Spectrum Management, Dynamic Spectrum Access and Cognitive Radio

Paul Sutton

5th March 2014

ICTP School on Applications of Open Spectrum and White Spaces Technologies

Software Radio Systems

CTVR the telecommunications research centre

Outline

- Spectrum Management
- Spectrum Policy Reform
- Dynamic Spectrum Access and Cognitive Radio

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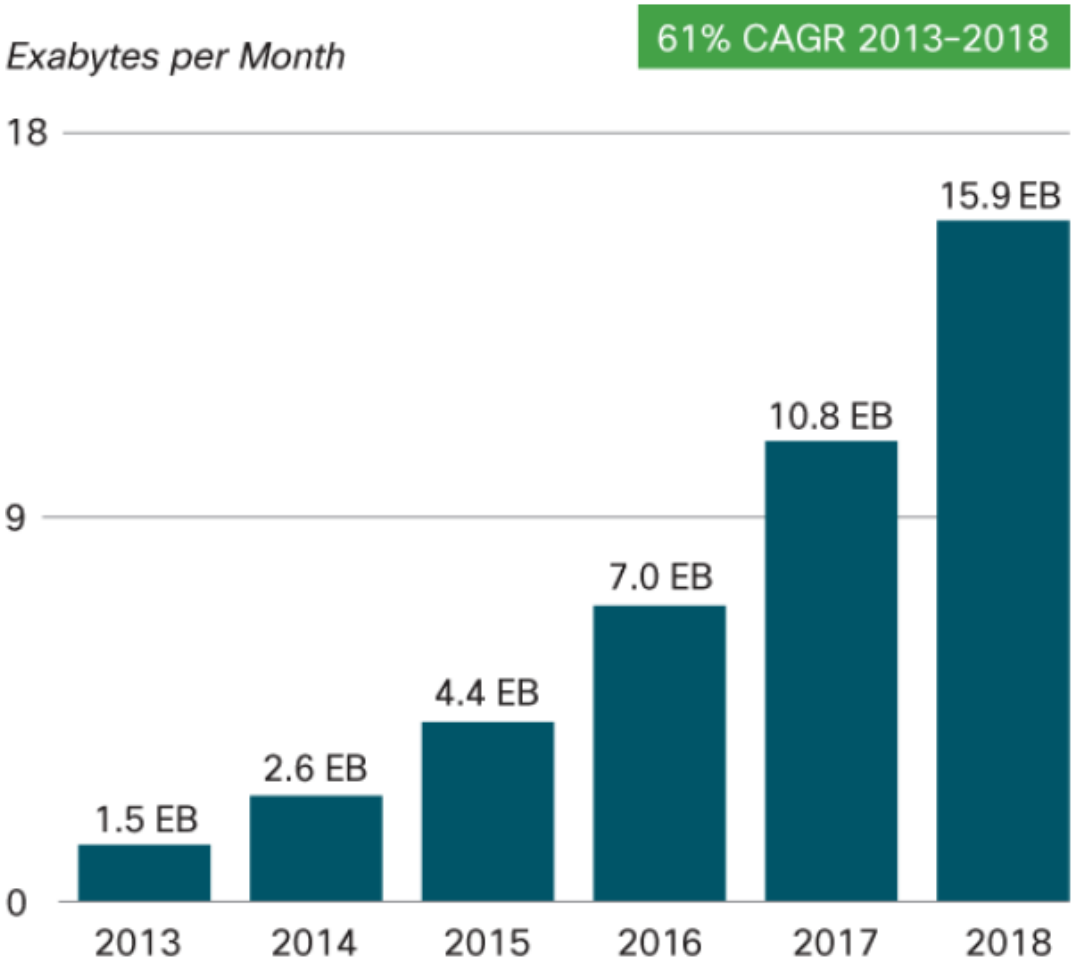
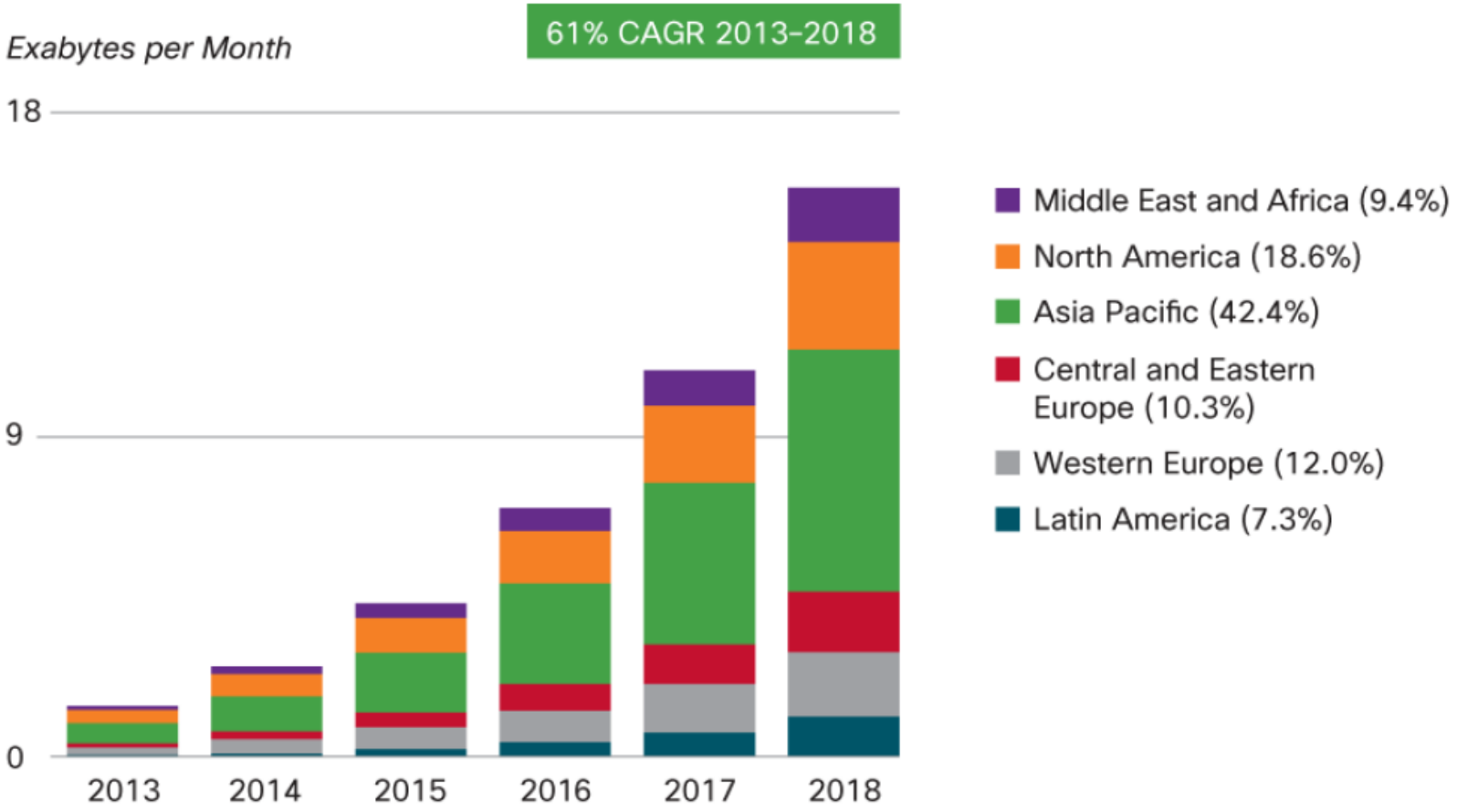
Figure 1. Cisco Forecasts 15.9 Exabytes per Month of Mobile Data Traffic by 2018



Source: Cisco VNI Mobile, 2014

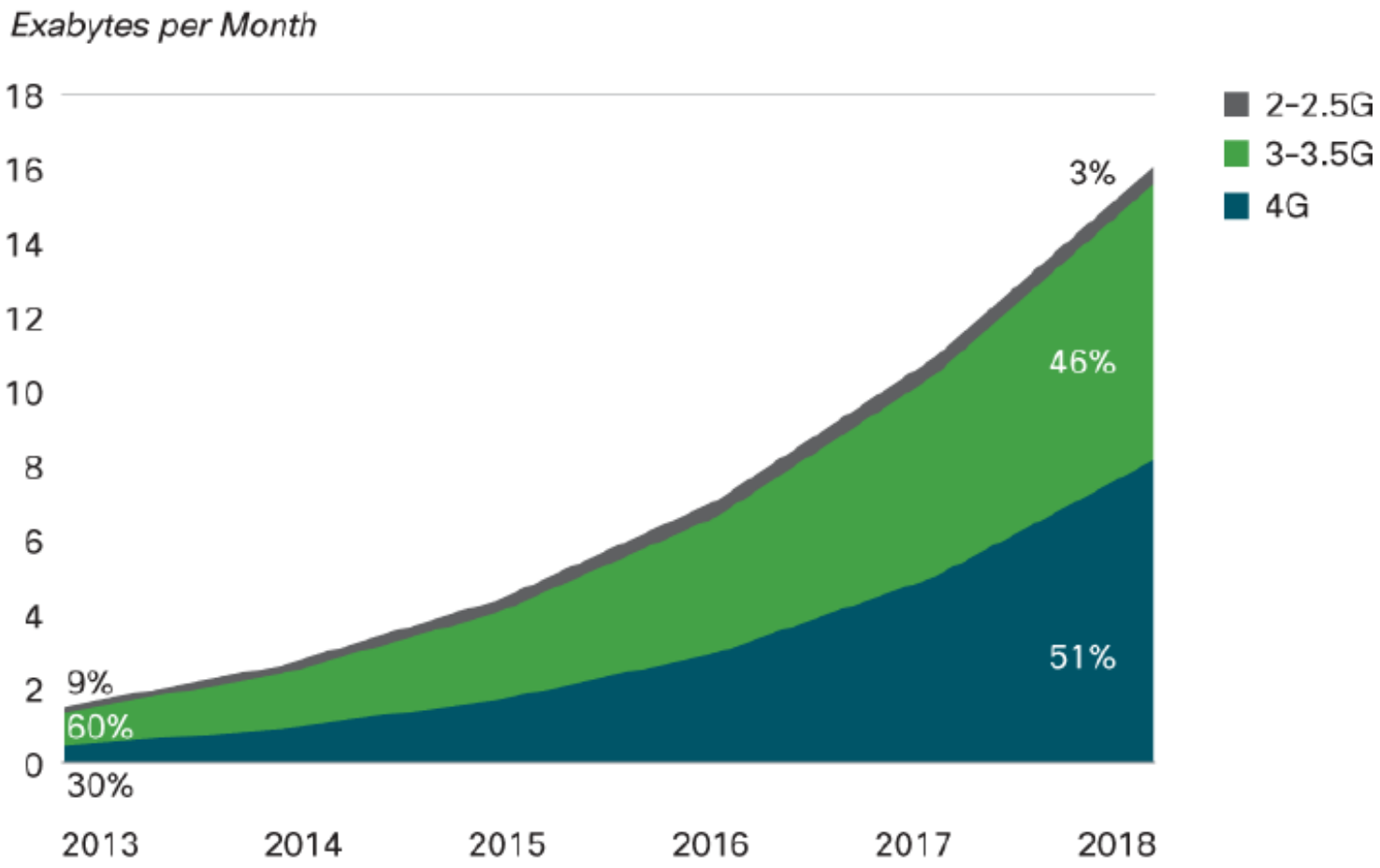
Figure 2. Global Mobile Data Traffic Forecast by Region



Figures in parentheses refer to regional share in 2018.

