Infrastructure and service provider games in crowdsourced networks

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MOTIVATION - FRAMEWORK

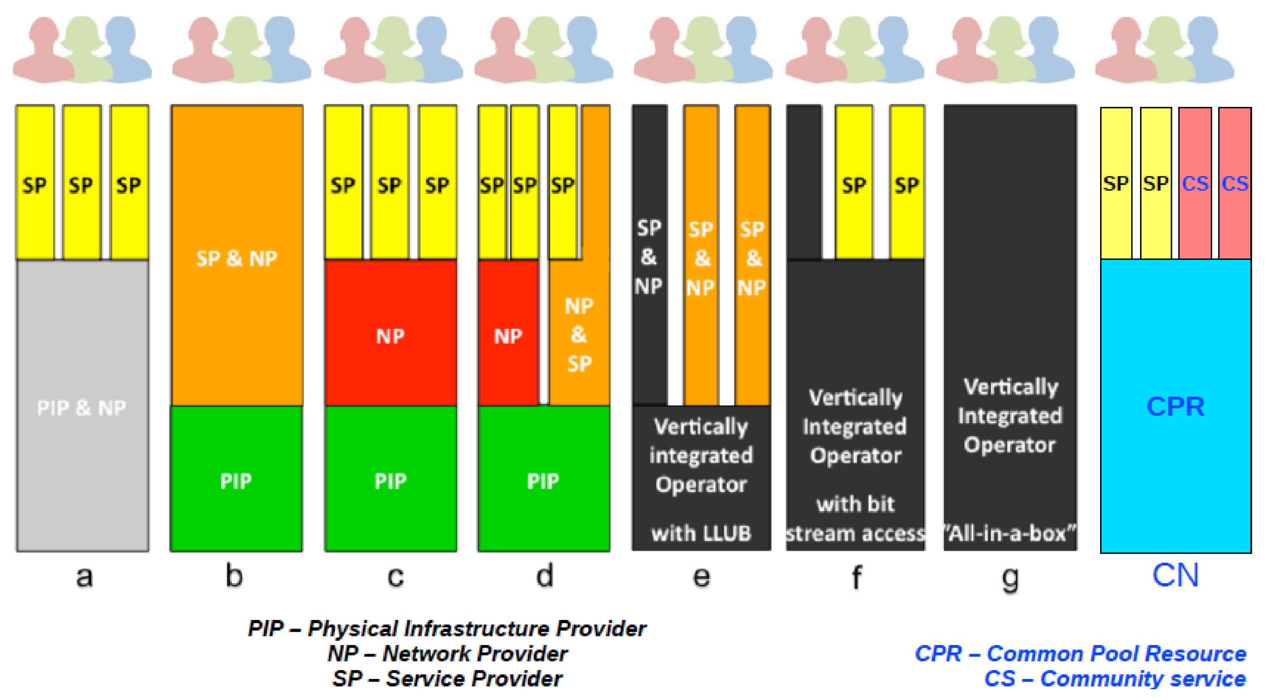
Ambitious network connectivity agendas demand costly network infrastructure

- *Broadband Europe 2020 and 2025* → digging costs for installing fiber
- *5G mobile cellular networks* → ultra-dense radio access points, site leasing and maintenance + digging costs for fiber at the backhaul
- *Connect another billion of users* → overall cheaper solutions but their sustainability is a challenge

Need to diffuse costs across as many stakeholders as possible (private sector, public agencies, users).

