Spectrum Sharing for License-Exempt and License-Light Use: A Practical Guide

Michael Daum
Director of Technology Policy CELA – Telecom
Microsoft Corporation

United States Telecommunication Training Institute
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Overview and Background

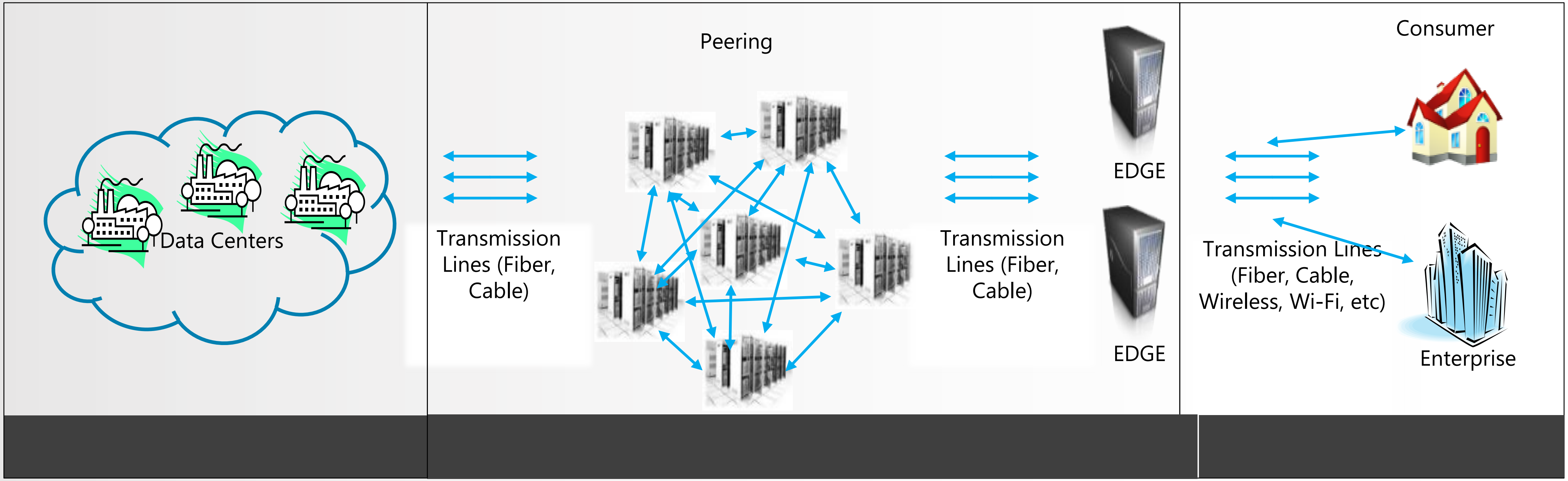
Microsoft Corporation

Microsoft Mission
Empower every person and every organization on the planet to achieve more.

Satya Nadella

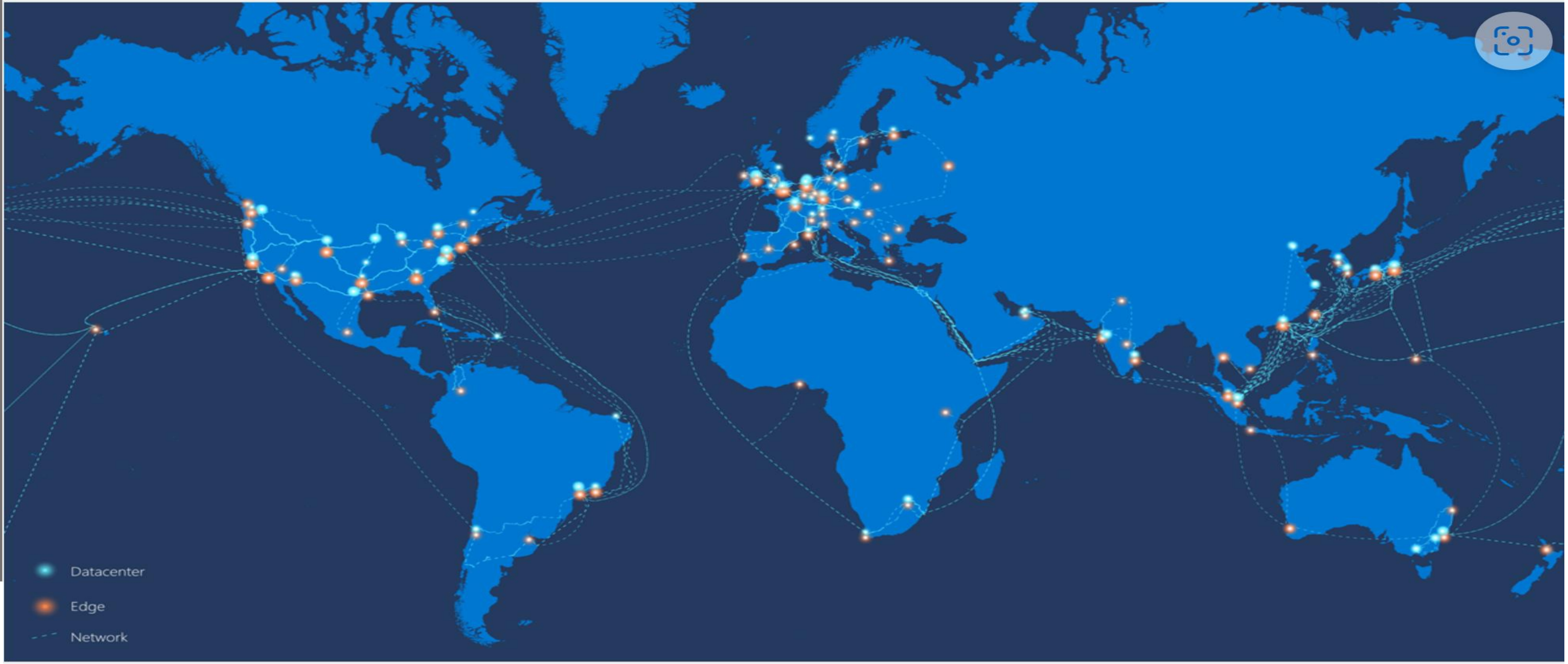
Microsoft Corporation

End-to-end Connectivity Underpins Cloud Computing



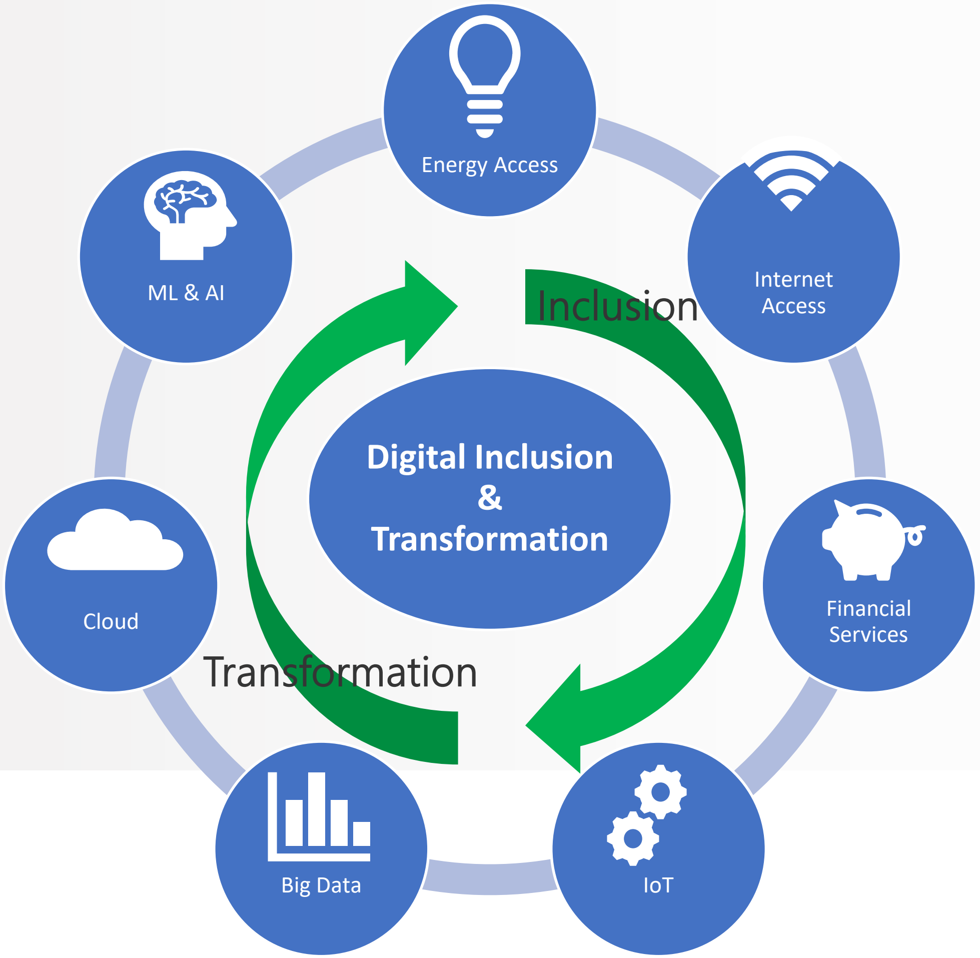
Microsoft Corporation

Microsoft's Global Network



Microsoft Corporation

Digital Transformation Starts with Digital Inclusion



Microsoft Corporation

AIRBAND PROGRAM MISSION STATEMENT

High-Speed Internet Access as a Fundamental Right

Our Mission

Microsoft is committed to help advance fundamental rights such as the ability to learn, create, share ideas, work together, and communicate.

Meaningful Connectivity

Technology plays a pivotal role in either supporting or hurting the protection of people's fundamental rights.

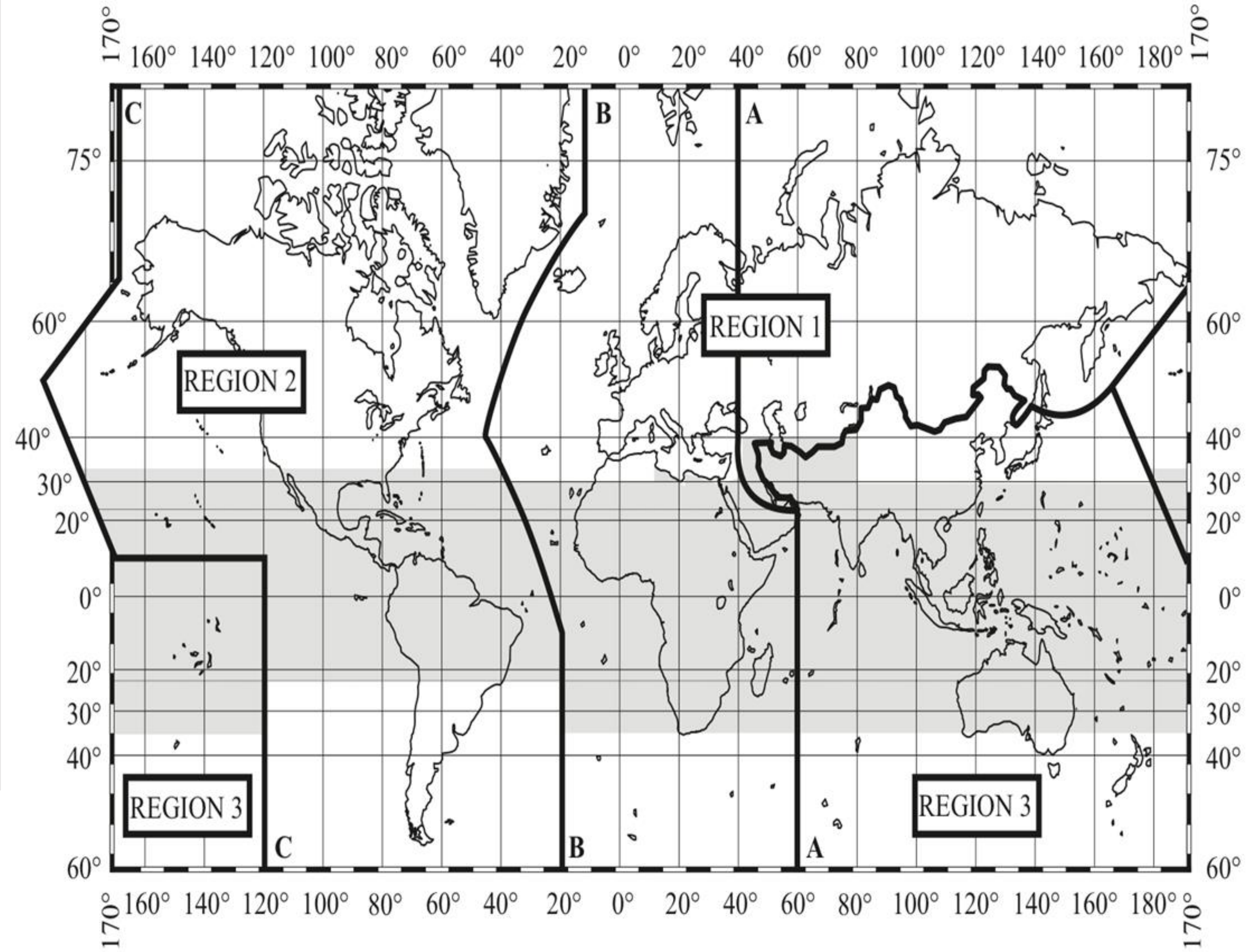
Access to high-speed internet

2.7 billion people around the world are not using the internet, which limits their ability to learn and interact with the world.

International Telecommunication Union (ITU)

- United Nations specialized agency for information and communications technologies.
- Founded 1865. Purpose has evolved over time.
- Headquarters in Geneva, Switzerland.
- Current membership – 193 countries, over 450 private sector organizations and academic members.
- Treaty – based organization.

International Telecommunication Union (ITU)



Regional Organizations

ITU Region 1

CEPT

ASMG

ATU

RCC

ITU Region 2

CITEL

ITU Region 3

APT

International Telecommunication Union (ITU)

Legal Framework

- Constitution
- Convention
- Radio Regulations / International Telecommunications Regulations

ITU Sectors

- ITU-Standards (ITU-T)
- ITU-Radiocommunication (ITU-R)
- ITU-Development (ITU-D)

International Telecommunication Union (ITU)

Radio Regulations (RR)

- Incorporates the decisions of the World Radiocommunications Conference.
- Legal instrument for international coordination of spectrum use.
- Provisions binding on ITU Member States.
- Consists of Articles, Appendices, ITU-R Recommendations incorporated by reference, WRC Resolutions and Recommendations.
- Modified /Revised during the Radio Assembly (RA) and World Radio Conference (WRC) held every four years.

International Telecommunication Union (ITU)

ITU-R Study Groups

- SG1: Spectrum Management
- SG3: Radiowave Propagation
- SG4: Satellite Services
- SG5: Terrestrial Services
- SG6: Broadcasting Services
- SG7: Science Services
- Coordination Committee for Vocabulary (CCV)

- Work of each ITU-R study group is directed by outcome of the previous WRC and RA. Coexistence and /or sharing studies are usually required to see if a proposed new radiocommunication service allocation or identification of an application of a radiocommunication service for a specific frequency band is feasible.
- <u>Output:</u> Recommendations, Reports, Handbooks and Questions.

- WRC – Through consensus, revises the Radio Regulations and any associated Frequency Allocation / Allotments, as appropriate; address any radiocommunication matter of worldwide or ITU regional character; determine the areas of study by the Study Groups in preparation for future WRCs, now held every 4 years. <u>Output:</u> Changes to the RRs. Changes to -, and new Resolutions directing new efforts.

- RA - Approves ITU-R Recommendations and Questions developed by the ITU-R Study Groups and sets the new work program for Study Groups. It can add new Questions or modify existing ones. The RA is held the week before the WRC.

International Telecommunication Union (ITU)

The RR classifies services that use radio communications by:

- Type of coverage, link type, type of use

Spectrum allocations are granted to Radiocommunications Services

- 41 different services. There can be multiple applications within a radiocommunications service, but the service is technology neutral. Applications do not have separate spectrum allocations, but application(s) can be 'identified' for spectrum allocated to a radiocommunication service. 'Identification' amounts to a market signaling mechanism. There are no conditions for sharing and coexistence between applications (IMT vs MGWS in the 66-71 GHz band)
- Services can be PRIMARY or secondary in a band. License-exempt spectrum is not even secondary.
- Geographically- and frequency-band based
- Footnotes – Can be geographic, can 'identify band', can 'designate band'
- Captured in the International Table of Frequency Allocations (ITFA) that covers each ITU Region.

International Telecommunication Union (ITU)

The RR defines the different types of radio stations (53 station types):

- Terrestrial, space
- Land, sea, air
- Fixed, mobile
- Broadcasting, amateur radio, etc.

Spectrum assignments are grants to Radiocommunications Stations.

Administrations provide the authorization for a radio station to use a radio frequency or radio frequency channel under specified conditions.

National Table of Frequency Allocations capture the ITFA plus any national footnotes.

Unlike ITU service allocations, a national table can associate national allocations to applications and/or technologies and can include channel plans.

International Telecommunication Union (ITU)

Key Radio Regulations

RR 18.1 No transmitting station may be established or operated by a private person or by any enterprise without a license issued in an appropriate form and in conformity with the provisions of these Regulations by or on behalf of the government of the country to which the station in question is subject.

