Spectrum Policy Lecture #1:

Spectrum Management Reform

William Lehr

Massachusetts Institute of Technology

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Outline

- Why regulate spectrum?
  - What wireless used for?
  - History of wireless technology
  - Broadcasting regulation
- Wireless industry trends and pressure for policy reform
  - Changing technology, industry and regulatory context
  - Spectrum management models
  - History of spectrum reform in US
- Stakeholders and Issues
  - Who are the stakeholders?
  - What are some of the issues?

What wireless used for?

- Broadcast TV & radio (AM, FM, DBS, PAL; terrestrial & satellite)
- Sensing, Imaging, Location (GPS, satellite photo, radar, x-ray)
- Communications (distance/area coverage)
  - WAN: cellular telephony (AMPS, GSM, CDMA, Satellite)
  - MAN: fixed wireless data (Microwave, LMDS, 802.16 WiMAX)
  - LAN: local area data nets (802.11x WiFI)
  - PAN: cable substitutes (Bluetooth, IRDA, Zigbee)
- All use RF Spectrum:
  - Who gets to use it, for what services, when?
  - Managing interference
    - Intentional v. Unintentional Radiators (microwave, computer CPUs, etc.)

RF Spectrum

- Radio spectrum (3Khz-300GHz): when Frequency ⇑, then
  - .. bandwidth ⇑ (info carrying capacity)
  - .. wavelength ⇓ (antenna ⇓)
  - .. propagation ⇓ (rain fade ⇑, Power Law)
- Line of sight?
  - Below 3GHz: not needed
    - Communication services (cellular, pagers)
    - Broadcast services (radio, TV)
  - Above 3 GHZ: needed
    - Point-to-point (e.g., wireless fiber @ 70GHz)
- Spectrum at different RF imperfect substitutes
  - But, usable spectrum expanded over time
  - Technology increases substitutability & opportunity cost

Need Multiple Wireless Networks

- Bandwidth
  - Control: <10Kbps (monitoring, signaling)
  - Real-time communications: < 100Kbps (telephone)
  - Broadband: 10-100s Mbps (streaming video)
- Coverage (power)
  - PAN (few feet), LAN (on campus, in home), MAN (metro), WAN (satellite)
- Architecture
  - Broadcast: one transmitter to many receivers
  - 2-way: point-to-point (fixed or mobile?)
  - Multipoint-to-multipoint (grid)
- How integrated are different networks?
  - Lots of technology: incompatible standards, uses, etc.

History of Wireless Technology

Early technology

- 1887: Hertz sends/receives radio waves
- 1895: Marconi invents spark transmitter
- 1912: Titanic and Ship radio
- 1918: Armstrong invents superheterodyne receiver

Broadcasting Age: AM radio → VHF TV → FM radio →UHF TV

- 1920: 100-watt KDKA starts broadcasting Pittsburgh
- 1922: BBC formed. (1926/27 NBC and CBS formed)
- 1928: Federal Radio Commission established
- 1948: CATV for rural
- 1951: CBS broadcasts in color

Wireless Communications: "Push-to-talk"→ AMPS → PCS → 3G → WiFi

- 1927: Wireless radiotelephone between Britain and US
- 1946: "Push-to-talk" radio communications
- 1983: Commercial AMPS (1G "analog") in Illinois
- 1990/1: TDMA digital (2G "digital") overbuilds to AMPs. GSM in Europe.
- 1994/5: PCS auctions in US
- 1997: UMTS-Forum (3G "wireless broadband")
- 1999: IEEE approves 802.11b ("WiFi")
- 2000: WRC2000: UMTS/W-CDMA

Why regulate spectrum?

- Government stewardship of public asset (airwaves)
- Scarce resource => how to allocate when congested
  - Interference regulation
  - Regulation or markets (Ronald Coase)?
    - Market failure? e.g., International spectrum harmonization
- Service/Industry structure regulation
  - Broadcast/Media Regulation (content/editorial)
  - Communications Regulation (common carrier)
- Other
  - Safety (harmful RF emissions)
  - Emergency services (policy access) & defense
  - Equipment licensing/certification (Trade policy)
  - Privacy, eCommerce, government revenues, etc.

