Development and management of collective network and cloud computing infrastructures

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PhD Defence

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UNIVERSITAT POLITÈCNICA DE CATALUNYA
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Models for infrastructure in common

2022-04-03


Development and management of collective network and cloud computing infrastructures

General contribution: in the search of new models for finance, deploy and manage infrastructure

General focus: Commons based

Basic action plan:

- infra in general
- → focus network infra
- → case study: model
- → (still in network:) scalability?
- → Jump to cloud infra: exportabilty?
- → back to infra in general: generalisation proposal

BE NEUTRAL, speak as a researcher, not as a practitioner/evangelist

Foreword
Industrial doctorate
Preliminary issues
Acronyms

Introduction
Infrastructure in our globalised world
Research overview
Research activities
Methodology

Research activities
RA1 – Gathering of performance indicators of Guifi.net
RA2 – Description of the differences between Guifi.net and the private initiative model
RA3 – Formalisation of the Guifi.net organisational model
RA4 – Identification of key factors in CNs scalability and related patterns
RA5 – Analysis of the suitability of the Guifi.net model for cloud computing infrastructure
RA6 – Proposal of a commons based participatory model for extensible infrastructure deployment and management
Scientific validation
Analysis of a case of cost-sharing

Conclusions
Conclusions
Further work

Bibliography



Industrial doctorate

Context

- PhD under the Industrial Doctorates Plan of the Catalan Government

Ambition

- Development of strategic research projects within a company through private sector and research institutions partnership
- Combination of academic research with elements of practice to tackle challenges of strategic importance for the industry
- Substantial bidirectional knowledge transfer

Affects

- Objectives
- Methodology
- Expected results

This PhD

- Partnership
  - UPC + Fundació Guifi.net
- Challenges
  - Analysis and documentation of the whole project, with a special emphasis on
    - Governance
    - Economics
  - Proposal, implentation and evaluation of improvements
- Skills requirements
  - Strong technological background
  - Social sciences + Economics + Law

Models for infrastructure in common
└Foreword
└Industrial doctorate
└Industrial doctorate

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Be quick
Basically say

- The Foundation is an NGO ⇒ the contributions expected must have high SOCIAL VALUE
- The main topics: dictated by the Foundation

Preliminary issues

Commons

- A model for resource management based on collective action
- Long-enduring examples in water irrigation systems, fishing grounds, pastures, forests, water
- *Not to be confused with the public management (bottom-up vs. top-down)*

Governance

- The internal processes of ruling and managing that a community undertakes

Capital expenditures (CAPEX)

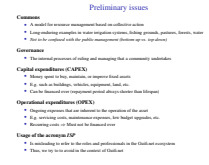
- Money spent to buy, maintain, or improve fixed assets
- E.g. such as buildings, vehicles, equipment, land, etc.
- Can be financed over (repayment period always shorter than lifespan)

Operational expenditures (OPEX)

- Ongoing expenses that are inherent to the operation of the asset
- E.g. servicing costs, maintenance expenses, low budget upgrades, etc.
- Recurring costs $\Rightarrow$ Must not be financed over

Usage of the acronym *ISP*

- Is misleading to refer to the roles and professionals in the Guifi.net ecosystem
- Thus, we try to to avoid in the context of Guifi.net



Acronyms

AR	action research
B4RN	Broadband for Rural North
BU	bottom-up
CAPEX	capital expenditures
CC	cloud computing
CN	community network
CPR	common-pool resource
ISP	internet service provider
IXP	internet exchange point
NSP	network service provider
OAN	open access networks
OF	fibre optic
OPEX	operational expenditures
WiFi	wireless fidelity

Acronyms
AR action research
B4RN Broadband for Rural North
BU bottom-up
CAPEX capital expenditures
CC cloud computing
CN community network
CPR common-pool resource
ISP internet service provider
IXP internet exchange point
NSP network service provider
OAN open access networks
OF fibre optic
OPEX operational expenditures
WiFi wireless fidelity

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Facts

Inefficiency while there is still scarcity



Optical fibre in Sants, Barcelona (February 2016).



Water facilities in Africa (Almost anywhere at any time in Africa and in many other places, source: [s1]).

⇒ Just with a better management we could serve more people

[s1] *https://www.facebook.com/519800271697848/photos/a.519800518364490/519800521697823#*



Left picture: The ‘Spanish OF miracle’, a reference for the EU

- *Note* The capacity of OF is, in practice, unlimited
- Duplication of infrastructure, while uncovered areas still exist
- Massive public subsidies to very few transnational corporations
- Fraudulent use of most of the subsidies
  - Suboptimal infrastructure delivery
  - Not truly made available to everybody: ~~SMEs~~, ~~citzens~~, ~~other public admins~~, etc.

Right picture: Who dares?

-

Main infrastructure models

& opportunities for bottom-up (BU) initiatives' engagement

Private

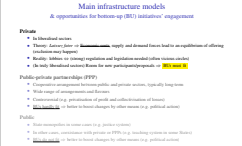
- In liberalised sectors
- Theory: *Laissez faire* ⇒ ~~Economic rents~~, supply and demand forces lead to an equilibrium of offering (exclusion may happen)
- Reality: lobbies ⇔ (strong) regulation and legislation needed (often vicious circles)
- (In truly liberalised sectors) Room for new participants/proposals ⇒ BUs must fit

Public-private partnerships (PPP)

- Cooperative arrangement between public and private sectors, typically long-term
- Wide range of arrangements and flavours
- Controversial (e.g. privatisation of profit and collectivisation of losses)
- BUs hardly fit ⇒ better to boost changes by other means (e.g. political action)

Public

- State monopolies in some cases (e.g. justice system)
- In other cases, coexistance with private or PPPs (e.g. teaching system in some States)
- BUs do not fit ⇒ better to boost changes by other means (e.g. political action)



Public-private partnerships (PPP)

- Monopoly *de facto*

Public-private partnerships (PPP)

- Monopoly *de jure*

Main infrastructure business sectors

- Finance
- Procurement
- Deployment
- Operation
- Maintenance
- Commercialisation
- Dismantling
- Waste management

→ Different models for different business sector on the same infrastructure are not uncommon

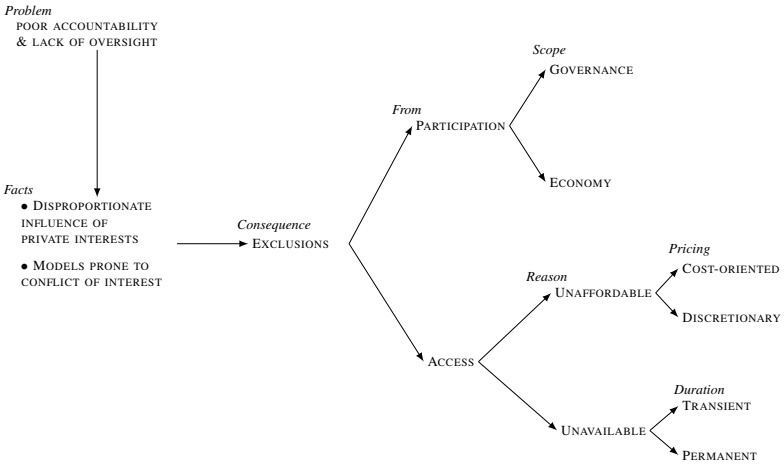
Example of combinations of business sector and deployment and management models
In a railway system,
the **railway network** may be funded and owned by the *state*,
the provisioning and deployment works made be made by *construction firms*,
the network operation can be *public or private*,
the **trains** may belong to *several investors* and be operated by *specialised companies*, and
the train tickets can be commercialised via a *chain of companies*.

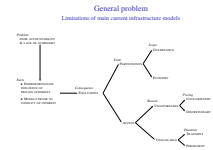
Example of PPP
An infrastructure funded and owned by the *state* and operated by a *private company*.



