TV White Space for Affordable Broadband Access

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Wireless Personal Multimedia Communications (WPMC) 2015 Tutorial, Hyderabad

Outline

- TV White Space: Indian Scenario and Quantitative assessment

- Architecture for Affordable Broadband using TV White Space

- TV White Space Test-Bed

- Test-Bed Results and Discussions

- Conclusions

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- TV White Space: Indian Scenario and Quantitative assessment

- Architecture for Affordable Broadband using TV White Space

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Terrestrial TV Spectrum Allocations

Region 1 (Europe, Africa, Russia, Middle East)	Region 2 (Americas, Pacific)	Region 3 (India - Asia, Oceania)
470-790 Broadcasting	470-512 Broadcasting, Fixed, Mobile 512-608 Broadcasting	470-585 Fixed, Mobile, Broadcasting

- Government's national broadcaster named Doordarshan holds all of the terrestrial TV broadcasting license

- ITU Regulations for Region 3 (applies to India) allows use of 470-585 MHz for

  "Fixed, Mobile, and Broadcasting" as Primary Services

National Frequency Allocation Plan (NFAP) 2012

- **IND 36** -Requirement of fixed and mobile services will be considered in 470-520 MHz and 520-585 MHz on case by case basis

- **IND 37** - Requirement of digital broadcasting including mobile TV will be considered in 585-698 MHz subject to coordination on a case by case basis

- **IND 38** -IMT (BWA) will be considered in 698-806 MHz subject to coordination on case by case basis
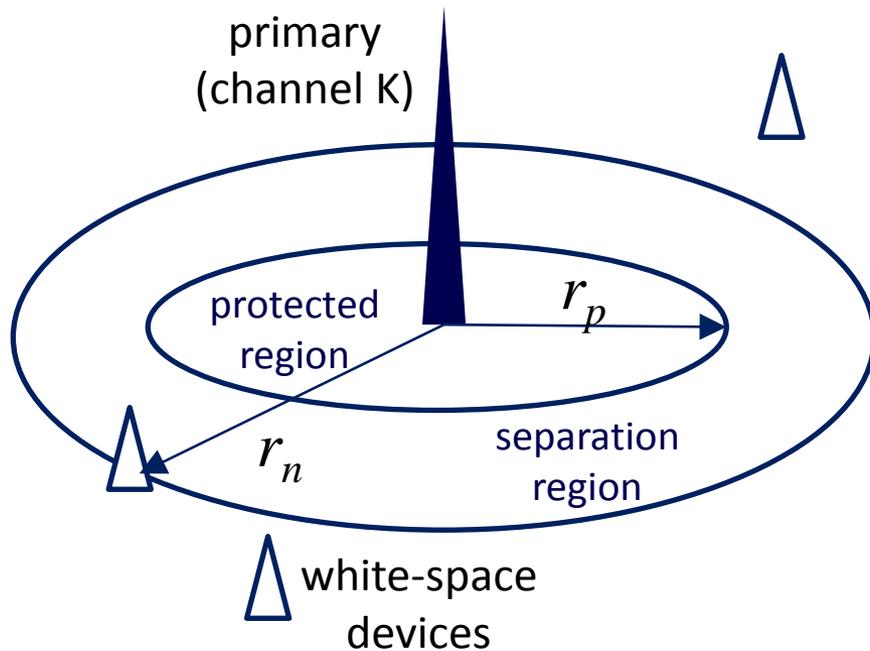
Terrestrial TV Transmitter Plan of India

- On record, there are 1415 Terrestrial TV transmitters operating in India only by Doordarshan
  - UHF Band-IV (470-590MHz)
    - **Fifteen channels** of 8 MHz each   **373 transmitters** across all India
  - VHF-I Band (54-68 MHz)
    - **Two channels** of 7 MHz each   **8 transmitters** across all India
  - VHF-III Band (174-230 MHz)
    - **Eight channels** of 8 MHz each   **1034 transmitters** across all India

