Wireless Spectrum Economics

S-38.041 Networking Business

Spectrum Licencing

Big Picture

- Governments can assign the national cellular spectrum licences through comparative evaluation (i.e. ”beauty contest”), lottery, or auction
- Many governments rely on comparative evaluation because they want to keep control on the spectrum usage while supporting the investment capabilities of telecom industry
- Lotteries have been abandoned because of large overhead (huge number of bidders) and low hit rate (wrong kind of winners)
- Auctioning has gained popularity because of fairness, transparency, good hit rate, and remarkable revenues
- Statistics tell that a government favors auctioning when
  - the density of country’s population is high (e.g. the Netherlands)
  - the government’s budget deficit is large (e.g. the UK)
  - the number of licences is high (e.g. the US)

Auction Basics

- Auctioning is economically efficient, i.e. maximizes the social welfare, if it allocates items to bidders who value them most
- Auction design for a particular situation is as much art as science, but the basic theory is still useful
- In tatonnement, prices adjust up-and-down to match demand and supply, while auctions typically allow prices to go one way, up or down

Types of Auction (1/2)

- *Open* (oral) auctions often have several rounds while *sealed-bid* (written) auctions may only take a single round
- Descending (*Dutch*) auctions are typically faster than ascending (*English*) auctions because the auctioneer alone drives the price down (using a ”*Dutch clock*”)
- In a *first-price sealed-bid* auction the bidders decide off-line their claim ⇒ no information is revealed ⇒ result equals to Dutch auction (winner pays the highest bid = his own)
- In a *second-price sealed-bid* (or Vickrey) auction the bidders tend to bid their true valuations ⇒ result equals to English auction (winner pays the second highest bid)
- In a *multi-unit* auction bids are made on one or more units of the same object (e.g. communication bandwidth)

Types of Auction (2/2)

- *Heterogeneous* multi-object auctions may be complex because of the possible dependences between the non-similar objects auctioned together (e.g. spectrum objects)
- In *simultaneous* auctions bids are initially sealed and later (partly) posted by the auctioneer (e.g. spectrum)
- In *sequential* auctions prices tend to decline in the later auctions due to fewer or poorer bidders (e.g. UMTS)
- In *double* auctions the are multiple bidders and sellers which are treated symmetrically (e.g. stock exchanges)
- *Simultaneous ascending* auction (SAA) is the most common approach for auctioning a set of spectrum licences

Simultaneous Ascending Auction

Basics (1/2)

- Simultaneous bidding on *multiple heterogeneous objects* (e.g. spectrum licences) occurs in rounds and continues until nobody posts a bid on any object
- In each round, bidders make *sealed bids* and the auctioneer posts the highest bid and bidder for each object
- *Minimum bid increments* are enforced to secure fast finish
- *Combinatorial bidding*, i.e. bundling of objects, can be allowed although it adds complexity
- Bidders gradually reveal information during rounds thus reducing the probability of *winner's curse* (i.e. a bid higher than value) and enabling more aggressive bidding
- Simultaneous bidding enables the bidders to efficiently consider *complementarity* between objects (e.g. adjacent bands of spectrum)

Simultaneous Ascending Auction

Basics (2/2)

- Eligibility, activity rule, waivers (pass activity rule)
- Closing rule
- Payment rule (deposits to prevent defaults)
- Quantity cap
- Bid information (bidder, bid, eligibility)
- Bid withdrawal

Simultaneous Ascending Auction

Inefficient Allocation

Bidder	v_A	v_B	v_{AB}
1	1	2	6
2	3	4	5

- Consider an auction of two spectrum licences, A and B, where
  - two bidders, 1 and 2, compete
  - individual valuations are v_A and v_B, and a combined valuation is v_{AB}
  - licences are complements for bidder 1, but substitutes for bidder 2
- Socially optimal allocation would be v_{AB} for 1, but there are no prices facilitating this
- A possible but complicated solution is to allow combinatorial bidding

Simultaneous Ascending Auction

Incentive to Delay Bidding

Bidder	v_A	v_B	Budget
1	15	30	20
2	10	0	20
3	0	5 w.p. 0.9 15 w.p. 0.1	20

- Consider an auction where bidder 3 values B at 5 or 15, with probalities 0.9 and 0.1, respectively
- This partial information on bidder 3 implies that 1 waits to see how 3 bids, and vice versa
- Deadends like this one are handled with proper *activity rules* enforcing bidders to continue

