Cognitive Radio: Lessons From the Past

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What exactly is a cognitive radio?

- Mitola & Maguire defined cognitive radio in 1998 as an extension of software radio with model-based reasoning about “radio etiquette.”

- Haykin, 2005, extended the concept to “brain-empowered wireless communications”

- Mostly applied to systems that share spectrum with unlike systems, however, one can argue that most modern wireless networks incorporate cognition:
  – Wi-Fi: Carrier Sense Multiple Access with Collision Avoidance (CSMA-CA) requires sensing and exponential back-off.
  – Cellular: Resource allocation, transmit power control, link adaptation all require elements of measurement and feedback, elements of cognition.
  – SDRs are not essential to the fundamental concept of cognition.

Relevance of cognitive radio today

The pressure on spectrum continues, but the toolkit has changed.

Spectrum demand

More bands are contested; all applications need more spectrum, sharing is no longer optional.

Operational complexity

Static coordination is too slow for dense, heterogeneous deployments.

Compute & AI

Edge AI, cheap sensing, cloud infrastructure, and digital twins change what devices and networks can know and do today.

Policy readiness

Database-mediated sharing has become a familiar regulatory tool, e.g. CBRS, 6 GHz AFC.

Then — **Now**

From “can a radio sense a channel?” to “can a spectrum ecosystem learn and adapt safely? ”

First flagship application: TV white spaces

The vision

Use geographically unused TV channels for broadband, while protecting broadcasters and wireless microphones.

Why it mattered

- Low-band propagation: coverage and penetration
- Rural broadband and last-mile access use cases
- A real-world test of opportunistic access under incumbent protection

TVWS became the regulatory proving ground for cognitive radio.

TVWS policy path: from sensing-first to database-first

The early vision favored autonomous sensing; implementation gravitated toward geolocation databases.

1999	2004–08	2008	2010–11	2010s
Cognitive radio term and vision enter the field	FCC TVWS rulemaking tests the practicality of unlicensed sharing with an incumbent	Rules adopted for unlicensed TV-band devices	Geolocation + database access becomes the practical protection path	Commercial TVWS systems deploy, but not with the original cognitive-radio vision

Sensing answer: “trust the device to detect what matters.”

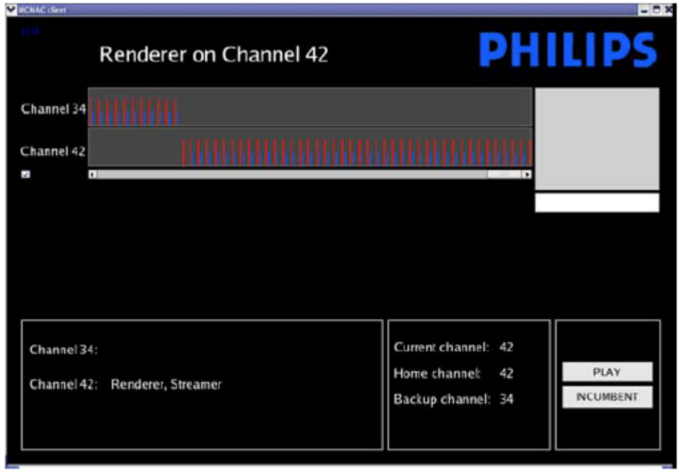
Database answer: “tell the device where and how it may operate.”

