The Role of White Spaces in the Realm of Wireless Broadband

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Long Ago…

BBC broadcast
1935

Today

Over the last 5 years wireless bandwidth deployed in the US has increased 553-fold.

George Gilder
Chairman, Gilder Technology Group

TV Band Spectrum Utilization

- Spectrum under 3 GHz has significant unused capacity
  - Average occupancy over various locations studied is 5.2% and the maximum occupancy is 13.1% (in New York City)
  - Shared Spectrum Company, NSF funded measurements, 9/2009
    http://www.sharedspectrum.com/measurements
- Only 8% of Americans receive broadcast TV
  - Consumer Electronics Association (CEA) survey, 2011
  - http://www.cesweb.org/shared_files/ECD-TOC/CEACordCuttingAnalysis.pdf
- The economic potential for the TV white spaces was estimated at $100 billion
  - R. Thanki, "The economic value generated by current and future allocations of unlicensed spectrum", 9/2009
    http://www.ingeniousmedia.co.uk/websitefiles/Value_of_unlicensed_-_website_-_FINAL.pdf

White Spaces – Brief History

- NPRM in May 2004
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-04-113A1.pdf
- November 4, 2008 FCC approved Report & Order 08-260, allowing unlicensed use of TV band spectrum
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/DA-01-260A1.pdf
- February 17, 2009, the FCC released the final rules for "Unlicensed Operation in the TV Broadcast Bands"
  - http://edocket.access.gpo.gov/2009/pdf/E9-3279.pdf
- Sep 23, 2010 The FCC reaffirmed a 2008 decision to open the broadcast airwaves


THE WALL STREET JOURNAL.
WSJ.com
SEPTEMBER 24, 2010
FCC to Open Unused TV Airwaves, Extending Wi-Fi's Possibilities

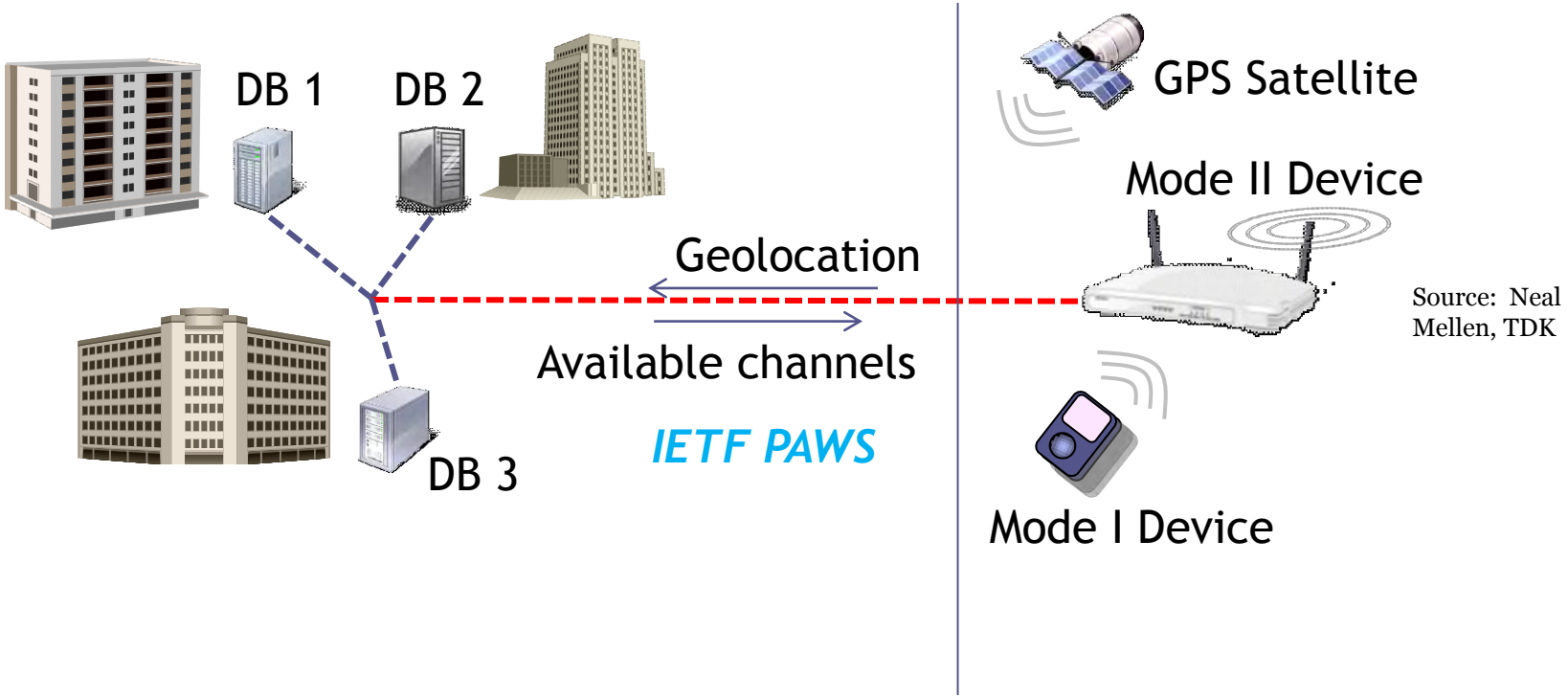
NPRM = Notice of Proposed Rule Making

European White Space Regulation

- Ofcom (UK) is in the process of making this Digital Dividend band available
  - https://mentor.ieee.org/802.18/dcn/09/18-09-0059-00-0000-ofcom-update-on-the-digital-dividend.ppt
  - http://stakeholders.ofcom.org.uk/consultations/geolocation/summary
- ECC of CEPT in Europe has published a report on White Spaces in Jan 2011
  - http://www.erodocdb.dk/Docs/doc98/official/pdf/ECCREP159.PDF
- China TV band regulations expected in 2015

ECC = Electronic Communications Committee
CEPT = European Conference on Postal and Telecommunications

White Space Spectrum Access



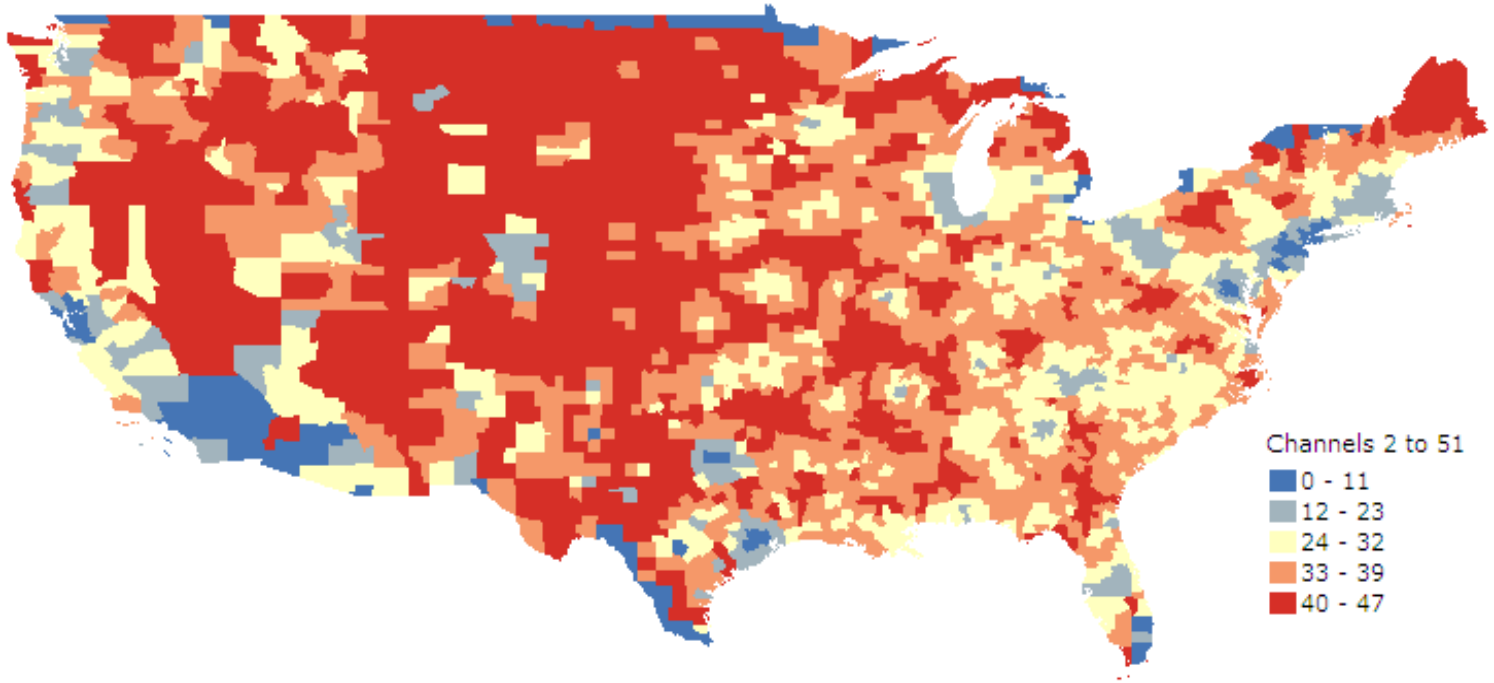
IETF = internet engineering task force
PAWS = protocol to access white space

Spectrum Sensing Technical Challenges

- Very low threshold of -114 dBm
  - Below noise floor of most receivers
  - Requires sophisticated averaging or other innovative techniques
  - Averaging could be time-consuming
- False detects
  - During initial FCC testing of early spectrum sensing prototypes, the key issue was false detects – due to unreasonably low threshold
  - Adjacent TV channel leakage can be about 30 dB above the sensing threshold
- Service boundaries are not well-defined. For example, if the sensing radio is a few feet outside the boundary of the TV station region, the sensing circuitry might still detect the TV signal.
  - Is this a failure?

