Game theory for wireless networks

Lecture 11

Today's topics

- Routing in wireless ad hoc networks
- Your presentations
  - Dynamic channel allocation
  - Bayesian routing

Ad hoc networks

- Peer to peer communication
- No central management/controller
  - Self-configuring
- Reach distant nodes through multiple hops → source-destination routes
  - How to choose a route ?
    - Best path according to some criteria → routing metrics
      - **Minimum hop count**
      - **Minimum energy**
      - **Lowest delay**
      - **Highest throughput**
      - ...

Routing for ad hoc networks

- Basic ideas → from wireline networks
- Some new problems in wireless:
  - Mobility → routes become unavailable as mobile nodes move away
    - High routing overhead to establish and maintain routes
  - Interference → changes with the routing paths
  - Energy
    - Choose minimum energy paths
    - Do not overuse some of the nodes → network collapse
      - Uniform energy consumption across the network maximizes the network lifetime
    - Nodes spend energy relaying other users' traffic
      - **Are nodes willing to relay?**

Relaying as a game

- Relaying problem: very similar to the prisoners' dilemma problem
  - Relay → cooperate
  - Not relay → defect (D,D)
  - Users have incentives to defect
    - Lower energy consumption
    - Lower delay for their own traffic
- Recall: one stage prisoner dilemma → NE: (D,D)
- How to induce cooperation?
  - Repeated games may induce cooperation
  - Potential problem: free riders?!

Repeated relaying game

- In theory, any strategy proposed for the repeated prisoners' dilemma problem may be used for incentivizing forwarding

- Recall table of strategies from lecture 4.

- Today we will study two examples

1) V. Srinivasan, P. Nuggehalli, C. Chiasserini, R. Rao, "Cooperation in Wireless Ad Hoc Networks", INFOCOM 2003.

1) GTFT solution

- GTFT – generous TIT for TAT
- Model
  - Network with N nodes and K classes, M relaying nodes in a path
  - Classes – characterized by
    - energy constraints E_i
    - Lifetime expectation L_i
    - Average power constraint: $\rho_i = \frac{E_i}{L_i}$ $\quad \rho_1 > \rho_2 > ... > \rho_k$
  - Each session lasts for one slot
  - Session belongs to type j, if the most restrictive node on the path is of type j (highest value for j).

GTFT performance measures

- Generic node h:
  - $B_h^j(k)$ = number of relay requests made by node h for a session of type j, till time k
  - $A_h^j(k)$ = number of relay requests generated by node h for a session of type j, which have been accepted till time k
  - $D_h^j(k)$ = number of relay requests made to node h for a session of type j, till time k
  - $C_h^j(k)$ = number of relay requests made to node h for a session of type j, which have been accepted by node h till time k

$$\phi_h^j(k) = \frac{A_h^j(k)}{B_h^j(k)}$$

$$\psi_h^j(k) = \frac{C_h^j(k)}{D_h^j(k)}$$

GTFT performance measures – cont.

- Normalized acceptance rate: NAR

$$NAR = \lim_{k\to\infty} \phi_h^j(k)$$

- Throughput of a node → determined by NAR

Feasible regions of operations: set of NARs, s.t.

- meet the energy constraints of the nodes
- are Pareto optimal values
- all nodes will find the allocation fair and will accept it

Derivation assumptions: All nodes → stationary policy:

- A node in class i accepts a relay request from a session of type j with probability τ_{ij}

NAR operating points

- Feasibility condition (for a node p):

$$\sum_{j=1}^{K}(e_{pj}^{(s)}+e_{pj}^{(r)})\leq\rho_{class(p)}\quad 1\leq p\leq N$$

$$\tau_{class(p)j}\in[0,1]\ 1\leq j\leq K,\ 1\leq p\leq N$$

The average energy per slot, spent by the node as a source

The average energy per slot, spent by the node as a relay

NAR operating points - example

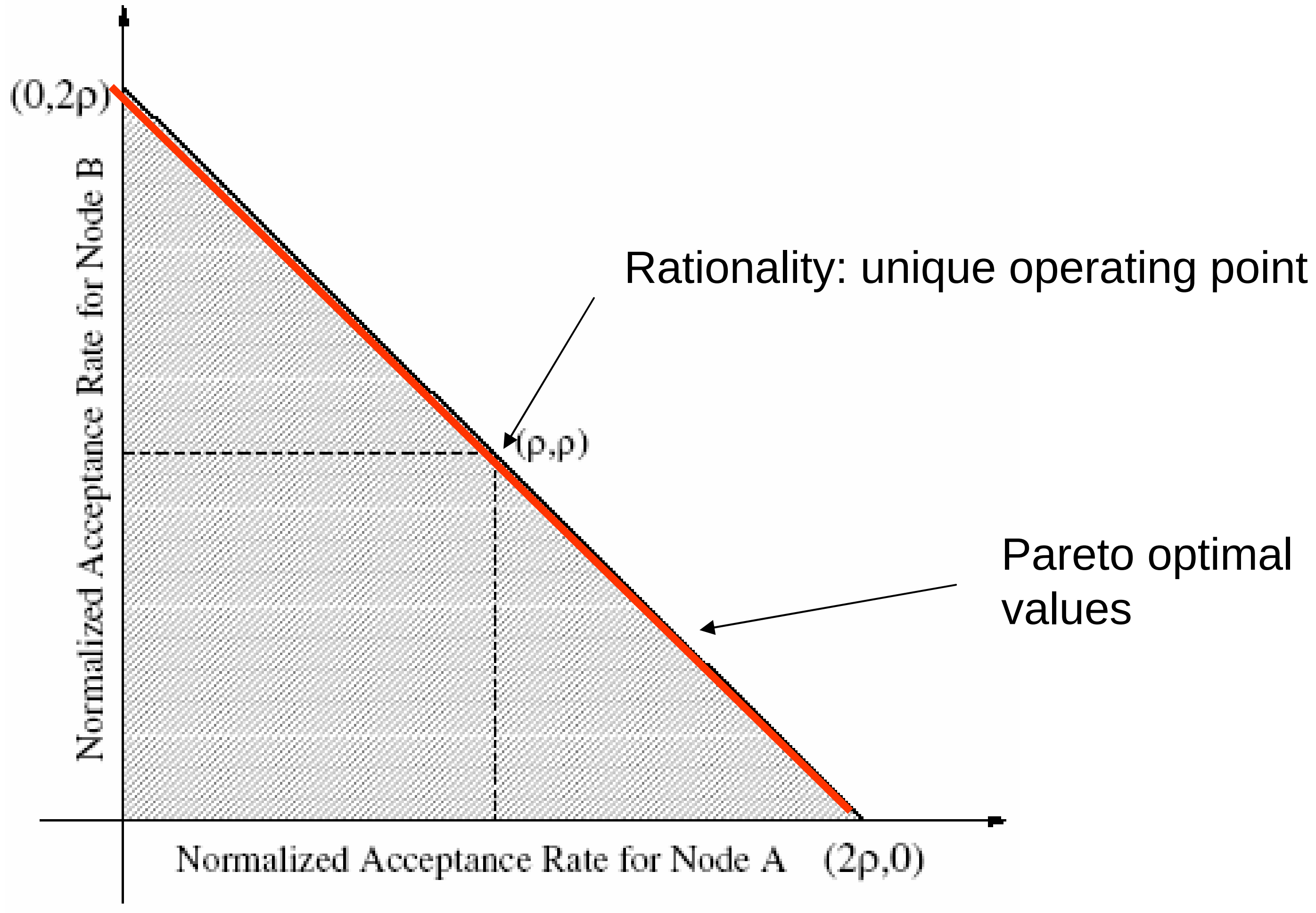


Fig. 1. Feasible Region for $N = 2$, $K = 1$, $\rho = 0.5$.

