A quantitative approach to spectrum regulation

Kate Harrison

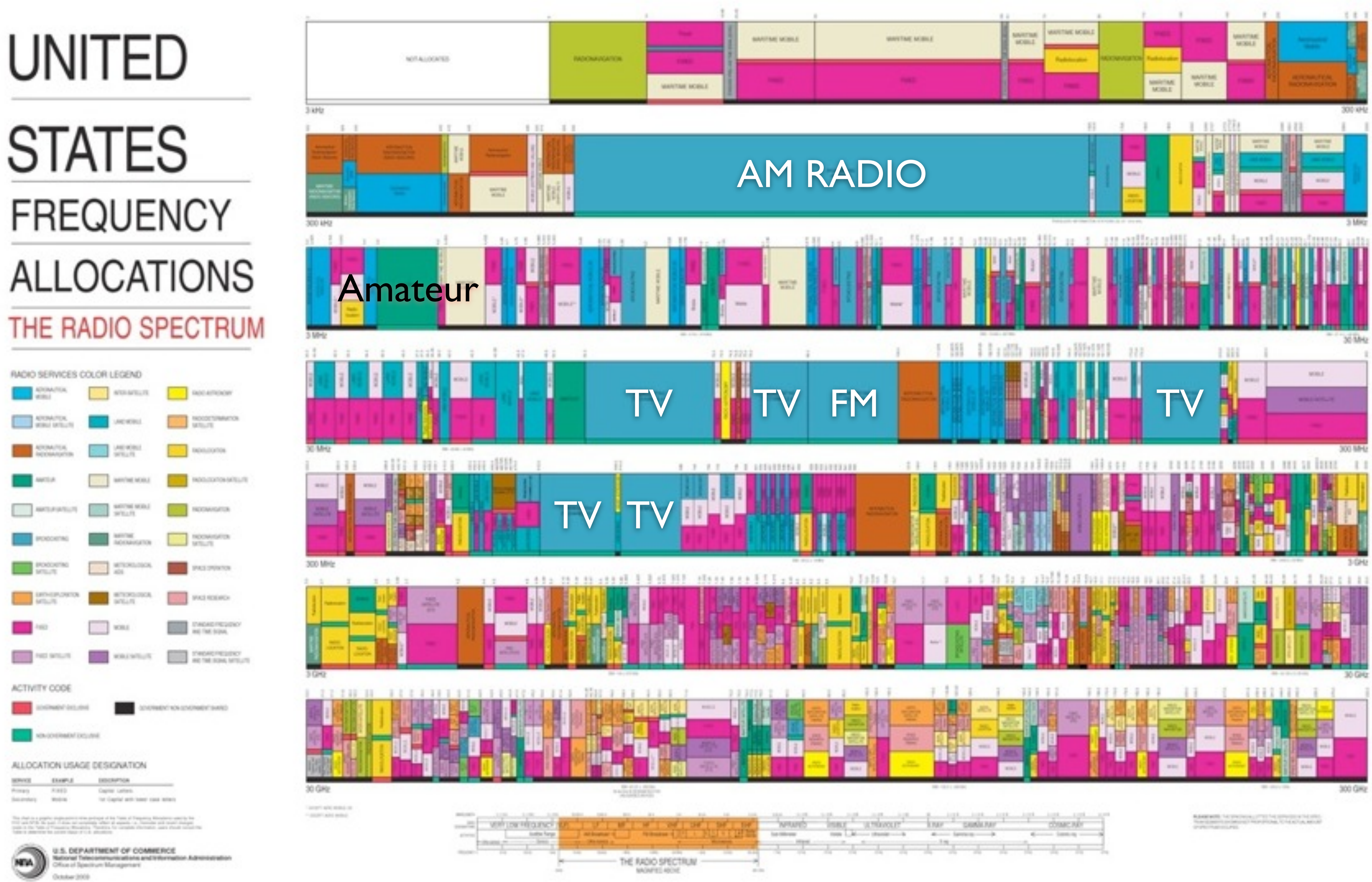
Dissertation talk

May 8, 2015

Outline

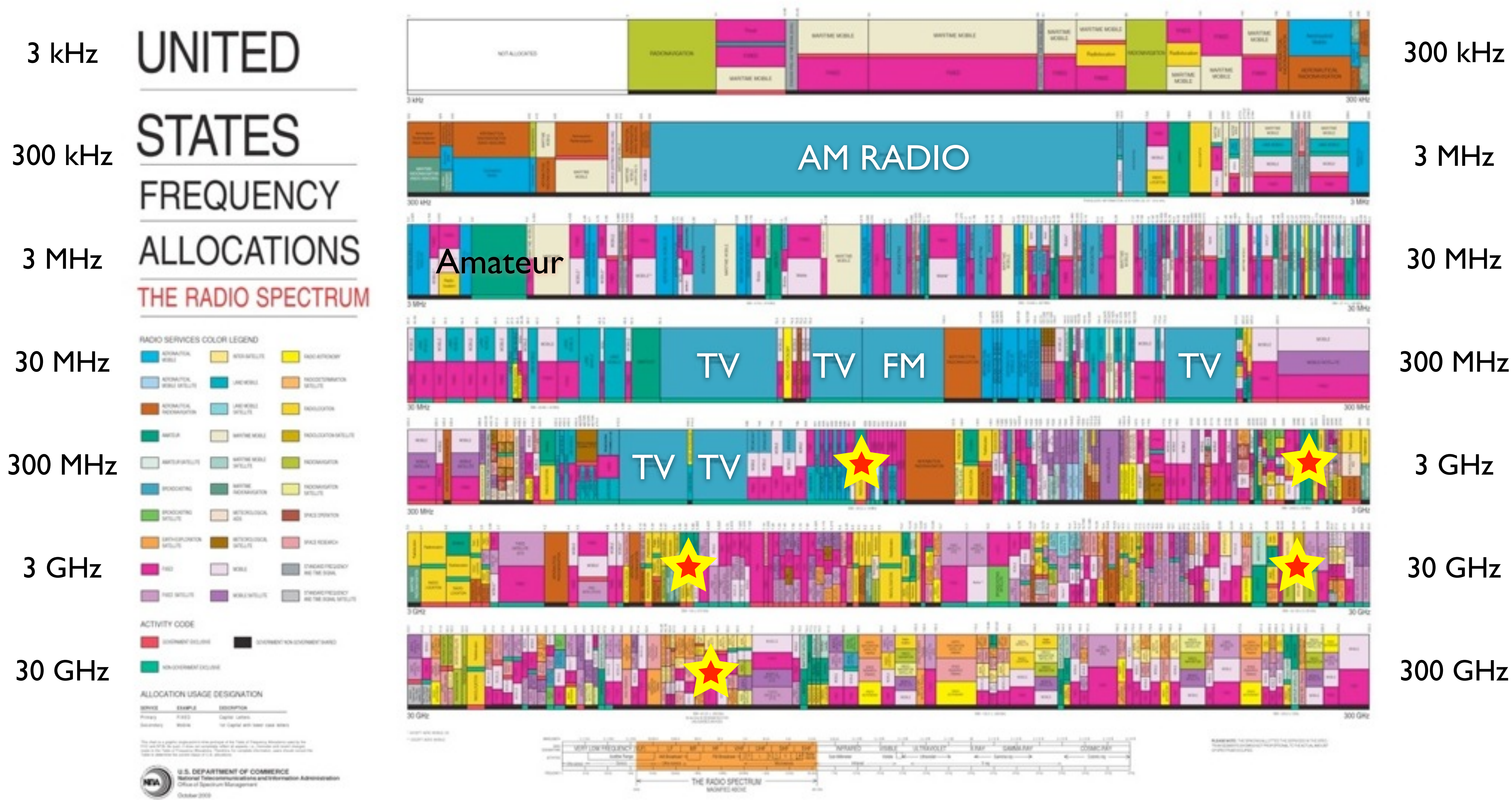
- Introduction to whitespaces
- Quantifying whitespaces
- Whitespace software
- Whitespace policy

Wireless spectrum today

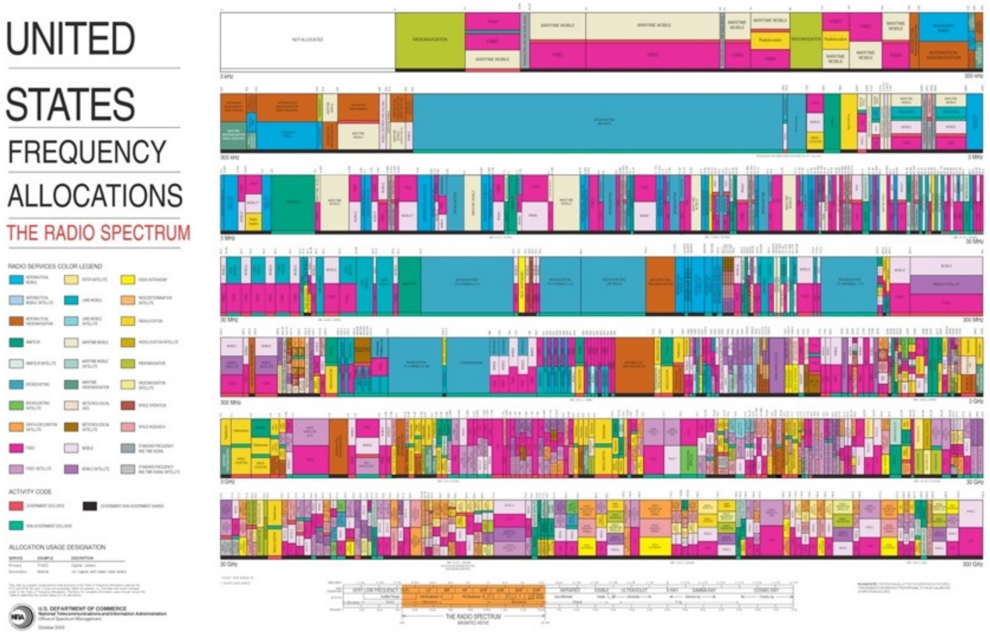


3 kHz – 300 kHz
300 kHz – 3 MHz
3 MHz – 30 MHz
30 MHz – 300 MHz
300 MHz – 3 GHz
3 GHz – 30 GHz
30 GHz – 300 GHz

Wireless spectrum today



Whitespaces correct a mismatch



2011 US spectrum allocation chart

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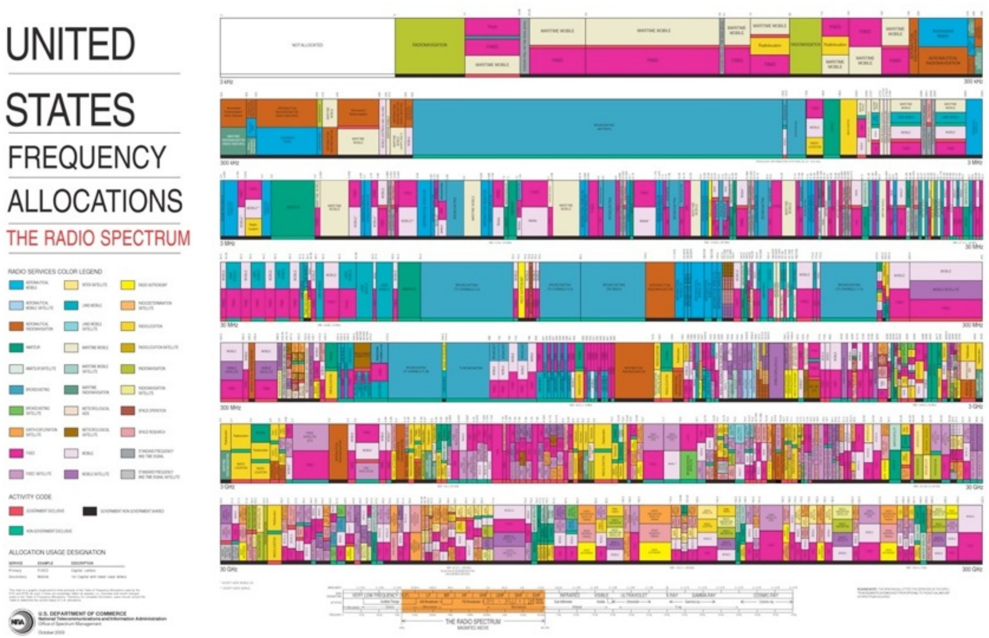

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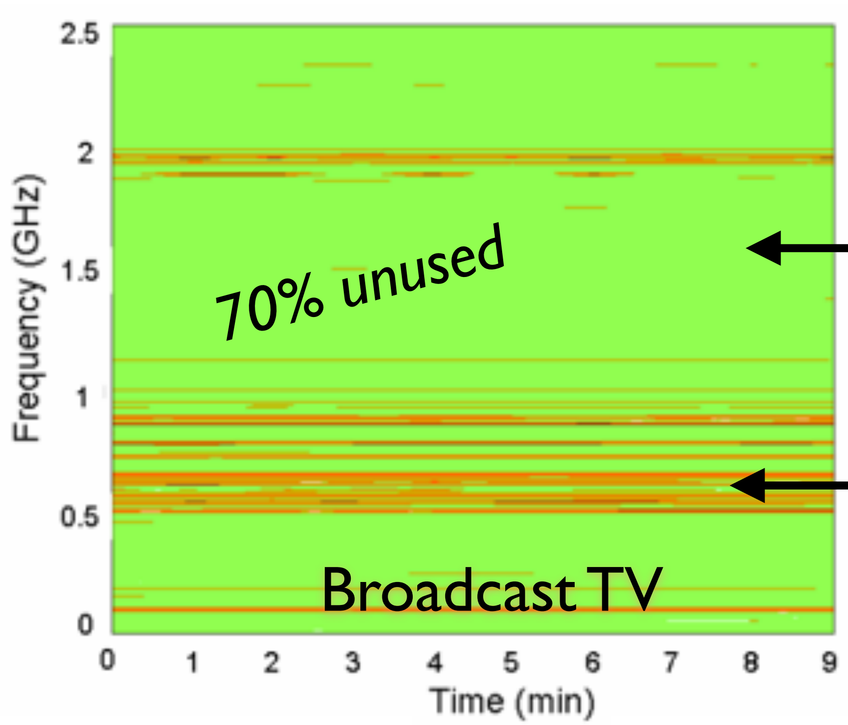

Free!

Used

Measurement from Berkeley Wireless Research Center (BWRC) in 2004 (Cabric, et al.)

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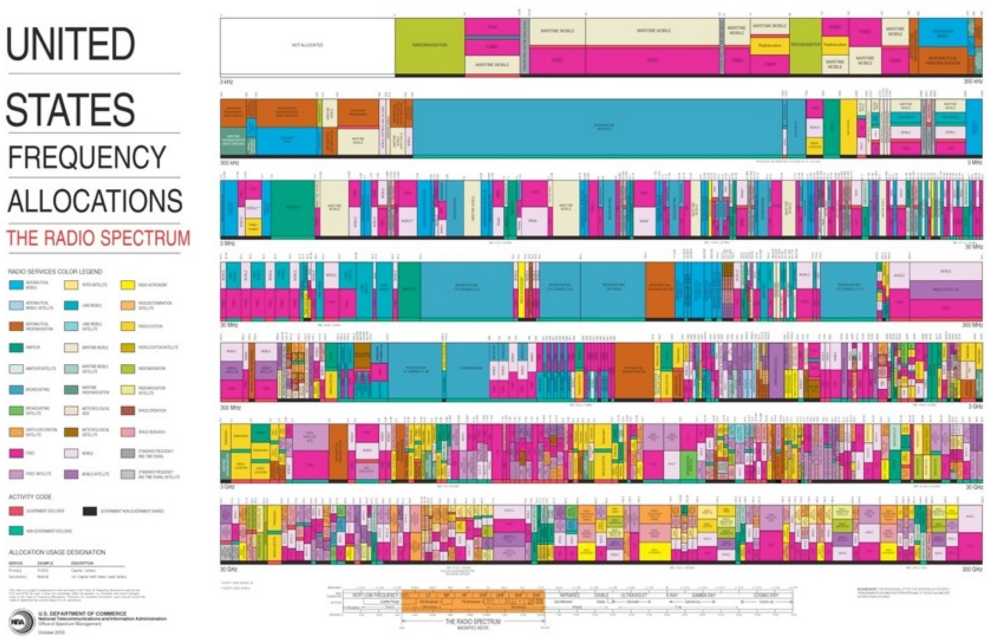
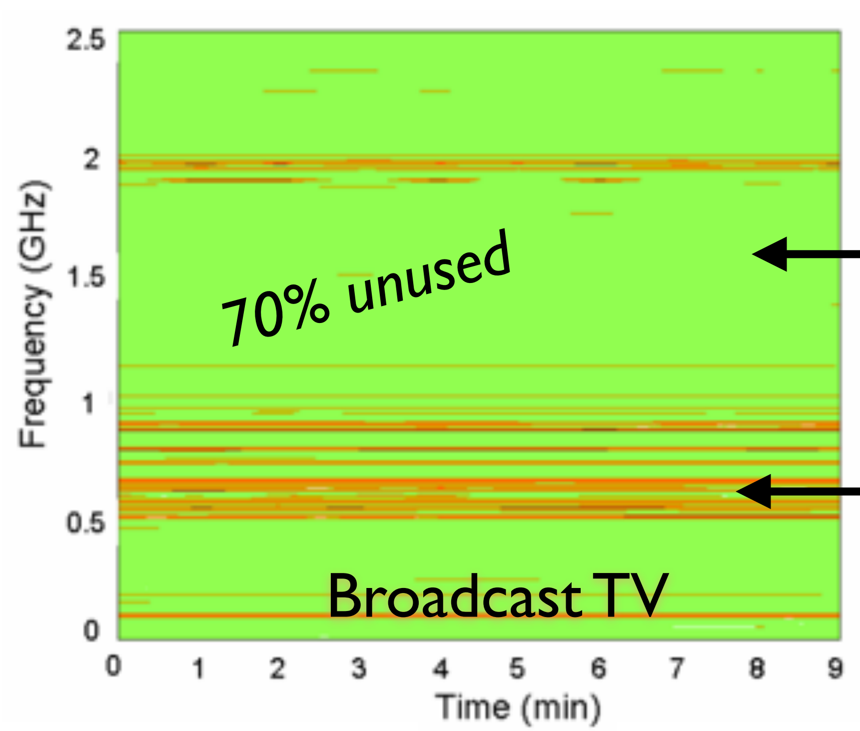


2011 US spectrum allocation chart

"14% of spectrum in 30-3000 MHz is occupied"

"Long-term Spectral Occupancy Findings In Chicago" (Taher, et al. 2011)



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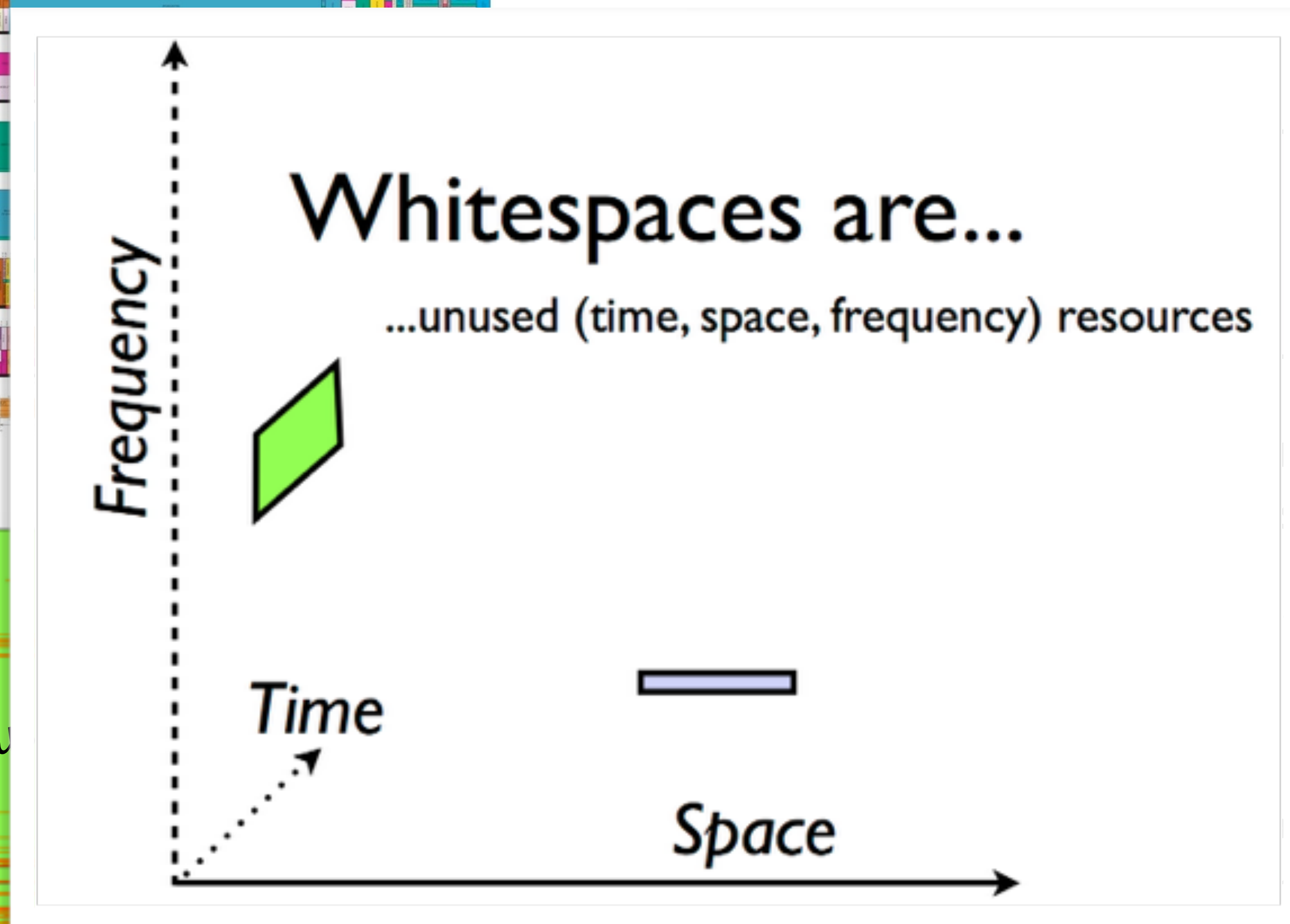

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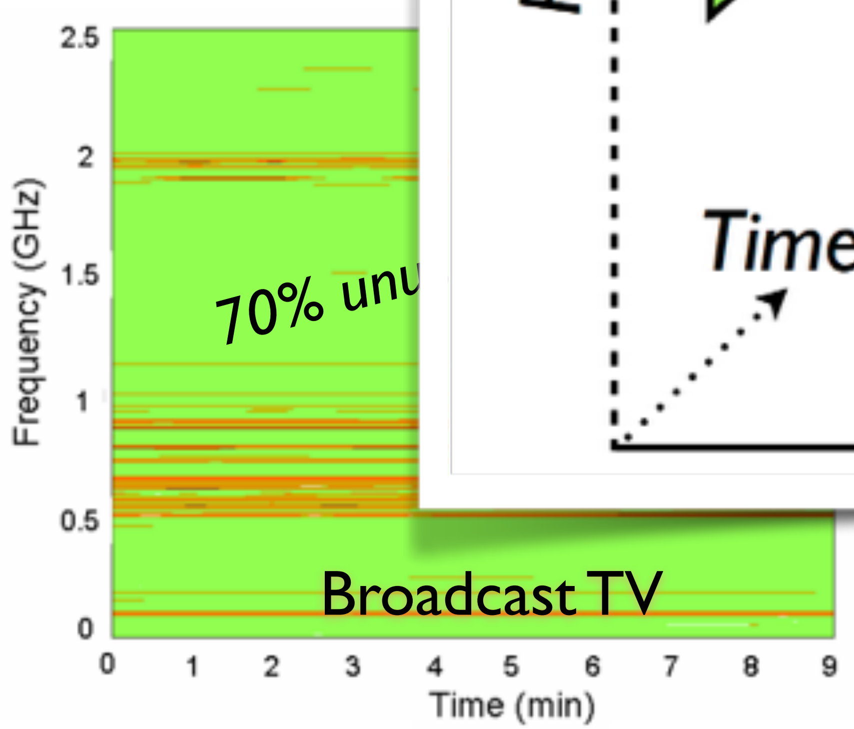

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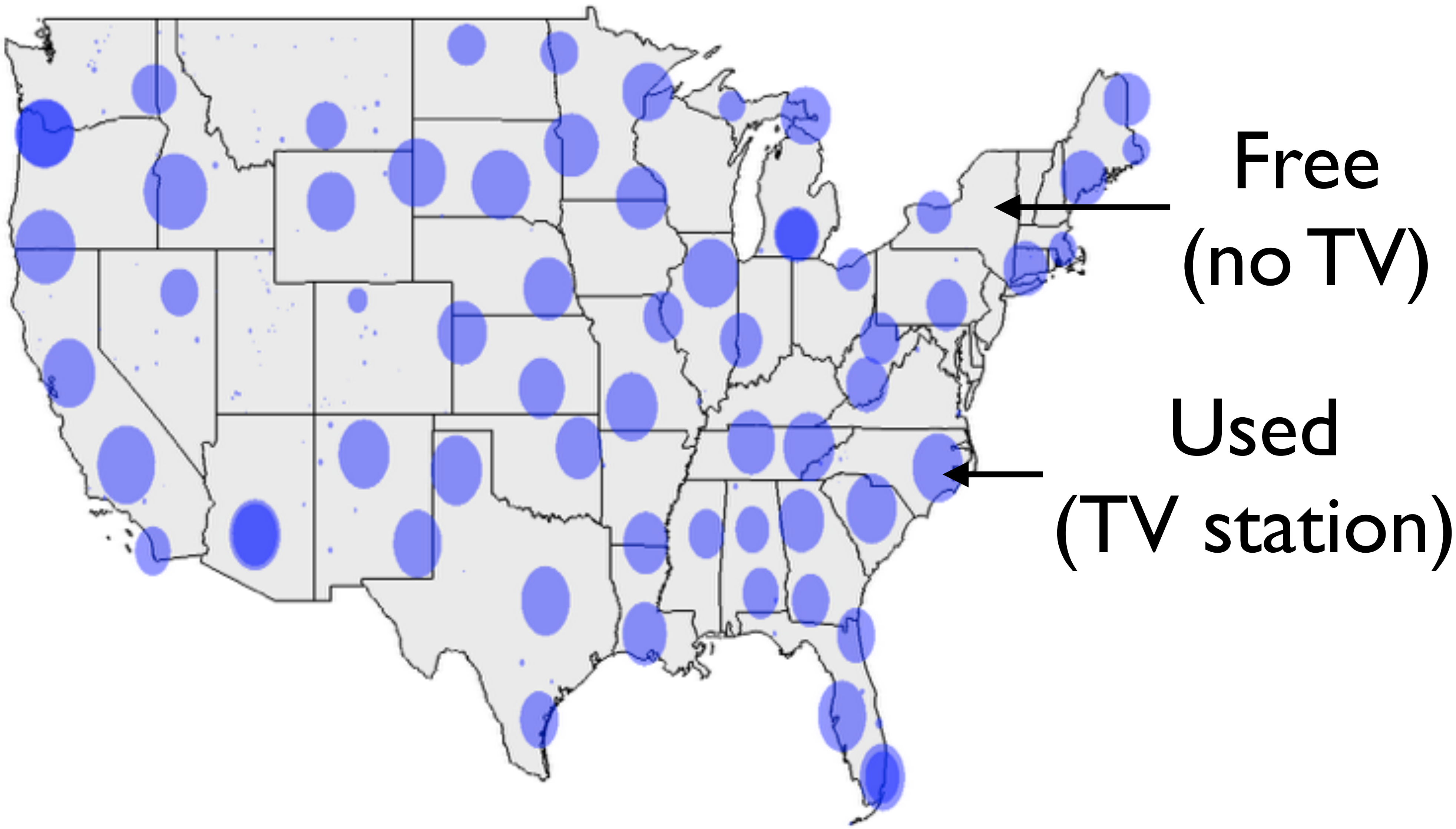
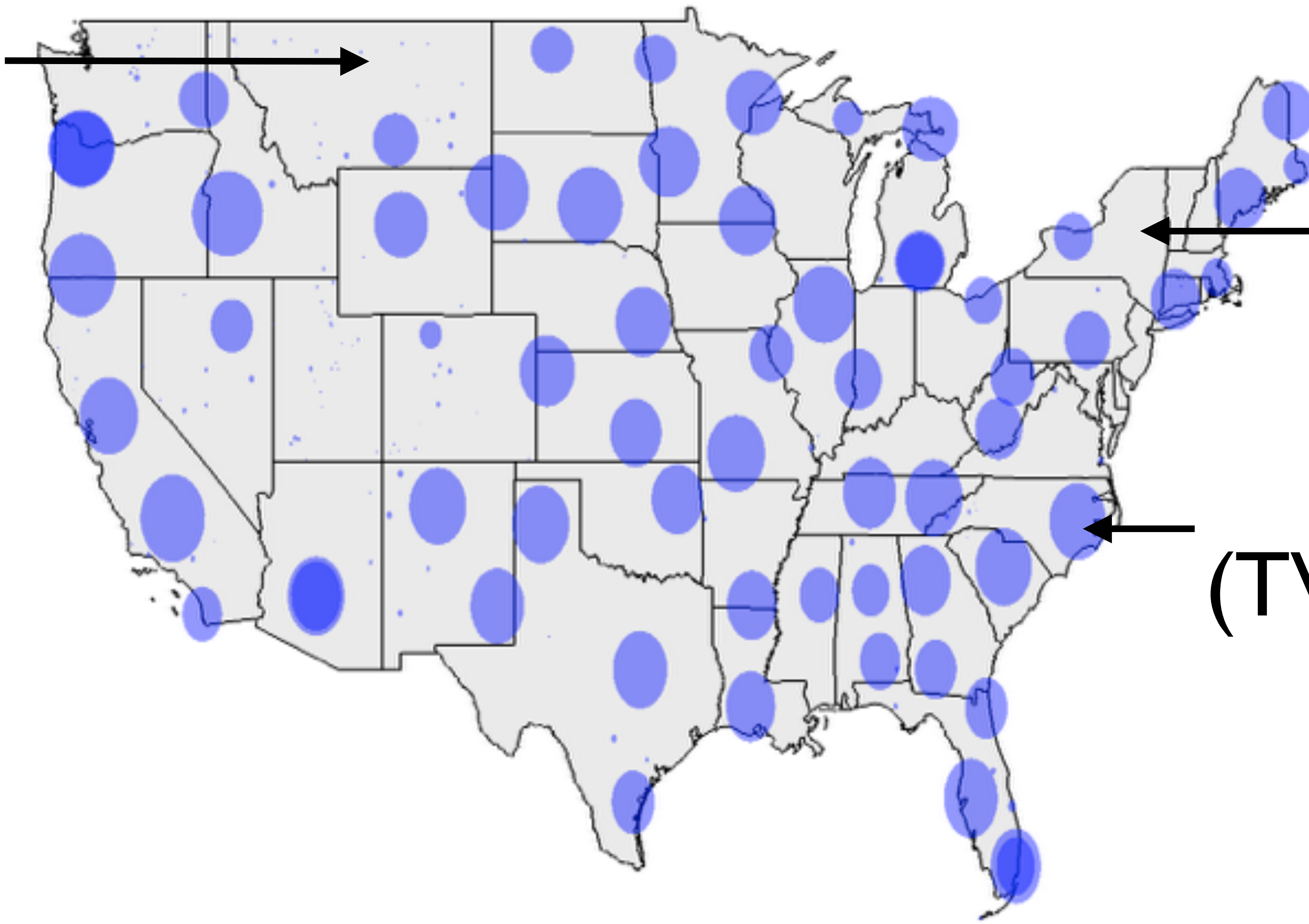
Availability of TV channel 10