Source: Cisco VNI Mobile, 2014

Figure 13. 51 Percent of Total Mobile Data Traffic Will Be 4G by 2018



Source: Cisco VNI Mobile, 2014

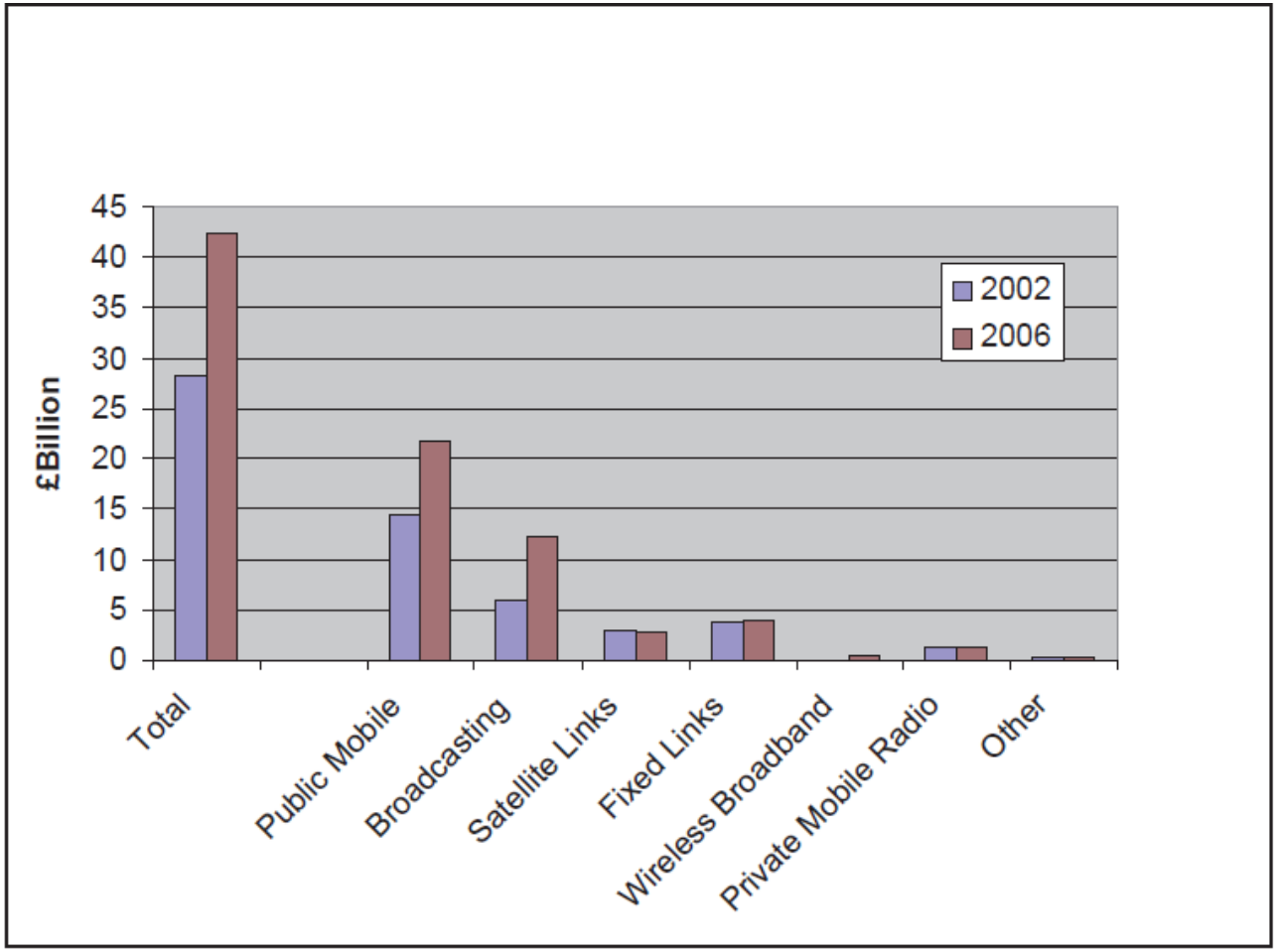


Fig. 2.2: Economic Impact of the Use of Radio Spectrum in the UK. Source:[2, 3]

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM

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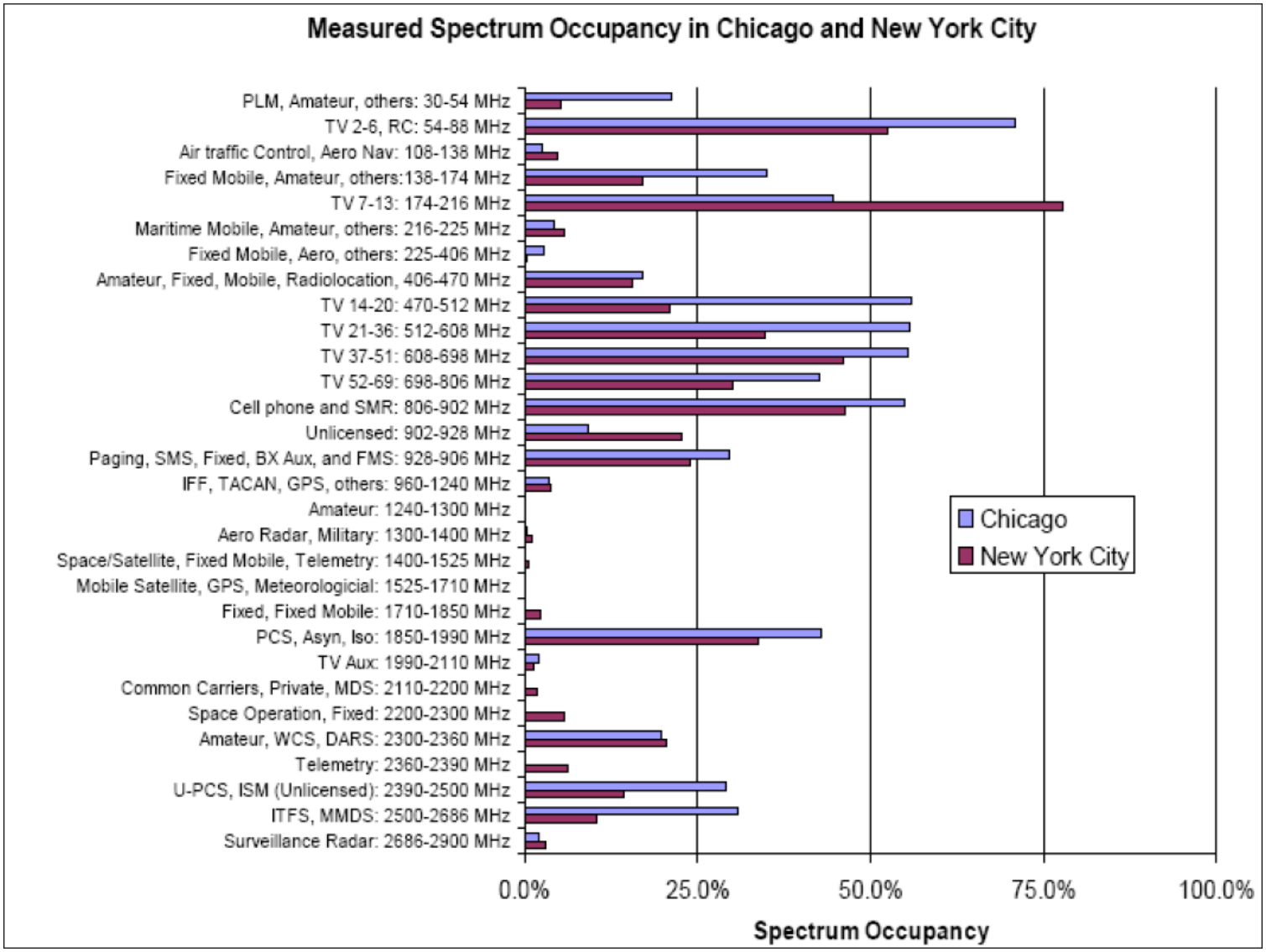
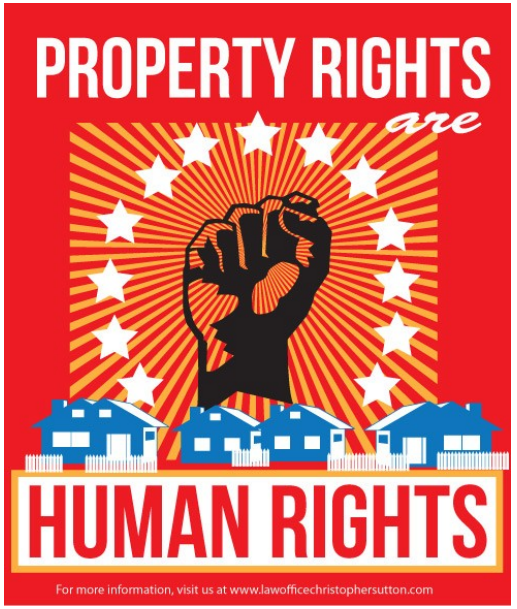
GOING...
GOING...


