Spectrum Sharing

The Basics (101)

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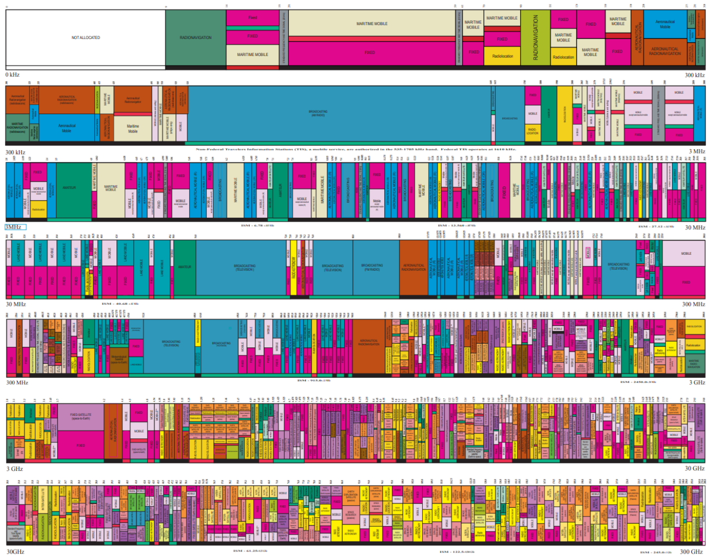
He has been analyzing and writing about spectrum sharing since 2016. (See articles in appendix.)

Spectrum Sharing Executive Summary

- Spectrum is a limited resource with many entities wanting to use it.
- Wireless technologies, such as 4G/5G and Wi-Fi, are extremely complex, designed for performance and efficiency, and work best in dedicated, licensed spectrum.
- Sharing can make sense in certain situations in which one entity does not use the spectrum all the time in all places; for example, DOD Navy radar. (More examples in subsequent slides.)
- But no turn-key solution exists today for generalized sharing across different types of systems.
- Given the shortage of spectrum, innovators have developed limited ways for different types of systems to share spectrum to address specific scenarios, given incumbent system operating characteristics.
- Today's sharing solutions range from simple, such as geographic separation, to extremely complex, such as 4G/5G sharing, Wi-Fi/cellular sharing of unlicensed bands, and CBRS.
- These solutions cannot easily be extended to other scenarios. Whether sharing is feasible, and the approach used, depends on the specific systems that would be sharing.
- Industry and government are researching more advanced sharing solutions for the future.
- Policy makers need to understand that sharing is not always the best approach; moreover, solutions take many years to develop and deploy.
- Imposing unrealistic or overly complex sharing requirements will hold back the industry at a critical time when countries are competing for 5G dominance.

Spectrum in the United States (3 Hz to 300 GHz)

Too many applications, too many users, too little spectrum.



https://www.ntia.doc.gov/files/ntia/publications/january_2016_spectrum_wall_chart.pdf

The chart is from the National Telecommunications and Information Administration (NTIA) and conveys how many different entities currently use spectrum.

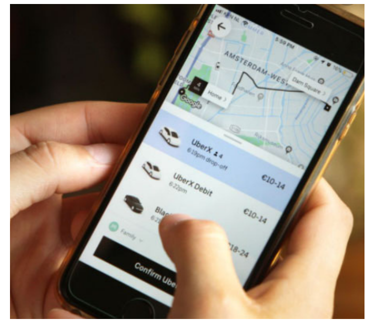
Practical radio spectrum today extends from 6 KHz to 300 GHz.

Most cellular deployments use frequencies from 600 MHz to 2.5 GHz, but 5G also uses mid-band frequencies (2.5 to 6 GHz) and mmWave frequencies (24 GHz to 39 GHz) with higher frequencies planned for the future.

The goal of spectrum sharing is that multiple entities can share the same radio band. In some scenarios, this can work well and is relatively straightforward, but in other proposed scenarios, solutions are complex and rely on technologies that do not yet exist.

