Efficient Coordinated Power Distribution on Private Infrastructure

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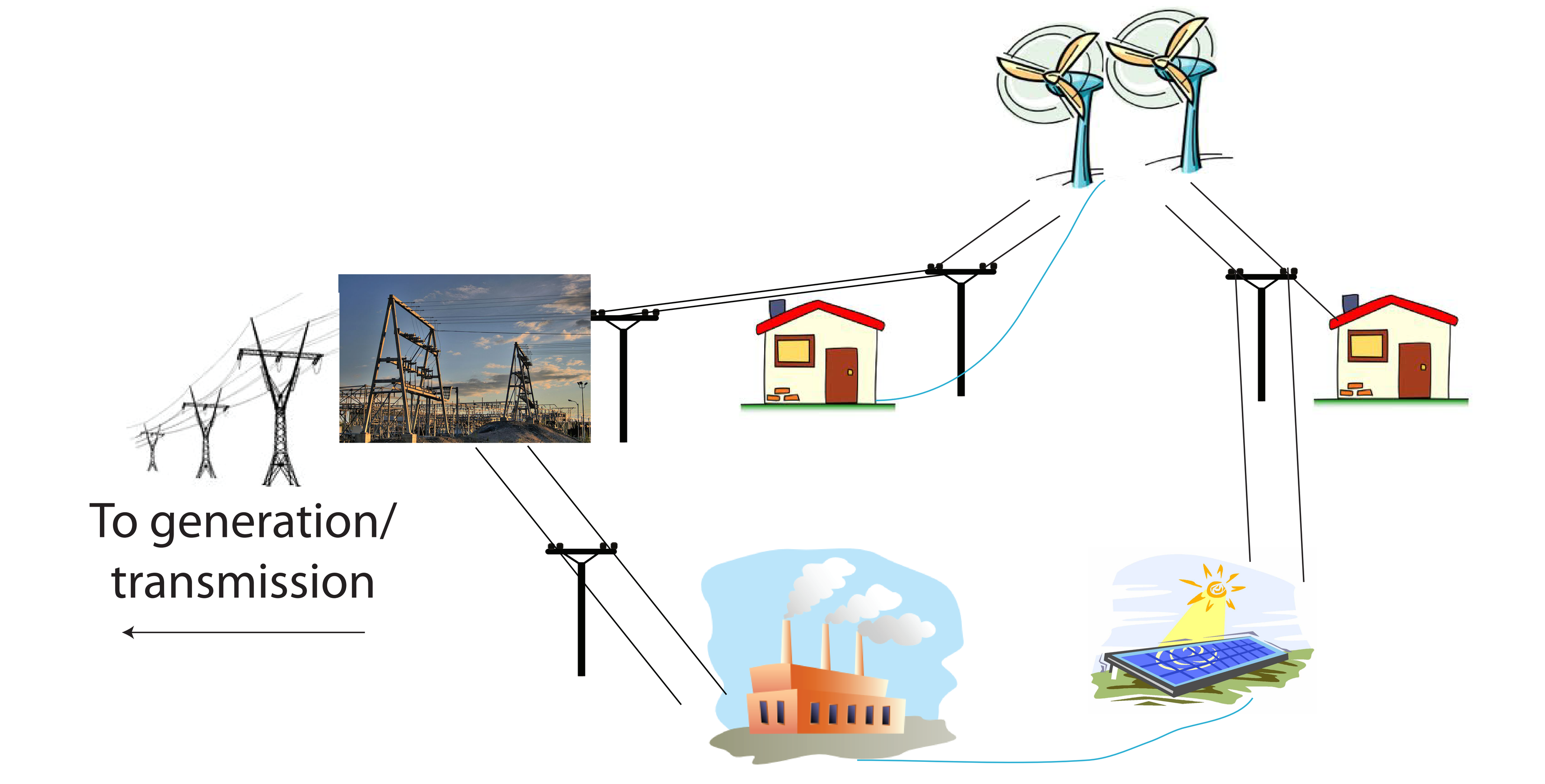
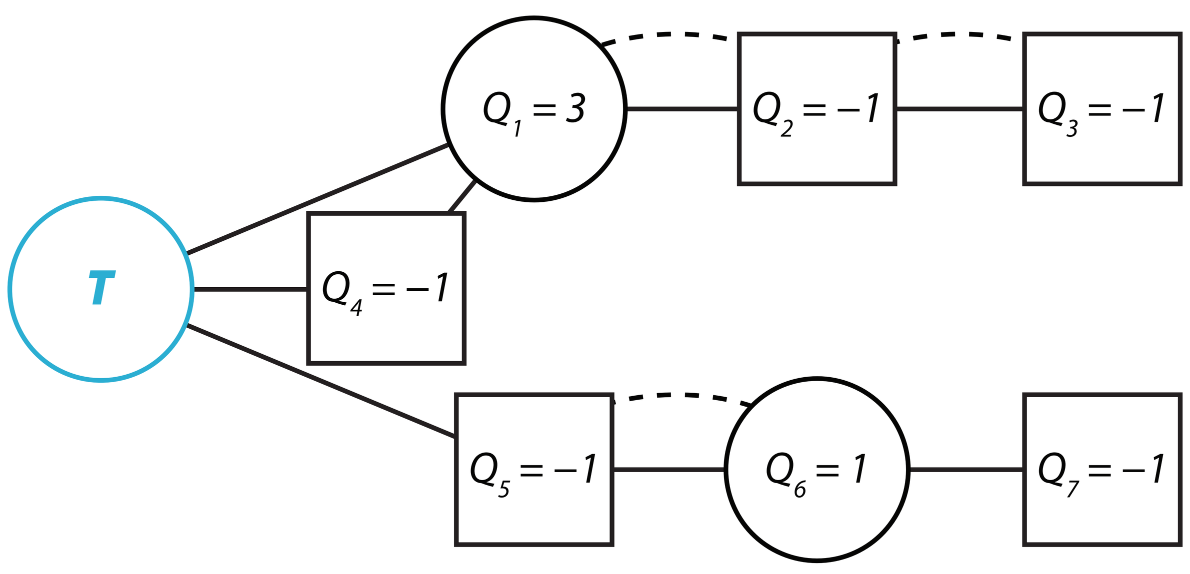
Motivation