Availability of TV channel 10

We call this *whitespace*



Free (no TV)

Used (TV station)

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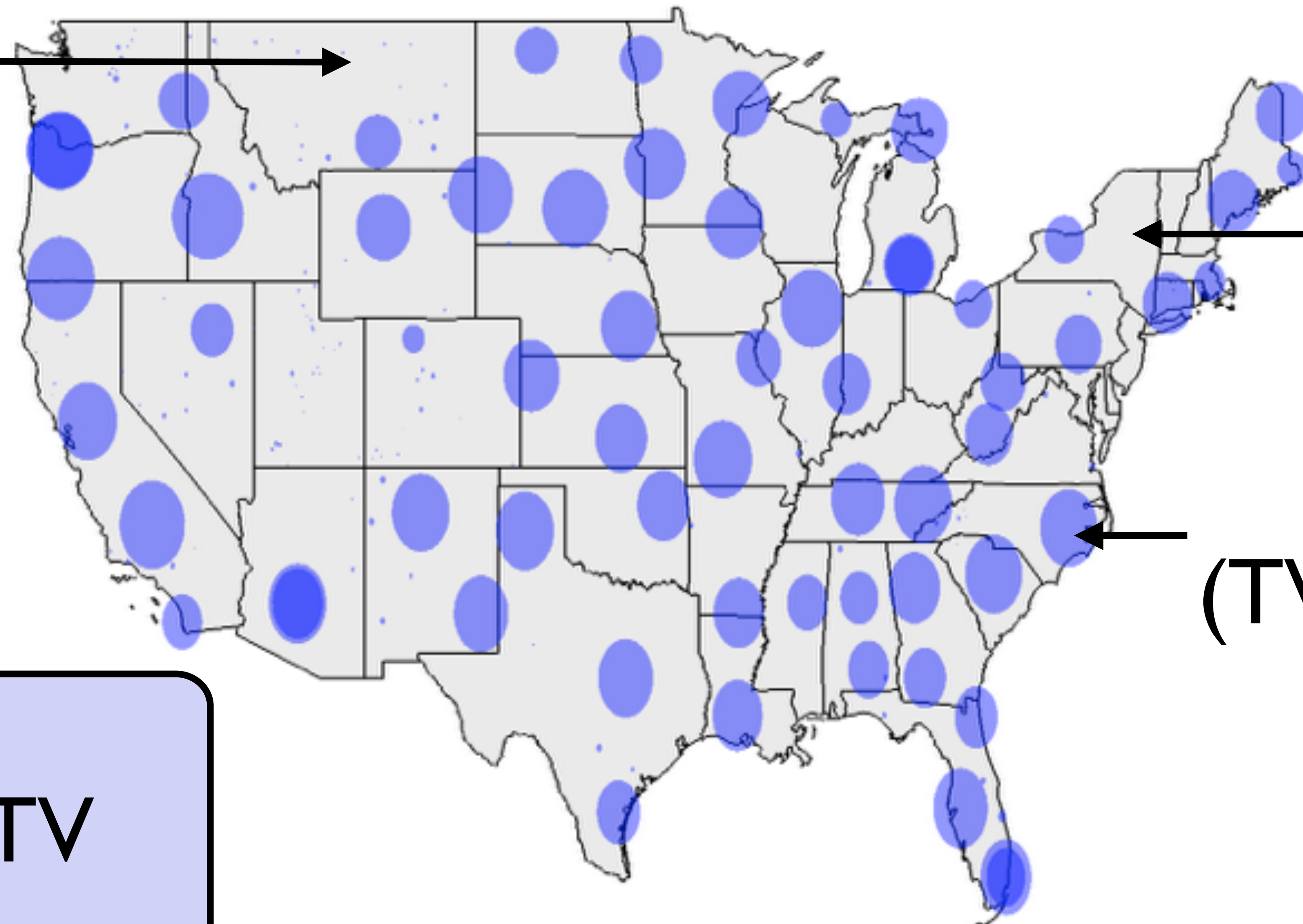
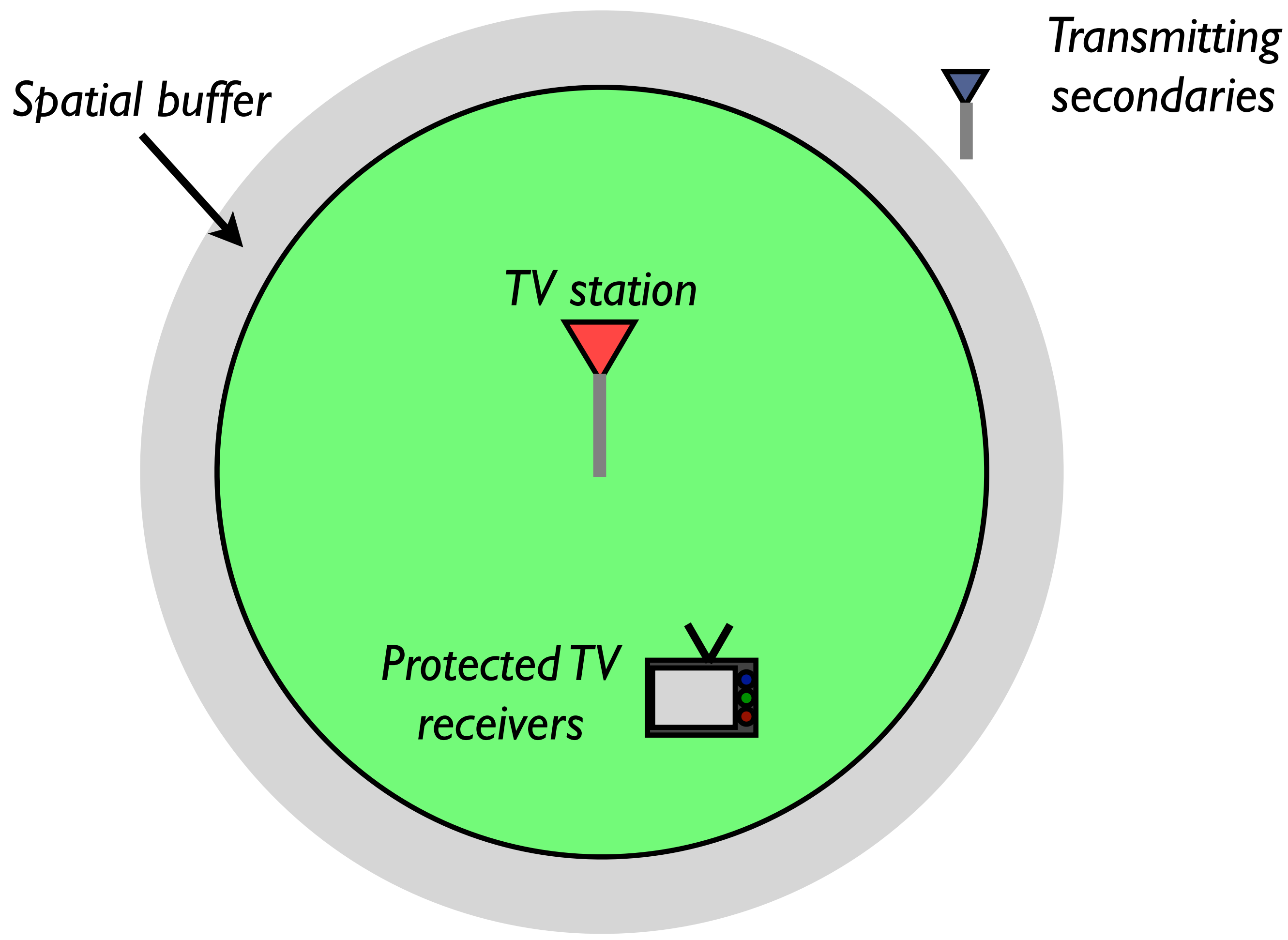


Free (no TV)

Used (TV station)

Focus on TV whitespaces

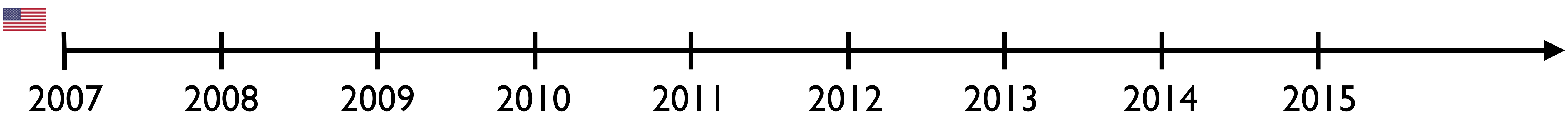
Current regulations



Plus…

- Power limits
- Height limits

Brief history of WS



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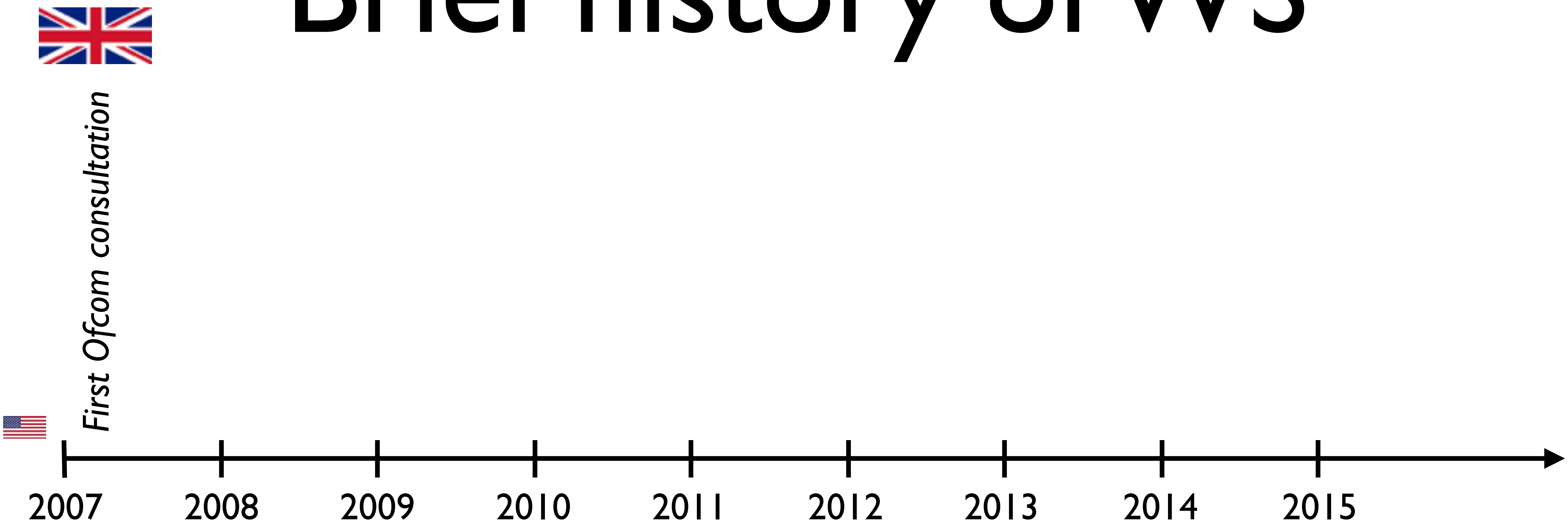

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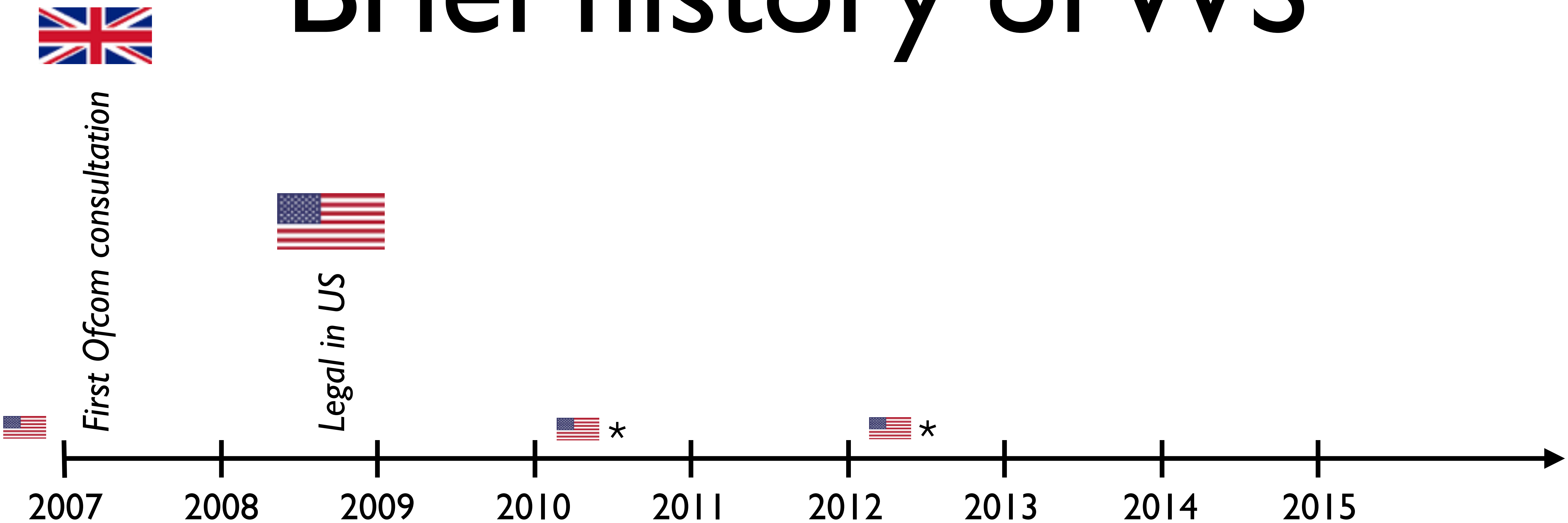

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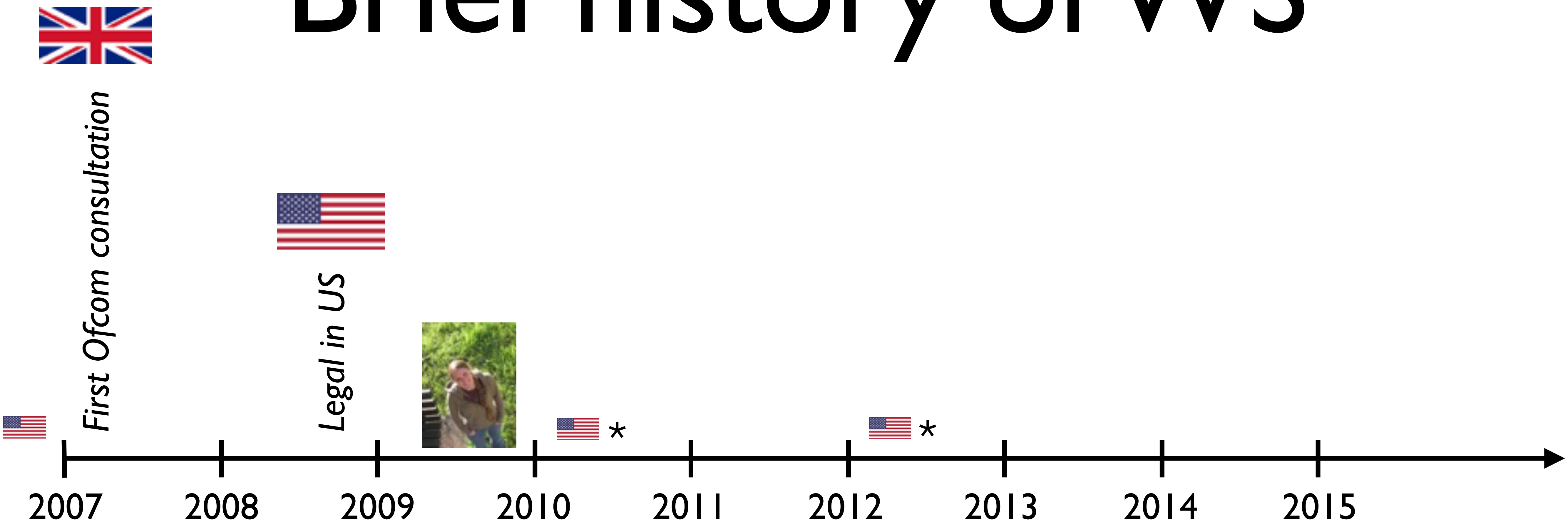

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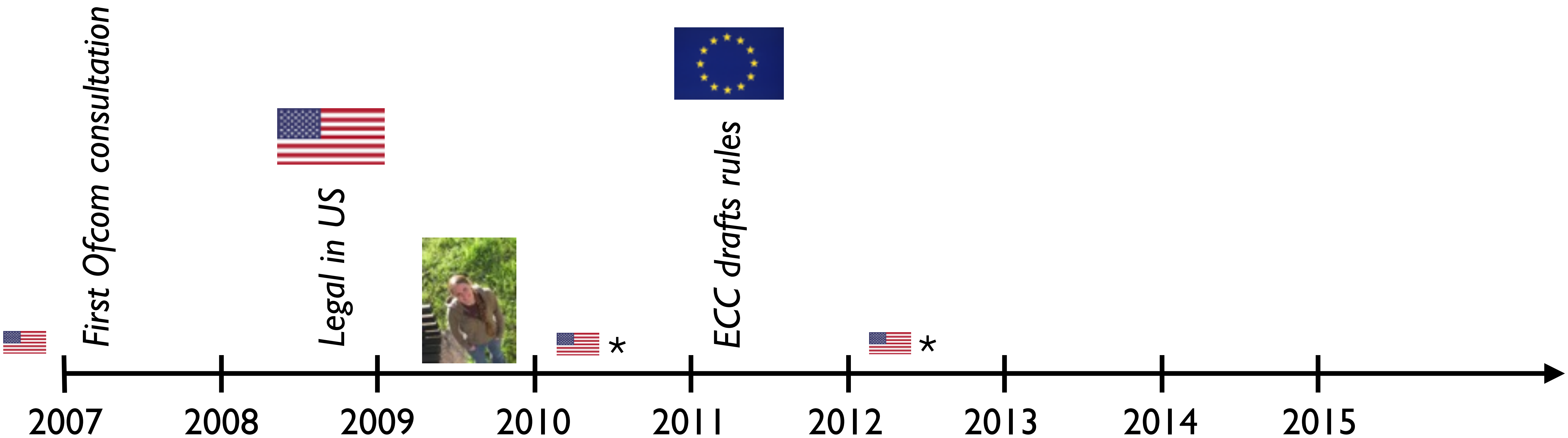

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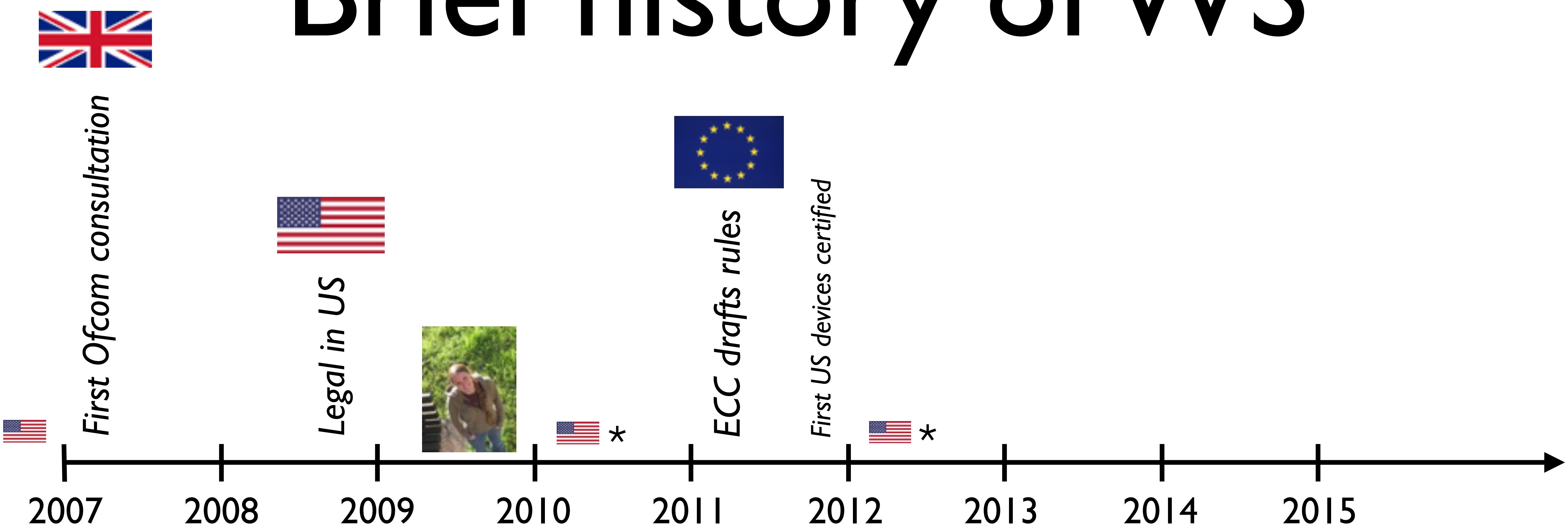

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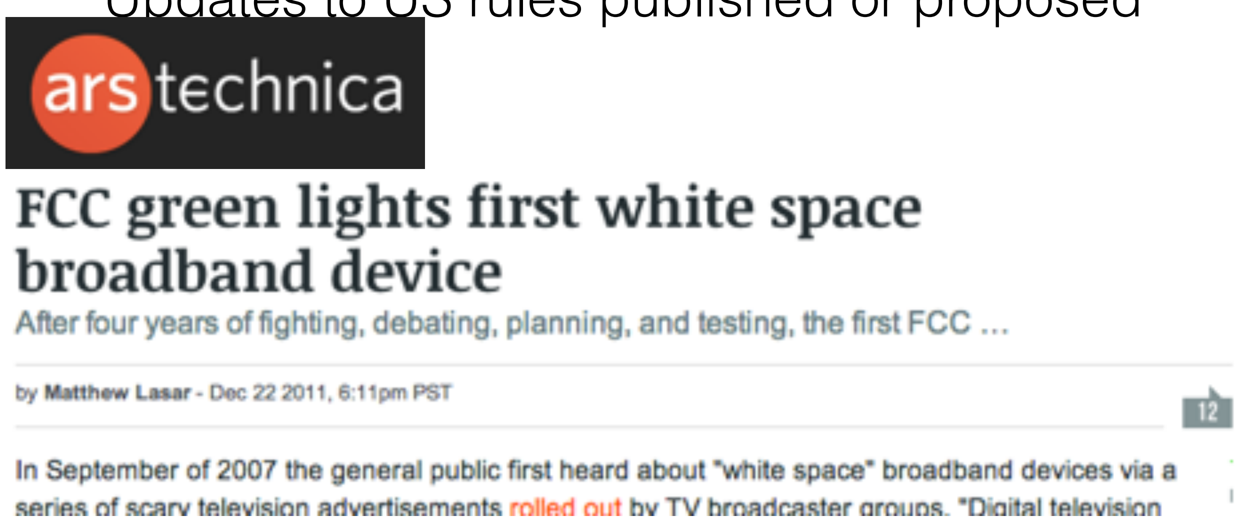


ars technica

FCC green lights first white space broadband device

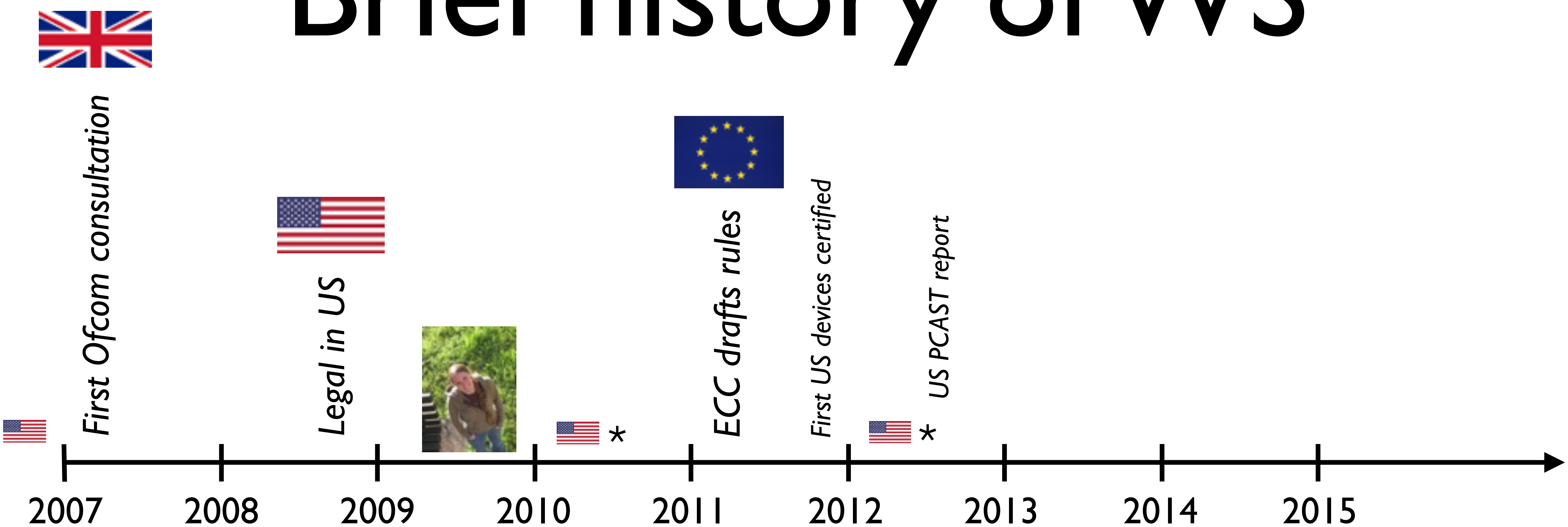
After four years of fighting, debating, planning, and testing, the first FCC …

by Matthew Lasar - Dec 22 2011, 6:11pm PST

12

In September of 2007 the general public first heard about "white space" broadband devices via a series of scary television advertisements rolled out by TV broadcaster groups. "Digital television

