White Spaces

Need for more spectrum to satisfy the growing demand.

Spectrum refarming: opportunistic spectrum usage

Many standard efforts

Only one formally approved by FCC in US and Ofcom in UK

Several trials have been conducted

Evolution of Spectrum usage

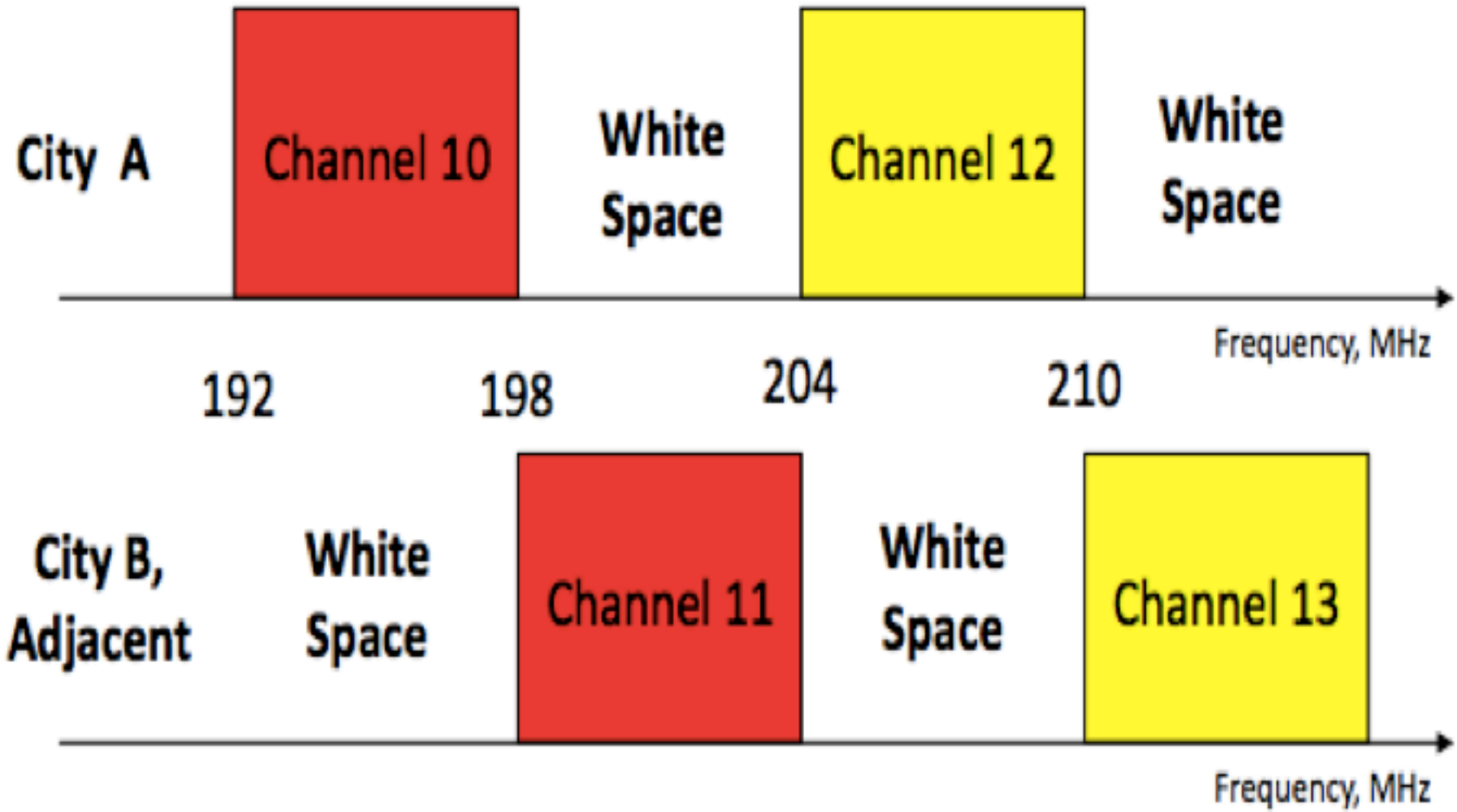
Fixed allocation

1) Government assigned
2) Auction
3) Beauty Contest

Dynamic Spectrum allocation

http://www.apc.org/en/faq/citizens-guide-airwaves

Television White Spaces



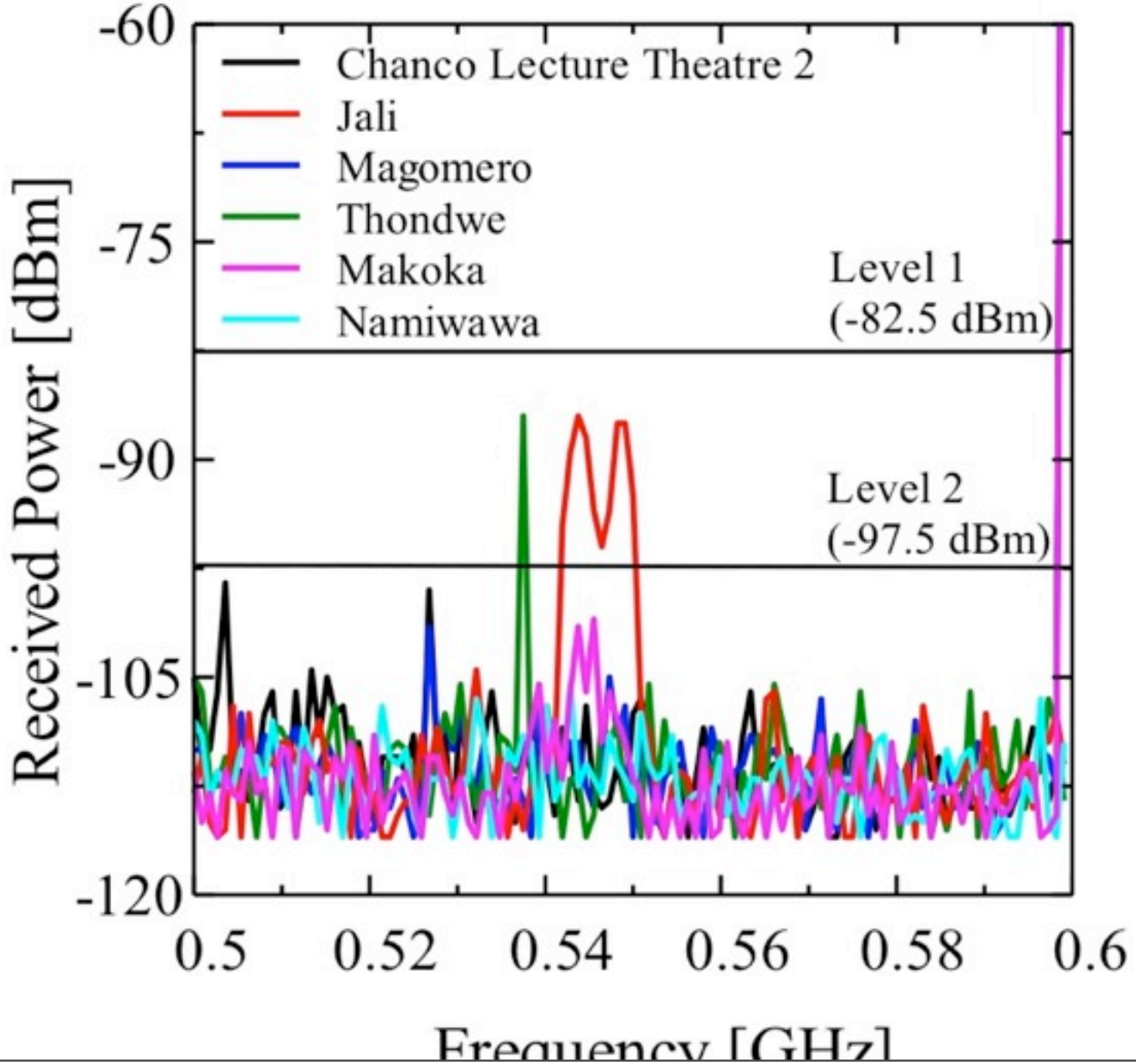
Television White Spaces: definition

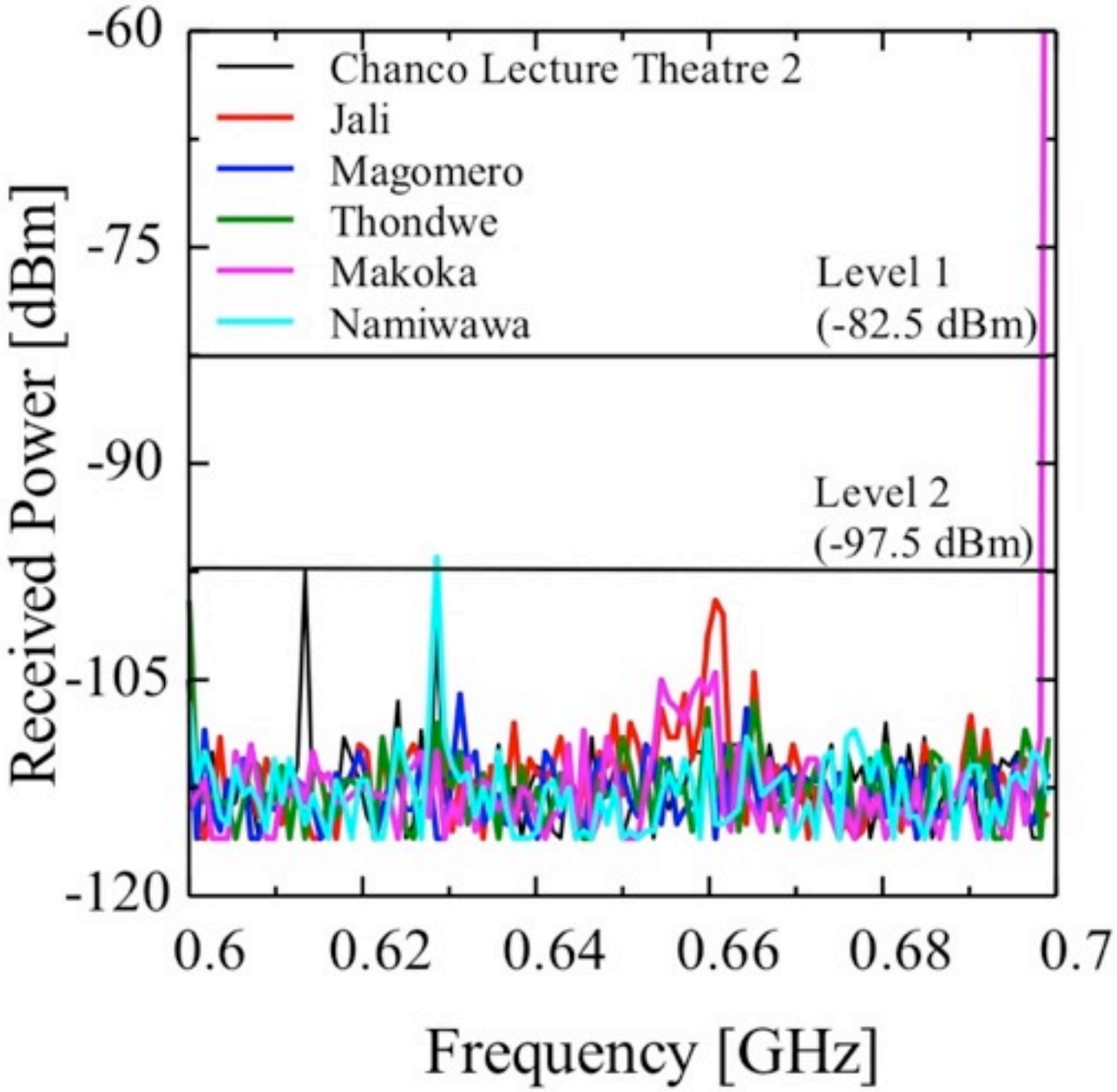