Analogies: Car Sharing, Home Sharing

- Car Sharing
  - Simple: wife uses car some days, husband other days
  - More complex: teenagers use car
  - Extremely complex: anybody any time
  - Solution: Uber and Lyft
- Vacation Home Sharing
  - Simple: parents some weeks, kids other weeks
  - More complex: parents, friends, kids, rentals
  - Extremely complex: anybody, any time
  - Solution: Airbnb, VRBO
- Conclusion: Generalized solutions require complex infrastructure



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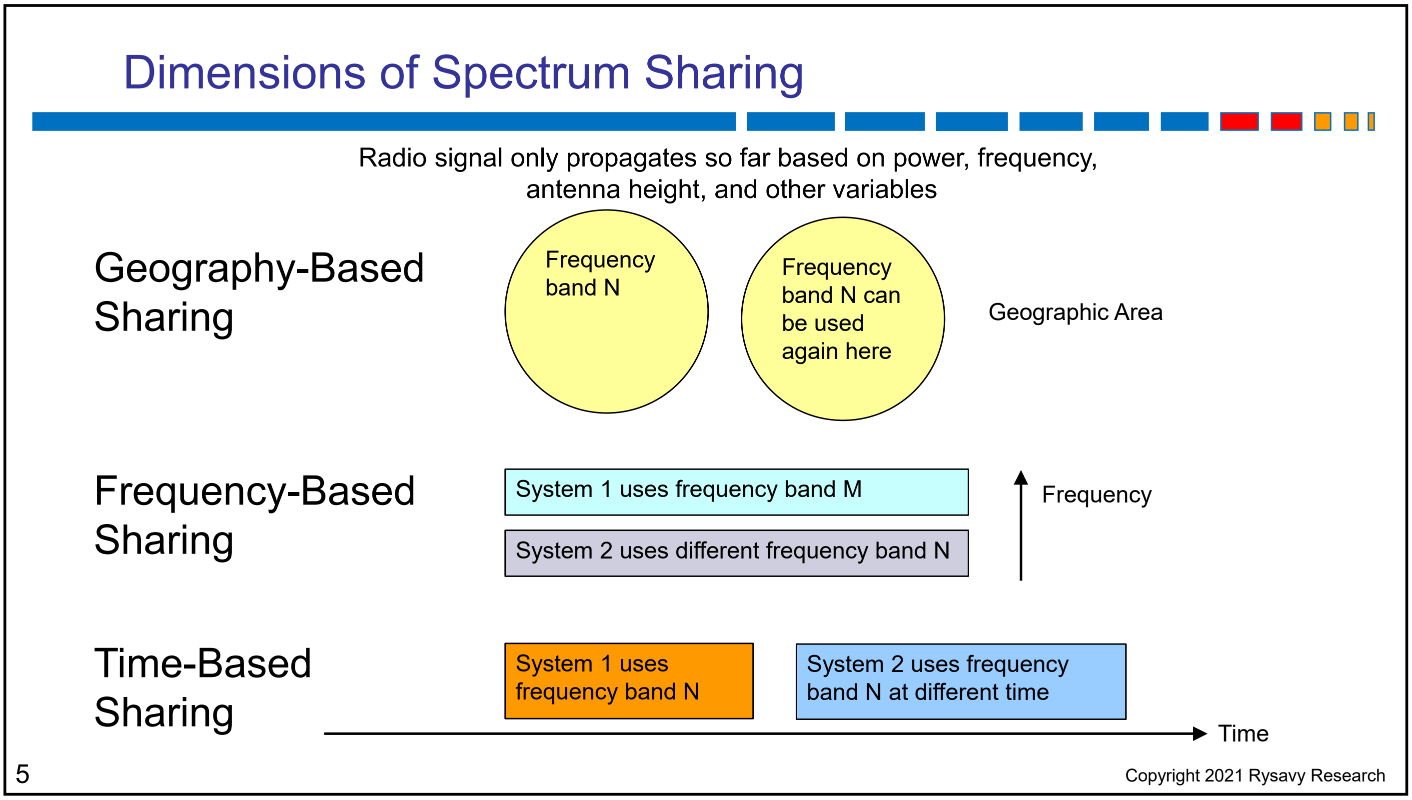
The concept of sharing applies to many facets of life. For nearly all items, sharing can be simple, or it can be complex.