Brief history of WS



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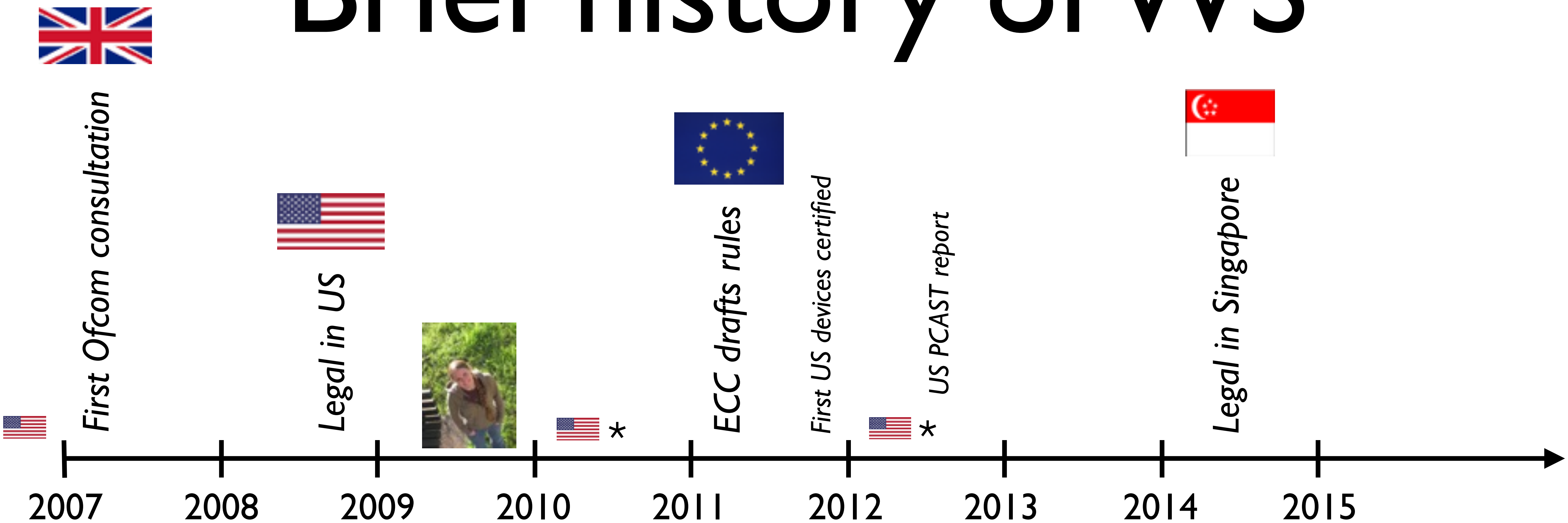

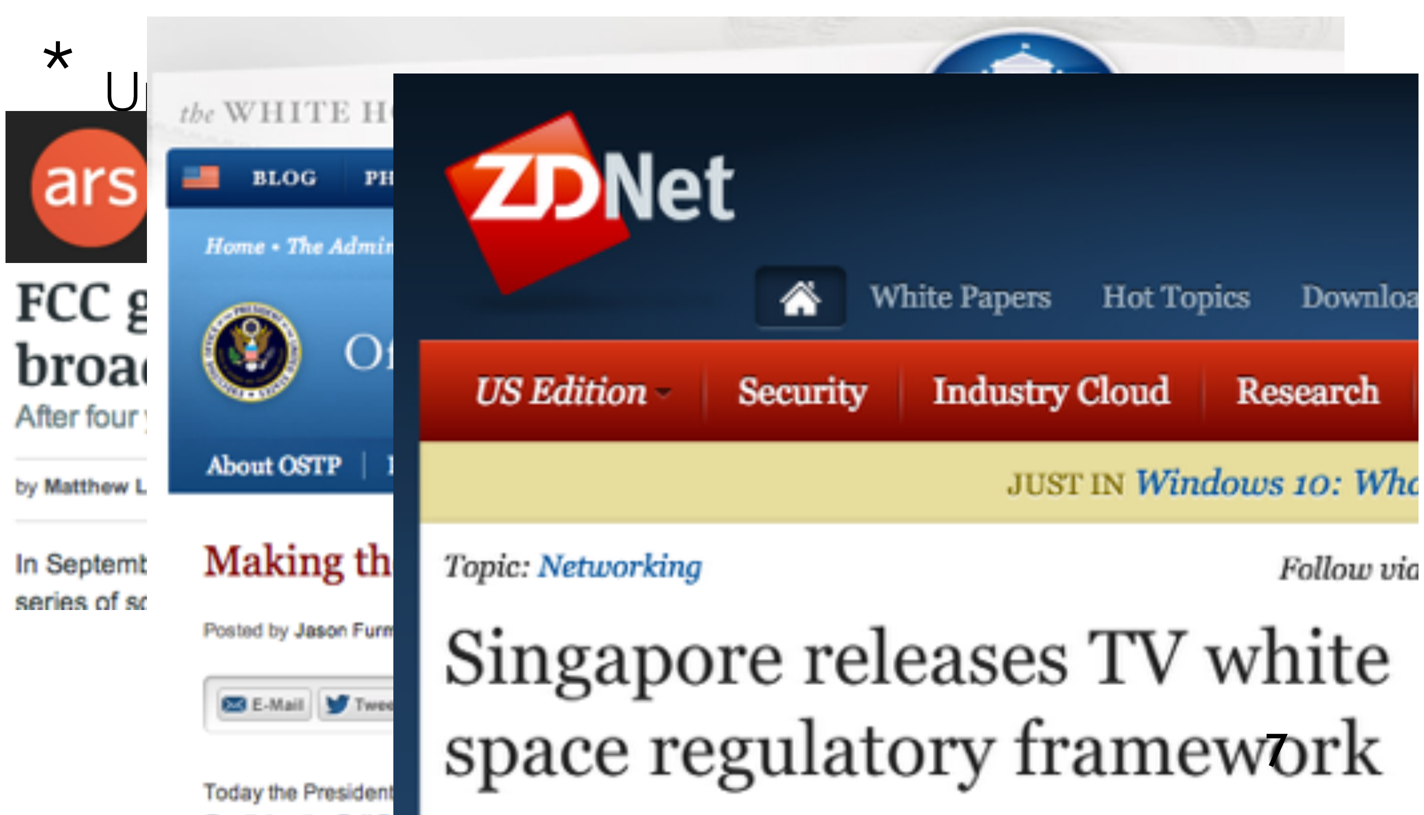

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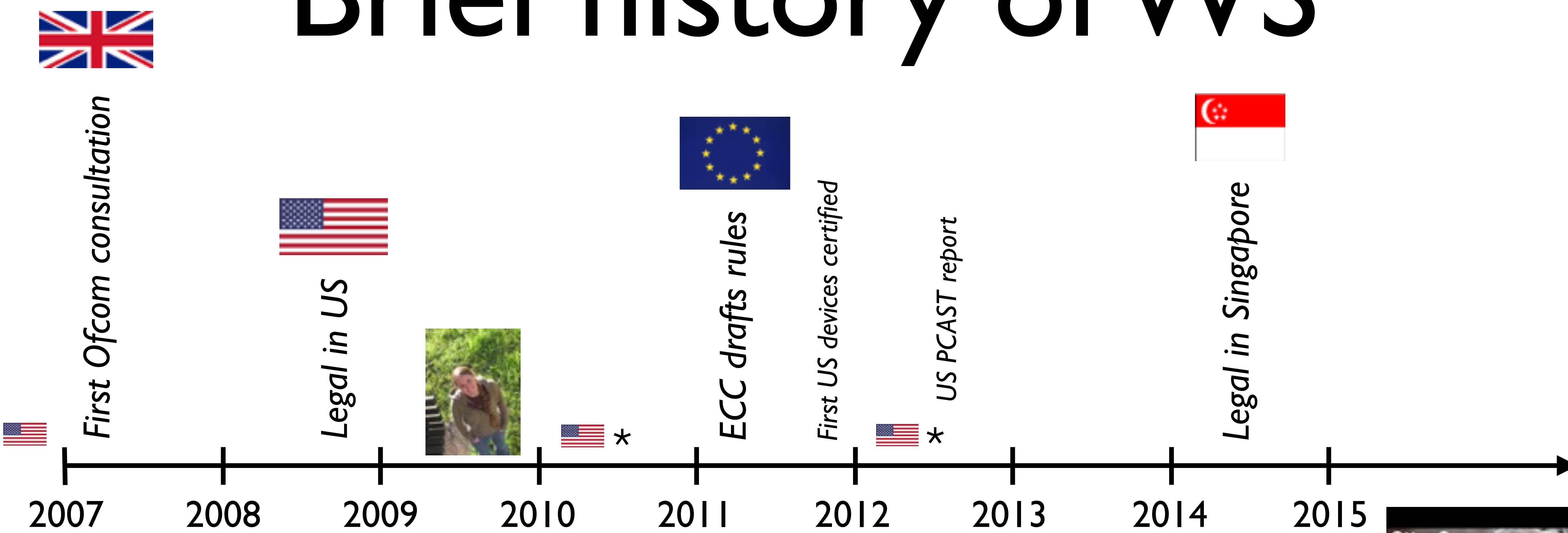
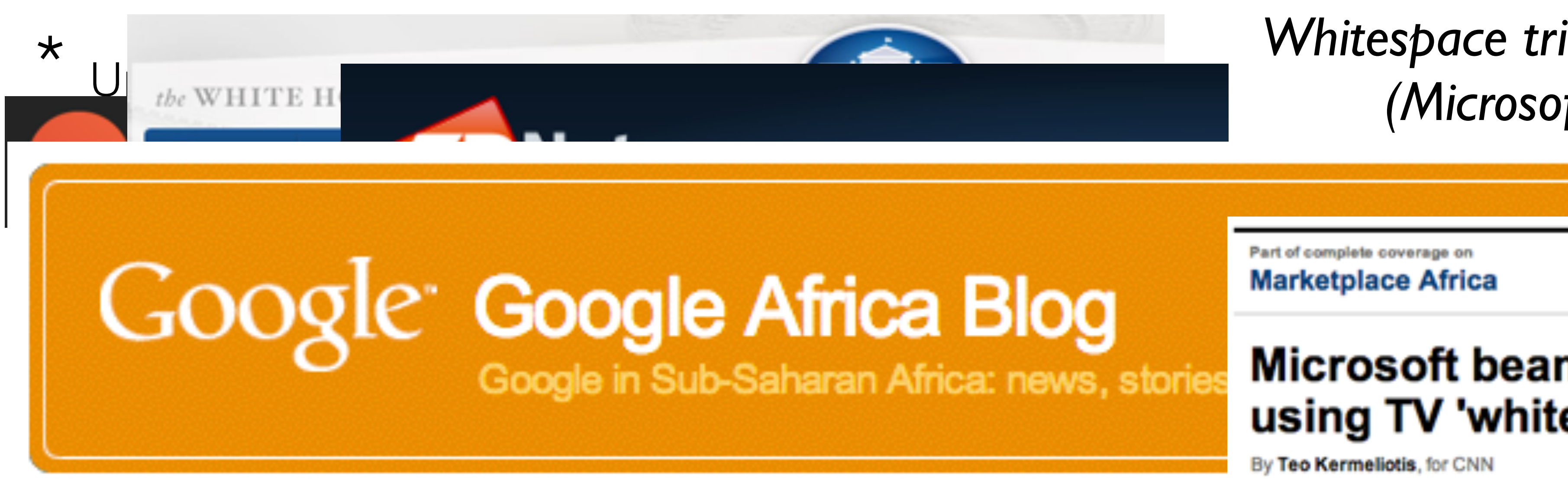


Whitespace trials in Africa, UK
(Microsoft, Google)

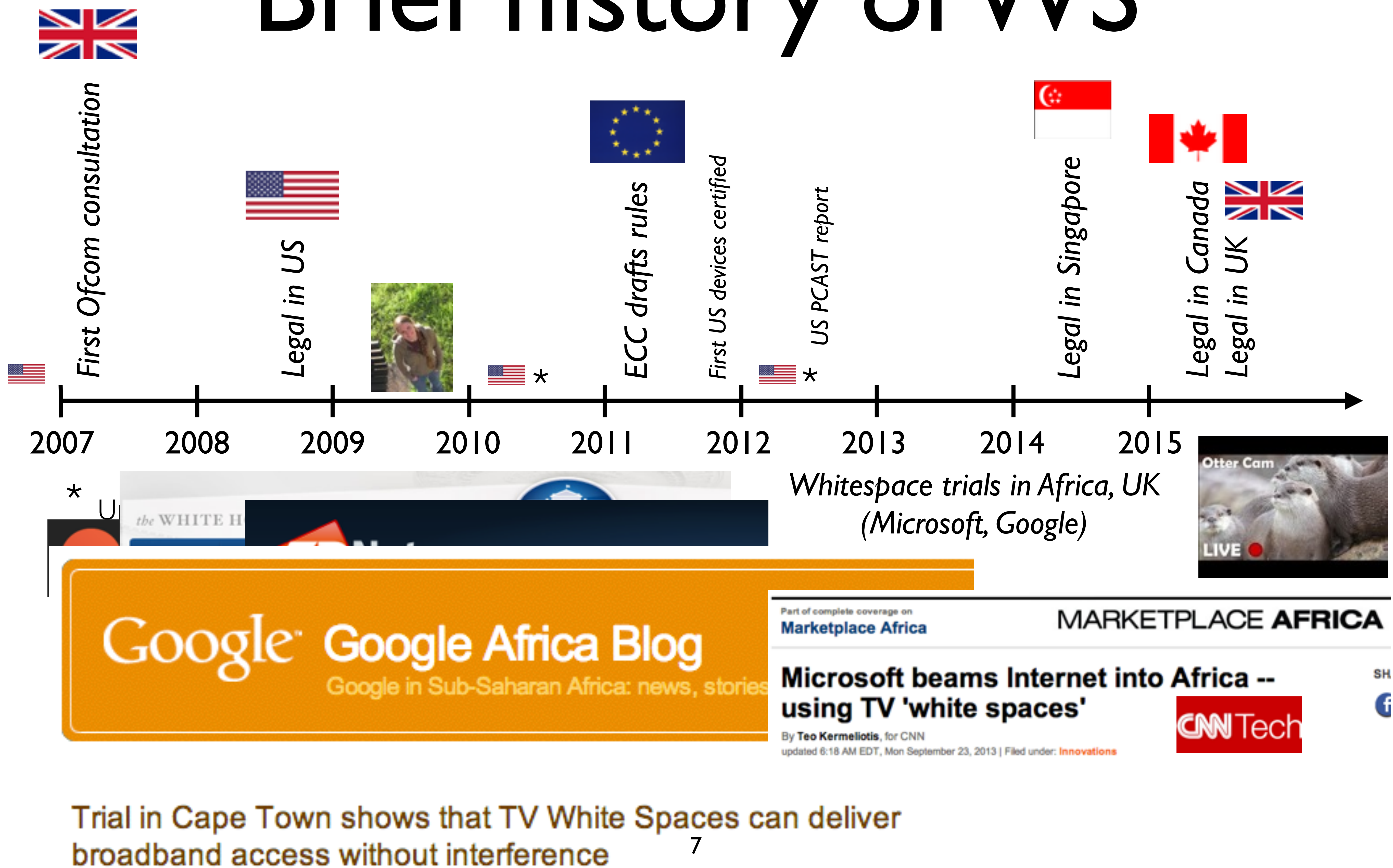


Microsoft beams Internet into Africa -- using TV 'white spaces'

By Teo Kermeliotis, for CNN
updated 6:18 AM EDT, Mon September 23, 2013 | Filed under: Innovations

Trial in Cape Town shows that TV White Spaces can deliver broadband access without interference

Brief history of WS



WS access methods

Sensing

Geolocation + databases

WS access methods

Sensing

- Favored in 2008 regulations
- Conservative threshold
- Shown infeasible in 2009 paper [Mishra, et al.]
- No longer required for all devices in 2010

Geolocation + databases

WS access methods

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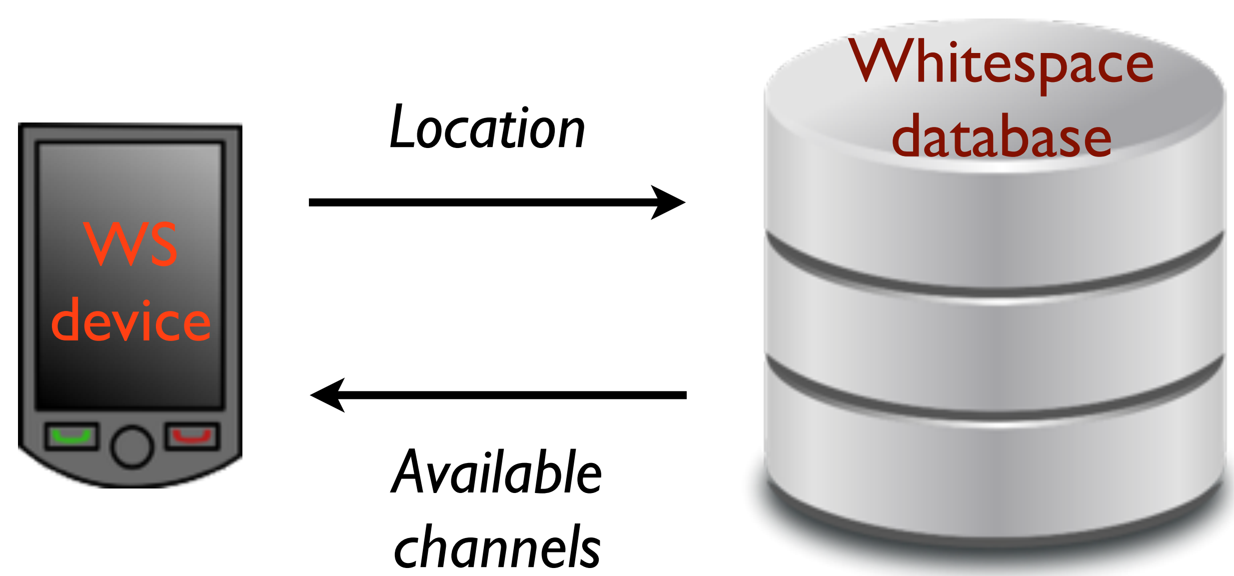
Geolocation + databases

- Currently preferred method
- Used for rest of talk



WS access methods

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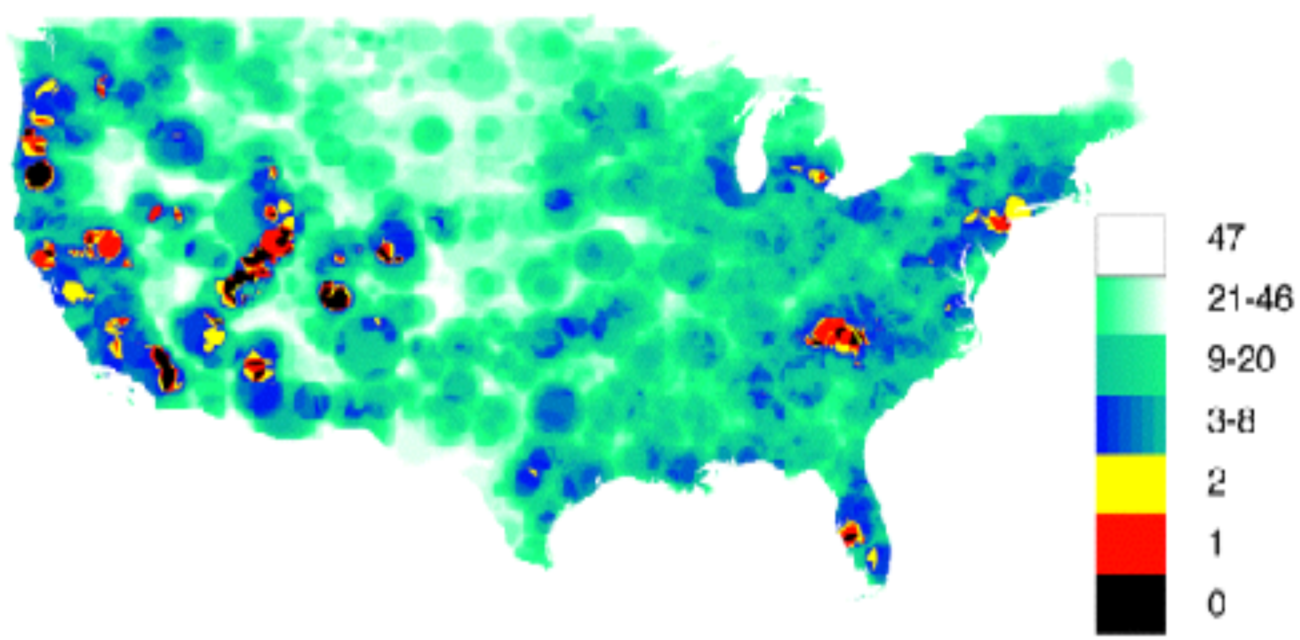

“How much whitespace has the FCC opened up?” (Mishra, et al. 2009)

WS access methods

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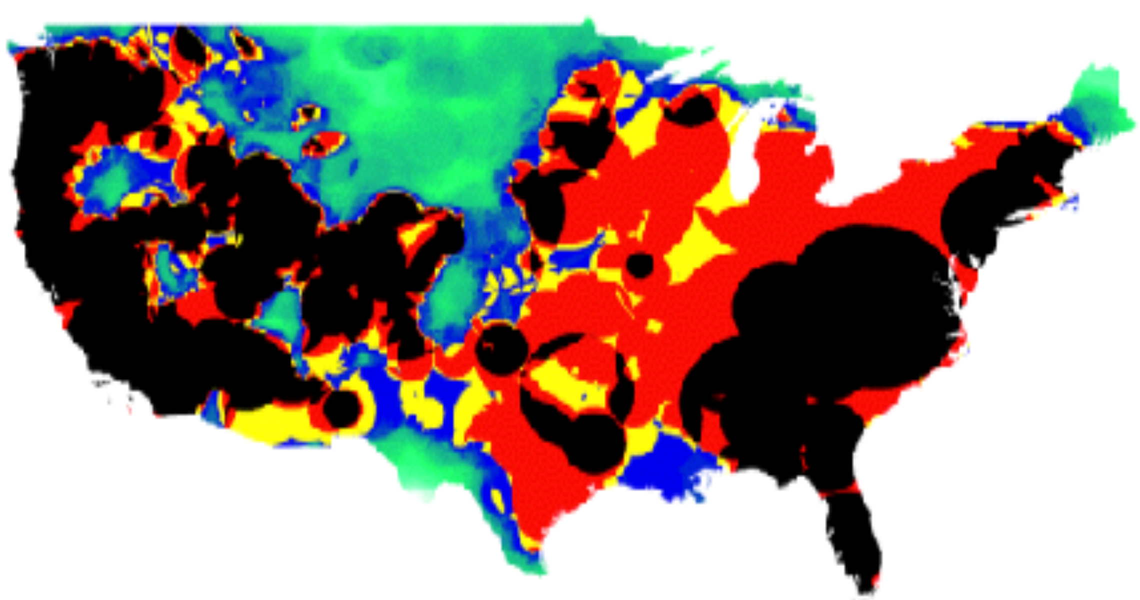

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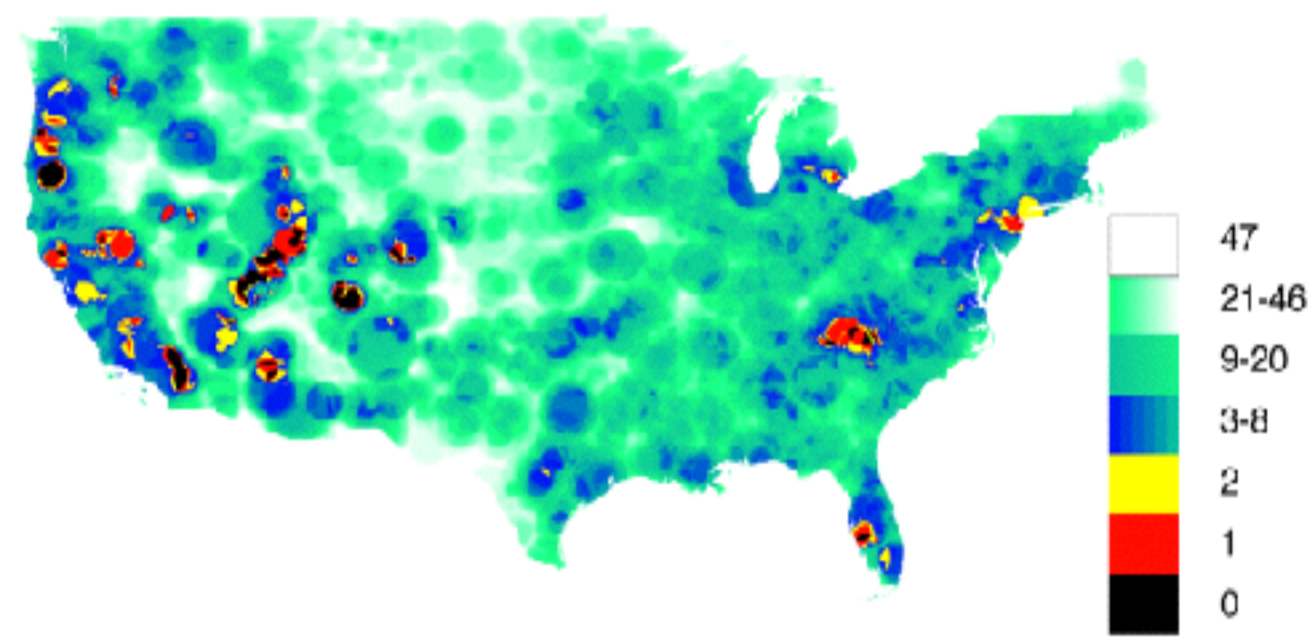

"How much whitespace has the FCC opened up?" (Mishra, et al. 2009)

Outline

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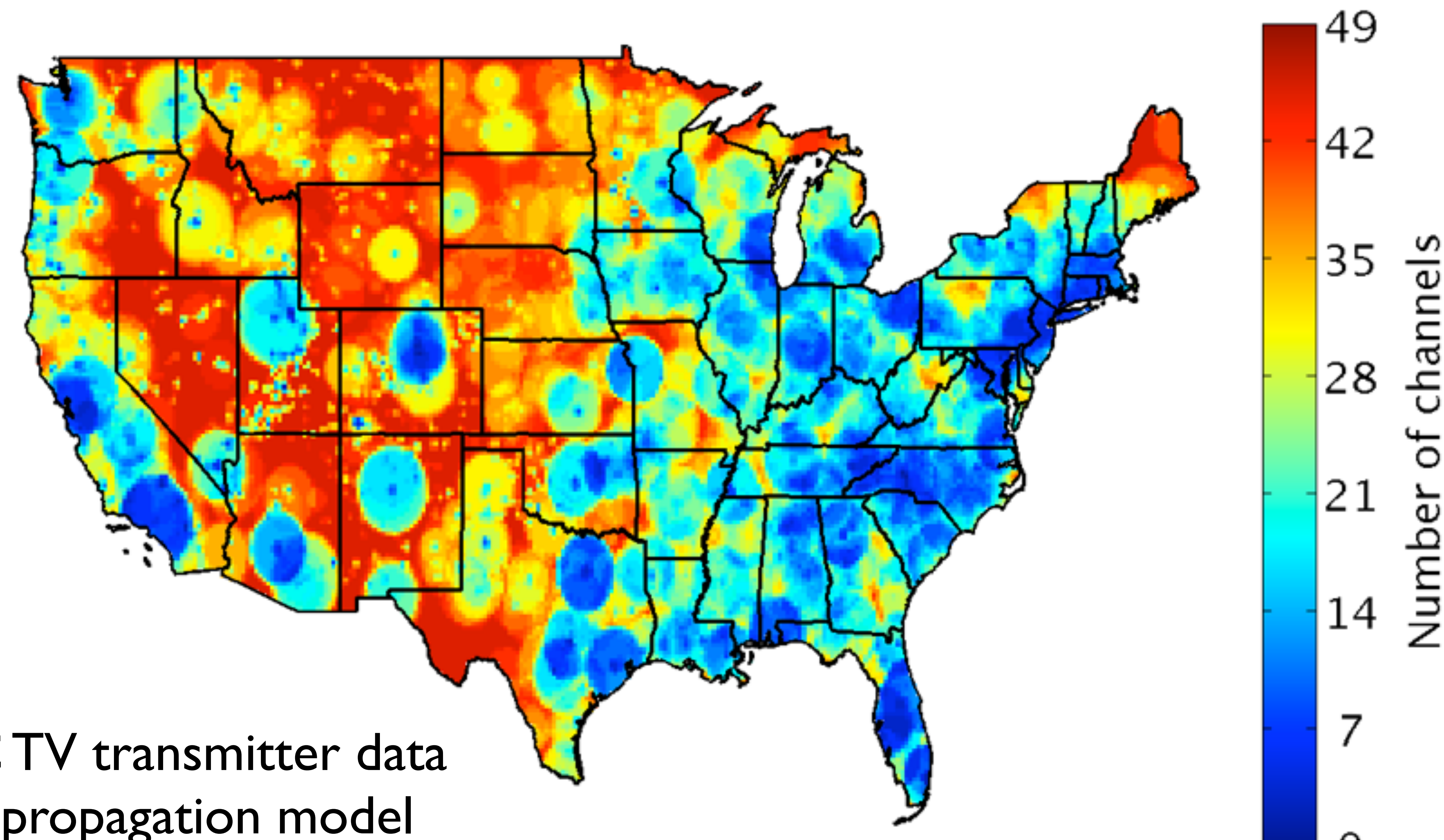
- Quantifying whitespaces
- Whitespace software
- Whitespace policy

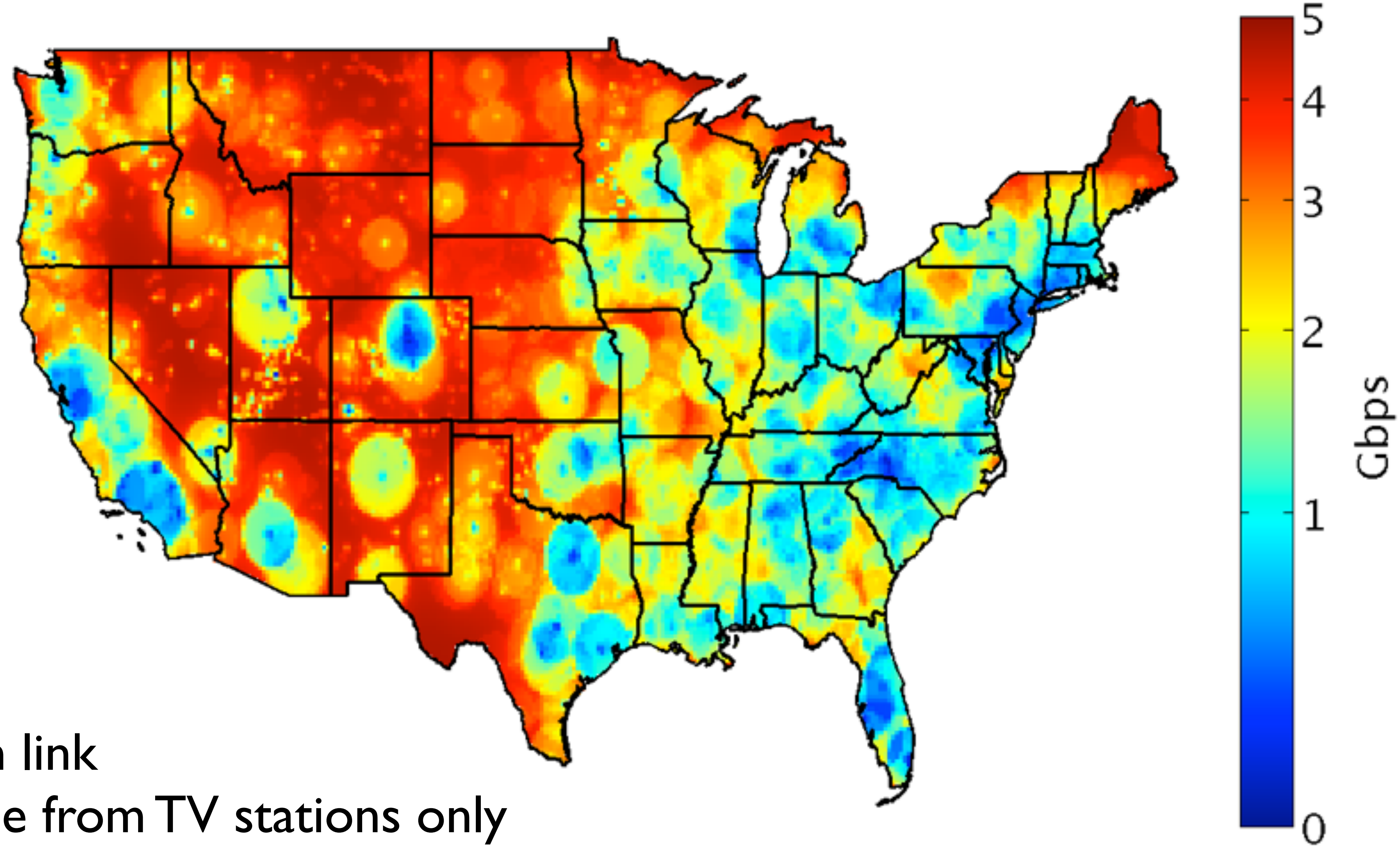
How much white space is there?



