Spectrum .......

Be Prepared for Sharing
Contributors

Apurva N. Mody, CTO, National Spectrum Consortium (NSC)
Julie Knapp, Chief, Office of Engineering Technology, Federal Communications Commission (FCC)
Sumit Roy, University of Washington, NSC
Jeff Evans, Georgia Tech Research Institute, NSC
Oliver Holland, Advanced Wireless Technology Group
Jay Holcomb, Itron, Chair, IEEE 802.18 Task Group
Overview

Apurva N. Mody, National Spectrum Consortium
apurva.mody@ieee.org, apurva.mody@WhiteSpaceAlliance.org
Straw Poll for Questions at the End of this Tutorial

• Is the IEEE 802 Community interested in accessing Shared Spectrum?
• Is the IEEE 802 Community interested in Shared Spectrum Solutions for 5G?
• There are three initial steps to turn Spectrum Sharing Technologies into Standards – IEEE 802 Executive Committee Study Group, Working Group Study Group or Industry Connections Activity
  • Should we form an EC Study Group to understand the problem of Spectrum Sharing and follow-up Activities?
  • Should we form a WG Study Group to understand the problem of Spectrum Sharing and follow-up Activities?
  • Should we form an Industry Connections Activity for Spectrum Sharing and follow-up Activities?
• Should IEEE 802 engage in creation of a Protocol to Access the Spectrum Database (Spectrum Access System)? (e.g. IETF Protocol to Access White Spaces - PAWS)
• Should IEEE 802 engage in creation of a standards for Beaconing?
• Which of the 5G bands are of most interest to the IEEE 802 Community?
What is Bi-directional Spectrum Sharing

**Geographic sharing** occurs when multiple users access the same frequencies in different geographic areas which are sufficiently separated to avoid interference.

**Sharing spectrum in time** occurs when multiple users access the same frequencies at different times to avoid interference. When a primary spectrum user is not using its spectrum, it could allow access to a secondary user—even if users are in close proximity.

For example, if a federal agency transmits high-powered radar around the clock over a large area at certain frequencies, other users cannot use those frequencies in that space without interference. However, if the radar is used intermittently, in theory the agency can provide other users with the times when the frequency is available for sharing.

Federal to Commercial Bi-directional Spectrum Sharing

Federal

Examples of general use

<table>
<thead>
<tr>
<th>Frequency</th>
<th>3 kHz</th>
<th>30 kHz</th>
<th>300 kHz</th>
<th>3 MHz</th>
<th>30 MHz</th>
<th>300 MHz</th>
<th>3 GHz</th>
<th>30 GHz</th>
<th>300 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maritime navigation signs</td>
<td>Navigational aids</td>
<td>AM radio, Maritime radio</td>
<td>Shortwave radio</td>
<td>Broadcast television, FM radio</td>
<td>Broadcast television, Cellular telephone</td>
<td>Space and satellite communications, Microwave systems</td>
<td>Radio astronomy</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Commercial

Spectrum ... Be Prepared for Sharing
Commercial to Commercial Bi-directional Spectrum Sharing

Commercial 1

Commercial 2
Spectrum Bands being Considered for Commercial Use

Presenter
Apurva N. Mody, National Spectrum Consortium

On behalf of
Julie Knapp, Chief of Office of Engineering and Technology, FCC

Jay Holcomb, Itron, Chair, IEEE 802.18 Radio Regulatory TAG
Mobile Now Act and Spectrum Bands Being Considered for Release

Julius Knapp, Chief
Office of Engineering and Technology
Federal Communications Commission

Presented to the
National Spectrum Consortium
November 1, 2018

Note: The views expressed in this presentation are those of the author and may not necessarily represent the views of the Federal Communications Commission.
Key FCC Spectrum Initiatives & Proceedings

• **Low Frequency Spectrum:**
  – TV Broadcast Incentive Auction (600 MHz band)

• **Mid Frequency Spectrum:**
  – 3.5 GHz (3550-3700 MHz)
  – Proposal for 3700 – 4200 MHz
  – Draft proposal for 5925 – 7125 MHz

• **High Frequency Spectrum:**
  – Spectrum Frontiers (above 24 GHz)
  – Spectrum Horizons (above 95 GHz)

All these bands require mechanisms for spectrum sharing
Mid Band
Citizen’s Broadband Radio Service (3.5 GHz)

Problem: How to share spectrum (3550 – 3700 MHz) with navy radars other incumbent users

Spectrum Access System (SAS) protects against interference and manages access to spectrum

Where We Are In The Process

• Multi-stakeholder process - WinnForum developing implementation
• Conditionally approved first Spectrum Access Administrators: Amdocs; Comsearch, CTIA, Federated Wireless, Google; Key Bridge; and Sony
• SAS testing by NTIA Institute for Telecommunications Science
• Initial commercial deployments – Applications under review by FCC

FCC planning to open 3.4 GHz to 4.2 GHz in the near future.
**Mid Band**

**3.7 & 6 GHz**

- Proposed to make spectrum available for licensed wireless service the in the **3.7 – 4.2 GHz C-band satellite DL band**