Having dedicated access to a resource, whether a car, a home, or spectrum, is always simplest. But a seldom used resource is not efficient.

Simple sharing arrangements are possible, but more ambitious sharing quickly becomes complicated. For example, sharing cars or homes across a large number of users at arbitrary times requires complex infrastructures such as provided by Uber and Airbnb.

Similarly, spectrum sharing solutions can range from simple to complex. Nearly all spectrum, is in fact, shared. For example, the cellular frequencies used in one country are often the same as in other countries, but the geographical separation creates a simple sharing solution. Spectrum sharing becomes much more complicated when different systems wish to use the same spectrum dynamically in the same place at the same time.



Nearly all wireless technologies must contend with interference. The basic problem is that signals from two transmitters in the same location at the same frequency at the same time interfere with each other and can make it impossible to receive either transmission. The problem is analogous to trying to understand two people speaking at the same time.

Technologists address this problem by separating the two transmissions using geography, frequency, or time.

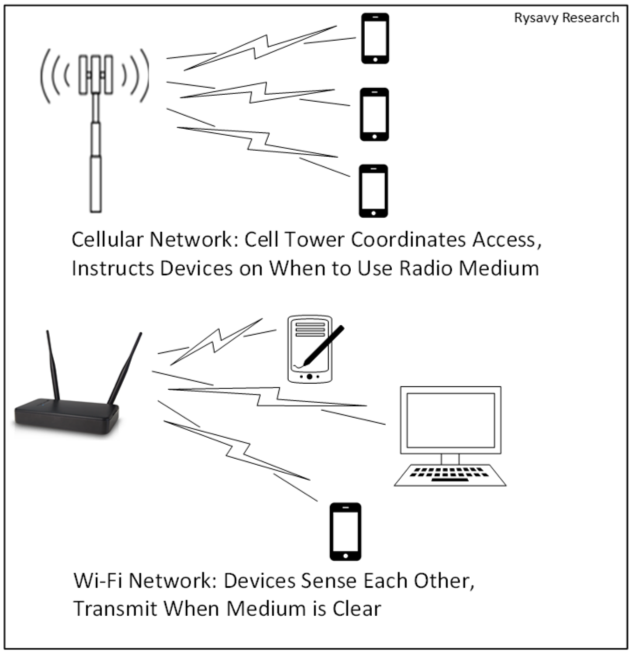
Geographic separation is the simplest and is how different countries, except at their borders, can have completely separate rules for radio use. Similarly, a cellular network can use the same frequencies at the same time so long as the cells are separated sufficiently to not interfere with each other.

Frequency separation is also simple. For example, different cellular operators have different frequency bands licensed to them in the same geographic area.

Time separation is the most complicated way of separating users.

Most modern wireless systems use a combination of time and frequency to manage use of the radio resource across multiple devices in a specific coverage area.

Nature of Sharing Radio Medium



Cellular and Wi-Fi use fundamentally different approaches for radio medium access

Each alone is complicated with detailed technical specifications

Yet innovators have developed means for cellular and Wi-Fi to share the same unlicensed spectrum

But the solution is complex and took many years to develop

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Wireless technologies such as cellular and Wi-Fi solve the difficult problem of how different devices can access the radio medium without interfering with each other. If any device, such as a smartphone, could transmit at any time, the signals from multiple devices would interfere with each other and make it either difficult or impossible for the receiver to correctly receive the signal.

Engineers have developed complex approaches that determine how devices wanting to transmit either wait their fair turn, as in Wi-Fi, or receive instructions from the base station, as in cellular systems. Detailed specifications comprising hundreds of pages of technical information describe the approaches.

Modern wireless systems control radio medium access many hundreds of times each second.

Sharing spectrum between two completely different types of systems, such as Wi-Fi and cellular, is a difficult problem. Innovators spent years making this possible, both with LTE and 5G. The process involved technical proposals, extensive discussion between constituents from the two industries, testing, trialing, and finalization of specifications.

