Next-Generation Wireless Backhaul Design for Rural Areas

Leonardo Maccari, DAIS: Ca' Foscari University of Venice,
leonardo.maccari@unive.it

GAIA Meeting @ IETF126

Intro: Leonardo Maccari

- Associate prof. at Ca' Foscari university of Venice (Italy)
- I work on networks and I was in the coordination team if the netCommons EU project, and other projects dealing with community networks
- This is a review of a work done together with Llorenç Cerdà-Alabern (UPC, Barcelona) and Gabriele Gemmi (NorthEastern, Boston)[1]

[1] G. Gemmi, L. Cerdà-Alabern, and L. Maccari, "Next-Generation Wireless Backhaul Design for Rural Areas" IEEE Transactions on Network and Service Management, 2025

Table of Contents

0. Introduction

1. Defining the Data Set

2. Designing a Wireless Backhaul

3. Modelling the Costs

4. Results

Sect. 0 Introduction

Goals

Initial Goals of the paper

- Estimating the cost of a mesh-based wireless distribution system based on realistic constraints
- Comparing with alternatives

Goals of this presentation

- Collect feedback from you: bad mistakes ? we missed something? better parameters?
- Encourage/discourage us to continue on this path, data-sets are 2 years old and keeping this alive is costly

  ↪ There are too many details to report here, but they are all in the paper

Ingredients

1. A practical strategy to **design a wireless backbone** with P2P wireless links.
   - We don't claim optimality: we aim at something that is implementable and makes sense
2. An associated **cost model**
3. Enough real-world data on which we can **do Monte Carlo simulations** to achieve a decent confidence on the robustness of the results

Backhaul

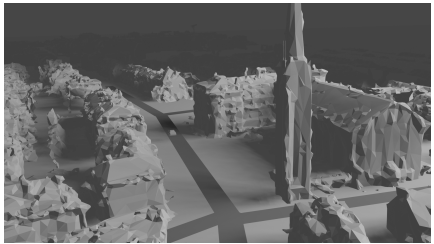
- Assume you have a set $\mathcal{V}$ of locations you want to connect, a set $\mathcal{E}$ of available LoS links, and a Point of Presence (PoP) of an ISP somewhere in the area
- Assume you want to provide a certain capacity per household
- Then how do you design your network?

Sect. 1 Defining the Data Set

The data (1)

- We consider ten rural municipalities in central Italy. The average maximum advertised download speed of traditional (xDSL) broadband connectivity (below 30 Mb/s)
- We take land surface models, building maps and building heights from public sources. We obtain a 3D model with buildings on it

- We compute line-of-sight from one building to another, and build a so-called *visibility graph* $\mathcal{G} = (\mathcal{V}, \mathcal{E})$



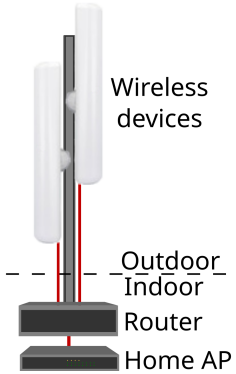
The data (2)

- We retrieved the population and household census from the Italian Institute of Statistics
- The municipalities have on average an area of 83 km^2, 1558 households, and 3110 buildings
- We set the subscriber ratio (s_r, the fraction of subscribers over the total households) to 25%, 50%, and 100% of households
- We can attribute a certain probability p that a subscriber is in a certain building
- Then we perform a random choice of subscribers' positions to obtain the set of served buildings (30 runs)

Sect. 2 Designing a mesh-based Wireless Backhaul

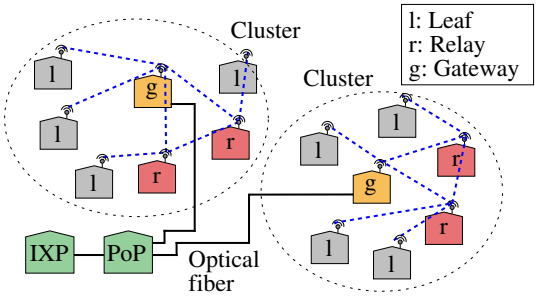
Assumptions on Wireless Nodes

- Typical configuration in many community networks
- Outside: A pole on the roof with some wireless managed P2P/P2MP devices
- Inside: a router to power and manage the devices, and/or an AP
- 2 frequencies: 5GHz (11ac) and 70 GHz (11ad)
- We used data from vendors and SoA path models to compute the link capacity as a function of distance