GTFT Algorithm

- New performance measure:

$$L_{ij} = \frac{\text{Prob(h is served in a type j session)}}{\text{Prob(h accepts to relay a type j session)}}$$

- GTFT:
  - Note: Any stationary strategy (accept request with some specified probability) – dominated by always deny strategy → need behavioral strategy (node base its decision on the past behavior of the nodes in the system)
  - Algorithm for N nodes, K classes, M=1 (1 relay node per session)

$$\begin{cases} If \;\; \psi_h^{(j)}(k) > \tau_j, \text{or } \; \phi_h^{(j)}(k) < \psi_h^{(j)}(k) - \varepsilon & \text{Reject} \\ \text{Else} \;\; \text{Accept} & \end{cases}$$

where $\tau_{ij} = \tau_{jj} = \tau_j, \; 1 \leq i \leq j \leq K$

GTFT – multiple relay case

- M-GTFT:

$$\begin{cases} If \;\; \psi_h^{(j)}(k) > \tau_j, \text{or} \;\; \phi_h^{(j)}(k) < L_{ij}\psi_h^{(j)}(k) - \varepsilon & \text{Reject} \\ \text{Else} \;\; \text{Accept} \end{cases}$$

The paper proves that GTFT and m-GTFT constitute Nash eq.

Some performance results

- Single relay case, 5 classes, 5 nodes per class, energy constraints:

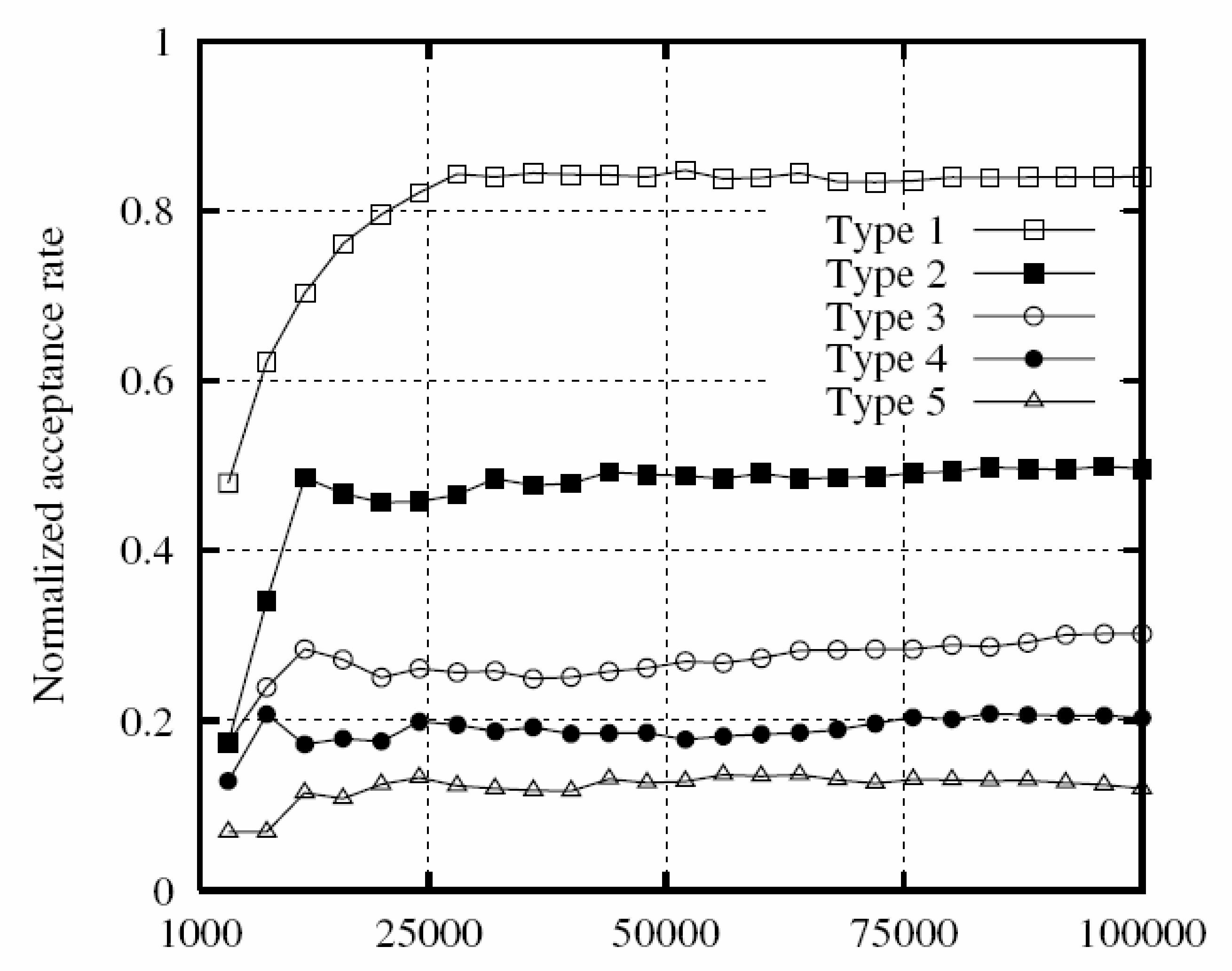
$$\rho_1 = 0.03,\ \rho_2 = 0.025,\ \rho_3 = 0.02,\ \rho_4 = 0.015,\ \rho_5 = 0.01.$$

- Theoretically derived Pareto optimal values of NARs:

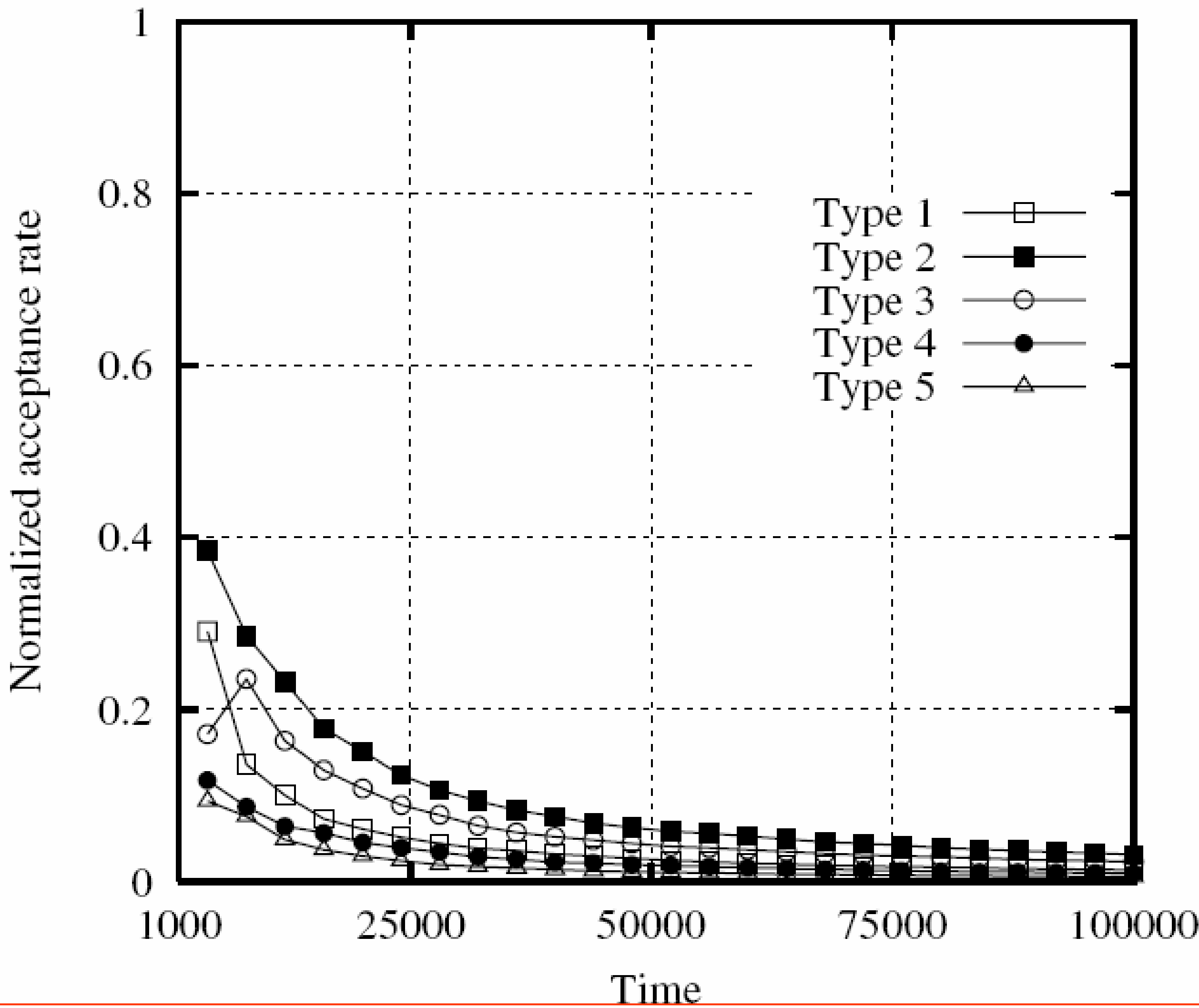
RATIONAL AND PARETO OPTIMAL VALUES OF THE NARS.

	Class 1	Class 2	Class 3	Class 4	Class 5
Class 1	0.84	0.49	0.30	0.20	0.12
Class 2	0.49	0.49	0.30	0.20	0.12
Class 3	0.30	0.30	0.30	0.20	0.12
Class 4	0.20	0.20	0.20	0.20	0.12
Class 5	0.12	0.12	0.12	0.12	0.12

Simulation results



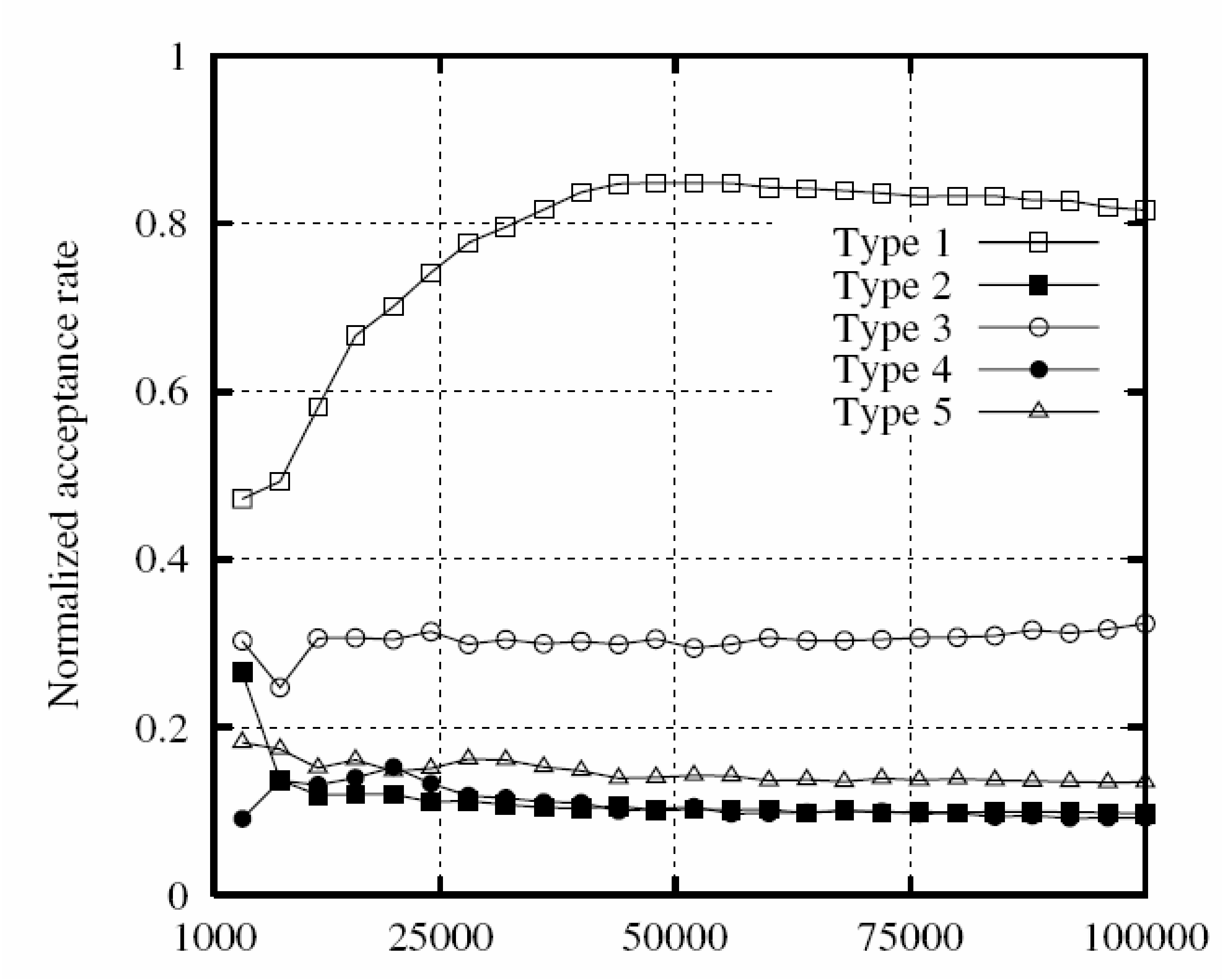
More simulation results - $\varepsilon<0$