Insights into Timeframes

- Citizens Broadband Radio Service (CBRS): Eight years from notice of proposed rulemaking to auction for licenses.
- NTIA: "Lesson 1: The **development time** for dynamic spectrum technologies, even when government and industry work closely and cooperatively together on the necessary technical and regulatory framework, can be something **on the order of a decade**. This is because innovation requires considerable advance work in the absence of existing implementations. The more innovative and technically challenging the new sharing scheme, the longer the advance-work timeline can be expected to be." [Emphasis added.]
  - NTIA, *Lessons Learned from the Development and Deployment of 5 GHz Unlicensed National Information Infrastructure (U-NII) Dynamic Frequency Selection (DFS) Devices*, Dec. 2019. https://www.ntia.doc.gov/report/2019/lessons-learned-development-and-deployment-5-ghz-unlicensed-national-information

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Multiple factors determine the complexity of spectrum sharing. One is how dynamic it is. Another is whether sensing methods are used by one system to detect the other's use of spectrum, or whether some device controls access by the respective systems.

Dynamic spectrum sharing means that sharing occurs in real-time or near real-time. The more dynamic the sharing arrangement, the more complex it is. For example, sharing between 5G and Wi-Fi in 5 GHz or 6 GHz bands occurs in small fractions of a second. In contrast, with CBRS, spectrum assignments for licensees change no more often than once a day, making it a semi-dynamic system. CBRS does require, however, that if an incumbent, such as a military radar system, starts using the band in a protected area, cellular networks have to stop using the band within 300 seconds.

Despite the semi-dynamic nature of CBRS, it remains a complex sharing system because it has three tiers of users and uses both sensing as well as a centralized database that controls spectrum use. Because of this complexity, CBRS took eight years to go from initial proposed rulemaking to auctions of licenses.

As noted in the slide, the National Telecommunications and Information Administration (NTIA) has observed that the development time for dynamic spectrum sharing to be on the order of a decade.

Some Existing Spectrum Sharing Solutions (United States)

Sharing Technology	What is Shared	Bands	Approach	Complexity
Advanced Wireless Service-3 Coordination Procedures	Federal systems and cellular networks	1.7 GHz	Geographic	Low
5G Dynamic Spectrum Sharing (DSS)	LTE and 5G	Current cellular bands	Dynamic coordination	High
LTE Licensed Assisted Access (LAA)	LTE and Wi-Fi	5 GHz unlicensed	Sensing	High
5G NR-Unlicensed (NR-U)	5G and Wi-Fi	5 GHz, 6 GHz unlicensed	Sensing	High
Citizens Band Radio Service (CBRS)	Government incumbents, licensed LTE/5G, "unlicensed" LTE/5G	3.5 GHz	Sensing and semi-dynamic coordination	High
White Space Networks	Computing devices and television	600 MHz	Static coordination	Medium
Industrial Scientific and Medical (ISM) FCC rules	Wi-Fi and Bluetooth	2.4 GHz unlicensed	Sensing	Medium
Wi-Fi Dynamic Frequency Selection	Radar and Wi-Fi	5 GHz	Sensing	Medium
Wi-Fi Automated Frequency Control (in development)	Fixed microwave and Wi-Fi	6 GHz	Dynamic coordination	High

- Sensing means a system measures radio environment to detect activity of other systems
- Coordination means central system assigns access to systems needing spectrum
- Static coordination means assignments do not change regularly and dynamic means they do
- Each of these sharing solutions took years to develop and deploy
- Each addresses a specific scenario for specific systems with specific parameters

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Multiple spectrum sharing systems exist today as shown in the table. The table details what they are called, what types of systems are sharing the spectrum, in what radio bands the sharing occurs, what the approach is, and the complexity of the sharing approach.

