# Rating for Spectrum: Impacts of TV Viewership on TV Whitespace

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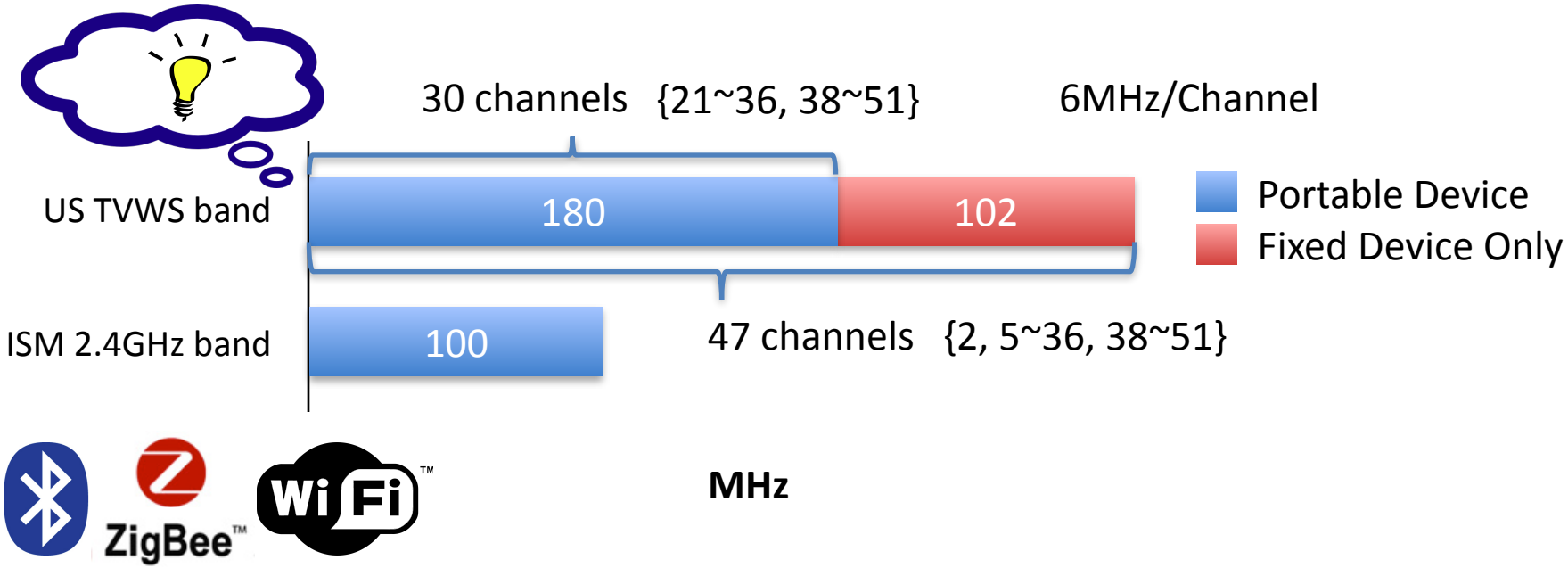
# TV Whitespace—A promising solution

TV whitespace: *"the broadcast television spectrum at locations where that spectrum is not being used by licensed services."[1]*

—Federal Communications Commission






[1] Second Memorandum Opinion and Order, FCC, Sep. 2010, http://www.fcc.gov

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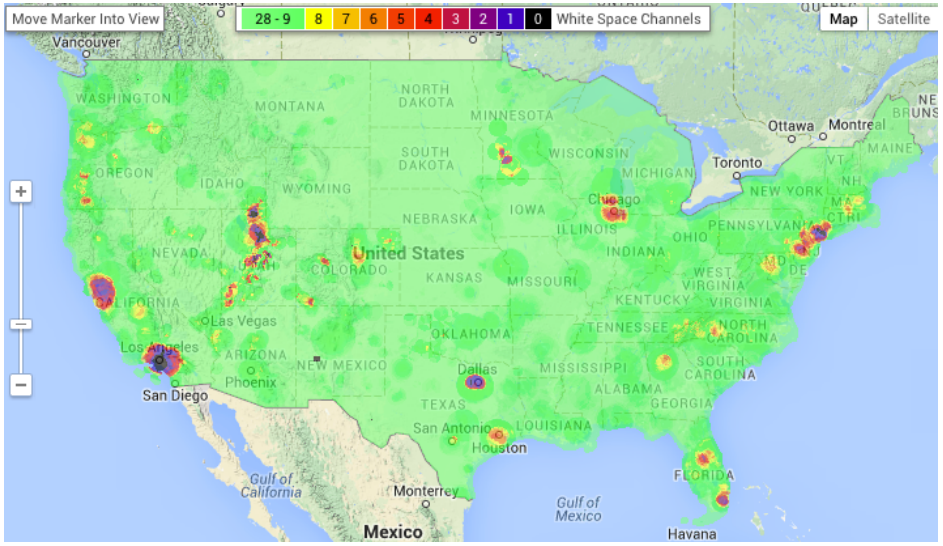
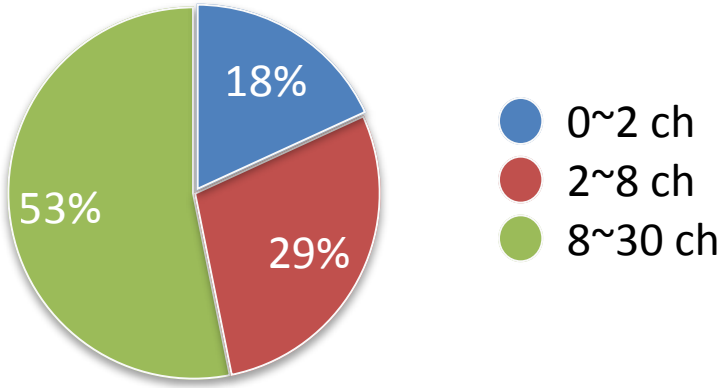
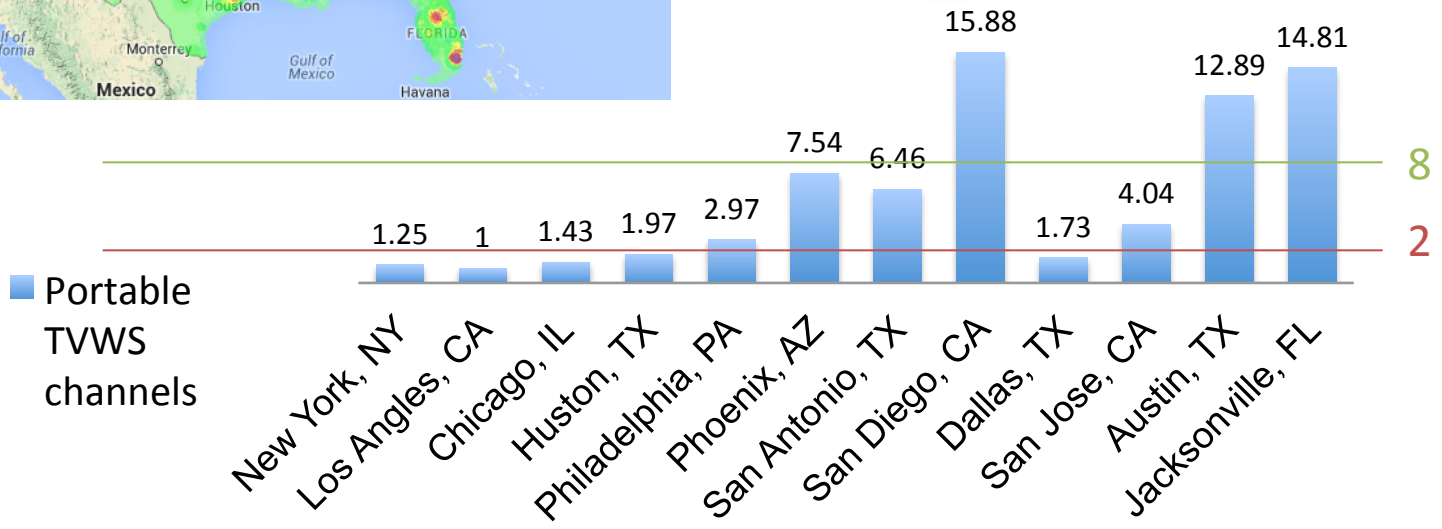
# TV Whitespace "Blind" Spots

