



ISART Seminar

Modern Spectrum Management Alternatives

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Spectrum Management

- Spectrum management is the process of arranging the use of the spectrum for communications and sensing.

Who gets to use spectrum?

For what functions?

Under what restrictions?

What are the processes to decide?



Outline

- Electrospace (spectrum)
- Receivers
- Interference
- Regulatory concepts
 - Command and Control
 - Property Rights
 - Underlays
 - Overlays
 - Commons
- New possibilities



Radio System Basics

Electrospac

Receivers



Radio System Basics - 1

Radio systems have:

- Transmitter (including transmitting ant)
- Propagation path
- Receiver (including receiving antenna)

Communications –

move data from transmitter to receiver.

Sensing –

Compare received signal with transmitted signal to study path (radars, sensors, etc.)



Radio System Basics - 2

The Electrospace describes radio signals: The Realm of transmitters & propagation.

A receiver processes the electrospace to receive communications.

A major goal of frequency management is to arrange the signals in the electrospace so that they can be separated by a simple and inexpensive receiver.



The Electrospace

Electrospace (described by Hinchman in 1969) is a 7-variable description of EM field strength (hyperspace).

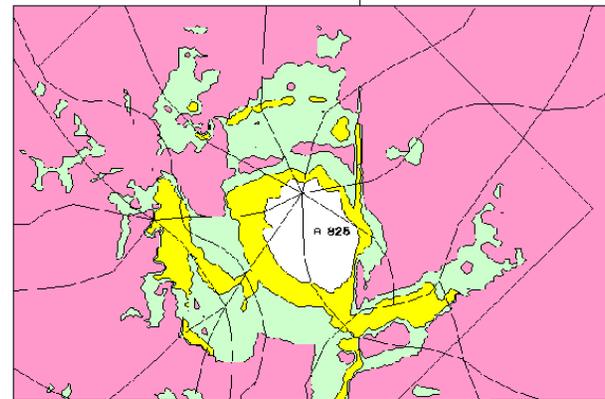
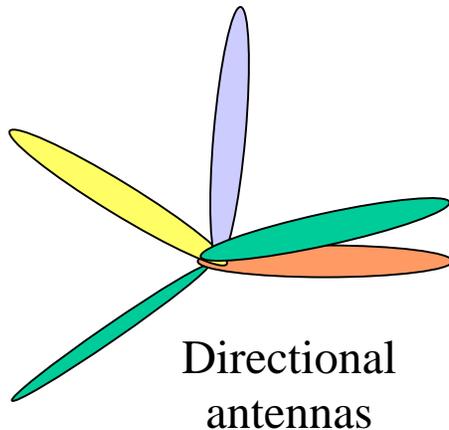
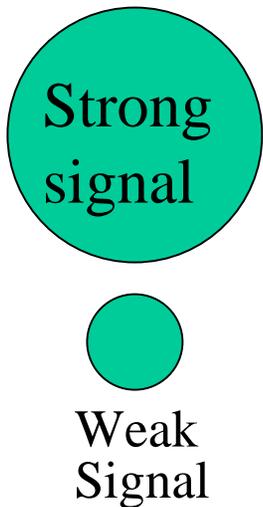
- Physical location – lat., long., altitude 3-dim
- Frequency – MHz 1-dim
- Time - μ S, hours, or years 1-dim
- Direction-of-arrival – azimuth, elevation 2-dim

A good-enough receiver can separate signals having non-identical electrospace descriptions.



Spatial Dimensions

Any spatial region: microcell to BTA, modify with directional antennas. Caution: some areas cannot be used well; coverage affected by terrain and buildings, height above ground. Match spatial to coverage.



825 MHz coverage

Base Transceiver (cell)

Less than 110,000
Area: 10.89 km
Population: 14,000
Households: 8000
110,000 to 111,000
Area: 20.90 km
Population: 80,000
Households: 21,000
122,000 to 110,000
Area: 40.90 km
Population: 180,000
Households: 71,000
Greater than 122,000
Area: 114.89 km
Population: 877,000
Households: 237,000



Frequency Dimension

- The frequency dimension is well behaved and intuitive, with a frequency band divided up into many non-overlapping channels.

▪



Time Dimension

FCC recently mentioned “time” as one additional dimension that they would allow users to divide.

Months – seasonal uses

Hours – to broadcast special football

Hours – midnight-to-5am daily to send low cost computer updates.

10 ms TDMA timeslots every 50 ms.