- Proposed to make spectrum available for unlicensed access in the **5.925 – 7.125 GHz (6 GHz) band**

- **Significance:**
  - **3.7 GHz is adjacent to 3.5 GHz band** - region is focus for 5G internationally
  - **6 GHz is close to 5 GHz unlicensed bands**

**Two Areas of Focus:**

- **3.7 – 4.2 GHz** – Proposed licensed access to C-band satellite DL spectrum
- **5.925 – 7.125 GHz** – Proposed unlicensed sharing with Pt-2-Pt microwave & satellite uplinks

3.7 GHz to 4.2 GHz will require sharing with Fixed Satellite Receivers
6 GHz Spectrum Sharing Requirements

Interested parties, in or adjacent to the 6 GHz band:

- Auto Makers, Broadcast, Microwave users in general, Public Safety, RLANs, Satellite, Utilities, UWB
- The 6 GHz band is exclusive non-federal spectrum and is host to several incumbent services operating on a primary basis, including fixed point-to-point services, Fixed-Satellite Service (FSS), Broadcast Auxiliary Service, and Cable Television Relay Service. A query of FCC databases shows 47,695 unique call signs between 5.925 and 7.125 GHz.

NPRM band segments:

<table>
<thead>
<tr>
<th>Band (GHz)</th>
<th>Primary Allocations</th>
<th>Reference used in this NPRM</th>
<th>Devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.925-6.425</td>
<td>Fixed Service FSS</td>
<td>U-NII-5</td>
<td>Standard-Power Access Point</td>
</tr>
<tr>
<td>6.425-6.525</td>
<td>Mobile Service FSS</td>
<td>U-NII-6</td>
<td>Low-Power Access Point</td>
</tr>
<tr>
<td>6.525-6.875</td>
<td>Fixed Service FSS</td>
<td>U-NII-7</td>
<td>Standard-Power Access Point</td>
</tr>
<tr>
<td>6.875-7.125</td>
<td>Mobile Service FSS</td>
<td>U-NII-8</td>
<td>Low-Power Access Point</td>
</tr>
</tbody>
</table>

6 GHz requires spectrum sharing with Microwave Links, Broadcast Auxiliary Services, Fixed Satellite Receiver Stations etc.
6 GHz Spectrum Sharing Requirements

Sharing is focusing on AFC – Automated Frequency Coordination

• In the 5.925-6.425 GHz and 6.525-6.875 GHz sub-bands, unlicensed devices would only be allowed to transmit under the control of an automated frequency control (AFC) system. AFC is nothing but a fancier Spectrum Database
  – These frequencies are heavily used by point-to-point microwave links and some fixed satellite systems.
  – The AFC system would identify frequencies on which unlicensed devices could operate without causing harmful interference to fixed point-to-point microwave receivers.

• In the 6.425-6.525 GHz and 6.875-7.125 GHz sub-bands, unlicensed devices would be restricted to indoor use and would operate at lower power, without an AFC system.
  – These frequencies are used for mobile services, such as the Broadcast Auxiliary Service and Cable Television Relay Service, as well as fixed and fixed satellite services. The itinerant nature of the mobile services makes the use of an AFC system impractical.
  – The combination of lower power and indoor operations would protect licensed services operating on these frequencies from harmful interference.

6 GHz requires spectrum sharing with Microwave Links, Broadcast Auxiliary Services, Fixed Satellite Receiver Stations etc.
6 GHz Spectrum Sharing Requirements

Sharing is focusing on AFC – Automated Frequency Coordination

6 GHz requires spectrum sharing with Microwave Links, Broadcast Auxiliary Services, Fixed Satellite Receiver Stations etc.
High Band Spectrum Frontiers

Spectrum Allocations

- 12.55 GHz of Spectrum added for mobile
  - Licensed Bands (Total 3.85 GHz): 24.25-24.45 GHz and 24.75-25.25 GHz; 47.2-48.2 GHz; 27.5-28.35 GHz; 37-38.6 GHz; 38.6-40 GHz;
  - Unlicensed Bands (Total 7 GHz): 64-71 GHz (added to 57 – 64 GHz)

Service Rules

- Part 30: Upper Microwave Flexible Use Service (UMFUS)
- Geographic Area Licensing, Area Size, Band Plan, License Term, Overlay Auctions
- Technical rules
- Performance Requirements

Often Associated with “5G”
## Overview of First Report and Order Bands

<table>
<thead>
<tr>
<th>Frequency</th>
<th>28 GHz</th>
<th>37 GHz</th>
<th>39 GHz</th>
<th>64-71 GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terrestrial Allocation</td>
<td>Licensed for fixed operations, with about 75% of the population covered by existing licenses; remaining licenses in inventory</td>
<td>Yes (no current use)</td>
<td>Licensed for fixed operations, with about 50% of the population covered by existing licenses; the remaining licenses are in inventory.</td>
<td>Yes (no current use)</td>
</tr>
<tr>
<td>Federal Allocation</td>
<td>No</td>
<td>Radio Astronomy / Space Research in 37-38 GHz @ 3 sites; Federal Fixed/Mobile in 37-38.6 GHz @ 14 locations</td>
<td>Fixed Satellite Service / Mobile Satellite Service in 39.5-40 (military use only)</td>
<td>Earth Exploration Satellite Fixed/Mobile/satellite</td>
</tr>
<tr>
<td>Satellite Allocation</td>
<td>Yes</td>
<td>Yes (no current use)</td>
<td>Yes (no current use)</td>
<td>Yes (no current use)</td>
</tr>
<tr>
<td>Licensing Scheme</td>
<td>Licensed</td>
<td>Licensed</td>
<td>Licensed</td>
<td>Unlicensed</td>
</tr>
</tbody>
</table>
## Overview of Second R&O Bands