TV Band Channel Availability

- Channel availability based on the geolocation query of TV band internet database



Source: Rick Tornado, Spectrum Bridge

TV Channels and White Space Allocation

US – FCC

	Channel #	Frequency Band	
Fixed TVBDs only	2-4	54-72 MHz	VHF
	5-6	76-88 MHz	
	7-13	174-216 MHz	
	14-20	470-512 MHz**	UHF
White Spaces	21-51*	512-692 MHz	

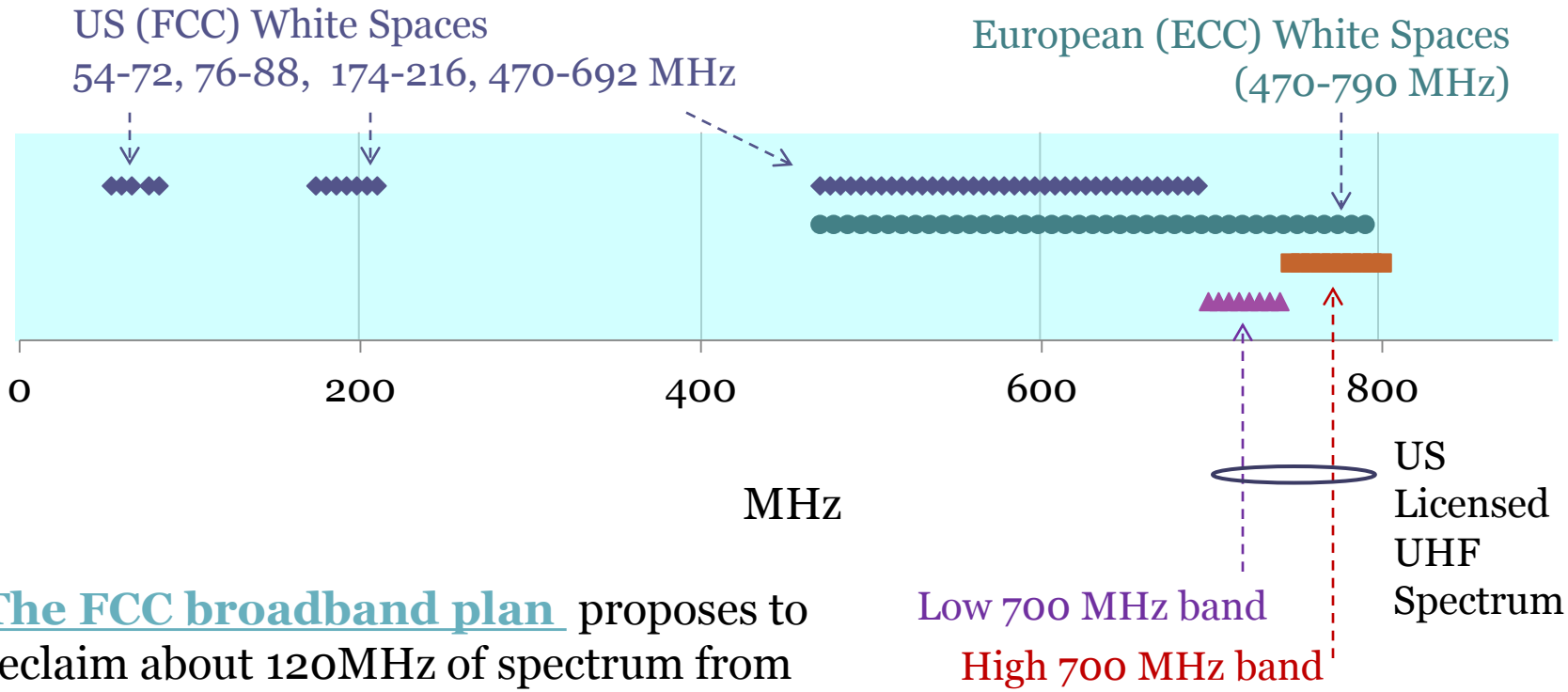
Transition from NTSC to ATSC (analog to digital TV) June 12, 2009 freed up channels 52-69 (above 692 MHz)

Europe – ECC

	Channel #	Frequency Band	
	5-12	174-230 MHz	VHF
White Spaces	21-60	470-790 MHz	UHF
	61-69	790-862 MHz	

*Channel 37 (608-614 MHz) is reserved for radio astronomy
**Shared with public safety

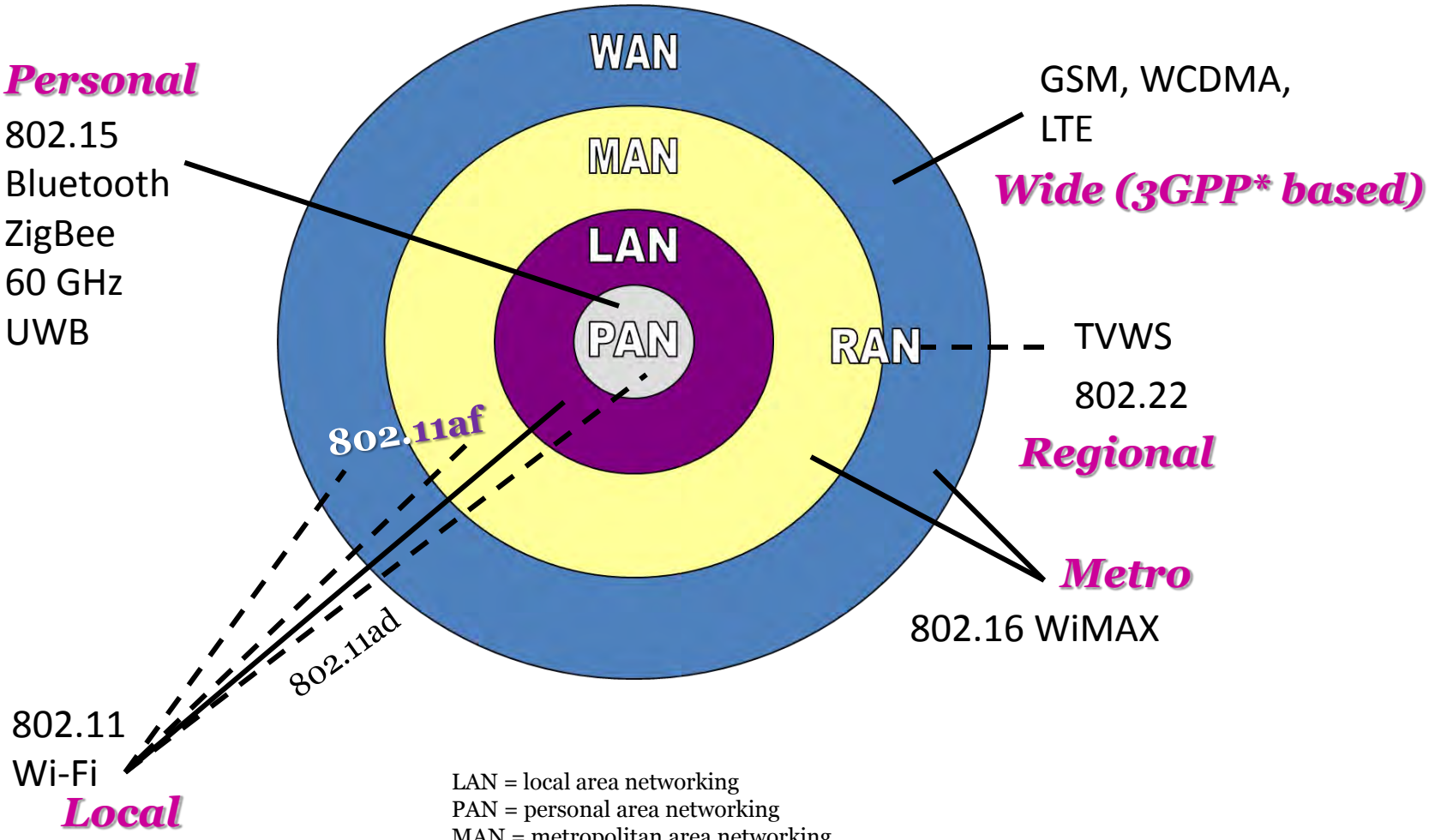
TV Band Spectrum



The FCC broadband plan proposes to reclaim about 120MHz of spectrum from broadcasters and sell it to the carriers.

This move may serve to discourage investment into white spaces.

