Street-aware Algorithm for Optimal dimensioning of protected-PON in very large regions

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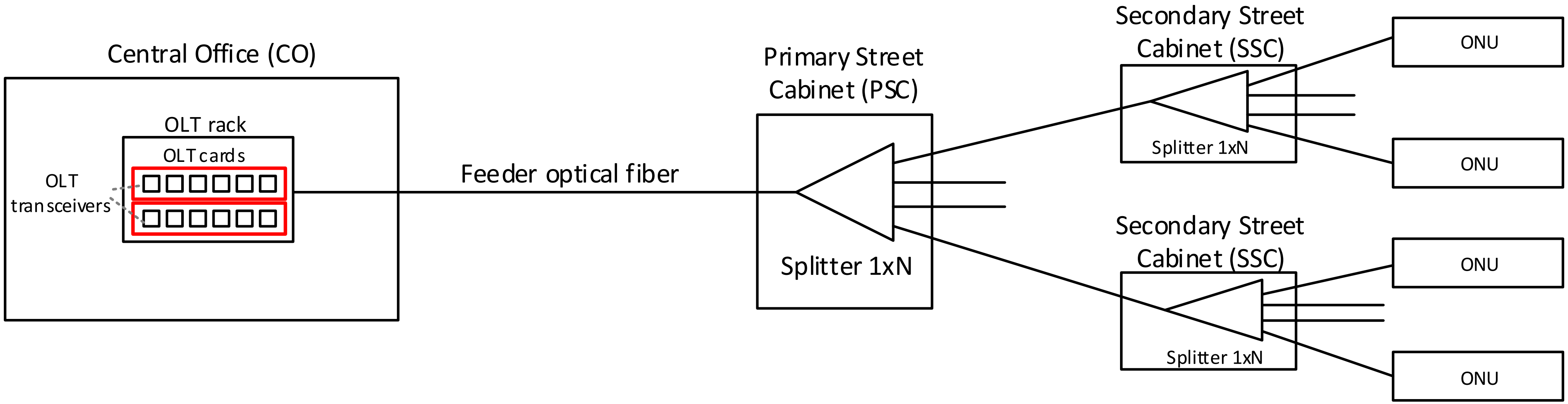
Outline

1. Introduction
2. Problem description
3. Employed Algorithms (heuristics)
4. Results
5. Conclusions

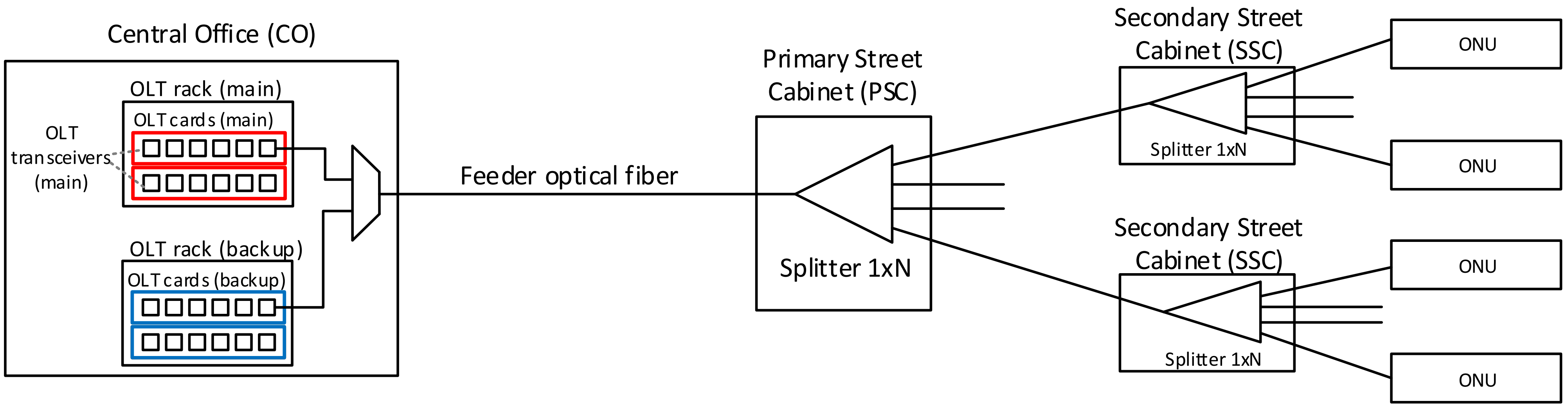
Introduction – our specific approach

- We base our analysis in the optimal dimensioning of multiple protected-PON deployment in a large region with very large number of users and with different bit rate demands.
- The PON topology we employ is the traditional two level tree topology.