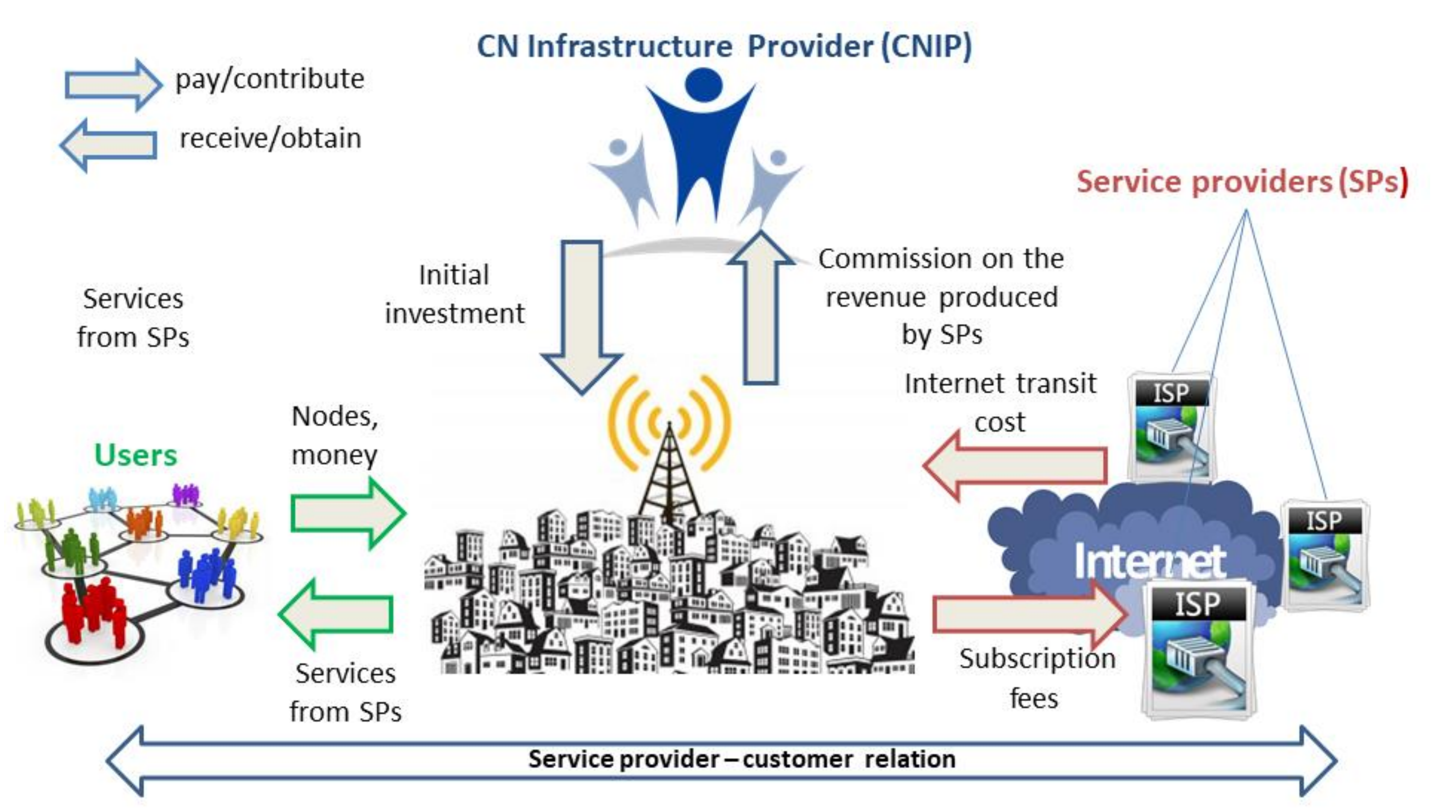
Different ways to share roles and costs in the telecommunication sector

- From "All-in-a-box" vertical integration (f) to open business models with full functional separation (c)
  - Physical infrastructure provider (PIP) ≠ Network provider (NP) ≠ Service provider (SP)



Scenario in this work : Community Networks as PIP + NP with SPs using the shared infrastructure to provide services

SYSTEM MODEL



Community Network Infrastructure Provider

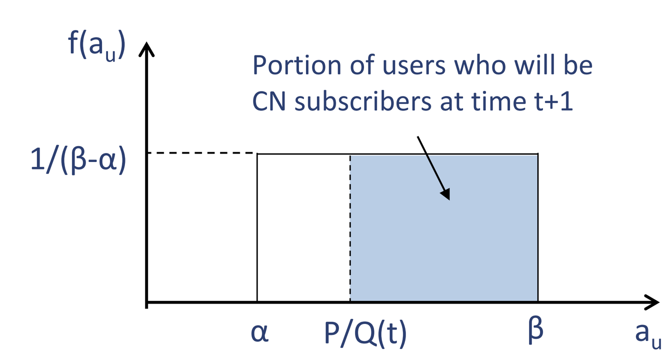
- makes the initial investment in the CN setting up the first nodes and endowing the CN with initial coverage $Q_0 = g(c_0)$
- charges a commission h on the profits of SPs

M Service Providers (SP)

- fixed pricing : charge a monthly subscription fee for Internet access over the CN, p_i
- share the Internet transit cost in proportion to the traffic q_i their customers generate, $c_i = \frac{q_i}{\sum_{j=1}^{M} q_j} C(\sum_{j=1}^{M} q_j)$

End users (in line with [1])

- join the CN at time t and contribute their own equipment to it if $a_u Q(t) - \text{avg}(\boldsymbol{p}) \geq 0$



Steady-state CN coverage $Q_e = f(Q_0, \boldsymbol{p})$

Market share per SP_i : $N_i = \frac{N Q_e}{1 + \sum_{j \neq i} e^{w_i p_i - w_j p_j}}$, w_i reflecting how SP_i scores beyond fees

[1] M. H. Manshaei, J. Freudiger, M. Felegyhazi, P. Marbach, and J.-P. Hubaux. On Wireless Social Community Networks. In Proc. 27th IEEE INFOCOM, 2008

[2] K. Kar and S. Banerjee. 2003. Node Placement for Connected Coverage in Sensor Networks. In Proc. IEEE WiOpt'03. Sophia Antipolis, France.

