DEVELOPMENTS TOWARDS A MORE ROBUST AND DYNAMIC SPECTRUM SHARING FRAMEWORK

Wireless Innovation Forum

Spectrum Sharing Solutions of the Future Webinar

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Link to the Technical Report (WINNF TR-2016)

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Introduction to the Wireless Innovation Forum

501(c)(6) Non-Profit Structure
- Operates under a trade-association model to serve collective industry needs.

Broad, Diverse, and Global Membership
- Unites component vendors, equipment vendors, subsystem vendors, software developers, technology developers, communication service providers, research and engineering organizations, academic institutions, government users, and regulators
- Ensuring wide representation of perspectives.

Mission
- Advancing technologies supporting the innovative utilization of spectrum and the development of wireless communications systems, including essential or critical communications systems.

Neutral, Consensus-Driven Forum
- Provides an impartial environment designed to reach industry-aligned agreements.

Technology-Focused
- Advances innovation by developing practical, forward-looking technical solutions and options.

Standards and Best-Practice Leadership
- Produces specifications, technical reports, and best practices to guide industry adoption.

Regulatory Alignment with Industry Execution
- Translates regulatory direction into actionable, industry-supported ecosystem solutions.

Introduction to the Wireless Innovation Forum

WInnForum Creates Multistakeholder and Domestic/Global Approaches to reach consensus and proffer :

- **Standards/specifications** meeting or exceeding regulatory requirements and agreed upon by the industry.
- **Documents** demonstrating technical **best practices.**
- **Advanced new technical and operational approaches** to the use of communication technology to share use, make use more efficient and effective, and promote deployment, use, and growth**.**
- **State of the Art Methods** of staying current and advancing technologies, use, and best practices for continuous and ongoing use.
- **Constant review and methodologies** with tangible metrics, deployments, and specifications to monitor lessons learned and continually advance, update, and facilitate best outcomes.

Section 1: Purpose

- **Leverage the expertise of WInnForum members to refine and extend the spectrum sharing frameworks standardized in CBRS and 6 GHz to enable potential sharing on significantly more dynamic timescales, and with a wider variety of incumbents**
    - Spectrum Access System (SAS) and AFC system operators
    - CBRS and 6 GHz equipment manufacturers
    - CBRS and 6 GHz network users.
- **Work on this Technical Report (TR) was originally for the purpose of addressing some of the potential challenges and opportunities of the "moonshot" (National Spectrum Strategy)/Advanced Dynamic Spectrum Sharing demonstration (ADSSD via National Spectrum Consortium) (now called Advanced Spectrum Coexistence, ASC)**
- **Resulting Technical Report (TR-2016) has applications beyond ADSSD/ASC, to any future bands (with any mix of incumbents and secondary users) that must be shared on a basis more dynamic than what is being implemented today**

