Poster: Infrastructure and service provider games in crowdsourced networks

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ABSTRACT

Our paper analyzes the role that crowdsourced community network (CN) infrastructures could undertake in coping with the financing needs of ambitious broadband connectivity visions. Key to this role are open business models fostering synergies of CNs with commercial Internet Service Providers (SPs). In such synergies, the SPs make their pricing policies commensurate with the investment of the community in order to fuel the CN growth and generate a market for their services. At the same time, they compete with each other for customer shares in this market. We formulate the leader-follower game that emerges out of the strategic interactions of the actors and compute numerically its equilibrium states under a broad range of scenarios drawing on real data. In all cases, our results point to mutual profits for all actors, rendering such synergies win-win strategies.

CCS CONCEPTS

• **Networks** → **Wireless local area networks**; **Network economics**; **Network performance analysis**.

KEYWORDS

Shared network infrastructures, community networks, pricing, game theory, cost sharing mechanisms

1 INTRODUCTION

Ambitious plans for fixed broadband connectivity such as the Broadband Europe 2020 and 2025 agendas [1] or the more universal 5G vision [2] for the next generation of mobile systems call for huge investments in network infrastructures. These investments are primarily related to the digging costs and rights of way for deploying fiber cables, either as ingredients of fixed access technologies such as Fiber to the Curb/Home or as backhaul support for the 4G and the forthcoming 5G radio access networks. Sharing the infrastructures and their deployment costs appears to be inevitable and gives rise to diverse models of cooperation and competition between the different business actors in the telecom sector (network infrastructure providers, network operators, service providers).

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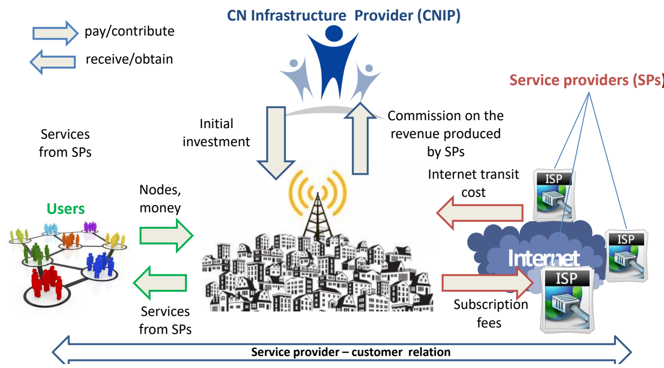

Figure 1: Shared CN infrastructure model.

In this paper, we focus on the dynamics that are brought to infrastructure sharing by grassroots network infrastructure deployment initiatives such as community networks (CNs). In view of ambitious yet costly connectivity agendas, CNs could evolve to catalysts of synergies between different telecom business actors for the economically sustainable deployment of network infrastructures.

We[1] explore these synergies through the lens of network economics. Contrary to prior studies, in our work the network infrastructure is deployed by a CN infrastructure provider (CNIP), which denotes the team of people who originally launch and operate the CN. They make an initial investment in the CN infrastructure, which then grows further as more users join the CN. The investment of the CNIP and the pricing policies of the SPs jointly determine the coverage of the CN at the steady-state, the market share attracted by each SP and the profits of involved actors.

2 SYSTEM MODEL AND GAME

Actors/roles. There are three actors in our model (Fig. 1):

The Community Network Infrastructure Provider (CNIP) corresponds to the small group of people who initiate and typically operate the CN. Often organized as a non-profit entity, their main concern is the sustainable funding of the CN. The CNIP invests an amount c_0, to purchase equipment and set up the first network nodes including labor expenses. The actual geographical coverage of the deployed network and the number of users N_0 the network can reach are non-decreasing functions of the invested amount, *i.e.*,

$$Q_0 = N_0(c_0)/N = g(c_0) \quad (1)$$

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The end users are typically community members who contribute their own equipment to the CN and assist with its growth, getting access to the services of one of the Internet Service Providers that operate over the CN. Their population N is taken equal to the maximum possible subscriptions out of the community; for instance, they could correspond to the number of households. Depending on the participation and contributions of end users, the CN may grow over time much larger than the original investment allowed; or, it may follow a path towards extinction. These two opposite possibilities for the CN evolution over time towards a final normalized user coverage Q_e are captured by the model in [4].

The (Internet) service providers (SPs) offer Internet access over the CN infrastructure, maintaining a customer relationship with the end users. Each service provider SP_i charges a monthly subscription fee p_i for its services. The fees that are chosen by the M SPs affect both the number of customers they will attract as a whole (portion Q_e of market) and their individual customer shares N_i

$$N_i(N, \mathbf{w}, \mathbf{p}) \doteq \frac{N \cdot Q_e}{1 + \sum_{j \neq i} e^{w_i p_i - w_j p_j}} \tag{2}$$

the vector of weights $\mathbf{w} = (w_1, w_2, .., w_M)$ essentially capturing how SPs score beyond the service fee (price) criterion.

