SpectrumConsult

Wireless LANs, spectrum sharing and the origins of Cognitive Radio

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Wireless LANs

- Booming technology for short distance, high capacity communications
- Standards development started in 1989
  - based on new rules for the “ISM” bands
  - leveraged the Ethernet paradigm
- Breakthrough came in 1999 with Apple “Airport”
  - Notebooks and Price!
- Additional 455MHz of frequency space allocated at WRC 2003 – shared with C-band radars
- Widespread use
  - more than 1B devices sold since 1999

Usage

- Used mostly for indoor, short range communications – “wi-fi networks”
  - At home
  - In offices, schools, hospitals
  - In factories
- Limited outdoor use in point-to-point and point-to-multipoint links
- Cloud computing and tablets will further drive volume
- Becoming an essential complement to 3G/4G

Regulatory parameters (Europe)

- 2400 – 2483.5MHz,
  - 100mW max, politeness required (as of 2011)
- 5150 – 5350MHz,
  - 200mW max, indoor only – to protect ESA's EESS SLR's
- 5470 – 5725MHz,
  - 1000mW max, radar detection and avoidance (DFS)

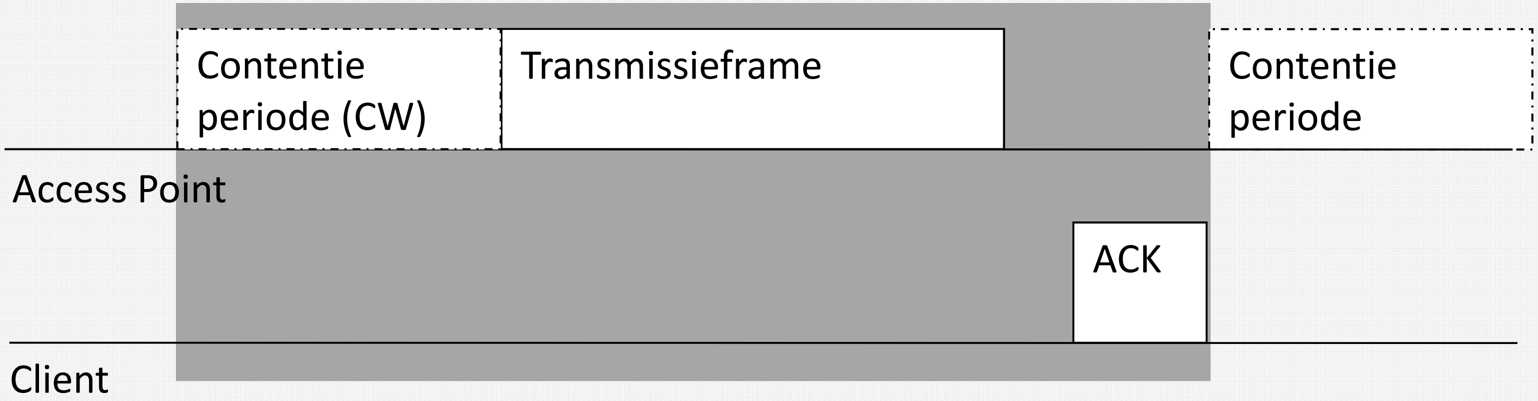
Technical requirements

- 2.4GHz: ETSI EN 300-328
  - Power and frequency limits, methods of measurement
  - *“polite spectrum access” requirements were recently added*
- 5GHz: ETSI EN 301-893
  - Power and frequency limits, methods of measurement
  - DFS - radar detection requirements and avoidance requirements and test methods

