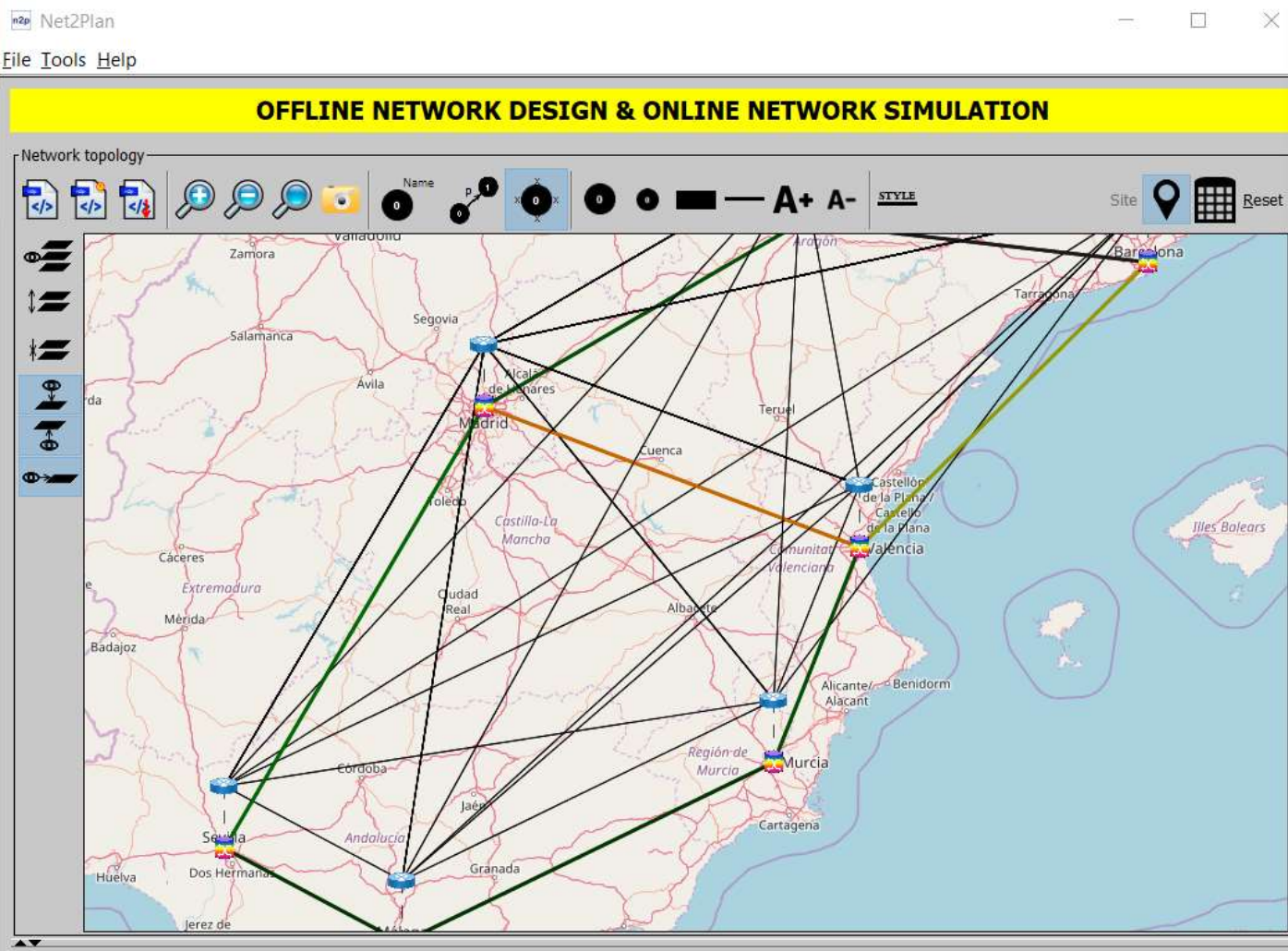
github.com/girtel/net2plan

- **Online (provisioning) algorithms for event-driven network simulation**
 - Plug in your event generation algorithm (or use a built-in one) that produces traffic shifts, failures and repairs etc.
 - Plug in your **network behavior algorithm** coding network reaction (same algorithm as in *what-if*, no need to code a new one!!!)



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- **Online (provisioning) algorithms for event-driven network simulation**
 - Run, step, continue, pause, stop the simulation
 - See the simulation report:
 - Tech-agnostic statistic are automatically computed by Net2Plan
 - User algorithms can create custom (e.g. tech-specific) reports



Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Report: C:\Users\Pablo\Desktop\Net2Plan-0.5.3-SNAPSHOT\workspace\BuiltInExamples.jar Load

Report_WDM_lineEngineering (com.net2plan.examples.general.reports)

Description: This report shows line engineering information for WDM links in the network. Further description in the HTML generated.

Parameters

Parameter	Value	Description
edfa_noiseFactorMinimumGain_dB	5	Noise factor at the EDFA when the gain is in...
edfa_noiseFactorReferenceBandwidth_nm	0.5	Reference bandwidth that measures the noi...
fiber_PMD_ps_per_sqrt_km	0.4	Polarization mode dispersion per km ^{0.5} of ...
fiber_attenuation_dB_per_km	0.25	Fiber attenuation in dB/km
fiber_worseChromaticDispersion_ps_per_n...	6	Chromatic dispersion of the fiber in ps/nm/km
oadm_addChannelNoiseFactor_dB	6	Noise factor observed by add channels
oadm_boosterPMD_ps	0.5	PMD off OADM booster amplifier
oadm_dropChannelNoiseFactor_dB	6	Noise factor observed by drop channels

Show Close all

WDM line engineering

View in navigator Save to file

WDM line engineering report for lighthpath-based networks

This report shows line engineering information for WDM links in a multilayer optical network. The impairment calculations are inspired in the procedures described in the 2009 ITU-T WDM manual "Optical fibres, cables and systems".

The report assumes that the WDM network follows the scheme:

- In the net2plan object, nodes are OADMs, links are fiber links, and routes are lighthpaths: WDM channels optically switched at intermediate nodes.
- Nodes are connected by unidirectional fiber links. Fiber link distance is given by the link length. Other specifications are given by fiber XXX input parameters. The fiber can be split into spans of optical amplifiers (EDFAs) and/or dispersion compensating...



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- **Reporting.** Plug in your report algorithm, or use a built-in one. Some interesting built-in reports:
 - WDM line engineering, OSNR (using GN model), PMD, CD, power at link & lighthpath level
 - RSA inspector: Spectrum occupation in the fibers
 - Availability analysis: Estimates service level availability (includes error margin)

PER LINK INFORMATION SUMMARY - Signal metrics at the input of end OADM

Link #	Length (km)	# EDFAs	# DCMs	Chromatic Dispersion (ps/nm)	OSNR (dB)	Power per WDM channel (dBm)	Polarization Mode Dispersion (ps)	Warnings
e0 (id 9) (Madrid --> Valencia)	301.92	3	3	0	27.64	-19	7.14	
e1 (id 10) (Madrid --> Sevilla)	391.43	4	3	0	25.89	-19	8.1	
e2 (id 11) (Madrid --> Zaragoza)	272.44	3	2	-0	30.95	-18.11	6.77	
e3 (id 12) (Barcelona --> Valencia)	303.36	3	3	0	27.52	-19	7.16	
e4 (id 13) (Barcelona --> Zaragoza)	256.51	3	2	0	30.95	-14.13	6.58	
e5 (id 14) (Valencia --> Madrid)	301.92	3	3	0	27.64	-19	7.14	
e6 (id 15) (Valencia --> Barcelona)	303.36	3	3	0	27.52	-19	7.16	
e7 (id 16) (Valencia --> Murcia)	177.19	2	2	0	32.68	-11.3	5.51	
e8 (id 17) (Sevilla --> Madrid)	391.43	4	3	0	25.89	-19	8.1	
e9 (id 18) (Sevilla --> Málaga)	157.56	1	1	118.36	34.76	-19	5.14	
e10 (id 19) (Zaragoza --> Madrid)	272.44	3	2	-0	30.95	-18.11	6.77	
e11 (id 20) (Zaragoza --> Barcelona)	256.51	3	2	0	30.95	-14.13	6.58	
e12 (id 21) (Málaga --> Sevilla)	157.56	1	1	118.36	34.76	-19	5.14	
e13 (id 22) (Málaga --> Murcia)	322.94	3	3	0	25.9	-19	7.38	
e14 (id 23) (Murcia --> Valencia)	177.19	2	2	0	32.68	-11.3	5.51	
e15 (id 24) (Murcia --> Málaga)	322.94	3	3	0	25.9	-19	7.38	