RR 4.4 Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in this Chapter or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.

National Regulatory Agencies – Licensed, License-Exempt, and License-Light

License spectrum for exclusive use

- Originally to prevent harmful interference
- Evolved to also focus on generating revenues
- Characterized by low spectrum capacity utilization
- Intra-service local interference often addressed through coordination agreements.

License-exempt or unlicensed use

- Around for longer than people think
- Power limits in most bands limit practical commercial use (U.S. FCC Part 15 rules)
- First in ISM bands – operate at meaningful power levels, learn how to operate in noisy environments
- As technologies have evolved, sharing in bands with licensed users.
- *De minimis* set of rules / Type certification

National Regulatory Agencies – Licensed, License-Exempt, and License-Light

License-light

- A much more recent development.
- Licensed by rule.
- Most often focused on increasing local capacity for industrial use / verticals (U.S. CBRS the exception).
- Licenses are geographically based.
- Usually, first come first served.
- Manually coordination by the national regulatory agency (except for U.S.)
- Germany was first.

National Regulatory Agencies – Licensed, License-Exempt, and License-Light

License-Light Regulatory Efforts

Europe

- Austria (24.3-24.9 GHz proposed)
- Belgium (3.8-4.2 GHz proposed)
- Denmark (3.8-4.2 GHz / 24.25-24.65 GHz)
- Finland (2.30-2.32 GHz / 24.25-25.1 GHz)
- France (2575-2615 MHz, 3.8-4.0 GHz test license, 26.5-27.5 GHz test license)
- Germany (3.7-3.8 GHz)
- Netherlands (1800 MHz, 3.4-3.45 GHz, 3.75-3.8 GHz, 3.8-4.2 GHz pilot, 26 GHz bands)
- Spain (2370-2390 MHz, 24.24-24.70 GHz)
- Sweden (1780-1785 / 1875 – 1880 MHz, 3720-3800 MHz, 24.25-25.1 GHz)
- United Kingdom: (1781-1785 / 1876.7 – 1880 MHz, 2380-2400 MHz, 3.8-4.2, 24,25-26.5 GHz)

Middle East

- Bahrain (3.8-4.2 GHz)
- Saudi Arabia (4.0-4.2 GHz proposed)
- UAE (4.0-4.2 GHz proposed)

North America

- Canada (3.90-3.98 MHz, 26.7-28.3 MHz, 38.4-40.0 GHz)
- United States (3.55-3.70 MHz)

South America

- Brazil (3.7-3.8 MHz)
- Chile (3750-3800 MHz)

Asia-Pacific

- Australia (3.7-3.8 GHz remote, 3.8-4.0 GHz)
- Japan (4.6-4.9 GHz, 28.2-29.1 GHz)
- Korea (28.9-29.5 GHz)

Spectrum Sharing Mechanisms

ITU-R Recommendations which address sharing between services

	Interferer:									
Victim:	**Broad-casting**	**Fixed**	**Mobile**	**EESS/ SR/SO**	**MSS**	**FSS**	**Radio-navigation**	**Radio-location**	**Met-sat/Met-aids**	**Inter-satellite**
Broadcasting		SM.851	SM.851							
Fixed	SM.851		F.1402	SA.1258 SA.1277 F.1502	M.1469 M.1472 M.1473 M.1474	SF.1006 SF.1486				
Mobile	SM.851	F.1402		SA.1154 SA.1277						
EESS/SR/SO		F.761 F.1247 SA.1277	SA.1154 SA.1277			S.1069 SA.1277 RS.1449			SA.1277	
MSS				SA.1277					RS.1264	
FSS		SF.1006 SF.1486	S.1426 S.1427 M.1454	SA.1277			S.1068 S.1151 S.1340			
Radio-navigation					S.1341	S.1151				
Radiolocation										
Met-sat/Met-aids					SA.1158 RS.1264					
Inter-satellite										
RNSS				RS.1347	M.1470					
Radio-astronomy[(1)]										
Aeronautical	SM.1009									

Source: ITU Handbook of Spectrum Management

Spectrum Sharing Mechanisms

Spectrum Sharing Can Be Based on:

- Time Separation [e.g., duty cycle control, dynamic real time frequency assignments, carrier sense multiple access]

- Frequency Separation [e.g., channeling plans, band segmentation, control of emission spectrum characteristics, dynamic variable partitioning, frequency tolerance limitation, pilot channel, dynamic sharing (e.g., dynamic spectrum access)]

- Spatial Location Separation [e.g., geographically shared allocations, site separation, antenna system characteristics, physical barriers / site shielding / building entry loss, transmit power control]

- Signal Separation [e.g., signal coding and processing, forward error correction, spread spectrum (direct sequence, frequency hopping, pulsed FM), Interference power / bandwidth adjustments (dynamic transmitter level control, power flux density (pfd) limitation and power spectral density (psd) limitation (energy dispersal), modulation complexity), antenna polarization.]

….. and combinations of the above

Dynamic Spectrum Access

Dynamic Spectrum Access

- Stands for the ability of a radio (possibly via implementing cognitive capabilities) to operate on temporarily unused / unoccupied spectrum and to adapt or cease the use of such spectrum in response to other users of the band.
- Allows for real-time adjustment of spectrum use in response to changing environment and circumstance and objectives. It starts with the protection of the incubent.
- Dynamic Spectrum Access technologies and techniques allow a radio device to:
  - Evaluate its radio frequency environment;
  - Determine which frequencies are available for use on a non-interference basis;
  - Operate on those frequencies; and
  - Vacate those frequencies when required.

Dynamic Spectrum Access

Software Defined Radio and Cognitive Radio at the ITU

- Origins are in the HF and MF bands over 25 years ago where operators had to adjust parameters for long-distance radios after accounting for different factors

- Cognitive Radio (CR)

  A radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained. [ITU-R Report SM.2152]

- Software Defined Radio (SDR)

  A radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard. [ITU-R SM.2152]

Dynamic Spectrum Access

Software Defined Radio and Cognitive Radio at the ITU

WRC-07

- **Resolutions 805 (WRC-07)** and **956 (WRC-07)** asked the responsible Study Groups and Working Parties to examine, respectively, software defined radio and cognitive radio.

- The fundamental question was whether these spectrum sharing technologies could operate under the existing international regulatory framework, i.e., the Radio Regulations.

WRC-12

- Recommendation 76 (WRC-12) stated that the Radio Regulations have enough flexibility to accommodate services that incorporate software defined radio and cognitive defined radio and that no new international framework was necessary. The Recommendation did make it clear that services incorporating these spectrum sharing technologies must operate according to the Radio Regulations and protect stations operating according to the Radio Regulations.

- Relevant Study Groups : (ITU-R WP 1A, ITU-R WP 5A)

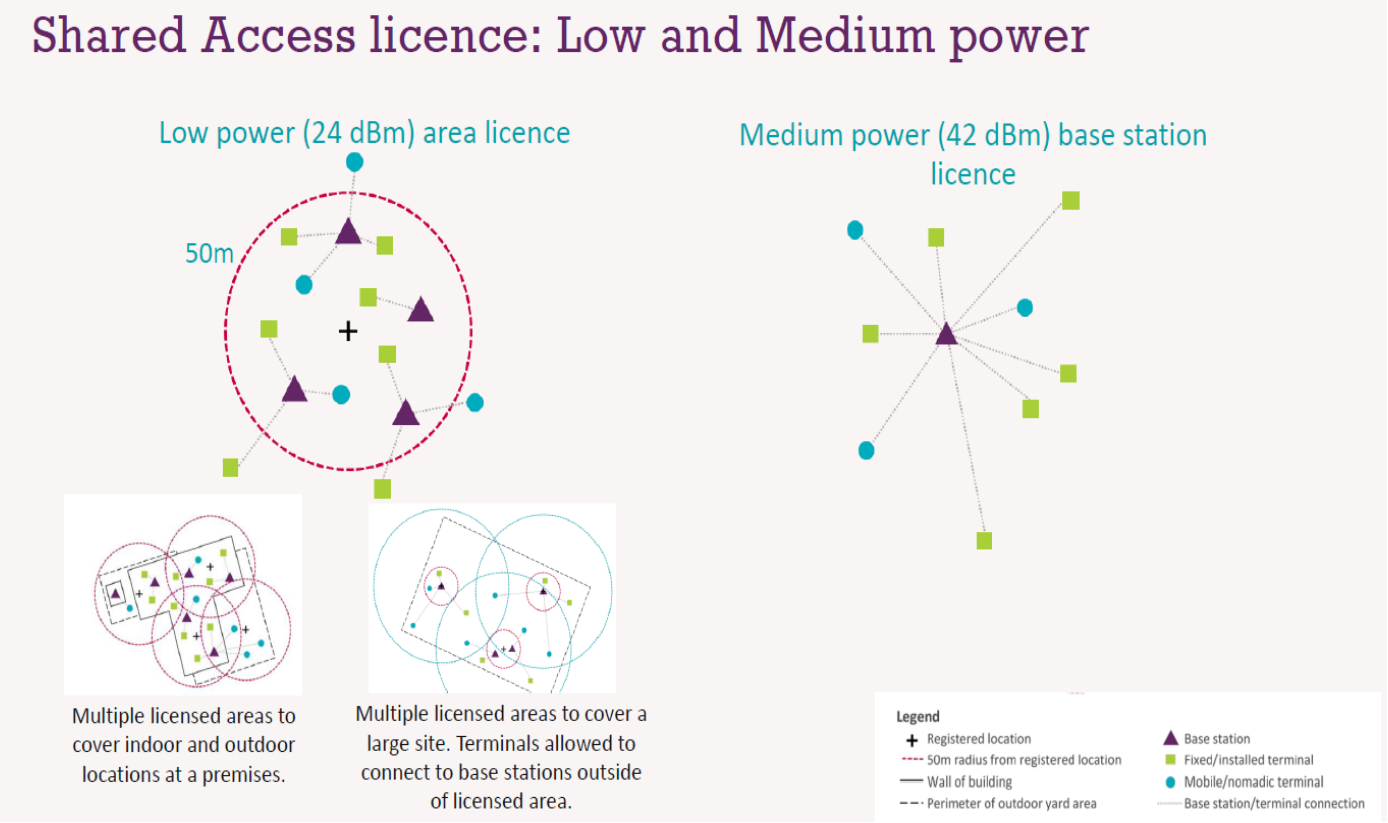
Non-Database Sharing Approaches and Examples

Non-Database Sharing Approaches

Administrative Approaches and Coordination Agreements between stakeholders

<u>Local Licensing (UK)</u>

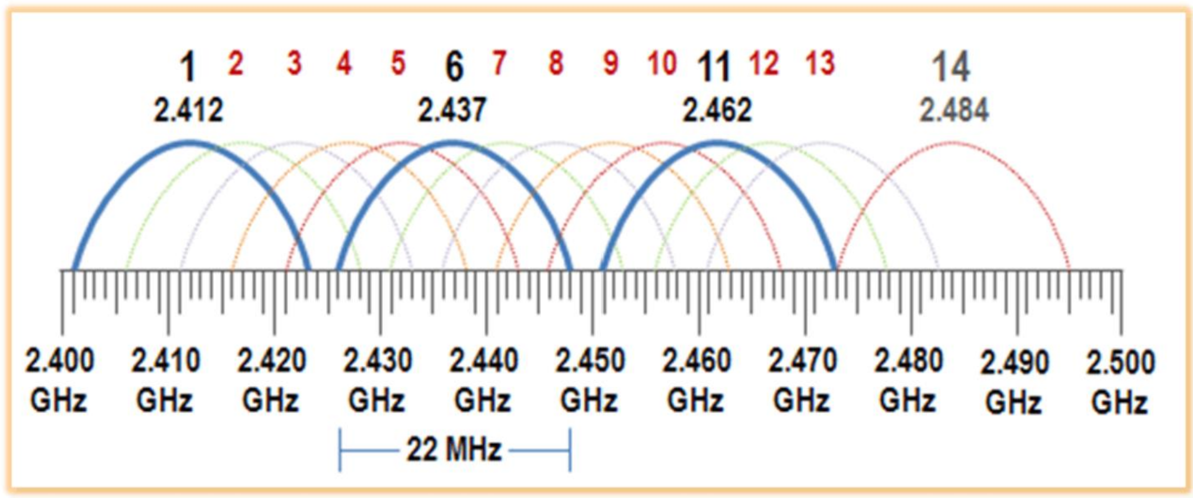
- Ofcom: Adopted low power (fixed & mobile) and medium power (fixed) local licenses – more than 1,600 licenses issued as of Dec. 2022.
- Ofcom: "[U]sers (particularly smaller spectrum users) . . . want simple and cost-effective access to spectrum and a managed interference environment, beyond what can be achieved using license exempt spectrum."
- Ofcom is studying how to automate the process.

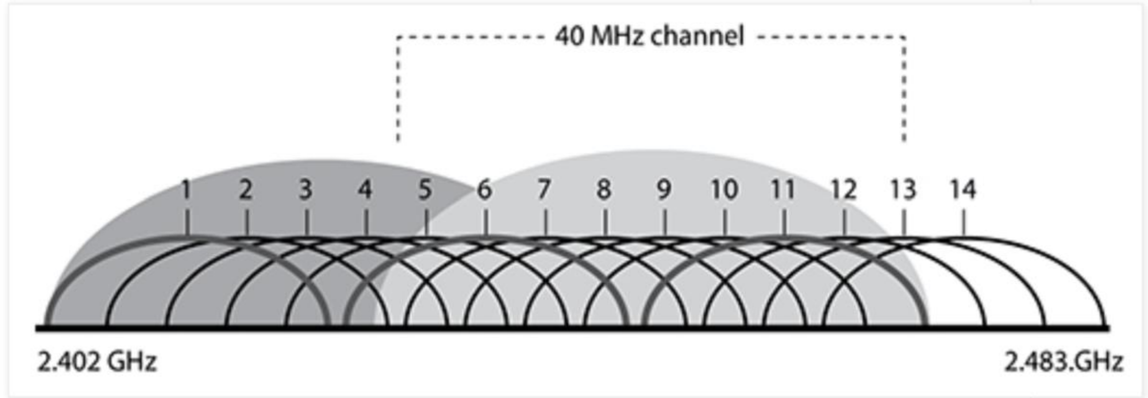


Non-Database Sharing Approaches

2.4 GHz Wi-Fi

- ISM Band
- Half-duplex
- Early versions of Wi-Fi had 3 non-overlapping 22 MHz channels w/ 3 MHz guard band
- More recent versions allow for 40 MHz wide channels.
- CSMA/CA – 'Listen Before Talk'

