TV White Space Asssessment in India and its Potential for Rural Broadband Usage

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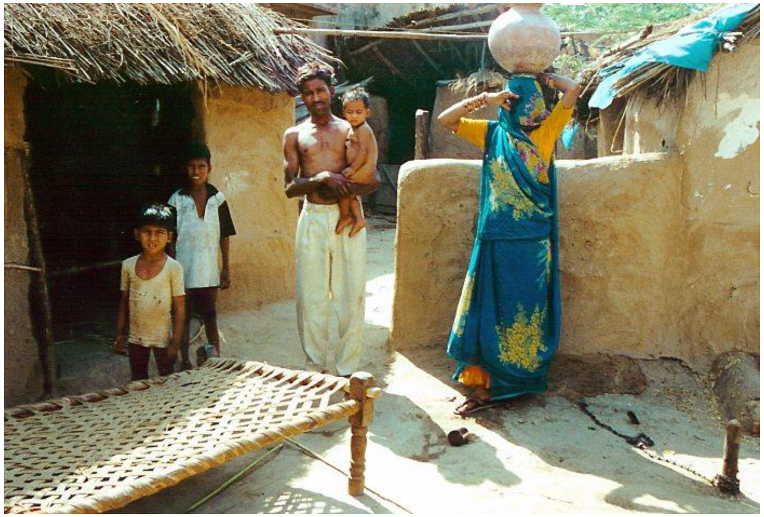
Two scenarios in contrast



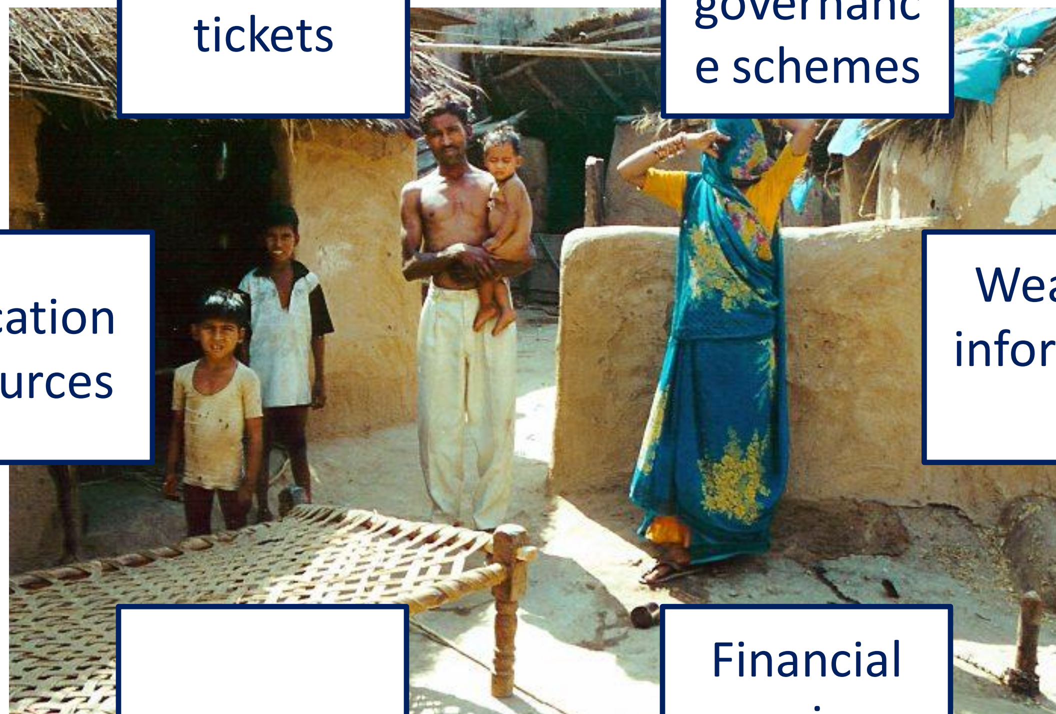
Images from Wikipedia: Mumbai (left); an Indian village (right)

Urban India or metro cities have optional access to broadband

Rural India, even though it contributes 50% to the GDP, has no access to broadband

This leads to or creates digital divide

The digital-divide: what does it mean?



Railway tickets

E-governance schemes

Education resources

Weather information

…

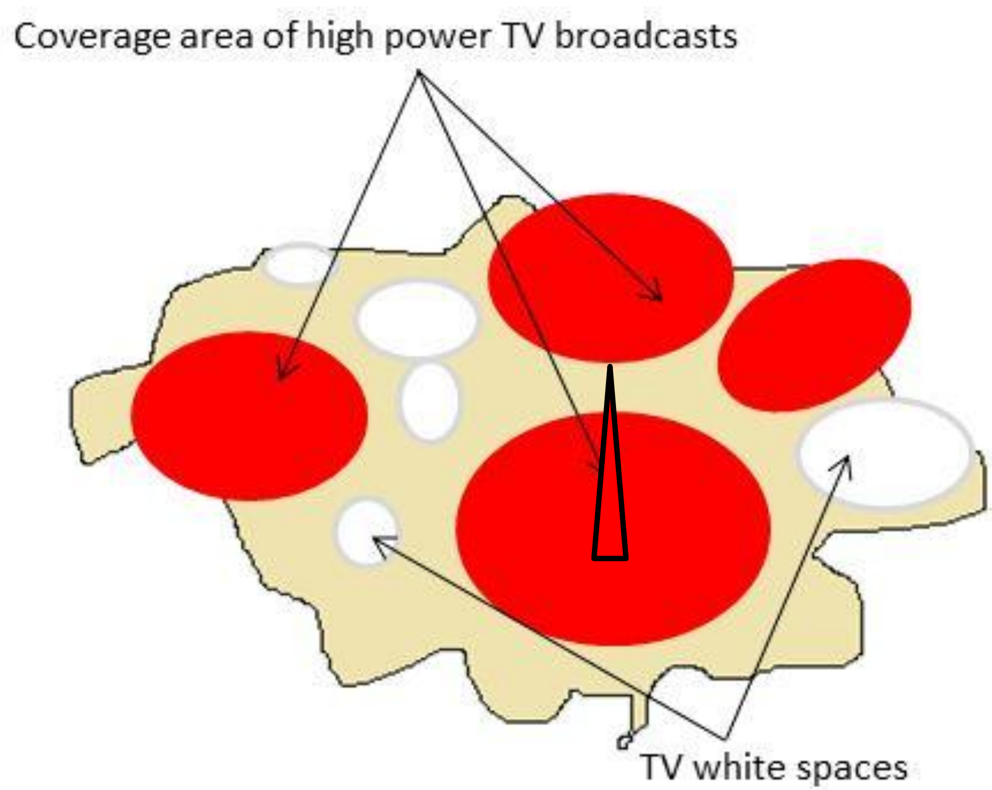
Financial services (banking)

Hurdles in rural broadband

- **Optical fiber:** expensive deployment costs and low return on investment
- **Cellular:** diminishing ARPU, high licensing fees or entry cost, lower density of rural users or higher infrastructure cost
- **Unlicensed WiFi solutions (2.4GHz):** poor propagation characteristics and low coverage area (200m-500m)

Is there really no solution?

TV white spaces, a potential antidote



- Analog TV channels are in sub-GHz band, which has better propagation characteristics than existing unlicensed bands
- Sparse television activity due to single broadcasting entity (Doordarshan)

Licensed but unused, good propagation characteristic, and low infrastructure cost spectrum available due to primary's inactivity

TV white spaces and broadband: key questions

- What is the amount of TV white space in India?
- Is it possible to use TV white space for affordable or rural broadband?
- What technological solutions can facilitate the use of TV white spaces for broadband applications?

