Institute for Telecommunication Sciences Spectrum Sharing: Past, Present, and Future

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ITS: The Nation's Spectrum and Communications Lab

Institute for Telecommunication Sciences
Boulder, Colorado

NTIA

- The President's principal advisor on telecommunications and information policy
- A Department of Commerce agency
- NTIA's Office of Spectrum Management (OSM) operates in parallel with ITS
  - ITS works closely with OSM to support Administration and Agency needs
  - ITS engages with other federal agencies via OSM, the IRAC, and Interagency Agreements (IAAs)
- ITS engages directly with Industry and academia via Cooperative Research and Development Agreements (CRADAs)

ITS Vision, Mission, and Role

- **Vision/Reach:** Realizing the full potential of telecommunications to drive a new era of innovation, development, and productivity.
- **Mission/Purpose:** To ADVANCE innovation in communications technologies, INFORM spectrum and communications policy for the benefit of all stakeholders, and INVESTIGATE our Nation's most pressing telecommunications challenges through research that employees are proud to deliver.
- **Role:** Support the U.S. Administration's goals for more efficient and effective use of spectrum
  - Inform data-driven regulation and policy
  - Advance, inform, investigate: Spectrum and communication engineering needs of all Federal agencies, U.S. Commerce & other stakeholders
  - Solution-oriented applied engineering research to support innovation: 5G and beyond

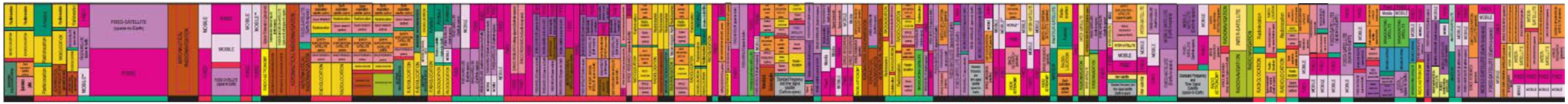
Yesterday

Spectrum Sharing: It's not New!

- ITS has been researching — and solving — spectrum sharing problems for 50 years.

- Historically, spectrum sharing was mostly confined: sharing with like/similar but compatible Services.
  - Radar Service historically shared with Radionavigation Service
  - Land Mobile Radio Service historically shared with other Mobile Radio Service
  - Point-to-Point Microwave Service historically shared with Space Communications Service

- Today, "Sharing" has come to implicitly mean "sharing between unlike Services"
  - Radar sharing with terrestrial communication systems
  - Requires more advance planning and careful study to craft regulation
  - Complexity increases. Risk increases. Opportunities for breakthrough and innovative engineering solutions increase.