General problem

Limitations of main current infrastructure models





Stress driving distictions:

Construction/Production – Consumption/Extraction

a) Participation – Governance

b) Participation – Economy

c) Access – Availability

d) Access – Affordability

Requirements & Working hypothesis

PPP model and private sector models suffer from design flaws
⇒ **alternative models needed**

Requirements for alternative models

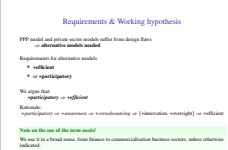
- **+efficient**
- or **+participatory**

We argue that:
+participatory ⇒ ***+efficient***

Rationale:
$+participatory \Rightarrow +awareness \Rightarrow +crowdsourcing \Rightarrow \{+\text{innovation}, +\text{oversight}\} \Rightarrow +\text{efficient}$

Note on the use of the term *model*

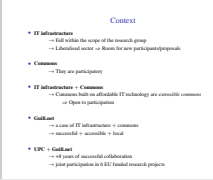
We use it in a broad sense, from finance to commercialisation business sectors, unless otherwise indicated.



alternative ⇒ either new or promoting existing ones
+efficient ⇒ +access (in Slide:'Facts')

Context

- **IT infrastructure**
  - → Fall within the scope of the research group
  - → Liberalised sector ⇒ Room for new participants/proposals
- **Commons**
  - → They are participatory
- **IT infrastructure + Commons**
  - → Commons built on affordable IT technology are *extensible commons*
    - ⇒ Open to participation
- **Guifi.net**
  - → a case of IT infrastructure + commons
  - → successful + accessible + local
- **UPC + Guifi.net**
  - → +8 years of successful collaboration
  - → joint participation in 6 EU funded research projects



Objective & Research questions

Objective

Contribute to the search of new models for infrastructure finance, deployment and management that overcome the limitations of the currently used

RQ1

Does the approach followed by Guifi.net outperform the private sector model?

RQ2

Does the Guifi.net case have enough unique and beneficial features to be considered a model on its own?

RQ3

Does the Guifi.net model apply other infrastructures?



Background

Network infrastructure

49 M. Forzatti *et al.* – A reference on network business models

- Cases of network infrastructure sharing: OAN, IXPs, CNs

Cloud computing infrastructure

106 M. Mell *et al.* – Definition of cloud computing

104 A. Marinos *et al.* – Community cloud computing

Commons

72 G. Hardin – *Tragedy of the commons*

113 E. Ostrom – 8 design principles for sustainable CPR institutions

116 E. Ostrom – 5 requirements of CPR institutions adaptability

53 B. Frischmann – Infrastructure as a commons

O6 CNs survey

Cost-sharing

139 L. Shapley – Reference of cost-sharing mechanism

Action research (AR)

33 D. Coghlan *et al.* – AR in organisations

149 W. Torbert – Handbook of AR

144 J. A. Tacchi *et al.* – Ethnographic AR

Regulation

- Topics
  - Telecommunications
  - Civil law: Legal entities, ownership forms and rights, etc.
  - etc.
- Geographical scope
  - EU → State → subnacional → municipal



Frischmann

- Seems to confuse commons with public management from the governance perspective
- ⇒ no BU governance solution

Ostrom

- focus on
  - natural resources
  - *moderately* artificial resources
  - immaterial resources

Works after Ostrom

- Seem to be stuck where she left them

Scientific innovation

- Documentation of an *intrinsically* artificial CAPEX intensive resource built and managed as an open CPR
- Contribution to the refinement of the policies and practices of the community

Research activities

RQ1 *Does the approach followed by Guifi.net outperform the private sector model?*

RQ2 *Does the Guifi.net case have enough unique and beneficial features to be considered a model on its own?*

RA1 Gathering of performance indicators of Guifi.net

RA2 Description of the differences between the Guifi.net approach and the private initiative model

RA3 Formalisation of the Guifi.net model

RQ3 *Does the Guifi.net model apply other infrastructures?*

RA4 Identification of the key factors in CNs' scalability and the related patterns

RA5 Analysis of the suitability of the Guifi.net model for cloud computing infrastructure

Beyond RQs

RA6 Proposal of a commons based participatory model for extensible infrastructure finance, deployment and management



Methodology

Action research

- Overall methodology

→ *A wide variety of methods to investigate and evaluate weaknesses (organisational, instructional, etc.) and help practitioners develop practical solutions to address them quickly and efficiently* [33, 144, 149]

- Direct involvement with the community of practice
  - We have directly intervened in the design and implementation of many of the processes that have led to the solutions we have documented
- Incremental through (small) iterations
  - Iterations: Diagnose → Planning action → Taking action → Evaluating action
  - Incremental: RQ1 → RQ2 → RQ3

For each research activity we present

- Objective
- Methodology
- Activities
- Results
- Analysis of the results



Stress:

- In the dissertation we mostly document the existing solutions to date, their implications and the interactions among them.
- We have omitted to describe our interventions as researchers because we aimed at a work useful for the community of practice.
- Here we essentially present the scientific results.

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RA1 – Guifi.net performance indicators

Objective

- Gather sufficient empirical evidence to support the answer to RQ1

Methodology

- *Data hunting* (from participants, databases, websites, etc.)
- Quantitative data wherever possible
- Impact analysis base on third-party statistics

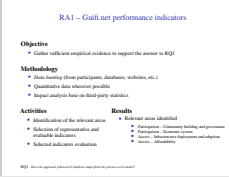
Activities

- Identification of the relevant areas
- Selection of representative and evaluable indicators
- Selected indicators evaluation

Results

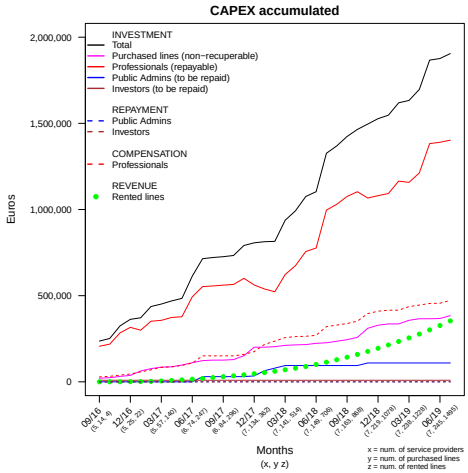
- Relevant areas identified
  - Participation – Community building and governance
  - Participation – Economic system
  - Access – Infrastructure deployment and adoption
  - Access – Affordability

RQ1 *Does the approach followed by Guifi.net outperform the private sector model?*



RA1 – Guifi.net performance indicators

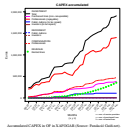
Results: Example of quantitative investment level in OF



Accumulated CAPEX in OF in XAFOGAR (Source: Fundació Guifi.net).

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RA1 – Guifi.net performance indicators

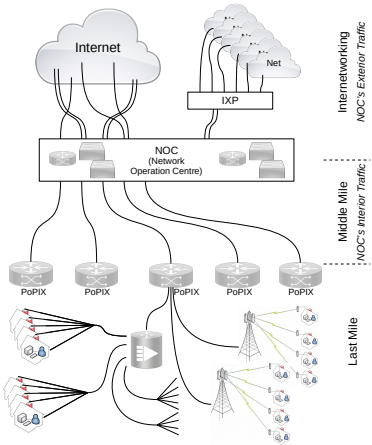
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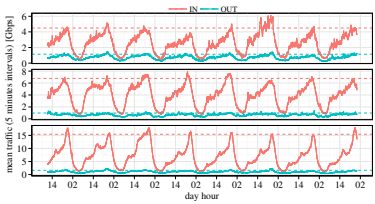
Super-lineal (TODO Eng?)

RA1 – Guifi.net performance indicators

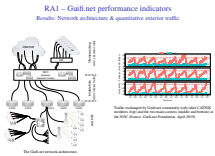
Results: Network architecture & quantitative exterior traffic



The Guifi.net network architecture.

