Wireless Community Networks and 5G: the 7-Billion-User Challenge

netCommons

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Department of Information Engineering and Computer Science

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Organization: Three Sections

- S1 – 5G Implementation Paths and Community Networks : A Review of Current State of Affairs (Renato Lo Cigno)
- S2 – Edge Computing in CNs (Renato Lo Cigno)
    - ⇒ ***Coffee Break***
- S3 – Economic Sustainability in CNs and Incentives for Participation (Merkouris Karaliopoulos)

Economic Sustainability in CNs and Incentives for Participation

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Outline

The CN ecosystem

- stakeholder and roles

Incentives for participation in CNs

- intrinsic motivation
- “incentive mechanisms” in CNs

The economics of CNs

- CapEX *vs.* OpEX

Two ways to build infrastructure

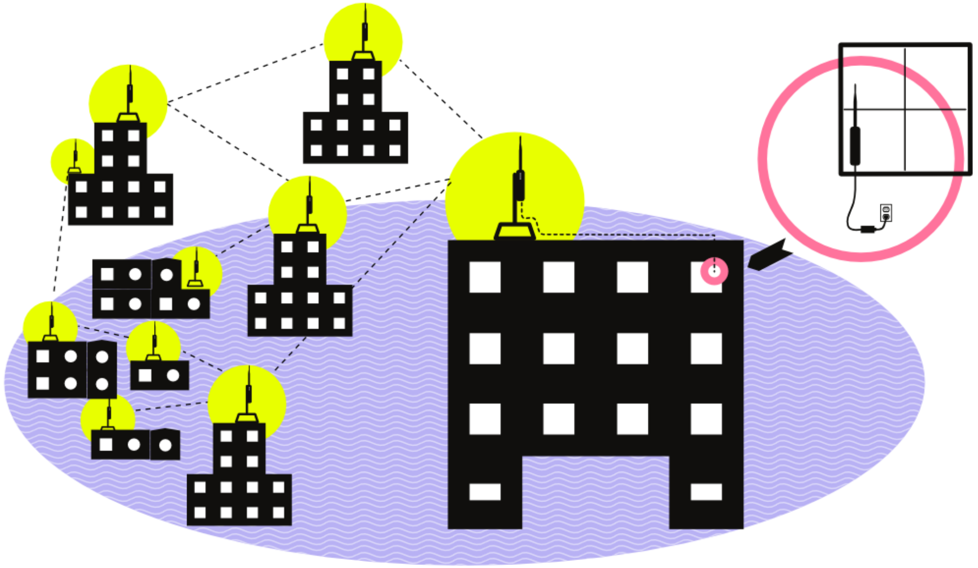
- evolutionary *vs.* up front
- modeling and insights

Sharing the operational cost

- among community members – collective subscriptions
- among for-profit service providers

The colorful mosaic of Community Networks

- High degree of differentiation with respect to
  - original motivation for their launch
  - topology
  - size
  - addressed local needs
  - organization and decision-making



- Similar variety in the “business models” of CNs
  - stakeholders
  - funding sources
  - cost-sharing mechanisms

CNs and economic sustainability

A battle on two fronts:

- **Within the community**
  - ensure the engagement of the community in the CN and their contributions to the CN maintenance and expansion
  - address the versatile aspirations of the community it serves : cultural, e.g., sensitivity to privacy, do-it-yourself mentality, autonomy; social, e.g., serve as a point of reference for strengthening the bonds within a community

- **Outside the community**
  - position itself properly with respect to other stakeholders such as commercial operators and service providers
  - call for sustainable synergistic business models!

Within the community : CN stakeholders

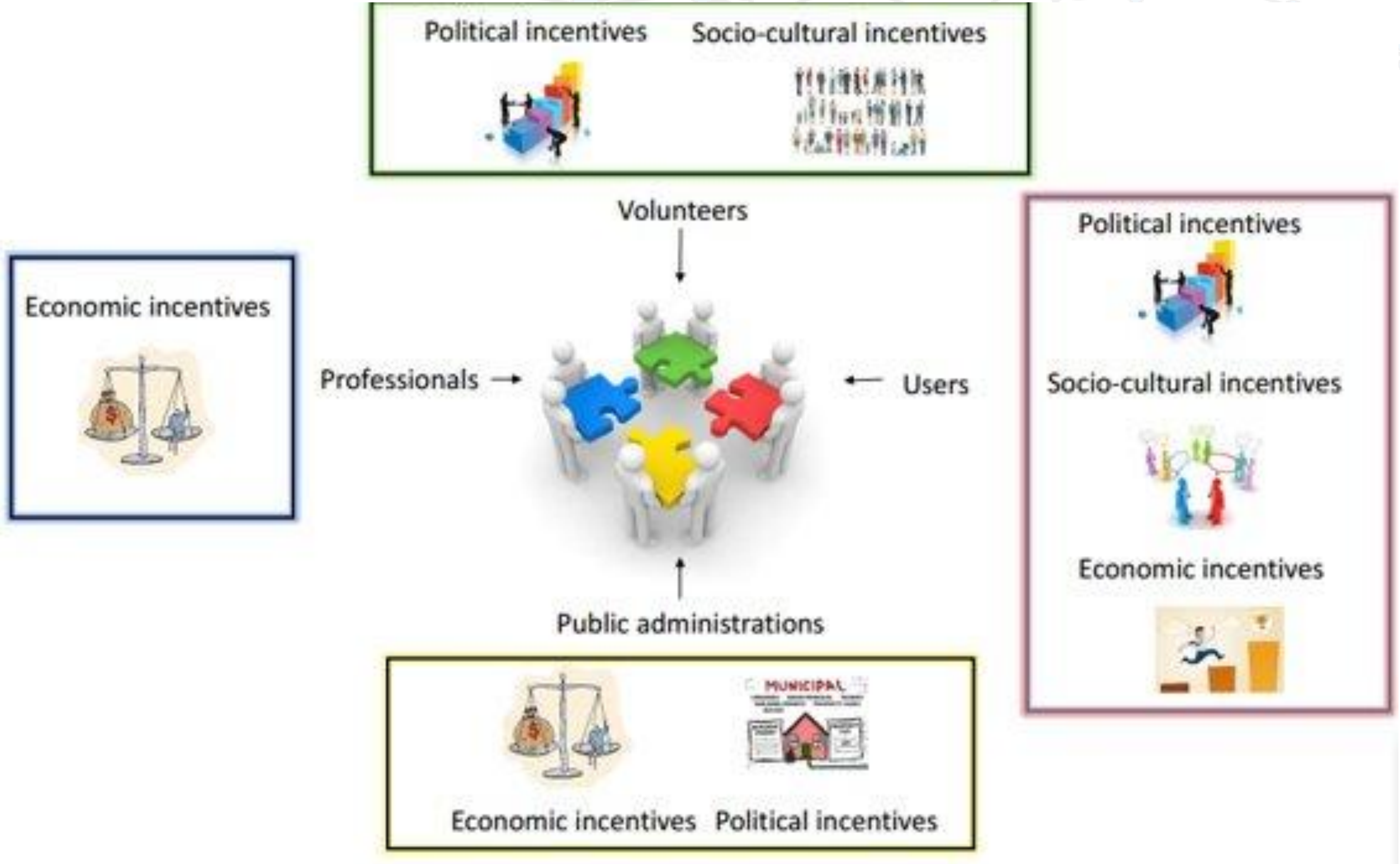
- **Group of volunteers :** people who set up, manage and maintain the CN
  - often bearing strong social and political ideals and organized in non-profit entities

- **Participant users :** people from the community who get engaged in the CN by contributing equipment, time, effort and use it
  - more often than not for Internet access, albeit not exclusively for it

- **Commercial for-profit entities (professionals) :** third-party entities that may want to provide services (e.g., Internet access, VoIP) over the CN infrastructure
  - their involvement is currently the exception rather than the rule
  - the trend slowly changes towards closer synergies

- **Public agencies (municipalities, regulation authorities, policy makers) :** public entities that may fund CN or support/undermine its purposes in indirect ways, e.g., through regulation actions

Intrinsic incentives for participating in CN



Motivation for different CN stakeholders

	Volunteers	CN users	Private sector entities	Public agencies
Economic motives		Direct economic benefits, indirect economic benefits	Economic incentives	
Political motives	Openness, net neutrality and privacy, autonomy and alternative communication models, bridging the digital divide	Openness, net neutrality and privacy, autonomy and self-organization	-	Bridging the digital divide, equal opportunities in the digital economy [15], market democratisation [17]
Socio-cultural motives	Experimentation with technology and DIY culture, community spirit and altruism	Experimentation and training with ICT, desire for social interaction, sensitivity to privacy	Social responsibility programs	Raising awareness for local community issues, favoring the engagement of citizens with the commons.

Incentive Mechanisms within the CN

- Measures taken by a CN to respond to the intrinsic motives of CN stakeholders or counteract phenomena and conditions that might weaken the motivation of CN participants (free riding/selfish behaviors, unclear CN legal status)

Incentive mechanisms

Enforcing fairness in users' contributions and interactions	Direct reciprocity-based mechanisms, indirect reciprocity-based mechanisms, punishment of free-riders, community currencies, game-theoretic mechanisms for enforcing participation, direct and indirect financial compensation.
Local data storage infrastructure	Community cloud computing.
Socializing processes and tools	Social events and meetings, new member induction processes.
Education and training	Workshops and seminars, online material for DIY fans.
Local applications and services as incentives	Proposed services (VoIP, community clouds, crowdsourcing applications), implemented services (instant messaging, email, wikis, forums, broadcasting, streaming, videoconferencing, etc.)
Lawful framework of operation	Operation as legal entities, licenses and agreements.

