

Incentivizing Peer-Assisted Services a Fluid Shapley Value Approach

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Structure of this talk

Motivation

Requirements for incentivizing peer-assistance

A Fluid-Atomic Shapley approach

Applications

Concluding remarks

Peer-to-Peer (P2P) is a double edged sword

P2P is technically beneficial ...

- Self-Scaling, Resilient, Versatile

... but it puts Internet economy under stress

- Content right owners see a shrinking revenue
- Access network providers see increasing traffic

Internet becomes engineering/regulatory battlefields

- Traffic filtering ... will it work?
- Network neutrality ... will it block innovation?

An alternative to P2P

We focus here on **peer-assisted services**

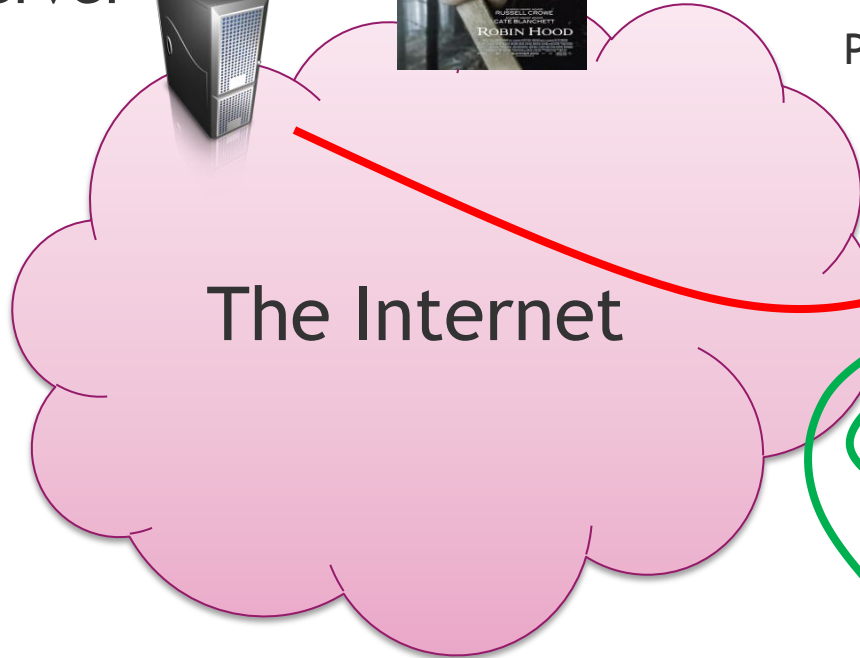
- A service offered by a provider, for a given price
- Some users commit their resources to assist in provision of service

Address P2P via an economic rethink

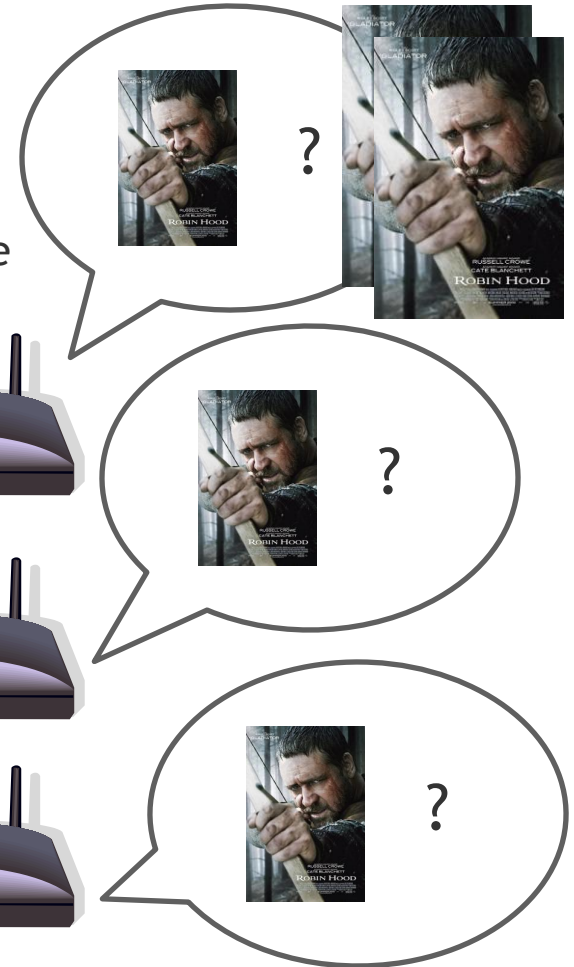
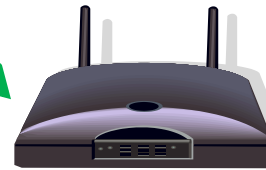
- Allows to fight illegal content with equal arms (through added features, authentication etc.)
- Focus on fairness and efficiency

