Time Scale Interpretations of Different Spectrum Sharing Frameworks, Including Dynamic and Highly Dynamic Spectrum Sharing

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Preface

The expressions "sharing" and "dynamic sharing" in the context of spectrum has been used by different organizations in various contexts and have diverse interpretations even within the technical community. Recently WInnForum has initiated a project "Highly Dynamic Spectrum Sharing". This contribution is intended to provide WInnForum members and other interested parties a common understanding of the different spectrum sharing terminologies. It is critical for all stakeholders to agree on basic terminology, not only for our internal discussions but also for our external communications. This document provides a breakdown of different time elements that contribute to the various concepts related to "dynamic sharing".

Additionally, this document also briefly addresses another use of the term "dynamic" in the context of "closed loop" controls.

Contributors

The following individuals made significant contributions to this document:

Editor and Group Co-Chair: Amit Mukhopadhyay, Nokia

Group Co-Chair: Andrew Clegg, Baylor University

Other Member Representative Contributors:

- Virgil Cimpu, Ericsson
- Abdulrauf Hafeez, Charter Communications
- Austin Egbert, Baylor University
- Minh LE, RED Technologies
- Richard Lee, iPosi
- Meihua Liang, MITRE
- Masoud Olfat, Federated Wireless
- Naotaka Sato, Sony
- Dawn Szelc, MITRE

Time Scale Interpretations of Different Spectrum Sharing Frameworks, Including Dynamic and Highly Dynamic Spectrum Sharing

1 Background

The National Spectrum Strategy and its Implementation Plan both refer to the term "Dynamic Spectrum Sharing (DSS)" and often refer to its implementation as a "moonshot project" [12][13]. The DoD CIO has also used the term DSS numerous times during the original PATHSS effort. Also, one of the interference mitigation techniques in PATHSS was called Dynamic Spectrum Management System (DSMS).

The National Telecommunication and Information Agency (NTIA) organized its first Multistakeholder (MSH) Group meeting on August 23, 2024 per the National Spectrum Strategy (NSS) Implementation Plan (I-Plan). The formation of two groups was announced:

1. Lower 3 GHz (3.1-3.45 GHz) group, which will run simultaneously with the PATHSS2 project
2. 7-8 GHz (7.125-8.4 GHz) group, that will NOT have a corresponding parallel group

When asked for clarification, NTIA responded that "there is no dynamic sharing" expected in 7-8 GHz and thus no need for a group similar to PATHSS2. This statement has raised a lot of questions about the very definition of the terminology "dynamic sharing".

This document intends to develop a common understanding of different spectrum sharing terminologies and the corresponding significance of any solution associated with the concepts. This understanding is based primarily on the anticipated functional requirements for the US market but we believe that the concepts could be applied broadly.

1.1 Terminology

Before delving into a discussion on spectrum sharing, it is important to understand the different types of spectrum users. In the Federal Communications Commission (FCC) frequency allocation table, there are two main types of allocations – primary and secondary. Primary allocations have higher priority than secondary allocations. It can also be noted that there can be multiple primary and/or secondary allocations in a given spectrum range. Furthermore, for any spectrum range, there can be a difference between federal and non-federal allocations.

In general, wewill also use the terms "federal incumbents" and "non-federal users" to denote the two types of spectrum users.

1.2 Acronyms

Here is a list of acronyms found in this document:

1. **3GPP** - 3rd Generation Partnership Project
2. **AFC** - Automated Frequency Coordination
3. **AWACS** - Airborne Warning and Control System
4. **AWS** - Advanced Wireless Services
5. **CBRS** - Citizens Broadband Radio Service
6. **CEPT** - European Conference of Postal and Telecommunications Administrations
7. **CIO** - Chief Information Officer
8. **CPA** - Coordination Protection Area
9. **DFMS** - Dynamic Frequency Management System
10. **DoD** - Department of Defense
11. **DPA** - Dynamic Protection Area
12. **DSS** - Dynamic Spectrum Sharing
13. **EMBRSS** - Enhanced Mobile Broadband Radar Spectrum Sharing
14. **EMS** - Element Management System
15. **ESC** - Environmental Sensing Capability
16. **FCC** - Federal Communications Commission
17. **I-Plan** - Implementation Plan
18. **ITU** - International Telecommunication Union
19. **MOCN** - Multi-Operator Core Network
20. **MORAN** - Multi-Operator Radio Access Network
21. **MRSS** - Multi-Radio Spectrum Sharing
22. **MSH** - Multistakeholder
23. **NIST** - National Institute of Standards and Technology
24. **NR** - New Radio
25. **NSS** - National Spectrum Strategy
26. **NTIA** - National Telecommunications and Information Administration
27. **PATHSS** – Partnering to Advance Trusted and Holistic Spectrum Solutions
28. **PPA** - Priority Protection Area
29. **PRB** - Physical Resource Block
30. **RIC** - RAN Intelligent Controller
31. **SAS** - Spectrum Access System
32. **SKE** - Surveillance and Control Equipment
33. **TR** - Technical Report
34. **WINNF** - Wireless Innovation Forum
35. **WRC** - World Radiocommunication Conference

2 Objective

Given that there are many uses of the words “sharing” and “dynamic” in the context of spectrum, this document is intended to establish a common set of terminologies. It will provide definitions of “sharing” in various contexts, including similar words used in some other fora (e.g., “sharing and compatibility” in ITU-R). It will also provide different interpretations of the word “dynamic” with respect to the timescales that various forms of dynamicity (including “highly dynamic”) can be associated with. Finally, a different interpretation of the word “dynamic” is also mentioned (as sometimes used by NTIA) for the sake of completeness where the word is used not only towards the timescale but also towards the nature of the proposed new control system (“closed loop” as opposed to the “open loop” system in CBRS or 6 GHz bands).