PER ROUTE INFORMATION SUMMARY - Signal metrics at the transponder

Route #	Length (km)	# EDFAs	# DCMs	Chromatic Dispersion (ps/nm)	OSNR (dB)	Power per WDM channel (dBm)	Polarization Mode Dispersion (ps)	Warnings
r0 (id 155) (Madrid --> Barcelona)	605.29	6	6	0	19.96	-19	10.11	



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- **Reporting.** Plug in your report algorithm, or use a built-in one. Some interesting built-in reports:
 - **WDM line engineering:** OSNR (using GN model), PMD, CD, power at link & lightpath level
 - **RSA inspector:** Spectrum occupation in the fibers
 - **Availability analysis:** Estimates service level availability (includes error margin)

TIP – Open Optical Packet Transport



TELECOM INFRA PROJECT



<http://telecominfraproject.com/>

- Photonic Simulation Environment (PSE) Group within [Open Optical Packet Transport \(OOPT\)](#) working on OpenSource Optical Link Emulator:
 - GN model for Non Linear impairment estimation
 - Python code delivery:
<https://github.com/Telecominfraproject/gnpy/>
 - Multi-vendor approach

TELECOM INFRA PROJECT
JULY 19TH 2017

**OPTICAL LINK EMULATOR (OLE) AND
OPTICAL ROUTE ANALYZER (ORA)**

ALESSIO FERRARI, ALESSIO.FERRARI@POLITO.IT

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VITTORIO CURRI, CURRI@POLITO.IT

OPTICAL COMMUNICATIONS GROUP – DIPARTIMENTO DI ELETTRONICA E TELECOMUNICAZIONI
POLITECNICO DI TORINO – TORINO – ITALY – WWW.OPTCOM.POLITO.IT



- Net2Plan incorporates two models for estimating nonlinear impairments, one of them applying a flavor of the Gaussian Noise model (thanks POLITO GN-group, thanks OOPT-PSE group!!)
- **Checkout OOPT-PSE GIT repository for a Python-based library for optical quality of transmission estimations!! Great work there!!**

WDM line engineering in x WDM Lightpath Routing x

file:///C:/Users/Pablo/AppData/Local/Temp/tmp_2605642235536216179.html

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% of carried traffic with at least one backup path 0 %

PER FIBER INFORMATION SUMMARY

This table shows information for each fiber. In particular, the slots occupied, with a link to the lightpaths occupying it, either for regular lightpaths (L), or lightpaths defined as protection segments (P) that reserve slots:

- Black: The slot number is higher than the capacity declared for the link, and is not assigned to any lightpath.
- White: The slot is within the fiber capacity, and is not assigned to any lightpath.
- Green: The slot is within the fiber capacity, and is occupied by one regular lightpath and assigned to no backup lightpath.
- Yellow: The slot is within the fiber capacity, and is occupied by zero regular lightpaths and assigned to one backup lightpath.
- Red: The slot is within the fiber capacity, and is occupied by more than one lightpath (summing regular and backup), or is outside the link capacity and is assigned to at least one lightpath.

Fiber #	Origin node	Dest. node	% slots used	Ok?	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36		
0 (id: 9)	n0 (Madrid)	n2 (Valencia)	0.825	Yes	L0	L2	L4	L6	L8	L10	L12	L14	L16	L18	L20	L22	L24	L26	L28	L32	L36	L40	L44	L48	L54	L58	L64	L66	L72	L80	L82	L88	L95	L108	L111	L114	L120						
1 (id: 10)	n0 (Madrid)	n3 (Sevilla)	0.35	Yes	L34	L42	L50	L52	L60	L62	L74	L78	L92	L102	L119	L122																	L90			L110							
2 (id: 11)	n0 (Madrid)	n4 (Zaragoza)	0.275	Yes	L30	L38	L46	L56	L68	L84	L116		L91			L118	L123																	L94									
3 (id: 12)	n1 (Barcelona)	n2 (Valencia)	0.625	Yes	L1	L3	L5	L7	L9	L11	L13	L15	L17	L19	L21	L70	L25	L86	L29	L98	L37	L100	L45	L128	L55			L67			L83		L90					L115					
4 (id: 13)	n1 (Barcelona)	n4 (Zaragoza)	0.075	Yes	L76	L96																		L121																			
5 (id: 14)	n2 (Valencia)	n0 (Madrid)	0.825	Yes	L1	L3	L5	L7	L9	L11	L13	L15	L17	L19	L21	L23	L25	L27	L29	L33	L37	L41	L45	L49	L55	L59	L65	L67	L73	L81	L83	L89	L90	L94	L109	L110	L115						
6 (id: 15)	n2 (Valencia)	n1 (Barcelona)	0.625	Yes	L0	L2	L4	L6	L8	L10	L12	L14	L16	L18	L20	L71	L24	L87	L28	L99	L36	L101	L44	L121	L54	L129		L66			L82						L114						
7 (id: 16)	n2 (Valencia)	n6 (Murcia)	0.2	Yes	L106	L112														L98		L100					L64			L80				L108				L120					



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- **Reporting.** Plug in your report algorithm, or use a built-in one. Some interesting built-in reports:
 - WDM line engineering: OSNR (using GN model), PMD, CD, power at link & lightpath level
 - **RSA inspector:** Spectrum occupation in the fibers
 - Availability analysis: Estimates service level availability (includes error margin)

Layer WDM, index = 0, id = 1

Unicast traffic

SRG Index failed	Offered traffic	Blocked traffic (%)	Offered traffic traversing oversubscribed links (%)	Offered traffic of demands with excessive latency (%)	Total blocked traffic [out of contract] (%)	% of demands fully ok
No failure	13000.000	0.000 (0.000 %)	0.000 (0.000 %)	0.000 (0.000 %)	0.000 (0.000 %)	(100.000 %)
0	13000.000	6600.000 (50.769 %)	0.000 (0.000 %)	0.000 (0.000 %)	6600.000 (50.769 %)	(49.231 %)
1	13000.000	2800.000 (21.538 %)	0.000 (0.000 %)	0.000 (0.000 %)	2800.000 (21.538 %)	(78.462 %)
2	13000.000	2200.000 (16.923 %)	0.000 (0.000 %)	0.000 (0.000 %)	2200.000 (16.923 %)	(83.077 %)
3	13000.000	5000.000 (38.462 %)	0.000 (0.000 %)	0.000 (0.000 %)	5000.000 (38.462 %)	(61.538 %)
4	13000.000	600.000 (4.615 %)	0.000 (0.000 %)	0.000 (0.000 %)	600.000 (4.615 %)	(95.385 %)
5	13000.000	1600.000 (12.308 %)	0.000 (0.000 %)	0.000 (0.000 %)	1600.000 (12.308 %)	(87.692 %)
6	13000.000	1400.000 (10.769 %)	0.000 (0.000 %)	0.000 (0.000 %)	1400.000 (10.769 %)	(89.231 %)
7	13000.000	800.000 (6.154 %)	0.000 (0.000 %)	0.000 (0.000 %)	800.000 (6.154 %)	(93.846 %)