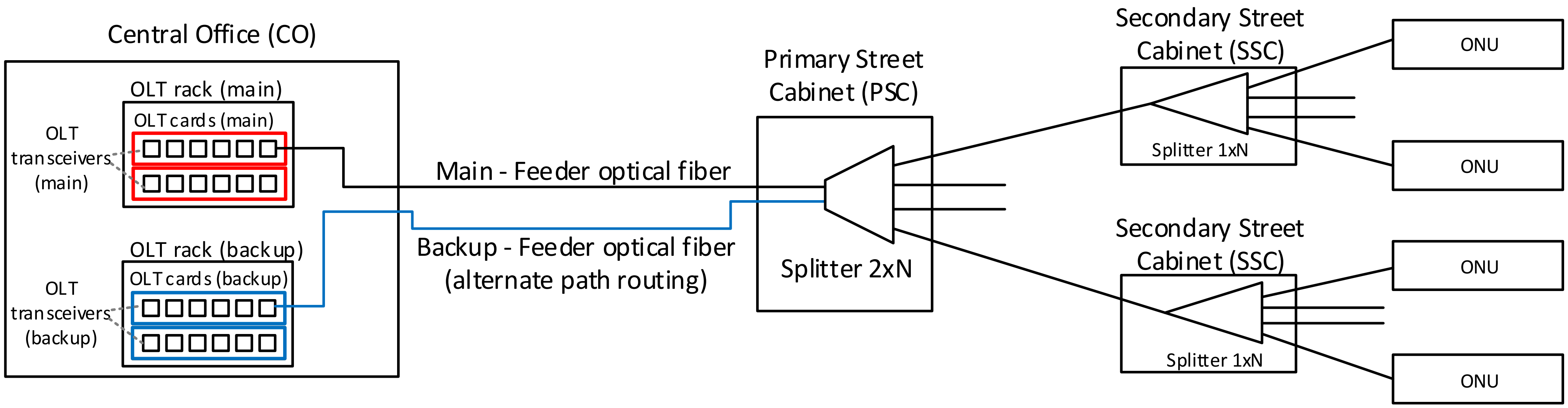
Introduction – our specific approach

- We consider three protection strategies:
  1) OLT protection:



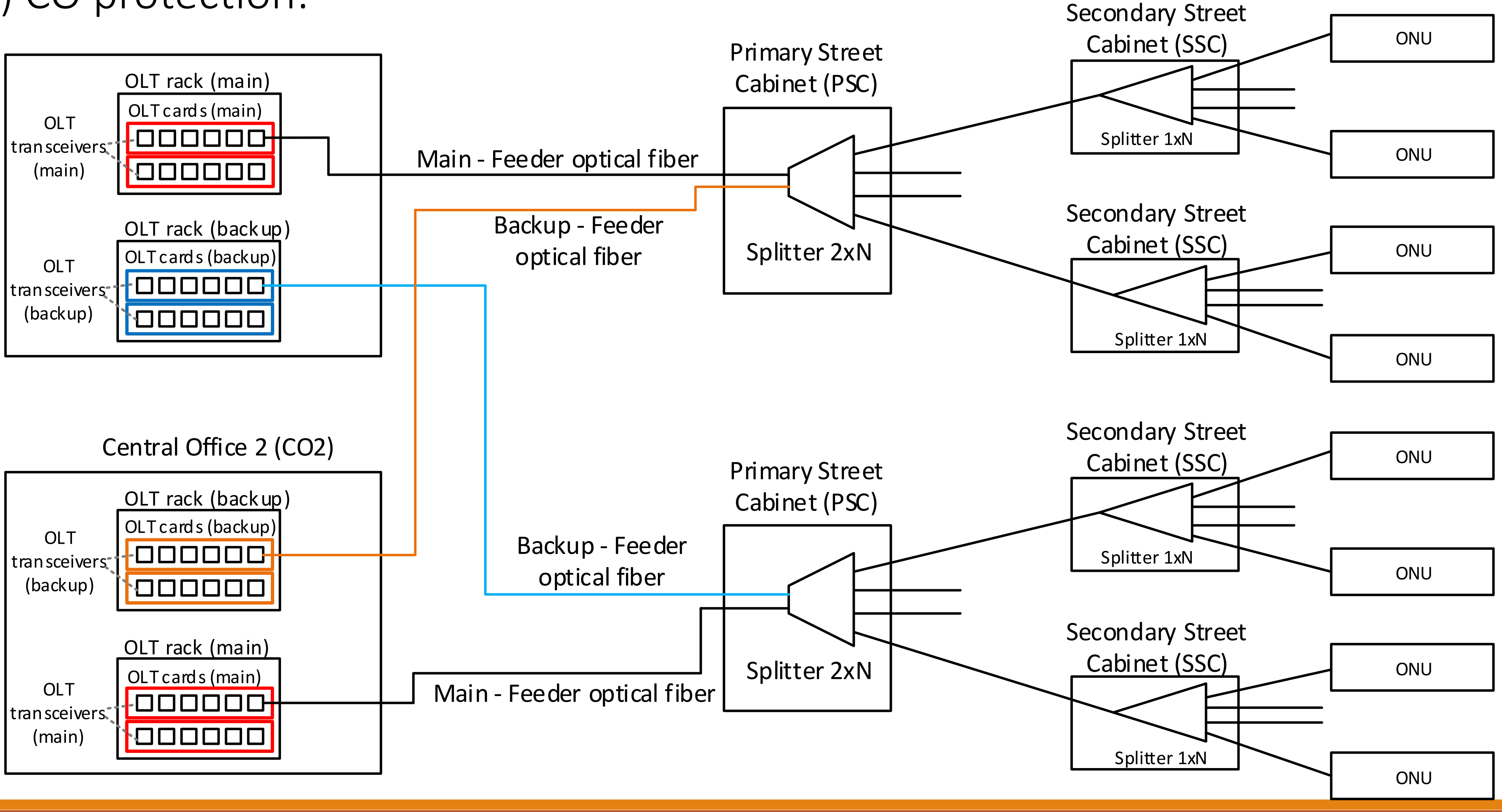
Introduction – our specific approach

- We consider three protection strategies:
  2) OLT and feeder-fiber protection:



Introduction – our specific approach

- We consider three protection strategies:
  3) CO protection:



Problem description

Defining the following sets:

- The set of Central Offices CO={CO};
- The set of OLT in a given CO: $O=\{o_m \in O / m = 1, 2, \ldots, M\}$, M = available OLTs at CO;
- The set of ONU in the users' premises: $U = \{u_n \in U / n = 1, 2, \ldots, N\}$, N = number of users;
- The set of wavelengths available in the OLT (depending on the PON technology):
  $L = \{\lambda_i \in L / i = 1,2,\ldots,N'\}$, N' = number of wavelengths;
- The set of splitters with splitting ratio (SR) equal to k: $S = \{S_k / k=2^i; i=1,\ldots,q\}$;
- The set of candidate sites for placing a PSC: $V = \{v \in V\}$;
- The set of candidate sites for placing a SSC: $W = \{w \in W\}$;
- The set of edges between the CO locations, the PSC and SSC candidate sites and the ONU locations: $E_{ij} = \{ e \in E_{ij} / e$ is a candidate link between $i \in \{CO,V,W\}$ and $j \in \{V,W,U\}\}$.

