Traffic flow optimization for urban xDSL based access networks

Enrico Lovisotto

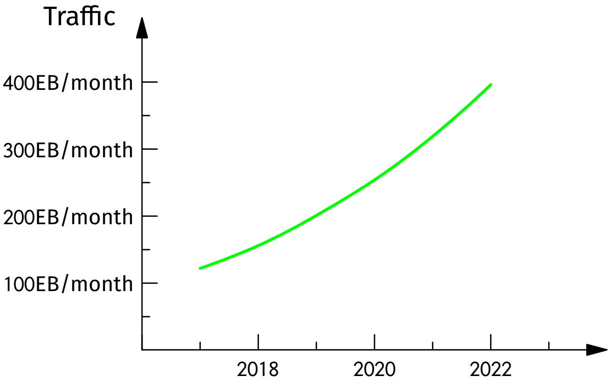
8 Aprile 2019

Università degli Studi di Padova

Outline

Introduction

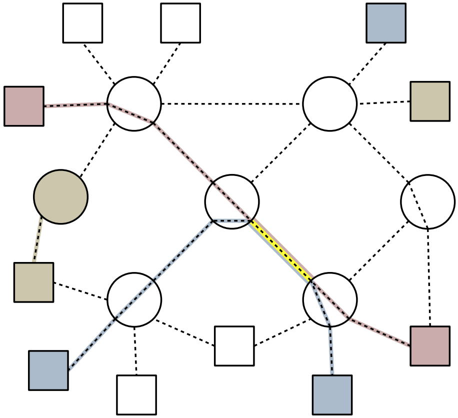
Internet is experiencing nowadays an unprecedented growth, both in terms of users and traffic.[1]



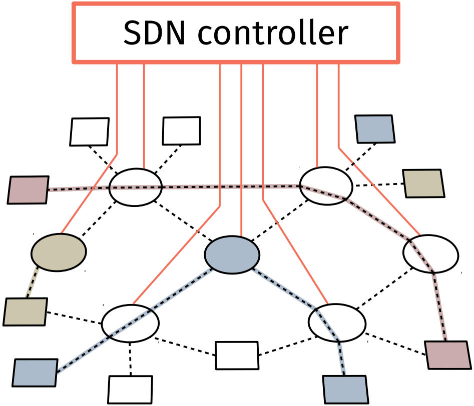
[1] Cisco VNI Forecast, "Cisco Visual Networking Index: Forecast and Trends, 2017-2022, *Cisco Public Information*"

Legacy infrastructure

Implementing flow balancing, congestion avoidance and QoS guarantees is complex in current IP networks: their fixed routing policies are in fact difficult to adapt to the dynamic modern setting.



To guarantee flexibility it is necessary to decouple data plane and control plane, moving the routing logic to a central entity.



Case of study

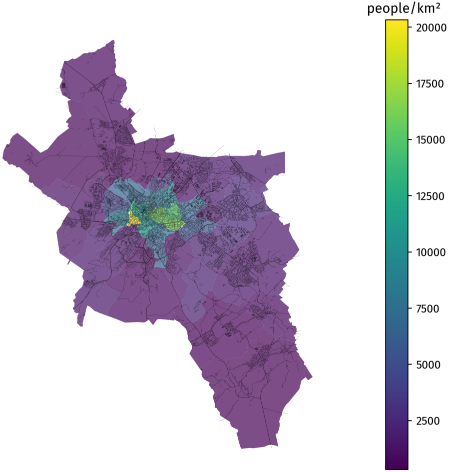
Currently no study quantifies the benefits provided by an SDN approach in common contexts, such as a city access network.

RWTH RHEINISCH-WESTFÄLISCHE TECHNISCHE HOCHSCHULE AACHEN

Network design

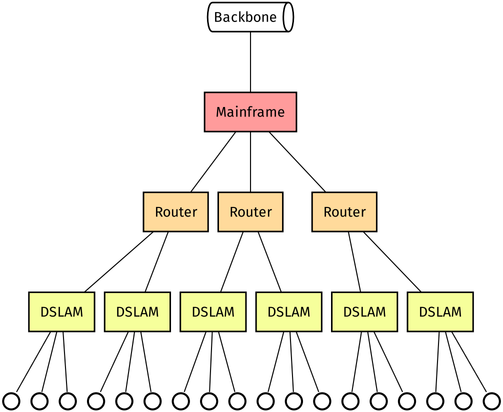
Topographical analysis

Aachen access network schematics are not publicly available, so it was necessary to infer it from freely-accessible data.



Topology hypothesis

An access network graph is tipically a tree, whose root is connected to the backbone and leaves reach the customers.



Variables and constraints

Variable	Description
$G = (V, E)$	Graph describing the city topology
$T \subseteq V$	Set of terminal nodes
$l_e = l_{ij}$	Length of edge $e = (i, j) \in E$
u_i	Number of users at terminal $i \in T$
x_e	Indicator variable for edge e activation
c_r	Cost of a single subtree root node
c_f	Cost of a fiber optic cable per meter
c_e	Cost of roadwork excavation per meter
d_M	Maximum distance from a terminal and its root
n_M	Maximum number of terminals per tree

Mathematical model

$$\min_{\{x_e\}_{e\in E}} \left(\sum_{t\in T} d_t\, u_t\right) c_c + \left(\sum_{e\in E} x_e\, l_e\right) c_e + \left(\sum_{e\in\delta^+(r)} x_e\right) c_r$$