3 Many interpretations of spectrum sharing

3.1 3GPP DSS

The expression "dynamic spectrum sharing (DSS)" was used in 3GPP technologies [1] in the context of spectrum sharing between 4G LTE and 5G NR. The context was that during the introduction of 5G, many countries hadn't yet allocated spectrum for the new technology and operators had to deploy it on the same spectrum that 4G was already deployed. The situation was not ideal as there was significant signaling overhead that reduced bearer traffic capacity, but many operators didn't have a choice in early deployments. Later on, when more spectrum became available for 5G, they switched to 5G deployment in dedicated spectrum – either new or re-farmed from older technologies.

In a similar vein, it is expected that "multi-radio spectrum sharing (MRSS)" will be a feature in 6G that will allow spectrum sharing between 6G and 5G.

3.2 3GPP Network Sharing

Another concept of spectrum sharing is contained within the concept of "network sharing" studied in 3GPP. There are two main types of network sharing defined – Multi-Operator Core Network (MOCN) and Multi-Operator Radio Access Network (MORAN). A summary comparison of the two is presented below:

MOCN	MORAN
With MOCN (Multi-Operator Core Network), two or more core networks share the same RAN, meaning carriers are shared	With MORAN (Multi-Operator Radio Access Network) everything in the RAN (antenna, tower site, power) except for the radio carriers is shared between two or more operators
Common spectrum pool	Separate spectrum for operators
Regulations can dictate whether allowed or not	Subject to anti-competition regulations
Most successful deployments in countries with vast geographic areas and low population densities	Observed challenges in operational issues

Table 1: 3GPP Network Sharing Alternatives

As can be seen above, MOCN [2] essentially enables operators to share a common pool of spectrum. With the evolution of Open RAN, there has been further technical advancements in network sharing. However, this arrangement has been constrained by various business and operational challenges, rather than technical ones. Today, this practice is prevalent only in a handful of countries typically characterized by vast geographical areas and low population densities. The technology is also discussed in the context of "neutral hosts".

3.3 NIST

The National Institute of Standards & Technology (NIST) has come up with its own definition [3]: "Spectrum sharing is a way to optimize the use of the airwaves, or wireless communications channels, by enabling multiple categories of users to safely share the same frequency bands."

While the NIST definition was carved in the context of CBRS, it is still worth noting the generic nature of its definition.

3.4 Ofcom "Hybrid Sharing"

UK's Ofcom has introduced the term "Hybrid Sharing" [4, 5] to imply possible spectrum sharing between 3GPP-based mobile networks and Wi-Fi networks in the upper 6 GHz (6.425-7.125 GHz) spectrum. Ofcom is also evangelizing this concept at CEPT. They have proposed in the referenced consultation two alternative implementations:

A. Variable spectrum split: The Upper 6 GHz band would be split into two parts: a priority portion for Wi-Fi and a priority portion for mobile. Both Wi-Fi and mobile would be allowed to freely deploy in their respective priority portions. Both systems would be able to use other parts of the band, in channels and places where the other service is not present. For this to be possible, each would have to implement "sense and avoid" techniques for the other service.

B. An indoor/ outdoor split supported by other mobile bands: Managing the amount of overlap between mobile and Wi-Fi is important to simplify the hybrid mechanisms that might be needed to ensure equitable access for both technologies. Using building entry losses to help isolate mobile and Wi-Fi networks could be critical to enabling both services to operate in the same geographical areas. Adjusting the power of mobile base stations, to some degree, will help to limit the overlap further. This would reduce the need for sharing spectrum resources in time or frequency between mobile and Wi-Fi at those overlap locations.

It can be noted that both approaches have significant technical and operational challenges that will not be easily overcome by regulations. CEPT is investigating the topic in great detail and the results are expected to be available in time for decisions at WRC-27.

3.5 National Spectrum Strategy R&D Plan

In the National Spectrum Strategy Research and Development Plan [6], Dynamic Spectrum Sharing (DSS) is used in a more generic way where it "means adaptive coexistence using techniques that enable multiple electromagnetic spectrum users to operate on the same frequencies in the same geographic area without causing harmful interference to other users (in cases where such users have an expectation of protection from harmful interference) by using capabilities that can adjust and optimize electromagnetic spectrum usage in real time or near-real time, consistent with defined regulations and policies for a particular spectrum band"

3.6 5 GHz Dynamic Frequency Management System

The FCC has introduced this concept in the context of allocating spectrum for use by drones in 5030-5091 MHz spectrum [7]. "The Report and Order circulated on April 5, 2024, would rely on dynamic frequency management systems (DFMSs) to manage and coordinate access to the spectrum and enable its safe and efficient use. These DFMSs would provide requesting operators with temporary frequency assignments to support Unmanned Aircraft System (UAS) control link communications with a level of reliability suitable for operations in controlled airspace and other safety-critical circumstances."

3.7 PATHSS Dynamic Spectrum Management System

In the Partnering to Advance Trusted and Holistic Spectrum Solutions (PATHSS) study conducted by the DoD, a concept of Dynamic Spectrum Management System (DSMS) was used to refer to the evolution of the CBRS SAS or 6 GHz AFC, that would be able to manage spectrum sharing between DoD radars and commercial base stations. The details are incorporated in the EMBRSS report for which a redacted version is publicly available [8].

