# Connecting Research to Spectrum Policy

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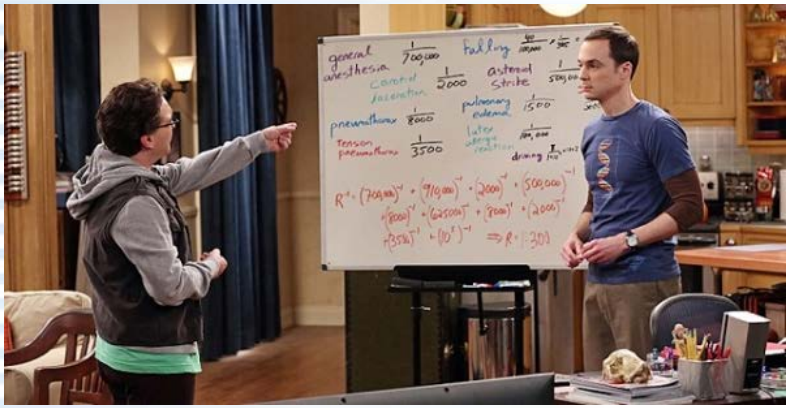
Office of Engineering and Technology

WinnComm 2016
National Science Foundation
Enhancing Access to Radio Spectrum
Principal Investigators Meeting
March 15, 2016

Note: The views expressed in this presentation are those of the author and may not necessarily represent the views of the Federal Communications Commission

# A Symbiotic Relationship



Just as Sheldon and Leonard need each other

FCC

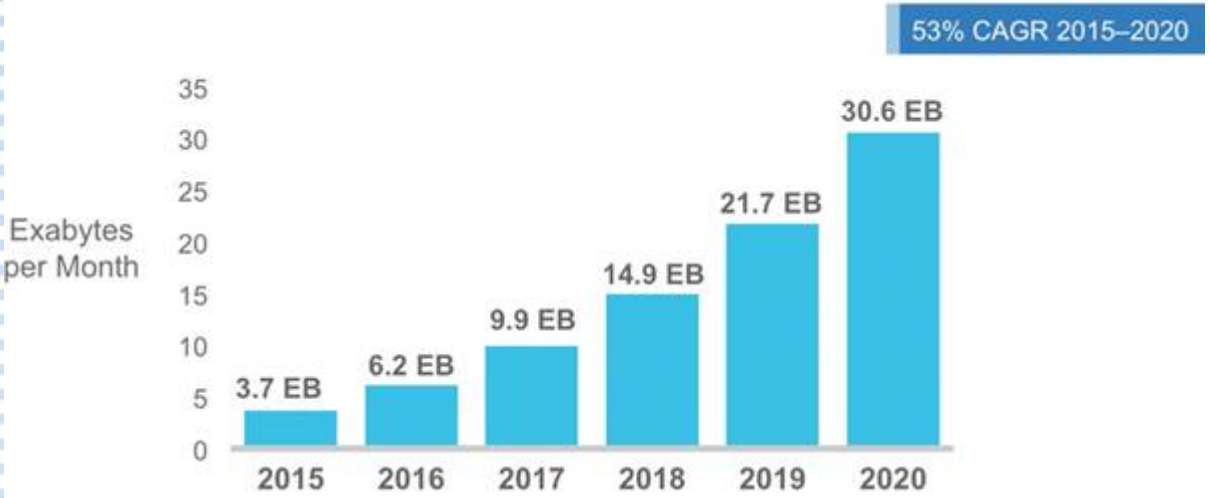
Principal Investigators

The FCC and PIs need each other

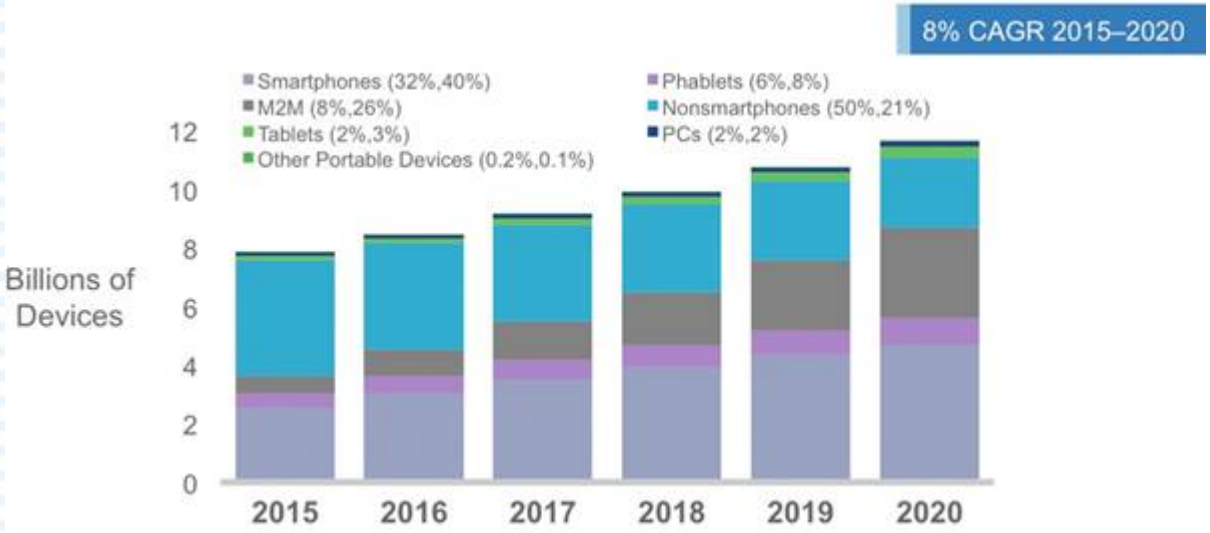
Speed of regulation

Speed of technology development

# Where We've Been / Where We're Going




Source: Cisco VNI Mobile, 2016

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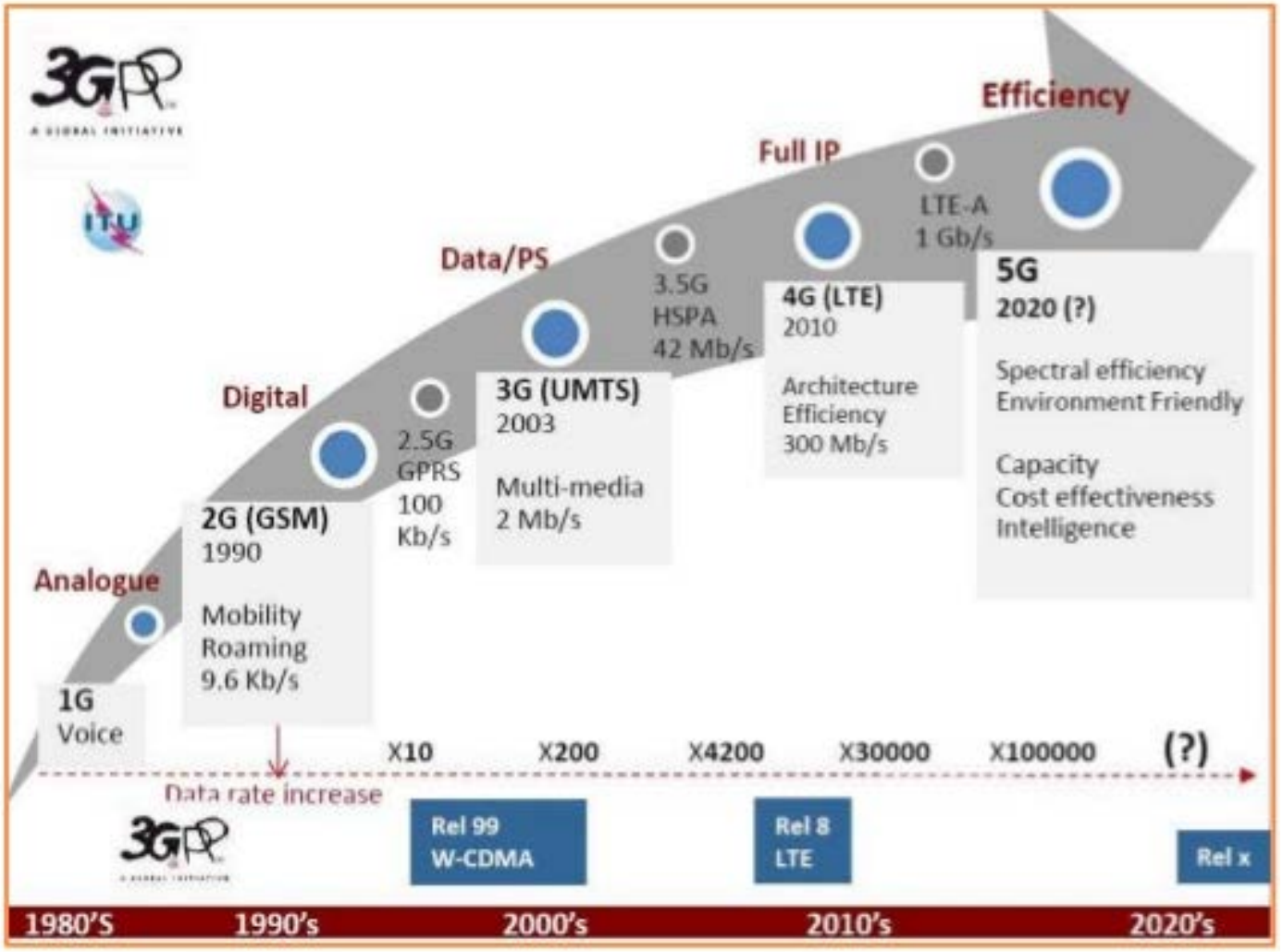
# Where We've Been / Where We're Going