Educational material and training

Rationale : Satisfy users who like Do-It-Yourself who want to learn more about networks and technlology

Examples

- Online training and DIY material:
  - Most networks (e.g, Ninux, guifi.net, AWMN, Sarantaporo.gr) provide documentation with detailed technical instructions on how to set up a network node, the hardware needed, Frequently Asked Questions (FAQs)s, guides, etc.

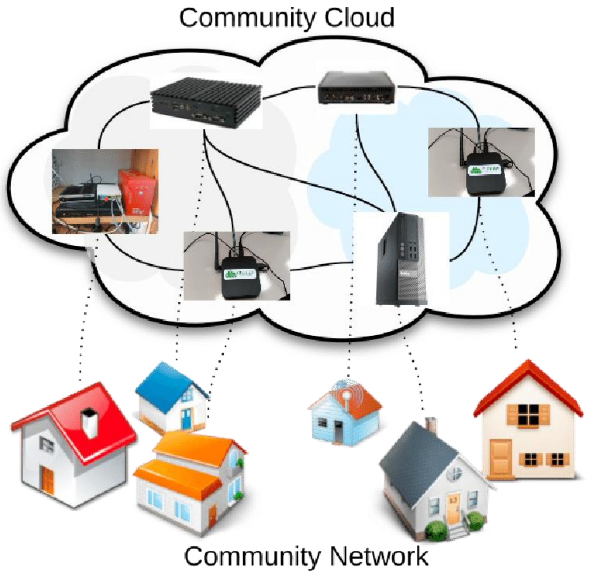
- Training seminars and sessions
  - Sarantaporo.gr : series of seminars and workshops in its area of coverage to inform people about the operation of the network and share knowledge over the wireless networking principles and the development of community networks.
  - guifi.net : workshops and learning seminars for end users or professionals known as guifi labs, the Salut, Amor i Xarxas (SAXs) ; supports related events, e.g., the GNOME Users And Developers European Conferences (GUADECs), World Summit for Free Information Infrastructures

Provision of local data storage infrastructure

Rationale : Addresses concerns of users about privacy, data sovereignty, and transparency with respect to data management practices

Examples

- Community clouds by guifi.net, a distributed cloud service implementation
  - Servers distributed across the CN
  - The Cloudy software, for managing services that use the community cloud infrastructure



Local applications

Rationale : Provide added value to the network through native applications running locally over the CN

Examples

- PeerStreamer in Ninux, Italy : P2P streaming application
- Cloudy in guifi.net , Spain: distributed community cloud solution
- AppLea in Sarantaporo.gr, Greece : an Android app-online assistant for farming activities and data sharing
- bunch of applications in AWMN, Greece
- …

Socializing processes

Rationale : Strengthen the community bonds and social links across members of the community

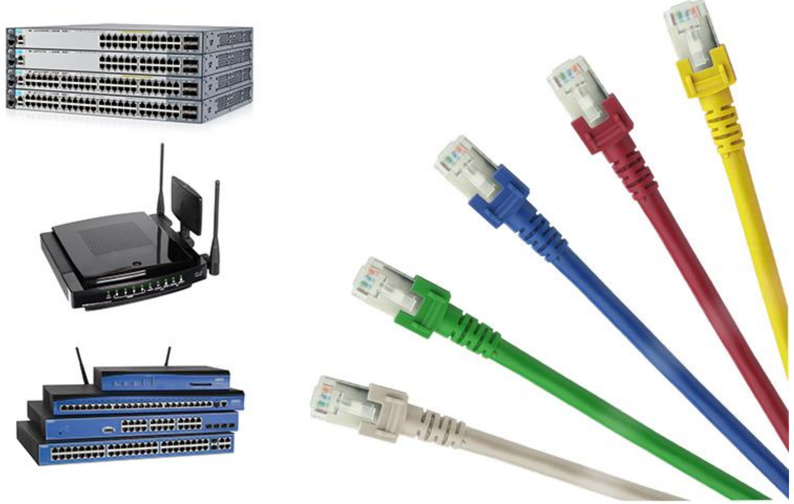
Examples (face-to-face meetings, new member induction processes)

- In guifi.net meetings take place every week or every month at the level of the local guifi.net communities and once a year at the level of the whole guifi.net.
- Meetings in Ninux are organized periodically at local level. Global meetings and events take place every few years.
- AWMN face-to-face meetings are also organized in AWMN by its Association; in most cases, groups of users take advantage of these events and go out together for coffee or drinks when they are over.
- Freifunk c-base gatherings and the annual ”Wireless Community Weekend” event is the way that Freifunk members and organizations get in touch with each other.

A network economics view of Community Networks

Capital *vs.* operational expenses

- **Capital expenses (CapEx)**
  - Equipment: access points, routers, antennas, servers
  - Installation costs
    - Mounting antennas and access points
    - Digging costs (when deploying fiber)



- **Operational expenses (OpEx)**
  - Cost of peering agreements for Internet access (leased lines)
  - Maintenance of network nodes
  - Software for network management, network monitoring, billing
  - Electricity costs

Revenue / funding sources

- **Member subscriptions and contributions in kind**
  - as in network equipment, time, effort
  - subscriptions maybe mandatory or voluntary

- **Donations from supporters**
  - crowd-funding, regular or one-time donations, investments in the infrastructure

- **Support from public agencies and institutions**
  - public funds from municipalities or local authorities
  - participation in European projects and grants from non-profit Institutions

- **Funding from private sector through commons-based policies**
  - synergies with entities undertaking commercial for-profit activities while keeping the non-profit character

High variety in the funding mix

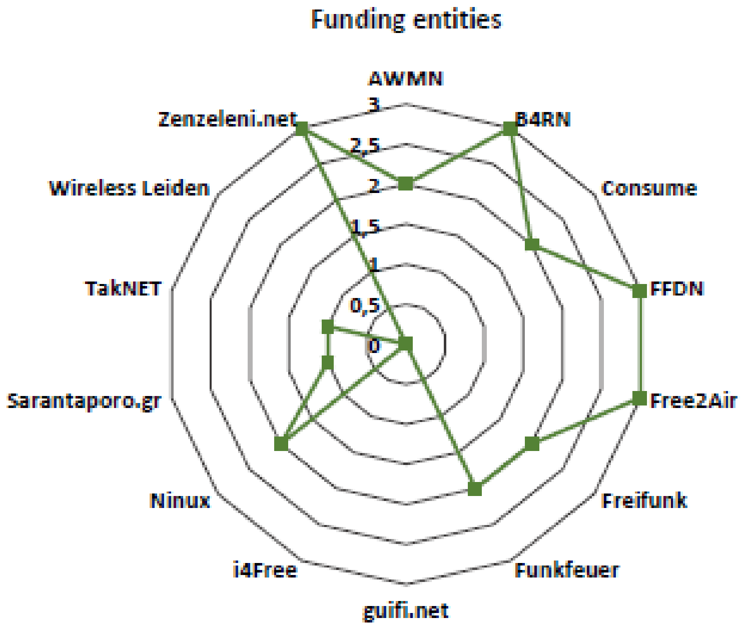


Fig. 5: Radar chart with CN funding entities in a 0-3 scale. *CN funding sources*. 0: mainly private entities' involvement, 1: mainly public agencies' involvement, small scale member contribution 2: mainly member contribution (donations, non regular fees), 3: member contribution only (regular fees).

- The dependence on each funding source varies across different CNs [1]
- In Europe, CNs that managed to scale in the order of 10k nodes rely primarily on member contributions
  - B4RN, guifi.net, Freifunk
- Little engagement of private sector in the initiatives
  - with a notable few exceptions (e.g., guifi.net in Spain)

The Sarantaporo.gr case study

Revenue mix 2016	Revenue mix 2017
• Grants/research programs: 63.7% • Donations: 10% • Member subscriptions: 23.7% • Services : 2.2%	• Grants/research programs : 57% • Donations: 2.5% • Member subscriptions: 36% • Services: 4%

- Heavy dependence on public funding
  - Internet Society programs, Ashoka, European R&D projects
  - occasional, non-sustainable funding source
- Community self-contributions grow
  - a sign of increasing participation and engagement

How is CN infrastructure deployed

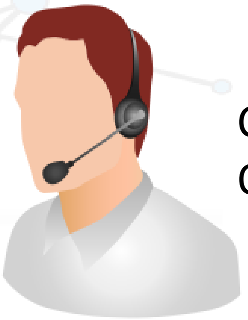
In two ways :

- In **evolutionary** manner – the usual way
  - First, some initial investment is made and some network nodes are set up
    - usually through contributions of volunteers from the community
    - othertimes based on public funding (grants, social cohesion or R&D programs)
  - Then, community members add their own nodes over time
    - an evolutionary process

- More rarely (e.g., B4RN case) the whole infrastructure is built **up front**
  - after securing the funding of the project by the community (consultation period)

Building CN infrastructure the evolutionary way

Stakeholders



Community Network Operator (**CNO**)