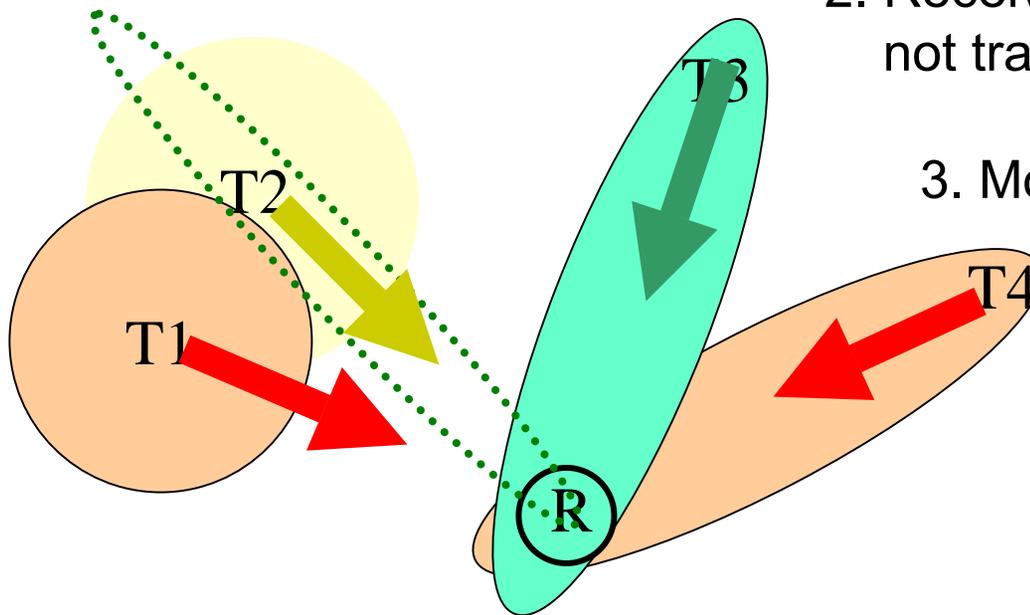
Useful for serving many intermittent activities.

Angle-of-Arrival - 1

1. Angle-of-arrival is different from coverage area.

2. Receiver beamwidth counts, not transmitter beamwidth.

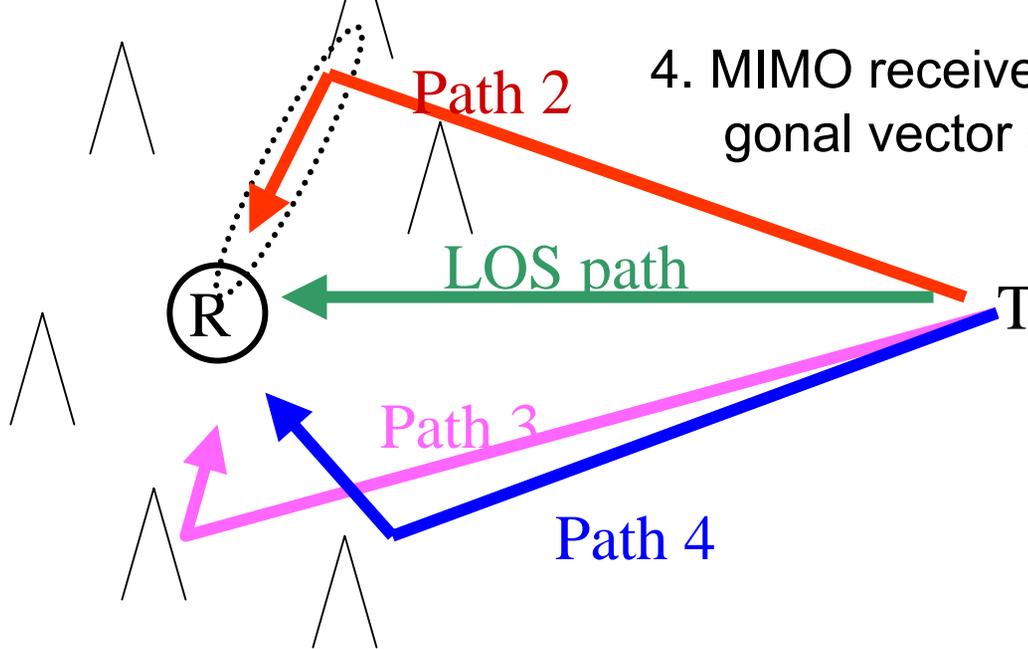
3. More transmitters, narrower receiver beamwidth.





Angle-of-Arrival - 2

1. Narrowbeam line-of-sight path (pt-pt microwave).
2. Multiple narrowbeam (NB) paths scattered from landscape.
3. NB receiver antenna isolates each path (difficult).



4. MIMO receiver forms multiple orthogonal vector sums to mathematically generate paths (easier).

5. Future application of generalized angle-of-arrival, using less-expensive techniques



The Electrospace

Electrospace is a 7-variable description of EM field strength (hyperspace).