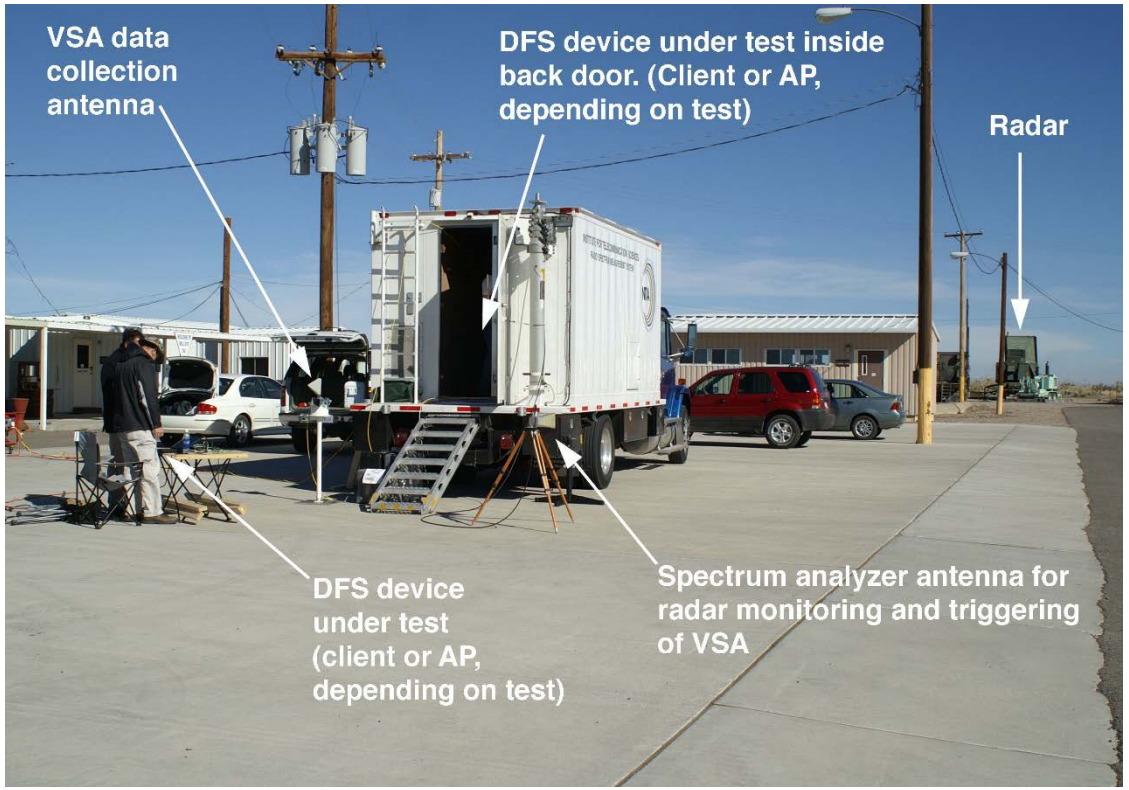
Spectrum Sharing: Past

- 2008: TR-08-454 Assessment of the Effects of Wind Turbines on Air Traffic Control Radars
- 2007: TR-08-450 Potential interference from broadband over power line (BPL) systems to federal government radiocommunications at 1.7-80 MHz - Phase 2 Study (Phase 1 was published in 2004)
- 2006: TR-06-437 Interference Potential of Ultrawideband Signals Part 3: Measurement of Ultrawideband Interference to C-Band Satellite Digital Television Receivers (Parts 1 and 2 were published in 2005)
- 2002: TR-02-391 Analysis of the RF Threat to Telecommunications Switching Stations and Cellular Base Stations
- 1994: TR-94-313: Analysis of Electromagnetic Compatibility Between Radar Stations and 4 GHz Fixed-Satellite Earth Stations
- 1981: TR-81-63 Analysis of a Phase-Locked Loop to Suppress Interference from a Solar Power Satellite
- 1980: TR-80-32 Sharing of the band 12.2-12.7 GHz between the broadcasting-satellite and fixed services
- 1978: TR-78-6 A Preliminary Estimate of the Effects of Spread–spectrum Interference on TV

Today

Spectrum Sharing Present: DFS at 5 GHz

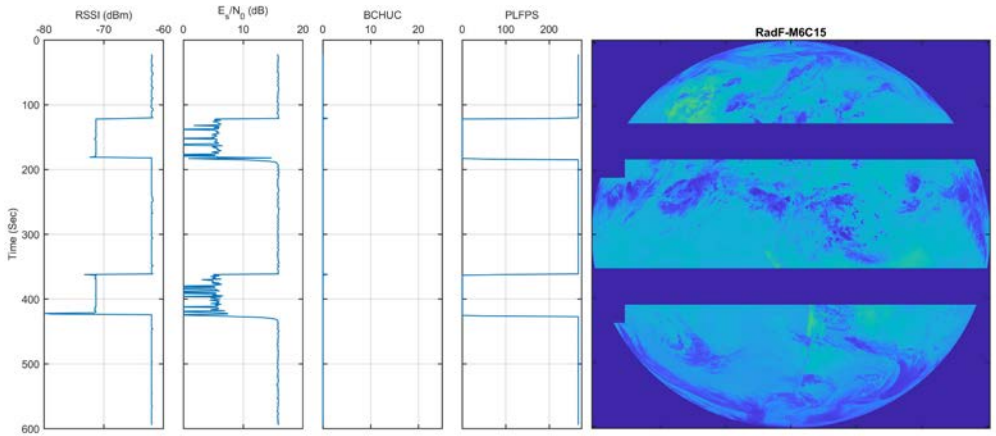
- ITS led the search for engineering solutions to enable spectrum sharing between *unlike* services: unlicensed (U-NII) devices ↔ FAA terminal Doppler weather radars
- 10-year series of studies (NTIA reports) describing how to implement **dynamic frequency selection** (DFS) detect-and-avoid technology for effective sharing
- "Lessons Learned" from the DFS experience report published in 2020
  - No technology solution is "fire and forget"
  - There always will be interference events to investigate and mitigate



ITS 5 GHz DFS spectrum sharing measurements with a classified radar system at McGregor Range, New Mexico

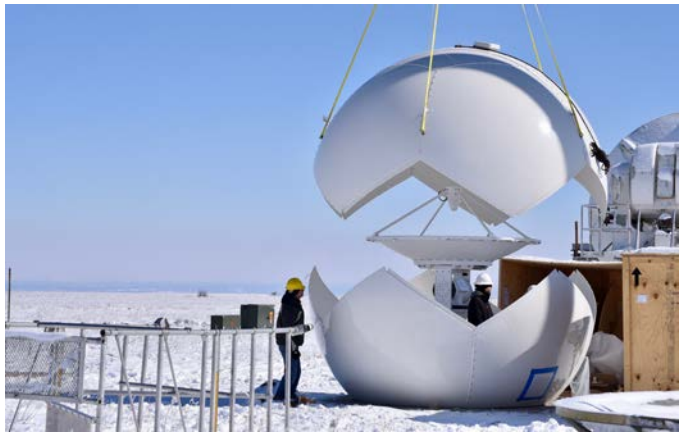
Spectrum Sharing Present: NOAA RFIMS Program

- Established a NOAA earth station test range facility at **ITS' Advanced Communication Test Site** for polar orbiting and geostationary weather satellites and the radio frequency interference monitoring system (RFIMS)
- **Objective is assessment of interference protection criteria** for key NOAA earth station systems based on receiver key performance indicators (below left) which will be correlated to image degradation (below right)
- **Empirical electromagnetic combability studies** between actual NOAA earth station systems and synthesized AWS-3 LTE uplink interference signals