Organization

- How much TV white space is there in India?
  - The protection/pollution viewpoints
  - The FCC rules
  - Our obtained TV white space estimates
  - Some TV-band utilization measurements
- Ongoing study of mesh-network for affordable/rural broadband coverage

Terrestrial TV spectrum allocation in India

- Government's national broadcaster named Doordarshan holds all of the terrestrial TV broadcasting license
- The frequency allocation plan (NFAP) of UHF TV band and onwards is as follows:

Frequency band	Services
470-585	FIXED, MOBILE, BROADCASTING
585-698	FIXED, MOBILE, BROADCASTING, RADIO NAVIGATION, RADIO ASTRONOMY
698-806	FIXED, MOBILE, BROADCASTING, RADIO ASTRONOMY

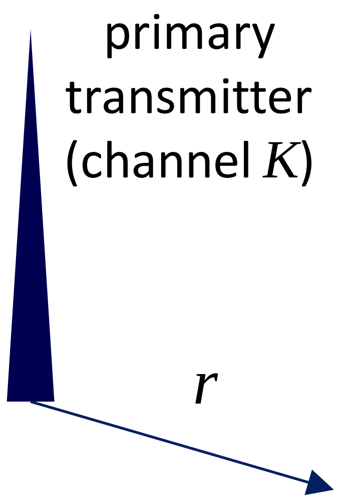
TV transmitter plan of Doordarshan

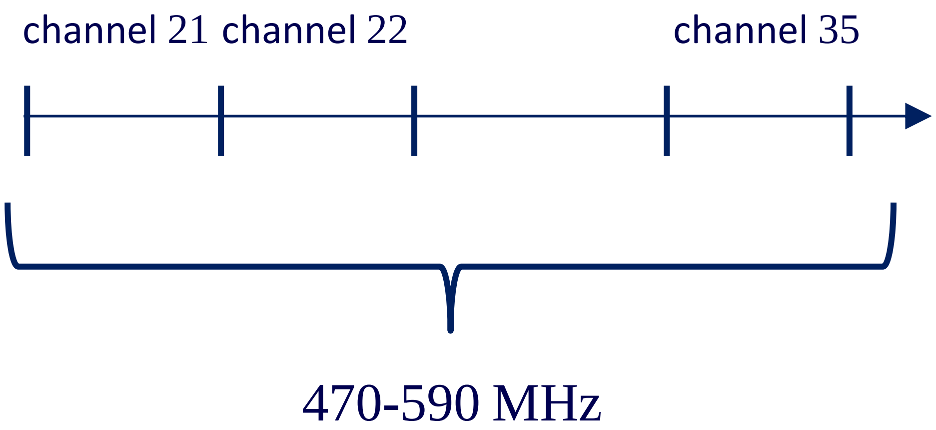
On record, there are 1415 TV transmitters operating in India

- ◊ UHF Band-IV (470-590MHz)
  - ◊ **Fifteen channels** of 8 MHz each — **373 transmitters** across all India
- ◊ VHF-I Band (54-68MHz)
  - ◊ **Two channels** of 7 MHz each — **8 transmitters** across all India
- ◊ VHF-III Band (174-230MHz)
  - ◊ **Eight channels** of 8MHz each — **1034 transmitters** across all India

- ◊ We focus on the UHF Band-IV, i.e., 470-590MHz spectrum band
- ◊ Use of microphones is very limited in India and will not be considered

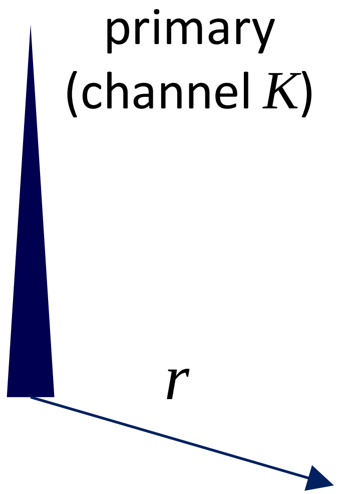
Channel K





The 470-590MHz has 15 channels of bandwidth 8MHz each. These channels will be indexed by an integer K. The K^{th} channel starting from 470MHz will be called as the channel K

The received power calculation method



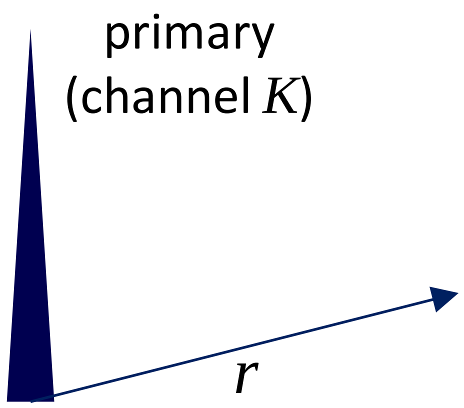
◊ The channel is the smallest entity for power calculations in TV white space estimation

◊ The primary transmitter emits a power of P_T on its channel K

For omnidirectional transmit antenna, at a distance r, in channel K, the received power will be less than P_T. In the dB (decibel) scale, the received power is written as $P_T - PL(r)$

The **path-loss** $PL(r)$ depends on the terrain, the transmit antenna height, the receive antenna height, the frequency of operation, and other parameters

Path-loss calculations: Okumura-Hata model



By the Okumura-Hata model, for omnidirectional transmit antenna, at a distance r, the path-loss is given by an affine function of $\log_{10} r$

$$PL(r) = A + B \log_{10} r$$

where

$$A = 69.55 + 26.16 \log_{10} f_c - 13.82 \log_{10} h_b - a(h_m)$$

$$B = 44.9 - 6.55 \log_{10} h_b$$

◊ The function $a(h_m)$, termed the correction factor, varies depending on terrain (sub-urban, urban, rural) **[Hata'1980]**

◊ Hata model is known to approximate Indian path-loss well **[Prasad-Ahmad'1997]**

◊ As an alternative, ITU-R propagation models can also be used **[ITU-R P.1546-1]**

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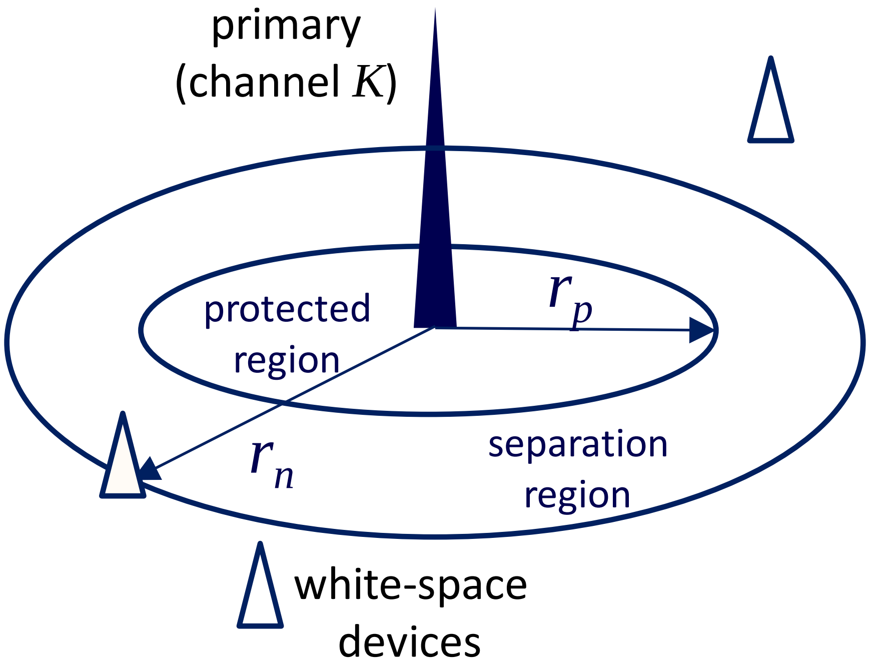
The protection viewpoint [Mishra-Sahai'2009]

Primary should be protected: minimum $SINR$ at the primary receiver on the edge of a "protected region" for the licensed user should be Δ (in dB scale)



The radius r_p is found using

$$P_T - PL(r_p) - N_0 = \Delta + \Psi$$

where

N_0 = the noise power (floor)

Ψ = fading margin in dB

The separation $r_n - r_p$ is found using

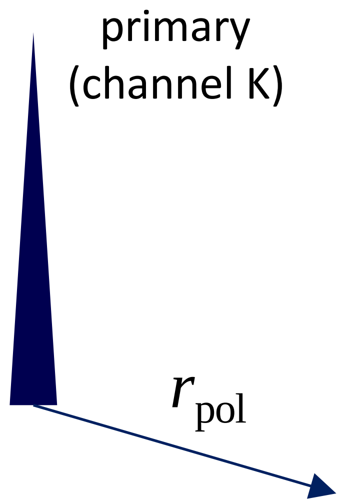
$$P_S - PL(r_n - r_p) = \Psi$$

where

P_S = the transmit power of secondary

The pollution viewpoint [Mishra-Sahai'2009]