Examples of peer-assisted services

Content Server



Peer-assistance enabled



Residential Gateways
(owned and managed by the ISP)

Examples of peer-assisted services (cont'd)

A principle found in multiple scenarios

- Content: broadband, mobile
peer-assistance: retrieve content locally



- Bandwidth: wireless community, femtocell
peer-assistance: make access available



- CPU: Crowdsourcing



peer-assistance: provide computing power

Incentivizing peer assistance

Incentives have been studied in P2P for several years

- Focus on churn, free-riding, sybil attacks
- Indeed, much of P2P today relies on altruistic users

Incentive is critical for peer-assisted services

- Deployment: users should decide to opt-in
- Stability: users keep control on their own resources (e.g. unplug or throttle their gateway)
- Provider wants to have guaranteed revenue.

Solutions deployed today

One-shot incentive to Opt-in

- receive a gift
(free upgrade or feature)
- or even make you pay!

Sharing common resource

- Restricted to a zero value economy

Revenue sharing

- Looks more general and promising but how to tune it?

Cher Client,

Dans le cadre de l'opération spéciale ÉCHANGE ET PARTAGE, Neuf s'associe avec FON, premier réseau WiFi mondial, pour vous offrir une Neuf Box de dernière génération, d'une valeur de 49€, avec l'option FON automatiquement activée.

En souscrivant à FON et en conservant l'option FON activée pendant 12 mois, les frais d'échange de la Neuf Box WiFi vous sont offerts (1).



En participant à l'opération ÉCHANGE ET PARTAGE

Vous bénéficiez de tous les avantages de la Neuf Box WiFi :

- Facile à installer et à configurer,
- Design épuré,
- Connectique étendue et possibilité de raccorder simplement une imprimante ou un disque dur compatibles.

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An incentive mechanism for peer-assistance

1. Stability/Fairness

- loose: individually rational users do not leave
- tight: derived from objective fairness axioms

2. Economically efficient

- loose: sum of incentives matches cost reduction
- tight: optimality = system leads to minimum cost