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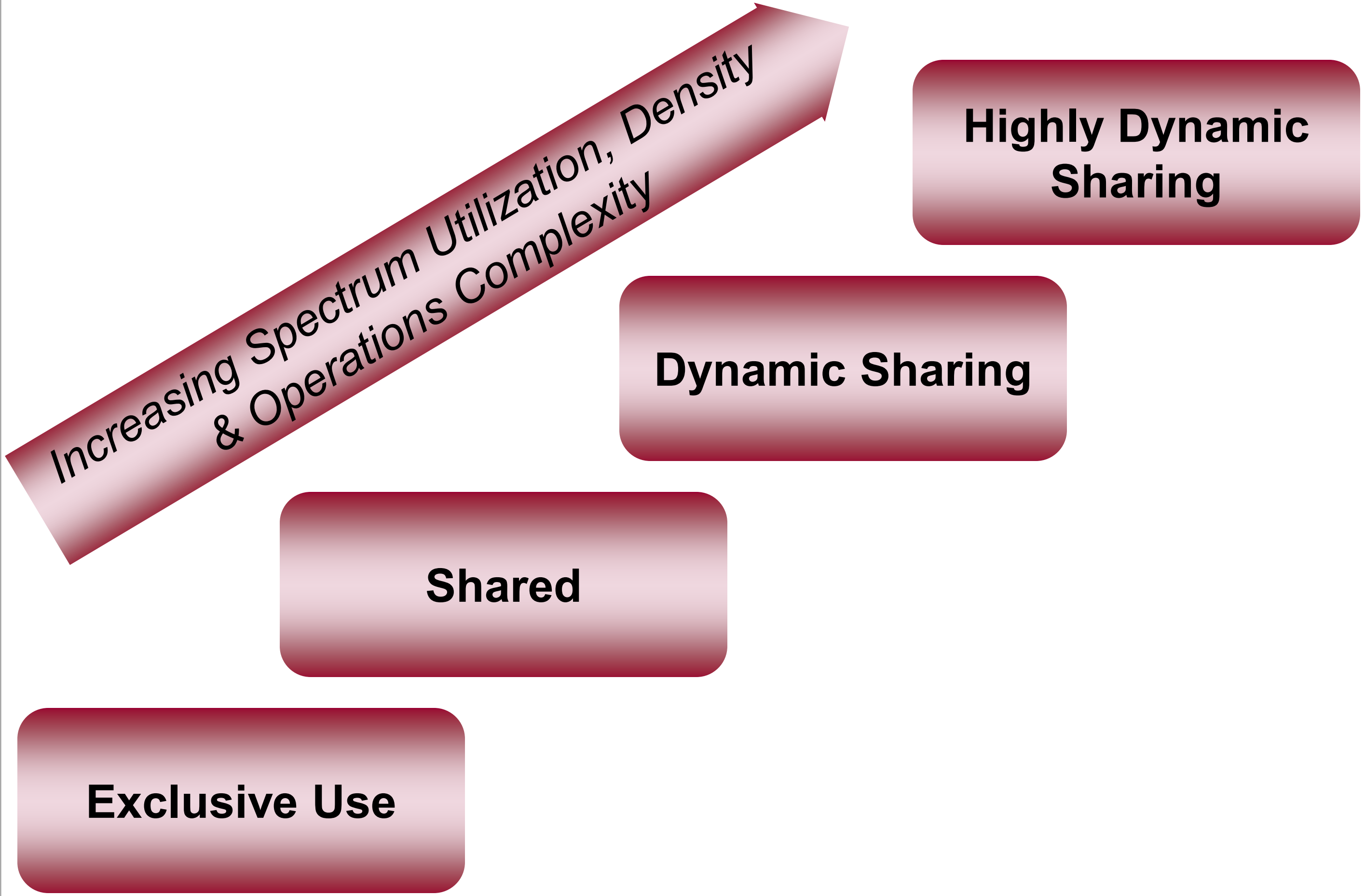
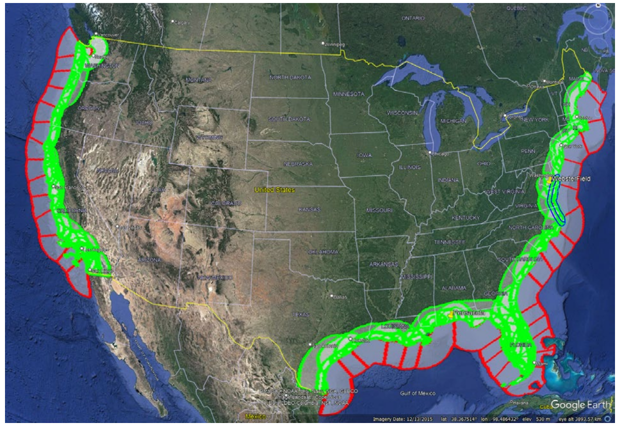
Section 1: Definitions



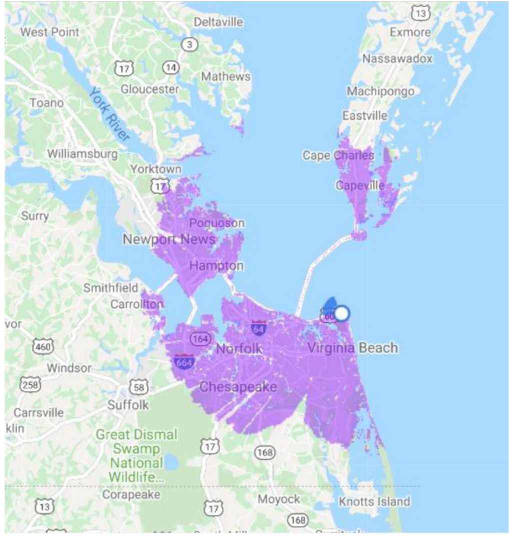
Exemplary Operational Settings	Access Availability & Response Time
Comprehensive incumbent & secondary sharing	Supports semi-static to most dynamic sharing. Sub-second to proactive response times.
Licensed and Un-licensed access. Same frequency, area access without harmful interference	Minutes
Multiple category of users to safely share (NIST) access	Hours to days
Standalone incumbent that defines, controls & internally coordinates access	Non-Time sensitive

Section 2: CBRS

- **Shared spectrum between primary government users and secondary users**
  - Primary: Mostly shipborne Navy radars
  - Secondary: 5G/4G and fixed wireless broadband access
- **Secondary users are managed by Spectrum Access Systems (SAS)**
- **Navy radar is detected by coastal monitoring stations (ESC)**
  - ESC informs SAS
  - SAS reconfigures secondary users as needed to avoid interference to Navy radars
- **Interference avoidance timescales**
  - ESC must detect radars with 99% reliability within 60 seconds
  - Within 5 minutes, secondary users must reconfigure so as to avoid interference
  - End-to-end timescale can be as long as six minutes from radar activation to interference avoidance
- **Other government incumbents such as land-based radars use a web-based portal to inform SAS of activity, in lieu of ESC detection**
  - SAS reads portal every two minutes or better
  - Five minutes for secondary users to reconfigure