Minimize total cost

$$\sum_{e\in\delta^-(j)} x_e \begin{cases} = 0 & j = r \\ = 1 & j \in T \\ \leq 1 & j \in V \setminus T \end{cases}$$

$$\sum_{e\in\delta^+(r)} x_e \geq 1$$

Solution is a *tree*

$$\forall j \in V \cup \{r\},\ d_j \leq \left(\sum_{e\in\delta^-(j)} x_e\right) d_M$$

$$\forall (i, j) \in A \begin{cases} d_j - d_i \geq l_{ij}\, x_{ij} - d_M\,(1 - x_{ij}) \\ d_j - d_i \leq l_{ij}\, x_{ij} + d_M\,(1 - x_{ij}) \end{cases}$$

Cable length is no more than d_M

$$\forall e \in A,\ n_e \leq x_e\, n_M$$

$$\sum_{e\in\delta^-(j)} n_e - \sum_{e\in\delta^+(j)} n_e = \begin{cases} p_j & j \in T \\ 0 & j \in V \setminus T \end{cases}$$

$$\sum_{e\in\delta^+(r)} n_e = \sum_{i\in T} u_i$$

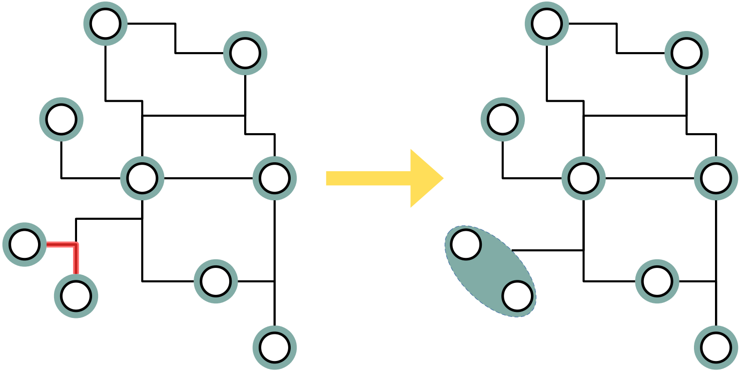
Users per group are up to n_M

$$\forall e \in A,\ x_e \in \{0, 1\},\ n_e \in \mathbb{N} \cup \{0\},\ \forall j \in V \cup \{r\},\ d_j \geq 0$$

Heuristic algorithm

Università degli Studi di Padova

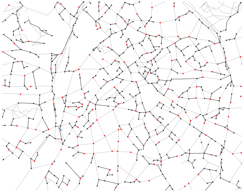
CPLEX, our reference ILP solver, cannot find the optimum exactly above a certain instance size, because of resource limitations. In these cases we developed then an heuristic algorithm, inspired by hierarchical clustering.



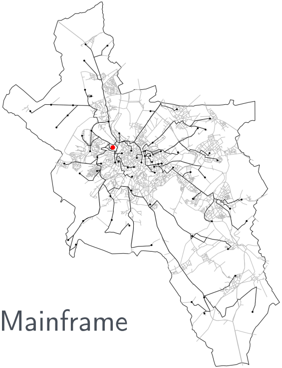
Resulting topology

Proposed algorithm provides DSLAM, router and mainframe positions, shown in the maps. Heuristic solution cost gap with respect to the theoretical optimum, obtained via CPLEX on our case of study, is no more than 4%.

DSLAMs



Routers

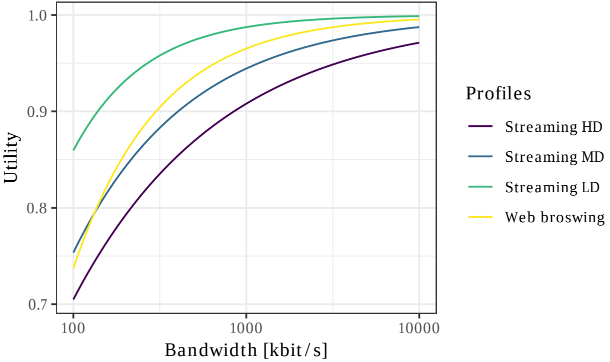


Mainframe

Resource allocation

Quality of Experience

Every kind of user considered judges connection quality in different ways, according to the requested service.[2, 3]



[2]Laghari *et al.*, Quality-of-Experience perception for video streaming services
[3]Georgopulos *et al.*, Towards network-wide QoE fairness using OpenFlow assisted adaptive video streaming

Nash arbitration scheme

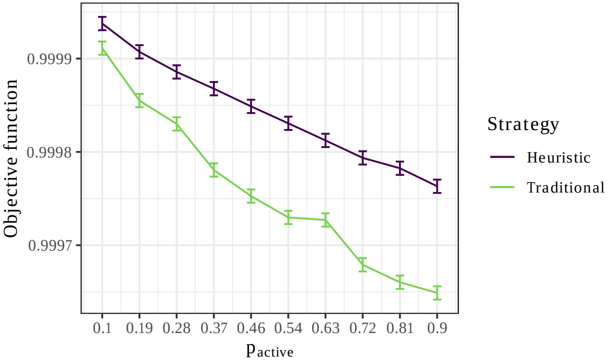
The only point that guarantees a fair resource distribution is the Nash arbitration scheme, an equilibrium point of the allocation game played among users.

$$f(\vec{\rho}) = \prod_i u_i(\rho_i) \tag{1}$$

This optimal working point is obtained maximizing the objective function f, product of the individual utilities.

Allocation performance

Proposed resource allocation improves, in terms of objective f value, with respect to the legacy approach of proportional fairness of a significant extent, especially as traffic increases.



Conclusions

Conclusions

- proposed heuristic is the most complete and performing available in literature, at the moment, to design an access network from geographical information
- using SDN principles can improve bandwidth allocation, and so network performance, especially when demand increases
- evaluating the Nash arbitration scheme requires limited computational resources