Spectrum Sharing: An Institutional Framework

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Outline

- What is FutureG?
- What are some DoD requirements for 6G?
- How is 6G being conceptualized for DoD use?
- What are the requirements for systems that are likely to be adopted by users?

Mobile Generations and Their Motivations

Generation	Goals	Some key drivers motivating this generation
1	Demonstrate that mobile communications at scale is possible	Supply limitations of centralized mobile systems for voice
2	Use digital transmission technology to provide voice mobile service; roaming at scale	Fragmentation of 1G systems (especially in Europe)
3	Provide usable data rates with mobility	Supporting emerging Internet and web applications
4	Support the demands of graphical smart phones	Unify standards for international roaming Need to increase data transmission rates
5	Support diverse use types (eMBB, ULLRC, Slicing) Virtualizing hardware resources via software	Scale data-oriented applications to speeds and volumes now demanded Emergence of cloud-based service model
6	**Discussions beginning this year**	Operations support with AI/ML? Rapid customizability? Spectral efficiency through Massive MIMO? Spectrum agility and sharing?

What are Some DoD Priorities?

- Private networking
  - RAN Sharing
  - Tactical bubbles
  - Private 5G where appropriate
  - Boutique applications
- "Adaptability *is* Utility"*
  - Strong supporters of Open RAN
  - Need high feature velocity
  - Need customizability
  - Spectrum sharing as a native capability

Spectrum sharing as a native capability

…ugh Zero Trust Architecture

- Need systems that are easy to deploy (Zero Touch)
- Open RAN and Open Source for DoD and government

* General Randy George, US Army Chief of Staff, speaking at the May 2024 TEM Conference

Observations of Spectrum Sharing Research

Most research and development work on spectrum sharing focuses on the requirement for physical deconfliction of spectrum uses

- These do not - *necessarily* - address what is needed for commercial success

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Questions:

1. What are the **institutional** requirements for spectrum sharing?
2. What do those requirements mean for the technical design of spectrum sharing systems?

What is "Institutional Economics"?

Institutional economics:

1. Focuses on the rules and norms around economic transactions
2. Efficient economic exchanges are limited by factors such as incomplete information and inherent human cognitive characteristics
3. These limits are summarized as **transaction costs**

Why does this matter?

- High transaction costs limit economic exchange and result in "private" markets where risks can be managed
- Contracts are a way to structure economic transactions

More on Risks

Each party to a transaction bears risk

- *Will the counterparty comply with the contract?*
- *What is the likelihood of a circumstance occurring that was not specified in the contract?*
- *How efficient is the enforcement of the contract?*

What are some spectrum sharing risks?

1. Will the secondary user vacate the spectrum in time so I can maintain QoS to my customers? (**primary**)
2. Will there be enough spectrum availability to meet my end user's QoS needs? (**secondary**)
3. How efficiently can disputes (*e.g.*, interference) be resolved?

How Does This Impact the Design of Systems?

What does this mean for spectrum sharing system design?

- Technical deconfliction of spectrum use is a necessary but not sufficient design goal
- Spectrum sharing systems must also focus on reducing transaction costs between spectrum sharing parties
- Include a focus on the **governance** of the spectrum sharing process

Contracts

Spectrum sharing is essentially a contract between the sharing parties. Which is often formed, or informed, by government/regulatory action

Content of a sharing “contract”

A. What gets shared
B. How sharing is orchestrated
C. How the sharing arrangement is governed
D. What enforcement mechanisms are

A. What Gets Shared?

Un or under-utilized spectrum in a particular geography

- Institutional economics encourages matching the scale and scope of solutions to the scale and scope of the resource
- The scope of spectrum use is **local** (in most bands) for most applications
  - Radio astronomy is a potential exception because of the low noise requirement of that application
  - HF bands (especially at night) can have continental and even global scope

Questions:

1. What do we mean by “un or under-utilized spectrum”?
2. How do you know or measure this?

B. How Can Sharing be Orchestrated?

That depends …

	Cooperative	Non-cooperative
Primary (equal rights)	Voluntary spectrum trading Spectrum Exchange (inter-service spectrum coordination)	Unlicensed uses
Secondary (rights hierarchy)	Listen-Before-Talk (LBT) methods TV White Spaces PALs in CBRS	EMBRSS band sharing

There are lots of gray areas in this simple framework

- Are WiFi and Bluetooth protocols a form of cooperation?
- Where does CBRS really fall?
- How to deal with rights mismatches?
- Do we treat technical and strategic non-cooperation the same?