Layer IP, index = 1, id = 285

Unicast traffic

SRG Index failed	Offered traffic	Blocked traffic (%)	Offered traffic traversing oversubscribed links (%)	Offered traffic of demands with excessive latency (%)	Total blocked traffic [out of contract] (%)	% of demands fully ok
No failure	10000.000	0.000 (0.000 %)	0.000 (0.000 %)	0.000 (0.000 %)	0.000 (0.000 %)	(100.000 %)
0	10000.000	0.000 (0.000 %)	9320.197 (93.202 %)	0.000 (0.000 %)	9320.197 (93.202 %)	(33.333 %)
1	10000.000	0.000 (0.000 %)	7727.512 (77.275 %)	0.000 (0.000 %)	7727.512 (77.275 %)	(40.476 %)
2	10000.000	0.000 (0.000 %)	5605.399 (56.054 %)	0.000 (0.000 %)	5605.399 (56.054 %)	(61.905 %)
3	10000.000	0.000 (0.000 %)	6503.431 (65.034 %)	0.000 (0.000 %)	6503.431 (65.034 %)	(54.762 %)



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- **Reporting.** Plug in your report algorithm, or use a built-in one. Some interesting built-in reports:
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 - RSA inspector: Spectrum occupation in the fibers
 - **Availability analysis:** Estimates service level availability (includes error margin)

Net2Plan

File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Focus panel

Layer: Route d
Demand
Demand
Route c
Is up?:
Worst fi
Worst r
Is servic
Route le
Route le
Is backu
Has bac
User-del

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Network Layers Nodes Links Demands Multicast demands Routes Multicast trees Resources Shared-risk groups

Number of entries: 125 Reset VFs

Unique id...	Index	Demand	Ingress n...	Egress n...	Demand ...	Carried t...	Occupied...	Sequenc...	Sequenc...	Number ...
1617	0	0.089	0 5 (IPLSng)	10 (STTLng)	0.089	0.089	0.0895	R46,L23,R...	N5,(R46),...	3
1638	1	0.044	24 (HSTNng)	10 (STTLng)	0.044	0.044	0.043625	L21,L25,R...	N4,N7,N9,...	3
1651	2	0.069	3 7 (LOSAng)	6 (KSCYng)	0.069	0.069	0.06915	R50,R49,L...	N7,(R50),...	2
1665	3	0.299	4 7 (LOSAng)	8 (NYCMng)	0.299	0.299	0.299225	R50,L20,R...	N7,(R50),...	4
1666	4	0.411	5 4 (HSTNng)	7 (LOSAng)	0.411	0.411	0.410925	R44,R43,L21	N4,(R44),...	1
1676	5	0.68	6 5 (IPLSng)	2 (CHIINng)	0.68	0.335	0.3350999...	L8,R40,R39	N5,N2,(R4...	1
1678	6	0.68	6 5 (IPLSng)	2 (CHIINng)	0.68	0.345	0.3445750...	R46,R45,L8	N5,(R46),...	1
1686	7	0.242	7 7 (LOSAng)	10 (STTLng)	0.242	0.242	0.2421	L25,R54,R...	N7,N9,(R5...	2
1696	8	0.573	8 7 (LOSAng)	9 (SNVAng)	0.573	0.573	0.57265	L25,R54,R53	N7,N9,(R5...	1
1707	9	0.041	9 3 (DNVRng)	0 (ATLAM5)	0.041	0.041	0.04105	L13,R48,R...	N3,N6,(R4...	4
1740	10	0.784	12 2 (CHIINng)	3 (DNVRng)	0.784	0.784	0.784075	L9,L23,R4...	N2,N5,N6,...	3
1754	11	0.096	13 6 (KSCYng)	8 (NYCMng)	0.096	0.096	0.095575	R48,L22,R...	N6,(R48),...	3
1757	12	0.083	14 4 (HSTNng)	5 (IPLSng)	0.083	0.083	0.083425	R44,L19,R...	N4,(R44),...	2
1766	13	0.192	15 3 (DNVRng)	5 (IPLSng)	0.192	0.192	0.19235	L13,R48,R...	N3,N6,(R4...	2
1778	14	1.002	16 11 (WASH...	8 (NYCMng)	1.002	1.002	1.001725	R58,R57,L26	N11,(R58)...	1
1792	15	0.113	17 6 (KSCYng)	11 (WASH...	0.113	0.113	0.112675	L18,R44,L...	N6,N4,(R4...	3
1799	16	0.136	18 9 (SNVAng)	8 (NYCMng)	0.136	0.136	0.136175	R54,R53,L...	N9,(R54),...	5
1810	17	0.402	19 11 (WASH...	3 (DNVRng)	0.402	0.402	0.40155	L6,L3,R44...	N11,N1,N4...	4
1816	18	0.049	20 6 (KSCYng)	10 (STTLng)	0.049	0.049	0.04865	R48,R47,L...	N6,(R48),...	2
1826	19	0.104	21 3 (DNVRng)	6 (KSCYng)	0.104	0.104	0.104125	L13,R48,R47	N3,N6,(R4...	1
1841	20	0.467	22 5 (IPLSng)	8 (NYCMng)	0.467	0.467	0.467375	R46,R45,L...	N5,(R46),...	2
1862	21	0.129	24 8 (NYCMng)	9 (SNVAng)	0.129	0.129	0.129225	L10,L9,L2...	N8,N2,N5,...	5
1866	22	0.22	25 1 (ATLAng)	8 (NYCMng)	0.22	0.22	0.219575	L7,L26,R5...	N1,N11,N8...	2
1886	23	0.128	27 9 (SNVAng)	3 (DNVRng)	0.128	0.128	0.1282	R54,R53,L14	N9,(R54),...	1
1901	24	0.253	28 11 (WASH...	6 (KSCYng)	0.253	0.253	0.25325	L6,L5,R46...	N11,N1,N5...	3
1907	25	0.929	29 1 (ATLAng)	11 (WASH...	0.929	0.929	0.92875	R38,L7,R57	N1,(R38),...	1
1918	26	0.07	30 6 (KSCYng)	7 (LOSAng)	0.07	0.07	0.069575	L18,R44,R...	N6,N4,(R4...	2
1928	27	0.072	31 6 (KSCYng)	4 (HSTNng)	0.072	0.072	0.072325	L18,R44,R43	N6,N4,(R4...	1
1942	28	0.854	32 8 (NYCMng)	7 (LOSAng)	0.854	0.854	0.854175	L27,L6,L3...	N8,N11,N1...	4
1946	29	3.058	33 8 (NYCMng)	2 (CHIINng)	3.058	0.267	0.2674249...	R52,R51,L10	N8,(R52),...	1
1948	30	3.058	33 8 (NYCMng)	2 (CHIINng)	3.058	2.791	2.79075	L10,R40,R39	N8,N2,(R4...	1
1959	31	0.194	34 10 (STTLng)	4 (HSTNng)	0.194	0.194	0.19385	L28,R54,R...	N10,N9,(R...	3
1966	32	0.099	35 6 (KSCYng)	3 (DNVRng)	0.099	0.099	0.09905	R48,R47,L12	N6,(R48),...	1
1976	33	0.121	36 5 (IPLSng)	6 (KSCYng)	0.121	0.121	0.121025	L23,R48,R47	N5,N6,(R4...	1
1998	34	0.127	38 2 (CHIINng)	10 (STTLng)	0.127	0.127	0.12705	L9,R46,L2...	N2,N5,(R4...	4

Export tables...



www.net2plan.com
github.com/girtel/net2plan

- Support for offline/online algorithms allocating IT & Network resources in NFV context
 - Concept of Resource (e.g. vFirewall) in the nodes, traversable by flows, with a given capacity (e.g. Gbps of traversing flows), consumes other resources (e.g. 1 CPU, 8 GB of RAM, 10 GB HD)
 - Service chain is a route from A to B, that needs to traverse resources of a given type in a particular order (e.g. first vNAT, then vFirewall, then vMonitor)