- Physical location – lat., long., altitude 3-dim
- Frequency – MHz 1-dim
- Time - μ S, hours, or years 1-dim
- Direction-of-arrival – azimuth, elevation 2-dim

▪



Same spectrum, more users

- The electrospace formalizes additional ways to divide up spectrum among more users.
- Point-to-point microwave divides up angle-of-arrival and uses shaped pencil beam coverage areas.
- Trunked radio systems adaptively divide time.
- MIMO mathematically finds multiple paths by processing angle-of-arrival part of electrospace.
- Advanced cognitive radios will be even better at dividing up the electrospace.



Receivers

- Receivers and the electrospace create a radio system.
- **Receivers** process the electrospace to give service (if successful) or interference (if not successful).
- A **sufficiently good** receiver can separate any signals having different electrospace descriptions. Interference is caused only when a receiver is not “good-enough”. Might require adaptive antennas to null interference.
- “Interference protection” means “able to use a cheaper receiver.”



Interference - 1

Interference – any distortion of the processed desired signal caused by unwanted extraneous radio signals (excludes multipath, internal noise).

Interference can be caused by co-channel operation, excessive sidebands, intermodulation in receiver, receiver overload, etc.

No sharp line between acceptable and unacceptable interference. All interference is unwanted. Even the possibility of interference is unwanted, since it requires more robust system design.



Interference - 2

- A faulty transmitter causes interference to other users – an “externalized cost” that transmitter owner has no motivation to control. Therefore, regulations must control transmitters.
- Externalized cost is either cost of interference, or cost of better receivers to prevent interference. Interference rules establish expected receiver capabilities.
- A faulty receiver causes interference only to receiver user, who is well-motivated to fix receiver. No external controls are needed.



Interference – 3

Interference is **always** caused by an inadequate receiver and could be fixed by a “good-enough” receiver (though “good-enough” for some situations might require adaptive antennas to null out interference, or other complex/expensive tools).

Therefore, using better receivers would decrease interference, and/or allow more signals to be transmitted before interference occurred.

Therefore, using better receivers would be expected to improve spectrum efficiency.



Better Receivers

“Better” receivers mean anything that helps a receiver to reject unwanted signals.

- Better IF filters to remove signals on adjacent channels
- Better dynamic range to reduce IM and overload from strong signals
- Better directional antennas to isolate desired signal from others
- Better intelligence to re-tune to less crowded frequency
- Better intelligence to change modulation and power
- Etc. e.g., cognitive radios



Receiver standards?

Using better receivers could improve spectrum efficiency.
Therefore: **Require minimum receiver performance standards.**

Yes, but ...

1. A major objective of good spectrum management is to design rules that allow the use of cheap equipment (receivers):

Keep low power and high power bands separated,

Use large duplex band structures,

Limit max transmitter power, etc.

Such features are intended to allow the use of cheaper receivers.

“The goal of spectrum design is to make the world safe for cheaper receivers.”



Receiver standards?

2. A receiver that is not “good-enough” causes interference only to receiver user. No need for standards to protect other users. (Note: “Good enough” is a very ambiguous term.)

Receiver user is already properly motivated to select a “good-enough” receiver. No need for a standard to motivate receiver user.

3. From (2), receivers must adapt to the electrospace. i.e., if you decrease frequency separation between transmitters, receivers will follow (whether or not you pass a rule for narrowband receivers).



Receiver standards?

4. Receiver standards tend to regulate brute-force receiver performance, whereas most modern radio systems improve spectrum efficiency through higher receiver intelligence.

Example: High rejection of adjacent-channel signal, or move to another channel?

5. Required receiver performance is highly dependent on local situation. User has better knowledge than central manager.



Receiver standards - yes

User groups who mutually depend on the performance of member's radio have good reasons to regulate member's minimum receiver performance.

Procurement of equipment simplified by referring to receiver procurement standards.

Receiver standards valuable to **educate user** about typical receiver performance requirements.

None of above primarily concern spectrum management.



Receiver Summary

- Receivers are a vital component of any radio system, greatly affecting performance of system. Receiver performance is an important part of system design.
- All interference is caused when receiver performance is not sufficient for the given electrospace environment. Better receivers can improve spectrum efficiency. Poor spectrum rules may make better receivers necessary.
- The receiver user is usually well-motivated to get a “good-enough” receiver.



- - - 5-minute break - - -

5-minute break



Regulatory Concepts

Primary regulatory concepts

- Command and Control
- Property rights
- Commons

Secondary regulatory concepts

- Underlays
- Overlays
- Geographic (?)