Wireless LANs – Industry standards

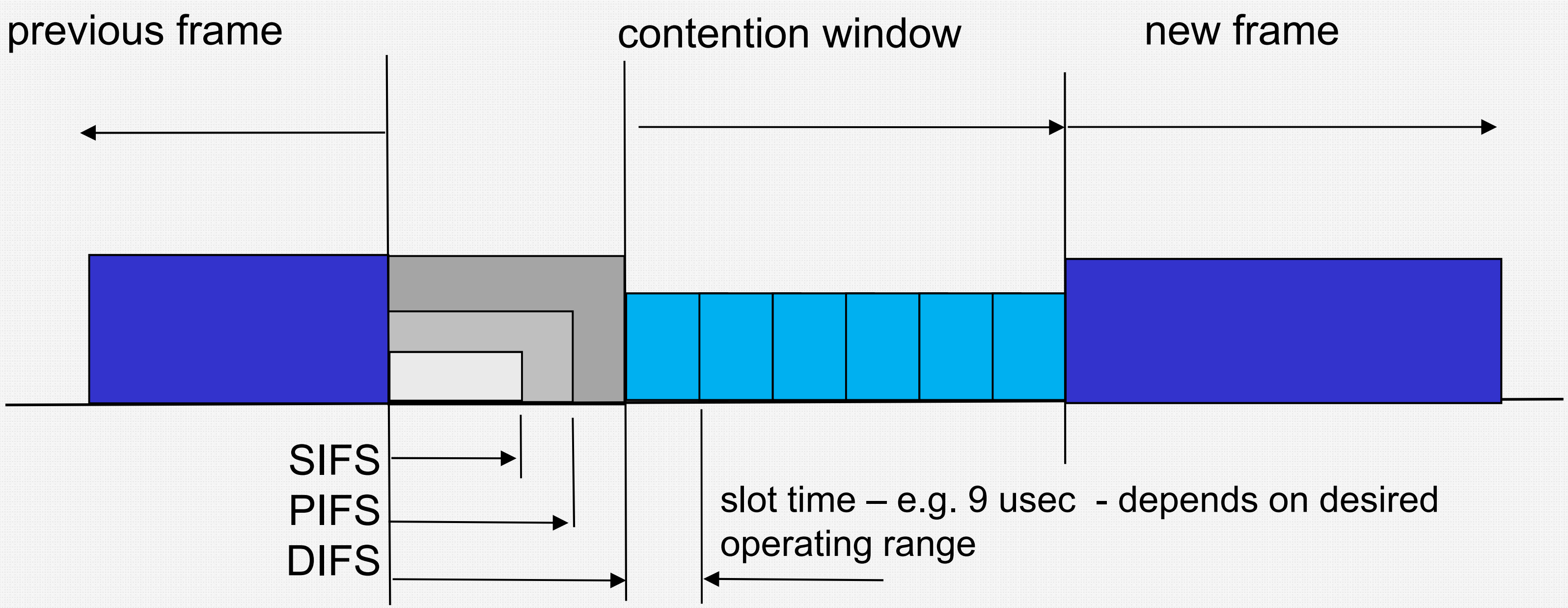
- IEEE 802.11 is the main standard
  - 11a = 5GHz, OFDM, < 54Mb/s
  - 11b = 2.4GHz, DSSS, < 11Mb/s
  - 11g = 2.4GHz, OFDM, < 54Mb/s
  - 11n = 2.4GHz and 5GHz, MIMO, ~ 400 Mb/s
  - Channelization = 10, 20 and 40MHz
- All use CSMA/CA for spectrum sharing
  - Allows large numbers of devices to share same RF channel
  - “Listen before talk” avoids collisions of transmissions

The CSMA/CA transmission cycle



- Is the same for all stations
- Is memoryless
- Assumes:
  - a fixed detection threshold CCA threshold)
  - a common time base , 1 slot > 9 usec
- Basic CW length is 32 slots
- Transmission loss causes CW increments up to 256 slots