IEEE 802 Wireless



LAN = local area networking
PAN = personal area networking
MAN = metropolitan area networking
WAN = wide area networking
RAN = regional area networking
TVWS = television white spaces
3GPP = 3rd generation partnership project

IEEE TV Band Related Standards

- **802.11af** – formed in January 2010 to adapt 802.11 to TV band operation
- **802.16h** – originally organized to adapt 802.16 to the 3650-3700 MHz contention band now working on TV band operation of 802.16
- **802.22** – Regional Area Networks
  - Guided the FCC in the recent TV band regulations
  - Introduced spectrum sensing and location information to determine whether given transmit frequencies and power levels will cause harmful interference to licensed services
- **802.18** TAG – regulatory
- **802.19** TAG – coexistence among dissimilar networks in the TV band
- **SCC 41** – defines layers above the MAC and PHY for dynamic spectrum access networks
  - http://grouper.ieee.org/groups/scc41/crinfo/
  - 1900.7 is the relevant group under SCC 41

TAG = technical advisory group

Ecma and CogNeA TV Band Standard

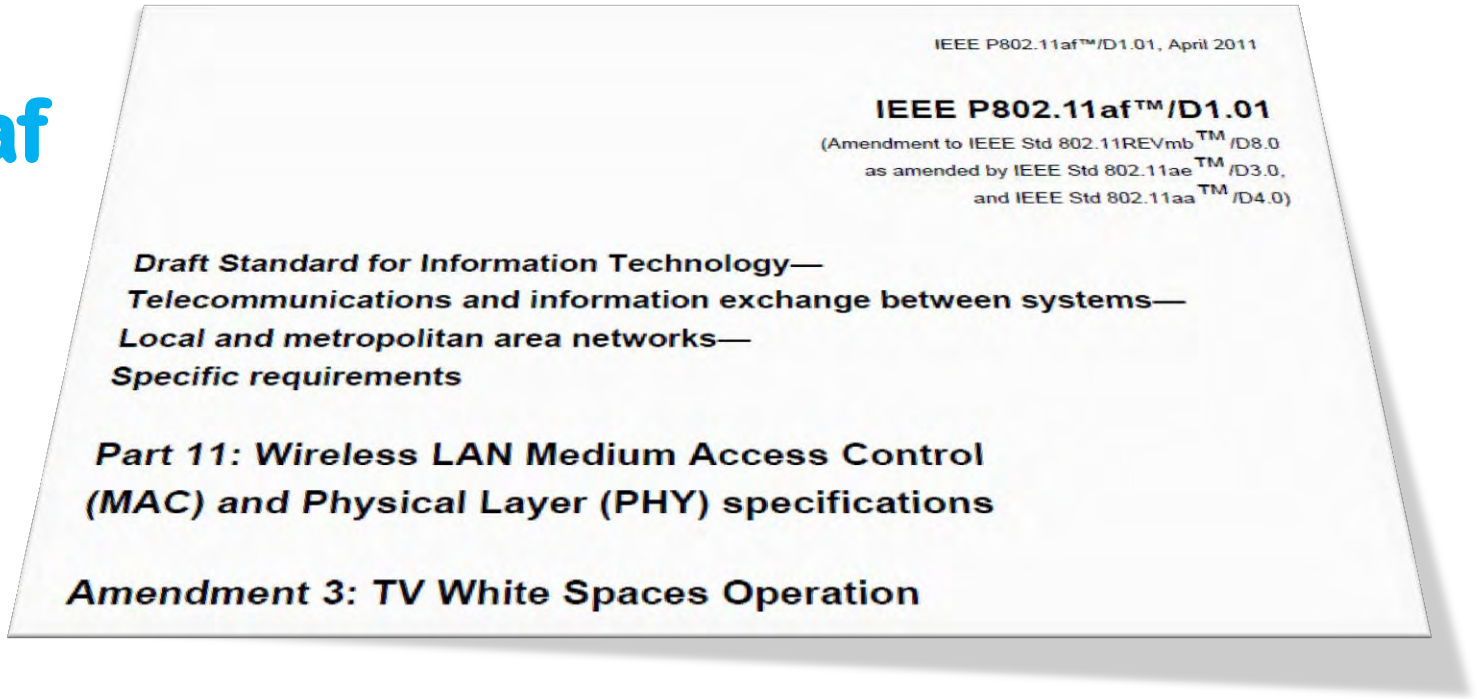
- Ecma TC48-TG1 standard for Personal/Portable devices in TV White Spaces
  - Physical (PHY) and Medium Access Control (MAC) layers including a protocol and mechanisms for coexistence
  - http://www.ecma-international.org/publications/standards/Ecma-392.htm
- Sponsor Organization: CogNeA (http://www.cognea.org)
  - Industry alliance formed in 2008 to develop a specification for white spaces

CogNeA = Cognitive Networking Alliance

802.11af

Database is out of scope of 802.11af

Being defined by IETF PAWS



- Re-band the popular 802.11 systems; capitalize on work already done for 802.11y and 802.11h
  - Use 5, 10, 20 and 40 MHz wide channels
  - FCC EIRP: 4 W, 100 mW, 50 mW
- Possible deployment scenarios
  - Indoor (< 100 m): like present WLAN
  - Outdoor (< 5 km): comparable to the range of typical urban model

IETF = internet engineering task force
PAWS = protocol to access white space

White Spaces Standards

802.11af

Most promising IEEE White Spaces standard with 802.11 chipset vendors evaluating the business opportunity; fast moving; Wi-Fi Alliance expects to certify in 2012

Most cost-effective **if** 802.11 chipsets support the band

802.22

Based on 802.16d Fixed WiMAX; no chipset vendors involved yet; small group dominated by broadcasters who oppose White Spaces

No products expected in the near-future

Ecma-based or proprietary

Proprietary implementation is already on the market (e.g. www.carlsonwireless.com) ; potential to disrupt 802.11 service since access protocol is unknown

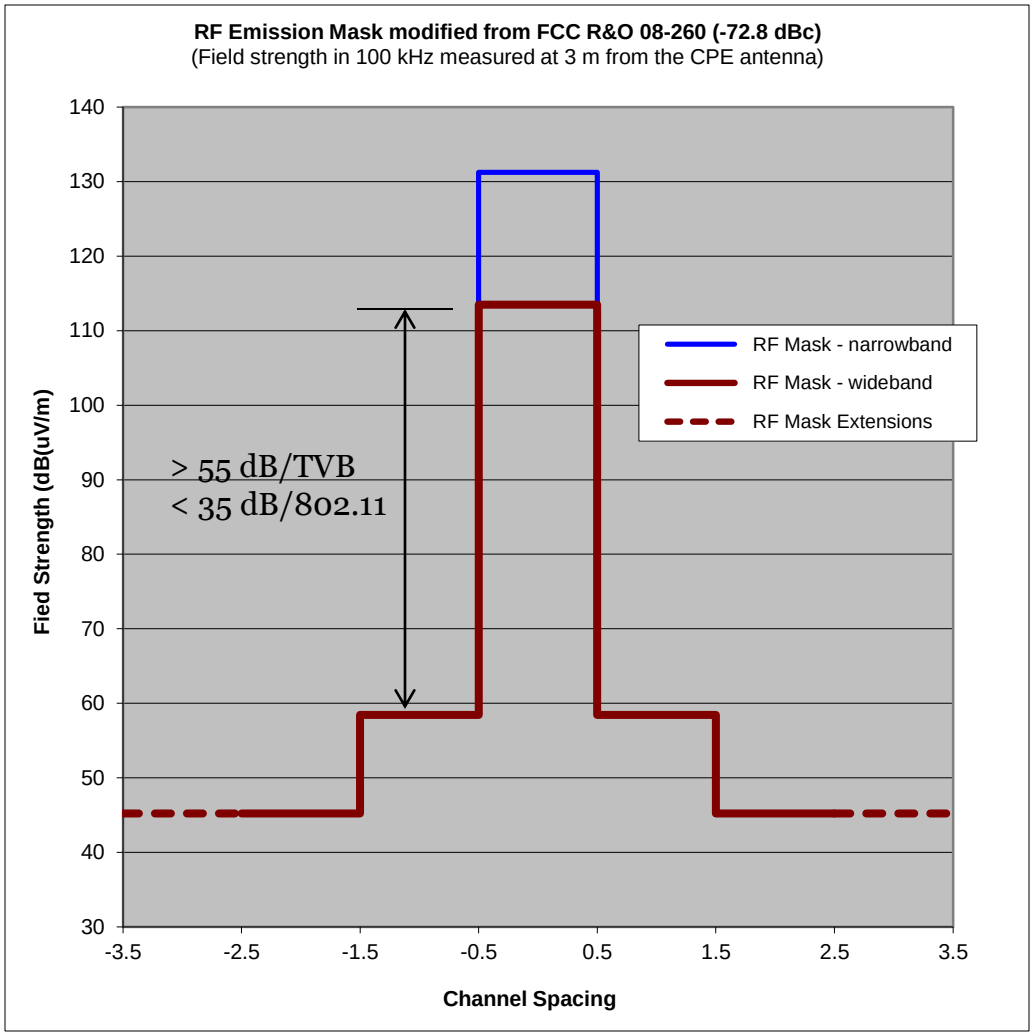
Products already announced

SCC41

Higher layer cognitive radio algorithms, such as Dynamic Spectrum Access; academic group; no near-term products expected

TV Band Technical Issues

- Biggest roadblock to 802.11af adaptation is the stringent spectrum mask mandated by the FCC for the TV Band
  - 20 dB more stringent than the most stringent 802.11 devices support today
- Another issue is the limit on antenna elevation, which limits the range of TV Band data service
  - Antennas no higher than 90 feet



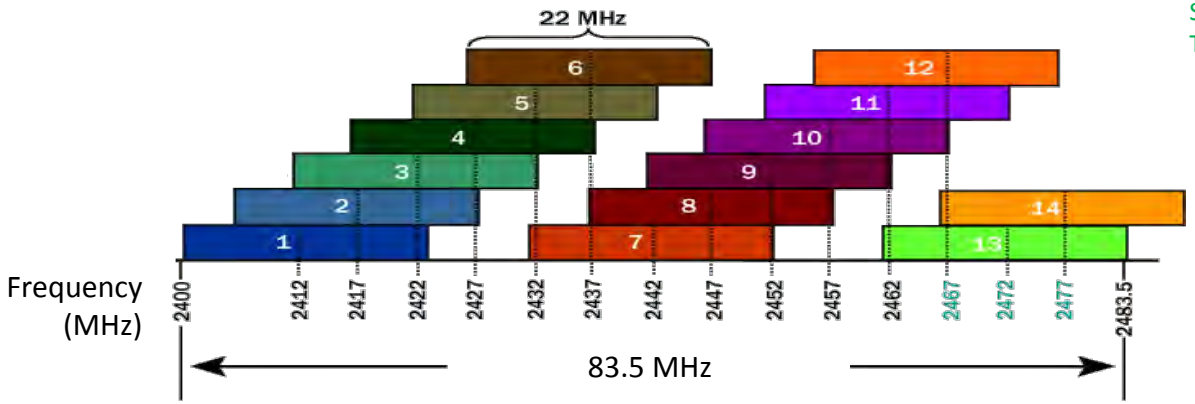
Contention Band

- March 2005 FCC made available 3650 to 3700 MHz for *contention-based* protocol
- Multiple services to share the band in an orderly way
  - IEEE 802.11y and 802.16h adopted their protocols to coexist in this band
- 300 Million licenses – one for every person or company; $300 per license for 10 years
- Registered stations (base stations): 1 W/MHz, ~15 km
- Unregistered stations (handsets, laptops): 40 mW/MHz, 1-1.5 km