# EARS Funded Projects
## A Random Sampling

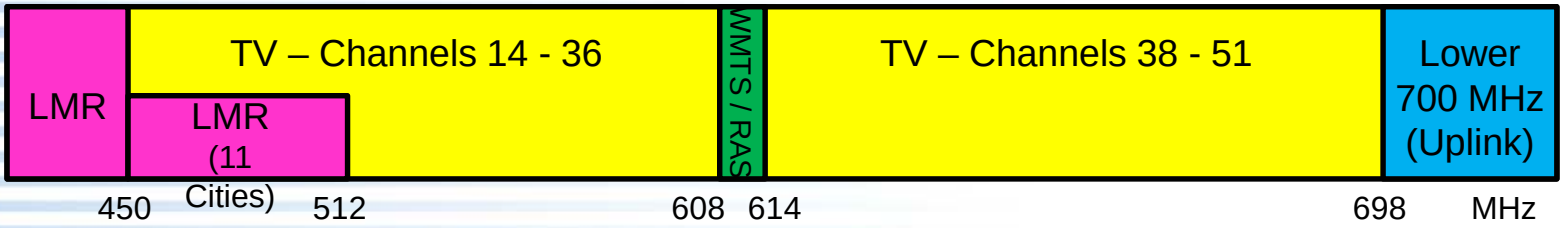
| | |
|---|---|
| Extreme Densification of Wireless Networks | Interference mitigation by stream decomposition enabled by liquid-metal adaptive antennas |
| Crowd-based Spectrum Monitoring and Enforcement | Pervasive Spectrum Sharing for Public Safety Communications |
| A System Dynamics Approach to Mobile Broadband Spectrum Requirement Analysis | Multi-Input Multi-Output (MIMO) Aware Cooperative Dynamic Spectrum Access |
| A Multi-Layer Approach Towards Reliable Cognitive Radio Networks | Spectrum Efficient Waveform Design with Application to Wireless Networks |
| Radio Frequency Interference Aware Radio Astronomy Systems | Virtualized Wireless Networks and Their Impact on Capacity Markets |
| Achieving Efficient Spectrum Usage in Active and Passive Sensing Through a Market-Based Approach | Large-Scale Statistical Learning based Spectrum Sensing and Cognitive Networking |
| Cognitive Networking for Wireless Communication in Rural Areas: A Directional Antennas and Propagation Modeling Approach with Low Cost Implementation | Applying Behavioral-Ecological Network Models to Enhance Distributed Spectrum Access in Cognitive Radio |

# TV Incentive Auction

# Reconfiguring The TV Broadcast Band (Again)

1. Repack television to a smaller portion of the band
2. Provide mobile broadband in vacated broadcast spectrum

Current TV Band



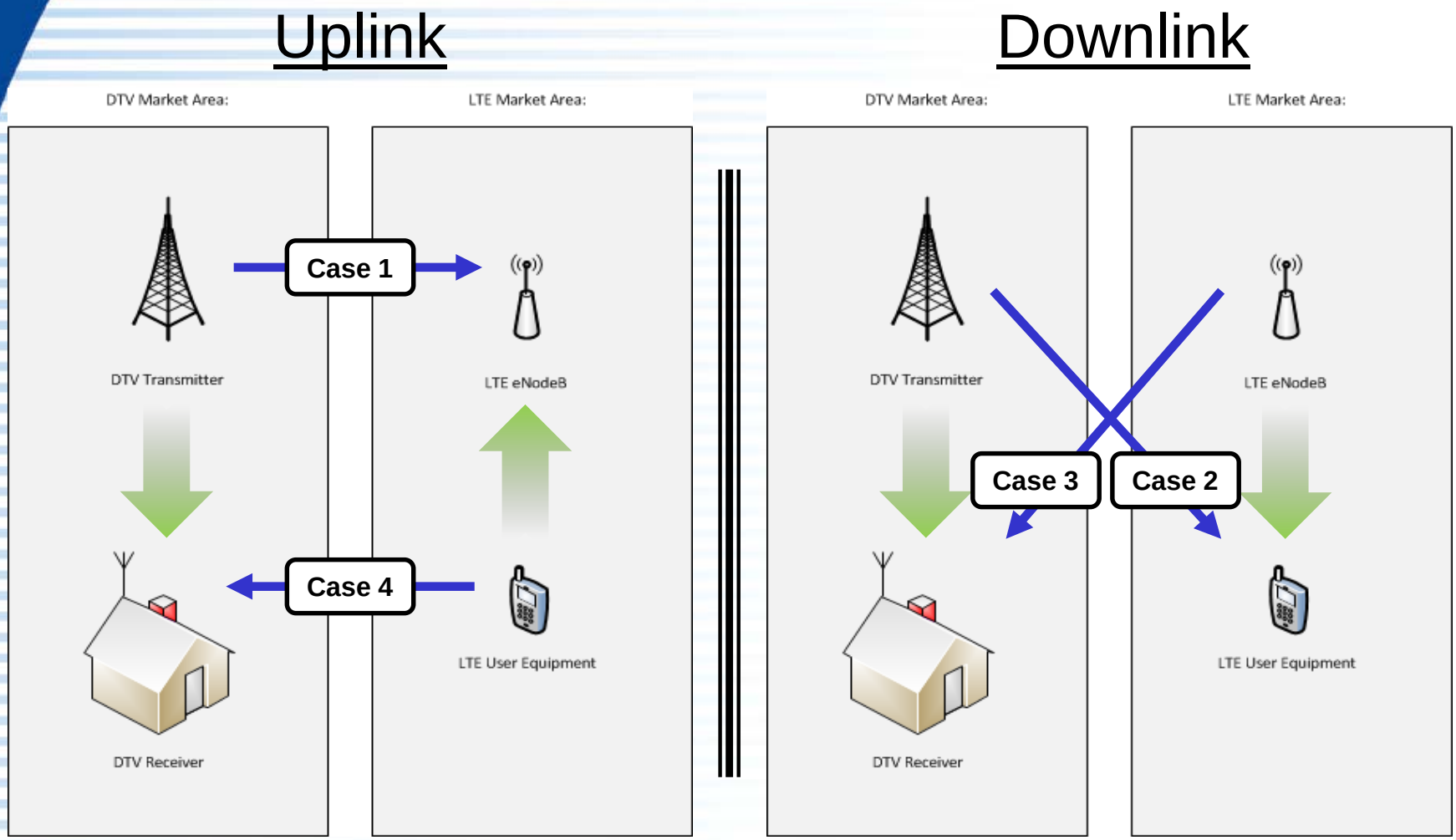

TV Band also contains: Broadcast Auxiliary Services, Low Power TV, Wireless Microphones, TV White Space Devices

## Considerations:

- Paired vs. unpaired spectrum
- Size of guard bands between TV and mobile
- Size of duplex gap
- Mobile equipment design issues - 1 vs. 2 duplexers
- How to address variations in spectrum among markets
- Protection of medical telemetry & radio astronomy (Channel 37)
- Provisions for Unlicensed (consistent with statute)
- Provisions for wireless microphones
- Coordination with Canada & Mexico

