# An Industry View

Andrew Clegg

IUCAF Summer School on Radio Astronomy Spectrum Management
Stellenbosch, South Africa
March 6th, 2020

“The popular anticipation of pocket wireless telephones by means of which a passenger flying in an aeroplane over France or Italy might ‘ring up’ a friend walking about the streets of London with a receiver in his pocket cannot be said to have been as yet practically realized but there is nothing inconceivable or even impracticable about such an achievement and the progress of wireless telephony seems to be pointing in that direction.”

“The popular anticipation of pocket wireless telephones by means of which a passenger flying in an aeroplane over France or Italy might ‘ring up’ a friend walking about the streets of London with a receiver in his pocket cannot be said to have been as yet practically realized but there is nothing inconceivable or even impracticable about such an achievement and the progress of wireless telephony seems to be pointing in that direction.”

-- Marconi, 1919

# An Industry View on Spectrum Issues

- These views are based on my own observations
- My views are informed mostly by developments in U.S.
- Industry is not monolithic -- opinions will vary
  - Industry doesn’t always (actually, virtually never) agrees with each other
- Big-picture spectrum issues evolve over time (~5-10 years)
  - Typical time scale for policy and regulatory processes to play out
- So this is a snapshot

# Today’s Two Hottest Spectrum Issues

- **The global race to 5G**
    - This presentation will include a very basic overview of 5G and its impact on spectrum management
- **Spectrum sharing**
    - I’ll provide one current sharing example from U.S.

# 5G

# 5G

- What is it?
- Why is it?
- Why is it important?
- How will it impact spectrum management?

# 5G: What is it?

- The next generation of mobile (and fixed) wireless networking (cell phones++)

| Generation | Decade | Technology(s) | Air Interface Type |
|---|---|---|---|
| 1G | 1980s | Analog | AMPS |
| 2G | 1990s | GSM, TDMA, CDMA | GSM/GMSK, IS-136, CDMA |
| 3G | 2000s | W-CDMA, HSPA/HSPA+/HSDPA | CDMA |
| 4G | 2010s | LTE | OFDM |
| 5G | 2020s | NR, NR-U | OFDM |

*Note*: From 3G onward, global standards are created by 3GPP and freely available online (https://www.3gpp.org/specifications)

# 5G: Why is it?

- 5G's operational goals:
  - Substantially increase data throughput
  - Reduce latency (end-to-end time to communicate information)
  - Efficiently support rapidly growing numbers of devices and applications, including:
    - Internet of Things (IoT)
    - Machine-to-machine (M2M)
    - Autonomous vehicles
    - Augmented reality (AR) & virtual reality (VR)
    - Mobile & fixed data
    - UHD streaming, etc.

# The Landscape of 5G

5G will differentiate itself by delivering various improvements:

## 5G compared to 4G

**10x**

**Decrease in latency:**
Delivering latency as low as 1 ms.

**10x**

**Connection density:**
Enabling more efficient signaling for IoT connectivity.

**10x**

**Experienced throughput:**
Bringing more uniform, multi-Gbps peak rates.

**3x**

**Spectrum efficiency:**
Achieving even more bits per Hz with advanced antenna techniques.

**100x**

**Traffic capacity:**
Driving network hyper-densification with more small cells everywhere.

**100x**

**Network efficiency:**
Optimizing network energy consumption with more efficient processing.

Source: Digital Trends

# Why is 5G Important?

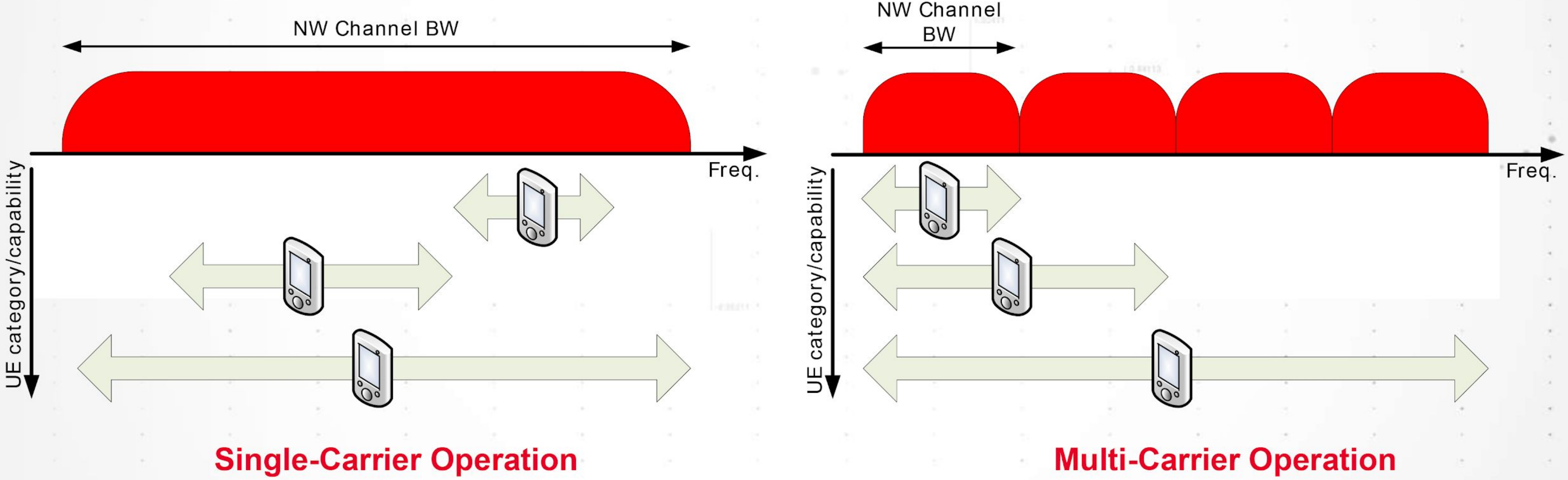
- Economic benefits that came to the early adopters of mobile 4G:
  - Mobile video streaming
  - On-the-go maps and online navigation
  - Uber and other app-enabled gig work
  - Mobile gaming
  - Mobile banking
  - Lots of others in the app-driven economy, enabled by higher and more economical throughput compared to 4G
- If first-to-4G provided great economic benefits, the first-to-5G must be 10x better!