802.11 Band – 2.4 GHz

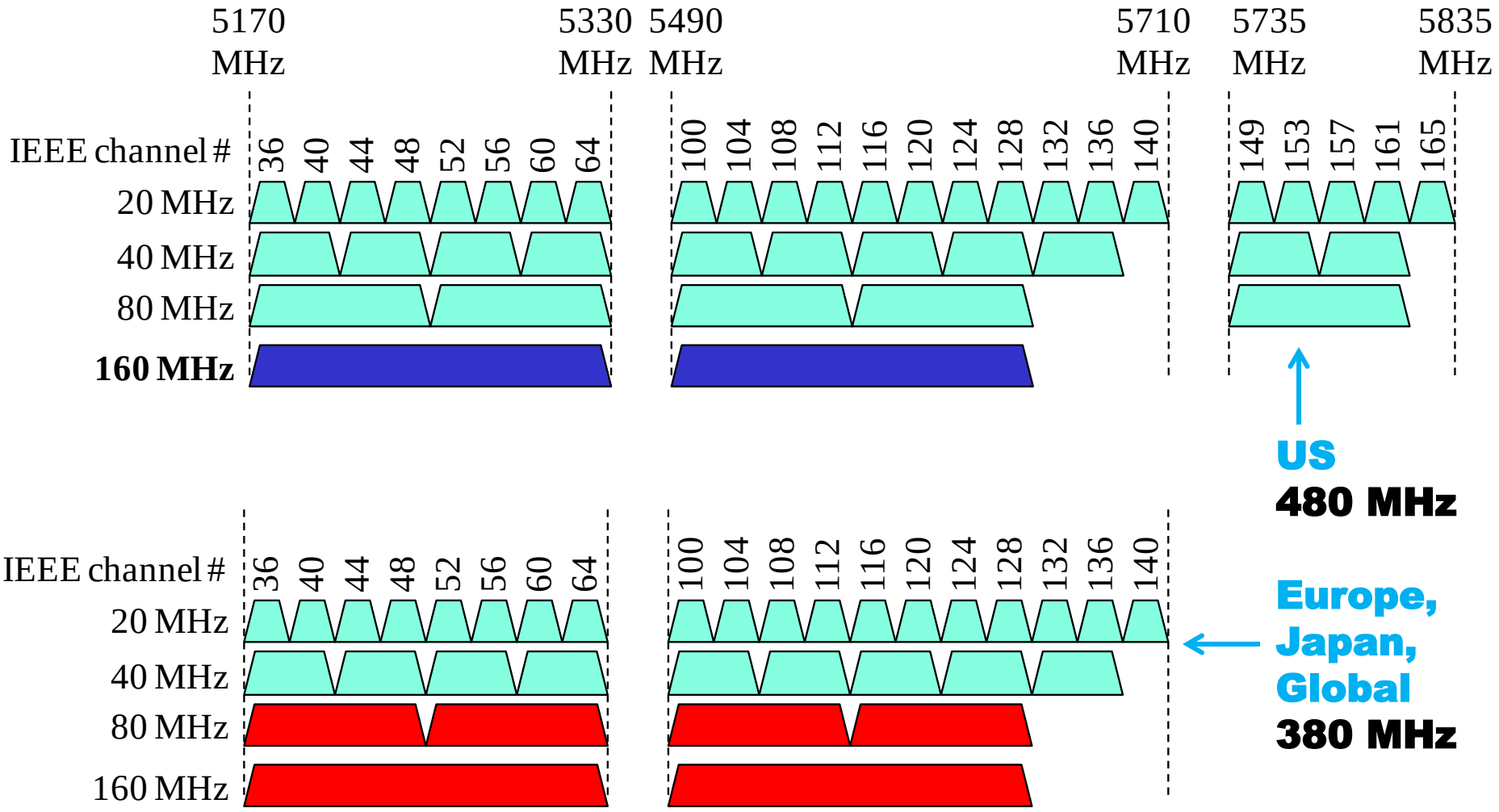
Chan ID	Center Frequency	Regulatory domains							
		FCC	IC	ETSI	Spain	France	Japan	Japan Hi rate	China
1	2412 MHz	X	X	X	-	-	-	X	X
2	2417 MHz	X	X	X	-	-	-	X	X
3	2422 MHz	X	X	X	-	-	-	X	X
4	2427 MHz	X	X	X	-	-	-	X	X
5	2432 MHz	X	X	X	-	-	-	X	X
6	2437 MHz	X	X	X	-	-	-	X	X
7	2442 MHz	X	X	X	-	-	-	X	X
8	2447 MHz	X	X	X	-	-	-	X	X
9	2452 MHz	X	X	X	-	-	-	X	X
10	2457 MHz	X	X	X	X	X	-	X	X
11	2462 MHz	X	X	X	X	X	-	X	X
12	2467 MHz	-	-	X	-	X	-	X	X
13	2472 MHz	-	-	X	-	X	-	X	X
14	2484 MHz	-	-	-	-	-	X	-	-

Source: IEEE 802.11-2007 Table 18-9



US
83.5 MHz

802.11 Band – 5 GHz



802.11 Spectrum – 60 GHz

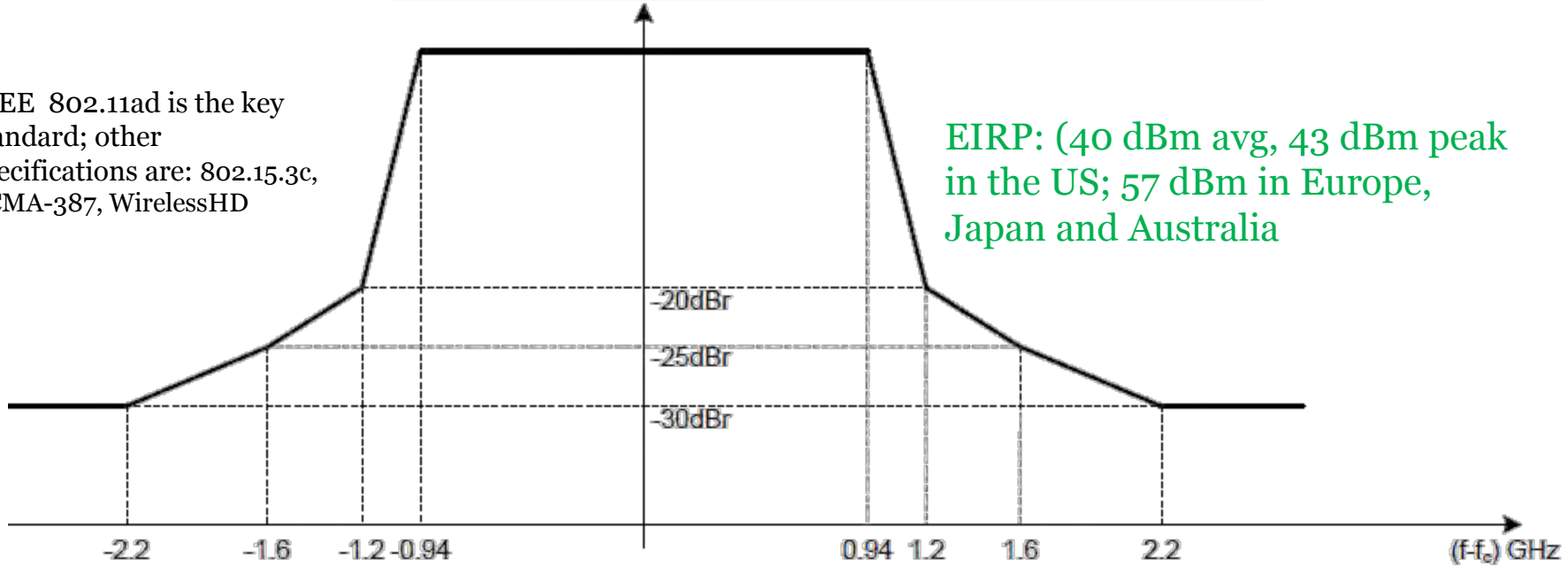
Channel	f_c (GHz)	Country
1	58.32	US
2	60.48	US, Japan, EU, Australia
3	62.64	US, Japan, EU
4	64.80	Japan, EU