Complementary Concepts

- Multiple frequency management concepts are complementary, not antagonistic.
- Will always be a requirement for multiple spectrum regulatory environments, because different system technical and business requirements.
- Real estate analogy - different kinds of property with different rules. Public spaces (parks, highways, class rooms), private spaces (stores, bedrooms).

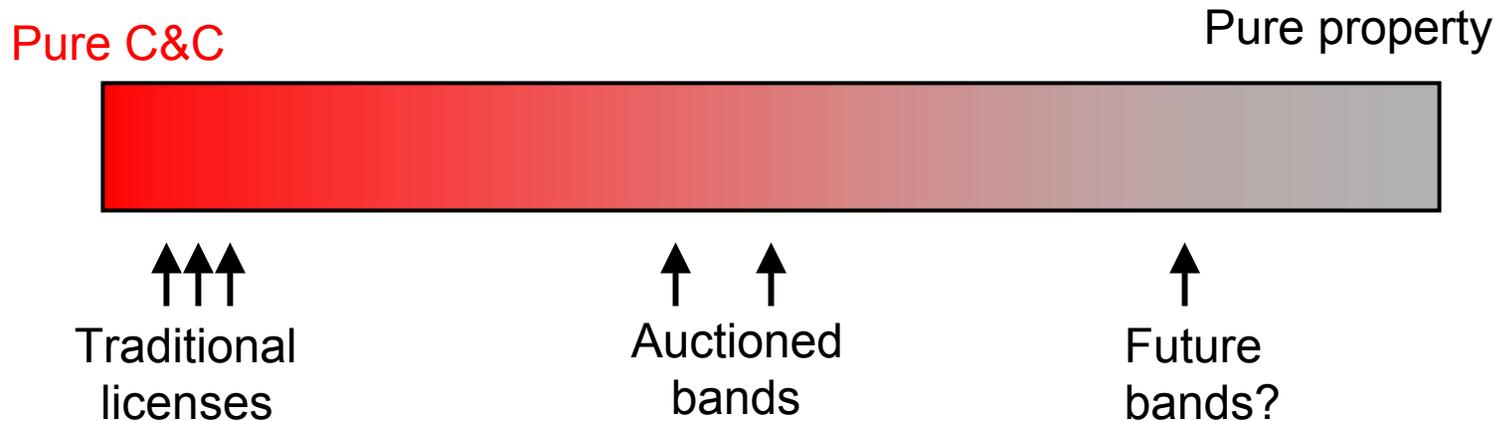


Choose the best fit

- Specific services, technologies, and frequencies will often fit much better under one concept than another.
- Actual band rules often mix rules from multiple concepts. Few pure concept bands. Figure out which mix of rules is best for each intended service and technology.
- Easy to apply different rules to different bands. No special advantages for having same rules for all bands, but many disadvantages.



C&C versus Property



The C&C and property rights represent extremes on a continuum representing the distribution of decision-making rights, from all-Govt to all-user. Both assume that each frequency has a specific user who has certain rights to use that frequency.

FCC is currently moving towards more property rights.



Command and Control

Regulator makes all of the decisions

- Which bands are used for which services, who is eligible to use band.
- Completely blended engineering and regulation. Definitions for transmitter sidebands, receiver off-frequency rejection, etc.
- Complete band recipe: Service provided, technical parameters, base station sites, service area, frequency re-use distance, def. of harmful interference, etc.
- Guaranteed service, if you follow the recipe.



Band Allocations

- C&C allocates specific bands for specific services. Each band is designed for services, channelization, service area, frequency re-use distance, modulation, receiver specs, allowable users, transmitter power, etc.

Band allocations include: Mobile, broadcasting (AM, FM, TV), point-to-point microwave, ISM, satellite, PCS, Radar, paging, MMDS, LMDS, etc.

Each band allocation contains detailed, specialized rules for successful operations in that band.



C&C Receivers

- Each band is engineered for all aspects of operation, including the desired receiver specifications.
- If you operate a receiver meeting the allocated band receiver specifications, you should not get interference.
- If you do get interference, there must be something wrong with receiver or transmitters. Investigation, possible need for a (new) transmitter to change operations, even though transmitter meets all specs.



In favor of C&C

- Well-engineered and optimized services, given a point in time, technology, and social needs. Standardized, stable, efficient.
- Highly-differentiated services – mobile, microwave, satellite, radar, broadcasting, Part 15, PCS/cellular, etc.
- Promotion of social good, best for Federal services and military flexibility (?)



Against C&C

- Slow to evolve with changing technology and social needs. New services? Obsolete services cleared? Re-farming, analog TV.
- Difficult to adequately engineer complex systems like cellular, or mixed services, without large top-notch engineering staff.
- Consensus mode of public review slows down any detailed planning.
- Tend to conservative, worst-case, less-productive.