Primary is a (radio) pollutant : maximum interference tolerable by the secondary receiver on the edge of "separation region" shown before should be γ (in dB scale)



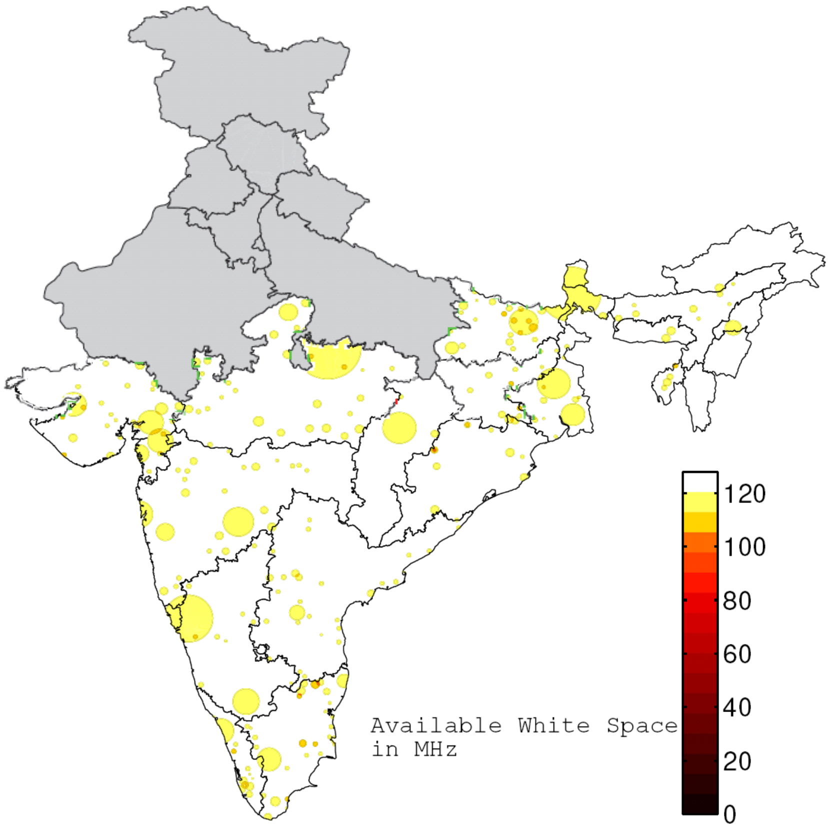
Max interference tolerable by a secondary receiver on edge of separation region is assumed to be γ

$$P_T - PL(r_{\text{pol}}) = N_0 + \gamma$$

◊ The parameters γ, Δ, and Ψ are unspecified and they can varied in simulation studies for TV white space estimation

◊ The actual TV white space will be the geographical regions where primary is protected and secondary is free from pollution

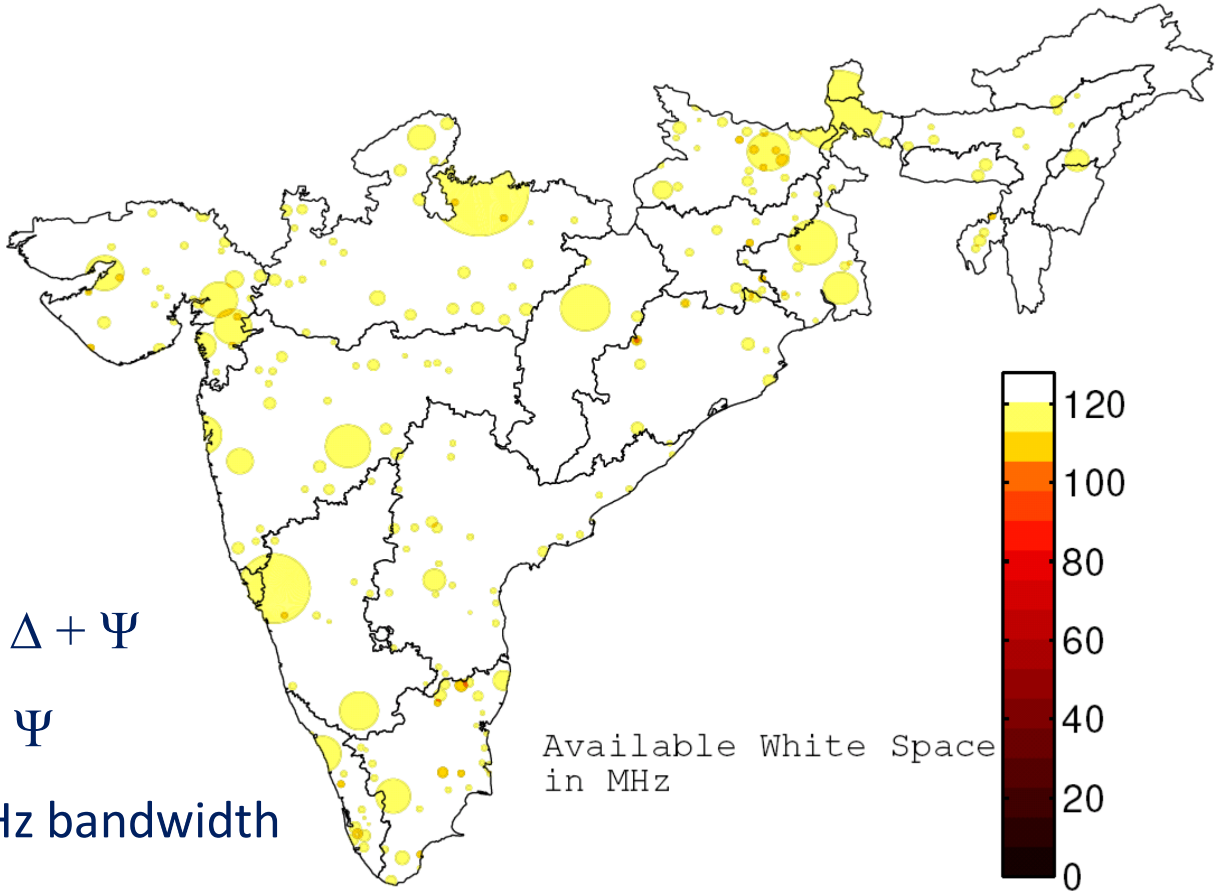
North-zone data not yet available



- So far, with significant efforts, we have been able to obtain the data for all zones except North in India
- The results will **omit** the North zone for this reason

All these calculations require propagation models and we use existing models discussed in the Indian context **[Prasad-Ahmad'1997, Hata'1980]**

