Networking Games
Outline

- Motivation and overview
- Concepts and definitions
- Game theory and networks
- Conclusions
Networking Games
Motivation and Overview

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Motivation and Overview
What is Game Theory?

- Discipline to analyze problems that \cite{S1999}—conflicts among decision makers
- Essentially optimization problem—selfishness (rationality) is the primary aspect
- A game is well-defined competitive situation \cite{P2001a}—with a set of strategies
- Generally two or more players involved
- Payoff for each player for different strategy
Motivation and Overview

Applications of Game Theory

- Applicable to various science fields [S1998a]
- Economics
  - auctions
  - market share
  - pricing
- Philosophy
  - rational behavior
- Evolutionary biology
  - study of animal population
- Engineering and computer science
Motivation and Overview

Applications of Game Theory in Networks

- Internet pricing for QoS
- Selfish routing
- Security, trust, reputation
- Analysis of wireless networks
- Spectrum allocation auctions
Motivation and Overview

History

• As early as 0-500 AD [GTH]
• John von Neumann’s minimax theorem 1928
• John von Neumann and Oskar Morgenstern 1944
  – “Theory of Games and Economic Behavior”
  – book about preference and utility theory
• John Forbes Nash [1950-1960]
  – Nash equilibrium
  – n-person games and non-cooperative games
• [1990-2017] plethora of
  – applications, publications, conferences etc.
Networking Games
Concepts and Definitions

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Concepts and Definitions

Types of Games

- Cooperative vs. non-cooperative
- Symmetric vs. asymmetric
- Zero-sum vs. nonzero-sum
- Simultaneous vs. sequential
- Perfect information vs. non-perfect information
- Infinitely long games
- Discrete vs. continuous
- Single player vs. n-player
- Metagames
The Prisoners’ Dilemma
Payoff Matrix Example

<table>
<thead>
<tr>
<th>players</th>
<th>prisoner 1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>strategy</td>
</tr>
<tr>
<td>prisoner 2</td>
<td>cooperate</td>
</tr>
<tr>
<td>cooperate</td>
<td>3,3</td>
</tr>
<tr>
<td>defect</td>
<td>0,6</td>
</tr>
</tbody>
</table>

- Prisoners are in separate cells, asked to confess
- Cooperate strategy is being silent against authorities
- Defect strategy is turning the other one in
- Worst outcome when both defects: 8+8=16 years
Game Representations

Normal vs. Extensive Form

- **Normal form** [MW2001]
  - represented as bimatrix
  - e.g. payoff matrix

- **Extensive form** [S1997]
  - depicted as a tree
  - $P_1$: decision maker
  - game ends: terminal node
  - branching: choice points
  - choice points are circled
  - lack of information sets

\[
P_1 = \begin{bmatrix} 3 & 6 \\ 0 & 8 \end{bmatrix} \quad P_2 = \begin{bmatrix} 3 & 0 \\ 6 & 8 \end{bmatrix}
\]
Concepts and Definitions
Zero-Sum and Nonzero-Sum Games

• Any benefit to player is balanced by a loss ...
• of the same amount by the opposition [GGH2003]
  – two-person zero-sum game (e.g. chess, checkers)
  – n-person zero-sum game (e.g. five-person poker game)
• Benefit of a player from a strategy is not ...
• equal to the loss of the opponent
  – two-person nonzero-sum game (e.g. the prisoners’ dilemma)
  – $P_1 + P_2 \neq 0$
Concepts and Definitions
Cooperative and Non-cooperative Games

• Cooperative games: bargaining problems [CSMW2002]
  – two players are bargainers
  – fair point chosen by two parties is called solution
• Non-cooperative games: leader-follower games
  – players make independent decisions
• Strategy example: price for ISP and demand for user
Outcome Comparison
Nash Equilibrium and Pareto Efficiency

• Nash equilibrium [MW2001]
  – a selection of strategies such that ...
  – neither player can improve own payoff by changing ...
  – strategies while other players’ strategies remain fixed

• It is the stable operating point for a defined game

• Pareto efficient outcome [MW2001]
  – impossible to increase the payoff of any player
  – without decreasing the payoff of another player
Concepts and Definitions

Mechanisms and Auctions

• GT maps individual benefits from different strategies
• Mechanism design is the inverse [P2001a, P2001b]
  – given desired goals, designing a game in which ...
  – individual players motivated by selfish (rational) behavior...
  – end up achieving designer’s goals
• Canonical example: Auctions
  – FCC auctions for electromagnetic spectrum licenses
    • Simultaneous Multiple-Round (SMR) auctions
    • package bidding
  – auction sites: eBay, Amazon, etc.
    • reputation and trust effects profitability
Networking Games
Game Theory and Networks

• Motivation and overview
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• Game theory and networks
  – layered games
  – game theory and security
  – Internet economics
• Conclusions
Game Theory and Networks

Layered Games

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Game Theory and Networks
Overview