C & C Summary

C&C has produced numerous specialized band plans that still work quite well. However, most new-technology bands are becoming too complex to design centrally, and the detailed rules in C&C bands prevent easy evolution to newer systems.

C & C can readily create bands with different rules, including more general rules that decentralize decisions to the user (property rights)

FCC is moving strongly towards decentralized command structures, away from pure C&C.

ITU is still very strongly C&C, but ITU actually controls very little spectrum



Spectrum Property Rights

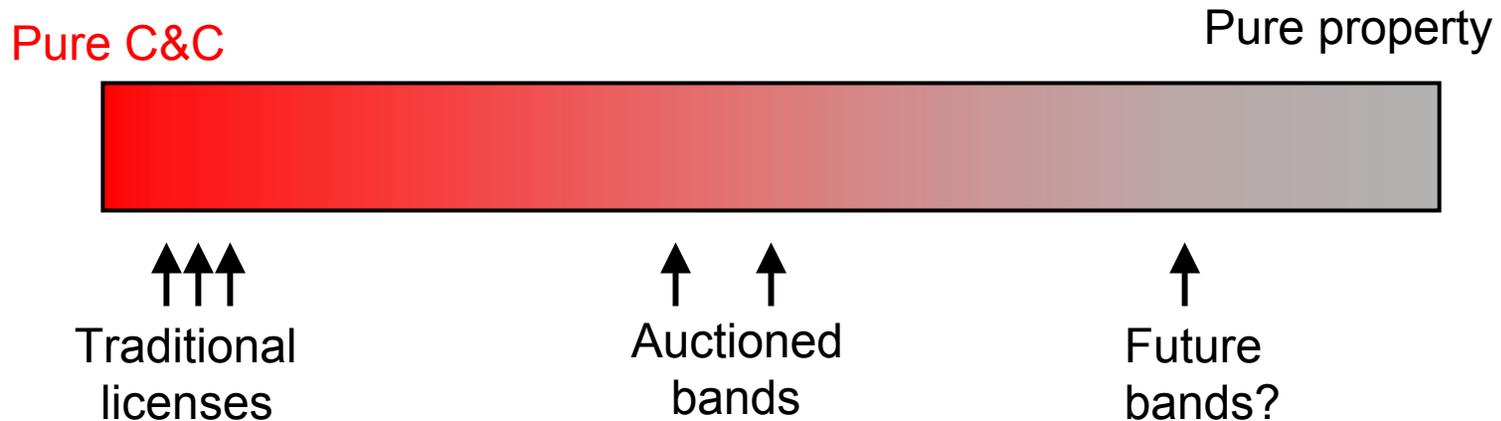
Spectrum property rights describe permissible ways to transmit radio signals, such that the user will be held harmless for those transmissions.

Ideally, such rules will permit the operation of a wide range of useful radio systems, among which the user can choose without asking the permission of regulators.

Note: Property rights (in this context) do not concern how one obtains spectrum initially, or whether possession is temporary or permanent.



C&C versus Property



The C&C and property rights represent extremes on a continuum representing the distribution of decision-making rights, from all-Govt to all-user. Both assume that each frequency has a specific user who has certain rights to use that frequency.

FCC is currently moving towards more property rights.



Spectrum Property Rights

Are there any ways to divide spectrum, such that simple rules describe a wide range of allowable uses?

What about interference to other systems?
Operating within rules must end legal liabilities.

Electrospace defines how spectrum could be unambiguously identified and used.



Pure Electrospace Rules:

Field strength above $X \mu\text{V}/\text{m}$ is a signal. All signals must be within licensed electrospace (frequency, location, time, direction-of-arrival)

No restrictions on services, architectures, power, modulation, sites, etc.

Any dimensions can be aggregated or divided, without limit; using secondary markets.

Only rule: Stay within electrospace boundaries.



Ideal Receivers?

Pure electrospace rules work only with ideal receivers that can separate signals perfectly along all electrospace dimensions.

How can electrospace rules be modified to allow practical receivers?

Consider how interference is caused in receivers and put reasonable limits on those cases. Limits could be different in various bands.



Modified Electrospace Rules

1. Unlimited power → Maximum power limit → maximum field strength limit (at ground level?).
(Note that receivers are overloaded by high field strength at receiver antenna, not merely transmitter power.)

