Chapter 10: Incentive Mechanisms for P2P Systems

Motivation (1)
1. Topic of previous chapter: P2P systems for data management, classification.
2. Nodes maintained by different persons/organizations. Assumption where current topic is different from all previous ones.
3. Why should peer cooperate?
4. No reason to do so (from purely economic perspective).

Motivation (2)
1. Measures that reward cooperative behavior are key to functioning of system. (Or would at least increase robustness.)
2. Interface to economics – fundamental notions are deployed (prisoners’ dilemma, second-bid auction, mechanism design).
3. Topic in what follows:
   - design of file-sharing systems (theory and practice),
   - incentive mechanisms for structured P2P networks,
   - heterogeneous peers and truthful information.

Outline
1. Entrance fees,
2. robustness in P2P environments – comparative study,
3. BitTorrent,
4. incentives for structured P2P networks,
5. distributed mechanism design.
P2P – Differences between the Models (1)

1. ‘One peer provides service’ (or well-defined part of service) vs. ‘sequence of peers provides service’ (and client knows/does not know which ones).
2. Examples: File sharing vs. overlay networks.

P2P – Differences between the Models (2)

1. Costs of an identifier change.
2. Examples: Overlay networks vs. community portals.
3. Community portals: registration with email address which one only obtains with ID card.

P2P – Differences between the Models (3)

1. Defections can be traced or are untraceable.
2. Illustration – gnutella:
   - I have the file.
   - I do not have the file!
3. Heterogeneity – may or may not be part of model.

Prisoner’s Dilemma

1. Terminology:
   - strategy,
   - equilibrium.
2. Without coordination no solution to Prisoner’s Dilemma.
**Prisoner’s Dilemma – Repeated Interactions**

1. Repeated interactions – incentive to cooperate.
2. Tit-for-Tat

**Generalized Prisoner’s Dilemma (1)**

1. Prisoner’s Dilemma: Typically either specific payoff matrix, or payoff matrix is symmetric.
2. Generalized Prisoner’s Dilemma – Illustration:

<table>
<thead>
<tr>
<th></th>
<th>Provide Service</th>
<th>Ignore Request</th>
</tr>
</thead>
<tbody>
<tr>
<td>Request</td>
<td>7, -1</td>
<td>0, 0</td>
</tr>
<tr>
<td>Do Not Request Service</td>
<td>0, 0</td>
<td>0, 0</td>
</tr>
</tbody>
</table>

**Generalized Prisoner’s Dilemma (2)**

1. Axioms to create social dilemma:
   - Mutual cooperation leads to higher payoffs than mutual defection.
   - Mutual cooperation leads to higher payoffs than one player suckerizing the other.
   - Defection weakly dominates cooperation at the individual level.

**Strategy-Proof Mechanisms**

1. Players act strategically – i.e., maximize payoff.
2. Design incentives to provide truthful information. Put differently, design mechanism s.t. fraud does not pay off. **Strategy-proof**.
3. Players will provide private information.
Second-Bid Auction (1)

Auction of an article, one-stage sealed-bid.

Item goes to highest bidder. Price: Bid of second-highest bidder.

Illustration:
- Red bids 20, Blue 12, Green 10.
- Article goes to Red; he must pay 12.

Optimal outcome for participant if he truthfully provides his valuation.
- i.e., participant should bid his reservation price.

Entrance Fees – Motivation

P2P systems have characteristic that peers may come and leave at any time.

How to treat newcomers?
- Intuitively: no advances.
- Usefulness of entrance fees can formally be shown.
- Entrance fees occur in real world as well.
**Model**

1. Infinite, synchronously repeated game.
2. Each player plays Prisoner's Dilemma once per round with random opponent.
3. Public history of all interactions in the past.
4. $M$ active players
   - $\alpha$ – rate of players exiting after each period.
   - $\epsilon$ – probability of trembling.
5. Player can obtain new identity after each round.