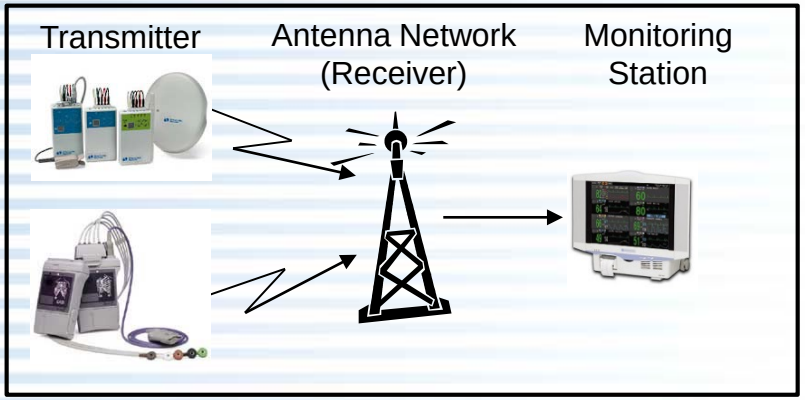
# Potential Interference Cases

## TV and Mobile Broadband

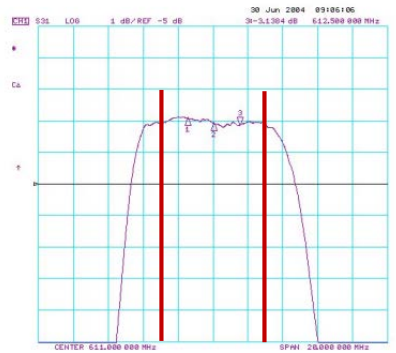


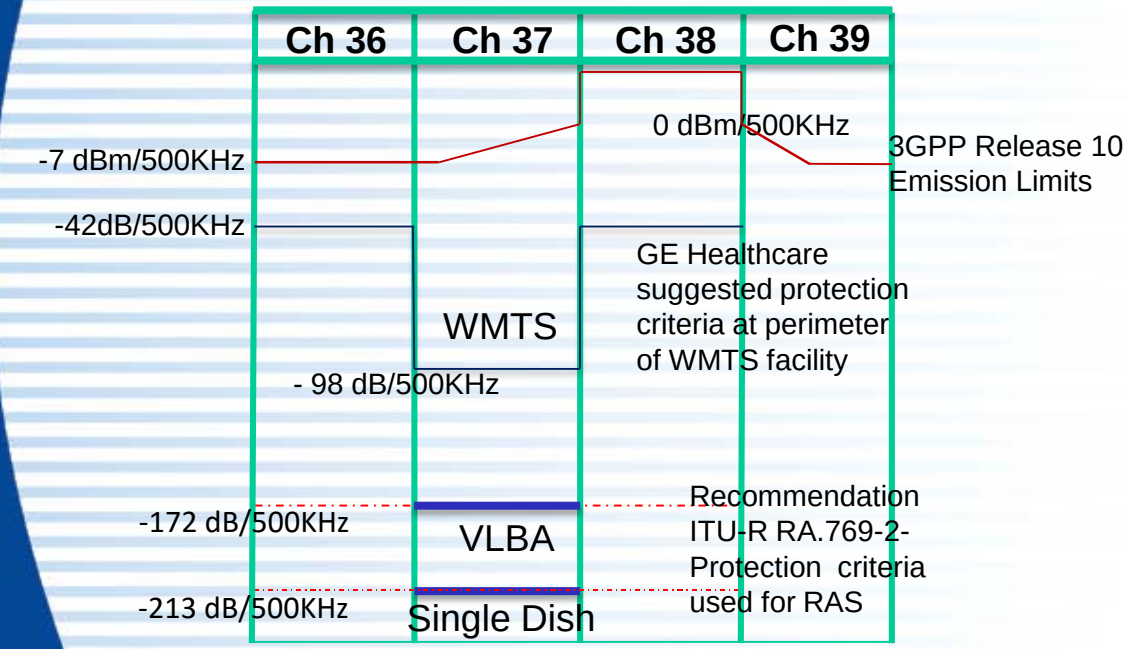
# Potential Interference Cases

## Mobile Broadband to WMTS and RAS




Typical WMTS Receive Filter






# Incentive Auction Band Plan

First time the Commission has needed to develop band plans without knowing how much spectrum will be available!

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 45 | 46 | 47 | 48 | 49 | 50 | 51 | 700 MHz UL |
| 2 | 42 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 44 | 11 | A | B | 11 | A | B | | 700 MHz UL |
| 3 | 48 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 42 | 43 | 7 | A | B | C | 11 | A | B | C | 700 MHz UL |
| 4 | 60 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 | 41 | 9 | A | B | C | D | 11 | A | B | C | D | 700 MHz UL |
| 5 | 72 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 11 | A | B | C | D | E | 11 | A | B | C | D | E | 700 MHz UL |
| 6 | 78 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 7 | A | B | C | D | E | F | 11 | A | B | C | D | E | F | 700 MHz UL |
| 7 | 84 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 3 | A | B | C | D | E | F | G | 11 | A | B | C | D | E | F | G | 700 MHz UL |
| 8 | 108 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 32 | 11 | A | B | 3 | 37 | 3 | C | D | F | F | G | H | 11 | A | B | C | D | E | F | G | H | 700 MHz UL |
| 9 | 114 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | 31 | 7 | A | B | C | D | 3 | 37 | 3 | E | F | G | H | I | 11 | A | B | C | D | E | F | G | H | I | 700 MHz UL |
| 10 | 126 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 9 | A | B | C | D | E | F | 3 | 37 | 3 | G | H | I | J | 11 | A | B | C | D | E | F | G | H | I | J | 700 MHz UL |
| 11 | 138 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 11 | A | B | C | D | E | F | G | H | 3 | 37 | 3 | I | J | K | 11 | A | B | C | D | E | F | G | H | I | J | K | 700 MHz UL |
| 12 | 144 | 21 | 22 | 23 | 24 | 25 | 26 | 7 | A | B | C | D | E | F | G | H | I | J | 3 | 37 | 3 | K | L | 11 | A | B | C | D | E | F | G | H | I | J | K | L | 700 MHz UL |

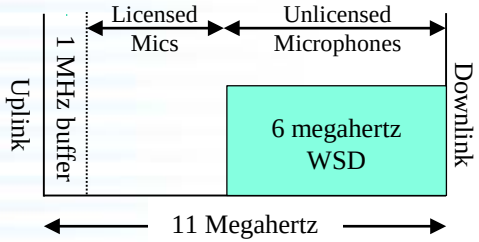
# Unlicensed Devices & Wireless Microphones

Electronic News Gathering

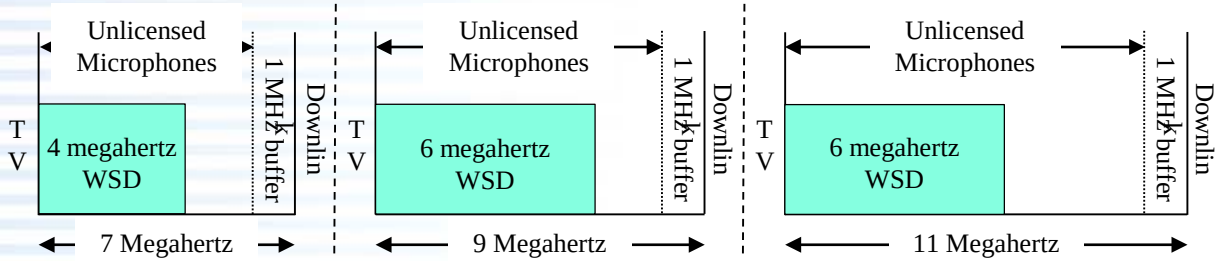

Wireless Microphones

White Space Devices


## Duplex Gap



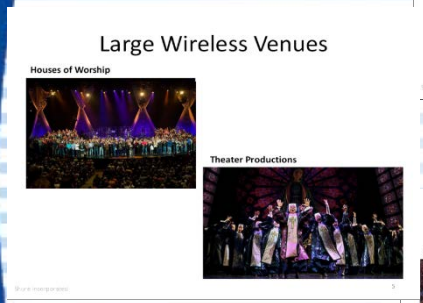

## Guard Band Options



# Wireless Microphones

# New Provisions for Wireless Microphones







Majority operate in the UHF-TV band

Report and Order

August 6, 2015

- Allows greater use of the TV channels
  - Permits some co-channel operations inside DTV contours without coordination
- Expands eligibility of the 4-megahertz portion of the 600 MHz Service duplex gap
- Provides access to additional spectrum on a secondary basis:
  - Expands use of the 900 MHz band
  - Allows use of the 1435-1525 MHz band, subject to coordination to protect aeronautical mobile telemetry
  - Allows use of the 6875-7125 MHz band