How spectrum regulated?

- Government owns spectrum --- “national asset”
  - Defense/government uses – major user
  - Licensed commercial applications – second (in US, about 6% spectrum below 3GHz)
  - Unlicensed – 2% of spectrum in use (amateur radio, science, WLANs)
  - Unregulated
    - “What not forbidden is permitted” or “what not permitted is forbidden”
    - e.g., Above 50GHz
- Expert federal agency: allocates and assigns spectrum, regulates services, general competition law
  - in US: NTIA (Government) & FCC (Commercial/Private); in UK: Ofcom
  - internationally, ITU-T
  - requires sophisticated engineering and technical oversight
- Command & control (tight admin of freq bands) => flexibility
  - Licenses specify (1) service (content?); (2) technology; (3) Ownership (foreign, transferability)
  - Renewal: Pro-forma or real review?
  - Allocation: assignment, fee, or auctions?

Broadcast/Media

- Radio & TV
  - Broadcast architecture: one-to-many
  - Free (advertiser supported) vs. Subscription (Pay-TV)
- Access to media channels (scarcity)
  - Public broadcasting
  - In US: “Free speech” 1st Amendment
- Content diversity
  - Industry structure? (Media cross-ownership rules, foreign ownership)
  - Local content requirements
  - Censorship (filtering)
- Current Issues: Transition from analog PAL/NTSC => digital
  - HDTV?
  - Over-the-air vs. cable/satellite?
- Content (Media)/Conduit (Telecom) convergence
  - Does Broadcast law apply to Telecoms or visa versa?

Legacy of Wireless Technology

- Transmitter & Dumb Receivers: frequency allocation
  - Armstrong: Superhet transceiver (1918).
    - Information modulated on carrier frequency.
    - Radio receiver demodulates signal and extracts information.
  - Multiple signals arriving at receiver, receiver cannot extract useful information (other signals are regarded as noise)
  - Assign a frequency band (channel) to specific use in each area
  - Range: S/N above floor at farthest receiver. Non-uniform signal density
- Spectrum coordination/management needed to limit destructive interference
  - Exclusive frequency allocation/assignment in geographic areas

Lots of Wireless Technology

- All along the RF spectrum (different RF not perfect substitutes)
  - Microwave
  - Satellite (geosync, LEO)
  - Mobile 2G => 3G (4G?)
  - WLANs (*e.g.*, WiFi) => WISPs and MESH (Tropos)
  - BWFA: MMDS => Alvarion => WiMax (802.16)
  - Free Space Optics, UWB, etc.
- Lots of complementary technology
  - Smart antennas, software radio, MUD, ad hoc routing, mesh networking, OFDM, etc.

Technology => Spectrum Efficiency

- Digital signal processing: From analog to digital “0s & 1s”
  - Regenerate, not amplify
  - Moore’s Law
  - Computation instead of digitization (spread spectrum)
  - Multimedia
- Networking and Communications Theory
  - Mobile routing. Smaller cell sizes
  - Modulation and signal processing
- Information Theory:
  - Capacity channel proportional to bandwidth (Shannon)
  - Multiuser theory => cooperation gain. Wireless grids.
- Smart antennas (spatial diversity, multipath can help)
- Software radios (cognitive radios: smart edge devices)

Changing industry/regulatory context

- Merging of computing & communications
  - WWII-1960s: Mainframes & dumb terminals
  - 1970s: Minicomputers & distributed processing
  - 1980s: PCs and LANs (edge-based computing)
  - 1990s: Internet (data services for masses) and Mobile Cellular (wireless services for the masses)
  - 2000s: Wireless broadband (3G, WiFi, Satellite, etc.)
- Merging of wireless & wireline
  - Pervasive computing: always on, connected
  - Mobility: ubiquity, flexibility, portability (nomadicity)