Measured Spectrum Occupancy in Chicago and New York City
PLM, Amateur, others: 30-54 MHz
TV 2-6, RC: 54-88 MHz
Air traffic Control, Aero Nav: 108-138 MHz
Fixed Mobile, Amateur, others:138-174 MHz
TV 7-13: 174-216 MHz
Maritime Mobile, Amateur, others: 216-225 MHz
Fixed Mobile, Aero, others: 225-406 MHz
Amateur, Fixed, Mobile, Radiolocation, 406-470 MHz
TV 14-20: 470-512 MHz
TV 21-36: 512-608 MHz
TV 37-51: 608-698 MHz
TV 52-69: 698-806 MHz
Cell phone and SMR: 806-902 MHz
Unlicensed: 902-928 MHz
Paging, SMS, Fixed, BX Aux, and FMS: 928-906 MHz
IFF, TACAN, GPS, others: 960-1240 MHz
Amateur: 1240-1300 MHz
Aero Radar, Military: 1300-1400 MHz
Space/Satellite, Fixed Mobile, Telemetry: 1400-1525 MHz
Mobile Satellite, GPS, Meteorologicial: 1525-1710 MHz
Fixed, Fixed Mobile: 1710-1850 MHz
PCS, Asyn, Iso: 1850-1990 MHz
TV Aux: 1990-2110 MHz
Common Carriers, Private, MDS: 2110-2200 MHz
Space Operation, Fixed: 2200-2300 MHz
Amateur, WCS, DARS: 2300-2360 MHz
Telemetry: 2360-2390 MHz
U-PCS, ISM (Unlicensed): 2390-2500 MHz
ITFS, MMDS: 2500-2686 MHz
Surveillance Radar: 2686-2900 MHz
Chicago
New York City
0.0%
25.0%
50.0%
75.0%
100.0%
Spectrum Occupancy

Outline

- Spectrum Management
- Spectrum Policy Reform
- Dynamic Spectrum Access and Cognitive Radio


PRIVATE PROPERTY
--NO--
TRESPASSING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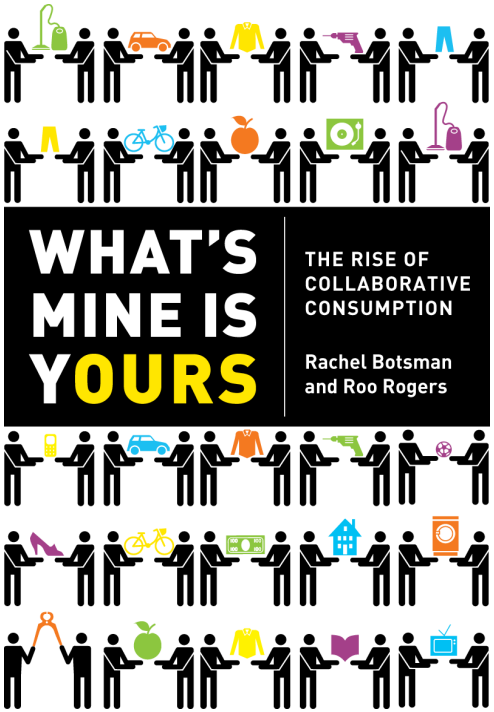
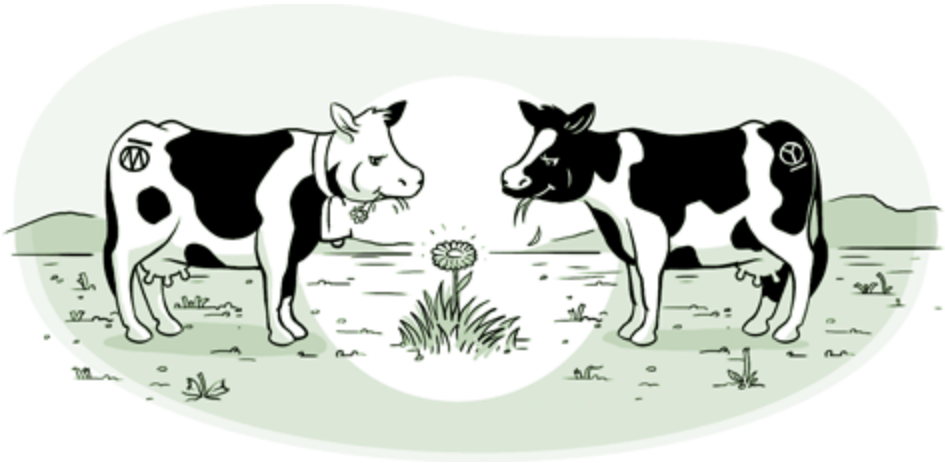
are
HUMAN RIGHTS
For more information, visit us at www.lawofficechristophersutton.com


FILLED WITH GOOD OL' LIBERTARIAN SPIRIT...
HORSEY
WHAT'S MINE IS MINE!
THE REST OF YOU CAN GO TO HELL.
SCRAM


WHAT'S MINE IS YOURS
THE RISE OF COLLABORATIVE CONSUMPTION
Rachel Botsman and Roo Rogers



Exclusive Use / Property Rights ← → **Commons / Open Spectrum**

1951 **Herzel** - "Public Interest" and the Market in Color Television Regulation

1959 **Coase** - The Federal Communications Commission

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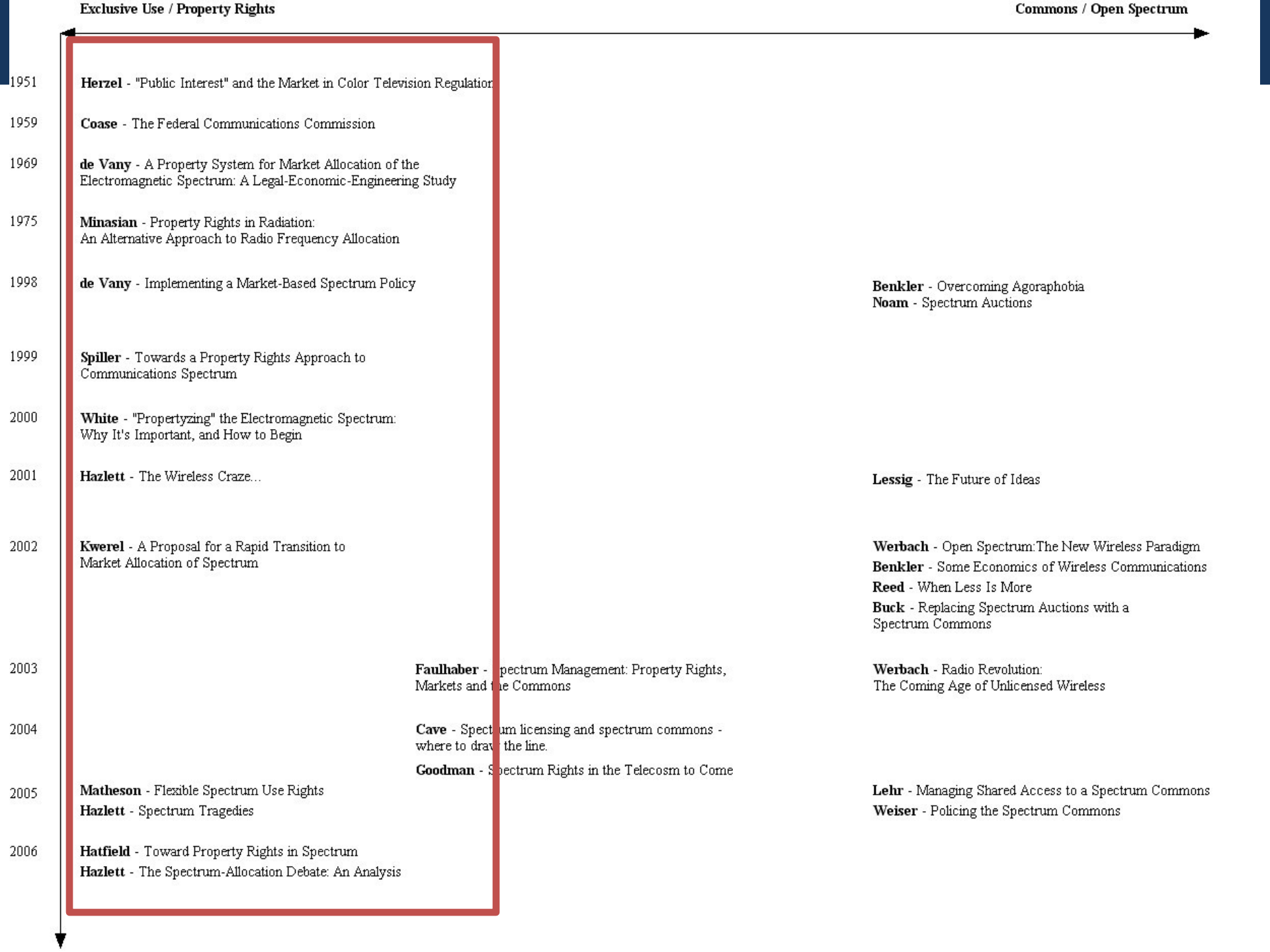
Lehr - Managing Shared Access to a Spectrum Commons
Weiser - Policing the Spectrum Commons

2006 **Hatfield** - Toward Property Rights in Spectrum
Hazlett - The Spectrum-Allocation Debate: An Analysis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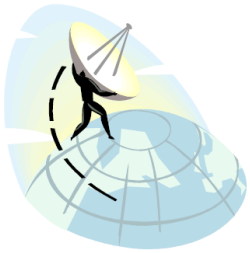
Spectrum Policy Task Force