# Unlicensed White Space Devices

# Unlicensed White Space Devices

**Adopted final rules in 2012**

- Fixed & Personal Portable devices
- Rely on geolocation database

**Fifteen devices approved**

- All fixed devices, designed for professional installation - location entered manually

**Five databases approved**

**IEEE 802.11af standard approved - Dec. 2013**

**Strong international interest**

**Rules updated August 2015**

- Implement Incentive Auction
- More flexible operation

**NPRM adopted December 2015**

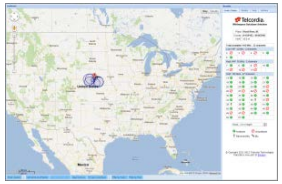
- Require geo-location capability in fixed devices
- Validation checks for databases


Meld

Carlson

Adaptrum

Spectrum Bridge



iconectiv

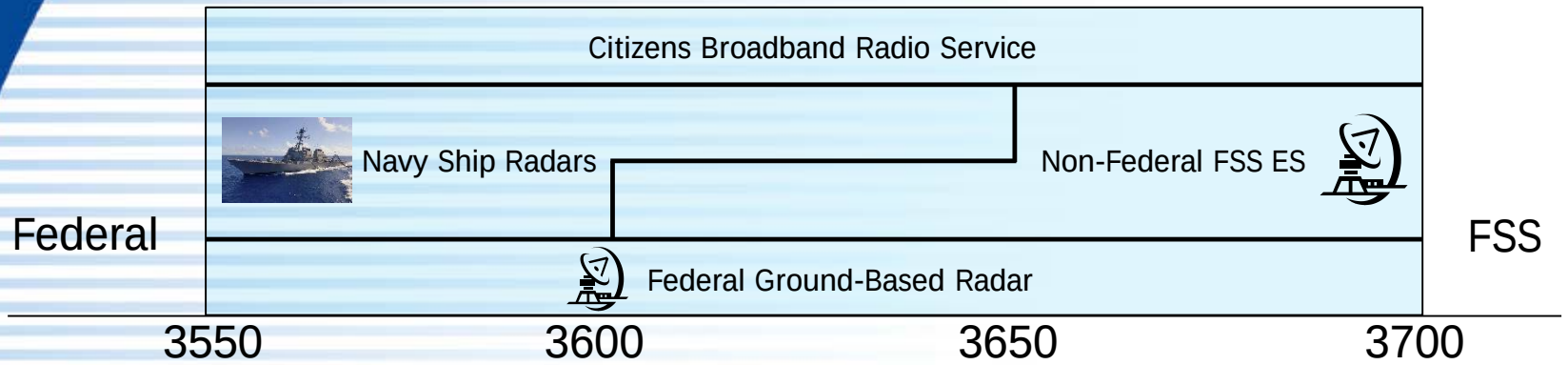
Wireless Cameras Cover Park in Wilmington NC