- We focus on the UHF Band-IV, i.e., 470-590 MHz spectrum band

- Use of microphones is very limited in India

TV White Space Assessment Methods

- The protection and pollution viewpoints **[Mishra and Sahai'2009]**

- The FCC regulations **[FCC'Nov2008]**

The Protection and Pollution Viewpoints

primary
(channel K)

protected
region

r_p

r_n

separation
region

white-space
devices

primary
(channel K)

r_{pol}

Min SINR at the primary receiver on edge of

protected region should be Δ **[Mishra-Sahai'2009]**
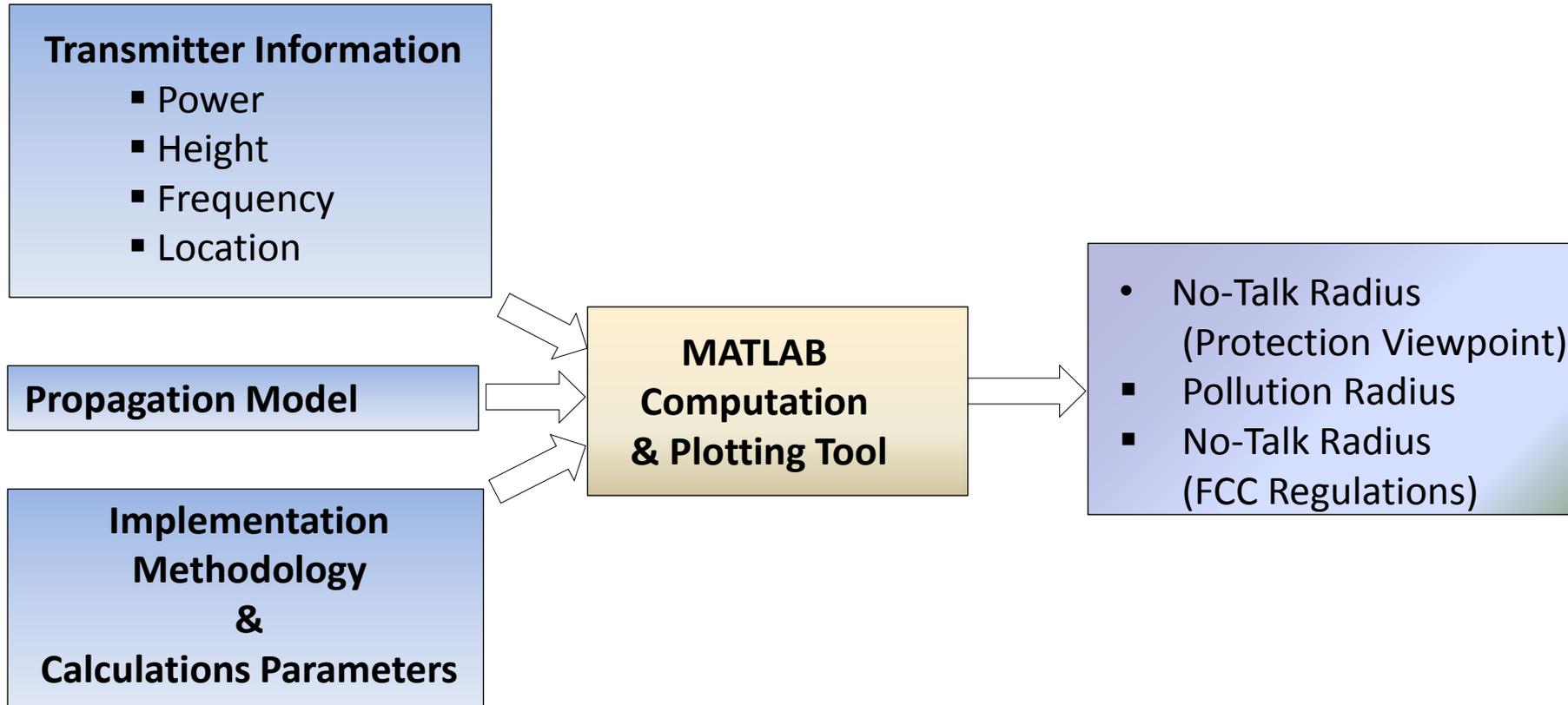
$$P_t - PL(r_p) - N_0 = \Delta + \Psi$$