a) The spectrum that has been assigned to TV broadcasting but it is not currently being used. This applies particularly to developing countries, in which there has been no economic incentive for broadcaster to use every available TV channel.

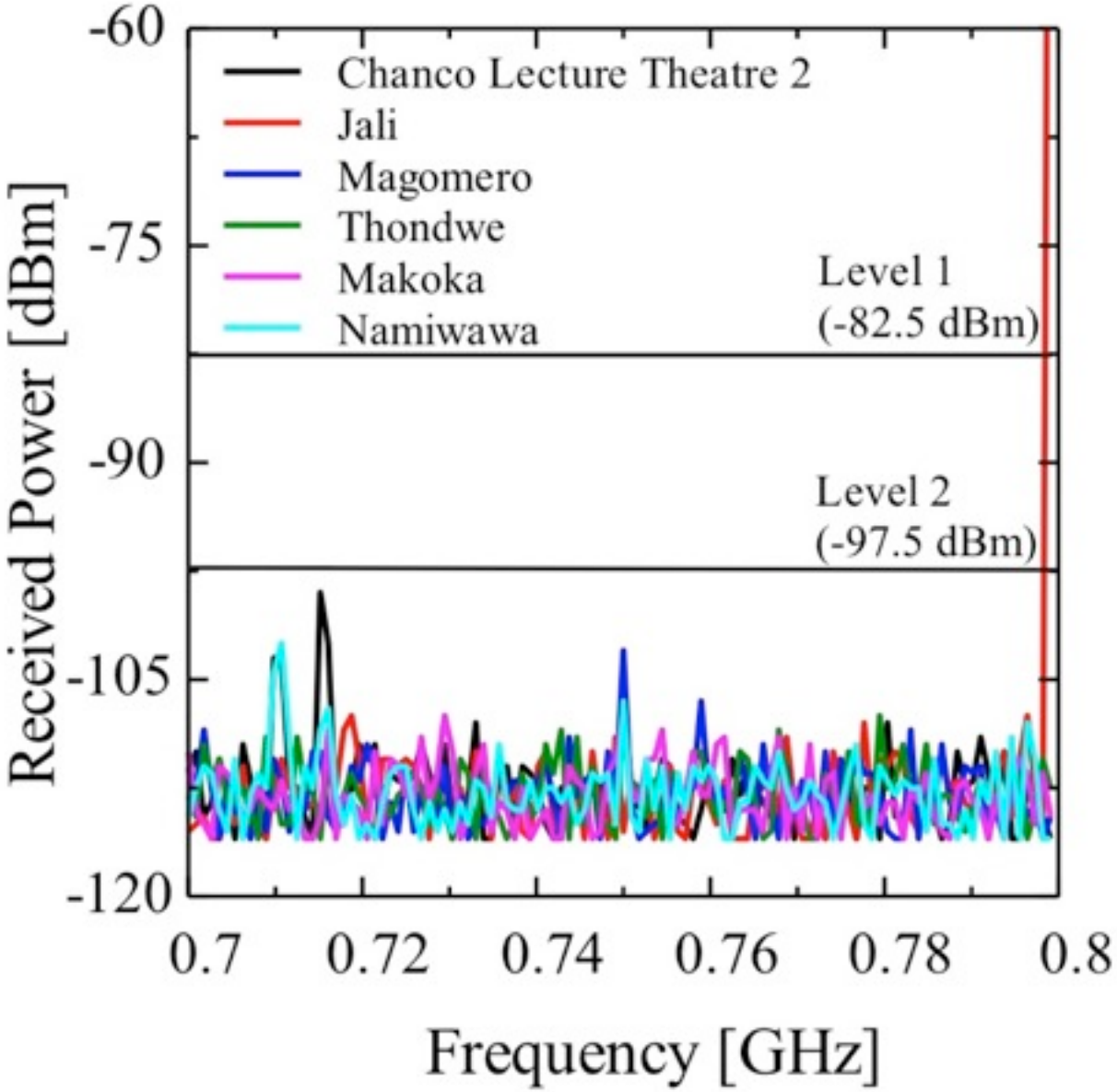
b) The spectrum that must be left free in between two analogous TV channels to prevent interference.

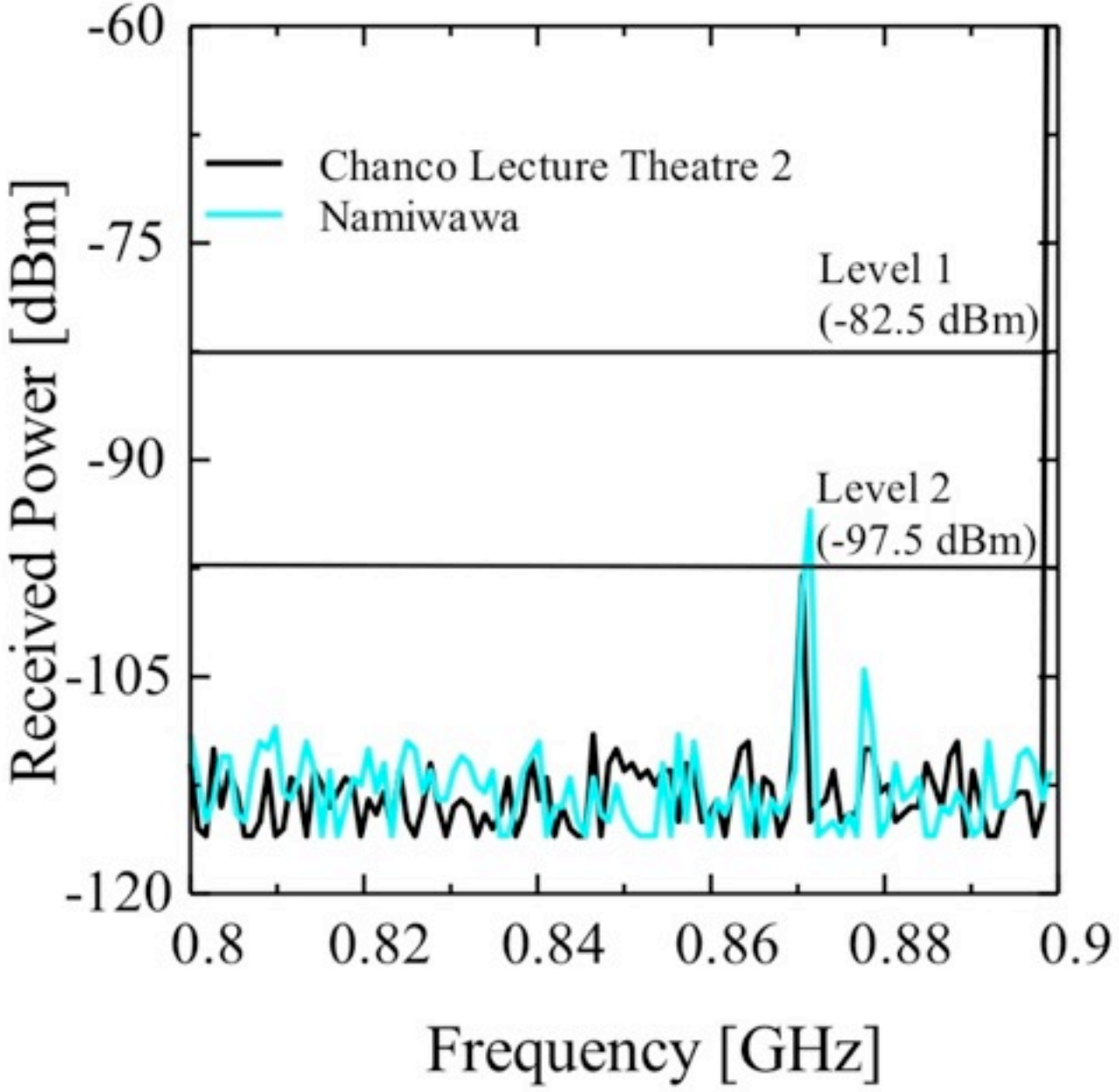
c) The spectrum that has been reclaimed as a consequence of the transition to digital terrestrial TV, which is more spectrum efficient.