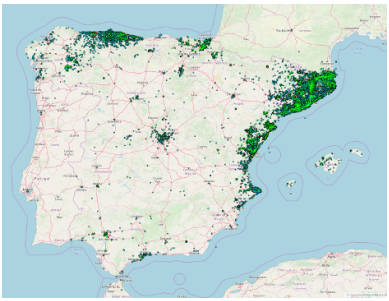


Traffic exchanged by Guifi.net community with other CATNIX members (top) and the two main carriers (middle and bottom) at the NOC (Source: Guifi.net Foundation, April 2019).

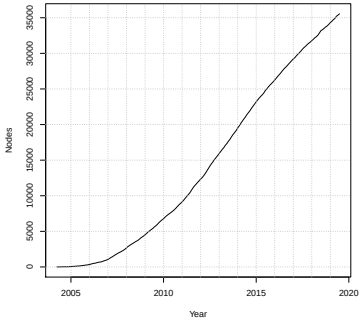


RA1 – Guifi.net performance indicators

Results: Quantitative adoption of the WiFi network

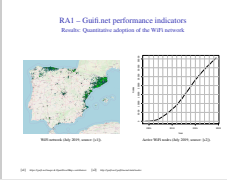


WiFi network (July 2019, source: [s1]).



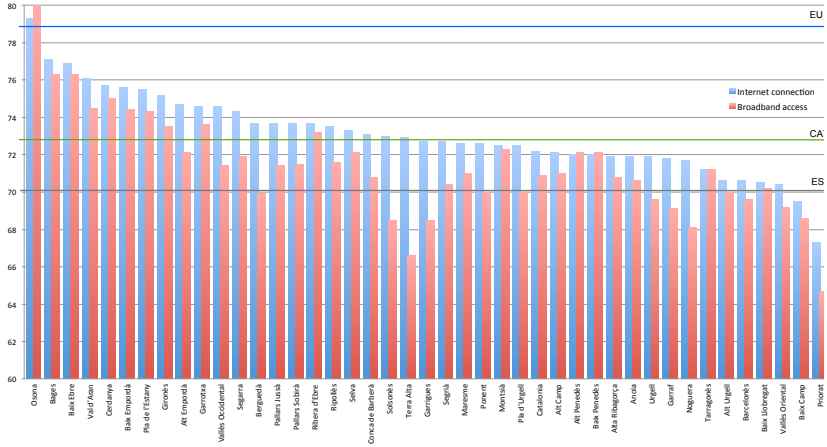
Active WiFi nodes (July 2019, source: [s2]).

[s1] *https://guifi.net/maps & OpenStreetMap contributors* [s2] *http://guifi.net/guifi/menu/stats/nodes*



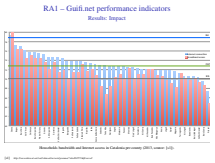
RA1 – Guifi.net performance indicators

Results: Impact



Households bandwidth and Internet access in Catalonia per county (2013, source: [s1]).

[s1] *http://www.idescat.cat/cat/idescat/serveis/premsa/?id=263571&fitxer=2*



RA1 – Guifi.net performance indicators

Analysis of the results

In comparison to other models and CNs

- Participation – Community building and governance
  - Priv Open to direct participation
  - Priv Diversity of participants and degree of commitment
  - CNs Legal identity
- Participation – Economic system
  - CNs Well-developed economy
  - Priv Local economy
  - Priv Crowdfunding
- Access – Infrastructure deployment and adoption
  - Priv Similar technology solutions & scale (mid-size operator)
  - Priv Crowdsorcing
- Access – Offering
  - Priv Similar services (contents, bandwidth, +mobile, etc.)
  - Priv Lower pricing
  - Priv Customised

Main weaknesses observed

- Strong dependency on specific *local champions*

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2022-04-03



RA2 – Differences between Guifi.net and the private model

Objective

- Gather sufficient empirical evidence to support the answer to RQ2

Methodology

- Literature review
- Data collection
- Comparison

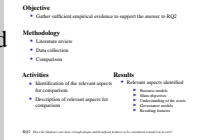
Activities

- Identification of the relevant aspects for comparison
- Description of relevant aspects for comparison

Results

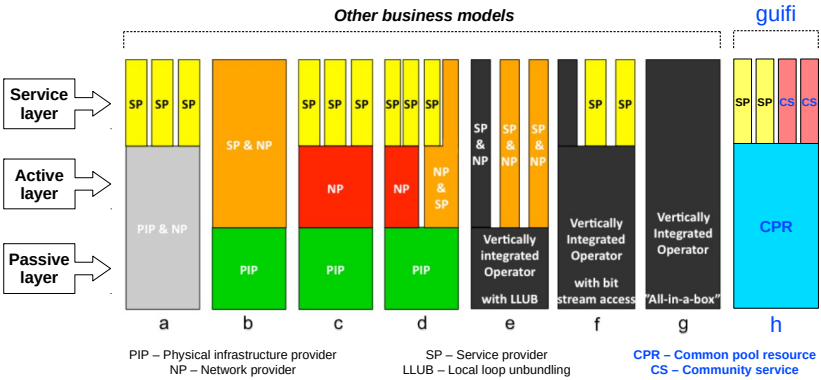
- Relevant aspects identified
  - Business models
  - Main objectives
  - Understanding of the assets
  - Governance models
  - Resulting features

RQ2 *Does the Guifi.net case have enough unique and beneficial features to be considered a model on its own?*

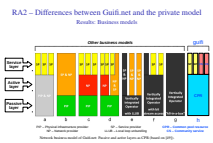


RA2 – Differences between Guifi.net and the private model

Results: Business models



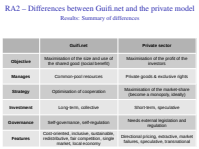
Network business model of Guifi.net: Passive and active layers as CPR (based on [49]).



RA2 – Differences between Guifi.net and the private model

Results: Summary of differences

	Guifi.net	Private sector
Objective	Maximisation of the size and use of the shared good (social benefit)	Maximisation of the profit of the investors
Manages	Common-pool resources	Private goods & exclusive rights
Strategy	Optimisation of cooperation	Maximisation of the market-share (become a monopoly, ideally)
Investment	Long-term, collective	Short-term, speculative
Governance	Self-governance, self-regulation	Needs external legislation and regulation
Features	Cost-oriented, inclusive, sustainable, redistributive, fair competition, single market, local economy	Directional pricing, extractive, market failures, speculative, transnational

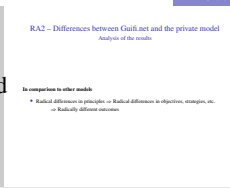


RA2 – Differences between Guifi.net and the private model

Analysis of the results

In comparison to other models

- Radical differences in principles ⇒ Radical differences in objectives, strategies, etc.
  ⇒ Radically different outcomes



RA3 – Formalisation of the Guifi.net organisational model

Objective

- Supplement the positive answer to RQ2 obtained in RA2 with a formal description of the organisational model.

Methodology

- Modelling, as a simplified and idealised understanding of an organisational system
- Establishment of our own modelling framework, due to a lack of an explicit external reference

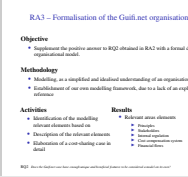
Activities

- Identification of the modelling relevant elements based on
- Description of the relevant elements
- Elaboration of a cost-sharing case in detail

Results

- Relevant areas elements
  - Principles
  - Stakeholders
  - Internal regulation
  - Cost compensation system
  - Financial flows

RQ2 *Does the Guifi.net case have enough unique and beneficial features to be considered a model on its own?*



RA3 – Formalisation of the Guifi.net organisational model

Results: Principles

Formally and summarised:

- A single infrastructure is collectively built and managed in a non-discriminatory manner,
- The resulting infrastructure is made available to everyone on equal and non-discretionary terms for any purpose, including, but not limited to, the commercial exploitation, and
- The participation in the construction and maintenance of the infrastructure is made according to its usage.