TV white space assessment: protection view



Recall

$$P_T - PL(r_p) - N_0 = \Delta + \Psi$$

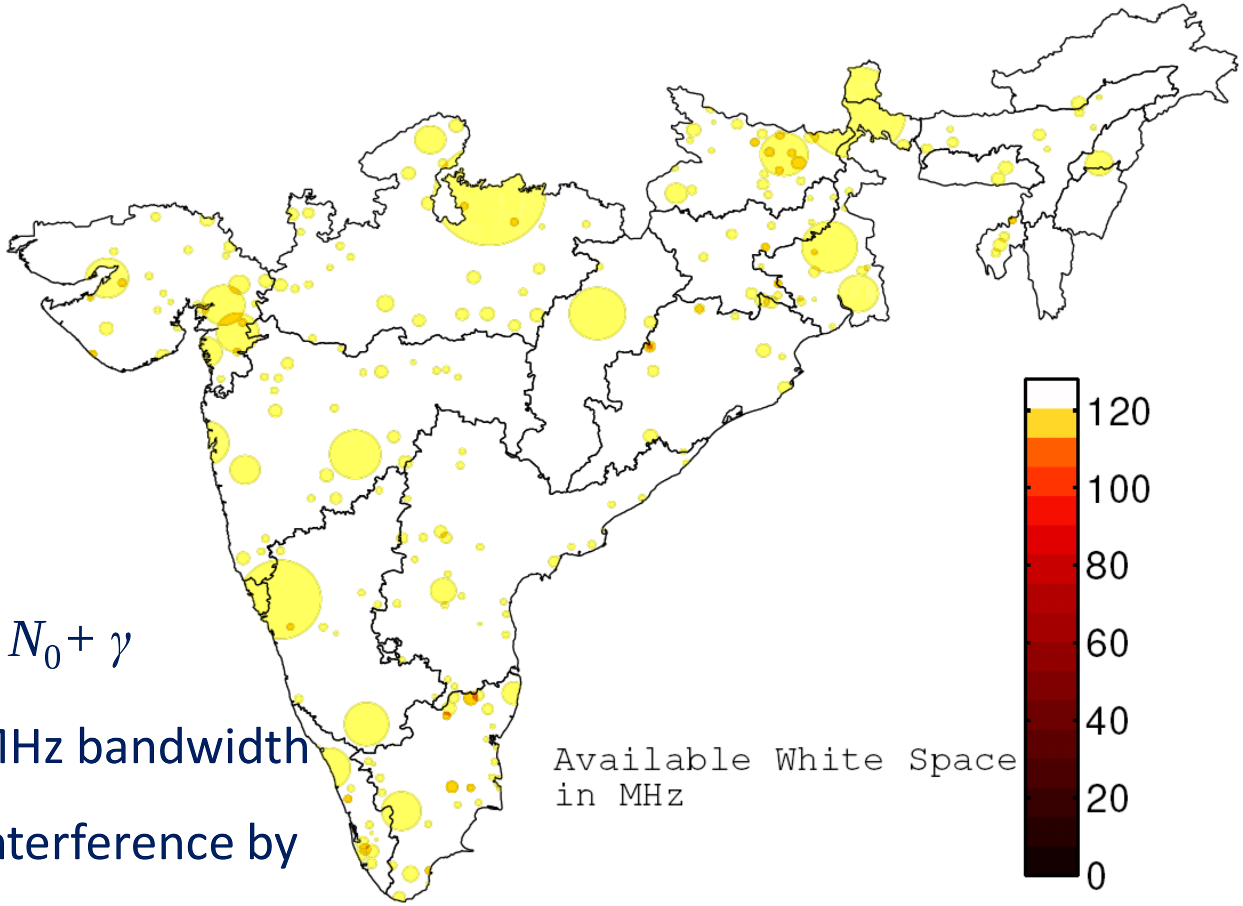
$$P_S - PL(r_n - r_p) = \Psi$$

N_0 = -105dBm for 8MHz bandwidth

Δ = SINR threshold (45dB)

Ψ = fading margin 0.1dB-1dB

TV white space assessment: pollution view



Recall

$$P_T - PL(r_{\text{pol}}) = N_0 + \gamma$$

N_0 = -105dBm for 8MHz bandwidth

γ = max. tolerable interference by secondary 5dB-15dB

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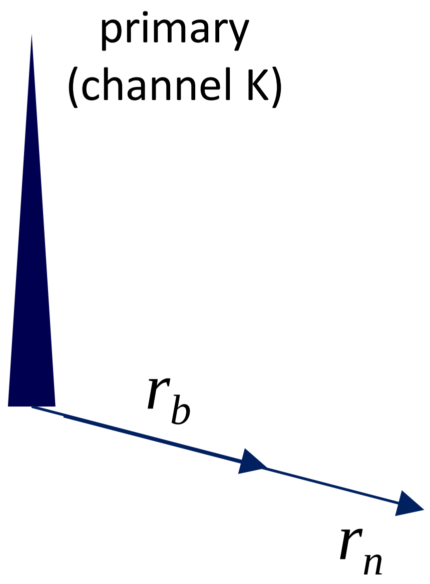
FCC rules for white space calculations

The FCC specifies a formula for transmit power using electric field:

$$P(\text{dBm}) = E(\text{dBu}) - 130.8 + 20 \log_{10} (1230/(f_H + f_L))$$



$P(\text{dBm})$ = transmit power in dBm

$E(\text{dBu})$ = electric-field strength in dBu

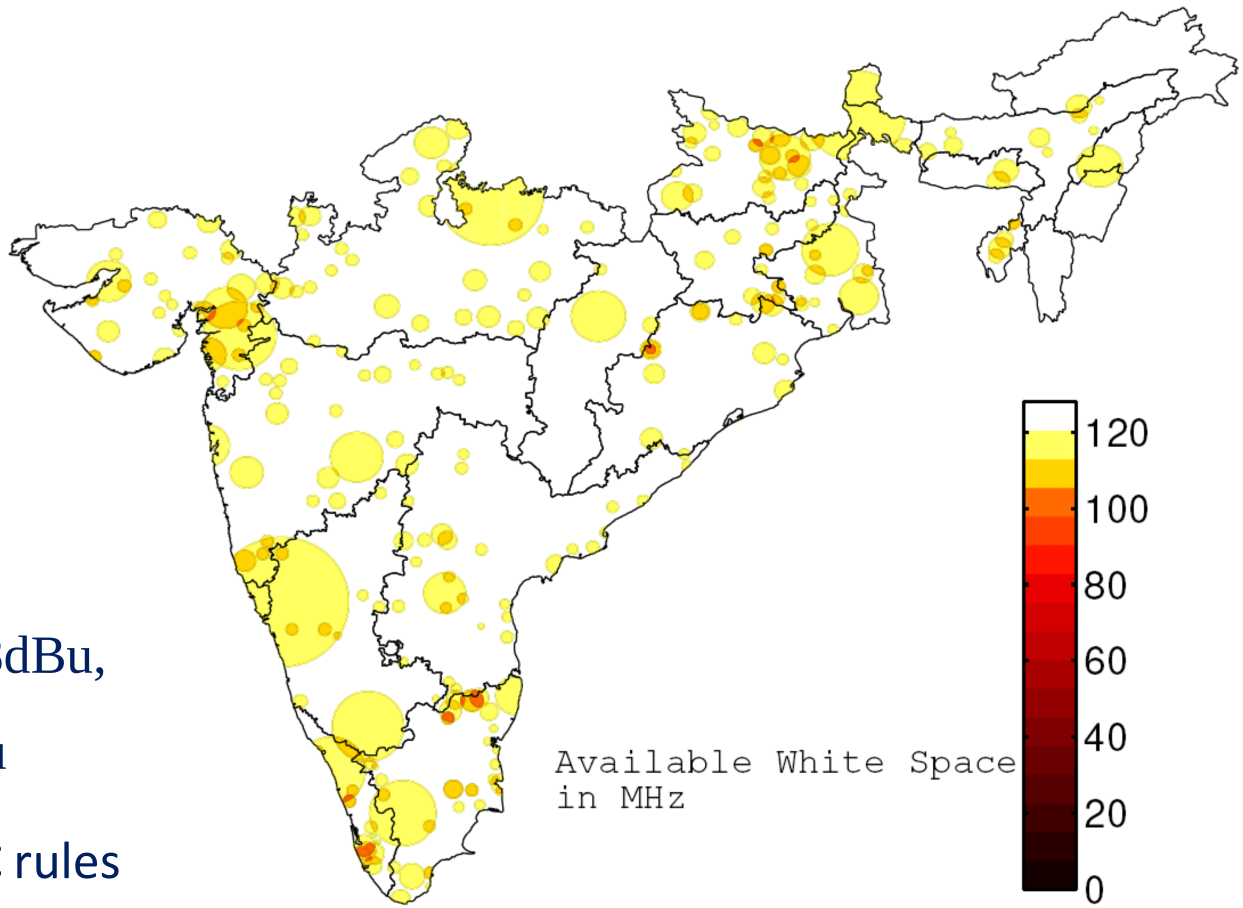
f_H, f_L = upper and lower frequency limits

r_b = distance where $E(r_b)$ is 41dBu

r_n = no-talk distance; secondary interference is 18dBu at r_b

All these calculations require propagation models and we use existing models discussed in the Indian context **[Prasad-Ahmad'1997, Hata'1980]**

TV white space assessment: FCC rules



Recall

$$E_S(r_n - r_b) = 18\text{dBu},$$

$$E_P(r_b) = 41\text{dBu}$$

P_S = specified by FCC rules

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Scope of our TV white space estimation

- The parameters vary as follows: γ = 5dB-15dB, Ψ = 0.1dB-1dB and $E(r_b)$ was fixed at 41dBu for the FCC rule calculations
- The height above average terrain for the secondary is considered to be 30m
- For the three methods outlined in this section, average number of primary channels available as TV white space (per unit area) is computed
- Similarly, a histogram of minimum number of channels available as TV white space is computed
- We will also examine whether Doordarshan can maintain existing TV coverage with a smaller band than 470-590MHz

Channels available per unit area (out of 15)

