Security and Privacy in Wireless Networks

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Chapter 11: (secowinet.epfl.ch)

Multi-domain sensor networks, Border games in cellular networks

WIRELESS OPERATORS IN SHARED SPECTRUM

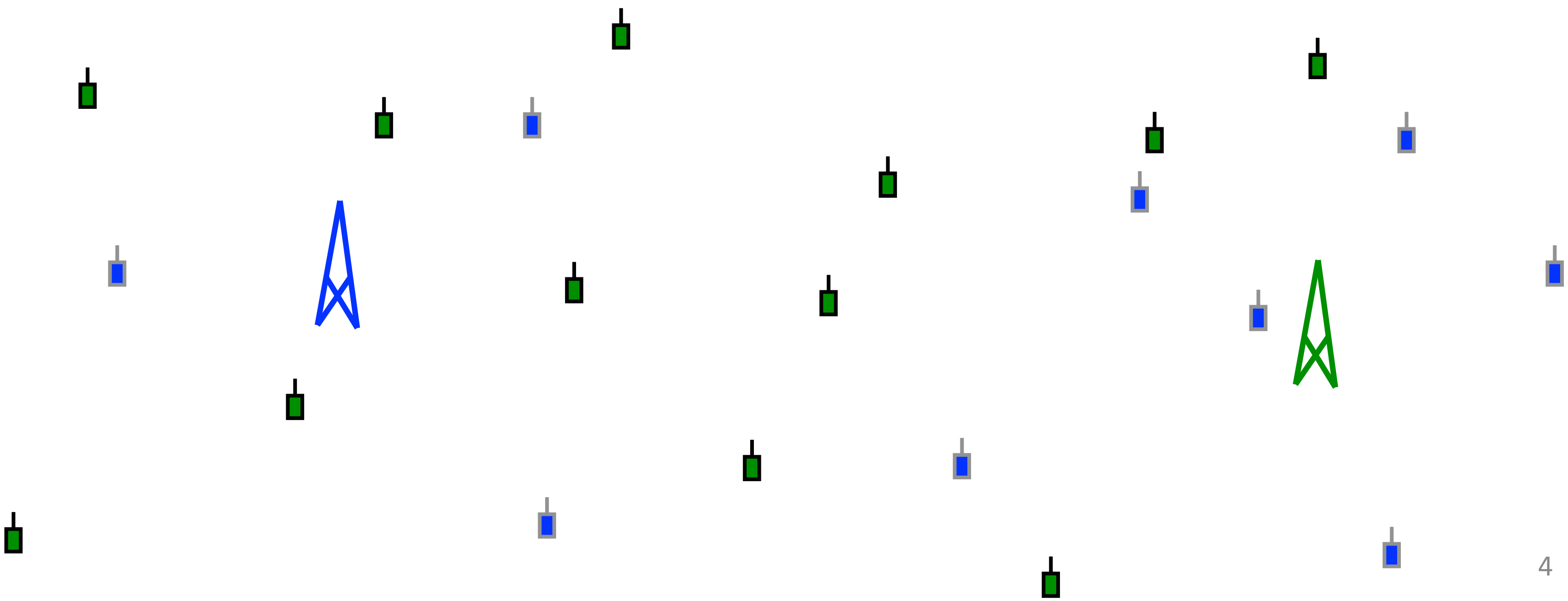
Chapter outline

11.1 Multi-domain sensor networks

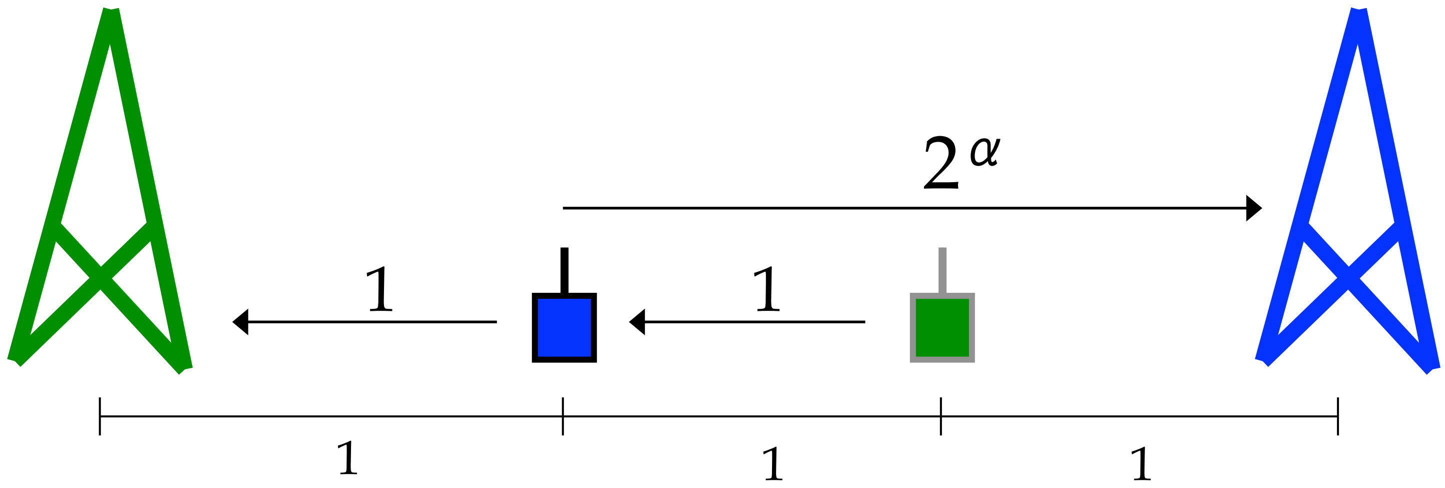
11.2 Border games in cellular networks

Multi-domain Sensor Networks

- Typical cooperation: help in packet forwarding
- Can cooperation emerge spontaneously in multi-domain sensor networks based solely on the self-interest of the sensor operators?



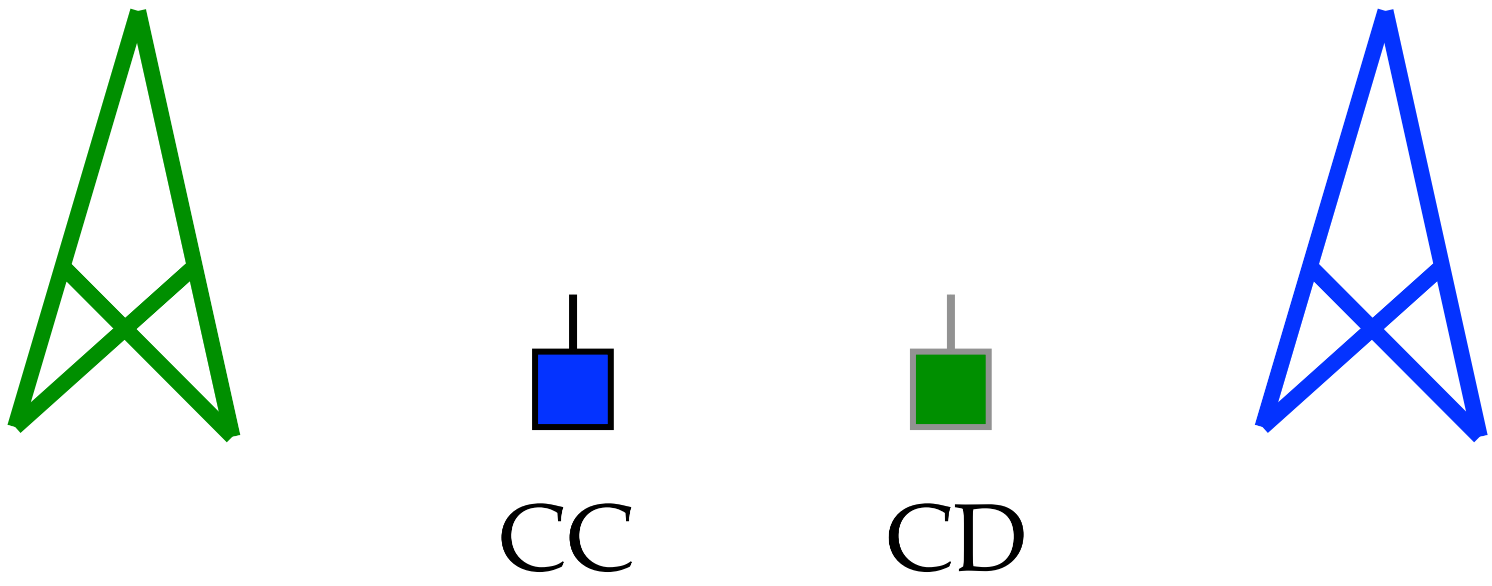
Simplified Model



- C: Cooperation   D: Defection

- **4 possible moves:**
- CC – the sensor asks for help (cost 1) and helps if asked (cost 1)
- CD – the sensor asks for help (cost 1) and does not help (cost 0)
- DC – the sensor sends directly (cost 2^{α}) and helps if asked (cost 1)
- DD – the sensor sends directly (cost 2^{α}) and does not help (cost 0)