3.8 ITU Coexistence/sharing

ITU has historically used "coexistence" studies to explore where multiple users can use the same spectrum, but WRC-23 saw a change in usage of terminology. Agenda Item 1.7 for WRC-27 has been described as the following: "To consider studies on sharing and compatibility and develop technical conditions for the use of International Mobile Telecommunications (IMT) in the frequency bands 4400 – 4800 MHz, 7125 – 8400 MHz (or parts thereof), and 14.8 – 15.35 GHz taking into account existing primary services operating in these, and adjacent, frequency bands, in accordance with Resolution 256 (WRC-23)."

4 WInnForum's Past Work on the Definition of Spectrum Sharing

WInnForum has studied different types of spectrum sharing in the past [9, 10]. A brief summary of the previous work is captured in this section for sake of maintaining continuity.

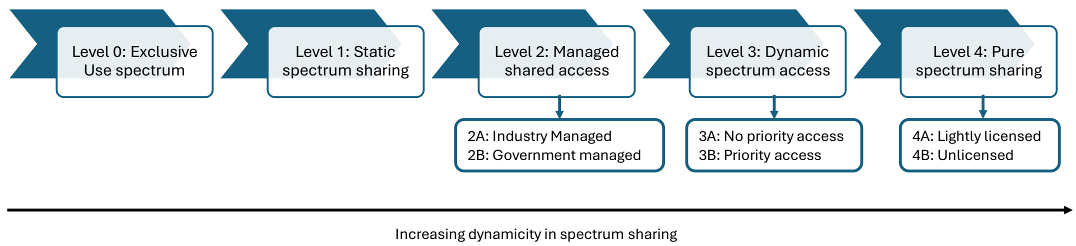


Figure 1: Different types of spectrum sharing

Level 0: Exclusive Use – Spectrum is assigned on an exclusive basis to a primary holder of spectrum rights (primary user) across the regulatory region

Level 1: Static Spectrum Sharing – Exclusive use spectrum is shared by primary users on a geographic basis, not a temporal basis

Level 2A: Industry Managed: Unused exclusive use spectrum in a specific location can be leased by the primary user to a 3rd party on a temporary basis (secondary user)

Level 2B: Government Managed – Exclusive use spectrum in a specific location can be assigned by a regulatory agency on a temporary basis to a 3rd party (secondary user)

Level 3A: No Priority Access – Spectrum access is non-exclusive. Spectrum held by a primary user that is not being utilized in a specific location and at a specific time is available for use by secondary users on a first come, first served basis so long as they do not interfere with the primary user

Level 3B: Priority Access (3 Tier Model) – Spectrum access is non-exclusive. Spectrum held by a primary user that is not being utilized in a specific location and at a specific time is available for use by a secondary user so long as they do not interfere with the primary user.

Level 4A: Lightly Licensed – Spectrum is not assigned to a specific primary user. Use of spectrum is protected while occupied. Rules can exist for length of time spectrum can be occupied.

Level 4B: Unlicensed – Spectrum is not assigned to a specific primary user. Use the spectrum is completely unprotected, and is available to any network or user within limitations/rules/policies established for each band.

5 Examples of Spectrum Sharing for Motivation

Different forms of spectrum sharing have been analyzed by WInnForum members in the past several years and some of them have also been implemented in practice by WInnForum. Below are a few examples, along with some reference to comparative timescale regarding how quickly the sharing mechanism needs to act:

1. CBRS (3.55-3.7 GHz):

Releasing spectrum when federal incumbent user is active in same geography (temporal sharing over pre-defined geography, i.e., DPA Neighborhood, time scale to respond “~5 minutes”)

2. 3.45 GHz Service (3.45-3.55 GHz):

Coordinating in geographical areas (CPAs) where incumbent can be active (coexistence), and actively managing in certain areas (PUAs) at times of radar activity (manual semi-static sharing for now, will be automated in the future)

3. US 6 GHz (5.9-7.125 GHz)

Spectrum use by Wi-Fi or other radio access users, e.g., 5G-NR, in higher power outdoor environment only to make sure it does not cause interference towards licensed 6 GHz Fixed Service or other incumbent users (e.g., radio astronomy). Automatic checks are carried out once a day for any necessary adjustments to spectrum usage (geographical semi-static sharing)

4. Emerging MidBand Radar Spectrum Sharing (EMBRSS) Feasibility Study Assessment Report (3.1-3.45 GHz):

Releasing spectrum when higher priority user is active in same geography (temporal sharing over any geography, potential time scale to respond “10 seconds” or even less)

5. TV White Space (US bands are 54-72, 76-88, 174-216, 470-614, 617-652, and 657-698 MHz. TV White Space bands vary in other countries.)

Unlicensed devices sharing the television band with TV broadcast stations connect to a centralized cloud-based system, called a TV White Space database, to request a list of frequencies on which they can operate. The database contains information on TV stations in the area and informs the device which frequencies are available that are not predicted to cause harmful interference to those stations.

6. Advanced Wireless Service (AWS 3) (1695-2200 MHz)

The AWS frequency range spans 1695 - 2200 MHz and constitutes four segments of paired spectrum. Parts of this spectrum range are subject to sharing requirements. In the 1710 - 1755 MHz band, DoD will continue to operate systems at some locations indefinitely, while transitioning systems out of the band at other locations.

6 Types of Spectrum Users

In order to start the discussion on spectrum sharing, we need to establish a few terms for the sake of common understanding. The word “incumbent” is used here to refer to users of services as already shown in the FCC spectrum allocation table [11]. These incumbents can be “primary” or “secondary” as currently classified in the table. The phrase “new entrant” is used in this document to describe any new user of spectrum expected in a spectrum range, but currently not mentioned in the allocation table or can be a more recent co-primary or secondary user in the allocation table. In case these users are currently not mentioned in the allocation table, they can become co-primary or secondary users in a future allocation, but no such assertion is contemplated in this document. In some rare instances if the sharing implies a secondary user becoming a co-primary user, such examples will be clearly articulated.

