Algorithmic Game Theory
for Mobile Opportunistic Networking

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Outline

- Mobile (ad-hoc and) opportunistic networking
  - Principle & demands to engineering
  - Our approaches @ distributed systems group
- Game theory
  - Basics
  - Two-player games / multi-player games: Examples
  - Algorithmic game theory
- Engineering interactions by defining strategies
  - Fair job processing
  - Dissemination of non-cooperativeness in networks
- Evolution of best strategies
- Concluding remarks, potentials for SOS

Mobile Ad-hoc and Opportunistic Networking

- Ad-hoc networking
  - Networks are set-up on demand, no pre-defined infrastructure
  - Network nodes are “equal”, used distributed algorithms for sharing the communication medium (e.g., CSMA/CA in WiFi ad-hoc modus)
- Opportunistic networking
  - Nodes use communication opportunities for data dissemination
  - Opportunities are modeled as contacts
  - Node mobility creates opportunities
- Style of data dissemination
  - Traditional Mobile Ad-hoc Networks (MANETs): Routing, end-to-end
  - Opportunistic networks: Information dissemination without end-to-end semantics

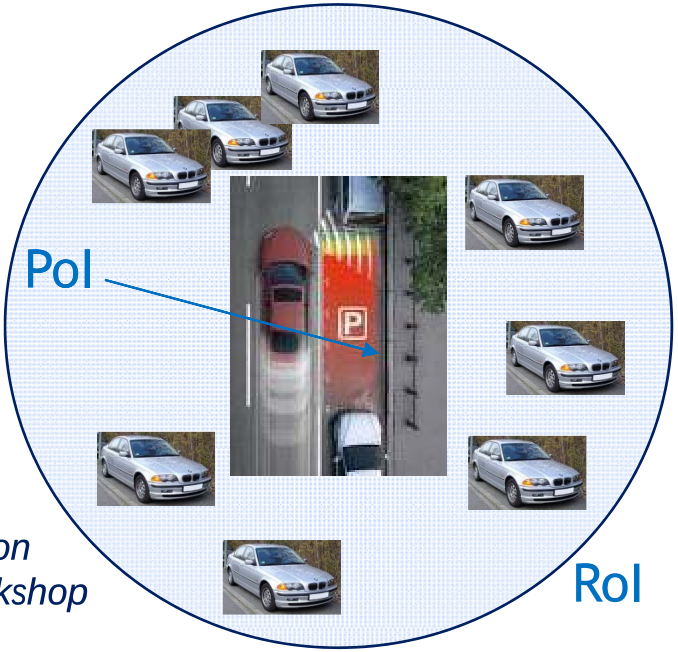
Mobile Opportunistic Networking Example

Scenario characteristics [Meyer09]

- Data is bound to geo-location (Point of Interest – PoI) and of local interest only (Region of Interest – RoI)
- No sufficient network infrastructure
- Mobile networked devices cooperate when in range
- [Positioning technology available (like GPS, D-GPS, etc.)]

Envisioned applications

- Parking assistance
- Emergency
- Networking in rural areas



[Meyer09] Harald Meyer and Karin Anna Hummel. A Geo-location Based Opportunistic Data Dissemination Approach for MANETs. In CHANTS '09: Forth ACM Workshop on Challenged Networks, 2009.

Our Approaches to Mobile Opportunistic Networks

Movement **causes**

- Varying wireless link quality
- Intermittent connectivity

Approaches

- Mobility-awareness based on accurate mobility models and prediction
- Algorithms and strategies for decentralized cooperation of nodes for efficient data dissemination

Mobility-Aware Decentralized (SO) Computing

Cooperation in Opportunistic Networking Research

Often assume always-cooperating, trustful mobile nodes

But …

- Devices are resource constraint (limited battery lifetime, processor capacity, wireless link capacity)
- Trust in other devices is a major requirement
- Central controlling instance is not feasible

--> Self-organization of “fair” cooperation is required

What about Using Game Theory?

- Agents are here termed Players
- Players act based on strategies and (more or less) on other players actions
- Actions based on payoff / cost / utility
- Competitive and cooperative players
- Aiming to reach a situation where no player can benefit by cheating on the other /stable state – Nash equilibrium

[Nisan07] N. Nisan, T. Roughgarden, È. Tados, V.V. Vazirani (eds.). Algorithmic Game Theory. Cambridge, 2007

Game Theory Concepts in (Ad-hoc) Networking

- Players: Network nodes
- Strategy: Actions based on functionality
  - Decision to forward packets
  - Setting of power level
  - Selection of modulation technique, etc.
- Utility function: Performance metrics
  - Throughput
  - Delay, etc.