- FCC TV transmitter data
- ITU propagation model

"How much white space capacity is there?" (**Harrison**, Mishra, and Sahai 2009)

Single-link data rates



- 1 km link
- Noise from TV stations only

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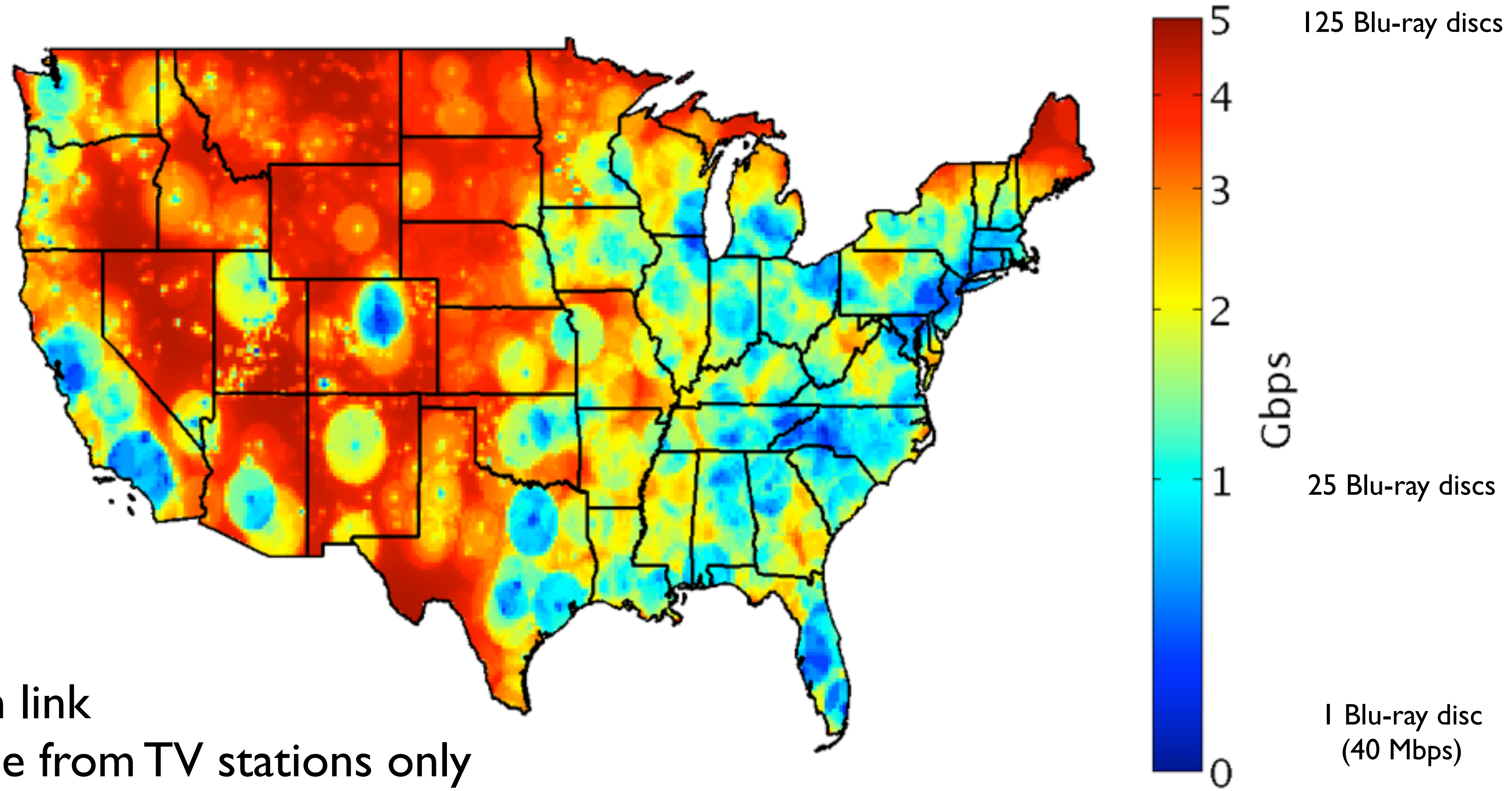

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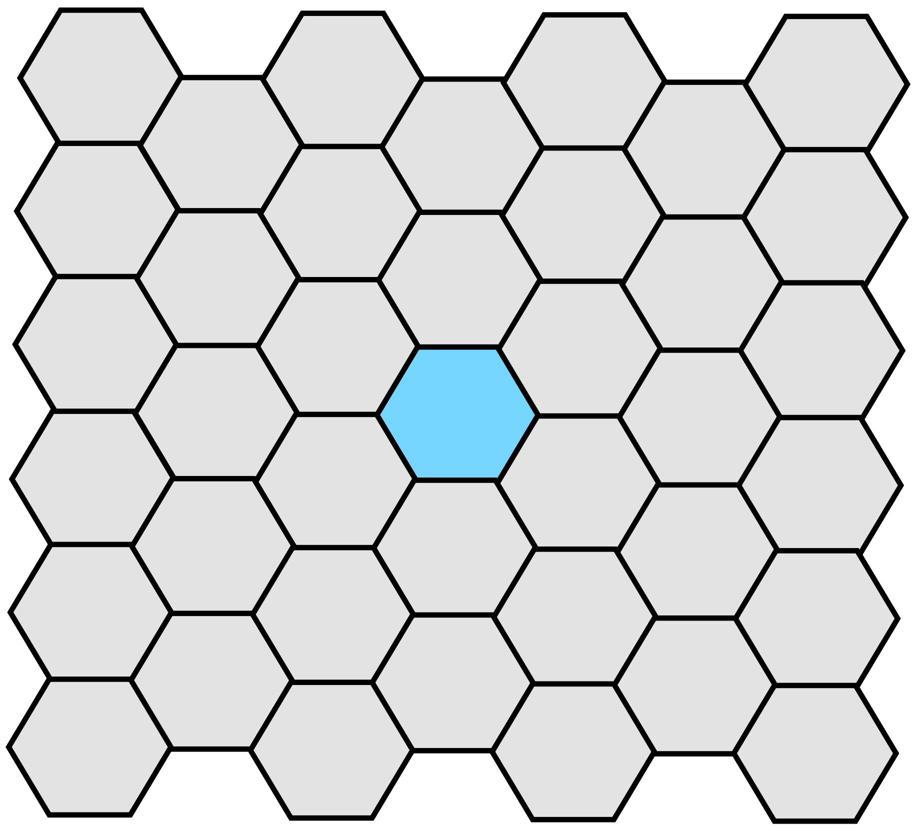
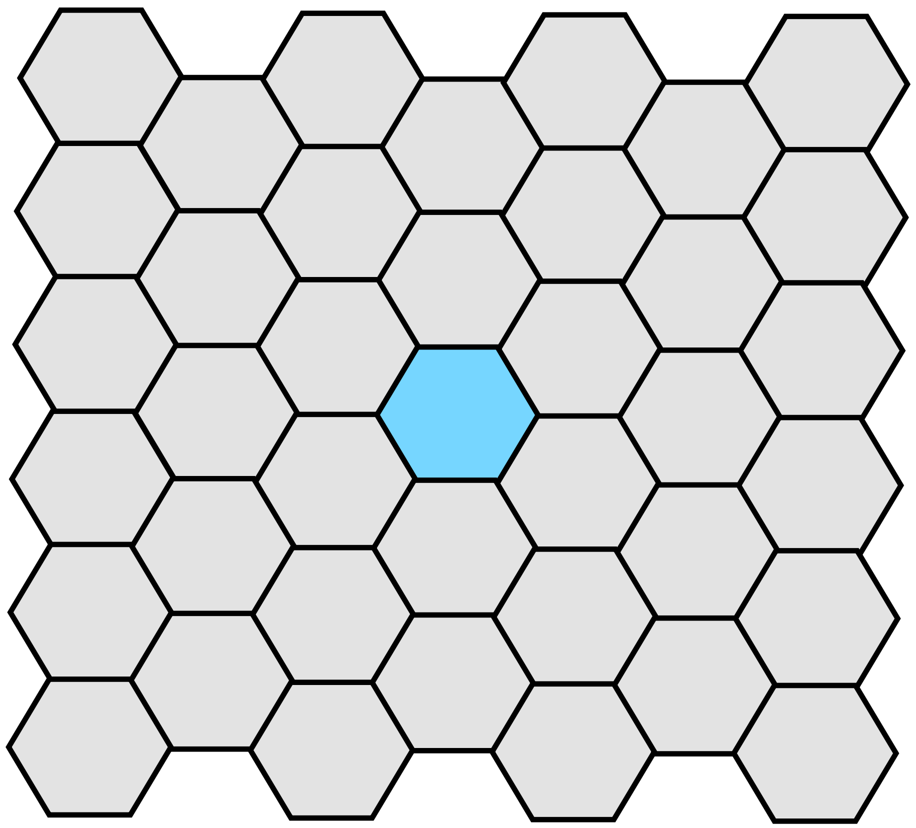
Secondary interference model



Assume nearby cells same size

Freq. reuse-1 (CDMA, OFDMA)

Secondary interference model



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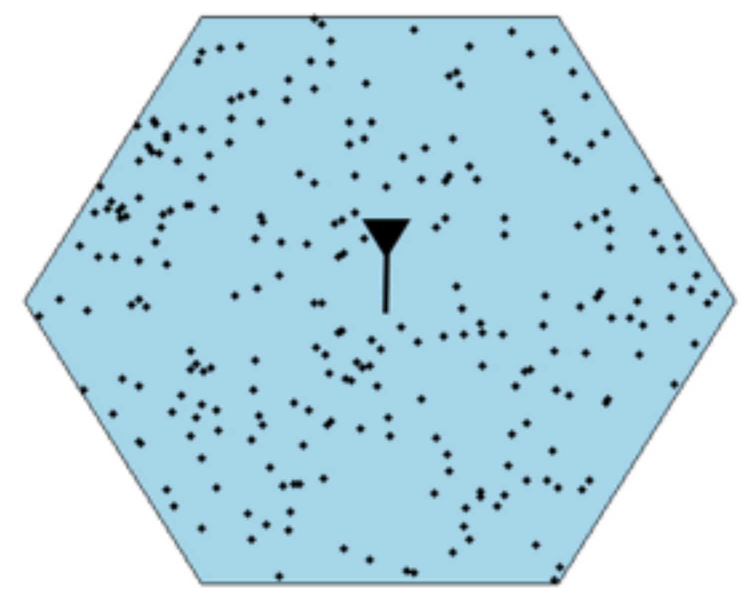

Downlink only (computational limitations)

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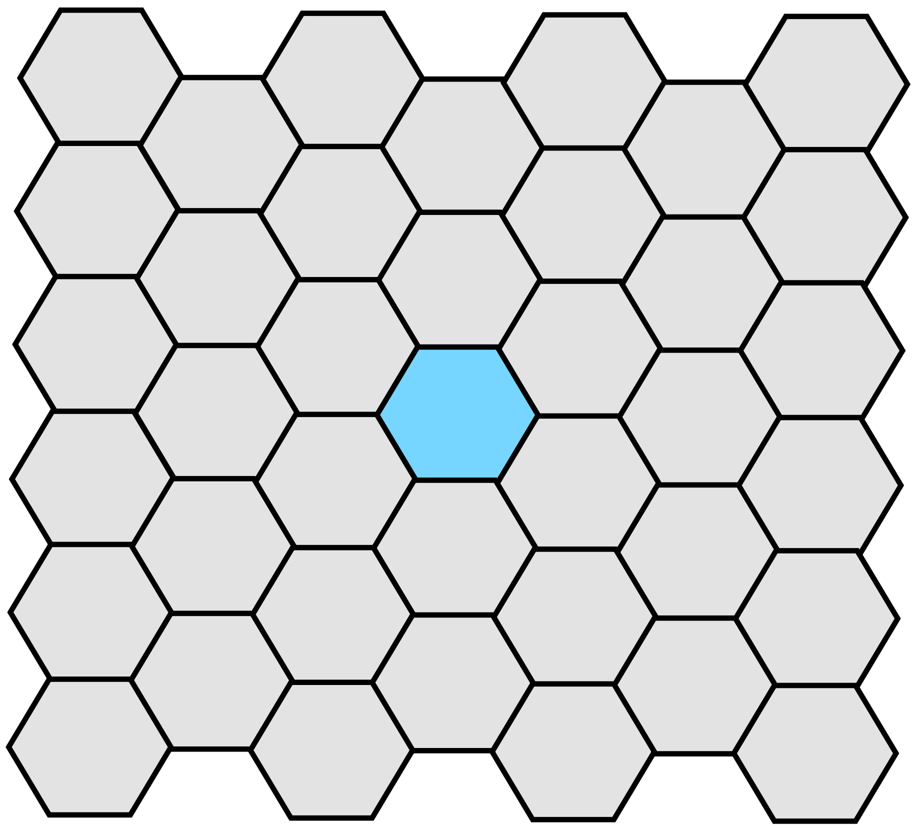

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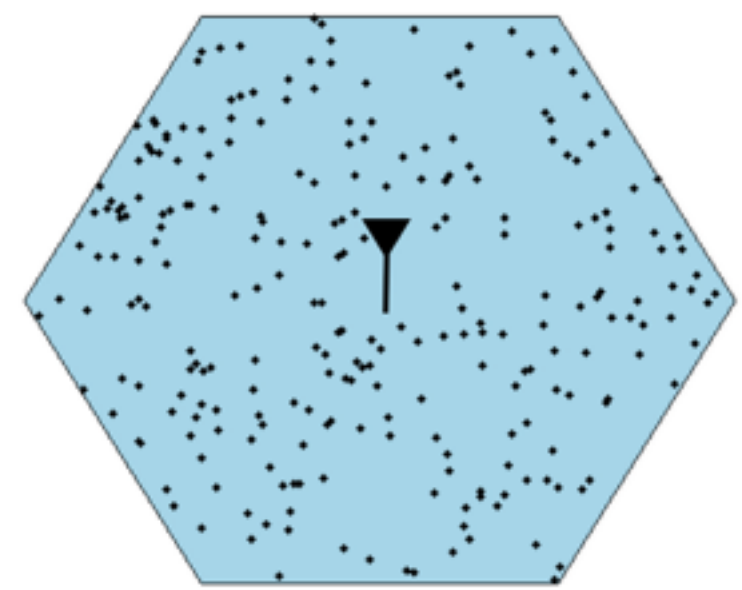
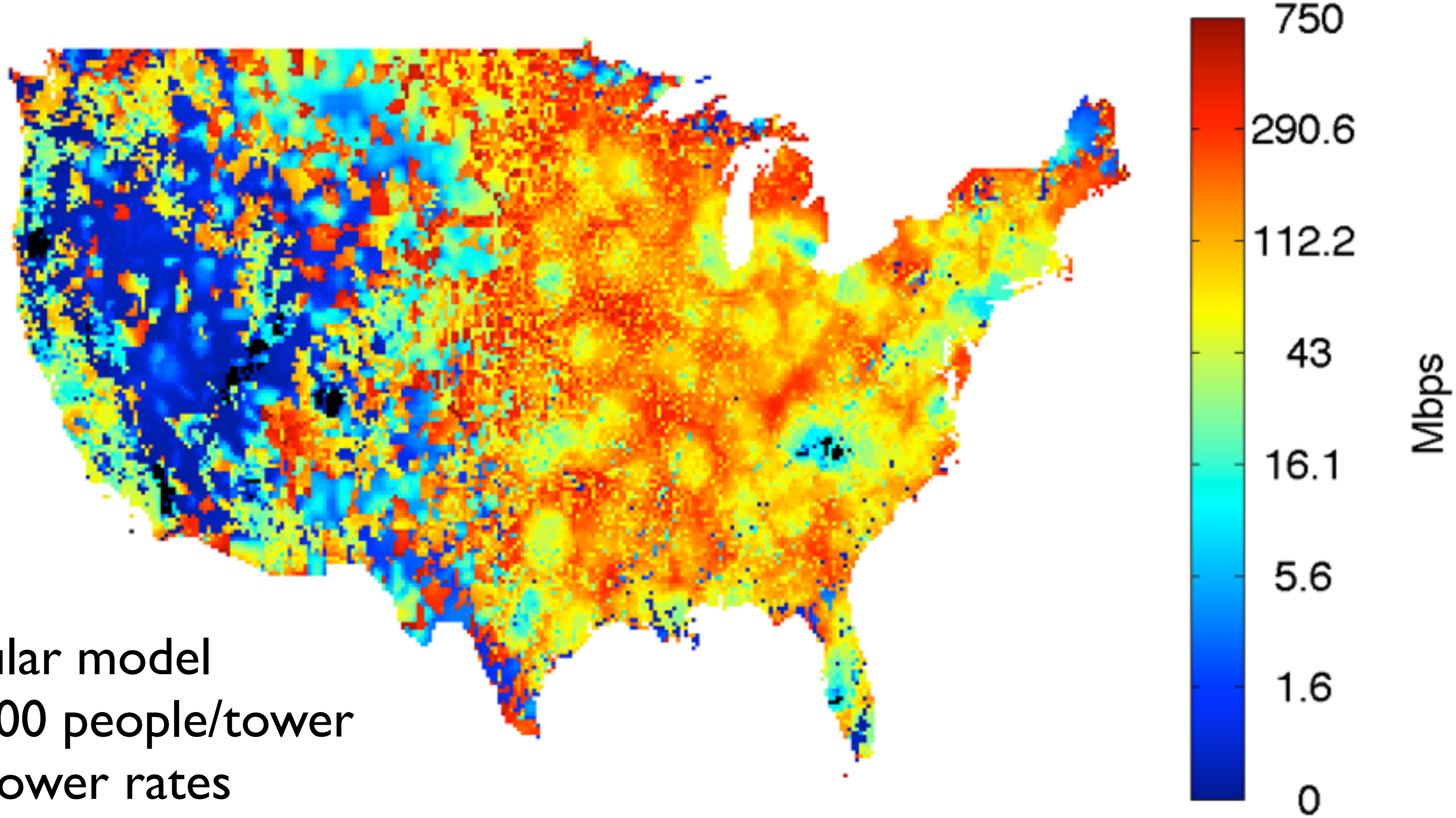


Downlink only (computational limitations)

Cell size depends on population
Simple economic model: 2000 people per tower
e.g. 10% of people paying $20/month → $50k/year

Rates with interference



- Cellular model
  - 2000 people/tower
- Per-tower rates
  - Rural areas suffer

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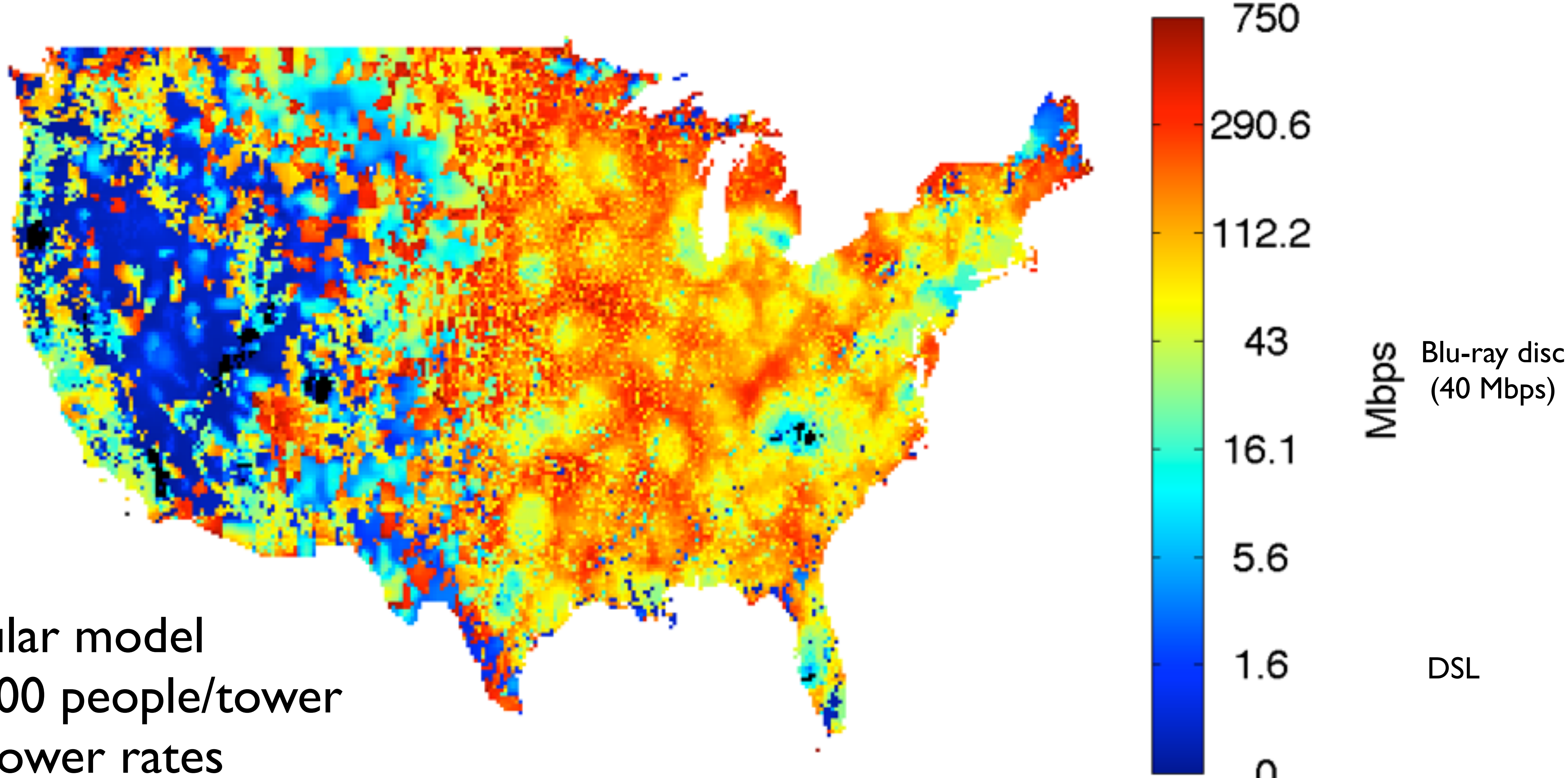

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A paradigm shift
(before)

Summary Analysis – White Space in Sample of U.S. Media Markets

(The full analysis of each market with channel data is available at www.spectrumpolicy.org.)

Market	No. of Vacant Channels Between Chs. 2-51 After DTV Transition	Percent of TV Band Spectrum Vacant After DTV Transition
Juneau, Alaska	37	74%
Honolulu, Hawaii	31	62%
Phoenix, Arizona	22	44%
Charleston, West Virginia	36	72%
Helena, Montana	31	62%
Boston, Massachusetts	19	38%
Jackson, Mississippi	30	60%
Fargo, North Dakota	41	82%
Dallas-Ft. Worth, Texas	20	40%
San Francisco, California	19	37%
Portland, Maine	33	66%
Tallahassee, Florida	31	62%
Portland, Oregon	29	58%
Seattle, Washington	26	52%
Las Vegas, Nevada	26	52%
Trenton, New Jersey	15	30%
Richmond, Virginia	32	64%
Omaha, Nebraska	26	52%
Manchester, New Hampshire	23	46%
Little Rock, Arkansas	30	60%
Columbia, South Carolina	35	70%
Baton Rouge, Louisiana	22	44%

"Measuring the TV "White Space" Available for Unlicensed Wireless Broadband"
(New America Foundation, 2006)

A paradigm shift

(after)

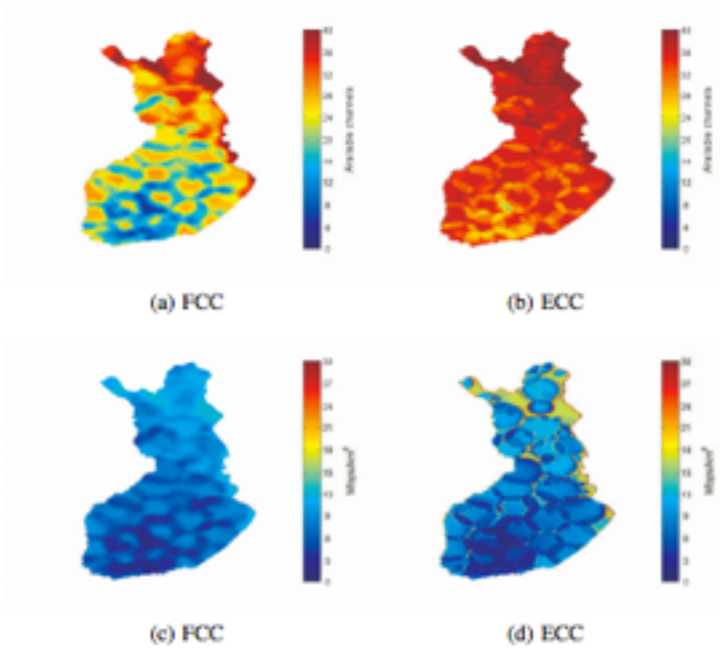

Fig. 1: Spatial distribution of available channels by using (a) FCC (b) ECC rules. Capacity per area for secondary cell size $d = 2$ km and antenna height $h = 30$ m calculated based on (c) FCC rules (d) ECC rules. For FCC the protection distance for the co channel is 14.4 km and for the adjacent channel 0.74 km. For ECC the margins are MI+SM = 10 dB, and the outage probability is $O_n = 10\%$.