# How will 5G impact spectrum management?

- 5G NR (3GPP Release 16) (2020) includes support for mmW frequencies
  - 5G NR, FR 1: 450 MHz - 6 GHz
  - 5G NR, FR 2: 24.25 - 52.6 GHz
  - 4G LTE has no mmW bands defined
- 5G NR supports significantly greater bandwidth
  - 3.2 GHz max BW for 5G NR (FR2) vs 100 MHz for 4G LTE
  - 100 MHz max typical for FR1 5G NR vs 20 MHz max typical for 4G LTE
- 5G NR supports advanced beamforming
  - 5G base stations will be able to concentrate RF power in directions where it's needed and avoid throwing power where it's not needed
  - Support for 3D multi-user beamforming
- 5G will tend to rely on 4G for the time being (non-standalone, NSA)
- For regulatory power limits based on PSD, per-carrier EIRP can be large

# Single-Carrier and Multi-Carrier Operation

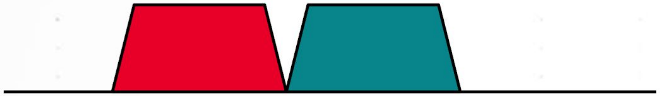
- Maximum single-CC bandwidth is 400 MHz
- Maximum number of CCs is 8




Source: Keysight 5G Bootcamp

# Carrier Aggregation Types

- Component Carriers may be in the same band and adjacent



- Or they could be in the same band, non-contiguous

- Or in different bands

Band A – sub-6 GHz

Band B – mm-wave (28GHz)

Google

# LTE vs. NR Comparison

| | LTE (Based on 3GPP Rel. 15) | New Radio (Based on 3GPP Rel. 15) |
|---|---|---|
| Frequency band | Sub-6 GHz | Sub-6 GHz, mmWave (up to 52.6 GHz) |
| Maximum Bandwidth (per CC) | 20 MHz | FR1: 5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100MHz<br>FR2: 50, 100, 200, 400 MHz |
| Maximum CCs | 5 (Rel.10) / 32 (Rel.12). Current implementation is 5. | 8 |
| Subcarrier Spacing | 15 kHz | **$2^n \cdot 15$ kHz** |
| Waveform | CP-OFDM for DL; SC-FDMA for UL | CP-OFDM for DL; CP-OFDM and DFT-s-OFDM for UL |
| Modulation | Up to 256 QAM DL (moving to 1024 QAM);<br>Up to 64 QAM UL | Up to 256 QAM UL & DL |
| Maximum Number of Subcarriers | 1200 | 3276 |
| Subframe Length | 1 ms (moving to 0.5 ms) | 1 ms |
| Latency (Air Interface) | 10 ms (moving to 5 ms) | 1 ms |
| Slot Length | 7 symbols in 500 µs | 14 symbols (duration depends on subcarrier spacing)<br>2, 4 and 7 symbols for mini-slots |
| Channel Coding | Turbo Code (data); TBCC (control) | LDPC (data); Polar Codes (control) |
| Initial Access | No beamforming | Beamforming |
| MIMO | Up to 8x8 | Up to 8x8 |
| Reference signals | UE Specific DMRS and Cell Specific RS | Front-loaded DMRS (UE-specific) |
| Duplexing | FDD, Static TDD | FDD, Static TDD, Dynamic TDD |