C. How is Spectrum Sharing Governed?

Regulation

- US government asserted right to license spectrum in 1912
- Roles include:
  - ✓ Allocating spectrum to uses (in conjunction with the ITU)
  - ✓ Assigning licenses to users (time/space/frequency)
  - ✓ Determining rules for use (e.g., amateur radio)
  - ✓ Determining sharing method (e.g. CBRS, LBT, etc.)
  - ✓ Approving license transfers (spectrum trading)
  - ✓ Enforcing rule/license violations
- Tends to result in global (national) solutions

But is that the only way?

- Since spectrum is a local phenomenon, how do we create the opportunity for local solutions to local problems
- How do we empower local actors to solve their own problems?
- Are technical deconfliction mechanisms local or global solutions?

What Does This Mean for System Requirements?

Risk		System implications
1. Will the secondary user vacate the spectrum in time so I can maintain QoS to my customers? (**primary**)	→	Systems should execute transactions frequently and very quickly
2. Will there be enough spectrum availability to meet my end user's QoS needs? (**secondary**)	→	Systems should publish historical spectrum availability distributions (and prices)
3. How efficiently can disputes (*e.g.*, interference) be resolved?	→	Sharing systems should be customizable to local requirements

Rapid Transactions

A primary *and* secondary user should be able to get the spectrum they need quickly when they need it

- ➢Quickly means that the transaction latency should be matched to the end user application requirements for both the primary and secondary user

- This argues for *micro* instead of *macro* transactions
- This reduces risk because users have more confidence that sufficient spectrum resources will be available on demand

Information Availability

- It is nearly impossible for a secondary user to make a rational decision about secondary use without information about availability
- Having probability distributions of spectrum availability in the localities required makes rational economic decision-making possible
- Transaction costs are reduced because access risk can be quantified and therefore managed

Notes on Enforcement

- Spectrum sharing arrangements are a form of contract between parties
  - Necessary for a contract to be meaningful
  - Important in commons governance as well
  - Interference implies contract enforcement
- Elements
  - Ex ante
    - Protection zones
    - Guard bands
  - Ex post
    - Detection
    - Forensics
    - Adjudication
    - Settlement

- Ex ante enforcement
  - Prophylactic approach to interference
  - Potentially high social cost
    - Guard bands and protection zones are usually conservative
    - Must anticipate all propagation anomalies
  - Generally static
- Ex post enforcement
  - Addresses interference only when “harmful”
  - Tends to be more dynamic
  - Does not protect against critical consequences of interference
  - Benefits from fast and inexpensive (automated) enforcement

What Could the Role of Open RAN Be?

1. Support for rapid transactions
   - Sharing can be implemented using xApps
   - Enables numerous orchestration strategies at different timescales
2. Improved information availability
   - Management and information can be implemented using dApps*
   - Can be easily customized to support end user decision-making needs
3. Matching scale and scope of governance to the scale and scope of the resource
   - Modularity of Open RAN systems allow for easy scalability
   - Combined with open-source software, Open RAN systems can be more rapidly be customized to particular end-user requirements

- dApps: Distributed Applications for Real-time Inference and Control in O-RAN Salvatore D'Oro, Michele Polese, Leonardo Bonati, Hai Cheng, Tommaso Melodia

Spectrum Sharing: Its Time Has Come

If data is the new oil, spectrum is the new railroad

Evolution of Railroads

- Early stage
  - Single track, privately owned
  - Highly specific geographies
  - Varying gauges
- Later stage
  - Locally, monopolistic competition
  - Nationally, federated networks of local companies
  - Standardized gauges
- Late stage
  - Track sharing
  - Competing national networks

Evolution of Wireless

- Early stage
  - Local systems
  - Highly specific geographies
  - Multiple standards
- Later stage
  - Multiple facilities-based competitors
  - Federated networks
  - Harmonized standards
- Late stage
  - Infrastructure sharing (e.g. towers)
  - Emergence of spectrum sharing

Conclusions

- The most challenging parts of spectrum sharing are institutional in nature
- Technological systems can be built that serve to mitigate institutional concerns

I look forward to your questions and discussion!

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