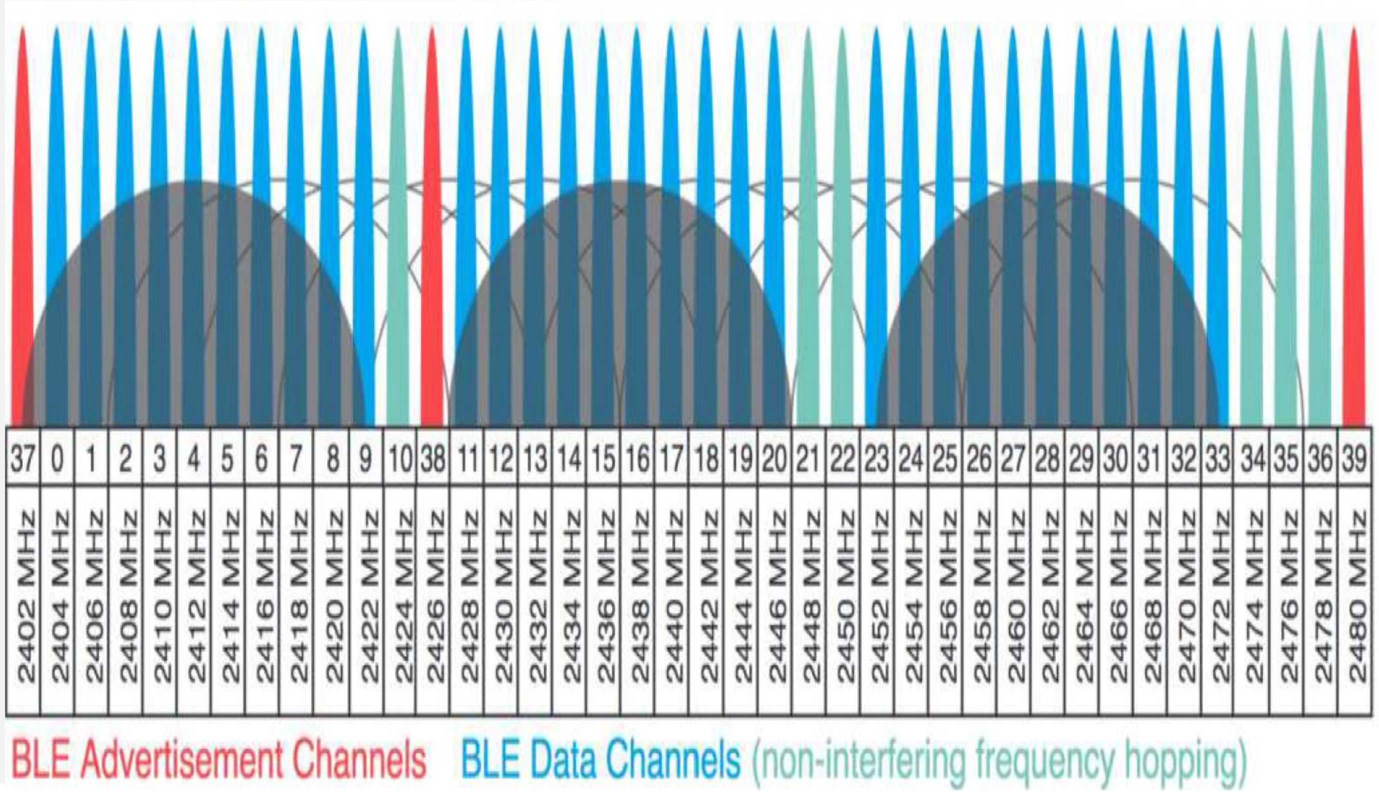




Non-Database Sharing Approaches

Bluetooth

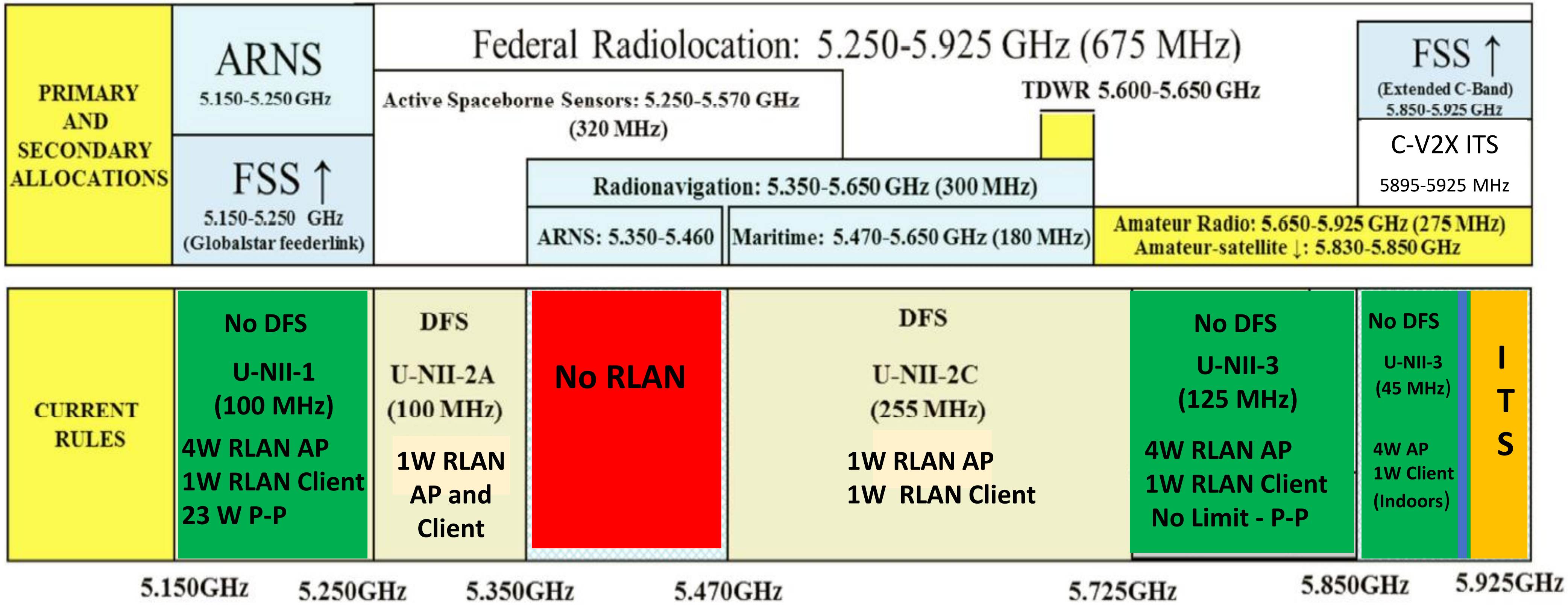
- 79, 1 MHz channels
- 40, 2 MHz Bluetooth low-energy
- Three device classes
  - Class 1 – Up to 100 mW
  - Class 2 – Up to 2.5 mW
  - Class 3 – Up to 1.0 mW
- Frequency hopping spread-spectrum – 1600 hops/sec



Taken from "Make Sense of Antenna Design and Matching Network" by Asem Elshimi in EDN Network, 27 March 2020.

Non-Database Sharing Approaches

5 GHz Wi-Fi (United States)



Non-Database Sharing Approaches

5 GHz Wi-Fi: 5150 – 5250 MHz Band (U-NII-1) in the United States

- Protection of Globalstar's FSS feeder uplink.
- Only the top 80 MHz of the band is used for Wi-Fi.
- Indoor access point:
  - EIRP limit is 4 W w/ conducted power limit of 1 W. If antenna gain is increased above 6 dBi, conducted power is reduced accordingly to maintain EIRP limit
  - Power Spectral Density limit: $\leq$7 dBm in any 1 MHz band
- Outdoor access point (additional):
  - Maximum e.i.r.p. at any elevation angle above 30 as measured to the horizon must not exceed 125 mW (21 dBm).
  - Up to 23 dBi antenna gain allowed before have to reduce conducted power
- Client devices:
  - EIRP limit is 1 W w/ conducted output power limit of 250 mW. If the antenna gain is increased above 6 dBi, conducted power is reduced accordingly to maintain the EIRP limit.
  - Power Spectral Density limit: $\leq$ 11 dBm in any 1 MHz band.
- Out-of-band Emission limits

Non-Database Sharing Approaches

5 GHz Wi-Fi: 5250-5350 MHz (U-NII-2a) & 5470-5725 (U-NII-2c) bands using Dynamic Frequency Selection

- WRC-23 decided through ITU-R Resolution 229 to allocate the spectrum between 5150 and 5350 MHz and between 5470 and 5725 MHz on a co-primary basis to "Wireless Access Systems including RLANs" under the proviso that RLANs should avoid interference into the other primary users – radar systems deployed on satellites, and on the ground, including mobile and maritime radars.

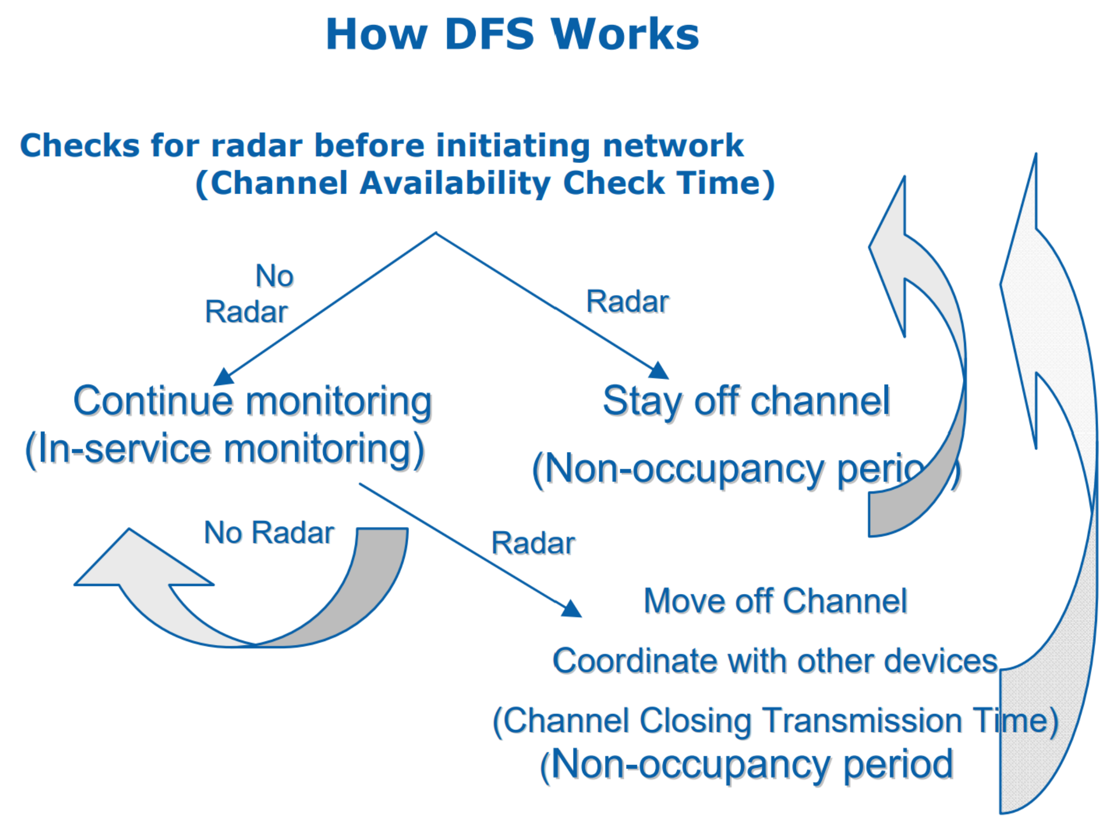
- Dynamic Frequency Selection (DFS) is an interference avoidance mechanism for RLANs to detect and avoid causing co-channel interference with these radars. Its purpose and performance criteria, including conformance testing procedures, were defined by separate ITU Recommendations.

- The DFS requirements can be split in two parts: the detection criteria and the "response criteria". The former specify the RF power and signal timings of radar signal that the wireless LANs must be able to recognize.

- Outside of the ITU, the Standards Development Organization, IEEE, approved a second interference avoidance mechanism, Transmit Power Control (TPC), to protect the (active) Earth Exploration Satellite Service. Clients that also support TPC can adjust their power to match the Access Point's transmit power

Non-Database Sharing Approaches

- Initial Channel Availability Check Time (CACT) of 60 seconds
- In Europe, there is a 10-minute CACT for channels overlapping airport Terminal Doppler Weather Radar.
- Test is for 6 different radar waveforms – 5 short pulse radars, 1 long-pulse radar. Matched filters. Energy detect threshold.
- Radar types evolve over time.
- Detect a radar signal, RLAN and clients have 10 seconds to move to another channel.
- Can't revisit the previous channel for a period of time.
- False positives is an issue.



Source: Wi-Fi Alliance

Non-Database Sharing Approaches

5 GHz Wi-Fi: 5725-5850 MHz (U-NII-3)

- ISM Band
- RLAN EIRP limit: 4 W.
- Conducted power limit: 1W.
- Power Spectral Density limit: < 30 dBm in any 500 kHz band.
- If transmitting antennas of directional gain > 6 dbi, both the maximum conducted output power and the maximum power spectral density shall be reduced by the amount in dB so that the maximum radiated power is limited to 4W EIRP.
- Out-of-band emissions limits.
- Outdoor use – no limit on antenna gain for fixed, point-to-point use.
- Previous concerns about OOBE from fixed P-P devices into TDWR but now resolved.

Non-Database Sharing Approaches

5 GHz Wi-Fi: 5850-5895 MHz (U-NII-4) – Builds on 6 GHz Report and Order

- Band partitioned between Wi-Fi (5850-5895 MHz) and C-V2X ITS (5895-5925 MHz)
- To protect ITS legacy and federal incumbent operations in this band, the Commission permitted immediate indoor unlicensed operations to operate across the entire 5.850-5.895 GHz portion of the 5.9 GHz band.
- Indoor AP: EIRP limit of 36 dBm, EIRP PSD limit of 20 dBm/MHz. Client: EIRP limit of 30 dBm. EIRP PSD limit of 14 dBm/ MHz.
- OOBE for U-NII-4 band Wi-Fi into ITS, the same as OOBE for U-NII-3 band Wi-Fi into ITS after taking BEL into account.
- Combine spectrum with that in the U-NII-3 band to create one additional 80 MHz and one additional 160 MHz channels.
- Indoor access points (and subordinate devices): (1) can’t be weather resistant, (2) must have integrated antenna, (3) can’t operate on battery power (except for back-up in case of a power outage), (4) labeled for indoor use only.
- No outdoor operations authorized yet. Outdoor use through waivers and Special Temporary Authorizations. The radars that operate in the 5.825-5.925 GHz band are primarily military surveillance and test range instrumentation systems and can be either mobile or transportable. In addition to the DoD operation, NASA, NOAA, and Department of Energy operate radar systems in the 5.85-5.925 GHz band throughout the United States.

Non-Database Sharing Approaches

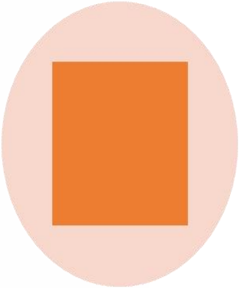
6 GHz band

- Numerous countries have authorized and issued technical rules for Low-Power Indoor (LPI) and subordinate devices over either the lower 500 MHz or full 1200 MHz of the 6 GHz band.
- As of end of CY 22, over 1200 LPI device models have been certified.
- The EU and other countries have authorized VLP indoor / outdoor devices and issued technical rules. To date there are no commercial devices.

Device Categories

VERY LOW POWER (VLP)

LOW POWER INDOOR (LPI) AND CLIENT TO CLIENT (C2C)



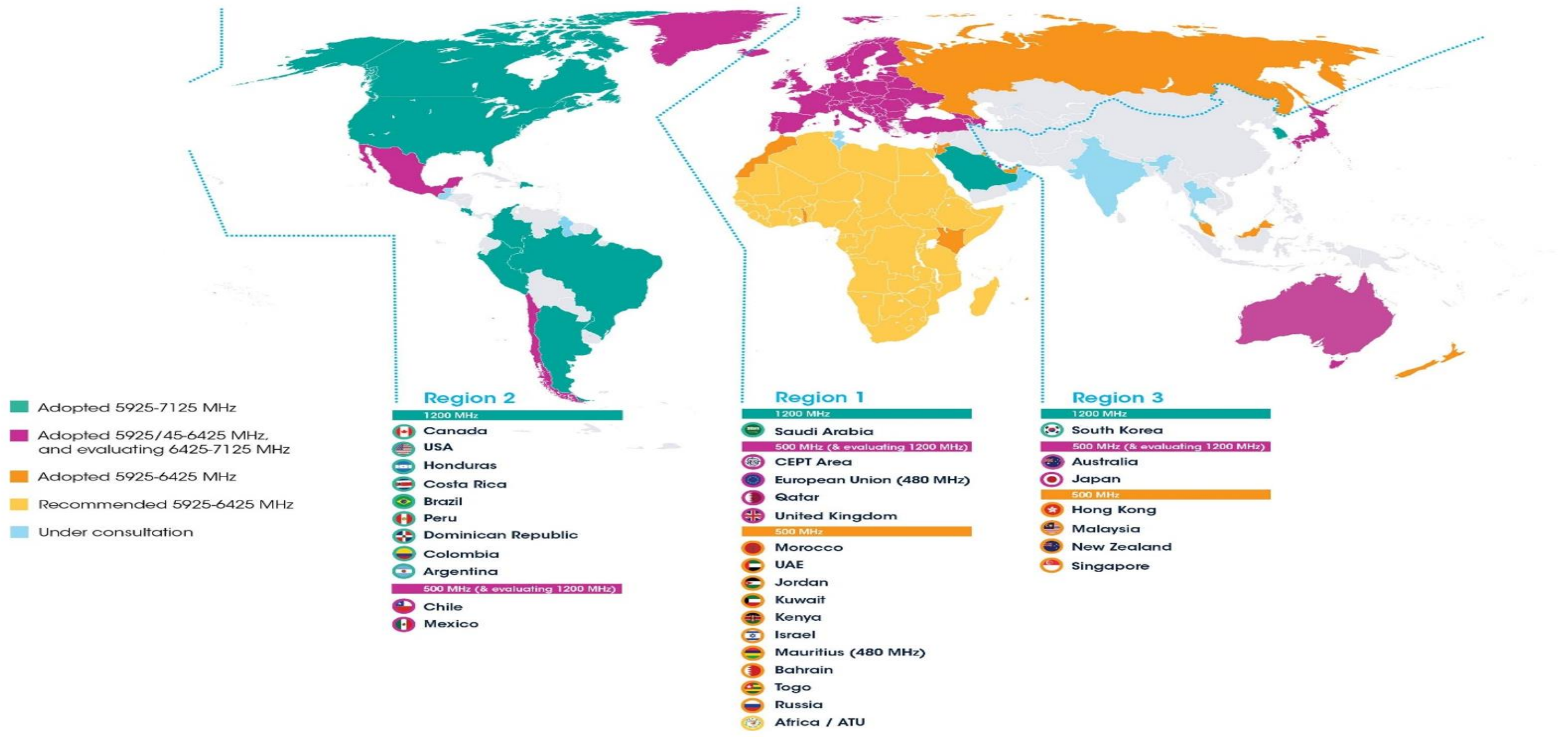
STANDARD POWER (SP) FIXED AND MOBILE

USED WITH AUTOMATED FREQUENCY COORDINATION (AFC)

- LPI and VLP devices can coexist with incumbent services in the band under the technical rules.
- Standard Power devices can coexist with incumbents using database-based Automated Frequency Coordination (AFC).
- Incumbent operations can continue to expand even after license-exempt devices are authorized in the band.