ITS' Advanced Communication Test Site

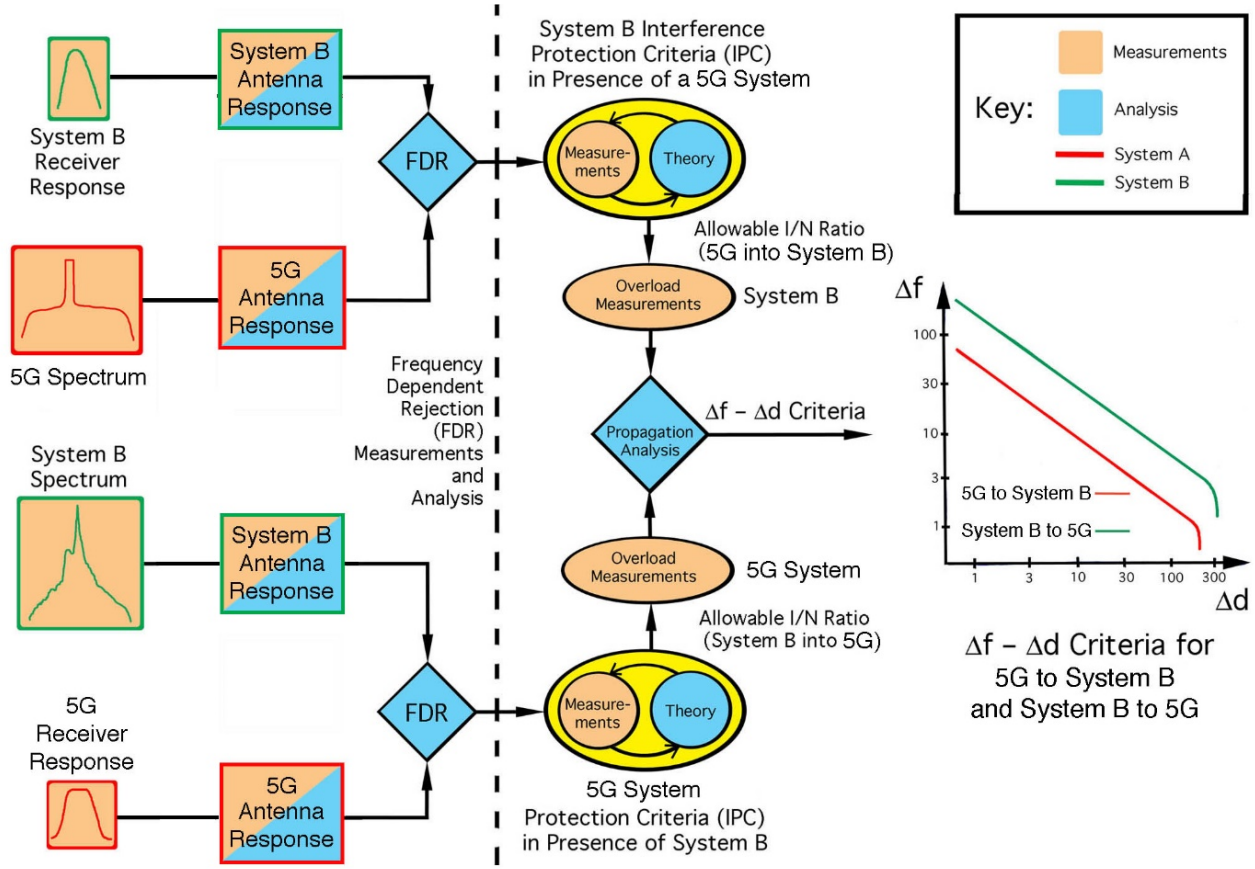
- Radio Quiet Zone
- Intermittent Transmit capable
- Modernized infrastructure



- Facility equipped with **state-of-the-art calibrated instrumentation**: signal analyzers, vector signal generators, modeling and simulation software and an LTE protocol decoder
- Detailed characterization of test range propagation, ambient AWS-3 uplink signals and antenna patterns

Spectrum Sharing: ITS' Method built, proven, applied
Present: Hill AFB & 5G

- Comprehensive, holistic engineering and scientific approach
- Rigorous and controlled methodology combines measurement and analysis
  - System emission measurements
  - Frequency dependent rejection measurements and analysis
  - Interference protection criteria: allowable I/N ratio entrant into incumbent, incumbent into entrant