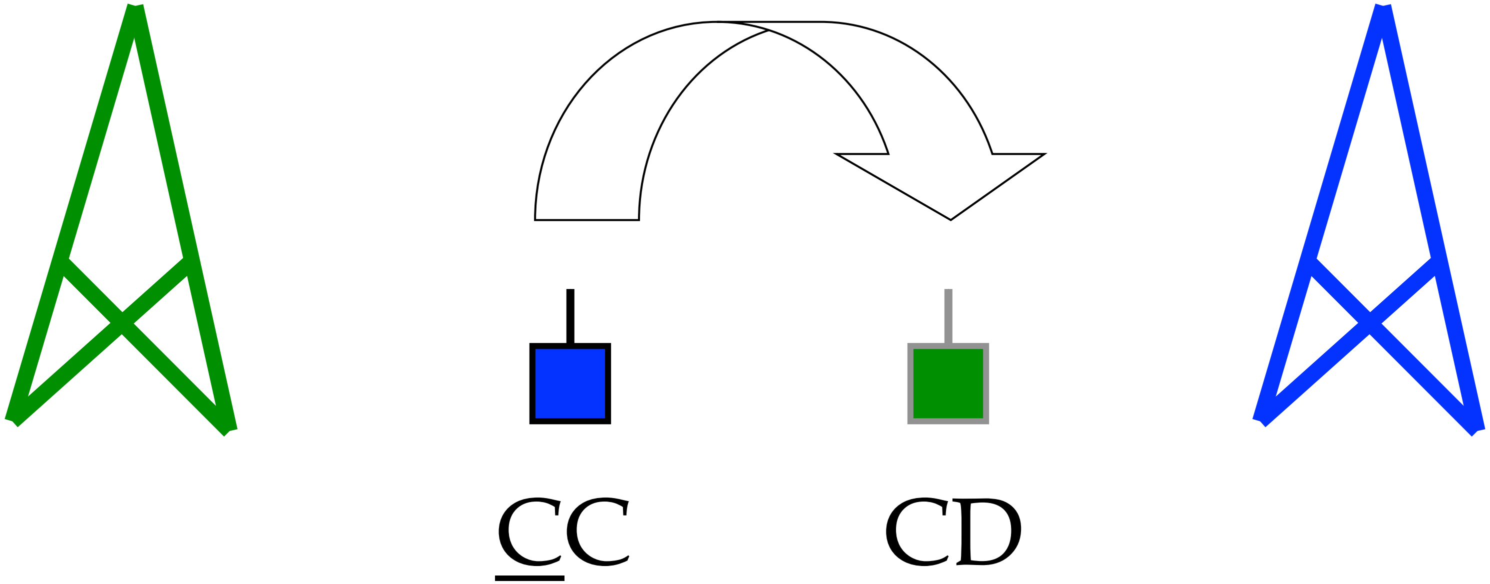
Example : CC – CD (1/6)



CC – the sensor tries to get help from the other sensor and helps if the other sensor requests it

CD – the sensor tries to get help but it refuses to help

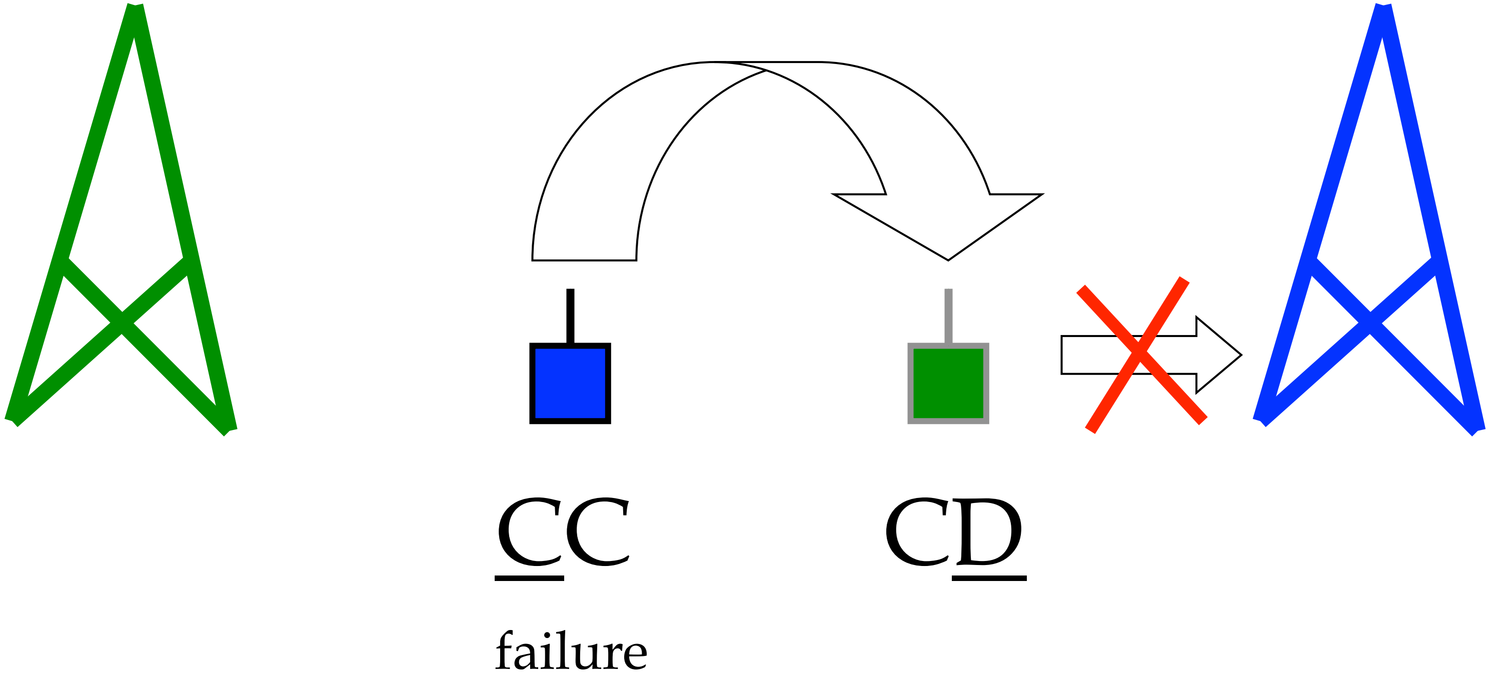
Example : CC – CD (2/6)



CC – the sensor tries to get help from the other sensor and helps if the other sensor requests it

CD – the sensor tries to get help but it refuses to help

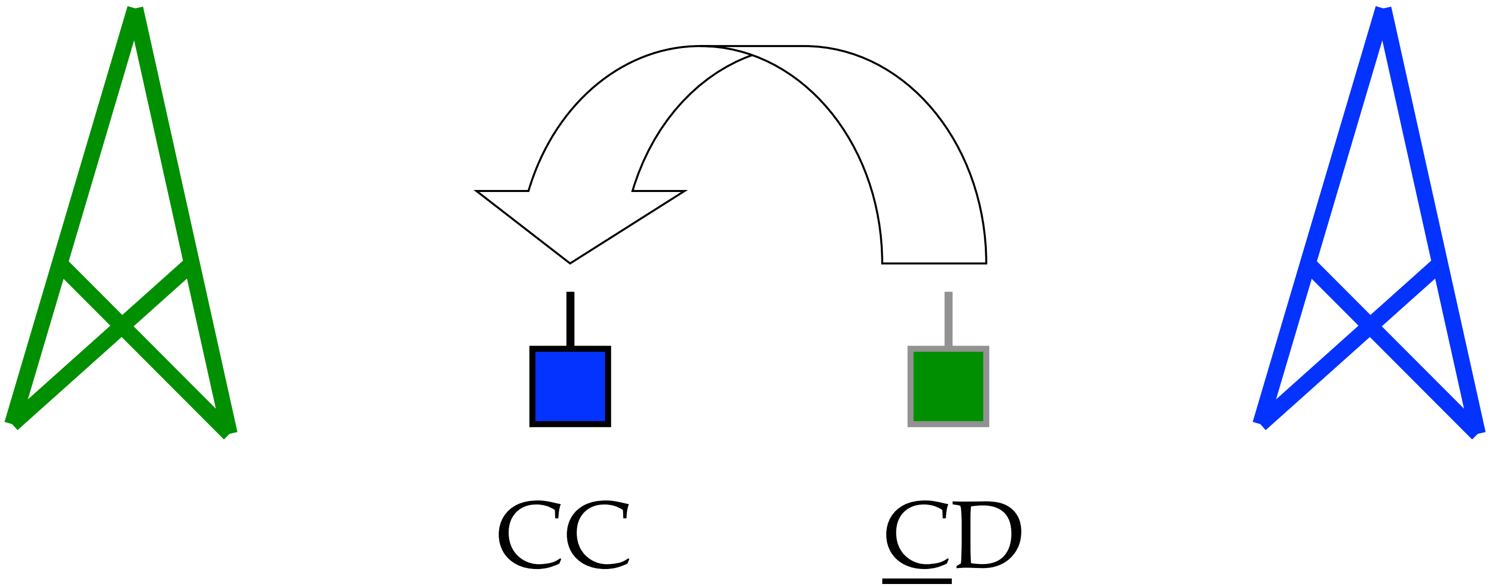
Example : CC – CD (3/6)



CC – the sensor tries to get help from the other sensor
and helps if the other sensor requests it