Method	Parameters	West	East	South	North-east	India
Pollution Viewpoint	$\gamma = 5$ dB	14.0	14.2	14.7	14.8	14.2
	$\gamma = 10$ dB	14.7	14.6	14.7	14.9	14.7
	$\gamma = 15$ dB	14.8	14.8	14.9	14.9	14.8
Protection viewpoint	$\Psi = 1$ dB	14.9	14.8	14.9	14.9	14.9
	$\Psi = 0.1$ dB	14.9	14.8	14.9	14.9	14.9
FCC regulations	$E_{rb} = 41$ dBu	14.8	14.7	14.6	14.8	14.7

At least 14 (out of 15) channels are available per unit area

Number of “white” TV channels with area

Method	Parameters	10-channels free	12-channels free	15-channels free
Pollution Viewpoint	$\gamma = 5$ dB	100%	100%	37%
	$\gamma = 10$ dB	100%	100%	71%
	$\gamma = 15$ dB	100%	100%	85%
Protection viewpoint	$\Psi = 1$ dB	100%	100%	88%
	$\Psi = 0.1$ dB	100%	100%	86%
FCC regulations	$E_{rb} = 41$ dBu	100%	100%	73%

12 (out of 15) channels are available as “unused” at any point

Key observations

- Per unit area, a minimum of **14 out of 15 channels** is always available as TV white space!
- At any place, a minimum of **12 out of 15** channels are almost always available as TV white space channel
- These results hold for various values of γ = 5dB-15dB, Ψ = 0.1dB-1dB and $E(r_{\mathrm{b}})$ was fixed at 41dBu for the FCC rule calculations

Most of the UHF-Band spectrum at most of the places in India is available as TV white space

Comparisons with international scenario

Country	TV white space available
Germany	48%
UK	58%
Denmark	61%
Switzerland	63%
Japan	41.7%
India	80%

This calculation is pessimistic, since the TV white space availability in other countries also examined the entire TV band and not just the 470-590MHz band

A hypothetical channel allocation algorithm

- Using interference avoidance by spatial reuse of frequencies, an algorithm can be used to find the **smallest number** of channels needed for existing TV coverage in India
- We find that **typically 3** and in the worst-case **4 channels** are sufficient to provide existing TV coverage spread over 15 UHF channels!

11 out of 15 channels (>70%) can be freed by reassignment of TV channel frequencies in India

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Measurements carried out by our group