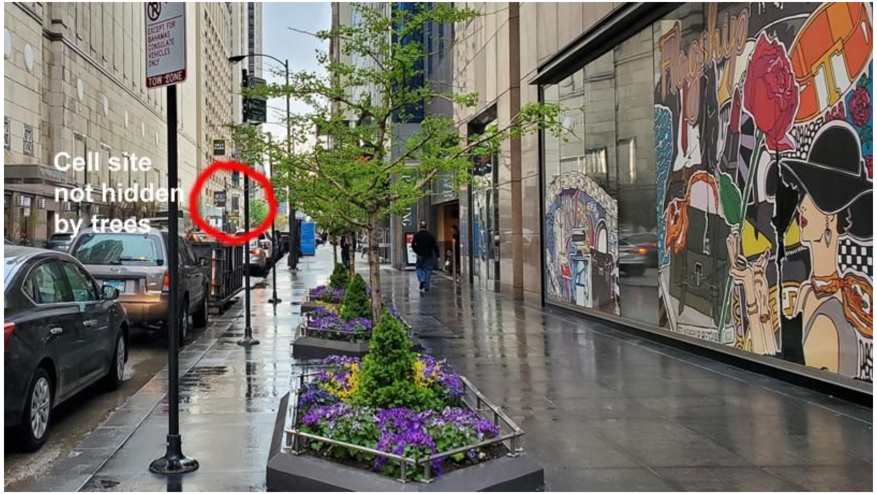
Source: Keysight 5G Bootcamp

# Impacts of the Race to 5G: Gobbling up Spectrum

- Countries are racing to allocate more spectrum for mobile broadband to support their 5G aspirations
  - Starting around 2014, we started adopting the *not-officially-defined* terminology of “low-, mid-, and high-band” spectrum

| **Band** | **Approx Range** | **Propagation** | **Spatial Re-use** | **Max Available Bandwidth** |
|---|---|---|---|---|
| Low | <2.5 GHz | Longer | Not great | Smaller |
| Mid | 2.5 - 7 GHz | Mid | Decent | Decent |
| High | >24 GHz | Short | Excellent | Excellent |

# Testing 28 GHz 5G in Chicago: “Speedy, But Watch Out for That Tree”




*This line of sight gave us 1.13Gbps down, 500 feet away from the site.*

*This line of sight, just a few steps to the right, caused a signal drop to 4G.*

PC Magazine: https://www.pcmag.com/news/testing-verizon-5g-in-chicago-speedy-but-watch-out-for-that-tree

# Spectrum Sharing

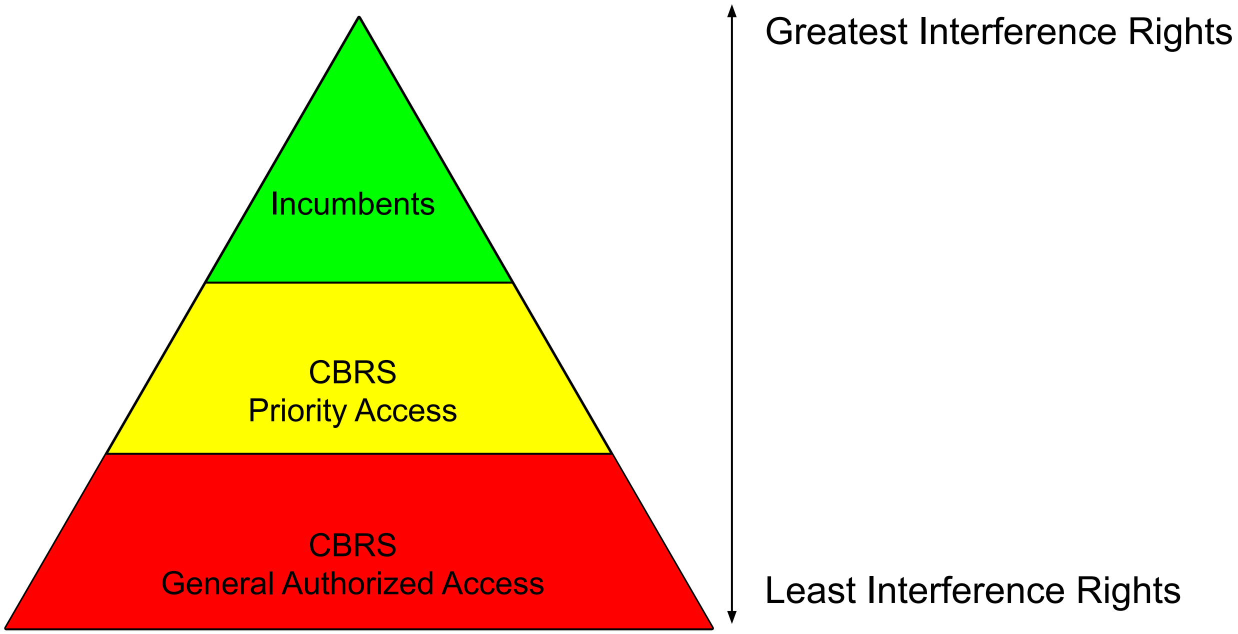
# No Clear Low- and Mid-Band Spectrum Remains