CD – the sensor tries to get help but it refuses to help

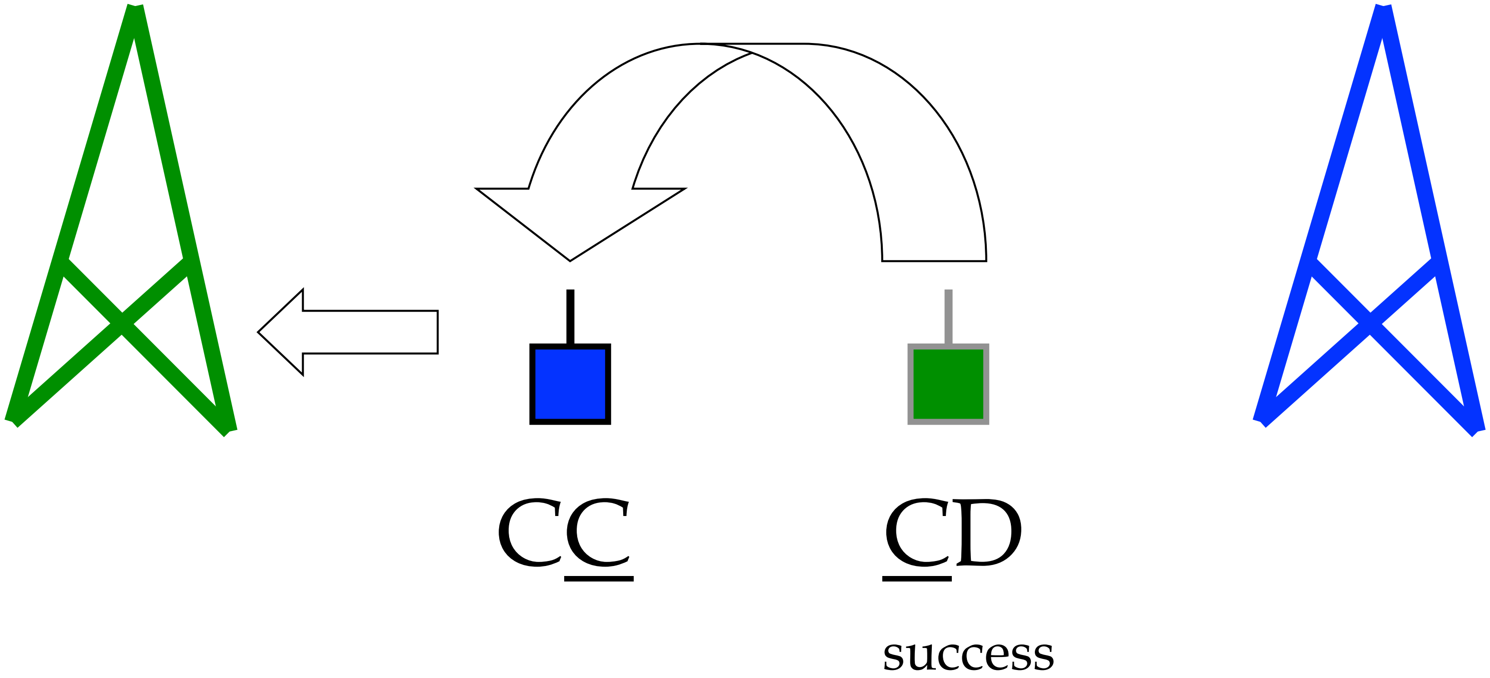
Example : CC – CD (4/6)



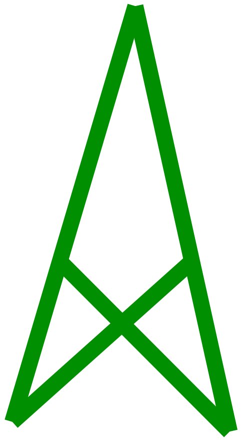
CC – the sensor tries to get help from the other sensor and helps if the other sensor requests it

CD – the sensor tries to get help but it refuses to help

Example : CC – CD (5/6)



Example : CC – CD (6/6)



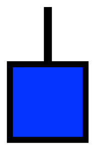
Black player

Cost: 2

- 1 for asking
- 1 for helping

Benefit: 0

(packet dropped)



CC

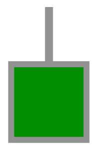
Gray player

Cost: 1

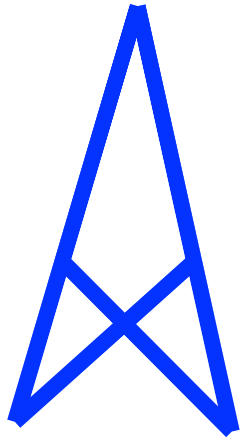
- 1 for asking

Benefit: 1

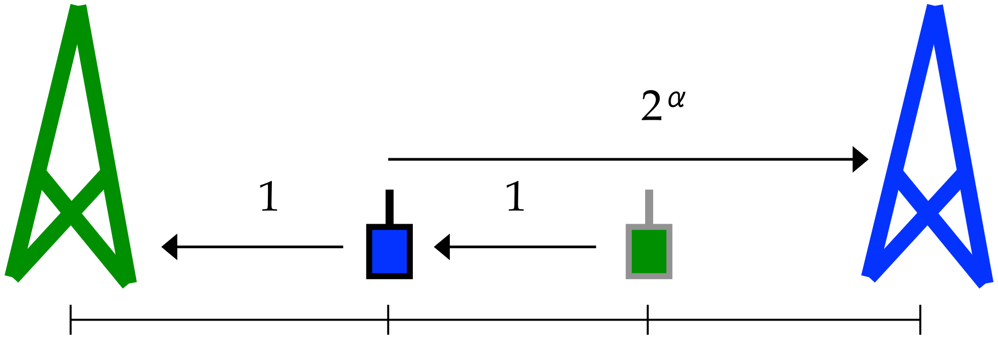
(packet arrived)



CD



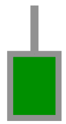
The simplified model in strategic form



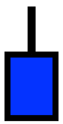
Outcome for black (0 = failure)

Cost for black

Cost for grey



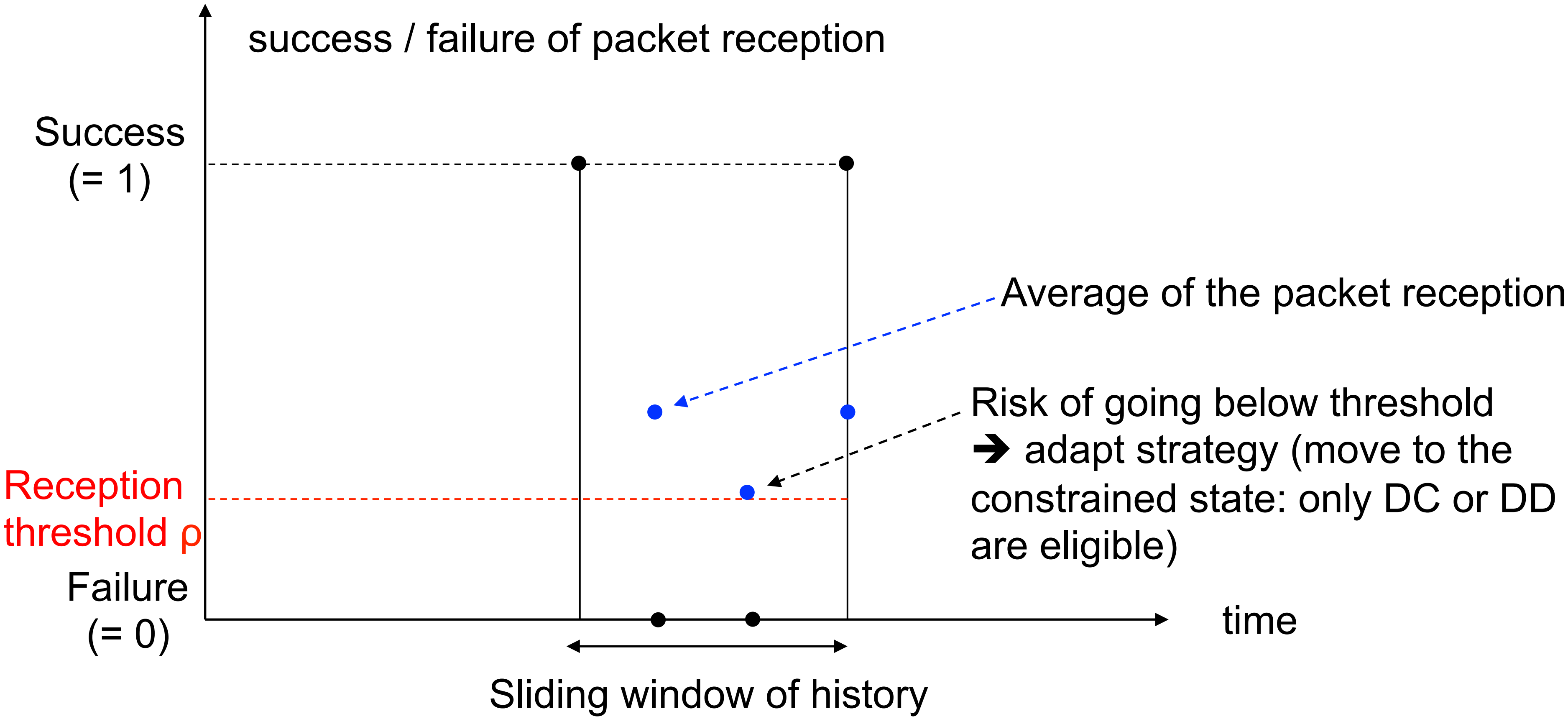
Outcome for grey (1 = success)



	CC	CD	DC	DD
CC	$2, 2 \;;1, 1$	$2, 1 \;;0, 1$	$1, 1+2^{\alpha};1, 1$	$1, 2^{\alpha} \;;0, 1$
CD	$1, 2 \;;1, 0$	$1, 1 \;;0, 0$	$1, 1+2^{\alpha};1, 1$	$1, 2^{\alpha} \;;0, 1$
DC	$1+2^{\alpha}, 1;1, 1$	$1+2^{\alpha}, 1;1, 1$	$2^{\alpha}, 2^{\alpha} \;;1, 1$	$2^{\alpha}, 2^{\alpha};1, 1$
DD	$2^{\alpha}, 1 \;;1, 0$	$2^{\alpha}, 1 \;;1, 0$	$2^{\alpha}, 2^{\alpha} \;;1, 1$	$2^{\alpha}, 2^{\alpha};1, 1$

Reception threshold

- Reception threshold: computed and stored at each sensor node
- The battery (*B*) level of the sensors decreases with the moves
- If the battery is empty, the sensor dies