<table>
<thead>
<tr>
<th></th>
<th><strong>24 GHz</strong></th>
<th><strong>47 GHz</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>24.25-24.45 GHz and 24.75-25.25 GHz</td>
<td>47.2-48.2 GHz</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>700 MHz</td>
<td>1000 MHz</td>
</tr>
<tr>
<td>**Terrestrial **</td>
<td>Lower segment is licensed for two types of fixed operations: 24 GHz service</td>
<td>Yes (no current use)</td>
</tr>
<tr>
<td><strong>Allocation</strong></td>
<td>and Digital Electronic Messaging Service (DEMS). 5 active 24 GHz licenses,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>and 38 active DEMS licenses; remaining licenses in inventory</td>
<td></td>
</tr>
<tr>
<td><strong>Federal</strong></td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td><strong>Allocation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Satellite</strong></td>
<td>Yes, 24.75-25.25 GHz band segment is non-Federal allocated for FSS (Earth-</td>
<td>Yes (no current use and the Commission designated this band for terrestrial use)</td>
</tr>
<tr>
<td><strong>Allocation</strong></td>
<td>to-space)</td>
<td></td>
</tr>
<tr>
<td><strong>Licensing Scheme</strong></td>
<td>Licensed</td>
<td>Licensed</td>
</tr>
</tbody>
</table>
Roll-out of MMW Bands & 5G

- Already happening - granted flexibility for incumbent fixed services to offer mobile
- Auctions planned this year for 28 GHz, then 24 GHz; upper 37 GHz, 39 GHz & 47 GHz next year
- Third Notice invited comment on 25.25-27.5 GHz (26 GHz) and 42.0 – 42.5 GHz

The FCC’s 5G FAST Plan

Under Chairman Pai, the FCC is pursuing a comprehensive strategy to facilitate America’s Unsprung 5G Technology (the 5G FAST Plan). The Chairman’s strategy includes three key components: (1) making more spectrum available to the marketplace; (2) updating infrastructure policy; and (3) modernizing outdated regulations.

Spectrum
The FCC is taking action to make additional spectrum available for 5G services.
- **High-band**: The FCC has made auctioning high-band, millimeter-wave spectrum a priority. The FCC will hold its first 5G spectrum auctions this year in the 28 GHz and 34 GHz bands. In 2019, the FCC will auction the upper 37 GHz, 39 GHz, and 47 GHz bands. With these auctions, the FCC will release almost 5 gigahertz of 5G spectrum into the market-more than all other flexible use bands combined. And we are working to free up another 2.75 gigahertz of 5G spectrum in the 26 and 55 GHz bands.
- **Mid-band**: Mid-band spectrum has become a target for 5G because it is balanced—neither too wide and capacity-intensive. With our work on the 2.5 GHz, 3.5 GHz, and 5.25-5.35 GHz bands, we could make up to 48 megahertz available for 5G deployment.
- **Low-band**: The FCC is acting to improve use of low-band spectrum (needed for wide coverage) for 5G services, with targeted changes to the 600 MHz, 700 MHz, and 800 MHz bands.
- **Unlicensed**: Recognizing that unlicensed spectrum will be important for 5G, the agency is creating new opportunities for the next generation of WiFi in the 6 GHz and above 50 GHz bands.

Infrastructure Policy
The FCC is updating infrastructure policy and encouraging the private sector to invest in 5G networks.
- **Speeding Up Federal Review of Small Cells**: The FCC adopted new rules that will reduce federal regulatory impediments to deploying small-cell infrastructure needed for 5G (as opposed to large cell towers) and help to expand the reach of 5G for faster, more reliable wireless service.
- **Speeding Up State and Local Review of Small Cells**: The FCC has reformed rules designed decades ago to accommodate small cells. The reforms have short-circuited municipal roadblocks that have the effect of prohibiting deployment of 5G and give states and localities a reasonable deadline to approve or disapprove small-cell using applications.