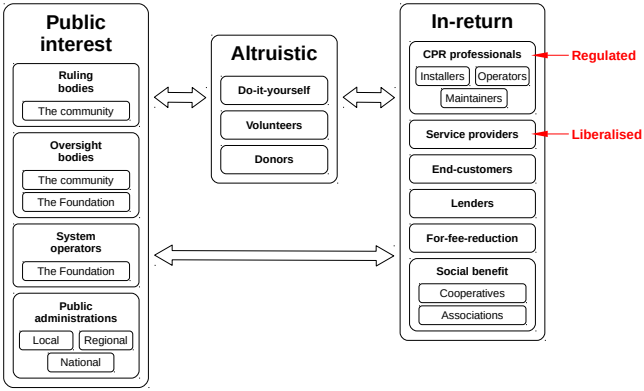
The spirit of sharing, social justice and freedom is well captured by the two main mottos of the community:

- '*Xarxa oberta, lliure i neutral*' in Catalan, 'neutral, free and open network'.
- '*Una Internet justa per a tothom*' in Catalan, 'A fair Internet for everyone'.

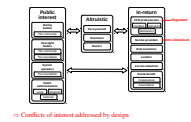
RA3 – Formalisation of the Guifi.net organisational model
Results: Principles
Formally and summarised:
A single infrastructure is collectively built and managed in a non-discriminatory manner,
The resulting infrastructure is made available to everyone on equal and non-discretionary terms for any purpose, including, but not limited to, the commercial exploitation, and
The participation in the construction and maintenance of the infrastructure is made according to its usage.
The spirit of sharing, social justice and freedom is well captured by the two main mottos of the community:
'Xarxa oberta, lliure i neutral' in Catalan, 'neutral, free and open network'.
'Una Internet justa per a tothom' in Catalan, 'A fair Internet for everyone'.

RA3 – Formalisation of the Guifi.net organisational model

Results: Stakeholders

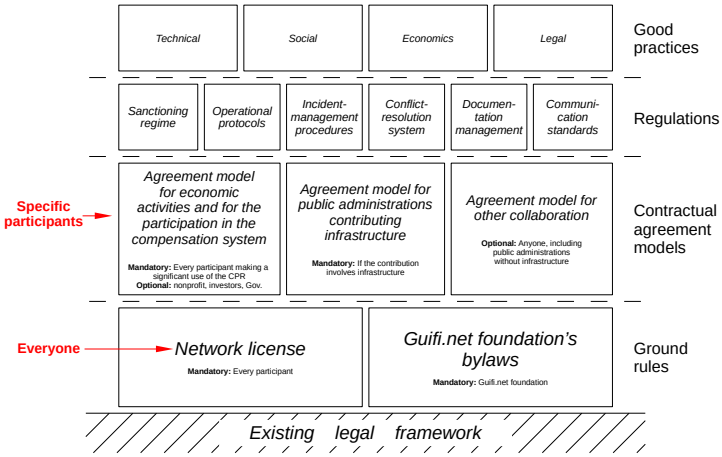


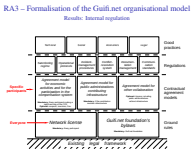
⇒ Conflicts of interest addressed by design



RA3 – Formalisation of the Guifi.net organisational model

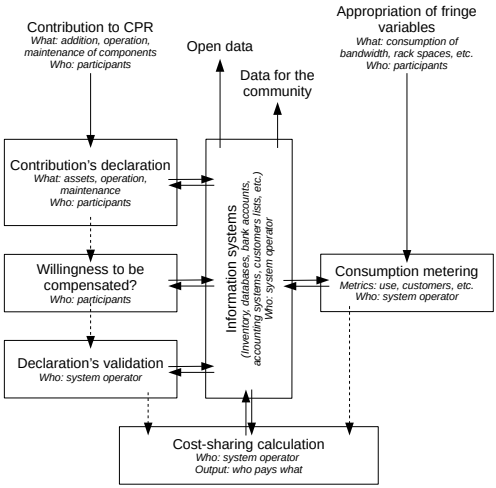
Results: Internal regulation





RA3 – Formalisation of the Guifi.net organisational model

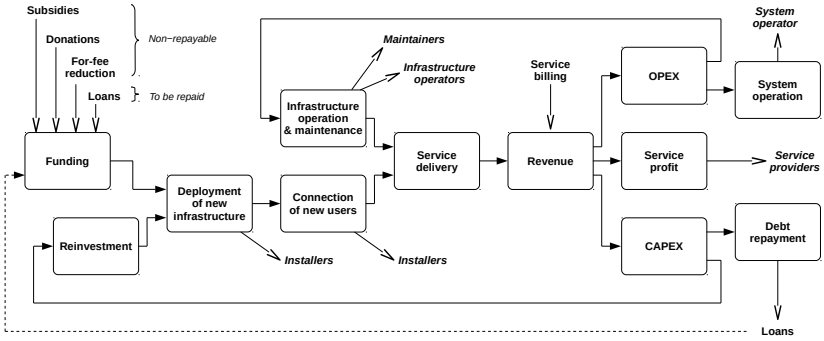
Results: Cost compensation system

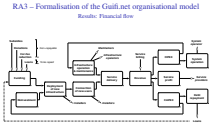




RA3 – Formalisation of the Guifi.net organisational model

Results: Financial flow

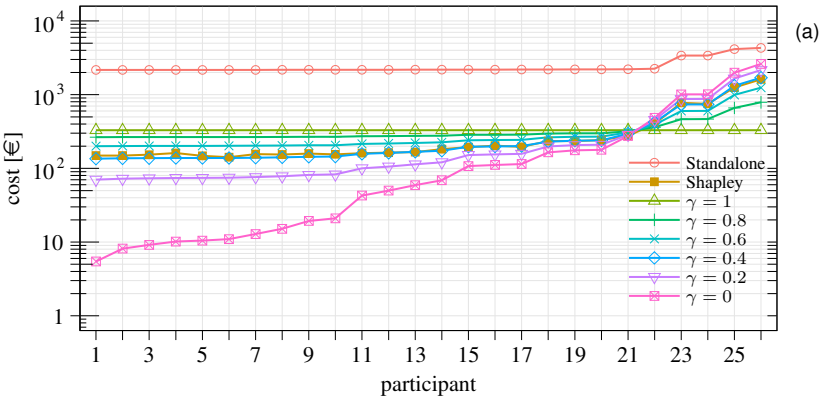




RA3 – Formalisation of the Guifi.net organisational model

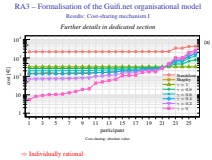
Results: Cost-sharing mechanism I

Further details in dedicated section



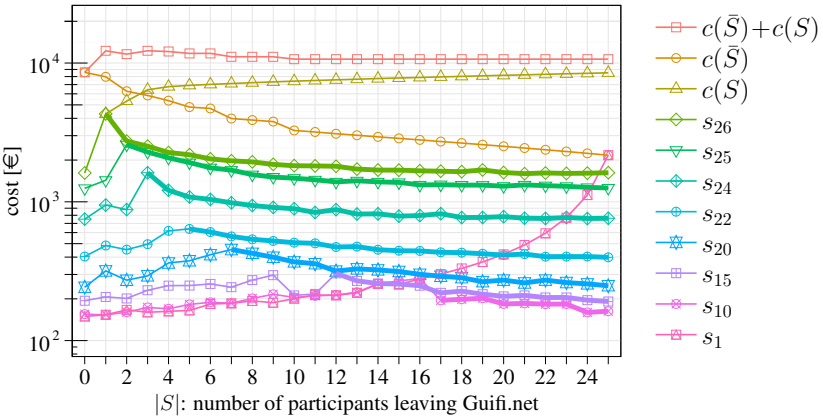
Cost-sharing: absolute value.