Game Theoretic Approach

- The mentioned concepts describe a game
- Players: network operators
- Moves (unconstrained state): CC, CD, DC, DD
- Moves (constrained state): DC, DD
- Information sets: histories
- Strategy: function that assigns a move to every possible history considering the weight threshold
- Payoff = lifetime
- We are searching for Nash equilibria with the highest lifetimes

Two-step Strategies

Cooperative Nash equilibrium

	CC/DD	CD/DD
CC/DD	$\frac{B}{2}$; $\frac{B}{2}$	$\frac{B}{\rho 2^{\alpha}+(1-\rho)}$; $\frac{B}{\rho 2^{\alpha}+(1-\rho)}+\epsilon_1$
CD/DD	$\frac{B}{\rho 2^{\alpha}+(1-\rho)}+\epsilon_1$; $\frac{B}{\rho 2^{\alpha}+(1-\rho)}$	$\frac{B}{\rho 2^{\alpha}+(1-\rho)}+\epsilon_2$; $\frac{B}{\rho 2^{\alpha}+(1-\rho)}+\epsilon_2$

Non-cooperative Nash equilibrium

B – initial battery

ρ – reception threshold

α – path loss exponent (≥2)

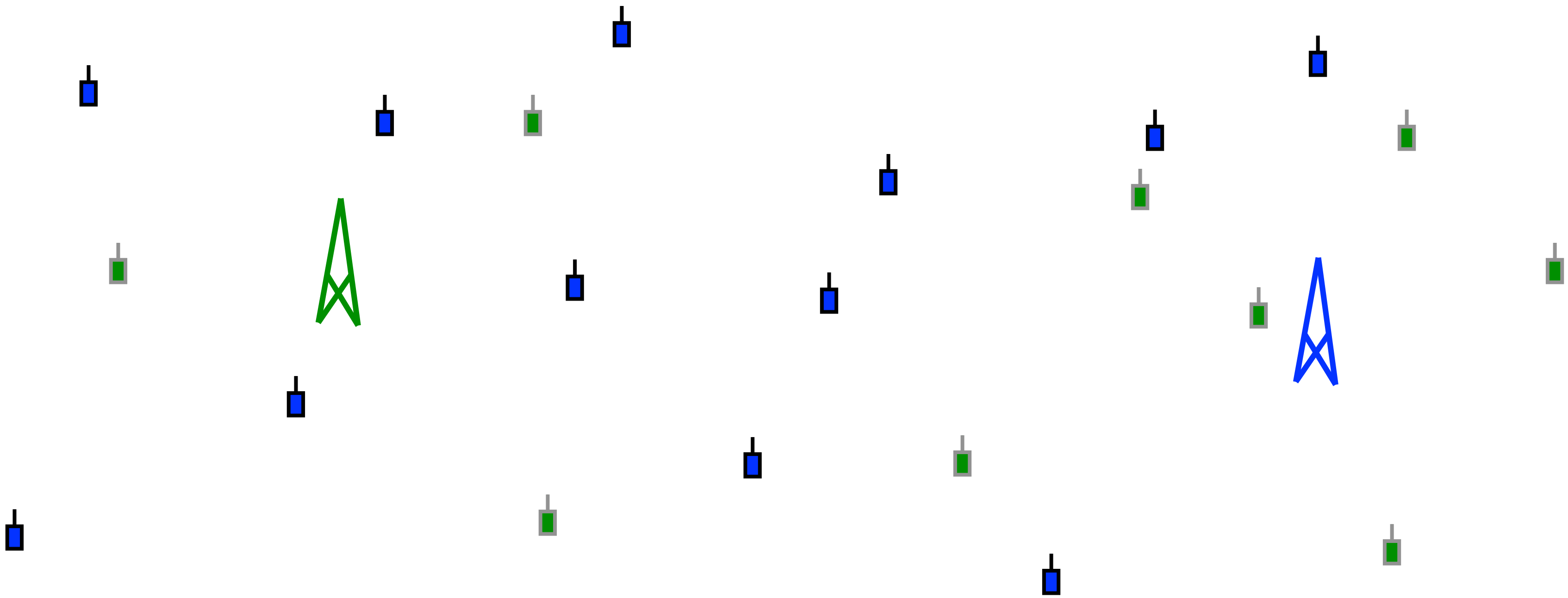
$\varepsilon_{1,2}$ – payoff of transient states

If ρ > 1/3, then (CC/DD, CC/DD) is more desirable

Generalized Model

Simplified model with the following extensions:

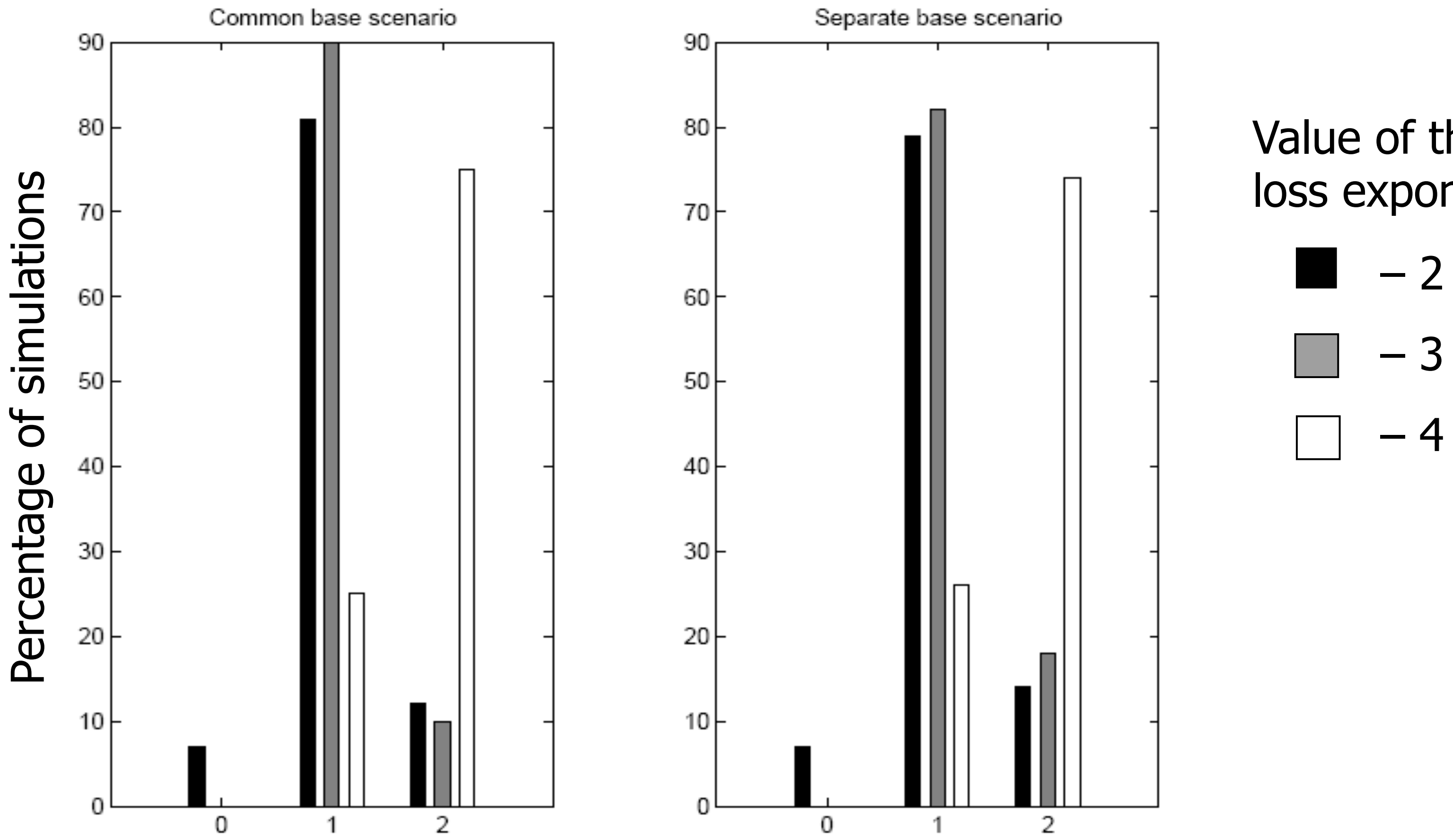
- many sensors, random placing
- minimum energy path routing
- common sink / separate sink scenarios
- classification of equilibria
  - Class 0: no cooperation (no packet is relayed)
  - Class 1: semi cooperation (some packets are relayed)
  - Class 2: full cooperation (all packets are relayed)



Main simulation parameters

Parameter	*Value*
Number of sensors per domain	20
Area size	100 x 100 m
Reception threshold ρ	0.6
History length	5
Path loss exponent	2–3–4 (3)

Impact of the path loss exponent



Equilibrium classes (0 – no cooperation, 1 – semi cooperation, 2 – full cooperation)