REPORT

ET Docket No. 02- 135

November 2002



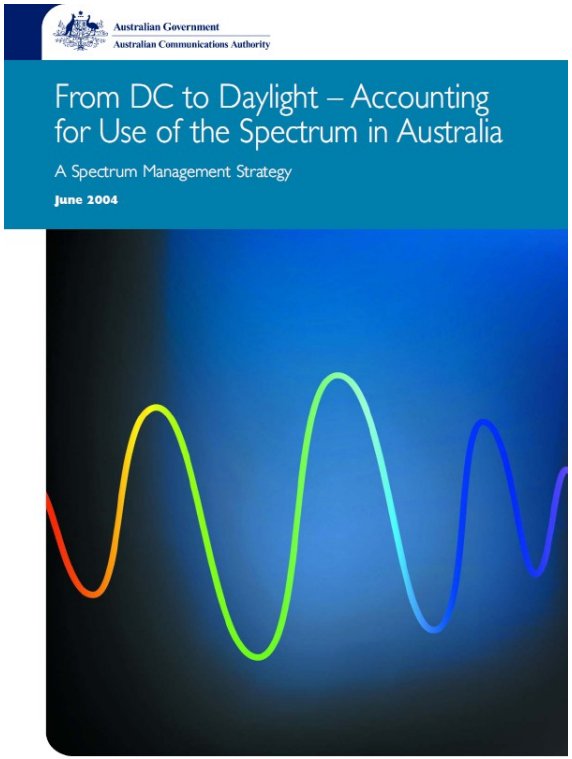
Federal Communications Commission

Review of Radio Spectrum Management

An independent review for
Department of Trade and Industry
and HM Treasury

by Professor Martin Cave

March 2002



SRS Software Radio Systems

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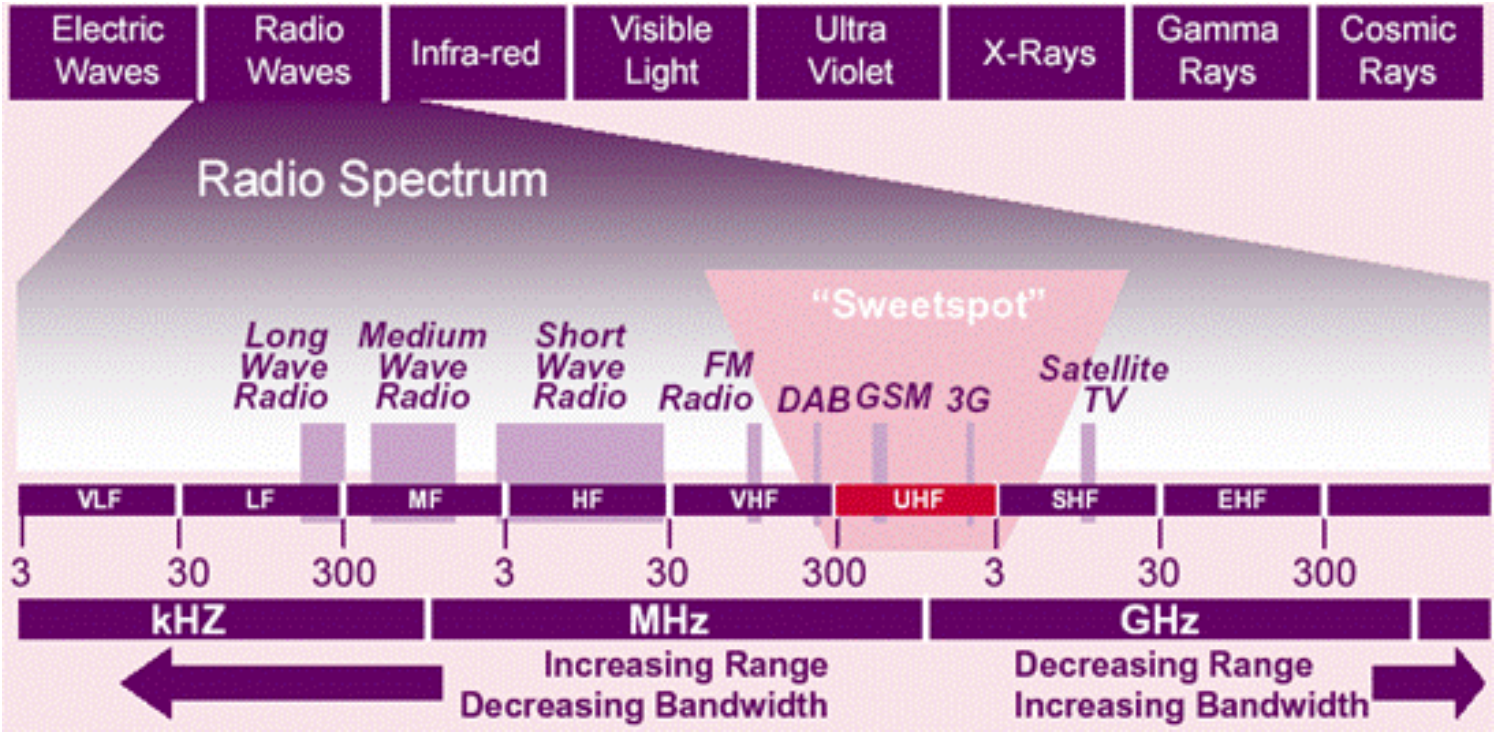
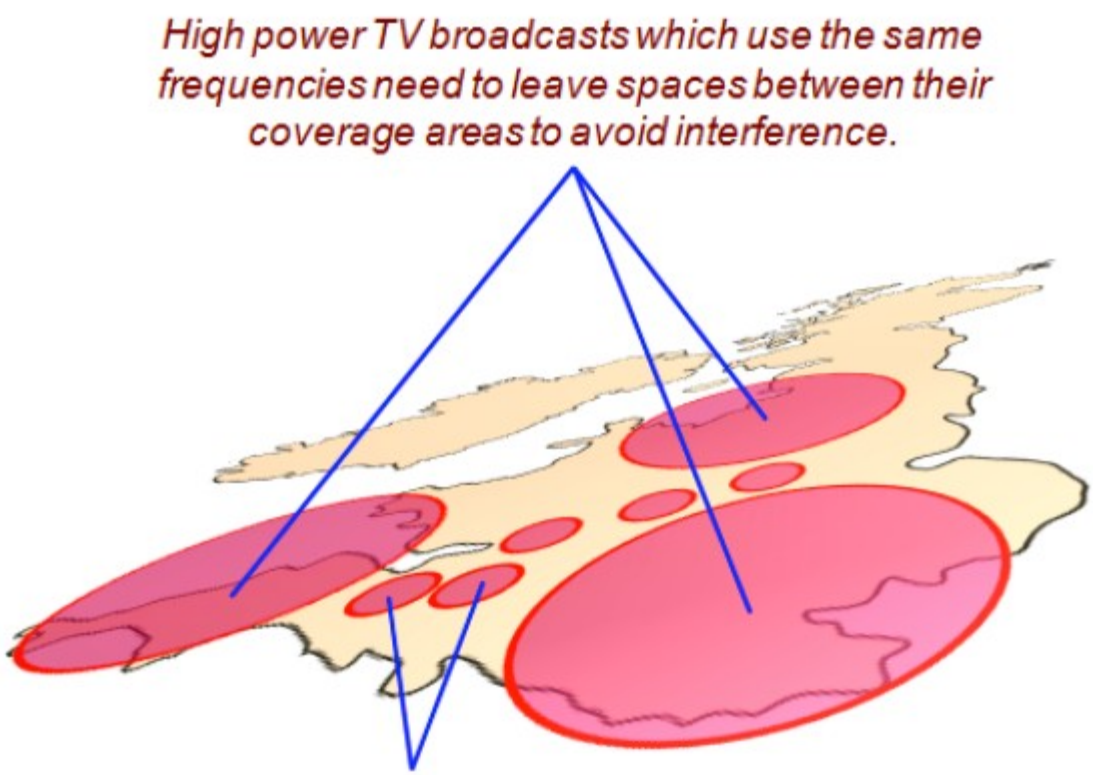
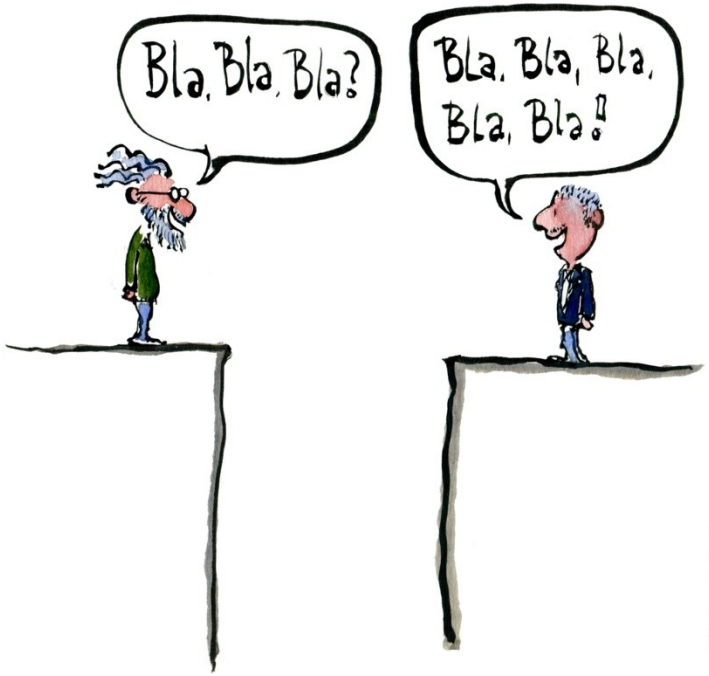

Electric Waves
Radio Waves
Infra-red
Visible Light
Ultra Violet
X-Rays
Gamma Rays
Cosmic Rays
Radio Spectrum
"Sweetspot"
Long Wave Radio
Medium Wave Radio
Short Wave Radio
FM Radio
DAB
GSM
3G
Satellite TV
VLF
LF
MF
HF
VHF
UHF
SHF
EHF
3
30
300
3
30
300
3
30
300
kHZ
MHz
GHz
Increasing Range
Decreasing Bandwidth
Decreasing Range
Increasing Bandwidth