Modernizing Outdated Regulations
The FCC is modernizing outdated regulations to promote 5G backhaul and digital opportunity for all Americans.
- **Restoring Internet Freedom**: To lead the world in 5G, the United States needs to encourage investment and innovation while protecting Internet openness and freedom. The FCC adopted the Restoring Internet Freedom Order, which sets a consistent national policy for Internet providers.
- **One-Touch Make-Ready**: The FCC has updated its rules governing the attachment of new network equipment to utility poles in order to reduce cost and speed up the process for 5G backhaul deployment.
- **Speeding the 5G Transition**: The FCC has revised its rules to make it easier for companies to invest in next-generation networks and services instead of the fading networks of the past.
- ** Emergency DSS Services**: In order to incentivize investment in modern fiber networks, the FCC updated the definition of high-speed, dedicated services by lifting rate regulation where appropriate.
- **Supply Chain Integrity**: The FCC has proposed to prevent taxpayer dollars from being used to purchase equipment or services from companies that pose a national security threat to the integrity of American communications networks or the communications supply chain.

Spectrum Horizons

• Proposed to expand access above 95 GHz
  – Total of 102.2 GHz to for licensed point-to-point services
    • 95100 GHz, 102-109.5 GHz, 111.8-114.25 GHz, 122.25-123 GHz, 130-134 GHz, 141-148.5 GHz, 151.5158.5 GHz, 174.5-174.8 GHz, 231.5-232 GHz, and 240-241 GHz band
    • Similar to 70/80/90 GHz rules
    • Licensed nationwide, non-exclusive basis
    • Register links with database manager
    • Seek comment on mobile use
  – Total of 15.2 GHz for unlicensed use
    • 122-123 GHz, 244-246 GHz, 174.8-182 GHz and 185-190 GHz bands
    • Similar to 60 GHz rules
    • Selected high absorption bands
  – New type of experimental licenses > 95 GHz
    • Longer license terms
    • Ability to sell devices

Much of the spectrum above 95 GHz is allocated for passive services

Achieve Fiber Capacity

Innovations
UNITED STATES PRESIDENTIAL MEMORANDUM
Presidential Memorandum on Developing a Sustainable Spectrum Strategy for America’s Future INFRASTRUCTURE & TECHNOLOGY
Issued on: October 25, 2018

• Within 180 days agencies report anticipated future spectrum requirements
• The Director of the Office of Science and Technology Policy (OSTP) shall report on emerging technologies and their expected impact on non-Federal spectrum demand
• The Director of OSTP shall report on recommendations for research and development priorities that advance spectrum access and efficiency
• Within 270 days submit a long-term National Spectrum Strategy that includes legislative, regulatory, or other policy recommendations
• The Chief Technology Officer and the Director of the National Economic Council, or their designees, shall co-chair a Spectrum Strategy Task Force
Spectrum Sharing Today

Oliver Holland, Advanced Wireless Technology Group, Ltd., UK
oliver.holland@ieee.org
Spectrum Sharing Today

- TV White Space (TVWS)
  - US, UK, Canada, Singapore, South Africa, Colombia, numerous other countries worldwide
- Citizens Broadband Radio Service (CBRS)
  - US; possible solution in other countries
- Licensed-Shared Access (LSA)
  - EU—France, Finland, Italy, Netherlands
- Local licensing innovation for sharing, e.g., 1800 MHz, 2.3 GHz, and 3.8-4.2 GHz in UK
- Others, e.g., light licensing, collective use of spectrum and concurrent spectrum access, and of course, sharing in unlicensed spectrum
Spectrum Sharing Today—Spectrum Databases

• Why (Geolocation/spectrum) “databases”?
  • High level of dependability/reliability/certainty required when users access another service’s/incumbent’s spectrum
  • Allows regulator to keep overall direct/indirect control at all times (e.g., in case of change needed, error or malicious operation, even suspension of framework, etc.)
  • Already prescribed for three bands – TV White Spaces, 3.5 GHz (CBRS Spectrum Access System) and 6 GHz (Automated Frequency Coordination)

• Spectrum sensing
  • Best way to obtain in-situ awareness of the environment
  • Device agnostic
  • New sensing techniques that have detection and characterization built in

Geolocation Database (e.g. Spectrum Access System) and Spectrum Sensing are two tried and trusted mechanisms for sharing
Spectrum Sharing Today—Spectrum Databases

TVWS example (Ofcom, UK)

1) Database discovery
2) Device-database communications.

Citizens Broadband Radio Service (CBRS) is also database (Spectrum Access System) driven
Spectrum Sharing Today—Spectrum Databases

- Can be:
  - License-exempt, e.g., if device entirely automated, integrated GPS (TVWS—UK, CBRS—GAA)
  - Licensed, e.g., if manual configuration of device required (TVWS—UK), local priority-licensed (CBRS—US)
  - Primary-secondary (or even tertiary) sharing (TVWS, CBRS)
  - Sharing among operators, new entrants, e.g., by agreement of those operators, e.g., with financial compensation (LSA—EU, France, Finland, Italy, Netherlands)
  - Device (TVWS, CBRS) or network (LSA, CBRS) interacting with the database
  - Manual (“Enabling Opportunities for Innovation”—UK, various light licensing approaches, etc.), or automated
Spectrum Sharing Today—Spectrum Sensing

- Energy detection
- Feature detection, e.g.,
  - Cyclic prefix
  - Autocorrelation
  - Cyclostationary