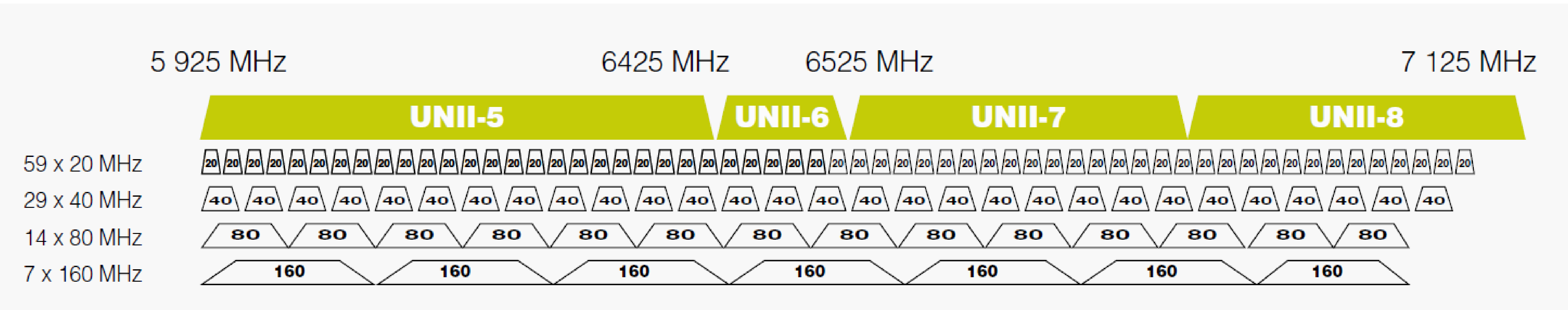
Non-Database Sharing Approaches

Map of License-Exempt Authorizations for the 6 GHz Band (as of 27 May 2023)



Non-Database Sharing Approaches

6 GHz Wi-Fi Channel Plan



- Wi-Fi Channel Diversity Required for High Bandwidth Use Cases in High Density Deployments

Non-Database Sharing Approaches

6 GHz band – Low Power Indoor Devices (LPI)

U.S. Based Model (FCC 20-51)

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Low-Power Access Point (indoor only)	U-NII-5 (5.925-6.425 GHz) U-NII-6 (6.425-6.525 GHz) U-NII-7 (6.525-6.875 GHz) U-NII-8 (6.875-7.125 GHz)	30 dBm	5 dBm/MHz
Client Connected to Low-Power Access Point		24 dBm	-1 dBm/MHz

- Subordinate devices are under control of an LPI access point and can operate with the same EIRP limit and EIRP PSD limit as LPI devices (e.g., Wi-Fi enabled TV receivers)
- Any emissions outside of the 5.925-7.125 GHz band must not exceed an e.i.r.p. of -27 dBm/MHz.
- LPI access points, client, and subordinate devices must employ a contention-based protocol.
- LPI access point devices cannot be weather resistant, must have integrated antennas, cannot operate on battery power, and require that the access points be marketed as "for indoor use only" and include a label attached to the equipment stating that "FCC regulations restrict to indoor use only."

Non-Database Sharing Approaches

6 GHz band – Low Power Indoor Devices (LPI)

EU Model (ECC Decision (20)01)

- Initial rules cover 5925-6425 MHz. Looking at the 6425-7125 MHz range in parallel to WRC-23 AI 1.2
- Limits EIRP rather than EIRP PSD. Larger channels will have lower EIRP PSD.
- EIRP PSD limit is 10 dBm/MHz
- LPI access point and client have same EIRP limits.

Parameter	Technical conditions
Permissible operation	Restricted to indoor use only (including trains where metal coated windows (note 1) are fitted and aircraft) Outdoor use (including in road vehicles) is not permitted.
Category of device	An LPI access point or bridge that is supplied power from a wired connection, has an integrated antenna and is not battery powered. An LPI client device is a device that is connected to an LPI access point or another LPI client device and may or may not be battery powered.
Frequency band	5945-6425 MHz
Channel access and occupation rules	An adequate spectrum sharing mechanism shall be implemented.
Maximum mean e.i.r.p. for in-band emissions (note 2)	23 dBm
Maximum mean e.i.r.p. density for in-band emissions (note 2)	10 dBm/MHz
Maximum mean e.i.r.p. density for out-of-band emissions below 5935 MHz (note 2)	-22 dBm/MHz
Note 1: Or similar structures made of material with comparable attenuation characteristics. Note 2: The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.	

Non-Database Sharing Approaches

6 GHz band – Very Low Power (VLP) devices

EU Model (ECC Decision (20)01)

Parameter	Technical conditions
Permissible operation	Indoors and outdoors Use on drones is prohibited
Category of device	The VLP device is a portable device
Frequency band	5945-6425 MHz
Channel access and occupation rules	An adequate spectrum sharing mechanism shall be implemented.
Maximum mean e.i.r.p. for in-band emissions (note 1)	14 dBm
Maximum mean e.i.r.p. density for in-band emissions (note 1)	1 dBm/MHz
Narrowband usage maximum mean e.i.r.p. density for in-band emissions (note 1) (note 2)	10 dBm/MHz
Maximum mean e.i.r.p. density for out-of-band emissions below 5935 MHz (note 1)	-45 dBm/MHz (note 3)

Note 1: The "mean e.i.r.p." refers to the e.i.r.p. during the transmission burst, which corresponds to the highest power, if power control is implemented.

Note 2: Narrowband (NB) devices are devices that operate in channels bandwidths below 20 MHz. Narrowband devices also require a frequency hopping mechanism based on at least 15 hop channels to operate at a PSD value above 1 dBm/MHz.

Note 3: ECC will study the appropriateness of this level of OOBE by 31/12/2024. In absence of the justified evidence, a value of -37 dBm/MHz will be adopted from 1 January 2025.

U.S. Model (FCC 20-51) – FNPRM

VLP supports portable use cases such as wearable peripherals including augmented reality/virtual reality and other personal-area-network applications as well as in-vehicle applications.

Asks questions including:

- 5925-7125 MHz, both indoors and outdoors, without using an AFC?
- EIRP Limit: 14 dBm EIRP?
- EIRP PSD limit: -8 dBm/MHz?

MORE TO COME

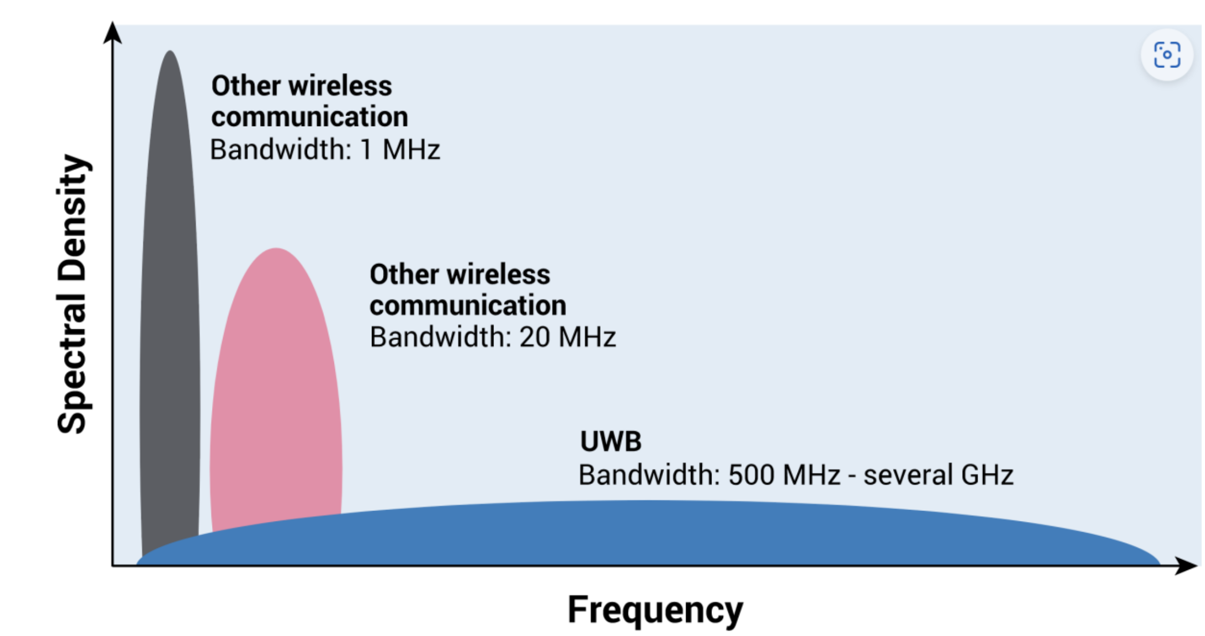
Non-Database Sharing Approaches

Ultra Wide Band (UWB)

- Ultra-wideband (UWB) is a short-range, pulsed, wireless technology that enables extremely precise location tracking.

- Once a UWB-enabled device like a smartphone, smartwatch, smart key or tile is near another UWB device, the devices start "ranging." Bandwidth is greater than 500 MHz and each pulse in the train is less then 2 nanoseconds. UWB-enabled devices can understand both motion and relative position. A typical range is up 200 meters for the radio,

- The frequencies range of operation is from 3.1 to 10.6 GHz. The FCC power spectral density (PSD) emission limit for UWB transmitters is −41.3 dBm/MHz.



[What UWB Does | FiRa Consortium]

- A low power underlay. As a Part 15 device the PSD limit for UWB devices was set low enough so as not cause harmful interference to the many services operating across this broad range. UWB devices must accept interference.

Non-Database Sharing Approaches

60 GHz Band

- Multiple Gigabit Wireless System (MGWS) radiocommunication networks can be used in short-range, line-of-sight and non-line-of-sight circumstances with traditional WLAN topologies. MGWS systems can also be used in very short-range high-rate proximity communications where the radio range is a few centimetres with devices pairing point-to-point in close proximity of each other.

- WiGig specification allows devices to communicate without wires at multi-gigabit speeds. The 60 GHz millimeter wave signal cannot typically penetrate walls but can propagate by reflection from walls, ceilings, floors and objects using beamforming built into the WiGig system.

- WiGig channels are 2.16 GHz wide. In countries, license-exempt operations are authorized in the 57-71 GHz range, 57-66 GHz range, and the 57-64 GHz range. This corresponds to 3, 4, and 6 contiguous WiGig channels.

- Note that at WRC-19, the 66-71 GHz band was identified for IMT. Both MGWS and IMT are applications of the Mobile Service. The RRs don't account for sharing among applications of the same radiocommunications service. There was supposed to be follow-on activities in the ITU Study Groups that did not happen. There is no IMT deployed in the band to date.

Non-Database Sharing Approaches

60 GHz Band

- In the U.S., license-exempt devices in the 60 GHz band generally include indoor/outdoor communication devices such as WiGig, wireless local area networks (WLANs), outdoor fixed point-to-point communication links, and Field Disturbance Sensors (FDS)—which includes radar operations. These users must protect the operations of authorized Federal and non-Federal users in the band.

- Google received a waiver for its "Soli" sensor technology in 57-64 GHz, which envisioned that smartphones and other personal devices would be able to sense hand gestures when a user is located at a very short distance from the device to perform functions such as controlling web pages or answering phone calls. Additional waivers for pulsed and FMCW radars were granted for vehicle cabin-mounted as well as health-care related and other applications in the 57-64 GHz range at the same power levels as those granted to Google. A waiver was granted for radar operations in the 60-64 GHz band on specialized unmanned aircraft for the specific purpose of avoiding collisions with structures, supporting wires, or other fixed objects during structure visual inspection operations.

- Industry stakeholders (WiGig and WLANs vs FDS proponents) negotiated a settlement for the lower three channels that the FCC blessed and turned into a Report & Order in April.

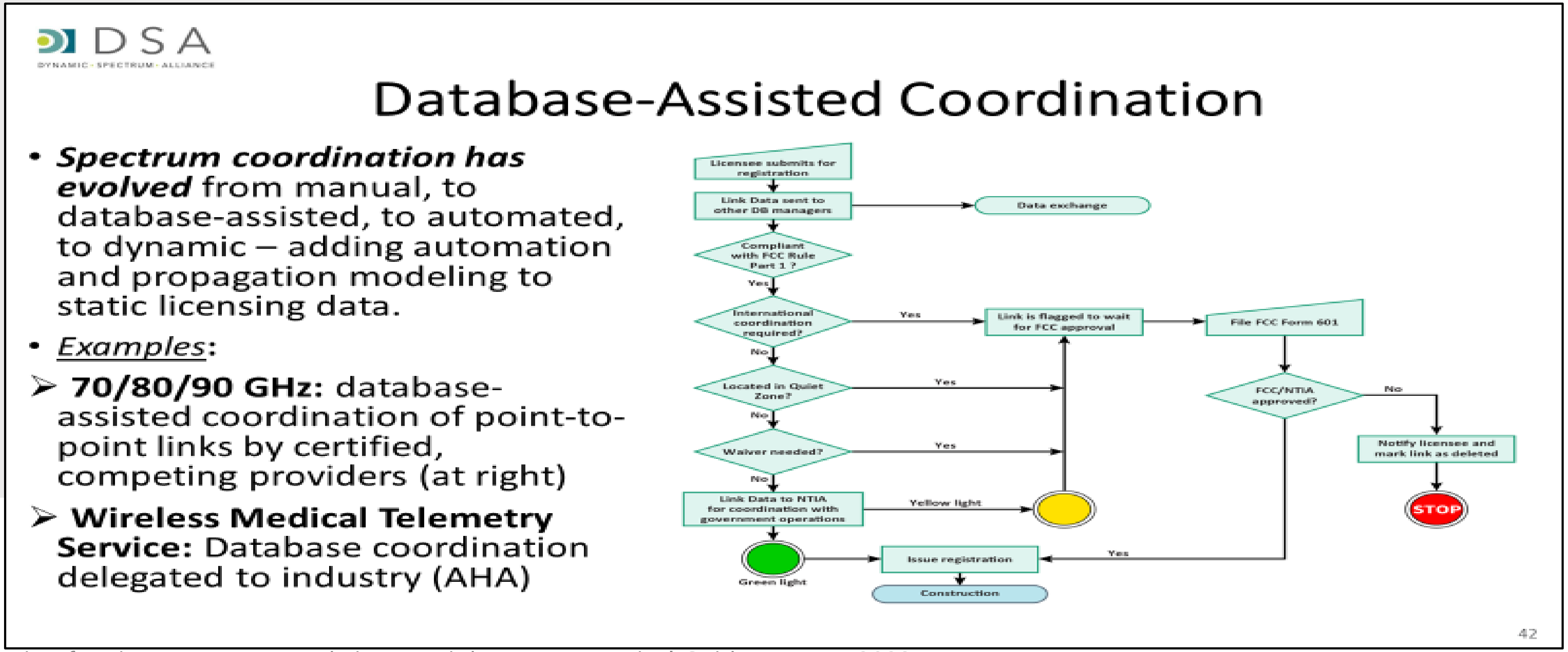
- The settlement used different power limits and duty cycles for each of the three lower channels in the band.

Database Sharing Methods Approaches and Examples

Database Sharing Methods Approaches and Examples

Use of databases to coordinate and automate spectrum sharing is ***nothing new*** – the first step is often automating the manual coordination process or using a database in an otherwise manual process. The new generation of spectrum management 'databases' incorporate calculation engines. The calculation engines are the mathematical embodiment of the regulations.