Set *N* of community members / potential CN users (**users**)

(optionally) public agencies funding the initial investment

Building CN infrastructure the evolutionary way

System model[2]: CNO

- The CNO carries out the initial investment and performs maintence and user/node management operations
  - at a cost c_s
- In return, it receives a subscription fee, f_s, from each CN user
  - typically, much smaller than what a commercial operator would charge
- His total revenue from the CN is
  - $R_{CNO} = N \cdot n_{sub} \cdot f_s - c_s$

  where n_{sub} is the portion of subscribers to the CN out of N, the pool of users (community members)

<u>Note</u> **:** · n_{sub} and R_{CNO} are both functions of time, that is $n_{sub}(t)$ and $R_{CNO}(t)$

Building CN infrastructure the evolutionary way

System model : CN users

- N = |N|, the size of the community (e.g., in households)
  - Essentially an upper bound on the number of subscriptions
- They decide to join the CN taking into account different criteria
  - e.g., in [2] the network coverage *Cov* and the subscription fee f_s so that the payoff of user u $\in N$ when joining the CN is

$$Poff_u = a_u \cdot Cov - f_s$$

- Users differentiate with respect to how much they weigh the network coverage, i.e., parameters a_u

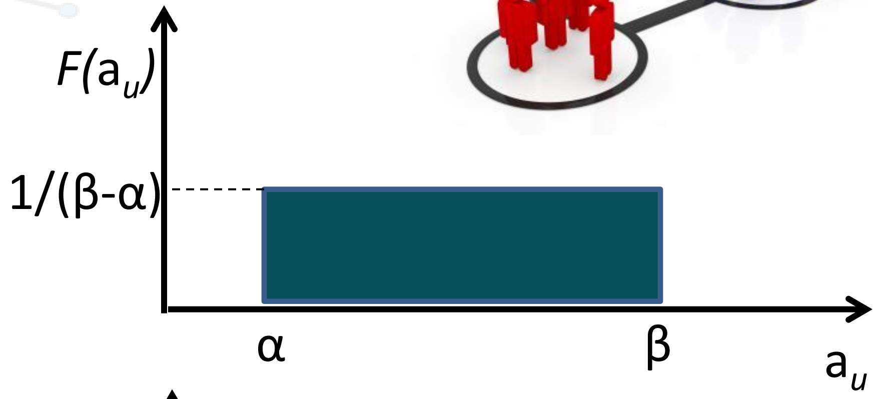
Building CN infrastructure the evolutionary way

System model : CN users

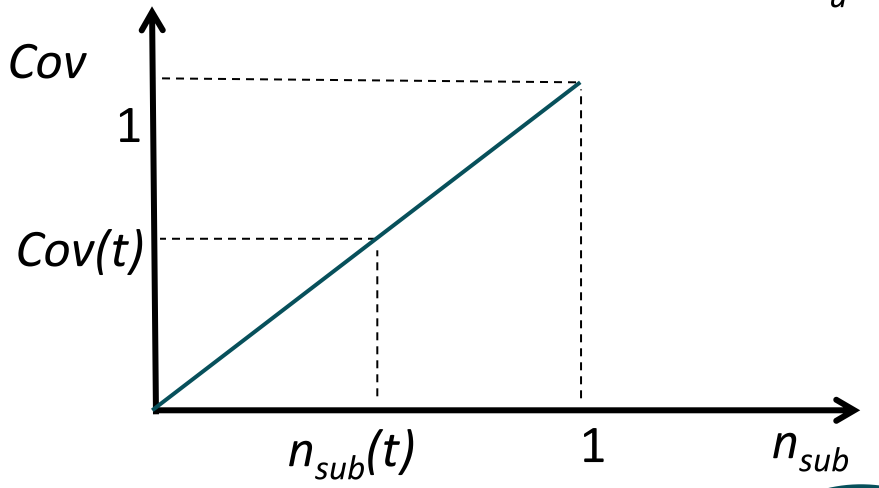
Two assumptions about users

- for the sake of model tractability rather than realism

- a_u ~ Unif (α,β) , with two cases:
  - $\beta \leq 2\alpha$ → *narrow* distribution
  - $\beta > 2\alpha$ → *wide* distribution



- Cov $\propto$ n_{sub}
  - also a function of time, Cov(t)



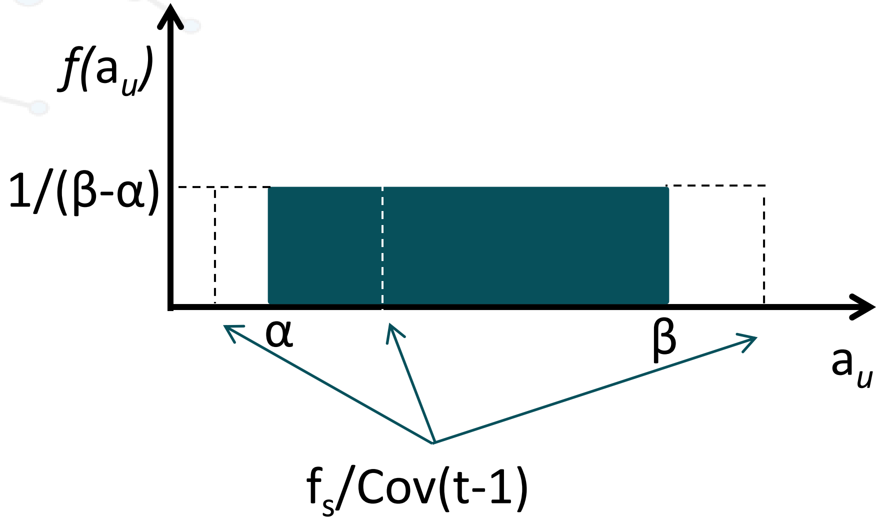
Building CN infrastructure the evolutionary way

Dynamics of CN growth

The CN coverage Cov(t) evolves over discrete time epochs

t =0, T, 2T, ….

$$Cov(t) = \frac{1}{\beta - \alpha} \max\{0, \beta - \max\{a, \frac{f_s}{Cov(t-1)}\}\}$$



<u>Remarks :</u>

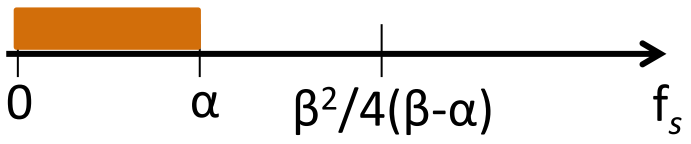
- if at time t-1, Cov(t-1) = 0, then Cov(t) = 0
  - no user will ever have positive $Poff_u(t) = a_u \cdot Cov(t-1) - f_s$ in order to join the CN
- if at time t-1, f_s/Cov(t-1) < α, then Cov(t) = 1 and all CN users subscribe to the CN
- otherwise, for given f_s, *a, β,* Cov(t-1) there are one or more equilibrium points Cov_{eq} with

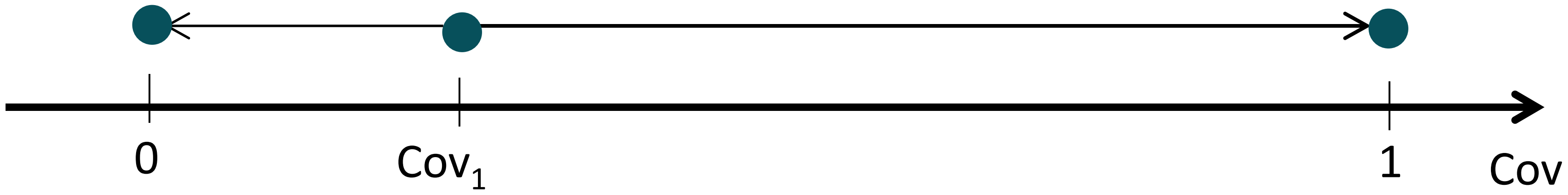
$$(\beta - \alpha) \cdot Cov_{eq}^2 - \beta \cdot Cov_{eq} + f_s = 0$$

Building CN infrastructure the evolutionary way

Dynamics of CN growth

Case $0 < f_s \leq \alpha$ (for both narrow and wide user distribution, small fee)



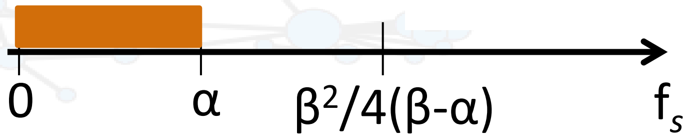


$$Cov_1 = \frac{\beta - \sqrt{\beta^2 - 4(\beta - \alpha) f_s}}{2(\beta - \alpha)}$$

- Three equilibrium points {0, Cov_1, 1}
  - if initial coverage Cov(0)= Cov_1, its coverage will remain Cov_1
  - If initial coverage Cov(0) < Cov_1, the CN will starve from users
  - If initial coverage Cov(0) > Cov_1, everyone will subscribe to the CN