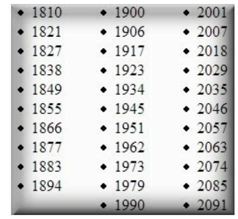
As already mentioned, the simplest sharing approach is geographic, where use of the spectrum band is separated by sufficient distance that the radio signal in one area does not interfere in another area. Geographic separation is the basis of cellular networks; signals from one cell do not interfere with signals in adjacent cells.

Sensing is the approach used by Wi-Fi systems. CBRS also uses sensing to detect operation of navy radar systems in an area. The advantage of sensing is that it does not necessarily require centralized coordination (although CBRS uses both sensing and centralized coordination). The disadvantage is that sensing does not always detect operation of other devices in the local area and imperfect sensing can result in what are called radio collisions, decreasing the efficiency of the system.

In coordinated systems, such as CBRS and White Space Networks, a centralized database controls which systems have access to what spectrum in what area. In CBRS, licensees of spectrum have higher priority than unlicensed users, but lower priority than incumbent government systems.

Some Adverse Consequences of Spectrum Sharing

- Longer time to deploy
  - Design of sharing approach
  - Testing and validation of sharing approach
  - Modification of wireless systems to incorporate sharing approach



- Higher costs
  - More complex system with more components
  - Integration with sharing databases or coordinating systems
  - Variability of spectrum assignments affecting efficiency and planning
  - If sharing approach only used in United States, lower economies of scale for devices and infrastructure

- Lower Usage
  - Shared spectrum usually harder to use
  - Sharing requirements make spectrum resources unpredictable
  - Incumbents may not share all available free capacity for security or other reasons

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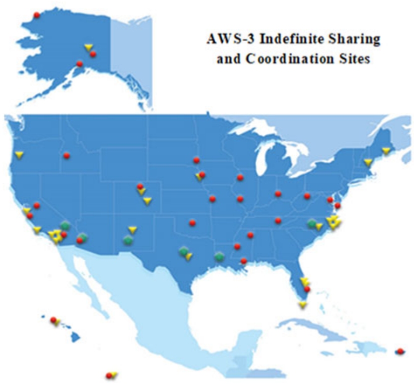
Adverse consequences can occur from spectrum sharing. Specifically, relative to using dedicated spectrum, spectrum sharing takes longer to deploy, test, and maintain. Additional vendors or components may be involved. For example, with CBRS, network operators must interface with a third-party Spectrum Access System (SAS) database.

Another problem is if a lower-priority (e.g., commercial operator) user cannot predict how often a higher-priority user (e.g., government incumbent) may use the radio resource, making it hard to plan and to deliver a consistent service. Even with equal sharing, for example cellular and Wi-Fi using the same unlicensed spectrum, an operator cannot rely on the spectrum providing a predictable amount of capacity.

The resulting constraints can make shared spectrum less desirable. One can see this with C-band and CBRS auction results. Adjusted for equal amounts of spectrum, the market valued spectrum with CBRS types of rules at less than one fourth the value of spectrum with C-band types of rules.

AWS-3 as Example of Simple Sharing

- 1.7/2.1 GHz cellular band coordinated with federal use on permanent basis by geography
- Protection of federal satellite uplink stations
- Details: FCC Coordination Procedures in the 1695-1710 MHz and 1755-1780 MHz Bands, https://www.fcc.gov/wireless/bureau-divisions/broadband-division/advanced-wireless-services-aws



NTIA, *Spectrum Sharing: An Emerging Success*, Aug. 2019.
https://www.ntia.gov/blog/2020/spectrum-sharing-emerging-success

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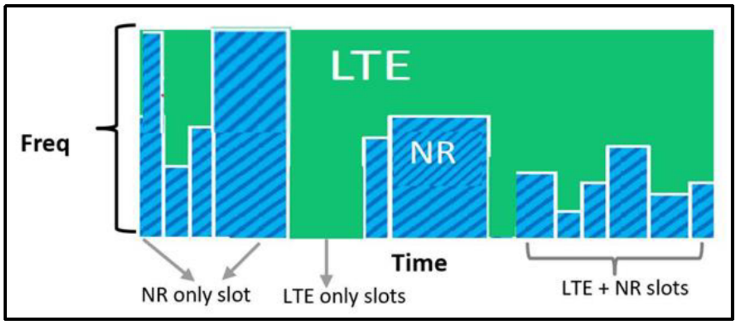
A geographic approach to spectrum sharing is the simplest. The AWS-3 cellular band at 1.7 GHz (and 2.1 GHz) has exclusion zones, areas where commercial operators cannot use the spectrum. These zones protect federal satellite uplink stations.