BUT there is a fundamental need current and accurate data of incumbent usage in the band



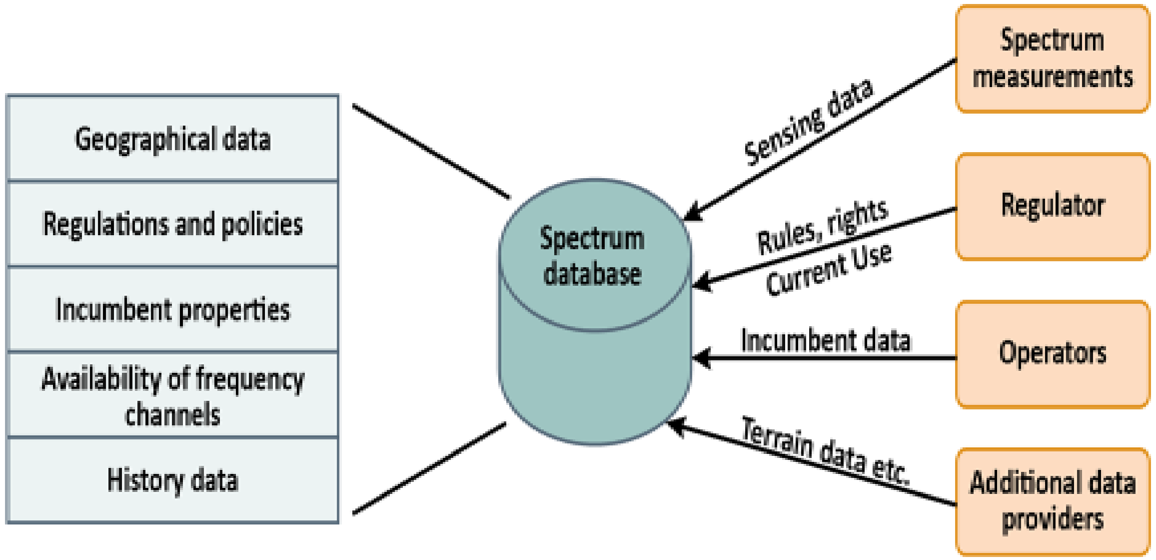
Database Sharing Methods Approaches and Examples

DSA
DYNAMIC · SPECTRUM · ALLIANCE

Dynamic Spectrum Coordination Systems (DSMS): Core Functions

***Core Functions of DSM Systems*:**

- Protect incumbent licensees from interference (and, in some bands, coordinate among users with the same priority)
- Provide authoritative and virtually real-time decisions on requests to transmit or assign usage rights
- Enforce the use of authorized devices
- Monitor spectrum assignments and, in some cases, actual usage



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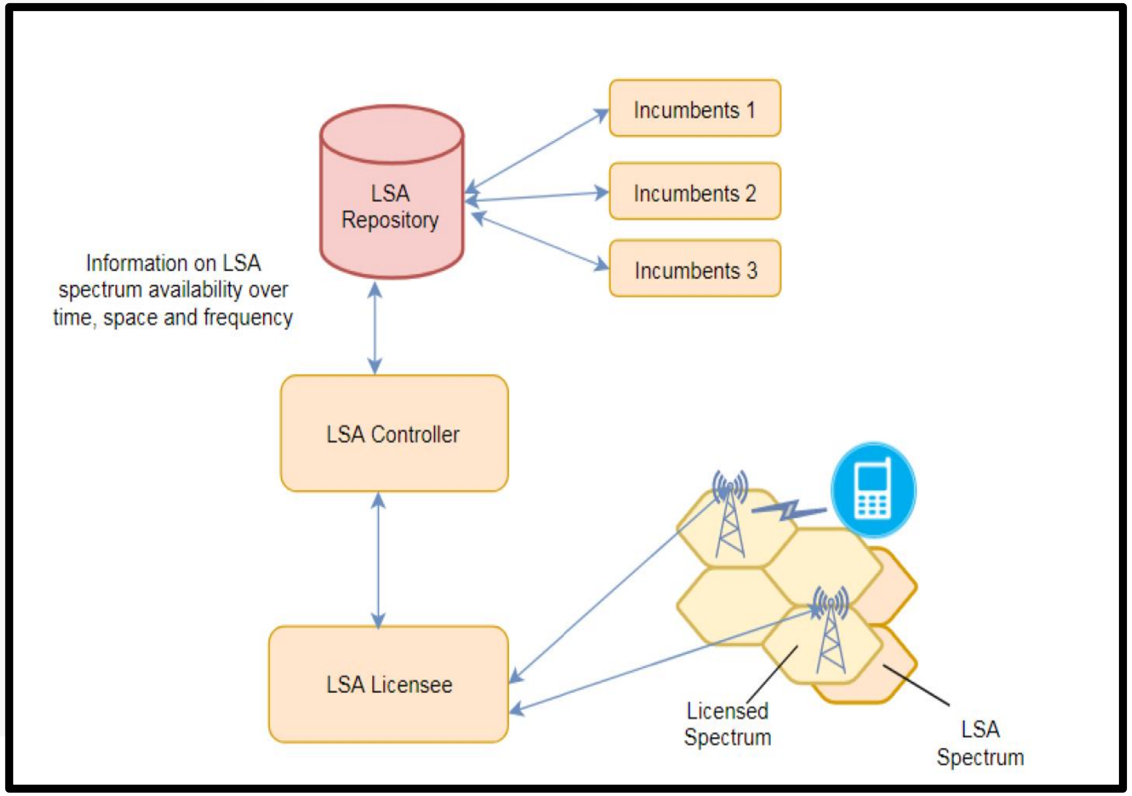
Database Sharing Methods Approaches and Examples

Licensed Shared Access (LSA)

- RSPG (Europe) adopted LSA approach in 2013 for bands where the incumbents cannot be fully cleared, and the band can be shared by new entrants (MNOs) and incumbent users because the new entrants are not using the spectrum at the same location and/or time as the incumbents.
- New entrants are licensed in order to provide for a certain quality or service
- Several pilots in 2300-2400 MHz band. Has not taken root. To date, UK has most extensive deployment, part of its local licensing efforts.



"Overview of Spectrum Sharing Models: A Path Towards 5G Spectrum Toolboxes" by Gcina Dludla, Luzango Mfupe, and Fisseha Mekuria, CSIR South Africa (July 2018)

Database Sharing Methods Approaches and Examples

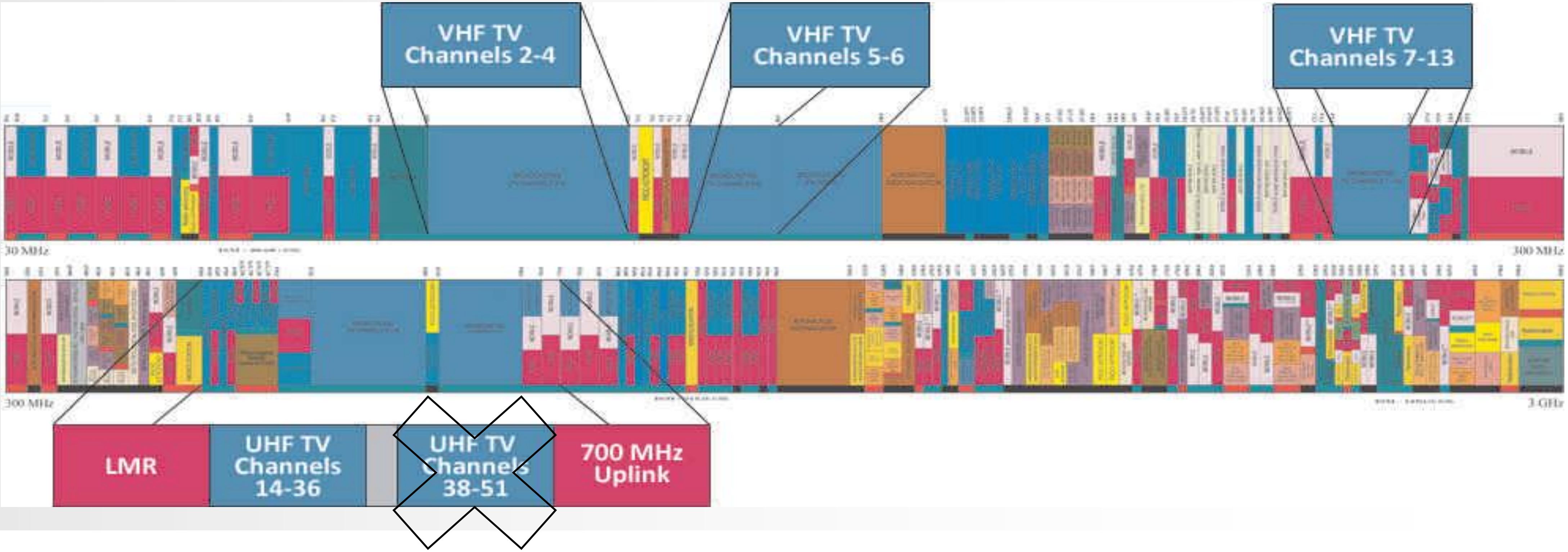
Television white spaces (TVWS)

"A portion of spectrum in a band allocated to the broadcasting service and used for television broadcasting that is identified by an administration as available for wireless communication at a given time in a given geographical area on a non-interfering and non-protected basis with regard to other services with a higher priority on a national basis"

- The idea began in the 2001-2002 time frame as 3G mobile service were just beginning to be deployed. First rules in the 2008-2010 time frame.
- Currently four categories (U.S.) – fixed, personal / portable, mobile within a geofenced area, and narrowband.
- Fixed TVWS networks are essentially Fixed Wireless Access over license-exempt spectrum.
- Personal / portable communications devices have been overtaken by events.
- Narrowband (IoT) TVWS devices can be used for precision agriculture, remote sensing, etc.
- Mobile within a geofenced area is being looked at for agriculture and other verticals operating in rural areas.

Database Sharing Methods Approaches and Examples

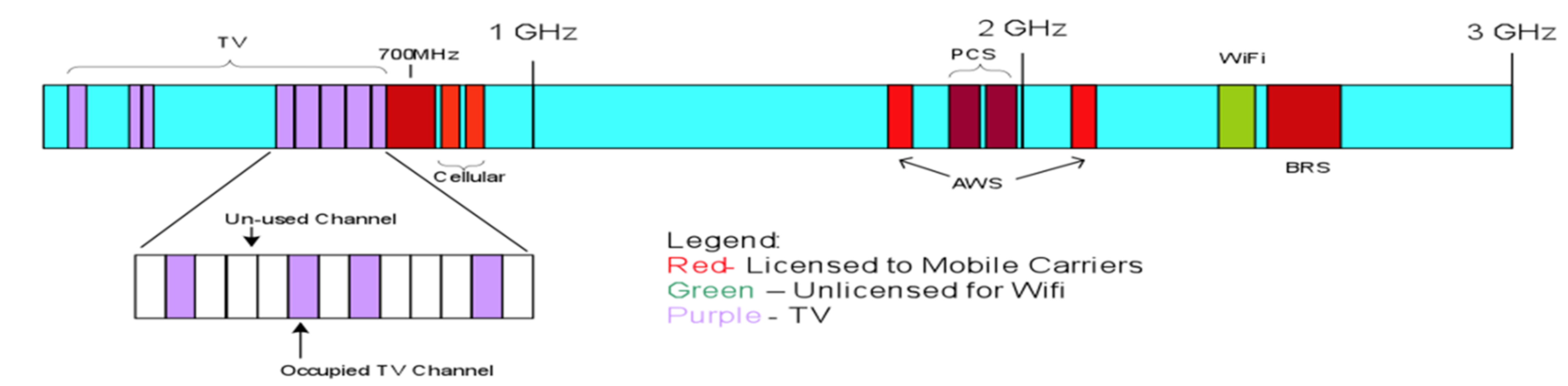
TVWS – United States



Source: Federal Communication Commission

Database Sharing Methods Approaches and Examples

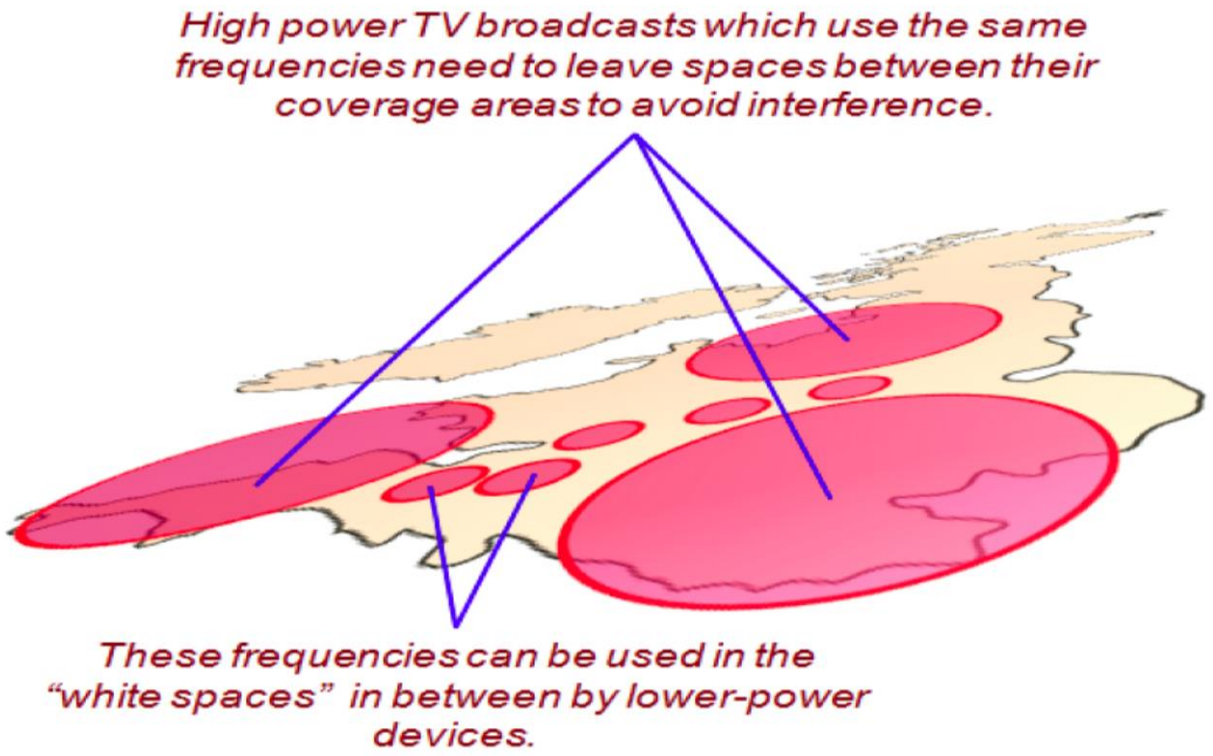
TVWS Availability at a Given Location Across the Channels in a Band



Source: Federal Communication Commission

Database Sharing Methods Approaches and Examples

TVWS Availability on a Given Channel Across a Geography



Source: Ofcom

Database Sharing Methods Approaches and Examples

Services that need to be protected from receiving harmful interference from TVWS device (U.S.)

- TV Broadcasters (Full power and lower power services)
- Multi-channel Video Programming Distributor receive sites
- Low Power Auxiliary Service including licensed wireless microphones
- Private Land Mobile Radio Service (including public safety users)
- Commercial Mobile Radio Service (mobile carriers)
- Radio Astronomy Services
- Wireless Medical Telemetry Service
- International Border with Canada and Mexico
- Offshore Radio-telecommunication Service

…………. Very complicated

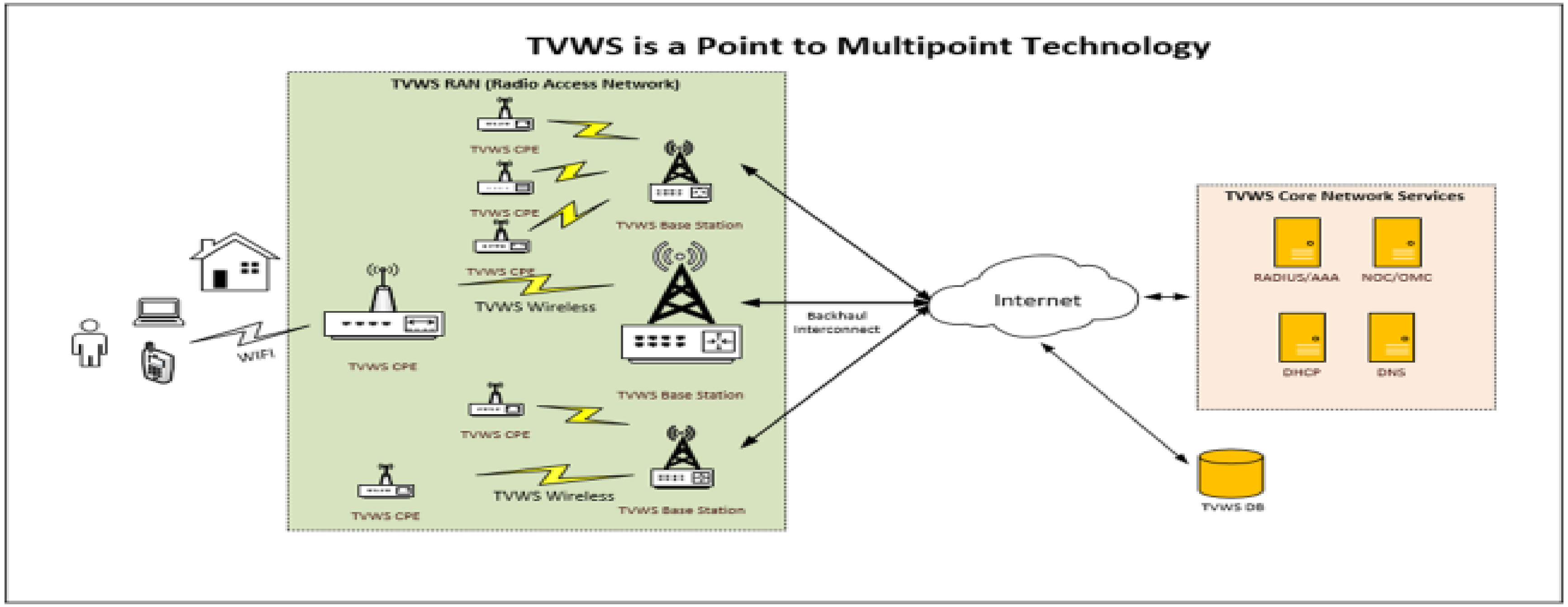
Database Sharing Methods Approaches and Examples

Use Cases Enabled By TV White Spaces

Enhanced Wi-Fi	The majority of current Wi-Fi devices operate in spectrum at 2.4 GHz. White spaces could provide new capacity, while boosting the range of devices, potentially enabling Wi-Fi networks that stretch across towns and cities. This is due to the lower frequency of TV white spaces (typically between 470 MHz and 790 MHz).
Wide Area Network Overlay	White spaces could be used to provide underserved communications, such as rural villages, with broadband services. In practice, this could be achieved by building a network of transmitters that use white spaces to link remote houses and villages to larger towns that are already connected to the internet.
Machine-to-Machine Communications	This relatively new area of innovation allows information to be exchanged between different devices. This could be especially useful for wirelessly measuring utility meters in consumers' home, for example, or allowing businesses to wirelessly track their inventory.