DPAs and their neighborhoods



Whisper zones

WInnForum created the standards upon which the CBRS industry operates

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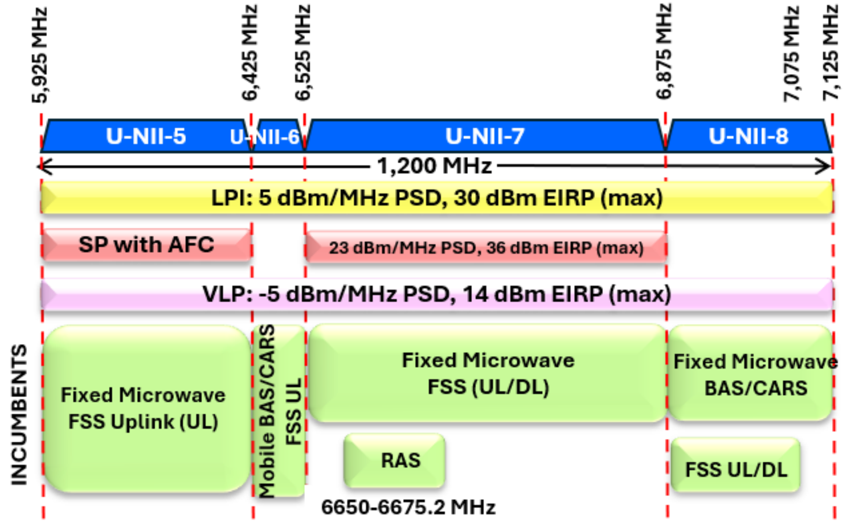
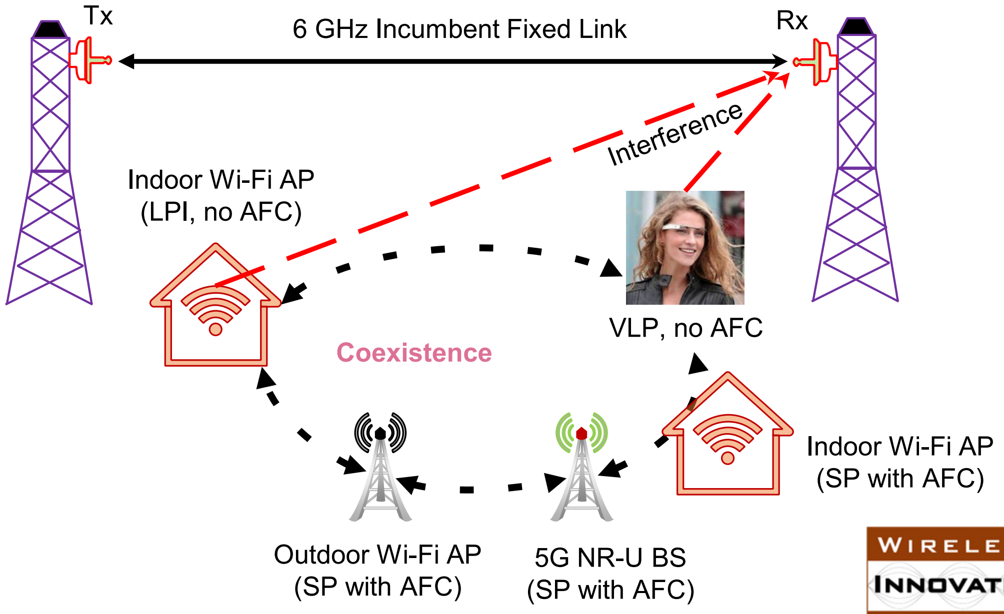
Section 2: 6 GHz Spectrum Sharing Options

- **The FCC 6 GHz sharing rules permit development of variety of use cases, while protecting incumbent users of the band from harmful interference**
  - **Incumbents:** Fixed Microwave links, Fixed Satellite Service (FSS), Broadcast Auxiliary Service (BAS), Cable Television Relay Service (CARS) and Radio Astronomy Services (RAS).
  - **Low-power-indoor (LPI):** Can be only used indoors, across the band, with max power spectral density (PSD) of 5 dBm/MHz and max EIRP of 30 dBm. Require contention-based access mechanism.
  - **Standard Power (SP) with Automated Frequency Coordination (AFC):** Can be used indoors or outdoors, in U-NII-5 (5,925 – 6,425 MHz) and U-NII-7 (6,525 – 6,875 MHz), with higher max PSD of 23 dBm/MHz and max EIRP of 36 dBm. Must check-in with AFC daily.
  - **Very Low Power (VLP):** Can be used indoors or outdoors, across the band, with max PSD of -5 dBm/MHz and max EIRP of 14 dBm. Require contention-based access mechanism.
- **WInnForum collaborated with Wi-Fi Alliance to create the AFC standards.**





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Section 3: Defining Highly Dynamic Spectrum Sharing

Spectrum Sharing (NIST): "… 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.

