Spatial Reuse in Spectrum Sharing: A Matrix Spatial Congestion Games Approach

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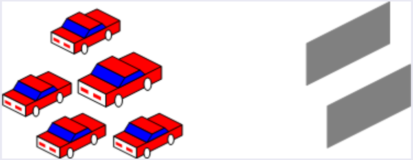
Outline

Motivations

Problems

When greedy users compete for scarce resources, congestion arises.



- How to model this resource competition ?
- What are the possible consequence of users' greedy action to maximize their own profits?

Solution 1.0: Congestion Games

Basic idea

Each user's payoff is a function of the level of congestion (number of active players using a certain resource).

Key property

FIP:local users' greedy updates of strategy will converge to an pure Nash Equilibrium (PNE) in a finite number of steps regardless of the updating sequence.

New problem

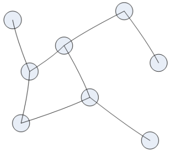
Spatial Reuse

When users are separated far away enough, they can use the same resource without causing interference.

But Congestion Games fail to capture this feature since all the users using the same resource are considered to contribute to the congestion.

Solution 2.0: Spatial Congestion Games on Graphs

- Conflict graph



- Conclusion: FIP or PNE exists only under some special cases.

New problem

- Interference is not constant. It's highly dependent on the distance between users.
- Modern devices have the ability to access multiple channels simultaneously.

Solution 3.0: Matrix Spatial Congestion Games

- Interference matrix:

users	1	2	3	4
1	0	0.3	0.5	0.8
2	0.3	0	0	0.7
3	0.5	0	0	1
4	0.8	0.7	1	0

- Channel selection matrix:

	Chanel 1	Channel 2	Channel 3
User 1	1	1	0
User 2	0	1	1
User 3	0	1	1
User 4	1	0	1

Main Contributions

- We introduce a MSCG model for dynamic spectrum sharing in CR networks. This model is realistic for it takes spatial reuse into consideration and the interference level among users can be variable and a single user can access multiple channels simultaneously.
- For type I and type II, we prove the existence of FIP, which guarantee that users local updates will finally converge to a PNE.
- For type III and type IV MSCG, we show that FIP does not hold and the PNE may not exist.

Related Work on Congestion Games

- A class of games possessing pure-strategy nash equilibria ,1973

  R. Rosenthal

- Congestion Games:Optimization in Competition,2007

  B.Vocking and R.Aachen

- Convergence Dynamics of Resource-Homogenous Congestion Games,2011

  Richard Southwell and Jianwei Huang

- Price of Anarchy for Cognitive MAC Games,2009

  Lok Man Law,Jianwei Huang, Mingyan Liu

Related work on spatial reuse

- Spectrum Sharing as Congestion Games,2008

  Mingyan Liu ,Yunnan Wu

  * Virtual resources approach

- Spectrum Sharing as Spatial Congestion Games,2010

  Sahand Ahmad, Cem Tekin, Mingyan Liu

  * Graph approach

System model

- MSCG is represented by

$$(N, R, (I_{ij})_{i,j\in N}, (S_{ir})_{i\in N, r\in R}, (\Sigma i)_{i\in N}, (g_r^i)_{r\in R})$$

$(g_r^i)_{r\in R}$: a function of the interference level, indicating the payoffs.

- user i's payoff:

$$p^i(\boldsymbol{\sigma}) = \sum_{r\in\sigma_i} g_r^i(\sum_{j=1}^{N} S_{jr} I_{ij})$$

Game formation

- Strategy: change the selection of channels to maximize the payoffs (an improvement step).
- Scheme: users update their selections asynchronously in a predefined sequence.
- Question: Will these improvement converge to an equilibrium (finite improvement property or FIP)?

Potential function approach

- Potential function: $\phi(\boldsymbol{\sigma})$.
- Key idea:
  user i change from strategy σ_i to σ_i', strategy profile changes from $\boldsymbol{\sigma}$ to $\boldsymbol{\sigma}'$,then

$$p^i(\boldsymbol{\sigma}') - p^i(\boldsymbol{\sigma}) = \phi(\boldsymbol{\sigma}') - \phi(\boldsymbol{\sigma}).$$

- FIP: $\phi(\boldsymbol{\sigma})$ has an upper bound$\Longrightarrow$ payoffs can't increase infinitely $\Longrightarrow$ improvement steps converge to an pure Nash Equilibrium.

Four types of MSCG

According to the payoff function $(g_r^i)_{r \in R}(\cdot)$, MSCG can be categorized as four types:

- non-resource-specific and non-user-specific$\Longrightarrow (g)(\cdot)$
- non-resource-specific and user-specific $\Longrightarrow (g^i)(\cdot)$
- resource-specific and non-user-specific$\Longrightarrow (g_r)(\cdot)$
- resource-specific and user-specific$\Longrightarrow (g_r^i)(\cdot)$

Type I and Type II

Type I

$$p^i(\boldsymbol{\sigma}) = \sum_{r\in\sigma_i} g(\sum_{j=1}^{N}) S_{jr} I_{ij}), \phi(\boldsymbol{\sigma}) = \sum_{i\in N}\sum_{r\in R} g(\sum_{j=1}^{i} S_{ir} S_{jr} I_{ij})$$

FIP holds $\Longrightarrow$ PNE exists.

Type II

$$p^i(\boldsymbol{\sigma}) = \sum_{r\in\sigma_i} g^i(\sum_{j=1}^{N}) S_{jr} I_{ij}), \phi(\boldsymbol{\sigma}) = \sum_{i,j\in N} n_{ij}(\boldsymbol{\sigma}) I_{ij}$$

FIP holds $\Longrightarrow$ PNE exists.

Type III and Type IV

Type III

Counter example exists that FIP does not hold.
But the existence of PNE is still an open question.

Type IV

Counter example exists that neither FIP nor PNE exists.

Conclusion and Application

Conclusion

- FIP holds for Type I and Type II MSCG.
- For type III, FIP does not hold. And PNE may exist.
- For type IV,neither FIP nor PNE exists.

Application

In wireless network systems, when a contiguous block of spectrum divided equally into multiple channels with similar propagation parameters (e.g., WIFI and Bluetooth). The channels can be viewed as non-resource-specific. MSCG suits well.

Future Work

Existence of PNE for type III and type IV under constrains

- Topology
- Specific payoff functions

Other issues

- Convergence speed to the PNE
- Performance of PNE (POA)

Thank you !