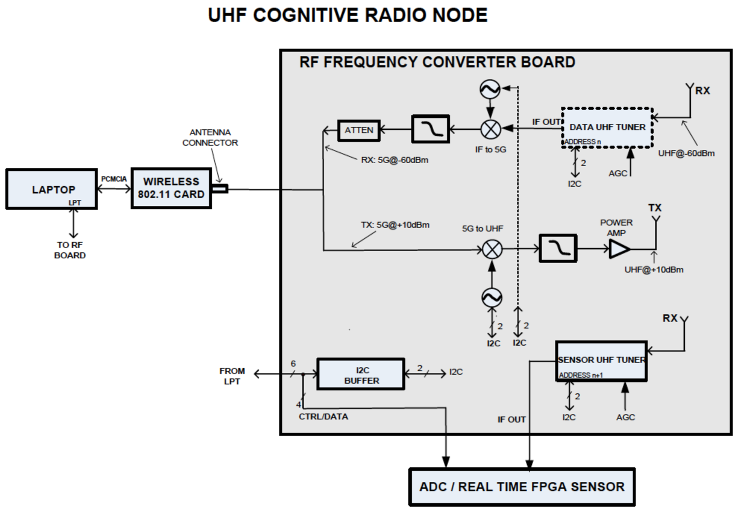
TVWS Demonstration to the FCC and in DySPAN, 2008

PHILIPS

Demonstration

- A Cognitive Network operating over UHF TV white spaces, consists of 3 nodes.
  - Sensing Unit: Constantly scans and senses UHF spectrum for analog and digital TV broadcasts, and indicates unused (white) channels.
  - Cognitive Operation: If an incumbent begins to transmit on the current channel of operation, all network nodes in cooperation jump to another available white channel.
  - Video Streaming Application: No interruptions in video occur while the cognitive radios switch over the available white channels





https://dyspan2008.ieee-dyspan.org/Uploads/Public/Docs_DYSPAN_2008/Philips_Demo_IEEE_DySPAN2008.pdf

A DVB-T sensor was also built and field tested in he UK

https://www.fcc.gov/ecfs/document/5515180345/1

TVWS: Databases Vs. Sensing

- To the FCC’s credit both schemes were rigorously tested in the lab and field.

- Geolocation databases translated coverage areas into protection contours, but were both under-protective and over-protective in different scenarios.
  - Relied solely on propagation models and precomputed coverage areas.
  - Actual TV receiver locations, where interference occurs, were not considered.

- Sensing-only protection made incumbents nervous, especially in personal/portable devices
  - 802.22 developed a standard for wide-area networks, based on 802.16, with quiet periods for sensing, but was never implemented.
  - 802.11af developed a specification for personal/portable devices, also not implemented

TVWS: Lessons learnt

- Propagation models for coverage are a guide and should not be considered infallible. A database mediated cognitive ecosystem is only as good as the models used.
- Sensing **must** be feature-based. The sensors that failed implemented energy based sensing, those that performed well incorporated features such as pilots (ATSC) and known sequences (DVB-T).
- Setting unrealistically low detection thresholds (-114 dBm or 30 dB below the threshold of visibility for TV) **will** lead to false alarms.
- Ultimately, the lack of a device ecosystem and regulatory uncertainty led to TVWS remaining a niche technology.
  - However, informed the development of the CBRS SAS and 6 GHz AFC

Cognitive radio continued to evolve —often without the label

The field shifted from autonomous radios toward coordinated spectrum-management systems.

TVWS	MBANs	CBRS	6 GHz AFC
2008+	2009	2015+	2024+
Mandatory Geolocation databases for unlicensed operation in vacant TV channels, optional sensing	Medical Body Area Networks in 2360 – 2400 MHz, shared with Aeronautical Telemetry. Database only, required MBAN Coordinator	Three-tier sharing with SAS and Environmental Sensing Capability	Automated Frequency Coordination for standard-power unlicensed APs, Geofencing for GVP devices