Database Sharing Methods Approaches and Examples

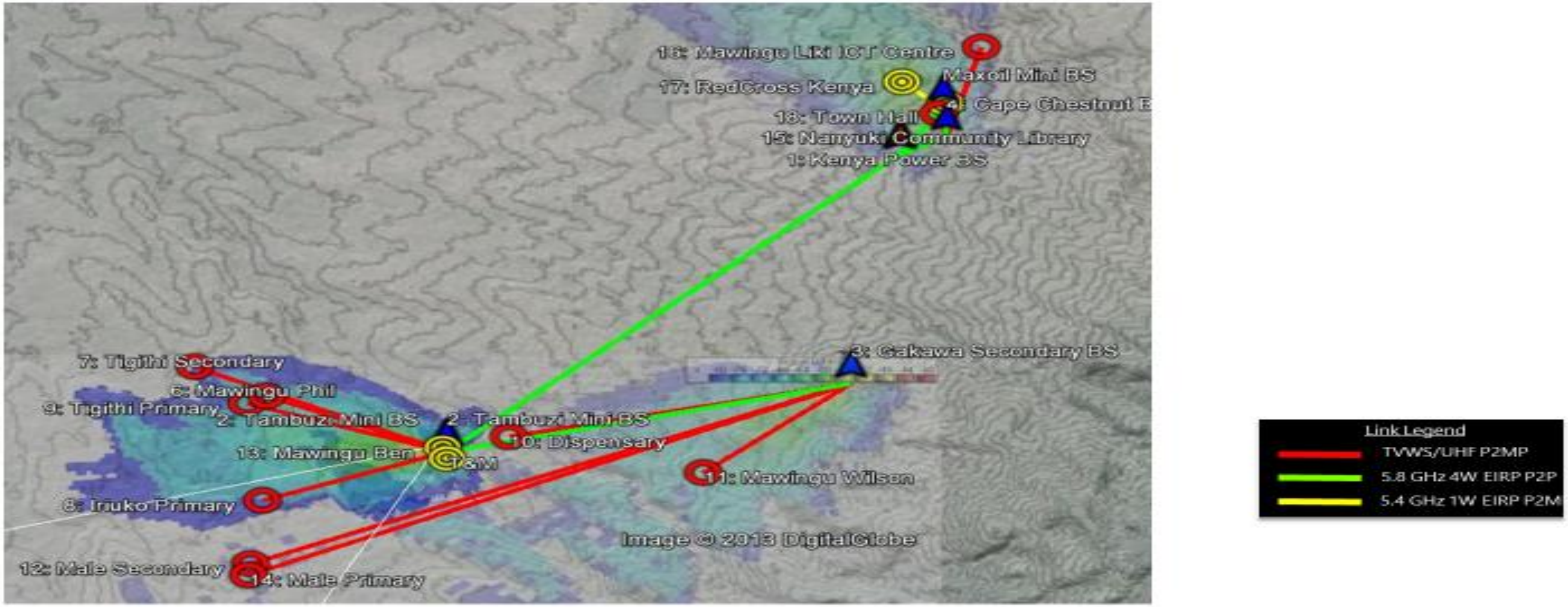
TVWS Network Architecture



Database Sharing Methods Approaches and Examples

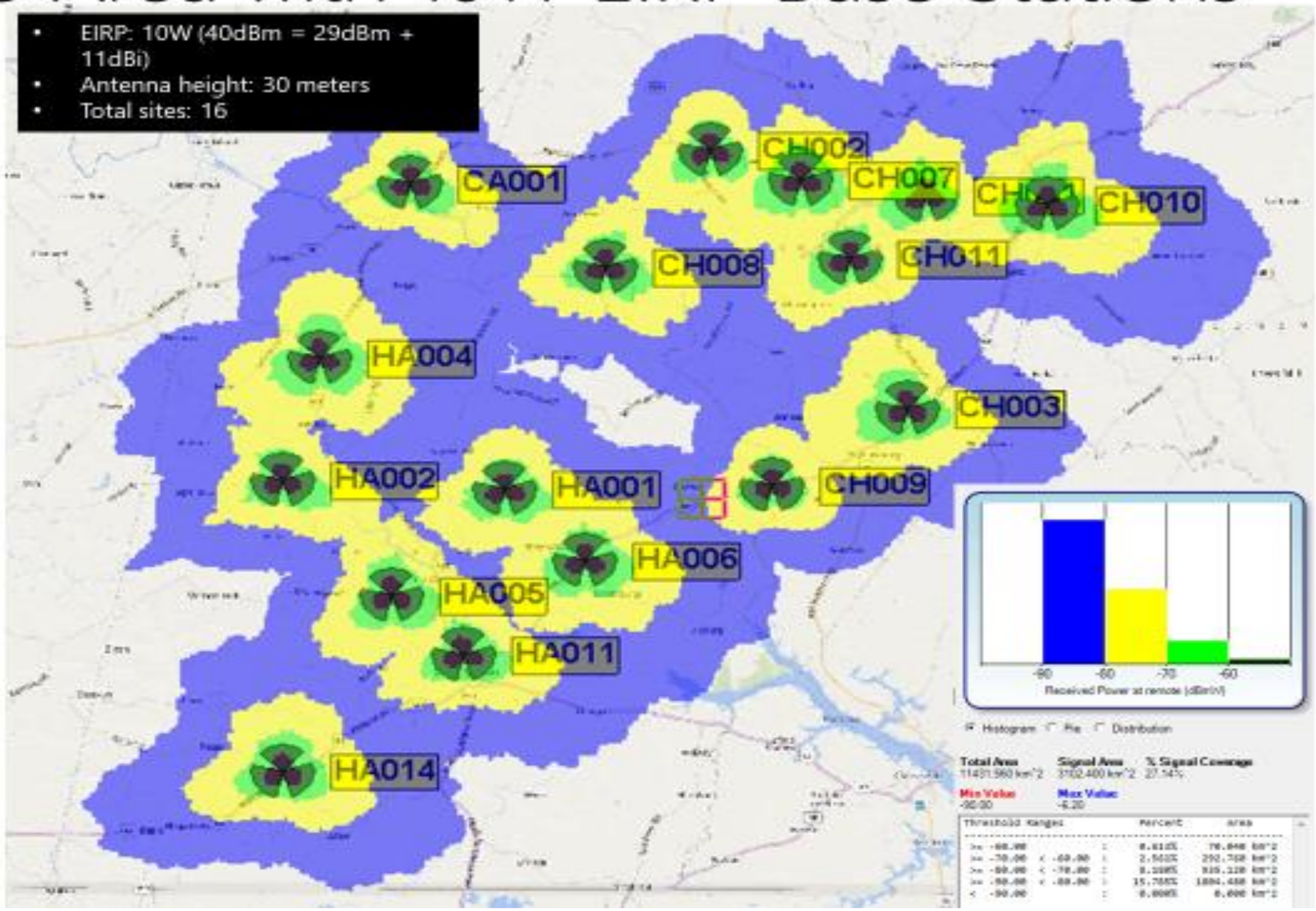
Part of a heterogenous fixed network

Mawingu Network in Nanyuki, Kenya



Database Sharing Methods Approaches and Examples

Coverage Area with 10W EIRP Base Stations



Database Sharing Methods Approaches and Examples

Narrowband TVWS Devices

Machine-to-Machine Communications

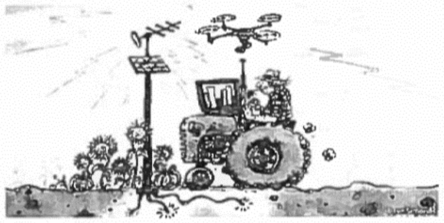
The Economist

Precision agriculture

TV dinners

Unused TV spectrum and drones could help make smart farms a reality

Sep 17th 2016 | CARNATION, WASHINGTON



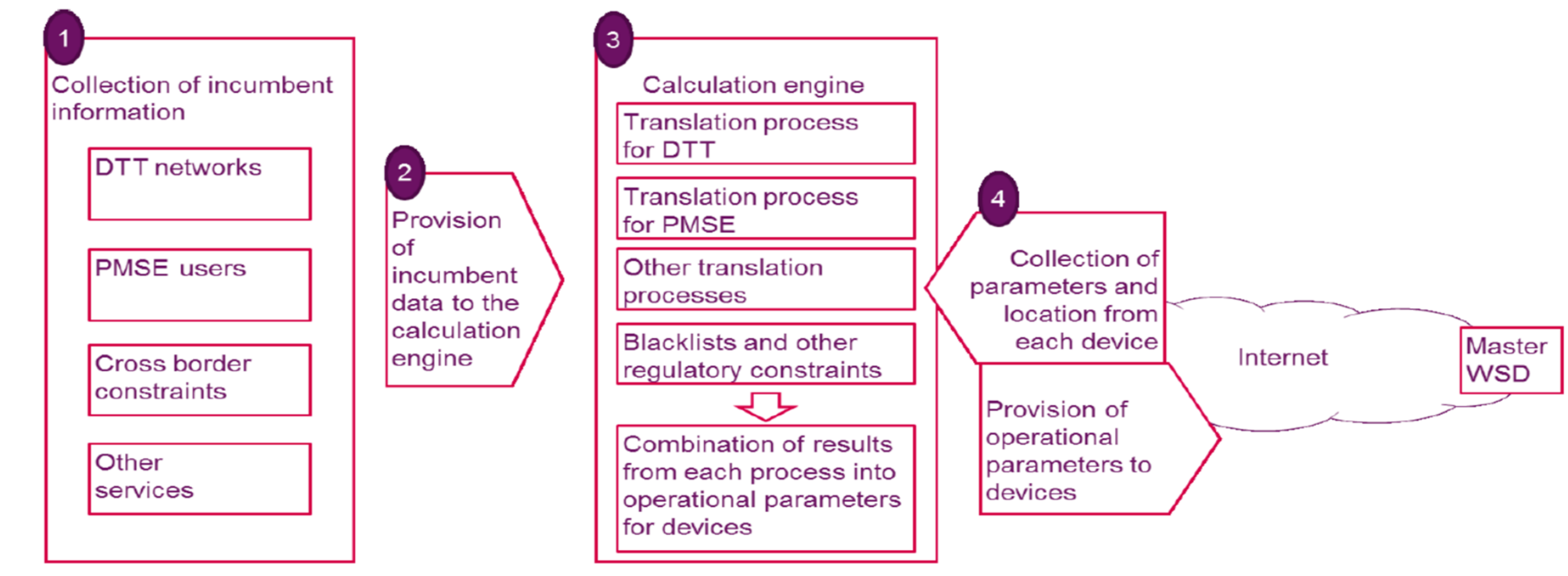
ON THE Dancing Crow farm in Washington, sunflowers and squashes soak up the rich autumn sunshine beside a row of solar panels. This bucolic smallholding provides organic vegetables to the farmers' markets of Seattle. But it is also home to an experiment by Microsoft, a big computing firm, that it hopes will transform agriculture further afield. For the past year, the firm's engineers have been developing a suite of technologies there to slash the cost of "precision agriculture", which aims to use sensors and clever algorithms to deliver water, fertilisers and pesticides only to crops that actually need them.

Precision agriculture is one of the technologies that could help to feed a world whose population is forecast to hit almost 10 billion by 2050. If farmers can irrigate only when

- **Precision agriculture**
- **Remote sensing**

Database Sharing Methods Approaches and Examples

TVWS Database Block Diagram



Source: ECC Report 236

Database Sharing Methods Approaches and Examples

Fundamental Operating Principle of White Space Device Rules

TV White Space Devices (WSD) shall not cause harmful interference to licensed services operating in the frequency bands authorized for its use and must accept interference (cannot claim protection) from these licensed services.

Harmful interference to licensed services is prevented through

- Interference protection requirements
  - Receiver protection requirement determines the protected service areas.

- Interference management methods
  - Use of a geo-location and database techniques
  - Use of sensing only devices

<u>Leads to technical and operational parameters for the different WSD types</u>

<u>Leads to technical and operational parameters for the white spaces database (WSDB)</u>

Database Sharing Methods Approaches and Examples

TVWS Interference Protection Requirements – Through Measurement & Modeling

- Measurement
  - Care about field strength levels that can cause receiver in-band blocking and de-sense for each licensed service
- Need to work backwards
  - Link budget – what are reasonable loss mechanisms and their values
  - Tracing it back through the atmosphere --- which propagation model to use, when and where
- Propagation models used / discussed in spectrum utilized by WSD include:

F-curves	Free space	FCC TM 91-1	ITU-R P.1812
Longley-Rice	Seamcat-Hata	Extended Hata	

Database Sharing Methods Approaches and Examples

WSD Technical and Operational Parameters For Managing Interference

- Device Technical Parameters
  - Conducted power
  - Power Spectral Density
  - Radiated Power
  - Out-Of-Block-Emissions
  - Transmit Power Control required
  - Secure (encoded) communications
  - Measures to prevent user from changing settings that could adversely affect compliance

- Device Operational Parameters
  - Antenna location (latitude and longitude coordinates)
  - Antenna height above ground level
  - Antenna height above average terrain
  - Geolocation capability / location accuracy
  - Device Emission Class (if applicable)
  - Device Type
  - Directional antenna

Database Sharing Methods Approaches and Examples

Interference Management Methods

Use of geo-location database

- **Regulator defines rules that govern the operation of the database and the characteristics of the WSDs**
- Interference protection requirements for all licensees are entered into a white spaces database
- WSDs are registered with the database, following a defined protocol/registration process
- WSD communicates its location to the database before initial operation, power on, and if it is moved beyond its geo-location accuracy range.
- Using secure communications, the database authenticates the WSD, computes, and then provides the WSD with the following operational parameters for that location, if applicable: Available channels; maximum power level on each channel; time validity of operational parameters; location validity of operational parameters.
- The database has full information about where Master devices are where, what their operating range is, and for what durations they are operating on which channels.
- Series of WSD re-check times depending on the device type to make sure operational parameters are valid
- In the event of reported interference, the Interference Protocol is invoked, and the offending WSD is located via the database and instructed to cease transmissions. An alternative channel can be requested.
- **Regulator can update TVWS rules over time and implement changes by updating the database software**

Database Sharing Methods Approaches and Examples

White Space Database Administrator

- Registers fixed WSDs, registers unlicensed wireless microphones, and collects the FCC Identifier, Manufacturer Serial Number, and geographic coordinates of Master personal / portable devices.

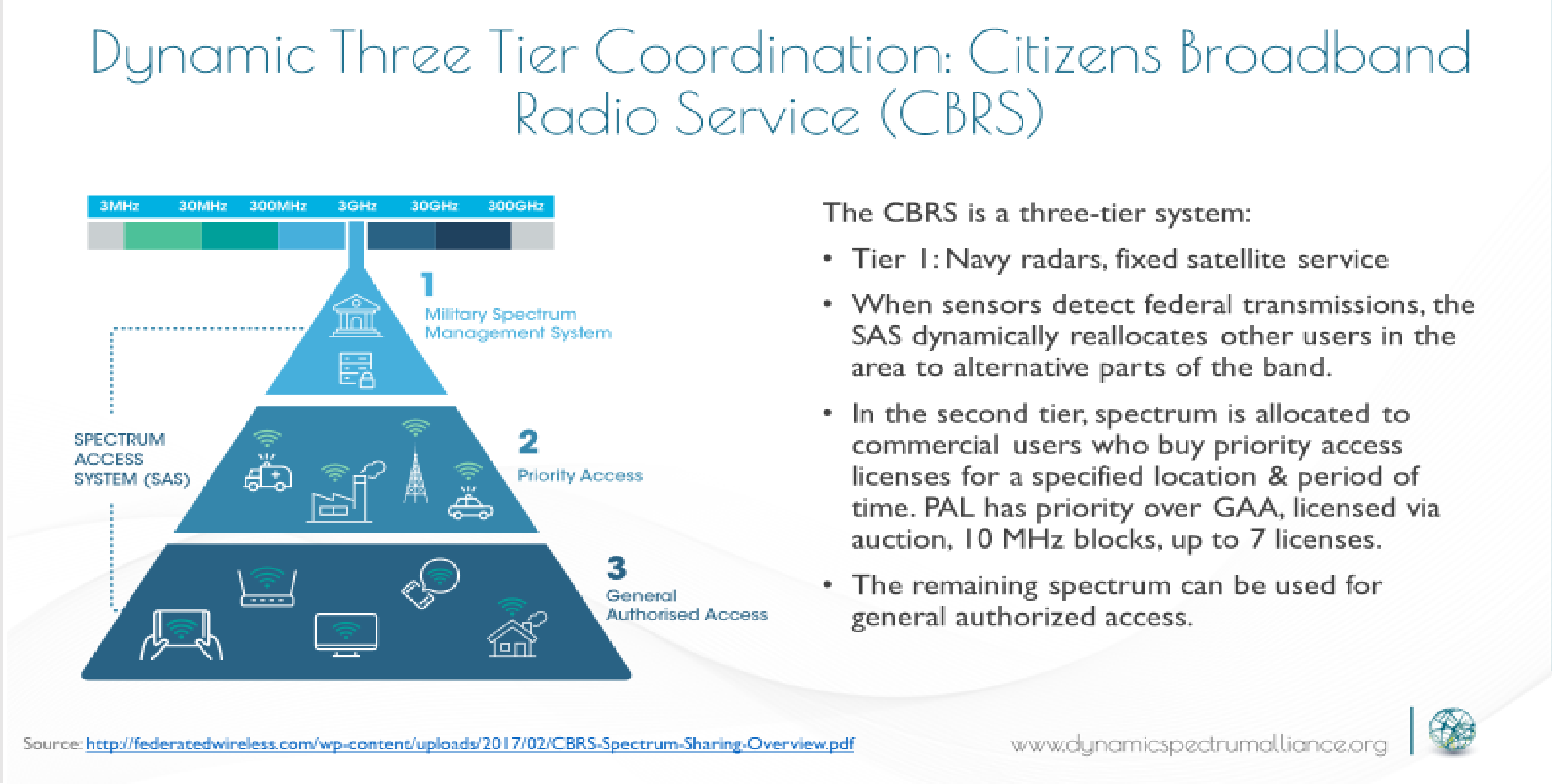
- Determines and provides to registered Master fixed and P/P WSDs, upon request, the available channels at the WSD's location, using the interference protection criteria, location information supplied by the WSD and the data for protected stations / locations registered in the database.
    - Increase the minimum separation distance from all protected services by the amount that the location uncertainty >50 m
    - Determining available frequencies in reclaimed spectrum
    - Knowing whether the Master fixed or P/P device is communicating with a Client device

- Determines and provides to an unlicensed wireless microphone user, upon request, the available channels at the microphone user's location in the 600 MHz guard bands, duplex gap, and reclaimed spectrum.