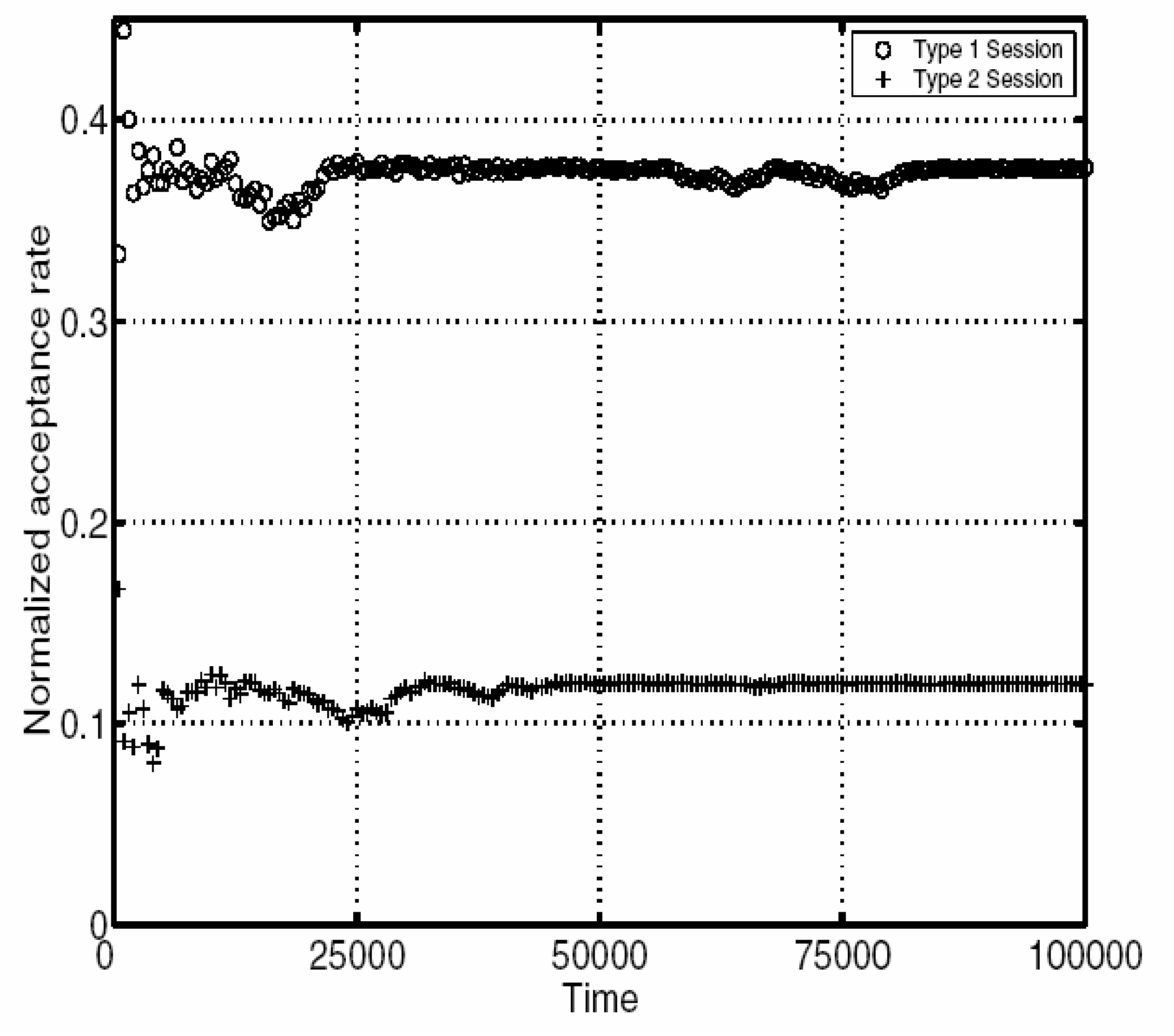
Note: when $\varepsilon = 0$ → the nodes behavior depends on the initial values of φ and ψ

Behavior with parasitic nodes

Example: one node in class 2, and one in class 4 (never relay traffic)



Convergence for M=2



Designing incentives to cooperate for random matching games

- Idea: players do not form long-lived relations – strategies of the type tit-for-tat may not work
- Model: players randomly matched
- Game: “social norm” strategy
  - Reputation system
    - Each node reputation: $\{0,1,...,\tau\}$
    - Trusted authority (centralized?) observes players’ actions and updates their reputation accordingly
  - Strategy
    - Cooperate if both players innocent
    - Defect if both guilty
    - If one innocent and one guilty: guilty cooperates and innocent deviates
  - Deviation → punishment – lasts for τ rounds

Peer to peer routing game

- Simplified model for routing
  - N nodes in a ring, routing table with *lg(N)* entries (finger table)
  - Choose next hop with probabilities proportional to the distance of the hop
- Game: matched nodes (requesting node (s) and potential relaying node (t)) asymmetric game:
  - s does nothing, t cooperates or defects
  - Payoffs:
    - If t defects → s has payoff 0
    - If t cooperates → s plays a new game for the next hop
      - t gets payoff –c (cost of routing)
      - s gets payoff b (at the end of last game if the path can be established)
      - each path: *lg(N)/2* hops on average →

$$b > (\lg(N)/2)c$$

Proof of equilibrium

- Requests arrive according to a Poisson process
  - Each node sends requests with λ_s, and receives requests with λ_r
  - Important assumption: non-burstiness (if requests arrive in bursts, a node can drop all of them without additional penalty)
  - Proof based on the expected payoff difference

1) Guilty node:

- time 0 drops a request and becomes guilty

- time T_1 – another request arrives → if forward → forgiveness at τ; if not forward → forgiveness at $\tau + T_1$

- expected payoff difference at time T1 between following the social norm and deviating from it is:

$$Diff = -c + E[\#\,\text{of requests sent in}\,[\tau, \tau + T_1]]\delta^{\tau} b =$$

$$= -c\lambda_s E[T_1]\delta^{\tau} b = -c + \frac{\lambda_s}{\lambda_r}\delta^{\tau} b \geq 0$$

$$\delta^{\tau} \geq \frac{\lambda_r c}{\lambda_s b}$$

Proof of equilibrium – cont.