Channel 2 must be supported →

US
~ 7 GHz

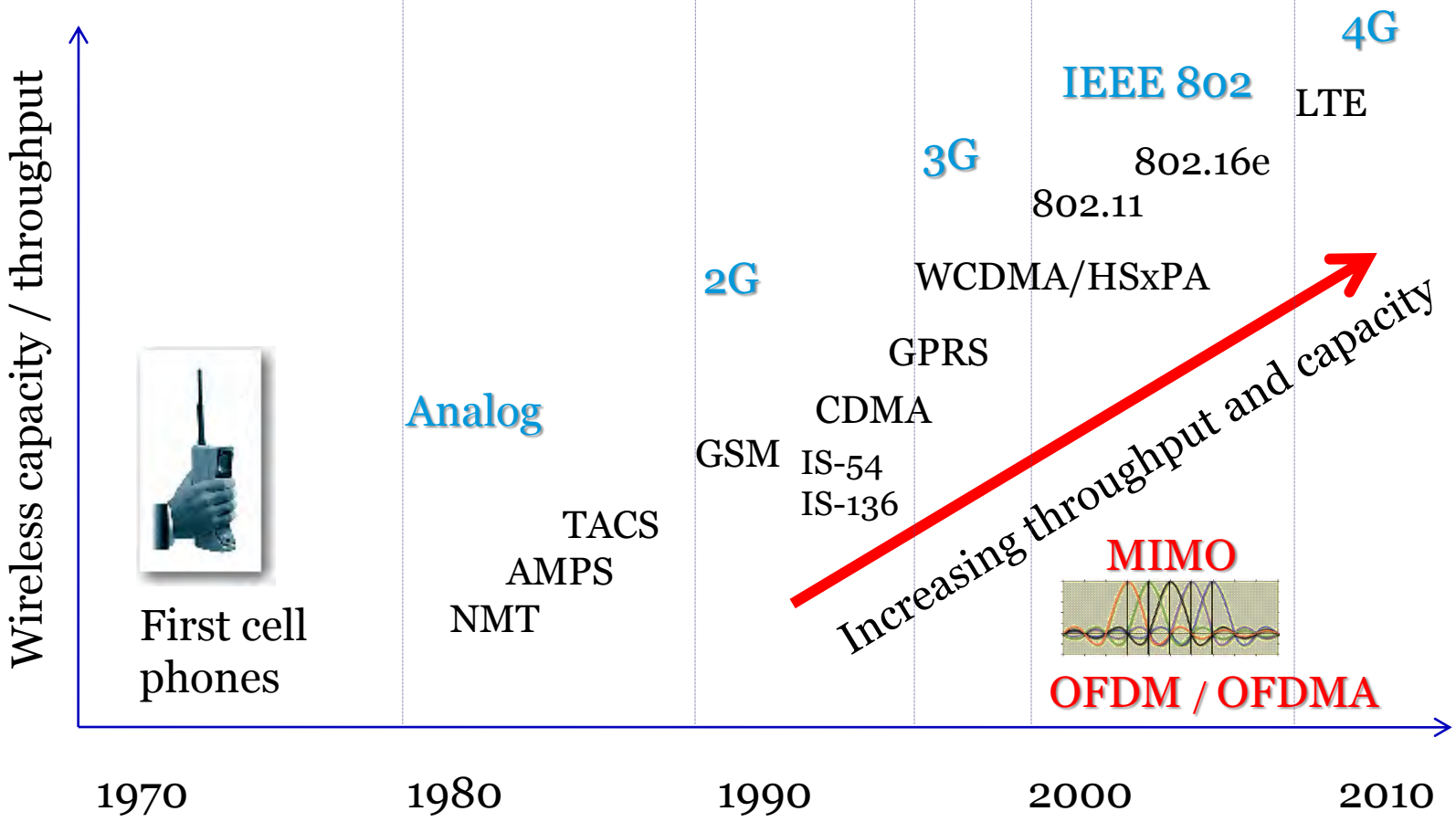
IEEE 802.11ad is the key standard; other specifications are: 802.15.3c, ECMA-387, WirelessHD

EIRP: (40 dBm avg, 43 dBm peak in the US; 57 dBm in Europe, Japan and Australia



Channel spacing = 2160MHz

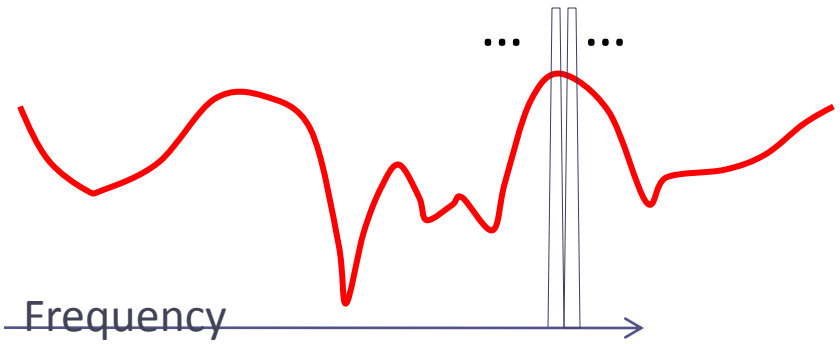
The Evolution of Wireless Broadband



OFDM/OFDMA = orthogonal frequency domain multiplexing / multiple access
MIMO = multiple input multiple output

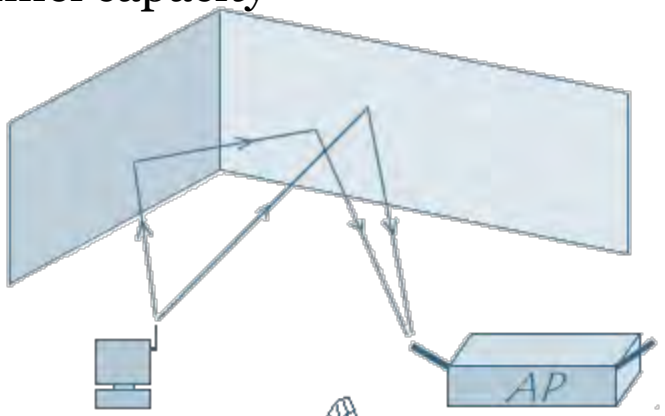
OFDM and MIMO

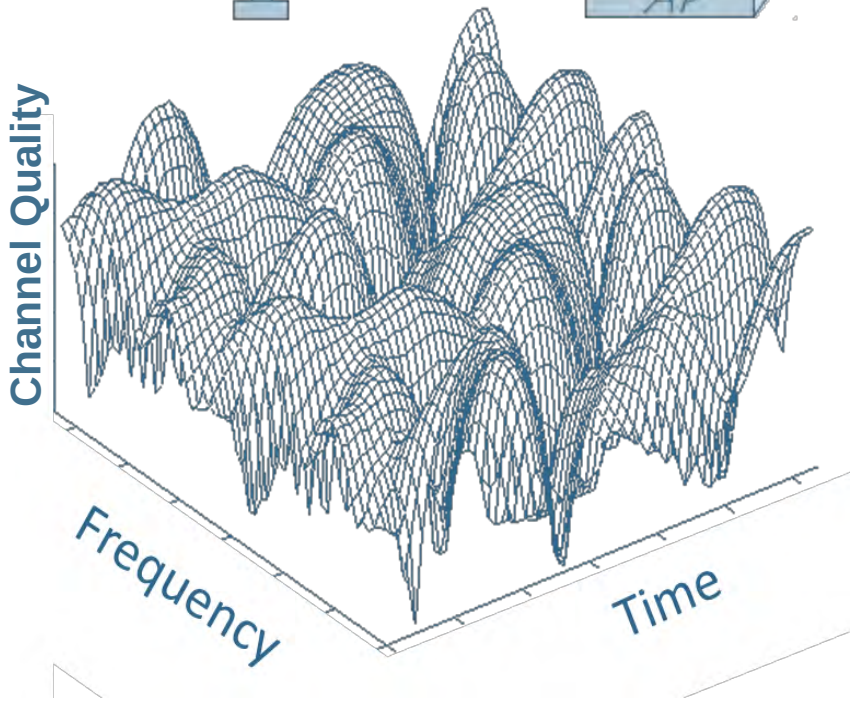
- OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, enabling wide bandwidth operation



Frequency-variable channel appears flat over the narrow band of an OFDM subcarrier.

MIMO uses multipath to increase channel capacity



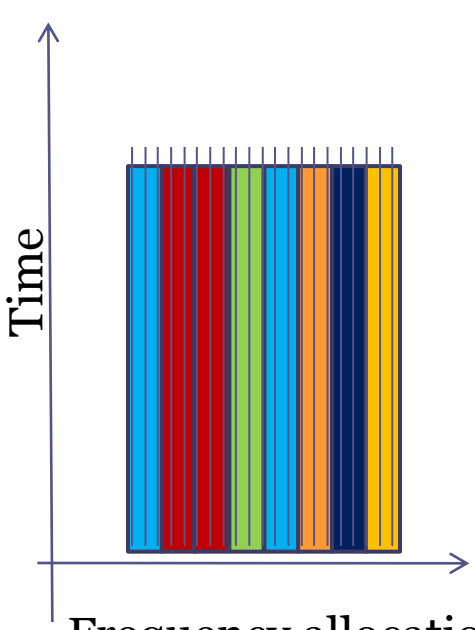


OFDM = orthogonal frequency division multiplexing
MIMO = multiple input multiple output