See: “On the relevance of using affordable tools for white spaces identification” at http://wireless.ictp.it/publications.html


-60
-75
-90
-105
-120
Received Power [dBm]
Chanco Lecture Theatre 2
Jali
Magomero
Thondwe
Makoka
Namiwawa
Level 1
(-82.5 dBm)
Level 2
(-97.5 dBm)
0.5
0.52
0.54
0.56
0.58
0.6
Frequency [GHz]


Chanco Lecture Theatre 2
Jali
Magomero
Thondwe
Makoka
Namiwawa
Level 1
(-82.5 dBm)
Level 2
(-97.5 dBm)
Received Power [dBm]
-60
-75
-90
-105
-120
0.6
0.62
0.64
0.66
0.68
0.7
Frequency [GHz]


-60
-75
-90
-105
-120
Received Power [dBm]
Chanco Lecture Theatre 2
Jali
Magomero
Thondwe
Makoka
Namiwawa
Level 1
(-82.5 dBm)
Level 2
(-97.5 dBm)
0.7
0.72
0.74
0.76
0.78
0.8
Frequency [GHz]


-60
-75
-90
-105
-120
Received Power [dBm]
Chanco Lecture Theatre 2
Namiwawa
Level 1
(-82.5 dBm)
Level 2
(-97.5 dBm)
0.8
0.82
0.84
0.86
0.88
0.9
Frequency [GHz]

TV Band Devices Standards

IEEE 802.22 for long range transmission Wireless Regional Area Networks (WRAN)
IEEE 802.11af for short range, OFDM PHYs with 5, 10 and 20 MHz channel widths
IEEE 802.15.4m for device control and command applications
IEEE 802.19 for coexistence among multiple TV white space networks
IEEE DySPAN aimed at Dynamic Spectrum Access Networks
IEEE 802.16h originally meant for the 3650-3700 MHz contention band but now also specified for the TV bands
ECMA 392 directed at personal and portable wireless devices,
Weightless mainly focused at Machine-to-Machine interactions
IETF PAWS covering the specification of the mechanism for discovering a white spaces database and method for its access.

Propagation advantages of TV bands

The superior propagation features of the lower frequencies bands for two way transmission have been proved in several trials of the CDMA 450 MHz technology, like the one in the Argentinian Patagonia operated by Cooperativa Telefonica de Calafate, with subscribers up to 50 km from the base station.

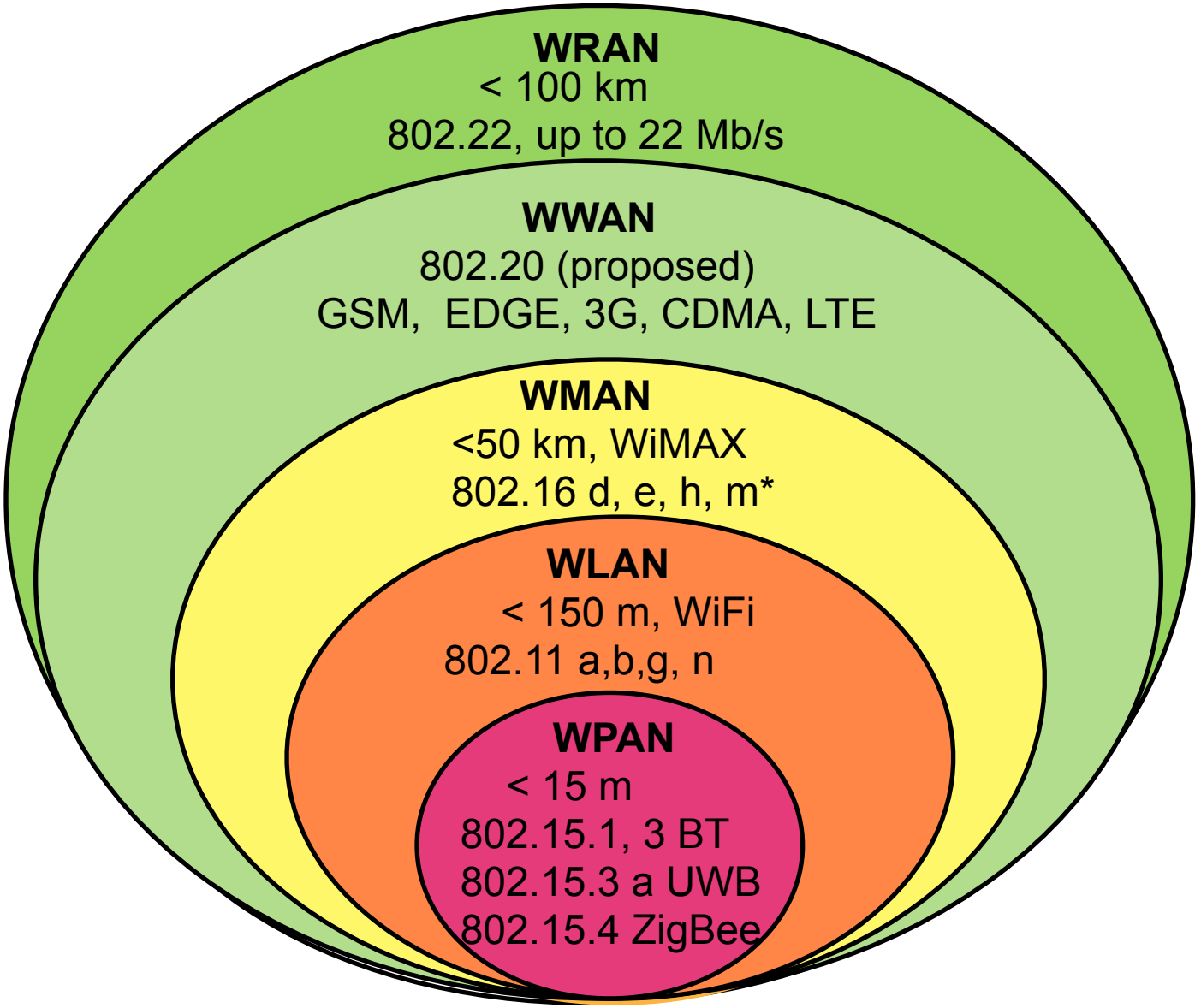
This is due to three factors:

a) Lower free space loss

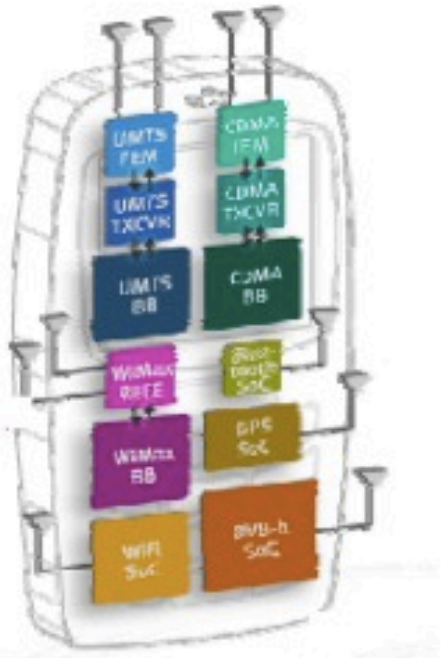
b) Better diffraction efficiency

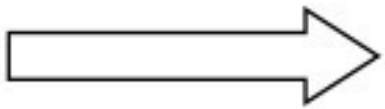
c) Lower building attenuation

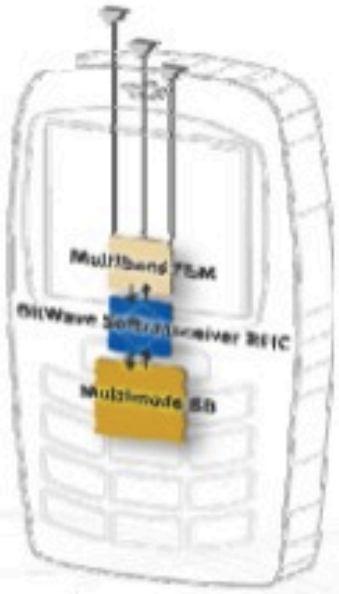
Wireless Standards



Software Defined Radio (SDR)







Conventional Approach

- Each radio interface is implemented through Integrated Circuits conceived for a set of specific functions
- Wireless device characteristics are fixed

Software Radio approach:

- the wireless terminal is reconfigurable via software
- It can be easily updated to ne or later versions of the air interface and allows multiple interfaces to be supported

ITU approved SDR definition

Software-defined radio is a radio transmitter and/or receiver employing a technology that allows the RF operating parameters including, but not limited to, frequency range, modulation type, or output power to be set or altered by software, excluding changes to operating parameters which occur during the normal pre-installed and predetermined operation of a radio according to a system specification or standard."