Changing industry/regulatory context

- From regulation to markets
  - Global trend towards privatization, liberalization
  - Transport (airlines, RR), Gas/electric power, banking, and telecoms
  - Inefficiency of government:
    - Soviet-style central planning vs. Western Capitalism
    - Slow: non-responsive to innovation
    - Vulnerable to capture/rent-seeking
    - Coase & Chicago School: Property rights & markets
- Telecom Crash of 2000
  - dot-com bomb: collapse in demand
  - Spectrum auctions (3G)
  - Worldwide recession (telecom/IT capital intensive)

Implications of Wireless Technology

- Increased performance
  - Spectral efficiency, NLOS, Improved reliability/security/QoS
- Lower costs
  - Moore's Law, Scale/scope economies, Standardization.
  - New architectures.
- Distributed control
  - MESH networks, edge-based networking => toward cognitive radio
  - Towards smart radio systems (antennas, receivers)
- Wireless everywhere..
  - WPANs, WLANs, MANs
  - Fixed & Mobile

Wireless Industry Trends

- Standardization:
  - Proprietary physical layers giving way to few industry standards (3G, 802.11, 802.16). Driven by chip economics.
- Trade-off between bit rate and reach & cost deploy
  - Rooftop antennas => high speed, long-reach
  - Desktop antennas => inexpensive deployment (and need to address mobility => PC cards, PDAs, etc.)
- Competing architectures: Large cell v. Small cell
  - Large => long reach => few cells => wired backhaul (Alvarion)
  - Small => short reach => lots of cells => wireless backhaul or mesh (Tropos)
  - New designs include QoS capability (VoIP)
- Merging of wireless & wireline
  - Pervasive computing: always on, connected
  - Mobility: ubiquity, flexibility, portability (nomadicity)
- Multiple models for spectrum mgmt: Unlicensed v. Licensed
  - Unlicensed => rapid, low-cost entry for WISPs
  - Licensed => better protection against congestion (QoS)

Why spectrum reform now?

- Lots of new technology and services that are being held back by legacy regulations…
  - Insufficient spectrum for commercial use
  - What is available, is not used efficiently
  - License rules limit market flexibility
- Problem: Artificial spectrum scarcity!
  - Sharing opportunities missed
  - Innovation blockaded: services, devices, and business models
  - High marginal cost for spectrum (auctions bankrupt providers)
- Solution: Spectrum Reform…

Goals for Spectrum Policy Reform

- Eliminate artificial scarcity: introduce market forces
  - Flexible use, secondary market trading
- Accelerate wireless broadband revolution
  - Convergence of Internet & wireless
  - Promote evolution from 2G to 3G
- Promote adoption of advanced technology
  - Refarm underused spectrum to high value uses
  - Enable new capabilities, promote investment (smart receivers)
- Last mile bottleneck: unleash 3rd mile competition
  - New, low cost infrastructure in developing world
- Enable new business models:
  - MVNOs and value-added service providers
  - Wireless grids and edge-based networks

Spectrum Management Models

- Three basic models:
  - Command & Control: (legacy model under attack)
    - Technology, provider, services specified by regulator
  - Exclusive license: “Property rights”
    - Flexible, transferable licenses to operate in area/band.
    - Licensee chooses technology, services
    - Secondary markets: licensee can trade rights to third parties
  - Unlicensed: “Commons”
    - Underlay: UWB, Part 15 devices (secondary use)
    - Opportunistic: interleaving, use white space (secondary use)
    - Dedicated: ISM 2.4 and 5 GHz bands used by WiFi
- Policy recommendation: increased reliance on exclusive licensed for scarce spectrum or commons otherwise
  - Especially for spectrum below 3GHz

