A novel algorithm for PON optimal deployment over real city maps and large number of users

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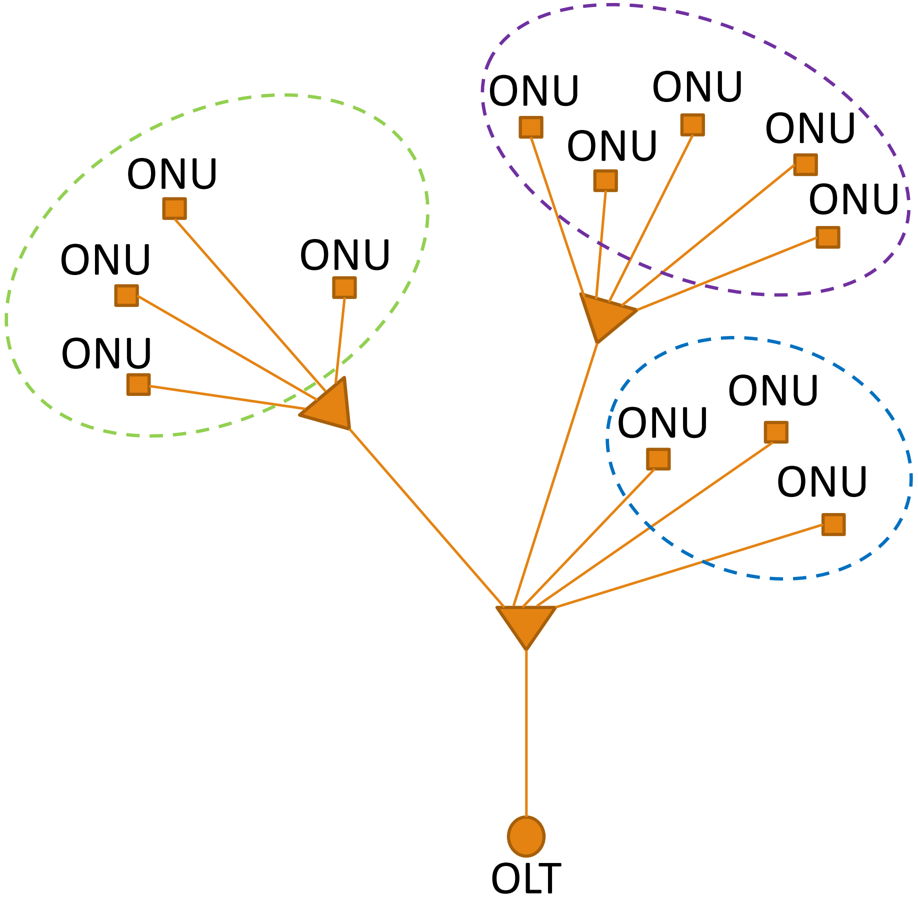
Outline

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

Introduction

The pro *Maybe too much text in this slide…* dimensioning of a PON can be approached in many different ways. The most cost-sensitive parameter for ODN design is the length of optical fiber and, in a lower grade of sensitiveness, the number of the distribution nodes.