3. Manage different scales

- Interaction of large user population and big players

4. Computationally efficient

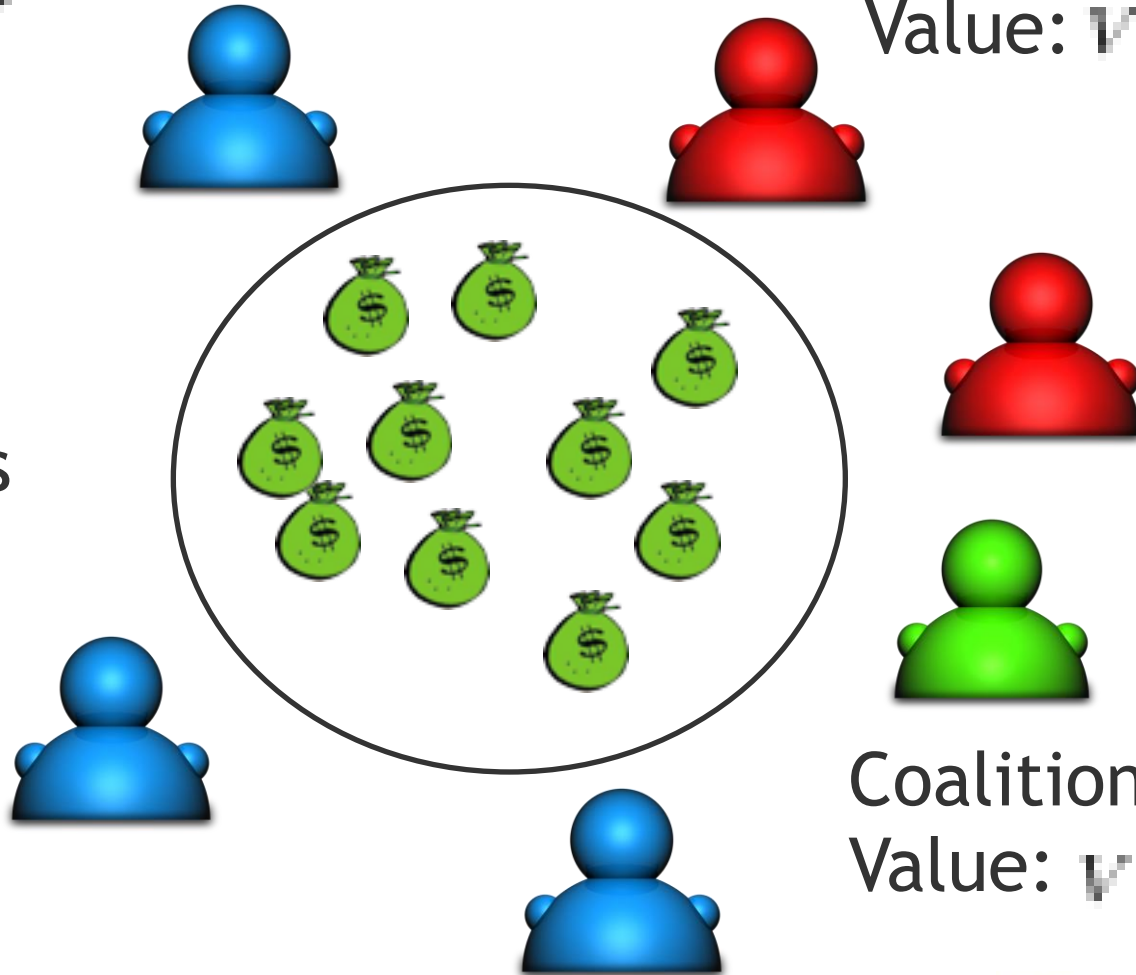
Cooperative Game, "Should I stay or should I go?"

Players: N

Coalition: $S \subseteq N$
Value: $V(S)$

Value: V

Coalitions



Coalition: $T \subseteq N$
Value: $V(T)$

Shapley Value

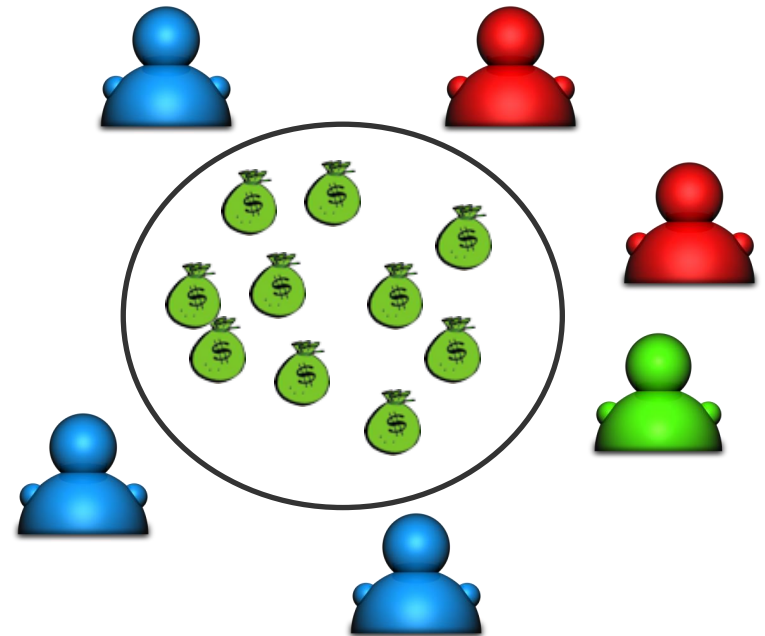
1. Efficiency

$$\sum_{i \in S} \phi_i(S, V) = V(S).$$

2. Symmetry

$$\forall T \subseteq S \setminus \{i, j\}, \quad V(T \cup \{i\}) = V(T \cup \{j\})$$