## Portable TV Whitespace Channels[2]




## Portable TVWS channels for U.S. urban population*




[2] Google Spectrum Database

*Continental US

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# Contribution

| | Existing Work[3,4,5,6,7,8,9] | Our Work |
|---|---|---|
| ***Purpose*** | ***Estimate the availability and capacity of TV whitespace*** | |
| ***Licensed User*** | **TV services** | **TV viewers** |
| ***Methodology*** | ***Geographical Analysis [3,4]*** *based on* ***TV Towers Database, Radio Propagation Model, CENSUS data,*** ***Spectrum Measurement [5,6,7,8,9]*** | ***Geographical + Temporal Analysis*** *based on* ***TV Towers Database, Radio Propagation Model, CENSUS data, TV Viewership Information*** |
| Scope | US, Europe, cities over the world | New York City(Urban); Lincoln, NE (Rural) |
| ***Conclusion*** | ***Rural broadband solution*** | *Rural broadband solution +* ***Urban spectrum crisis solution*** |
| other | … | Feasibility |

[3] K. Harrison, S. Mishra, and A. Sahai, "How much white-space capacity is there?" in IEEE Symposium on New Frontiers in Dynamic Spectrum, Apr. 2010, pp. 1–10.
[4] J. van de Beek, J. Riihijarvi, A. Achtzehn, and P. Mahonen, "TV White space in Europe," IEEE Transactions on Mobile Computing, vol. 11, no. 2, pp. 178–188, Feb 2012.
[5] T. Taher and et.al., "Long-term spectral occupancy findings in Chicago," in IEEE Symposium on New Frontiers in Dynamic Spectrum Access Networks (DySPAN), May 2011, pp. 100–107.
[6] M. Islam and at.al., "Spectrum survey in singapore: Occupancy measurements and analyses," in Int. Conf. Cognitive Radio Oriented Wireless Networks and Communications (CrownCom), May 2008, pp. 1–7.
[7] M. A. McHenry and et.al., "Chicago spectrum occupancy measurements & analysis and a long-term studies proposal," in Proc. 1st Int'l Workshop on Technology and Policy for Accessing Spectrum (TAPAS '06). Boston, MA, USA: ACM, Aug. 2006.
[8] S. Yin, D. Chen, Q. Zhang, M. Liu, and S. Li, "Mining spectrum usage data: A large-scale spectrum measurement study," IEEE Transactions on Mobile Computing, vol. 11, no. 6, pp. 1033–1046, June 2012.
[9] X. Ying, J. Zhang, L. Yan, G. Zhang, M. Chen, and R. handra,"Exploring indoor white spaces in metropolises," in Proc. Int. Conf. on Mobile Computing and Networking (MobiCom '13). ACM, Oct. 2013, pp. 255–266.

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# Outline

- Motivation
- **Cog-TV Architecture**
- Methodology
- Geographical analysis results
- Conclusion

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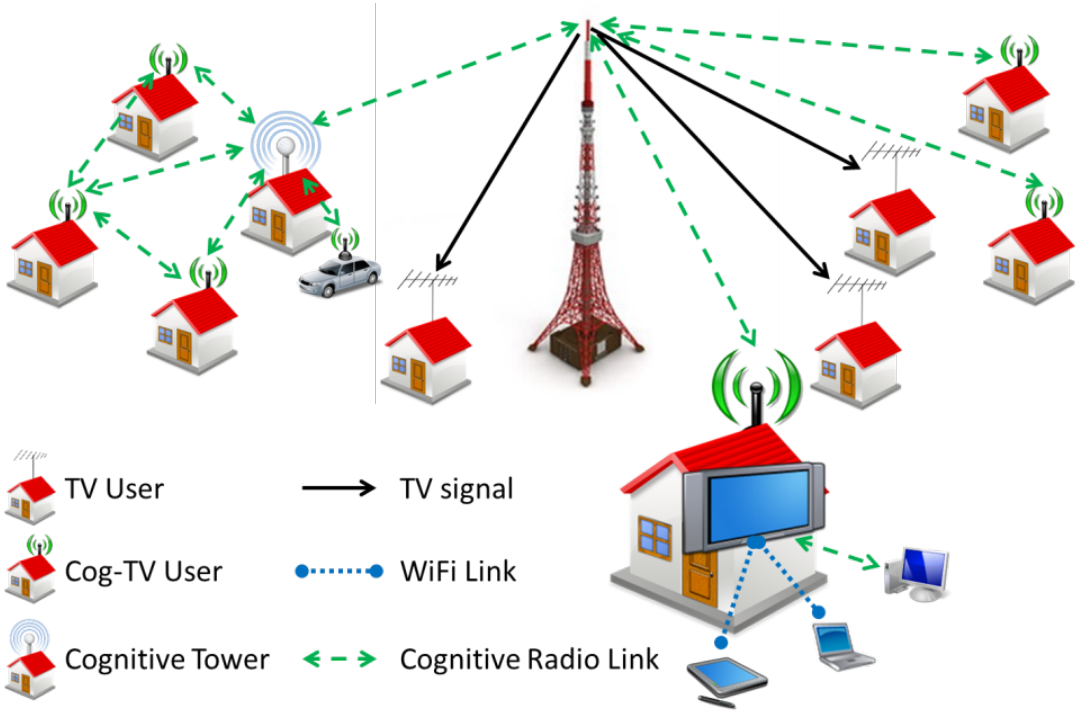
# Cog-TV Architecture




- Cognitive TV set (Cog-TV)
- Wireless Local Area Network (WLAN)
- Co-exist with co-channel TV services

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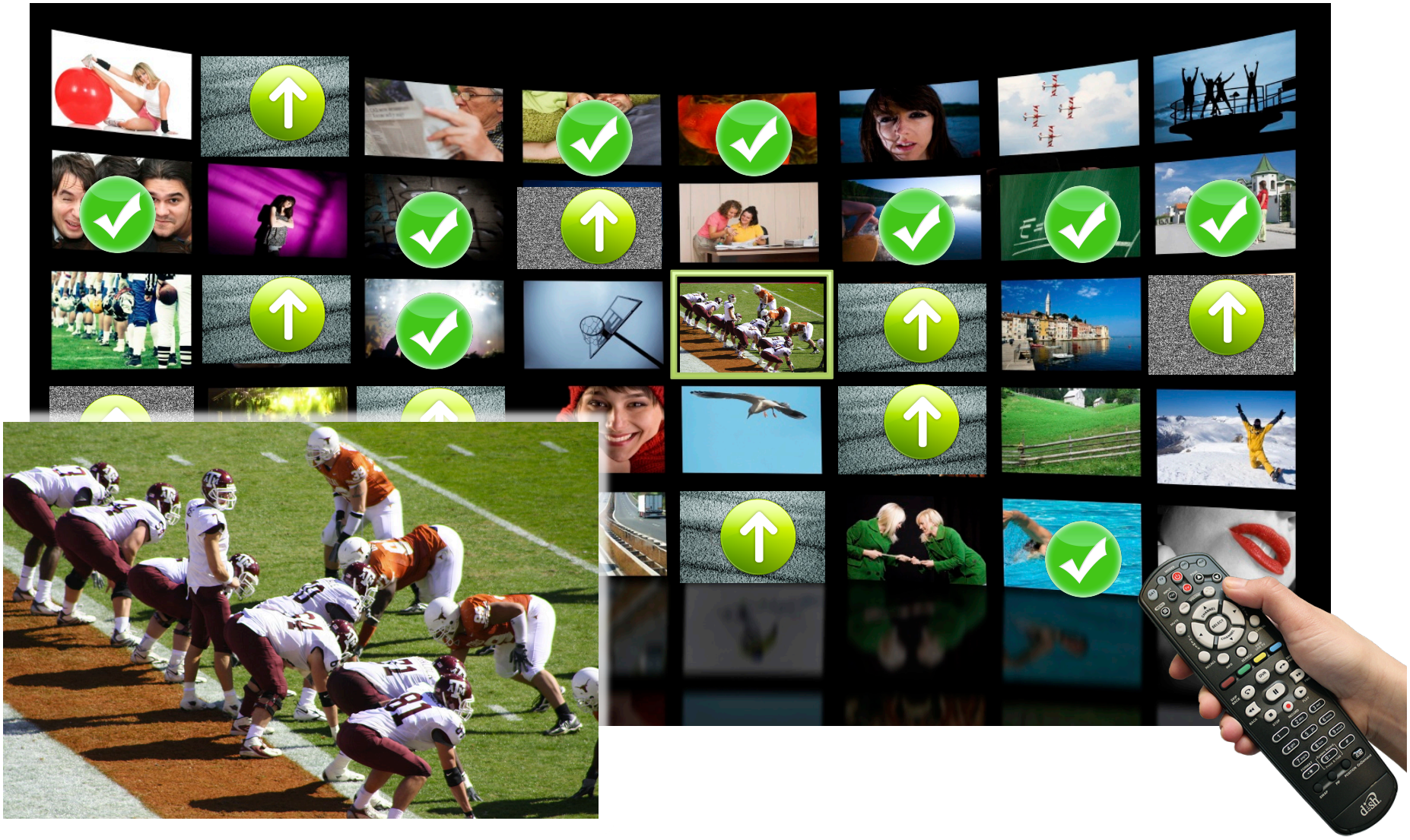
# Cog-TV: Primary User= TV Viewer