Net2Plan

File Tools Help

OFFLINE NETWORK DESIGN & ONLINE NETWORK SIMULATION

Network topology

Focus panel

Resource 44 (No name). Type: FW

Information table

Resource index/id:
 Name:
 Type:
 Host node:
 Capacity occupied / total:
 Processing time:
 Is up?:
 # base resources:
 Resource 13 (No name). Type: RAM (RAM)
 Resource 14 (No name). Type: HD (HD):
 Resource 12 (No name). Type: CPU (CPU)
 # upper resources:
 # Traversing routes:

Net2Plan - Design tables and control window

View/Edit network state Offline algorithms Online simulation What-if analysis View reports

Network Layers Nodes Links Demands Multicast demands Routes Multicast trees Resources Shared-risk groups

Number of entries: 59 Reset VFs

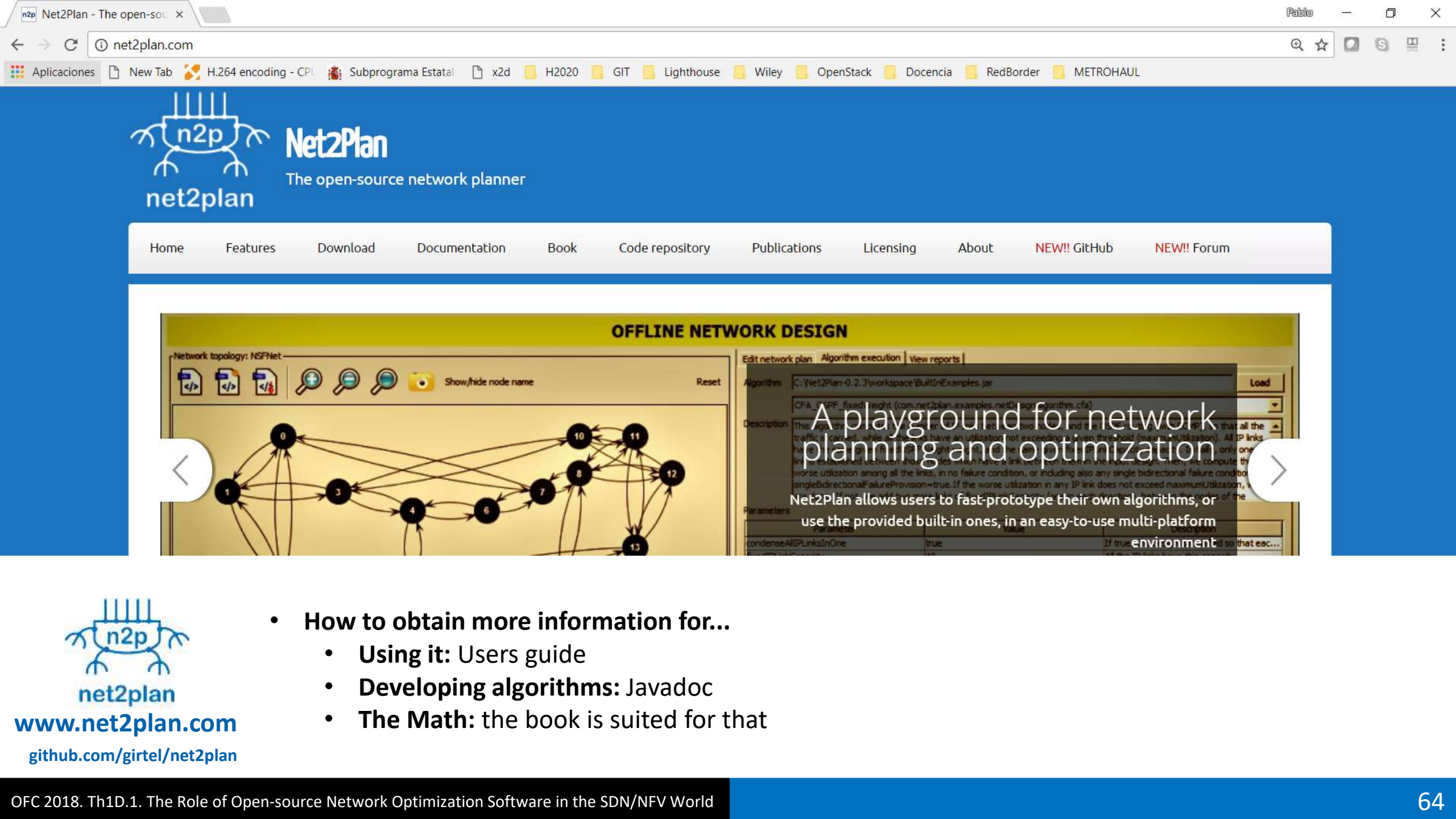
Unique Id...	Index	Name	Type	Host Node	Capacity	Cap. Units	Occupied...	# Trav. ...	# Upper ...	# Base R...
1581	25		RAM	n8 (id 10)	100		6	0	2	0
1582	26		HD	n8 (id 10)	100		6	0	2	0
1583	27		CPU	n9 (id 11)	100		9	0	2	0
1584	28		RAM	n9 (id 11)	100		9	0	2	0
1585	29		HD	n9 (id 11)	100		9	0	2	0
1586	30		CPU	n10 (id 12)	100		7	0	2	0
1587	31		RAM	n10 (id 12)	100		7	0	2	0
1588	32		HD	n10 (id 12)	100		7	0	2	0
1589	33		CPU	n11 (id 13)	100		7	0	2	0
1590	34		RAM	n11 (id 13)	100		7	0	2	0
1591	35		HD	n11 (id 13)	100		7	0	2	0
1592	36		NAT	n0 (id 2)	6		0.016	1	0	3
1594	37		NAT	n1 (id 3)	7		1	6	0	3
1595	38		FW	n1 (id 3)	2		20.707	8	0	3
1596	39		NAT	n2 (id 4)	4		3.876	4	0	3
1597	40		FW	n2 (id 4)	5		6	7	0	3
1598	41		NAT	n3 (id 5)	1		1	2	0	3
1599	42		FW	n3 (id 5)	21		0	0	0	3
1600	43		NAT	n4 (id 6)	3		37.653	19	0	3
1601	44		FW	n4 (id 6)	20		4.692	15	0	3
1602	45		NAT	n5 (id 7)	2		3	8	0	3
1603	46		FW	n5 (id 7)	1		3	11	0	3
1604	47		NAT	n6 (id 8)	38		5.887	31	0	3
1605	48		FW	n6 (id 8)	7		5	25	0	3
1606	49		NAT	n7 (id 9)	3		6	4	0	3
1607	50		FW	n7 (id 9)	3		19.947	9	0	3
1608	51		NAT	n8 (id 10)	1		2.929	8	0	3
1609	52		FW	n8 (id 10)	5		3	8	0	3
1610	53		NAT	n9 (id 11)	6		6.934	31	0	3
1611	54		FW	n9 (id 11)	3		6.95	32	0	3
1612	55		NAT	n10 (id 12)	1		2	5	0	3
1613	56		FW	n10 (id 12)	6		2	5	0	3
1614	57		NAT	n11 (id 13)	4		4	6	0	3
1615	58		FW	n11 (id 13)	3		3	5	0	3
---	---	---	---	---	3752.00	---	604.59	250.00	69.00	69.00

Export tables...



www.net2plan.com
github.com/girtel/net2plan

- Support for offline/online algorithms allocating IT & Network resources in NFV context
 - Includes built-in algorithms in this scope
 - Includes a *utils* library with algorithms for solving the *k* minimum cost service chain problem



Net2Plan

The open-source network planner

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- Code repository
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OFFLINE NETWORK DESIGN

Network topology: NSFNet

Tools:

Algorithm: C:\Net2Plan-0.2.3\workspace\BuiltInExamples.jar Load

Algorithm: CFA_CSPF_fixed_weight (com.net2plan.examples.net2plan.algorithm.cfa)

Description: This algorithm computes the shortest paths for all IP links in the network, ensuring that all the traffic carried by each link has an utilization not exceeding a given threshold (maximumUtilization). All IP links have a fixed weight (weight) assigned to them. The algorithm ensures that only one link is selected for each source-destination pair, and that the total utilization of all links does not exceed the maximumUtilization. The algorithm also computes the worst utilization among all the links, in no failure condition, or including also any single bidirectional failure condition (singleBidirectionalFailureProvision=true). If the worst utilization in any IP link does not exceed maximumUtilization, the algorithm returns the shortest paths for all IP links. Otherwise, it returns an empty set of paths.