Dynamic Spectrum Sharing (NSRDP): "…means adaptive coexistence using techniques that enable multiple electromagnetic spectrum users to operate on the same frequencies in the same geographic area… by using capabilities that can adjust and optimize electromagnetic spectrum usage in real time or near-real time.…"

Highly Dynamic Spectrum Sharing (WInnForum): Need for further refinement "…involves temporal apportioning of spectrum resources among various users, but the time scale of apportioning will vary upon the applications. … from slowest "semi-static" to faster "dynamic" to eventually fastest "highly dynamic"

Spectrum Sharing

- Semi-static
  - Once the operating conditions (location, power, antenna parameters etc.) for new entrants are established, they do not change in 24 hours (e.g., AFC-managed devices in the U.S. 6 GHz band)
- Dynamic
  - 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 incumbents)
- Highly Dynamic
  - The new entrant will have to detect operation of an incumbent, decide on a course of action (which can be pre-computed) and execute to reduce interference in a matter of "a few seconds"

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Section 4: Primary User Protection Concepts (1/4)

Spectrum Sharing Protection Types (May be incorporated in one Unified Framework)

- ***Planned Spectrum Sharing:*** PU schedules its spectrum usage in advance and communicate this schedule to Secondary Users (SUs) via a centralized notification system (e.g., portal).
  - Current technologies (e.g. TARDYS3 used in CBRS) support updates with granularity as low as one minute.
- ***Unplanned Spectrum Sharing:*** No advanced PU notification available. PU protection relies on real-time sensing of PU activity.
  - PU Self-Sensing and communicating back to SUs in real time
  - Third-Party Sensing, using external sensor networks (e.g. ESC in CBRS). Sensors require protection from interference.
  - SU-Based Sensing, with Sensing integrated into SU devices

Protected Entity Categorization

- ***Based on the location of the PE:*** PU may be fixed, mobile within an arbitrary or predefined area, or with distributed components requiring protection inside a Protection Area (PA), such as DPA in CBRS.
  - PA applied to both PEs with distributed components, and Mobile PEs to avoid tracking the real-time position of the PE
- ***Based on PE activity:*** Always Active or Intermittently Active Protected Entities
- ***Based on observability of PE activity:*** Detectable PE, requiring protection when PE transmits a signal (e.g. radar), and Undetectable Pes operating in receive-only mode (e.g. radio astronomy)

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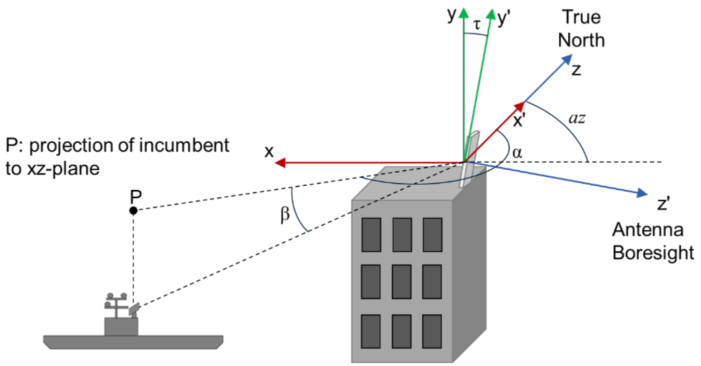
Primary User Protection steps and Methods

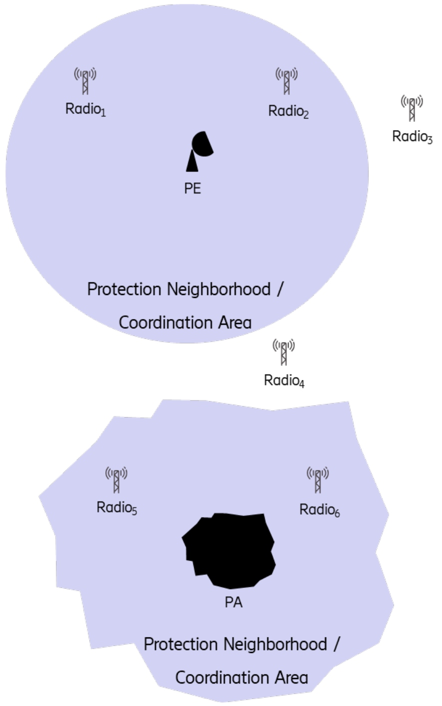
1. ***Determine PU activity (including time, geographical location and frequency range of PU activity)***
   - PU Self-Reporting via Notification Portal
   - PU Self-Sensing with Automated Reporting
   - SU-Based Detection (Passive Sensing)
   - Third-Party Sensor Networks

2. ***Interference Level Estimation, using Max SU Tx power and a pre-defined propagation model using***
   - PE location, height, antenna orientation and characteristics (PE could be grids of PA)
   - SU location, height, antenna orientation and characteristics, as well as transmit power
   - Terrain and Clutter information
   - Requires identification of the direction from the SU toward the PE and applying proper antenna gain/attenuation from both transmitter and receiver



Primary User Protection steps and Methods (Cont'd)

3. ***Identifying List of SUs to apply Mitigation***
    - Considering SU's interference level (or aggregate from SUs) not to exceed PE's Interference Protection Threshold
    - SUs within the Protection Neighborhood/Coordination Areas (areas around the PE/ PA wherein SUs have the potential to cause relevant interference towards the PE/PA) are considered.
        - Applies when SU frequency range overlaps with the frequency range of the PE
        - limits the number of SUs analyzed when determining the interference impact towards the PE/PA.
        - SU unencumbered operation while PE/PA is not active



4. ***Applying Mitigation/Coexistence on determined SUs, could include:***
    - Stop signal Tx on any frequency that have any overlap with PE frequency range
    - Avoid transmission in the PE frequency range (e.g. PRB blanking), allows only portions of the signals to be affected
    - Reduce transmission power
    - Using beamforming, create a null in the direction of the incumbent

5. ***Determine PE Deactivation to stop Protection***
    - Using portal notification or PE activity sensing.