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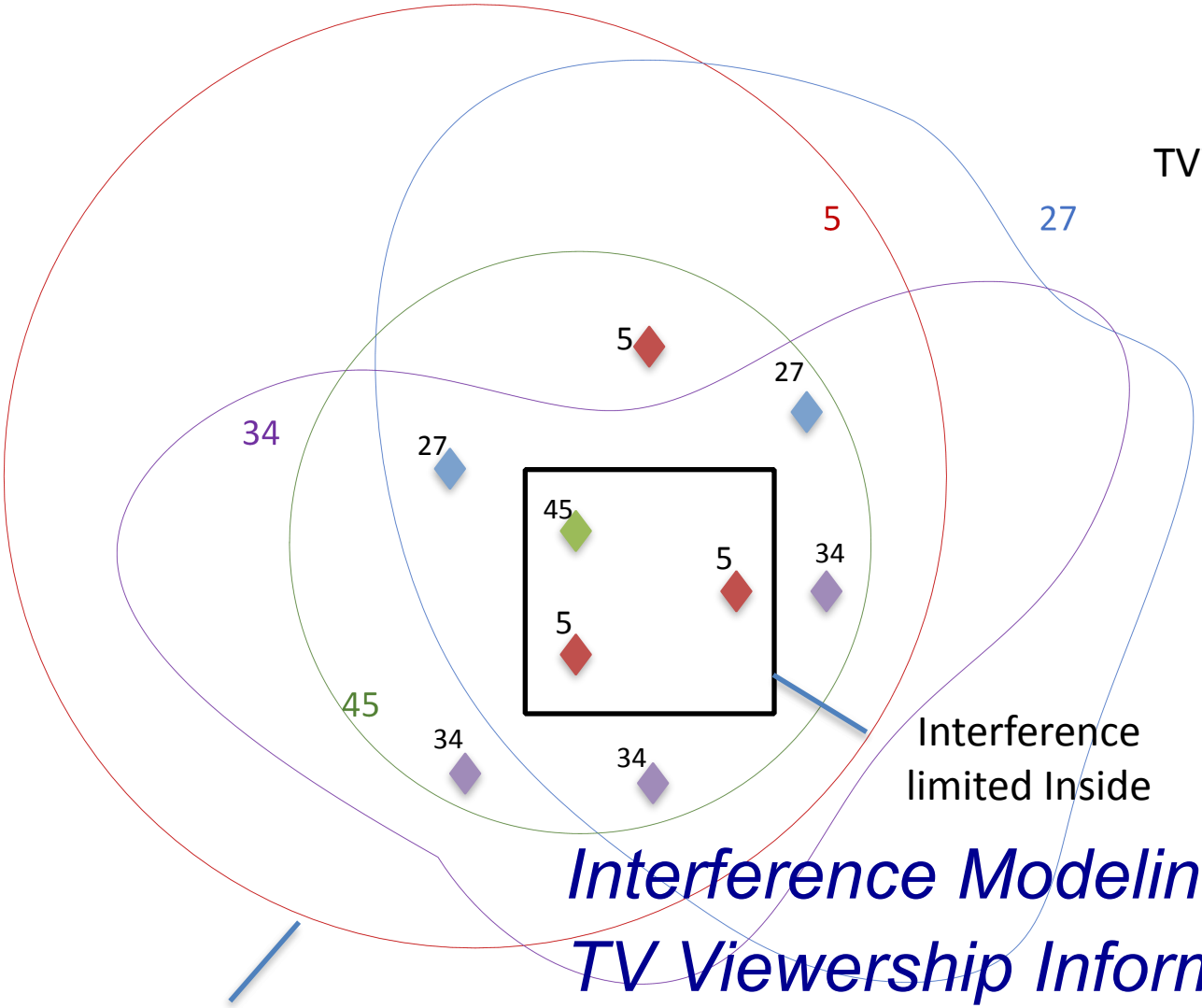
# TVWS Channel Availability




Broadcast TV service contour

Interference limited Inside

TVWS channels in squared area

| Channel | FCC | Cog-TV |
|---|---|---|
| *5* | ⊘ | ⊘ |
| *27* | ⊘ | ✓ |
| *34* | ⊘ | ✓ |
| *45* | ⊘ | ⊘ |

+2

*Interference Modeling*

*TV Viewership Information*

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# Interference Model

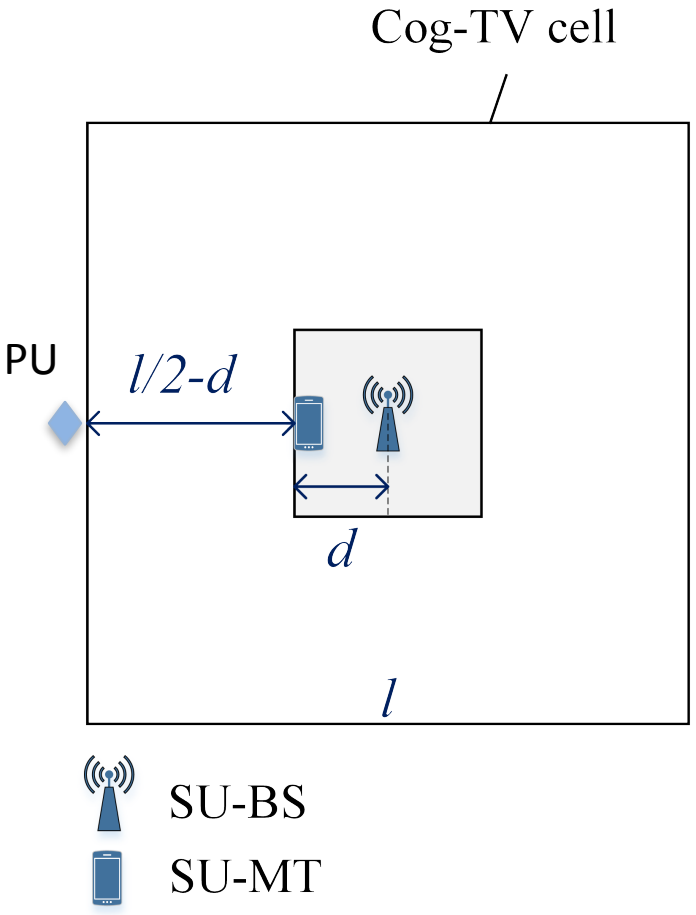
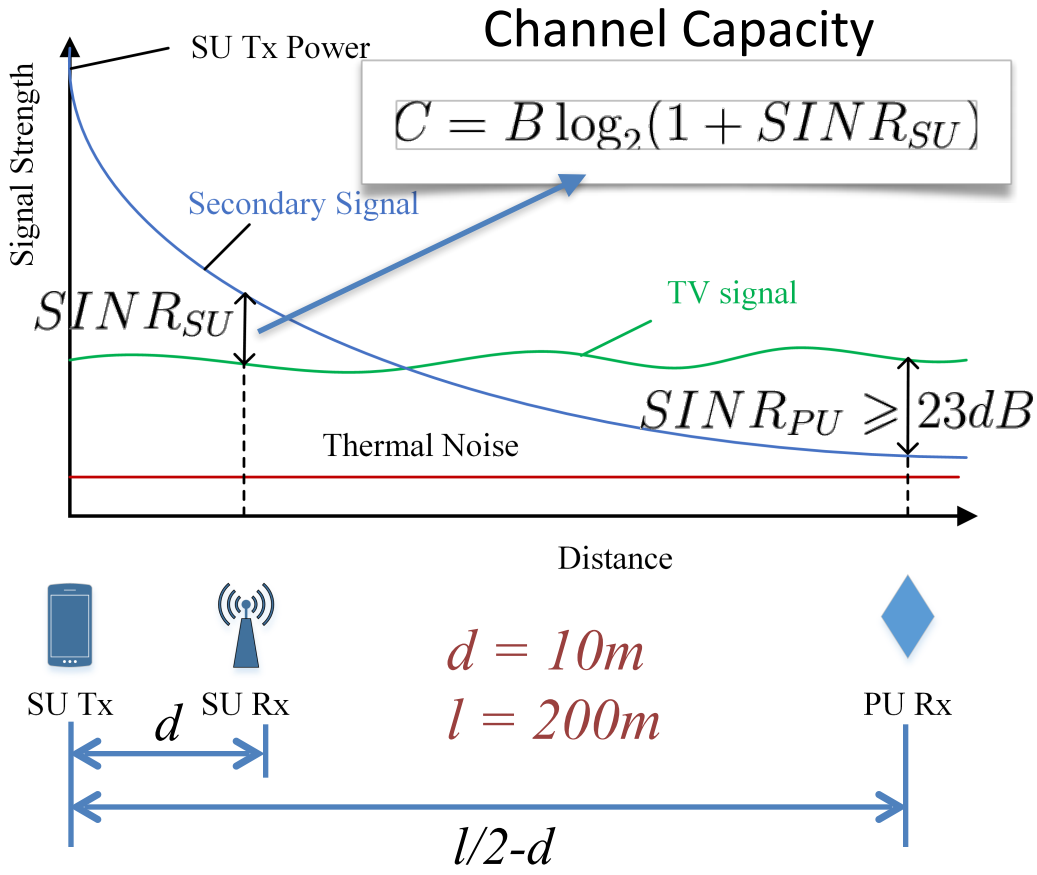