$$P_S - PL(r_n - r_p) = \Psi$$
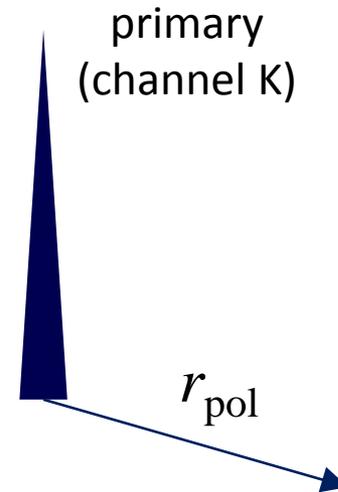
Min SINR at the secondary

receiver on edge of separation

region should be γ

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

Computational Tool

Transmitter Information
- Power
- Height
- Frequency
- Location

Propagation Model

Implementation Methodology & Calculations Parameters

MATLAB Computation & Plotting Tool

- No-Talk Radius (Protection Viewpoint)
- Pollution Radius
- No-Talk Radius (FCC Regulations)

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

Available White Space in MHz

100

50

0
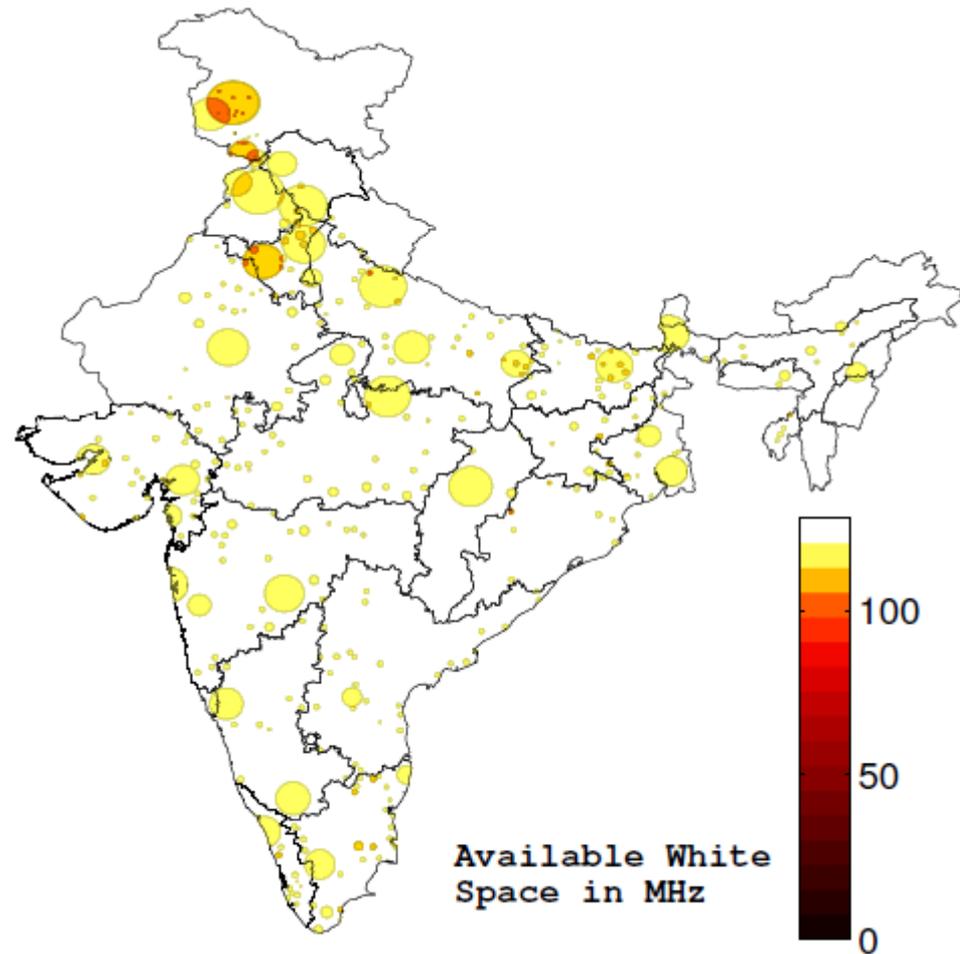
TV White Space Assessment: Pollution View

