A Decision-Analytic Approach for P2P Cooperation Policy Setting

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Our Motivation & Goal

- Overall performance of P2P systems depends on resource contributions of individual peers.

- Rational peers decide on their cooperation policies according to their individual utilities.

- **Inherent conflict** among individual utilities of the rational peers results in
  - free-riding
  - unfair contribution
  - low participation

- Our goal is dealing with the inherent individual utility conflicts to improve overall performance of the system.
Our Approach

- We employ decision-theory to model cooperation policy setting of participating peers:
  - Each peer chooses its strategy according to observable strategies of the other peers.
  - Through a swarm-based iterative learning process:
    - Rational peers set their cooperation policies so as to maximize their own utility.
    - Their decisions are coordinated in a distributed manner to improve the social welfare of the system.

- The game-theoretic analysis lacks an explicit and tractable handling of the individual strategy dynamics present in the interactions among individual peers.
SYSTEM MODEL
Individual-based Lagrangian Swarm Model

- Interacting participants of a P2P system exhibit general properties of an individual based Lagrangian swarm model:
  - composed of many individual peers;
  - the interactions are based on local information exchange;
  - emergence;
  - self-organization.

- We made two modifications to adopt this model in the context of a P2P system:
  - Distributed local objectives (utility functions) are defined for individual peers.
  - The interaction of particles is represented as a non-cooperative game.
Definitions

- We assume that $N$ peers $p_i ; i: 1, \ldots, N$ participate in the system.

- Policy ($d_i$)
  - a peer’s policy is its level of cooperation (a numerical assessment of the peer’s contributed resources to the system).

- Strategy ($s_i$)
  - the strategy of a peer reflects its decision on the change in its cooperation level (policy).

- Utility ($U_i$)
  - A peer's utility is determined by its strategy choices and depends on several parameters - discussed as follows.
Utility Function

- Cost and Benefit
  - the total cost for participating in the system with cooperation level of $d_i$ will be $c_i d_i$
  - the benefit of cooperation of $p_j$ to $p_i$ is represented by $b_{ij} d_j$; where $b_{ij}$ is measured (e.g.) as the inverse of latency

- Incentives for high contribution
  - it is modeled by a monotonically increasing function of the cooperation policy of a peer $p_i$, denoted by $bc_i$

- Utility:
  \[
  U_i = bc_i \sum_{j \in N} b_{ij} d_j - c_i d_i ; b_{ii} \equiv 0
  \]
DECISION-ANALYTIC APPROACH
Overall

- Observable strategies of other peers are monitored by each peer in a sequence of iterations.

- Based on this empirical evidence, each peer can decide rationally on a strategy in every iteration.

- This chain of decisions are made based on a method inspired by particle swarm optimization (PSO).

- Through this chain of decisions each participating peer concludes its final cooperation policy with respect to the other peers' behavior.
More Formally

- To maximize its expected utility $U_i$, each peer $p_i$ sets its final cooperation policy through an iterative decision making process:
  - $p_i$ monitors the strategies of the other peers in its neighborhood $N_i$ locally and evaluates their strategies.
  - It chooses its strategy $s_i^{\text{next}}$ in the next iteration with respect to the evaluation result and to its own experience:
    
    $$s_i^{\text{next}} = s_i^{\text{current}} + r_1 c_1 (d_p - d_i^{\text{current}}) + r_2 c_2 (d_n - d_i^{\text{current}})$$

  - $d_p$ is the best previous policy of $p_i$ and $d_n$ denotes the best policy of the other peers in $N_i$.

  - Then the cooperation policy $d_i$ of peer $p_i$ is revised as follows:
    
    $$d_i^{\text{next}} = d_i^{\text{current}} + s_i^{\text{next}}$$
ANALYSIS - EVALUATION
NE Analysis

- We employ Nash equilibrium analysis to investigate the predicted strategies for the participating peers by the decision-analytic approach.

- According to [Buragohain et al. P2PComputing03] for a similar quantitative model of the system in a homogeneous setting (for all $p_i, b_{ij} = b, c_i = c$), the NE is given by:

$$d^* = \left( \frac{b(N - 1)}{2c} - 1 \right) \pm \left( \left( \frac{b(N - 1)}{2c} - 1 \right)^2 - 1 \right)^{1/2}$$

- As we numerically show:
  - The expected NE of the game is not the Pareto-optimal one.
  - The outcome derived from the proposed decision-analytic approach would make all players better-off.
The comparison of the average cooperation level

- Tendency toward Pareto efficiency
- Better outcome than NE
- Both homogeneous and heterogeneous settings evolve similarly
Convergence to a set of Pareto efficient strategy

- Fast convergence regardless of the target cooperation level
CONCLUSION
Conclusion – Future Work

- We propose a decision-analytic approach based on the modified swarm model, to set and coordinate rational decisions of the individual peers on their cooperation policies in a distributed manner.

- The resulting cooperation policies constitute the final set of decisions that maximize rational peers' utility in-line with the social welfare of the system.
  - Incentive-compatible for peers to follow

- Our approach quickly approximates a Pareto-optimal operating point of the system.

- In our future work, we will investigate information exchange mechanisms that involve incentives for neighbor truthfulness or own observation and verification.
THANK YOU FOR YOUR ATTENTION.
MORE QUESTIONS TO:

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