ITS approach to spectrum sharing studies, 5G example

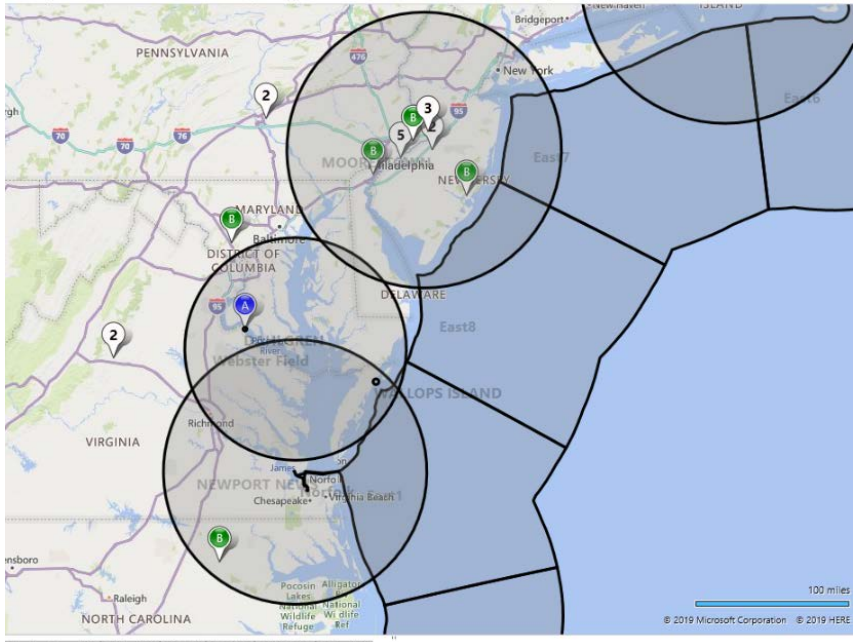
Spectrum Sharing: Full Cycle

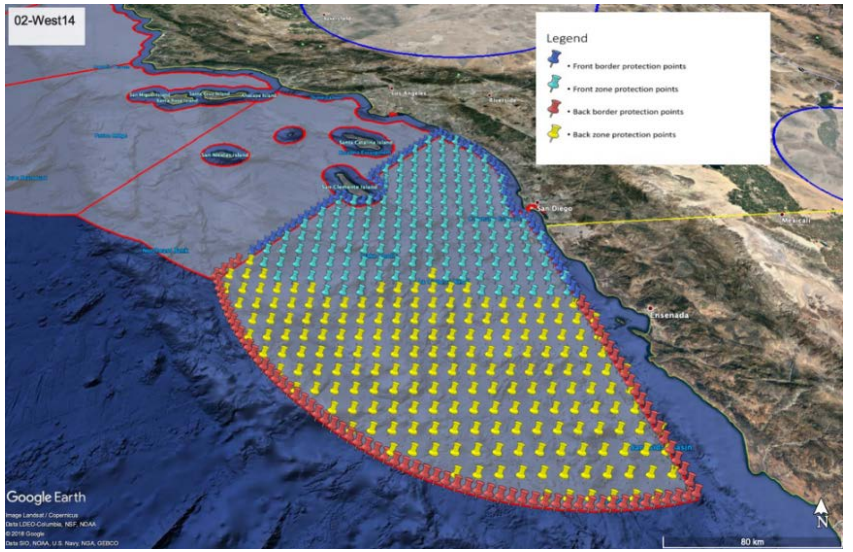
What are system characteristics?	*What designs are feasible?*	*Measure and model key metrics*	*Consider other link budget factors*	*Does the system work?*	*Address the inevitable…*	*Confirm that solutions work*
RF Environment Assessment	EMC Analysis	Interference Protection Criteria	Technical Input for Rulemakings	Conformity Assessment	Interference Mitigation	Equipment Surveillance Testing
• Spectrum Monitoring • 100-18,000 MHz Spectrum Surveys in several metro areas (1995-2012) • Radar Spectrum Engineering Criteria (RSEC) measurements	• 3.5 GHz CBRS eHata propagation model (2017) • USCG maritime radar → broadband comms • AWS-3 enhanced clutter loss and aggregate interference measurements (ongoing)	• Ultrawideband (2000-2006) • Broadband over power line (2003-2004) • 3.5 GHz LTE ←→ radar (2014) • General criteria for spectrum sharing with radars (2002-ongoing)	• AWS-3 recommended clutter loss metrics • 3.5 GHz CBRS aggregate interference modeling	• Designed U-NII DFS certification system used by FCC/OET (2004-2010) • 3.5 GHz ESC testing (2019) • 3.5 GHz SAS testing (2019)	• DFS → TDWR (2009-2011) • WiMAX-LTE Interference → NEXRAD (2010+) • NASA/SMAP Radar → DoD-FAA-DHS air defense and traffic control radars (2009) • FAA radar → NEXRAD (2006)	• DFS access points tested following manufacturer mitigation (2004-2010)

Holistic systems engineering under one roof: Lifecycle support from concept to interference mitigation

ITS Supports NTIA/OSM Example CBRS

- 2010 ISART – Spectrum Sharing
- 2010 NTIA Fast Track Report
- 2011 ISART – Spectrum Sharing with Radar
- 2012-14 ITS Report on Measured 3.5 GHz Incumbent Usage
- 2014 NTIA Reduces Exclusion Zones (ITS' eHata model: 77% reduction)
- 2015 FCC adopts new rules for CBRS
- 2015 NTIA Introduces Dynamic Sharing
- 2017 ITS Releases official eHata propagation code used by SAS
- 2018-19 ITS SAS and ESC Certification Test and Evaluation
- 2020 ITS Report on 3.5 GHz Long-term Occupancy