Fig. Secondary signal propagation[1][3]




[3] K. Harrison, S. Mishra, and A. Sahai, "How much white-space capacity is there?" in IEEE Symposium on New Frontiers in Dynamic Spectrum, Apr. 2010, pp. 1–10.

[1]Field strength is calculated by the F(50,10) curve for propagation distance >= 15km, and TM91-1 model for distance < 15km, Longley-Rice methodology OET69 is used to convert the field strength to signal strength.

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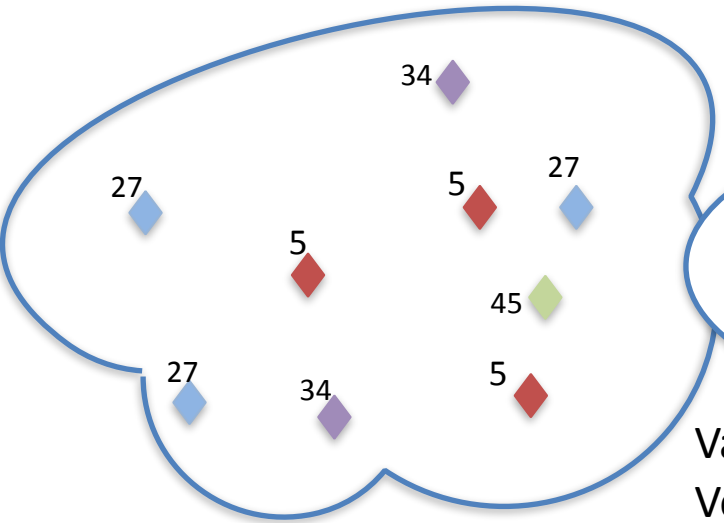
# TV Viewer Approximation

Statistics

Sample TV Households[10]

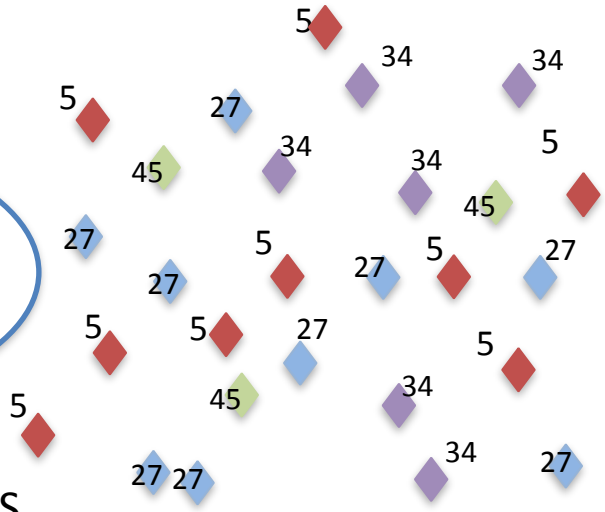
- TV Ownership —CENSUS→ Number of Broadcast TV sets
- TV Usage → Number of Broadcast TV viewers
- TV Rating → TV viewers' preferences




TV Viewers Population

Metrics of TV channel popularity

Valuable for advertisers,
Very limited public data in US




Virtual TV Viewers

[10] A.C. Nielsen Co., Television Measurement, [www.nielsen.com]

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# Number of TV Viewers

Local Population[12]  TV Usage

$$N_{pu} = N_{pop}\eta\varphi(t)$$

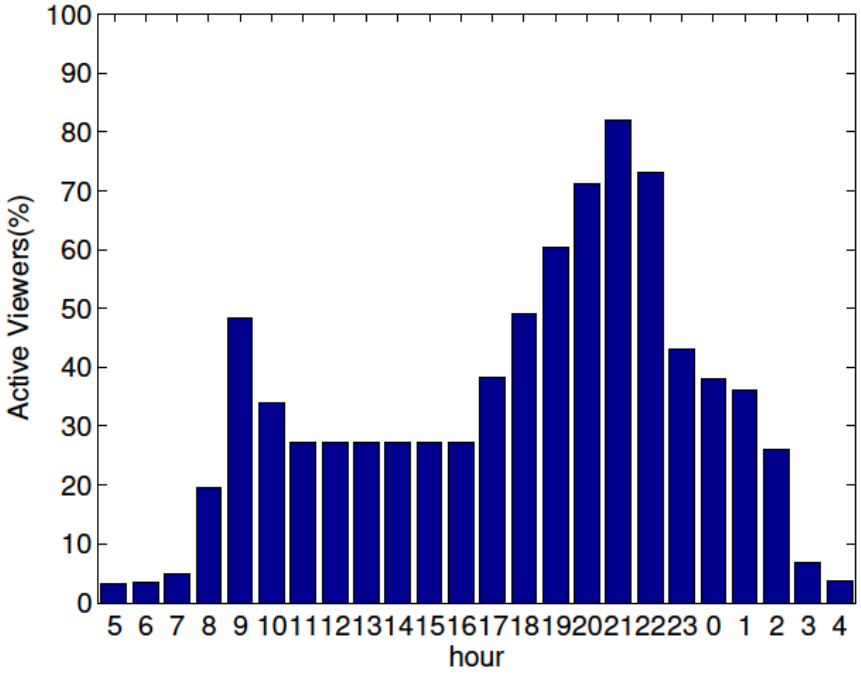
Number of broadcast TV viewers

Broadcast TV set ownership

| | |
|---|---|
| ***2008*** | ***12% [14]*** |
| ***2009*** | ***11% [14]*** |
| ***2010*** | ***10% [14]*** |
| ***2013*** | ***6% [11]*** |

$$\eta = 8\%$$

TV Usage Intra-Day Dynamics[13]




[11] Human Capital, "The Limits to terrestrial television's case for further spectrum," Feb. 2009 [www.gsma.com]
[12] CENSUS 2010
[13] A.C. Nielsen Co., "Advertising & Audiences: State of the Media," Apr 2013. [www.nielsen.com].
[14] F.C.C.,"Spectrum Analysis: Options for Broadcast Spectrum," OBI Technical Paper No.3, Jun. 2010