- Emergence of *private infrastructure*, e.g., in *microgrids*, creates an organization problem on the electricity grid
- The problem can be addressed using the tools of game theory and optimization
- Want to coordinate the distribution of locally-generated and main-grid power of varying cost across private and public infrastructure
- We assume that we do not control private infrastructure—we must *incentivize* its owners to use it in the most efficient way.



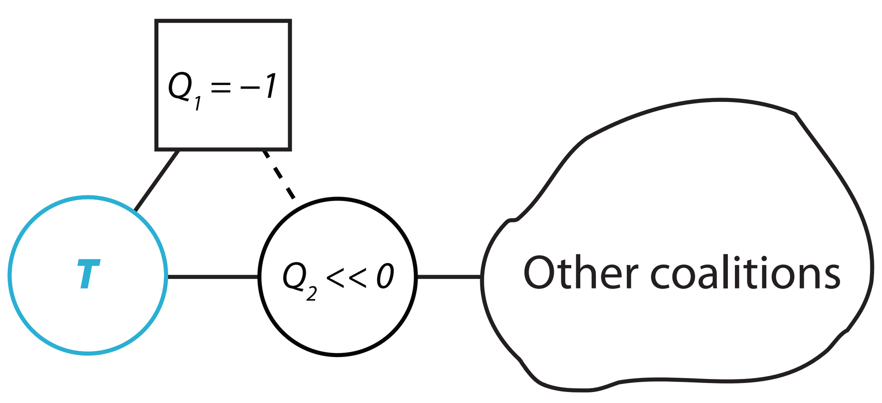
Formulation as a Cooperative/Competitive Game

- Players decide what coalition (trading group) to join
- Coalition chooses a strategy—the strategies available depend on the actions of other coalitions
- Payoff distributed to members of coalition
- Example of network infrastructure:



- Transmission losses proportional to square of the amount distributed
- Closest known model is the Market Game (Shapley and Shubik, 1975)
  - Each agent has an endowment, utility function
  - Core always exists, is easy to find
  - No natural generalization to non-independent losses
- Open question as to whether supporting payments always exist, but examples to date always have them

Coalitions Are Not Independent



Models of Agent Behavior

- Different models represent different control assumptions about agents
- All models calculable or closely approximable efficiently in CPLEX. Because of quadratic losses, they require quadratically-constrained quadratic programs (QCQP).
- The behavior of each model is described on the 8-node example

Four Models of Agent Behavior

Ad hoc
- Agents trade with other nearby agents to heuristically maximize profit.
- Trades with nearer agents occur first to model *limited knowledge of trading agents*.
- Flow on public edges constrained by physics.
- Private trades on example: (A_4,A_5): 1 unit and (A_1,A_2): >1 unit.
- Public trades: remaining requirements of A_3, A_4, A_5 and A_7 and purchase leftovers from A_1.