To allow unlimited division/aggregation of bandwidth, follow principle that interference potential cannot be worse after a transaction. Therefore:

2. Maximum transmitter power (or field strength) is:
 - a. proportional to bandwidth
 - b. approximately evenly spread across bandwidth



Receivers

- A “suitable” receiver can separate any signals having different electrospacetime descriptors. However, a “suitable” receiver could be very complex and expensive.
- Modified electrospacetime rules place limits on the signals that can be encountered in the environment, no matter what services, architectures, or modulations are developed. Rules permit moderately cheap receivers.
- Receiver owner is solely responsible for choosing a “good enough” receiver.



Flexible Use

- Complete flexibility of use in band, though bands might be tailored for particular categories of use (e.g. adjust signal threshold, max power).
- Initially auctioned in larger (wholesale) standard blocks. Secondary (retail) markets to specific customers to allow directional systems, time – sharing, customize coverage areas to match terrain, reconstitute larger blocks, etc. (Note: Future SDRs are easily re-tuned, reducing “friction” in transactions).



Property Rights Trade-offs

- Electrospace block is “two-sided.” Inside, it allows freedom to use any signal, and it insists that no extraneous signal be present. Outside, it insists that your transmitted signal is absent, and it allows extraneous signals to be present.
- Given a block of electrospace, you can use it right up to the edges of every dimension, but your transmitters can’t spill over outside. Similarly, your radio receivers will need to be capable of receiving the desired signal at the edge, but rejecting extraneous signals just over the edge outside.
- User choice: Minimum separation from edges of electrospace block gives greatest efficiency, but requires best components. Where is “sweet spot” in the tradeoff?



Property Rights - For

Spectrum property rights can provide immediate procurement of spectrum for new systems without regulatory involvement. These new systems will be held harmless from interference complaints by other users.

Property rights especially benefit infrastructure-intensive applications needing protection from extraneous signals. (Commons cannot protect against extraneous signals.)

Property rights principles give certainty and flexibility needed to encourage large investment.



Property Rights - Con

- Never tried, yet. How much flexibility will actually work without too much interference?
- Will total freedom lead to fragmentation of spectrum blocks needed for economy-of-scale device production?
- Mixed C&C/PR bands could provide large duplex structures and other helpful tools.
- Will permanent ownership freeze out possibilities for future regulatory changes?



Property Rights - Summary

- Property rights can provide great flexibility and rapid response to opportunities for new services and new technologies, without excessive interference to other systems. Responsibility for interference is well-defined. Market forces provide economically efficient allocation of frequencies. However --

“ Limitations Associated with the use of Marketplace Forces in Spectrum Management” - Dale Hatfield, Wednesday, 10:15.



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5-minute break



Underlays

Underlays - A very-low-power unlicensed use, expected to cause no interference to the primary band users. Part 15 – General and UWB

Generally operates at very short range, so potential victim receivers are likely to be very close by and aware of operation.

Very low power permits user to operate blindly, assuming that no interference will occur. User held harmless if interference does occur (but must stop use).



Underlays

Primary Band use can be C&C, Property rights, or Commons. Underlays could operate at any frequency, ignoring the rules of the primary band, except Part 15 lists restricted bands where underlays are not allowed.

Part 15 – describes both underlays and commons. General very-low-power systems described in 15.201-15.209 are underlays, as are UWB systems.

Part 15 descriptions of high-power spread-spectrum systems operating in ISM bands and specific channels allocated for cordless phones are commons.



Underlays

Underlays are extremely valuable and are growing rapidly. Cheap, small, single-chip radios for short-range convenience. RFID, in-home and office wireless links, Bluetooth, proximity sensors, etc.

Underlays logically fall below the electrospatial signal amplitude threshold, therefore they don't count as a signal.

Underlays encumber so little electrospatial, that the transaction cost of managing it costs more than the electrospatial is worth.



Interference Temperature

- The max power from single underlay device is calculated to cause no interference to primary services. Will the total power from many underlay devices cause interference?
- **Interference Temperature** concept is intended to control total interference power, and to disable underlay operation if additional underlay power would increase total to exceed an allowable interference power.
- Difficult for simple underlay device to estimate total interference power at victim receiver. Network to collect necessary info? Protocol for all underlay and primary devices? Include noise and spurious emissions?



Future of Underlays

Underlay devices will continue to grow in number, variety, and value of services offered.

Though underlay devices will surely get smarter, they will continue to operate at very low power, with a presumption of non-interference to other systems.

Underlays are distinct from Commons. UWB and general Part 15 devices.



- - - Overlays - - -

Overlays assume that any unused spectrum is available for temporary opportunistic use, as long as an overlay user will not interfere with the licensed primary user.

Overlays are not legal, but someday might be made legal upon sufficient confidence of non-interference.

Note that today many frequencies have licensed primary and secondary users; secondary user must quit when primary user has interference. Secondary user has specific licensed rights, coordinated with other users.