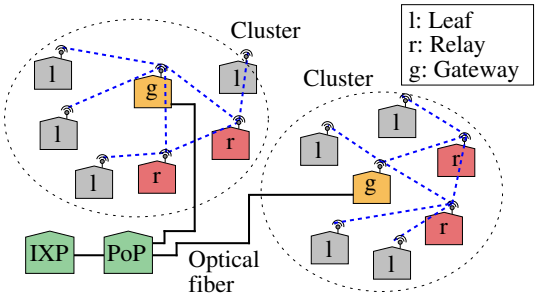
A sketch of the Backhaul design (1)

1. We use the METIS algorithm to group nodes in similar-size clusters
2. For each cluster, the node with the highest closeness centrality is the gateway
3. We build a minimum distribution tree rooted at the gateway to all nodes
4. We make it 2-edge connected for reliability



A sketch of the Backhaul design (2)

5. We assign a capacity demand to every node in $\mathcal{V}$ and consequently dimension the links, adding as many devices as needed.
6. We compute the shortest street path from the gateway to the closest PoP to estimate fiber deployment cost



Sect. 3 Modelling the Costs

We take into account:

CapEx:

- Devices cost for all the physical infrastructure
- Deployment cost: wireless backhaul
- Deployment cost: fiber to the PoP

OpEx:

- wholesale capacity at the IXP
- transport to reach the IXP
- maintenance (based on mttf/mttr)
- energy costs

All data come from public sources, previous papers, interview with guifi.net people.

S_c: Cost per subscriber per month

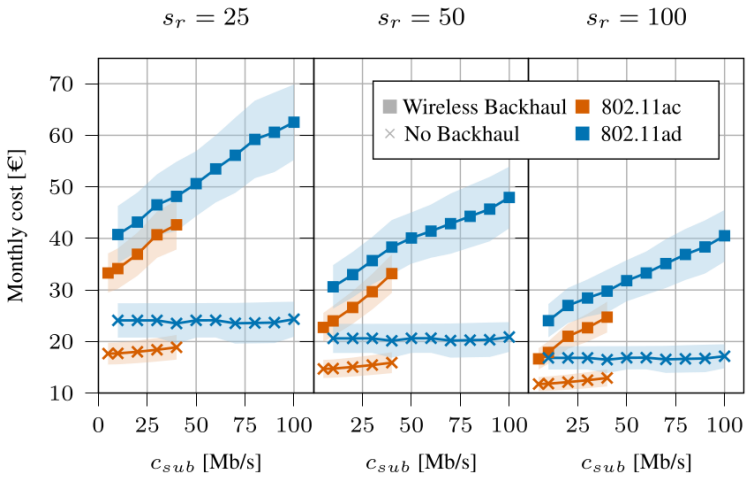
$$S_c = \underbrace{\frac{1}{u}\left(\frac{C_f(\mathcal{B})}{180} + \frac{C - C_f(\mathcal{B})}{60}\right)}_{\text{Monthly CapEx}} + \underbrace{\frac{1}{u}\left(\frac{O}{12}\right)}_{\text{Monthly OpEx}} \tag{1}$$

Where:

- C is the whole CaPex
- $C_f(\mathcal{B})$ is the part for fiber deployment (amortized in 15 years)
- We amortize the devices in 5 years
- u is the number of subscribers

Sect. 4 Results

Monthly Cost



Comparison with Commercial Offers (2 profiles)

	P1 (11ac)		P3 (11ad)			
	0.25	0.5	0.25	0.5	xDSL	SAT
Min Speed (Mb/s)	6.5	6.0	70.1	65.7	7.2	-
Upfront cost (€)	524.2 $\pm 30\%$	372.5 $\pm 29\%$	857.9 $\pm 29\%$	641.1 $\pm 28\%$	480	369
Monthly cost (S_c)	33.3 $\pm 11\%$	22.7 $\pm 12\%$	48.2 $\pm 14\%$	38.3 $\pm 14\%$	34	46.2
Unconnected Households (%)	12	6	7	7	18	-