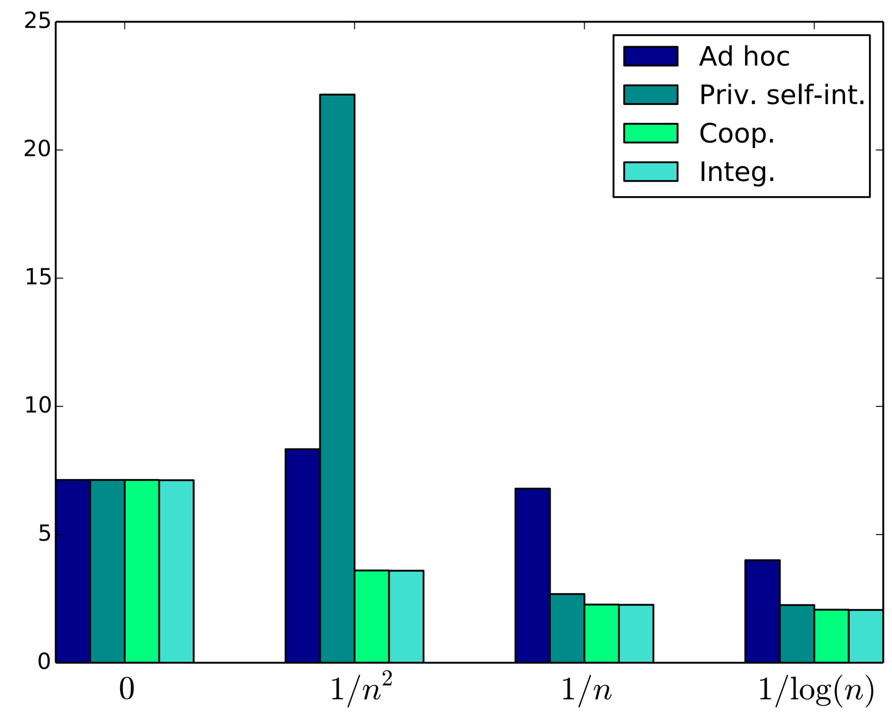
Private self-interested
- Groups of agents trade to collectively *maximize their profits*.
- Flow on public edges constrained by physics.
- Private trades on example: (A_4,A_5): 1 unit, (A_1,A_2): 2 units, and (A_2,A_3): 1 unit.
- Public trades: remaining requirements to A_4, A_5, and A_7 and purchase leftovers from A_1.

Cooperative
- Groups of agents cooperate with the grid to *minimize the overall cost of supplying electricity*.
- Flow on public edges constrained by physics.
- Private trades on example: (A_1,A_2): >1 unit and (A_2,A_3): >0.5 units.
- Public trades: Remaining demands met, but A_4 receives half from A_1 and half from the public grid.

Intergrated
- Same as cooperative model, but do not restrict public flow to physics
- Trades: same as cooperative, but A_4 receives 1 unit from A_1.

Effect of Coordination on Efficiency

- Use IEEE 300-bus system as public network
- Generate private network as Erdös-Renyi random graph
- Total losses in distribution: lower = better



Node density	Model	Edge density on priv. net. 0	$\frac{1}{n^2}$	$\frac{1}{n}$	$\frac{1}{\log(n)}$
1 km x 1 km	Ad hoc	7.13	8.33	6.79	4.00
	Priv. self-int.	7.13	22.16	2.68	2.25
	Coop.	7.13	3.60	2.27	2.07
	Integrated	7.12	3.59	2.26	2.06
100 km x 100 km	Ad hoc	7.12	8.08	6.89	4.05
	Priv. self-int.	7.12	24.95	2.70	2.25
	Coop.	7.12	3.62	2.28	2.08
	Integrated	7.10	3.60	2.26	2.06

Conclusion

Contributions
- Calculate optimal flow and payments in idealized model
- Open problem: Market Games with non-independent losses
- Importance of coordination

Future Work
- Richer agent preference spaces—time-based decisions, trading off comfort vs. cost
- New game type—representation as partition function game?