Simultaneous Ascending Auction

Free Rider Problem

Bidder	v_A	v_B	v_{AB}	Budget
1	4	0	0	3
2	0	4	0	3
3	$1+\varepsilon$	$1+\varepsilon$	$2+\varepsilon$	2

- Consider that combinatorial bidding is allowed: bidder 1 bids 1 on v_A, 2 bids 1 on v_B, and 3 bids 2 on v_{AB} ⇒ seller announces that 3 wins if no further bids are made
- The combined bid of 3 wins with a socially suboptimal value 2 if 1 and 2 decide to wait for each others' bid in order to save money ⇒ 3 gets a free ride

Spectrum Auctions

Advice to Governments (the U.S. Perspective)

- Allocating the spectrum is as important as its assignment
  - Avoid useless spectrum by listening to experts (e.g. interference issues)
  - Define cleaning rules for spectrum occupied by poor usage
- Use care when modifying succesful auctioning rules (e.g. SAA)
- Allow adjusting the auction parameters between rounds
- Reduce effectiveness of bidders' revenue-reducing strategies
  - nationwide licences eliminate demand reduction due to spectrum split
  - anonimity eliminates retaliation ("you stay off my licence and I stay off your licence")
- Use spectrum caps to limit anticompetitive concentration
- Implement special treatment for designated entities with care
- Promote market-based tests in spectrum management

Source: P.Cramton, 2002

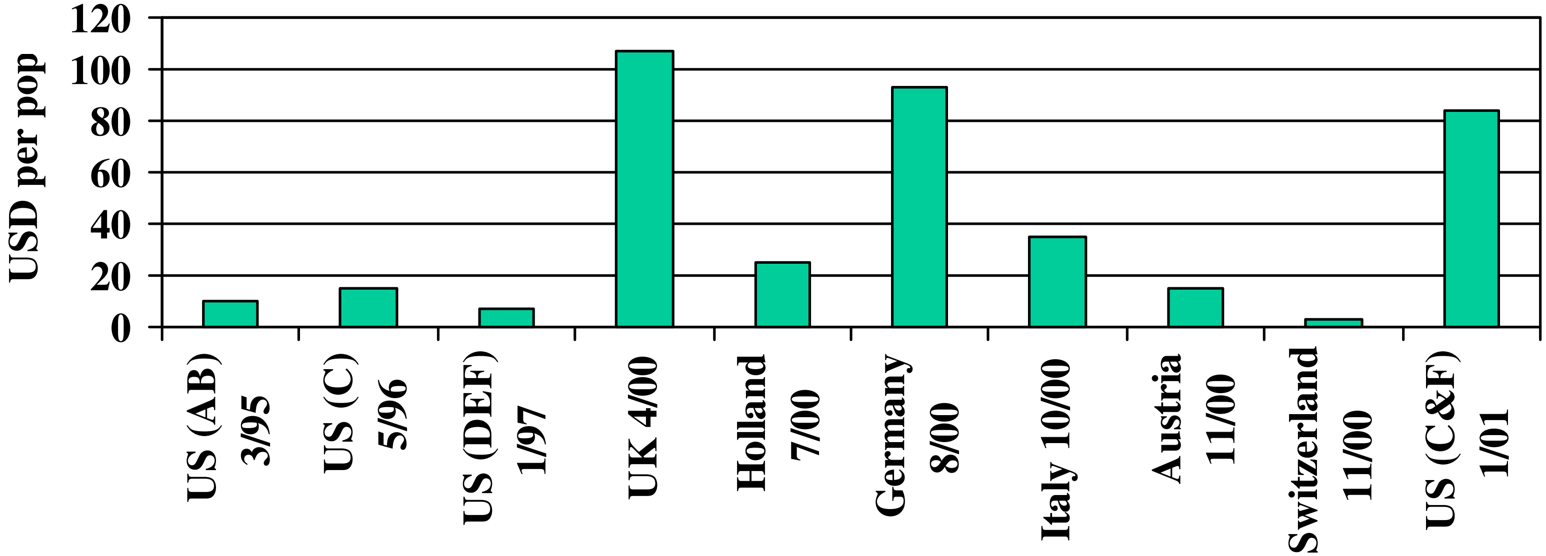
UMTS Licence Auctions

Case Europe

- European governments copied the american experience, i.e. the simultaneous ascending auction
- The UK and Netherlands chose a simple version where a bidder can win at most a single licence, while Germany allowed multiple bids
- In Holland, 5 licences and 5 incumbents ⇒ entrants allied with incumbents ⇒ price level remained low
- In the UK, 5 licences and 4 incumbents ⇒ tough competition lasting 150 rounds ⇒ price level record high (e.g. Vodafone paying 160USD per person for 2x15MHz)
- In Germany, 12 blocks (2x5MHz), 4 incumbents, and 4-6 possible winners ⇒ 173 rounds ⇒ 6 winners a 2x10MHz with record prices

UMTS Auctions

Comparison: European 3G (2x10MHz) vs. the US 2G



- Auction revenue varies significantly due to context sensitivity of auction design
- UMTS auction revenues decreasing over time (international operators running out of money?)
- Spectrum in the US has lately reached the European price levels (impact of allowing resalability?)