- ◊ Mumbai
- ◊ Pune
- ◊ Ajmer

Spectrum scan in the 470-806MHz band

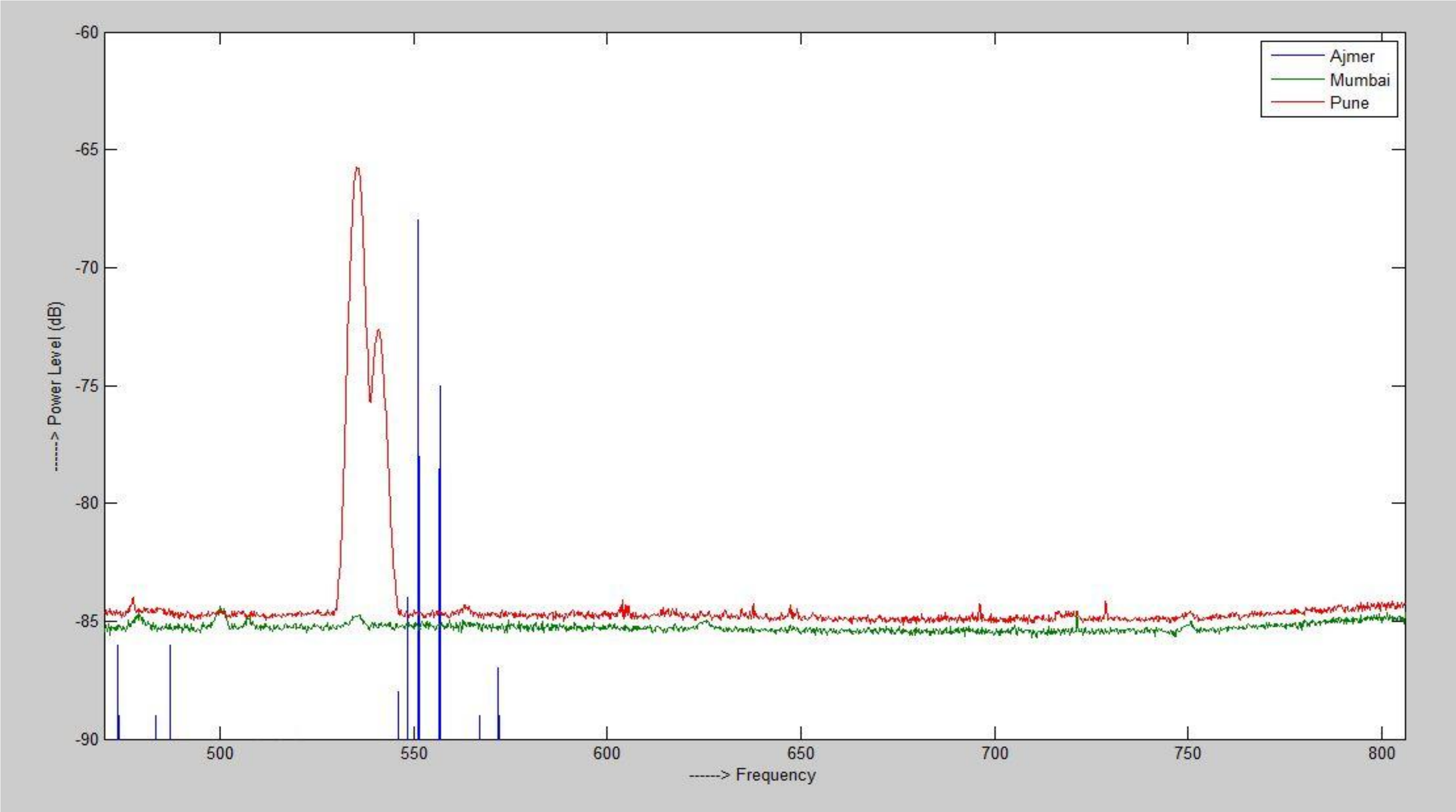


Figure : Received Signal Strength v/s Frequency

Utilization of the 470-806MHz band

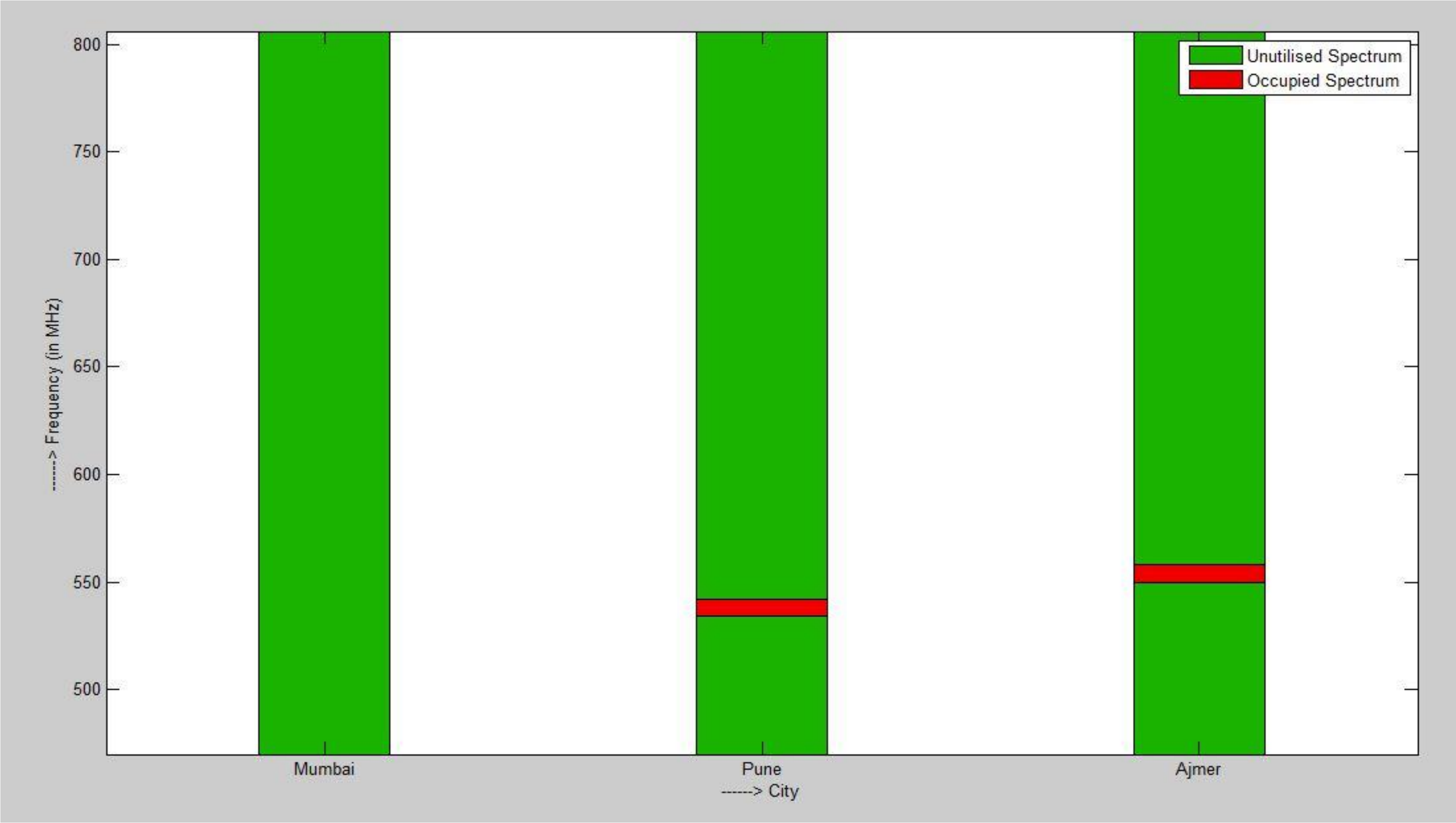


Figure : Availability of TV White Space

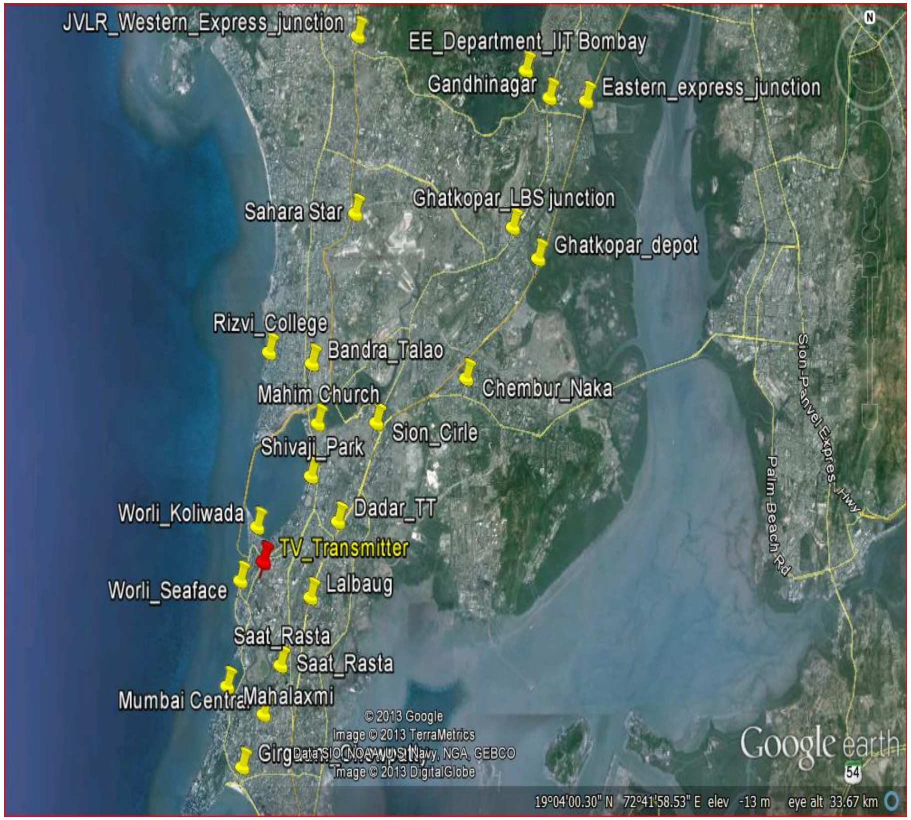
Quantitative Analysis in Mumbai

◊ Measurements carried out at 42 locations

◊ Two channels transmitted by Doordarshan (DD) terrestrial TV tower (DD-1 and DD-2)

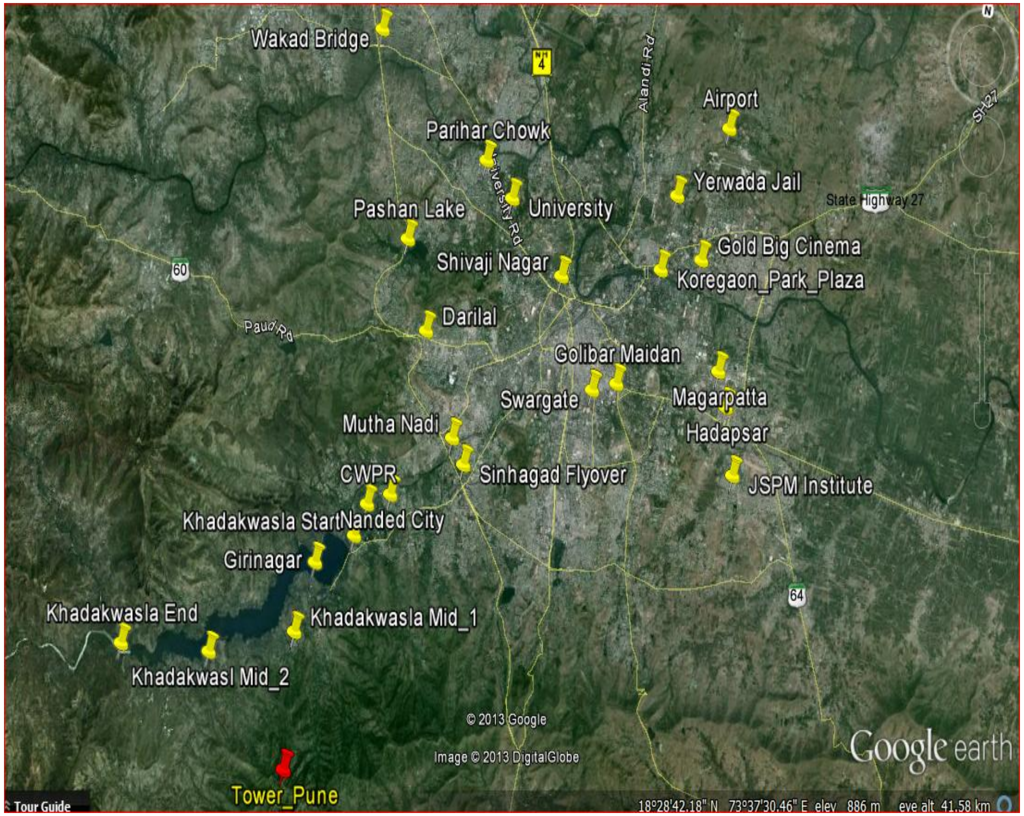
◊ Channel 1 (182MHz) and Channel 2 (224MHz) – Both in VHF Band

◊ The bands 470-585MHz, 585-698 MHz, and 698-806MHz are presently unutilized.