- Demand for spectrum continues to grow
- 5G and other applications vying for bandwidth
- All low- and mid-band spectrum is already occupied
  - mmW spectrum is better situated, but challenging to use for many applications
- No spectrum left for clearing and relocating
- Only remaining option is to share
- Sharing has become sufficiently necessary that even defense departments, mobile network operators, and satellite service providers have been forced to share spectrum

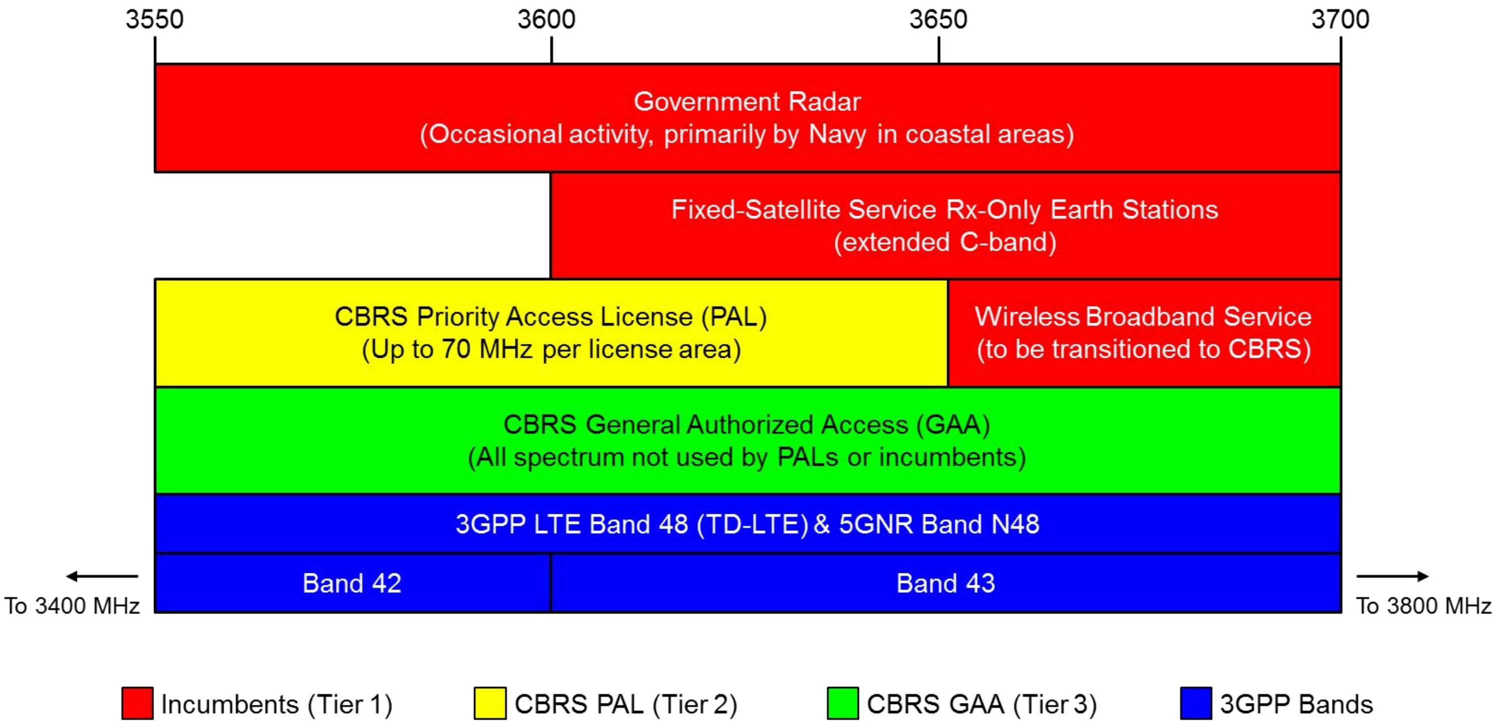
# Spectrum Sharing Example: U.S. 3.5 GHz Band

- Citizens Broadband Radio Service (CBRS)
- Operates in shared “mid-band” spectrum
- Extensive engagement with incumbents (mostly military), the potential CBRS industry, and potential users, over a period of 7 years to make this band happen
- Commercial service approval from FCC issued just a few weeks ago