Building CN infrastructure the evolutionary way

Dynamics of CN growth : Case 0 < fs < a



Example

$\alpha = 4, \beta = 7, f_s = 3 \rightarrow Cov_1 = 0.5657$

$$Cov(t) = \frac{1}{\beta - \alpha} \max\{0, \beta - \max\{a, \frac{f_s}{Cov(t-1)}\}\}$$

if $Cov(0) = Cov_1 - 0.01$

t	Cov[t]
0	0.5557
T	0.5339
2T	0.4604
3T	0.1615
4T	0

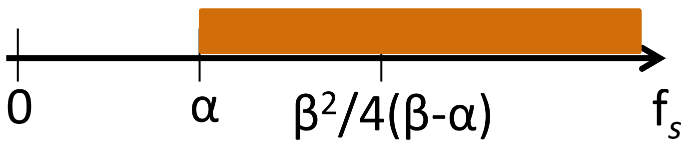
if $Cov(0) = Cov_1 + 0.01$

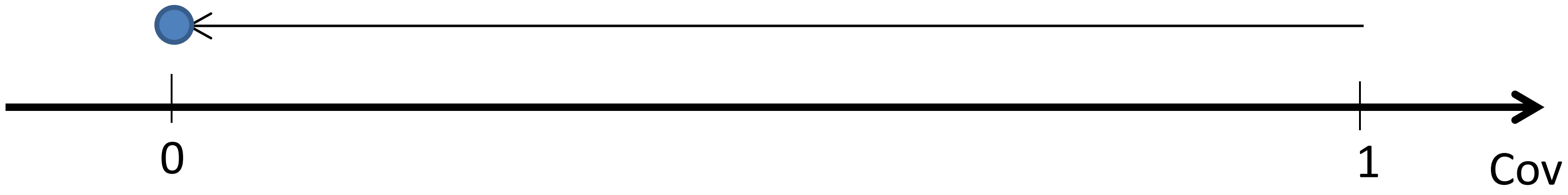
t	Cov[t]
0	0.5757
T	0.5964
2T	0.6567
3T	0.8106
4T	1.00

Building CN infrastructure the evolutionary way

Dynamics of CN growth : $\beta \leq 2\alpha$

Case $f_s > \alpha$ (higher fees)





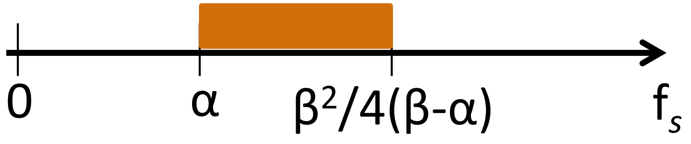
- The CN is condemned to starve from users!
  - regardless of the initial investment on it (initial coverage Cov(0))

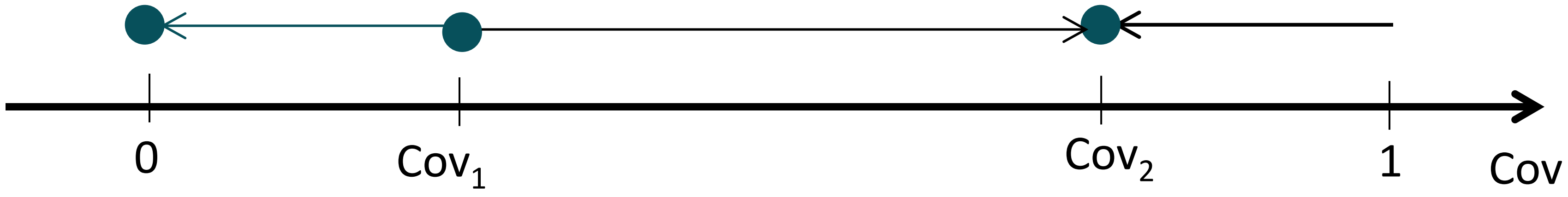
Independent of how much effort /money is initially invested in the CN (from community or public resources) , if the pricing policy is too "aggressive", the CN will end up with no users and die out.

Building CN infrastructure the evolutionary way

Dynamics of CN growth : $\beta > 2\alpha$

Case $\alpha < f_s \leq \beta^2/4(\beta-\alpha)$





$$Cov_1 = \frac{\beta - \sqrt{\beta^2 - 4(\beta-\alpha) f_s}}{2(\beta-\alpha)}$$

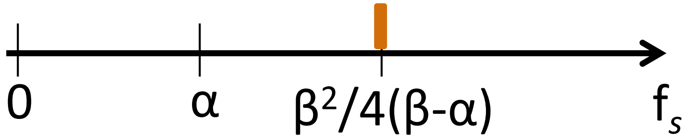
$$Cov_2 = \frac{\beta + \sqrt{\beta^2 - 4(\beta-\alpha) f_s}}{2(\beta-\alpha)}$$

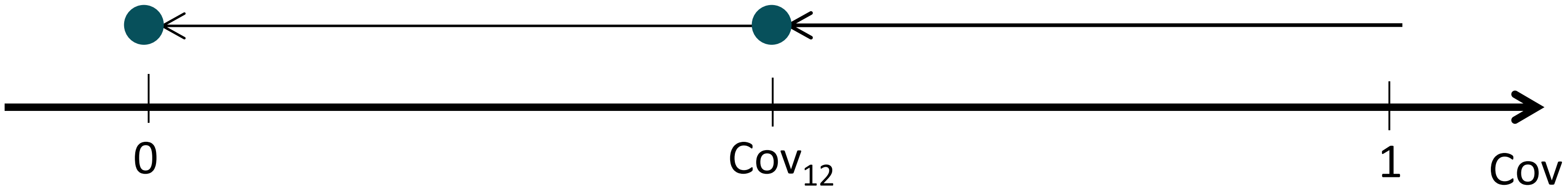
- Three equilibrium points {0, Cov_1, Cov_2}
  - If initial coverage Cov(0) < Cov_1, the CN will starve from users
  - If initial coverage Cov(0) > Cov_1 or Cov(0) > Cov_2 the CN coverage converges to Cov_2

Building CN infrastructure the evolutionary way

Dynamics of CN growth : $\beta > 2\alpha$

Case $f_s = \beta^2/4(\beta-\alpha)$





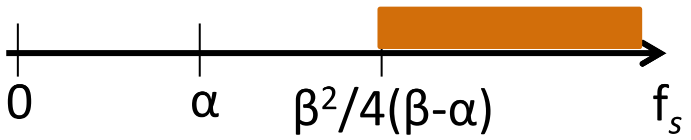
$$Cov_1 = \frac{\beta}{2(\beta-\alpha)} = Cov_2 = Cov_{12}$$

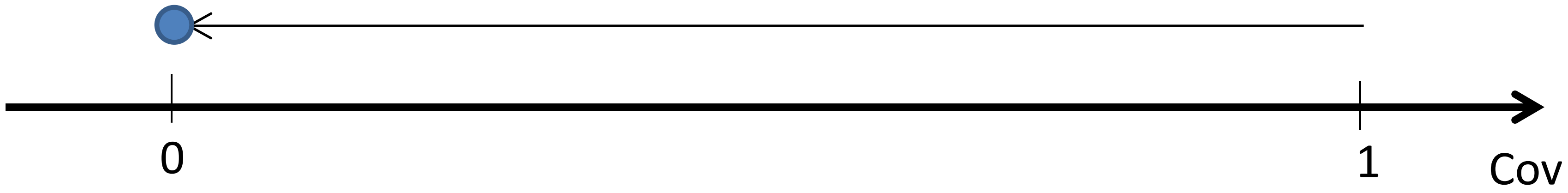
- Two equilibrium points $\{0, Cov_{12}\}$
  - if initial coverage $Cov(0) < Cov_{12}$, the CN will end up without any subscribers
  - If initial coverage $Cov(0) \geq Cov_{12}$, the CN will balance at $Cov = Cov_{12}$

Building CN infrastructure the evolutionary way

Dynamics of CN growth : $\beta > 2\alpha$

Case $f_s > \beta^2/4(\beta-\alpha)$





- The CN will not attract any subscribers
  - regardless of the initial investment on it (initial coverage Cov(0))

Hints for pricing and original investment

For narrow distribution of user types (β < 2α),

- The CN cannot attract subscribers as far as the initial network coverage is

$$Cov(0) < Cov_1 = \frac{\beta - \sqrt{\beta^2 - 4(\beta - \alpha) f_s}}{2(\beta - a)}$$

- The maximum subscription fee for which every user will subscribe to the CN relates to the initial coverage (investment) Cov(0) as

$$f_s = \mathrm{Cov}(0) \cdot (\beta - (\beta - \alpha) \cdot \mathrm{Cov}(0)) \leq \alpha$$

- For a wide distribution of user types, the CNO can opt for higher revenue, even if not everyone joins the CN

$$R_{CNO} = N \frac{4}{27} \frac{\beta^3}{(\beta - a)^2} - c_s$$

Building CN infrastructure up front

- The other approach, far less usual, to building infrastructure
  - more challenging → costs have to be gathered up front
  - fits better to the fiber network deployment, where digging is involved

- B4RN case
  - The deployment of fiber is carried out along projects set up between B4RN and villages
  - Projects are launched as far as 50% of the expenses are gathered from the community
  - Fiber is installed throughout the village, covering every house
    - Provisions are made for the financially weaker

Building CN infrastructure up front

Two main questions

Q1 : Should the project be launched at first place?

- Does it bear for the community members value that exceeds its cost?