This form of coordination is simple because it does not change over time.

After network deployment that takes into account the coordination procedures, commercial operators do not have to do anything on an ongoing basis. In areas outside the coordination zones in their licensed areas, operators have exclusive use of the spectrum.

5G DSS as Example of Complex Sharing

- LTE and 5G New Radio (NR) can share same radio channel
- Resources shared in time and frequency blocks
- Dynamically coordinated by base station scheduler
- Facilitates rollout of 5G by not needing clear spectrum
- Not extensible to sharing 5G with non-cellular systems



Rysavy Research, *Global 5G: Rise of a Transformational Technology*, Sep. 2020, p. 41, also pp. 177-180.
https://rysavyresearch.files.wordpress.com/2020/09/2020-09-global-5g-rise-of-a-transformational-technology.pdf

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A complex example of spectrum sharing is the 5G Dynamic Spectrum Sharing (DSS) capability, with which both LTE and 5G can share the same radio channel.

Referring to the figure, with frequency in the vertical dimension and time in the horizontal dimension, the base station can allocate radio resources to LTE and 5G NR devices in a variety of ways. In some instances, such as the left-most time slot, 5G devices have exclusive use of the entire radio channel. In other time slots, LTE devices have exclusive use. At yet other times, the base station allows both LTE and 5G NR to operate at the same time, although in different frequency subchannels. The base station scheduler allocates these resources dynamically, on a millisecond-by-millisecond basis depending on the moment-to-moment needs of different users.

This form of sharing is extremely complex and took many years to design, specify, test, and implement. Designed specifically for LTE and 5G, this specific technology is not readily extensible to other scenarios.

Confusion about DSS Terminology

- "Dynamic spectrum sharing" has general meaning
  - Precedes 5G
  - Often called Dynamic Spectrum Access (DSA)
  - A research topic for decades
- 5G has feature called "Dynamic Spectrum Sharing (DSS)"
  - Specific to 5G
  - Ability for same radio channel to carry both 5G New Radio (NR) and LTE signals
- DOD brought up dynamic spectrum sharing in RFI
  - Does not mean 5G version of DSS
  - FCC/NTIA/DOD currently examining future of 3.10 to 3.45 GHz

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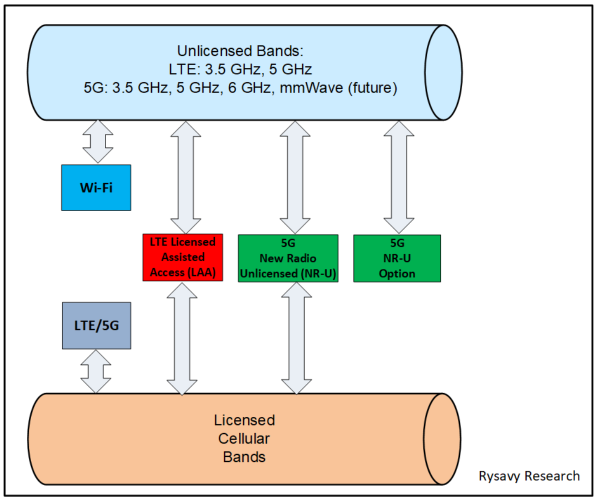
In 2020, the Department of Defense (DOD) issued a request for information for dynamic spectrum sharing (DSS) solutions that might apply to spectrum that DOD currently uses. This caused some confusion in the industry because the 5G DSS capability is specific to LTE and 5G sharing the same radio channel. However, the term DSS can be thought of more generally. More commonly, people have used the term dynamic spectrum access (DSA) to refer to dynamic approaches by which different systems can share spectrum.