Detection hypothesis

\[ H_0 : y(k) = w(k) \quad \text{signal absent} \]
\[ H_1 : y(k) = w(k) + s(k) \quad \text{signal present} \]

\[ z = z(y(1), y(2), \ldots, y(N)) \quad \text{test statistic} \]

if \( z > \zeta \) then \( H_1 \)
else \( H_0 \)

\( \zeta : \) sensing threshold


Probability of detection

\[ PD = \text{prob}(H_1 | H_1) \]

Probability of mis-detection

\[ PMD = \text{prob}(H_0 | H_1) = 1 - PD \]

Probability of false alarm

\[ PFA = \text{prob}(H_1 | H_0) \]
Spectrum Sharing Today—Spectrum Sensing

- Still is (or can be) used in some cases
  - Environmental Sensing Capability (ESC)
  - Very low-power white space devices in US
  - Coordination among license-exempt devices
  - 5 GHz
- Of course, can greatly assist regulatory processes
  - E.g., interference potential/interferer detection, spectrum forensics
  - Understanding of the spectral situation, e.g., to assess potential for sharing gains

Sensing as in Environmental Sensing Capability (ESC) has been already adopted in the 3.5 GHz Band. 5G Eco-system is involved in adopting it.
Spectrum Sharing Today—Beacons

- One of the best techniques for avoiding the hidden node issue
- Beacons is one of the few options to protect Primary User that is Passive (e.g., Satellite Receiver Stations)
- Beacons are also very good for Dynamic Coordinated Spectrum Sharing
- Beacons can be designed for robustness or for fast information transfer depending on the use-case.

Beacons is one of the few options to protect Primary User that is Passive (e.g., Satellite Receiver Stations)
Spectrum Sharing Insights

Sumit Roy
Integrated Systems Professor
U. of Washington, Seattle
sroy@uw.edu
Federal / Non-Federal Sharing


- NTIA Fast Track Rpt. 2010 identifying 1st set of Federal Spectrum to be re-purposed

- AWS-3 SPECTRUM AUCTION (1695-1710, 1755-1780, 2155-2180 MHz)

- 3.5 GHz CBRS (3550-3700 MHz)

Primary System to be protected: Federal licensed incumbent
Secondary System: New (either un-licensed or licensed with lower priority than incumbent)
AWS-3 (1695-1710, 1755-1780)

- 38+ systems/capabilities affected by the AWS-3 transition → must relocate to another DoD band, compress into, or stay & retrofit (share spectrum)

- US Govt. will modify selected systems to operate at both 1780-1850 MHz and 2025-2110 MHz
  - Small Unmanned Aerial Systems - Tactical Radio Relay
  - Tactical Targeting Network Technology - High Resolution Video

- US Govt. systems will remain in the 1755-1780 MHz band and share spectrum with commercial users as follows
  - Satellite Operations at 25 locations - Air Combat Training System
  - Electronic Warfare - Joint Tactical Radio System (6 sites)

- US Govt. will compress the remaining 1755-1780 MHz operations into 1780 - 1850 MHz
  - Air Combat Training System - Precision Guided Munitions
  - Joint Tactical Radio System at all other sites - Aeronautical Mobile Telemetry

3GPP Eco-system is heavily involved in enabling spectrum sharing in these bands
Operational Approaches to Spectrum Sharing

• **Non-collaborative** (no information exchanged at operational time)
  – Easier (retro-fitting, particularly on secondary with no requirements on primary (Federal system)

• **Collaborative** (side channel for info exchange at operation time/scale)
  – Knowledge of incumbent parameters (pulse duration/burst length, beam pattern, angular rotation speed) *can potentially reduce exclusion regions*
  – Encourage new **interference tolerance** approaches for primary

There are regulatory use-cases for both Non-collaborative and Collaborative Sharing
EXCLUSION REGION (3.5 GHz): Ship Borne Radar

NTIA Rpt. 15-517
Jun 2015
(Exclusion Zone Analyses & Methodology:

Highlights impact of Model Assumptions!

Figure B-1. Shipborne Radar 1–exclusion zone lower 48 states (yellow line–fast track exclusion zone and blue line–revised exclusion zone).
Incumbent Protection
EXCLUSION & PROTECTION REGIONS

- **Exclusion Zone**: A region around the primary with no co-channel active secondary transmission
- **Protection Zone**: A region with active secondary transmitters, but with constraints so as to stay within `acceptable interference’ limits
- **Design Objective**: minimize exclusion region subject to protection of primary.