Q2 : If yes, how should the cost be shared among the community members

- One possible answer : "equally among all participants"
  - Fair ? – a long discussion
  - This might render the project unfeasible (since cost shares adapt to the minimum a user is willing to pay)
    - although there are users who are willing to pay more because they benefit more
- Hence, the hint is that the cost share of each user should reflect the benefit she extracts from the project
  - but then how do we ensure that each user declares its real benefit from the project

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism [9]

- c : cost of the project
- $b_1, b_2, \ldots b_N$: real benefits of a set N of agents, $|N|$= N, if the project is carried out

Stage 1 : The agents simultaneously submit bids v_i about the *joint* benefit out of the project. Say, wlog, that v=v_{i^*} is the maximum bid and i* the agent who submits it

- if $v \leq c$ –> no project; otherwise, proceed in stage 2

Stage 2 : The agents submit bids $\beta_i \geq 0$ about their own valuations of the project.

- If $\Sigma\beta_i > v$, the project is carried out and the agents pay proportionally to their bids β_i
- If $\Sigma\beta_i < v$, the project is NOT carried out and agent 1 pays "compensation" fees to the rest
- If $\Sigma\beta_i = v$, agent 1 decides about the fate of the project

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism

- c : cost of the project
- $b_1, b_2, \ldots b_n$: real benefits of n agents if the project is carried out

If $\beta_N = \sum_{j \in N} \beta_j$ and $\gamma(\beta_i; \beta_1, \beta_2, \ldots, \beta_{i-1}, \beta_{i+1}, \ldots, \beta_n) = \gamma(\beta_i; \beta_{-i}) = \frac{\beta_i}{\beta_N} c$

then at stage 2

If the project is carried out ($\Sigma\beta_i > v$)

agent $i \in N \backslash \{i^*\}$ pays $csh_i = \gamma(v-\beta_{N\backslash\{i\}} ; \beta_{-i})$ if $\beta_{N\backslash\{i\}} \leq v$

agent i^* pays the residual cost , $csh_{i^*} = c - \sum_{j \in N \backslash \{i^*\}} csh_j$

If the project is NOT carried out ($\Sigma\beta_i < v$)

agent i^* pays each agent $j \in N \backslash \{i^*\}$ a fee $f_j = v-\beta_{N\backslash\{j\}} - \gamma(v-\beta_{N\backslash\{j\}} ; \beta_{-j})$

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism : properties

- truthful
  - at the Nash Equilibria, the agents submit the true total valuation of the project in the 1st stage ($v_i = \Sigma b_i$) and their true personal valuations ($\beta_i = b_i$)
- makes the right decisions
  - decides to carry out a project when its cost is outweighed by its benefits
  - the agents share the project cost according to their benefits from it
    - proportionately or in line with some other function
- budget-balanced
  - the cost shares of the agents sum up to the project cost; no more than this, no less than this

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism

Example : $N = 3$, $c = 10$, $b_1 = 8$, $b_2 = 5$, $b_3 = 2$

Scenario 1 (equilibrium) : $v_1 = 15$, $v_2 = 13$, $v_3 = 14$ and $\beta_1 = 8$, $\beta_2 = 5$, $\beta_3 = 2$

Winning bid at 1st stage $v = 15$ by agent 1. Since $v > c$ the project can be carried out

At stage 2, sum of bids $\beta_N = v$. Say that agent 1 decides that the project is carried out.

- Agent 2 pays $csh_{2,eq} = \gamma(v-\beta_{\{1,3\}}; \beta_1, \beta_3) = (15-8-2)c/15 = 5c/15 = c/3$
- Agent 3 pays $csh_{3,eq} = \gamma(v-\beta_{\{1,2\}}; \beta_1, \beta_2) = (15-8-5)c/15 = 2c/15$
- Agent 1 pays $c - csh_{2,eq} - csh_{3,eq} = c - c/3 - 2c/15 = (15-5-2)c/15 = 8c/15$

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism

Example : $N = 3$, $c = 10$, $b_1=8$, $b_2= 5$, $b_3 = 2$

Scenario 2 : $v_1 = 18$, $v_2= 13$, $v_3 = 14$ and $\beta_1 = 12$, $\beta_2 = 5$, $\beta_3 = 2$

Winning bid at 1st stage $v = 18$ by agent 1. Since $v > c$ the project can be carried out

At stage 2, sum of bids $\beta_N > v$, hence the project is carried out.

- Agent 2 pays $csh_2 = \gamma(v-\beta_{\{1,3\}}\,;\beta_1, \beta_3) = (18-12-2)c/18 = 4c/18 < c/3 = csh_{2,eq}$
- Agent 3 pays $csh_3 = \gamma(v-\beta_{\{1,2\}}\,;\beta_1, \beta_2) = (18-12-5)c/18 = c/18 < 2c/15 = csh_{3,eq}$
- Agent 1 pays $c - csh_2 - csh_3 = c - 4c/18 - c/18 = 13c/18 > 8c/15$

$\Rightarrow$ Agent 1 has no reason to pump up the *joint* and the *own* valuations since it ends up paying a higher cost share.

Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism

Example : $N = 3$, $c = 10$, $b_1=8$, $b_2= 5$, $b_3 = 2$

Scenario 3 : $v_1 = 15$, $v_2= 13$, $v_3 = 14$ and $\beta_1 = 6$, $\beta_2 = 5$, $\beta_3 = 2$

Winning bid at 1st stage v = 15 by agent 1. Since v > c the project can be carried out

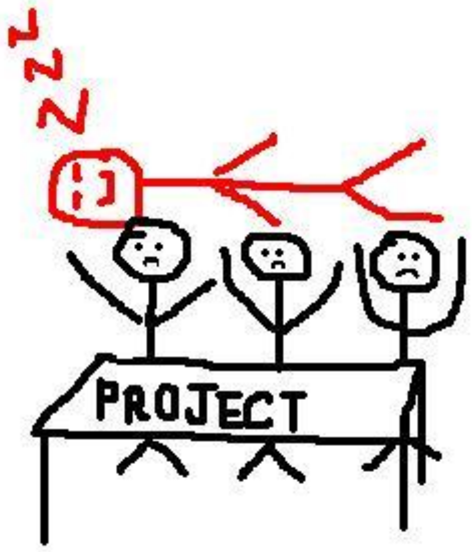
At stage 2, sum of bids $\beta_N < v$, hence the project is NOT carried out.

- Agent 1 pays agent 2 $f_2 = v-\beta_{N\backslash\{2\}}- \gamma(v-\beta_{N\backslash\{2\}}\,;\, \beta_{-2}) = 15-8 -7c/15 = 7-70/15 = 35/15 = 7/3$
- Agent 1 pays agent 3 $f_3 = v-\beta_{N\backslash\{3\}}- \gamma(v-\beta_{N\backslash\{3\}}\,;\, \beta_{-3}) = 15-11-4c/15 = 4-40/15 = 20/15 = 4/3$
- Agent 1 pays $f_2+ f_3 = 11/3$

$\Rightarrow$ Agent 1 has no reason to try to reduce its cost share after securing that the project is carried out

OpEX and free-riding

- Member subscriptions are more often that not optional and upon the user discretion
  - in many cases, this results in excessive **free riding** phenomena



- CNs cope with this in various ways
  - some of them trying innovative ideas to incentivize the user engagement
  - **Collective subscriptions** is one such idea tried in the case of Sarantaporo.gr

Collective subscriptions

the idea

- Turn users subscriptions to mandatory
  - but instead of charging individual CN users, charge the CN node owners/holders
    - attempt to accommodate the varying amounts users are willing to pay for membership and connectivity – *price ceilings*

- CN node subscription fees are common across nodes and equally shared between all CN users joining the subscription of a node
  - Two subscribers to the same node pay the same amount (equal share of the node subscription fee)
  - Two subscribers to different CN nodes may pay different amounts, depending on how many users join the subscription and what each one is willing to pay for joining the CN

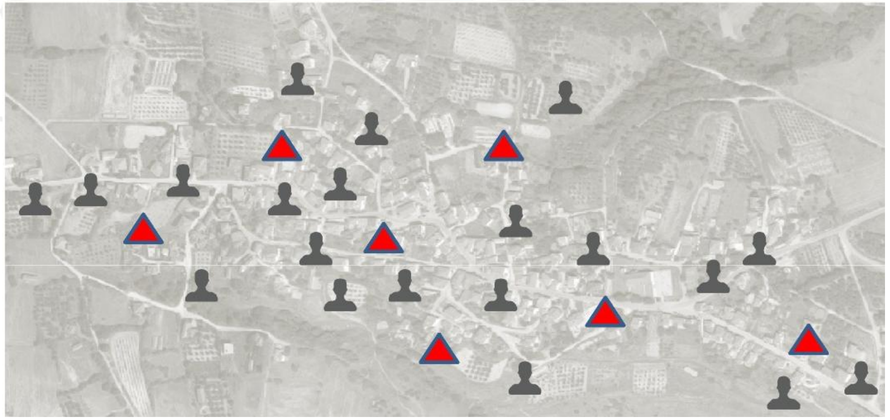
⇒ the more users join a CN node's subscription, the less the cost for each user (positive externality)

  - an incentive for CN node owners to recruit more users and for users to join CN nodes