6. ***Apply Deactivation of Mitigation/Coexistence***

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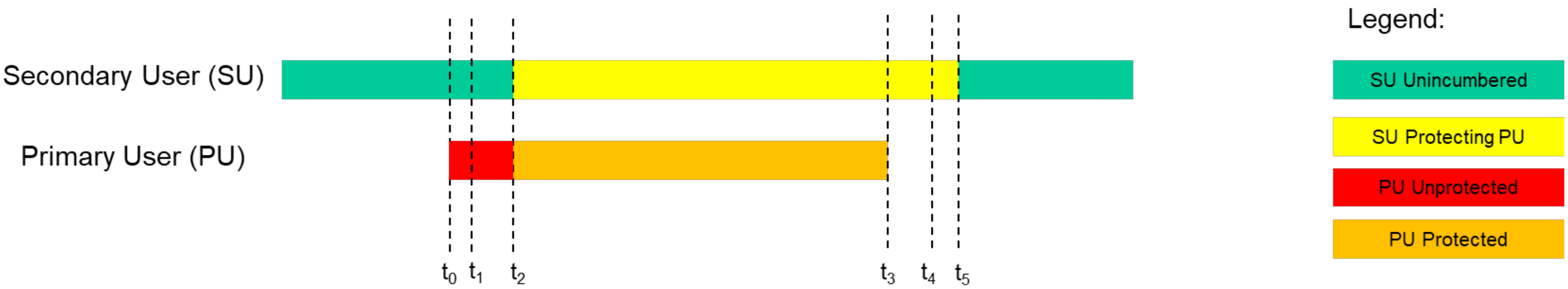
Section 4: Primary User Protection Concepts (4/4)

Timeline for PU and SU Shared Spectrum Usage

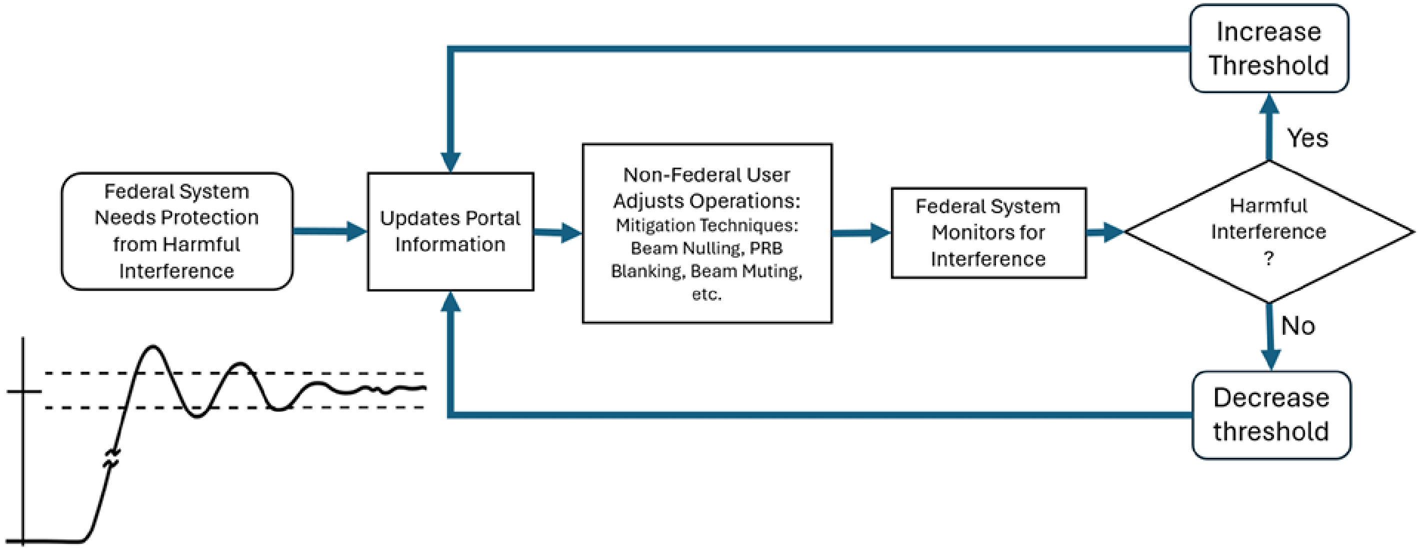
- ***Relevant Time Instants:***
  - t_0 : PU has started using the spectrum;
  - t_1 : PU spectrum activity has been detected;
  - t_2 : SU has activated the mitigation/coexistence;
  - t_3 : PU has stopped using the spectrum;
  - t_4 : cool-off period, when PU is considered no longer active;
  - t_5 : SU has deactivated the mitigation/coexistence features.