Source: Report ITU-R SM.2152.

ITU approved Cognitive Radio definition

"Cognitive radio system is a radio system employing technology that allows the system to obtain knowledge of its operational and geographical environment, established policies and its internal state; to dynamically and autonomously adjust its operational parameters and protocols according to its obtained knowledge in order to achieve predefined objectives; and to learn from the results obtained."

Source: Report ITU-R SM.2152.

Capabilities of Cognitive Radio

Spectrum Sensing

- Spectrum Sharing (by agreement or compulsory)

Location Identification by the Mobile

Network/System/Service Discovery

Frequency Agility

Dynamic Frequency Selection

- Avoid co-channel operation

Adaptive Modulation/Coding

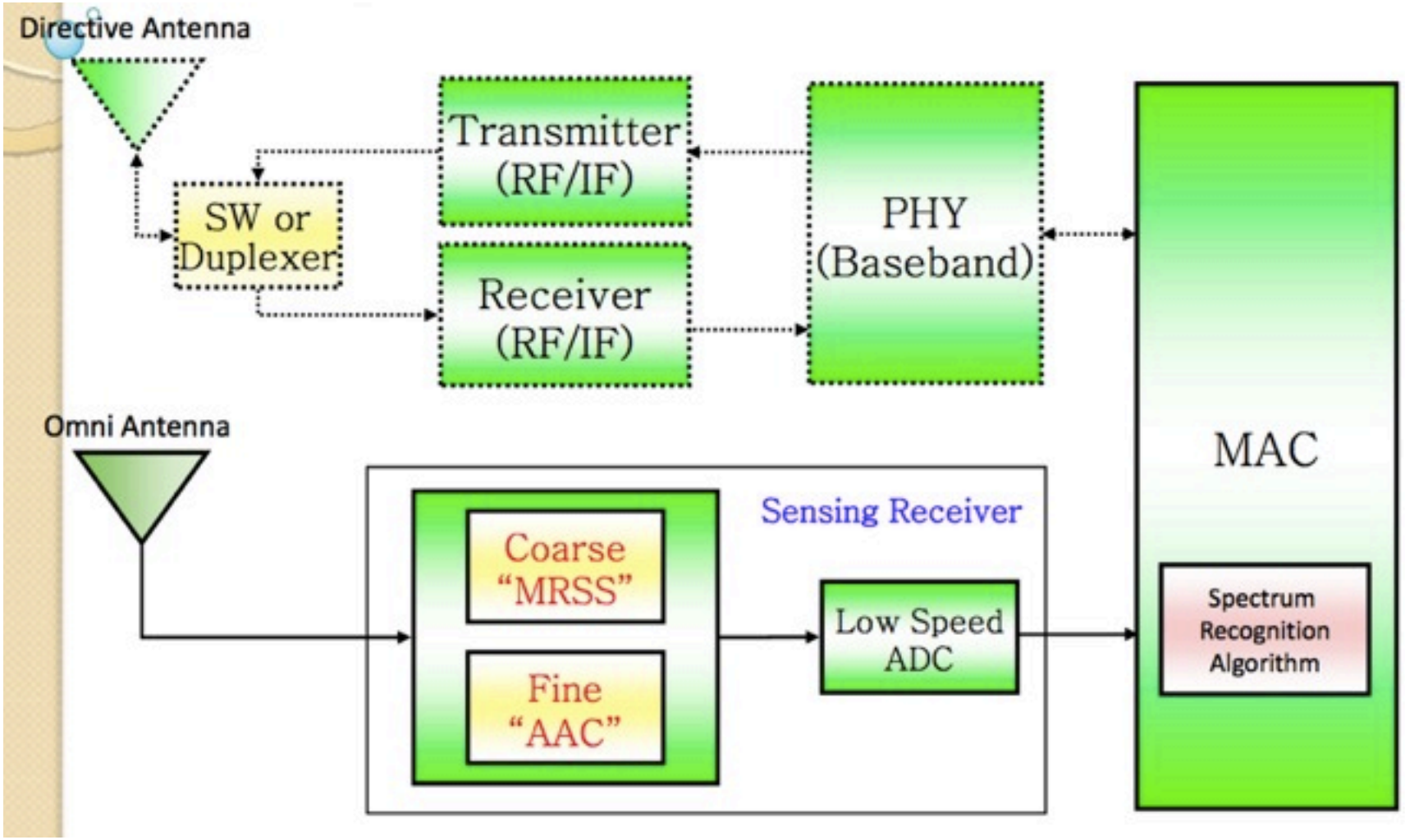
Transmit Power control

Dynamic System/Network Access

Mobility and Connection Management

Security Management

Sensing and Communicating



Sensing

Sensing clock is separated from transceiver

Multiple sensing strategy: Coarse and Fine

Sensing during communication and also at idle times

Critical computation is performed in the analog domain

Sensing Techniques

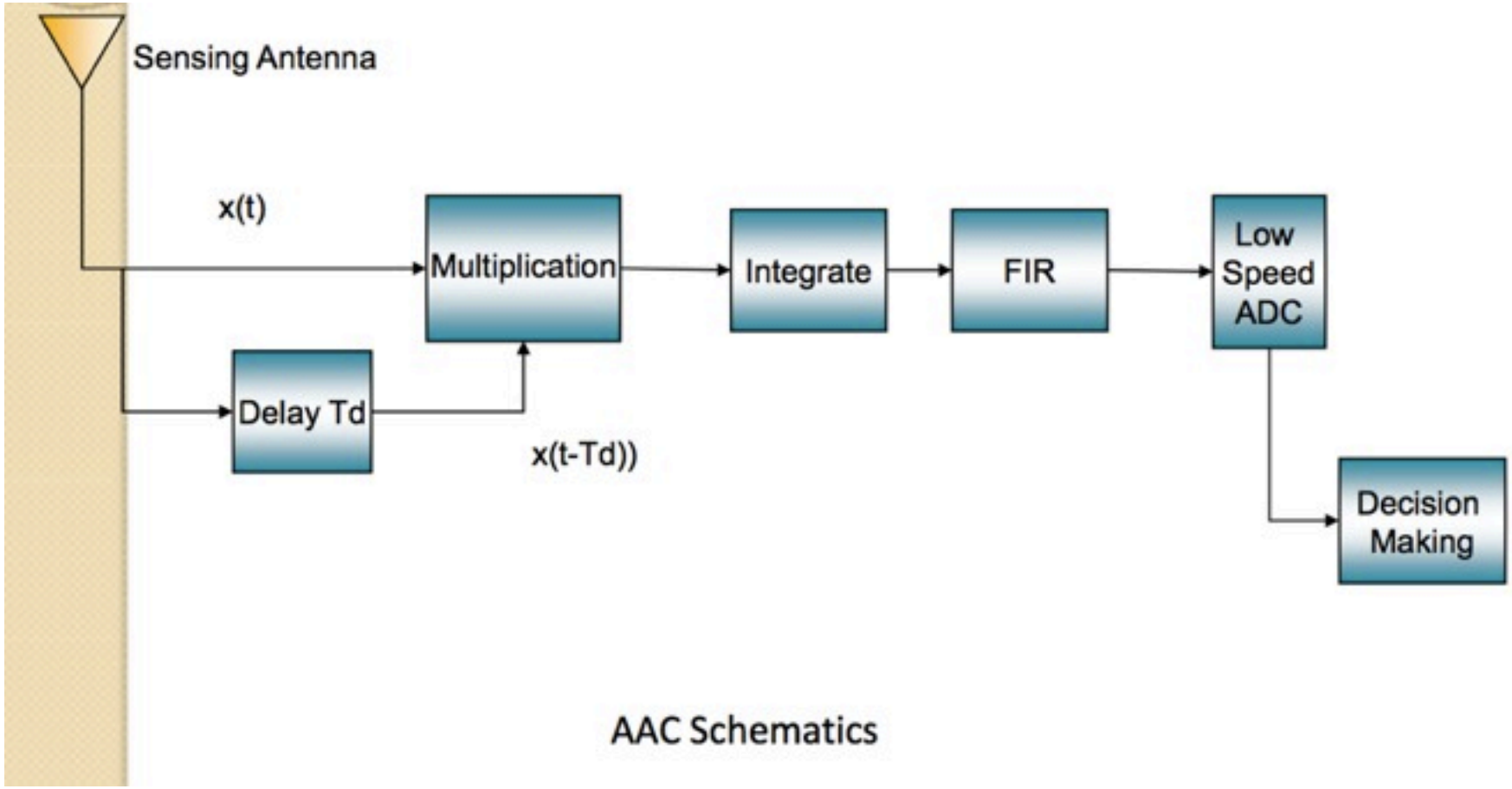
Multi Resolution Spectrum Sensing Sensing (**MRSS**)

Coarse Sensing: Detect the presence of signal, for instance by Fourier transform

Analog Autocorrelation (**AAC**)

Fine sensing: categorization of the signal type

Analog Auto Correlation



AAC Schematics

Fine Sensing

Detect the periodic features of the input signals unique to each modulation scheme or format

AAC can recognize the following signals:

IS-95, WCDMA, EDGE,GSM, WiFi, WiMAX, ZigBee, Bluetooth, Digital Terrestrial Television (ATSC,DVB) etc.