The Federal Communications Commission (FCC), NTIA, and Department are investigating how DOD might share spectrum in future mid-band spectrum such as 3.10 to 3.45 GHz.

LAA and NR-U: Further Examples of Complex Sharing



- LTE Licensed Assisted Access (LAA) and 5G New Radio Unlicensed (NR-U) share unlicensed spectrum with Wi-Fi
- LTE and 5G operate as good Wi-Fi neighbors taking only “fair” amount of capacity
- 5G/LTE senses Wi-Fi operation and Wi-Fi senses 5G/LTE

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LTE Licensed Assisted Access (LAA) and 5G New Radio Unlicensed (NR-U) are examples of complex sharing technologies. Both LAA and NR-U enable cellular systems to use unlicensed spectrum, the same spectrum used by Wi-Fi devices. LAA relies on a simultaneous connection with a licensed cellular band whereas NR-U can operate both in this mode or using just unlicensed spectrum.

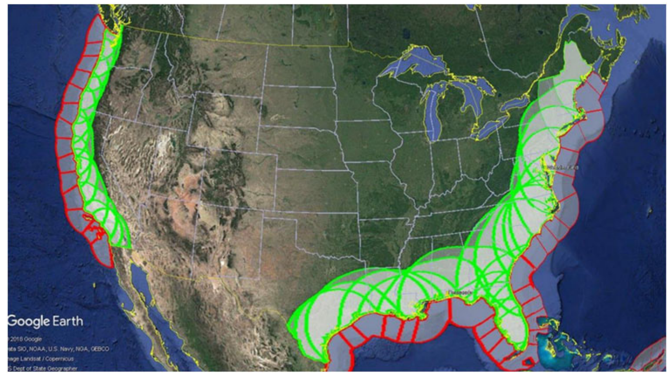
Engineers spent years developing these solutions. The cellular base station must sense other Wi-Fi users and access points and must appear to Wi-Fi users as if it were another Wi-Fi user, taking only its “fair” share of the radio resource.

LAA and NR-U attempt to use radio channels not in use by other Wi-Fi devices and if those aren’t available, use those that are less congested.

This sharing approach works well in coverage areas without much Wi-Fi usage, but if many Wi-Fi users are using the spectrum, then the cellular network does not gain much additional capacity, highlighting one of the inherent problems of spectrum sharing.

Citizens Broadband Radio Service (CBRS), Also Complex

- Three tiers: Incumbents (mostly Navy radar), Priority Access Licenses (LTE and 5G), General Authorized Access (LTE and 5G)
- CBSDs (base stations) register and request spectrum
- Spectrum Access System (SAS) dynamically coordinates access, subject to incumbent (government) use
- Environmental Sensing Capability (ESC) along coastlines senses Navy radar (has limitations)
- Not a good solution for wide-area cellular coverage due to small license areas and low power
  - See Rysavy, *5G Mid-Band Spectrum Deployment*, https://rysavyresearch.files.wordpress.com/2021/02/2021-02-5g-mid-band-spectrum-deployment.pdf



CBRS Navy Protection Areas:[1]
Red: Where Navy Ship May Be Located
Green: Where Bases Stations May Have to Adjust Operation

[1] Source: https://www.wirelessinnovation.org/assets/documents/winnf-20-in-0065%20cbrs%20incumbents%20and%20enumbrances.pdf.

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CBRS is the most complex spectrum management system in the world.

First, it has three tiers of users: incumbent government systems, licensed users with Priority Access Licenses (PALs), and unlicensed users referred to as General Authorized Access (GAA). Both PAL and GAA users must have base stations that coordinate with a Spectrum Access System (SAS) database.

Second, CBRS not only coordinates spectrum using the SAS, but it also employs a network of sensors along the coast called the Environmental Sensing Capability (ESC). The ESC detects Navy radar, informs the SAS, and for affected areas, the SAS informs commercial networks to cease operation in specific radio channels, which they must do within 300 seconds.

The map shows in red where navy ships may be located and in green where base stations may have to adjust operation.