Problem description

Defining the following parameters:

- The maximum number of users per PON: n_{max};
- The PON power budget: ODN_{loss};
- The normalized PON bit rate capacity (defined by an OLT $o \in O$): Γ;
- The normalized bit rate demanded by an ONU $n \in U$: γ_n;
- The distance between two points $(i,j) \in \{O,V,W,U\}$: $d_{i,j}$;
- The cost of the optical fiber (OF) installation per unit length, including the trenching, reinstatement, manholes, splicing and the optical cable cost: C_{FO};
- The installation and operational cost of an street cabinet with capacity r: C_{st}^{r};
- The cost of a splitter with SR=k: C_{Spl}^{k};
- The OF attenuation per unit length: α_{FO};
- The attenuation in a splitter with SR=k: α_{Spl}^{k}.
- The capacity of an OLT rack (number of OLT cards): η

OPTCOM GIETEC

Problem description

And considering the following binary variables:

- $x_{i,j}$: is equal to 1 if there's a link between two points (*i,j*) ∈ {*O,V,W,U*}, otherwise is 0.
- $y_{i,j}^{n}$*:* is equal to 1 if the link between *(i,j)∈{O,V,W,U}* belongs to the path from a CO up to an ONU *n∈U;* otherwise is equal to 0.
- $z^{n,o}$: is equal to 1 if ONU n ∈U is connected to OLT *o∈O;* otherwise is equal to 0.
- $l_{i,j}^{k}$*:* is equal to 1 if the link between *(i,j)∈{O,V,W,U}* employs the wavelength $\lambda_k \in L$, otherwise is equal to 0.
- $s_i^{k,o}$: is equal to 1 if an splitter with SR=*k* is placed in site *i∈{V,W}* and belongs to OLT *o∈O*, otherwise is 0.
- c_i^{r} : is equal to 1 if an street cabinet enclosure for placing splitters with capacity *r* is placed in site *i∈{V,W}*, otherwise is 0.

Problem description

The search of optimal cost for the multiple PON deployment may be formulated by the following optimization problem:

Minimize:

$$
\begin{aligned}
\min \sum_{c\in CO} & \left(\begin{array}{l} C_{lbr} + C_T \left(\displaystyle\sum_{o\in Om, i\in V} \alpha_o^c x_i^o d_{i,o} + \sum_{i\in V, j\in B} \alpha_o^c x_{j,i} d_{j,i} \right) + \\ C_{OF}^f \displaystyle\sum_{o\in Om, i\in V} \alpha_o^c x_{i,o} d_{i,o} + C_{OF}^f \sum_{o\in Ob, i\in V} B_i^{O_b} \alpha_o^c x_{i,o} d_{i,o} \end{array} \right) \\
& + C_{OF}^d \left(\sum_{i\in V, j\in B} x_{j,i} d_{j,i} + \sum_{j\in B, n\in U} x_{n,j} d_{n,j} \right) + \sum_{i\in V\cup B, l\in L_i} S_{i,l} C_{i,l} + \\
& \sum_{i\in V\cup B} C_{encl}^r \alpha_i + 2\frac{N}{\eta}\left(C_{OLT}^{rck,\eta} + C_{ODF} \right) + 2\sum_{o\in O} C_{OLT}^{crd} \alpha_o + C_{ONU} N
\end{aligned}
$$

Cost of Optical Fiber cables (including redundancy)

Cost of primary street cabinets and secondary street cabinets

Cost of OLT and ONU (including redundancy)

Problem description

Subject to:

$$z_n^o = \sum_{i \in V, j \in B} x_{n,j} x_{j,i} x_{i,o} ; \qquad \forall n \in U, \forall o \in O$$

$$\sum_{c \in CO} N_c = N$$

$$N_c = \sum_{n \in U, o \in O} \alpha_o^c z_n^o ; \qquad \forall c \in CO$$

$$\sum_{n \in U} z_n^o \le n_{\max} \alpha_o ; \qquad \forall o \in O$$

$$\sum_{n \in U} z_n^o \gamma_{US/DS}^n \le \Gamma_{US/DS} \alpha_o ; \qquad \forall o \in O$$

$$\sum_{j \in B} x_{n,j} = 1 ; \qquad \forall n \in U$$

$$\sum_{i \in V} x_{j,i} = \alpha_j ; \qquad \forall j \in B$$

Problem description

Subject to:

$$\alpha_{OF}\left(\sum_{j\in B} x_{n,j} d_{n,j} + \sum_{i\in V, j\in B, o\in O} x_{n,j} x_{i,o} x_{j,i} d_{i,j} + \sum_{i\in V, o\in O} x_{i,o} d_{i,o}\right)$$
$$+ \sum_{j\in B, l\in Lj} y_n^{j,l} S_{j,l} \alpha_{j,l} + \sum_{i\in V, p\in Li, j\in B, l\in Lj} y_n^{j,l} y_{j,l}^{i,p} S_{i,p} \alpha_{i,p} + \alpha_{ex}$$
$$\leq ODN_{loss}; \qquad \forall n \in U \qquad (16)$$