CSMA/CA – access differentiation

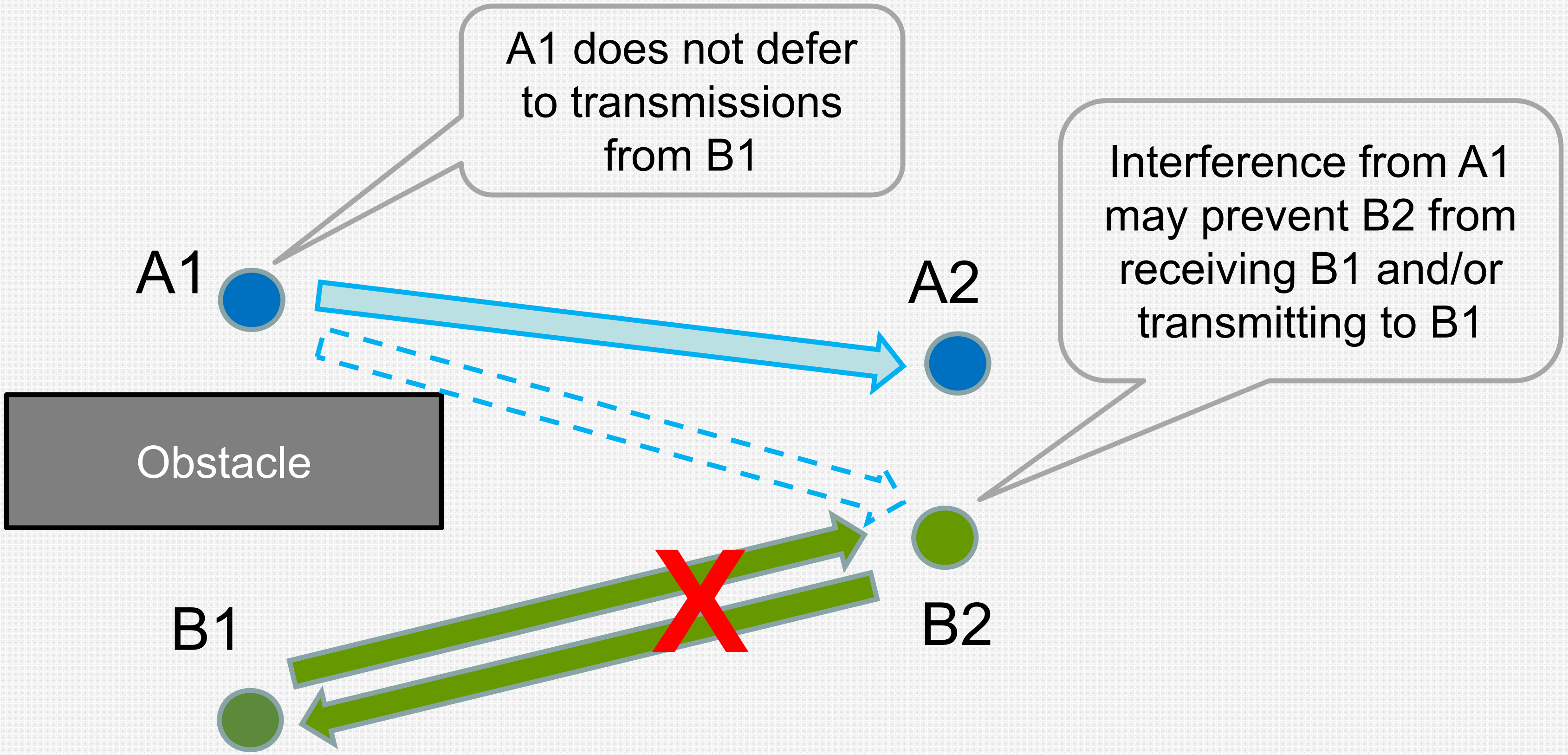


SIFS: binds response
PIFS: pre-emptive access (HCCA)
DIFS: distributed access control (EDCA)

CSMA/CA Issue 1: Detection uncertainty

- Detection capability is limited by:
  - the "SNR wall": energy sensing has limitations
  - unpredictable, high exponent pathloss conditions
  - uncertainty about the victim receiver's location
- The CCA threshold is set at -84dBm(-64dBm) for a 20MHz channel
  - for own signals that is 24dB above the typical receiver noise floor
  - for non-self signals it is (44dB) above the typical receiver noise floor
- The consequence is significant interference for self and even more for non-self systems
  - reduces operating range or data rate
  - the impact increases with the density of spectrum users