"Aggregate interference with FCC and ECC white space usage rules: case study in Finland" (Jäntti, et al. 2011)

A paradigm shift

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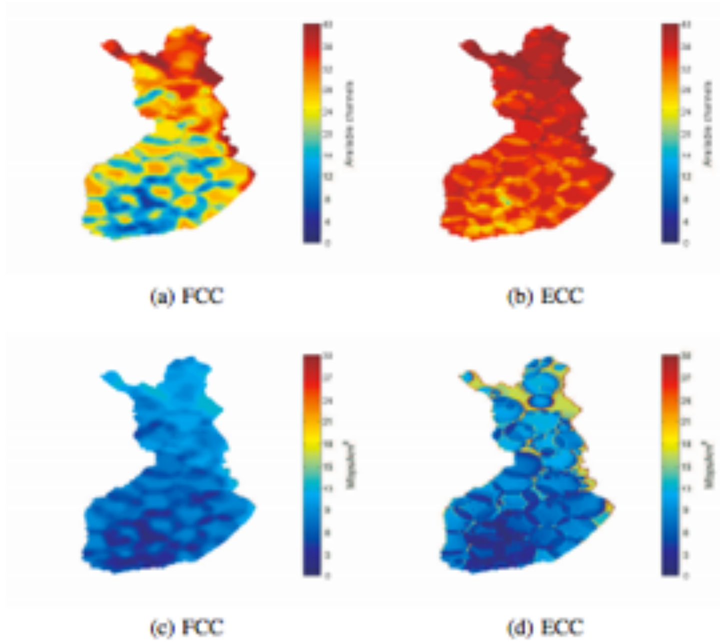

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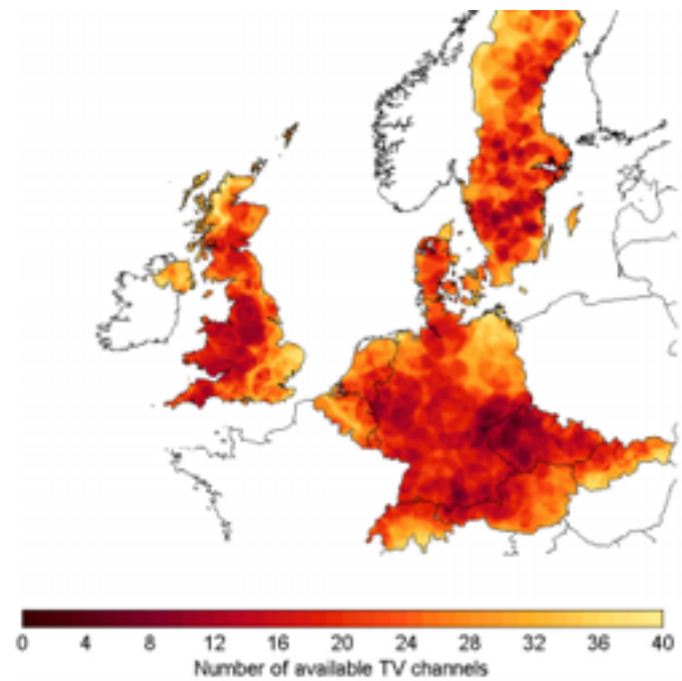
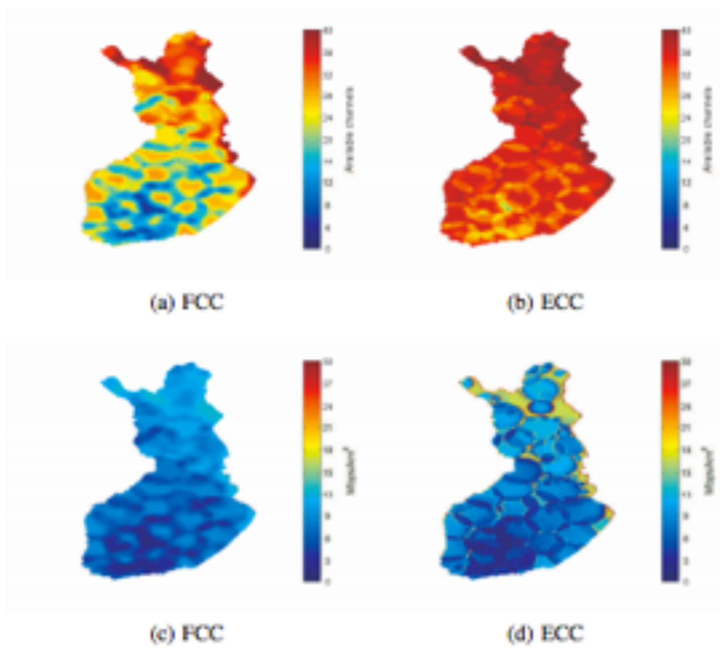


Fig. 2. White space map of $S(\mathbf{x})$ for 11 European countries.

"UHF white space in Europe — A quantitative study into the potential of the 470–790 MHz band" (Beek, et al. 2011)

A paradigm shift
(after)



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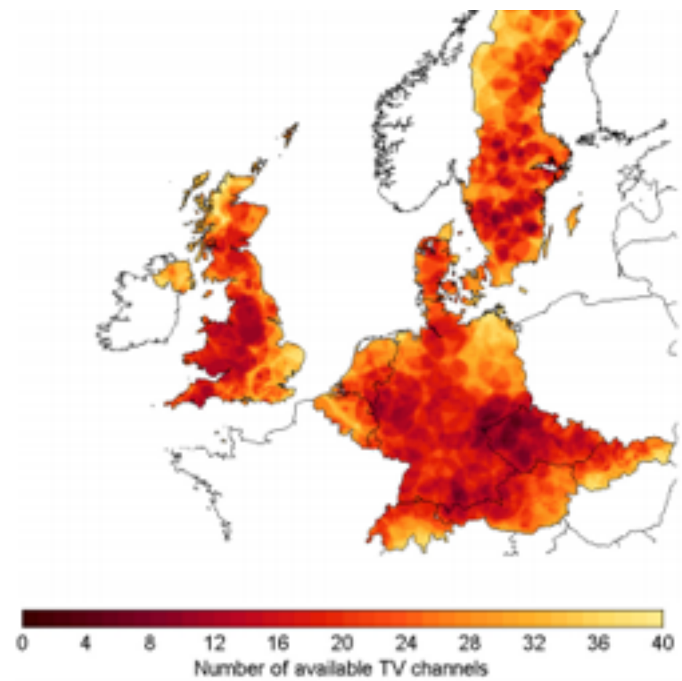

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Ofcom 2013 consultation

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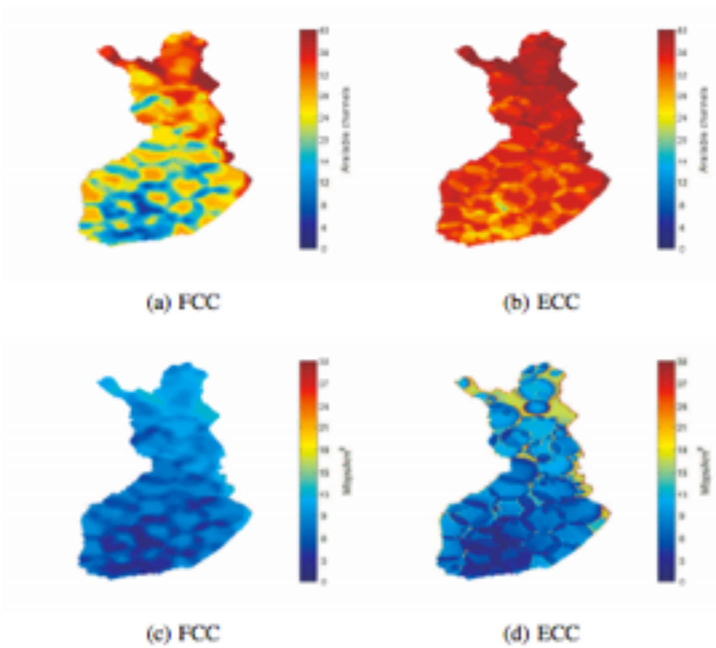

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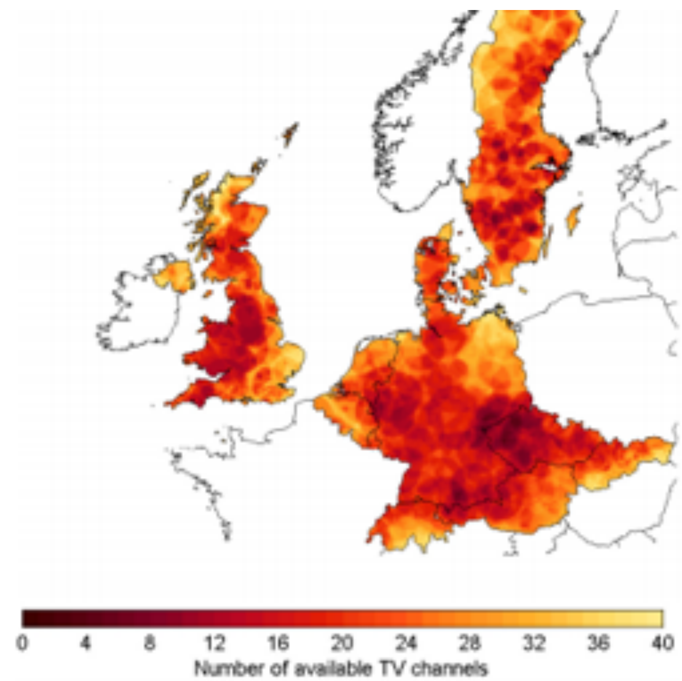

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Ofcom 2013 consultation

"Opportunities for white space usage in Australia"

Freyens and Loney, 2011

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- Introduction to whitespaces
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- Whitespace policy

Motivating example

+

AM/FM whitespace

→

FEDERAL COMMUNICATIONS COMMISSION · USA ·

Motivating example

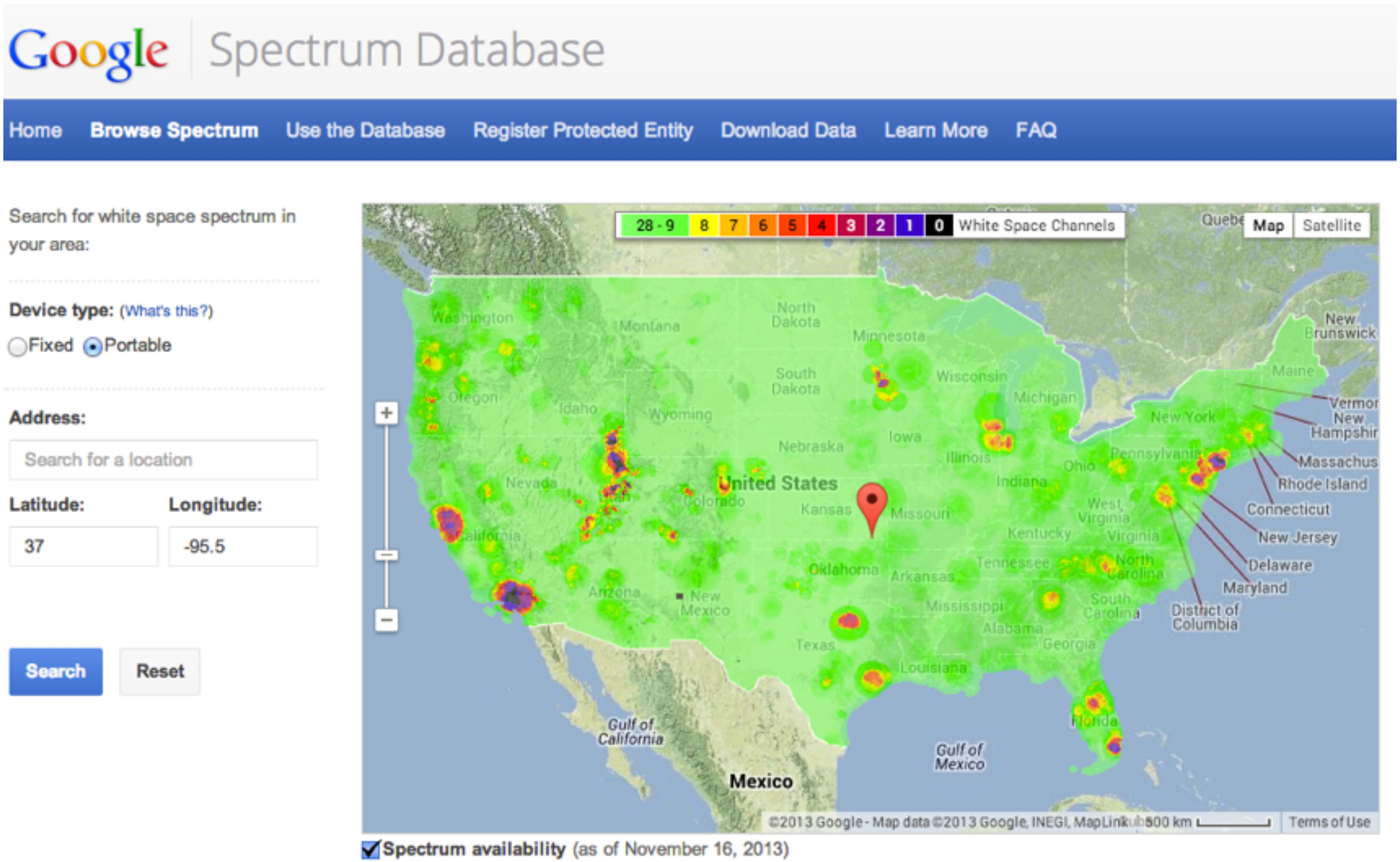
+

AM/FM whitespace

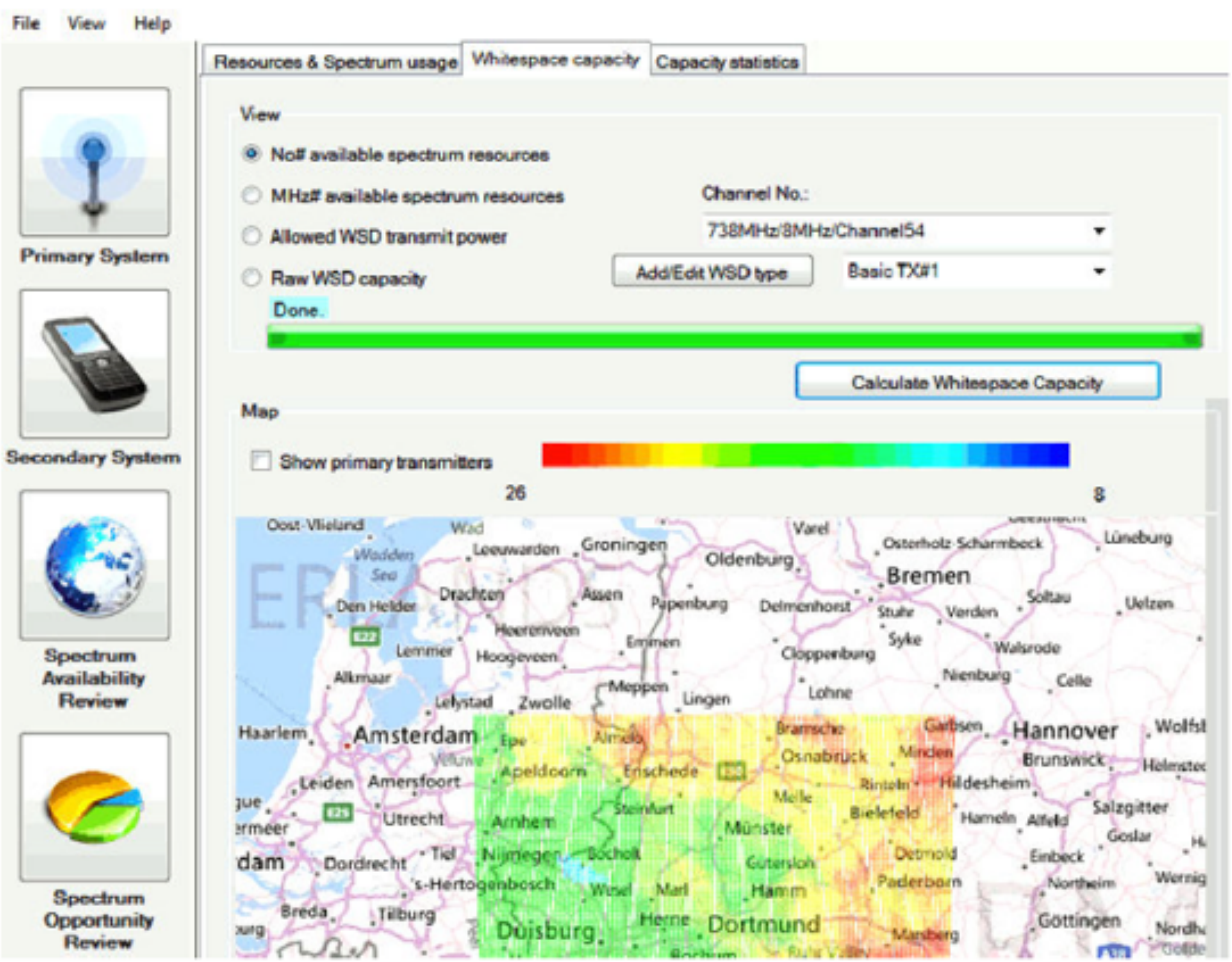
→

- Easy to use
- Free
- Reliable
- Flexible/extensible

Existing tools

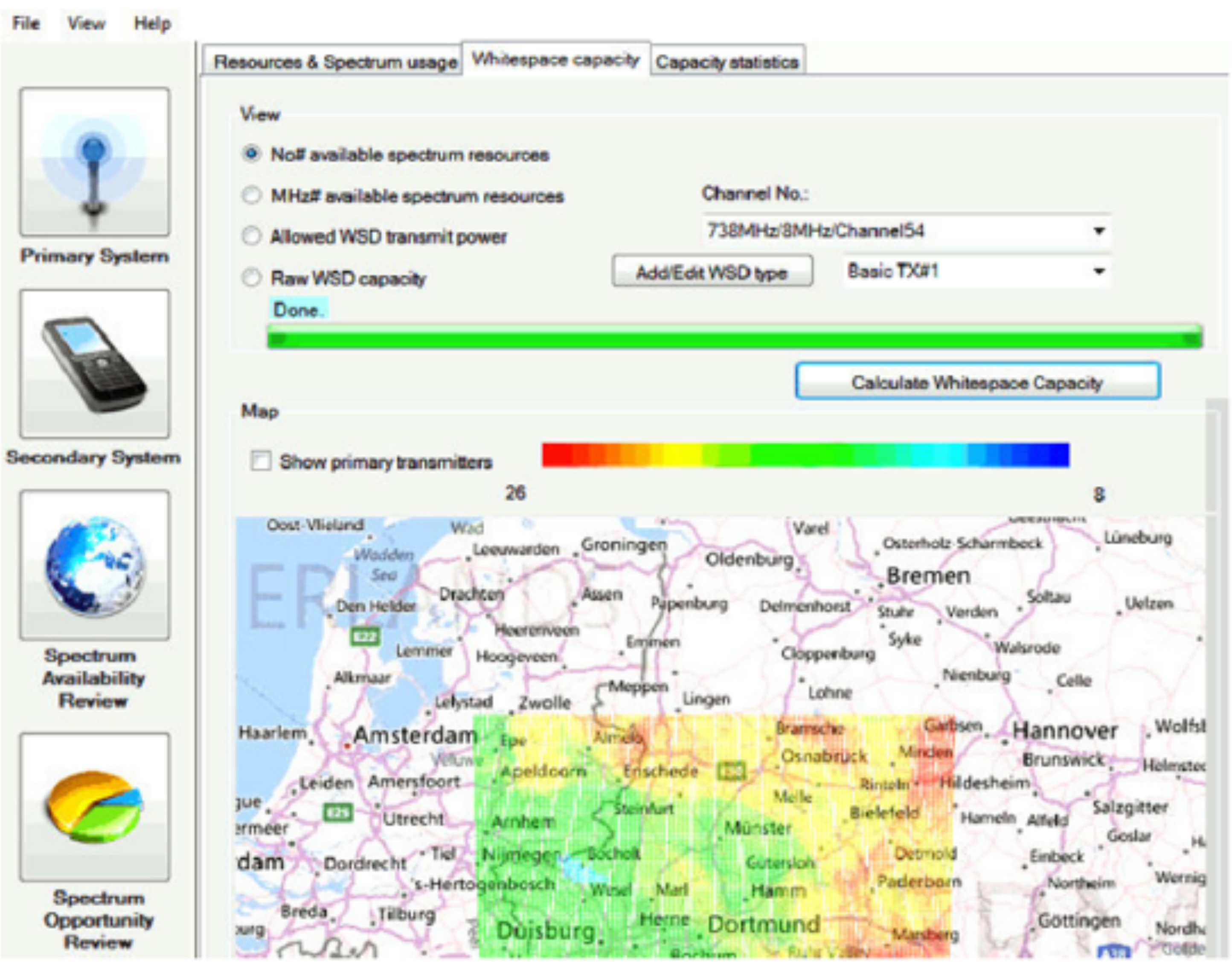


Existing tools



“Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces”
(WoWMoM 2013)

Existing tools



- Many tunable parameters but still targeting TVWS

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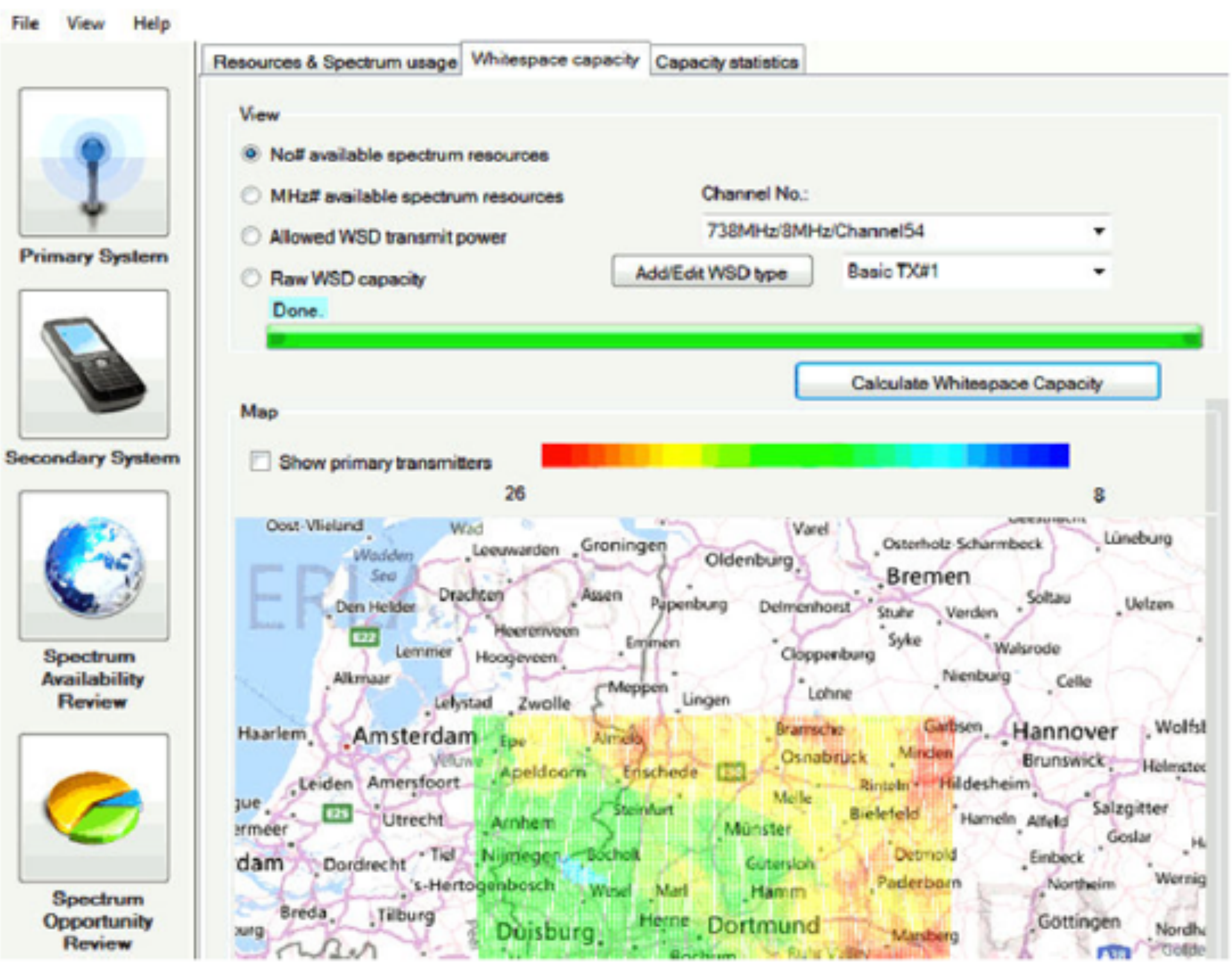
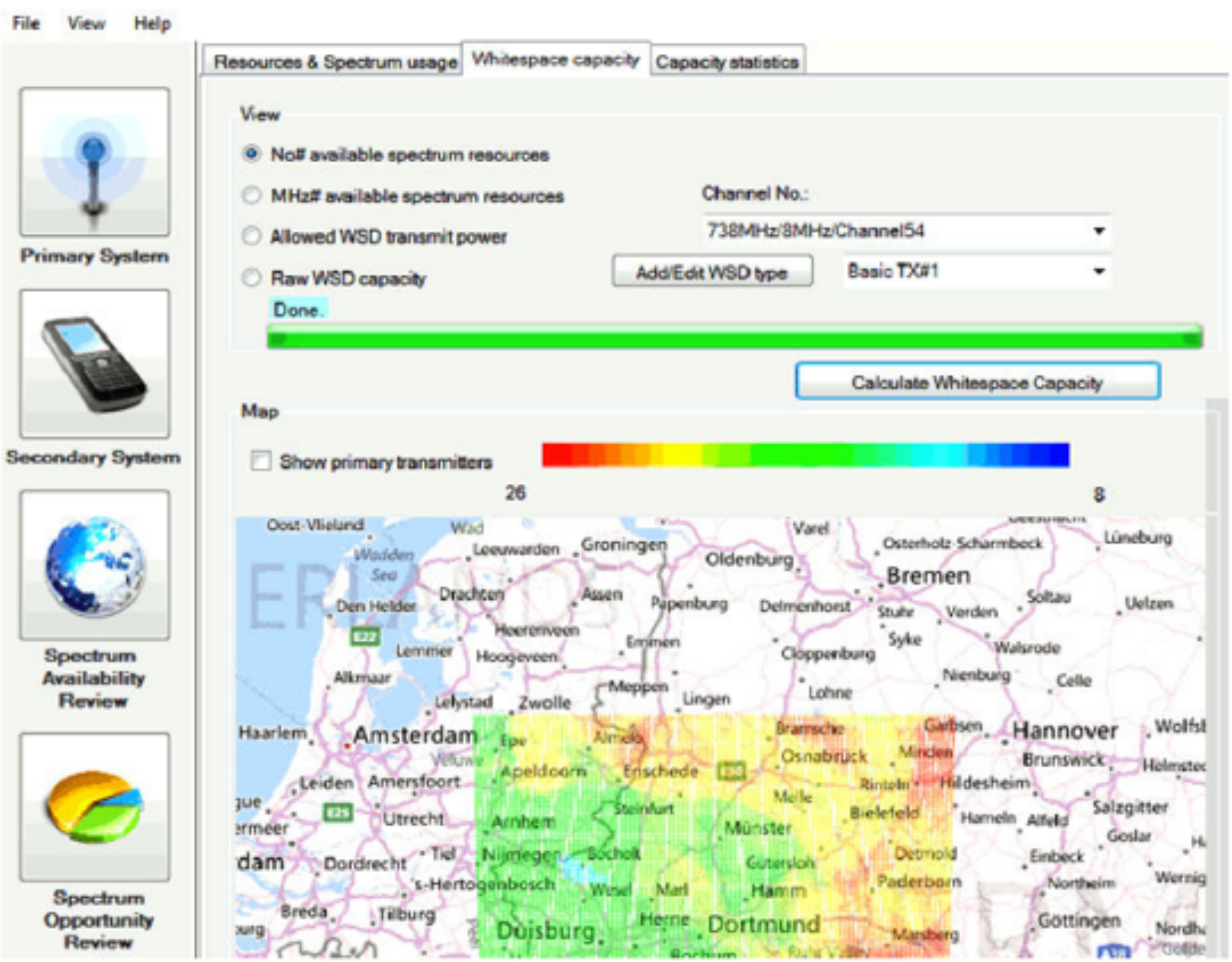