# Three-Tier Spectrum Sharing



# The 3.5 GHz Band



# Tier 1: Incumbents

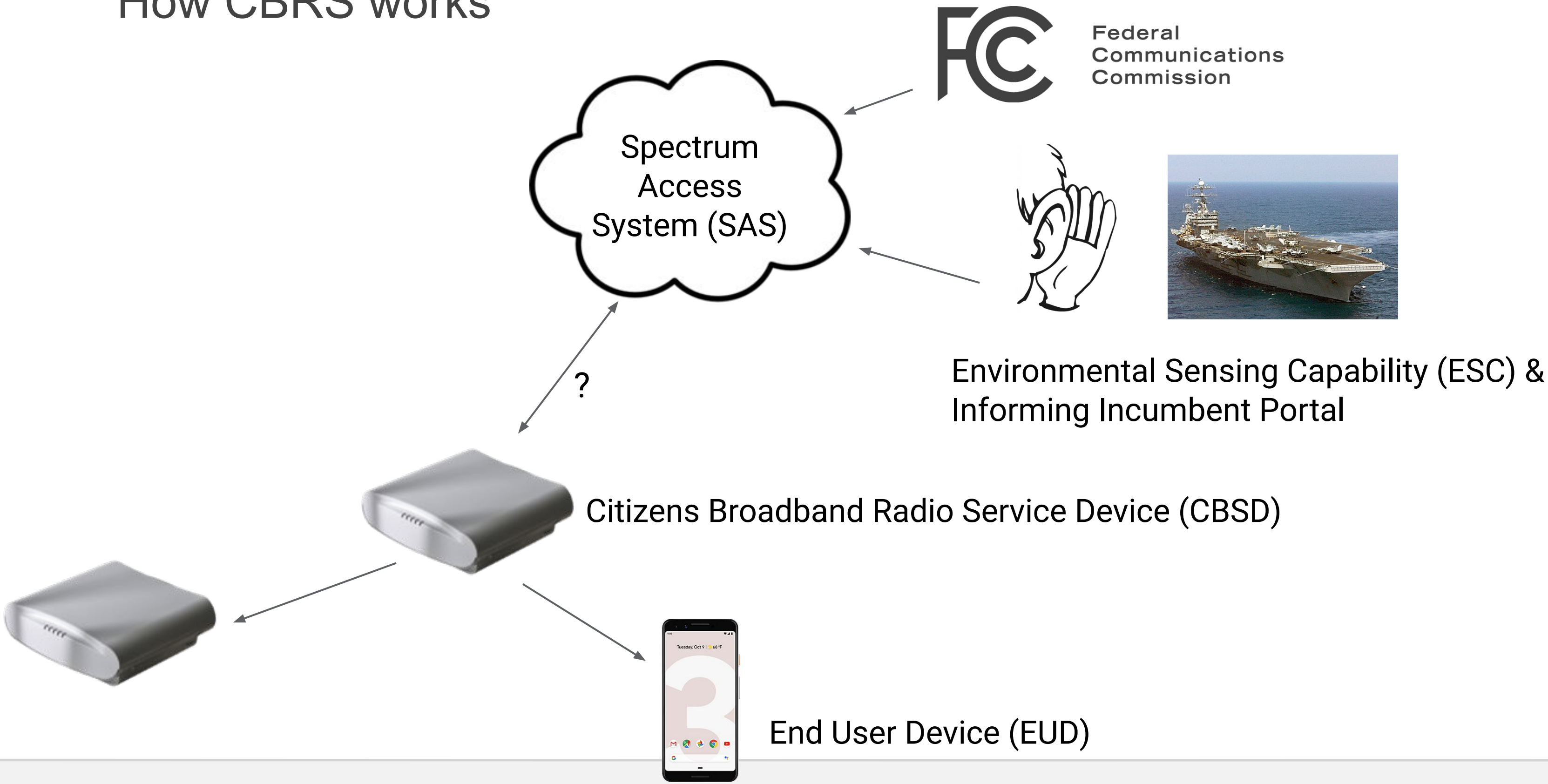
U.S. Navy Radar


Satellite Earth Stations

# The Spectrum Access System (SAS)

- The SAS is what makes CBRS work
- All CBRS base stations ("CBSDs") must check with a SAS before commencing operation to obtain approval to transmit
- CBSDs must check with a SAS on a regular basis after that for continued authority to transmit
    - Check-in period is as short as every four minutes in current implementation, but is software-defined (can be shorter or longer)
- Google and five other companies are now operating cloud-based SASs under commercial service in the U.S.

# How CBRS works

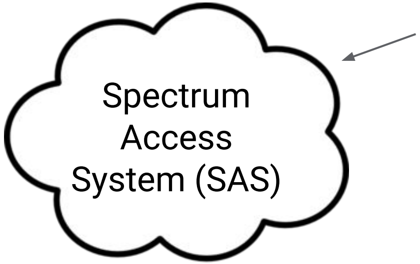


# How CBRS works

Citizens Broadband Radio Service Device (CBSD)

