Auctions in Wireless Networks

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This talk ...

- Background on Auctions
- Application in Wireless Networks
- Evolving role of Auctions

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- ❖ Ebay Case Study
- ❖ Overview of Auction theory
- ❖ Challenges in Auction Mechanism Design

Case Study: Ebay

- Auction-based marketplace
  - Second-Price Ascending Auction
  - Terminates at a Fixed Time
  - *Not sealed Bid*
  - Proxy Bidding
  - Willingness to Pay

Ref: Greenwald, Amy. "Game theory and the design of electronic markets." *Information Systems* 12, no. 1 (2003): 30-40.

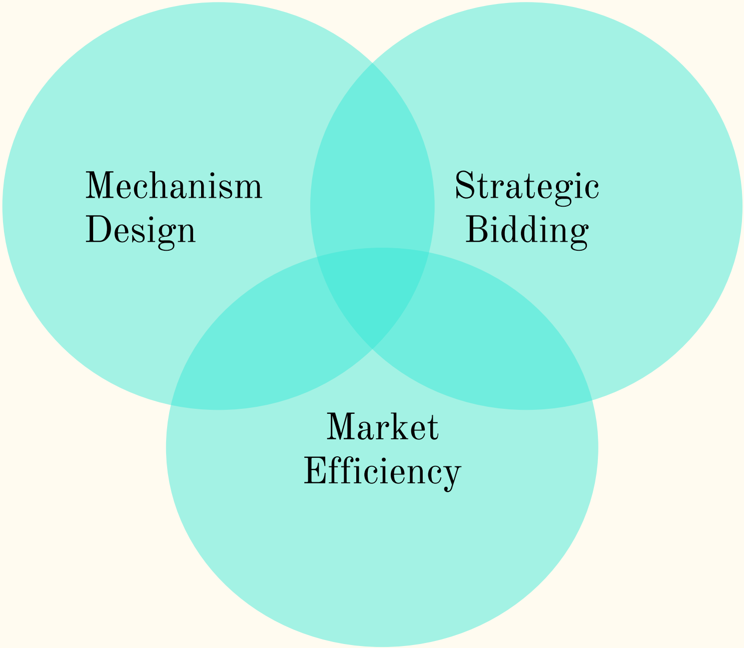
Case Study: EBay (Cntd.)

"Enter the highest amount you'd be willing to pay for the item. eBay will automatically raise your bid, only as much as is needed for you to remain the high bidder. (This is called proxy bidding...) This means that you may win an item for less than your maximum bid."

- Is this *the dominant strategy*?
- Scenario:
  - Bob uses Proxy Bidding
  - Alice is a *Manual Bidder*
  - Bob and Alice are the only 2 bidders in the auction
  - WTP A > WTP B
  - Who wins?
  - What if Bob *sniped?*
    - Sniping: Placing a bid likely to exceed the current highest bid as late as possible—usually seconds before the end of the auction—giving other bidders no time to outbid the sniper.

Auction Mechanism Design

- Mechanism Challenges
  - Very domain specific
    - Eg: Representational challenges in succinctly specifying bids
- Game-Theoretic Challenges
  - Bidder Strategies
  - Auctioneer Allocation Strategy
  - Incentivizing Truthfulness
- Algorithmic Challenges
  - Efficiently solving the resulting Allocation problems
    - Time constraints
    - NP-Hardness