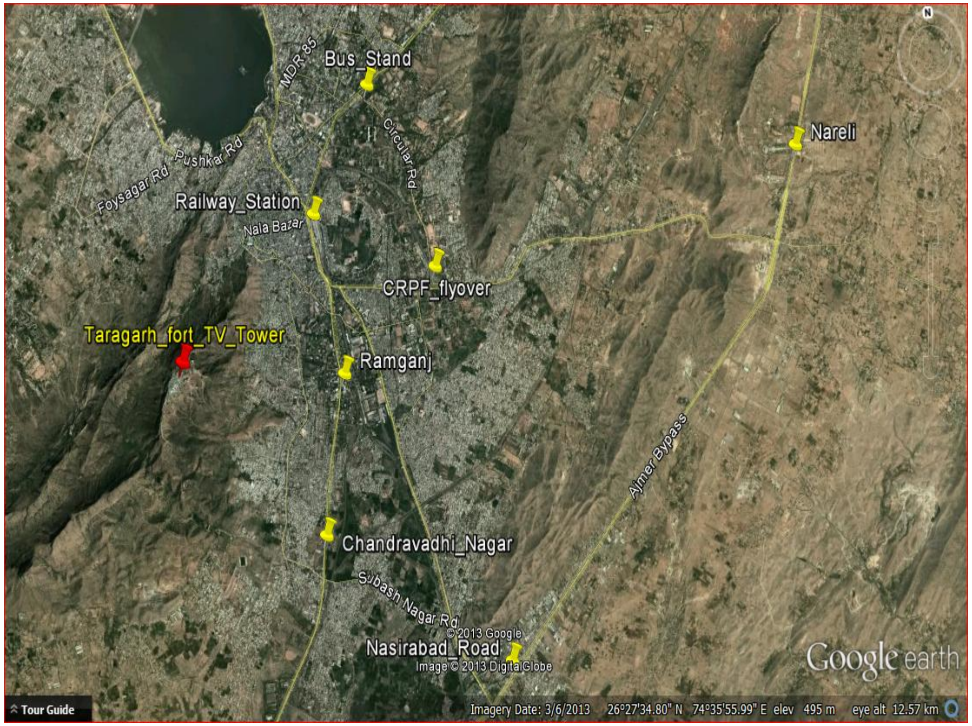
Quantitative Analysis in Pune

- Measurements carried out at 30 locations
- Two channels (DD-1 and DD-2) being transmitted at 175MHz and 535MHz respectively
- Only one channel used in the 470-585MHz band
- The bands 585-698 MHz and 698-806 MHz are presently unutilized.



Quantitative Analysis in Ajmer

- Measurements carried out around TV tower at 7 locations
- Two channels (DD-1 and DD-2) being transmitted at 168MHz and 550MHz respectively
- Only one channel in 470-585MHz band
- The bands 585-698MHz and 698-806MHz are presently unutilized.