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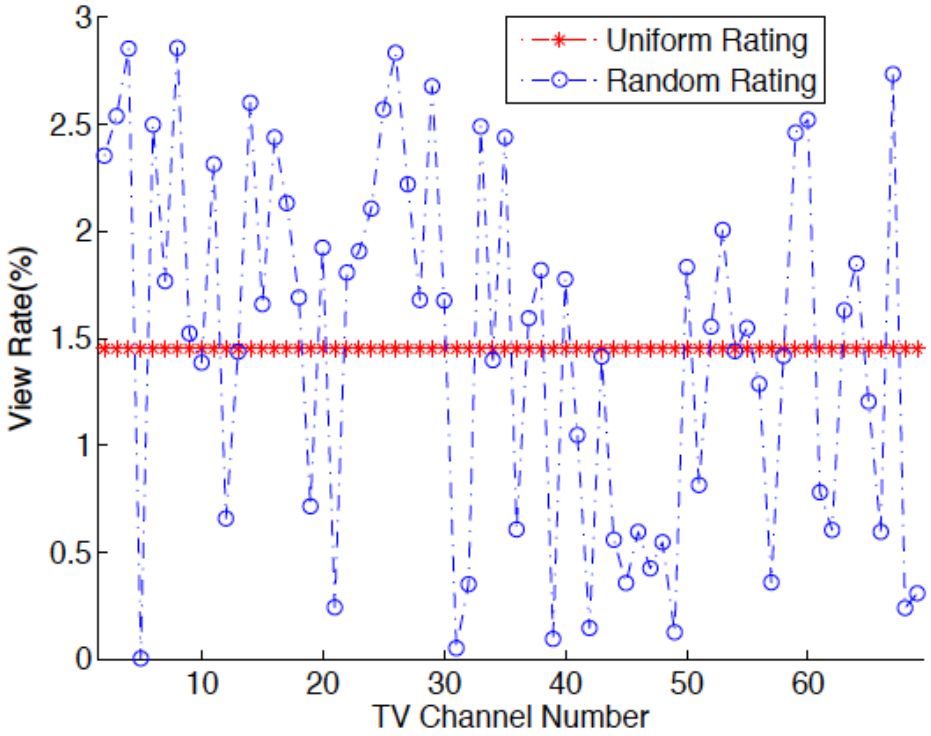
# TV Viewers' Channel Selection

- TV Rating Assumptions
  - Random Rating (Real-life experience)
  - Uniform Rating (worst case)



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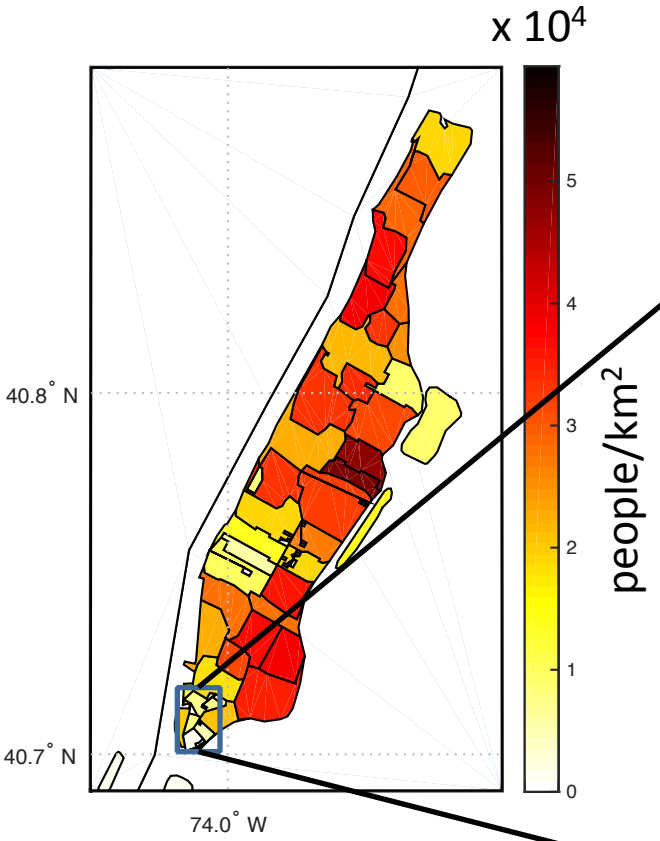
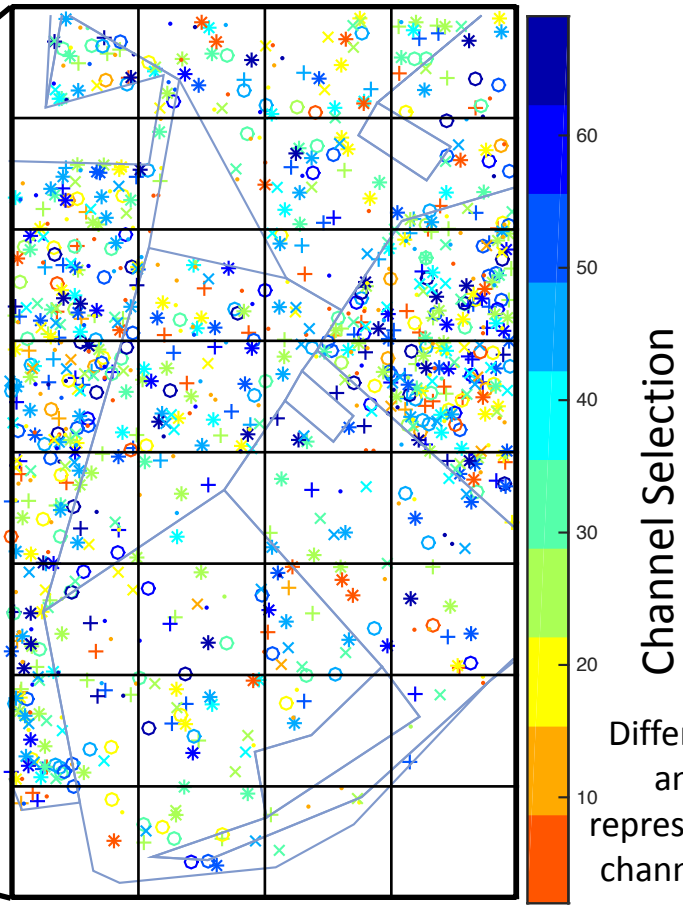
# Generate TV Viewers




New York City
Population Density[4]




Broadcast TV Viewers

Different shapes and colors represent different channel selection



[12] CENSUS 2010

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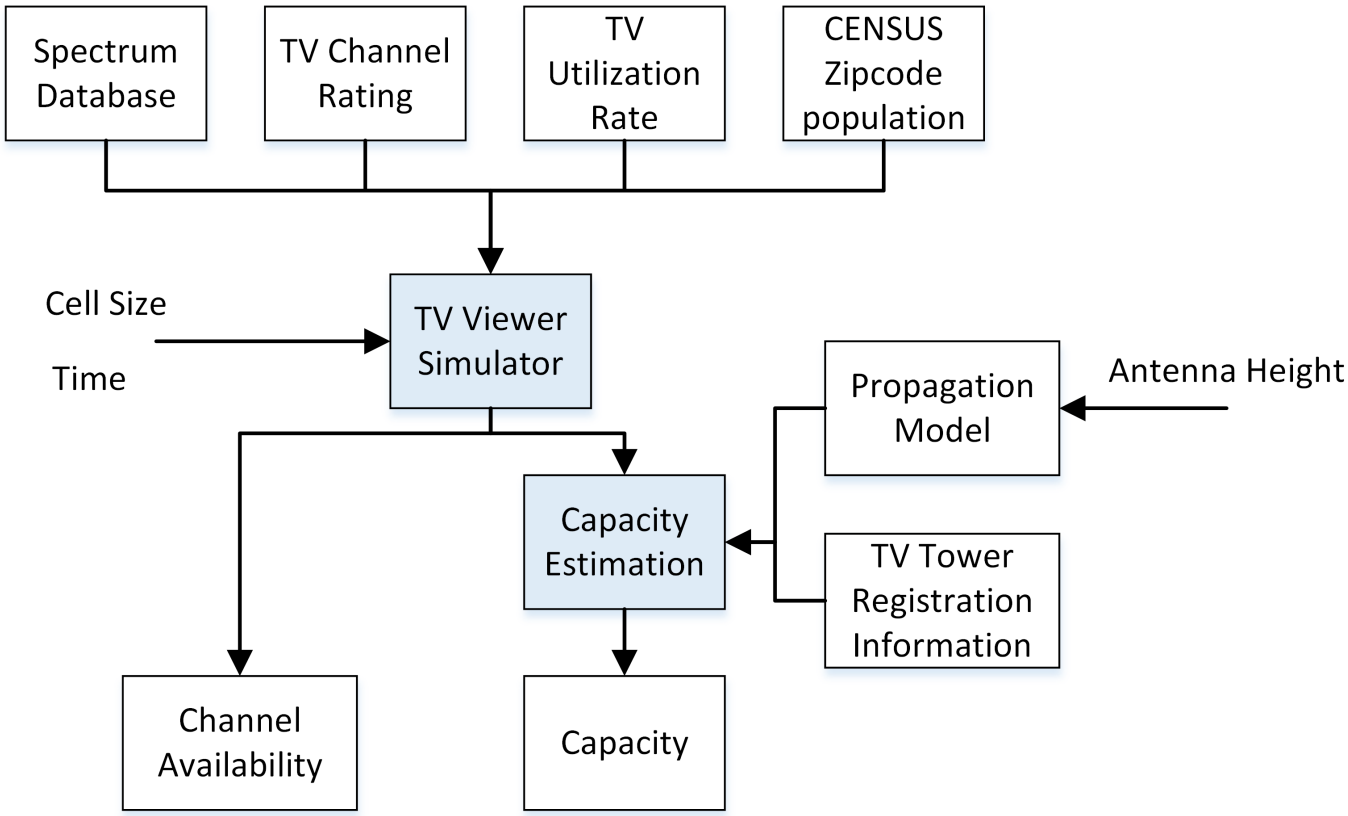
# Geographical Analysis