If a new allocation is expected in a spectrum range that currently does not exist, the user will be referred to as a “new entrant”. There is no implication as to whether this new entrant will have a primary or secondary allocation in the future, nor does it imply it will have primary or secondary user designation in any regulatory decision.

7 Types of Multi-User Spectrum Access

As mentioned before, spectrum studies in ITU and 3GPP have mostly investigated "coexistence" while US regulators and the industry has delved into "sharing", including some variations of it (e.g., "dynamic sharing"). Below is a brief summary of the main differences between the two concepts, with the goal of establishing a common understanding of the concepts:

Coexistence (Static)	Sharing (Semi-Static, Dynamic, Highly Dynamic)
Operating conditions are static in nature. It is assumed that incumbents do not change their use of spectrum in temporal, geographical, or frequency dimensions.	Operating conditions are dynamic in nature. Incumbents and new entrants share the spectrum in the time dimension.
Incumbents continue service unencumbered. New entrants operate in a way that does not interfere with incumbents.	Incumbents continue to get protection from new entrants, at least in the short term. New entrants take all the responsibility to avoid interference towards incumbents.
New entrant expected to avoid interference towards incumbent. • Maintain separation distance • Avoid radiating in certain directions	Interference mitigation can be achieved through key levers: • Time and possibly frequency, power, geography
Historically no expectation from incumbents to improve Tx/Rx capabilities that could benefit new entrants.	New entrant expected to live with some interference resulting in a certain degree of performance degradation

Table 2: Comparing Coexistence and Sharing in the Context of 3GPP and ITU Spectrum Studies

However, in the context of CBRS, the term "spectrum sharing" and coexistence have been used to refer to different concept as below: Spectrum sharing is a general term that refers to sharing of spectrum among multiple users and is mainly contrasting with the concept of exclusive licensing of spectrum. Sharing may occur among primary (e.g. incumbents) and secondary users, or among users without any primary spectrum authorization. However, the term "Coexistence" refers to methodologies used to share the spectrum among users having the same level of authorization (e.g. among all secondary users). Using this framework, coexistence is a subset of general spectrum sharing methodologies. Additional methodologies needed in a spectrum sharing framework is the incumbent protection schemes.

If we apply this definition to CBRS, the CBRS framework is the spectrum sharing concept that includes federal and non-federal incumbent protection and coexistence among GAA users. Another example is 6 GHz standard power AFC application, where coexistence is mainly performed using WiFi techniques (e.g. Listen Before Talk), 3GPP 5G NR-U, or other proprietary unlicensed techniques.

It can be noted that "sharing" of spectrum can be theoretically implemented in any of the three following dimensions (or combinations thereof): time, geography, frequency. For the purposes of this document, the discussion focuses on the time dimension only and thus dynamic spectrum sharing implies temporal apportioning of spectrum, which can result in more efficient use of spectrum in case the nature of spectrum usage is fundamentally episodic.

7.1 Static

Static Sharing can be viewed as a static form of spectrum sharing, mostly implemented in geographic and/or frequency dimensions but not in the time dimension. Once the operating conditions (location, antenna parameters etc.) for new entrants are established, their operational parameters (e.g., frequency, power etc.) typically do not change over time.

7.2 Sharing

Following the previous discussions, dynamic spectrum sharing involves temporal apportioning of spectrum resources among various users, but the time scale of apportioning will vary upon the applications of all the users, not just incumbents.

7.2.1 Semi-static

This form of spectrum sharing is stable over a substantial period of time. Once the operating conditions (location, power, antenna parameters etc.) for new entrants are established, they will not change in 24 hours (e.g., US 6 GHz).

7.2.2 Dynamic

This form of spectrum sharing will be stable over a relatively short period of time. The new entrant will have to detect operation of incumbent, decide on course of action and execute to reduce interference in a matter of "~5 minutes" (e.g., CBRS for federal incumbent).

7.2.2.1 Highly Dynamic

This form of spectrum sharing will have to be executed at a fairly fast timescale. The fast timescale is essential due to the fact that the incumbent radio characteristics (location, antenna characteristics, height, etc.) change very rapidly. The new entrant will have to detect operation and fast changing characteristics of the incumbent, decide on course of action and execute to reduce interference in a matter of "a few seconds" (e.g., to deal with AWACS for lower 3 GHz). It can be noted that the requirement will be further reduced (e.g., to 1 second or even less) in the future, once more detailed studies and possibly some field trials are carried out.