Conclusion on Multi-Domain Sensor Networks

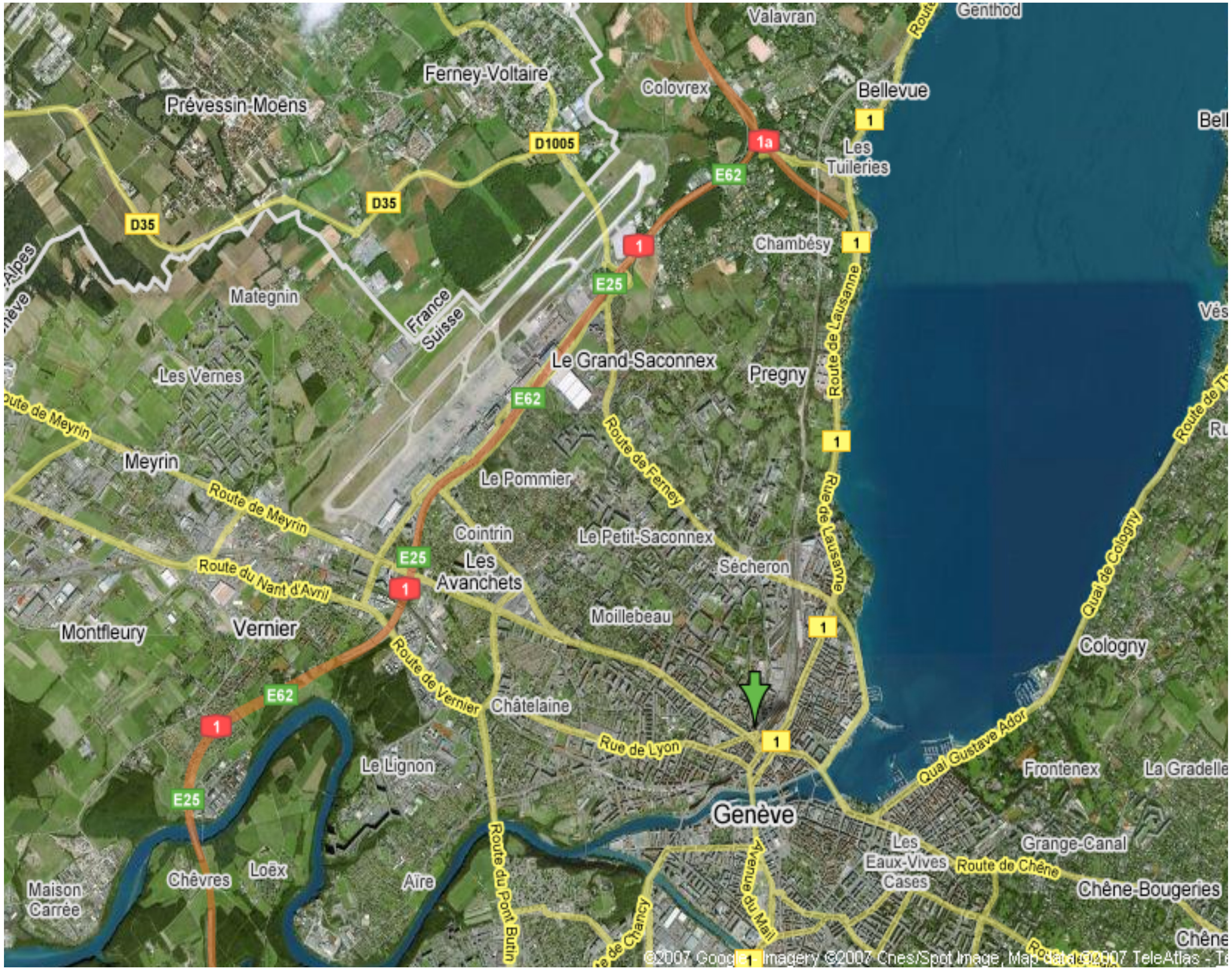
- We examined whether cooperation is possible without the usage of incentives in multi-domain sensor networks
- In the simplified model, the best Nash equilibria consist of cooperative strategies
- In the generalized model, the best Nash equilibria belong to the cooperative classes in most of the cases

Chapter outline

11.1 Multi-domain sensor networks

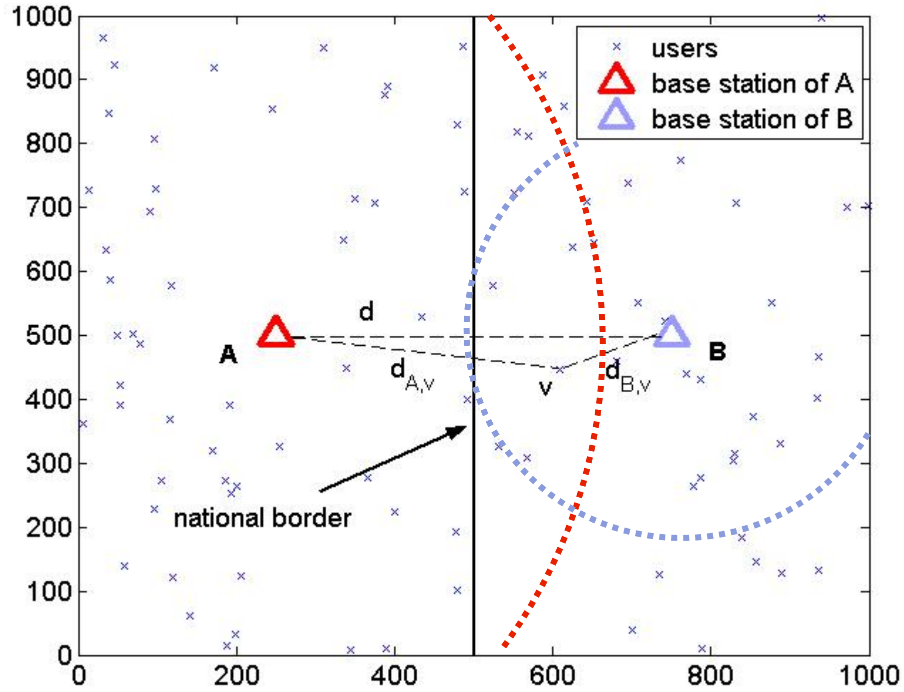
11.2 Border games in cellular networks

Motivating example



Introduction

- spectrum licenses do not regulate access over national borders
- adjust pilot power to attract more users



Is there an incentive for operators to apply competitive pilot power control?

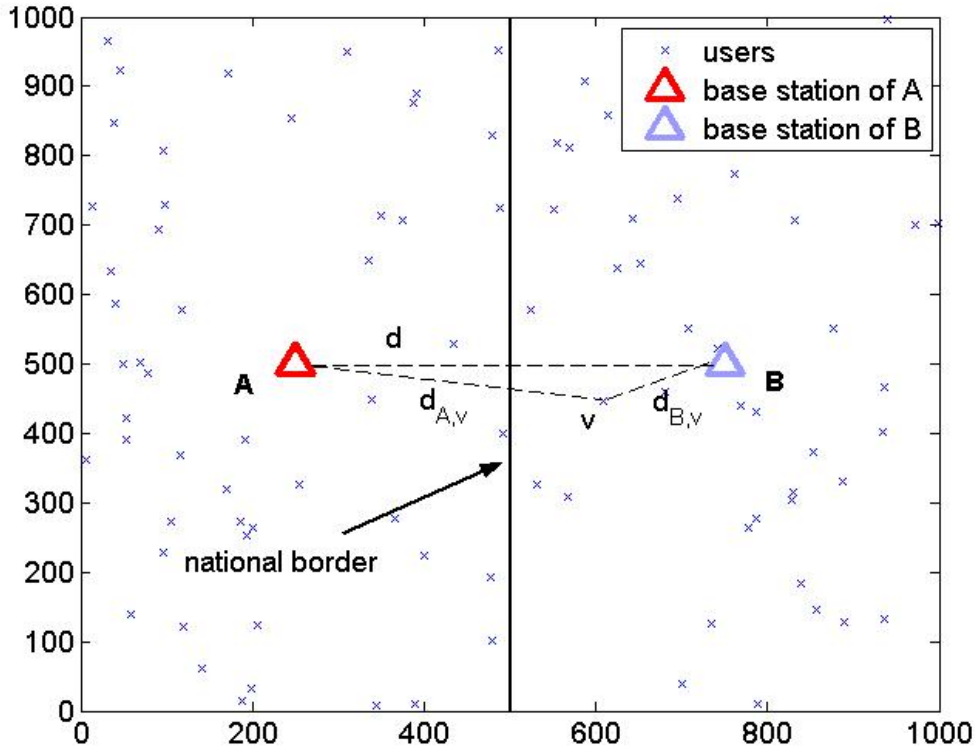
System model (1/2)

Network:

- cellular networks using CDMA
  - channels defined by orthogonal codes
- two operators: A and B
- one base station each
- pilot signal power control

Users:

- roaming users
- users uniformly distributed
- select the best quality BS
- selection based signal-to-interference-plus-noise ratio (*SINR*)



System model (2/2)

pilot signal *SINR*:

$$SINR_{iv}^{pilot} = \frac{G_p^{pilot} \cdot P_i \cdot g_{iv}}{N_0 \cdot W + I_{own}^{pilot} + I_{other}^{pilot}}$$

$$I_{own}^{pilot} = \varsigma \cdot g_{iv} \cdot \left(\sum_{w \in M_i} T_{iw} \right)$$