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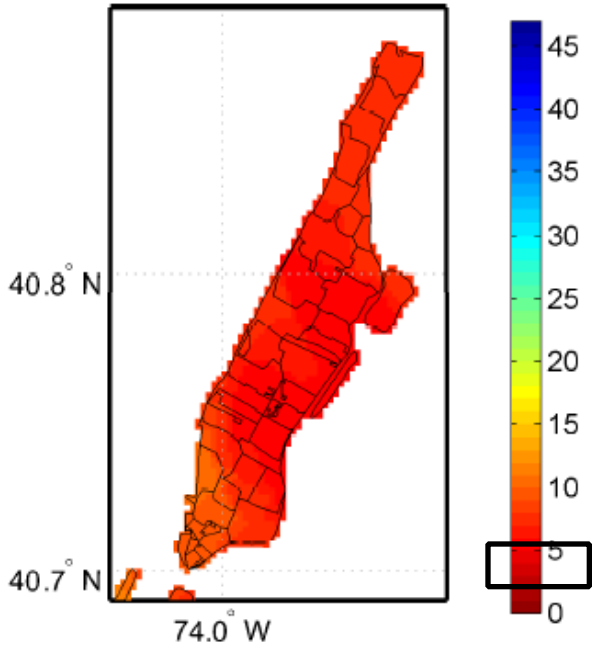
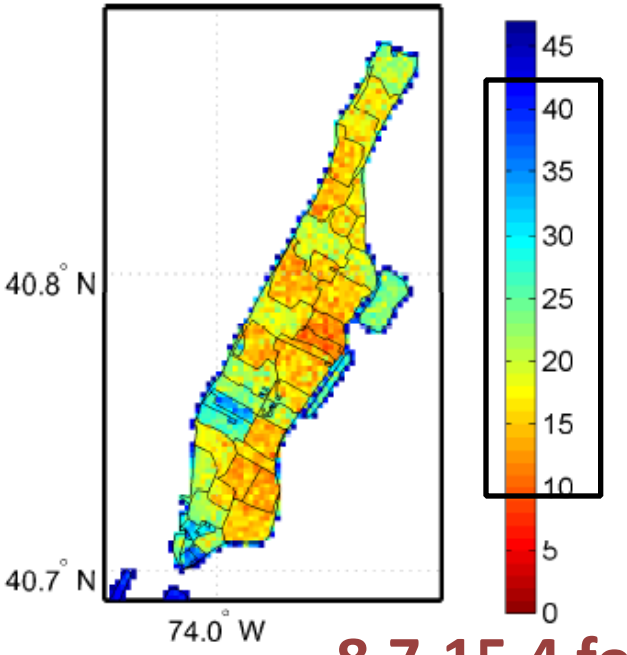
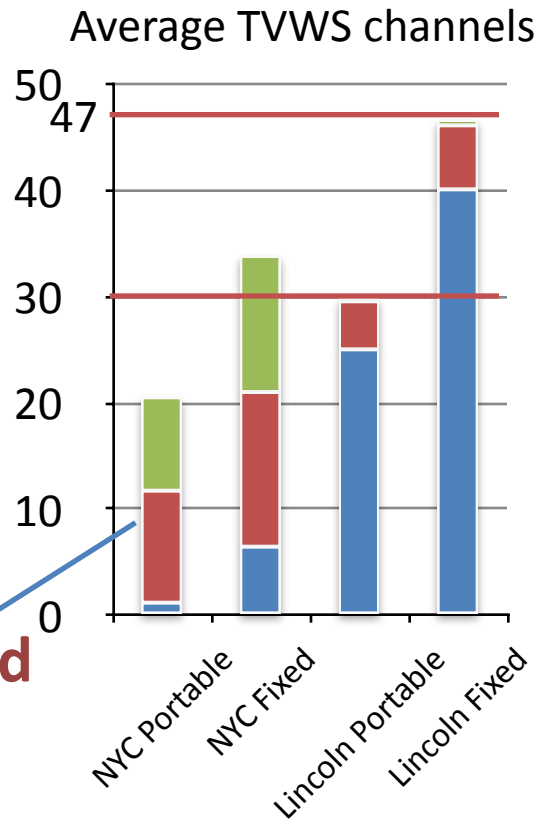
# Channel Availability




(a) FCC rule




(b) Cog-TV




**8.7-15.4 fold**

Stochastic
Population density

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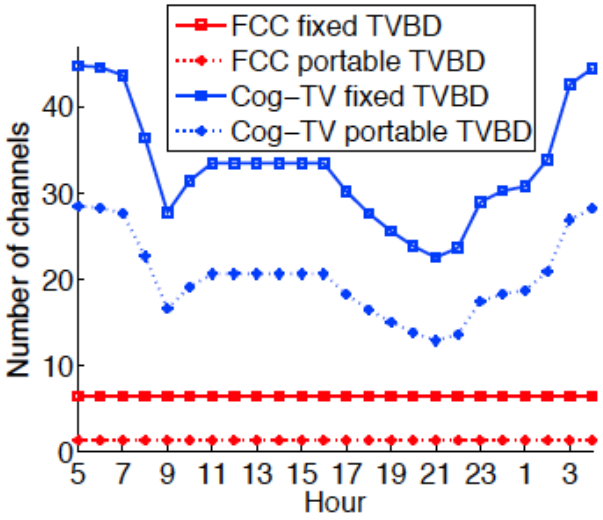
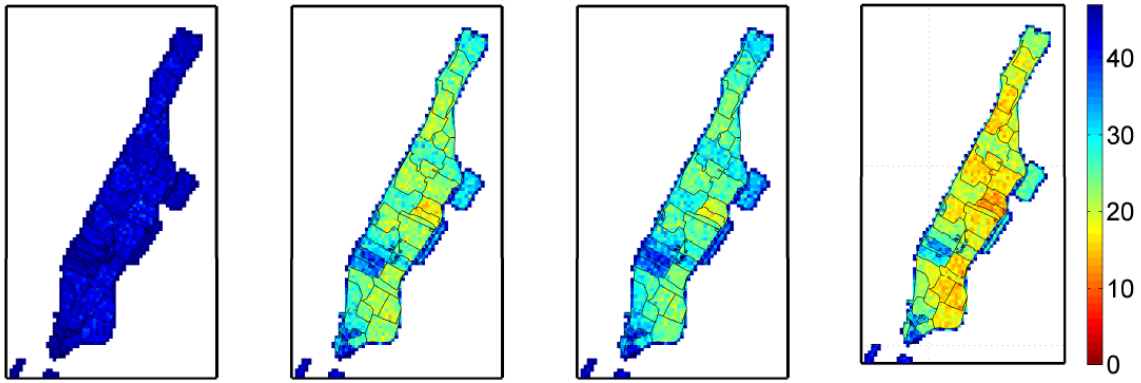
# Intra-day dynamics