As outlined in a Rysavy report of Feb. 2021, the restrictions on CBRS, including coordination, small license areas, and low-power requirements, make it a poor solution for wide-area 5G cellular networks.

Conclusion

- 4G LTE and 5G already share spectrum
- But only in highly specific ways
- Other spectrum sharing systems also developed, but for specific scenarios
- General problem of dynamic spectrum sharing/access is complex
- CBRS not necessarily a good model for future bands
- Sharing solutions take many years to develop and deploy
- In many cases, cleared, dedicated spectrum is the best solution
- Imposing unrealistic or overly complex sharing demands on 5G will hamper U.S. competitiveness

Appendix

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Rysavy Research on Spectrum Sharing

- *5G Mid-Band Spectrum Deployment*
  - https://rysavyresearch.files.wordpress.com/2021/02/2021-02-5g-mid-band-spectrum-deployment.pdf

- *DoD's Proposed 5G Spectrum Sharing Fraught with Problems*
  - https://www.fiercewireless.com/wireless/industry-voices-rysavy-dod-s-proposed-5g-spectrum-sharing-fraught-problems

- *Bad Idea of Nationalized 5G Network Put to Rest*
  - https://www.fiercewireless.com/wireless/industry-voices-rysavy-bad-idea-a-nationalized-5g-network-put-to-rest

- *Scary Experimentation at 3.5 GHz*
  - https://hightechforum.org/scary-experimentation-3-5-ghz/

Extra: White Space, Wi-Fi 5 and 6 GHz

- White Space Networks
  - FCC Explanation
  - "Both fixed and personal/portable devices can operate in the white spaces in the TV bands on an unlicensed basis.
  - "The primary method of preventing interference to TV and other services is a geo-location capability of the white spaces devices combined with database access to identify vacant TV channels at specific locations. The databases are established and administered by parties selected by the Commission."
  - Rfc 7545 Protocol to Access White-Space (PAWS) Databases
  - https://www.fcc.gov/general/white-space
- 5 GHz Wi-Fi Dynamic Frequency Selection
  - Wi-Fi Alliance explanation:
  - "[S]ome of the Unlicensed National Information Infrastructure (U-NII) bands are used by radar systems. Wi-Fi networks operating in those bands are required to employ a radar detection and avoidance capability. The IEEE 802.11h standard addresses this requirement by adding support for DFS and transmit power control (TPC) on every DFS channel."
  - https://www.wi-fi.org/knowledge-center/faq/what-is-dynamic-frequency-selection-dfs
- 6 GHz Wi-Fi Automatic Frequency Control
  - Juniper Networks explanation:
  - "The way it works is an access point, or more probably a central control point such as a cloud management system or on-prem controller acting as proxy for APs under control will send the geolocation, including location confidence, antenna height, FCC ID and device serial number to an AFC operator. The AFC will do a lookup in the FCC Universal Licensing System (ULS) and calculate the ratio of interference to noise power (I/N) using one of several attenuation models based on the distance from the licensed antenna. The AFC checks that I/N is less than -6 for ch-channel and adjacent channels, and then returns a list of allowable frequencies and output powers, for which the Wi-Fi AP, based on the list, can choose its operating channel and power. Standard Power APs must check in with the AFC once a day, and are allowed to operate until 11:59pm the following day without a check in."
  - https://www.mist.com/afc-and-6-ghz-incumbents/

Abbreviations

- AWS Advanced Wireless Service
- CBRS Citizens Broadband Radio Service
- CBSD Citizens Broadband Radio Service Device
- DOD Department of Defense
- DSA Dynamic Spectrum Access
- DSS Dynamic Spectrum Sharing
- ESC Environmental Sensing Capability
- FCC Federal Communications Commission
- GHz Gigahertz
- Hz Hertz
- IIC Incumbent Informing Capability
- LAA Licensed Assisted Access
- LTE Long Term Evolution
- NR New Radio
- NR-U New Radio Unlicensed
- NTIA National Telecommunications and Information Administration
- RFI Request for Information