# FCC Hot Topics

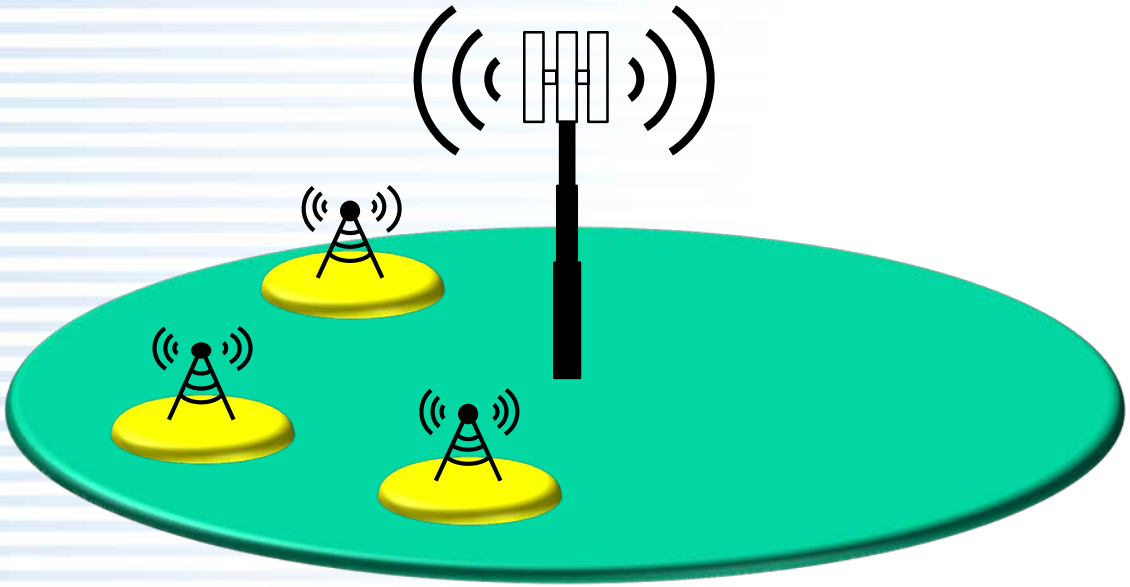
## 3.5 GHz

# Citizens Broadband Radio Service

Report & Order Adopted April 17, 2015

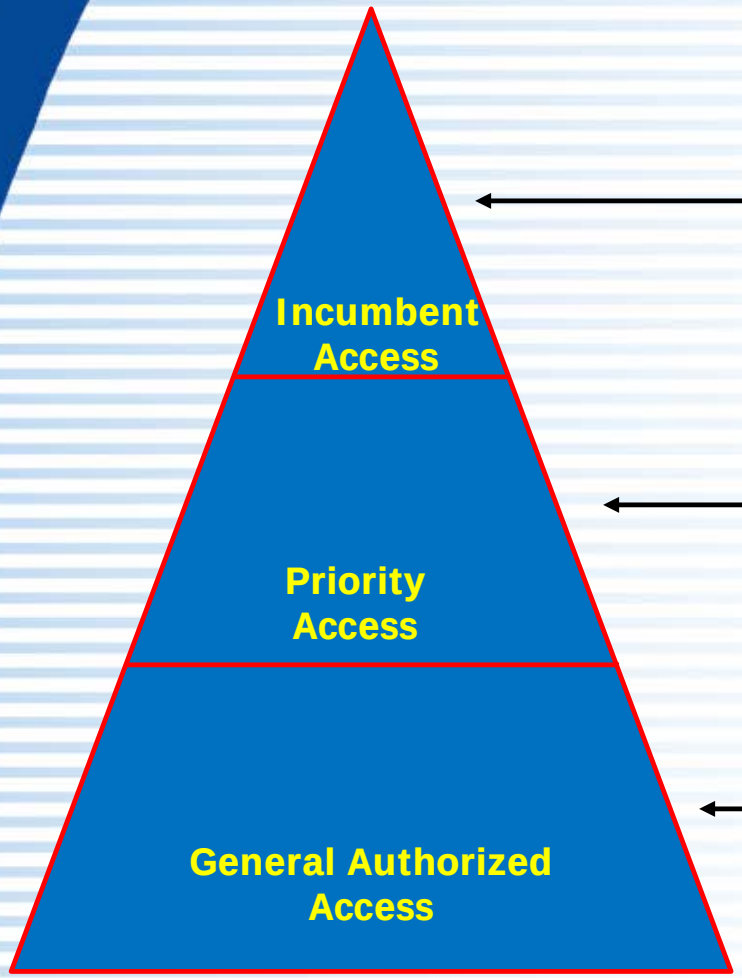



150 MHz of contiguous spectrum



Dynamic spectrum access for small cells

# Three Tier Access



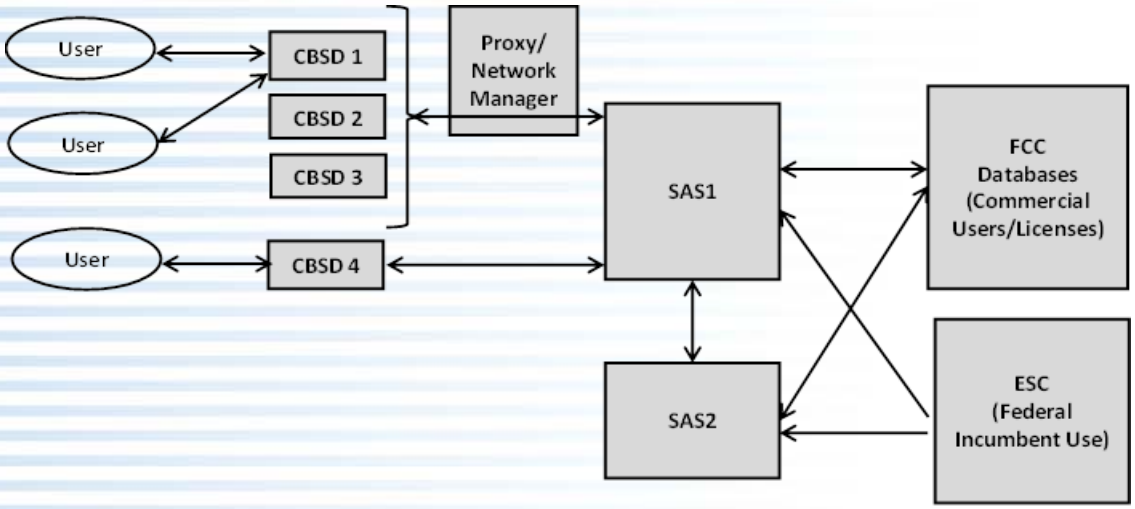

**Incumbent Access:** Includes authorized federal and grandfathered Fixed Satellite Service (FSS) users currently operating in the 3.5 GHz Band.

**Priority Access License (PAL):** Authorize certain users to operate with some interference protection in portions of the 3.5 GHz Band at specific locations

**General Authorized Access (GAA):** Users authorized to use the 3.5 GHz Band opportunistically. GAA users required to accept interference from Incumbent and Priority Access tier users.

# Spectrum Access System (SAS)

A next generation sharing system building on white spaces



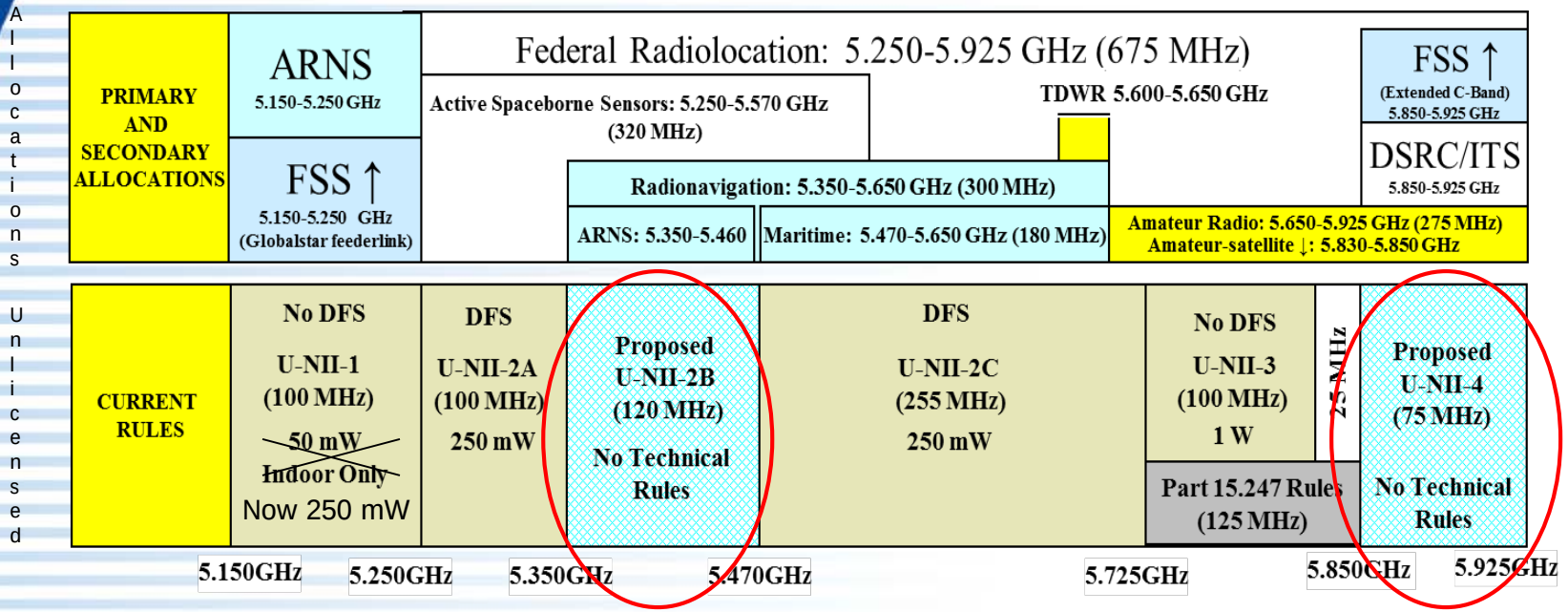

## SAS Functions

- Determine available frequencies at a location and assign them to CBSDs
- Determine maximum permissible power level for CBSDs at a location
- Register and authenticate CBSDs
- Enforce Exclusion and Protection Zones
- Protect PALs from IX from other users
- Facilitate coordination between GAAs
- Ensure secure and reliable transmission of information between the SAS, ESC, and CBSDs
- Protect Grandfathered Wireless Broadband Licensees
- Facilitate coordination and information exchange between SASs

# Unlicensed at 5 GHz

# Expanding Spectrum For Unlicensed Devices at 5 GHz

555 megahertz of spectrum currently available for unlicensed devices




Some of this spectrum relies on dynamic frequency selection to avoid interfere with radars

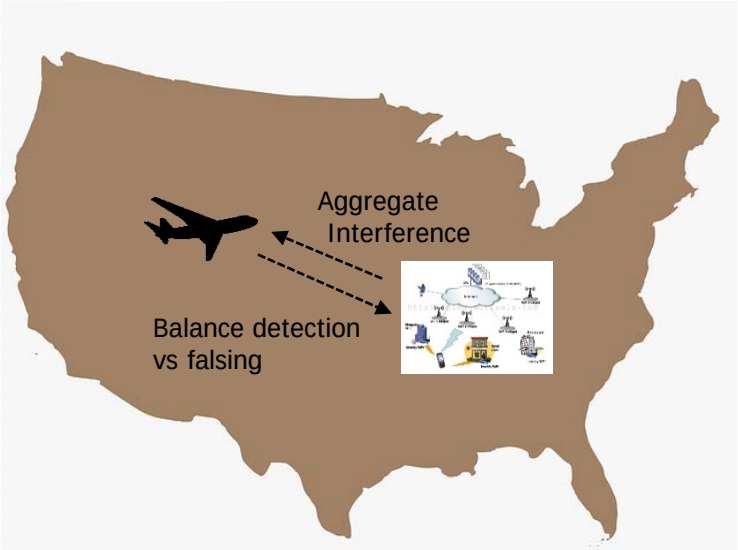
## FCC Notice of Proposed Rule Making

- Proposed access to U-NII-2B and U-NII-4 for unlicensed devices
- No change to existing spectrum allocations - - existing allocations/services are protected against harmful interference

# Ongoing Work:
## U-NII-2B: 120 MHz (5350 – 5470 MHz)

- Sharing with federal plane/ship/terrestrial radars & earth exploration satellite
- US proposed to continue international work for WRC-19
- Moving forward domestically
- Work group established:
  - FCC/NTIA/DoD/NASA
  - Considering IX protection studies & developing ways to share
  - Evaluating sharing with indoor low power/then outdoor high power

Aeronautical radar must pick up weak reflected signals from far away




Wireless networks must “hear” very weak signals from radar

# Ongoing Work

## U-NII – 4: 75 MHz (5725 – 5850 MHz)

- Sharing with Dedicated Short Range Communications
  - Vehicle to Vehicle
  - Vehicle to Infrastructure
- IEEE Tiger Team considered sharing options & completed work March 2015 (No consensus)
- DoT released test plan
- FCC/NTIA/DoT collaborated on a way forward:
  - FCC to refresh record
  - Invite submittal of prototype devices
  - Testing in three phases

