Cooperative Stochastic Differential Game in P2P Content Distribution Networks

CHEN Xiaowei

Supervisor: Dr. CHU Xiaowen
Co-supervisor: Prof. NG, Joseph Kee Yin

Outline

- Introduction
- Related work
- Analysis of Tit-for-Tat Strategy
- Basic Elements of Game Theory
- Incentive Framework
- Future Work

Introduction

- Who generates most traffic?

  Peer-to-Peer

- Who is the dominating P2P protocol?

  BitTorrent

- How to distribute content in a non-cooperative environment?

  Swarming

- How to solve the free-riding problem?

  … …(opinions differ)

Introduction (cont.)

Example: BitTorrent TFT Strategy

- ➢ Tit-for-Tat (from game theory)

Is it really effective?

Yes?

- ✓ Is proved in the repeated prisoner’s dilemma.
- ✓ Improves download rate by increases upload rate

Introduction (cont.)

Example: BitTorrent TFT Strategy

- ➢ Tit-for-Tat (from game theory)

Is it really effective?

No!

- ✓ High variability in download rate
- ✓ Unfairness in terms of ratio of upload & download Bandwidth allocation is not Pareto-optimal
- ✓ No reason to contribute once peers have satisfied their immediate demands.

Introduction (cont.)

- Two Questions
  - ➢ Does another strategy exist which outperforms BitTorrent's TFT strategy?
  - ➢ Does a strategy exist which ensures fairness between peers although they behave selfishly?
- How to model P2P network?
  strategic, rational, cheat, maximize own payoff, incentive … …
  - ➢ Game Theory is a proper tool

  But …

Introduction (cont.)

- **Our work**
  - ➢ Analyze the root issue of TFT strategy
  - ➢ Define the basic elements of game theory from P2P content distribution perspective
  - ➢ Incentive framework based on cooperative stochastic differential game
    - o Payoff distribution procedure
    - o Subgame consistency
    - o Dynamic Shapley value
    - o Equilibrating transitory compensation
    - o Follow the original optimality principle and cooperative state trajectory path

Related Work

- Micro-payment
  - relies on centralized server
  - Use virtual currency
- Game Theory
  - Mechanism Design
    J. Shneidman (IPTPS'03)
  - Cournot Game
    Richard T.B. Ma (Sigmetrics'04)
    Simon G. M. Koo (Telecommun Syst'07)
  - Others
    F. Wu (ACM STOC'07)
    W. Sabrina Lin (ICASSP'08)
    Bridge Q. Zhao (Infocom'09)