CSMA/CA Issue 2: Hidden Nodes

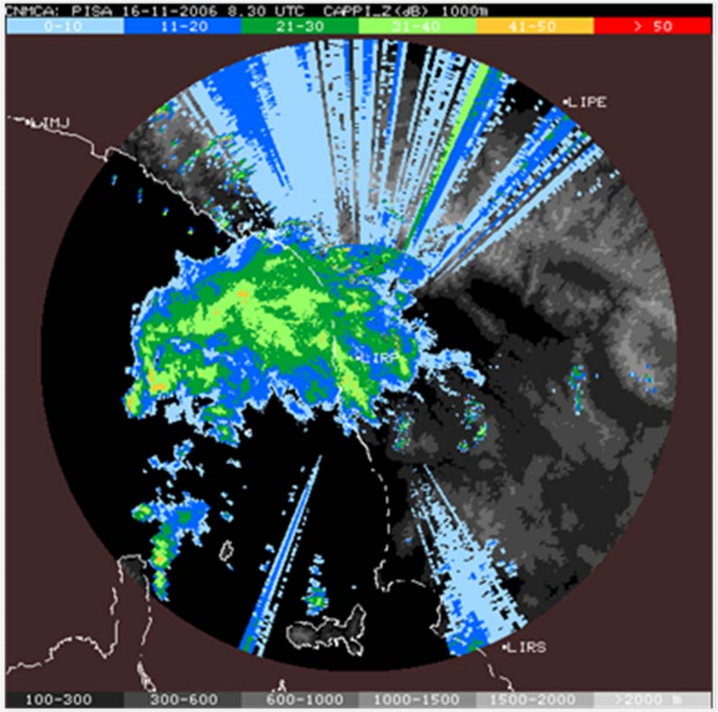


Sharing in the 5GHz band

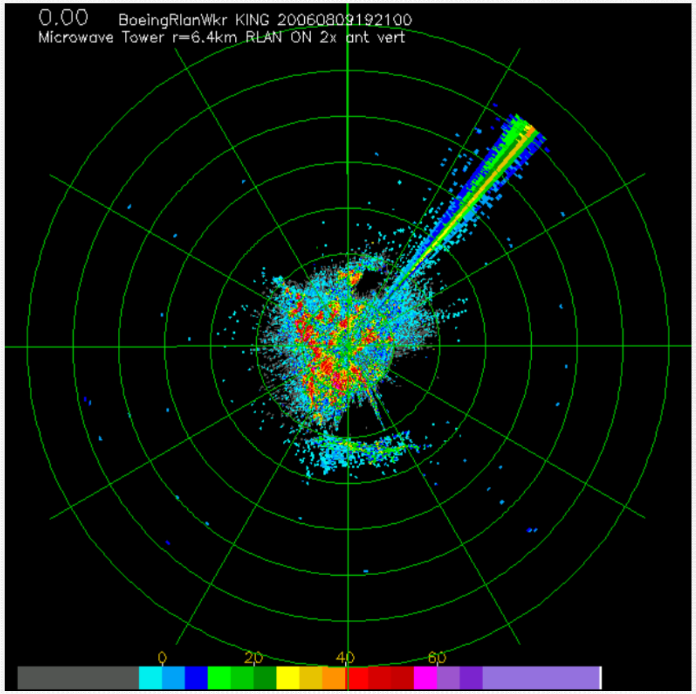
- 5GHz is used by many “C-band” radars
  - Military, marine and meteo/windshear
  - RLANs are considered co-primary with radars but operate on a no-protection/no interference basis

- ITU-R M1652 requires protection of radars by means of DFS in license-exempt devices:
  - *Test a channel for radar signals before using it*
  - *Detect radar pulses while using it*
  - *Stop using the channel if a radar is detected*
  - *Do not re-use the channel for 30 minutes*

Impact examples



1 watt, ground based, 5km



50mW watt, airborne, 8km

Sources: EUMETNET, Boeing

DFS Basics

- The principle is “detect and avoid”: if a radar signal is recognized, the RLAN must move to a frequency - known to be free of radar signals.
- Detection is required above a threshold – established by extensive simulations (US NTIA, 2003) covering many different scenarios including mobile radars (ground, maritime and airborne.
- DFS performance is measured through a test regime that mimics a number of radars.
- Recently, special test provisions were added to assure adequate protection of weather radars – which have peculiar scan patterns – from large numbers of terrestrial RLANs.

DFS parameters (EN 301-893,v1.5.1)

- Detection thresholds (ref to a zero gain antenna):
  - -62dBm indoor
  - -64dBm outdoor
- Pulse width & rate:
  - >.8usec, (multiple) PRF(s) between 200 and 4000 pps
- Response time: < 200msec, leave channel completely in 10seconds
- Clear channel check: 1 minute, 10 minutes for meteo radar band (5600 – 5650MHz)

DFS Detection Modes

- Channel Availability Check: the RLAN is silent and listens for radar signals for 60 seconds (≥ 1 RPM)
  - Detection efficiency is maximum; this is done prior to making use of a channel
  - In the case of weather radars, the CAC time is 10 minutes to cover a full helical scan cycle.
  - Optional: Off-line CAC: the RLAN listens for radar signals on other channels while operating on a “free” channel
    - This takes hours but avoids the need to do a 10 minute CAC
- In Service Monitoring: the RLAN listens for radar signals in between its own transmissions
  - Detection efficiency depends on the RLAN load factor: at zero channel load, ISM detection = CAC detection