Recall

$$P_t - PL(r_{\mathrm{pol}}) = N_0 + \gamma$$

N_0 = -105dBm for 8MHz bandwidth

γ = max. tolerable interference by

secondary 5dB-15dB

Available White
Space in MHz

100

50

0
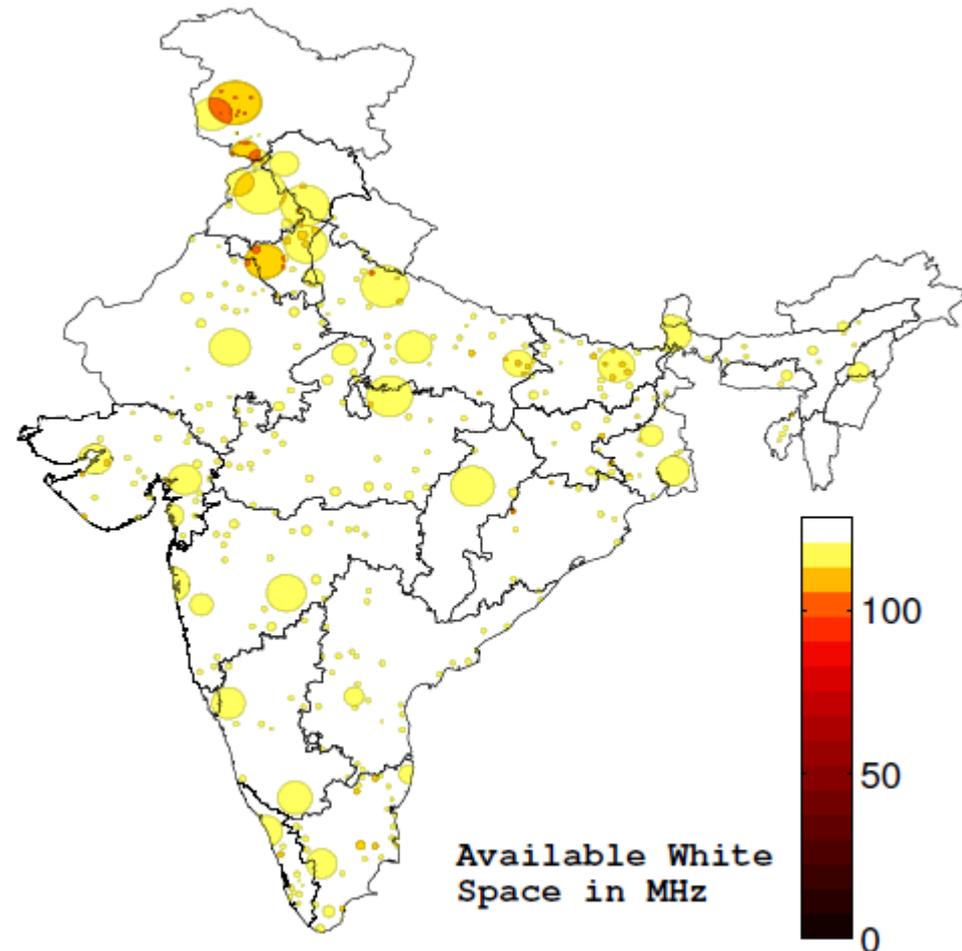
Complementary Cumulative Distribution Function (CCDF)
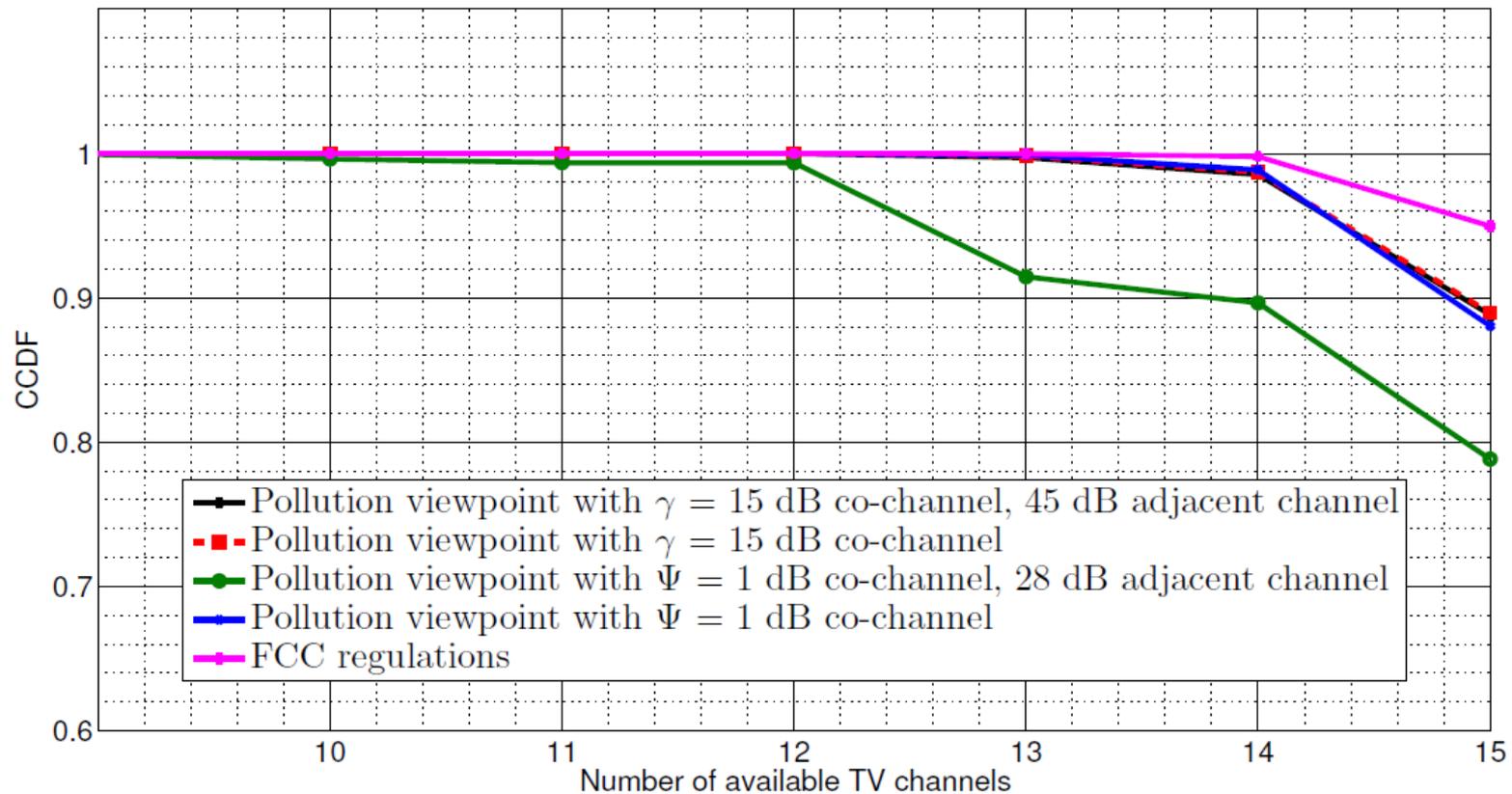
Average available TV White Space in India is more than 100 MHz!