- Enters reservations for licensed wireless microphones by venues for large events and production / shows into database and transmit updates to other database providers.

- Upon request for immediate access to a channel by a licensed wireless microphone user, the contacted database provider must share with all other database providers within 10 minutes. Each database provider shall push the updated available channel list to all Master fixed and P/P devices within the protected contour.

Database Sharing Methods Approaches and Examples



CBRS operates under a “license-light regime”

A Spectrum Access System (SAS) is a cloud-based service that manages the wireless communications of devices operating in the CBRS spectrum.

The SAS assigns spectrum to CBRS devices and moderates power transmit levels of these devices to prevent harmful interference to higher priority users.

Database Sharing Methods Approaches and Examples

CBRS

Protecting Incumbents

Navy Shipborne Radar (SPN-43)
- 3550-3650 in coastal areas
- On only 19 ships
- To be replaced in 2025(?) with SPN-50

Military Ground-Based Radars
- Protected at three sites:
  - Pensacola, FL
  - Pascagoula, MS
  - St Inigoes, MD
- Operations can extend below 3550 MHz at several sites
- Over 50 total GB radars

Fixed Satellite Systems (FSS)
- In band (3600-3700 MHz) at 35 sites
- Adjacent-band operation (3700-4200 MHz) at thousands of sites, but only TT&C sites protected

Wireless Broadband and Utility Services (Part 90, subpart Z) (3650-3700 MHz)
- Many thousands around the country (~4700)
- Will be transitioned to PAL or GAA operation in 2020 (most) through 2023 (few)

Database Sharing Methods Approaches and Examples

CBRS

Protecting Incumbents

Database Sharing Methods Approaches and Examples

CBRS

Protecting Incumbents

Environmental Sensing Capability: ESC

Components installed at the top of the tower:
- Two 3 ft. 3.5 GHz 90 deg. Antennas
- One Stub Transmit Antenna
- Wideband Receiver

Components installed at the bottom of the tower:
- Power Over Ethernet Injector
- Backhaul Modem

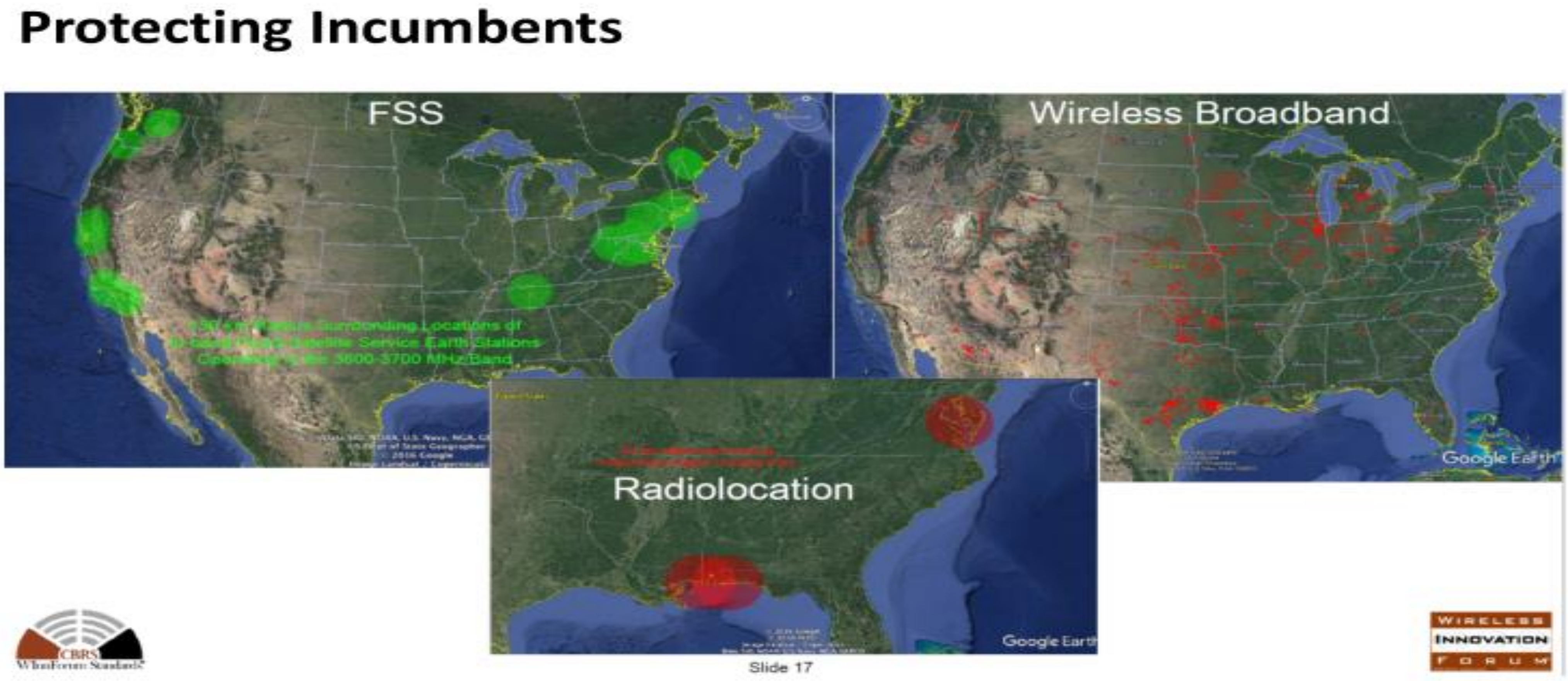
Cat 5 Ethernet is the only cable going up the tower to support the sensor.

Modem may not be required if sensor can use existing site backhaul.

Slide 19

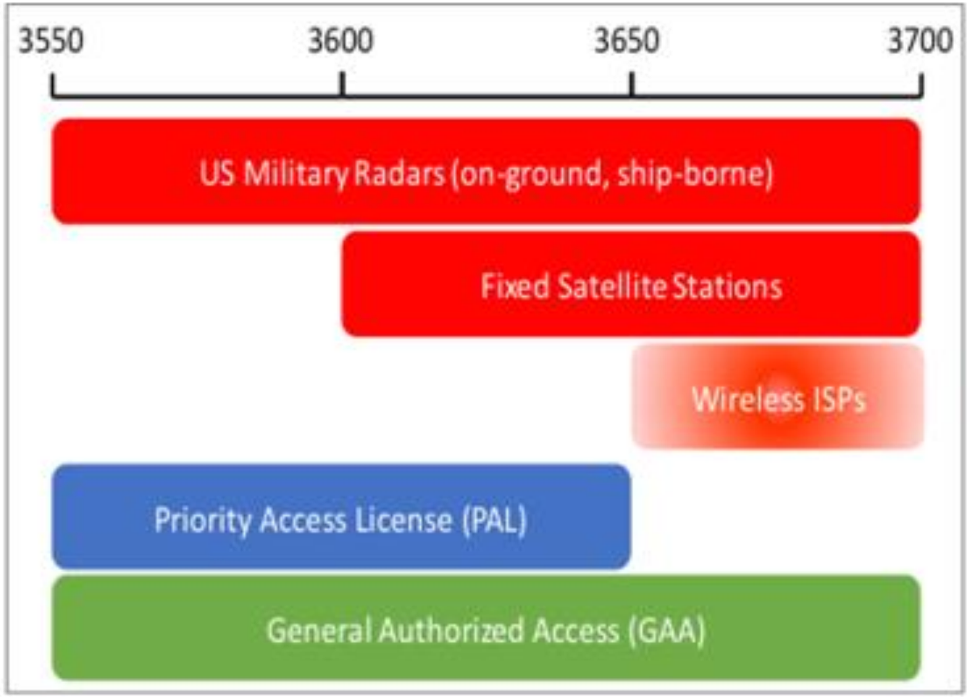
Database Sharing Methods Approaches and Examples

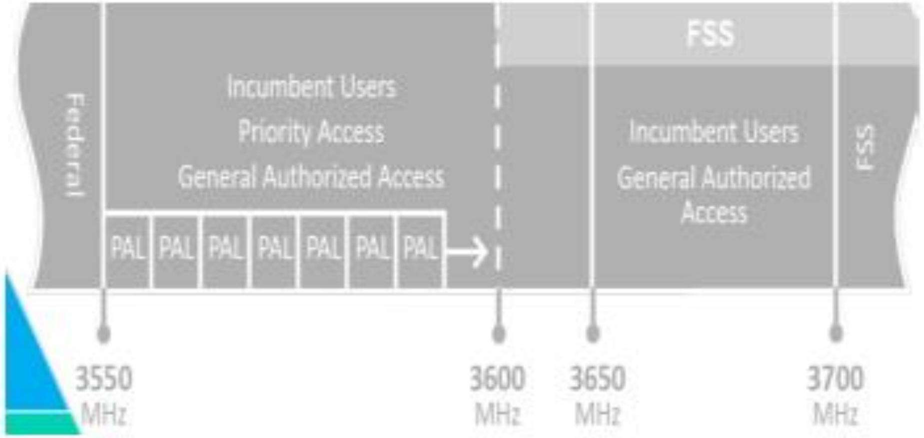
CBRS



Database Sharing Methods Approaches and Examples

CBRS Description





- 10 MHz Channel
- No more than 70 MHz in an area can be allotted for PALs
- 'Use-or-share': Where PAL is not being used, opportunistic access for GAA
- Channels for PALs are determined by the SAS in near real time – 'Dynamic Spectrum Authorization'

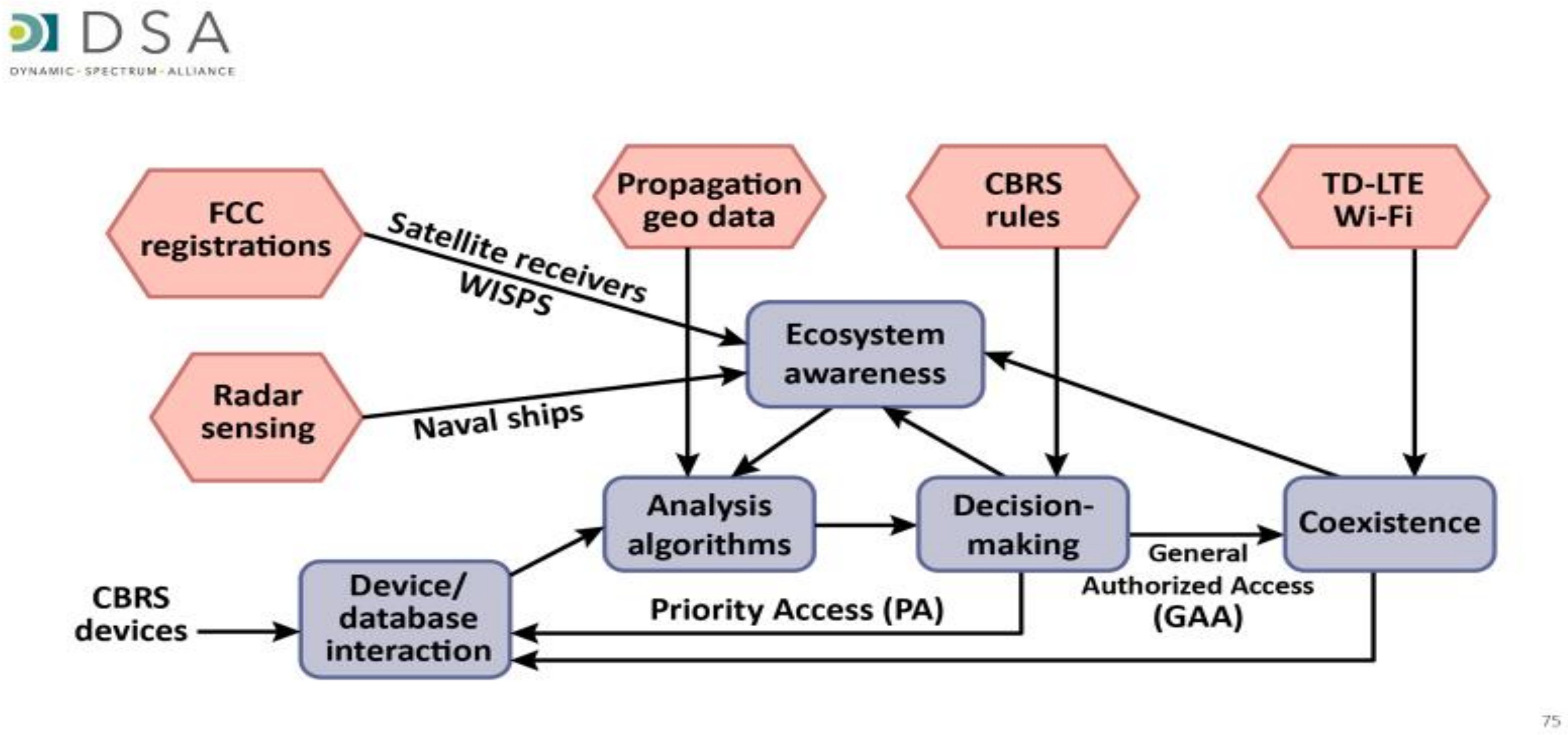
Database Sharing Methods Approaches and Examples

- ***All CBRS*** **devices must:**
  - Be capable of changing channels & operating across entire band (in case Navy radar turns on)
  - Operate under control of the SAS – renewing permission

- ***Category A (small cells) -***
  - Lower power (similar to Wi-Fi)
  - Need only report EIRP to SAS

- ***Category B (larger coverage areas)***
  - Higher EIRP in rural, low pop density areas
  - Outdoor only with professional installation required
  - Required deployment of Environmental Sensing Capability (ESC) system

Database Sharing Methods Approaches and Examples



Database Sharing Methods Approaches and Examples

Citizens Broadband Radio Service (CBRS)

- More than 312k base stations deployed across U.S. in only 3 years
  - Wide variety of mobile broadband, FWA & private wireless networks
- CBRS PAL auction had a record number of participants
  - 228 winners of 20,625 PALs for >$4.58 billion
  - >900 of GAA operators (enterprises, smart cities, education, healthcare, rural WISPs)
- Vibrant competitive ecosystem
  - Nine authorized SAS Administrators
  - 187 commercial CBSD models
  - 496 authorized client devices
  - >4000 certified professional installers

More information: https://ongoalliance.org/resource/cbrs-ongo-for-dummies/

www.dynamicspectrumalliance.org

Database Sharing Methods Approaches and Examples

- 6 GHz Standard Power (SP) devices under control of an Automated Frequency Coordination (AFC) System

- Indoor / outdoor operations.

- Will be used by Wireless Internet Service Providers (WISPs) outdoors to provide point-to-multi-point broadband access.

- Builds on the learnings of the TVWS database and the CBRS SAS, but so much simpler as all that needs to be protected in the bands are fixed service links.

- Operating frequency range will vary by country. Used in bands w/o mobile operations.