THE CROWDSOURCED NETWORK INFRASTRUCTURE GAME

A. SP pricing game $G_M(c_0) = \langle \mathcal{M}, (p_i)_{i \in \mathcal{M}}, (u_i)_{i \in \mathcal{M}} \rangle$

Payoff functions: $u_i = (1-h) N_i p_i - c_i,\ i \in \mathcal{M}$ (1)

At equilibrium : $\frac{\partial u_i}{\partial p_i} = 0,\ i \in \mathcal{M} \rightarrow p_i = f(c_0)$ (2)

B. Optimization of CNIP initial investment

CNIP payoff: $u_0 = h \sum_{i=1}^{M} N_i p_i - \frac{c_0}{d}$, d: desired investment recuperation period

Problem faced by CNIP

$$\max_{c_0} \quad u_0(c_0, \boldsymbol{p}(c_0))$$
$$\text{s.t.} \quad \text{avg}(\boldsymbol{p}(c_0)) \leq Q_0(\beta - (\beta - \alpha) Q_0)$$
$$(1), (2)$$
$$c_0 \geq 0,\ p_i \geq 0,\ i \in \mathcal{M}$$

NUMERICAL EVALUATION

A. Data-driven model parameterization

- Territorial characterization data

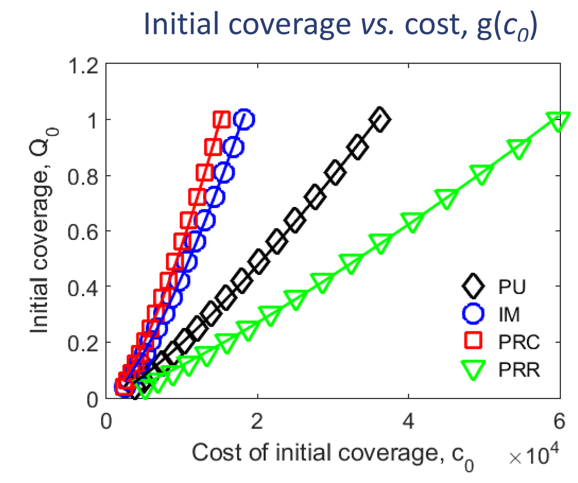
Scenario-Abbrv.	Buildings	km^2	Buildings/km^2
Pred. Urban - PU	43853	102	429
Intermediate - IM	6663	45	148
Pred. Rural close to a city - PRC	2052	34	60
Pred. Rural remote - PRR	4414	182	24

- Datasheets of networking devices

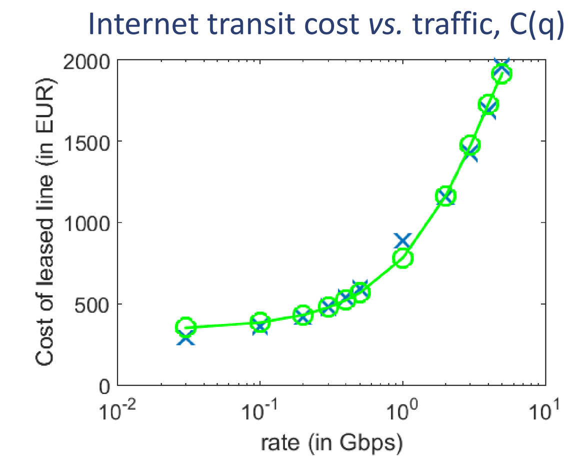
Name	Avg. Price (EUR)	Beamwidth (H,V) (degrees ^{0})	Transmission range (Km)
ISO90	200	90,30	1.34
ISO45	112	45,45	1.34
LB	73	20,10	3.79
NB	100	30,30	2.39
NS	134	60,20	1.69
NSL	49	50,40	1.20

- Connected coverage model [2]
- Online available tariff data from Spanish connectivity provider Xarxa Oberta)

