Location-Oriented Evolutionary Games for Price-Elastic Spectrum Sharing

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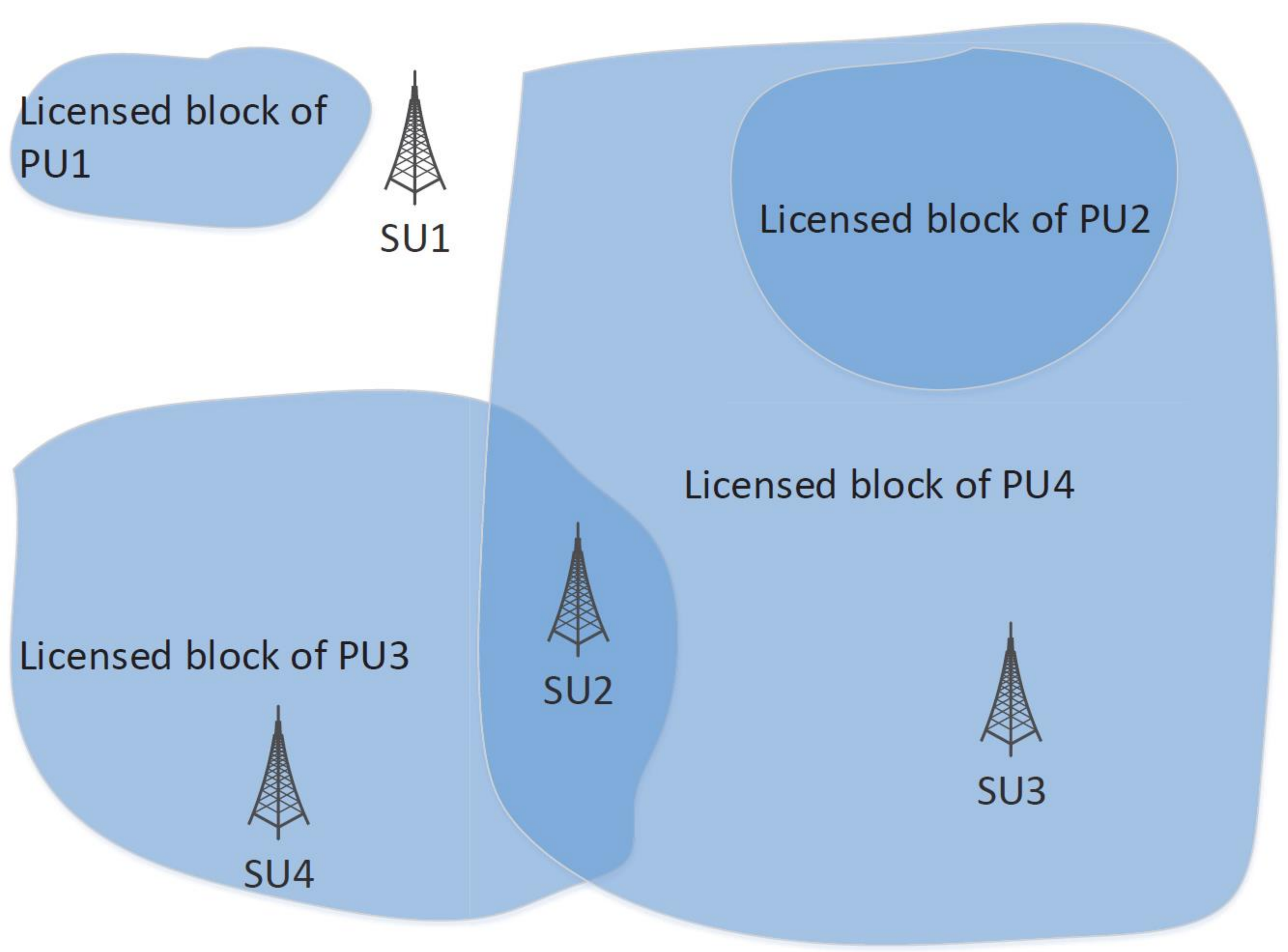
BACKGROUND

- Spectrum Sharing Using Economic Approaches
  - A hierarchical system, composed of primary users (PUs) and secondary users (SUs).
  - Idle channels of PUs can be traded as merchandise.
  - Channels of different PUs are differentiable products, providing different utilities.
- Related Work
  - Without geographical consideration, channel selection preference of each SU, channel selling preference of each PU, and channel prices of different regions cannot be handled.
- Motivation
  - We consider both the locations of SUs and the licensed blocks of PUs. By modeling the multi-price policy of the PUs and the price-elastic demand of the SUs, we want to specify the following issues.
  - ✓ Channel selling preferences of the PUs.
  - ✓ Channel selection preferences of the SUs.
  - ✓ Channel prices of the PUs in different regions.