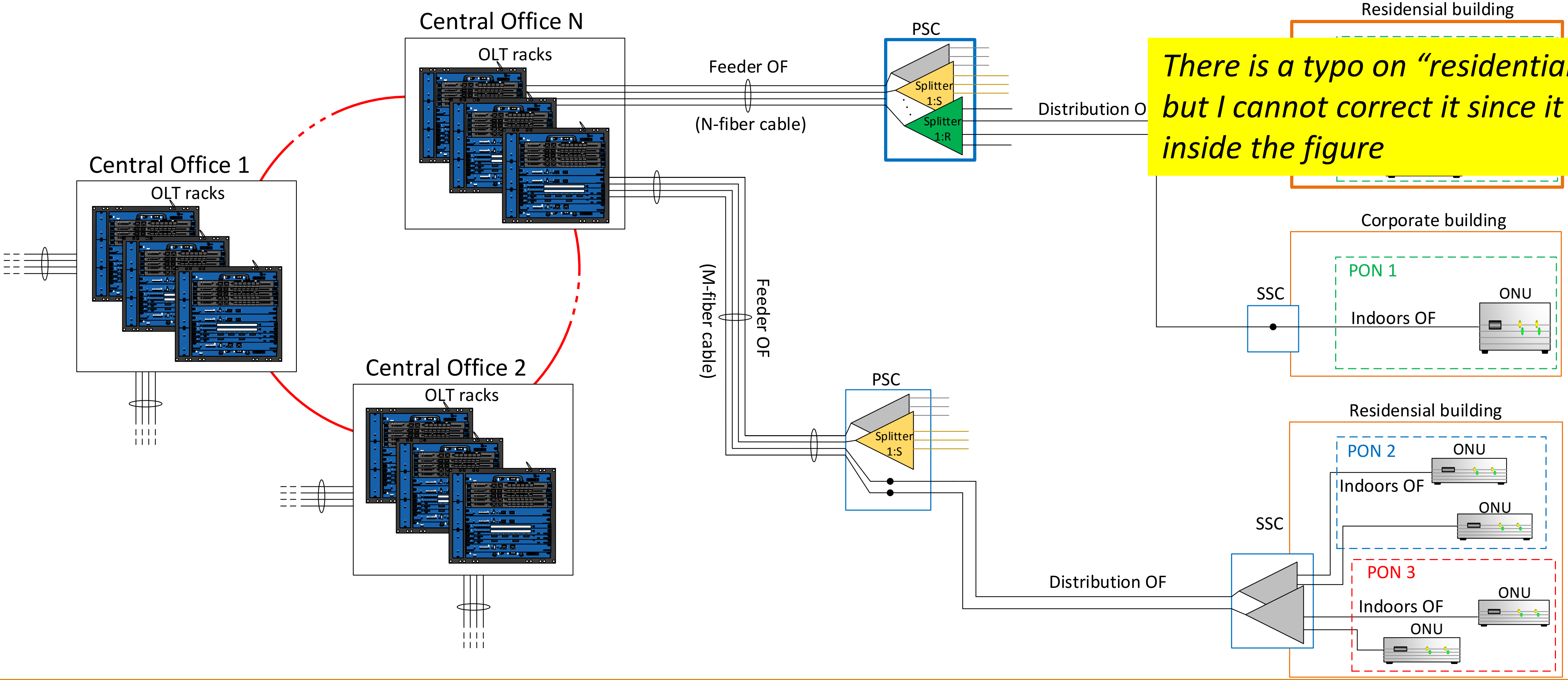
The first step for finding the topology which minimizes the ODN deployment cost is choosing the proper way the users connect to the optical distribution network.



One of the facts related with the ODN deployment is the users’ clustering among central offices (CO) and the way the users connect with their CO.

Introduction – our specific approach

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



There is a typo on "residential" here but I cannot correct it since it is inside the figure

Problem description

You should go very fast when you present this slide and the following ones

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

You should go very fast when you present this slide and the following ones

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

Problem description

You should go very fast when you present this slide

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 (MILP):

This the one that you should try to explain in more detail, since this is what we are optimizing:

Minimize:

$$C_{FO}\left(\sum_{i\in O, j\in V} x_{i,j}d_{i,j} + \sum_{i\in V, j\in W} x_{i,j}d_{i,j} + \sum_{i\in U, j\in \{V,W\}} x_{i,j}d_{i,j}\right)$$
$$+ \sum_{k,r,o\in O}\sum_{i\in V}\left(C_{Spl}^{k}s_i^{k,o} + C_{st}^{r}c_i^{r}\right) + \sum_{k,r,o\in O}\sum_{i\in W}\left(C_{Spl}^{k}s_i^{k,o} + C_{st}^{r}c_i^{r}\right)$$
$$+ \frac{N}{\eta}C_{OLT} + \sum_{u\in N_c} C_{ONU}$$

Cost of Optical Fiber cables

Cost of PSC and SSC

Cost of OLT and ONU

Maybe you should write openly PSC and SSC

Problem description

You should go very fast when you present this slide

Subject to:

- Maximum number of users per PON (per OLT) must be at most n_{max}:

$$\sum_{n \in U} z^{n,o} \leq n_{max}; \qquad \forall\, o \in O$$

- Maximum bit rate demand per PON (per OLT) must be at most Γ:

$$\sum_{n \in U} z^{n,o} \gamma_n \leq \Gamma; \qquad \forall\, o \in O$$

- An ONU must be connected to one (and only one) branching device in a first/second level street cabinet:

$$\sum_{j \in \{V,W\}} x_{i,j} = 1; \qquad \forall\, i \in U$$

- An OLT must be connected to one (and only one) branching device in a first level street cabinet:

$$\sum_{j \in V} x_{i,j} = 1; \qquad \forall\, i \in O$$

Problem description

You should go very fast when you present this slide

Subject to:

- An second level branching device must be connected only to one first level branching device:

$$\sum_{j \in w} x_{i,j} = 1; \qquad \forall\, i \in V$$

- In a site {v,w} ∈ V it must be placed at least one splitter for a given OLT (located in a CO):

$$\sum_{i \in \{V,W\}} s_i^{k,o} = 1; \qquad \forall\, o \in O$$

- In downstream direction, a branching device in PSC or SSC must have at least one outgoing link and no more outgoing links than the device's capacity (splitting ratio):

$$\sum_{j \in \{V,W\}} x_{i,j} \le k * s_j^{k,o}; \quad \forall\, i \in \{V, W, U\}, \forall\, o \in O$$

- Maximum power losses in the ODN, must be lower or equal to ODN_{loss}.

$$\sum_{(i,j) \in E} \alpha_{FO} d_{i,j}\, y_{i,j}^{n} + \sum_{i \in V, o \in O} \alpha_{Spl}^{k} s_i^{k,o}\, z^{n,o} + \sum_{i \in W, o \in O} \alpha_{Spl}^{k} s_i^{k,o}\, z^{n,o} \le ODN_{loss}; \quad \forall\, n \in U$$

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:

I put in red the lines that you should in my opinion emphasis in your talk

  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;

Bit rate demand scenarios:

I put some "colors" on this slide. Maybe you can do the same also in other slides…

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

Remember to say in your talks that these costs come after interactions with vendors and operators

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

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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 (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

I would downgrade this slide to a "backup slide" after the end, just in case you have questions

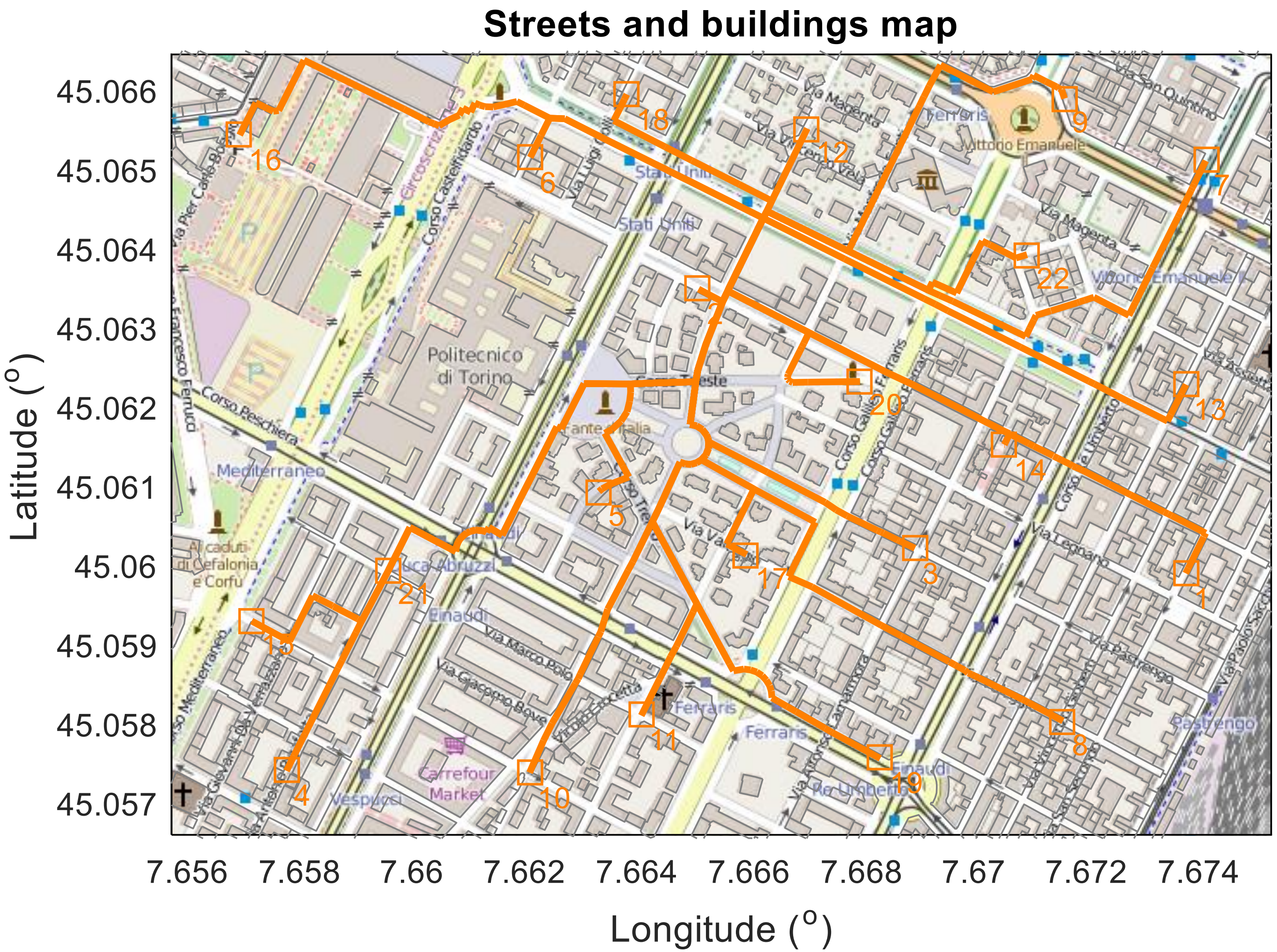
Algorithm 1: Optimal Topology Search (OTS)