RLAN – Radar link budget

- Basic formula:

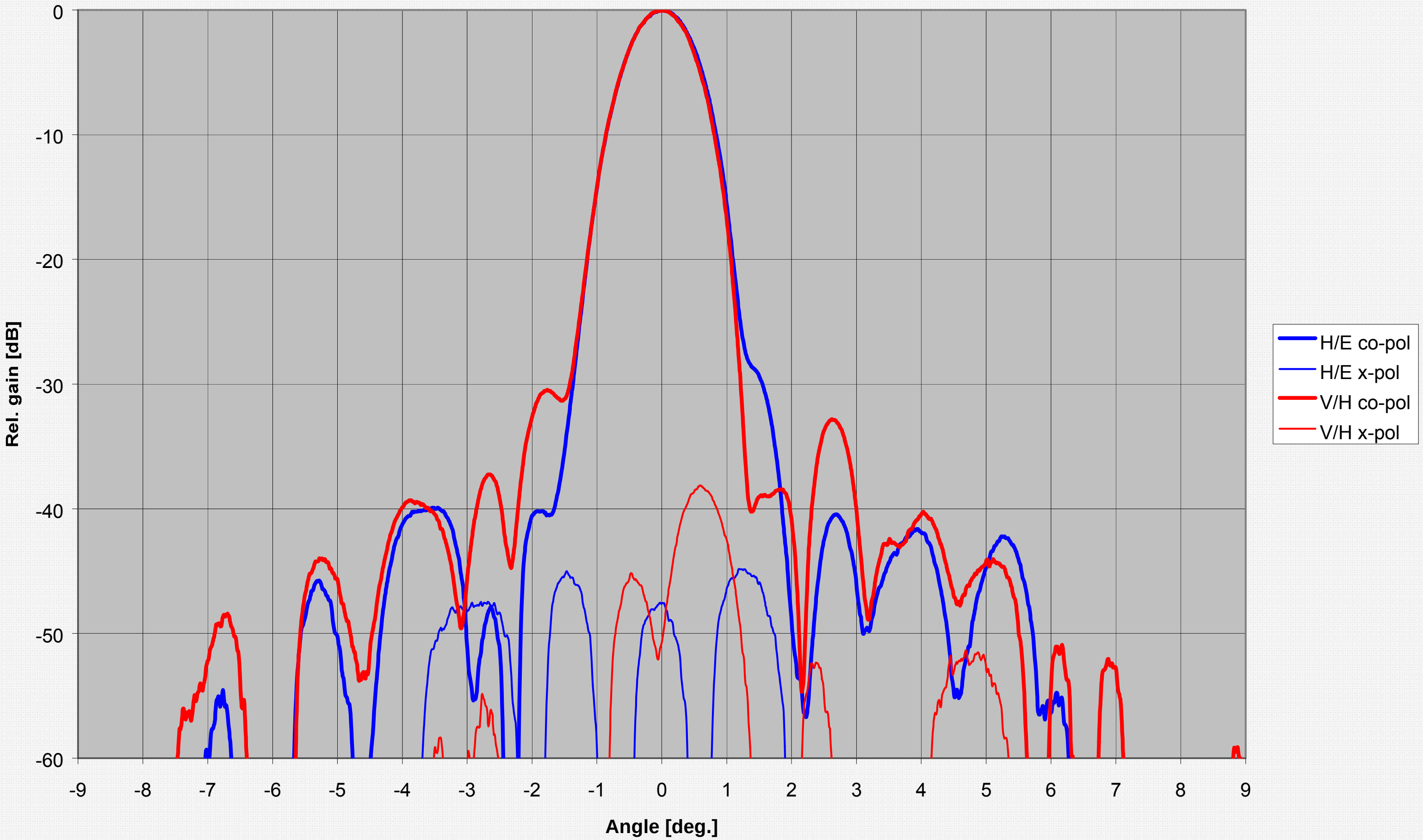
$$P_{rad}+(G_{rad}+G_{rlan)}-PL-T_{DFS} \geq P_{rlan}+(G_{rlan}+G_{rad})-R_{BW}-PL-T_{rad}$$