SYSTEM MODEL



- Utility Model
  - The value assessment of a channel is price-related. Channel utility related to channel capacity and price sensitive function, i.e.,

$$U_{mn} = u_{mn} + \Xi_{mn}$$

- Price-Elastic Demand Model
  - Our demand model is applicable to both oligopoly and monopoly markets.
  - Prevent the PUs from irrational high prices.

- Problem Formulation
  - We assume that each PU tries to achieve its maximum payoff. For a PU, the problem of interest is

$$\max_{\substack{(p_{m1},\cdots,p_{mN})\\(b_{m1},\cdots,b_{mN})}} \pi_m(p_{m1},\cdots,p_{mN},b_{m1},\cdots,b_{mN})$$

ANALYSIS

- We design a quota transaction process, in which the PUs set the numbers of channels they would like to sell to particular SUs, or quotas.
  - Channel transaction number should be under the quota, i.e.,

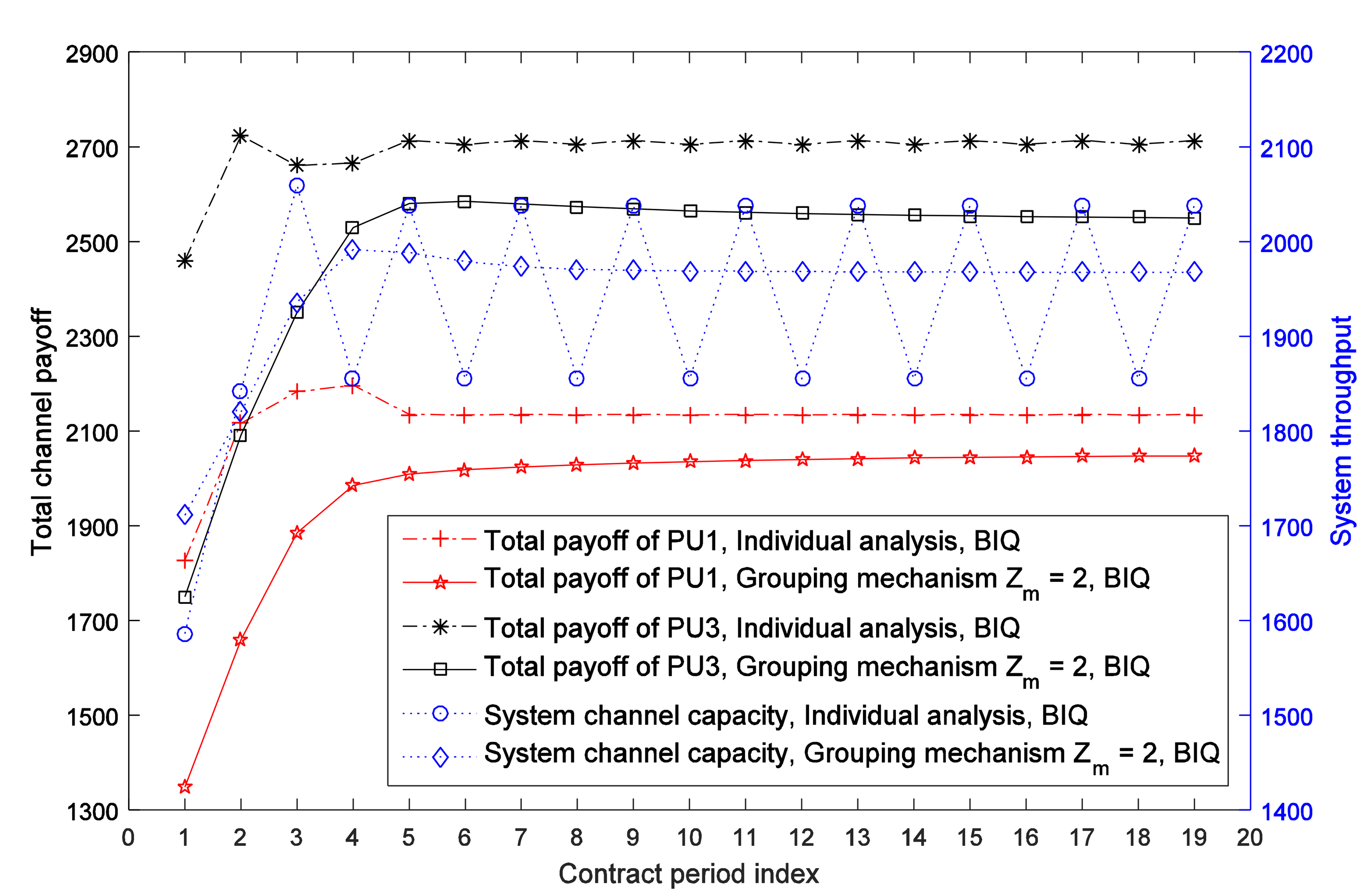
$$b_{mn} \le k_{mn}$$

  - Selling channels without reserve $\sum_{n=1}^{N} k_{mn} = S_m$
  - Selling channels with reserve $\sum_{n=1}^{N} k_{mn} < S_m$
  - We eliminate transaction situations that could not maximize the payoffs of the PUs.
- To sell more channels to the SUs that bring more payoff, the evolutionary procedure is defined as replicator dynamics. Specifically,