<table>
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<th>D</th>
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<tr>
<td>C</td>
<td>1,1</td>
<td>-1,2</td>
</tr>
<tr>
<td>D</td>
<td>2,-1</td>
<td>0,0</td>
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**Objective**

1. Target value: Expected average payoff per period.
2. Which equilibria (i.e., which strategies should one play), and what does this mean?

**Fixed Identifiers**

1. Because of public history cooperation is an equilibrium.
   - **Localized Punishment Strategy (LPS):**
     1. Play D against veteran who has not played LPS in previous period.
     2. Otherwise, play C.
2. Proof that LPS is equilibrium:
   1. Compute expected payoff.
      E.g., how likely that two defectors meet etc. ($\epsilon$ was given.)
   2. Compute payoff of player that defects when it should cooperate.

**Terminology**

1. Newcomer,
2. veteran.
**Identifier Changes are Free.**

1. Is LPS still an equilibrium?
   If not, why?
2. "Public Grim Trigger Strategy" (PGTS)
   - Defect if there has ever been a defection in an earlier period.
   - Otherwise cooperate.
3. Excessive sensibility.
   Think of trembling. Problems with network connection, hit wrong key on keyboard etc. Unrealistic.

**"Paying Your Dues" Strategy (PYD) (1)**

1. Target again situation where identifier changes are free.
2. Better than "Public Grim".
3. Idea: Reward positive reputation.
4. Idea 2: Entrant meets compliant veteran – entrant plays C, veteran plays D.
5. Compliance – all past interactions are in line with PYD.
6. Players cooperate if their type is same (entrant vs. veteran), and both are in compliance.

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**Entrance Fees (1)**

1. Dues with PYD – endogenous entrance fee.
2. How about explicit entrance fee?
3. Approach 1:
   - Entrance fee for Period t+1 evenly distributed among participants of Period t.
   - Advantage: Does not impact efficiency.
   - Problems:
     - Players tend to stay in the game beyond their natural interest.
     - Players' lifetimes may be heterogeneous – players might not recoup their entrance fee.
### Entrance Fees (2)

1. **Approach 2:**
   - **Entrance fees are not redistributed, but, say, go to charity.**
   - Player payoffs/player valuations of money may be heterogeneous.

\[
\frac{V(s)}{\alpha} = F
\]

(\(\lambda = 1\) for poor players, \(\lambda = 0.01\) for rich players)

1. **Adjustment of entrance fee difficult in P2P environments.**
   - Price discrimination not applicable.

### Entrance Fees – Summary

1. Entrance fees are indispensable.
2. Entrance fee should be as low as possible – can be quantified under assumptions.
3. Problematic if entrance fee = money (i.e., exogenous).

### Objectives

2. Terminology – in particular regarding different kinds of uncooperative behavior.
3. Which countermeasures exist, and how has their effectiveness been assessed?
4. What is state of the art?
5. Why not sufficient?

### Micropayments – Counterarguments

1. Relatively involved,
2. Participants have reservations.
3. Transaction costs are too high (both in absolute and in relative terms).
4. Certified delivery expensive as well.
Which Difficulties/Peculiarities of P2P Systems?

1. Large number of nodes.
2. High turnover, churn, population dynamics.
3. Asymmetry of interest (illustrated below).
5. Coalition attacks (with feedback/shared histories).
6. Heterogeneity – not much work so far.

Heterogeneity

1. Extent of services is different. (E.g., download of files of different sizes, but nodes themselves are identical.)
2. Different private costs (of physical resources and of intellectual input),
3. Different valuation of certain service (on the level of instances, as opposed to preceding bullet).

Population Dynamics (1)

2. Options at end of round:
   - mutate,
   - learn,
   - turnover,
   - stay the same.

Population Dynamics (2)

1. Learning:
   - compare strategy performance to the one of players you interact with,
   - switch to highest rated strategy,
   - prevent young samples from skewing the rating
     \[
     \frac{\text{RunningAverage}(s \cdot \text{age})}{\text{RunningAverage}(\text{age})}
     \]
Population Dynamics (3)

Comments:

- Why not 'best response', as opposed to 'imitate'?
- Why should peers truthfully communicate their strategy? (Defectors in particular.)
- Why should peers share their history?