- Many tunable parameters but still targeting TVWS
- Based on Matlab

"Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces" (WoWMoM 2013)

Existing tools



- Many tunable parameters but still targeting TVWS
- Based on Matlab
- Not available

"Software Tool for Assessing Secondary System Opportunities in Spectrum Whitespaces" (WoWMoM 2013)

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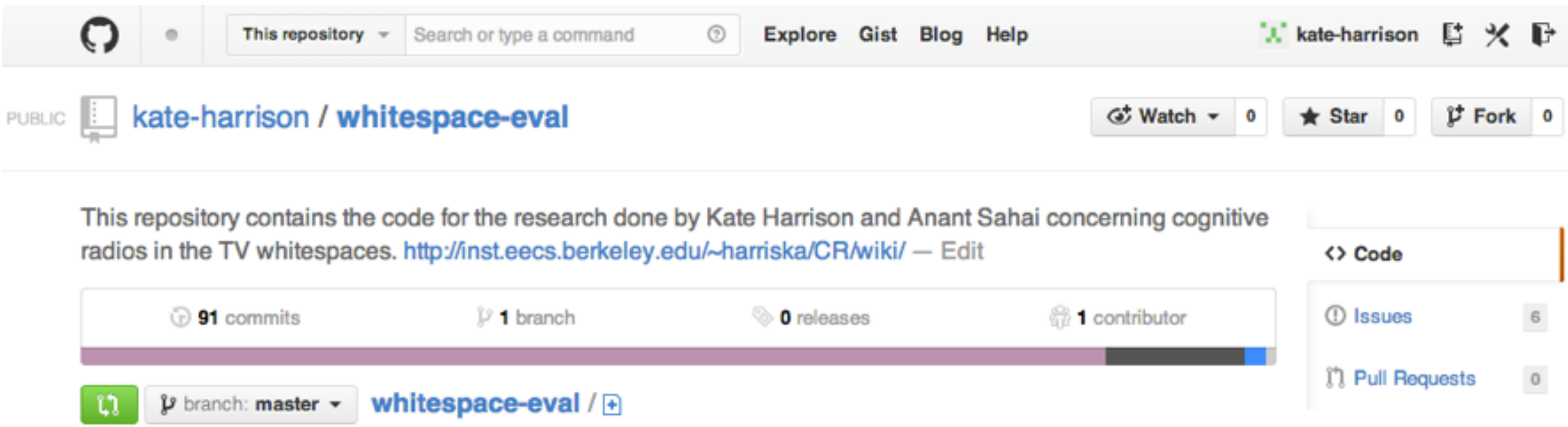


- Written in Matlab
- Grew organically

WEST

(Whitespace Evaluation SofTware)

Written in... python™ matplotlib

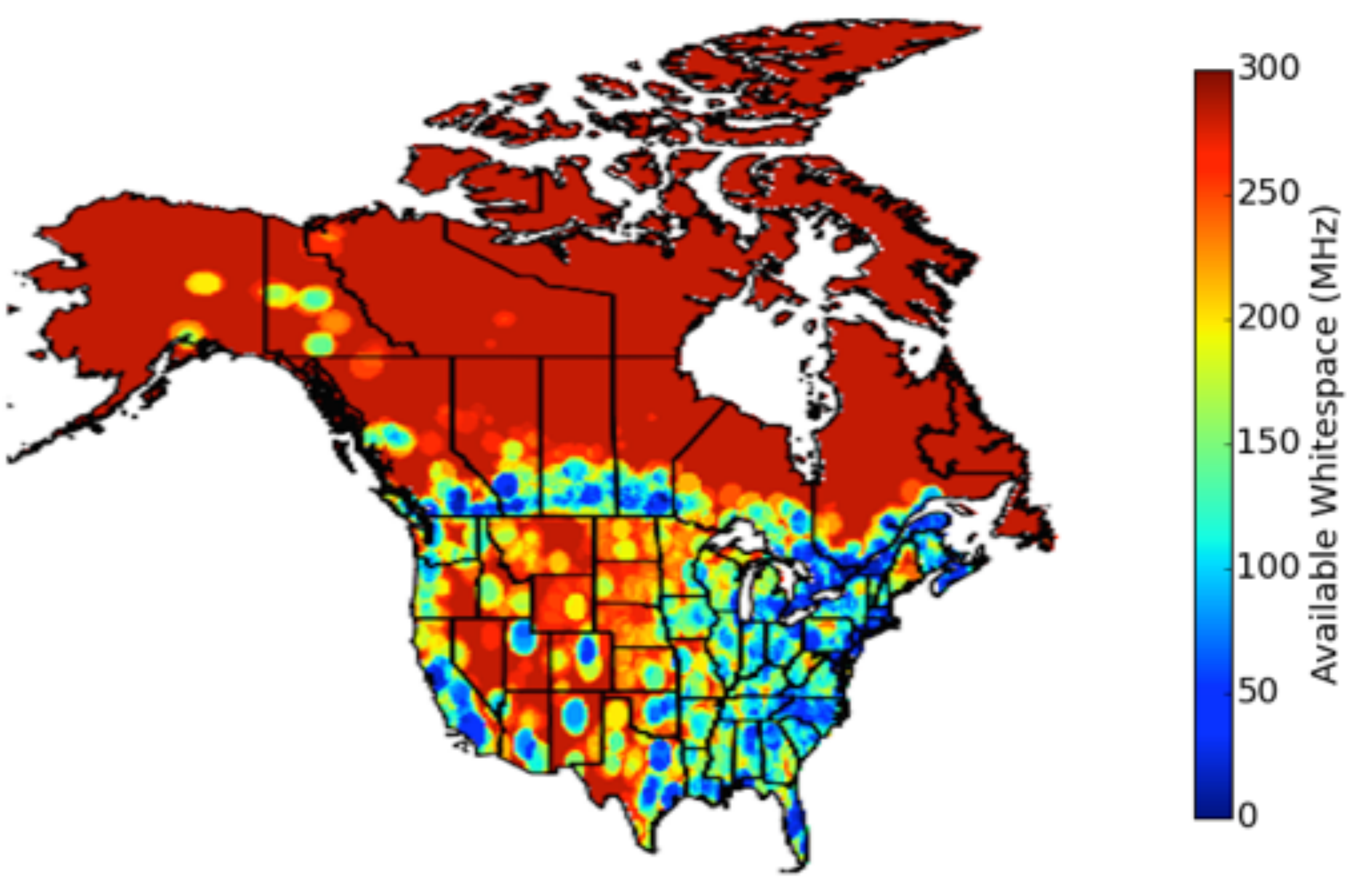
Posted on... GitHub

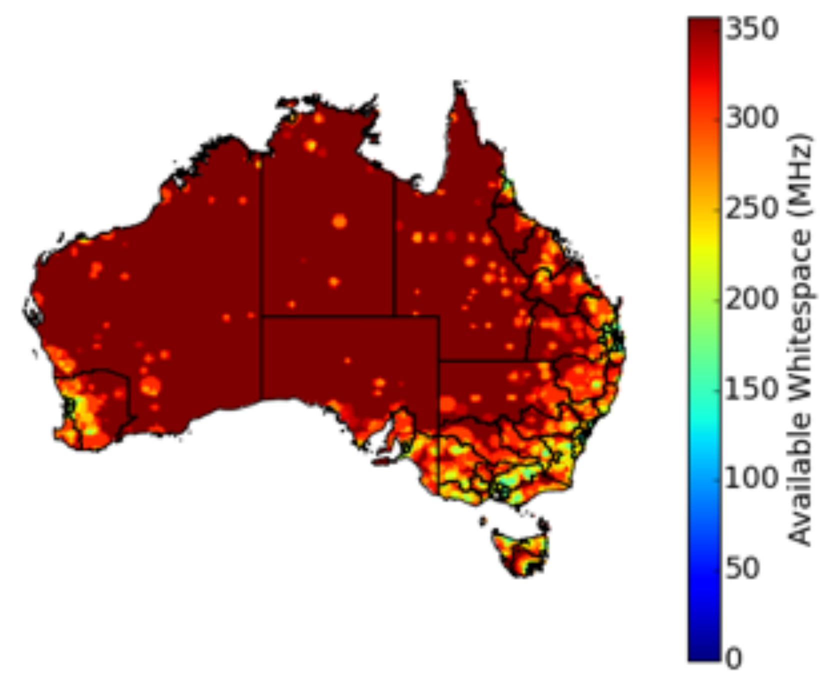
west.kateharrison.net

Key features

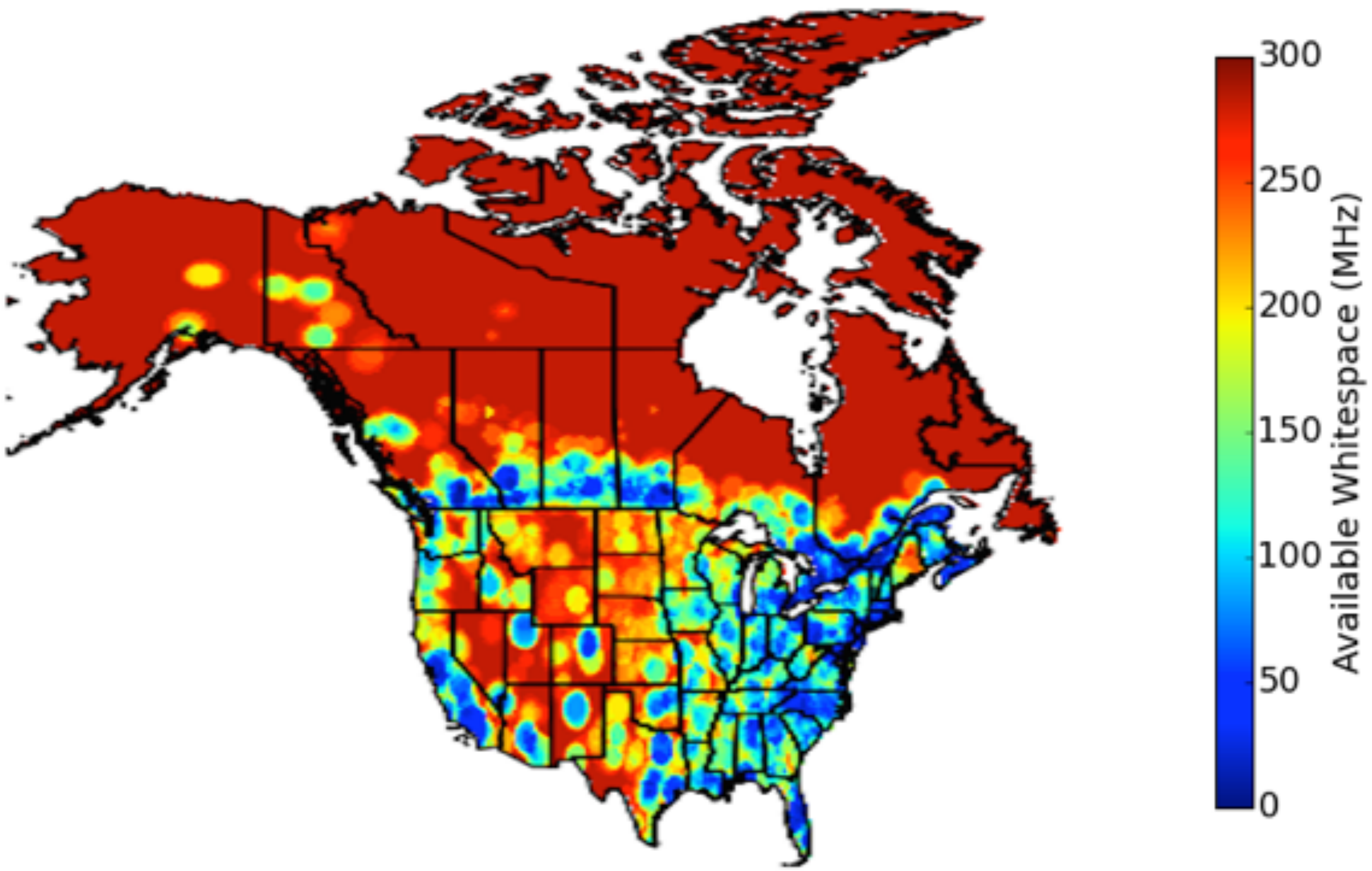
- Support for other bands
- Free, easier to integrate (e.g. AWS)
- Modular, extensible
- Open-source with GPLv2

Use case: explore new regions



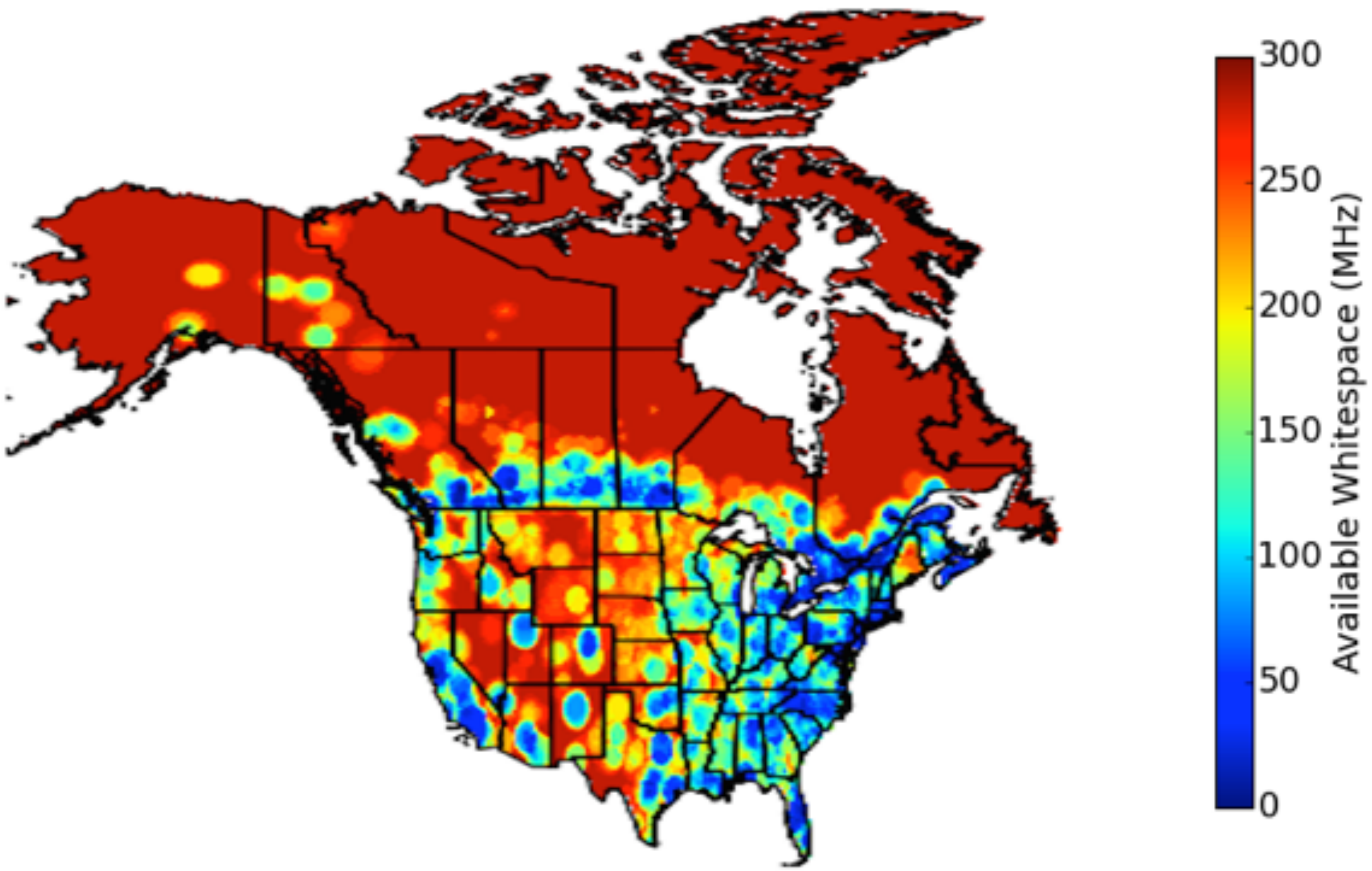


Use case: explore new rulesets



Industry Canada 2015

Use case: explore new rulesets



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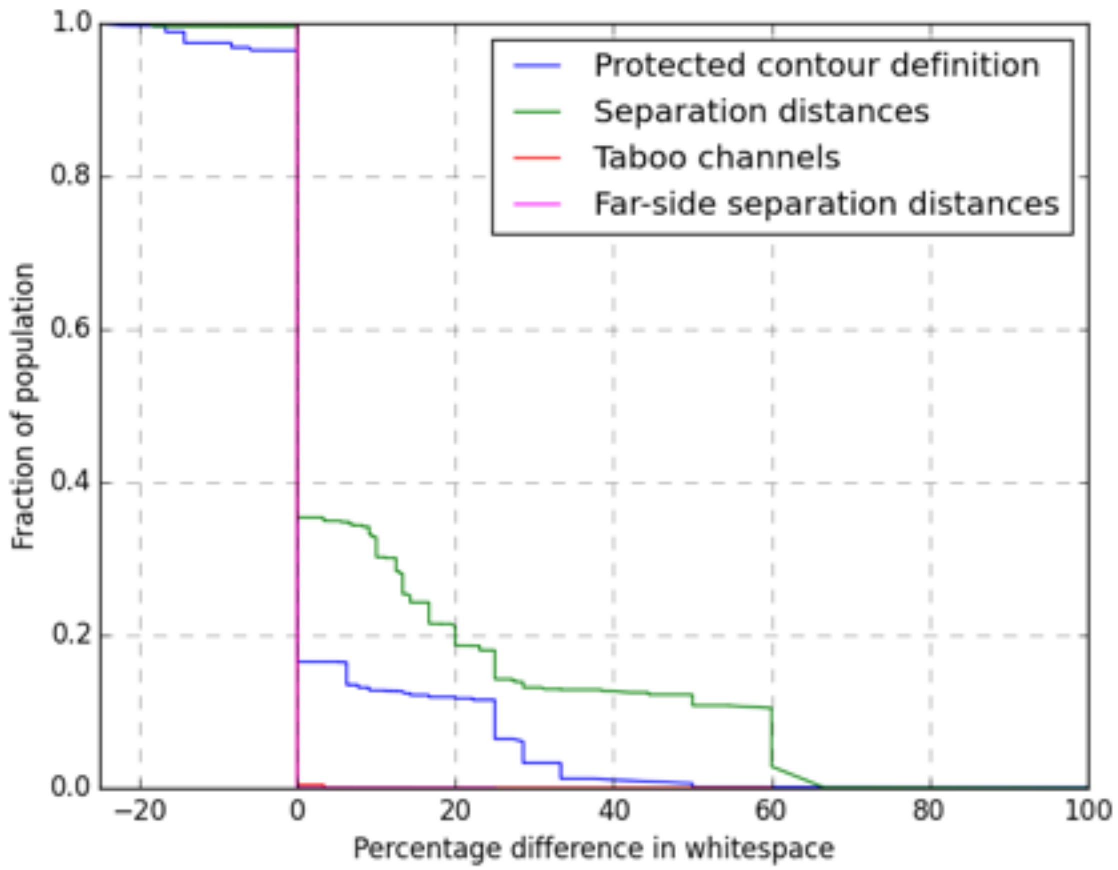
Canada 



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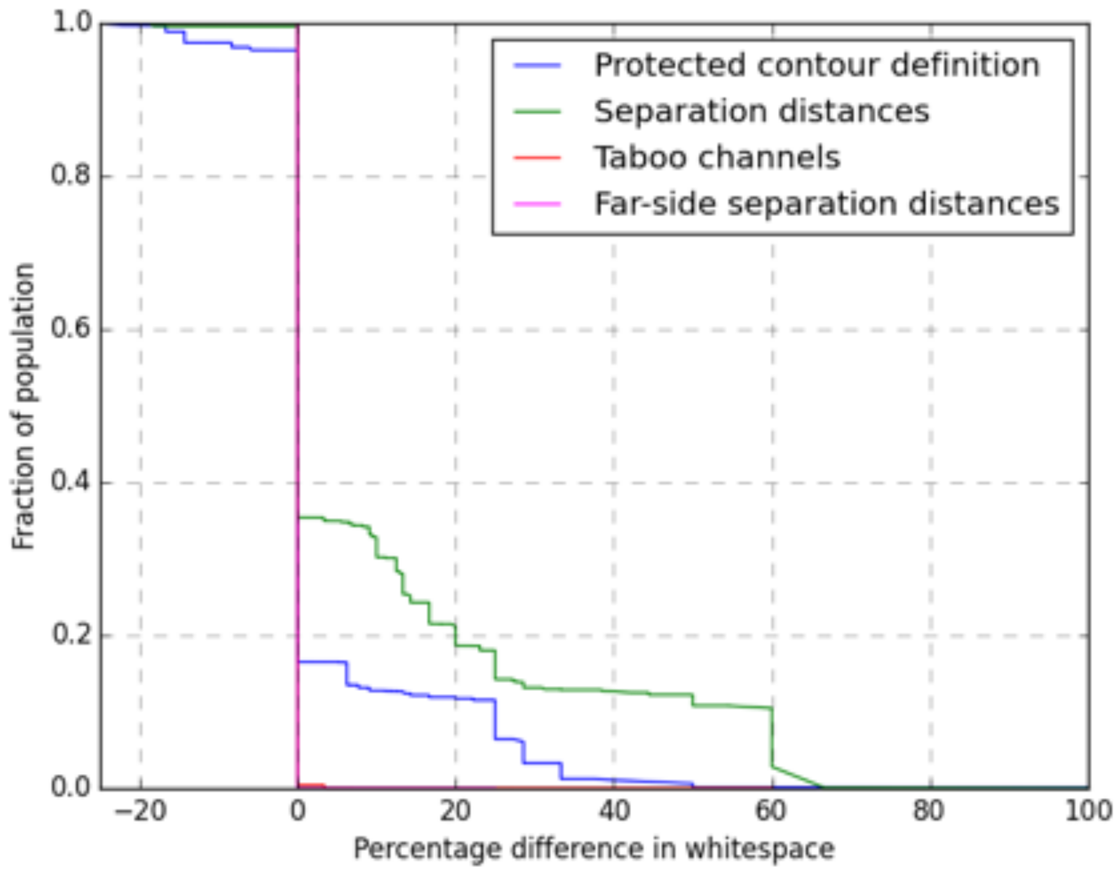
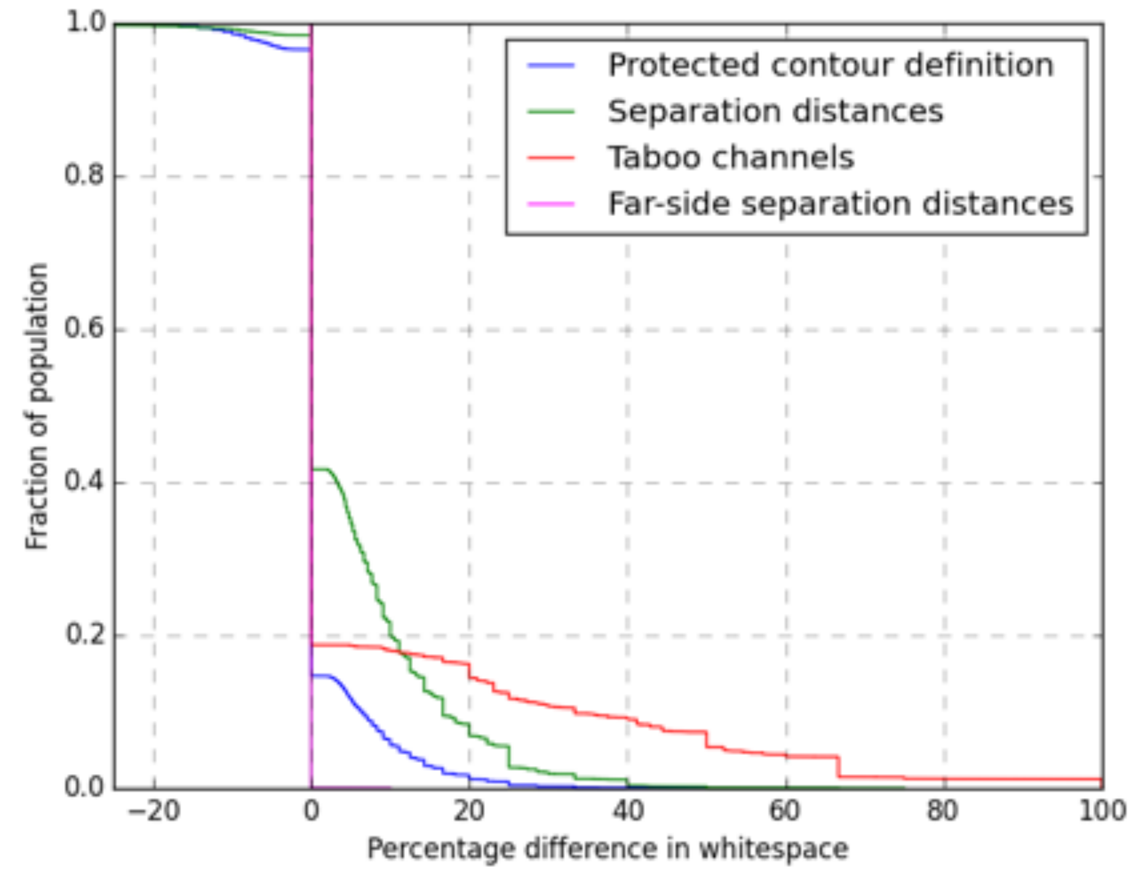
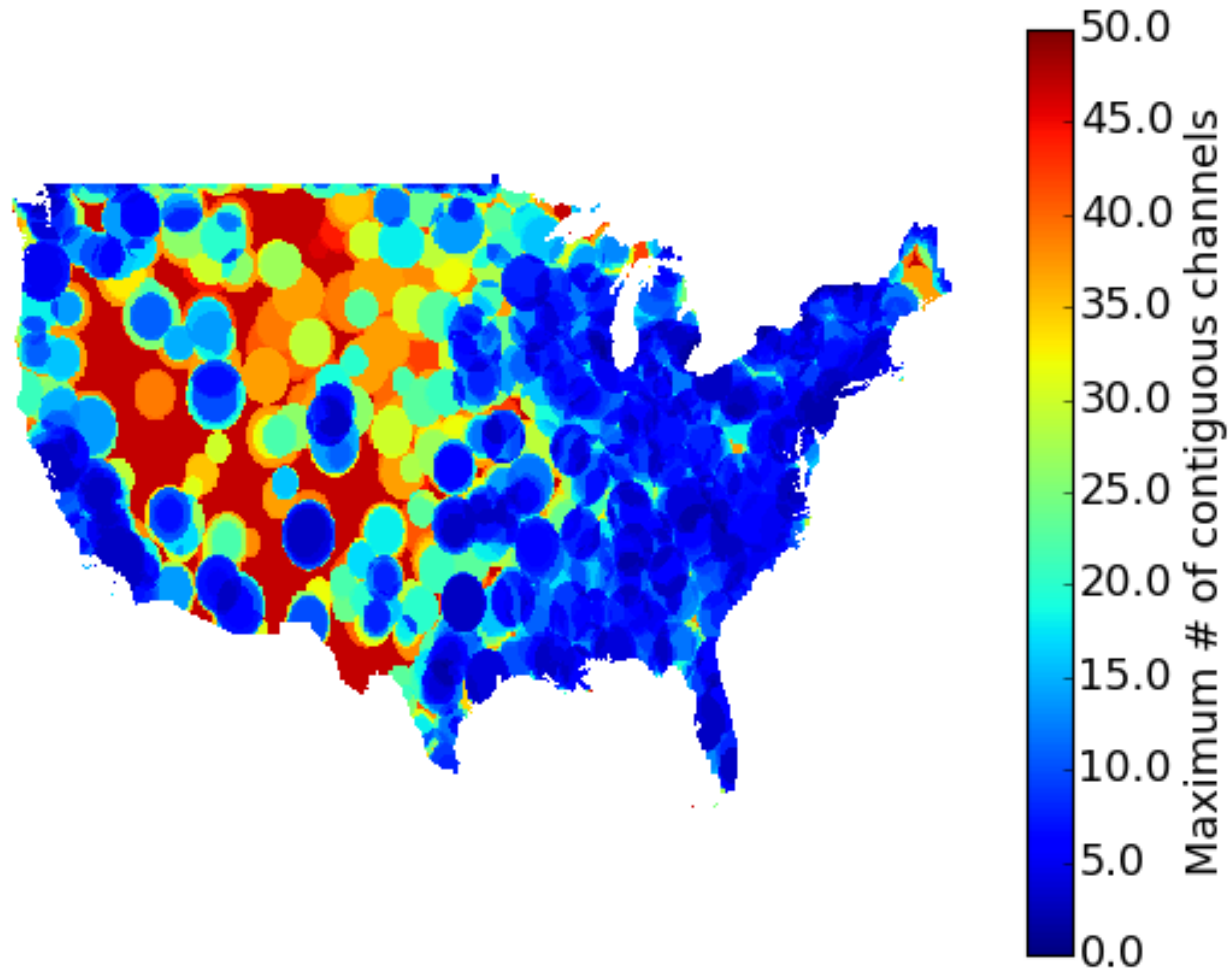
Canada