- Innocent node:
  - Decision to forward or not – affects payoffs during $[0,\tau]$
  - Denote

$$\delta_{effs} = \text{effective discount factors for sending requests}$$

$$\delta_{effr} = \text{effective discount factors for receiving requests}$$

  - Expected payoff difference:

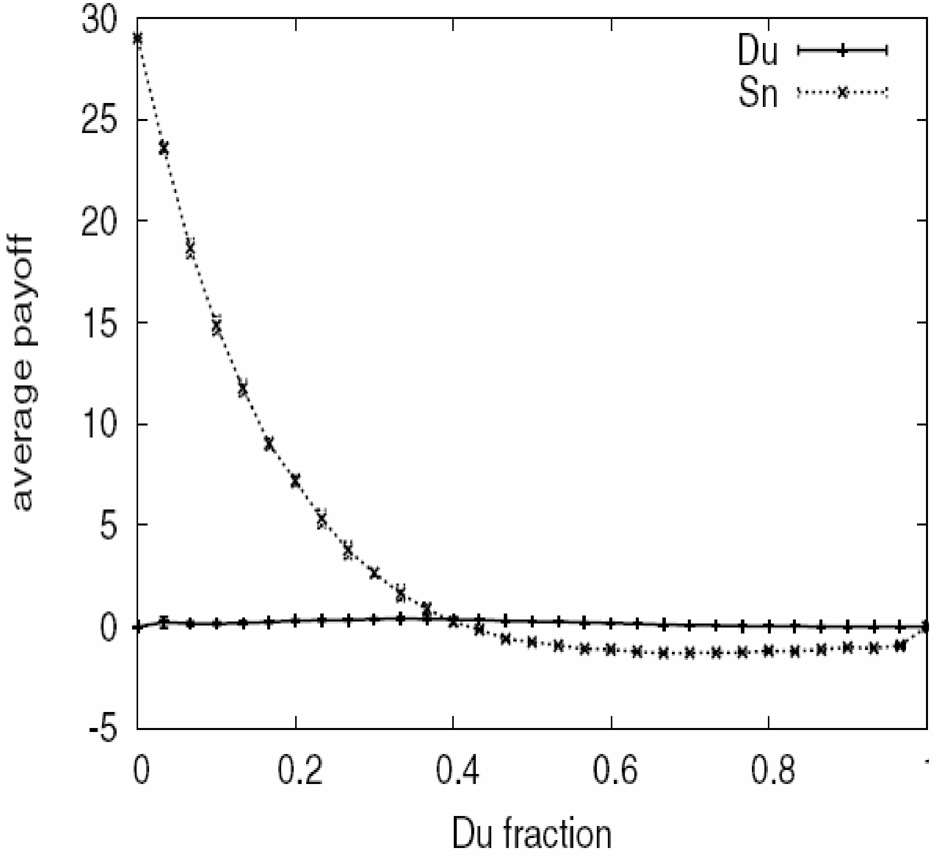
$$Diff = -c + (1-\delta^{\tau})b\frac{\delta_{effs}}{1-\delta_{effs}} - (1-\delta^{\tau})c\frac{\delta_{effr}}{1-\delta_{effr}} =$$

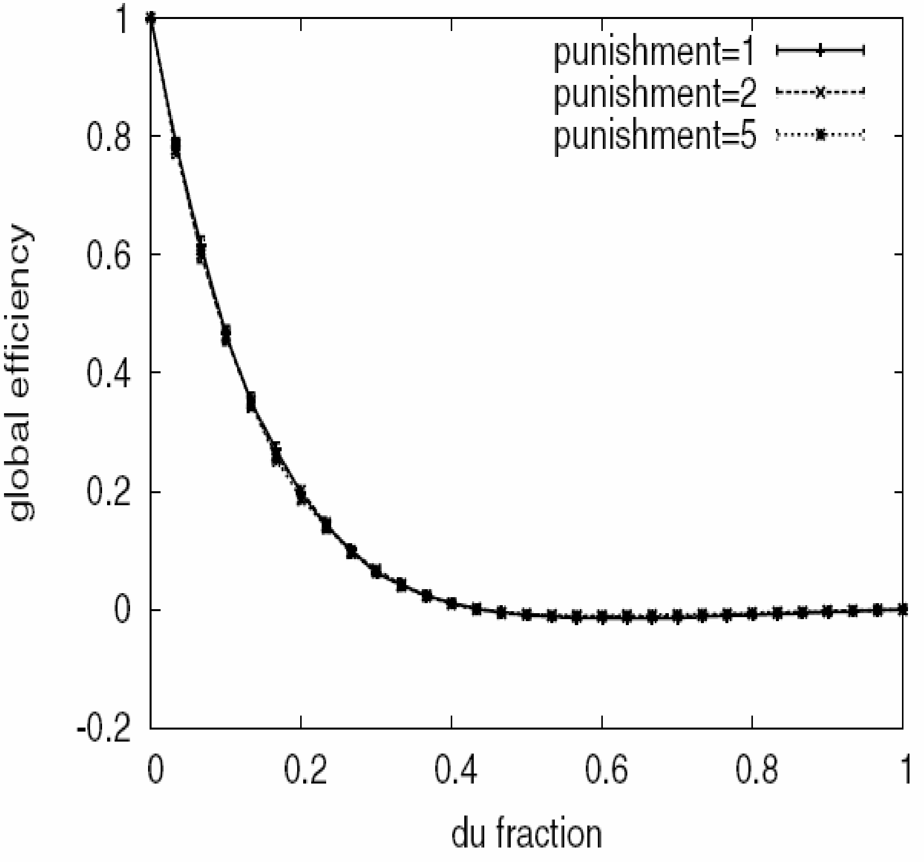
$$= \text{-c} + (1\text{-}\delta^{\tau})\frac{\lambda_s b - \lambda_r c}{-\log\delta} \geq 0$$

Simulations

- Simulate a game with discrete rounds: c=2, b=40, 1024 nodes, 5.5 hops on average, various punishment periods
- Malicious nodes → may weaken the incentive to cooperate
  – Always defect Du
  – Nodes that abide social norm: Sn