Introduction
P2P Models
Prisoners' Dilemma
Strategy-Proof Mech.
Entrance Fees
Comparison
- Intro.
- Setup
- Turnover
- Collusions
- Conclus.
BitTorrent
Structured
LCP Routing
Conclusions

Population Dynamics – Base Experiments (1)

- 'Reciprocative':
  - Generosity \( g(i) = \frac{p_i}{c_i} \) (services \( i \) has provided/consumed)
  - Generosity computation based on interactions in the past.
  - In the presence of entrance fees, player may consume more than he provides.
  - With plain generosity, reciprocative players may defect on each other.

Population Dynamics – Base Experiments (2)

- Normalized generosity: entity's \( i \) generosity relative to generosity of current peer \( j \)
  \[ g_j(i) = \frac{g(i)}{g(j)} \]
  - Strategy then: cooperate with probability proportional to normalized generosity.

Population Dynamics – Base Experiments (3)

<table>
<thead>
<tr>
<th>Run Time</th>
<th>1000 rounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ratio using “100% Cooperate”</td>
<td>1/3</td>
</tr>
<tr>
<td>Ratio using “100% Defect”</td>
<td>1/3</td>
</tr>
<tr>
<td>Ratio using Reciprocative</td>
<td>1/3</td>
</tr>
<tr>
<td>Mutation Probability</td>
<td>0.0</td>
</tr>
<tr>
<td>Learning Probability</td>
<td>0.05</td>
</tr>
<tr>
<td>Turnover Probability</td>
<td>0.0001</td>
</tr>
</tbody>
</table>
Population Dynamics – Base Experiments (4)

(a) Total Population: 60
(b) Total Population: 120

Reason for little cooperation: asymmetry of interest.

Robustness under Different Conditions

1. Overview:
   - large population, high turnover,
   - collusions,
   - zero-cost identities.

Large Populations and High Turnover (1)

1. Repeat interaction with familiar entity is unlikely.
2. Private history together with asymmetry of interest is problematic.
3. Mechanisms proposed:
   - server selection,
   - shared history.

Large Populations and High Turnover (2)

1. Server selection:
   - Player holds (fixed size) list of past donors and recipients.
   - Server selection from this list – allows for reciprocative behavior.
Large Populations and High Turnover (3)

Server selection – simulation results:

- Repeat interactions more likely.
- Reciprocative behavior becomes more favorable.

Shared history:
- We call it feedback dissemination.
- Boost performance – cf. previous graph.
- Helpful with regard to high turnover rates.
(Simulations not shown here.)

Disadvantages:
- How to disseminate feedback?
- Spofing/coalition attacks/collusion.

Collusions

- Collusion can be positive or negative.
- Problem becomes more severe with zero-cost identities:
  I can create false identities.

Maxflow

- Given: directed graph with weighted edges.
- What is capacity from source node to target node?
- Illustration:

  Maxflow is 2.
Relationship between Maxflow and Reputation (1)

1. Underlying structure: "feedback graph"
   - nodes – peers
   - edges – labeled with feedback (only positive)

Relationship between Maxflow and Reputation (2)

1. Illustration:
   - Feedback graph with collusion
   - How much trust does A put into B?
     - Maxflow.
     - 0, in this case.

Relationship between Maxflow and Reputation (3)

1. Comments:
   - Computation of trust, not reputation.
   - Assumes that uncooperative behavior and dishonest behavior are correlated.
   - Normalization
     - "subjective reputation of j as perceived by i"
     \[
     \text{min}\left( \frac{\text{maxflow}(j \to i)}{\text{maxflow}(i \to j)}, 1 \right)
     \]
   - Maxflow computation is costly. Approximations with reduced complexity are available (and used here).