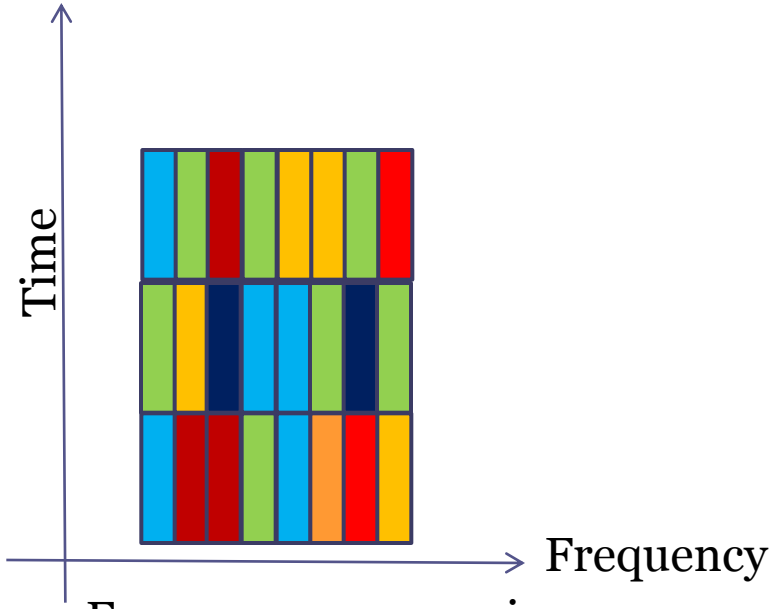
OFDM vs. OFDMA

OFDM is a modulation scheme

OFDMA is a modulation and access scheme



Frequency allocation per user is continuous vs. time



Frequency per user is dynamically allocated vs. time slots

OFDM/OFDMA = orthogonal frequency domain multiplexing / multiple access

octoScope

The G's

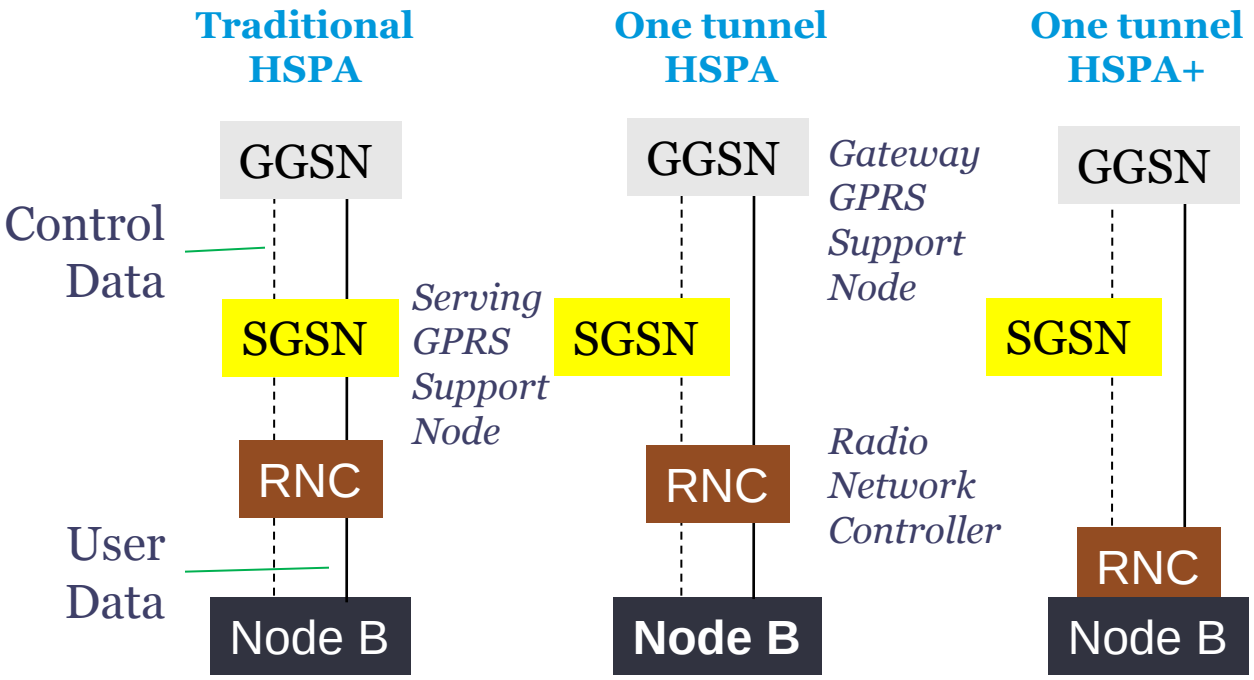
G		Peak Data Rate (Mbps)	
		Downlink	Uplink
1	Analog	19.2 kbps	
2	Digital – TDMA, CDMA	14.4 kbps	
3	Improved CDMA variants (WCDMA, CDMA2000)	144 kbps (1xRTT); 384 kbps (UMTS); 2.4 Mbps (EVDO)	
3.5	HSPA (today)	14 Mbps	2 Mbps
3.75	HSPA (Release 7) DL 64QAM or 2x2 MIMO; UL 16QAM	28 Mbps	11.5 Mbps
	HSPA (Release 8) DL 64QAM and 2x2 MIMO	42 Mbps	11.5 Mbps
3.9	WiMAX Release 1.0 TDD (2:1 UL/DL ratio), 10 MHz channel	40 Mbps	10 Mbps
	LTE, FDD 5 MHz UL/DL, 2 Layers DL	43.2 Mbps	21.6 Mbps
	LTE CAT-3	100 Mbps	50 Mbps

OFDM

Maximum LTE data rates in the 20 MHz channel are 326 Mbps DL (4 streams), 172 Mbps UL (2 streams)

HSPA and HSPA+

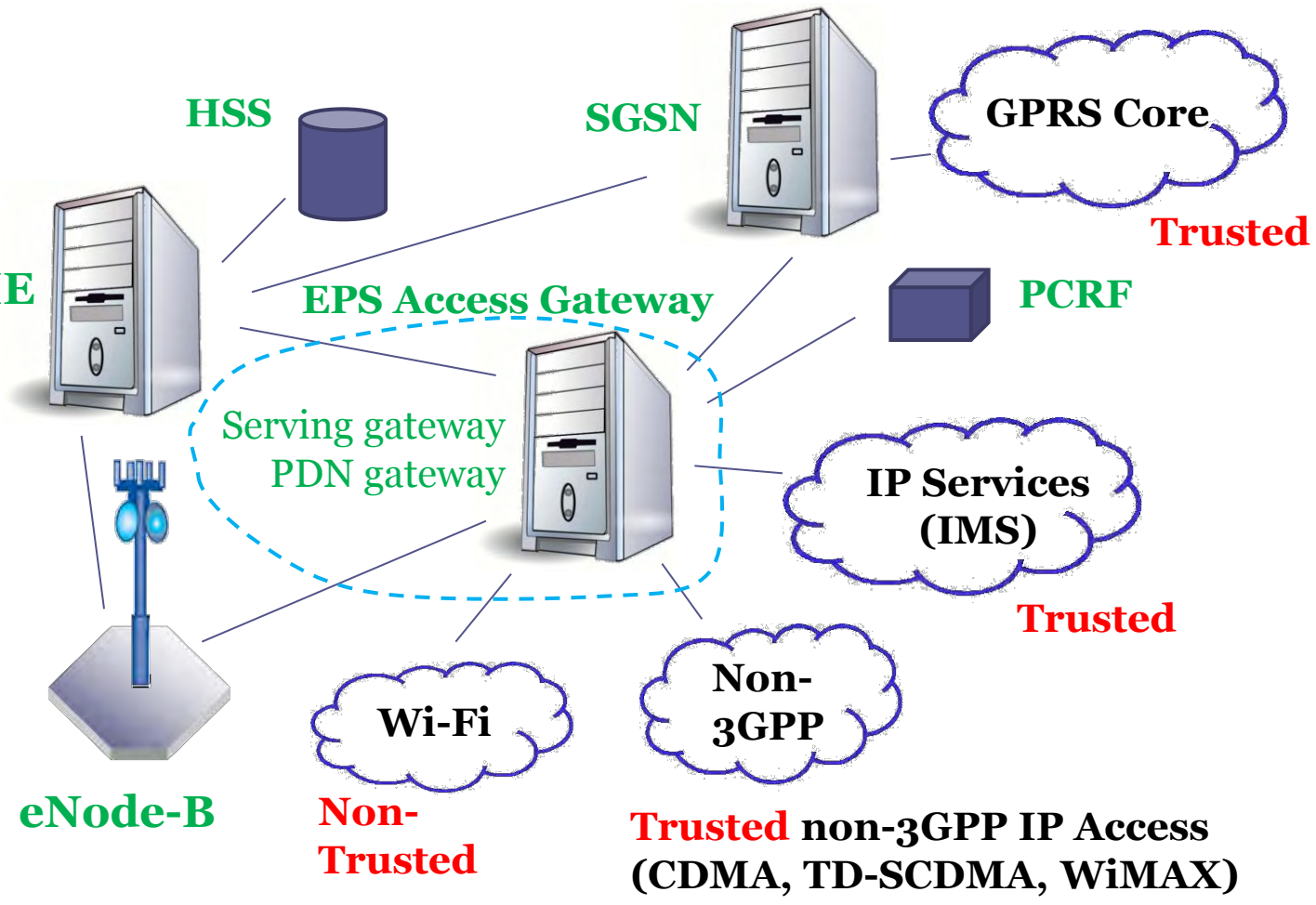
- HSPA+ is aimed at extending operators' investment in HSPA
  - 2x2 MIMO, 64 QAM in the downlink, 16 QAM in the uplink
  - Data rates up to 42 MB in the downlink and 11.5 MB in the uplink.