- Network game components:
  - players: nodes
  - strategy: network functionality, protocol, algorithm
  - utility: performance metrics

- Game theory can be useful:
  - analysis of network systems
  - cross-layer optimizations
  - design of incentive schemes

- Challenges of networking games
  - complex models in wireless and mobile environments
Game Theory and Networks

Games at Lower Layers

- **Physical layer** [SNM+2005], [MW2001]
  - power control
    - each node targets to achieve SINR
  - waveform adaptation
    - selection of waveform to reduce interference at the receiver

- **MAC layer**
  - models access of the channel by user
  - selfish users seek to maximize their utility
    - by unfair access to the channel
  - games can be cooperative or non-cooperative
Game Theory and Networks
Games at Network Layer

- Network-level routing [QYZS2006]
  - inefficiencies due to:
    - routing hierarchy and policies, stability problems
    - results in suboptimal latency, loss rate, TCP throughput

- Selfish routing [RT2002]
  - user autonomy
  - selfish routing is not malicious
  - non-cooperative to reduce latency
  - examples: source routing and overlay routing

- Game theoretic analysis of ad hoc routing [SNM+2005]
  - zero-sum game between routers and the network
  - routing overhead vs. correct view of the paths
Game Theory and Networks

Games at Transport Layer

- Game theory primarily analyses congestion control
- Evaluation of greedy end-point behavior
  - TCP and its variants
- Wireless and mobility effects are not well studied
- Further info: [A+2002, GK1999]
Game Theory and Networks
Games at Application Layer

- Trust is essential part of Semantic Web
- Semantic web entails machine understandable info.
- More info about Semantic Web can be found in:
  - [AG2007], [LH2001], [SHL2006], [H2001]
Game Theory and Networks

Game Theory and Security

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Game Theory and Security
Overview

- Game theory used to model network security
  - what is the best strategies for attacker and administrator?
- Games are modeled non-cooperative among players
- Game theory and cryptography
  - application of cryptography to game theory
  - application of game theory to cryptography
- Game theory helps incentive mechanism design
Incentive mechanisms for desirable equilibrium

Credit exchange mechanisms:
- charge and reward
- credit for cooperating the rest of the network
- debited for requesting service from the network

Reputation-based mechanisms
- positive reputation for cooperation
- negative reputation for non-cooperation

Centralized authoritative mechanisms possible
- central authority not involved in game strategy
Game Theory and Security

Non-cooperative Security Games

- GT for tradeoff between cost vs. level of security
- GT help deciding strategies for attacker and defender
- Finding Nash equilibrium
  - best response strategies for attacker and defender
- Non-cooperative games in security [R+2010]
  - static
    - one-shot game with imperfect information
  - dynamic
    - multi-staged sequential games
Game Theory and Networks

Internet Economics

• Motivation and overview
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  – game theory and security
  – Internet economics

• Conclusions
Internet Economics
Overview

• Primarily deals with pricing
  – how to set the price?
    • cooperative vs. non-cooperative games
    • non-cooperative games for ISP vs. user
    • cooperative games with some regulations and arbitration
      [CSMW2002]

• Pricing supported by accounting architectures
• Many pricing policies exist
• Network models support QoS
Internet Economics

Pricing

- Service differentiation is essential for QoS
- Pricing help service differentiation in commercial net.
  - congestion control
  - call admission control
  - resource management
- Network pricing studies include [D2000]
  - choice of pricing policy
    - dynamic vs. static
    - more pricing policies [F+2000]
  - setting of prices
    - primarily a marketing and strategic decision
    - dynamic pricing according to current state of the network
Internet Economics
Accounting

• Internet accounting provides:
  – monitoring network resources
  – collecting and storing data
  – processing and communicating relevant data
    • signalling messages

• Accounting architectures vary depending on:
  – policy
  – data collection sources and methods
  – interactivity
  – supported network protocols
  – more on [KP2002]
Internet Economics

Internet Pricing and Accounting Relationship

- Accounting and pricing reciprocal
- Pricing deals with
  - policy and charging strategies
- Accounting determines
  - feasible pricing models
- Network models alternative to:
  - IntServ
  - DiffServ

Pricing Models
- auctions
- static pricing
- dynamic pricing
- priority pricing
- time of the day pricing

Accounting
- traffic measurement
- transaction recording
- resource monitoring
- control messages

Network
- data transmission
- QoS provisioning

[KP2002]
Networking Games

Conclusions

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Networking Games

Conclusions

- Game theory has a very rich tools and history
- Recently applied to communication networks
- Application of GT to system problems can be difficult
  - uncertainty of outcome of systems [MRWZ2004]
  - complexity of systems (e.g. mobility)
Networking Games

Generic References

Networking Games

Generic References

Networking Games

Wireless Game References

Networking Games
Routing Games References

Networking Games

Internet Economics References


Networking Games
TCP Games References


Networking Games
Semantic Web References

Networking Games
Trust and Reputation References

Networking Games

Security References