Exclusion Region depends on multiple factors: sensitivity of victim receiver, interference margin, secondary transmit power, path loss model

Incumbent Licensee: ‘primary’ (to be protected from interference)
New User: `secondary’ (no interference protection)
Spectrum Sharing Tomorrow

Sumit Roy
Integrated Systems Professor
U. of Washington, Seattle
sroy@uw.edu

Jeff Evans, GTRI,
jeff.evans@gtri.gatech.edu
Example: Radar-IEEE 802.11 Coexistence

Homogeneous Poisson Process Deployment

\[ P(\Phi(A) = n) = \frac{(\lambda_{AP}|A|)^n}{n!} e^{-\lambda_{AP}|A|} \]

\[ I_{agg} = \sum_{x \in \Phi} \frac{P_{su} G(\theta_x)}{FDR(\Delta f)} l(||x||) \]

\[ l(r) = r^{-\alpha} \]

\( \alpha = 4 \rightarrow \) closed form expression

\[ f_{I_{agg}}(x) = \frac{\pi \lambda}{2x^{3/2}} \exp \left( -\frac{\pi^3 \lambda^2}{4x} \right) \]

Levy distribution

Aggregate interference presented by the incumbent is often Non-Gaussian – Hence requires new methods
Distribution of $I_{aggr}$ with Protection region

- Gaussian Approximation – works lower aggregate Interference (large protection regions)
- Otherwise significantly Non-Gaussian

Aggregate interference presented by the incumbent is often Non-Gaussian – Hence requires new methods
Incumbent Protection vs Incentivizing Secondary

- Radar protection from IEEE 802.11:
  - sensing by IEEE 802.11 nodes + Dynamic Frequency Selection (DFS)
  - sensing by IEEE 802.11 for radar incurs some cost (IEEE 802.11 throughput degradation)!
    - e.g. insert quiet periods in IEEE 802.11 to listen/detect radar

Good Design → Acceptable Trade-offs
satisfy radar protection requirements while minimizing
IEEE 802.11 throughput loss (latter has been often neglected)
Detection – Search Radar

Spatio-temporally varying use of Spectrum Resources

Radar rotates in azimuth with angular rotation speed (e.g. once in few sec)

At any location: emits a burst of pulses →

a) pulse duration (e.g. 1 μs)

b) pulse repetition interval (10 μs)

A pulse burst

Example of balancing incumbent protection with secondary enablement
IEEE 802.11 MAC: CSMA/CA

Nodes use Carrier Sensing Followed by Random Back-Off

Node 2
DIFS 6 5 4 3
pause back-off count
DIFS 2 1
Payload

Node 1
DIFS 4 3 2 1
Payload
SIFS
ACK
DIFS 7 6
pause count

Node 1 selects new backoff
Node 2 selects new backoff
Node 1 selects new backoff
Node 2 resumes old backoff

$t_{\text{slot}}$ $t_{\text{bo}}$ $t_{\text{difs}}$ $t_{\text{sifs}}$ $t_{\text{ack}}$ $t_{\text{payload}}$

$1\mu s$ $9 \times t_{\text{slot}}$ $34 \times t_{\text{slot}}$ $16 \times t_{\text{slot}}$ $48 \times t_{\text{slot}}$ up to $\approx 3000 \times t_{\text{slot}}$

Quiet Periods in IEEE 802.11 (all nodes backed off)
Throughput vs Detection Trade Off

IEEE 802.11 Knobs: Payload Size & DIFS duration

- Increased DIFS $\rightarrow$ more quiet periods $\rightarrow$ better detection, lower throughput
- Increased Payload $\rightarrow$ higher throughput

Example of balancing incumbent protection with secondary enablement
Robustifying IEEE 802.11 to Pulsed Radar

The circle boxes illustrate the elements added to the modified IEEE 802.11 system.
Histogram at decoder input

- No radar interference histogram follows a Generalized Exponential distribution
- Radar interference histogram has a very large magnitude with zero mean and large variance.

(a) No radar interference

(b) Radar interference
Fair Spectrum Sharing

- Should define a **criterion** that takes as input a given instance of spectrum usage pattern of the **systems or users** in the shared spectrum and delivers as output a measure of fairness for this instance of spectrum sharing (802.19-14)

- Spectrum usage is highly impacted by the access protocol used by each system
  - The fairness criterion should be defined in terms of **accepted network QoS parameters** (throughput, time share, access...)

In a Fair frame-work, everyone brings out their best techniques
Example: LTE-LAA/IEEE 802.11 Fair Sharing

3GPP

Step 1: Both operators A and B are IEEE 802.11 co-channel on separate SSID

Step 2: Replace operator A network with LTE LAA

4 co-channel cells per operator (eNB or IEEE 802.11 AP)

5 UEs/STAs per cell per operator (20 UEs or STAs per operator) randomly dropped

Non-mobile indoor scenario (IEEE propagation loss model)

Downlink on shared channel; LTE has separate licensed uplink

Idealized backhaul network

Performance metrics:
- File transfer throughput
- File transfer latency
- Voice flow latency
LTE-LAA /IEEE 802.11 Fair Coexistence: Comments

- Multiple categories (Cat 1-4) of LTE-LAA, behave very diff. with IEEE 802.11
- Even for Cat 4 (most DCF like LTE-LAA)
  Impact of LTE-LAA → IEEE 802.11 and IEEE 802.11 → LTE-LAA asymmetric

- By tuning of resp. ED thresholds (IEEE 802.11 and LTE-LAA), TXOP (LTE-LAA), per-user t’put of the resp. networks can be changed favorably!

Time Fairness does not equal Throughput Fairness!