Figure 1. UHF Bands IV and V after DSO per current proposals



Interleaved spectrum and TV white spaces.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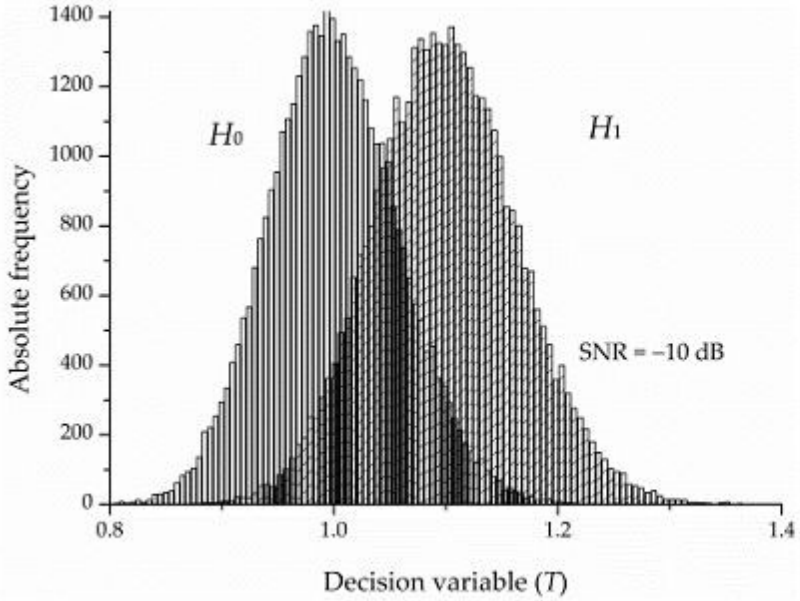
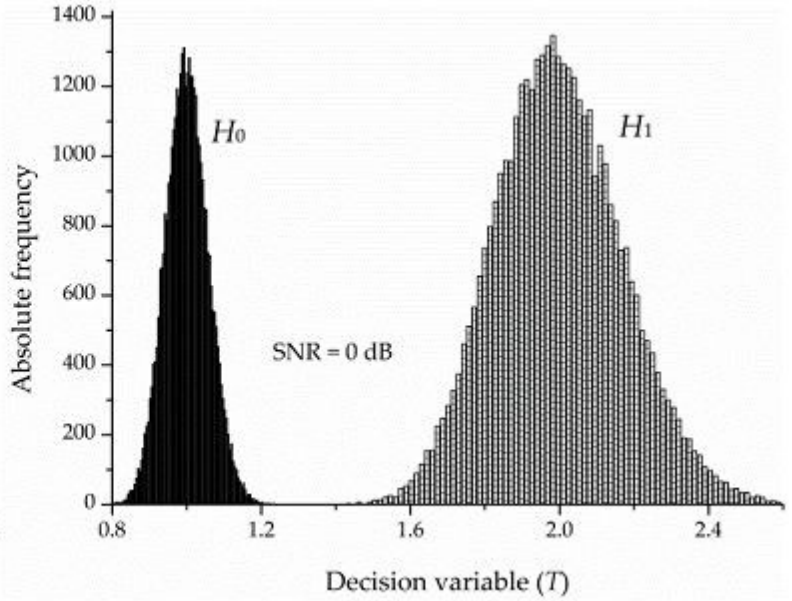
Bla, Bla, Bla, Bla, Bla!
HikingArtist


1400
1200
1000
800
600
400
200
0
Absolute frequency
H_0
H_1
SNR = –10 dB
0.8
1.0
1.2
1.4
Decision variable (T)


1400
1200
1000
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200
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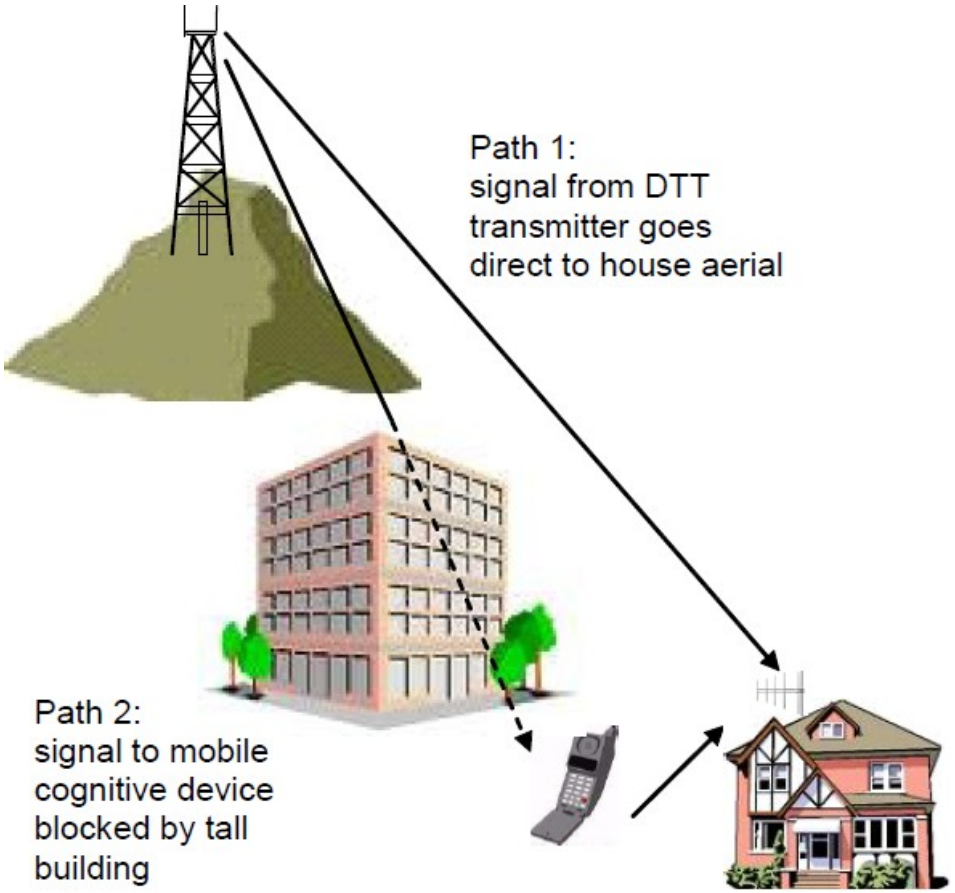
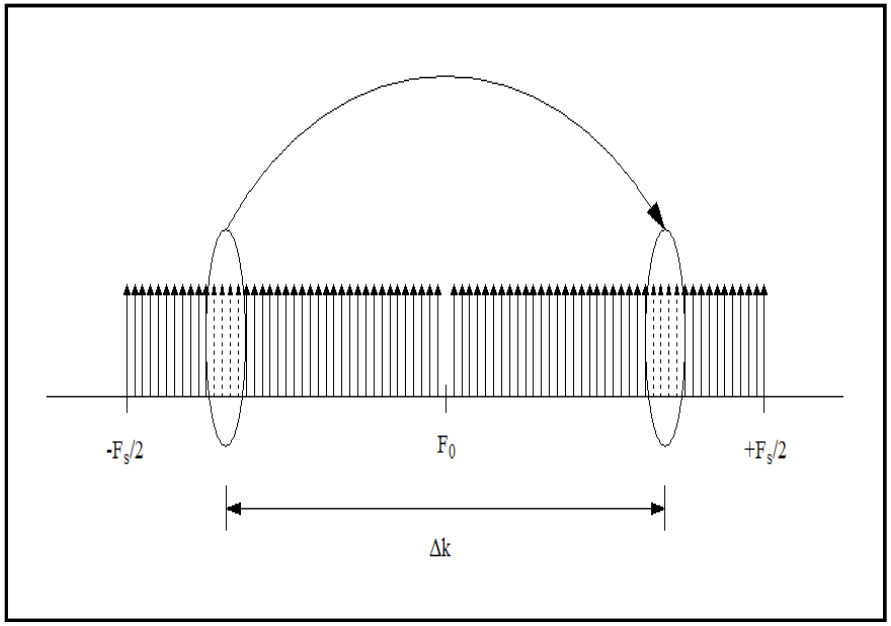
Absolute frequency
H_0
H_1
SNR = 0 dB
0.8
1.2
1.6
2.0
2.4
Decision variable (T)


Path 1:
signal from DTT
transmitter goes
direct to house aerial
Path 2:
signal to mobile
cognitive device
blocked by tall
building
Path 3:
signal from mobile cognitive
device to house aerial


visualparadox.com


-Fs/2
F0
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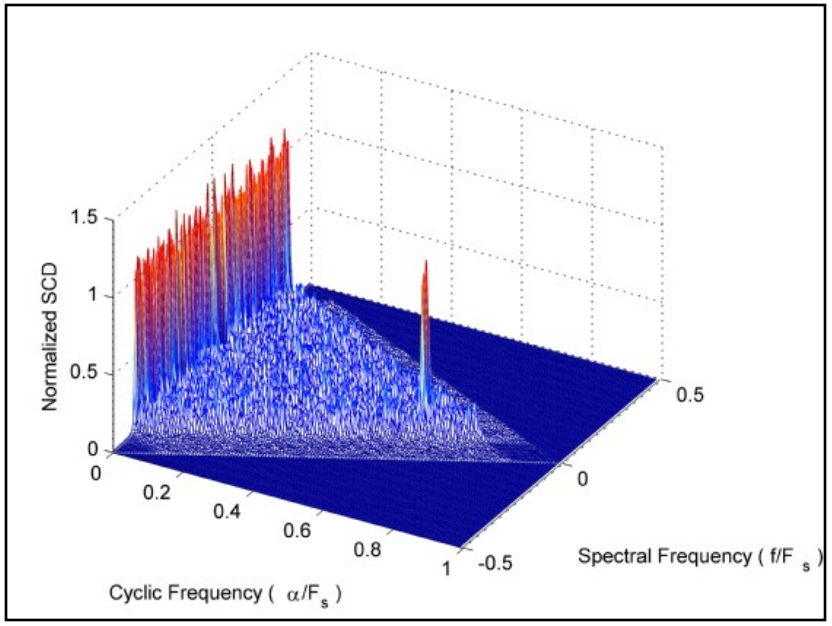
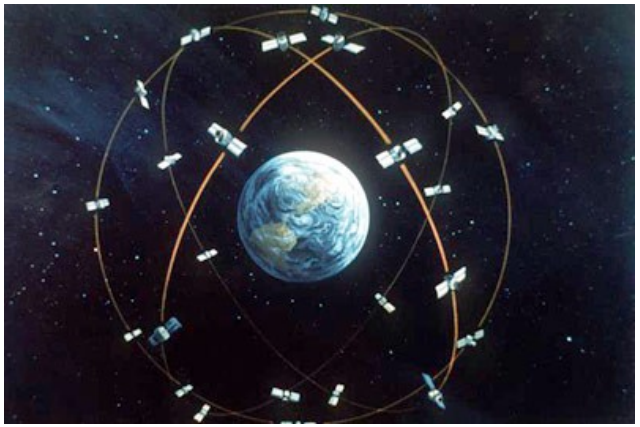
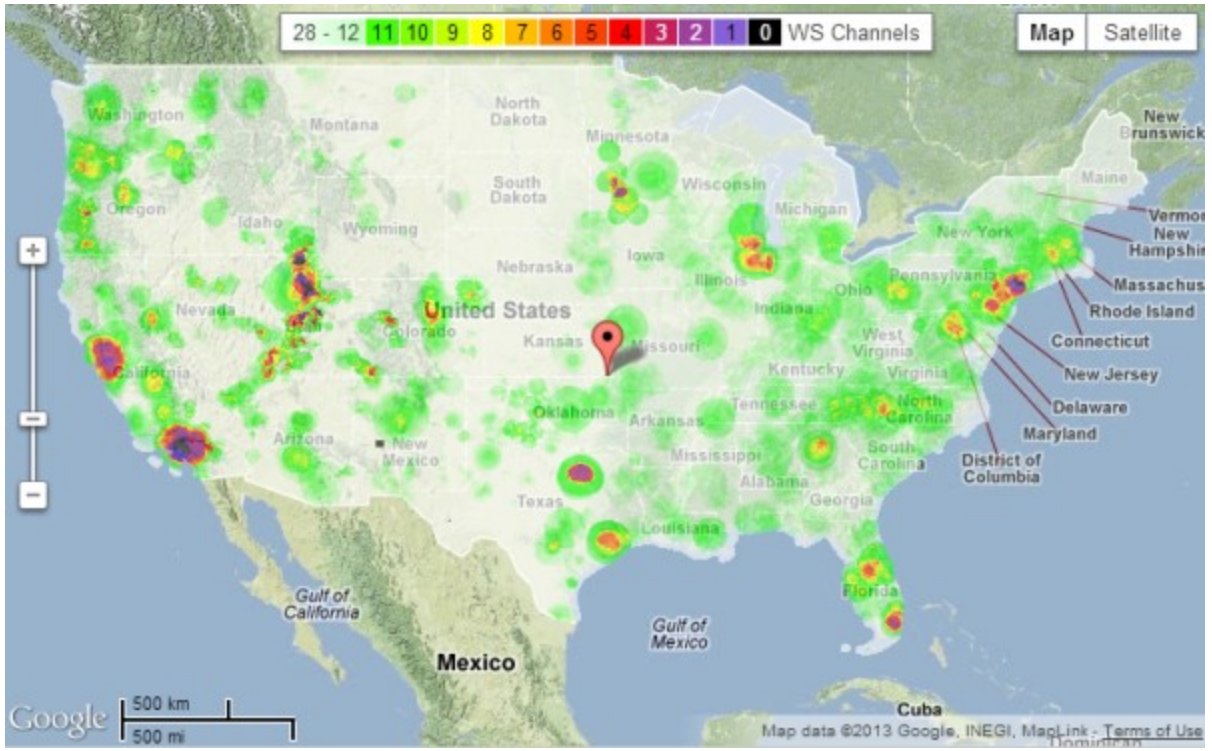
Δk