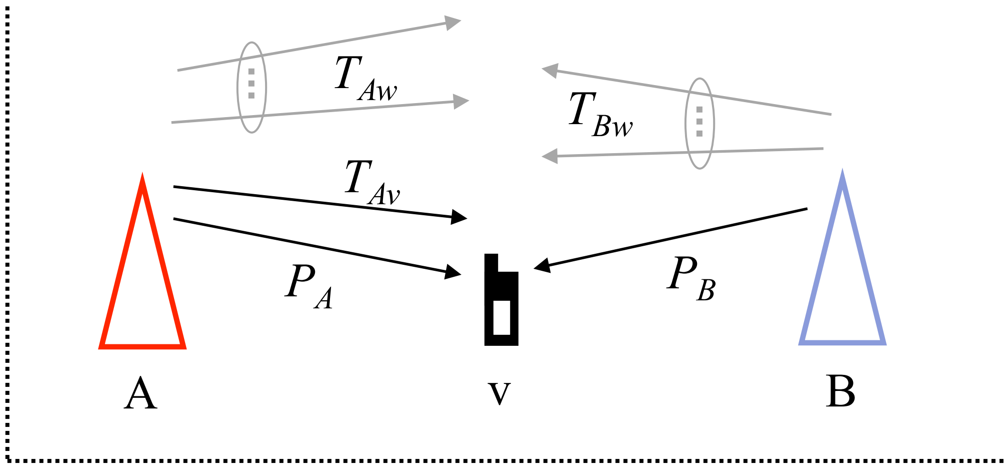
$$I_{other}^{pilot} = \eta \cdot \sum_{j \neq i} g_{jv} \cdot \left(P_j + \sum_{w \in M_i} T_{iw} \right)$$

traffic signal *SINR*:

$$SINR_{iv}^{tr} = \frac{G_p^{tr} \cdot T_{iv} \cdot g_{iv}}{N_0 \cdot W + I_{own}^{tr} + I_{other}^{tr}}$$

$$I_{own}^{pilot} = \varsigma \cdot g_{iv} \cdot \left(P_i + \sum_{w \neq v, w \in M_i} T_{iw} \right)$$

$$I_{other}^{tr} = I_{other}^{pilot}$$



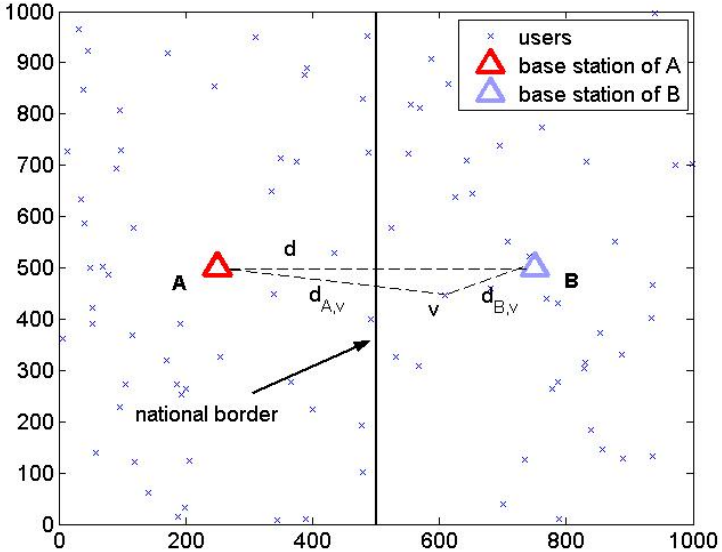
- P_i – pilot power of i
- G_p^{pilot} – processing gain for the pilot signal
- g_{iv} – channel gain between BS i and user v
- N_0 – noise energy per symbol
- W – available bandwidth
- I_{own}^{pilot} – own-cell interference affecting the pilot signal
- ς – own-cell interference factor
- T_{iv} – traffic power between BS i and user v
- M_i – set of users attached to BS i
- η – other-to-own-cell interference factor

Game-theoretic model

- Power Control Game, G_{PC}
  - players → networks operators (BSs), A and B
  - strategy → pilot signal power, 0W < P_i < 10W, i = {A, B}
  - standard power, P^S = 2W
  - payoff → profit, $u_i = \sum_{v \in M_i} \theta_v$ where θ_v is the expected income serving user v
  - normalized payoff difference:

$$\Delta_i = \frac{\max_{s_i}\left(u_i\left(s_i, P^S\right) - u_i\left(P^S, P^S\right)\right)}{u_i\left(P^S, P^S\right)}$$

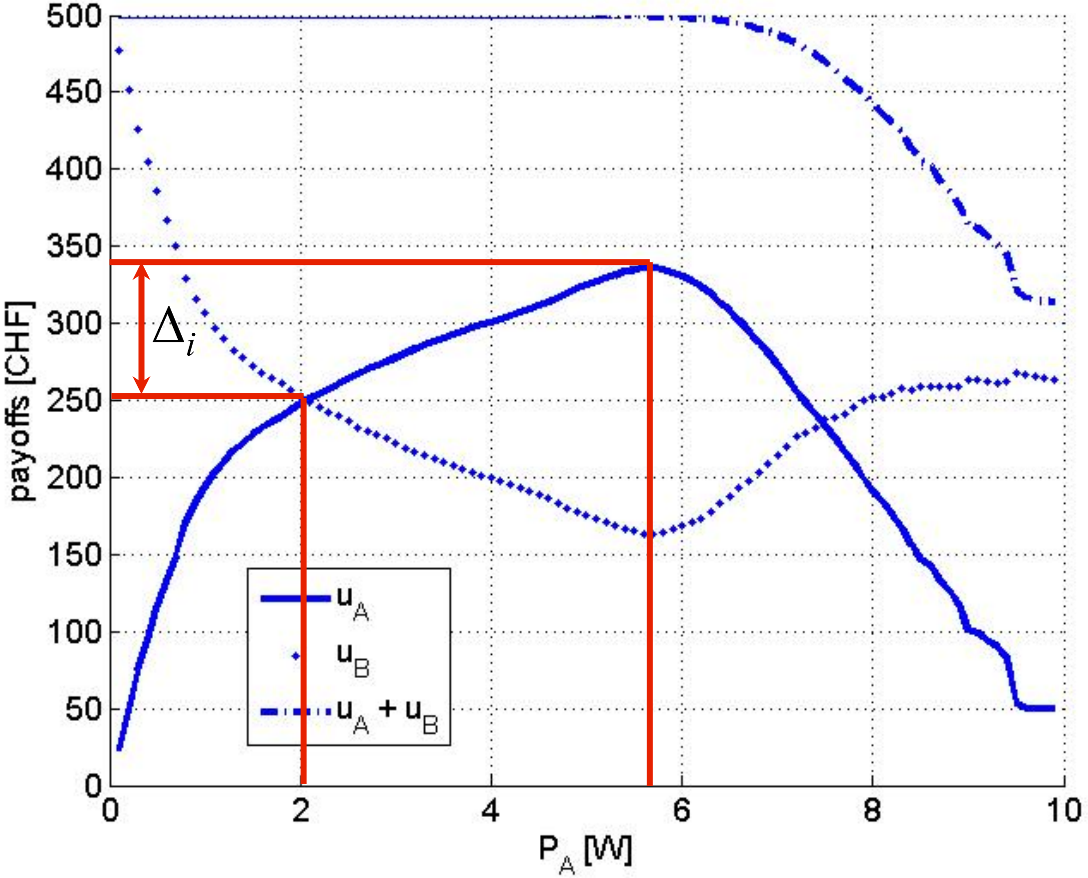
Simulation settings



Parameter	*Value*
simulation area size	1 km^2
BS positions	(250 m, 500 m) and (750 m, 500 m)
default distance between BSs, d	500 m
user distribution	random uniform
number of simulations	500
default path loss exponent, α	4
BS max power	43 dBm = 20 W
BS max load	40 dBm = 10 W
BS standard power, P^s	33 dBm = 2 W
BS min power	20 dBm = 0.1 W
power control step size, P_{step}	0.1 W
orthogonality factor, ζ	0.4
other-to-own-cell interference factor, η	0.4
user traffic types:	audio, $\mathbb{R}^{tr}$ = 12.2 kbps
	video, $\mathbb{R}^{tr}$ = 144 kbps
	data, $\mathbb{R}^{tr}$ = 384 kbps
required CIR (audio, video, data):	-20 dB, -12.8 dB, -9 dB
expected incomes (θ_{audio}, θ_{video}, θ_{data}):	10, 20, 50 CHF/month

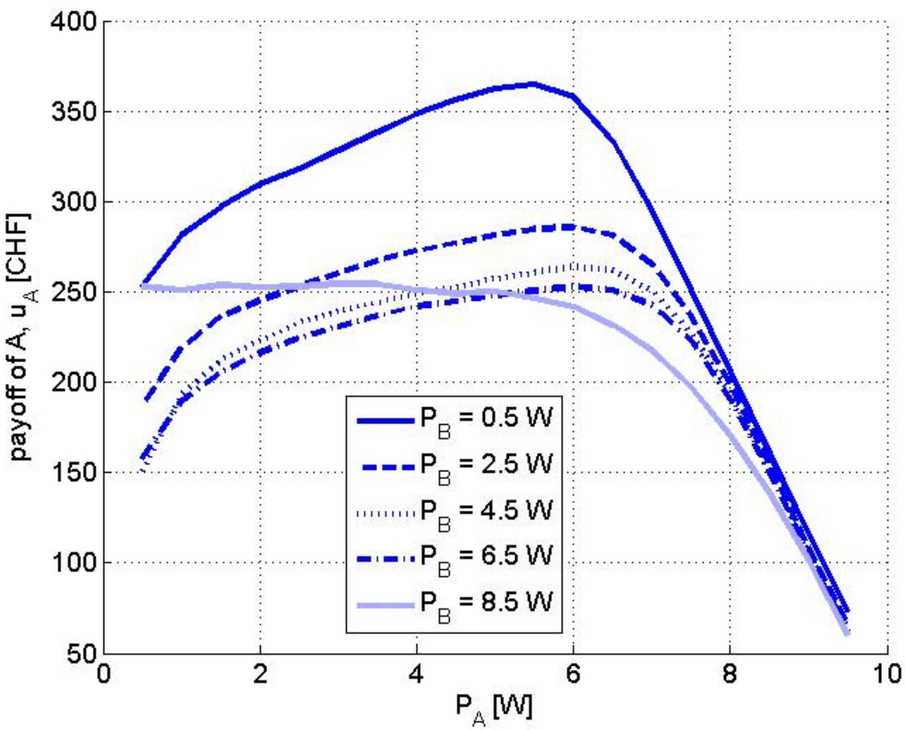
Is there a game?