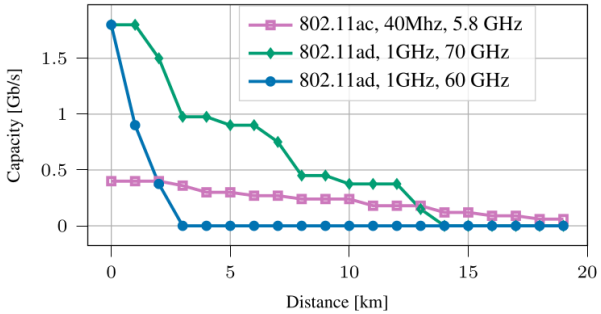
Conclusions

- We have a well-documented model for planning and evaluating the cost of a mesh-based wireless backhaul
- It can be parametrized as needed
- The price ranges we computed in our scenarios are comparable to the commercial offers

Thanks

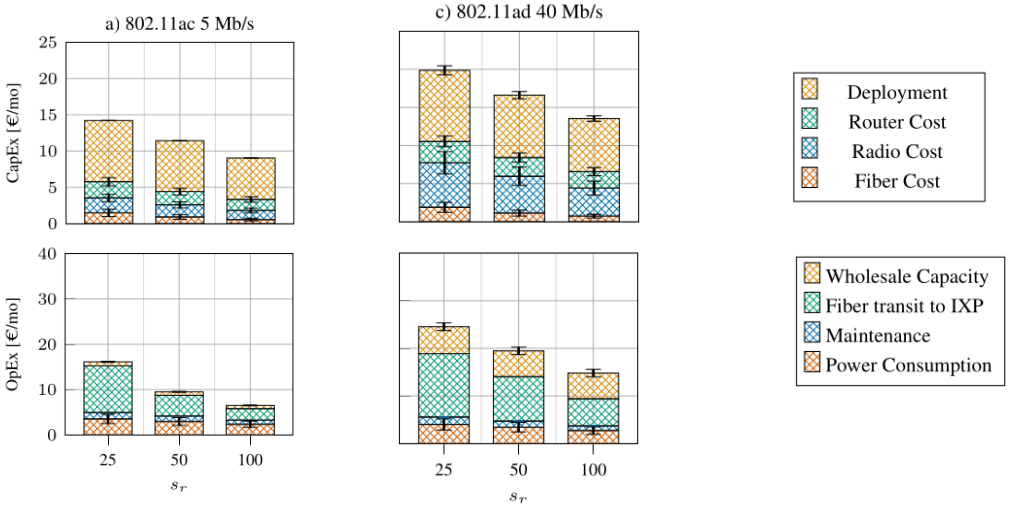
Links details

- We collected data on commercial devices (Mikrotik and Ubiquiti)
- We used two SoA path loss models from the literature
- We respected Italian laws in terms of power
- We used 2 frequencies: 5GHz (11ac) and 70 GHz (11ad)



We set a threshold of 10 km and opt for 11ac and 11ad/70GHz

Cost Breakdown



CapEx

$$C = \sum_{g \in \mathcal{B}} C_g + \sum_{r \in \mathcal{R}} C_r + (d_l + a_l)|\mathcal{L}| + C_f(\mathcal{B}) \tag{2}$$

Where:

- $\mathcal{B}$ is a choice for the gateway nodes, $C_f(\mathcal{B})$ is the CaPex for deploying fiber to the gateways, C_g is the cost of gateways
- $\mathcal{L}$ is the set of leaf nodes, d_l and a_l are the cost of deployment and hardware for a leaf node.
- We used market costs for devices, interviews for deploy costs (most non-public info comes by guifi.net)

OpEx

$$O = O_w + O_t + O_m + O_p \tag{3}$$

Where:

- O_w is the cost of leasing the needed wholesale capacity at the closest IXP
- O_t is the cost of the transit from the closest PoP of some operator to the IXP
- O_m is the cost of maintenance of the backhaul (derived from mean-time-to-fail/repair and repair costs for interviews)
- O_p is the cost of powering the whole infrastructure

Satellite Option

- We may avoid the cost of the fiber + transport if every cluster has a satellite link
- We did not find any available pricing option besides *Starlink community gateways*
- The cheapest offer starts at \$75,000/Gb/s/month with a one-time upfront cost of \$1,250,000
- This was completely out of scale compared to the fiber option