Main features of IEEE 802.22

Spectrum Reuse, White Spaces, combatting the spectrum crunch.

Lower frequencies, greater range thanks to less attenuation by walls, greater diffraction and lower free space loss.

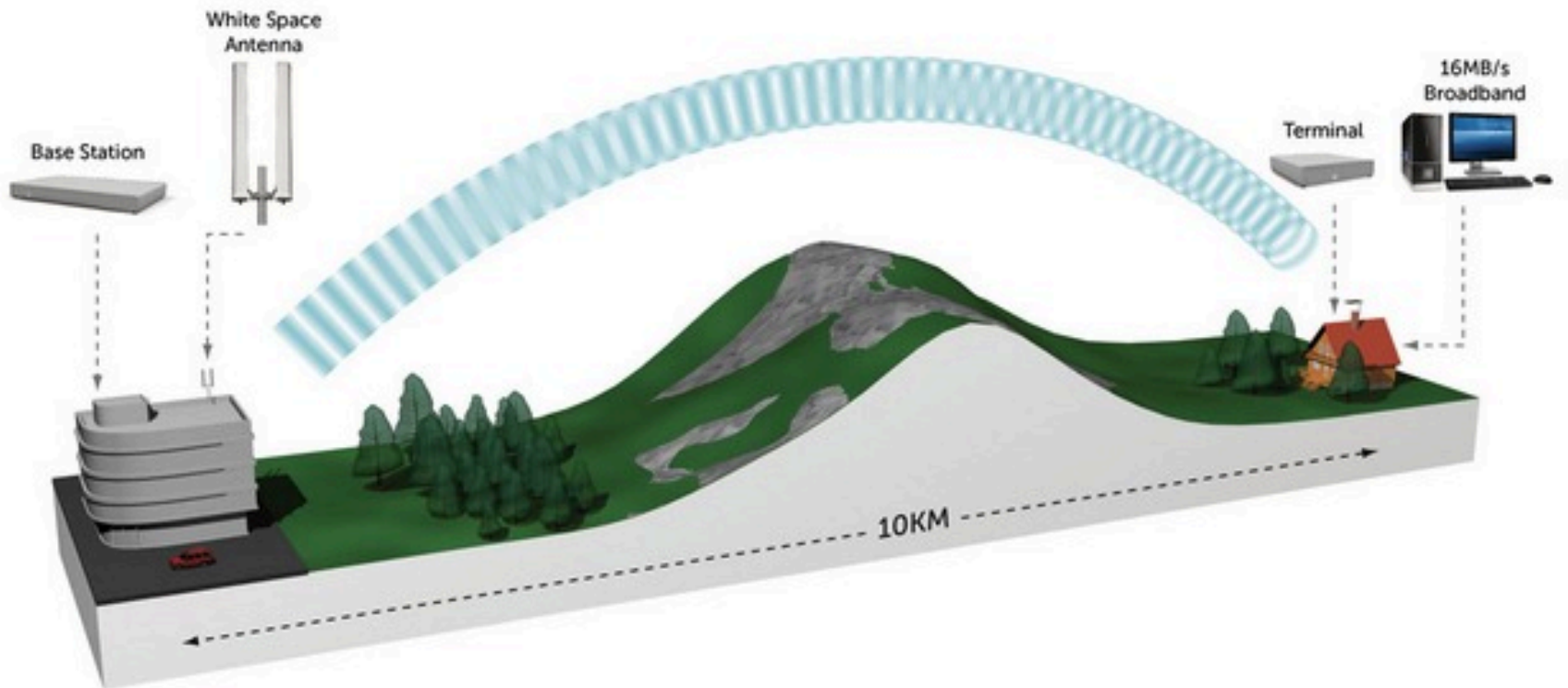
Lower energy consumption as compared with WiFi or ZigBee.

Non Line Of Sight propagation.

High spectrum efficiency.

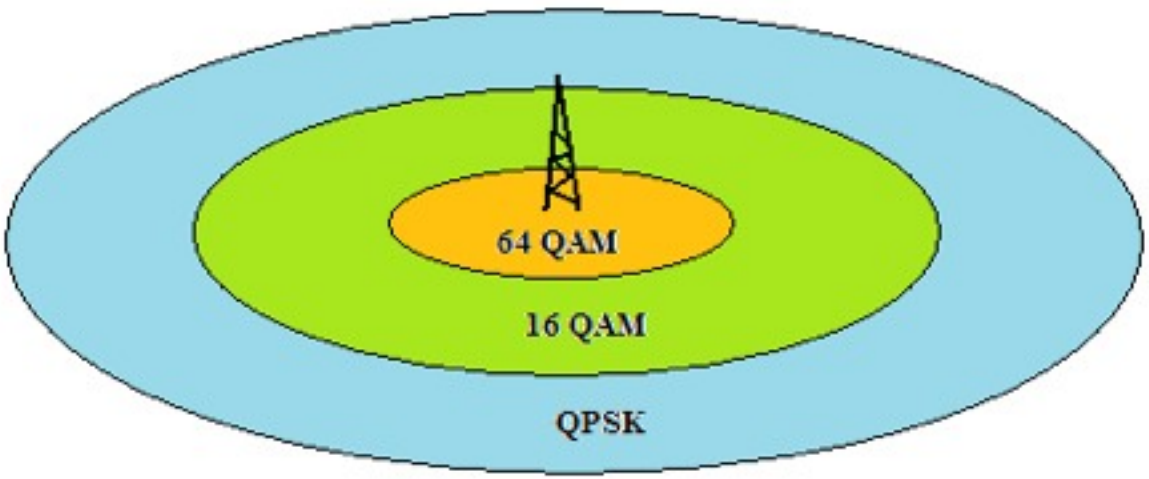
Use of software defined radio (SDR) as a stepping stone towards Cognitive Radio (CR)

Greater range because of lower frequency

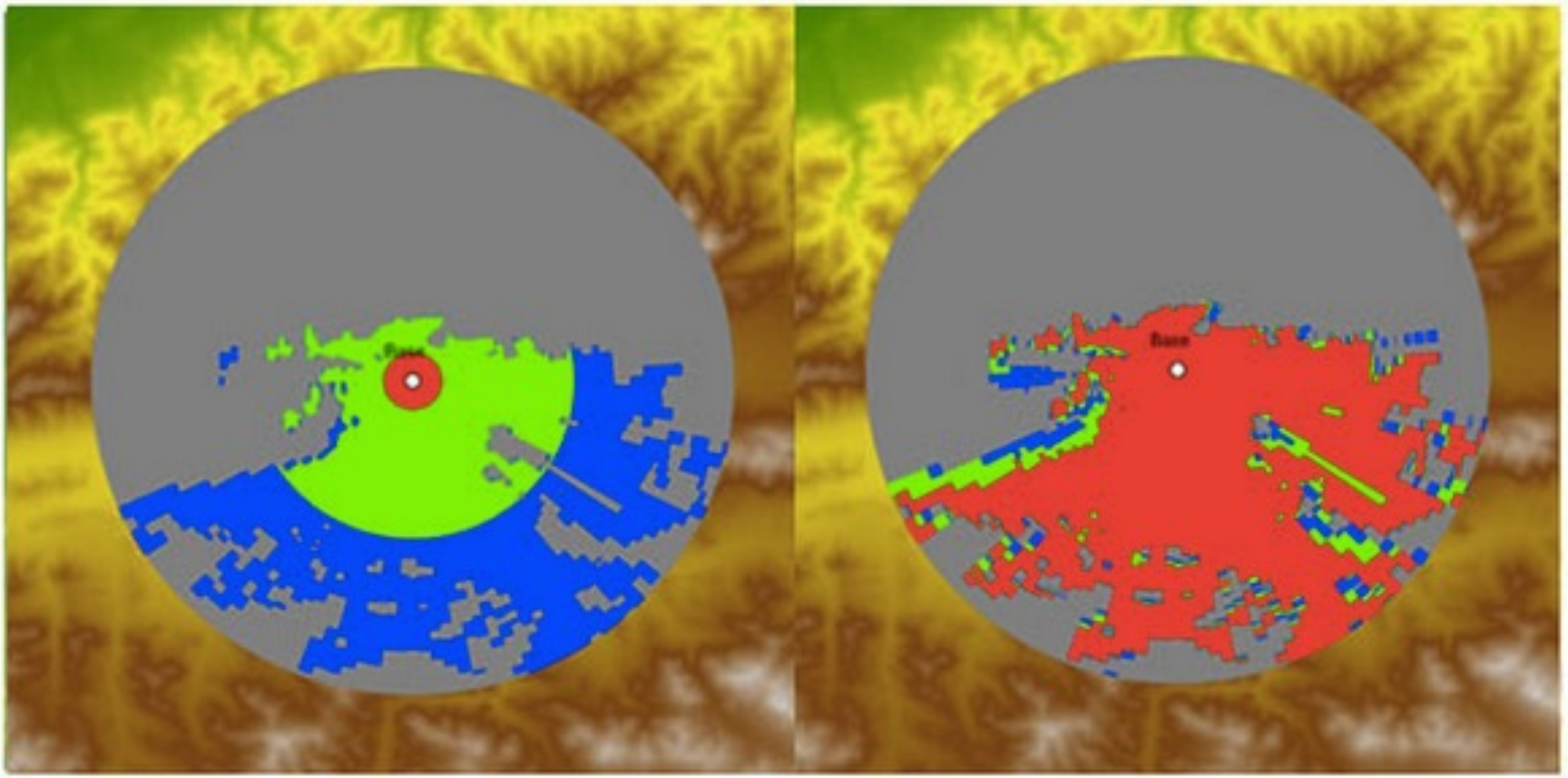


802.22 Coverage

- BS can reach a CPE up to 100 km away at 22 Mb/s.
- From the CPE the range is 33 km if the EIRP is 4W
- TV frequency bands from 54 to 862 MHz
- Ideally suited for rural areas
- Modulation: 64 QAM, 16 QAM, QPSK, distance dependent