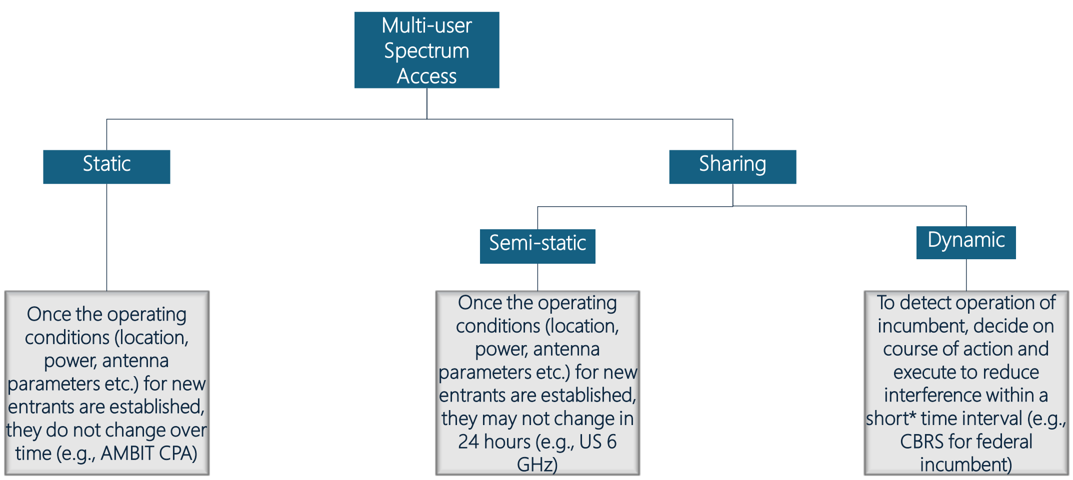
The key is to remember that the time scale is significantly lower than those spectrum management schemes WInnForum has worked on in the past (i.e., CBRS SAS, 6 GHz AFC). The fundamental architecture of these schemes is centralized, i.e., the SAS or AFC decides on the courses of action and instructs the radio network elements about their operating parameters.

A centralized architecture typically requires a number of signaling messages to be exchanged among the various components to establish procedures and this adds up to latency in execution.

Conversely, in a decentralized architecture, the radio network elements themselves will independently take appropriate actions to avoid interference towards incumbents without any centralized decision making entity such as a SAS or AFC system.. Since this requires minimal exchange of signaling messages with external entities, the radio network entities can implement required changes in operating parameters relatively quickly. The low latency requirements necessary to support radar operations in the lower 3 GHz spectrum, will potentially require an implementation architecture that is decentralized.

7.2.3 Summary comparison

Below is a simple comparison chart for the different spectrum sharing types described above:



*Communication with NTIA regarding a demo of "Dynamic Spectrum Sharing" indicated an initial requirement of 10 seconds was desirable.

Figure 2: Different time scales of spectrum sharing

7.2.4 Mission dependent service latency

It can be noted that the time scale for the new entrant to control its transmission to minimize interference towards incumbents will vary depending on many criteria, with the mobility speed of the incumbent being a critical one. While interference towards stationary or slow-moving radars can be managed in relatively longer time scales, faster moving radars, especially airborne ones (e.g., AWACS, SKEs) will require very quick action on part of the spectrum management systems. The figure below provides a schematic view of relative latency challenges:

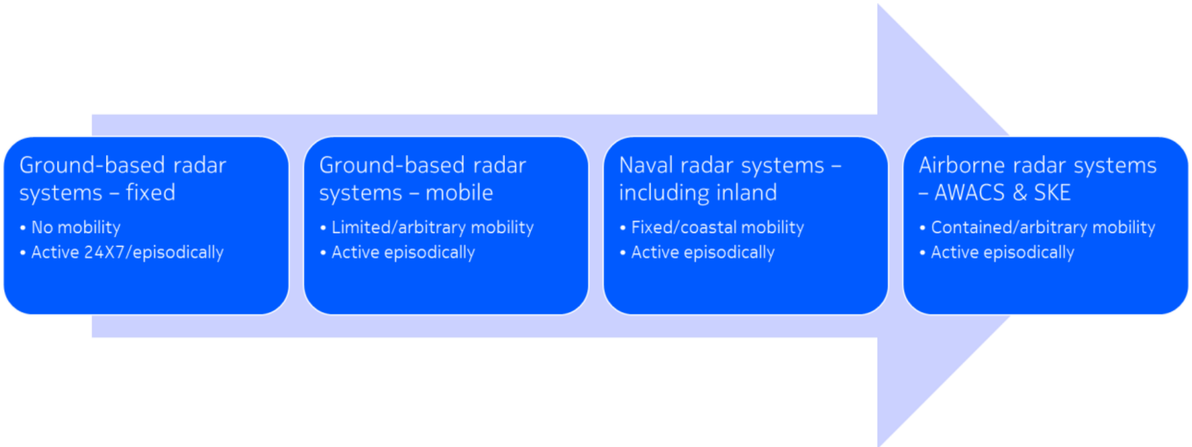


Figure 3: Decreasing time scale for interference management

8 CBRS Incumbent Protection Timeline

In practice, the protection timeline applied in the implementation of CBRS rules and regulations bear the closest resemblance of what will become relevant for 3.1-3.45 GHz spectrum. This section briefly captures the CBRS criteria so one can foresee how similar (though likely much stricter due to potential high-speed mobility of some of the radars) timelines will be applicable in the new spectrum band.

8.1 Relevant Rules and Technical Standards

47 CFR 96.15(b)(4)

Within 300 seconds after the ESC communicates that it has detected a signal from a federal system in a given area, or the SAS is otherwise notified of current federal incumbent use of the band, the SAS must either confirm suspension of the CBSD's operation or its relocation to another unoccupied frequency….

WInnForum TS-0112 R2-ESC-08

Figures of Merit: For a signal exceeding the threshold of detection as established in [NTIA Technical Memorandum 18-527], an ESC shall be capable of detecting, and informing the SAS of, in-band incumbent radar activity within 60 seconds with 99% probability. These time scales and performance characteristics may be adjusted as a consequence of future periodic ESC review. [Ref NTIA Technical Memorandum 18-526.]