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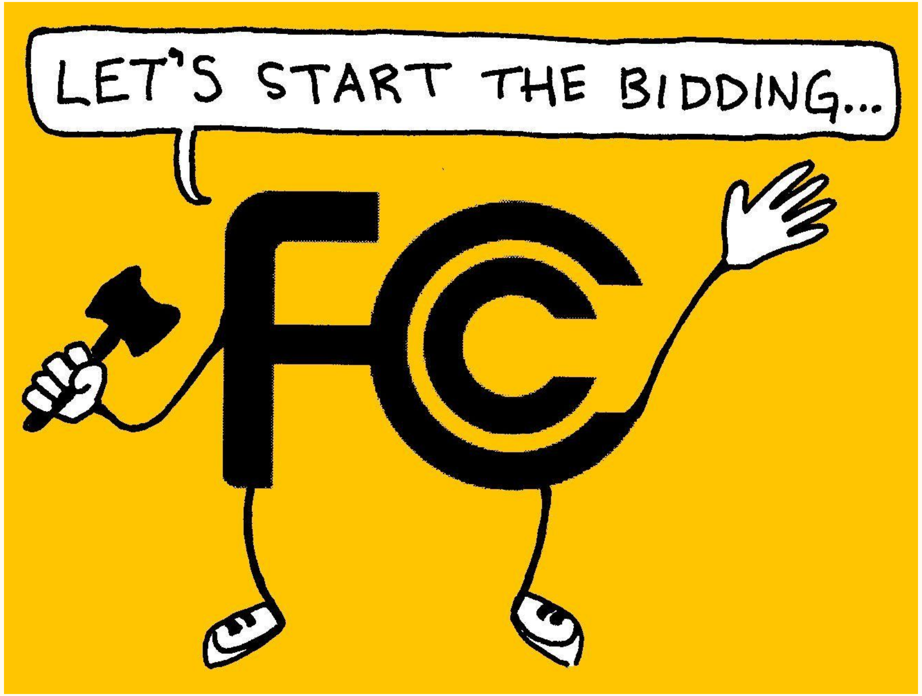
- Paper: Spectrum Auction Design
  - Spectrum Auction Overview
  - Challenges
  - Simultaneous Ascending Auction Review
  - Combinatorial Clock Auction Design

Paper #1: Spectrum Auction Design

- But not really…

"*... given the reality of that schedule, the complexity of designing and implementing the auction, and the need for all auction participants to have certainty well in advance of the auction, we now anticipate accepting applications for the auction in the fall of 2015 and starting the auction in early 2016.*" *– Gary Epstein, FCC's Incentive Auction Task Force*"

Spectrum Auctions are hard to *correctly* design.



Ref: Cramton, Peter. "Spectrum auction design." *Review of Industrial Organization* 42, no. 2 (2013): 161-190.

Motivation

- Auction spectrum licenses to service providers
  - Long-term: Winner holds on to the license for 10-15 years
- Simultaneous ascending auction typically used
      - Rapid advancements in wireless technology affects how the spectrum is organized

Need to allocate sufficient spectrum in a technology-agnostic manner. Can the auction itself determine the ultimate band plan?

Challenges

- **Heterogeneous** but similar items
  - ***Substitutes*** and ***Complements***
- Efficiency vs Revenue Maximization
- Battling Monopolies
  - Regional Market-splitting by dominant incumbents
- Potential Market Failures due to
  - Fragmenting the spectrum and prohibiting aggregation
    - More "winners" than the market can efficiently support
  - Limited competition in the market of wireless services

How can we design a Spectrum Auction that handles this?

The Spectrum Auction needs to ...

- Enhance Substitution
  - Via,
    - Product design, and/or
    - Auction format
- Encourage Price Discovery
  - How can bidders handle uncertainty about what product worth is?
  - How do they develop valuation models?
- Induce truthful bidding
  - Accomplished through an effective:
    - Pricing Rule, and
    - Activity Rule

The Simultaneous Ascending Auction

- Workhorse for FCC Spectrum Auctions since 1994
- Generalization of the *English Auction*
  - All items auctioned *simultaneously*
- Basic design
  - Each item/lot has a price
  - In a round:
    - Bidders raise the bid of the lots of interest
    - Auctioneer identifies provisional winner for each lot
  - Proceed to next round unless nobody is willing to bid any higher

The Simultaneous Ascending Auction (Cntd.)