Simulation for malicious nodes





Noise

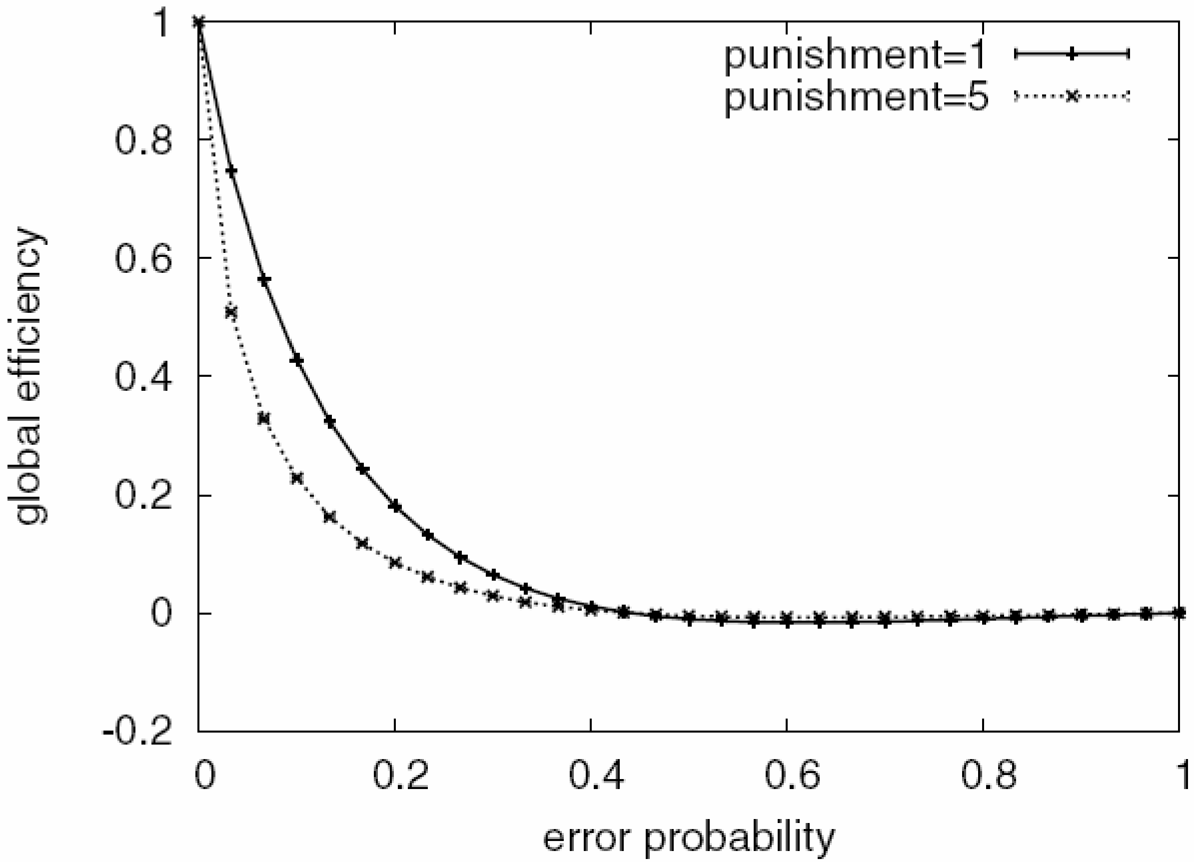
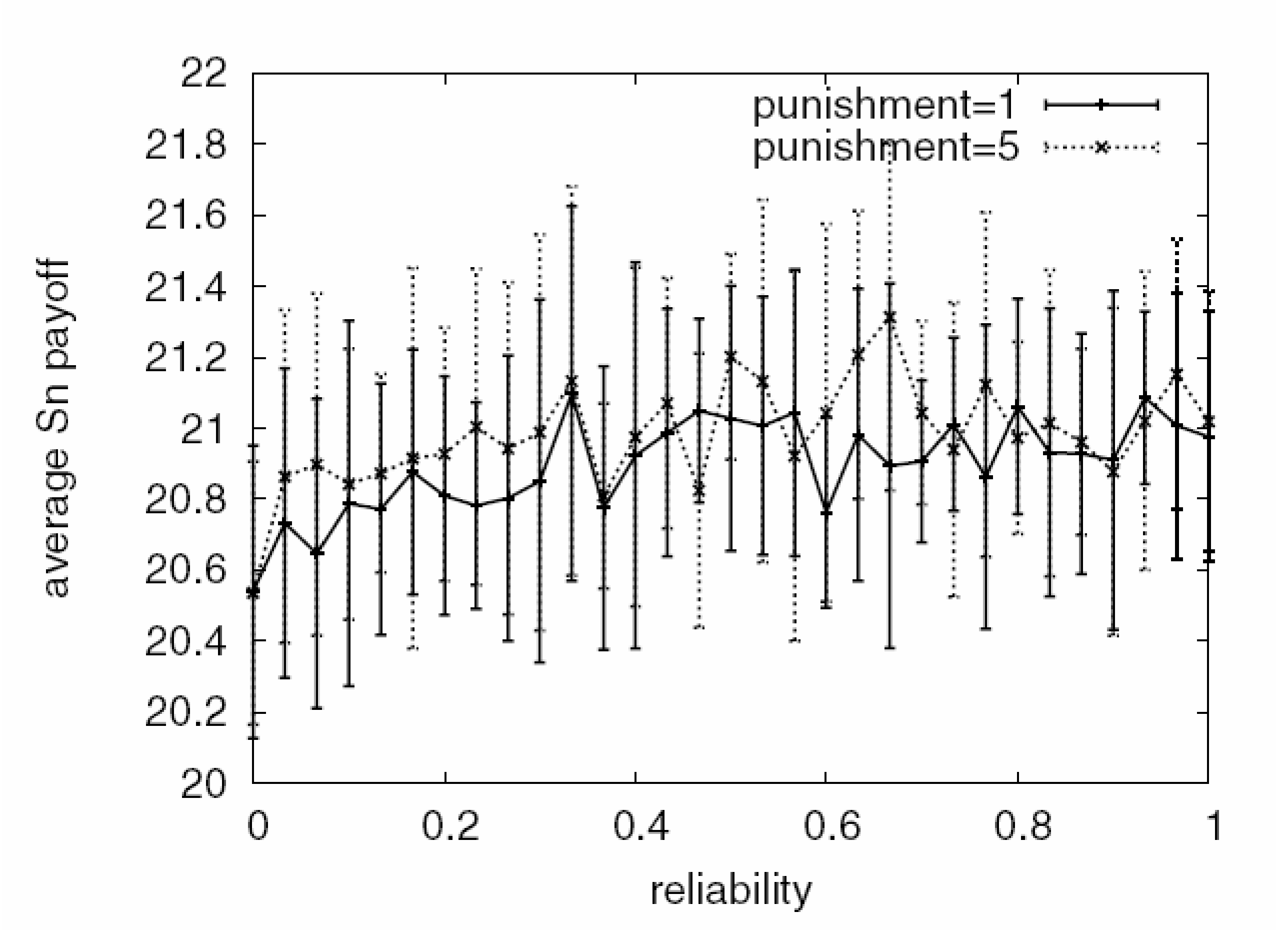