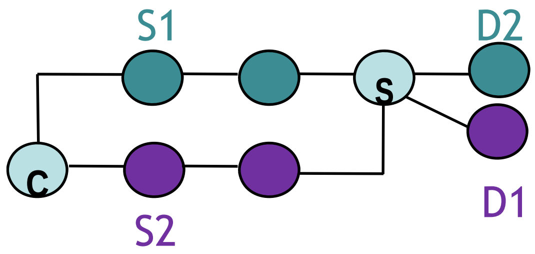
Some Well-Known Examples from Game Theory

- "Prisoner's Dilemma"
  - Player (silent)
  - Player (confess)
  - Being silent (coop.) is not

  a stable strategy

Player 1 \ Player 2	Confess	Silent
Confess	4, 4	1, 5
Silent	5, 1	2, 2

- "ISPs routing game"
  - Application to networking, e.g., two ISPs (ISP1, ISP2) using the resources of the other ISP, transmissions: *S1* → *D1*, *S2* → *D2*



Same Well-Known Examples from Game Theory contd.

- "Pollution game"
  - Multiple players
  - Cost of introducing ecological changes C_e, cost of each country for each other country polluting the environment C_p
  - *k* polluting countries, *N-k* ecologically responsive
  - For each responsive country: $k\ C_p + C_e$
  - Stable solution: all countries pollute, optimum for each country: C_e

- "Tragedy of the commons"
  - Overuse resource → deviation

- Coordination games: Additional constraints
  - "Battle of sexes" (evening activities under the constraint that the two players want to go out together)
  - "Routing congestion games" (cooperation leads to congestion avoidance) ….

[Roughgarden10]

- Game Theory results revisited and extended
- Concrete optimization problems
  - Optimal solutions
  - Impossibility results
  - Upper and lower bounds
  - Feasible approximation guarantees, etc.

  - Keeping in mind: Computational complexity

[Roughgarden10] T. Roughgarden. Algorithmic Game Theory. Communications of the ACM, July 2010, vol. 53, no. 7

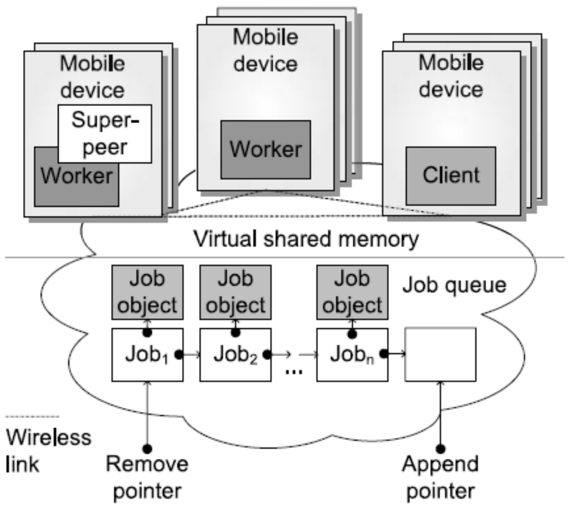
Job Scheduling Fairness Among Mobile Nodes

[Hummel08a] K.A. Hummel and H. Meyer. Self-Organizing Fair Job Scheduling Among Mobile Devices. In SELFMAN 2008, 2008.

Example: Robust, Decentralized Job Scheduler

Overview

- Based on distributed virtual shared memory
  - > Persistence of data, asynchronous communication
- Coordination based on distributed queues
- Mobile workers decide autonomously when to take a job, considering:
  - > User policies
  - > Job requirements
  - > Current and predicted performance values
- Proactive Fault Tolerance (FT): redundant job execution to prevent job loss
- Reactive FT: handle system failures
- Very reliable nodes run critical tasks (e.g., FT services)



Fairness - Strategies

Idea

- Decision whether to take or skip a job is based on chosen strategy
- Each strategy evaluates all performance values in *group T*

Classification

- Lazy strategy
  - *not best*: job is not taken, if at least one device in *T* is better
- Assiduous strategy
  - *worst*: job is not taken, if all devices in *T* are better
- Evaluation of average or majority
  - *Worse than average*: job is not taken, if average of devices in *T* is better
  - *Worse than majority*: job is not taken, if majority of devices in *T* are better
  - *Equal or worse than majority*: job is not taken, if majority of devices in *T* are equal or better