$$84 +(44) – PL+62 \geq 20 + (44)– PL -12.2+118$$

$$190 – PL \geq 176.8 – PL$$

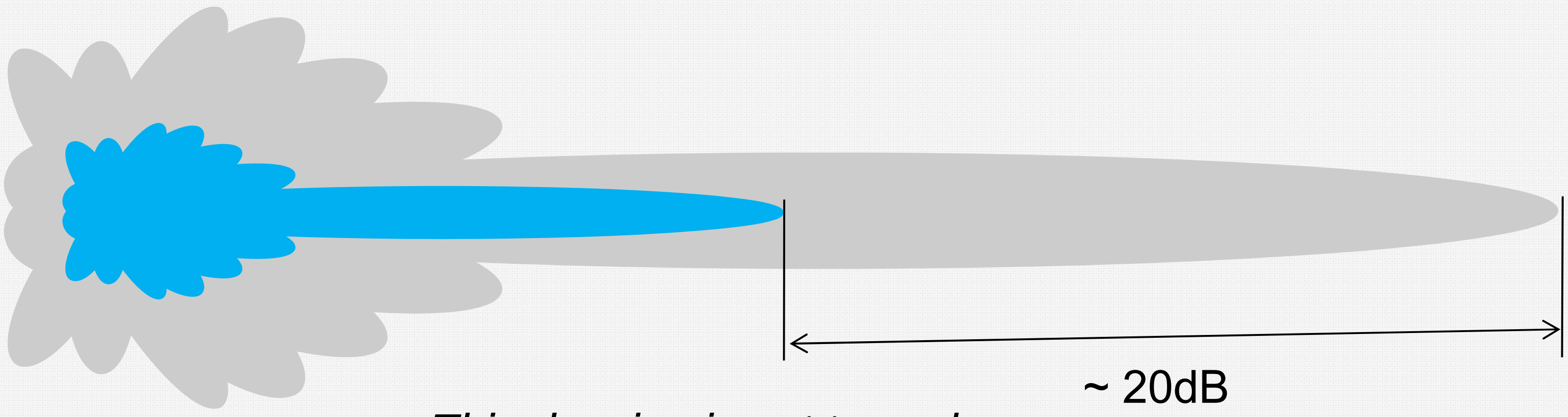
- Radar's high power density and narrow bandwidth are key factors.
- Even for low power radars, the bandwidth ratio assures that DFS will detect "before" the RLAN causes interference
- These considerations were part of the WRC2003 preparations that led to the Recommendation M.1652.