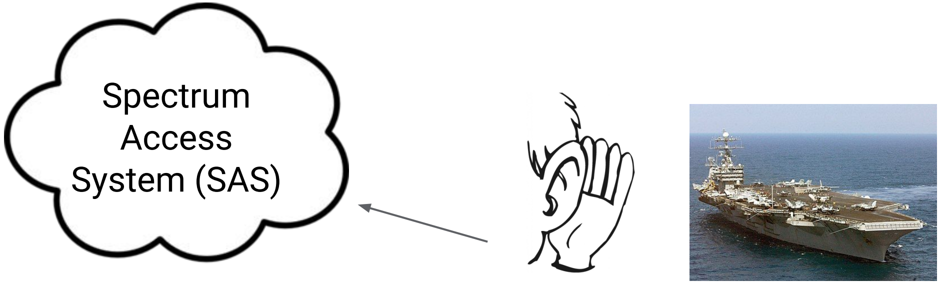
# How CBRS works

# How CBRS works




Federal
Communications
Commission

# How CBRS works



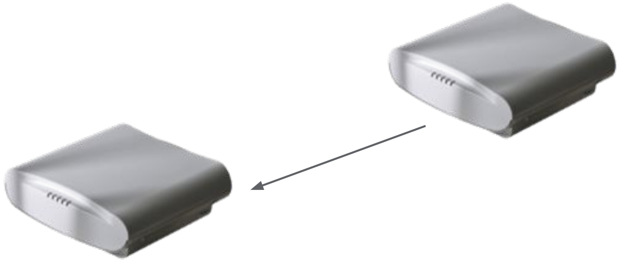

Environmental Sensing Capability (ESC) &
Informing Incumbent Portal

# How CBRS works

# How CBRS works

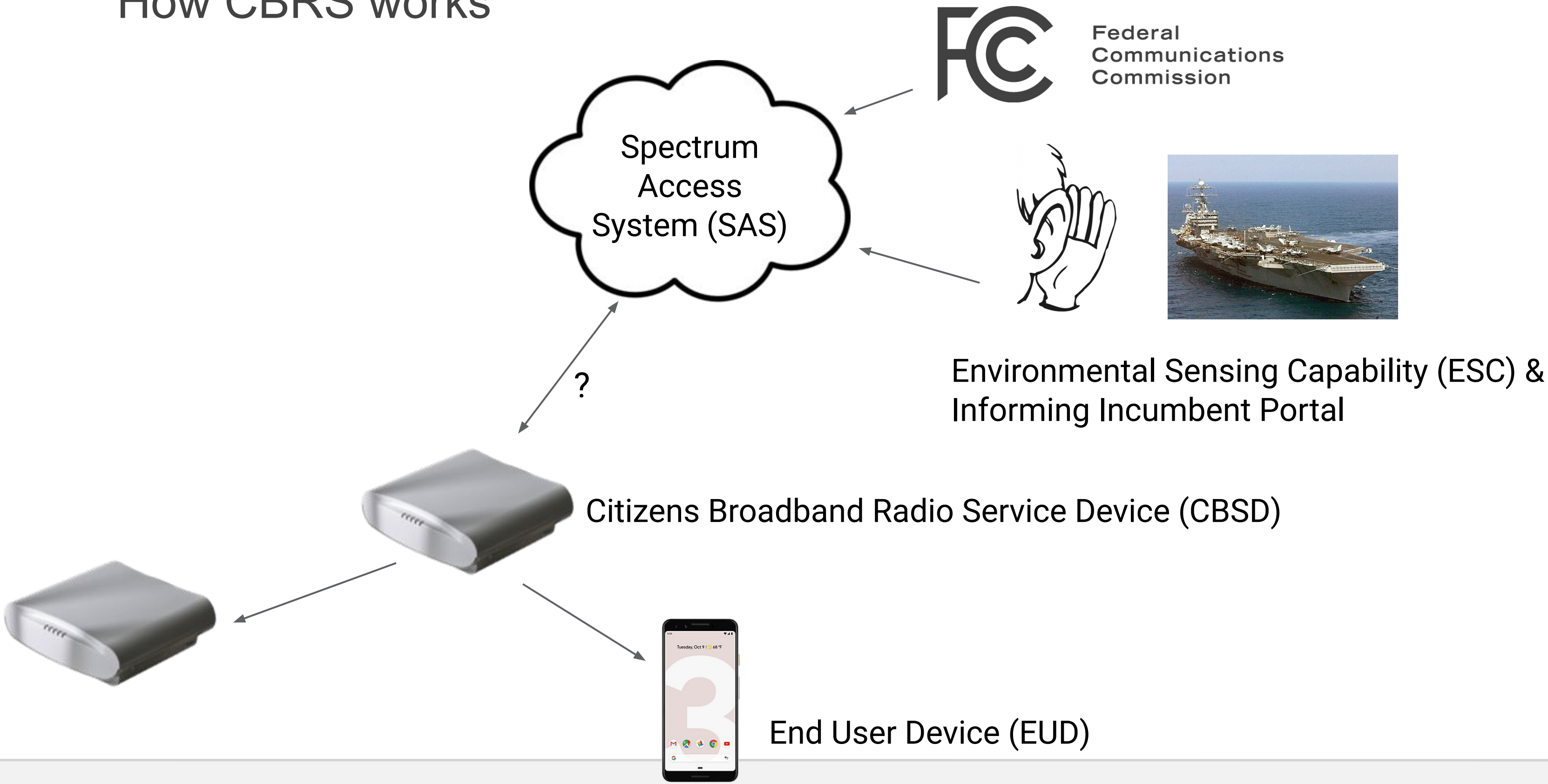
End User Device (EUD)