Problem description

PON Technologies considered in the study: GPON, XGPON, NGPON2

- Maximum links’ length: *40 km*
- Type of optical fiber: SSMF (G652)
- Power Budget: ODN_{loss} = 30 dB
- Type of users: Residential, Business.
- Maximum number of users per PON: n_{max} = 64
- Maximum number of wavelengths:
  GPON, XGPON: N’ = 1
  NGPON2: N’ = 4 upstream and 4 downstream
- Type of branching device: splitters
- Attenuation in splitters (SR=k): α^{k}_{spl} =3.5 $\log_2$(k) dB;
- Maximum number of cascaded splitters: 2
- Bit rate capacity (upstream “US”; downstream “DS”):
  GPON: 1.25 Gb/s US; 2.5 Gb/s DS;
  XGPON: 2.5 Gb/s US; 10 Gb/s DS;
  NGPON2: 10-40 Gb/s US; 40 Gb/s DS;

Problem description

Bit rate demand scenarios:

Scenario	Intervals of demanded bit rate (Mbit/s)	
	Residential users	Corporative users
#1	10 up to 100	100 up to 1000
#2	100 up to 400	400 up to 2500
#3	100 up to 1000	1000 up to 10000

Problem description

Costs of ODN components:

COMPONENT	COST ($)
OF Feeder cable, 6 - 288 fibers /km	600 – 4000
OF distribution cable, 2 - 6 fibers /km	1000
Indoor OF cable installation / user	50
Trenching and reinstatement	30000
Ducts and fenders	10000
Manholes /unit	500
Junction box for 8 up to 144 fibers	300 - 500
Splitter 1:2 up to 1:64	20 - 120
Street cabinet installation	1600
Indoor OF cable installation / user	50

Problem description

Costs of PON hardware:

COMPONENT	COST ($)
OLT chassis - GPON (10^3 users)	16000
OLT chassis - XGPON (10^3 users)	28000
OLT chassis - NGPON2 (10^3 users)	50000
OLT card - 4xGPON	9000
OLT card - 4xXGPON	15000
OLT card - 4xNGPON2	25000
ONU residential - GPON	100
ONU residential - XGPON	350
ONU residential - NGPON2	600
ONU corporative - GPON	350
ONU corporative - XGPON	600
ONU corporative - NGPON2	1100
ODF (for each OLT rack)	3500

Algorithm description

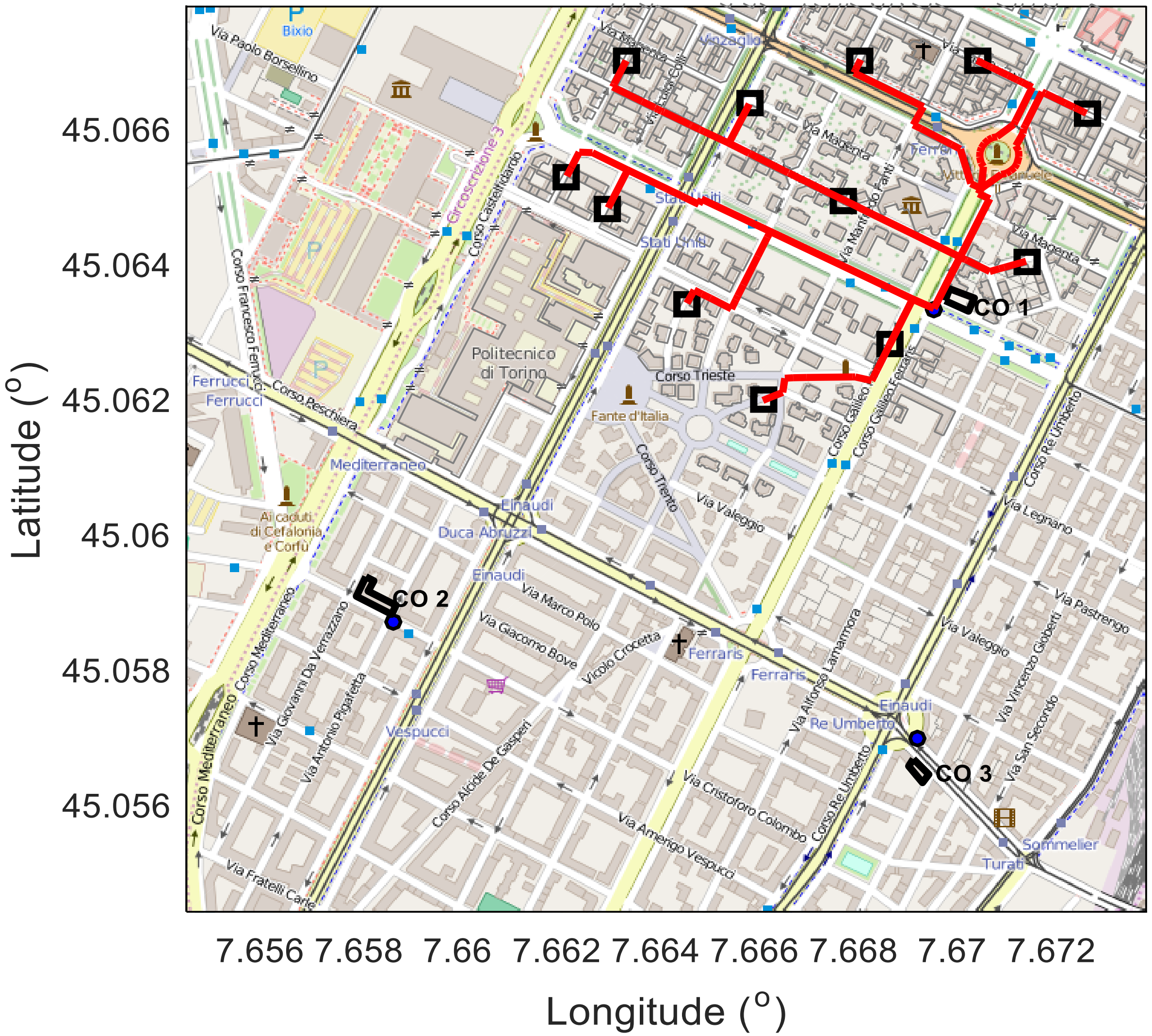
The previously described MILP problem is a well-known NP-hard problem. Therefore we had to employ some heuristic approaches in order to find an optimal solution. Therefore, we developed an optimization scheme, based on a series of heuristics, named "Optimal Topology Search" (OTS).