Data: $Data = load\_data\ (City, Users, CO)$
Result: Optimal_Topology=OTS(Data)

```
begin
    for  i ∈ {Heuristic_modifier_counter} do
        Data_i = i^th_heuristic_variation (Data)
        for c ∈ CO do
            SSC = allocate_ssc (Data_i)
            PON_hardware = cluster_buildings (SSC, Data_i)
            PSC = aggregate (PON)
            OF_cables = find_paths (SSC, PSC, Data_i)
            ODN = {OF_cables, PSC, SSC}
            Trenching = share (ODN)
            Topology_i = {ODN, PON_hardware }
        end
        C_i = evaluate_cost (Topology_i)
        if  C_i < C_opt then
            Optimal_topology = Topology_i
            C_opt = C_i
        end
    end
end
```

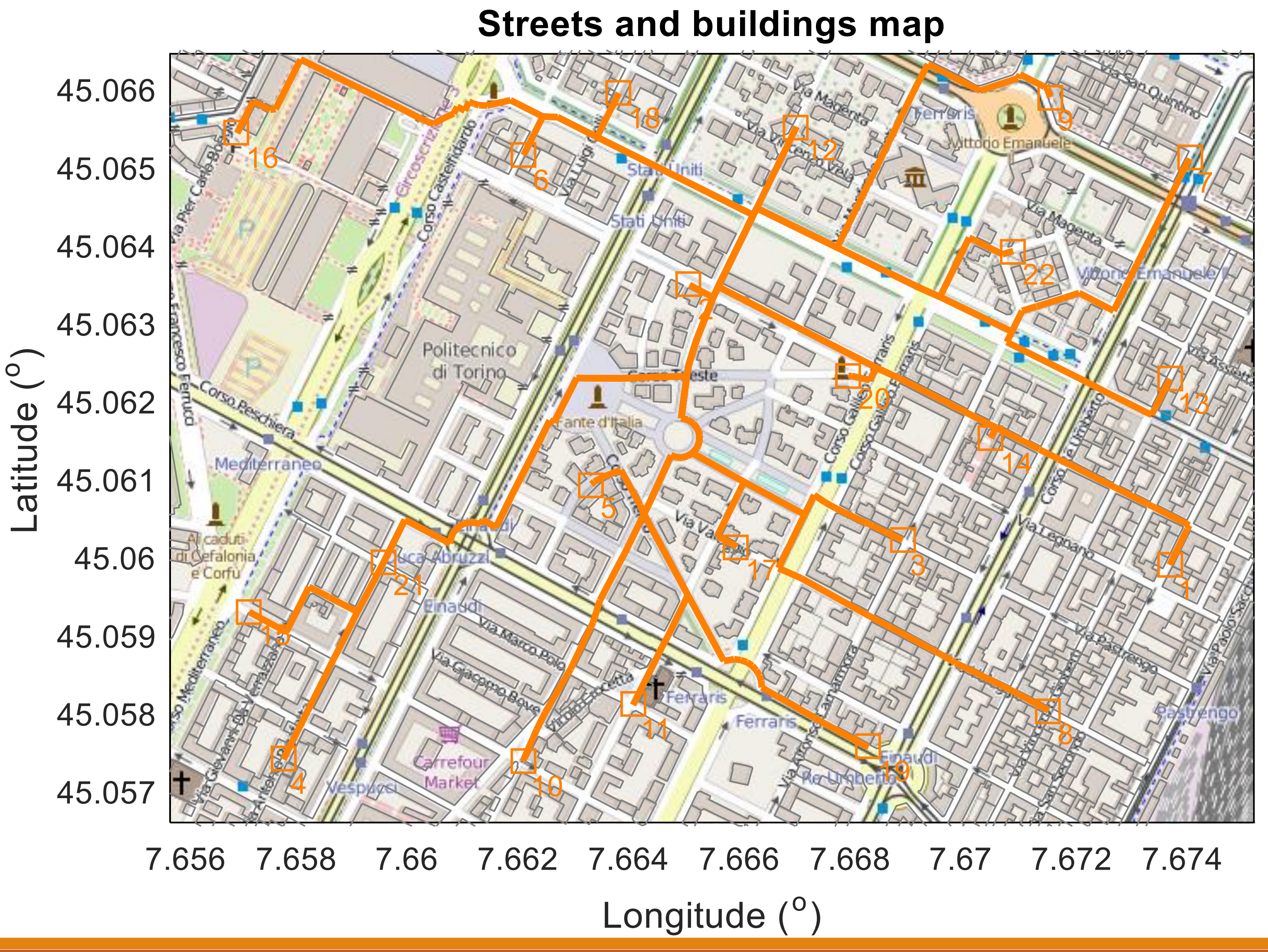
Algorithm description

BEST PATH SEARCH:



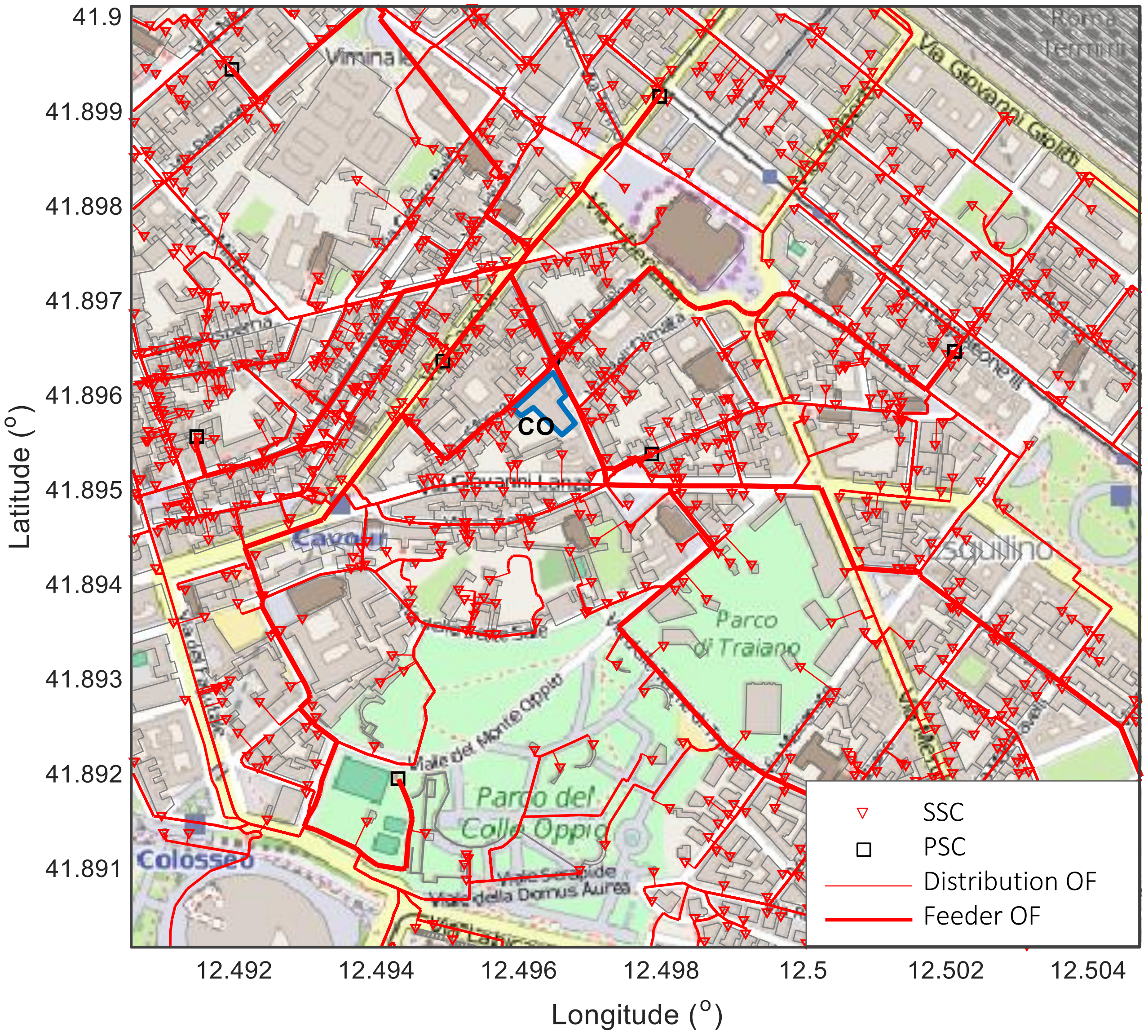
Algorithm description

BEST PATH SEARCH:



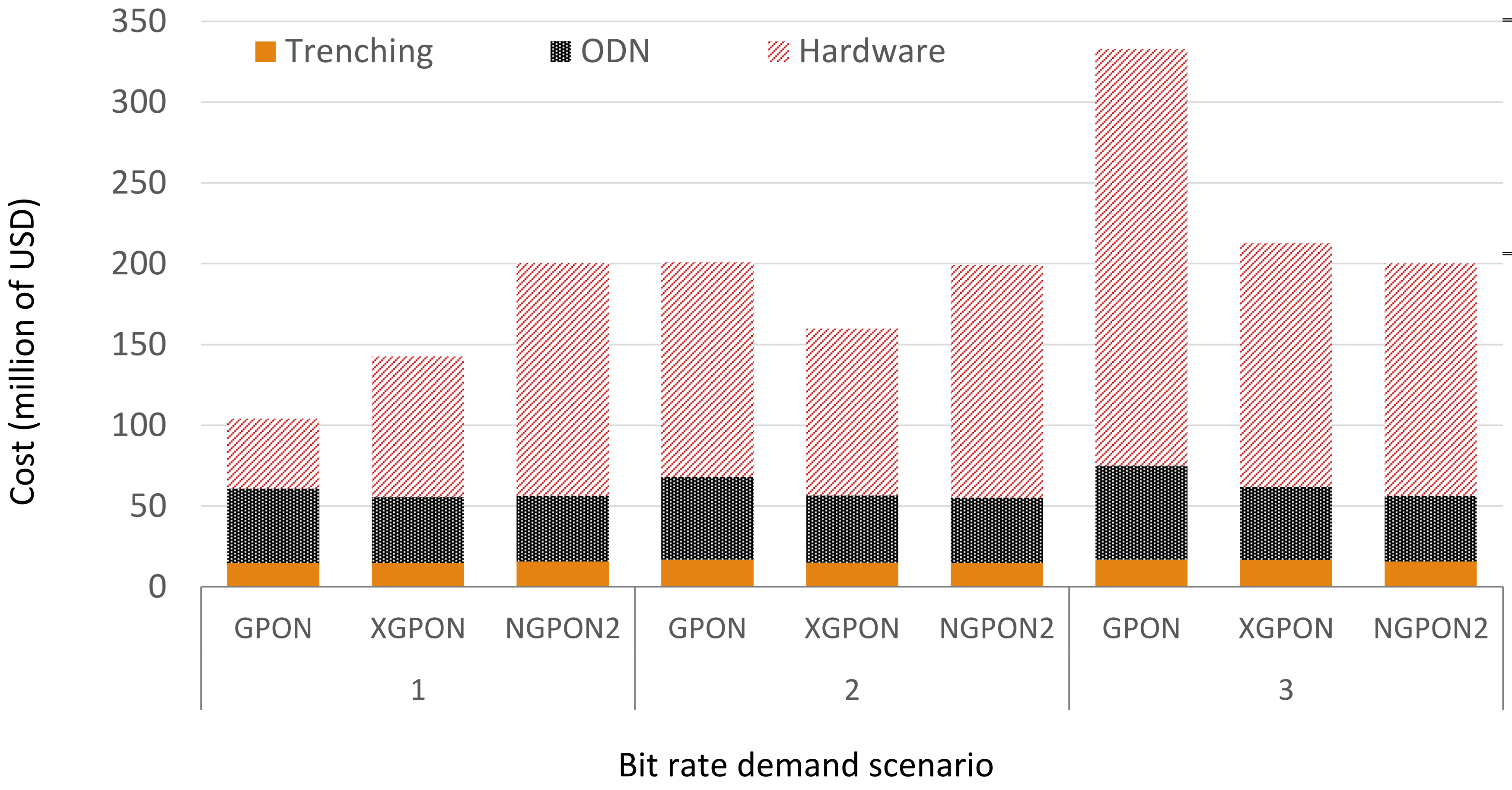
Results

Best topology:



This is by far the most important slide, so stay at least a couple of minutes to comment it

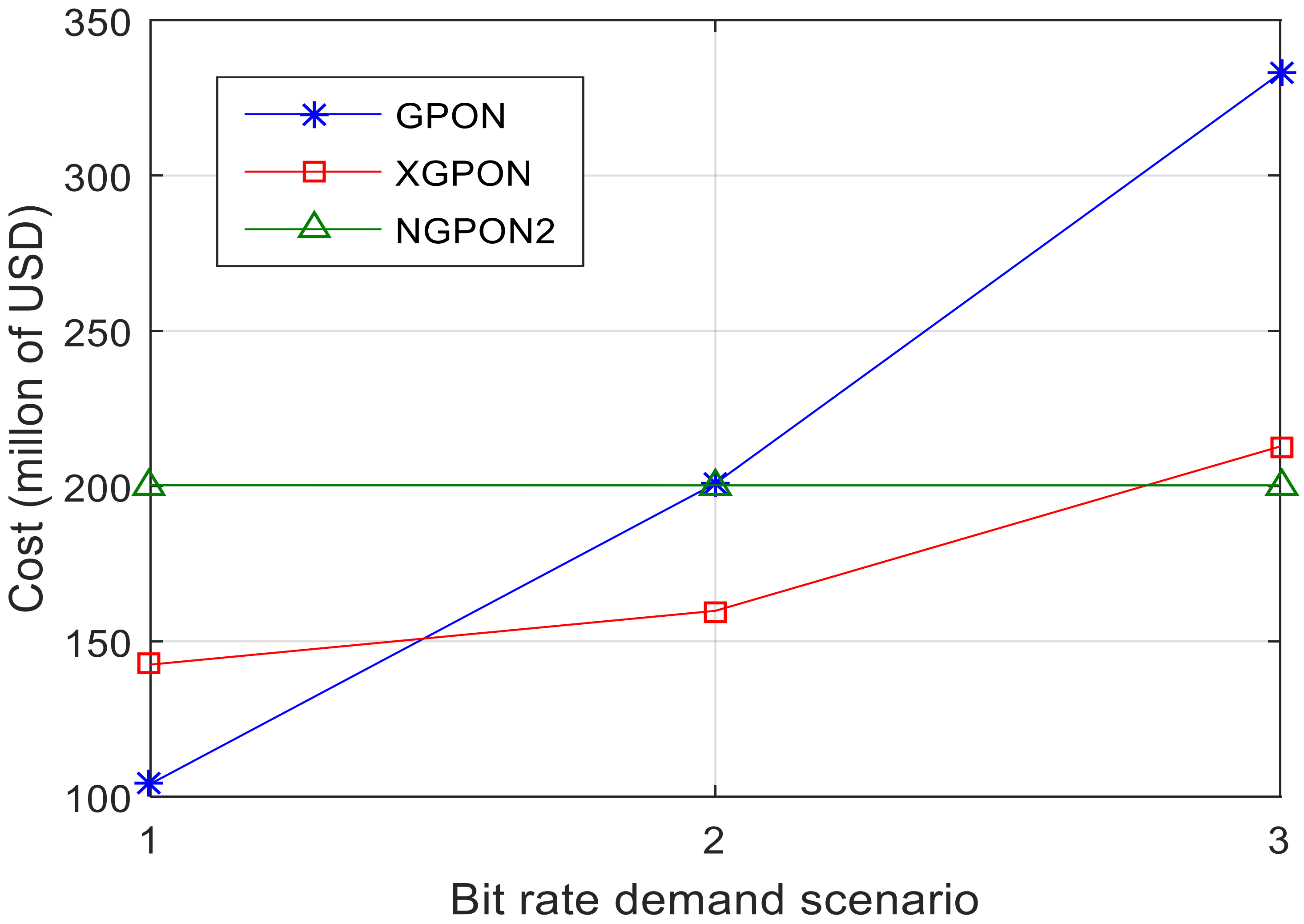
Costs of deployment for the three PON technologies:



	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

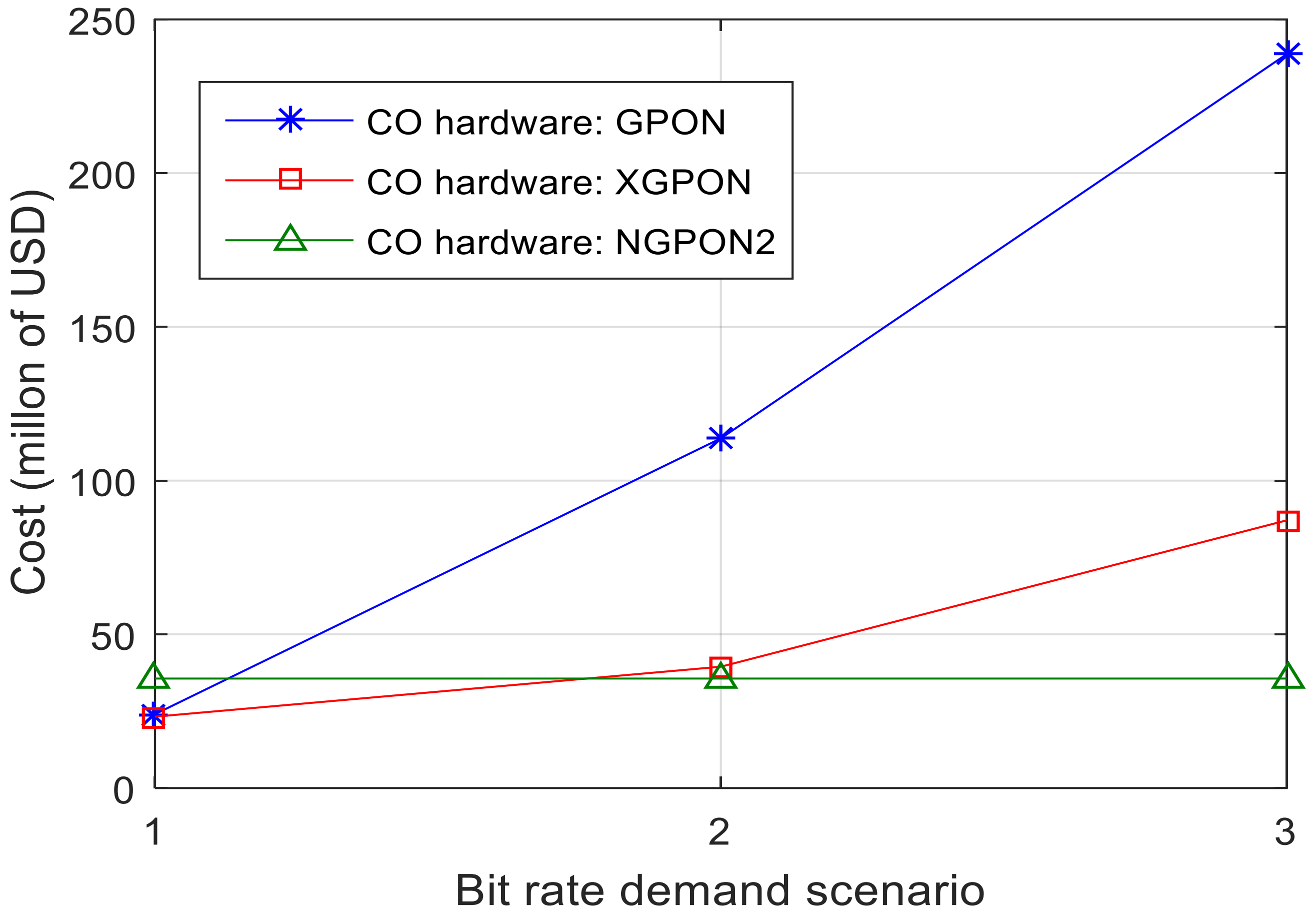
Results

Total cost of deployment for the three PON technologies:



Results

Cost of CO hardware for the three PON technologies:



Conclusions

The OTS algorithm reported in this paper makes an effective use of a set of heuristics in order to find optimal solutions for multiple PON dimensioning in real city maps scenarios with very large number of users and different bit rate demands.

Our analysis demonstrates that PON hardware constitutes a very important factor in the global implementation cost when deploying next generation PON technologies like NGPON2 in scenarios of high bit rate demands.

An interesting result of our study is the fact that NGPON2 becomes a better solution than GPON and XGPON when the bit rate demand reaches few hundreds of Mb/s for residential users and some units of Gb/s for corporate users.

THANKS FOR YOUR ATTENTION!

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Backup slides