## High Intra-Day Dynamics




(a) 0.2km Cell, Manhattan, NY

## Snapshots in different times




(a) 3:00 (b) 8:00 (c) 14:00 (d) 20:00

Cog-TV: Dynamic TV Whitespace channels
Fixed device: 22~45 ch, 47%~96% TV whitespace band
Portable device: 12~28 ch, 40%~93% portable TV whitespace band

FCC
6.43 ch, 14% TVWS band
1.35 ch, 4.5% portable band

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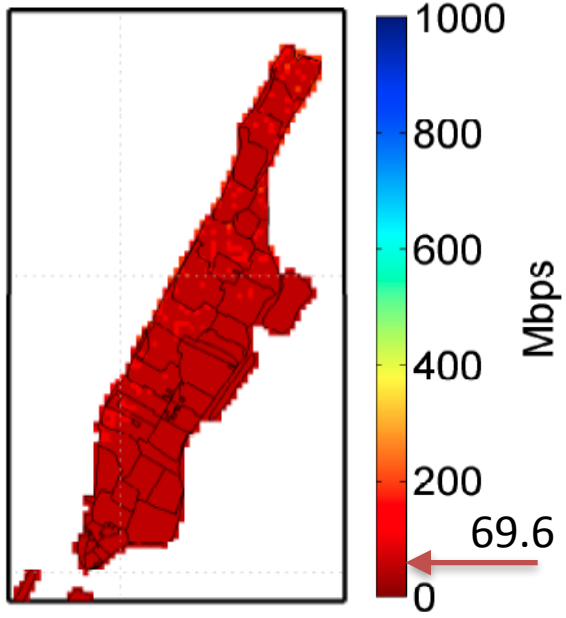
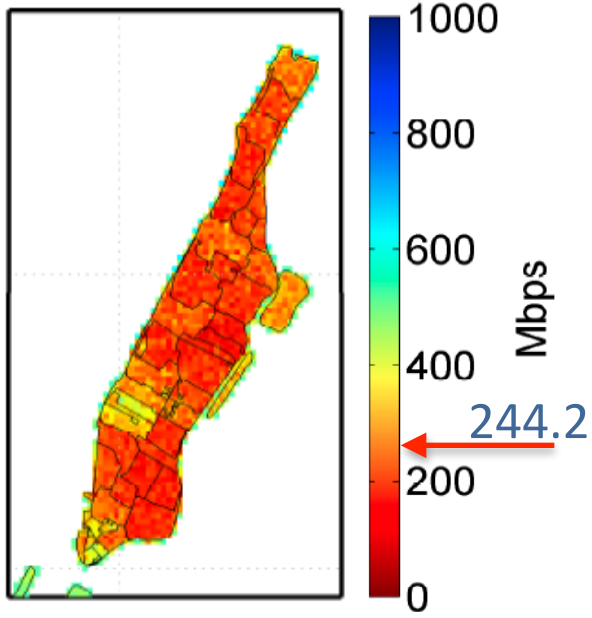
# TVWS Channel Capacity

SISO




(c) FCC, SN

SISO

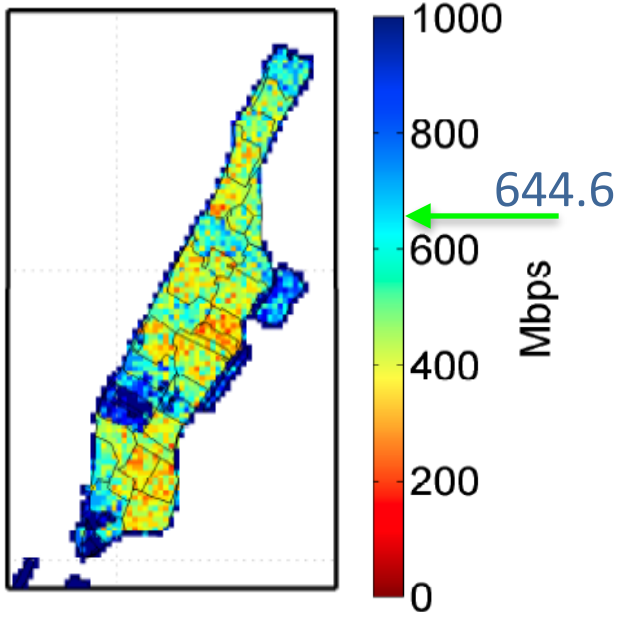



(d) Cog-TV, SN

*351% for FCC*

*163% for WiFi*

SISO + Interference Cancellation[14]




(e) Cog-TV, SN-IC

*926% for FCC*

*430% for WiFi*

SN: Secondary Network

Cog-TV

*d = 10m, 400m² coverage*

WiFi(802.11n): 150Mbps [15]

2.4GHz, SISO, 64-QAM, 5/6 code rate, 40MHz channel, 400ns-GI



[14] N. Miridakis and D. Vergados, "A survey on the successive interference cancellation performance for single-antenna and multiple-antenna ofdm systems," IEEE Communications Surveys Tutorials, vol. 15, no. 1, pp. 312–335, Feb. 2013
[15] AirMagnet, "802.11n Primer", [airmagnet.flukenetworks.com]

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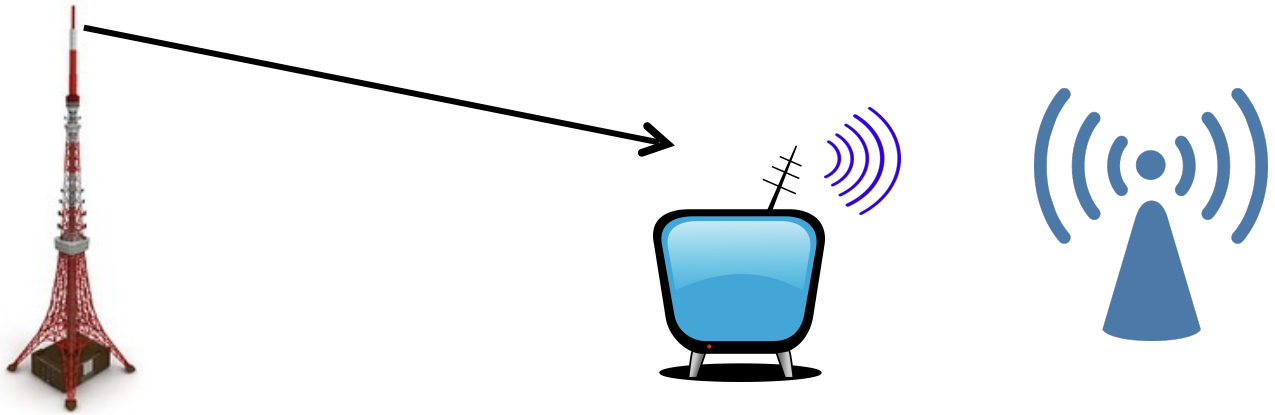
# Obtain TV viewership Information



Neighborhood sensing


Set top box

Next Generation TV set

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# Conclusion

Having full information of the broadcast TV Viewers

can greatly increase urban area

**Technology**

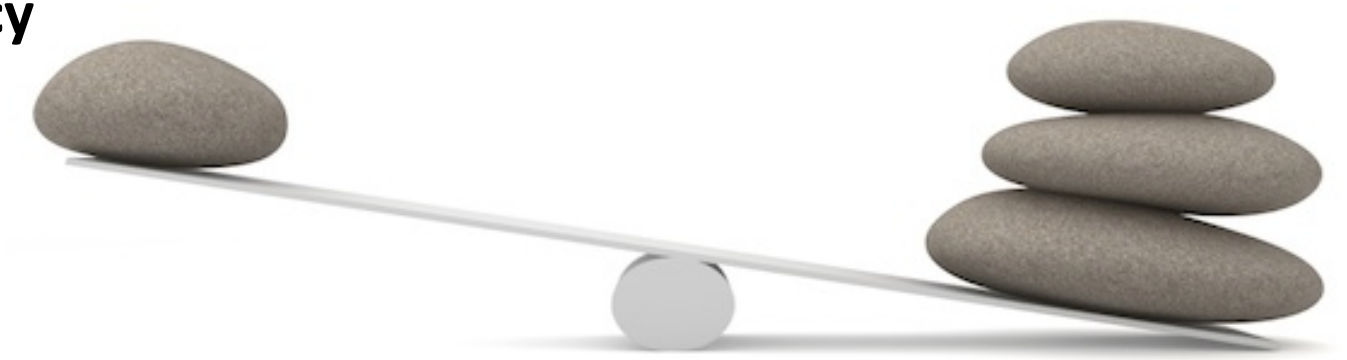
**Privacy**

**Policy**

**Business Model**

**TV WhiteSpace Availability**

**Capacity**



Challenges

Benefit

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# Results

TABLE I
AVERAGE CHANNEL AVAILABILITY WITH $200m \times 200m$ CELL SIZE, UNIT: NUMBER OF CHANNELS

| Rules | Rating | NYC | | Lincoln | |
|---|---|---|---|---|---|
| | | Fixed | Mobile | Fixed | Mobile |
| FCC | - | 6.43 | 1.35 | 40.08 | 25.08 |
| Cog-TV | Random | 20.91 | 11.73 | 46.21 | 29.48 |
| | Uniform | 17.22 | 8.98 | 46.23 | 29.44 |