NTIA Technical Memorandum TM-18-526 (Distinction between Radar Declaration and Pulse Burst Detection)

[T]here must be two stages in the discovery of radar signals by ESC-SAS combinations: first, a pulse burst detection stage based on a single burst and then a second stage in which detection of one or more radar pulse bursts causes an ESC-SAS to declare that a radar is present in a protection area on some frequency or frequencies.

WInnForum TS-0112 R1-DEV-02

When a CBSD Grant expires, the CBSD shall cease transmissions on the channel within 60 seconds, in accordance with 96.39(c)(2).

47 CFR 96.39(c)(2)

A CBSD must receive and comply with any incoming commands from its associated SAS about any changes to power limits and frequency assignments. A CBSD must cease transmission, move to another frequency range, or change its power level within 60 seconds as instructed by an SAS.

8.2 High-level Reference Architecture for CBRS SAS/ESC implementation

The diagram below captures the key functional elements in CBRS. It is useful for discussions in the next subsection where individual delay budgets are captured.

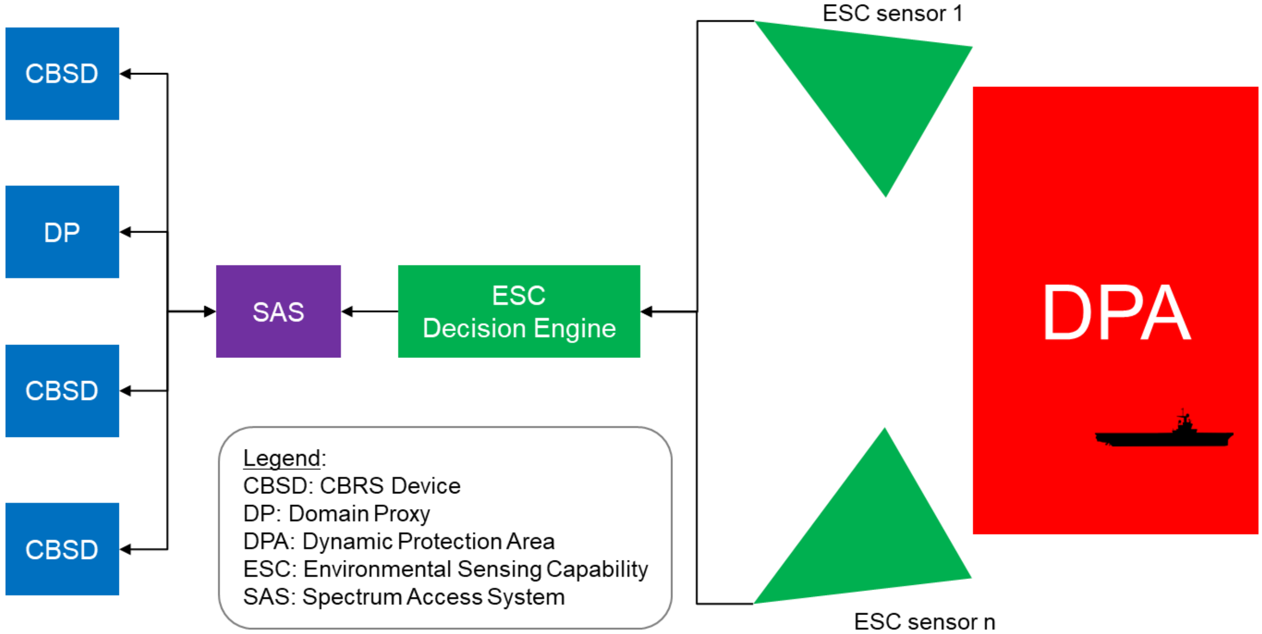


Figure 4: Basic functionality of ESC + SAS

8.3 Timeline for implementation in CBRS

The figure below captures the timelines for individual events so that the over-arching requirements can be met.

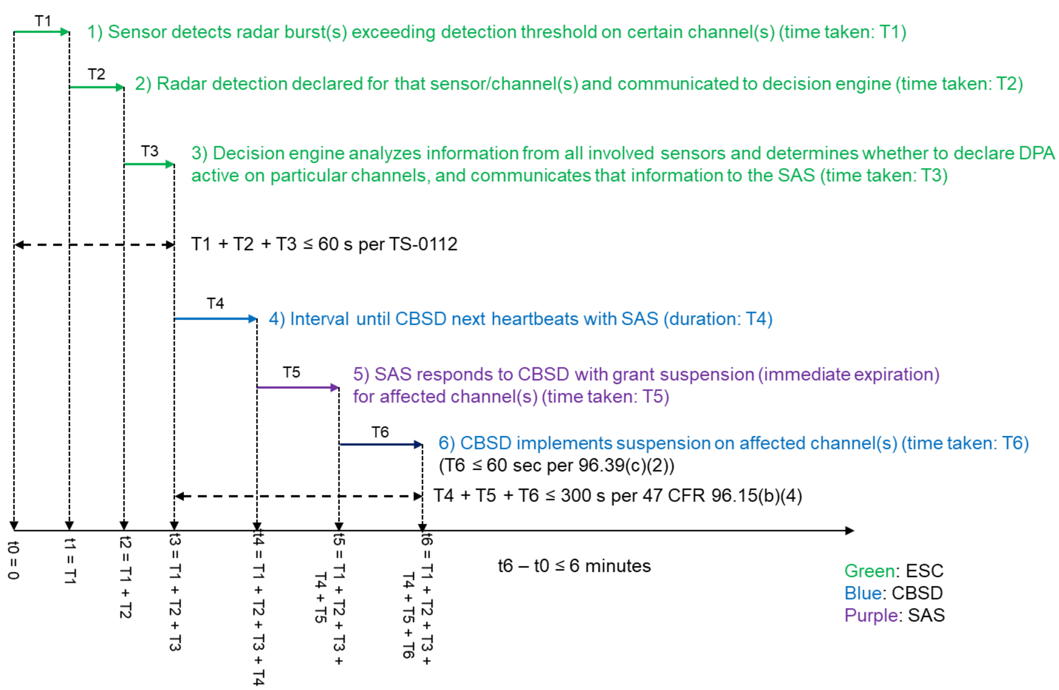


Figure 5: Timeline for individual actions

9 A Closer Look at Time Scale Requirements in 3.1-3.45 GHz spectrum

While latency requirements to mitigate interference at an aggregate level can come from the incumbent, it is important to agree upon the precise conditions. The problem needs to be investigated from two perspectives – incumbent requirements and interference management implementation.