Collective subscriptions : model

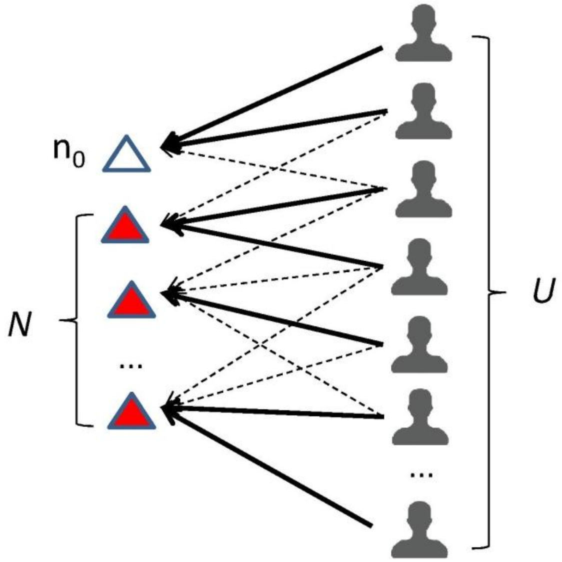
Set of (potential) CN users, *U*

- assess differently the Internet connectivity value → individual **price ceilings** prc_j , $j \in U$, with $|U| = U$
- each prefers to join a certain set of CN nodes N_u out of the full node set N, with $|N| = N$
  - e.g., those she uses most frequently, close to her house or neighborhood



CNO

- sets the node subscription fee f_s and distributes users to node subscriptions
  - when *k users* join a node, the fee each one pays is f_s/k
- seeks to maximize what can be collected but also let as many as possible join (non-profit orientation)



Collective subscriptions

Example : single node

5 users, with price ceilings (say in Euro) : $prc_1 = 15 > prc_2 = 13 > prc_3 = 12 > prc_4 = 8 > prc_5 = 5$

If the node subscription fee is set to:

- $f_s \leq$ 25, all five users can join, paying up to 5 each
- 25 $\leq f_s \leq$ 32, the first four users can join, paying up to 8 each
- 33 $\leq f_s \leq$ 36, the first three users can join, paying up to 12 each

CN node fee, f_s	25	32	36	26	15
Users who can subscribe	5	4	3	2	1

Optimizing collective subscriptions

Let $P = (p_0, p_1, p_2, \ldots, p_N)$ be a partition of CN users to the N nodes

- p_0 : set of users who do not join the CN (they cannot afford the fee)
- $k_n = | p_n |$, the number of users joining the subscription of node i

Then:

- The maximum fee the CNO can collect out of node *n* is $fee(n) = k_n \min_{u \in p_n} prc_u$
- The total fee that the CNO can collect out of the CN is $F_{CNO} = \min_{\substack{n \in N \\ k_n > 0}} fee(n) \cdot \sum_{n \in N} 1_{k_n > 0}$
- The objective of CNO is to

$$\begin{aligned} \max_{P} \quad & F_{CNO} \\ s.t. \quad & k_n = \sum_{u: n \in N_u} x_{un} \quad \forall n \in N \cup n_0 \\ & \sum_{n \in N_u} x_{un} = 1 \quad \forall u \in U \\ & x_{un} \in \{0,1\} \quad u \in U, n \in N \cup n_0 \end{aligned} \qquad \text{(OPT)}$$

Optimizing collective subscriptions (cont'd)

The problem (OPT) is NP-hard in the general case

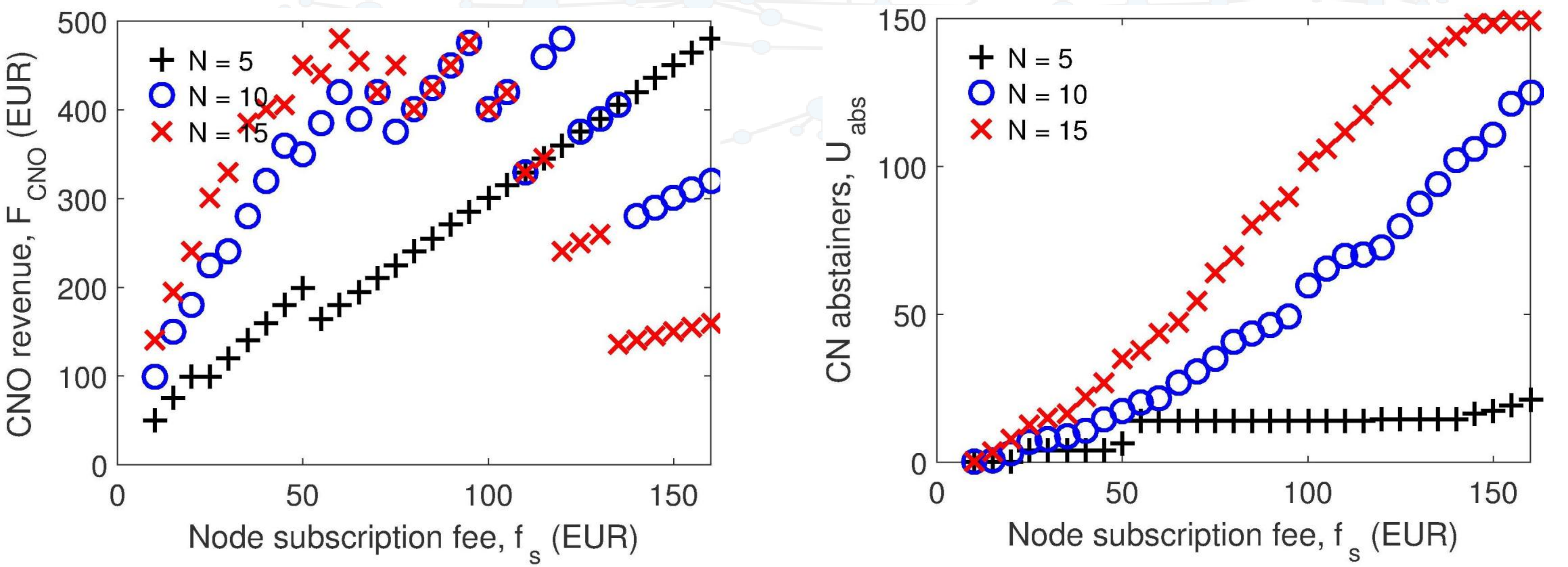
- different user price ceilings
- different user connectivity preferences (subscription sets N_u)

The problem simplifies under special cases:

- Common user price ceilings ($prc_u = prc_v = prc \ \forall u,v \in U$), symmetric connectivity preferences ($N_u = N$)
  - trivial solution to the assignment problem
- Different user price ceilings, symmetric connectivity preferences
  - restricted enumeration of possible solutions, complexity $O(U^N)$ rather than $O(N^U)$ in brute-force enumeration