Normalized SCD
1.5
1
0.5
0
0
0.2
0.4
0.6
0.8
1
Cyclic Frequency (α/Fs)
0.5
0
-0.5
Spectral Frequency (f/Fs)




28 - 12 11 10 9 8 7 6 5 4 3 2 1 0 WS Channels
Map
Satellite
United States
Mexico
Gulf of California
Gulf of Mexico
Cuba
Washington
Montana
North Dakota
Minnesota
Oregon
South Dakota
Wisconsin
Michigan
Idaho
Wyoming
Nebraska
Iowa
Illinois
Nevada
Colorado
Kansas
Missouri
Indiana
Ohio
Pennsylvania
New York
Maine
West Virginia
Kentucky
Virginia
Tennessee
North Carolina
Oklahoma
Arkansas
Arizona
New Mexico
Mississippi
South Carolina
Alabama
Georgia
Texas
Louisiana
Florida
New Brunswick
Massachus
Rhode Island
Connecticut
New Jersey
Delaware
Maryland
District of Columbia
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500 mi
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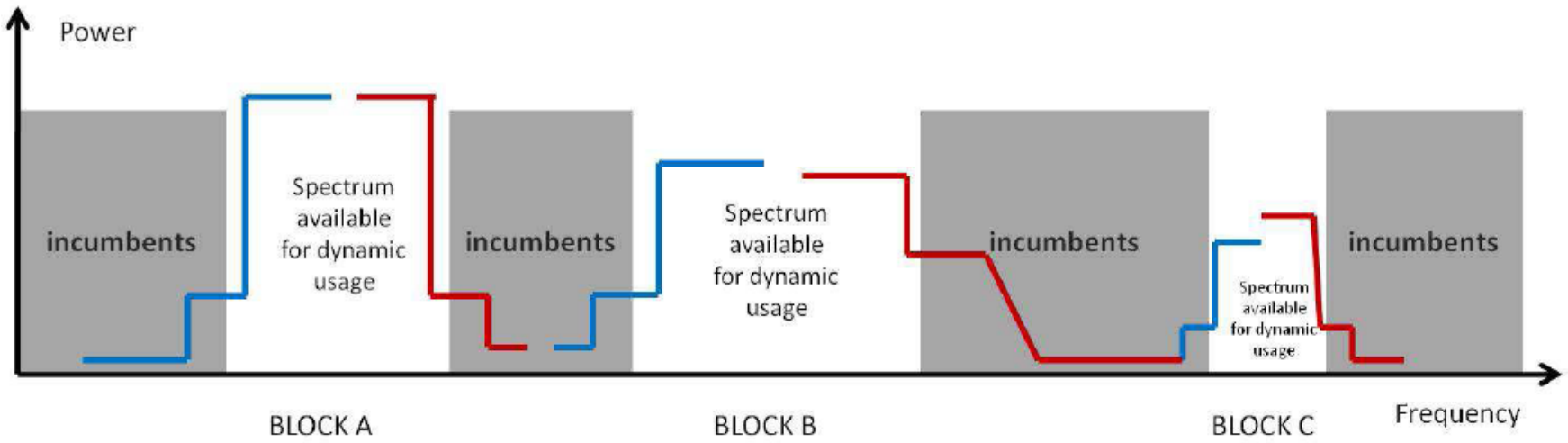
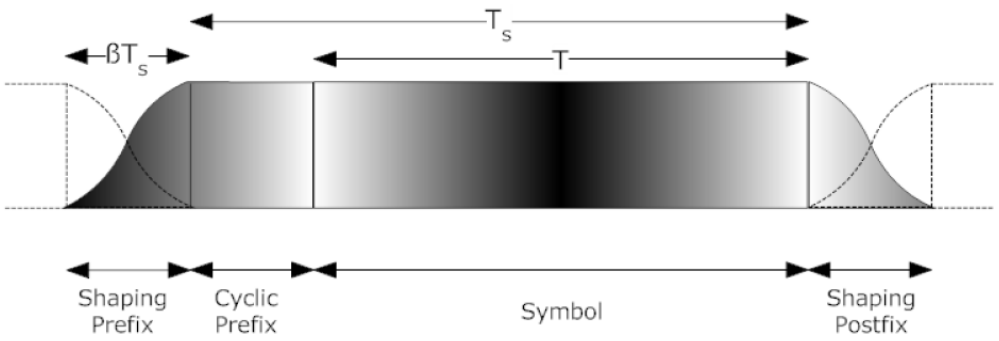
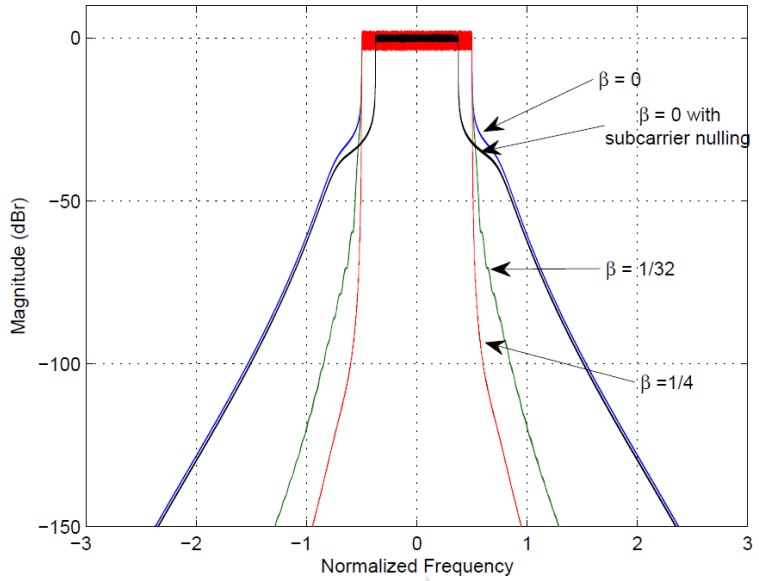
tumblr.
Like
velp







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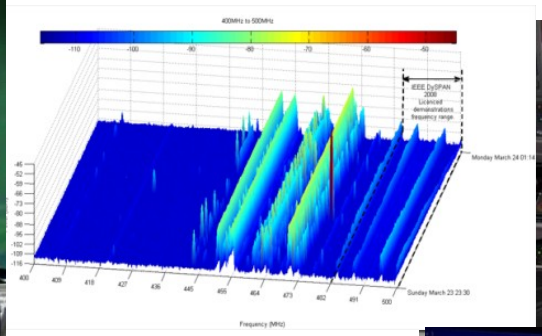
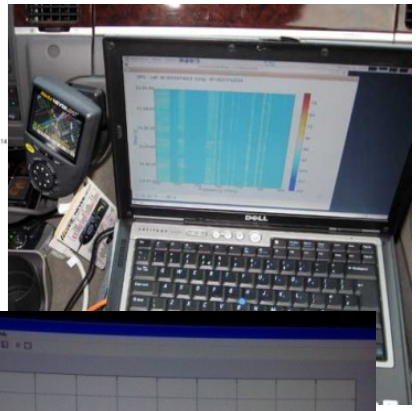
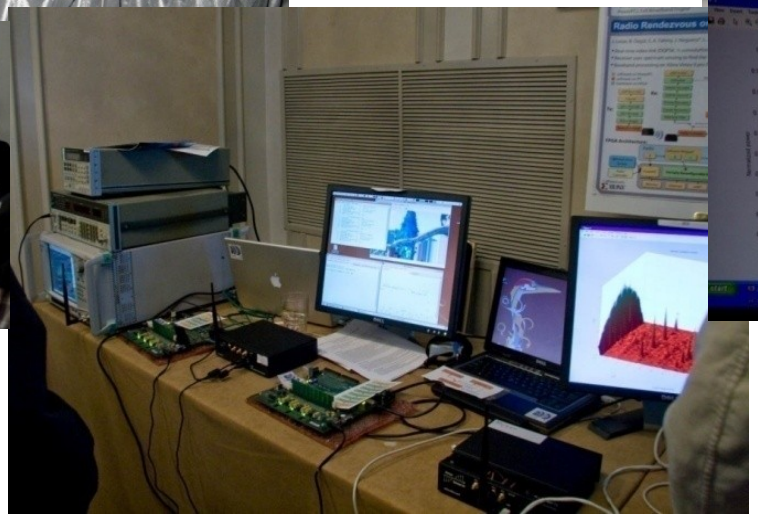
IEEE DySPAN 2007

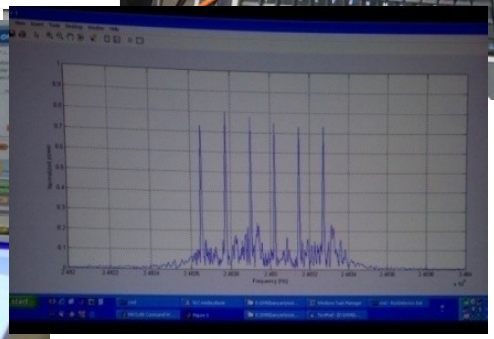
SDR forum

DySPAN 2008
Dynamic Spectrum Access Networks









IEEE DySPAN 2012
Dynamic Spectrum Access Networks
OCTOBER 16-19, BELLEVUE, WASHINGTON, USA

IEEE DySPAN 2010
Dynamic Spectrum Access Networks

SRS Software Radio Systems

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Before the
Federal Communications Commission
Washington, D.C. 20554

In the Matter of	)	
	)	
Unlicensed Operation in the TV Broadcast Bands	)	ET Docket No. 04-186
	)	
Additional Spectrum for Unlicensed Devices Below 900 MHz and in the 3 GHz Band	)	ET Docket No. 02-380
	)	

SECOND REPORT AND ORDER AND MEMORANDUM OPINION AND ORDER

Adopted: November 4, 2008 **Released: November 14, 2008**

By the Commission: Chairman Martin, and Commissioners Copps, Adelstein, and McDowell issuing separate statements; Commissioner Tate approving in part, dissenting in part and issuing a statement.