⇒ Individually rational



RA3 – Formalisation of the Guifi.net organisational model

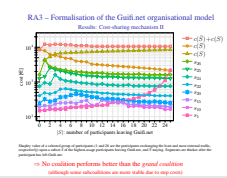
Results: Cost-sharing mechanism II



Shapley value of a selected group of participants (1 and 26 are the participants exchanging the least and most external traffic, respectively) upon a subset S of the highest-usage participants leaving Guifi.net, and $\bar{S}$ staying. Segments are thicker after the participant has left Guifi.net.

⇒ No coalition performs better than the *grand coalition*

(although some subcoalitions are more stable due to step costs)



RA3 – Formalisation of the Guifi.net organisational model

Analysis of the results

Strengths

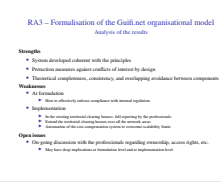
- System developed coherent with the principles
- Protection measures against conflicts of interest by design
- Theoretical completeness, consistency, and overlapping avoidance between components

Weaknesses

- At formulation
  - How to effectively enforce compliance with internal regulation
- Implementation
  - In the existing territorial clearing houses: full reporting by the professionals
  - Extend the territorial clearing houses over all the network areas
  - Automation of the cost-compensation system to overcome scalability limits

Open issues

- On-going discussion with the professionals regarding ownership, access rights, etc.
  - May have deep implications at formulation level and at implementation level



RA4 – Model scalability

Scalability The capacity *to maintain or even increase its level of performance or efficiency even as it is tested by larger and larger operational demands* [89]

Objective

- Gather sufficient evidence to support the answer to RQ3 in terms of scalability

Methodology

- Survey of CNs
- Comparison

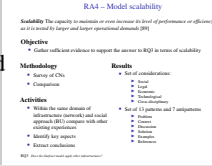
Activities

- Within the same domain of infrastructure (network) and social approach (BU) compare with other existing experiences
- Identify key aspects
- Extract conclusions

Results

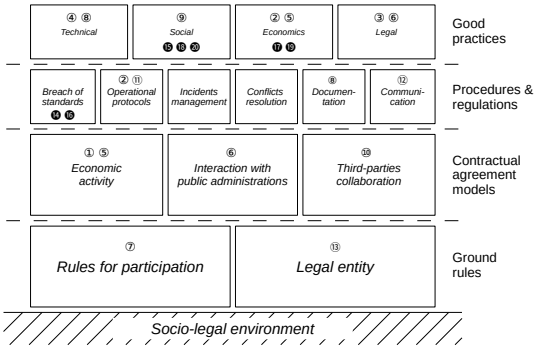
- Set of considerations:
  - Social
  - Legal
  - Economic
  - Technological
  - Cross-disciplinary
- Set of 13 patterns and 7 antipatterns
  - Problem
  - Context
  - Discussion
  - Solution
  - Examples
  - References

RQ3 *Does the Guifi.net model apply other infrastructures?*



RA4 – Model scalability

Results: Patterns and anti-patterns



Patterns
(top)

① Crowdsourcing/sponsorships
② Economic compensation
③ Regional network
④ Shared backhaul Internet
⑤ Community Investment – Shares and Loans
⑥ Legal/regulatory mechanism for cooperative resource sharing
⑦ Community participation agreement
⑧ Shared network infrastructure information
⑨ Mutual support
⑩ Identification of stakeholders and the associated roles
⑪ Community work
⑫ Community meetings
⑬ Enforcement of the rules and agreements – Legal entity

Anti-patterns
(bottom)

⓮ External implementation
⓯ The club of techies
⓰ Flamewars
⓱ Overbuilding
⓲ Customer stealing
⓳ Internal dumping
⓴ Social imbalance



RA4 – Model scalability

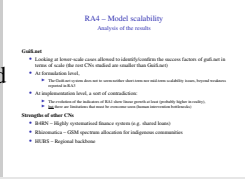
Analysis of the results

Guifi.net

- Looking at lower-scale cases allowed to identify/confirm the success factors of gufi.net in terms of scale (the rest CNs studied are smaller than Guifi.net)
- At formulation level,
  - The Guifi.net system does not to seem neither short-term nor mid-term scalability issues, beyond weakness reported in RA3
- At implementation level, a sort of contradiction:
  - The evolution of the indicators of RA1 show linear growth at least (probably higher in reality),
  - but there are limitations that must be overcome soon (human intervention bottlenecks)

Strengths of other CNs

- B4RN – Highly systematised finance system (e.g. shared loans)
- Rhizomatica – GSM spectrum allocation for indigenous communities
- HUBS – Regional backbone



RA5 – Suitability of the Guifi.net model for CC

Objective

- Investigate the exportability of the model to other infrastructure to support the answer to RQ3

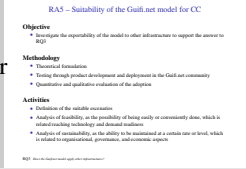
Methodology

- Theoretical formulation
- Testing through product development and deployment in the Guifi.net community
- Quantitative and qualitative evaluation of the adoption

Activities

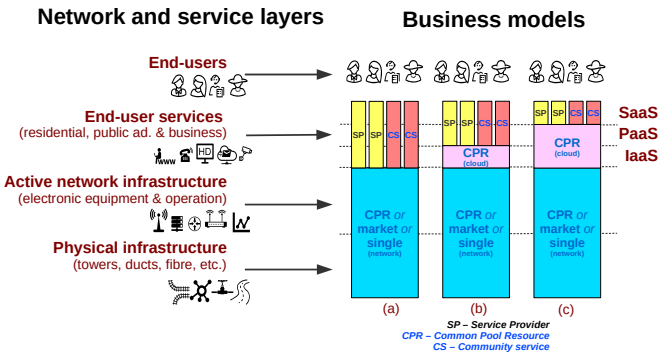
- Definition of the suitable escenarios
- Analysis of feasibility, as the possibility of being easily or conveniently done, which is related reaching technology and demand readiness
- Analysis of sustainability, as the ability to be maintained at a certain rate or level, which is related to organisational, governance, and economic aspects

RQ3 *Does the Guifi.net model apply other infrastructures?*

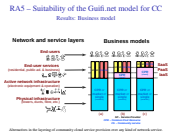


RA5 – Suitability of the Guifi.net model for CC

Results: Business model

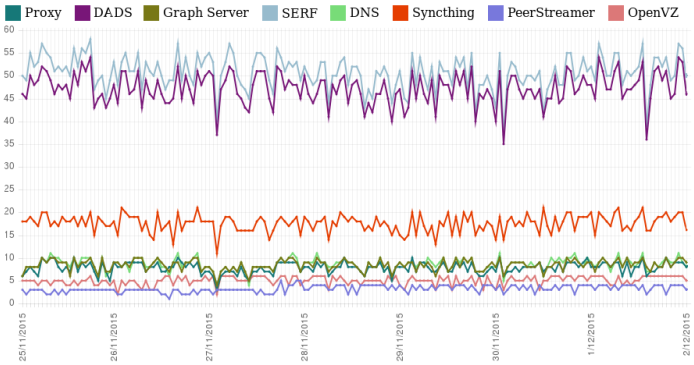


Alternatives in the layering of community cloud service provision over any kind of network service.



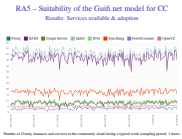
RA5 – Suitability of the Guifi.net model for CC

Results: Services available & adoption



Number of Cloudy instances and services in the community cloud during a typical week (sampling period: 1 hour).