TABLE II
AVERAGE CHANNEL CAPACITY, UNIT: MBIT/S

| Rules, rating | $d$ (m) | NYC | | | Lincoln | | |
|---|---|---|---|---|---|---|---|
| | | IS | SN | SN-IC | IS | SN | SN-IC |
| FCC | 10 | 126.2 | 69.6 | - | 1,397 | 744.0 | - |
| | 20 | 97.0 | 37.8 | - | 1,094 | 409.0 | - |
| Cog-TV, random | 10 | 512.4 | 244.2 | 644.6 | 2597 | 1,045 | 1725 |
| | 20 | 238.8 | 56.7 | 322.9 | 1,851 | 442.2 | 901.1 |
| Cog-TV, uniform | 10 | 383.7 | 200.5 | 496.7 | 2,560 | 1,042 | 1,714 |
| | 20 | 173.9 | 53.1 | 248.1 | 1,821 | 441.9 | 895.5 |

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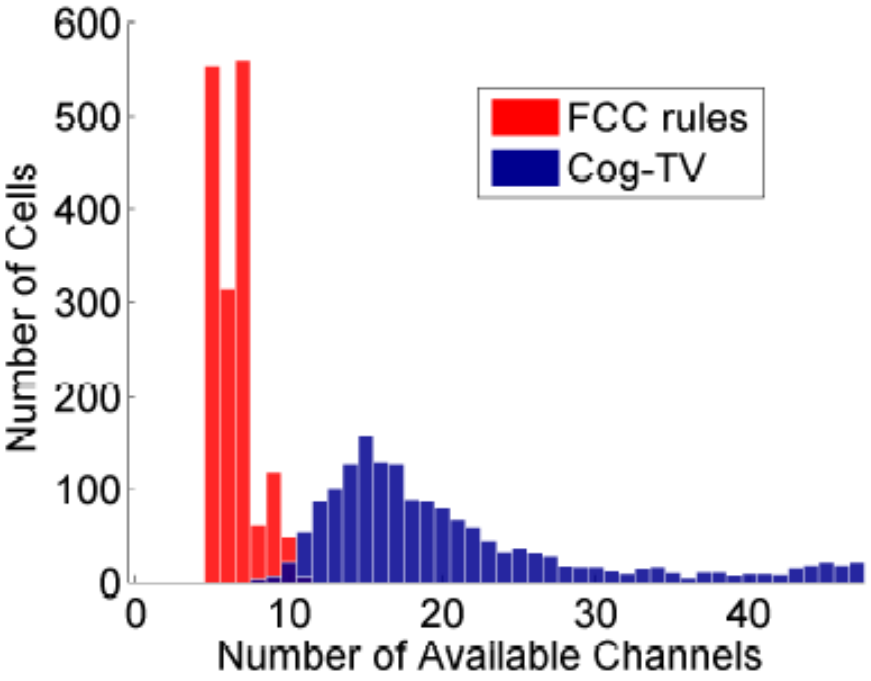
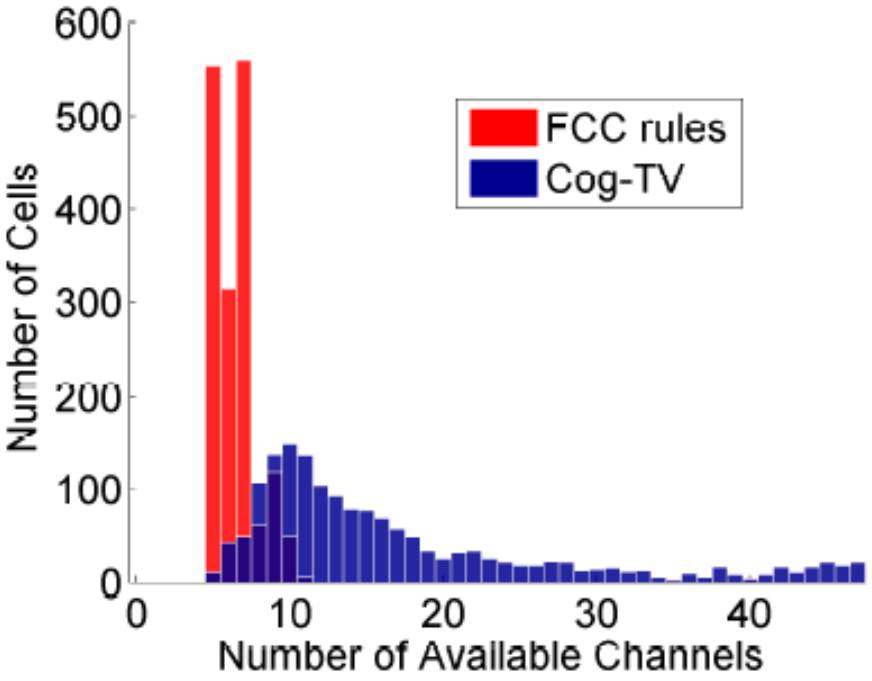
# Histogram of Channel Availability




(a) NYC, Random




(b) NYC, Uniform

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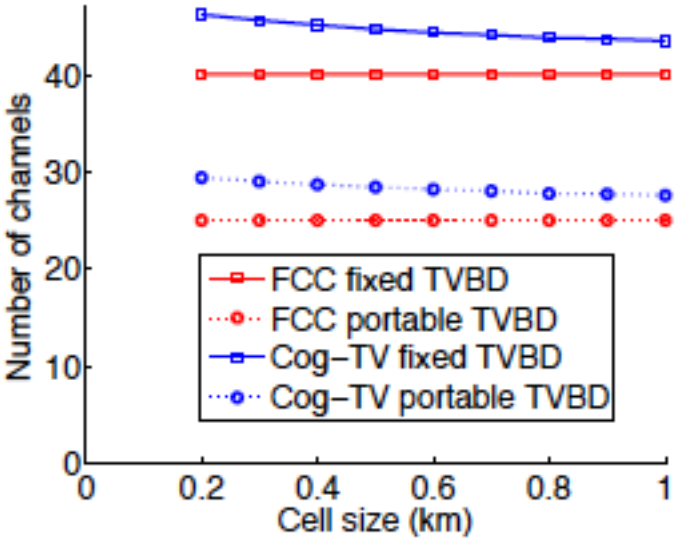
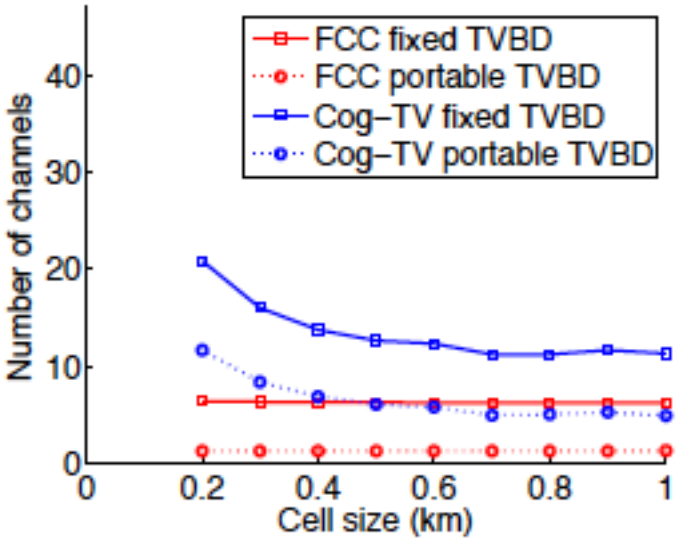
# Channel Capacity v.s. Cell Size




(a) Lincoln




(b) NYC