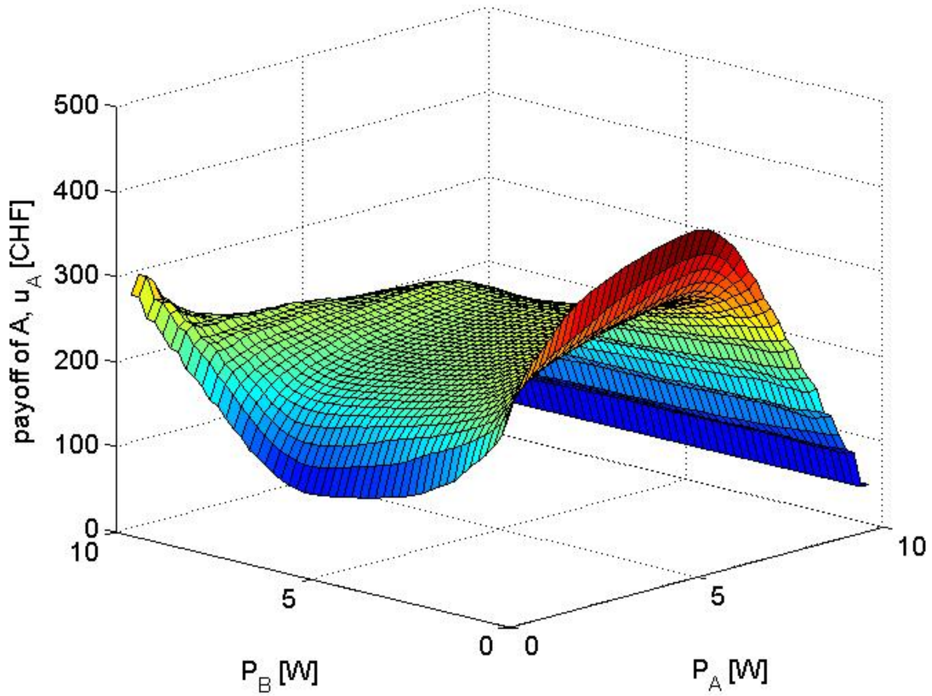
- only A is strategic (B uses P_B = P^S)
- 10 data users
- path loss exponent, α = 2