Source: P.Cramton, 2002

Spectrum Allocation

Demand vs. Supply

- International bodies (ITU-R) create global recommendations on spectrum allocations, but governments make decisions
- Governments consider spectrum as a scarce resource requiring extremely strict regulation
- Strong demand of mobility together with advances in mobile device technologies maintain demand for new spectrum
- When and how will the gap between demand and supply of spectrum be filled?
- The answer consists of new technologies, new regulation, and new business models

Spectrum Allocation

New Technologies

- Spectrum is not a concrete nor finite resource to be licenced. Instead, a licence simply allows deployment of particular transceivers/receivers
- Interference is not an inherent property of spectrum. Instead, it is a property of devices evolving rapidly
- *Digitalization* saves spectrum (e.g. 5:1 compression ratio in TV signals)
- Spectrum can be shared more efficiently through *spread spectrum* technologies (e.g. WCDMA)
- The low power levels of *ultrawideband* enable the local use of spread spectrum as an underlay for the pre-existing spectrum licences
- *Smart directional antennas* reduce interference between devices
- Cooperative *mesh networks* promise to reduce power levels further
- Better compression through optimal coding algorithms (e.g. turbo codes)
- Software radio and network intelligence enable exploitation of the above mentioned new technologies (when?)

Source: G.Staple, K.Werbach, 2004

Spectrum Allocation

Sources of New Spectrum (in the U.S.)

Assigned service	**Frequency band**	**Usable MHz**
Terrestrial (3G)	1.7-2.1 GHz, 0.7-0.8GHz	120, 84
MVDDS/ITFS (flexible use)	2.5-2.7 GHz	132
Satellite (MSS)	1.6-2.0 GHz	98
Terrestrial MVDDS	12.2-12.7 GHz	500
Broadcast digital TV (DTV)	54…698 MHz	294
Satellite (fixed service)	17.2-20.2 GHz, 27.5-30GHz	5500
Direct broadcast sat. (DBS)	12.2-12.7 GHz	240
Unlicensed (NII)	5.5-5.7 GHz	255
Broadband wireless, sat/terr	38.6-40GHz, 47.2-48.2 GHz	5600
Broadband video/data	71-76, 81-86, 92-95 GHz	13300

- New spectrum: 300MHz for mobile and 1500MHz for broadcast
- The GSM and WLAN success required less than 100 MHz, each

Source: G.Staple, K.Werbach, 2004

Spectrum Allocation

Optimizing the Rules (the U.S. View)

- Spectrum reallocation
  - scanning the licenced radio spectrum in urban areas shows that significant portions of spectrum are unused at any given point of time
  - more efficient reallocation can unleash spectrum for new services (e.g. MVDDS: terrestrial reuse of satellite spectrum)
- Spectrum leases
  - allowing the flexible use (e.g. hybrid use) of licences to speed up deployment of new technology
  - allowing the resell of licences to speed up the search for best exploitation of spectrum
- Spectrum sharing
  - the success of WLAN on unlicenced band has created a new paradigm
  - new spectrum at 5GHz has been reserved for unlicenced use
  - unlicenced use of underlays may be possible on licenced bands

Source: G.Staple, K.Werbach, 2004

Spectrum Allocation

New Business Models

- Future mobile handsets with multiple radio interfaces (e.g. WCDMA, WLAN, and DVB-T) will necessarily connect to multiple traditionally separate radio-specific value chains
- Each existing value chain has its own merits and is likely to extend its life-cycle through the new multi-radio handsets
- New value chains/nets are likely to emerge based on new and multiple radio interfaces
  - digital TV (DVB-T) with return channel (WCDMA)
  - broadcast services over WLAN or WCDMA
  - seamless roaming (e.g. WLAN access when visiting a neighbor)
- An economically efficient market favors business models that attract traffic from bottleneck radios (e.g. WCDMA) to abundant radios (e.g. WLAN and DVB-T) when possible

Source: G.Staple, K.Werbach, 2004