The revenue of SP_i equals $N_i \cdot (1 - h) \cdot p_i$, after accounting for the commission h of the CNIP for the operation and maintenance of the shared CN infrastructure. At the same time, the SPs share the cost of Internet transit connectivity according to the average cost pricing (ACP) rule [5], implemented and supervised by the CNIP. The cost share of SP_i is given by

$$c_i^M(C; \overline{q}) = \frac{q_i}{\sum_{j=1}^{M} q_j} C(\sum_{j=1}^{M} q_j) \tag{3}$$

where $C(q)$ is the cost of the total Internet transit traffic produced by the customers of all M SPs and q_i is the traffic share produced by the customers of SP i. Hence, the net profit of SP_i out of the shared network infrastructure is

$$u_i = (1 - h) \cdot N_i \cdot p_i - c_i^M(C; \overline{q}), \; i \in \mathcal{M} \tag{4}$$

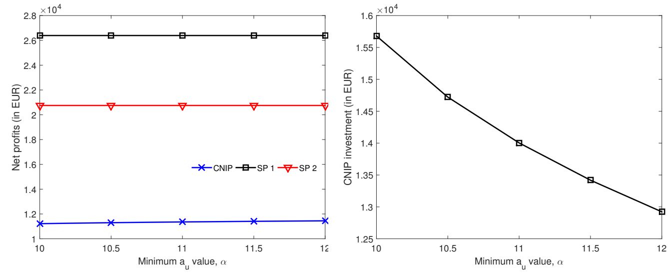
whereas the net profit of the CNIP is

$$u_0(c_0, \mathbf{p}) = h \cdot \sum_{i=1}^{M} N_i \cdot p_i - \frac{c_0}{d} \tag{5}$$

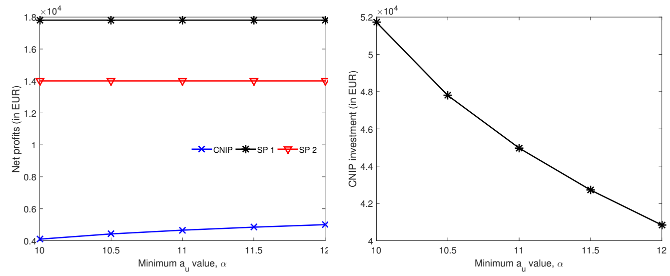
where d amortizes the investment cost c_0 over time (investment recuperation time).

The crowdsourced network infrastructure sharing game. The ultimate profit (or damage) of the CNIP and the SPs out of this layered network model depend on the original investment c_0 of the CNIP on network infrastructure and the pricing strategies of the SPs (pricing vector $\mathbf{p}$). SPs compete with each other for attracting customers but coordinate with the CNIP in generating a market large enough to render the business model profitable for all of them.

The strategic interactions of the actors can be captured within the framework of leader-follower games: the leader role is with the CNIP, and the follower players are the M SPs. For a given choice of the c_0 value invested by the CNIP, the choice of service subscription fees by SPs gives rise to the continuous *SP pricing* game $G_M(c_0)$. Solving the first-order optimality conditions for its Nash Equilibria (NE) strategies yields the service fees as function of the CNIP initial investment, $\mathbf{p}(c_0)$. The CNIP then, seeks to maximize its net profit $u_0(c_0, \mathbf{p}(c_0))$ (5) within the constraints of the first optimality conditions and the dynamics of the CN evolution. For the mathematic formulation and solution of the game, please refer to the technical report in [3].



a. Intermediate density network deployment area



b. Predominantly rural network deployment area

Figure 2: Net profits and initial investment needed by the CNIP at the equilibria of the game.

3 NUMERICAL RESULTS AND IMPLICATIONS

We compute numerically the game equilibrium states in scenarios with two Internet SPs. We have relied on real data to parameterize our model with realistic values (ref. [3]).

Results from a first set of experiments in Fig. 2 suggest that at the equilibrium states, all three entities, the CNIP and the two SPs, have profits. This is a necessary condition for such synergies. The second remark is that having users that assign higher weight to the network connectivity (higher a_u values) does not favor somehow the SPs: the subscription fees at the game equilibrium do not change. On the contrary, the CNIP entity can save in the order of 15-20% on the initial investment it has to make to launch the CN. This investment is significantly higher for areas with sparsely distributed population since its coverage demands more node installations. Higher investment costs demand higher cash flow on the CNIP side, who might need to resort to loans or seek for public subsidies.

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