Parameters:

Parameter	Value	Description
condenseAllIPLinksInOne	true	If true, all IP links are condensed into one link, so that each...

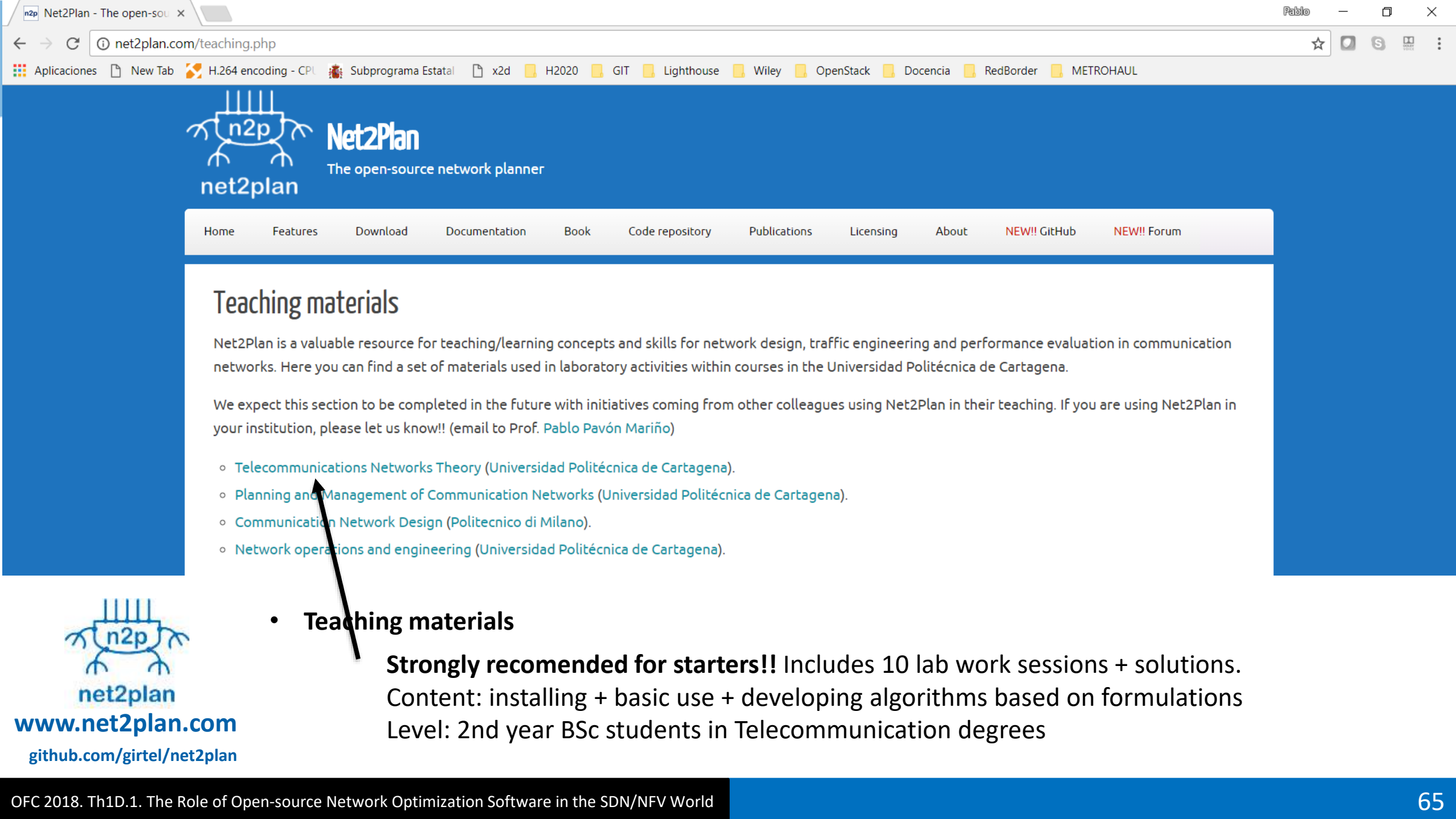
A playground for network planning and optimization

Net2Plan allows users to fast-prototype their own algorithms, or use the provided built-in ones, in an easy-to-use multi-platform environment



www.net2plan.com
github.com/girtel/net2plan

- **How to obtain more information for...**
 - **Using it:** Users guide
 - **Developing algorithms:** Javadoc
 - **The Math:** the book is suited for that



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Teaching materials

Net2Plan is a valuable resource for teaching/learning concepts and skills for network design, traffic engineering and performance evaluation in communication networks. Here you can find a set of materials used in laboratory activities within courses in the Universidad Politécnica de Cartagena.

We expect this section to be completed in the future with initiatives coming from other colleagues using Net2Plan in their teaching. If you are using Net2Plan in your institution, please let us know!! (email to Prof. [Pablo Pavón Mariño](#))

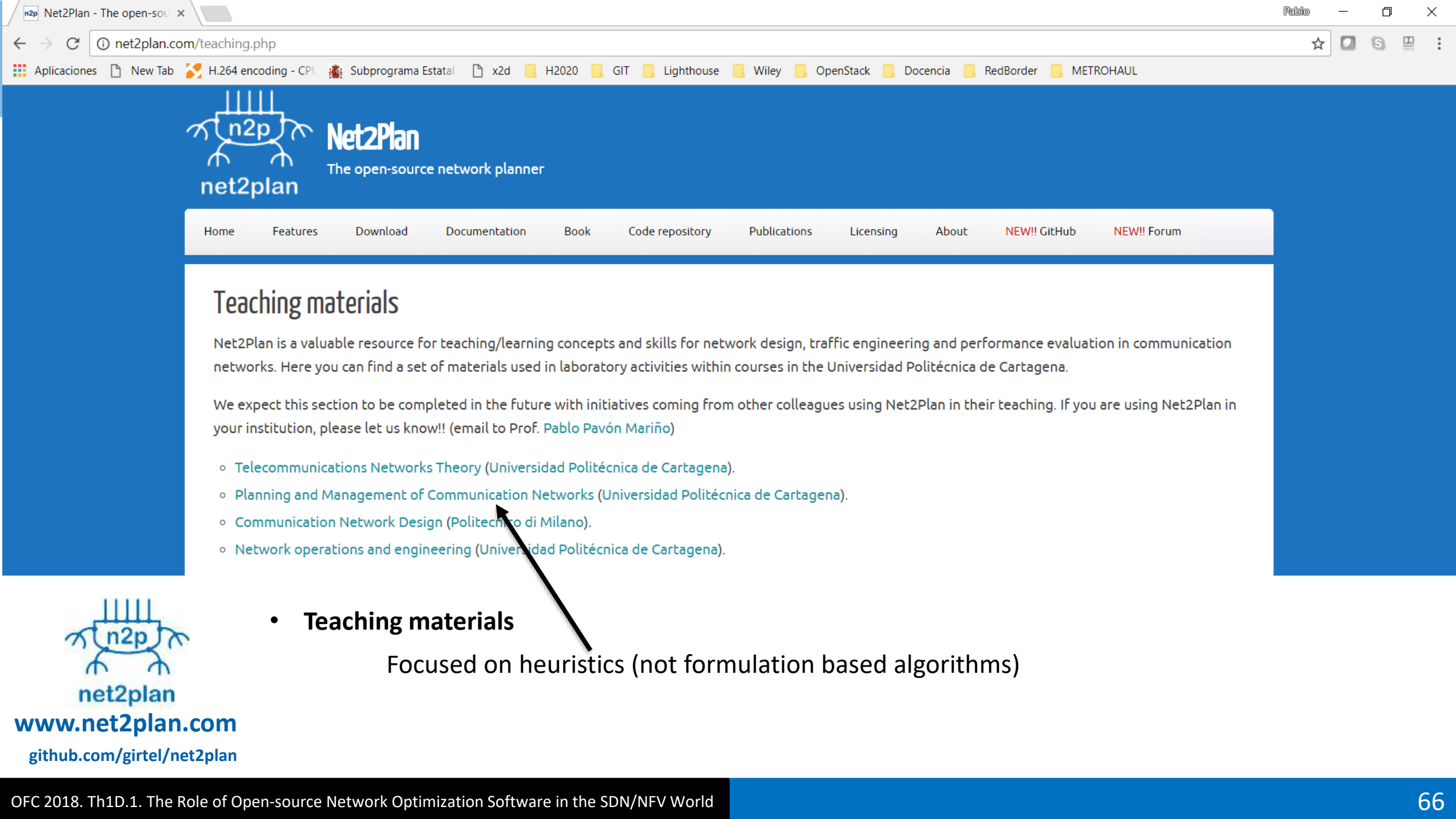
- [Telecommunications Networks Theory \(Universidad Politécnica de Cartagena\)](#).
- [Planning and Management of Communication Networks \(Universidad Politécnica de Cartagena\)](#).
- [Communication Network Design \(Politecnico di Milano\)](#).
- [Network operations and engineering \(Universidad Politécnica de Cartagena\)](#).