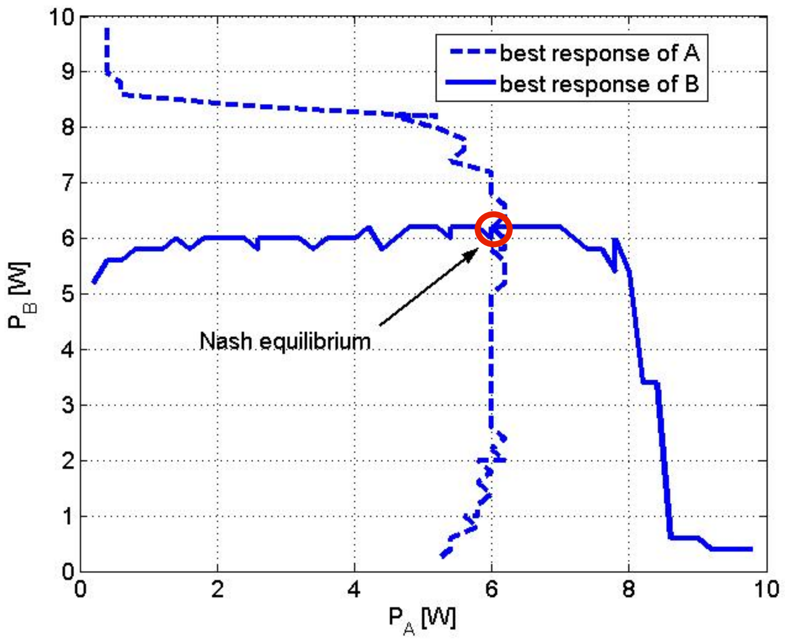
When both operators are strategic

- 10 data users
- path loss exponent, $\alpha = 4$

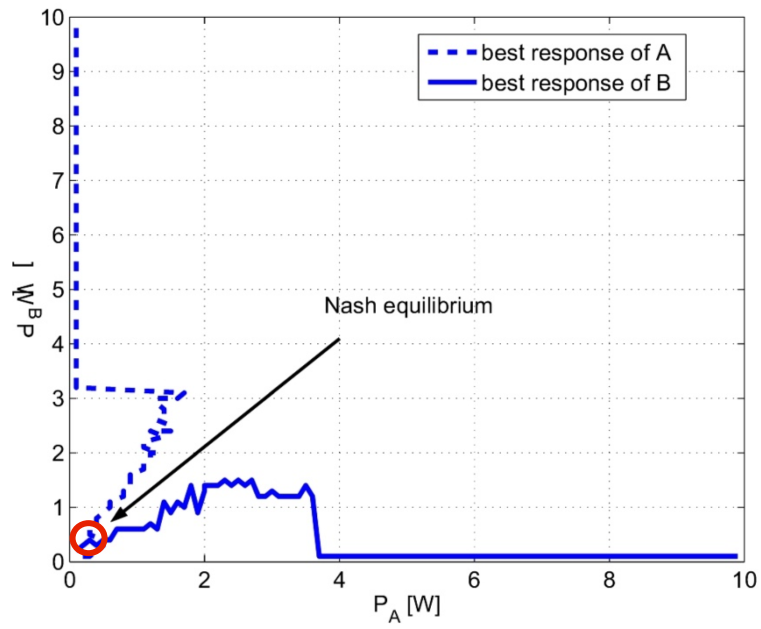




Nash equilibria



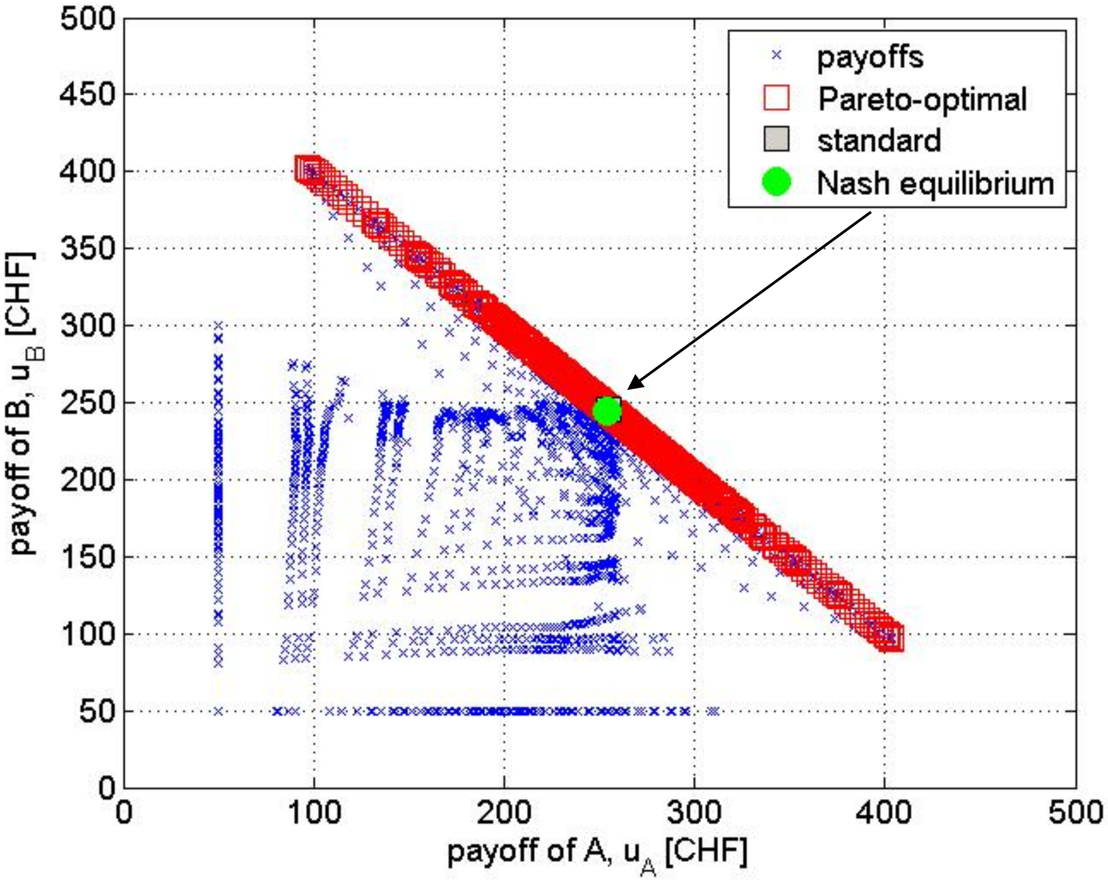
10 data users



100 data users

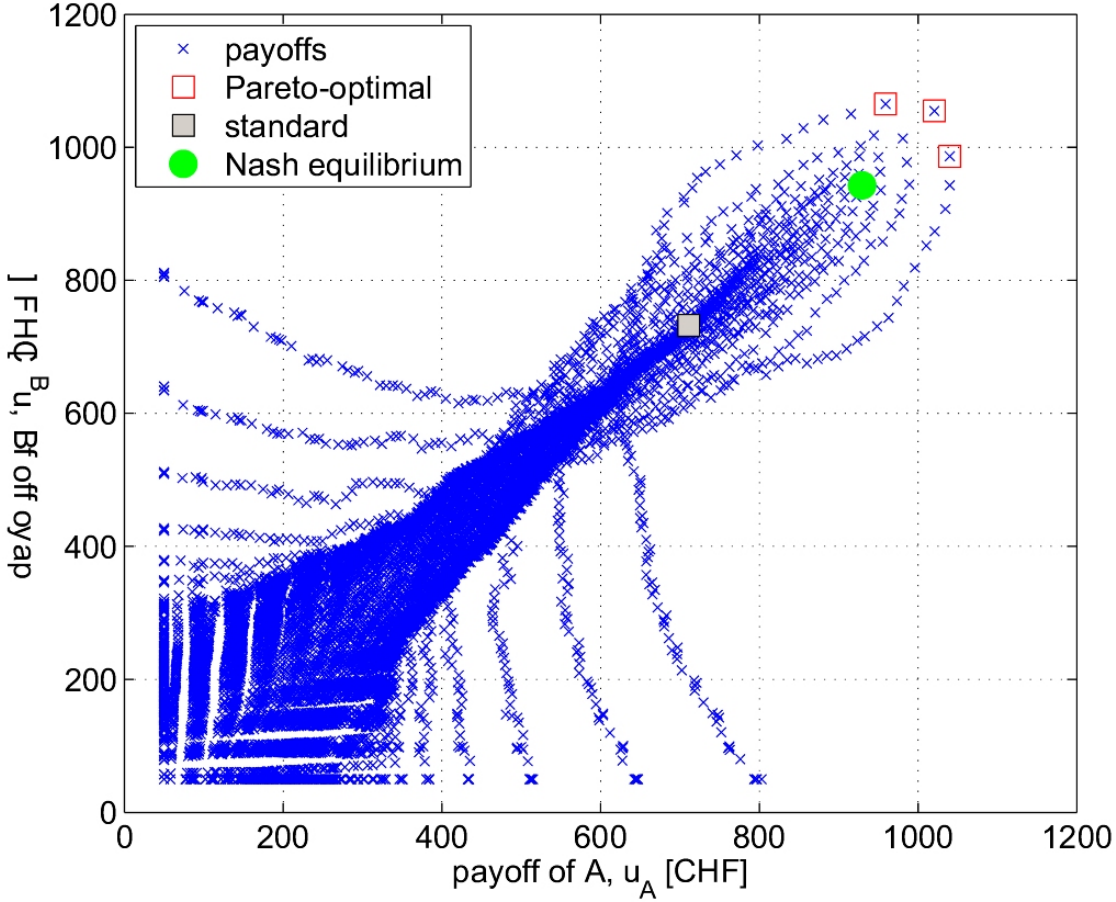
Efficiency (1/2)

- 10 data users



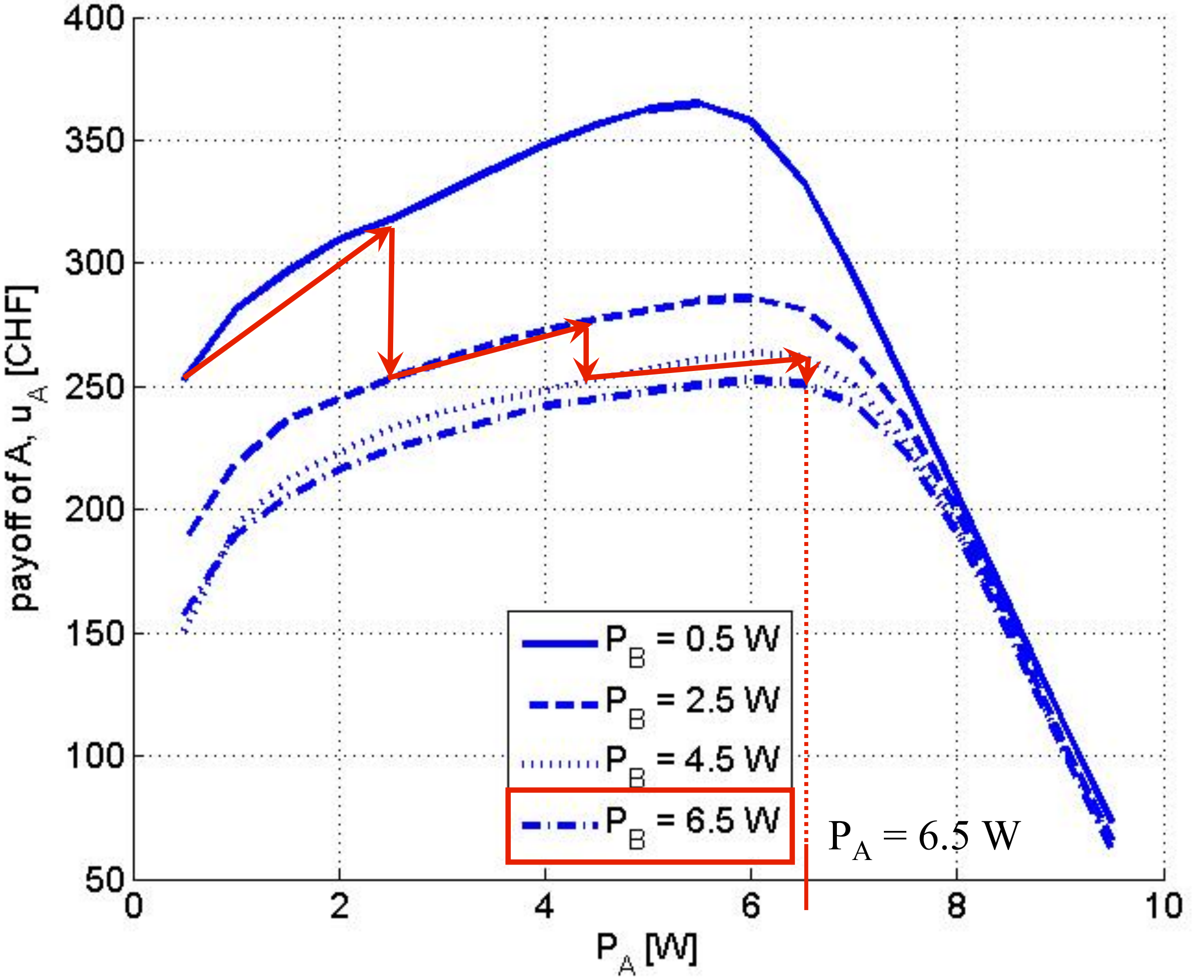
Efficiency (2/2)

- 100 data users



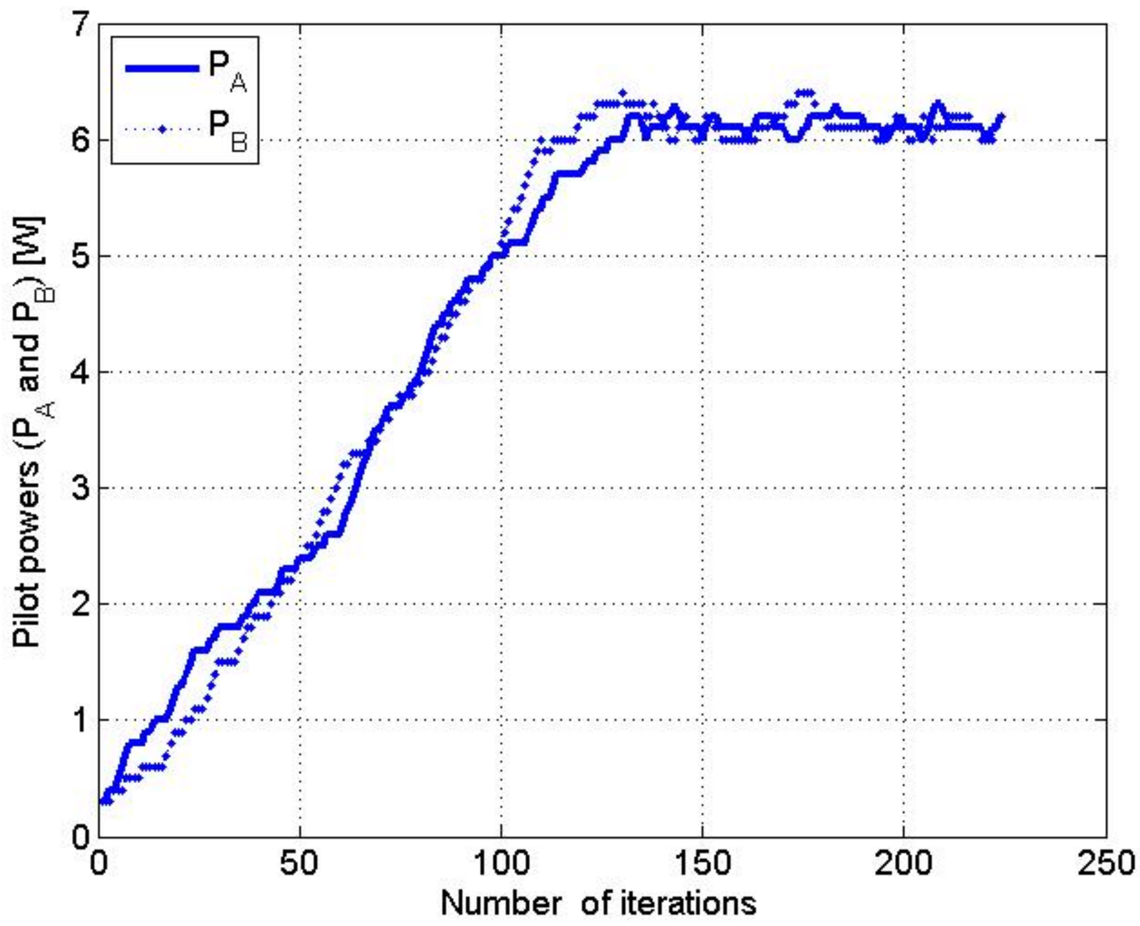
Convergence to NE (1/2)

- convergence based on better-response dynamics
- convergence step: 2 W



Convergence to NE (2/2)

- convergence step: 0.1 W



Conclusion on border games

- not only individual nodes may exhibit selfish behavior, but operators can be selfish too
- example: adjusting pilot power to attract more users at national borders
- the problem can be modeled as a game between the operators
  - the game has an efficient Nash equilibrium
  - there's a simple convergence algorithm that drives the system into the Nash equilibrium