One-tunnel architecture flattens the network by enabling a direct transport path for user data between RNC and the GGSN, thus minimizing delays and set-up time

HSPA+ is CDMA-based and lacks the efficiency of OFDM

LTE EPS (Evolved Packet System)



SGSN (Serving GPRS Support Node)

PCRF (policy and charging rules function)

HSS (Home Subscriber Server)

MME (Mobility Management Entity)

PDN (Public Data Network)

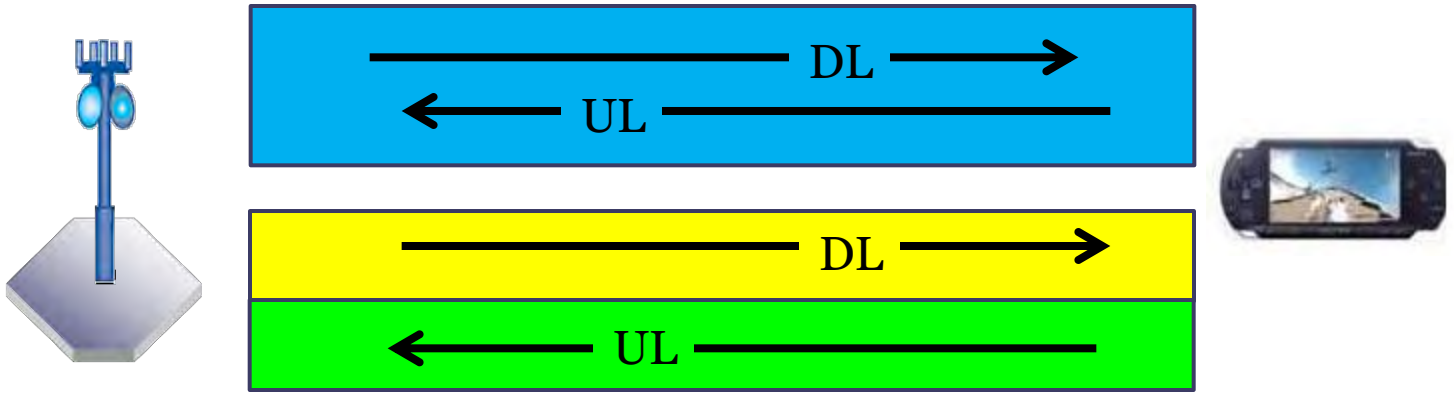
Flat, low-latency architecture

- 3GPP = 3rd generation partnership project
- Partnership of 6 regional standards groups that translate 3GPP specifications to regional standards
- LTE = long term evolution

FDD vs. TDD

- FDD (frequency division duplex)
  - Paired channels
- TDD (time division duplex)
  - Single frequency channel for uplink an downlink
  - Is more flexible than FDD in its proportioning of uplink vs. downlink bandwidth utilization
  - Can ease spectrum allocation issues

TD-LTE



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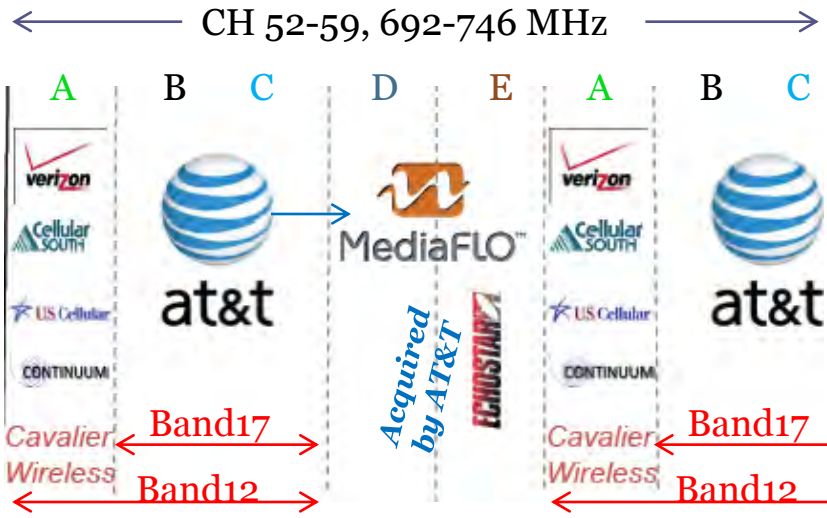
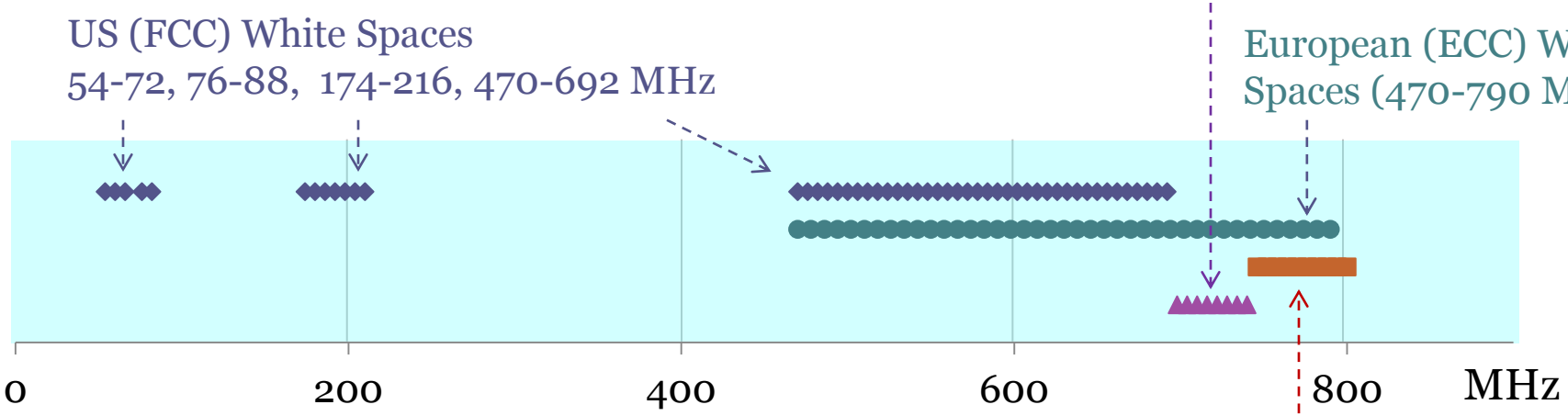
LTE Frequency Bands - FDD

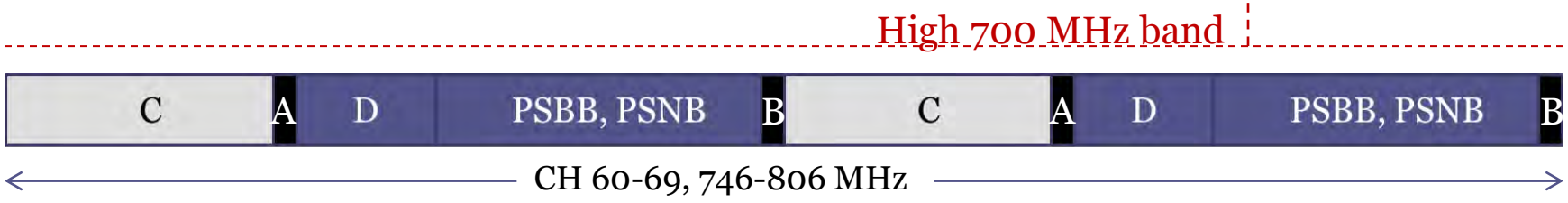
Source: 3GPP TS 36.104; V10.1.0 (2010-12)

Band	Uplink (UL)	Downlink (DL)	Regions
1	1920 -1980 MHz	2110 - 2170 MHz	Europe, Asia
2	1850 -1910 MHz	1930 - 1990 MHz	Americas, Asia
3	1710 -1785 MHz	1805 -1880 MHz	Europe, Asia, Americas
4	1710 -1755 MHz	2110 - 2155 MHz	Americas
5	824-849 MHz	869 - 894 MHz	Americas
6	830 - 840 MHz	875 - 885 MHz	Japan
7	2500 - 2570 MHz	2620 - 2690 MHz	Europe, Asia
8	880 - 915 MHz	925 - 960 MHz	Europe, Asia
9	1749.9 - 1784.9 MHz	1844.9 - 1879.9 MHz	Japan
10	1710 -1770 MHz	2110 - 2170 MHz	Americas
11	1427.9 - 1452.9 MHz	1475.9 - 1500.9 MHz	Japan
12	698 - 716 MHz	728 - 746 MHz	Americas
13	777 - 787 MHz	746 - 756 MHz	Americas (Verizon)
14	788 - 798 MHz	758 - 768 MHz	Americas (D-Block, public safety)
17	704 - 716 MHz	734 - 746 MHz	Americas (AT&T)
18	815 – 830 MHz	860 – 875 MHz	
19	830 – 845 MHz	875 – 890 MHz	
20	832 – 862 MHz	791 – 821 MHz	
21	1447.9 – 1462.9 MHz	1495.9 – 1510.9 MHz	