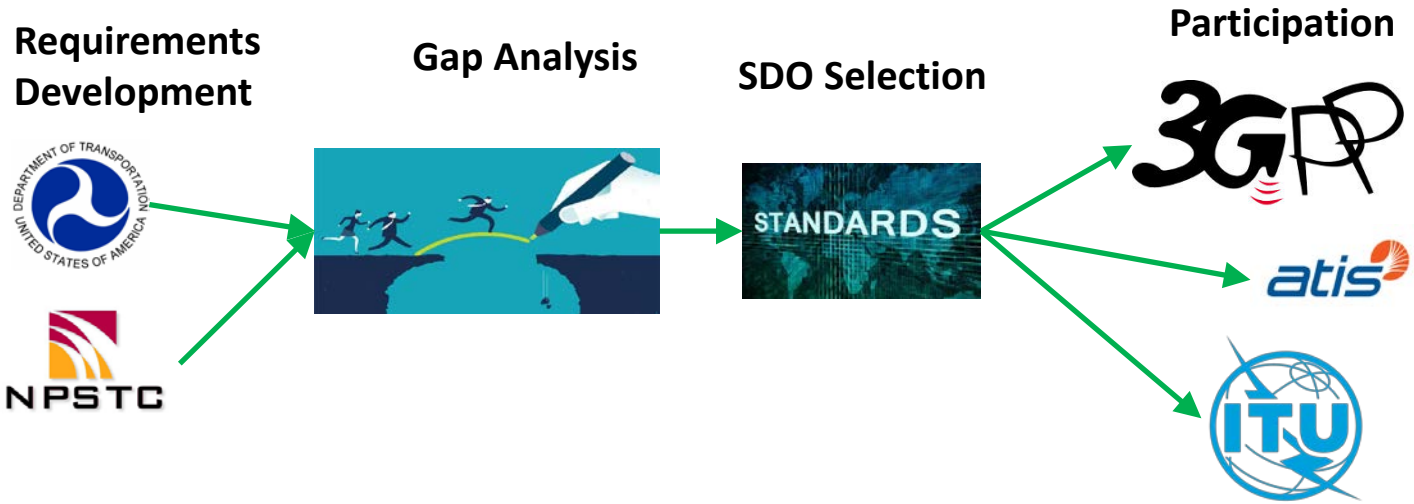


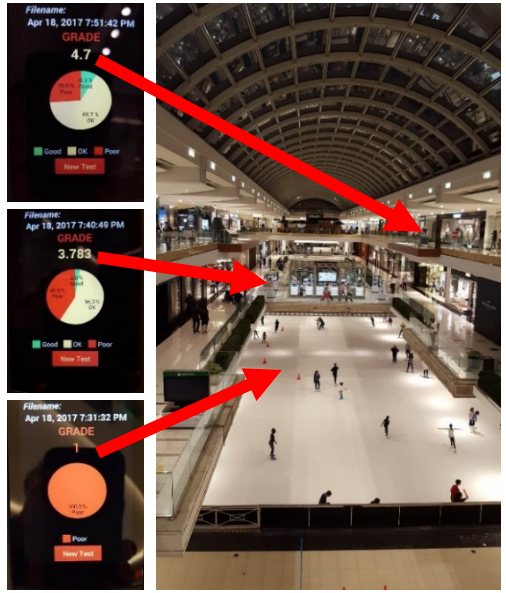
Spectrum Sharing: Toolbox

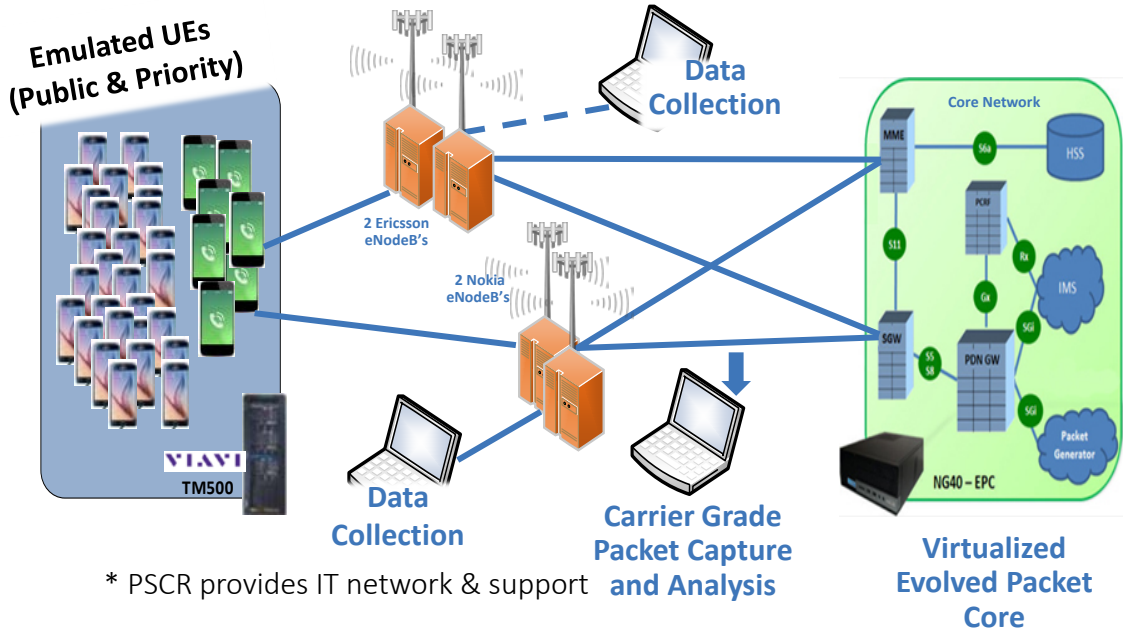
- Radio propagation model measurements and model development
- Radio spectrum usage studies, including individual band assessments and broadband spectrum survey measurements
- Measurements, modeling, theory, and analysis of interactions between transmitting and receiving systems to determine interference protection criteria between and among radio systems
- Studies of compatibility issues including overload responses of receivers and technologies for protecting receivers from interference effects
- Studies of antenna systems, including MIMO
- Testing and evaluation of spectrum sharing technologies such as DFS, ESCs, and SASs
- Publication record, to document results and to share the results with the engineering communities in both Industry and Government
- 5G capability
- Data science