Models for infrastructure in common
Research activities
RA5 – Analysis of the suitability of the Guifi.net model for cloud computing infrastructure
RA5 – Suitability of the Guifi.net model for CC
2022-04-03



RA5 – Suitability of the Guifi.net model for CC

Analysis of the results

Model as a whole

- Requires minor changes to fit cloud computing infrastructure

Economic system

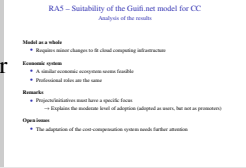
- A similar economic ecosystem seems feasible
- Professional roles are the same

Remarks

- Projects/initiatives must have a specific focus
  → Explains the moderate level of adoption (adopted as users, but not as promoters)

Open issues

- The adaptation of the cost-compensation system needs further attention



RA6 – Generalisation

Objective

- Generalise the results obtained through the proposition of a model suitable for other infrastructure

Methodology

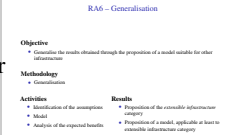
- Generalisation

Activities

- Identification of the assumptions
- Model
- Analysis of the expected benefits

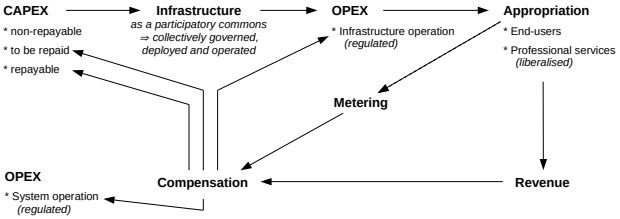
Results

- Proposition of the *extensible infrastructure* category
- Proposition of a model, applicable at least to extensible infrastructure category

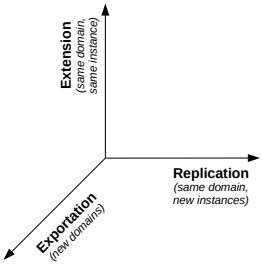


RA6 – Generalisation

Results



Flowchart of the model proposed.



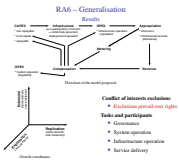
Growth coordinates.

Conflict of interests exclusions

- Exclusions prevail over rights

Tasks and participants

- Governance
- System operation
- Infrastructure operation
- Service delivery



RA6 – Generalisation

Analysis of the results

Expected benefits

- Optimisation of resource usage
- Non-discrimination
- True single market
- Lower prices
- Self-sustainable ecosystem
- Collective empowerment
- Local small-scale economy and funding
- Innovation
- Self-governed
- Replication and federation
- Decentralisation



Publications I

RQ1 *Does the approach followed by Guifi.net outperform the private sector model?*

RQ2 *Does the Guifi.net case have enough unique and beneficial features to be considered a model on its own?*

RA1 Gathering of performance indicators of Guifi.net [P2, P3] (Ch3)

RA2 Description of the differences between the Guifi.net approach and the private initiative model (Ch3)

RA3 Formalisation of the Guifi.net model [P2, P3, P5] (Ch4, Ch5)

Publications

[P2] Baig, R., Roca, R., Freitag, F., and Navarro, L. "Guifi.net, a crowdsourced network infrastructure held in common". In: *Computer Networks* 90 (Oct. 2015), pp. 150–165

[P3] Baig, R., Dalmau, L., Roca, R., Navarro, L., Freitag, F., and Sathiaseelan, A. "Making Community Networks Economically Sustainable, the Guifi.Net Experience". In: *Proceedings of the 2016 Workshop on Global Access to the Internet for All (GAIA)*. GAIA '16. Florianopolis, Brazil: Association for Computing Machinery, Aug. 2016, pp. 31–36

[P5] Cerdà-Alabern, L., Baig, R., and Navarro, L. "On the Guifi.net Community Network Economics". Unpublished, submitted at: *Computer Networks*. July 2019 (Moderate revision: resubmitted on 14 November, 2019)

Dissertation

(Ch3) Chapter 3 *Guifi.net– Overview*
(Ch4) Chapter 4 *Guifi.net– Governance*
(Ch5) Chapter 5 *Guifi.net– Economics*



In 1.5 *Contributions* and in Figure 1.2 *This dissertation structure* Ps and Os are organised around RQs. Conversely, in these slides are only Ps are mapped and are organised around RAs (following the reviewers' advice).

Publications II

RQ3 *Does the Guifi.net model apply other infrastructures?*

RA4 Identification of the key factors in CNs' scalability and the related patterns [P4, 01, O7, O8] (Ch6)

Publications

[P4] Baig, R., Navarro, L., and Roca, R. In: *The Community Network Manual: How to Build the Internet Yourself*. Ed. by Belli, L. Rio do Janeiro: FGV Direito Rio, Nov. 2018. Chap. Multiple Dimensions of Community Network Scalability, pp. 133–158

[O1] Micholia, P., Karaliopoulos, M., Koutsopoulos, I., Navarro, L., Baig, R., Boucas, D., Michalis, M., and Antoniadis, P. "Community Networks and Sustainability: A Survey of Perceptions, Practices, and Proposed Solutions". In: *IEEE Communications Surveys Tutorials* 20.4 (Dec. 2018), pp. 3581–3606

[O7] Crabu, S., Navarro, L., Baig, R., Dulong de Rosnay, M., Franquesa, D., and Treguer, F. *netCommons Deliverable D1.3 Report on the Governance Instruments and their Application to CNs*. Deliverable. European Commission, June 2017

[O8] Navarro, L., Baig, R., Freitag, F., Dimogerontakis, E., Treguer, F., Dulong de Rosnay, M., Maccari, L., Micholia, P., and Antoniadis, P. *netCommons Deliverable D1.2 Report on the Existing CNs and their Organization (v2)*. Deliverable. European Commission, Sept. 2016

Dissertation

(Ch6) Chapter 6 *Scalability in community networks*



Publications III

RQ3 *Does the Guifi.net model apply other infrastructures?*

RA5 Analysis of the suitability of the Guifi.net model for cloud computing infrastructure [P1, O4] (Ch7)

Publications

[P1] Baig, R., Freitag, F., and Navarro, L. "Cloudy in Guifi.net: Establishing and sustaining a community cloud as open commons". In: *Future Generation Computer Systems* 87 (Oct. 2018), pp. 868–887

[O4] Baig, R., Centelles, R. P., Freitag, F., and Navarro, L. "On edge microclouds to provide local container-based services". In: *2017 Global Information Infrastructure and Networking Symposium (GIIS)*. St. Pierre, France, Oct. 2017, pp. 31–36

Dissertation

(Ch7) Chapter 7 *Applicability to cloud computing*



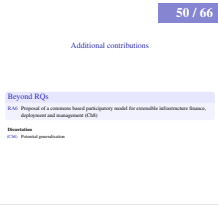
Additional contributions

Beyond RQs

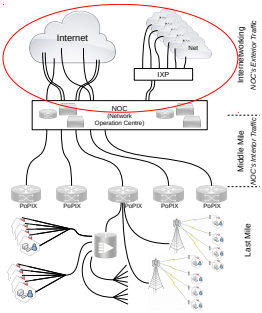
RA6 Proposal of a commons based participatory model for extensible infrastructure finance, deployment and management (Ch8)

Dissertation

(Ch8) Potential generalisation



Exterior traffic cost-sharing in Guifi.net



The Guifi.net network architecture.

Item	Cost centre: Exterior t.	Interior t.	Rack s.	MAP [months]
Hardware (routers, switches, etc.)	✓	✓	–	36
Insurance (annual fees)	✓	✓	✓	12
Administration	✓	✓	✓	–
Management	✓	✓	–	–
Technical support	✓	✓	–	–
Legal support (outsourced – monthly fee)	✓	✓	✓	–
Housing – acquisition cost	–	–	✓	36
Housing – monthly fee (including electricity)	–	–	✓	–
Housing – shared hardware slots	✓	✓	–	–
IXP – monthly fee	✓	–	–	–
carriers – monthly fee	✓	–	–	–
Middle-mile circuit – acquisition cost	–	–	✓	36
Middle-mile circuit – interconnection costs	–	–	✓	36
Middle-mile circuit – monthly fee	–	–	✓	–

Most significant NOC's costs, cost centre's assignments (✓: assignment applies, –: assignment does not apply) and maximum amortisation period (MPA).