Real radar beam parameters



Source: Vaisala company

Impact of apparent beamshape

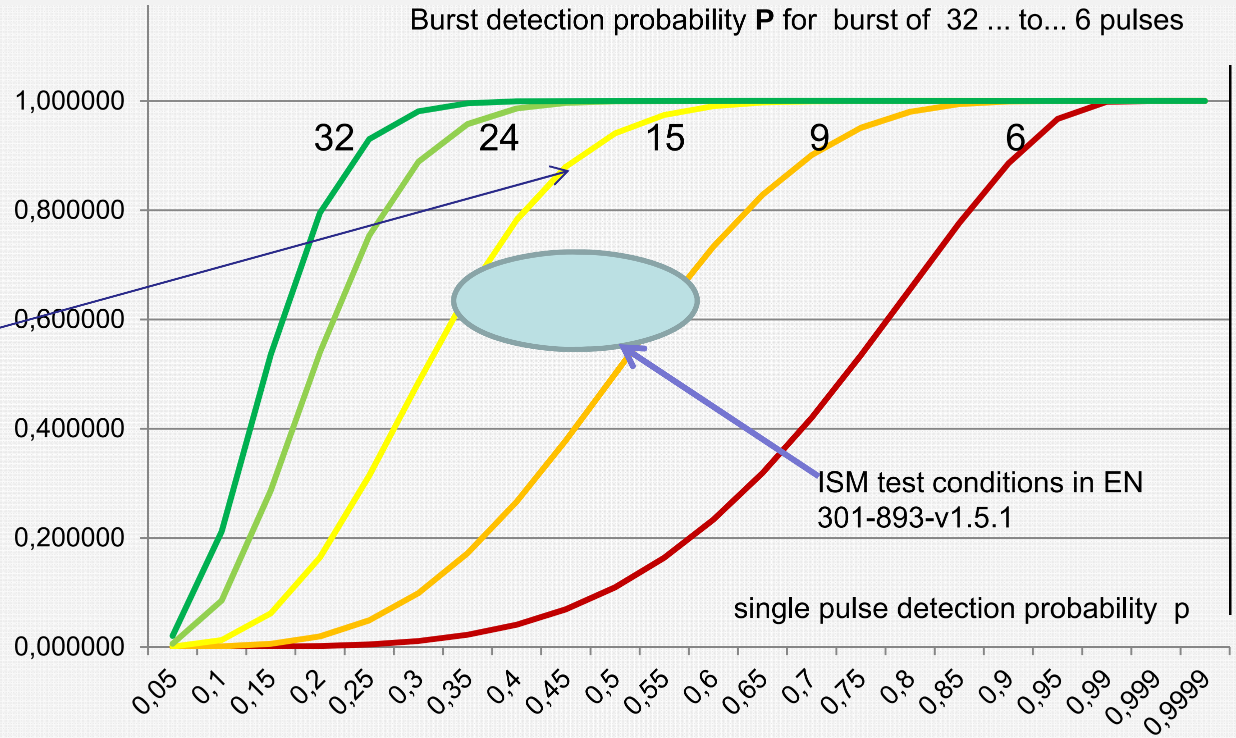


This drawing is not to scale

- Detection of a radar at -62dBm occurs in the gray area
- RLAN may cause interference in the blue area
- The difference assures DFS is effective for radar protection in a wide variety of scenarios and many different radar types

Detection probability and burst length

- Detection probability P varies exponentially *) with the number of pulses received from the radar and the RLAN load factor - these curves assume a false alarm “filter” of 5 pulses.



15 pulses give P > 95% for channel loads less than ~50%

Why DFS works

- Detection equation:
  - Radar EIRP – pathloss >> WLAN threshold
- Interference equation:
  - WLAN EIRP – pathloss > radar interference limit
- Protection is assured if:
  - Radar power – WLAN threshold > WLAN power – radar interference limit
  - Example: a 250kW radar, MUS = -100dBm, 1W WLAN

    86+64 >> 30+100 (~20dB margin)

- ***Within the radar's horizon, Radar EIRP – pathloss >> WLAN threshold for all but small mobile radars***

Practical results

- CSMA/CA is designed for short range situations – at home, office, etc
  - Works very well and requires no management
  - Tolerates other technologies like Bluetooth and WiMAX – but not the other way around
- "Hidden nodes" may cause low throughput or even blockage
  - Notably in outdoor networks with long distances and obstacles that shade some transmitters
  - Can be worse in case of interference
- DFS works well – if implemented & tested properly
  - Even on board aircraft
- Non-RLAN technologies are adequately protected – mostly due to the low power limit of RLANs (2.4GHz)

Summarizing

- Spectrum sharing features protect primary spectrum users and facilitate ease of deployment
- Spectrum sensing only works well in case of very large asymmetry in power (PFD victim >> PFD interferer)

What is "Cognitive Radio"?

- Originally proposed by Mitola (1999) in a seminal paper that emphasized autonomy and system aspects – see notes below

- Taken up by the FCC in 2005. FCC 05-57A1 states that:

  [Cognitive Radio is] *a collection of techniques that allow flexible use of radio spectrum rather than pre-designated frequencies by using:*

  - ***Dynamic Frequency Selection*** = *Sensing*
  - *Location Awareness*

  and applying:

  - ***Transmit Power Control***
  - *Frequency Agility*
  - *Adaptive Modulation*
  - *Negotiated Use*

Is DFS technology "CR"?

- Yes!
  - It is autonomous
  - DFS = sensing + transmitter power control
  - Today it is the most successful implementation of the CR concept
- But….
  - DFS is effective **only** relative to high power co-primary incumbents
  - DFS is a specific solution for a specific sharing case

Other thoughts

- CR is a concept, not a technology in the same sense as Wi-Fi or Bluetooth
  - but it may very well enhance such technologies
- SDR is not necessarily CR
  - But SDR can embody a CR concept
- 802.11y – Dynamic Spectrum Enablement - is not necessarily CR
- In general, dynamic spectrum access (DSA) is the broader concept that contains but is not limited to CR
- Databases used for DSA may require actual sensing at the victim receiver locations and/or wide safety margins
- Different DSA techniques enable different regimes of spectrum usage and sharing; this may influence licensing policies

Thank you for your attention