5G

- FirstNet, DOT, & DOD standards approach
- Hill AFB Spectrum Sharing Study
- 5G Link Simulation Study
- LTE Priority Services Test Bed*
- Quality of Experience (QoE)
- Traffic emulation — hardware that simulates 500 UEs
- Cell-phone app-based indoor propagation measurements





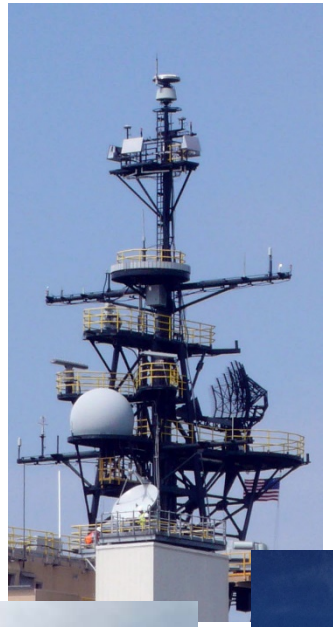


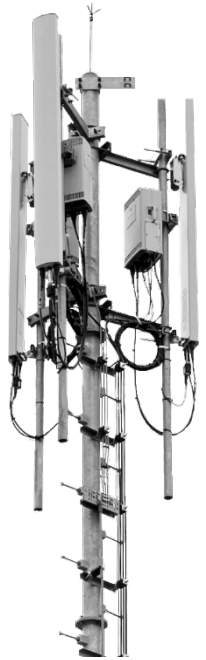
* PSCR provides IT network & support

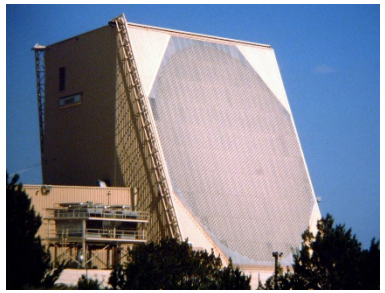
Government Systems Experts

As NTIA's applied engineering and research lab, ITS has longstanding experience collaborating with federal agencies to characterize systems, resolve interference issues, and address spectrum policy questions impacting:

- Radar
- Meterological satellite communications
- Military tactical, telemetry, training
- Public Safety LMR and LTE
- Intelligent Transportation
- HF Communications