OTS uses real city-map data, retrieved from OSM database, and performs recursive region divisions employing a Voronoi´s tessellation for clustering the region among the different central offices. Then, in every CO sub-region it clusters the users in a per-building basis using a SNN algorithm (i.e. clustering buildings instead of directly clustering users).

By means of a Tabu-Search metaheuristic, OTS finds an optimal-cost solution for dimensioning and locating street cabinets as well as for feeder and distribution optical fiber cables routes.

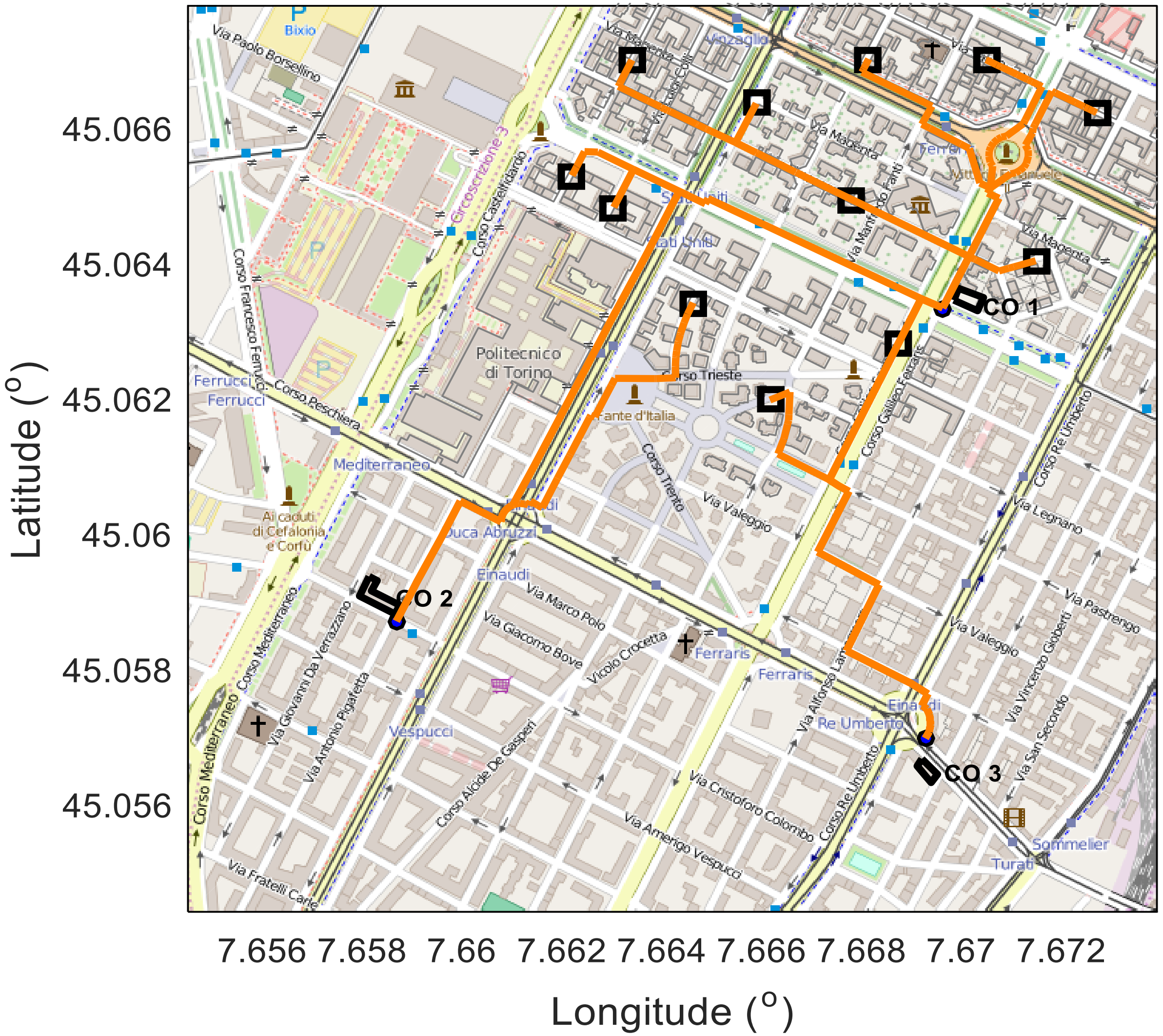
Algorithm description

Main feeder-fibers optimal routes:



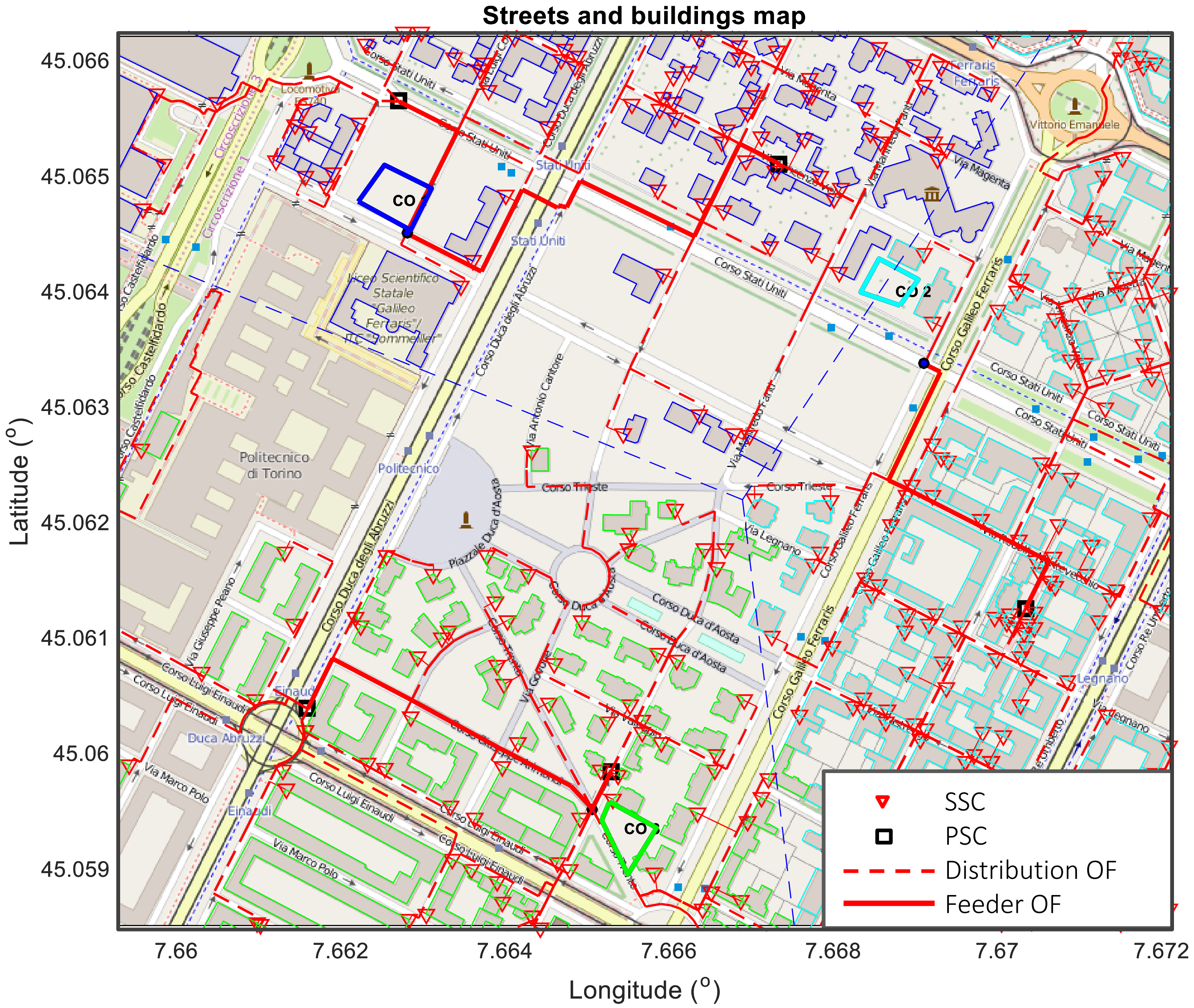
Algorithm description

Backup feeder-fibers optimal routes:



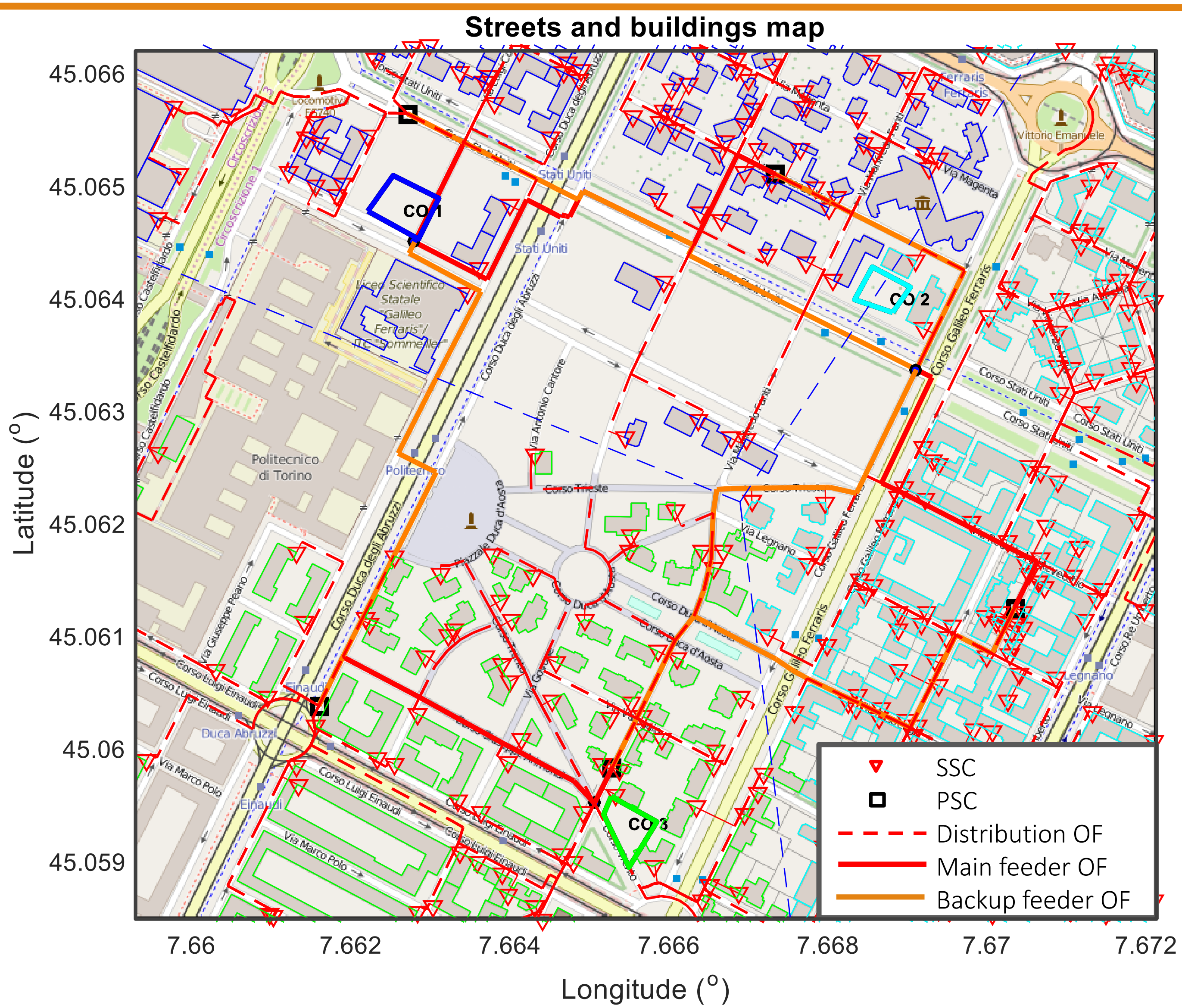
Results

Best topology:



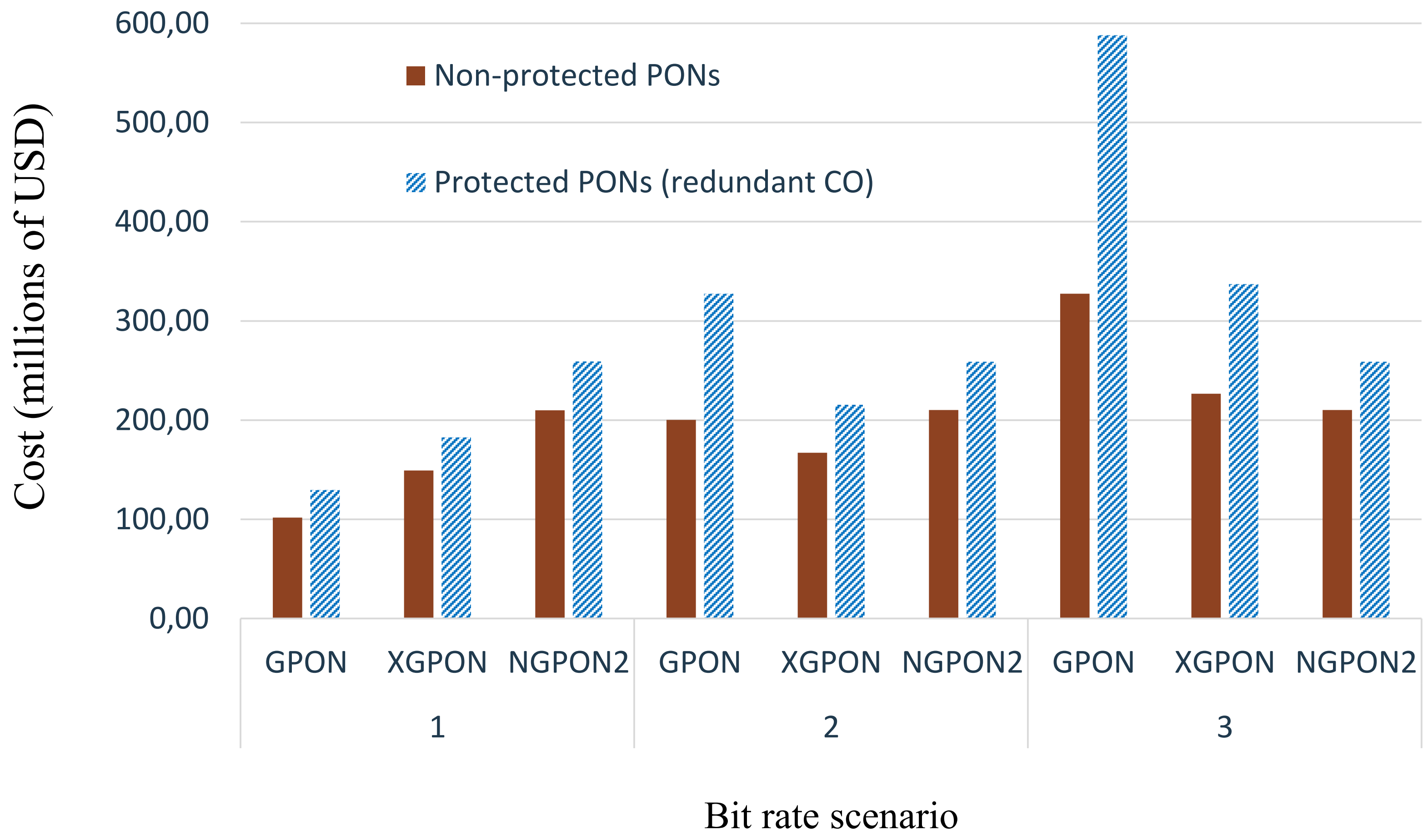
Results

Best topology:



Results

Costs of deployment for the three PON technologies:

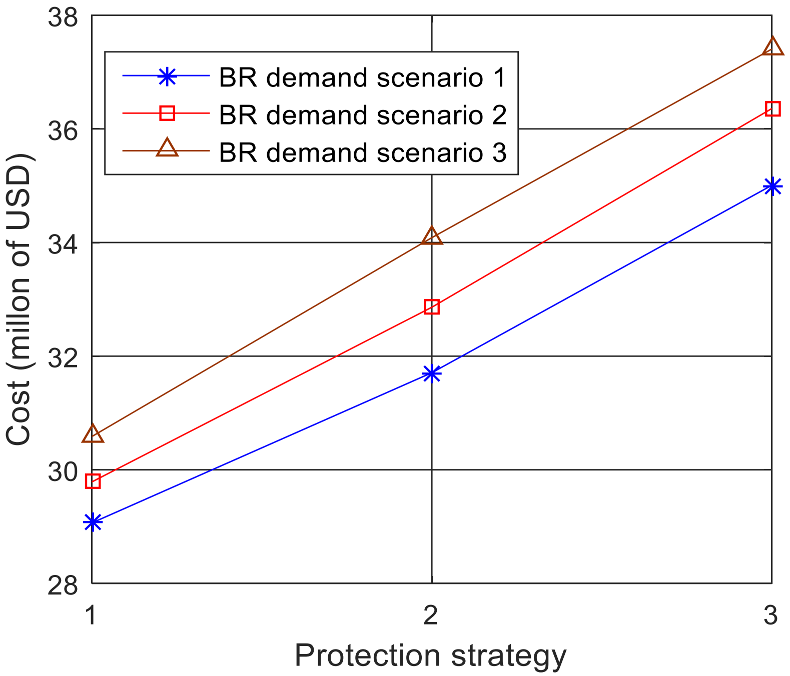


	Intervals of demanded bit rate (Mbit/s)	
	Residential users	Corporative users
#1	10 up to 100	100 up to 1000
#2	100 up to 400	400 up to 2500
#3	100 up to 1000	1000 up to 10000

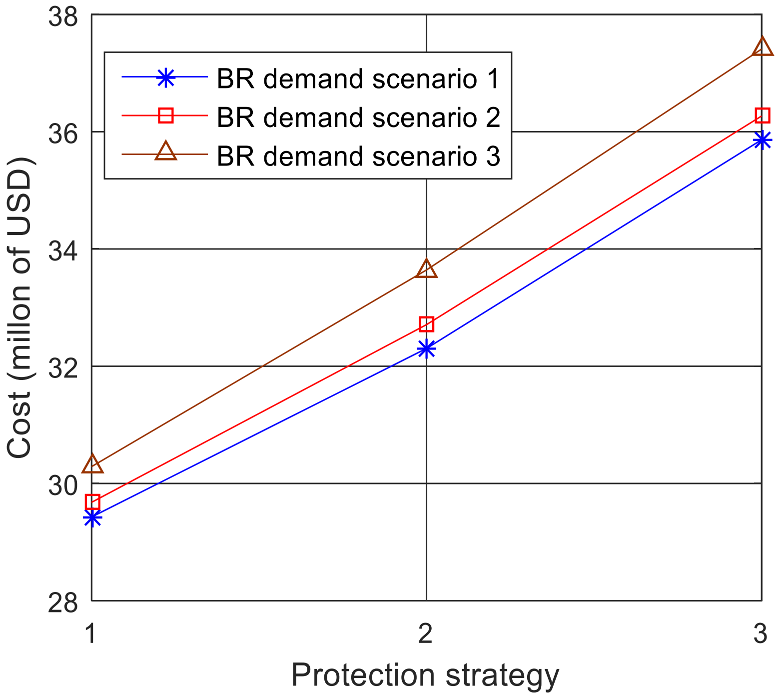
Results

Total cost of ODN deployment for the three PON technologies:

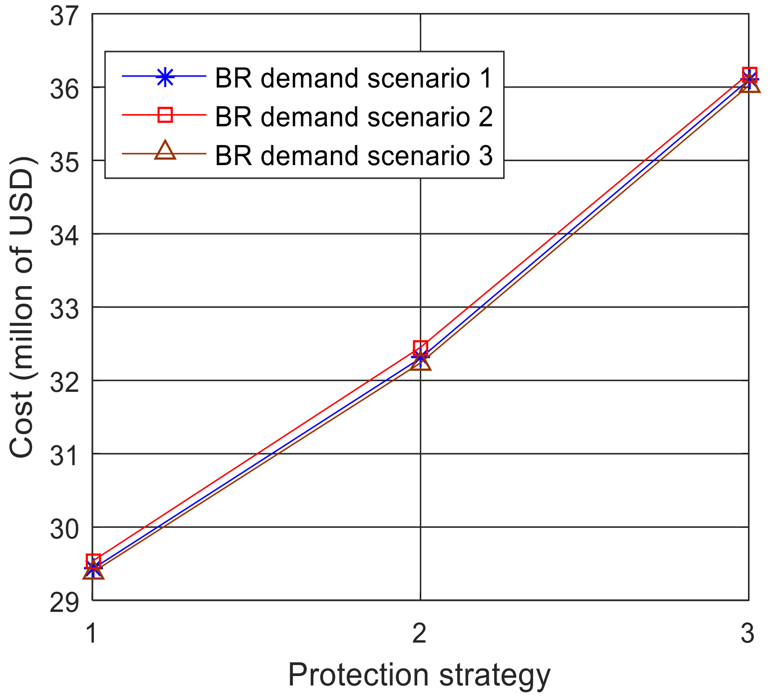
GPON



XGPON



NGPON2



Conclusions

OTS constitutes a versatile and accurate tool for optimal dimension of protected and non-protected PON topologies even in very large regions with a very large number of users and for different technologies.

It has been found that even though GPON is a technology that supports very well the current and short term users' bit rate demands, regardless if the deployment includes or not protection strategies, in the near future due to the increase of bit rate demands it would be necessary to deploy technologies with more bit rate capacity like XGPON and specially NG-PON2 in order to have a better techno-economic performance.

THANKS FOR YOUR ATTENTION!

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