- ***Relevant Time Periods:***
  - t_1-t_0 : PU activity detection time
  - t_2-t_1 : Activation of PU protection
  - t_4-t_3 : Cool-off time after PU stops using the spectrum
    - obfuscation of incumbent activity
    - avoid hysteresis effects if the incumbent is inactive for only a brief period of time
  - t_5-t_4 : Deactivation of PU protection



Section 5: Closed-Loop Interference Feedback

- **An adjustable interference threshold can be applied by using a feedback loop on coordination.**
  - In the loop, the Federal System is the Primary User and always monitors the interference and updates this information to a portal, and the non-Federal/Secondary Users read the information in that portal.
  - If the Primary User detects harmful interference, the interference threshold will be decreased (more stringent). Otherwise, it can be increased (relaxed).
  - The Secondary Users adjust their operations based on the updated information on the detection of harmful interference.
- **Several potential benefits**
  - Maximizes access to the spectrum.
  - Feedback reduces reliance on propagation/clutter modeling in coordinating shared access
  - The Primary User is protected from aggregate interference without the complexity of aggregate interference calculation



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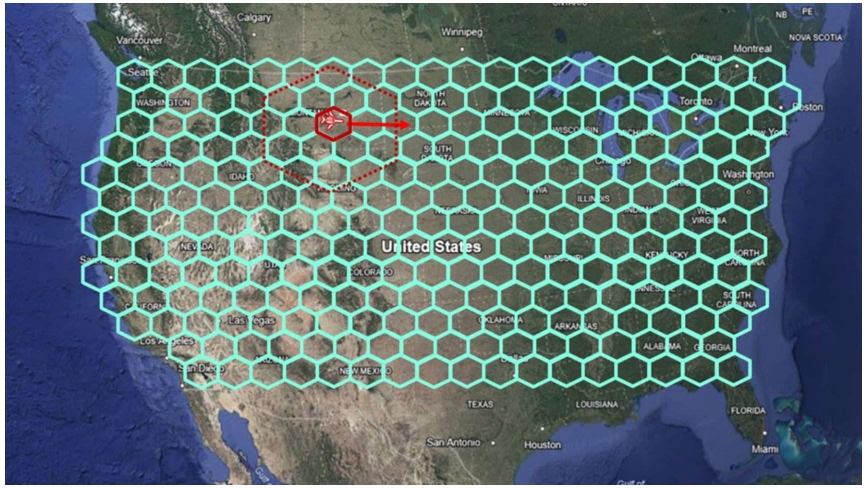
Section 6: Solutions Based on a Notification System -- Airborne

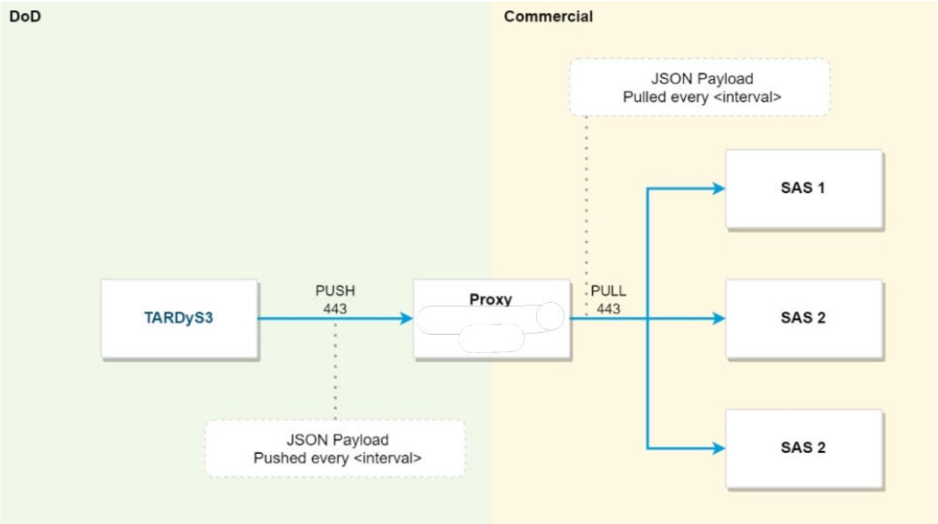
- **The following method is applicable if the Primary User would consider planned spectrum sharing or self-sensing**
  - For example, the portal can start activating a DPA as soon as the plane takes off, and then it can use GPS position to active/deactivate DPAs
- **In the highly-dynamic case, portal-activated DPAs are defined to cover CONUS.**
  - The DPA diameter could be approximately 200 km, which means that the plane would take 20 min to traverse the DPA at a cruising speed of 600 km/h.
  - The DPAs can be distributed in a 21 x 14 honeycomb matrix, as shown in the figure below.
  - If the plane is operating at a higher speed than the normal cruising speed, there is an option to activate a cluster of DPAs to reduce the rate of DPA activations/deactivations.