Overlays

- Overlays are risky, and presumably carry full liability for damages of interfering with licensed user (or maybe even for criminal use of spectrum).
- It is very difficult to know surely that transmitting will not cause interference (because receivers are totally invisible and transmitters suffer from hidden nodes). How poor a receiver should be legally protected?
- Cooperative database of receivers or “beacons” might need to be compiled and continually updated.



Overlays

- Systems are continually getting smarter (e.g., cognitive radios). How smart does a system have to be, to reliably operate without causing interference to others?
- What burden will overlays place on the primary systems using the band? How good should primary receivers be, in order to be protected against overlay interference?
- How would an overlay system know that it was causing interference? How would the victim know interferer ID?



Overlays – Users Views

- Much of electrospace is not being used. If I can operate and guarantee no interference to primary users, why not?
- Overlays increase level of spectrum efficiency, since additional users operate with no additional spectrum.
- Overlay users might need to keep logs, transmit clear ID's, use other easily recognizable protocols, etc. However, requiring primary users to change operations, turns band into a type of Commons with preferred levels of users.



Overlays – Victim Views

- An unnecessary interference possibility that requires building more robustness into system.
- Very difficult to identify unknown interferer. Most overlay interferences will not be identified successfully. Interference should carry criminal penalties and severe fines.
- Why should “they” get free use of my frequencies, that I had to pay for? Possibly a rent is required?



Federal Overlays

In many Federal (especially Military) bands, a single agency controls whole band, with some permanent licenses, some less flexible radios, and many temporary tactical assignments that are quickly adjusted to match a specific mix of forces.

For these situations, the normal frequency assignment process is very similar to the “overlay” process.

The Next Generation (XG) philosophy extends these capabilities radically to allow military systems to work around existing civilian and friendly Govt systems.



Proposed Overlays

- Proposals to allow additional nonlicensed services to operate as overlays in certain existing bands.
- Currently, for example, new nonlicensed wireless LANs in parts of the 5 GHz band need to incorporate the DFS (dynamic frequency selection) protocols to prevent interference to some radars still operating in that band.
- Proposals to put broadband wireless access into unused TV channels.



Overlay Summary

- Overlays are not legal in most bands, and it is uncertain what legal liabilities they would face.
- Overlays will need to be made very reliably non-interfering, before they will be allowed to share primary bands.
- Very smart radios, possibly networks, will be needed to make Overlays generally practical.



- - - Commons - - -

Basic rule: All users have equal rights to use the spectrum.

Rules can be highly structured or not.

Cordless phones at 46/49 MHz are a highly-structured commons. FRS,

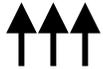
The new 5 GHz U-NII bands, “Amateur” bands, future Wireless mesh network represent different types of commons.



Commons versus Commons

Specific rules

General rules



Specific services
Cordless phone, FRS



Future wireless mesh networks?
OpenSpectrum Commons?



U-NII, Wi-Fi,
ISM bands

No user has any specific rights to any specific part of electrospace. In the past, interference has been controlled by very specific rules/protocols (e.g., 46 MHz cordless phones) or low power. Commons have been very successful, for short-range systems.

Long range systems? Interference endurance? Protocols?



Tragedy of Commons?

Folk lore is that 900 MHz band is quite crowded now, 2.4 GHz band is getting crowded, 5-6 GHz bands are the place to design new systems. (Lots of spectrum at 5 GHz; not yet too crowded. But what about 5 years from now?)

True? Very little reliable data available. But look at the cordless phones at Radio Shack.

Probably, most Part 15 interference is intermittent, noticed as a reduction in reliability and max range.

Wi-Fi is the big new Part 15 population. How soon crowding?



Commons – Interference?

Property Rights and C&C control interference by rigorously restricting who can transmit on a frequency.

Commons: Interference mainly controlled by restricting transmitter power. Typical devices operate only for several hundred feet or less, with very intermittent duty cycles, for low priority functions.

Some commercial point-to-point microwave operates in commons at 5.8 GHz (highly directional antennas help provide isolation from interference, can also move to licensed band).

Wi-Fi systems. Look for other signals in band, hook-up or move to different frequency and begin operation. DFS requires protection of operating radars.



Rules for Commons - 1

Very little serious thinking about what are the best rules for a Commons. (How can Big-Commons proposals be taken seriously, without carefully considered rules?)

Suggested spectrum etiquette (by Microsoft):

1. Listen before you transmit. (Protect existing circuits)
2. Transmit with minimum practical power .
3. Discontinue transmitter use when not needed.

If these rules are not obeyed, sufficient to get near-maximum productivity from Commons? Will Commons be self-policing?