9.1 Incumbent requirements

The incumbent requirements are bounded by two terminal events:1) notification to new entrant or sensing by spectrum management system, and 2) cessation of interference from new entrant. Let us denote this time interval by T_{IR}.

9.1.1 Sensing or Notification of incumbent action

The incumbent activity will be notified to the new spectrum management system, or the system will be able to sense the activity of the incumbent. It is to be noted that it will be necessary for the incumbent to obfuscate or obscure its activity information in order to protect its operational security. The sensing mechanisms will not be able to detect exactly where/when the incumbent has become active, but it will still have to infer that it is time to take action. Similarly, the notification system will convey the need for action without giving precise details about the exact logistics of incumbent activity.

Without loss of generality, it will be assumed that the sensing system will be an independent entity or embedded in the new entrant's radios.

If it is a notification-based system, there is a specific time at which the incumbent sends out the notification. Let this instant be called t_N.

If it is a sensing-based system, there is an expectation from the incumbent that the sensing mechanism would be able to detect its presence. Let this instant be called t_S.

9.1.2 Relief from Interference

This is the time at which the incumbent is no longer experiencing interference from the new entrant. Let us denote this instant as t_R.

9.1.3 Definition of Incumbent Requirement

Based on the discussions above, we get:

$T_{IR} = t_R - t_N$, if the system is notification-based, or

$T_{IR} = t_R – t_S$, if the system is sensing-based

9.2 Interference Management Implementation

From the perspective of spectrum management, there are three key milestones.

9.2.1 Notification Reception or Activity Detection

In the case of a notification-based system, it will be assumed that the instant of notification reception is the time difference between the instant of notification sent by the incumbent (t_N) and the instant at which it is delivered for action, t_D, i.e.,

$$T_{ND} = t_D - t_N.$$

In the case of a sensing-based system, there are further nuances. Let t_A be the instant when the incumbent becomes active, and t_P be the instant when the sensing system positively detects the incumbent activity. Then the time for activity detection is defined as:

$$T_{AP} = t_P – t_A.$$

9.2.2 Course of Action Determination

The time to determine the course of action (TC) is the time interval required for the interference mitigation system to compute the set of base stations that may be impacted by the activation of the incumbent. It also includes the time to decide what action each element must take to mitigate the interference. The interference mitigation system may be either centralized like a SAS or decentralized like a RIC or EMS..

9.2.3 Mitigation Implementation

Finally, this is the time interval (T_M) consumed by the interference management system to implement the interference mitigation action (e.g., null steering, beam muting, PRB Blanking etc.) determined in the previous step.

9.2.4 Total Time for Implementation of Mitigation

Thus, the total time to implement interference mitigation is:

$$T_{IM} = T_{ND} + T_C + T_M, \text{ if the system is notification-based, or}$$

$$T_{IM} = T_{AP} + T_C + T_M, \text{ if the system is sensing-based.}$$

9.3 Matching Requirements with Implementation

Since the time to implement must be short enough for the incumbent to operate without compromising performance, the over-all requirement thus translates to:

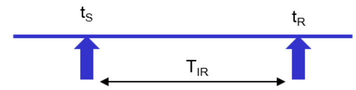
$$T_{IM} \le T_{IR}.$$

It can be noted that the individual components T_{AP}, T_C and T_M will have some flexibility so long as the over-all T_{IM} budget is not exceeded.

The conditions are further illustrated in the figures below.

Incumbent system perspective:

t_S: Instant when commercial system senses incumbent activity
t_R: Instant when incumbent experiences relief from commercial interference
T_{IR}: Time interval for incumbent requirement of relief from commercial interference = $t_R - t_S$

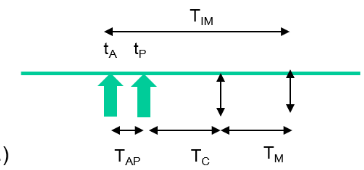


Commercial system perspective:

t_A: Instant when incumbent becomes active
t_P: Instant when the sensing system positively detects incumbent activity
T_{AP}: Time interval for positive identification of incumbent activity = $t_P - t_A$

T_c: Time interval to determine course of action for the spectrum management system

T_M: Time interval to implement interference mitigation (e.g., beam muting, channel shifting etc.)
T_{IM}: Time interval for commercial system to implement interference mitigation = $T_{AP} + T_C + T_M$

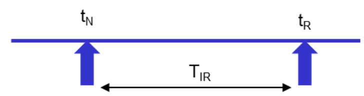


$T_{IM} \leq T_{IR}$

Figure 6: Example with sensors

Incumbent system perspective:

t_N: Instant when incumbent sends out notification of becoming active
t_R: Instant when incumbent experiences relief from commercial interference
T_{IR}: Time interval for incumbent requirement of relief from commercial interference = $t_R - t_N$