# How CBRS works

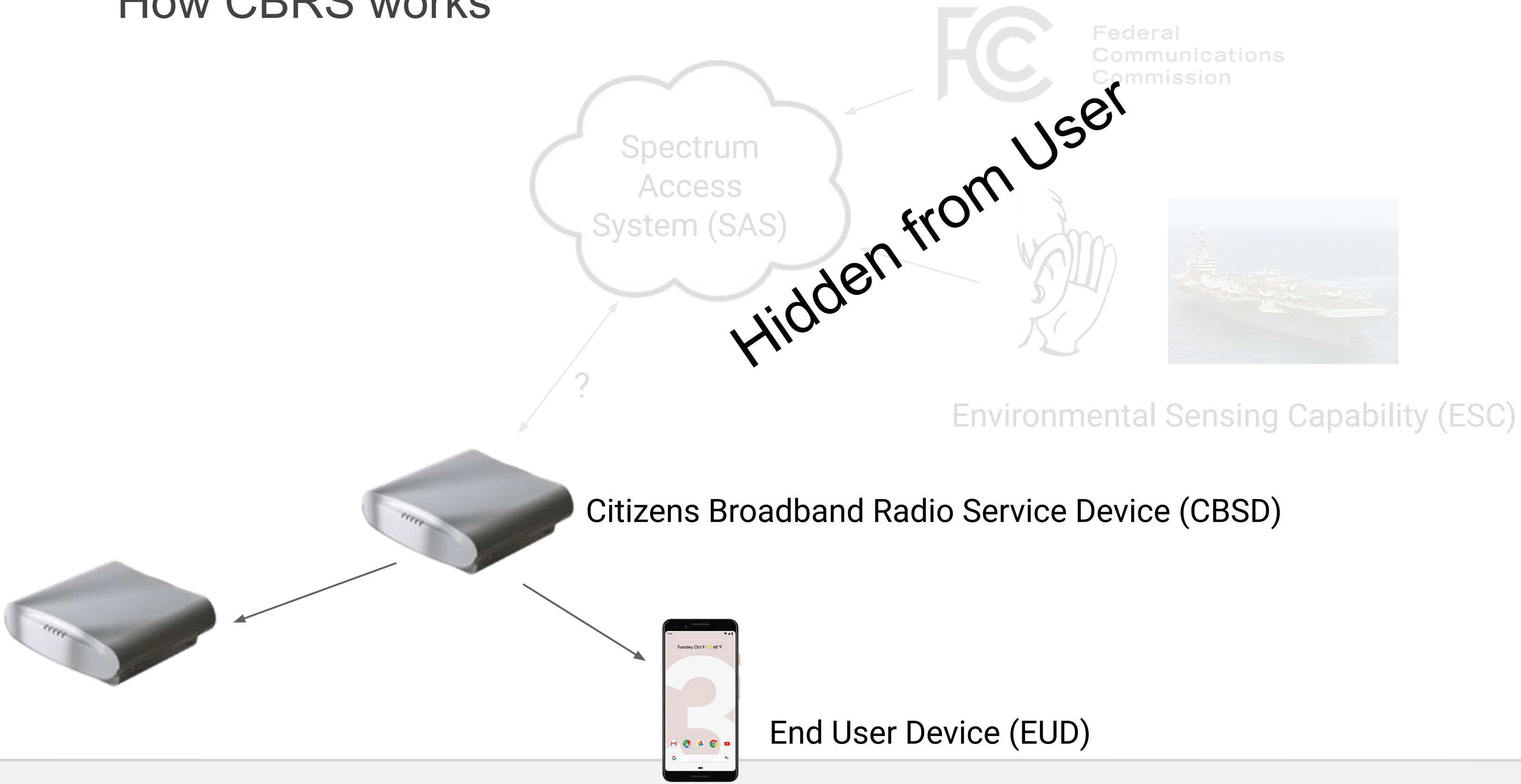


# How CBRS works

# How CBRS works



# How CBRS works



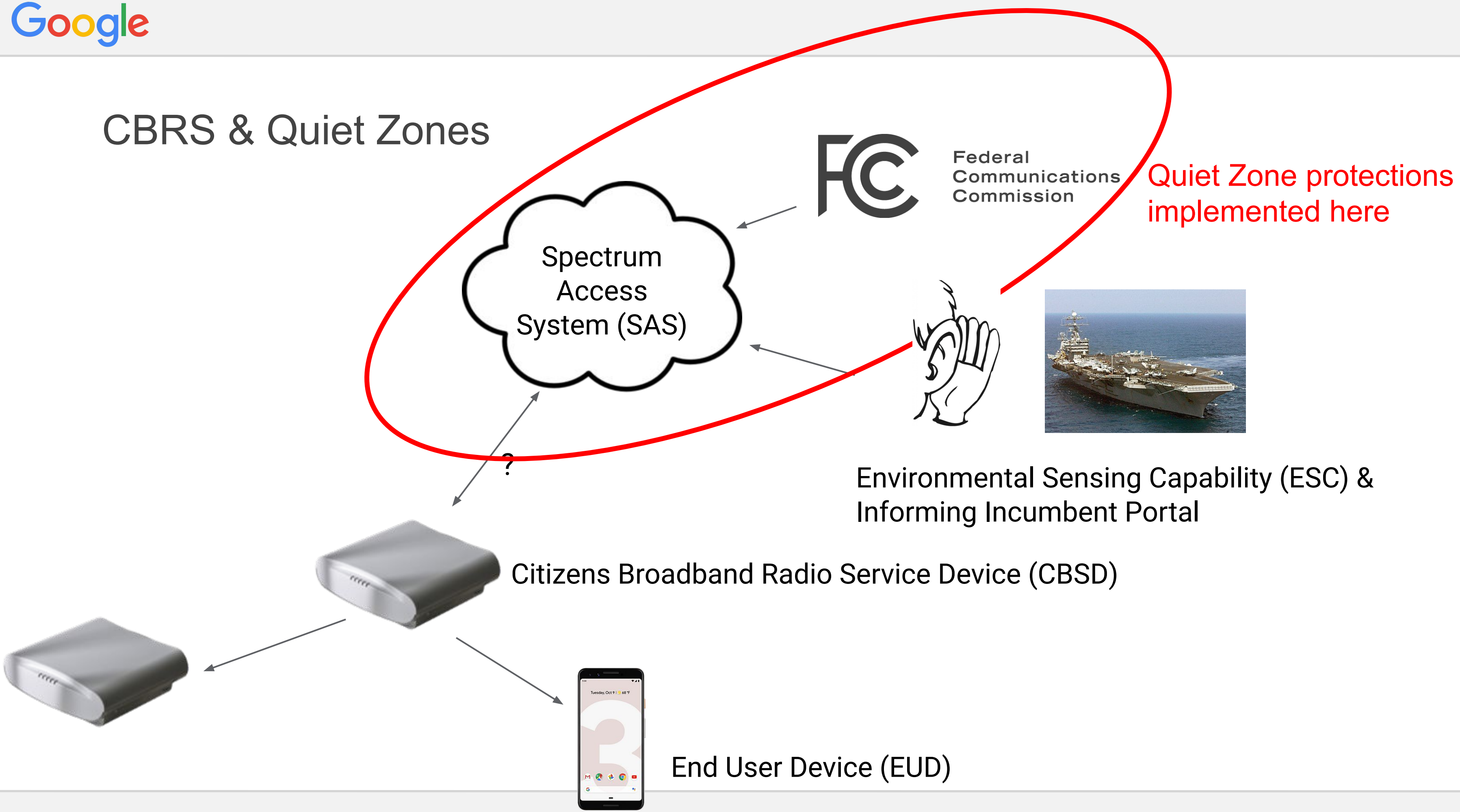
# Quiet Zones in 47 CFR 1.924

- CBRS covers U.S. & possessions
- Quiet Zones that must be protected per 1.924
  - NRAO and NRRO (i.e., the National Radio Quiet Zone)
  - Table Mountain (Dept of Commerce site near Boulder CO)
  - FCC field offices
  - Arecibo Observatory, PR

# CBRS Quiet Zone Protection Standards

- NRQZ and PRCZ are fully protected
- WInnForum standard TS-0112
  - ***R2-SGN-18****: Unless directed otherwise by the FCC, SASs shall authorize no CBSD activity within the borders of quiet zones without the appropriate coordination as specified in 47 CFR 1.924.*
- NTIA's Institute for Telecommunications Sciences (ITS) (part of Dept. of Commerce) participated in standards developments and was responsible for SAS certification testing. ITS established thorough procedures for protecting Table Mountain Radio Research Station and thoroughly tested those procedures.
- No significant procedures were adopted for other Quiet Zones
- Without procedures or coordination agreements, first-generation SASs are not currently allowing any CBSD grants within the National Radio Quiet Zone or PRCZ

# CBRS & Quiet Zones



Google

# Summary

- CBRS dynamically operates in shared spectrum with military and with sensitive satellite receive systems
- A centralized SAS coordinates operation of CBRS without causing any interference or disruption to incumbent operations
- The SAS does not control or significantly impact incumbent operations

# Improving Out-of-Band Access for RAS?

- Could the CBRS model be used to mutually benefit RAS and active users?
- Could a SAS arrange for passive access to active bands (for example, CBRS)?
- Could RAS observing schedules inform a SAS, to allow for active access to RAS band when not being used locally by an observatory (and taking into account other passive users)?
- Could RAS leverage such an arrangement to help pay for (or even expand) observatory operations and instrumentation?