Wireless Spectrum Economics

(Courcoubetis&Weber: Chapter 14)

Lecture outline

- Introduction
- Spectrum management approaches
  - Command-and-control approach
  - Market-based approach
  - Commons approach
- Spectrum allocation
- Spectrum assignment
  - Auctions

Radio spectrum is

- A valuable resource
  - pre-requisite for all wireless communications systems: e.g. television, mobile networks, satellite and radar systems, fixed radio links
  - The economic value derived from radio spectrum is around 2% - 2.5% of EU's GDP (Analysys 2004)
- Regulated
  - to ensure that there is no interference between different systems and users
- Increasing in demand
  - Demand for mobility
  - Rapid development of new technologies

Spectrum management

Three issues to be solved

- Spectrum allocation
  - What types of uses should be allowed?
- Spectrum assignment
  - Who should be allowed to operate the frequencies?
- Centralized vs. decentralized decision-making
  - Allocation & assignment decided by state or by users?

Command-and-control approach

- Traditional way, government decides on both allocation and assignment
- Secondary spectrum trading not allowed
- Primary assignment methods:
  - First-come-first-served
    - Fixed WiMAX frequencies in Finland
  - Beauty contests
    - TV, Radio, 3G in Finland and Sweden
  - Auctions
    - 3G in Britain, Germany

Market-based approach

- Primary assignment by government by e.g. auctions
- Secondary trading allows rights to be sold
- Owner may decide how to use spectrum
  - Technology neutrality: Government decides the service, spectrum owner can choose the technology
  - Service neutrality: Spectrum owner can decide also the service
  - Limitations to avoid interference still required
- European Commission plans to introduce spectrum markets in the EU by 2010

Commons approach

- Government allocates license-exempt spectrum
  - Anyone can utilize the spectrum
- Limitations
  - Transmission power levels to avoid interference
  - Parts of spectrum for specific technologies
- Fertile ground for innovations
  - WLAN, Bluetooth
- Further harmonisation on EU-level considered

Spectrum management summary

Approach	Spectrum allocation	Spectrum assignment
Command-and-control approach	Centralized, use of spectrum pre-defined	Centralized, trading not allowed
Market-based approach	Liberalized, license holders may choose how to utilize the spectrum	Primary assignment centralized, secondary trading allowed
Commons approach	Centralized, restrictions on technology and Tx power levels	Unlicensed spectrum, no assignments

Spectrum Allocation

Demand vs. Supply

- International bodies (ITU-R) create global recommendations on spectrum allocations, but governments make decisions
- Governments have traditionally considered 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 better exploitation of the above mentioned new technologies (when?)

Source: G.Staple, K.Werbach, 2004

Spectrum Allocation

New regulations

- 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. terrestrial reuse of satellite spectrum)
- Technology/service neutrality
  - allowing the flexible use (e.g. hybrid use) of licences to speed up deployment of new technology
- Spectrum trading and leasing
  - allowing the resell of licences to speed up the search for best exploitation of spectrum
- Unlicensed spectrum
  - the success of WLAN on unlicenced bands has created a new paradigm
  - new spectrum at 5GHz has been reserved for unlicenced use
  - unlicenced use of ”underlay spectrum” may be possible on licenced bands

Source: G.Staple, K.Werbach, 2004

Spectrum Allocation

New Converged 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 radio-specific value chain has its own merits and is likely to extend its life-cycle through the new multi-radio handsets
- New converged 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

Spectrum Assignment

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 government 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 licenses is high (e.g. the US)

Auction Basics

- An auction is a sale in which the price of an item is determined by bidding
- 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

Types of Auction

- *Open* (oral) auctions often have several rounds while *sealed-bid* (written) auctions may only take a single round
- Descending price (*Dutch*) auction is typically faster than ascending price (*English*) auction, 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 $\Rightarrow$ no information is revealed $\Rightarrow$ 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 $\Rightarrow$ result equals to English auction (winner pays the second highest bid)

Multi-object auctions

- In a homogeneous multi-object (i.e. *multi-unit)* auction a number of identical units of a good are auctioned, whereas in *heterogeneous* auction, the objects are not identical
- Multi-object auctions can be either *simultaneous* or *sequential*; in secuential auctions prices tend to decline in the later auctions due to fewer or poorer bidders
- In *double* auctions multiple bidders and sellers 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

- 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
- 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)
- *Minimum bid increments* are enforced to secure fast finish
- Can be modified to allow *combinatorial bidding*, i.e. bundling of objects, although in the basic form this is not allowed

Simultaneous Ascending Auction

Inefficient allocation, due to complementarity

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+ε	1+ε	2+ε	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}
  $\Rightarrow$ seller announces that 3 wins if no further bids are made
- To save money, bidder 1 may wait for 2 to raise its bid, and vice versa
- If both 1 and 2 decide to wait, the combined bid of 3 wins with a socially suboptimal value $\Rightarrow$ 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 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 Auctions

- 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 the Netherlands, 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

Revenues from European 3G Mobile Spectrum Auctions, euros per capita:

Year 2000		**Year 2001**	
Austria	100	Belgium	45
Germany	615	Denmark	95
Italy	240	Greece	45
Netherlands	170		
Switzerland	20		
United Kingdom	650		

- Auction revenue varies significantly due to context sensitivity of auction design
- UMTS auction revenues decreasing over time
  - international operators running out of money
  - change in the perceived value of licences

References

- Courcoubetis, C. & Weber, R., 2003. Pricing Communication Networks. West Sussex: Wiley.
- ITU, 2007. ICT Regulation Toolkit. Available at: http://www.ictregulationtoolkit.org
- The World Bank, 2000. Telecommunications Regulation Handbook. Available at: http://rru.worldbank.org/Toolkits/TelecomsRegulation/
- Staple, G., Werbach, K., 2004. The end of spectrum scarcity. IEEE Spectrum 2004. Vol 41, No. 3, March 2004.
- EU radio spectrum policy web site: Available at: http://ec.europa.eu/information_society/policy/radio_spectrum/index_en.htm

Exam

- The first exam will be held on Wednesday May 7 at 9:00-12:00 in hall S4.
- List of possible questions available at the course web pages
- Core readings:
  - Lecture slides
  - Book ”Pricing communications networks”

(Example exam)