- **Teaching materials**

Strongly recommended for starters!! Includes 10 lab work sessions + solutions.
 Content: installing + basic use + developing algorithms based on formulations
 Level: 2nd year BSc students in Telecommunication degrees



www.net2plan.com
github.com/girtel/net2plan



Net2Plan

The open-source network planner

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- **Teaching materials**

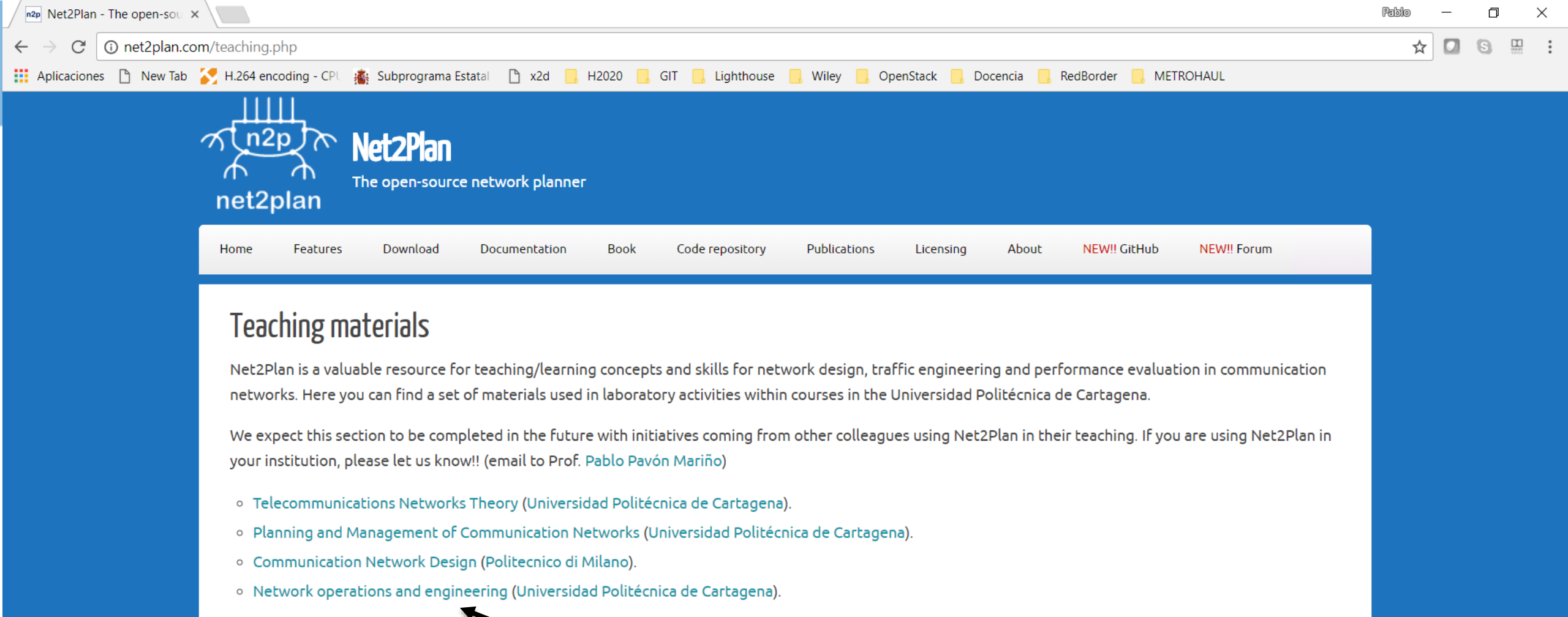
Focused on heuristics (not formulation based algorithms)



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net2plan

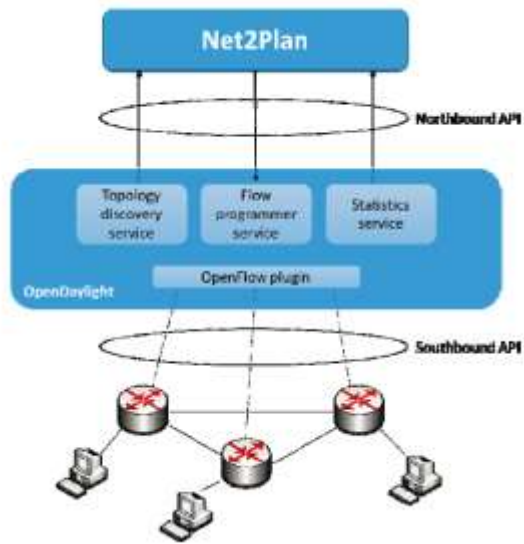
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- **Teaching materials**

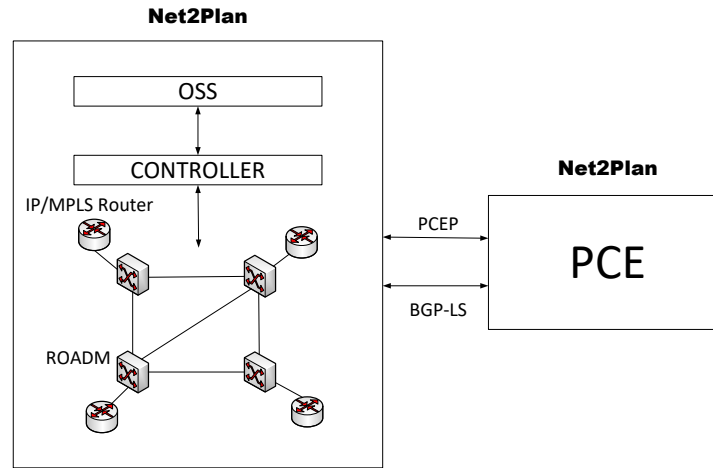
Long case studies planning IP over WDM using Net2Plan using real equipment catalogues. EDFA placement, IP chassis & cards provisioning, virtual topology design, service level availability, total cost evaluations