UHF Spectrum, Including White Space Bands

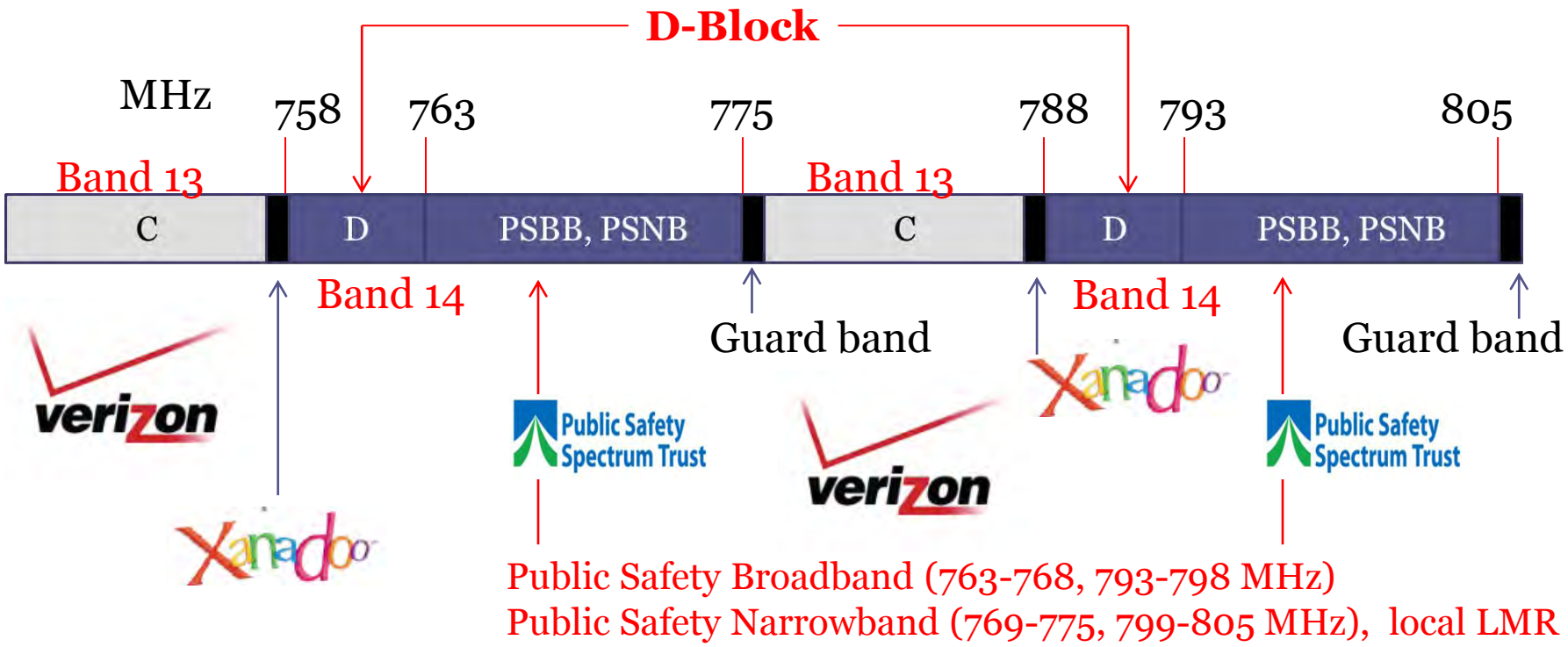






ECC = Electronic Communications Committee

High 700 MHz Band



LMR = land mobile radio

LTE Frequency Bands - TDD

TD-LTE

Band	UL and DL	Regions
33	1900 - 1920 MHz	Europe, Asia (not Japan)
34	2010 - 2025 MHz	Europe, Asia
35	1850 - 1910 MHz	
36	1930 - 1990 MHz	
37	1910 - 1930 MHz	
38	2570 - 2620 MHz	Europe
39	1880 - 1920 MHz	China
40	2300 – 2400 MHz	Europe, Asia
41	2496 – 2690 MHz	Americas (Clearwire LTE)
42	3400 – 3600 MHz	
43	3600 – 3800 MHz	

Source: 3GPP TS 36.104; V10.1.0 (2010-12)

WiMAX Frequency Bands - TDD

Band Class	(GHz) BW (MHZ)	Bandwidth Certification Group Code (BCG)
1	**2.3-2.4**	
	8.75	1.A
	5 AND 10	1.B
2	**2.305-2.320, 2.345-2.360**	
	3.5	2.A (Obsolete, replaced by 2.D)
	5	2.B (Obsolete, replaced by 2.D)
	10	2.C (Obsolete, replaced by 2.D)
	3.5 AND 5 AND 10	2.D
3	**2.496-2.69**	
	5 AND 10	3.A
4	**3.3-3.4**	
	5	4.A
	7	4.B
	10	4.C
5	**3.4-3.8**	
	5	5.A
	7	5.B
	10	5.C
7	**0.698-0.862**	
	5 AND 7 AND 10	7.A
	8 MHz	7.F

WiMAX Forum Mobile Certification Profile v1.1.0

A universal frequency step size of 250 KHz is recommended for all band classes, while 200 KHz step size is also recommended for band class 3 in Europe.

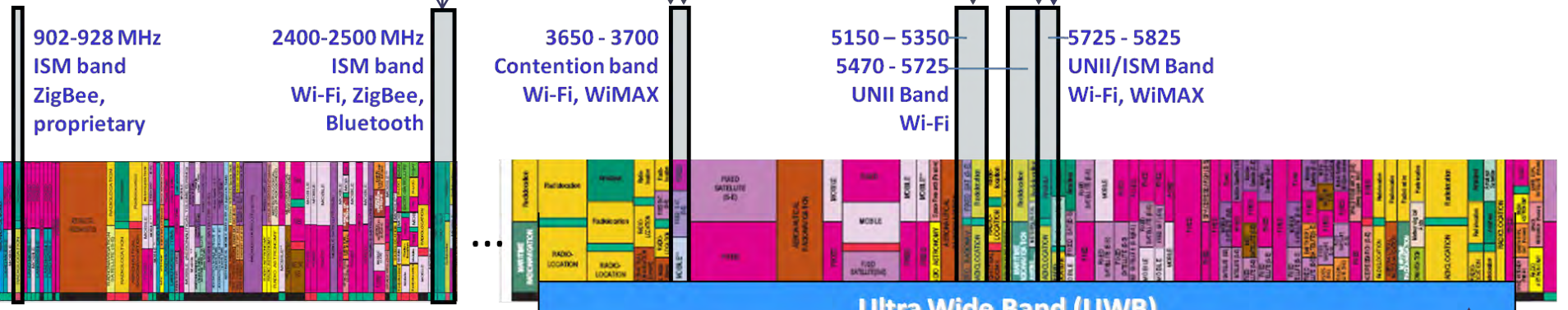
WiMAX Frequency Bands - FDD

Band Class	(GHz)BW (MHZ)	Duplexing Mode BS	Duplexing Mode MS	MS Transmit Band (MHz)	BS Transmit Band (MHz)	Bandwidth Certification Group Code (BCG)
2	**2.305-2.320, 2.345-2.360**					
	2x3.5 AND 2x5 AND 2x10	FDD	HFDD	2345-2360	2305-2320	2.E**
	5 UL, 10 DL	FDD	HFDD	2345-2360	2305-2320	2.F**
3	**2.496-2.690**					
	2x5 AND 2x10	FDD	HFDD	2496-2572	2614-2690	3.B
5	**3.4-3.8**					
	2x5 AND 2x7 AND 2x10	FDD	HFDD	3400-3500	3500-3600	5.D
6	**1.710-2.170 FDD**					
	2x5 AND 2x10	FDD	HFDD	1710-1770	2110-2170	6.A
	2x5 AND 2x10 AND Optional 2x20 MHz	FDD	HFDD	1920-1980	2110-2170	6.B
	2x5 AND 2x10 MHz	FDD	HFDD	1710-1785	1805-1880	6.C
7	**0.698-0.960**					
	2x5 AND 2x10	FDD	HFDD	776-787	746-757	7.B
	2x5	FDD	HFDD	788-793 AND 793-798	758-763 AND 763-768	7.C
	2x10	FDD	HFDD	788-798	758-768	7.D
	5 AND 7 AND 10 (TDD), 2x5 AND 2x7 AND 2x10 (H-FDD)	TDD or FDD	Dual Mode TDD/H-FDD	698-862	698-862	7.E*
	2x5 AND 2x10 MHz	FDD	HFDD	880-915	925-960	7.G
8	**1.710-2.170 TDD**					
	5 AND 10	TDD	TDD	1785-1805, 1880-1920, 1910-1930, 2010-2025	1785-1805, 1880-1920, 1910-1930, 2010-2025	8.A

Unlicensed Bands and Services

IEEE 802.11 (Wi-Fi) operates in the ISM-2400 and ISM-5800 bands and in the 5800 UNII band; recently standardized for 3650-3700 contention band

IEEE 802.16 (WiMAX) operates in the UNII/ISM band and in the 3500-3700 MHz contention band



ISM-900 traditionally used for consumer devices such as cordless phones, garage openers and baby monitors, now also used on smart meters

Cordless phones

UWB based WiMedia is a short-range network operating in the noise floor of other services

Standards-based

proprietary

FCC spectrum allocation chart
http://www.ntia.doc.gov/osmhome/allochrt.PDF

Unlicensed Bands and Services

Frequency range	Bandwidth	Band	Notes
433.05 – 434.79 MHz	1.74 MHz	ISM	Europe
420–450 MHz	30 MHz	Amateur	US
868-870 MHz	2 MHz	ISM	Europe
902–928 MHz	26 MHz	ISM-900	Region 2
2.4–2.5 GHz	100 MHz	ISM-2400	International allocations (see slides 7, 8 for details)
5.15–5.35 GHz	200 MHz	UNII-1,2	
5.47–5.725 GHz	255 MHz	UNII-2 ext.	
5.725–5.875 GHz	150 MHz	ISM-5800 UNII-3	
24–24.25 GHz	250 MHz	ISM	US, Europe
57-64 GHz 59-66 GHz	7 GHz	ISM	US Europe

Medical devices
Remote control

RFID and other unlicensed services

Smart meters, remote control, baby monitors, cordless phones

802.11b/g/n, Bluetooth
802.15.4 (Bluetooth, ZigBee), cordless phones

802.11a/n, cordless phones

Emerging 802.11ad
802.15.3c, ECMA-387
WirelessHD

TVB

Americas, including US and Canada; Australia, Israel

European analog of the ISM-900 band

ISM = industrial, scientific and medical
UNII = unlicensed national information infrastructure

Summary

- Wireless broadband industry will likely get some of the TV band spectrum
- Will it be licensed or unlicensed?
- For success of unlicensed White Spaces, significant bandwidth is needed with low barriers for inexpensive consumer technology (e.g. relaxed out of band emissions; simple rules)

For More Information

- White papers, presentations, articles and test reports on a variety of wireless topics

www.octoscope.com

White Space – Key FCC Documents

- FCC 08-260 2nd Report and Order and Memorandum Opinion and Order
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-08-260A1.pdf
- FCC DA-09-20 Erratum
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-287799A1.pdf
- FCC 10-174 2nd Memorandum Opinion and Order
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-174A1.pdf
- FCC Doc 302279 Erratum
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-302279A1.pdf
- FCC 10-16 Report and Order and Further Notice of Proposed Rulemaking
  - http://hraunfoss.fcc.gov/edocs_public/attachmatch/FCC-10-16A1.pdf
- Consolidation of above documents:
  - https://mentor.ieee.org/802.11/dcn/11/11-11-0067-00-00af-fcc-tvws-orders-jan-11-consolidated-text.pdf