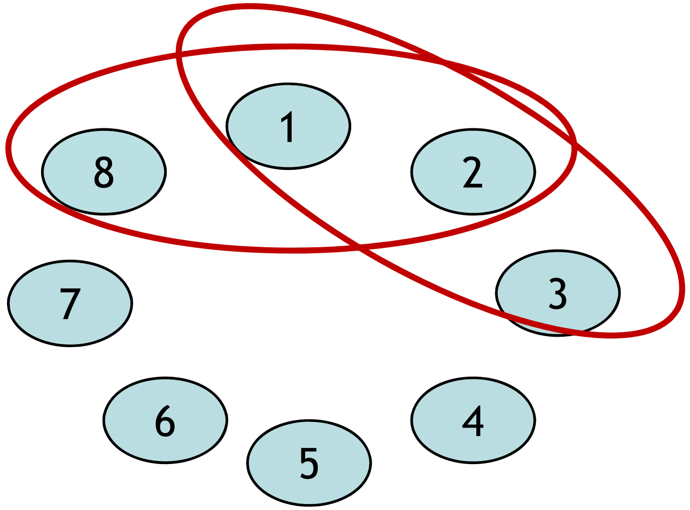
Deadlock prevention

- If job remains in queue for a defined time, job management without fairness is temporary activated, deactivate strategy

Groups Considered for Comparing Own Capabilities

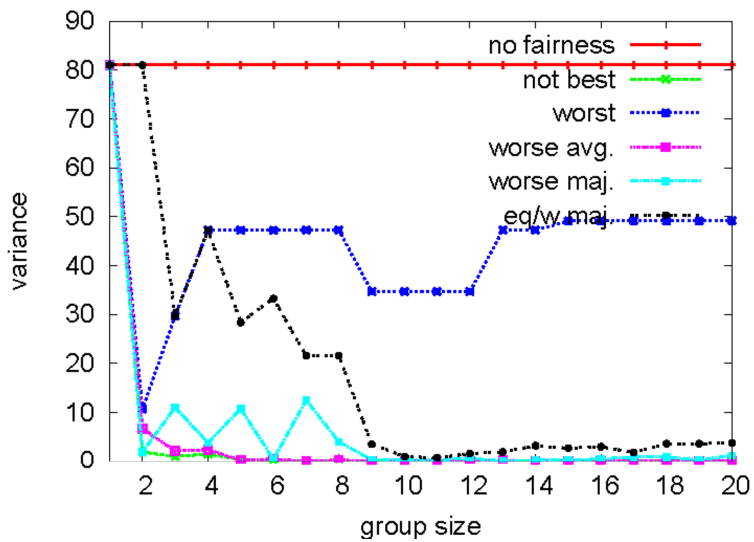
Based on non-disjoint groups

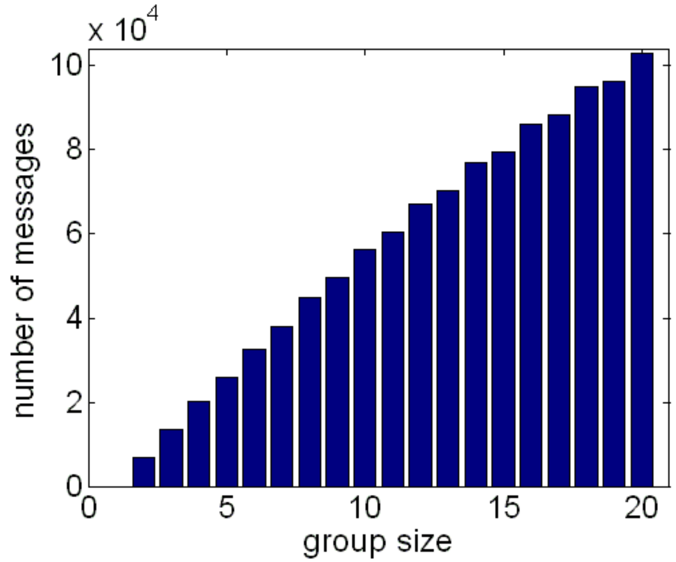
- Assures spreading of information/decisions throughout the system
- Avoids communication overhead (e.g., when compared to gossiping with all nodes)
- Group size *n*
- Example *n* = 3



- Should provide a system structure allowing self-organization

Selected Results





Simulation approach (60 jobs; one every 110 secs), disconnections simulated by timeline

Observations

- Strategy *not best* outperforms other strategies with respect to fairness (incl. deadlock prevention)

Propagation of Non-cooperative Mobile Nodes

[Hummel08b] K.A. Hummel and H. Meyer. On Properties of Game Theoretical Approaches to Balance Load Distribution in Mobile Grids. In IWSOS '08: Third International Workshop on Self-organizing Systems, 2008.

