Incomplete information, dynamics, and wireless games

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FLoWS

STATUS QUO

Previous work studied ad hoc wireless resource competition among multiple nodes using game theoretic techniques, but typically in a stationary setting, where each node knows all other's channel conditions (see Huang et al., Etkin et al.)

We aim to understand the importance of a lack of information about channel conditions over time.

NEW INSIGHTS

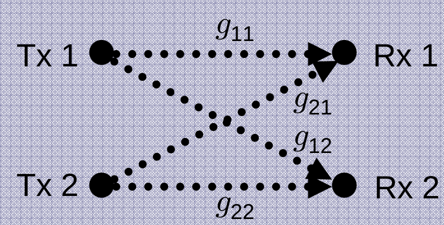
We bring in the importance of incomplete channel information via the use of both static and dynamic *Bayesian games,* and in particular exploit results on reputation effects in economics to study primary/secondary competition.

(S. Adlakha, R. Johari, A. Goldsmith)

FLOWS ACHIEVEMENT(S)

MAIN RESULT: *The presence of incomplete channel information among nodes, as well as dynamic interaction among nodes, can dramatically alter the game theoretic conclusions drawn in standard complete information settings.*

Example: A primary user may deter entry by secondary users at some cost to himself, even if it is not immediately in his best interest to do so.



HOW IT WORKS: We use the theory of *Bayesian games* to find symmetric equilibria of a Bayesian Gaussian interference game.

We use the theory of *reputation effects in dynamic games of incomplete information* model to study the behavior of a primary user interacting with multiple secondary users.

ASSUMPTIONS AND LIMITATIONS:

We assume one primary and several secondaries arriving over time; we assume the channel remains stationary over several periods of interaction between primary and secondary.

Key assumption (and limitation): there is no "protocol" for transmission, so all other transmission treated as pure noise (hence the Gaussian interference model).

END-OF-PHASE GOAL

We need to extend the model to handle not only a finite horizon model, but also an infinite horizon model with changing channel conditions.

Journal paper is being prepared for submission to JSAC.

Longer term: we need to focus more on implications for *algorithm design for ad hoc wireless nodes in a reactive environment.* Our insights set a foundation for this.

COMMUNITY CHALLENGE

Status quo is useless for designing node strategies.

Employ methods from learning and dynamic equilibrium in large games to build better algorithms for competition and cooperation.

Real environments are reactive and non-stationary; this dramatically changes incentives and game theoretic predictions

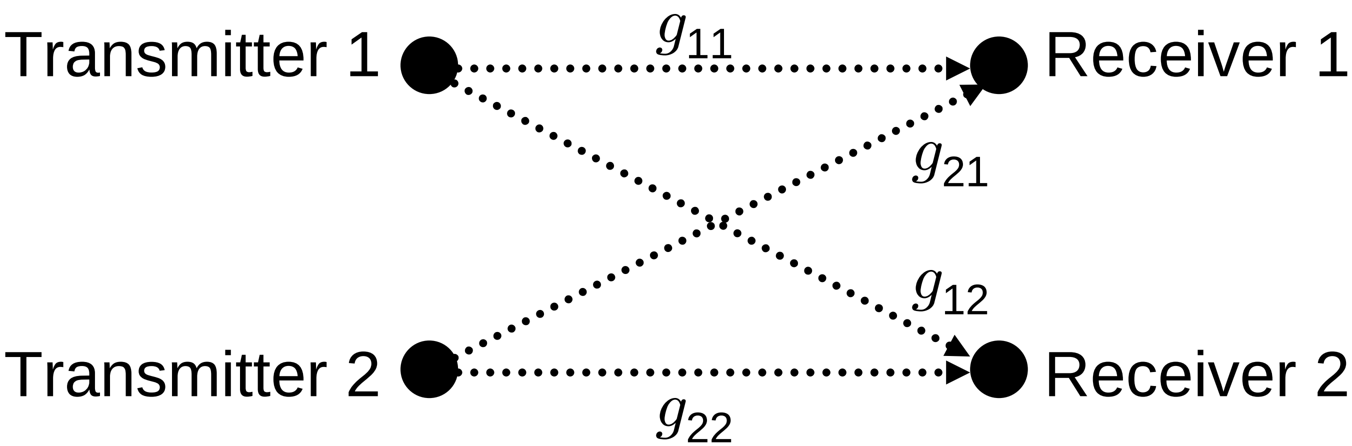
Motivation and overview

- In game theory, “incomplete information” refers to uncertainty players have about the payoff structure (and thus, behavior) of their opponents
- In wireless systems: incomplete information = nodes are *uncertain* about each other’s channel conditions
- Most prior work assumes *complete information* among nodes, and often only works with *static* models
- Our work studies the implications of imperfect information in wireless game settings
- Part I: Static Bayesian Gaussian interference game
- Part II: Reputation effects in a dynamic interference game