Area of Coverage Comparison
40 km radius



Coverage with 5 GHz

Coverage with 470 MHz

http://www.carlsonwireless.com/products/ruralconnect-ip.html

802.22

Protection of TV broadcasting

Protection of Part 74 wireless microphones

802.22.1 wireless microphone beacon

Quiet periods for sensing

Self-coexistence among WRAN systems

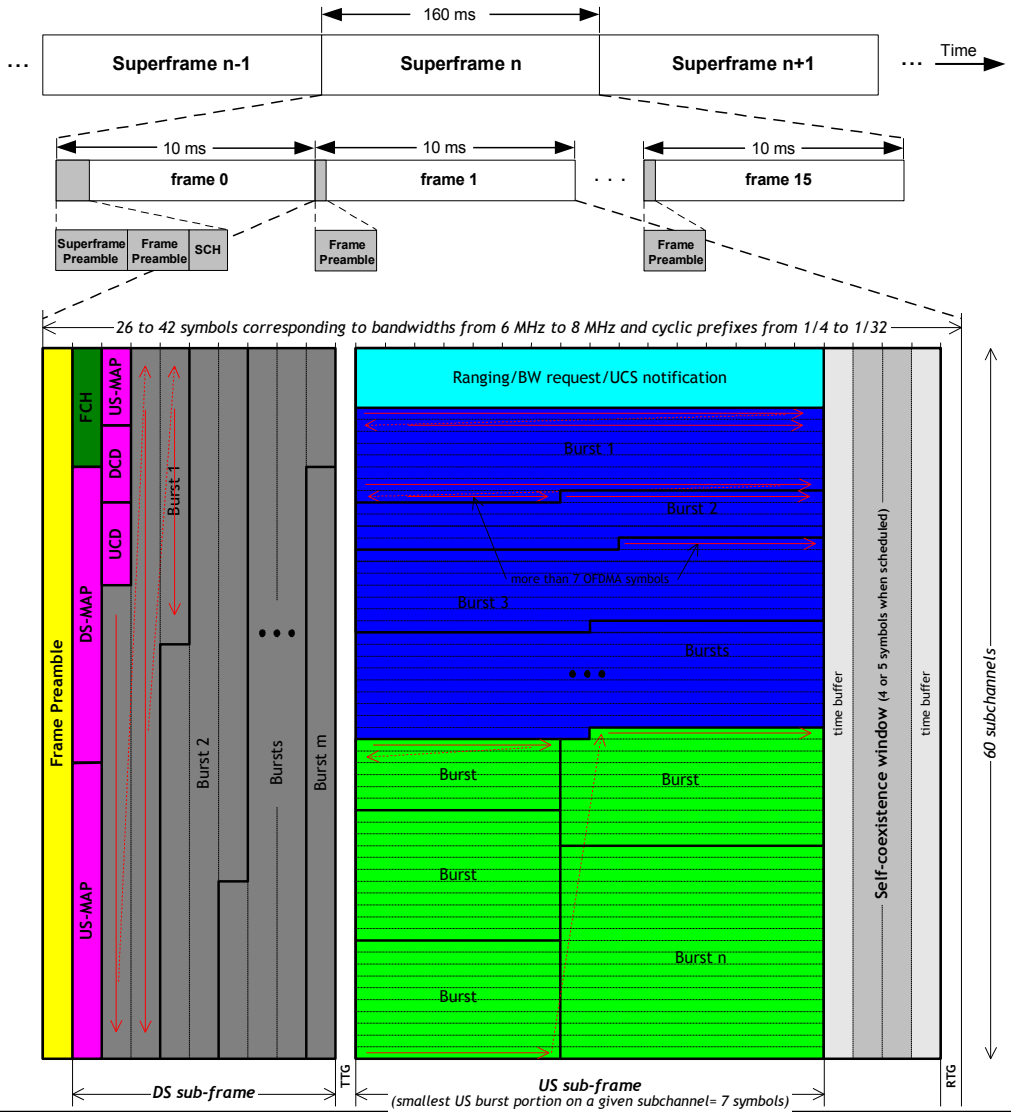
Frame Structure

802.22 Frame Structure

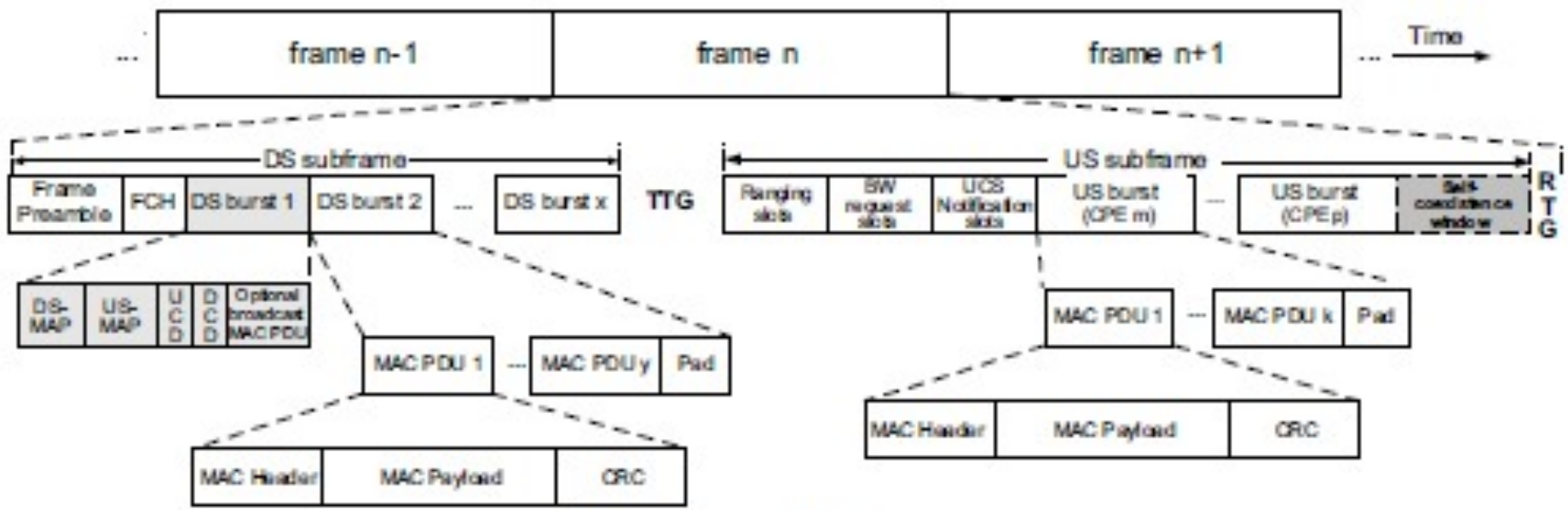
Superframe = 160 ms

Frame = 10 ms

Superframe =16 frames



Frame



MAC Frame structure

Regulatory Issues

- Target performance

Items	Requirements
Service Coverage	Typical 33 km ~ Max 100 km
Active subscribers	Minimum 12 users
Minimum Peak Throughput at Cell Edge	Forward link : 1.5 Mbps / subscriber (18 Mbps in total) Reverse link : 384 kbps / subscriber
Spectral Efficiency	Minimum : 0.5 bps/Hz Typical : 3 bps/Hz ➔ 18 Mbps for 6 MHz BW
Service Availability	50% of locations & 99.9% of time

Data Base Query

In the U.S. radios authorized and operating as white space devices (**TVBDs**) are required to provide their geographic location, by means of a secure Internet connection, to a TV band database system authorized by the Commission. The database will return a list of authorized channels available for operation by the TVBD for its reported location.