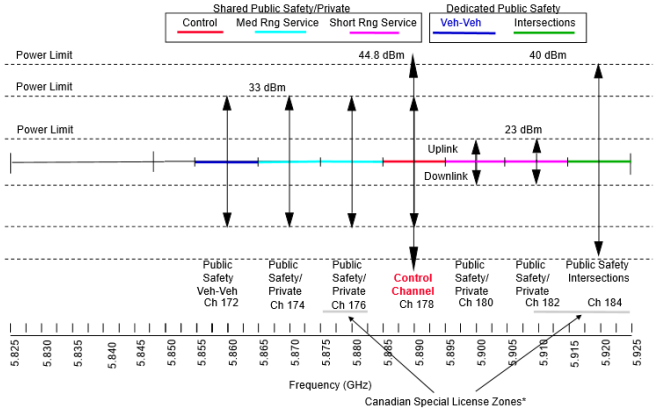
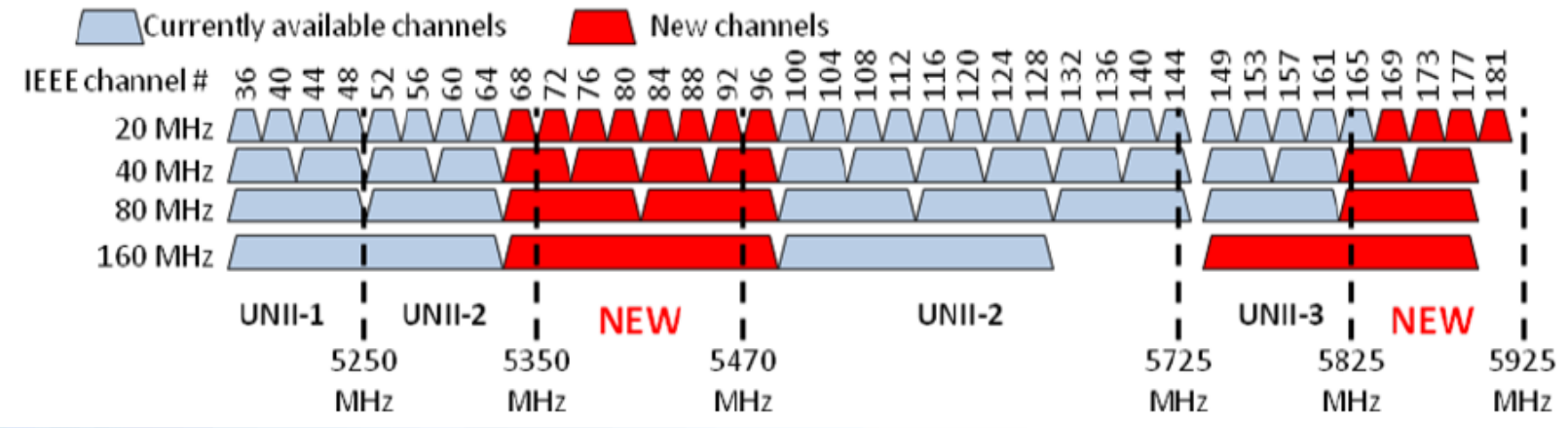



Figure 1-1 DSRC Channel Plan in the ITS Band[6 7]

# Importance of Additional Spectrum at 5 GHz for Wi-Fi




The IEEE 802.11ac standard enables speeds in excess of 1 Gb/s and increased capacity to meet growing demand, particularly for video

- Provides for 20, 40, 80 and 160 MHz channels
- Current spectrum provides only two 160 MHz channels
- New spectrum would provide four 160 MHz channels

# LTE-U, LAA & Wi-Fi

LTE for unlicensed spectrum:

- LTE-U Forum specification
- LAA Licensed Assisted Access
  - Standard adopted in LTE Rel. 13 (March 2016)
- LWA – LTE / WI-FI Aggregation

Focused on U-NII 1 & 3 (no DFS) for supplemental downlink

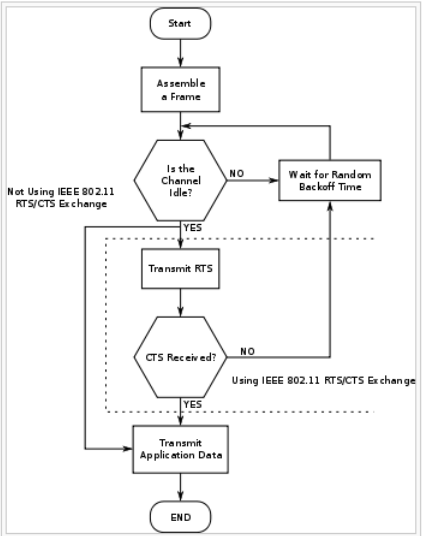
Fair sharing? CSMA vs CSAT

Industry dialogue thru Wi-Fi Alliance

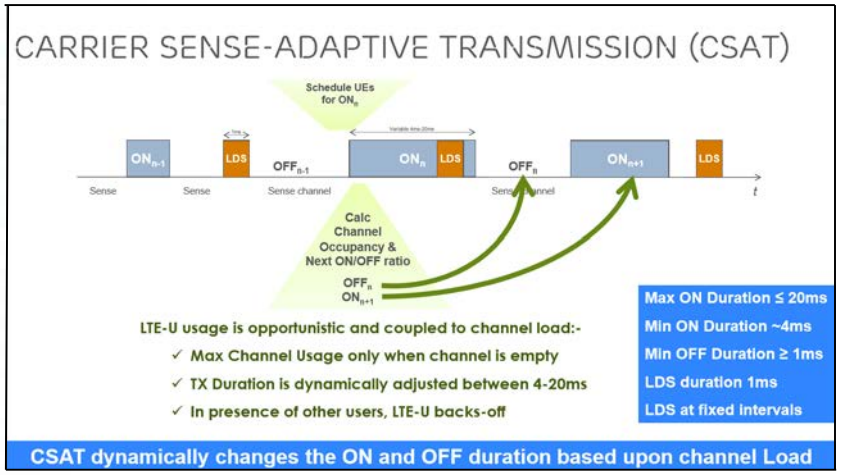
- Developing co-existence guidelines and test plan

FCC issued experimental license to Qualcomm for testing in NC and TN

Wi-Fi: Carrier sense multiple access with collision avoidance (CSMA/CA)



Simplified Algorithm of CSMA/CA



LTE-U

# Expanding Use of the Millimeter Wave Spectrum (5G)

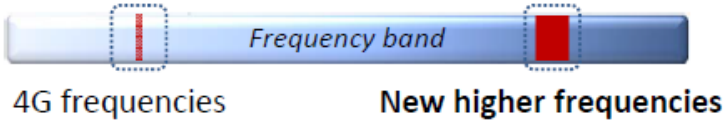
# Why mmW Bands?