M. Mehrnoush et al `On Fairness of IEEE 802.11 & LTE-LAA Coexistence"
Near term Technologies wireless/5G Spectrum Sharing

Numerous technologies across wireless (and fixed) exist to support future spectrums Sharing:

1. Advances in RAN capabilities
2. Multi-user MIMO
3. Beamforming
4. Network controllers
5. Software Defined Networking
6. Network Functions Virtualization
7. Location Data Base for Unlicensed/Shared spectrum
8. Geo-location specific Devices

Many of these are already being used to some degree in today’s networks and initial 5G NR deployments -- *In the future low latency, efficiency, and SLAs for a range of end-user requirements, will matter as much as bandwidth*
Advancing Spectrum Sharing Techniques

(1) Dynamic Spectrum at the RAN in coordination with Slicing requirements
   – New Radio Access techniques
   – Massive MIMO with spatial awareness/adaptive beamforming
   – Device to Device (D2D) control with high mobility – eMBB

(2) And Network Slicing, supported at the core/RAN by:
   – a wireless software-defined network,
   – network function virtualization,
   – Separate of control/data planes and new orchestration functions

Supporting Maximum Efficient use of Spectrum Sharing for:
   – network ultra-densification,
   – Edge Computing
   – big data and mobile cloud computing,
   – scalable Internet of Things

Looking forward to 5G Release 17
Emerging Technologies Must Support Disparate Needs

Massive Machine-Type Communication (mMTC)
- Network and device energy efficiency
- Massive number of connections
- Very large coverage

Ultra-Reliable Low Latency Communication (URLLC)
- Ultra-high reliability
- Ultra-low latency

Enhanced Mobile Broadband (eMBB)
- High peak throughput
- High spectral efficiency
- High capacity
- Mobility

Cost Savings | Power Savings

From: Dark As Dark Can, The Untold Keynote – May 2015, Sabine Roessel, Intel Corporation

mMTC and URLLC are the new kids on the block in 5G
New requirements for the RAN architecture

Radio Front-end

- **Scalable OFDM** – use “sub slots to enhance flexibility and latency which supports:
  - **Shortened TTI** – reduces latency
  - **Massive MIMO** – large numbers of bearers (hundreds) to increase bandwidth in sub-6GHz bands integrated with:
  - **Spatial Adaptive Beam Forming** – extends range/cell size

RAN innovations/new complexities

- **vRAN** – Virtualizing the BBU
- **Versus C-RAN** (cloud/centralized RAN – with “Front Hauling” to BBU
- **CoMP** – coordinate muUE attached to multiple cells to provide greater reliability (Qualcomm)
- **Deployment**: Dense cell
- **Decoupling traditional management functions** (i.e., session-mobility)
- **Peer to Peer** (Device to Device – D2D) provisioning
- **Edge/End-point slicing/computing** – SWAP and complexity trade-offs
- **Cross Domain management**

Reconfiguration of the Core vs the Edge
End-to-End Dynamic Network Slicing

Aligning with Network functions and multiple end user requirements to optimize end-to-end Service Level Agreements (SLA) from Core to RAN and End Device

- **Core Leverages:** NFV (Network Functions Virtualization & SDN (Software Defined Networking) techniques, Cross Domain Orchestration, and related “Awareness” concepts

- **RAN:** Use hardware radio resources and spectrum, with technologies/concepts to include: Edge computing, Flexible NR front-end, massive MIMO, low-latency (sub frame for <1ms), etc

**Key End-User requirements:**
- low latency and high reliability
- massive connection
- high spectrum efficiency
- high data rate
- Distributed & wide coverage

**Networked Virtualization needs to happen end to end – Core as well as RAN**
5G Slicing – Multiple Use Cases

5G network slicing

5G network slicing enables service providers to build virtual end-to-end networks tailored to application requirements.

Source: https://news.itu.int/why-end-to-end-network-slicing-will-be-important-for-5g
Questions & Opportunities for End-to-End Network Slicing

- Implement so that the network control is agnostic to each vertical use (i.e. V2I – V2V, massive IoT, VR, etc)
- Initial RAN slicing has been show to improve performance and resource allocations for the user – can base stations handle the added complexity
- Spectrum re-use, especially at the higher bands, is a big opportunity
- Service Provider (SP) spectrum slices: how many & customer control?
- Slice hand-offs: how to connect to other SPs slices? How to connect to a Multiple System Operator Slice? (i.e., integrate with cable providers and for MEACs)
- Policy concern on Slicing QoS: Potential legal avenue around Net Neutrality?
- User management options – addressing complexity and autonomous of multiple varying Slices with AI implementation?
- Slicing standards and final definition are still ongoing (scheduled for Rel 17 2020)
Massive MIMO Concept and Needs

• mmW – above 10 GHz, reflection/scattering will be the key for NLOS propagation
• Basestations at this frequency and higher would need to be inbuilding
• Antenna in array exceeds users; adding high gain adaptive beamforming to increase coverage and minimize interference; Use with Spatial and Time Domain controls to maximize Spectral Reuse
• Evolving research with AI/ML techniques to add/enhance blind source identification, direction finding, etc.