Game Strategies

Terms

- Defecting/selfish: do not contribute resources
- Ever defecting: only defecting
- Cooperate: contribute resources

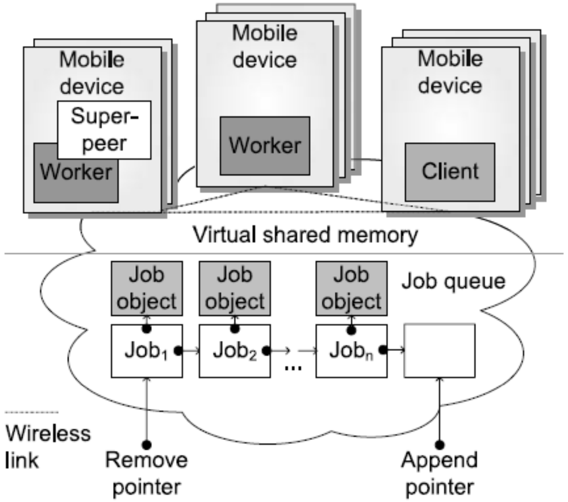
Strategies

- Tit For Tat (TFT)
- Generous TFT (g-TFT)
- Go By Majority (GBM)

System Architecture

Decentralized Scheduler

- pro- and reactive fault tolerance
- critical tasks are assigned to reliable nodes
- coordination based on distributed queues



Game Strategies

- State (corporate/defect) is transmitted to neighbors
- Node's decision is based on neighbors' state

Experiments

Setup

- 15 nodes playing TFT/g-TFT/GBM
- 5 nodes ever-defecting
- group sizes 5, 10, 15 and 20

Scenario 1

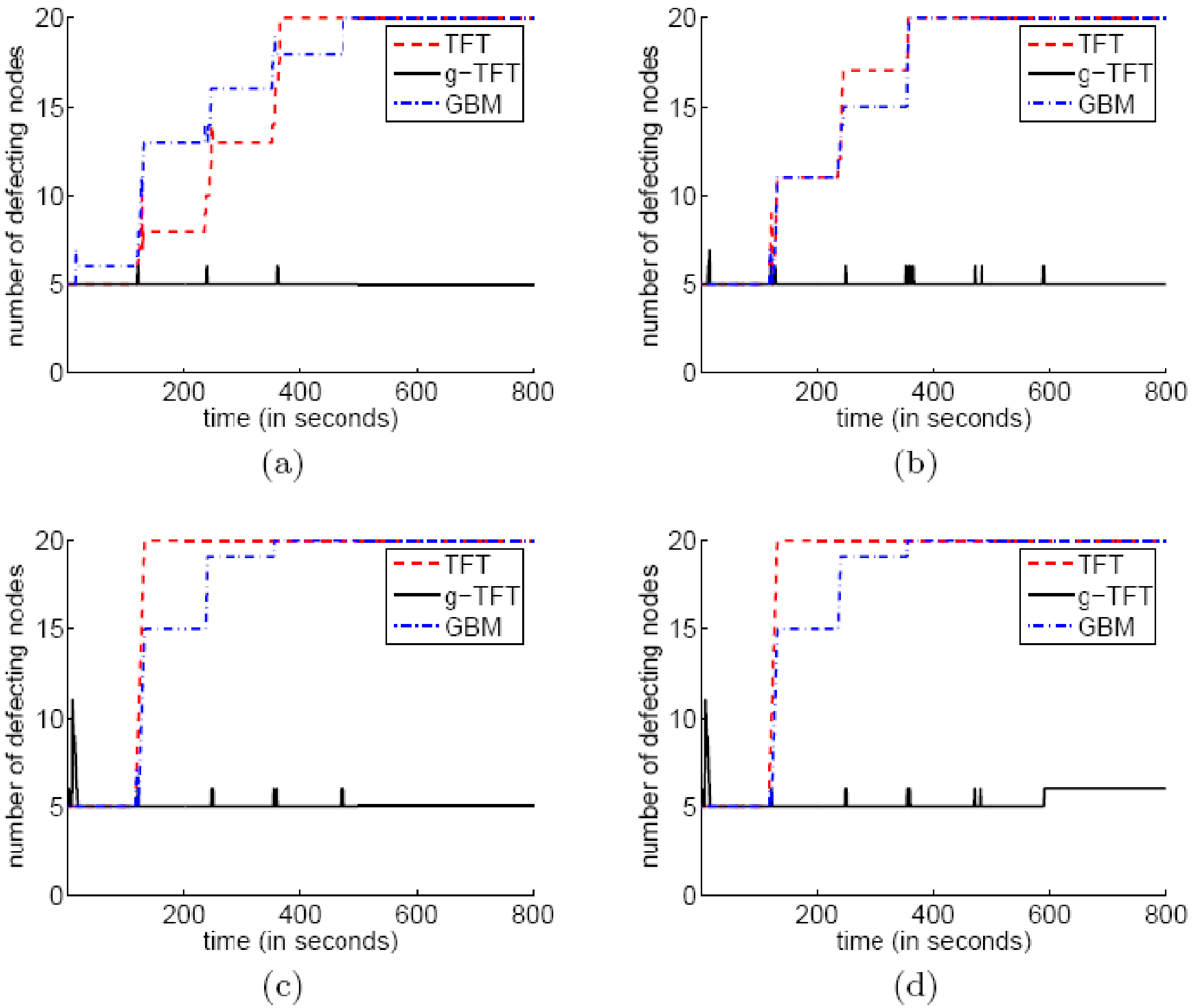
- Propagation of selfishness among homogeneous strategies

