Wireless 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 theory

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
Auction theory
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)
Auction theory

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
Auction theory
Simultaneous ascending auction: basics

- 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).
Auction theory
Simultaneous ascending auction: inefficient allocation

<table>
<thead>
<tr>
<th>Bidder</th>
<th>$v_A$</th>
<th>$v_B$</th>
<th>$v_{AB}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

- 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
Auction theory
Simultaneous ascending auction: incentive to delay bidding

<table>
<thead>
<tr>
<th>Bidder</th>
<th>$v_A$</th>
<th>$v_B$</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
<td>30</td>
<td>20</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>0</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>5 w.p. 0.9</td>
<td>20</td>
</tr>
</tbody>
</table>

- Consider an auction where bidder 3 values B at 5 or 15, with probabilities 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.
Auction theory
Simultaneous ascending auction: free rider problem

<table>
<thead>
<tr>
<th>Bidder</th>
<th>$v_A$</th>
<th>$v_B$</th>
<th>$v_{AB}$</th>
<th>Budget</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>4</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>$1+\varepsilon$</td>
<td>$1+\varepsilon$</td>
<td>$2+\varepsilon$</td>
<td>2</td>
</tr>
</tbody>
</table>

- Consider that combinatorial bidding is allowed: bidder 1 bids 1 on $v_A$, 2 bids 1 on $v_B$, and 3 bids 2 on $v_{AB} \Rightarrow$ 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 $\Rightarrow$ 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 successful 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
  – anonymity 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.)

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

- 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