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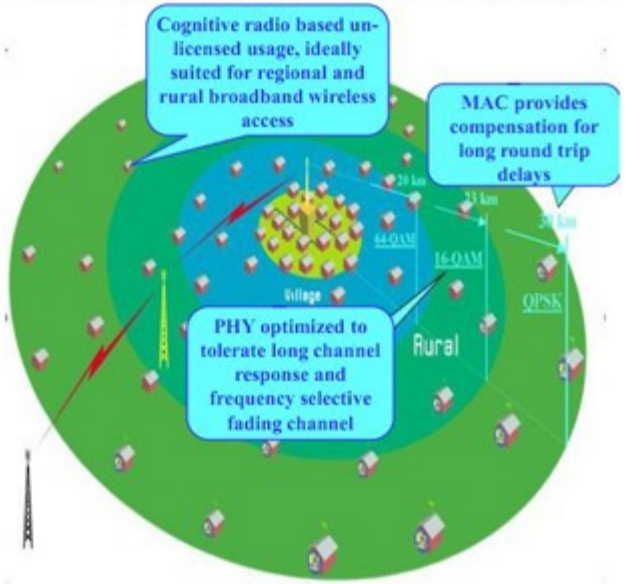
Wi Fi™

IEEE 802

Overview of the IEEE 802.22 Standard



IEEE WirelessMAN® 802.16

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DARPA *Spectrum* Challenge

DARPA *Spectrum* Challenge

"A competition to demonstrate a radio protocol that can best use a given communication channel in the presence of other dynamic users and interfering signals"

DARPA *Spectrum* Challenge

"A competition to demonstrate a radio protocol that can best use a given communication channel in the presence of other dynamic users and interfering signals"

• Use a standardized radio hardware platform (USRP N210).

• Head-to-head competitions between your radio protocol and an opponent's in a structured testbed environment.

• The best strategies for guaranteeing successful communication in the presence of other competing radios will win.

DARPA *Spectrum* Challenge

Multiple Phases:

- Qualification
- Wildcard selection
- Tournament
  - Competitive
  - Cooperative

DARPA *Spectrum* Challenge

Qualification:

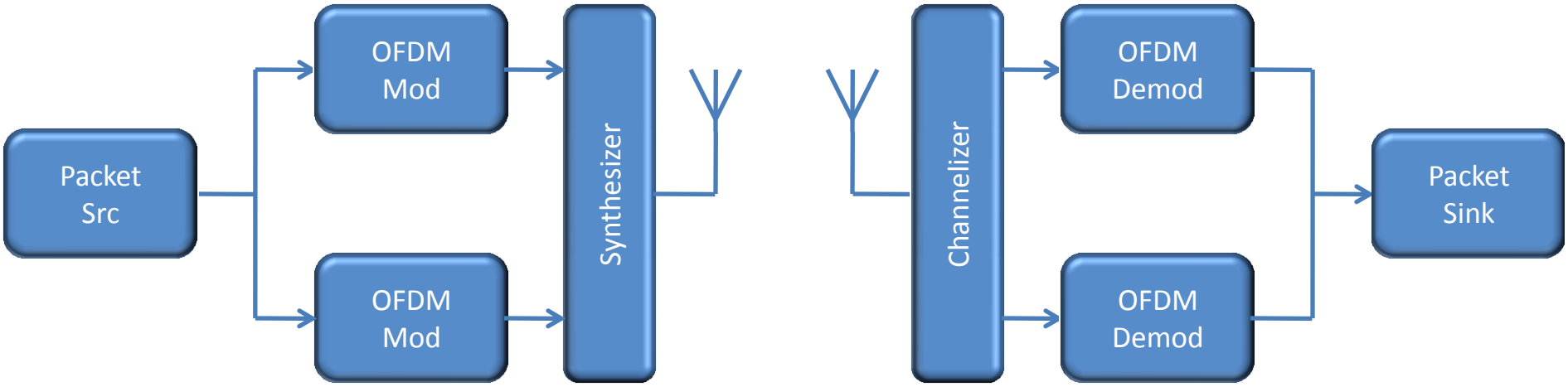
- Single radio pair (Transmitter – Receiver)
- Take input data from a source, packetize, transmit and receive.
- 2.5MHz band to operate in.
- Total number of correct packets received in 5 minutes.
- 3 types of possible interference (random time sequence):
  - N0 = one second period of no interference
  - N1 = one second period of short-term 1.25MHz band-limited white noise interference signal that resides in the lower half of the 2.5MHz band
  - N2 = one second of short-term 1.25MHz band-limited white noise interference signal that resides in the upper half of the 2.5MHz band.

DARPA *Spectrum* Challenge

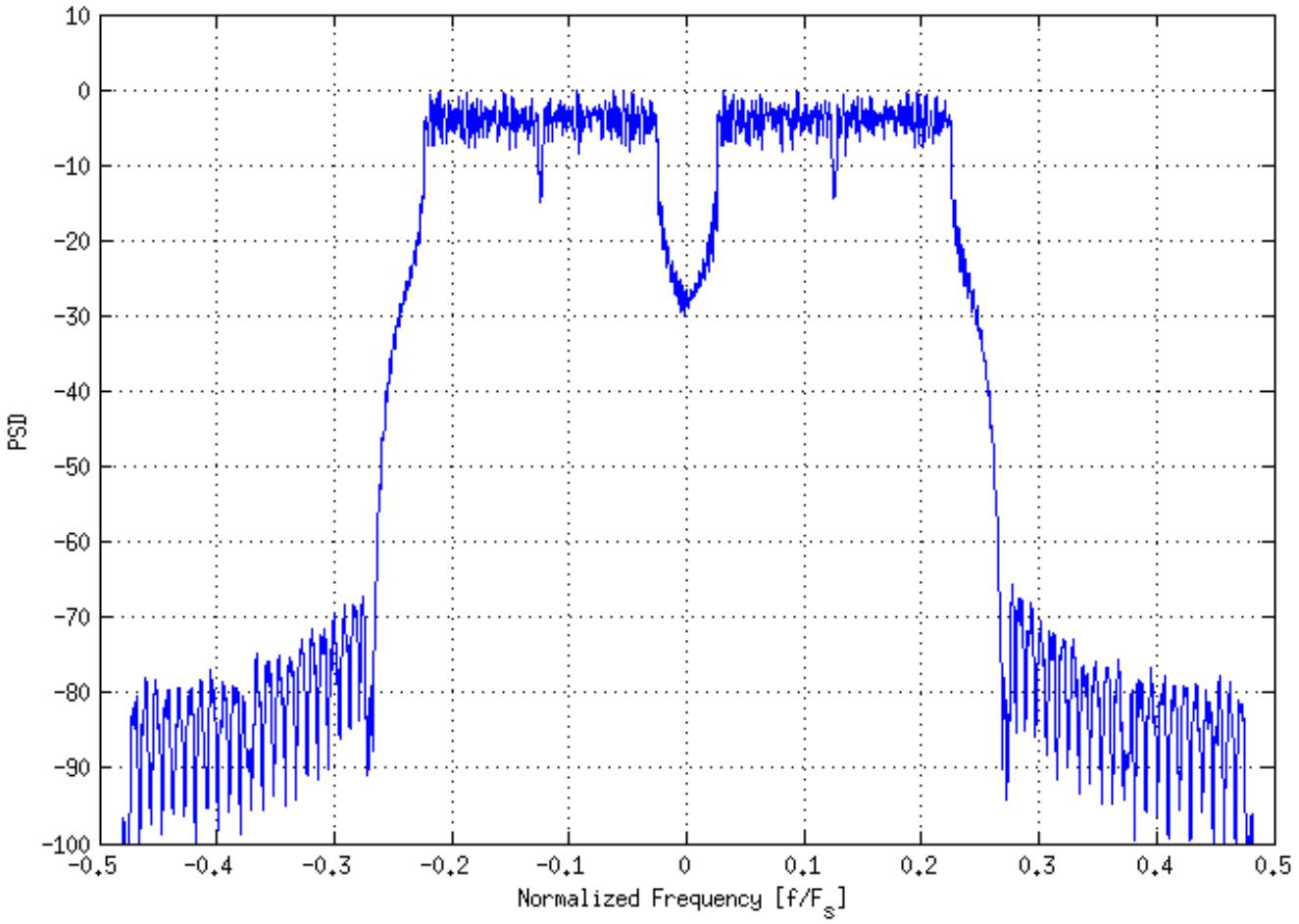
System Design?

- Simplex/Duplex?
- Robust waveform or detect & reconfigure?
- Single/Multi-carrier?
- Channelization?