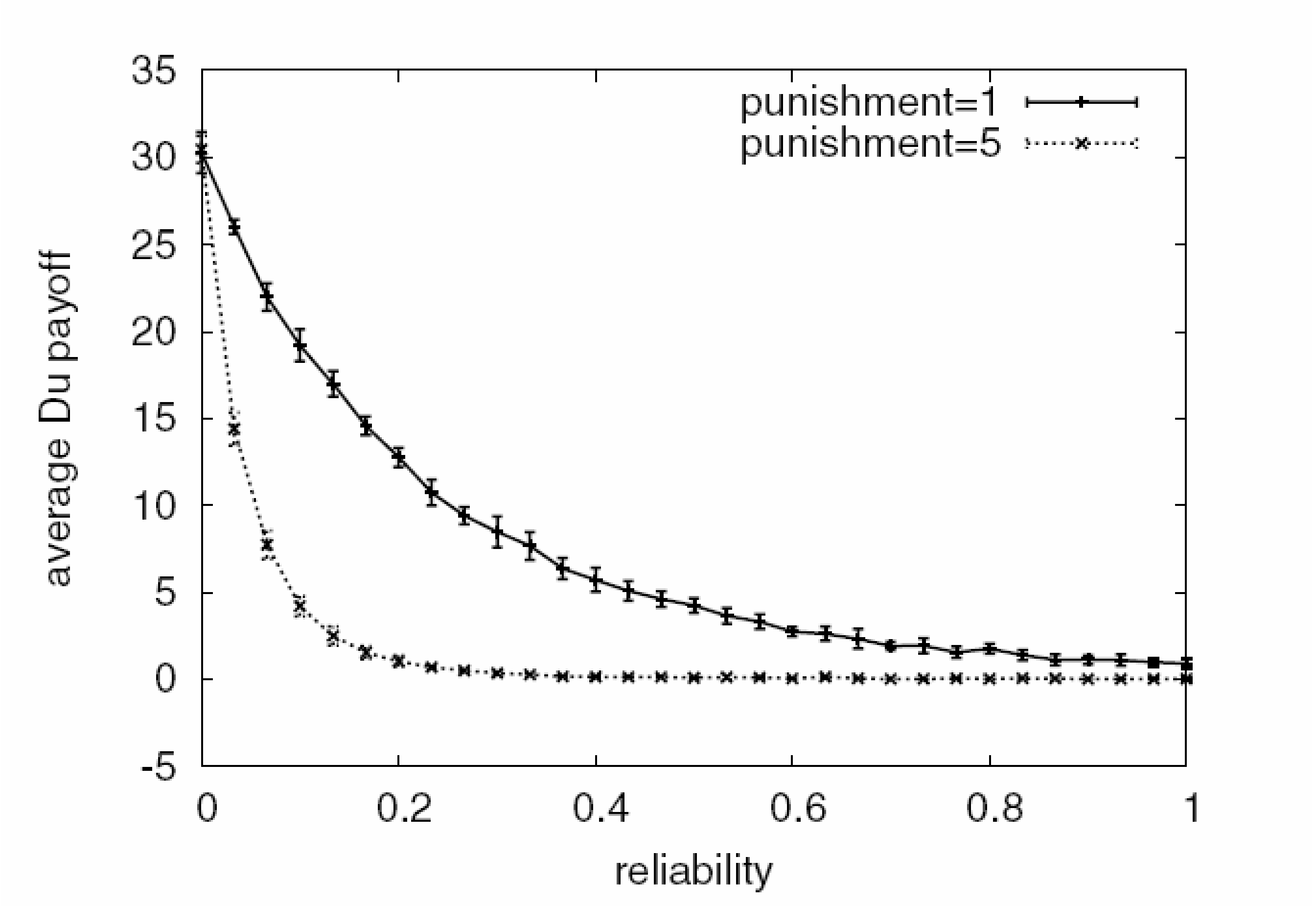
Fig. 3. Global efficiency with varying levels of noise

Unreliable reputation system

- Nodes behaves properly → reputation correctly updated
- Nodes defect → detected with probab. p_{rel}
- Simulation: 10% Du nodes

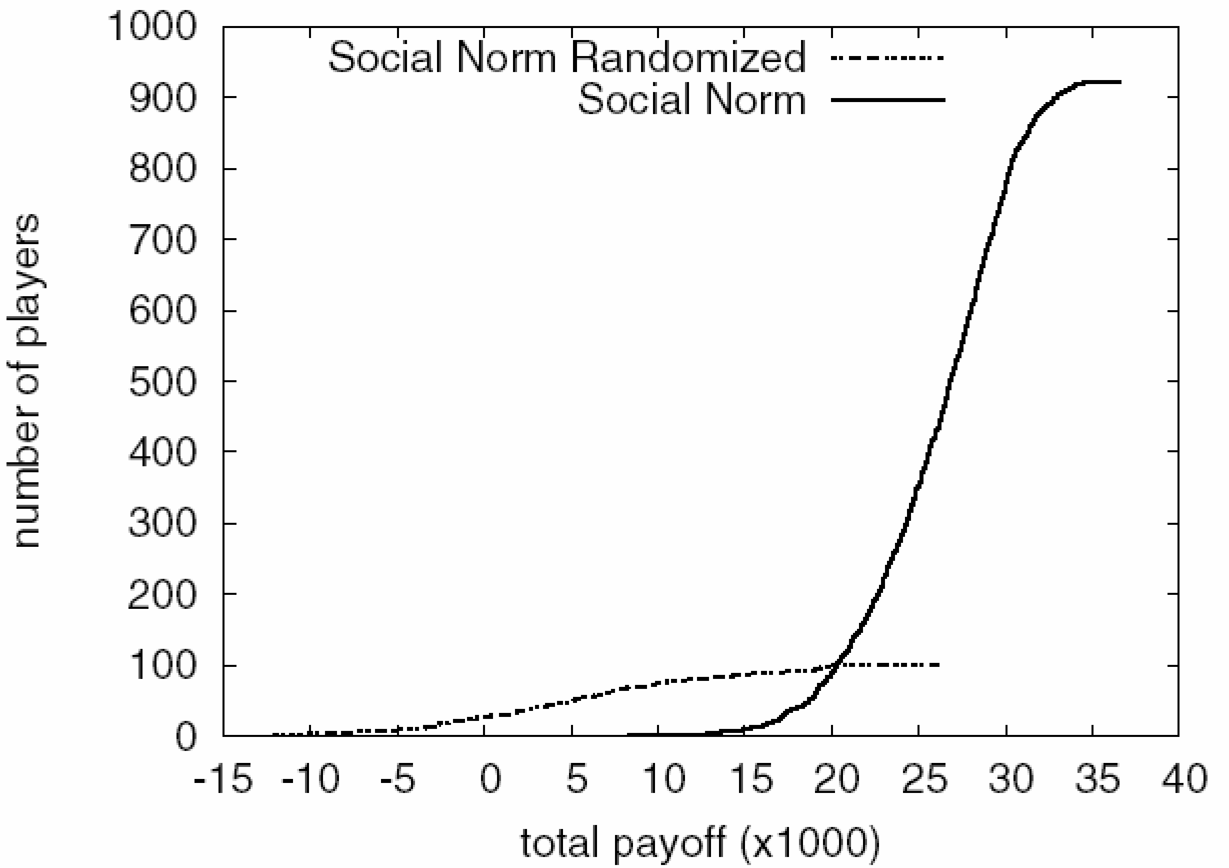


Unreliable reputation system – cont.