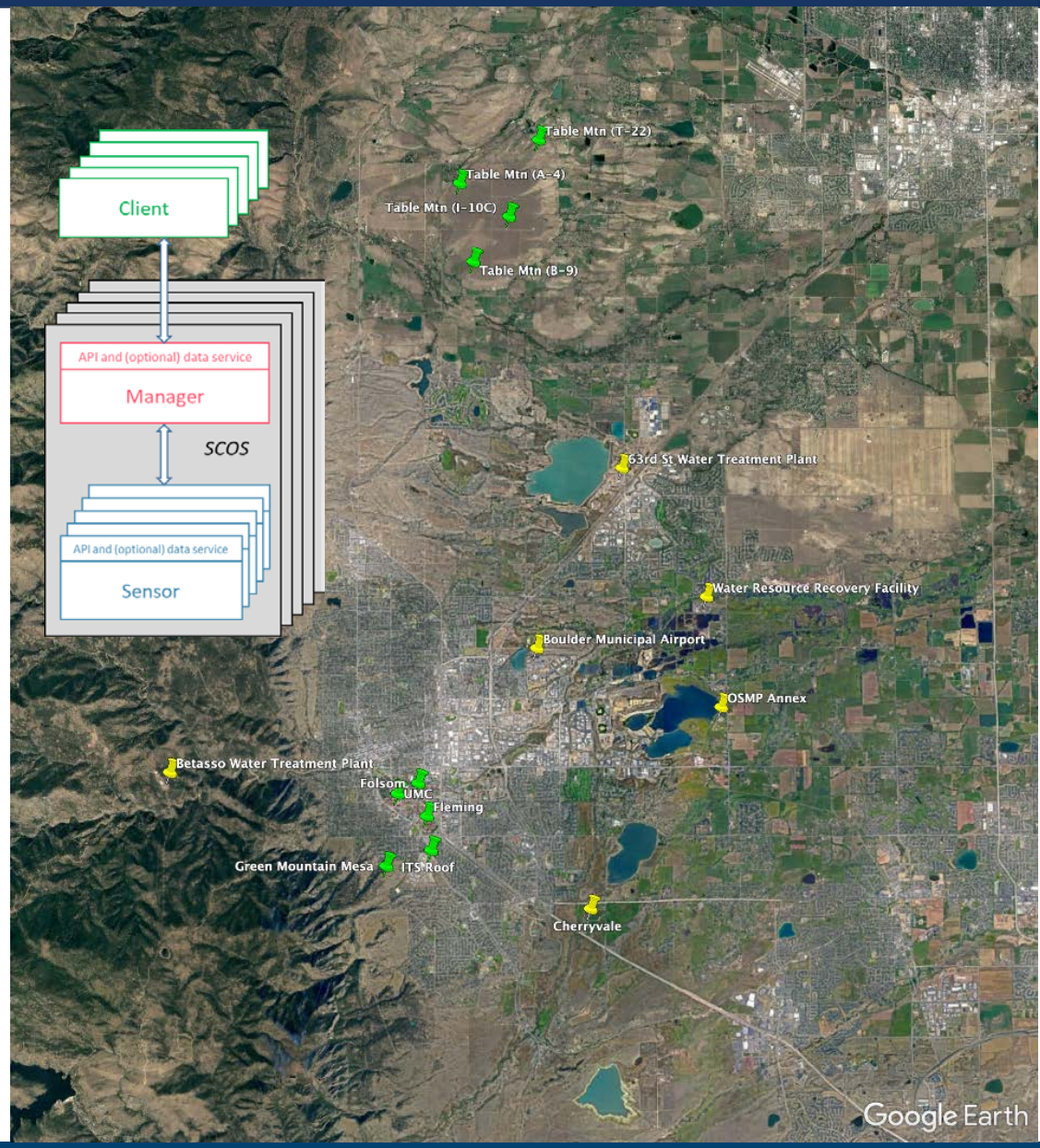






Spectrum Monitoring/Surveying: Wireless Test City

- **Real-world research test bed to experiment and spur innovation**
- Software: standardized (IEEE 802.15.22) and open software for distributed sensing and automation
- Operationalize production data distribution adhering to government security controls
- Sensor hardware: Architected to be scalable, reliable, and evolvable
- Data Informs & Advances
  - Partnerships
- Workshops in FY21



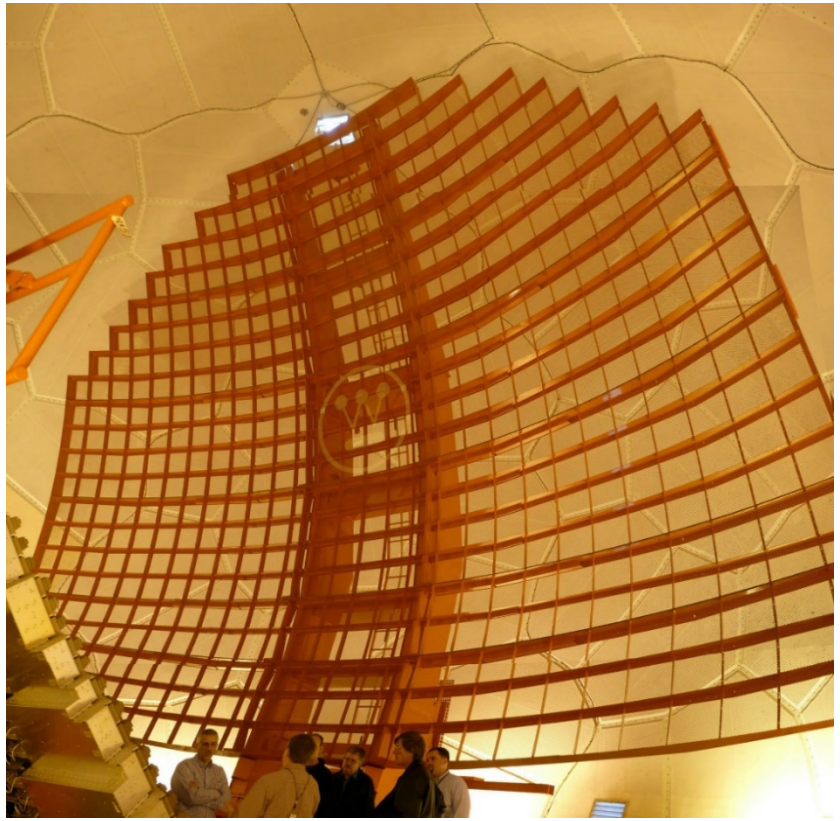
Tomorrow

What's next at ITS?