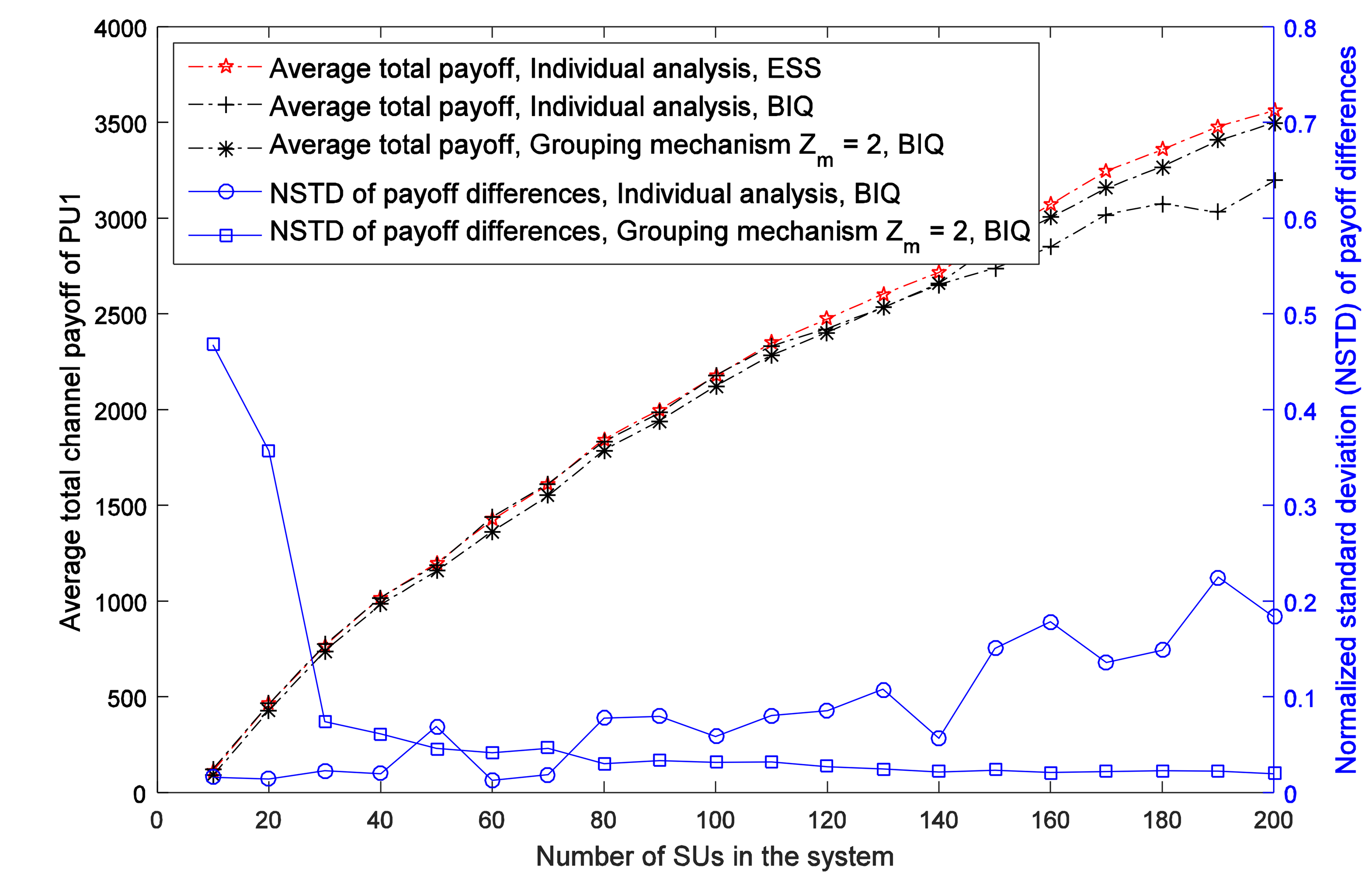
$$\Delta k_{mn}(\tau) = \mu_m\left[\bar{\pi}_{mn}\left(k_{mn}(\tau), k_{-mn}(\tau)\right) - \bar{\pi}_m\left(\mathbf{k}_m(\tau), \mathbf{k}_{-m}(\tau)\right)\right] k_{mn}(\tau)$$

  - We can determine a stable quota vector $\mathbf{k}_m^* = (k_{m1}^*, \cdots, k_{mN}^*)$
  - We prove that k_m^* is asymptotically stable.