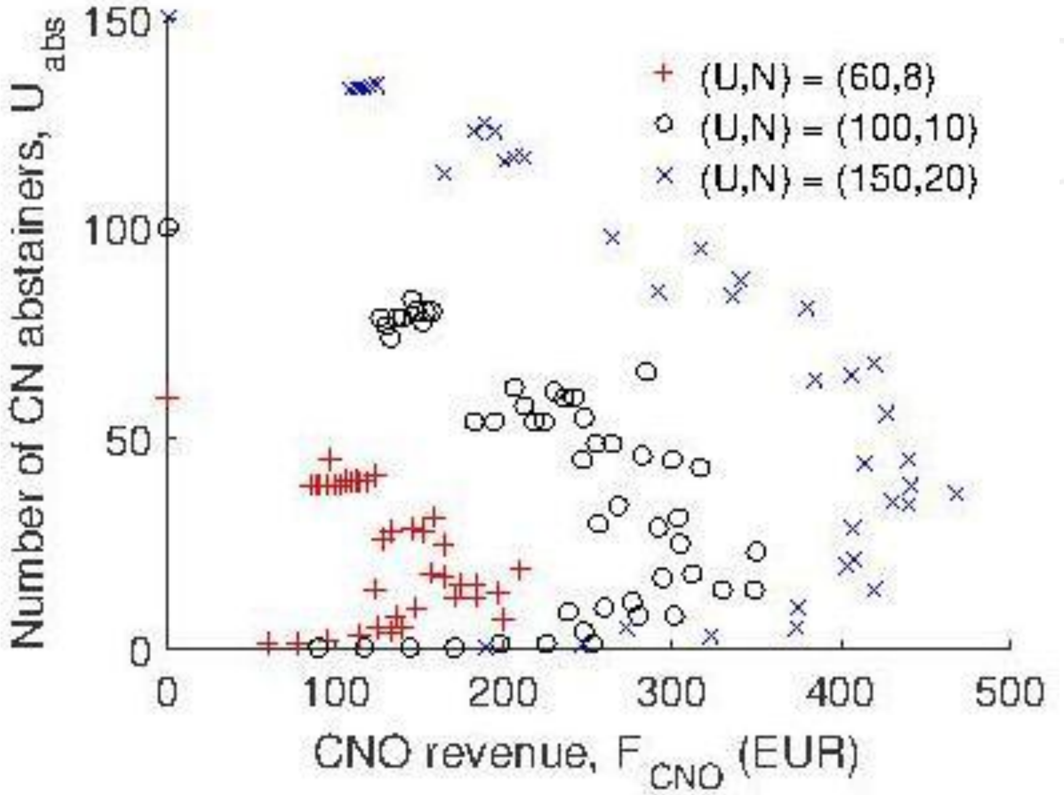
Collective subscriptions : results

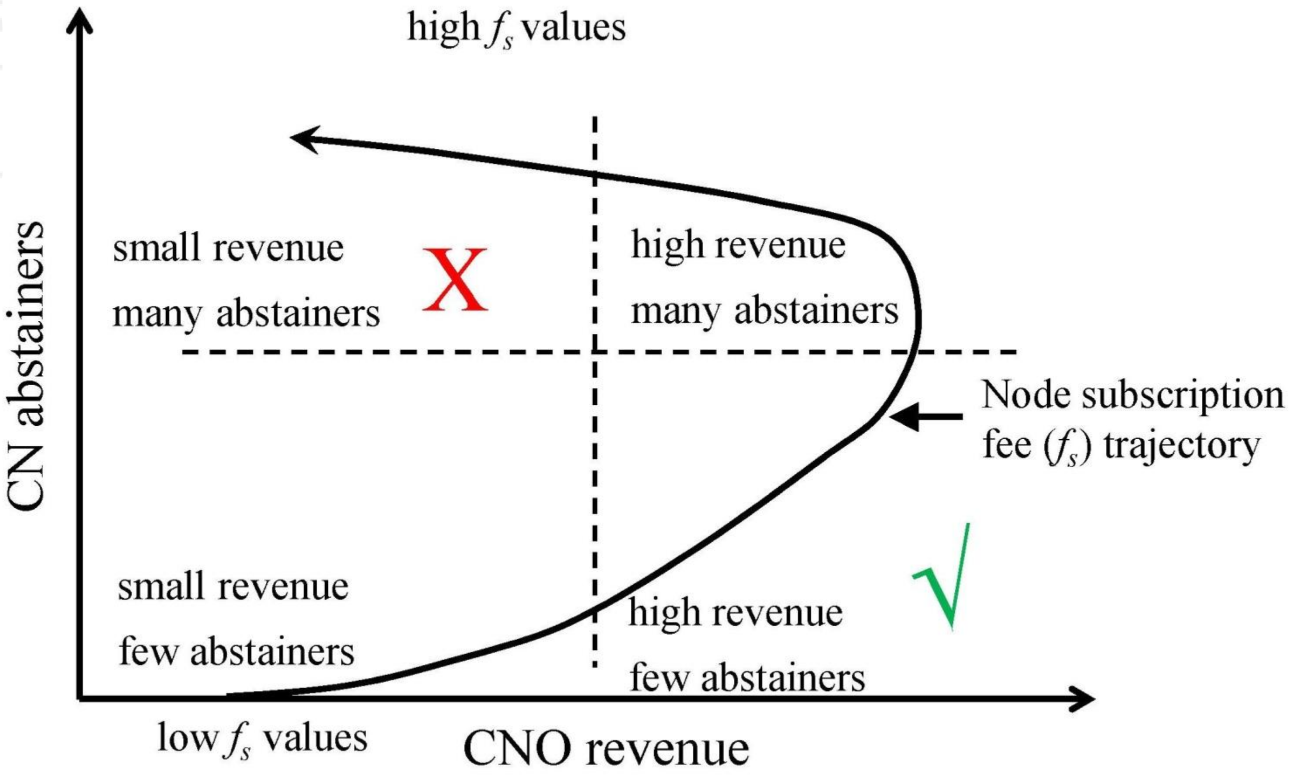
|U| = 150



- Higher fees result in increasing number of users who cannot join a subscription
  - beyond some fee value, the resulting revenue losses cannot be compensated by users who are willing to pay more

Collective subscriptions : implications for the CNO





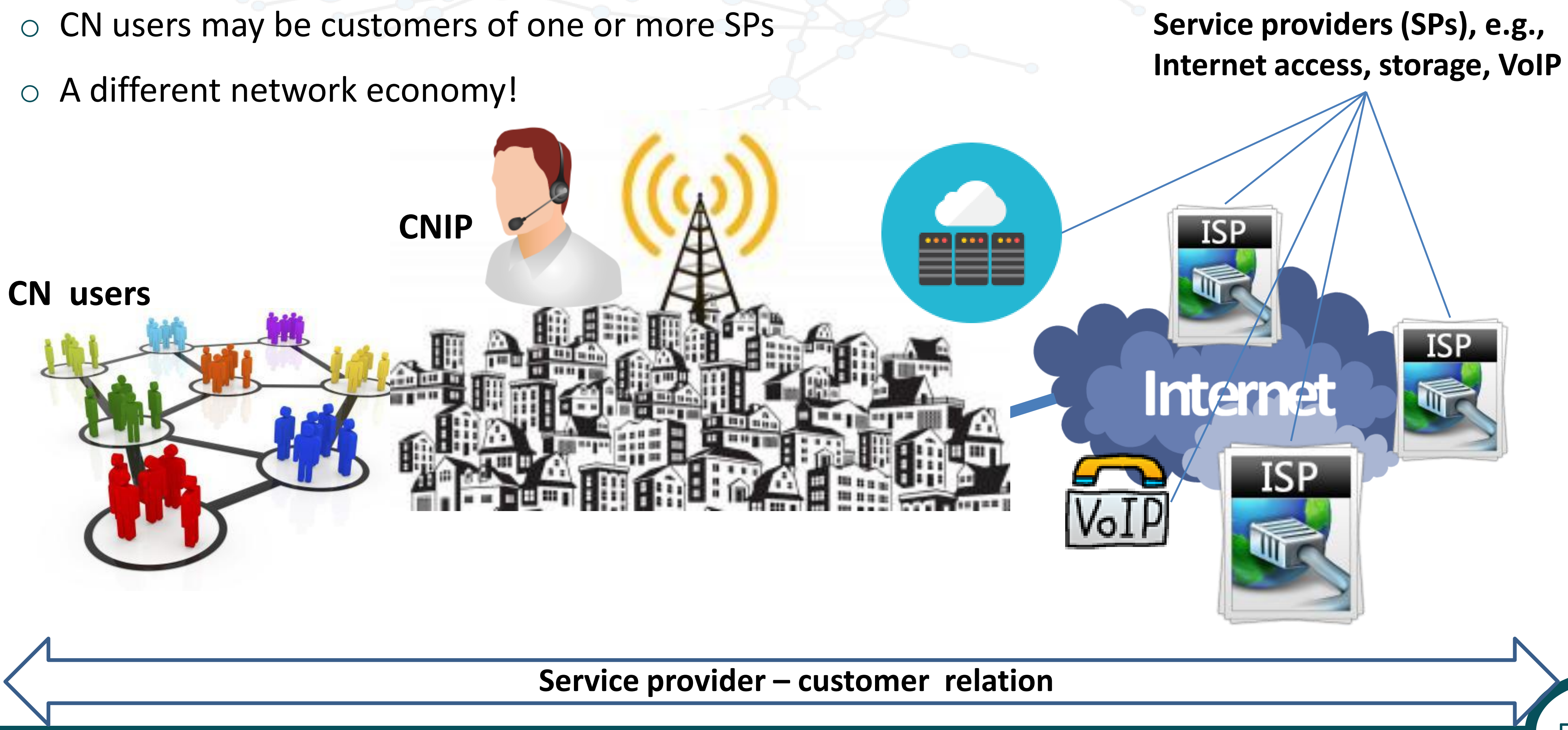
- CNO revenue – user engagement curves
  - the CNO could tune the node fee so that it optimally combines the two requirements

Bringing commercial actors into the CN picture

…and CNs closer to the real world

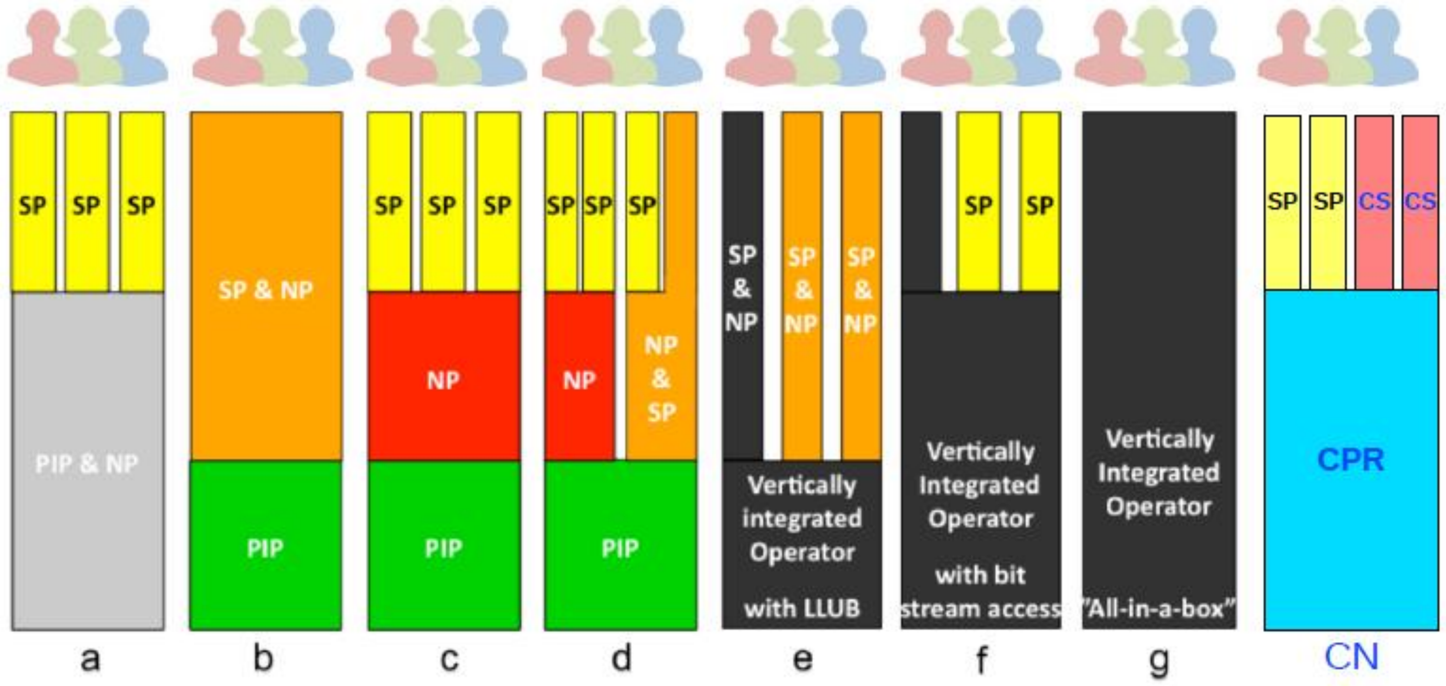
CNO as pure network infrastructure provider (CNIP)