## mmWave System Tech.

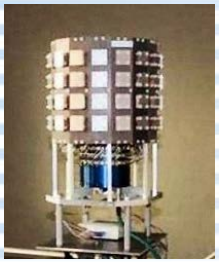
- Fixed 1 Gbps
- Mobile 100 Mbps

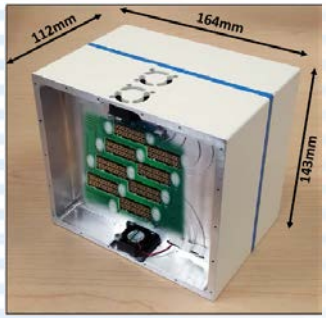
→

- Fixed >50 Gbps
- Mobile 5 Gbps




4G BS Antenna

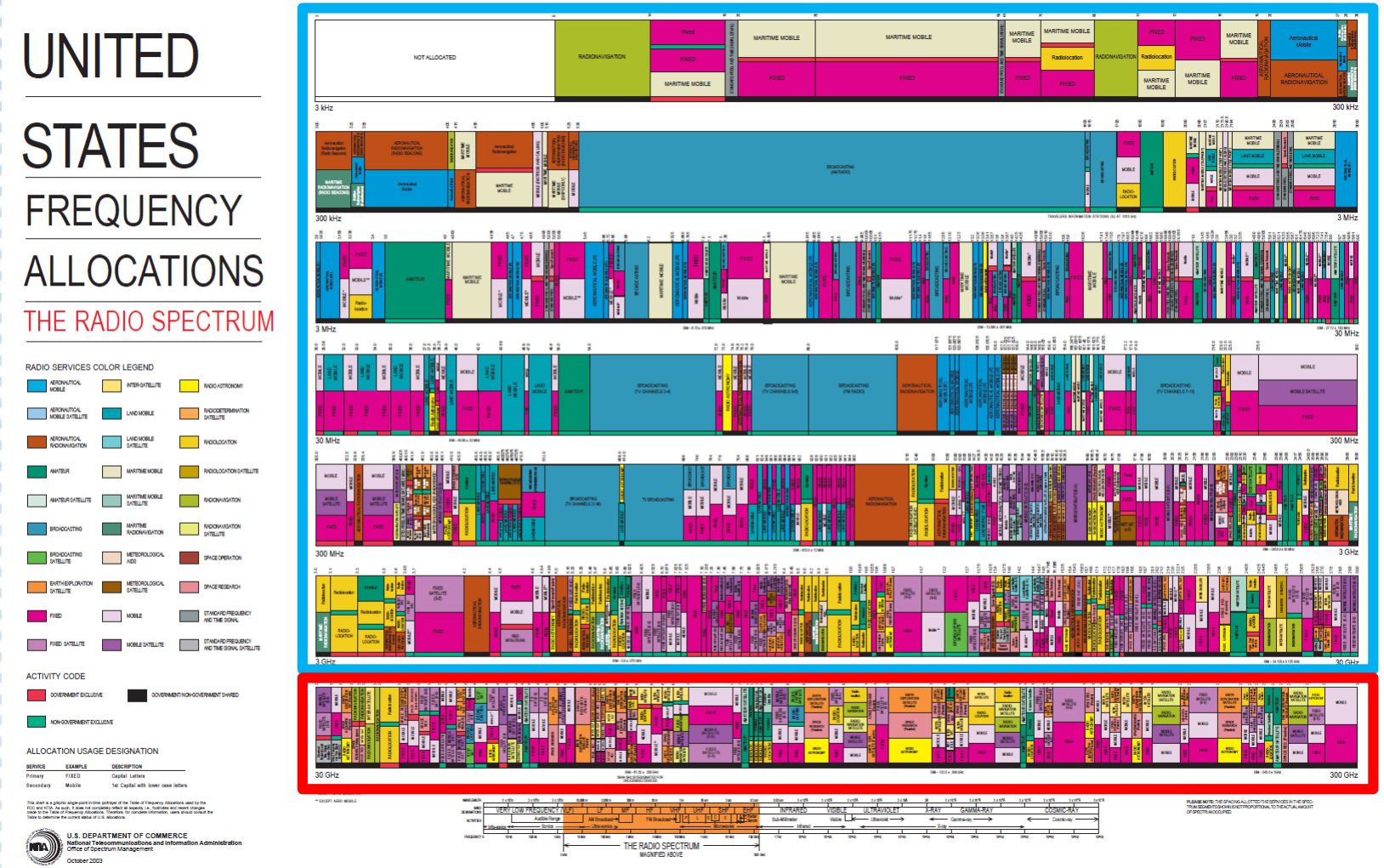





5G BS Massive MIMO Antenna Array

- Availability of large blocks of contiguous bands of 500MHz or greater
- Integrated access and backhaul
- Lower cost per Gbit delivery
- Spatial multiplexing from antenna arrays
- Higher degree of reuse
- Antenna arrays at the transmitter and receiver effectively compensate for path loss of mmW band
- Higher directionality can reduce intercellular interference

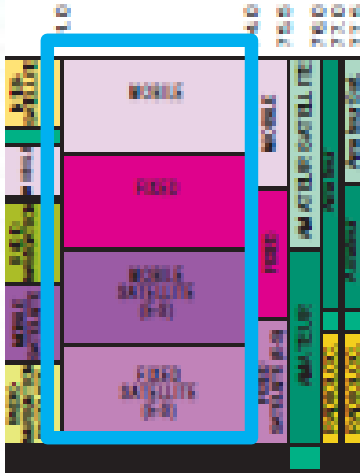
# U.S. Table of Frequency Allocations




Allocation table available at: http://www.ntia.doc.gov/osmhome/allochrt.html

# Massive Bandwidth Available

850 megahertz in
27.50 – 28.3 GHz band



3 gigahertz in
71-74 GHz band

By contrast, only 865 megahertz
is allocated to existing commercial mobile services

In the millimeter wave bands
we can do
MORE with MORE!

# Expanding Use of the Millimeter Wave (mmW) Spectrum

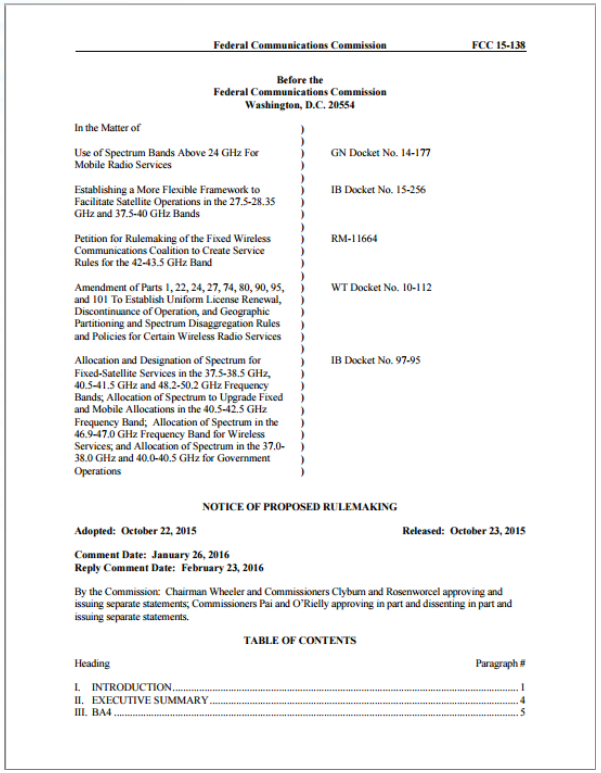
FCC Technological Advisory Council recommended study of increased access to millimeter wave spectrum

FCC Notice of Inquiry (NoI) adopted October, 17, 2014

FCC Notice of Proposed Rulemaking (NPRM) adopted October 15, 2015

NPRM proposed a mix of licensed and unlicensed use in the millimeter wave spectrum to create sharing opportunities among different kinds of users

- Fixed/mobile
- Federal/nonfederal
- Terrestrial/satellite
- Carrier networks/private networks



Federal Communications Commission FCC 15-138

Before the
Federal Communications Commission
Washington, D.C. 20554

| | | |
|---|---|---|
| In the Matter of | | |
| Use of Spectrum Bands Above 24 GHz For Mobile Radio Services | ) | GN Docket No. 14-177 |
| Establishing a More Flexible Framework to Facilitate Satellite Operations in the 27.5-28.35 GHz and 37.5-40 GHz Bands | ) | IB Docket No. 15-256 |
| Petition for Rulemaking of the Fixed Wireless Communications Coalition to Create Service Rules for the 42-43.5 GHz Band | ) | RM-11664 |
| Amendment of Parts 1, 22, 24, 27, 74, 80, 90, 95, and 101 To Establish Uniform License Renewal, Discontinuance of Operation, and Geographic Partitioning and Spectrum Disaggregation Rules and Policies for Certain Wireless Radio Services | ) | WT Docket No. 10-112 |
| Allocation and Designation of Spectrum for Fixed-Satellite Services in the 37.5-38.5 GHz, 40.5-41.5 GHz and 48.2-50.2 GHz Frequency Bands; Allocation of Spectrum to Upgrade Fixed and Mobile Allocations in the 40.5-42.5 GHz Frequency Band; Allocation of Spectrum in the 46.9-47.0 GHz Frequency Band for Wireless Services; and Allocation of Spectrum in the 37.0-38.0 GHz and 40.0-40.5 GHz for Government Operations | ) | IB Docket No. 97-95 |

NOTICE OF PROPOSED RULEMAKING

**Adopted: October 22, 2015** **Released: October 23, 2015**

**Comment Date: January 26, 2016**
**Reply Comment Date: February 23, 2016**

By the Commission: Chairman Wheeler and Commissioners Clyburn and Rosenworcel approving and issuing separate statements; Commissioners Pai and O'Rielly approving in part and dissenting in part and issuing separate statements.