$$\text{then } \phi_i(S, V) = \phi_j(S, V).$$



Shapley Value

1. Efficiency

$$\sum_{i \in S} \varphi_i(S, V) = V(S).$$

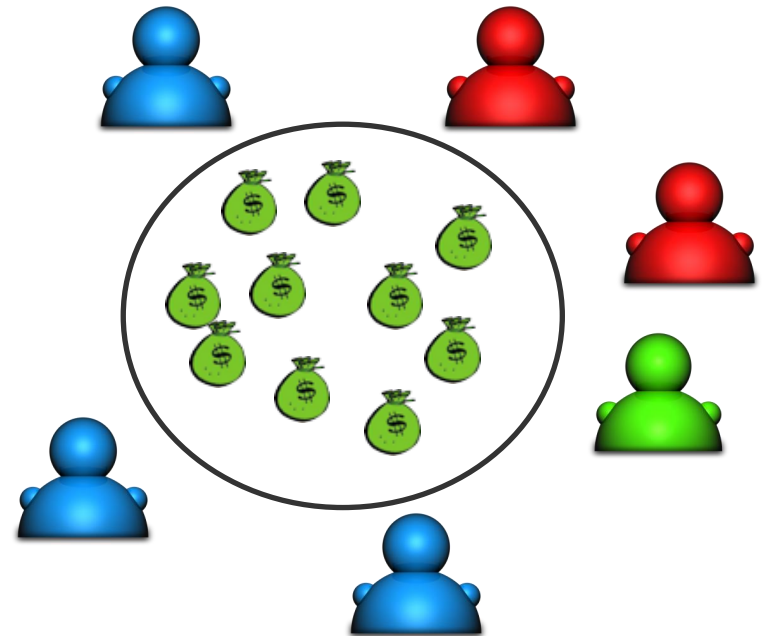
2. Symmetry

$$\forall T \subseteq S \setminus \{i, j\}, \quad V(T \cup \{i\}) = V(T \cup \{j\})$$

$$\text{then } \varphi_i(S, V) = \varphi_j(S, V).$$

3. Balanced contribution

$$\begin{aligned} \varphi_i(S, V) - \varphi_i(S \setminus \{j\}, V) = \\ \varphi_j(S, V) - \varphi_j(S \setminus \{i\}, V). \end{aligned}$$



Shapley value is equal to

$$\frac{1}{|S|!} \sum_{\pi \in \Pi} V(S(\pi, i) \cup \{i\}) - V(S(\pi, i)).$$

Exponential Complexity!

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Incentivizing peer-assistance

A new multi-class fluid-atomic approach

- 1 atomic player: the provider P (revenue R per user)
- Peers represented by continuous fluid in m classes.

Let $\bar{x} = (N_1/N, \dots, N_m/N)$ denote the fraction of participating peers in each class

Let $C(\bar{x})$ be the marginal service cost per user

$$V(\{P\}) = R - C(\bar{0}) \quad (\text{Traditional service})$$

$$V(\bar{x}) = 0 \quad (\text{Provider is a veto player})$$

$$V(\{P\} \cup \bar{x}) = R - C(\bar{x}) \quad (\text{Peer-assisted service})$$

Shapley Value

1. Efficiency

$$\sum_{i \in S} \varphi_i(S, V) = V(S).$$

2. Symmetry

$\forall T \subseteq S \setminus \{i, j\}, V(T \cup \{i\}) = V(T \cup \{j\})$
then $\varphi_i(S, V) = \varphi_j(S, V)$.

3. Balanced contribution

$$\varphi_i(S, V) - \varphi_i(S \setminus \{j\}, V) = \\ \varphi_j(S, V) - \varphi_j(S \setminus \{i\}, V).$$

Shapley value is equal to

$$\frac{1}{|S|!} \sum_{\pi \in \Pi} V(S(\pi, i) \cup \{i\}) - V(S(\pi, i)).$$

Fluid limit

1. Efficiency

$$\bar{\varphi}_P(\bar{X}) + \sum_{i=1}^m X_i \varphi_i(\bar{X}) = R - C(\bar{X})$$

2. Symmetry

Users in class i have $\varphi_i^N(\bar{X})$

3. Balanced contribution

$$\frac{\partial \varphi_i}{\partial x_j} = \frac{\partial \varphi_j}{\partial x_i}, \quad \text{and} \quad \varphi_i(\bar{X}) = \frac{\partial \bar{\varphi}_P}{\partial x_i}$$

$$\varphi_i(\bar{X}) = - \int_0^1 s \frac{\partial C}{\partial x_i}(s\bar{X}) ds.$$

$$\bar{\varphi}_P(\bar{X}) = R - \int_0^1 C(s\bar{X}) ds$$

An intuitive proof

Shapley value equals $E[V(S(\pi_i, i) \cup \{i\}) - V(S(\pi_i, i))]$

- where $S(\pi_i, i)$ containing predecessors of i in a random "permutation" chosen uniformly
- Let s in $[0;1]$ be the relative "rank" of a player i in the permutation π_i . (essentially it is uniform on $[0;1]$)