United States



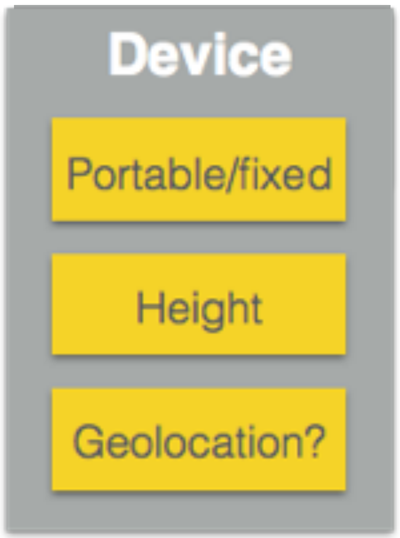
Use case: number of contiguous channels



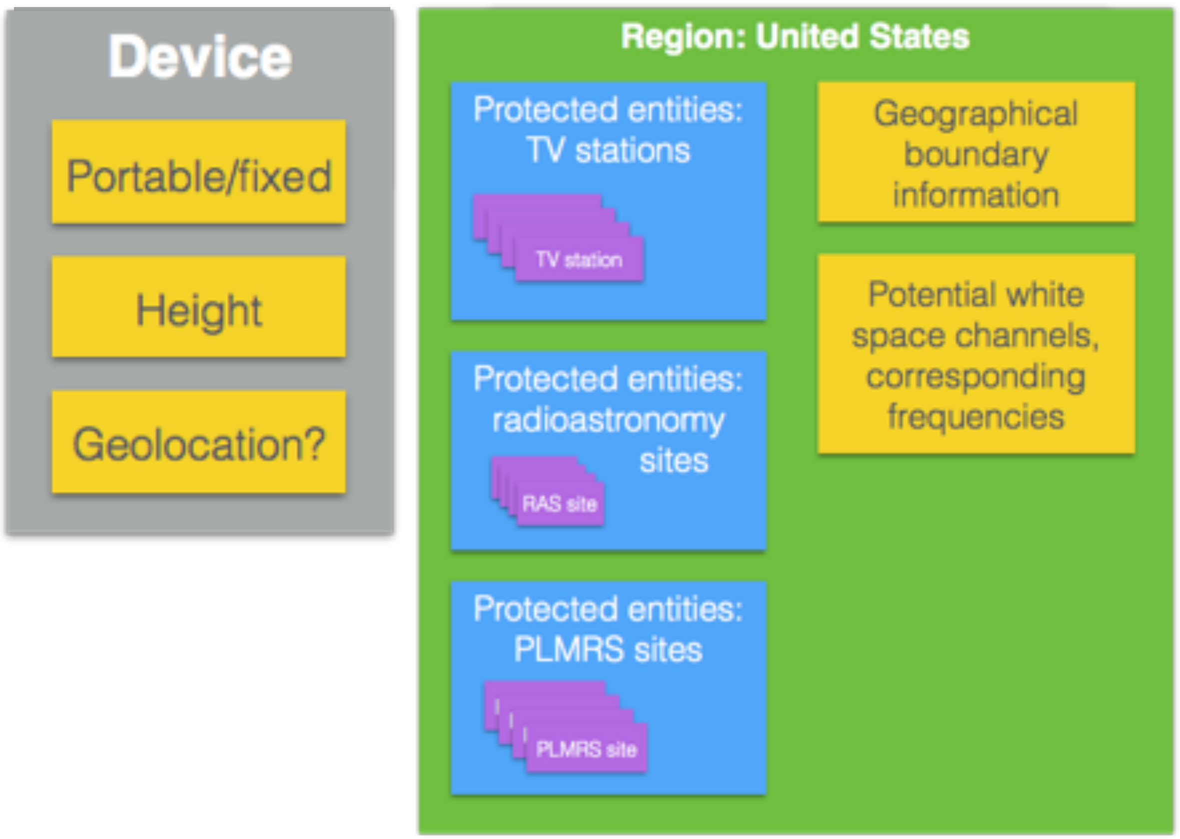
Other uses

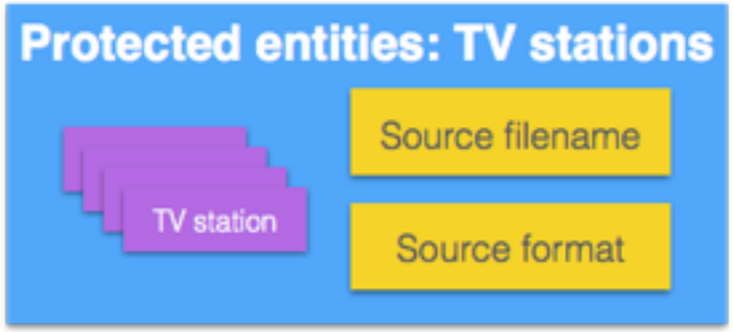
- Comments to regulators
- Reproducible research
- New economic models
- Cloud-based for greater impact, engagement

Design

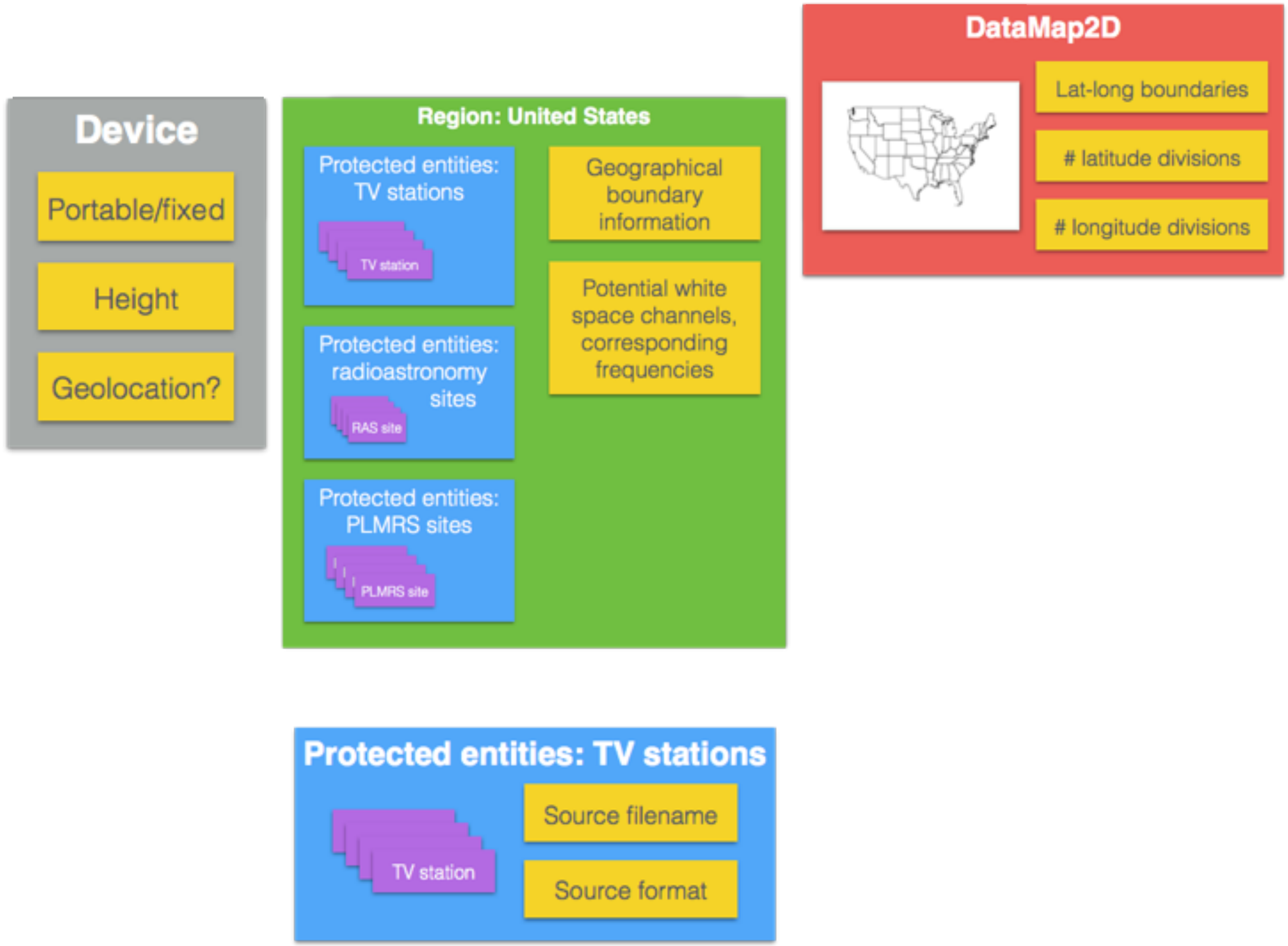


Design


Device
Portable/fixed
Height
Geolocation?
Region: United States
Protected entities: TV stations
TV station
Geographical boundary information
Potential white space channels, corresponding frequencies
Protected entities: radioastronomy sites
RAS site
Protected entities: PLMRS sites
PLMRS site


Protected entities: TV stations
TV station
Source filename
Source format

Design



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DataMap2D
Lat-long boundaries
latitude divisions
longitude divisions
Protected entities: TV stations
TV station
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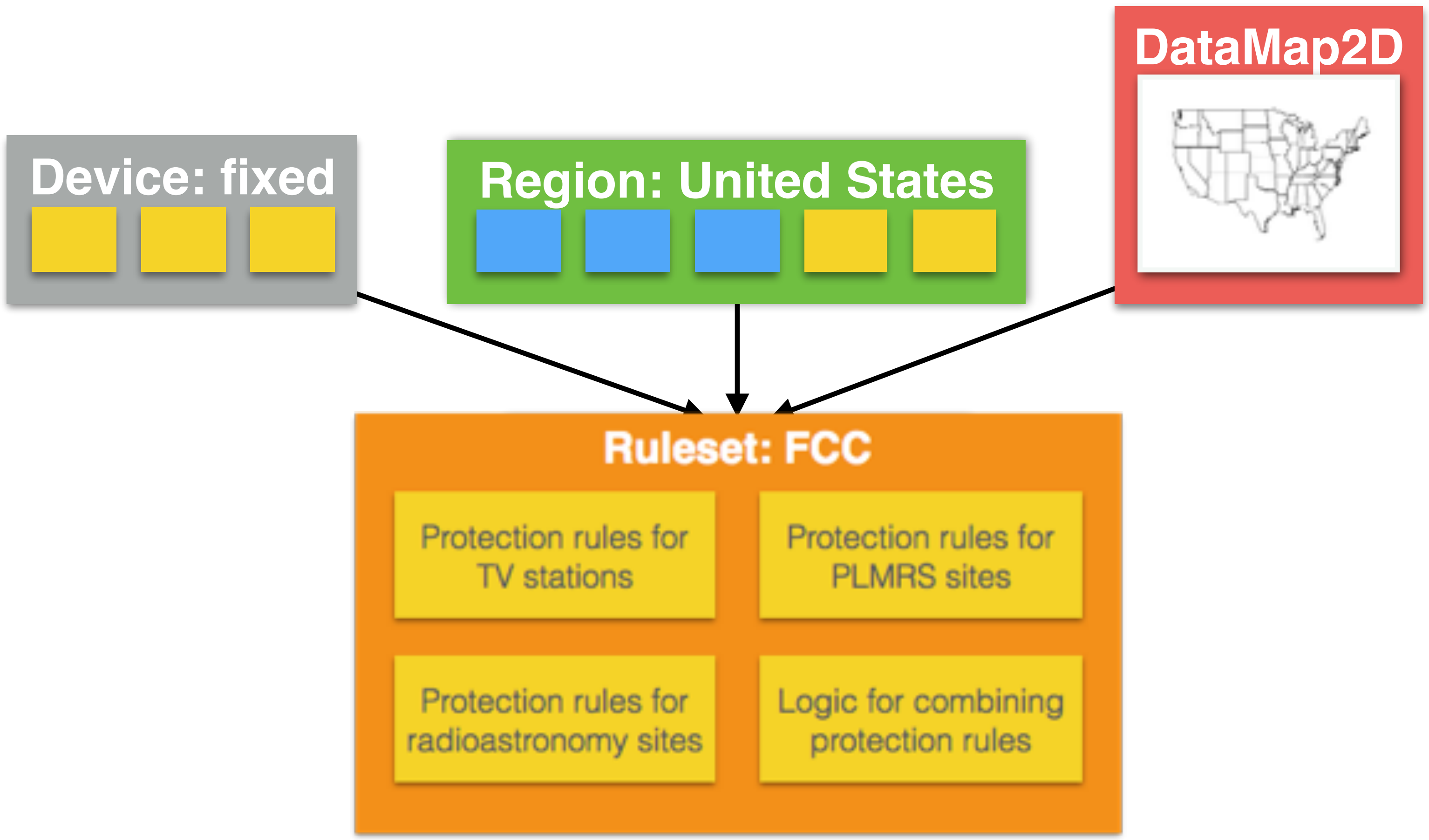
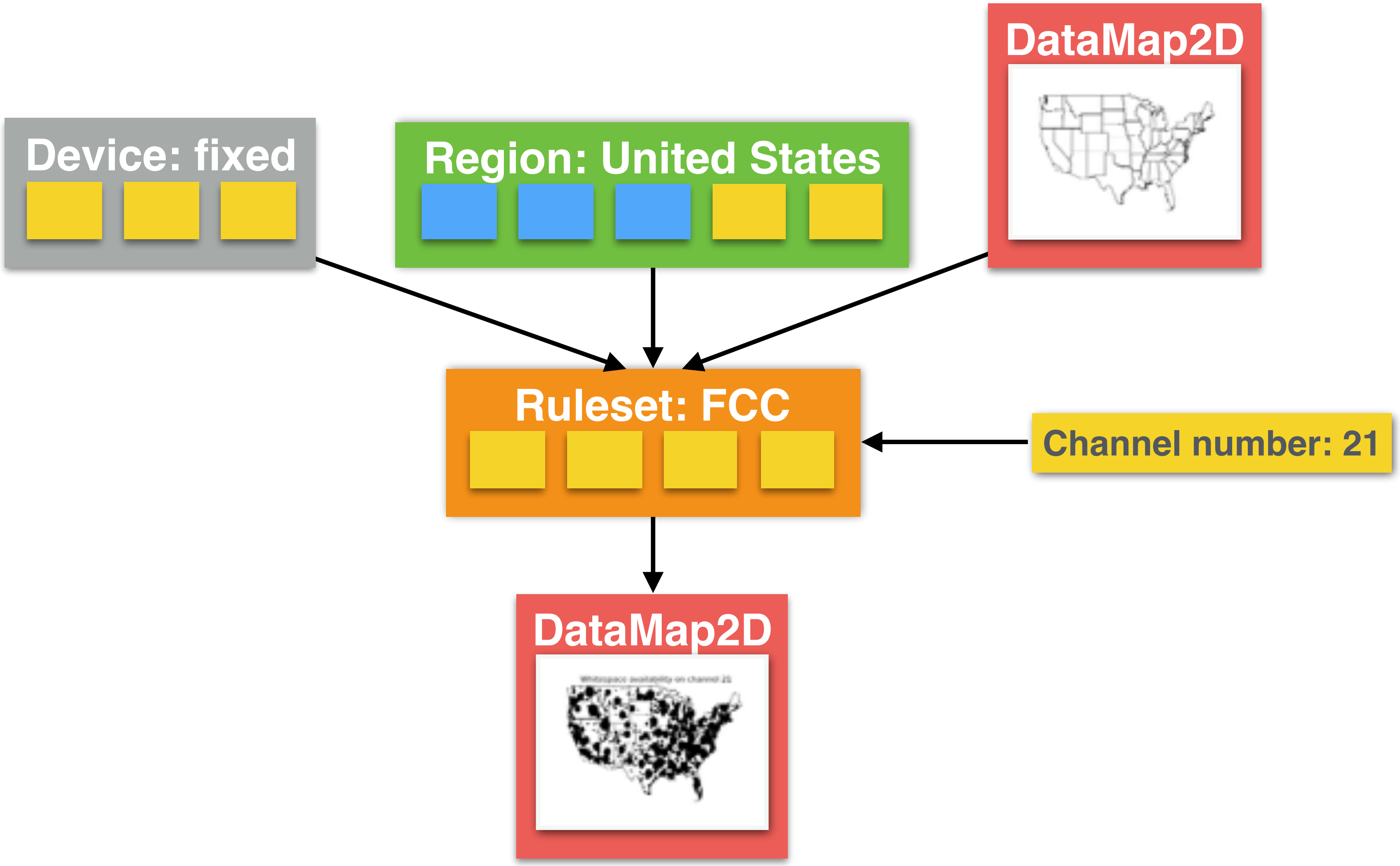
Design

Design

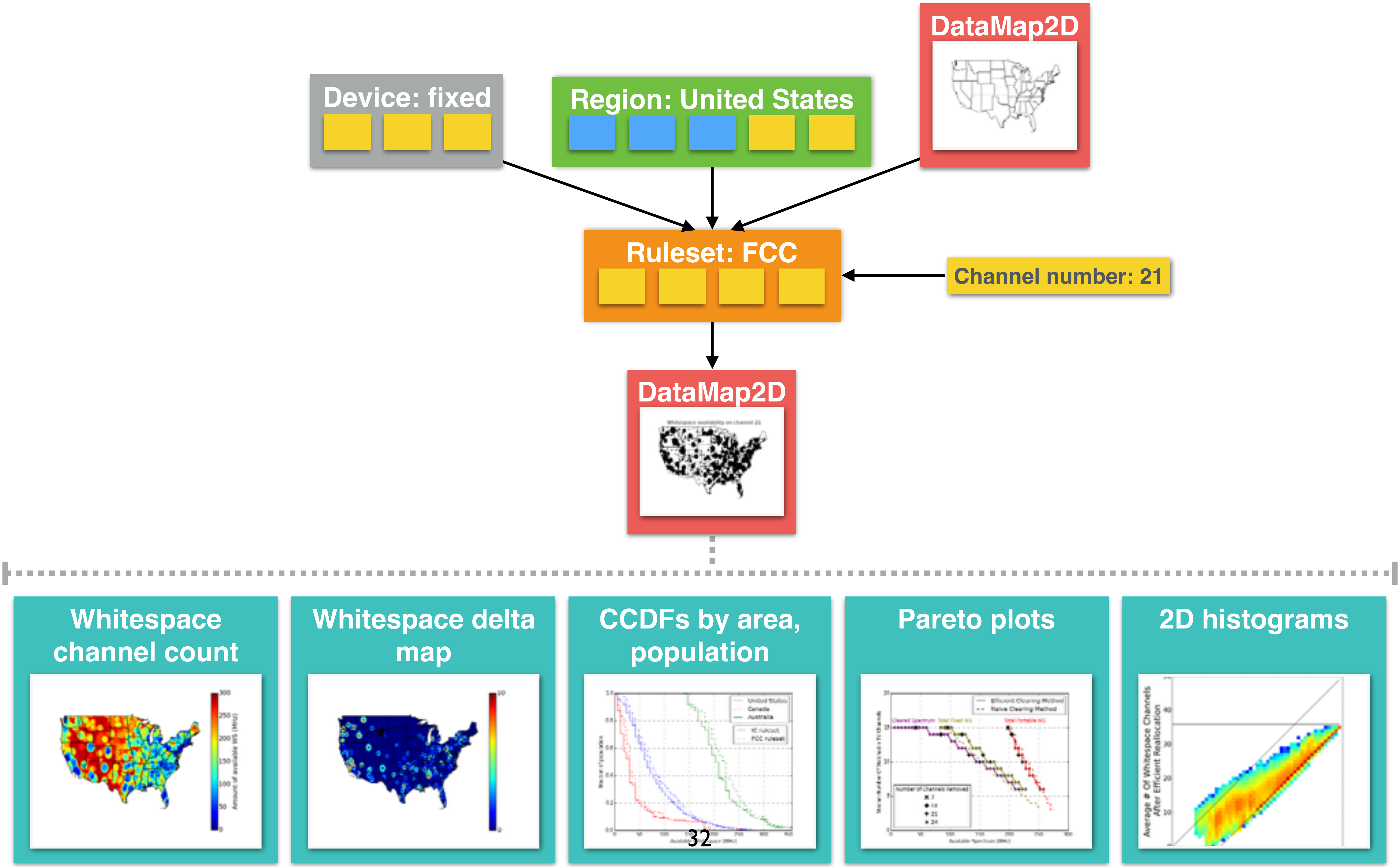

DataMap2D
Device: fixed
Region: United States
Ruleset: FCC
Protection rules for TV stations
Protection rules for PLMRS sites
Protection rules for radioastronomy sites
Logic for combining protection rules

Design

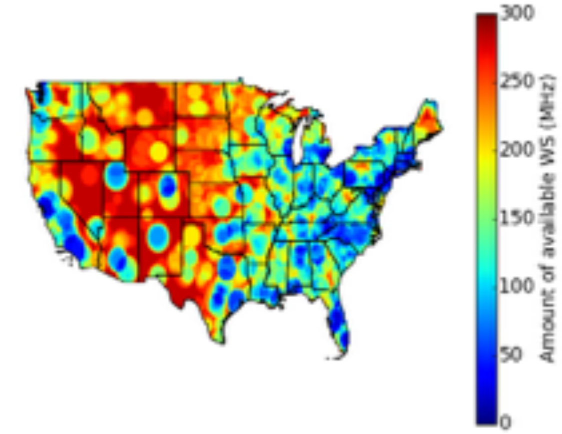


Device: fixed
Region: United States
DataMap2D
Ruleset: FCC
Channel number: 21
DataMap2D

Design


DataMap2D
Device: fixed
Region: United States
Ruleset: FCC
Channel number: 21
DataMap2D
Whitespace channel count
Whitespace delta map
CCDFs by area, population
Pareto plots
2D histograms

Generating a whitespace map




```
from west.data_management import *
from west.data_map import *
from west.boundary import BoundaryContinentalUnitedStates, \
    BoundaryContinentalUnitedStatesWithStateBoundaries
from west.region_united_states import RegionUnitedStates
from west.ruleset_fcc2012 import RulesetFcc2012
from west.device import Device

test_device = Device(is_portable=False, haat_meters=30)

datamap_spec = SpecificationDataMap(DataMap2DContinentalUnitedStates, 200, 300)

region_map_spec = SpecificationRegionMap(BoundaryContinentalUnitedStates,
                                         datamap_spec)

is_whitespace_map_spec = SpecificationWhitespaceMap(region_map_spec,
                                                    RegionUnitedStates,
                                                    RulesetFcc2012, test_device)

is_whitespace_map = is_whitespace_map_spec.fetch_data()

total_whitespace_channels = is_whitespace_map.sum_all_layers()

is_in_region_map = region_map_spec.fetch_data()

plot = total_whitespace_channels.make_map(is_in_region_map=is_in_region_map)

plot.add_boundary_outlines(boundary=BoundaryContinentalUnitedStatesWithStateBoundaries())
plot.set_boundary_color('k')
plot.set_boundary_linewidth('1')

plot.save("Number of TVWS channels in the United States.png")
```

Outline

- Introduction to whitespaces
- Quantifying whitespaces
- Whitespace software
- Whitespace policy

Whitespace policy

"What's better, whitespaces or refarming?"

- Spectrum reallocation [ICC 2015]
- Architecture (briefly) [ICC 2015]
- *Variable power limits [DySpAN 2011, DySpAN 2012]*
- *Alternative methods for localization [DySpAN 2014]*

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"How can we make devices/deployments cheaper, easier, and faster?"

"How can we increase data rates while protecting the primaries?"

"How can we make WS access more flexible, robust without losing secondary QoS?"

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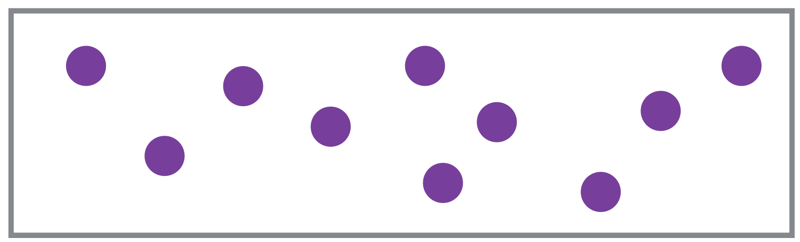
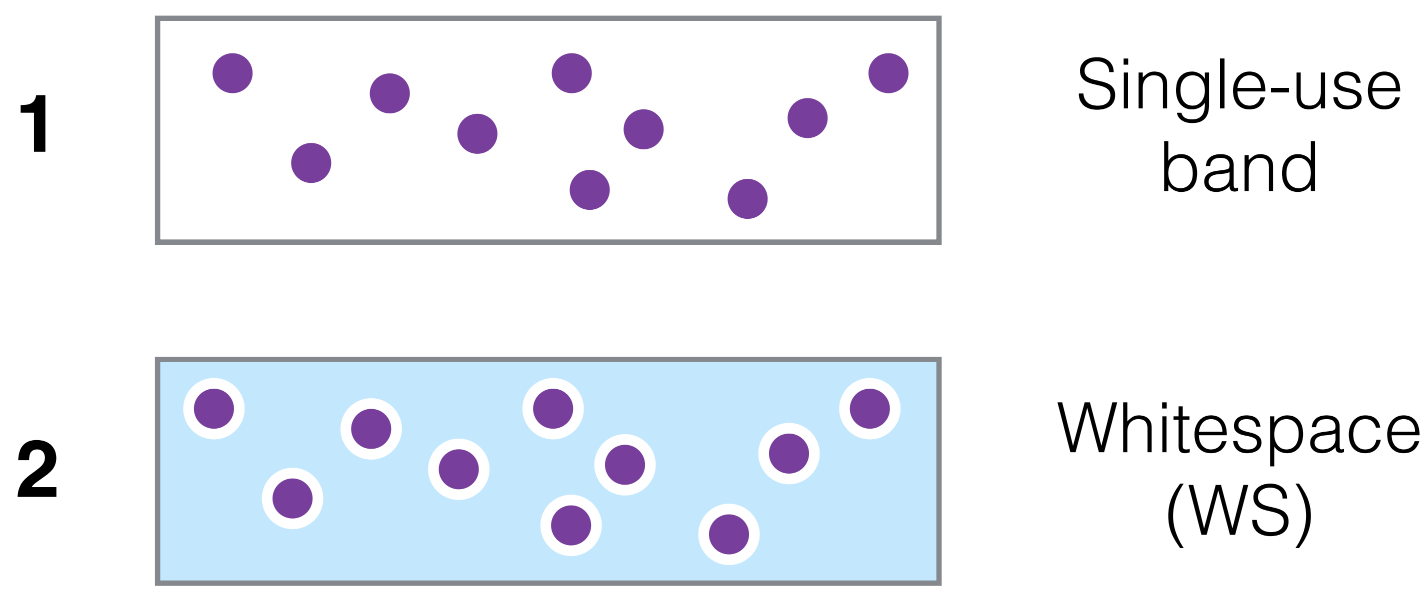
Spectrum sharing scenarios