Lunchtime Policy Panel Discussion: “Policing the Spectrum Commons” 12:15, Thursday



Rules for Commons - 2

Assuming that policing is a solvable problem:

How is Commons most productive? (For what kind of devices?)

1. Open "free-for-all? No Rules? No power limits?
2. Power limits, but few other rules?
3. Power limits and spectrum etiquette?
4. Power limits and general set of system protocols ?
5. Different specific system protocols for each Commons band?

Should some Commons band support Duplex band structures, while others use time-dependent duplexing (TDD)?

Multiple specializes Commons, or single multipurpose?



Liability in Commons?

- All current Commons Rules assume that user accepts any interference that user encounters; user is not liable for any interference that they cause. Low power Commons systems act more like Underlays than Commons.
- The development of more intelligent and flexible radios suggests that future radios will be more able to evaluate local electrospace and adapt to it. Technological ability plus mobile/proximate users, suggest larger future applications for Commons.
- Future commons could require elaborate specific protocols and hold users liable for interference. If existing current links are given protection, operation in Commons will have many characteristics of Overlays. Existing users temporarily gain primary status.



Thinking about the Future

- Will always be a requirement for multiple spectrum regulatory environments, because different system technical and business requirements.
- Real estate analogy - different kinds of property rules. Public spaces (parks, highways, class rooms), private spaces (stores, bedrooms).
- Trends include: smarter adaptive systems, higher frequencies, wider bandwidths (bit rates), more mobility.



Geographical

Could signals be licensed as a part of geographical control of real estate? ([Local Spectrum Sovereignty, An inflection point in Allocation](#) Mike Chartier, Wednesday, 9:30)

These licensing rights would allow property (real estate) owner to say what signals can exist above his property. Presumably, these signals would need to be suppressed outside property line. But, how do you get radio signals to respect a property line?

Shielding. Precedence: Okay to transmit any signal inside a screen room (as long as it doesn't leak out).

Could you shield a whole office complex and re-license the spectrum inside? Would a cellphone company be able to demand access to their whole licensed territory (including inside)? Why or why not?



Next Generation (XG)

Military XG concepts: To fit military operations in between local (friendly) licensed services.

“DARPA XG Opportunistic Spectrum Program”
Preston Marshall, Wednesday, 1:45.

Development of good Overlay technologies.
Possibly, solving some problems and allowing much wider use of Overlays.



Management by Tort

“Everyone has the right to transmit, but are responsible for any interference.”

- Existing users must be protected from interference by new users.
- Typical overlay regulations for Commons or Property.
- Possible tiered responses
 - Low power – not responsible for interference
 - Medium power – Use Protocol A to avoid possible victims
 - High Power – Use Protocol B and database broker/insurer
- Difficult details defining interference, very large data needs



Wireless Mesh Networks

- A self-organizing network of “Wi-Fi-like” short-range systems. Data is passed from node to node until it arrives at destination.
- **Scalability.** As more users (nodes) are added, the distance between nodes decreases and the spectrum efficiency of the network increases. Some models show that each additional user brings as much capacity to the network as they individually consume. Therefore, potential growth to almost infinite capacity.
- Very large Commons proposed by supporters, but little agreement regarding needed rules. Only mesh devices? Mandatory protocols? Selfish behavior? Security? Connections to wired infrastructure? Any fees or expenses?
- Very interesting concept. Will it work **better than** other concepts?



Squatter's Rights

- New allocations in 70-, 80-, and 90-GHz bands.
- Choose a frequency and use it. File it via Internet to protect that frequency/location from future users. Like Old West land claims.
- Huge bandwidths available for short range, line-of-sight systems.
- Probably a while before technology is cheaply available in the 70-90 GHz band.



Property Rights

Assuming that substantial amounts of future spectrum is available under property rights rules: active secondary markets for long- and short-term uses.

SDR devices tune easily to a broad range of frequencies (base, as well as mobile), leading to “commoditization of frequencies.” Any frequency will do. PCS expands into different bands in different cities and countries; daily changes in frequencies, according to traffic demand.

If frequencies were “rented by the minute” by frequency brokers, then Overlays would look very much like theft of property by unauthorized (and non-paying) users. What will the rules say?



Tutorial Summary

- Spectrum Management is changing rapidly, driven by new technology (smaller smarter radios, higher frequencies), changing services (huge demand, portable terminals, wideband digital), and

Older C&C concepts of spectrum management are being replaced by spectrum property rights (where dedicated spectrum is needed) and Commons bands (where non-licensed operation is preferred).

- Although the general nature of the spectrum property rights bands seem fairly predictable, the future Commons bands may include mesh networks and other completely new ways to communicate.