2014 - ODL



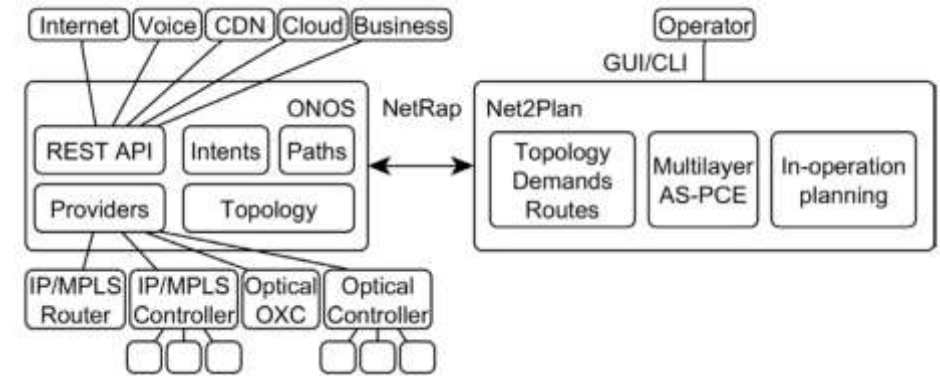
J.-L. Izquierdo-Zaragoza, A. Fernandez-Gambin, J.-J. Pedreno-Manresa and P. Pavon-Marino, "Leveraging Net2Plan planning tool for network orchestration in OpenDaylight", in *SaCoNeT 2014*

2016 – ABNO



J.L. Izquierdo-Zaragoza, J.J. Pedreno-Manresa, P. Pavon-Marino, O. Gonzalez-de-Dios and V. Lopez, "Dynamic Operation of an IP/MPLS-over-WDM Network Using an Active Stateful BGP/LS-Enabled Multilayer PCE", in *ICTON 2016*

2017 - ONOS



Pontus Sköldström, Ćiril Rožić and Jose-Juan Pedreno-Manresa, "Making powerful friends: Introducing ONOS and Net2Plan to each other," in 19th International Conference on Transparent Optical Networks (ICTON 2017).

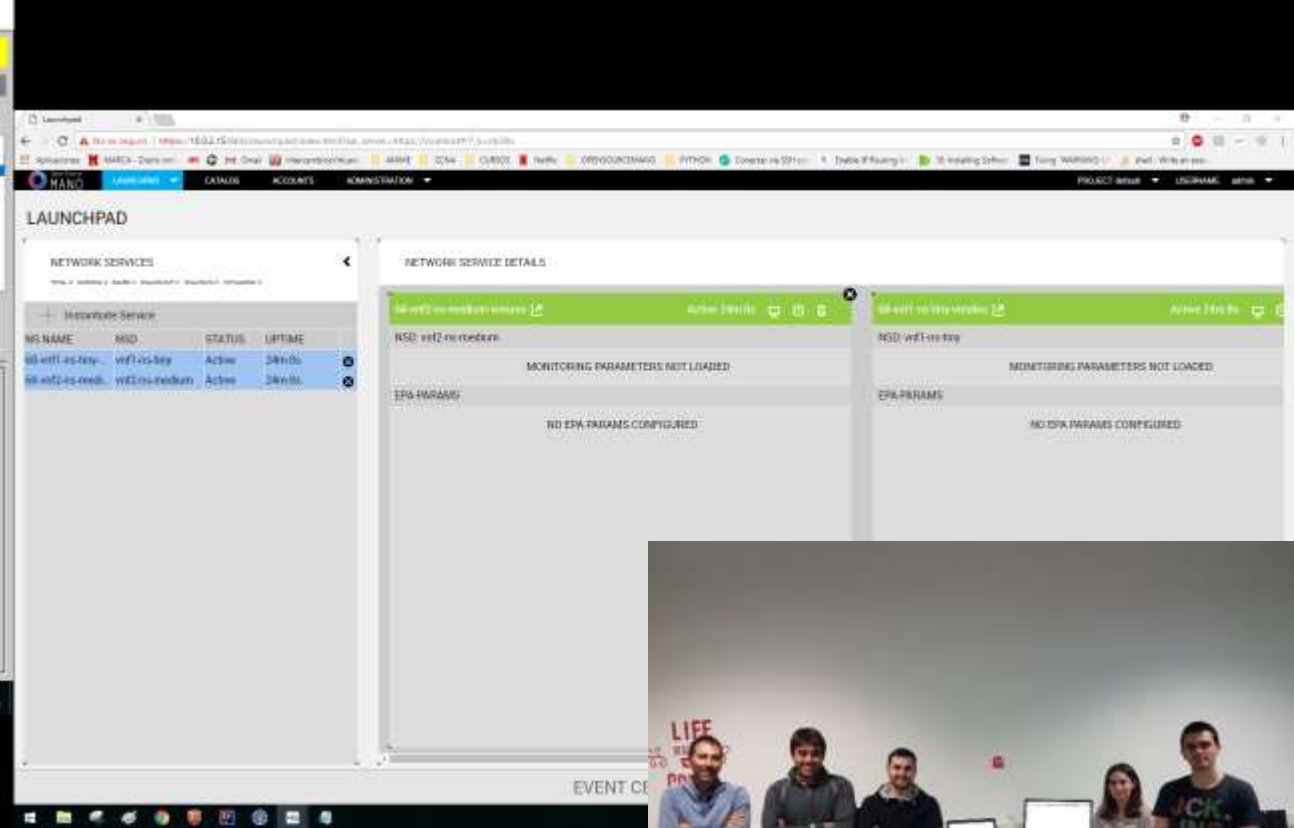
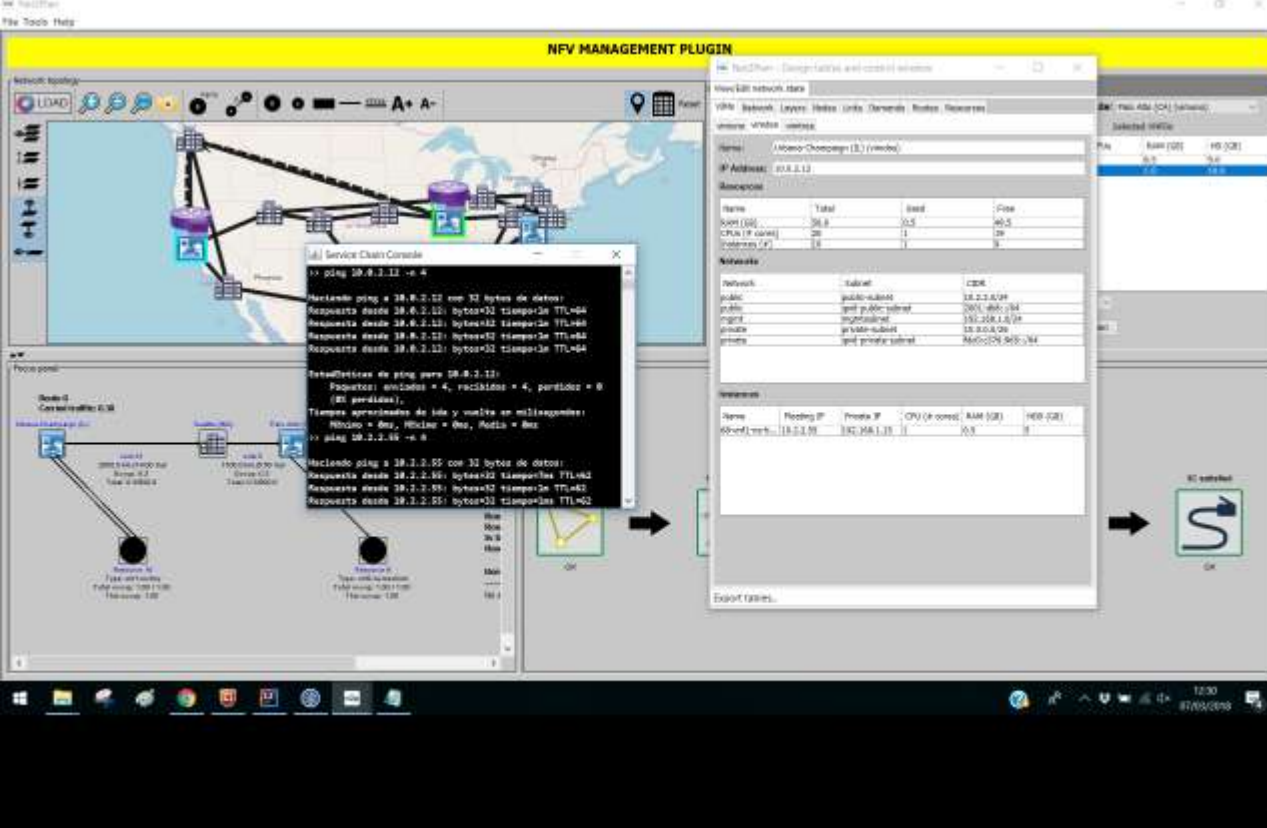