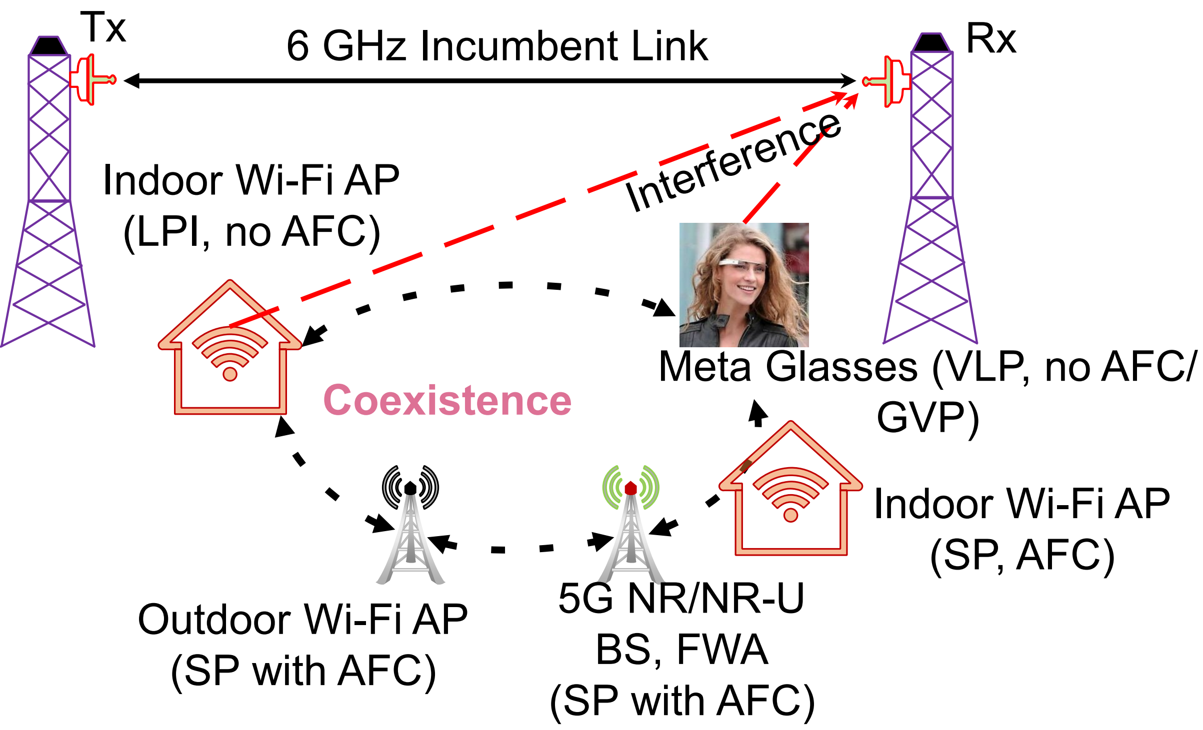
Unsuccessful

- The model for database coordinators was unclear.
- Regulations took too long for industry to sustain interest.

Successful

- The CBRS SAS model took a while to set-up, but the wireless ecosystem was more mature.
- 6 GHz created a two-pronged approach: LPI which did not need database and SP which did. This jumpstarted the ecosystem.

Thoughts on the merits of a truly cognitive ecosystem



The 6 GHz cognitive ecosystem

- Real-time environment awareness has to be device level. However sensing alone cannot be used to protect very directional incumbents, e.g. in 6 GHz.
- The database itself is the easy part: the propagation modeling and evaluation of aggregate interference should be aided by local sensing and measurements.
- Expand the notion of “sensing”: does it have to be RF? What if a device could just determine, reliably, if it where indoors or outdoors? Or use geofencing? Use images?

Concluding thoughts: cognitive networks not just radios

- Cognition is more than just localized sensing
  - Awareness of the local RF environment of a wireless device is the first step.
  - Distributed sensing and actuation is essential for a cognitive network.
- Data + AI/ML will be drivers of the future of cognition
  - Major hurdles need to be overcome here: trust, reproducibility, new models, access to data, certification.
- Propagation models
  - Absolutely need to incorporate real-world measurements, ray-tracing, AI/ML to refine models.
- Every network being designed today needs to be cognitive
  - The new entrant of today may be an incumbent tomorrow: prepare for that future