Scenario 2

- Propagation of selfishness with TFT + g-TFT + GBM

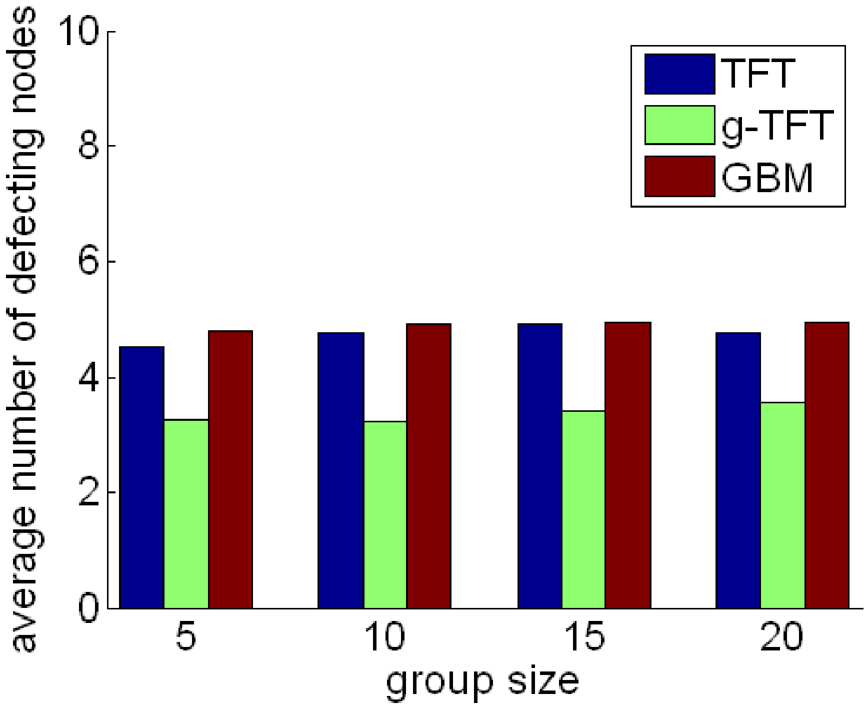
Results Scenario 1

- 5 ever-defecting nodes
- group size (a) n=5, (b) n=10, (c) n=15, and (d) n=20



Results Scenario 2

- 5 TFT, 5 g-TFT, 5 GBM nodes
- 5 ever defecting nodes



- How does placement of nodes influence propagation?

On Strategies and Decisions

- Set of strategies
  - Players usually use *mixed strategies*
  - Probabilities describing the likeliness

- Properties of strategies

Strict dominant strategy equilibrium (e.g. [Wu08])

↙ ↘

Dominant strategy equilibrium* Strict Nash equilibrium

↘ ↙

Nash equilibrium*

Utility ≥ *

Stronger than →

[Wu08] Fan Wu et al. Incentive-Compatible Opportunistic Routing for Wireless Networks. Mobicom'08

Engineering and Evolution

- Derive a set of best strategies
  - In principle: Can dynamically change
- Searching for “best” strategies
- Searching for configurations of payoff and cost matrices / metrics to be used
- Approach: Population dynamics as in evolutionary dynamics (fitness function: winning or loosing according to an assumed benefit)

Conclusions

- Game Theory provides in-depth research results
  - Two and multi-player games can be modeled
- Algorithmic game theory
  - Considering computation aspects
  - Particular Issue: Distributed/partial knowledge
- Evolution
  - Particular Issue: Search for best fitting strategies and cost/payoff, evolving over time, stopping / re-starting search

Thank you for your attention!

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