Base Station

To use the system, a device first supplies its location to the database, using a frequency that is known to be permanently free in that area
The system then tells the device which other chunks of spectrum are available to use at that time

802.22 parameters

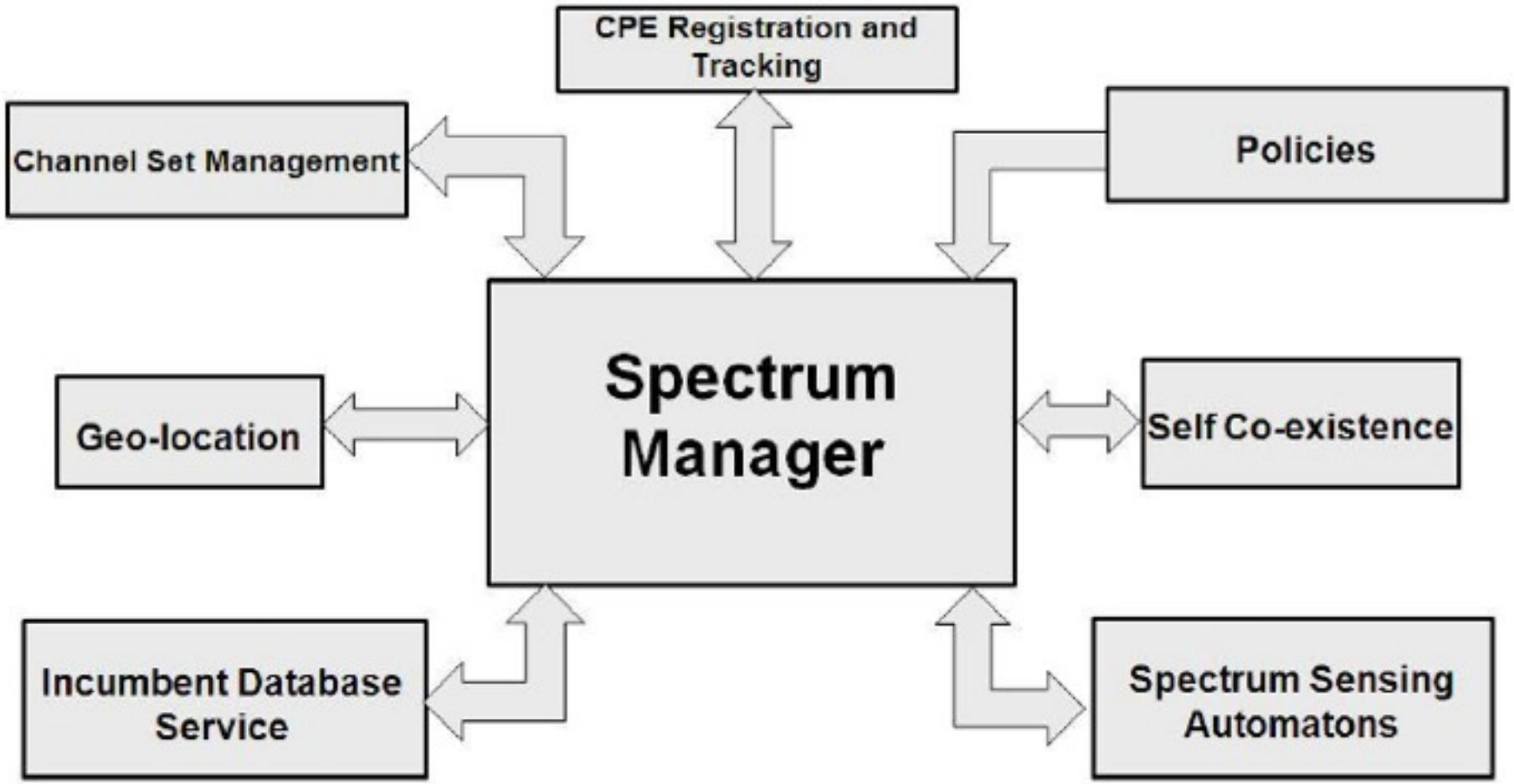
Channel Bandwidth	6, 7, 8 MHz
Data Rate	4.54 to 22.69 Mb/s
Spectrum Efficiency	0.76 to 3.78 ((bit/s)/Hz)
Modulation	QPSK, 16-QAM, 64-QAM
EIRP	Local reg. dependent, typ. 4 W
Media ACCES	OFDMA
Cyclic Prefix	1/4, 1/8, 1/16, 1/32
Duplexing Technique	TDD (Time Division Duplex)
Number of CPE supported by BS	512

With 12 simultaneous users the minimum data rate per CPE would be 1.5 Mb/s downlink and 384 kb/s uplink

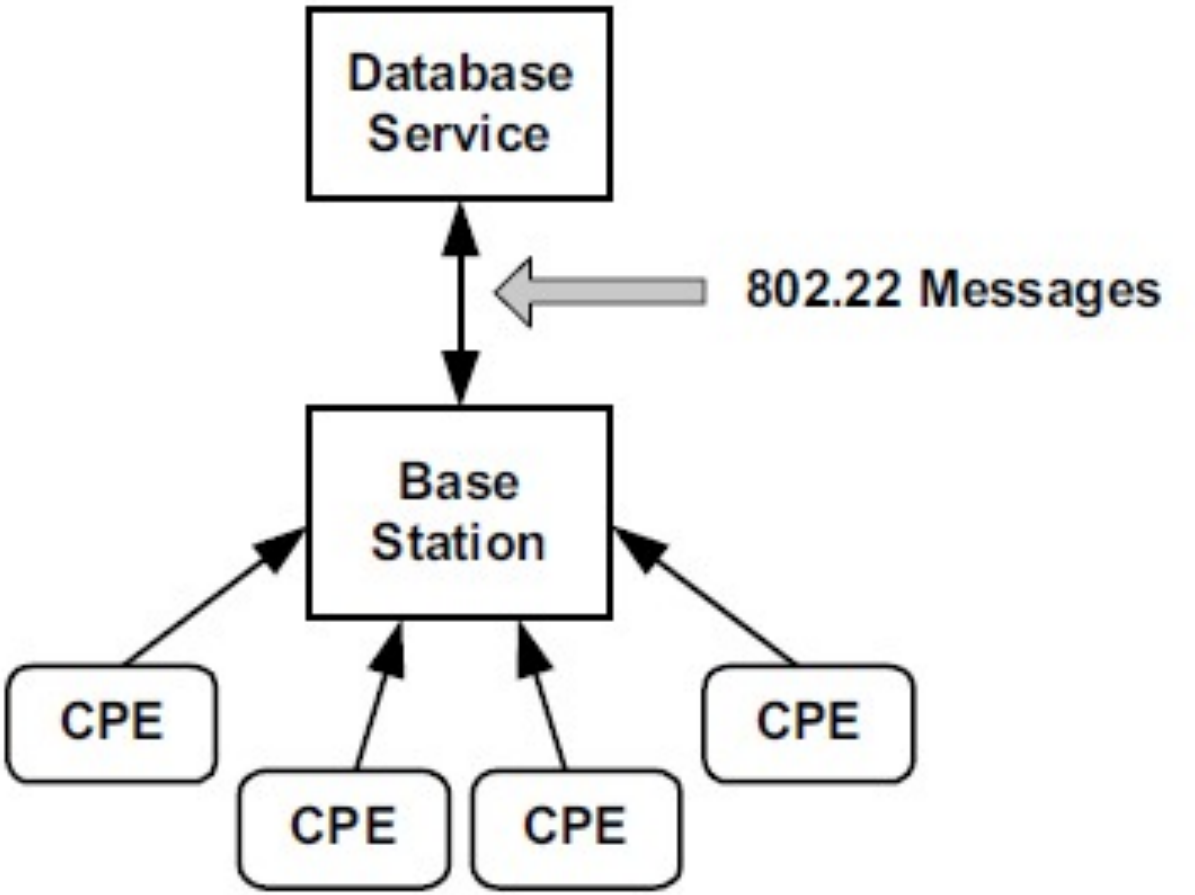
Physical Layer (PHY)

- OFDMA
- WRAN typical propagation time from 25 μs to 50 μs
- 40 μs cyclic prefix preamble
- Flexible modulation and coding schemes (QPSK, 16QAM and 64QAM)
- 48 subchannels

Spectrum Management



Database Service



Structure of the IEEE 802.22 WRAN access to the database service

Antennas

- Each CPE would need two antennas: one omni and one directional
- Omni used for spectrum sensing and measurement
- Directional used for actual data communication.
- There might be need for a third antenna to perform database consultation, say through a cellular system

802.22 in the UK

- The Communications Regulator,Ofcom UK, has announced the introduction of licence exempt **White Space** wireless broadband technology in the UK. This uses the radio spectrum that exists between digital terrestrial TV channels to deliver internet access over a **Wireless Regional Area Network** (WRAN).
- Ofcom has decided to allow multiple third-party providers to develop databases, which it believes will create a competitive marketplace and incentivise operators to provide the best database service to consumers.

802.22 in South Africa

- TV white spaces can open up low-cost high-speed internet across Africa: All we need is the regulatory go-ahead.
- “Unused TV white spaces could be the way to get highspeed wireless internet to millions in Africa including those who have been enforcedly “offline” till now because they live outside major cities.