1

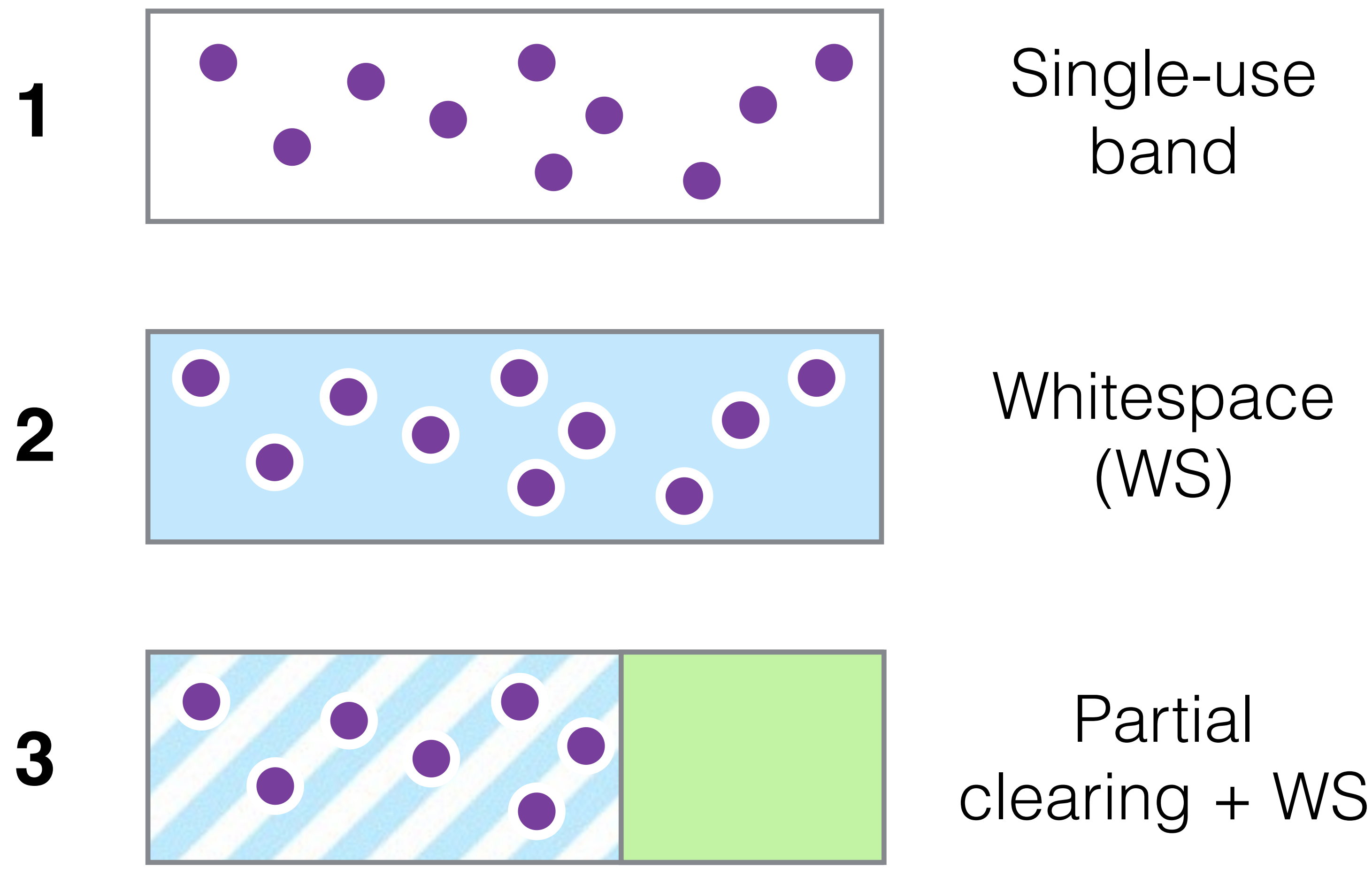


Single-use band

Spectrum sharing scenarios



Spectrum sharing scenarios



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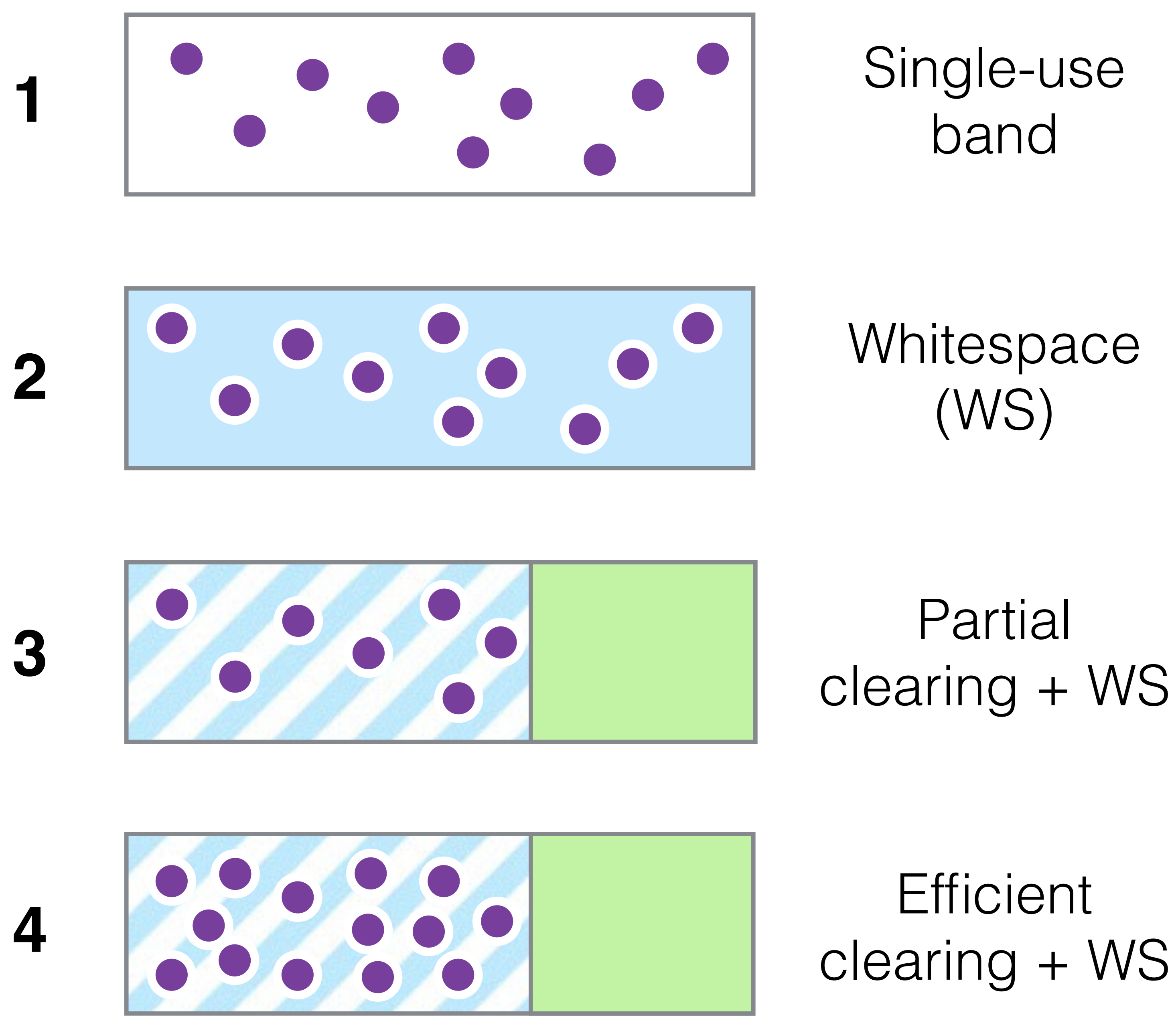
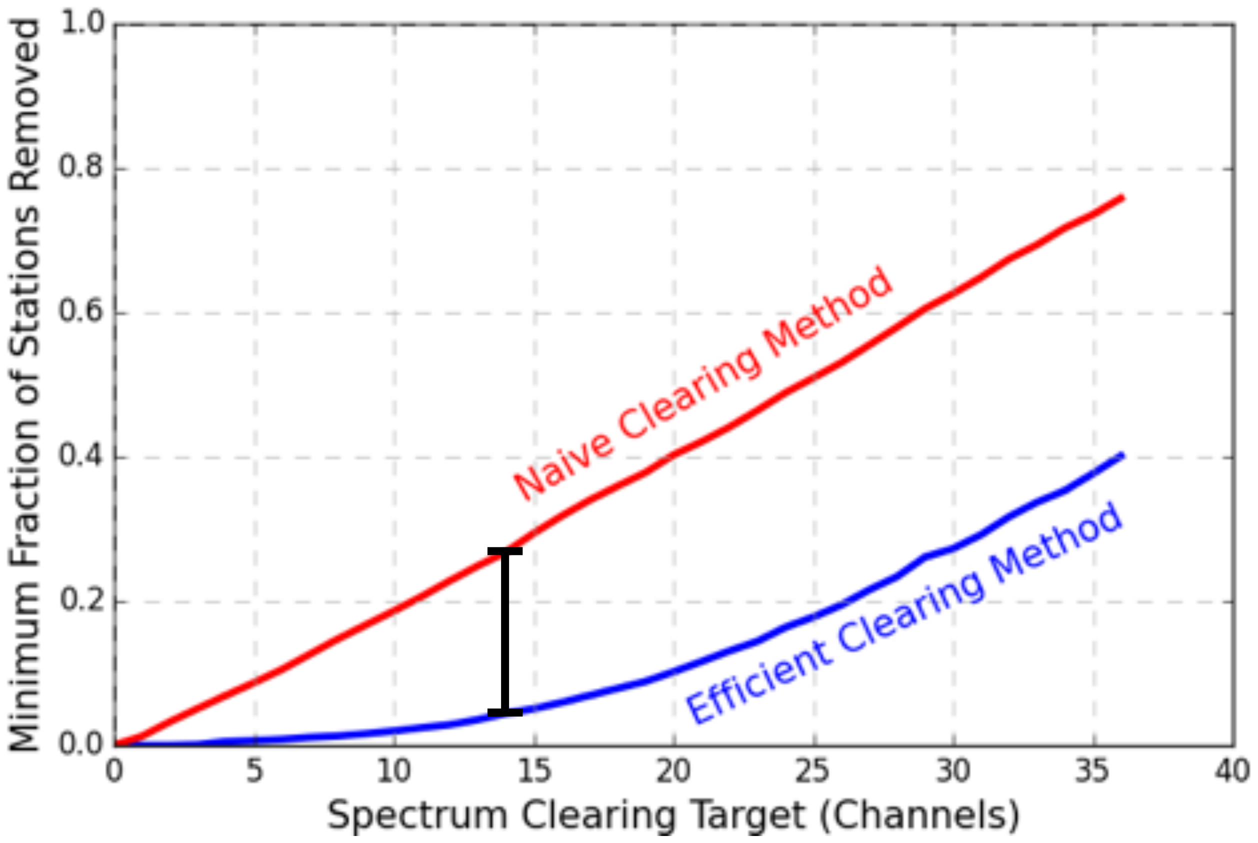
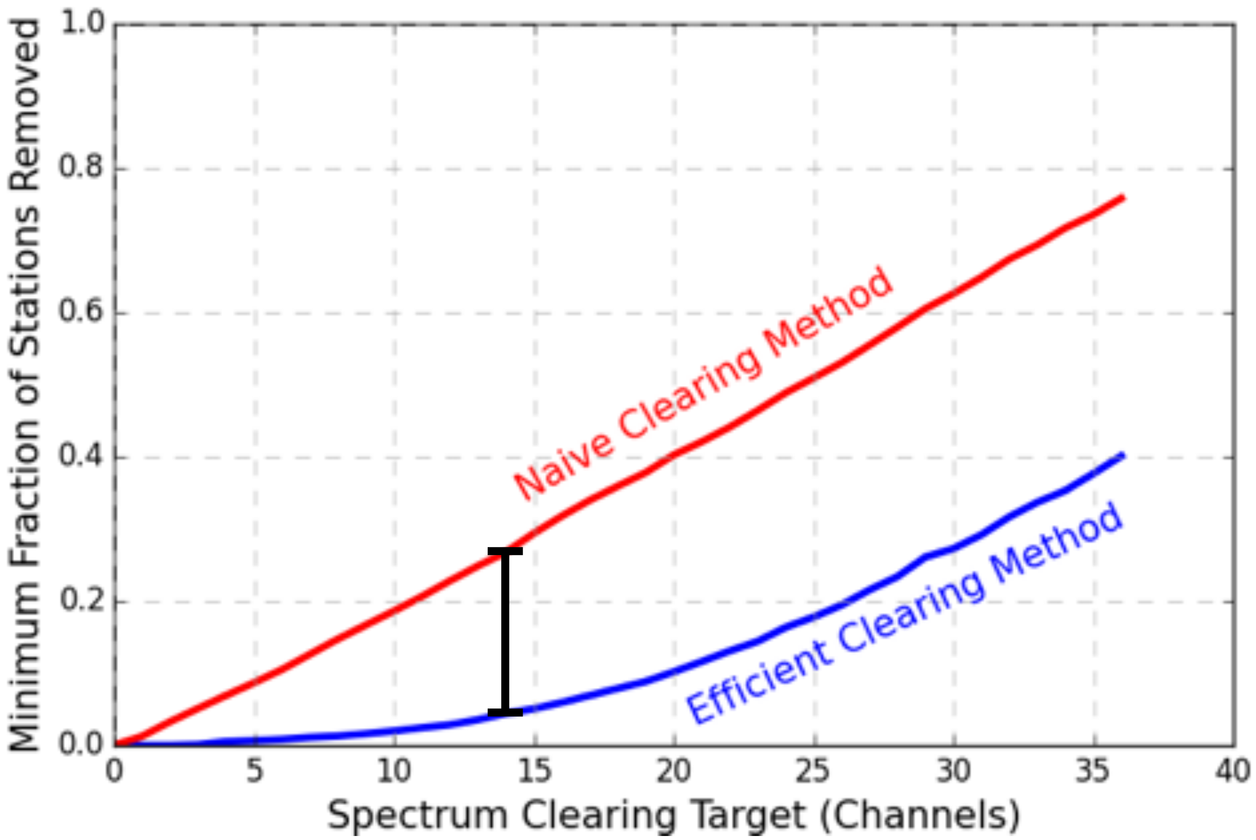


Impact on incumbents

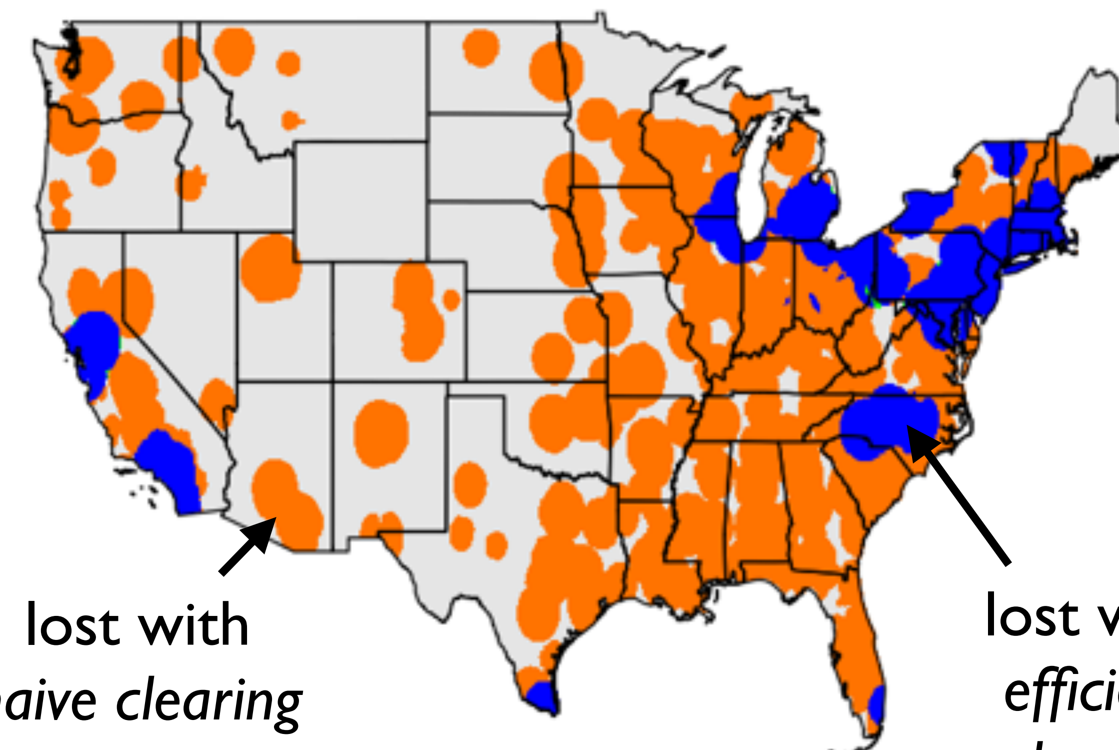


Efficient clearing allows more incumbents to stay with same clearing target

Impact on incumbents



14 channels repurposed



Efficient clearing allows more incumbents to stay with same clearing target

Team + tools

Anant Sahai

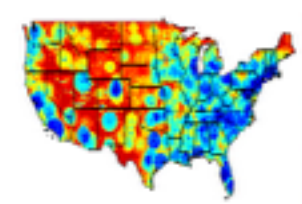
Angel Daruna

Vidya Muthukumar

Vijay Kamble

PycoSAT
(PicoSAT)

python™



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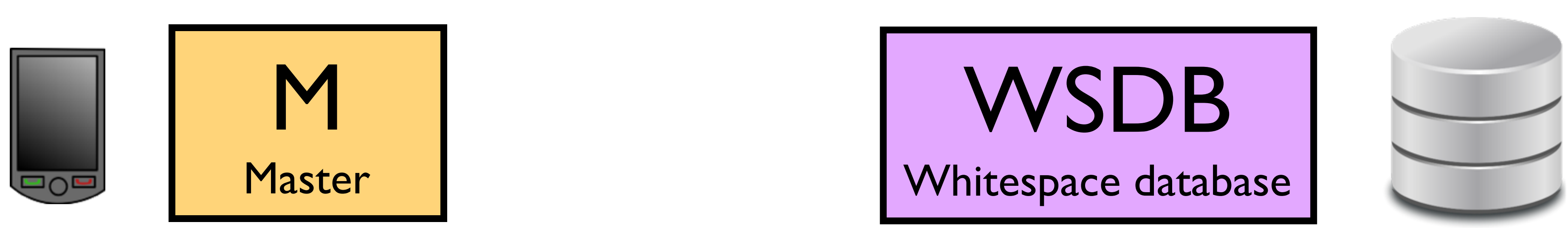

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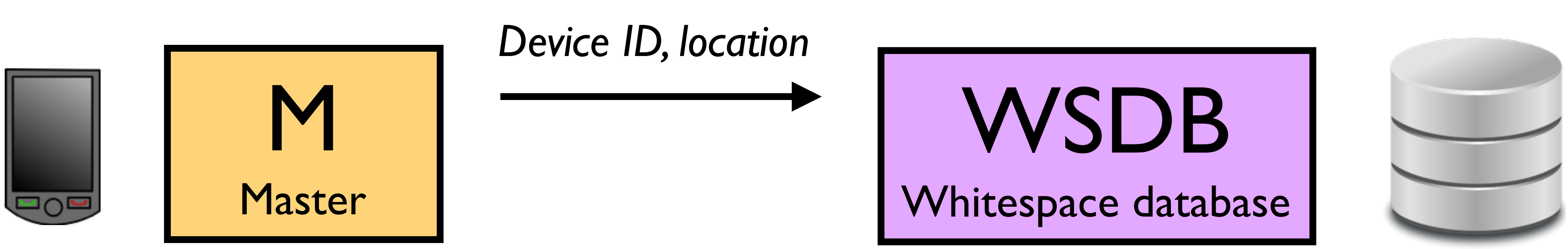

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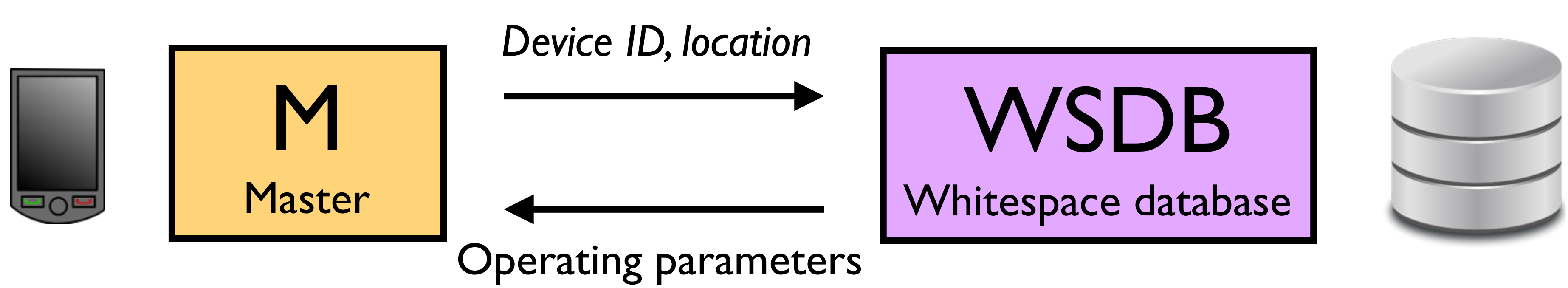

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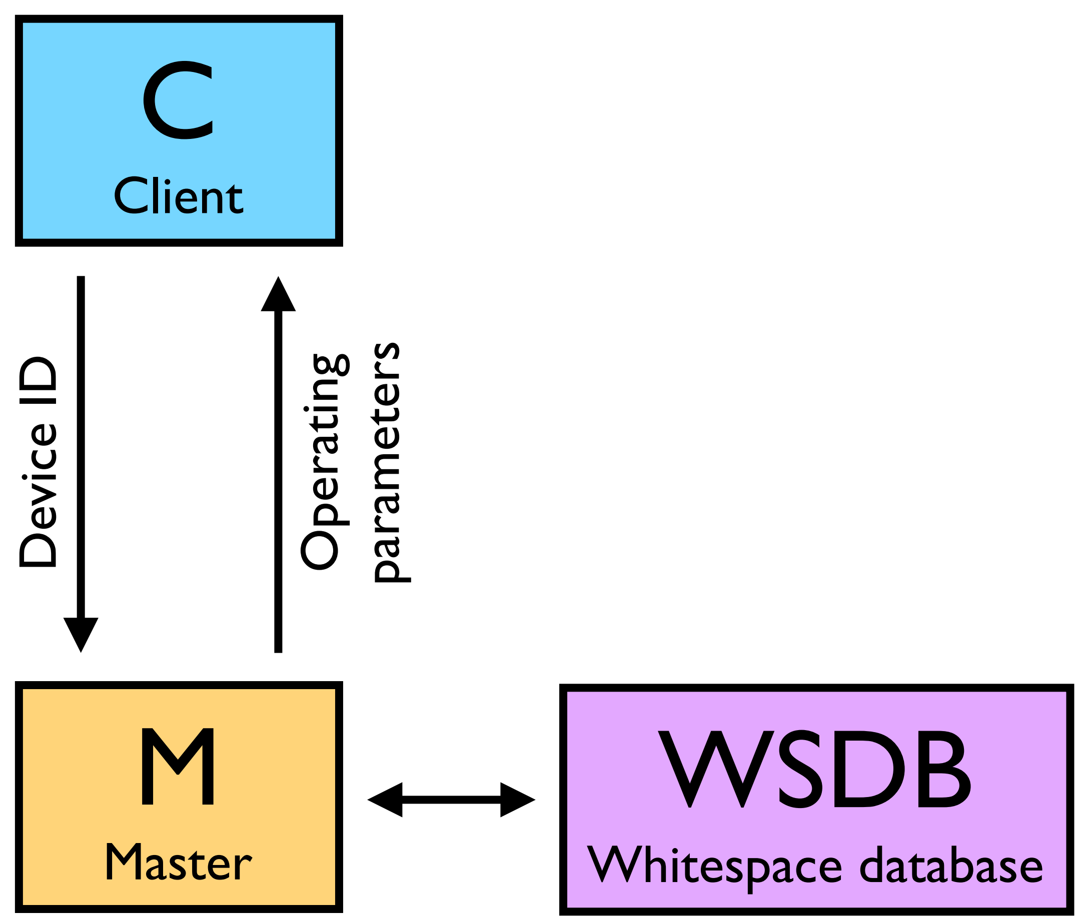

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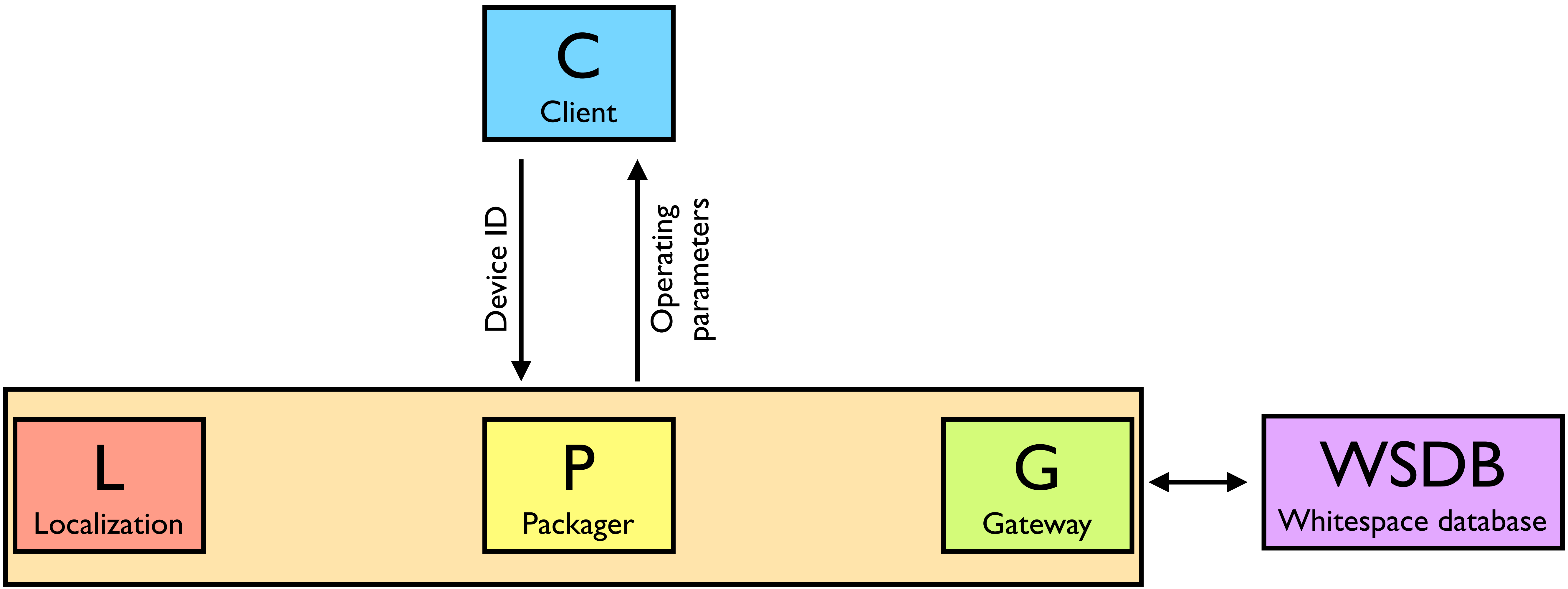
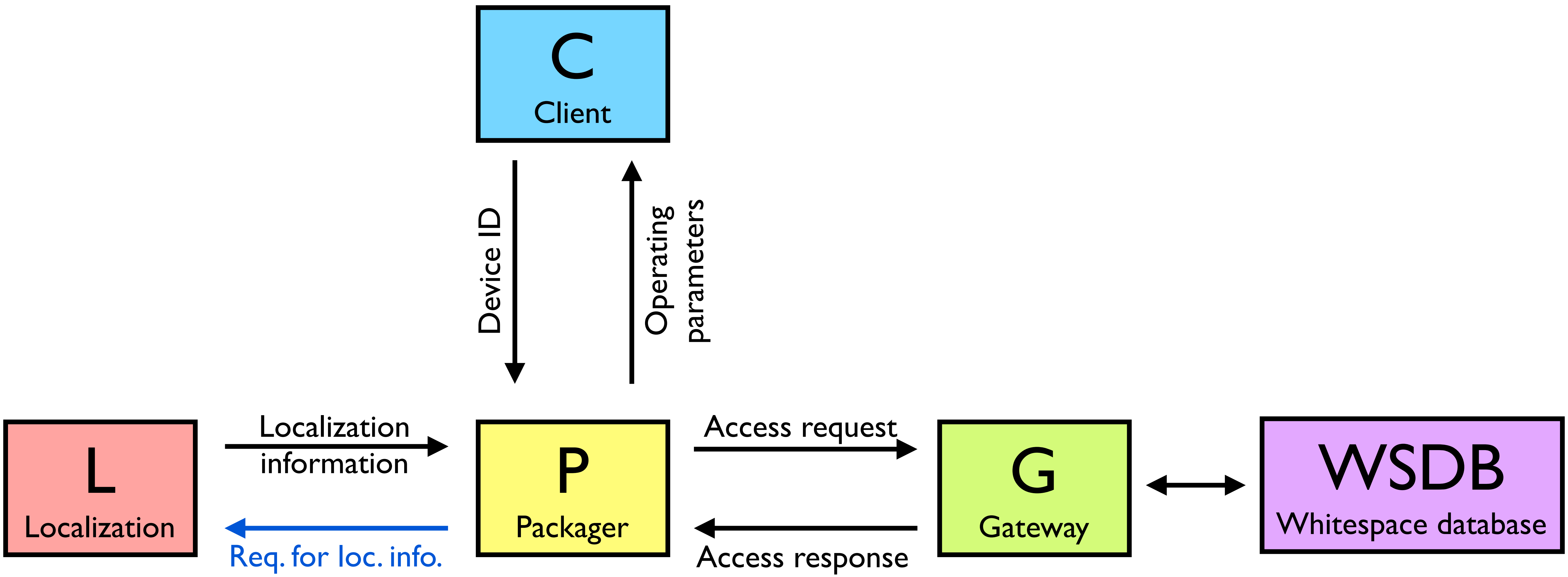


WS architecture

Proposed model



Main benefits

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- Can certify using unit tests (*testability*)

Themes

- Data-driven policy
- Reproducible research
- Spatial variation → interesting, important challenges
- Make whitespaces as attractive as possible
  - Efficient use of spectrum, enable innovation