Utilization of the 470-585MHz band

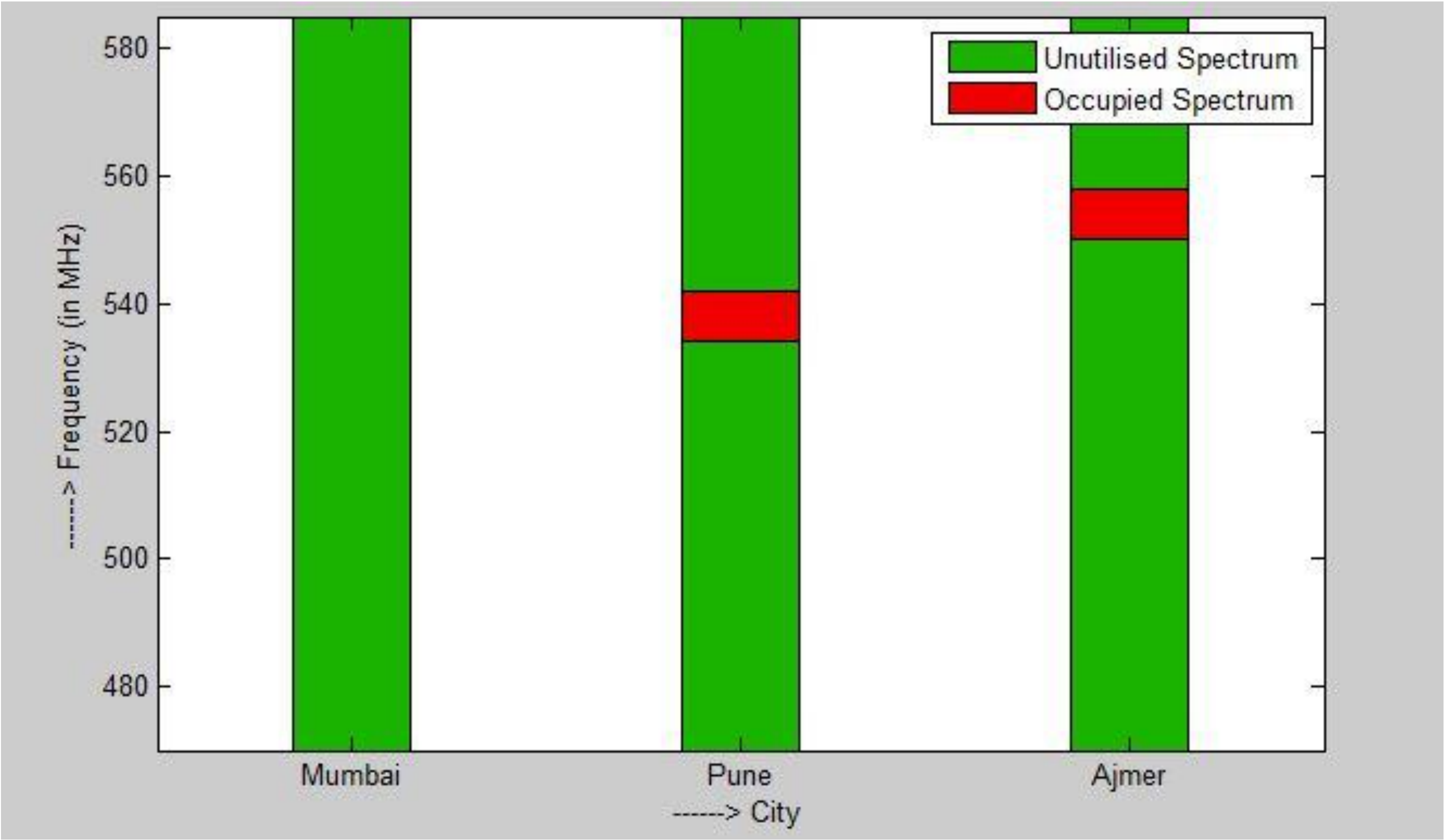


Figure : Availability of TV White Space

Utilization of the 470-585MHz band

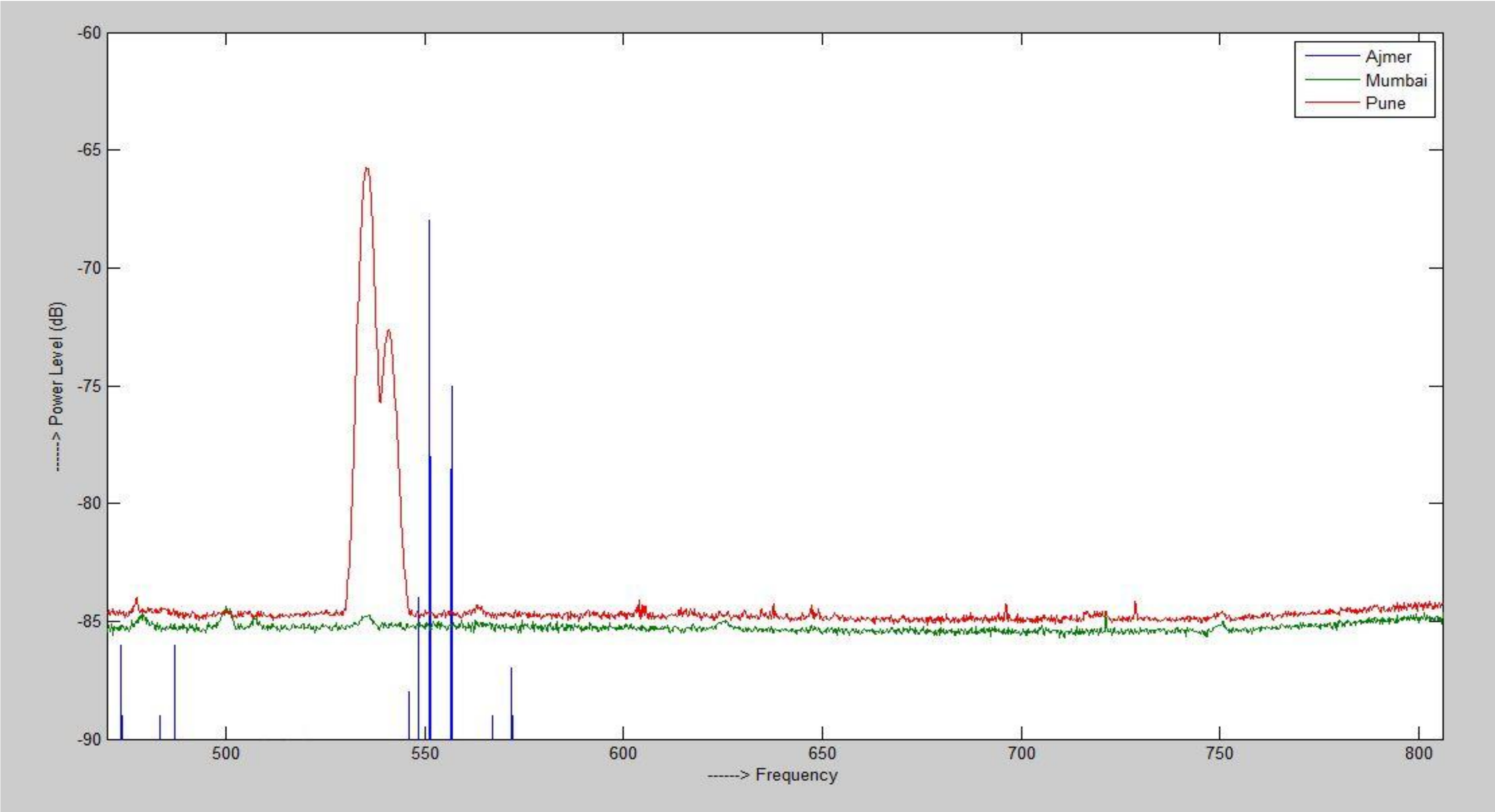


Figure : Received Signal Strength v/s Frequency

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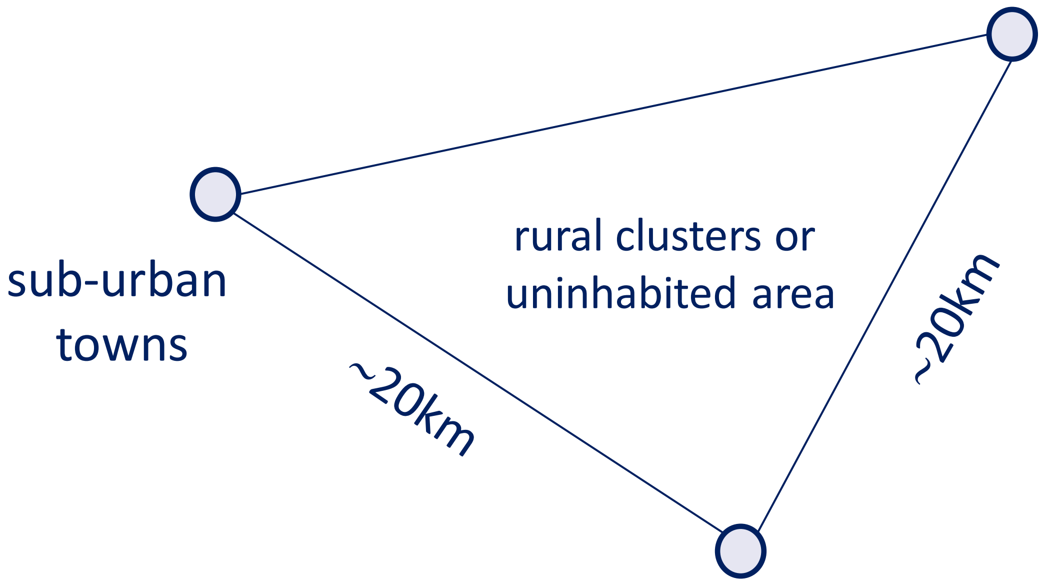
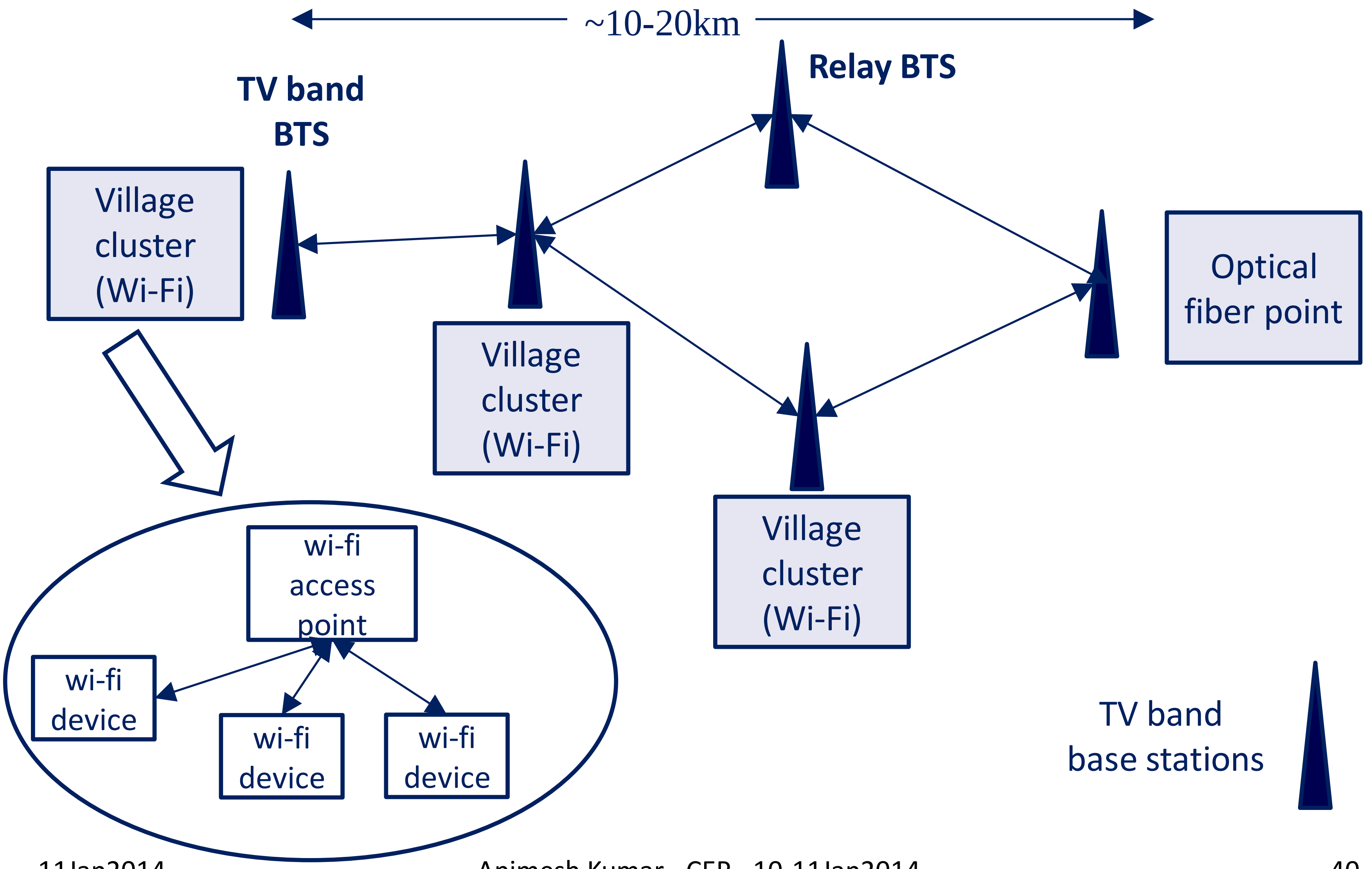
Key problem in broadband coverage

- Broadband coverage in rural areas is desirable but it is difficult due to cost and low return on investment
- Recently, Government of India has announced a National optical fiber network (NOFN) to link all sub-urban towns with optical connectivity



- It is a challenge to provide an affordable broadband to sparsely populated rural areas due to backhaul considerations

Middle-mile mesh-network in TV white spaces



Analysis to be done/test-beds to be deployed

- Throughput analysis with bandwidth for the mesh-network has to be done
- Interference management has to be figured out. In particular,
  - Co-channel interference or coexistence, power limits
  - Adjacent channel coexistence, frequency of operation
  - Spectral mask, out of band performance
- On-site test-beds to experimentally verify everything mentioned above

Conclusions in brief

- Lots of TV white space in India in the 470-590MHz band
- While it is in inception, we believe that a suitably designed mesh-network in the TV band will significantly address the lack of rural broadband coverage in India.

Acknowledgments

◊ Research supported by the Ford Foundation

◊ Support from and consultation with Dr. Ashok Chandra