TABLE OF CONTENTS

Heading Paragraph #



http://transition.fcc.gov/Daily_Releases/Daily_Business/2015/db1023/FCC-15-138A1.pdf

# Spectrum Frontiers NPRM

Bands of interest

Bands proposed in NPRM

| 24.25-24.45 GHz | 25.05-25.25 GHz | 27.5-28.35 GHz | 29.1-29.25 GHz | 31-31.3 GHz | 31.8-33 GHz | 37-38.6 GHz | 38.6-40 GHz | 42-42.5 GHz | 64-71 GHz | 71-76 GHz | 81-86+ GHz |
|---|---|---|---|---|---|---|---|---|---|---|---|

Licensing, Operating and Regulatory Rules/Issues

- Part 30: Upper Microwave Flexible Use Service
- Geographic Area Licensing, Area Size, Band Plan, License Term
- Performance Requirements; Spectrum Holding

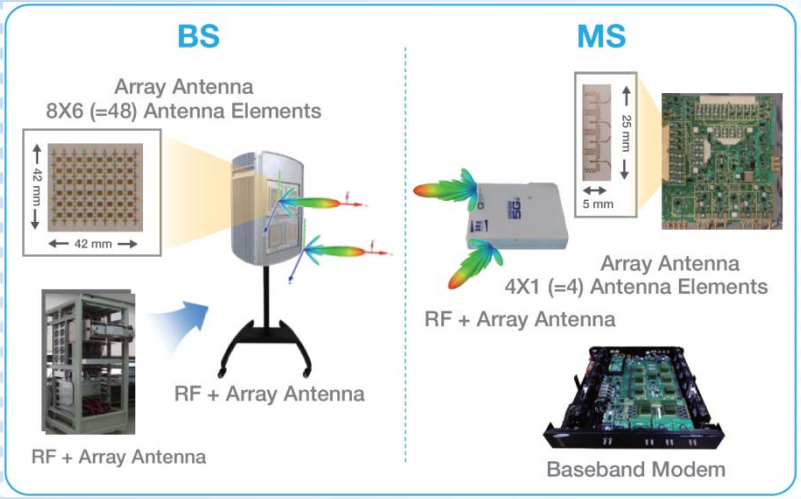
Technical Rules

- Duplexing; TX Power, Emission Limit; IX Protection and Coordination; Equipment Authorization; Part 15 Rules for 64-71

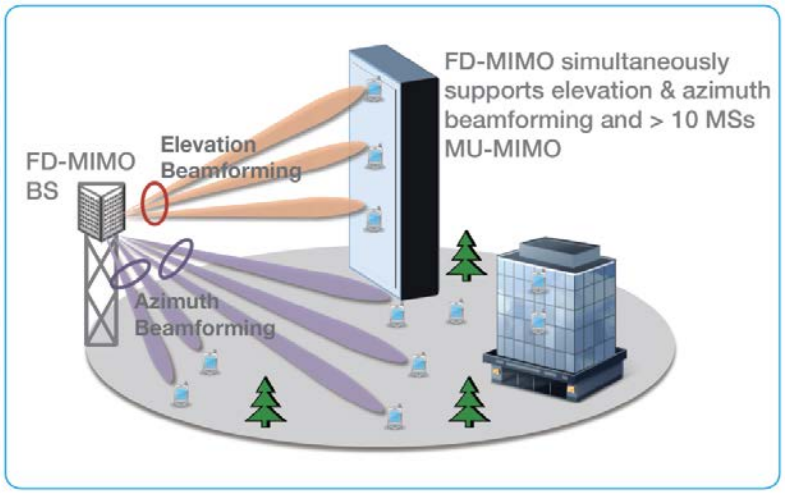
Satellite Sharing

Federal Sharing

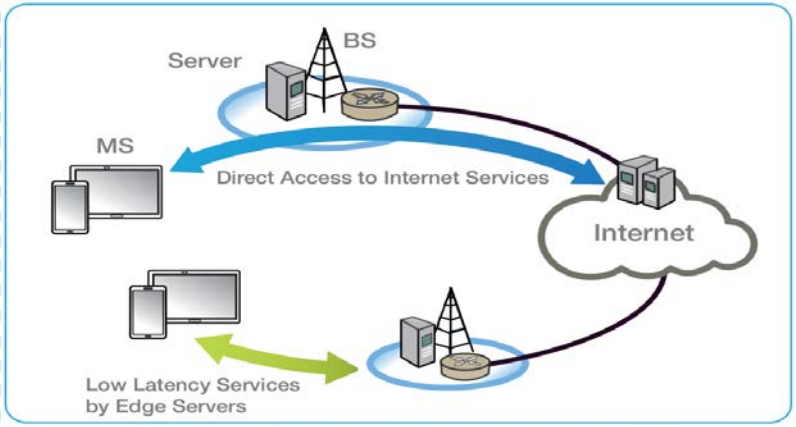
# Continued Research Is Key



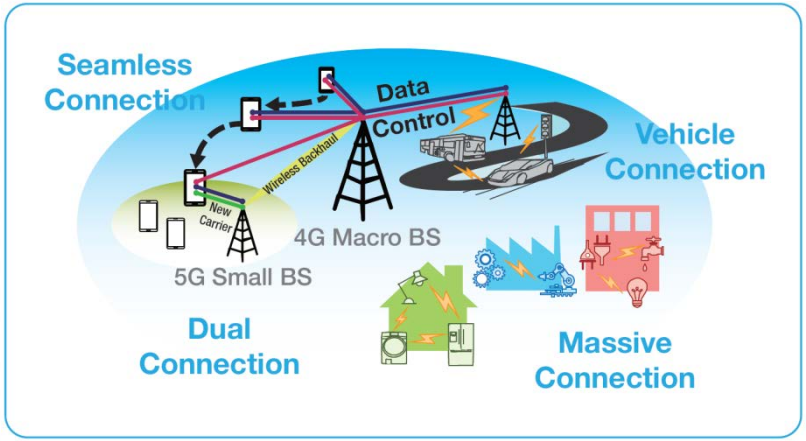

Adaptive Pencil Beamforming




Full Dimensional MIMO




5G Flat Network Architecture

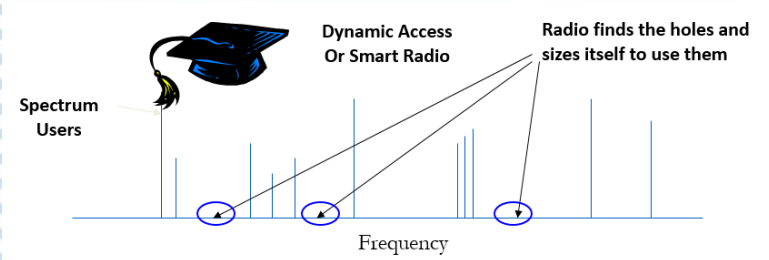



5G Deployment Scenario

# Technology Game Changers

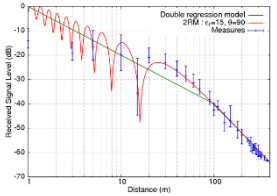
## Research Opportunities

- Technology Advances:
  - LTE
  - Wi-Fi
  - And many others . . .
- Advanced sharing techniques:
  - Software Defined Radio
  - Cognitive Radio
  - Dynamic Access
  - Data base access

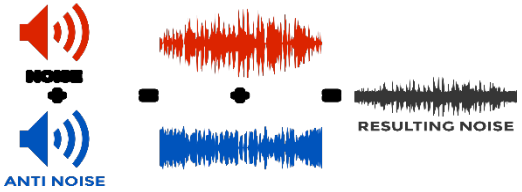



- Small Cells

- Propagation modelling and validation
  - Indoor
  - Outdoor

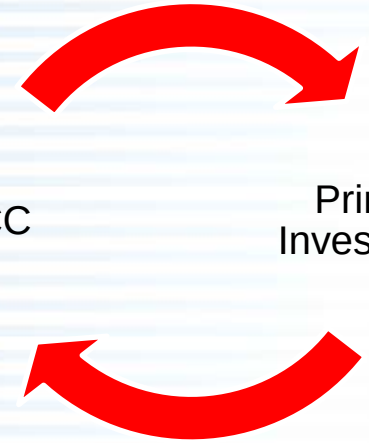



- Interference cancellation:
  - Full duplex
  - Adaptive modulation
  - Coding techniques



# The FCC Needs You

| Participate in FCC Rulemakings | National Spectrum Consortium | Industry Groups |
|---|---|---|
| | | WinnComm<br>Dyspan<br>DSA |



FCC

Principal Investigators

| Funding Programs | Model City | Center for Advanced Communication & National Advanced Spectrum and Communication Test Network |
|---|---|---|
| EARS | | |


To Millimeter Wave
and
Beyond!!
SPACE RANGER
LIGHTYEAR

# Thank You