Short-term Incentive

Fail to see **whole** for the **part**

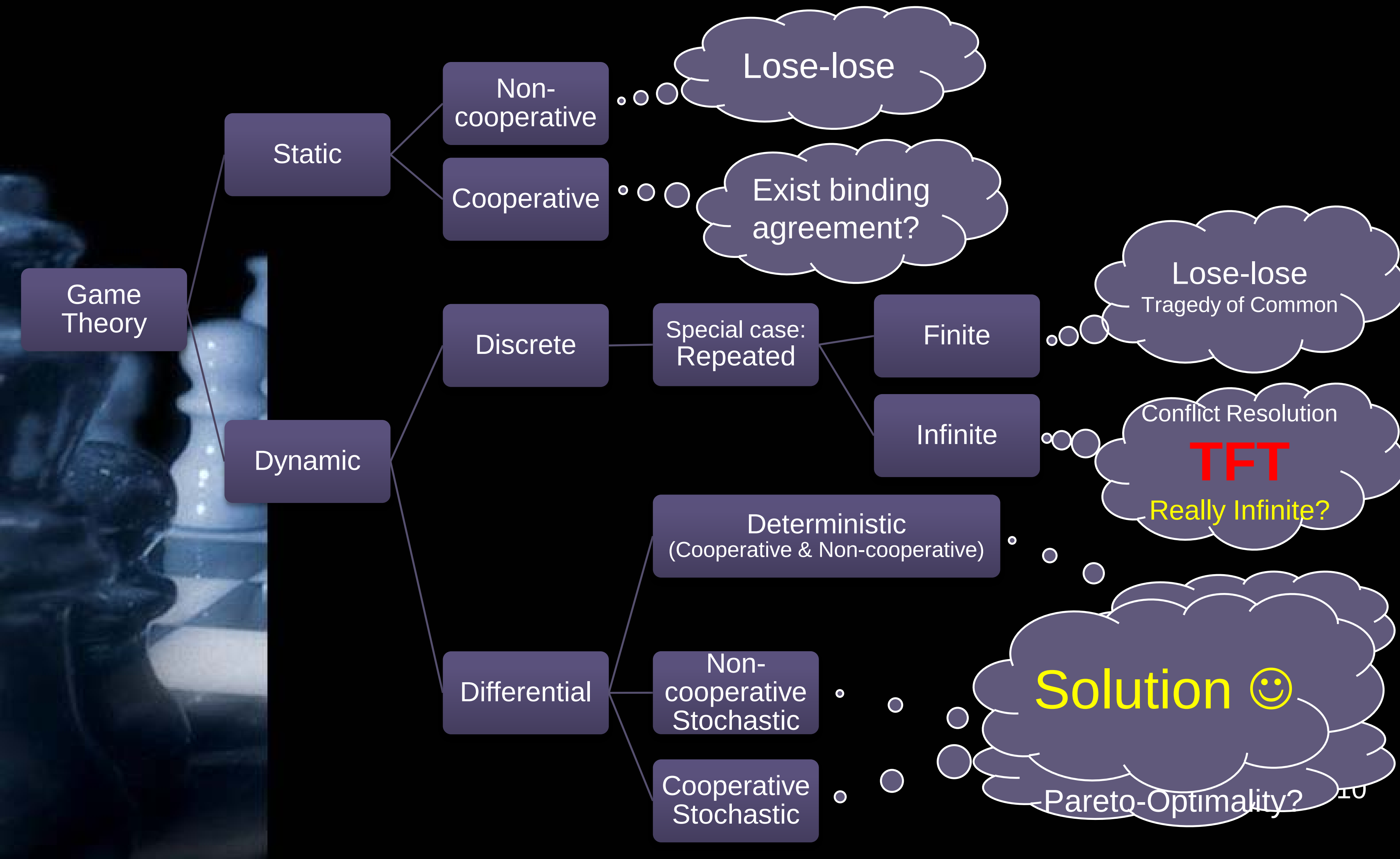
Pareto-optimality!

Analysis of TFT Strategy

- Non-cooperative environment will be far away from Pareto-optimality
  “solitary, poor, nasty, brutish & shot.”
  -- Tomas Hobbes, <Leviathan>, 1651

- Difficulty of cooperation is rooted from free-riding problem, if do further study, that is:
  Temporary profit of each peer exists conflicts

Analysis of TFT Strategy (cont.)



Basic Elements of Game Theory

- Player – peer
- Action – bandwidth peer wants to upload
- Information –peer type, strategy, payoff, etc.
- Strategy – rule or plan, not action only
- Payoff – download bandwidth peer gets
- Rationality – maximizing peer’s own payoff
- Objective – optimizes peer’s payoff function by strategy or choosing action
- Order of play – selects time point to take action
- Outcome – related terminal values, e.g. reputation
- Equilibrium – combination of optimal strategies

Incentive Framework

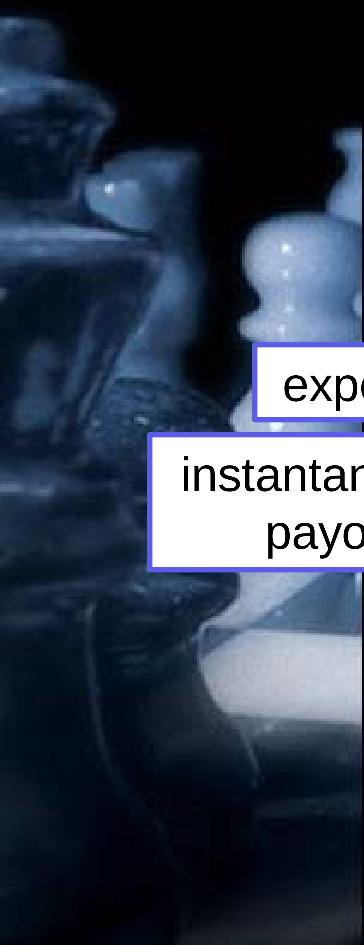
- Stochastic Environment:
  Time Consistency → Subgame Consistency
  Definition: A cooperative solution is subgame-consistent if an extension of the solution policy to a situation with a later starting time and any feasible state brought about by prior optimal behavior would remain optimal.