As the system becomes large

- By law of large numbers, $S(\pi_i, i)$ contains $s\bar{X}$
- If i is not P , then $S(\pi_i, i)$ contains P with probability s

$$\varphi_i(\bar{X}) = - \int_0^1 s \frac{\partial C}{\partial x_i}(s\bar{X}) ds .$$

More remarks

The formal proof uses limit axioms

- Simplifies results from Aumann-Shapley74 and Hart73
- Using a limit of balanced contribution Myerson77

The limit axioms offers a flexible methodology

- multiple atomic players
- other scenarios like network neutrality
- cost of peer-assistance incurred by user

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Qualitative properties

General conditions to achieve grand coalition

- Cost saving should compensate cost of sharing

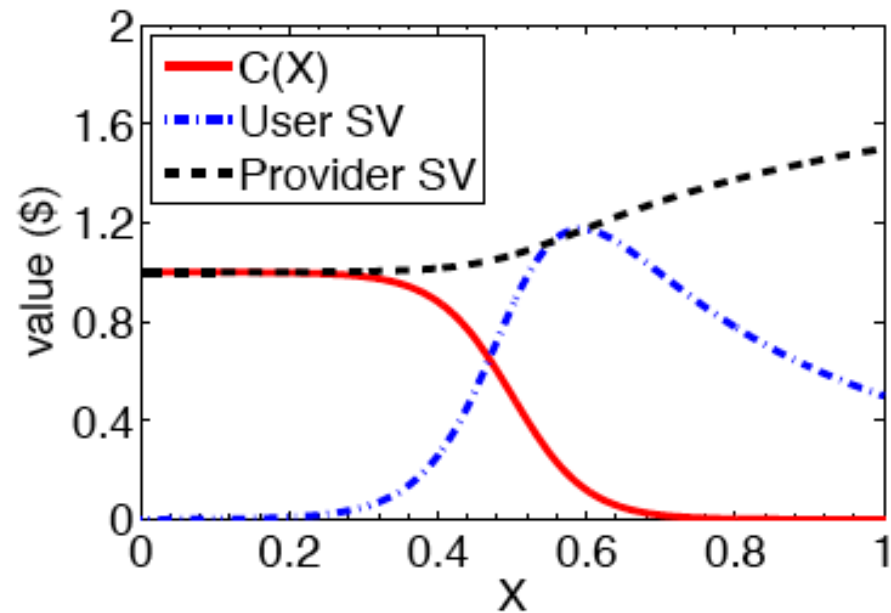
Provider's Shapley value always increases with X

Peer's Shapley Value

- Combination of 2 effects

1. Cost reduction
2. Loss of bargaining power

- Characterized by concavity/convexity



Quantitative properties

Linear cost:

- Shapley value independent of X

Example: VoD with peer-assistance

- File size S ; class i upload S_i bits; cost bwidth K

Cost per user becomes $C(X) = KS - \sum_i x_i K S_i$

Shapley value: $\varphi_i = \frac{K S_i}{2}$

- "Serve two, get one free" is fair and optimal

Conclusion

Economic rethink of peer-assistance

- Provides strong fairness/efficiency guarantee
- Flexible: interaction of peers and big players, ...
- Computationally simple: closed form expressions

Future works

- Can we apply this model to energy-efficient operation of (distributed) services?
- Can we handle competing providers?

Thank you!

R. T. B. Ma, D. Chiu, J. C. Lui, V. Misra, and D. Rubenstein. Internet Economics: The use of Shapley value for ISP settlement. *Proc. ACM CoNEXT*, 2007.

R. T. Ma, D. Chiu, J. C. Lui, V. Misra, and D. Rubenstein. On cooperative settlement between content, transit and eyeball internet service providers. In *Proc. of ACM CoNEXT*, 2008.

V. Misra, S. Ioannidis, A. Chaintreau, L. Massoulié, Incentivizing Peer-Assisted Services: a Fluid Shapley Value Approach. In *Proc. of ACM. SIGMETRICS*, 2010