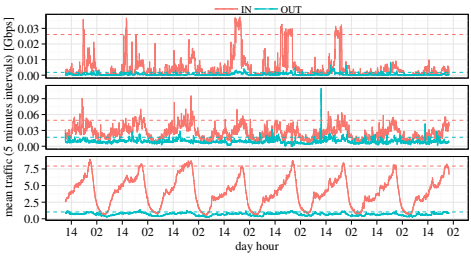
Exterior traffic cost-sharing in Guifi.net



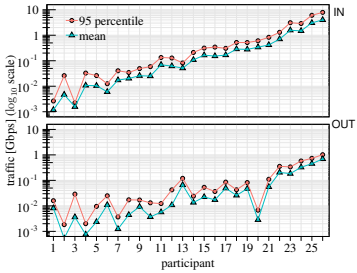
The Guifi.net network architecture.

Most significant NOC's costs, cost centre's assignments (✓: assignment applies, –: assignment does not apply) and maximum amortisation period (MPA).

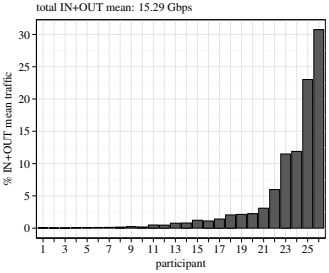
Datasets – Traffic



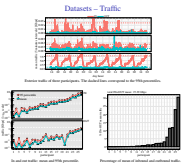
Exterior traffic of three participants. The dashed lines correspond to the 95th percentiles.



In and out traffic: mean and 95th percentile.



Percentage of mean of inbound and outbound traffic.



Datasets – Costs

	Cost centre			
	Exterior t. [€]	Interior t. [€]	Rack s. [€]	Total [€]
Exclusive	6,362.00	14,501.00	2,558.00	23,421.00
Shared	2,963.00	6,754.00	339.00	10,056.00
Total	9,325.00	21,255.00	2,897.00	33,477.00

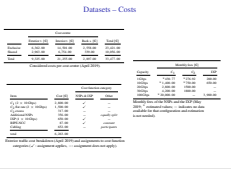
Considered costs per cost centre (April 2019).

		Cost function category	
Item	Cost [€]	NSPs & IXP	Other
C_1 (2 × 10 Gbps)	2,800.00	✓	—
C_2 flat rate (2 × 10 Gbps)	1,500.00	✓	—
C_2 excess	317.00	—	—
Additional NSPs	356.00	—	*equally split*
IXP (1 × 10 Gbps)	650.00	✓	—
RIPE-NCC	87.00	✓	*constant*
Cabling	652.00	—	*participants*
total	6,263.00		

Exterior traffic cost breakdown (April 2019) and assignments to cost function categories (✓: assignment applies, —: assignment does not apply).

	Monthly fees [€]		
Capacity	C_1	C_2	IXP
1 Gbps	*430.77	*276.92	200.00
10 Gbps	*1,400.00	*750.00	650.00
20 Gbps	2,800.00	1500.00	—
30 Gbps	4,200.00	1800.00	—
100 Gbps	*20,000.00	—	3,900.00

Monthly fees of the NSPs and the IXP (May 2019; * estimated values; — indicates no data available for that configuration and estimation is not needed).



Cost estimation model of a coalition A

Total cost of A:

$$c(A) = \sum_{i \in \{C_1, C_2, \text{IXP}\}} c_i(A) + c_h(A)$$

NSPs and IXP costs:

$$c_i(A) = \min \sum a_{ij}\, n_{ij},$$
$$\text{s.t.} \sum b_{ij}\, n_{ij} \geq d_i(A)$$
$$n_{ij} \geq 0,\ n_{ij} \in \mathbb{Z}$$

where n_{ij} is the number of links of type j, with cost a_{ij} for a bandwidth of b_{ij} Gbps (rows in *Monthly fees of the NSPs and the IXP* table), and $d_i(A)$ is the demand given by:

$$d_i(A) = K_i\, \alpha_i\, q(A), \quad i \in \{C_1, C_2, \text{IXP}\}$$

with:

$$q(A) = \max(q_{in}(A), q_{out}(A))$$

and:

$$\alpha_i = \frac{q_i}{\sum q_i}, \quad i \in \{C_1, C_2, \text{IXP}\}$$

Other costs:

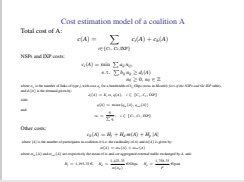
$$c_h(A) = H_f + H_d\, m(A) + H_p\, |A|$$

where $|A|$ is the number of participants in coalition A (i.e. the cardinality of A) and $m(A)$ is given by:

$$m(A) = m_{in}(A) + m_{out}(A)$$

where $m_{in}(A)$ and $m_{out}(A)$ are respectively the mean of *in* and *out* aggregated external traffic exchanged by A, and:

$$H_f = 1{,}193.33\,€, \quad H_d = \frac{1{,}423.33}{m(A_P)}\,€/\text{Gbps}, \quad H_p = \frac{1{,}758.33}{P}\,€/\text{part.}$$



Cost-sharing

Guifi.net's cost-sharing mechanism

Let P be the total number of participants, $P = 26$, and A_P the set of all participants. The total cost assigned to the set of all participants is:

$$c_T = c(A_P)$$

In Guifi.net a portion of the costs are equally weighted among the participants, and the rest are allocated according to their resource consumption:

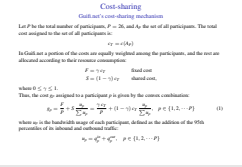
$$\begin{aligned} F &= \gamma\, c_T && \text{fixed cost} \\ S &= (1-\gamma)\, c_T && \text{shared cost,} \end{aligned}$$

where $0 \leq \gamma \leq 1$.
Thus, the cost g_p assigned to a participant p is given by the convex combination:

$$g_p = \frac{F}{P} + S\,\frac{u_p}{\sum u_p} = \frac{\gamma\, c_T}{P} + (1-\gamma)\, c_T\,\frac{u_p}{\sum u_p}, \quad p \in \{1, 2, \cdots P\} \tag{1}$$

where u_p is the bandwidth usage of each participant, defined as the addition of the 95th percentiles of its inbound and outbound traffic:

$$u_p = q_p^{in} + q_p^{out}, \quad p \in \{1, 2, \cdots P\}$$



Cost-sharing

Shapley value – Optimal γ

Let s_p be the cost assigned to participant p by the Shapley value. We call γ^* the value of γ in Equation (1) that minimises the mean square error with Shapley values (i.e. $\min_\gamma \sum (g_p - s_p)^2$).