(Joint with S. Adlakha and A. Goldsmith)

Part I: Bayesian Gaussian interference game

- Two devices, N non-overlapping channels
- Both devices have same power constraint P
- Flat fading (i.e., same gains in each channel)
- Gains randomly drawn



Part I: Bayesian Gaussian interference game

- Assume transmit/receive pair 1 observes the incident gains g_{11}, g_{21}, but not g_{22} or g_{12} (similarly for Tx/Rx pair 2); assume flat fading
- This is a Bayesian game:
  Once random gains are realized, each TR pair knows its own gains but not the gains of the other.
- This is a supermodular Bayesian game; in particular, local search dynamics converge (see also R. Berry's work)
- Nodes can either use a single channel,
  or spread power across all channels

Part I: Bayesian Gaussian interference game

- We focus on *symmetric equilibrium*:
  As a function of channel gain, all devices
  have the same strategy.

  Motivation:
  Asymmetric equilibrium requires prior coordination

- *Theorem*:
  Equal spreading is unique symmetric equilibrium

  Implications: This can be quite inefficient!

Part II: Reputation effects in a dynamic game

- Now assume Tx/Rx 1 = primary, Tx/Rx 2 = secondary; same system model, but now assume only 2 channels
- Primary is *long-lived* and *fully rational*
- Secondary user is *myopic* (only optimizes one period payoff), but *history-aware* (remembers the past)
- Secondary user decides each period whether to "enter" (i.e., transmit), or "leave" (i.e., stay silent)
- Secondary user is assumed to have a cost for power consumption
- Primary user can "share" (give up a channel to secondary) or "spread" (spread power equally over channels)

Part II: Reputation effects in a dynamic game

- Assume: $g_{11} = g_{22} = 1$, and primary knows g_{21}, secondary knows g_{12}.
- For simplicity, assume primary also knows g_{12}
- Gains are constant over the time horizon of interest
- At each time period:

1) Arriving secondary user decides whether to enter or leave

2) Primary user decides transmission strategy: either all power in 1 channel, or power spread equally across both channels

3) Secondary user chooses transmission strategy: same options as primary user

Part II: Reputation effects in a dynamic game

In a single period game, when the secondary chooses to enter:

- g_{12} small $\Rightarrow$ in equilibrium, both primary and secondary user spread power
- g_{12} large, g_{21} small $\Rightarrow$ in equilibrium, both primary and secondary user spread power
- g_{12} large, g_{21} large $\Rightarrow$ in equilibrium, both primary and secondary user share the channel

Part II: Reputation effects in a dynamic game

Now consider multiperiod horizon.

Then when both g_{12}, g_{21} are large,
there can be a *reputation effect*:
Despite the fact that the primary would be better off sharing (in one period) if secondary enters,
the primary may choose to spread (“act” threatening)
because this deters future entry by the secondary

Key point:
This cannot happen in a complete information model!
(For complete information case, see Etkin et al.)

Next steps

- Results provide insight into the role of incomplete information
- Assumptions that are problematic:
  - Supermodularity breaks down with more than two nodes
  - Primary-secondary interaction heavily stylized
  - Equilibrium is suspect:
    How did nodes coordinate on that equilibrium
    in the first place?

Large scale stochastic games

- We will leverage recent results in analysis of *large scale stochastic games* to address the central question of this project:
  How should nodes behave when their environment is reactive?

- Approach:
  - Standard solution concept is *Markov perfect equilibrium,* but is hard to compute and requires too much information
  - Recent suggestion by Weintraub et al. for economic models: *oblivious equilibrium*
  - In OE, optimize *as if* the rest of the system behaved according to its stationary average (good in large scale systems)
  - We are generalizing this approach for arbitrary stochastic games *(joint with V. Abhishek, S. Adlakha, G. Weintraub)*

Large scale stochastic games

- The OE methodology is appropriate for cognitive radio design
- Model: large system of many interacting nodes
- Use low-dimensional dynamic programming computation to solve for approximately optimal strategy
- Resulting strategy close to optimal in exact problem

Our goal: apply this approach to wireless system modeling