DARPA *Spectrum* Challenge



DARPA *Spectrum* Challenge



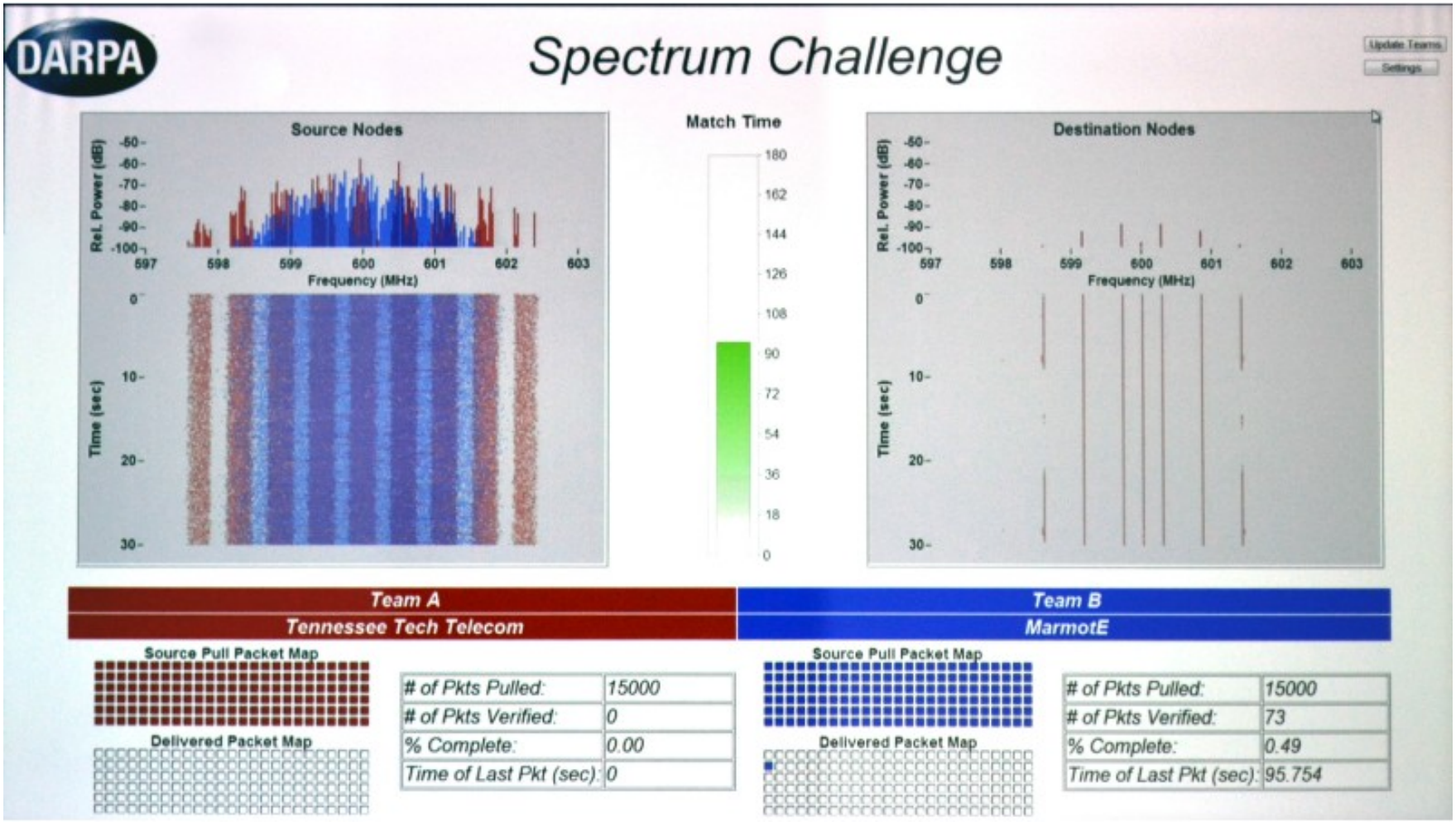
SR

ications

DARPA *Spectrum* Challenge

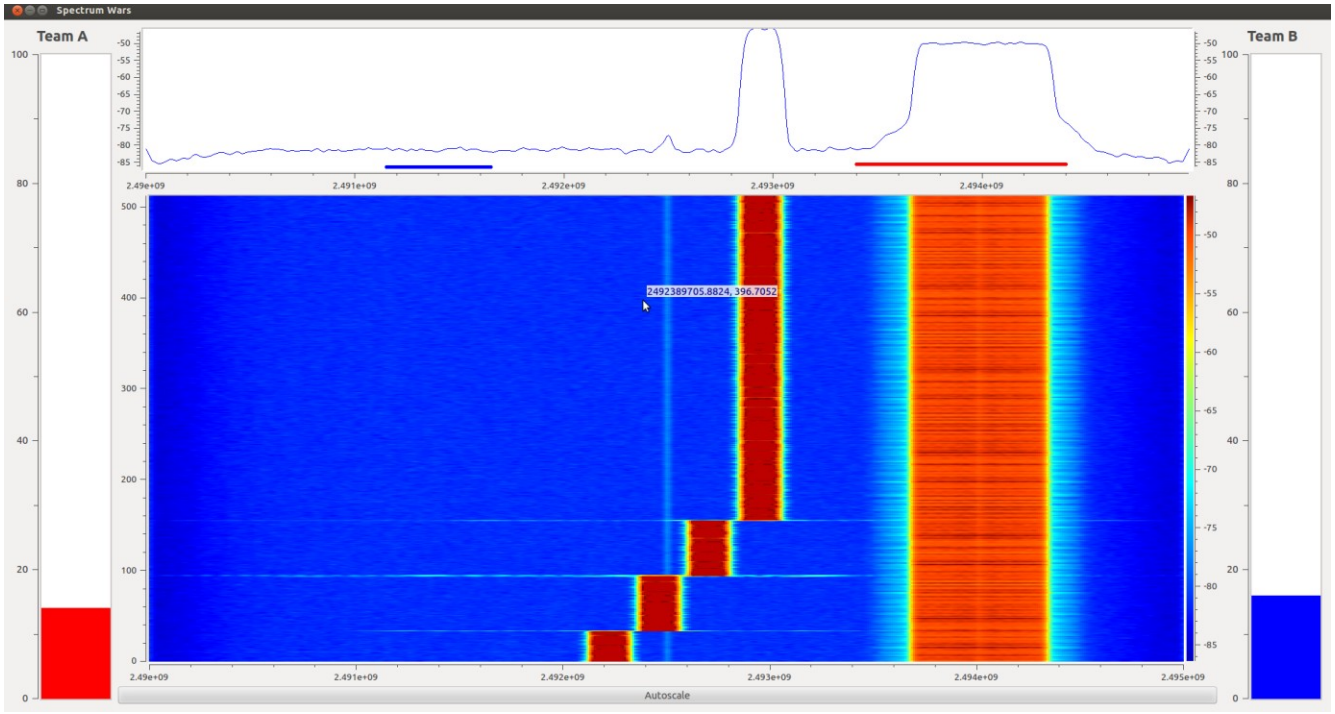
Wildcard Selection:

- Single radio pair (Transmitter – Receiver)
- Tested against “house radios” and other possible interferers.
- Transfer a data file *without errors* as fast as possible.
- Competitive match
  - Tested against single house radio pair.
  - Fastest team wins.
- Cooperative match
  - Tested with two house radio pairs.
  - Weighted average of time taken and the number of error-free packets received by *each radio pair*.


DARPA
Spectrum Challenge
Update Teams
Settings
Source Nodes
Rel. Power (dB)
-50
-60
-70
-80
-90
-100
597
598
599
600
601
602
603
Frequency (MHz)
Time (sec)
0
10
20
30
Match Time
180
162
144
126
108
90
72
54
36
18
0
Destination Nodes
Rel. Power (dB)
Frequency (MHz)
Time (sec)
Team A
Tennessee Tech Telecom
Source Pull Packet Map
Delivered Packet Map
# of Pkts Pulled: 15000
# of Pkts Verified: 0
% Complete: 0.00
Time of Last Pkt (sec): 0
Team B
MarmotE
Source Pull Packet Map
Delivered Packet Map
# of Pkts Pulled: 15000
# of Pkts Verified: 73
% Complete: 0.49
Time of Last Pkt (sec): 95.754

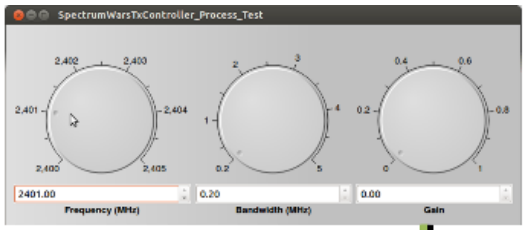
SPECTRUM WARS

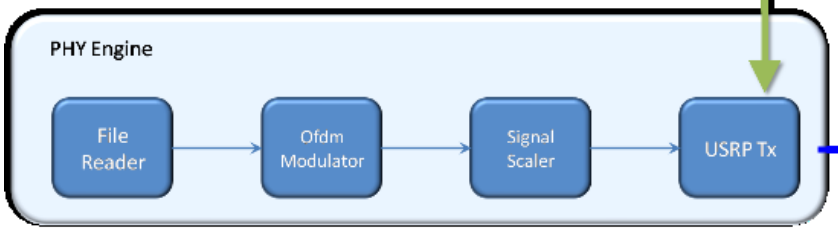
An Iris Demonstration

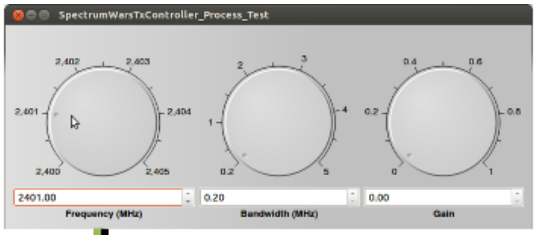


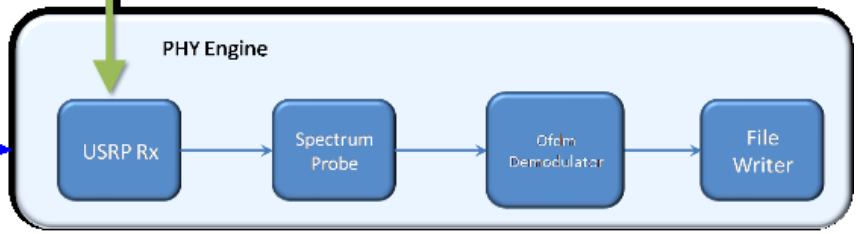
Software Radio Systems

CTVR the telecommunications research centre


SpectrumWarsTxController_Process_Test
2401.00
Frequency (MHz)
0.20
Bandwidth (MHz)
0.00
Gain


PHY Engine
File Reader
Ofdm Modulator
Signal Scaler
USRP Tx


SpectrumWarsTxController_Process_Test
2401.00
Frequency (MHz)
0.20
Bandwidth (MHz)
0.00
Gain


PHY Engine
USRP Rx
Spectrum Probe
Ofdm Demodulator
File Writer

Thanks for your attention

Questions?