Spatial Adaptive Beamforming with Massive MIMO is corner-stone of the 5G Spectrum Re-use … One of the Utopia

https://www.edn.com/electronics-blogs/5g-waves/4459761/Realizing-5G-New-Radio-massive-MIMO-systems; January 8, 2018
Multi-access Edge control – The Best of Both Worlds

Edge Computing (akin to FOG – a superset) allows different parts of the system to maximize their strengths

- **Cloud**
  - Massive storage
  - Heavy computation
  - Global coordination
  - Wide-area connectivity

- **Edge/Fog**
  - Real-time processing
  - Rapid innovation
  - Client-centric
  - Edge resource pooling

- **Issues**
  - More complex and power-hungry edge devices
  - Parsing of data – efficiency vs. loss of context

RAN to the Mobile Edge and back to the Core
Agnostic but Smart MEC

- Edge computing is feasible (required) for high bandwidth, connectivity afforded by 5G and App demands.
- Spans the enterprise data enter, the WAN, the cloud, and the Edge
- SWAP constraints – need hybrid with functions at the edge

* Contribution from Nokia

Characteristics
- LTE WAN baseline
- 5G low & mid band WAN
- 5G mmWave Hot Spots
- URLLC Hotter Spots

Creating a seamless user experience will be important ...in throughput & latency

Smart Edge Computing is Increasingly Necessary for ALL Networked Systems

Low and high latency zones based on use case
New Technologies that are Needed

Apurva N. Mody, National Spectrum Consortium
apurva.mody@ieee.org, apurva.mody@WhiteSpaceAlliance.org

Jeff Evans, GTRI, NSC
jeff.evans@gtri.gatech.edu

Sumit Roy, U. of Washington, NSC
sroy@uw.edu

Oliver Holland, Advanced Wireless Technology Group, Ltd., UK
oliver.Holland@ieee.org
Emerging Technology: Beyond the Networks

“DATA is the new OIL” (Kyle Conner, Cisco)

- Integration of AI for dense, dynamic end user requirements
- Machine Learning (Can machines teach machines functions?)
- Mobility as a Service will be a feature
- Virtualized devices
- Atomic clock chips – geo-location
- Connections and Service Level Agreements (SLA’s) automated with SDN/NFV, Context Aware = AI
- 3D-Ultra-Massive MIMO at Terra Hz…….

Smart Edge Computing is Increasingly Necessary for ALL Networked Systems
New Technologies and Standards to make this happen

- Technologies that assist in improved electromagnetic spectrum awareness, sharing and use
- Spectrally efficient communications technologies
- New bi-directional spectrum sharing policies
- Spectrum Sharing Tools – Spectrum Access Systems, Sensing and Beaconing Techniques
- Understanding Federal Systems – e.g. Radars, SATCOM that need protection
- New interference mitigation technologies
- Optical links that can off-load high-capacity point to point traffic
- Networked Slicing
- Security, trusted micro-electronics and computing
- Co-existence analysis, Interference Assessment and Monitoring
- Full-Duplex and Simultaneous Transmit and Receive,
- Spectrum sharing in new frontiers – mmWave and Terra Hz
Why IEEE 802 Community Needs to be Involved and Follow-on Actions

Apurva N. Mody, National Spectrum Consortium
apurva.mody@ieee.org, apurva.mody@WhiteSpaceAlliance.org
Why IEEE 802 should look into this and Next Steps

- Licensed eco-system is already looking into this. AWS-1 and AWS-3 spectrum will result in bi-directional spectrum sharing between LTE networks and Federal systems.
- IEEE 802 has always thrived on disruption.
- We need a new disruptive paradigm and policy whose time has come ...

Next Steps

- Set up an Executive Committee Study Group to look at Spectrum Sharing needs arising from various regulations for various spectrum bands.
- Identify the mechanisms that will be needed (e.g. Spectrum Database, Sensing, Beaconing etc.)
- Socialize the adoption of these techniques with various working groups OR start a new project on Spectrum Access System (Spectrum Database)
- Establish liaison relationships with organizations like the National Spectrum Consortium.

IEEE 802 Needs to Act Now to be Relevant to New Spectrum Bands
Straw Poll for Questions at the End of this Tutorial

- Is the IEEE 802 Community interested in accessing Shared Spectrum?
- Is the IEEE 802 Community interested in Shared Spectrum Solutions for 5G?
- There are three initial steps to turn Spectrum Sharing Technologies into Standards – IEEE 802 Executive Committee Study Group, Working Group Study Group or Industry Connections Activity
  - Should we form an EC Study Group to understand the problem of Spectrum Sharing and follow-up Activities?
  - Should we form a WG Study Group to understand the problem of Spectrum Sharing and follow-up Activities?
  - Should we form an Industry Connections Activity for Spectrum Sharing and follow-up Activities?
- Should IEEE 802 engage in creation of a Protocol to Access the Spectrum Database (Spectrum Access System)? (e.g. IETF Protocol to Access White Spaces - PAWS)
- Should IEEE 802 engage in creation of a standards for Beaconing?
- Which of the 5G bands are of most interest to the IEEE 802 Community?