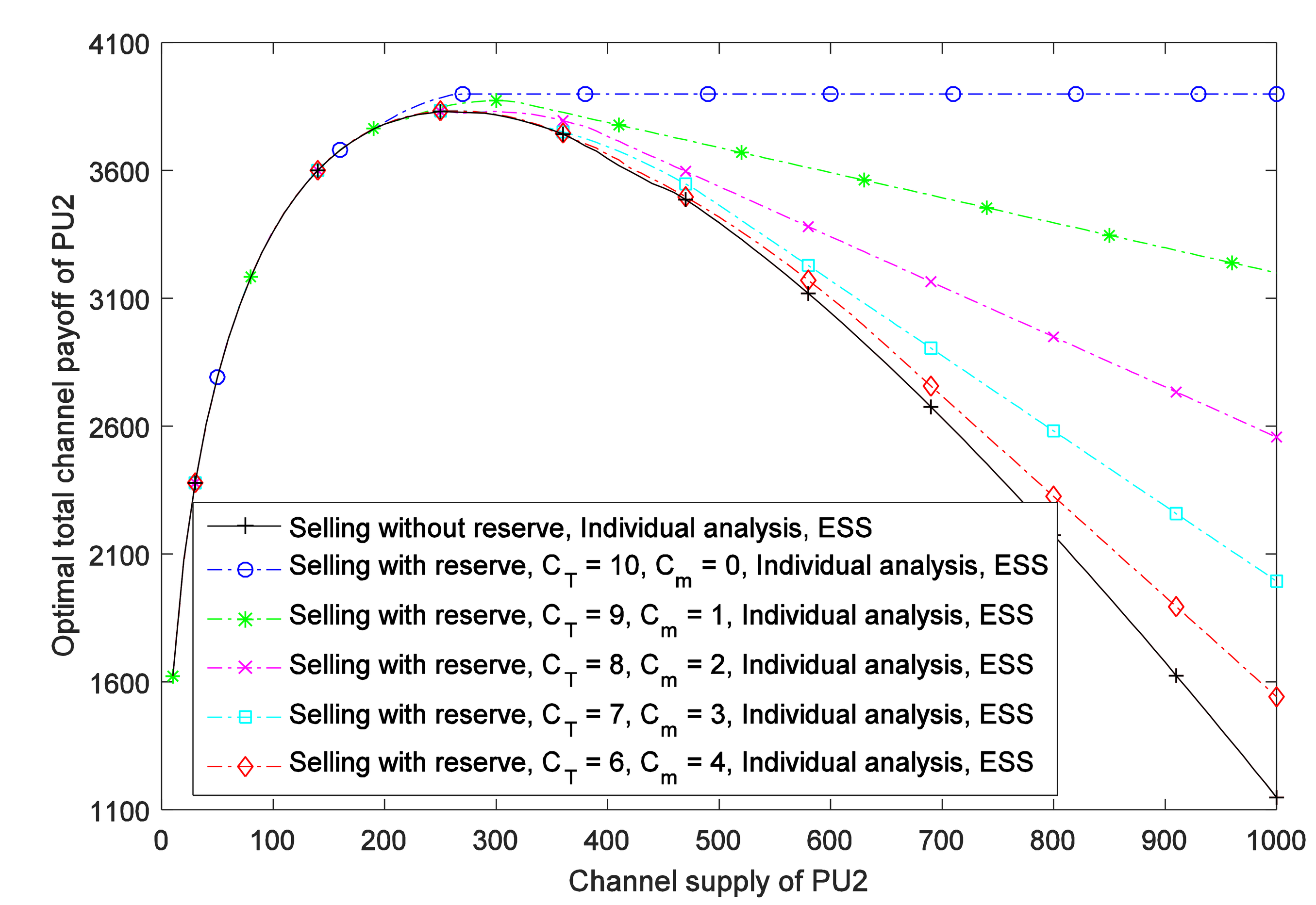
SIMULATIONS



- Total channel payoffs for selected 2 PUs and system throughput in individual analysis and grouping mechanism.



- Average total channel payoff of PU1, and normalized standard deviation (NSTD) of the payoff differences between BIQs and ESS quotas.



- Total channel payoff of PU2 when selling channels with reserve.

CONCLUSIONS

- We develop a model where geographic information, including licensed areas of PUs and locations of SUs, plays an important role in the spectrum sharing system.
- The value assessment of a channel is price-related and the demand from the SUs is price-elastic.
- We prove the existence and uniqueness of the evolutionary stable strategy quota vector of each PU, which leads to the optimal payoff for each PU selling channels without reserve.
- In the scenario of selling channels with reserve, we predict the channel prices for the PUs leading to the optimal supplies of the PUs and hence the optimal payoffs.