Database Sharing Methods Approaches and Examples

6 GHz Band Standard Power Devices Under Control of an AFC

United States 6 GHz Band – Primary Allocations

Sub-band	Frequency Range (GHz)	Primary Allocation	Predominant Licensed Services
U-NII-5	5.925-6.425	Fixed FSS	Fixed Microwave FSS (uplinks)
U-NII-6	6.425-6.525	Mobile FSS	Broadcast Auxiliary Service Cable Television Relay Service FSS (uplinks)
U-NII-7	6.525-6.875	Fixed FSS	Fixed Microwave FSS (uplinks/downlinks)
U-NII-8	6.875-7.125	Fixed Mobile FSS	Broadcast Auxiliary Service Fixed Microwave Broadcast Auxiliary Service Cable Television Relay Service FSS (uplinks/downlinks) (6.875-7.075 GHz only)

In Canada, the range for SP devices is 5925-6875 MHz

Database Sharing Methods Approaches and Examples

6 GHz Band Standard Power Devices Under Control of an AFC

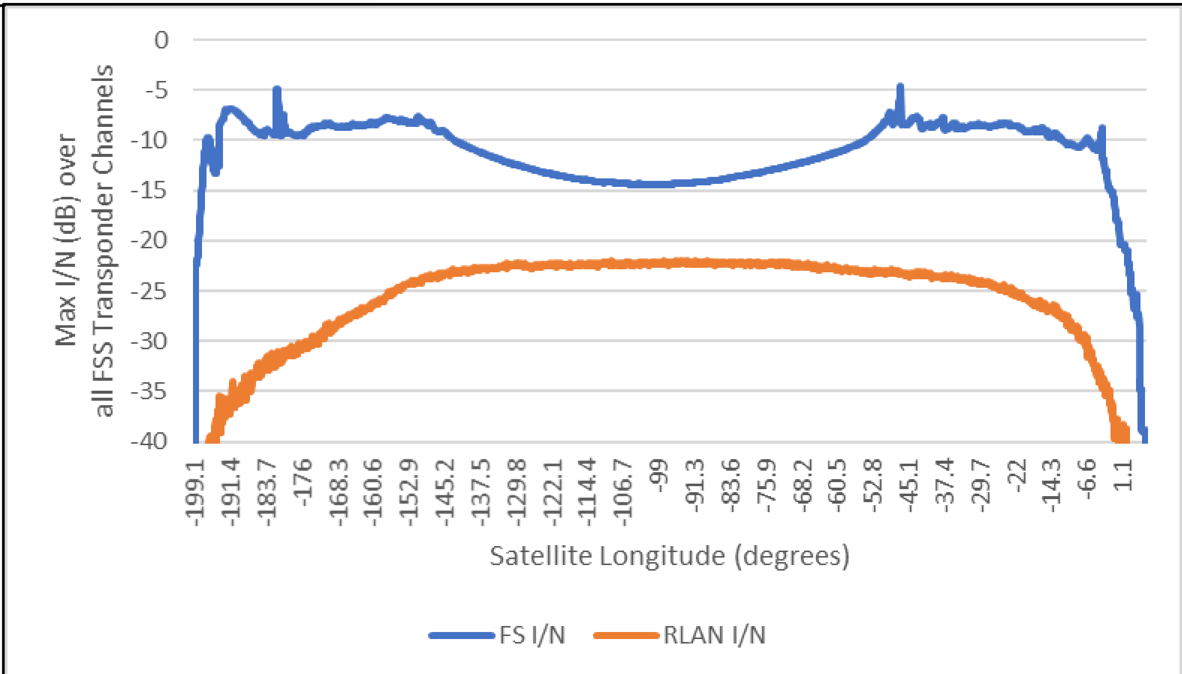
Reviewed the C-Band FSS uplinks to determine typical performance parameters of the 58 satellites with partial or full unlicensed beam coverage over U.S.

Performed a simulation to baseline the I/N to the GEO arc from the existing 57,086 CONUS FS stations to the Conventional C-Band satellites.

Performed a simulation to estimate I/N into the GEO arc from random RLAN deployments to determine what impact can be expected. Assumed both east and west coast operating at busy hour levels.

Performed comparative analysis of the results of Step 2 and 3 to assess the impact of interference to the FSS space station receiver.

<u>Key measure: Aggregate interference from RLANs</u>



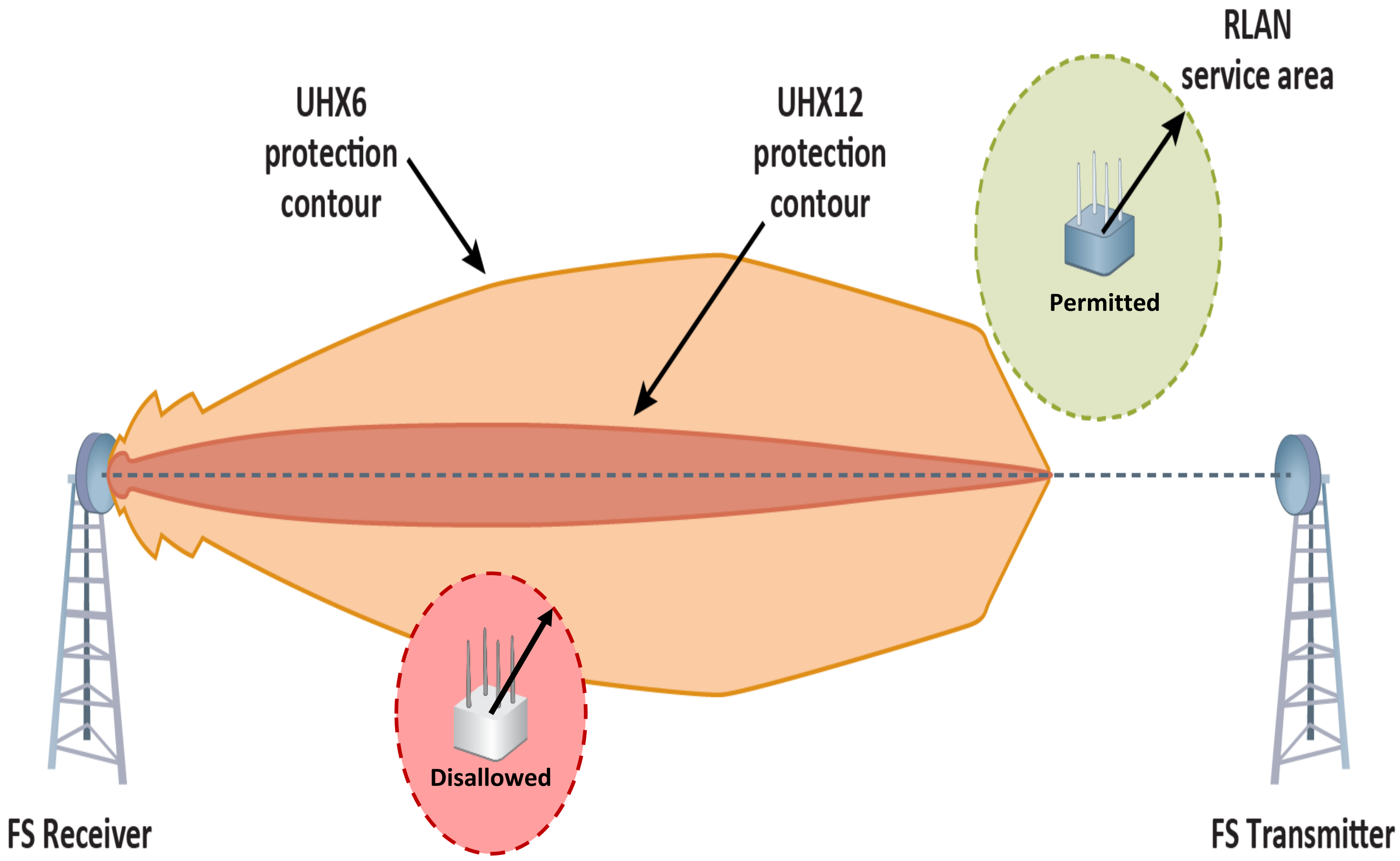
Max I/N (over FSS transponder channels) due to RLAN and FS transmitters in 5,925-6,425 MHz to satellites across the visible GEO arc

- **Simulation results indicate the highest RLAN I/N < -20 dB to the GEO arc and therefore has minimal impact on FSS performance.**
- **RLAN interference is negligible compared to the FS interference and won't be detectable.**

Database Sharing Methods Approaches and Examples

6 GHz Band – Standard Power devices operating under an Automated Frequency Coordination system

- The AFC calculates a protection area around every incumbent receiver using licensee data in the FCC's Universal Licensing System (ULS) and RLAN operating data, including its 3D position and effective EIRP
- The AFC accounts for device uncertainty by calculating an RLAN service area (RSA) with radius equal to uncertainty
- Permissible RLAN operating frequencies are those where the RSA does not collide with any incumbent contour



Database Sharing Methods Approaches and Examples

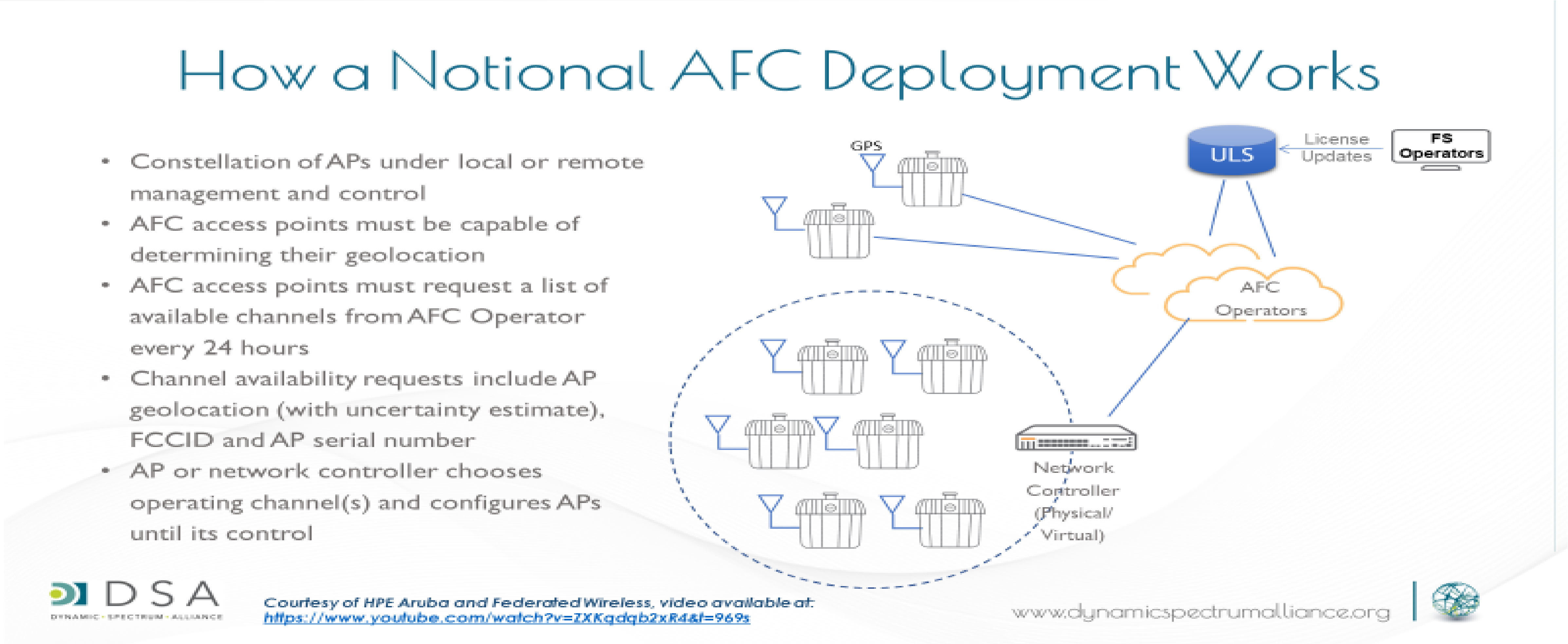
6 GHz Band – Standard Power Devices under control of an AFC system

Device Class	Operating Bands	Maximum EIRP	Maximum EIRP Power Spectral Density
Standard-Power Access Point (AFC Controlled)	U-NII-5 (5.925-6.425 GHz) U-NII-7 (6.525-6.875 GHz)	36 dBm	20 MHz: 23 dBm/MHz 40 MHz: 20 dBm/MHz 80 MHz: 17 dBm/MHz 160 MHz: 14 dBm/MHz 320 MHz: 11 dBm/MHz
Client Connected to Standard-Power Access Point		30 dBm	20 MHz: 17 dBm/MHz 40 MHz: 14 dBm/MHz 80 MHz: 11 dBm/MHz 160 MHz: 8 dBm/MHz 320 MHz: 5 dBm/MHz

The FCC adopted a rule requiring outdoor standard-power access points to limit the maximum EIRP above a 30-degree elevation angle to 21 dBm, which the Commission noted in the Notice would be similar to what the Commission already requires in the U-NII-1 band to protect fixed satellite services.

Database Sharing Methods Approaches and Examples

6 GHz Band – Standard Power Devices under control of an AFC system



Database Sharing Methods Approaches and Examples

6 GHz Band – Standard Power Devices under control of an AFC

Industry Work Products on AFC

- WInnForum Technical Specification 1014 "Functional Requirements for the U.S. 6 GHz Band under the Control of an AFC System"
  - Section 9.1 details the propagation models to be used for the protection of incumbent Fixed Service (FS) receivers
  - Section 9.2 details the use of exclusion zones in the 6650-6675.2 MHz frequency range to protect incumbent Radio Astronomy observatories (similar exclusion zones could be utilized to protect other types of "point" incumbent operations)

- Wi-Fi Alliance AFC Work Products
  - AFC System Reference Model
  - AFC System to Device Interface (SDI) Specification
  - AFC System (System Under Test) Compliance Test Plan
  - AFC Standard Power Device (Device Under Test) Compliance Test Plan

WInnForum Technical Report 1008 "Incumbent Fixed Service Data in the U.S. UNII 5 & 7 Bands"

- This report contains an analysis of the FCC's ULS data on incumbent FS operations with recommendations in terms of incorrect or missing information

www.dynamicspectrumalliance.org

Database Sharing Methods Approaches and Examples

- **FCC has conditionally approved 13 AFC operators** (Nov. 2, 2022)
  - Broadcom, Google, Comsearch, Sony Group, Kyrio, Key Bridge Wireless, Nokia Innovations, Federated Wireless, Wireless Broadband Alliance, Wi-Fi Alliance (WFA), Qualcomm, Plume Design and RED Technologies
- Different business models. Some will compete directly, others will focus on industry segments
- ***Next Steps***: FCC will define the process and metrics for lab testing and a public trial period informed by detailed industry multi-stakeholder recommendations:
  - **Lab Testing** (controlled environment)
  - **Field Testing** (demonstration project/public trial)
- Commercial operation follows final FCC certification (~ Q3/2023)
- Other countries are also pursuing standard power devices under control of an AFC.

On the Horizon

Application of Blockchain and AI / ML to Dynamic Spectrum Sharing

Blockchain

- Blockchain is an open and distributed database maintained by nodes in a peer-to-peer network (distributed ledger)
- Transactions between nodes are validated and recorded in a block. New blocks are connected to previous blocks.
- There is a time stamp when the block is created. There are cryptological tools employed to ensure it is tamperproof.
- The distributed database can be used to record any kind of information as a form of transaction.
- Conceptually, it can enable dynamic (licensed) secondary spectrum markets and opportunistic spectrum use.
- Due to the “transparency” of the distributed ledger, any real-time spectrum usage recorded can be accessed by users.
- Spectrum utilization can be improved (and administrative costs reduced) by allocating spectrum in bands according to the dynamic demands submitted by users through blockchain.
- The technical rules for using spectrum in given band and sensing of the local environment get incorporated into the ledger.
- Early stages.

Artificial Intelligence and Machine Learning

- General objective is the optimization of spectrum resources in real time.
- Allows for decentralization – each device will learn from its immediate environment and either seek the requisite spectrum resources or adapt to its environment.

On the Horizon

"Dynamic spectrum sharing between active and passive users above 100 GHz"

by Michele Polese[1], Viduneth Ariyarathna[1], Priyangshu Sen[1], Jose V. Siles[2], Francesco Restuccia[1,3], Tommaso Melodia[1] & Josep M. Jornet[1]

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"Sixth-generation wireless networks will aggregate higher-than-ever mobile traffic into ultrahigh capacity backhaul links, which could be deployed on the largely untapped spectrum above 100 GHz. Current regulations however prevent the allocation of large contiguous bands for communications at these frequencies, since several narrow bands are reserved to protect passive sensing services. These include radio astronomy and Earth exploration satellites using sensors that suffer from harmful interference from active transmitters. Here we show that active and passive spectrum sharing above 100 GHz is feasible by introducing and experimentally evaluating a real-time, dual-band backhaul prototype that tracks the presence of passive users (in this case the NASA satellite Aura) and avoids interference by automatically switching bands (123.5–140 GHz and 210–225 GHz). Our system enables wideband transmissions in the above-100-GHz spectrum, while avoiding harmful interference to satellite systems, paving the way for innovative spectrum policy and technologies in these crucial bands."

[1] Institute for the Wireless Internet of Things, Northeastern University, Boston, MA, USA. [2] Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA. [3] Roux Institute, Northeastern University, Portland, ME, USA

Summary

Spectrum sharing has always been part of the ITU's work in spectrum management – but generally a static analysis using the worst of the worst-case parameters.

The key ITU Radio Regulation that is applied by National Regulatory Agencies (NRAs) for license-exempt use is RR 4.4. NRA's also apply RR 4.4 in situations where the service is authorized on a non-interference / non-protection basis.

Sharing can occur through time separation, frequency separation, spatial location separation, and signal separation.

Cognitive radio techniques are mature and is being applied in different spectrum sharing scenarios

Initially, spectrum sharing by license-exempt devices relied exclusively on non-database methods.

License-light is in an early stage and is done manually except for CBRS in the United States.

Database-based method combine a database plus a calculation engine

The database approach only works if the NRA has good data regarding incumbent operations.

The simplest method(s) available should be used to share spectrum between different services and applications.

In terms of complexity: LSA < 6 GHz Band AFC < TVWS Database < CBRS SAS. The AFC is relatively easy.

THANK YOU