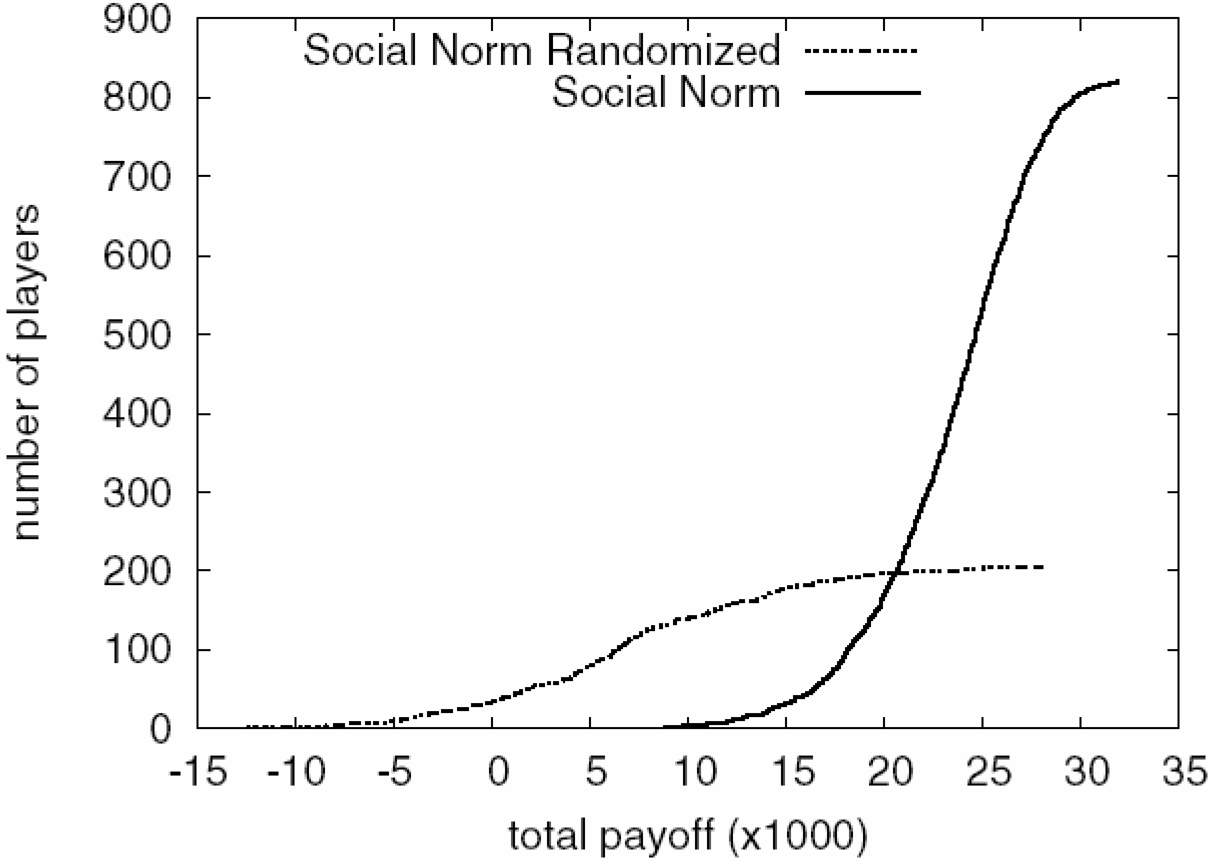
Social norm with random defections

- If opponent innocent → cooperate with prob. $1\text{-}p_{def}$ and defect with probab. $p_{def.}$ (choose $p_{def} = 0.2$)
- Unreliable reputation system → may not detect occasional defections



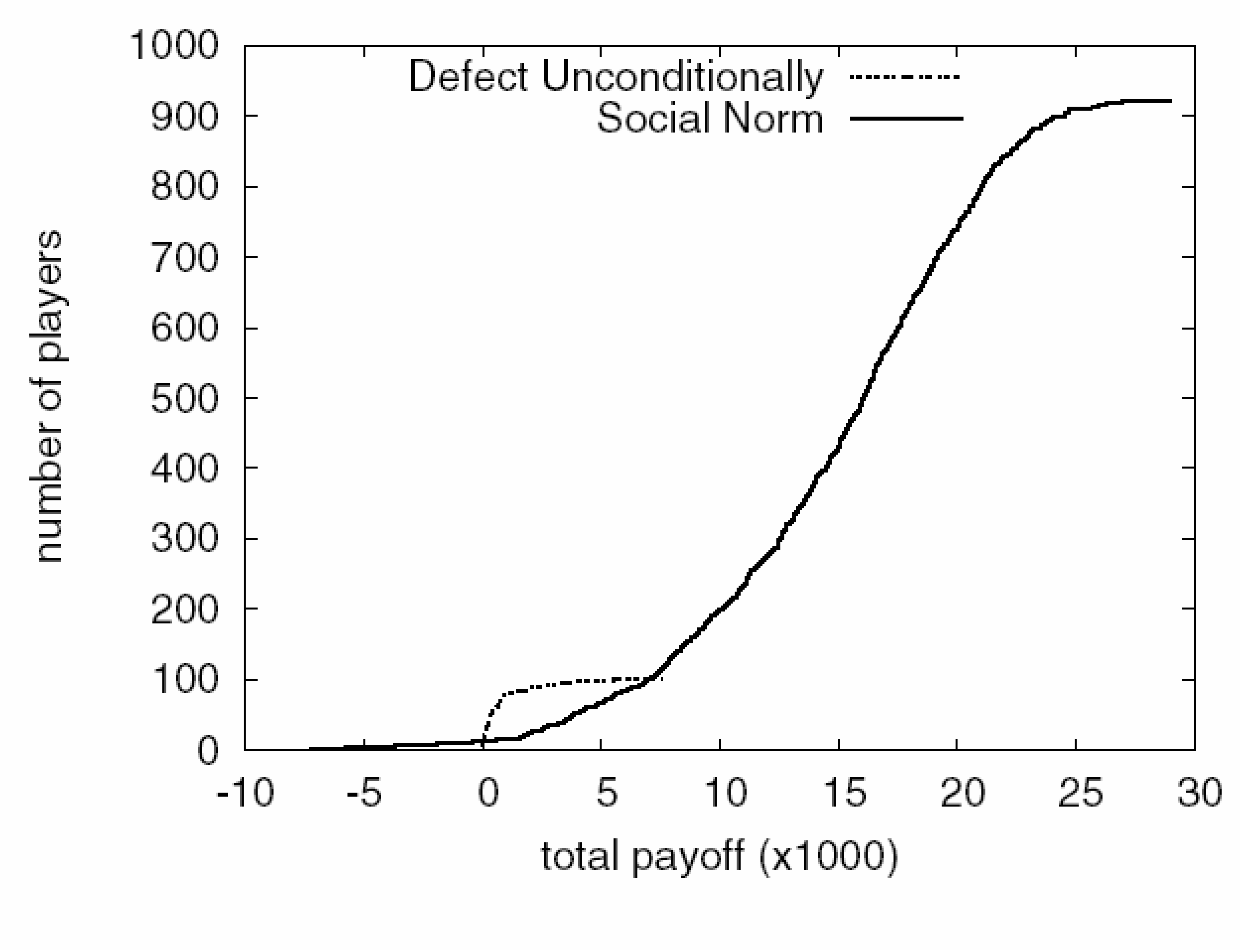
(a) 10% Snr nodes

Social norm with random defections – cont.



(b) 20% Snr nodes

Compare to



Defect Unconditionally
Social Norm
number of players
total payoff (x1000)
1000
900
800
700
600
500
400
300
200
100
0
-10
-5
0
5
10
15
20
25
30

Reference

- A. Blanc, Y-K. Liu, A. Vahdat, “Designing Incentives for Peer-to-Peer Routing”, INFOCOM 2005.