- **Advanced Communication Test Site (ACTS)**
  - Field test environment with flexible spectrum access in a radio quiet zone
  - Infrastructure for characterizing systems, supporting spectrum sharing concept development, and testing prototypes in an over-the-air transmission environment
  - Just minutes from the ITS lab in Boulder
- **Spectrum Data**
  - "All of Nation" approach to facilitate the speed to need
  - Workshops and recommendations on authentic data collection and on standardized/guidelines for the use of models and simulations
  - Monitoring, surveying, incumbent informing
  - Partnerships for Wireless Test Cities
  - ITS Workshops
- **5G (next G) and other systems**
- **Propagation modeling**

Spectrum Sharing: Future

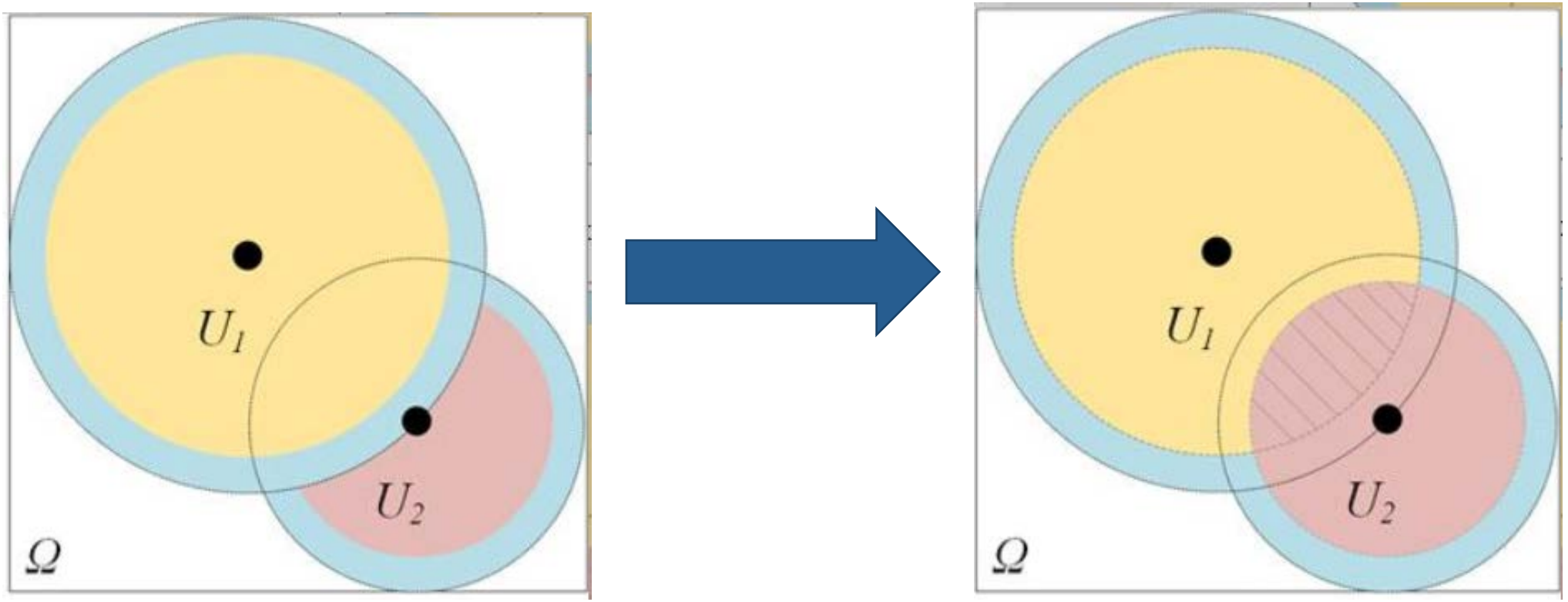
- **Propagation models**: clutter, 3.1-4.2GHz
- New sharing studies for **radars sharing with 5G** communications at 1300 MHz and 3.3 GHz
- Spectrum Frontiers / **Millimeter Wave**
  - Bi-directional sharing
  - 24GHz frontier
- Examine efficacy of dynamic sharing between **CBRS and radars at 3.5 GHz**
- Quantified utility, validated usage, and incentivized **efficiency**
- **Real-time RF awareness** via continuous monitoring and/or surveys



ITS leading studies on new spectrum sharing involving the national air defense ARSR-4 (above) and other radars

Spectrum Sharing: Future Evolution

- Target: eliminate the need for exclusion or protection zones altogether
- Concepts: Spectral efficiency, system utility



What's coming ?

- High Performance spectrum sharing
  - Automated modular spectrum management
  - Standardized and high-resolution propagation models
  - Interference protection criteria based on real-world scenario instead of worst case
  - Improved info and quantification about services and systems
  - Improved comms between disparate services
- Advanced Wireless Testing
  - Conducted experimental platforms (e.g, ACTS)
  - Real-world test environments with flexible spectrum access (e.g., ACTS)
  - Controlled radiated platforms
- Spectrum sharing: data science, security
  - Leveraging technologies – management, deployment, analysis
  - Usage to inform sharing opportunities and incentivize "good behavior"
  - ISART 2020 – 5G Spectrum and a Zero-Trust Network
- 6G →next G!
  - Optical - expanding carrier options
  - Satellite - barriers to entrance lowering
  - Quantum – Differential phase-shift (DPS) Quantum key distribution (QKD)
- ISART 2021 - topic ideas ?

Thank You!

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