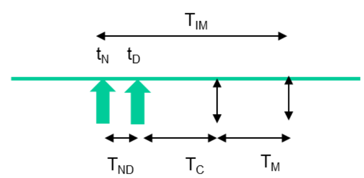


Commercial system perspective:

t_N: Instant when incumbent sends out notification of becoming active
t_D: Instant when the notification is delivered to mitigation system for action
T_{ND}: Time interval reception of notification of incumbent activity = $t_D - t_N$

T_c: Time interval to determine course of action for the spectrum management system

T_M: Time interval to implement interference mitigation (e.g., beam muting, channel shifting etc.)
T_{IM}: Time interval for commercial system to implement interference mitigation = $T_{ND} + T_C + T_M$



$T_{IM} \leq T_{IR}$

Figure 7: Example with notification system

9.4 Real-life Implementation Implications

From the perspective of the incumbent, the following events are highly important:

- Becoming active or sending out notification of becoming active (in the context of t_S or t_N)
- Getting relief from new entrant interference (in the context of t_R and T_{IR})

In implementing interference mitigation, the following events are of critical importance:

- Sensing or notification initiation of incumbent activity (in the context of t_S or t_N)
- Positive identification or notification delivery of incumbent activity (in the context of t_P or t_D)
- Determination of the course of action by the centralized or decentralized mitigation system (in the context of T_C)

- The mitigation system communicating with base stations of necessary actions and the radio network performing necessary implementation actions (in the context of T_M)
- The mitigation system could receive an implicit or explicit indication confirming actions being taken (in the context of T_{IM})

10 Closed Loop (Dynamic) Control

The discussions so far have been limited to an "open loop" system, i.e., the interference mitigation system is supposed to take action "blindly" based on the notification from the incumbent or sensing information. There is no feedback mechanism to learn whether the mitigation action was sufficient or overly conservative. The action is fully dependent on modeling with no real-life feedback to enhance the one-time action.

An alternative, and likely more effective way would be to have a "closed loop" system where the incumbent will be able to provide feedback to the new entrants about the efficacy of their mitigation actions. There could be a series of back-and-forth messages between the incumbent and new entrant systems until the desired level of mitigation is achieved at the incumbent with minimal service disruption for new entrants. Some people have been referring to this type of arrangements as a "Dynamic System". A closed-loop must not increase the time required to provide relief to incumbents. The initial starting action could be based on the conservative approach of open-loop systems (to ensure a speedy mitigation) which could be followed by further actions to relax or tighten the transmission characteristics of the non-federal systems.

It can be noted that the discussion in the previous section about the need to obfuscate/obscure incumbent details due to operational security is still applicable here. Any closed loop system implementation does not fundamentally change the nature of operations of federal systems.

In the spirit of making the most efficient use of available spectrum, it is important for the non-federal system to regain unrestricted access to spectrum as soon as the federal systems stops using it. To that end, there could be a continual checking whether the federal system is active or not and if it is not active, the non-federal system can quickly resume normal operations.

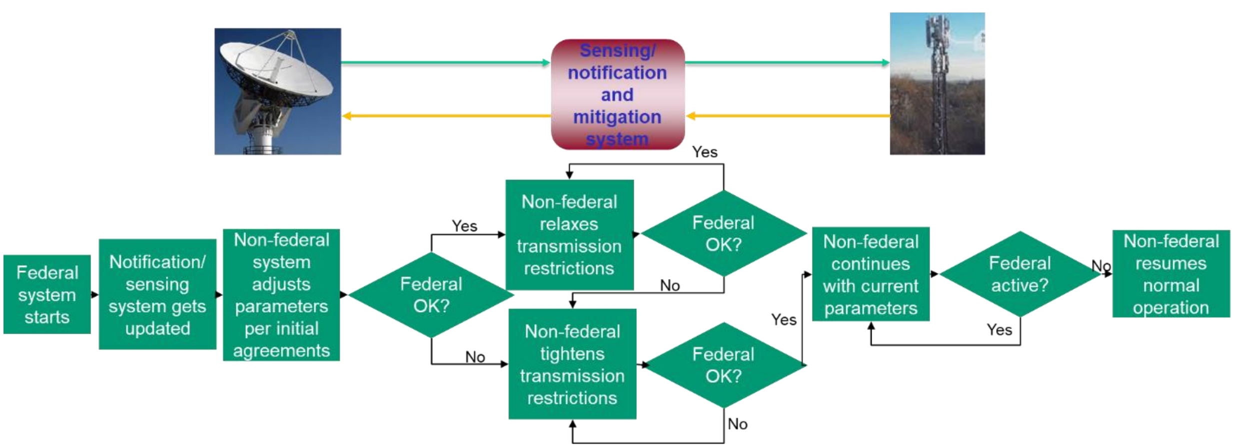


Figure 8: Example of Closed Loop System for Single Incumbent and Single Secondary User

11 Commercial Service Restoration

It can be noted that there is another aspect of the spectrum management system that is equally important for efficient use of spectrum but will not be always recognized – as soon as the incumbents have stopped using the spectrum, the non-federal users would be able to use it. It is just as important to detect (or be notified about) the absence of federal incumbent use and start normal non-federal use as it is to detect federal use and stop non-federal use.

This aspect is particularly important for episodic usage and/or fast-moving federal users, where spectrum will be available for use by non-federal users most of the time.

12 Regulatory Implications

Since currently there exists no regulatory framework for the lower 3 GHz spectrum range, there are no specific items to be captured here. However, we can logically expect technical conditions for sharing to be similar or even stricter than the conditions that exist today for CBRS and the 3.45 GHz service.

13 References

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