Relationship between Maxflow and Reputation (4)

1. Assessment:
   - Private somewhat better than shared – less susceptible wrt collusions.
Conclusions

1. Summary:
   - Differences between P2P models,
   - Characteristics of P2P systems,
   - Difficulties
     incentive mechanisms for P2P systems
     must cope with, together with countermeasures.

1. Open issues:
   - Why should nodes
     truthfully report their strategy?
   - Heterogeneity
     – costs – various facets,
     – different services,
     – load (generated, and to be worked off).

BitTorrent – Introduction/Overview (1)

1. So far: state of the art in the literature.
1. In what follows: current status
   regarding existing systems (one, to be specific).

BitTorrent – Introduction/Overview (2)

1. Distributed system for file download,
   download not only from original source,
   but also from other peers.
1. Not 100% peer-to-peer –
   - distinguished role of original source,
   - system contains distinguished component,
   - so-called tracker.

BitTorrent – Introduction/Overview (3)

1. Main ideas:
   - Decompose file to pieces.
   - While I download piece that I do not have yet,
     I serve other pieces (which I already have)
     to other peers. Incentives to do so.
1. Application: Fast distribution of new software,
   e.g., Debian, but also hot ripoff movies.
BitTorrent – Why Interesting? (1)

1. Important kind of distributed system. BitTorrent is popular. Commercial entities do use it.
2. System design assumes that participants are rational. “tit-for-tat”, if you wish.
3. Default client displays default behavior. Opportunities for manipulation exist:
   a. Source code is available.
   b. Reasonable size in common programming language (approx. 5700 loc Python script).

BitTorrent – Why Interesting? (2)

1. Different classes of rational users exist. → Analysis is spiced up.
   a. Perform download without providing upload bandwidth/with little upload bandwidth.
   b. Perform download as fast as possible.
   c. Prevent others/certain others from downloading.

BitTorrent – Specifics (1)

(Only one file.)

1. Structure issues:
   a. tracker – distinguished component, tracker maintains list of active peers.
   b. Peers have connections established to other peers.
2. Complete peers vs. incomplete peers.
3. New node joins:
   1. Registers to tracker
   2. Obtains random set of peers
   3. Attempts bidirectional connection to some.
**BitTorrent – File Sharing (1)**

1. Particularity: *unchoked connection.* (choke = drosseln)
   - I.e., node allows other endpoint to download pieces of file.
1. Peer marks small share of its connections as unchoked.
1. Peers exchange messages which pieces they have.

**BitTorrent – File Sharing (2)**

1. Complete peer – altruistic, unchokes peers that can download pieces the fastest. *Why?*
1. Incomplete peer – selfish, unchokes peers that provide pieces with high throughput. *Why?*
1. Peers optimistically unchoke other peers from time to time, hoping to find better trading partners, and choke less useful ones.

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**Classification of Users (1)**

1. *Obedient users vs. rational users.*
   - Obedient users:
     - Users who do not modify the software (because are unable to do so, or because they simply do not feel like it).
Classification of Users (2)

- Rational users
  - Try to maximize their utility,
  - Different kinds of rational behavior exist, e.g.,
    - Speed-critical,
    - Free rider
      (i.e., minimize upload bandwidth)
    - "Overnight downloaders"
      (as long as download finishes before morning, everything is fine)
    - Driven by discontinuous pricing model of ISP
      (e.g., continued use of bandwidth above a certain time threshold costs more)

Faithfulness (1)

1. Ideal: show faithfulness for all utility models.
2. Definition: A system is faithful wrt some knowledge assumption if a rational node follows an algorithm that always has the same externally visible effects as following the suggested strategy.
3. In other words: faithfulness – robustness to rational manipulations.

Faithfulness (2)

1. Counterexample – Napster
   - Suggested strategy – let others download while my Napster client is open.
   - Other strategy – interrupt such downloads, e.g., by hand.
   - Reduced resource consumption on my side.
   - I.e., I should deviate from suggested strategy.
   ⇒ System is not faithful.

Faithfulness (3)

1. Example – system that implements second-bid auction.
   - Suggested strategy:
     Reveal your true preferences.
   - Other strategy does not increase utility.