Initial coverage *vs.* cost, $g(c_0)$

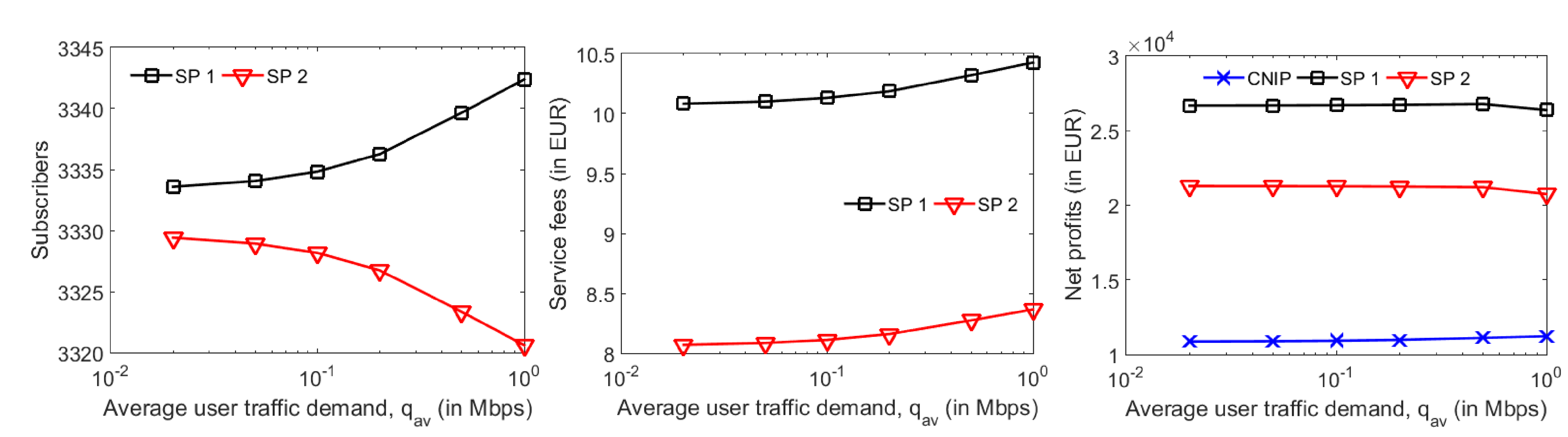


Internet transit cost *vs.* traffic, C(q)

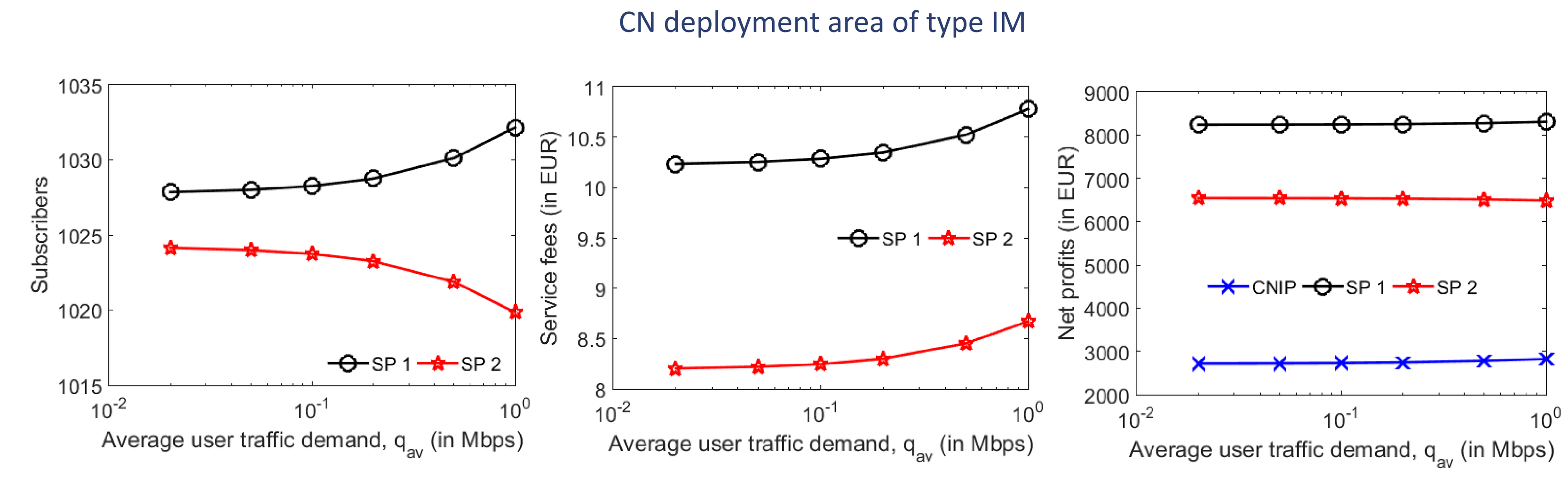


B. Numerical results

Two SPs, one CNIP, several different areas and user population profiles (a_v value distribution)



CN deployment area of type IM



CN deployment area of type PRC

- Overall, win-win Nash equilibria appear to exist for all actors
- Higher demand from users does not translate to higher revenues for SPs
  - the marginal increase of equilibrium fees is balanced out by the increased Internet transit costs
  - Yet, the CNIP investment needs to rise to make up for users who do not join the CN with the increased fees
- The CNIP is more vulnerable to the type of the area. Sparsely populated areas (PRR) need a higher up-front investment to trigger a sustainable market

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