The figure illustrates the DPA matrix, with the red DPA being active, the dotted red line represents the Protection Neighborhood of the DPA and the red arrow represents the plane's travelling direction



Section 6: Solutions Based on a Notification System – TARDyS3

- **TARDyS3 (Telecom Advanced Research and Dynamic Spectrum Sharing System) is an example of a portal**
- **TARDyS3 notifies SASs by sending upcoming events to an HTTP storage proxy (referred to as the proxy), and the SASs retrieve the data from the proxy**
- **The data are in JSON format, and therefore easily extensible**
  - It can be extended to all kinds of incumbents that exist in the 3.1 GHz band or other bands
  - An example of extensibility so as to support highly-dynamic spectrum sharing is to move the incumbent's protection criterion from a static value stored in a KML file to a dynamic value (perhaps as the result of interference feedback) communicated by the portal



The current portal architecture for TARDyS3, which works well for CBRS and can be easily extended

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Section 7: Solutions Based on Sensing

- **Sensing to enable spectrum sharing can be performed by RAN and/or devices designed to determine clutter loss or sense incumbent signals**
- **Clutter sensing**
  - Commercial systems are often deployed in urban and suburban environments with antennas situated below clutter, such as in- or around buildings and vegetation
  - The signals from these radios undergo additional (clutter) losses before reaching the incumbent
  - Propagation models (such as ITM) either don't model clutter loss or the loss modeled is statistical in nature (ITU-R P.2108, eHata, etc.)
  - No model exists for antenna heights close to clutter height (low elevation angles, antenna heights <6m)
  - Site-specific clutter sensing / measuring (for any antenna height) allows the commercial system to use the spectrum more efficiently without causing interference to incumbents
- **Incumbent sensing**
  - A commercial system may avoid interference to incumbents by sensing their signals without the need for propagation modeling, which is generally conservative
  - Sensing of incumbent signals by standalone systems (such as ESC) still requires propagation modeling to determine the propagation loss between the commercial system and incumbent
  - RAN and device-based sensing can augment standalone sensing to make spectrum sharing more efficient

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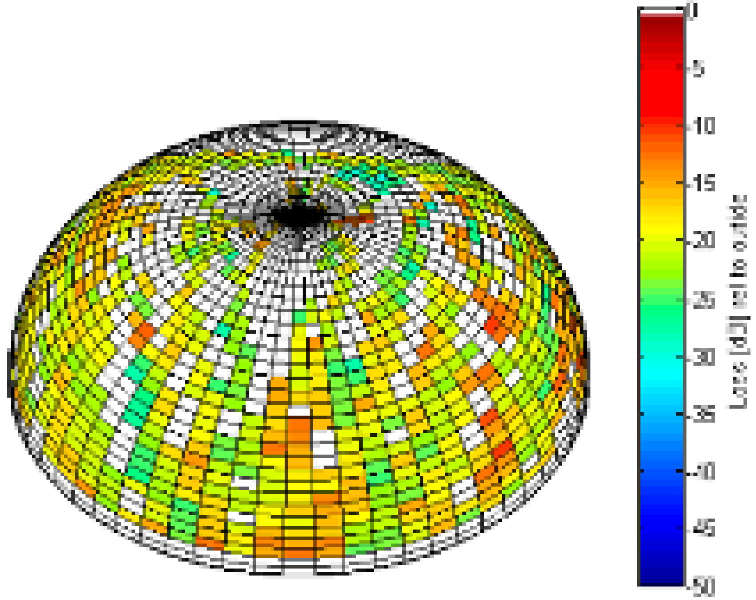
Section 7: Clutter Sensing using External Signals

- **External signals, such as GPS, GNSS, LEO PNT, ADS-B, can be used at RAN-embedded sensors to measure propagation loss through buildings and clutter**
- **Difference between a sensor-measured signal strength (through clutter) and a known reference signal strength (without clutter) is projected to the mid-band frequency of concern to determine clutter loss**
- **A 3D map of clutter loss is created around each RAN node by calibrating loss from known satellites at different angles**
- **Pros and Cons**
  - Accurate clutter loss determination per site and angle of tx
  - Adapts to changing clutter environment
  - Passive method, does not require active incumbent sensing
  - Requires RAN to share clutter loss map with spectrum manager, or
  - Requires RAN to know incumbent location to determine propagation loss toward incumbent directly without spectrum manager
  - Determining loss at low elevation angles at horizon may be challenging