Example of commercial device specs

Frequency Bands	UHF 470-786 MHz (US and ETSI)
Channel Spacing	6 MHz (US), 8 MHz (ETSI)
Bandwidth	100 kHz (M2M) to 4.5 MHz (Rural BB)
Modulation	QPSK, 16QAM
Data Rates	4, 6, 8, 12, and 16 Mb/s
Data Rate Control	Dynamic or fixed
Receive Interface	Proprietary to reduce co-channel interference
RX Sensitivity (6 or 8 MHz)	-89 dBm for 10-6 BER using QPSK 1/2 -86 dBm for 10-6 BER using 16QAM 1/2
RX Blocking Resistance	-50dBm TV transmission on chan N+2 -20 dBm cellular station transmissions
RX Max Signal	-16dBm with full linearity
Operating Mode	TDD (Time Division Duplexing) or optionally FDD for point-to-point use
User Ports	Mini-B USB or 10/100 baseT Ethernet

Example of commercial device specs

NETWORK SPECIFICATIONS

Multipoint Client Capacity	4096
Typical Client Loading	60 clients with 3Mb/1Mb residential SLA
Management	Web-based browser using https interface
End-to-End Latency	30-100 ms typ.
REGULATORY SPECIFICATIONS	
ACP and Spectrum Mask	Meets FCC and Ofcom specifications -55 dBr +/- 3 MHz relative to 12.2 dBm

ENVIRONMENTAL SPECIFICATIONS

Operating Temperature	-40° to 55° C
Operating Humidity	Up to 95%, non-condensing
Shock and Vibration	MIL-STD-810
Security Mechanism	WPA2/AES-128 bit shared secret key

Example of commercial device specs

BASE STATION	
RF Transmit Power	+30dBm level across band within +/- 1dB
Antenna System	4.8 dBi Omni, MIMO Space Diversity option
Antenna Connector	“F” type female 75 Ohms, 1.3:1 VSWR
Unit Dimensions	19.6” x 6” x 1.75”
Weight	5 lbs
Mounting	19 inch EIA 1 unit rack
CPE	
RF Transmit Power	+27dBm level across band within +/- 1dB
Antenna System	12 dBi, 15° Beamwidth, 1.5:1 VSWR
Antenna Connector	“F” type female 75 Ohms
Unit Dimensions	9.20” x 7” x 1.6”
Enclosure Material	Anodized aluminum
Weight	3 lbs 12 oz
Mounting	Outdoor on Mast
Voltage	100-240 VAC, 50-60 Hz or 12 VDC
Power Consumption	Tx: 12W, Rx: 5W, Idle: 3W

Another Manufacturer

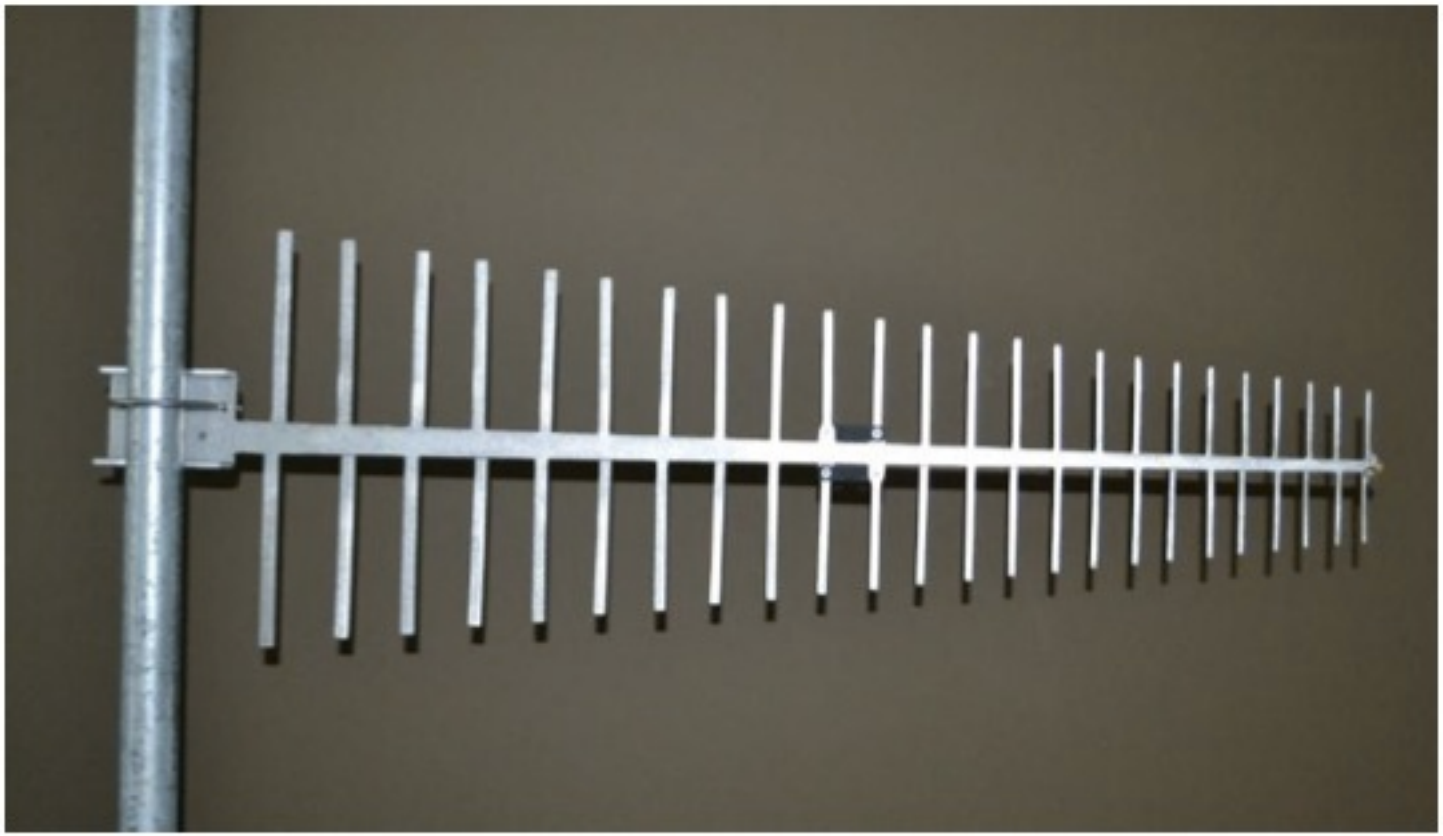
Specifications:

Electrical	
RF Module frequency bands (factory selectable)	
VHF	174 - 216 MHz (TV Channels 7-13)
UHF	470 - 698 MHz (TV Channels 14-52)
RF Transmit Power	10 to 20 dBm with ATPC
Noise Figure	4 dB
Spurious & Harmonic Emissions	FCC Part 15 compliant
Data Rates	2.0 or 3.1 MB/s
Modulation	FSK, SOQPSK
Channel Bandwidth	6 MHz
Frequency Selection	100 kHz steps
Selectivity	>60 dB
Operating mode	Half-duplex or simplex
User Port	Ethernet (10/100 BT)
Mechanical	
Dimensions	3.25" x 5.5" x 1.6"
Enclosure material	AL Anodized
Weight (w/o mount)	1.2 lb
Mounting	
Hub	Optional bracket for DIN rail or wall
Remote/Subscriber	1" – 2" pole
Connectors	
Antenna	Type N (F)
Ethernet/Power (18 or 24 VDC)	Watertight RJ45

Antenna Example, other m.

Specifications	Units	Value
Electrical		
Frequency Range	MHz	470-930
Nominal Gain	dBi	10
Number of Elements		48
Polarization		H or V
Horizontal Beamwidth	Deg	65
Vertical Beamwidth	Deg	65
Front to Back Ratio	dB	20
Power Rating	W	50
Impedance	Ohms	50
Return Loss (min)	dB	10
Lightning Protection		DC Gnd
Connector		Type N(F)
Mechanical		
Length	in/cm	38/96
Width	in/cm	13/32
Weight	lbs/kg	2.4/5.3
Rated Wind Velocity (No ice)	mph	100/161
Rated Wind Velocity (0.5" ice)	m/hr-km/hr	85/137
Pole Mast OD Supported	in/cm	1-2/2.5-5

Antenna Example, other m.



Weightless Standard

Weightless is a royalty-free open standard focussed on M2M (Machine to Machine Communication) in white spaces. The draft Weightless specification is available at http://www.weightless.org/what-is-weightless and is aimed at: great flexibility in the data rate provided depending on the application, range and environment. It uses frequency hopping at the frame rate to minimize the impact of interference - both received and caused and a design that minimizes costs and power consumption employing a highly efficient MAC-level protocols that result in small headers per transmission and hence little overhead even when the payload is only a few bytes long.

Weightless Standard
Meant for M2M applications

Table 7.1 *Overview of variation in PHY parameters [Source: Weightless* standard*]*

Modulation scheme	Coding rate	Spreading factor	Downlink PHY data rate (Mbps)	Required SNR before FEC & spreading (dB)	FEC gain (dB)	Spreading gain (dB)	Required SNR for 10^{-4} BER (dB)	Noise figure incl. digital losses (dB)	Required signal level at Rx input (dBm)
16-QAM	1	1	**16.0**	18.5	0.0	0	**+18.5**	6.0	**−82.5**
16-QAM	3/4	1	**12.0**	18.5	4.0	0	**+14.5**	6.0	**−86.5**
16-QAM	1/2	1	**8.0**	18.5	7.5	0	**+11.0**	6.0	**−90.0**
QPSK	3/4	1	**6.0**	11.5	4.0	0	**+7.5**	6.0	**−93.5**
QPSK	1/2	1	**4.0**	11.5	7.5	0	**+4.0**	6.0	**−97.0**
BPSK	1/2	1	**2.0**	8.5	7.5	0	**+1.0**	6.0	**−100.0**
BPSK	1/2	4	**0.5**	8.5	7.5	6.0	**−5.0**	6.0	**−106.0**
BPSK	1/2	16	**0.125**	8.5	7.5	12.0	**−11.0**	6.0	**−112.0**
BPSK	1/2	63	**0.040**	8.5	7.5	18.0	**−17.0**	6.0	**−118.0**
BPSK	1/2	255	**0.010**	8.5	7.5	24.0	**−23.0**	6.0	**−124.0**
DBPSK	1/2	1023	**0.0025**	10.5	7.5	30.0	**−27.0**	6.0	**−128.0**

Thank You

ICTP (International Centre for Theoretical Physics)

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Ermanno Pietrosemoli

http://wireless.ictp.it