- How to realize subgame consistency?
  Equilibrating transitory compensation $B_i(s)$
  Explanation: player *i* receives at time *s* given the state is the sum of the following three items:

Incentive Framework (cont.)

- Equilibrating transitory compensation $B_i(s)$ is the sum of:
  - Player *i*'s agreed upon marginal share of total expected cooperative profit,
  - Player *i*'s agreed upon marginal share of his own expected non-cooperative profit plus the instantaneous effect on his non-cooperative expected payoff when the change in the state variable x_τ^* follows the cooperative trajectory instead of the non-cooperative path, and
  - Player *i*'s agreed upon marginal share of Player *j*'s non-cooperative profit plus the instantaneous effect on Player *j*'s non-cooperative payoff when the change in the state variable *x* follows the optimal trajectory instead of the non-cooperative path.

Incentive Framework (cont.)



- Payoff distribution procedure
  restricted by stochastic differential dynamic system

$$E_{t_0}\{\int_{t_0}^{T} g^i[s, x_i(s), u_i(s)]\exp[-\int_{t_0}^{s} r(y)dy]ds + \exp[-\int_{t_0}^{s} r(y)dy]q^i(x_i(T))\}$$

expectation

instantaneous payoff

time

state variable

control/path

Discount factor: $\exp[-\int_{t_0}^{s} r(y)dy]$

Equilibrating transitory compensation: $B_i(s)$ is $g^i[s, x_i(s), u_i(s)]$

Optimal terminal value: $q^i(x_i(T))$

Incentive Framework (cont.)

- Dynamic Shapley value
  Condition: At time *τ*, peer *i*'s share of profits be:

$$v^{(\tau)i(\tau, x_N^{\tau*})} = \sum_{K \subseteq N} \frac{(k-1)!(n-k)!}{n!}[W^{(\tau)K}(\tau, x_K^{\tau*}) - W^{(\tau)K\backslash i}(\tau, x_{K\backslash i}^{\tau*})]$$

$$W^{(t_0)K}(T, x_K) = \sum_{j \in K} \exp[-\int_{t_0}^{T} r(y)dy]q^j(x_j)$$

Incentive Framework (cont.)

- We can prove and get following

  Theorem: A payment to peer *i* ∈ *N* at time *τ* ∈ [t_0, *T*] equaling

$$
\begin{aligned}
B_i(\tau) = -\sum_{K \subseteq N} \frac{(k-1)!(n-k)!}{n!} \{ & [W_t^{(\tau)K}(\tau, x_K^{\tau *})\big|_{t=\tau}] - \\
& [W_t^{(\tau)K \backslash i}(\tau, x_{K \backslash i}^{\tau *})\big|_{t=\tau}] + ([W_{x_N^{\tau *}}^{(\tau)K}(t, x_K^{\tau *})\big|_{t=\tau}] - \\
& [W_{x_N^{\tau *}}^{(\tau)K \backslash i}(\tau, x_{K \backslash i}^{\tau *})\big|_{t=\tau}]) \times f^N[\tau, x_N^{\tau *}, \psi_N^{(\tau)N}(\tau, x_N^{\tau *})]\} + \\
& \frac{1}{2} \sum_{h,\zeta=1}^{m} \Omega_K^{h\zeta}(\tau, x_\tau^*)[W_{x_t^h x_t^\zeta}^{(\tau)K}(t, x_t^*)\big|_{t=\tau}] - \\
& \frac{1}{2} \sum_{h,\zeta=1}^{m} \Omega_{K \backslash i}^{h\zeta}(\tau, x_\tau^*)[W_{x_t^h x_t^\zeta}^{(\tau)K \backslash i}(t, x_t^*)\big|_{t=\tau}]\}
\end{aligned}
$$

Stochastic environment factor

-

will lead to the realization of the Condition.

Future Work

- Design practical protocol based on our incentive framework
- Implementation and validation of our protocol based on Virtual BT platform

End

- Review
  - ➢ Analysis of Tit-for-Tat Strategy
  - ➢ Basic Elements of Game Theory
  - ➢ Incentive Framework (theoretical)

- Thanks ☺