Site-specific 3D clutter loss

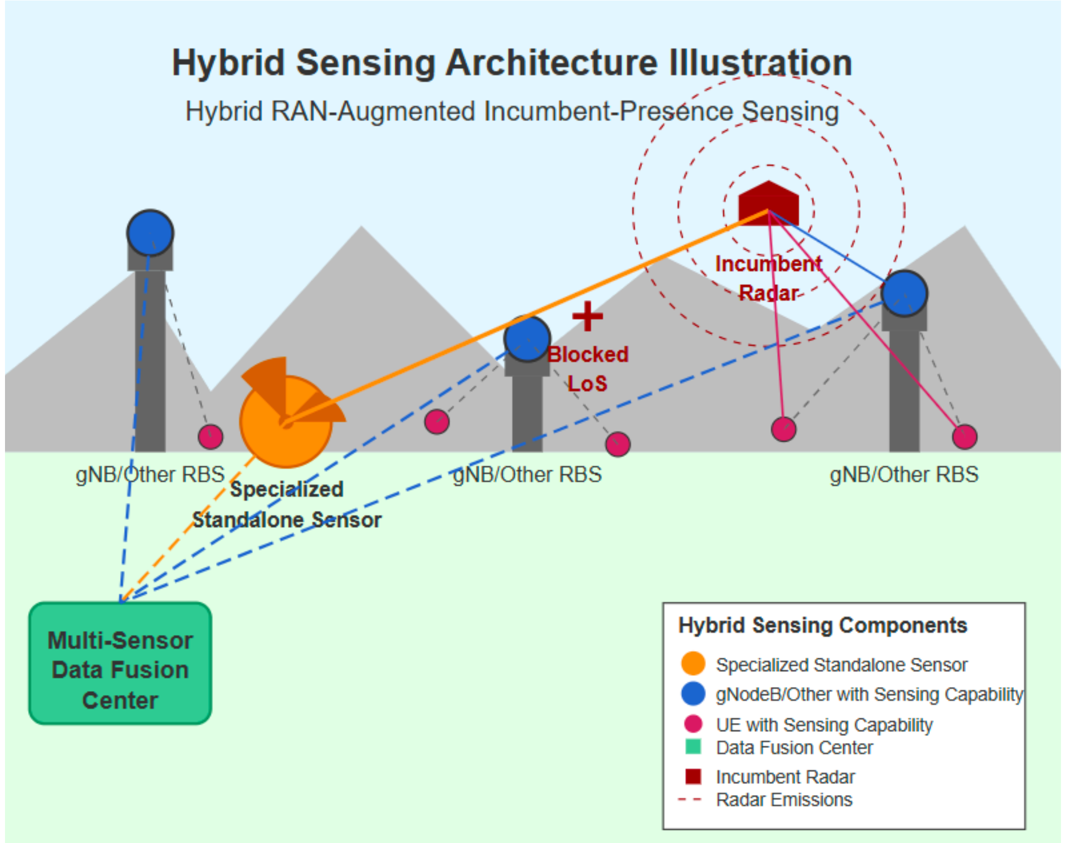
Section 7: Clutter Sensing using Internal Signals

- **Integrated Sensing and Communication (ISAC) is a new technology that integrates sensing of passive objects into the mobile communication system**
- **RAN node(s) with ISAC capability can sense and map clutter around them**
- **Propagation loss can be determined between each RAN node and each incumbent by site-specific modeling, including the effects of both terrain and clutter present along the path**
- **Pros and Cons**
  - Accurate clutter loss determination per site and angle of tx
  - Adapts to changing clutter environment
  - Passive method, does not require active incumbent sensing
  - Emerging ecosystem of 3GPP and IEEE RAN with ISAC
  - Requires RAN to share clutter loss map with spectrum manager, or
  - Requires RAN to know incumbent location to determine propagation loss toward incumbent directly without spectrum manager

Site-specific clutter loss determination using ISAC

Section 7: Incumbent Sensing using RAN and Device

- **RAN and UE / device embedded sensors may sense incumbent radar signals / waveforms**
- **Hybrid approach combining ESC based sensing with a distributed RAN / UE based sensing can improve sensing performance (detection, false alarm) through diversity**
- **RAN can coordinate quiet periods for its UE / client devices to sense incumbent signals and report incumbent presence. E.g., IEEE 802.22**
- **Pros and Cons**
  - Improves spectrum sharing by avoiding interference when and where it exists rather than based on models
  - Improves incumbent signal sensing performance
  - Requires scheduling of quiet periods / coordination among various sensors
  - Requires information sharing across sensors
  - Requires knowledge of incumbent signal waveforms



Section 8: Conclusions & Where Do We Go From Here?

- **TR-2016 has presented considerations related to spectrum sharing in highly dynamic environments:**
  - Reducing the time over which secondary users react to changes in incumbent use from 24 hours (AFC) and 5 minutes (CBRS) to potentially seconds
  - Various incumbent detection/informing methods and their application of highly-dynamic spectrum sharing (HDSS), including:
    - Portal, including extensions to TARDyS3 to support HDSS
    - Dedicated sensing, RAN-based sensing, and hybrid models
    - Improvements to propagation prediction, such as the use of known signals for in-situ clutter loss characterization
  - The use of closed-loop interference reporting to reduce dependence on propagation models altogether while ensuring incumbent protection
- **Going forward**
  - The Technical Report will be applicable to, for example, any potential sharing in the 3.1 GHz band, but also applies to essentially any future band in which sharing on a significantly more dynamic timescale than achieved to date may be necessary (2.7 GHz, 4 GHz, 7 GHz, and others)
  - The first release of TR-2016 was to meet ADSSD/ASC timescales
  - The HDSS task group is continuing discussions and will be issuing subsequent releases with additional refinements