Computing $\partial \sum (g_p - s_p)^2 / \partial \gamma = 0$, it can be easily found that a unique critical point exists and has a positive second derivative; thus, it is a global minimum. The value is given by the following:

$$\gamma^* = \frac{\sum_{p=1}^{P} (s_p / c_T - \eta_p)\,(1/P - \eta_p)}{\sum_{p=1}^{P} (1/P - \eta_p)^2}$$

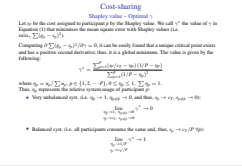
where $\eta_p = u_p / \sum u_p$, $p \in \{1, 2, \cdots P\}$, $0 \leq \eta_p \leq 1$, $\sum \eta_p = 1$.
Thus, η_p represents the relative system usage of participant p:

- Very unbalanced syst. (i.e. $\eta_{\hat{p}} \to 1$, $\eta_{p \neq \hat{p}} \to 0$, and thus, $s_{\hat{p}} \to c_T$, $s_{p \neq \hat{p}} \to 0$):

$$\lim_{\substack{\eta_{\hat{p}} \to 1,\ \eta_{p \neq \hat{p}} \to 0 \\ s_{\hat{p}} \to c_T,\ s_{p \neq \hat{p}} \to 0}} \gamma^* \to 0$$

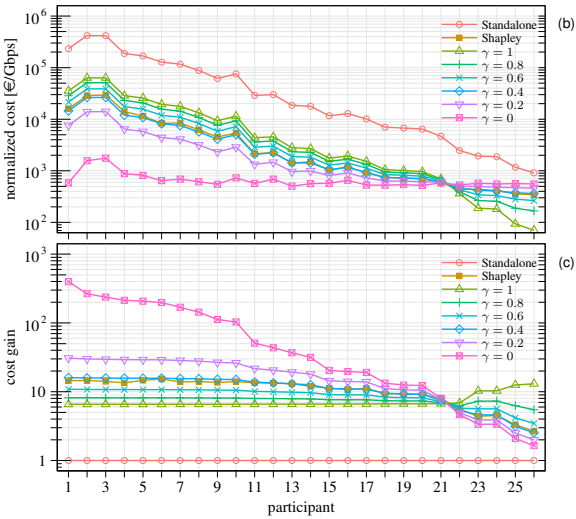
- Balanced syst. (i.e. all participants consume the same and, thus, $s_p \to c_T / P\ \forall p$):

$$\lim_{\substack{\eta_p \to 1/P \\ s_p \to c_T / P}} \gamma^* \to 1$$

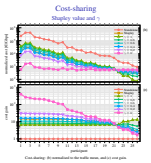


Cost-sharing

Shapley value and γ

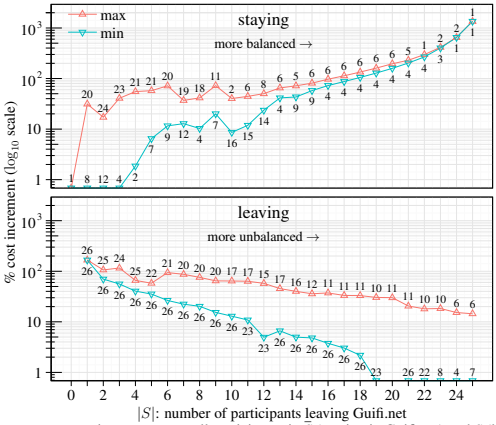


Cost-sharing: (b) normalised to the traffic mean, and (c) cost gain.

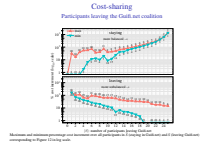


Cost-sharing

Participants leaving the Guifi.net coalition



Maximum and minimum percentage cost increment over all participants in $\bar{S}$ (staying in Guifi.net) and S (leaving Guifi.net) corresponding to Figure 12 in log scale.



Foreword
Industrial doctorate
Preliminary issues
Acronyms

Introduction
Infrastructure in our globalised world
Research overview
Research activities
Methodology

Research activities
RA1 – Gathering of performance indicators of Guifi.net
RA2 – Description of the differences between Guifi.net and the private initiative model
RA3 – Formalisation of the Guifi.net organisational model
RA4 – Identification of key factors in CNs scalability and related patterns
RA5 – Analysis of the suitability of the Guifi.net model for cloud computing infrastructure
RA6 – Proposal of a commons based participatory model for extensible infrastructure deployment and management
Scientific validation
Analysis of a case of cost-sharing

Conclusions
Conclusions
Further work

Bibliography



Summary of contributions

In the search of new models for infrastructure deployment and management, our main contributions are:

- Demonstration that Guifi.net outperforms the current models for infrastructure management in many aspects, and, that in no case performs worse
- Refinement of some of the policies and practices of Guifi.net (e.g. clarification of roles, improvement of cost-sharing mechanisms)
- Documentation of an *intrinsically* artificial CAPEX intensive resource built and managed as an open CPR
- Verification of the application of the E. Ostrom principles to our case study
- Identification of scalability and exportability factors of the Guifi.net model
- Proposal of a generalisation of the model for *extensible infrastructure*
- Documentation of a case in which +participation in the governance $\Rightarrow$ +better performance

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Conclusions

Related to RQ1

- The approach followed by Guifi.net, and its underlying conception of the network infrastructure as a CPR, outperform the main current infrastructure models in terms of
  1. Opportunities for participation in the governance and the economic systems
  2. Resilience against unbalanced influences
  3. Capacity to aggregate sources of funding
- using similar
  - technical solutions

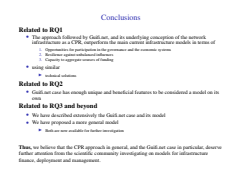
Related to RQ2

- Guifi.net case has enough unique and beneficial features to be considered a model on its own

Related to RQ3 and beyond

- We have described extensively the Guifi.net case and its model
- We have proposed a more general model
  - Both are now available for further investigation

Thus, we believe that the CPR approach in general, and the Guifi.net case in particular, deserve further attention from the scientific community investigating on models for infrastructure finance, deployment and management.



Open issues & further work

As a whole, a significant part of our work are contributions to relatively unexplored fields, thus, they require further analysis and validation.

In addition, we have left open the following **specific** open issues:

- Submit the generalisation presented in Ch8 to the peer-review process (paper), and
- Further investigate its the consistency and completeness, on the proposed concept of *extensible infrastructure*, and on the suitability for other infrastructure (PhD?)
- Follow the on-going discussion in the Guifi.net (field study)
- Investigate how to address the research requiring significant amount of resources which is currently in the hands of the private sector. Through partnerships with universities? An opportunity to boost public knowledge? (paper?, PhD?)

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Related publications

Main publications

[P1] Baig, R., Freitag, F., and Navarro, L. "Cloudy in Guifi.net: Establishing and sustaining a community cloud as open commons". In: *Future Generation Computer Systems* 87 (Oct. 2018), pp. 868–887

[P2] Baig, R., Roca, R., Freitag, F., and Navarro, L. "Guifi.net, a crowdsourced network infrastructure held in common". In: *Computer Networks* 90 (Oct. 2015), pp. 150–165

[P3] Baig, R., Dalmau, L., Roca, R., Navarro, L., Freitag, F., and Sathiaseelan, A. "Making Community Networks Economically Sustainable, the Guifi.Net Experience". In: *Proceedings of the 2016 Workshop on Global Access to the Internet for All (GAIA)*. GAIA '16. Florianopolis, Brazil: Association for Computing Machinery, Aug. 2016, pp. 31–36

[P4] Baig, R., Navarro, L., and Roca, R. In: *The Community Network Manual: How to Build the Internet Yourself*. Ed. by Belli, L. Rio do Janeiro: FGV Direito Rio, Nov. 2018. Chap. Multiple Dimensions of Community Network Scalability, pp. 133–158

[P5] Cerdà-Alabern, L., Baig, R., and Navarro, L. "On the Guifi.net Community Network Economics". Unpublished, submitted at: *Computer Networks*. July 2019 (Moderate revision: resubmitted on 14 November, 2019)

Other publications

[O1] Micholia, P., Karaliopoulos, M., Koutsopoulos, I., Navarro, L., Baig, R., Boucas, D., Michalis, M., and Antoniadis, P. "Community Networks and Sustainability: A Survey of Perceptions, Practices, and Proposed Solutions". In: *IEEE Communications Surveys Tutorials* 20.4 (Dec. 2018), pp. 3581–3606

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[O7] Crabu, S., Navarro, L., Baig, R., Dulong de Rosnay, M., Franquesa, D., and Treguer, F. *netCommons Deliverable D1.3 Report on the Governance Instruments and their Application to CNs*. Deliverable. European Commission, June 2017

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Development and management of collective network and cloud computing infrastructures

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PhD Defence

18 November, 2019



Models for infrastructure in common

2022-04-03