Spectrum Mgmt in U.S.: a brief history

- pre-1927: Priority in use, Commons model
  - (Radio Act 1912: spectrum use requires Federal license)
- Radio Act 1927, then Communications Act 1934: Exclusive use
  - Federal agency (FCC) manages commercial spectrum, NTIA manages government.
  - (1) Block Allocation; then, (2) Assignment
    - Exclusive use, restrictive licenses: Technology/Service/Build-out/Transferability all limited by FCC
    - Minimum frequency allocation per license to deliver service.
    - Interference model based on capabilities of dumb receivers
  - Unlicensed for low power, not valuable spectrum
- Slow trend towards liberalization
  - Waivers, Private management interference, sharing, overlays
- Auctions authorized in 1993 for license assignment.
  - Beauty Pageant (1927-1981), then lotteries (1981-1993)
- Telecom Act 1996
  - Eliminate cap for non-broadcast licenses; increased flex for broadcast spectrum use; and authorized spectrum fees

A history of "regulatory capture" by broadcast industry (Hazlett, 2001)

e.g., AM blocks FM (1930s), Du Mont fails (1950s), VHF blocks CATV (1960s), etc.

Spectrum Management and Wireless Markets

- Broadcasting Spectrum (exclusive, inflexible licenses) – example of problem
  - Architecture for high power transmission for over-the-air broadcasters uses (low power) spectrum inefficiently
  - Move terrestrial TV to satellites or wires (cable)
  - Encourage development of smart receivers
  - Legacy of using "interference" threat to oppose competition (FM radio, UHF broadcasting) and slow to deploy new technology (digital TV conversion)
  - What about over-the-air digital TV?
- Mobile Telephone Services (exclusive, (semi)-flexible licenses) – success!
  - Poster child for competition success: consumer choice, declining prices, service innovation.
  - Use spectrum very efficiently. Lots of sharing.
  - Allocated via auctions (but what about 3G auctions and telecom meltdown in 2000?)
  - Benefits of mandating a single standard? 2G in Europe v. US
  - Further growth constrained by lack of access to available spectrum
- WiFi success (open access, unlicensed) – success!
  - Power limits on equipment. No exclusive right to interference protection.
  - Congestion emerging as problem.
  - Is this model generalizable?

Stakeholders in Spectrum Debates: perspective?

- Users: Commercial: consumers & businesses (small/large) v. Govt.
- Providers – Value chain…
  - Equipment: chips, software, edge and network hardware and software
  - Network service providers: mobile, BWFA, DBS
  - Content/Application providers: Hollywood, music, games
- Regulators/governments
- Industries: Broadcast v. Telecom (Internet) v. Users
- Entrants v. Incumbents
- Nations (and w/in nations, cities v. states v. feds; member states v. EC)

e.g., Why is govt spectrum different from commercial?

- In US and abroad: largest share of spectrum is government
- Government spectrum:
  - US: NTIA → government spectrum; FCC→ commercial
  - Government: Defense, Public safety, Aviation, NASA, Agriculture, etc.
- Commercial v. Government
  - Profit/Competition v. Mission/Bureaucracy
  - Trade and business law v. Constitution/treaties
- *But if spectrum is scarce, shouldn't all users bear opportunity cost?*
  - Resources that have alternative uses have value.
  - Opportunity Cost = Value in next best use
  - WHAT IS VALUE? HOW TO ESTIMATE?

Summing Up

- Wireless industry and technology: rapid growth and seismic changes
  - From analog → digital
  - From broadcast → communications → multimedia
  - From dedicated to shared use
- From regulation to markets: deregulation
  - Promote innovation, investment, and competition
  - Key issues:
    - (1) Markets v. Regulation
    - (2) Auctions v. Free Use
    - (3) Spectrum scarcity & transaction costs
    - (4) Defining interference
    - (5) Industry structure and models for management
      - Transition politics, Windfall Gains
    - (6) International Coordination
    - (7) Commercial v. government spectrum use
- Balancing stakeholder interests
    - Incumbents v. Entrants
    - Service providers v. equipment makers
    - Suppliers v. end-users (existing or new apps?)

How best to introduce market forces:
** Managing the transition?*
** Licensed v. Unlicensed models?*