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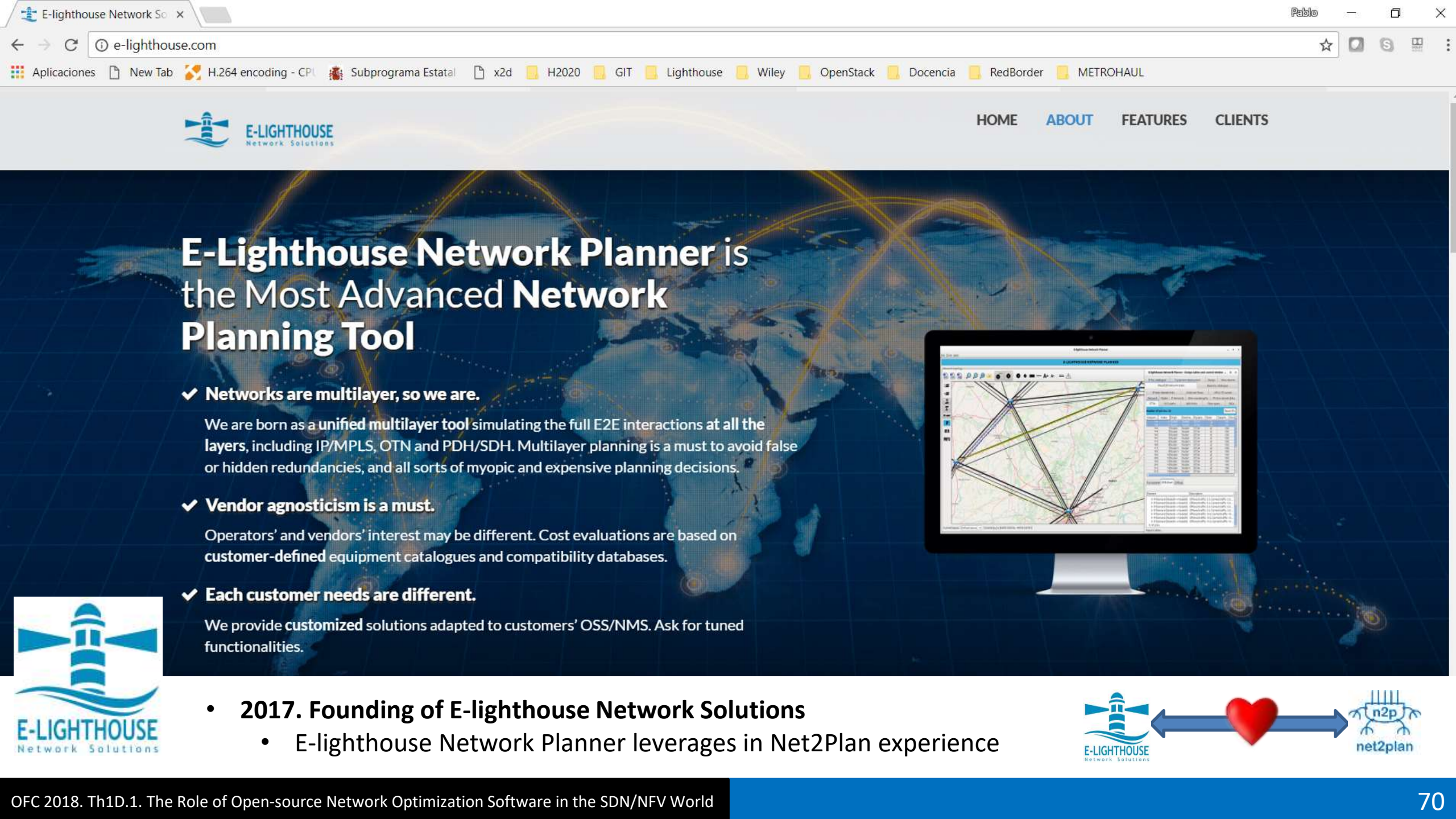
- **Net2Plan and SDN**
 - Several prototypes and PoCs have been made



F.J. Moreno-Muro, C. San-Nicolas-Martinez, E. Martin-Seoane, M. Garrich, P. Pavon-Marino, O. Gonzalez de Dios, V. López, “Joint Optimal Service Chain Allocation, VNF instantiation and Metro Network Resource Management Demonstration”, OFC 2018 (SDN/NFV Demo Zone)

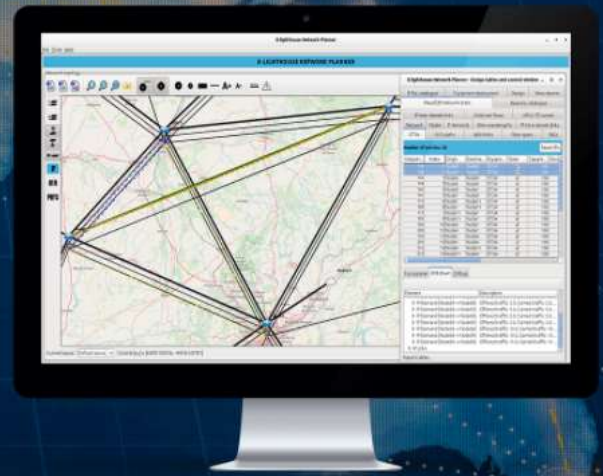
net2plan
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- **Net2Plan and SDN/NFV**
 - **OFC 2018 SDN/NFV Demo zone.** Connection of Net2Plan to **OpenStack & OSM** for making optimized allocations of service chains in multi-VIM environment
 - **Demonstrating joint allocation of IT (CPU, RAM, HD) and network resources**



E-Lighthouse Network Planner is the Most Advanced Network Planning Tool

- ✓ **Networks are multilayer, so we are.**
We are born as a unified multilayer tool simulating the full E2E interactions at all the layers, including IP/MPLS, OTN and PDH/SDH. Multilayer planning is a must to avoid false or hidden redundancies, and all sorts of myopic and expensive planning decisions.
- ✓ **Vendor agnosticism is a must.**
Operators' and vendors' interest may be different. Cost evaluations are based on customer-defined equipment catalogues and compatibility databases.
- ✓ **Each customer needs are different.**
We provide customized solutions adapted to customers' OSS/NMS. Ask for tuned functionalities.



- **2017. Founding of E-lighthouse Network Solutions**
 - E-lighthouse Network Planner leverages in Net2Plan experience



1. Introduction
2. Use cases
3. Theoretical limits, heuristics, solvers
4. Network optimization software. Net2Plan
- 5. Wrap up**

Conclusions

- ▶ SDN/NFV means an unprecedented network control, for an unprecedented resource dynamicity

The era of network optimization

- ▶ **Stay focused!!** Many use cases appear now in PRODUCTION networks, where optimization is decisive and manual provisioning is unmanageable, let's go for them!
- ▶ There are some good open-source resources to exploit, let's use them!

Thanks!!!

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