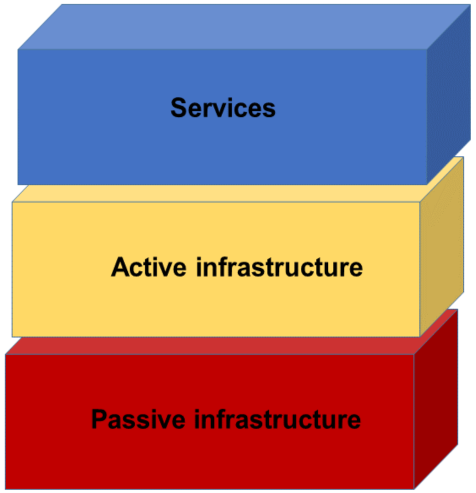
- Service providers (SPs) operate over the CN network
  - CN users may be customers of one or more SPs
  - A different network economy!



Counter-verticals telecom network model

- Separation of roles in the telecom pyramid
  - Physical infrastructure providers *vs.* network providers *vs.* service providers





Stakeholders : roles and (strategic) objectives

Service providers (SPs)

SPs

- offer services (e.g. Internet access) to the CN users over the CN infrastructure
- get paid by the user-customers a (monthly) subscription fee to their services
- (may) invest on the commons infrastructure
  - to expand its coverage or upgrade its capacity
- share the operational cost of the network infrastructure with other SPs

They ***strategically*** decision upon two things

- The price they charge for their service
  - in competition with other SPs
- The amount of investment on the network infrastructure
  - in co-operation with other SPs and the CNIP

Stakeholders : roles and (strategic) objectives

End users - customers

They may join or not the CN

- when they do, they may subscribe for a fee to services (e.g., Internet access) over the common infrastructure

They may consider multiple criteria in their decisions

- the network coverage and charged fees for joining the CN
- the service fees charged by the service provider(s)

Stakeholders : roles and (strategic) objectives

CN infrastructure provider (CNIP)

- Manages the network infrastructure undertaking its operational cost
- Devises and applies cost-sharing policies for splitting the operational cost among CN users and service providers that benefit from the infrastructure
  - implicitly generates (dis-)incentives for the participation of service providers and their involvement to the network growth
- May establish peering agreements to higher-tier ISPs (in that acting as an ISP itself)
  - pays them monthly the cost of Internet traffic produced over the commons infrastructure (according to some SLA and normal charging processes)

Cost-sharing mechanisms

Average cost sharing/pricing [10]

Model:

- N agents generate (monthly) traffic d_i
- The operational cost is $C(\Sigma d_i)$
  - matches the current model of pricing network lines (SLAs)

Cost-share: each agents pays $d_i \cdot C(\Sigma d_i) / \Sigma d_i$

- Cost shares are proportional to the demand on (use of) the network infrastructure

Properties:

- Plausible (proportionality principle) and computationally simple
- Budget balanced : the agents’ payments cater for the full operational cost
- Robust to coalitions or manipulation of demand : the agents cannot gain by either merging or splitting their demands in smaller parts

Cost-sharing mechanisms

Serial cost sharing [8]

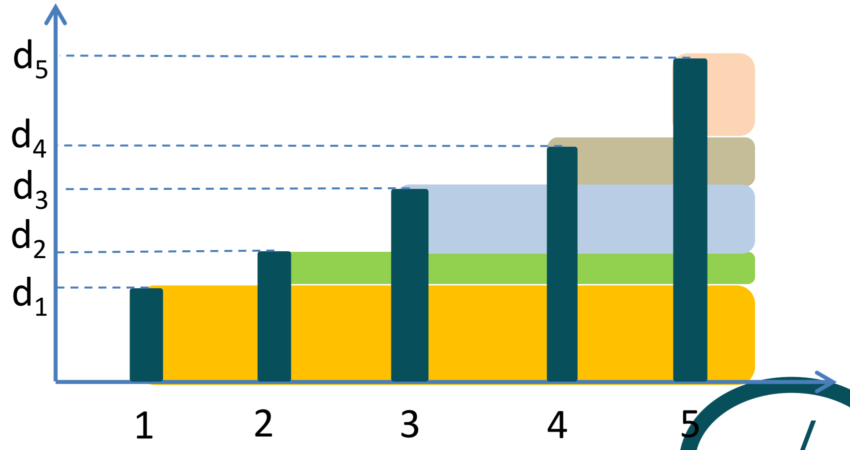
Model : the same

Cost-share : demands are ranked in increasing order, wlog $d_1 < d_2 < d_3 < \ldots < d_n$ and

- The 1st agent (demand d_1) is charged with $C(n\, d_1)/n$
- The 2nd agent (demand d_2) is charged with $C(n\, d_1)/n$ for its demand part up to d_1 and shares with the other n-1 agents the incremental cost beyond d_1, $\dfrac{C(d_1 + (n-1)d_2) - C(nd_1)}{n-1}$

Properties :

- Less robust than average cost sharing to demand manipulation
- Fairer to agents with low demand levels



Cost-sharing mechanisms

Example : $N = 3$, $d_1 = 5$, $d_2 = 8$, $d_3 = 10$

$csh_1 = C(15)/3$ $csh_2 = csh_1 + [C(21) – C(15)]/2$ $csh_3 = csh_1 + csh_2 + [C(23) – C(21)]/1$

case 1 : $C(d) = 0$, if $d \leq 15$ and $C(d) = a\,(d\text{-}15)$ → convex function

Serial sharing : $csh_1 = 0$ $csh_2 = 6a/2=3a$ $csh_3 = csh_1 + csh_2 +8a\text{-}6a = 5a$

Average cost sharing : $csh_1 = 5 \cdot 8a/23$ $csh_2 = 8 \cdot 8a/23$ $csh_3 = 10 \cdot 8a/23$

case 2 : $C(d) = ad$, if $d \leq 15$ and $C(d) = 15a + a\,(d\text{-}15)/4$ → concave function

Serial sharing : $csh_1 = 15a/3=5a$ $csh_2 =... = 5.75a$ $csh_3 = ... = 6.25a$

Average cost sharing : $csh_1 = 5 \cdot 17a/23 =85a/23$ $csh_2 = 8 \cdot 17a/23=136a/23$ $csh_3 = 10 \cdot 17a/23$

Current state of affairs

- Very few instances of CNs involve commercial entities in their business model

- guifi.net has a first in this
  - it applies the average cost sharing model for sharing the operational cost of the network infrastructures
  - it also caters for the investments SPs make on the network
    - Investment expenses are subtracted from the cost shares of SPs
  - it goes one step further to regulate the pricing of services over its network
    - It imposes a fixed subscription fee for all SPs providing similar services (e.g. ISPs)

- A lot more to do, search and optimize in this direction!

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Economic Sustainability in CNs and Incentives for Participation

netCommons

Merkourios Karaliopoulos, Iordanis Koutsopoulos, Renato Lo Cigno,
Leonardo Maccari, Leandro Navarro

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Building CN infrastructure up front

The Jackson – Mullin cost-sharing mechanism : 2 agents

- c : cost of the project
- b_1, b_2 : real benefits of the two agents if the project is carried out

The mechanism proceeds in two stages – the 2nd one conditional on the outcome of the 1st

Stage 1 : The two agents simultaneously submit bids v_1, v_2 of the *joint* benefit out of the project. Say, wlog, that v_1 is the winning bid and agent 1 the one who submits it

- if $v_1 \leq c$ –> no project; otherwise, proceed in stage 2

Stage 2 : The two agents submit bids β_1, β_2 about their own valuations of the project.

- If $\beta_1 + \beta_2 > v_1$, the project is carried out and users are charged proportionally to their bids β_1, β_2
- If $\beta_1 + \beta_2 < v_1$, the project is NOT carried out and 1 pays 2 a "compensation" fee
- If $\beta_1 + \beta_2 = v_1$, 1 decides about the fate of the project