- Feature #1: Protection against Sniping
  - A bidder that wants to be a big bidder at the end of the auction must be a big bidder throughout the auction
  - A bidder *cannot win* by making its true intent known until the last instance
- Feature #2: Good price discovery
- Feature #3: Arbitrage across substitutes
- Feature #4: Allows bidders to piece together complements
- Feature #5: Reduces *winners curse*

The Simultaneous Ascending Auction: Failings

- Under weak competition, bidders have an incentive to engage in *tacit collusion*
- Allows for *parking strategies*
- Does *not* allow for package bids
  - Cannot sufficiently express complementaries
- Vulnerable to *hold-up*
- Large bidders have strong incentive to engage in demand reduction
- No substitution across licenses

Approach: The Combinatorial Clock Auction

- Allow the competing bids to determine the ultimate band plan, and hence the technology, by expressing **combinatorial** bids
    - Eg: LTE vs WiMAX
- Overcomes the inefficiencies of the Simultaneous Ascending Auction
- How is this accomplished?

Product Design

- Anonymous bids
  - Much of the game-playing is eliminated
- Generic Spectrum wherever possible
  - Spectrum is treated as a homogenous good inside each region
  - Contiguous spectrum is sold
  - Treat each MHz of spectrum within a geographic region and a particular frequency band as perfect substitutes
- Assignment of actual spectrum lots at the end

Price Discovery - The Combinatorial “Clock”

- “Clock” stage wherein the Clock shows the most recent bid price
  - Each product has its own “clock”, indicates its current price
  - In each round, bidder indicates quantity of lots desired at the current price for each product.
  - Auctioneer adds the individual bids and reports demand for each product
  - Prices ascend *for each product* until there is no excess demand it.
  - Information Revelation: Relationship between prices and aggregate demand

The “Combinatorial” Clock

- Handling Complements
  - At each clock round, bidders essentially express complements
  - Hence, combinatorial bid!
- Supplementary round
  - Post the Clock stage
  - Bidders can express preferences for additional packages that were missed by the Clock process
  - Bidders can improve bids on packages that were already bid in the Clock stage

How can we avoid Bid Sniping in Supp. round?

- *Eligibility point rule*
  - Bidder cannot increase package size during Clock stage
  - If bidder reduces package size, the bid on all larger packages is capped by prices at the time of reduction
  - Issue?
- *Revealed Preference rule*
  - During the clock stage, bidder can only shift to packages that are relatively cheaper at time t
  - Every supplementary bid on a package must be less profitable than the revised package bid at t

Truthful Bidding

- Induce Truthful Bidding
  - Minimize the bidders' total payments subject to competitive constraints (no group of bidders has offered the seller more)
  - Complements sometimes result in payments greater than Vickrey payment for some bidders
- Example: Consider 2 items, A & B, and 3 bidders
  - Bidder 1-> $4 for A
  - Bidder 2-> $4 for B
  - Bidder 3-> $4 for A and B
- Problem with the Vickrey outcome?

Vickrey Nearest-Core Pricing

- Need to find prices in the core
  - Find the lowest payments that are in the core, i.e., no alternative coalition of bidders has offered the seller more than the winning coalition is paying
- Problem: Payment-minimizing core prices are not unique when the Vickrey prices are outside the core
  - How do we select the bidder optimal one?
- Solution: Select the payment-minimizing core prices that are closest to the Vickrey prices
  - Set of core prices is always convex
  - The Vickrey prices are always unique
  - Hence, there is a unique vector of core prices that is closest in Euclidean distance to the Vickrey prices

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- ❖ Applications in Cognitive Radio
- ❖ QoS Management

Other applications of Auctions in Wireless

- More spectrum auctions...
- Dynamic real-time spectrum auctions
- Cognitive Radio Auctions
- **Real-time fast combinatorial** auctions to enable
  - QoS management at the edge by mobile devices
  - Incentivized sensing and information sharing in IoT
  - Vehicular network management
  - Smart Cities .. etc
  - Open-marketplace for negotiation of network resources among entities with different interests and capabilities
    - My research project!

The End