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

- These results hold for various values of γ = 5dB-15 dB, Ψ = 0.1 dB -1 dB.

Our analysis reveals about 100MHz unused in UHF Band-IV

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

Outline

Indian Scenario: Rural broadband using UHF-IV

- Recently, Government of India has announced a National Optical Fiber Network (NOFN) -Bharatnetto link all Gram Panchayats with optical connectivity.

- Leveraging on the NOFN of Government of India, we envisage the use of (currently under-utilized) UHF Band-IV to provide affordable broadband in (rural) India

- Summary statistics of NOFN / Gram Panchayats

Number of Blocks (NOFN Phase-I)	6,382
Number of Gram Panchayats (NOFN Phase I/II)	2,50,000
Number of Villages	6,38,619
Avg. number of Gram Panchayats per block	40
Avg. number of Villages per Gram Panchayat	2.56
Avg. number of Hamlets per Village	4

Topology 1: Middle-Mile Point-to-Point Network
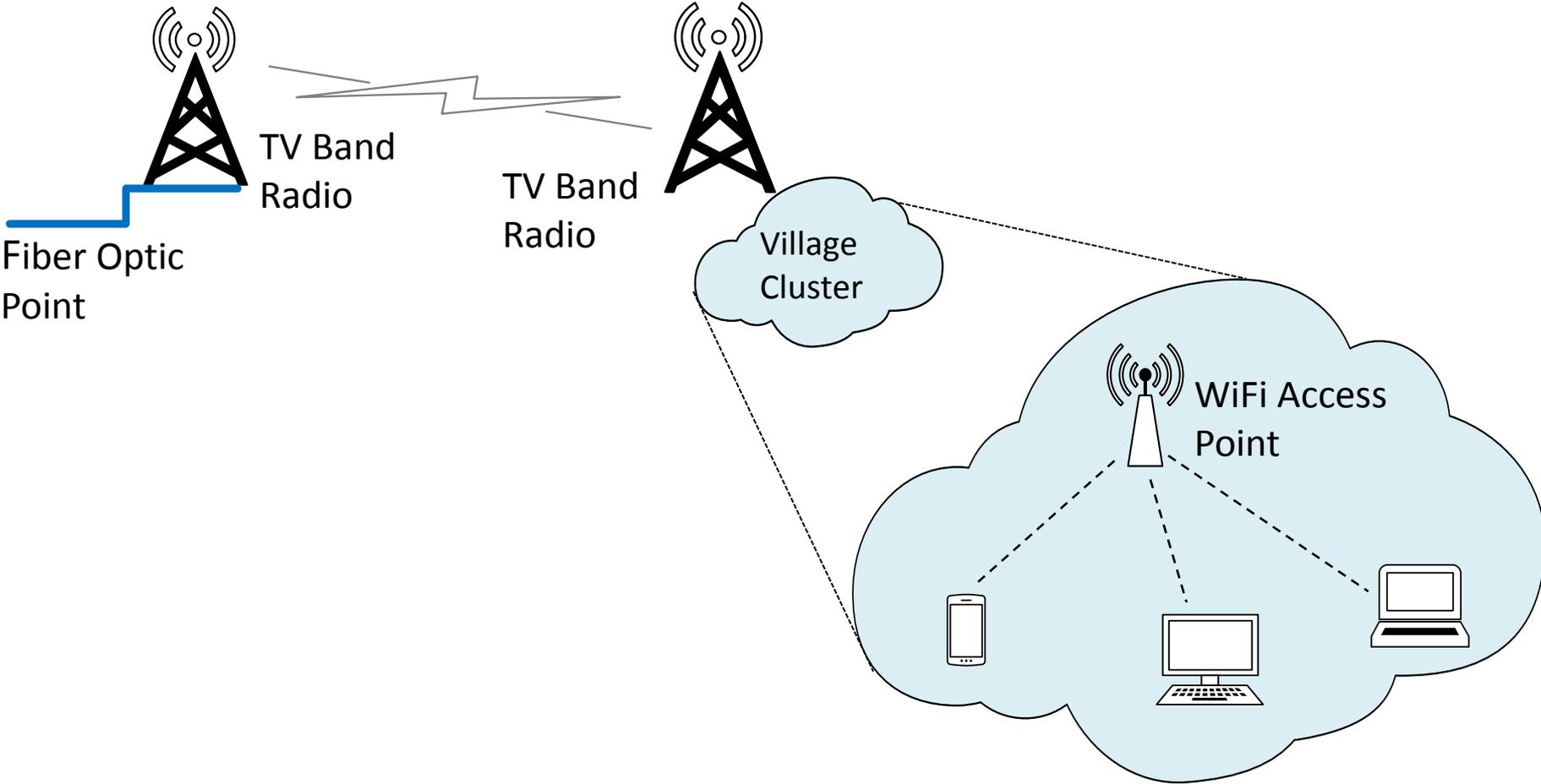
Topology 2: Middle-Mile Point-to-MultiPoint Network
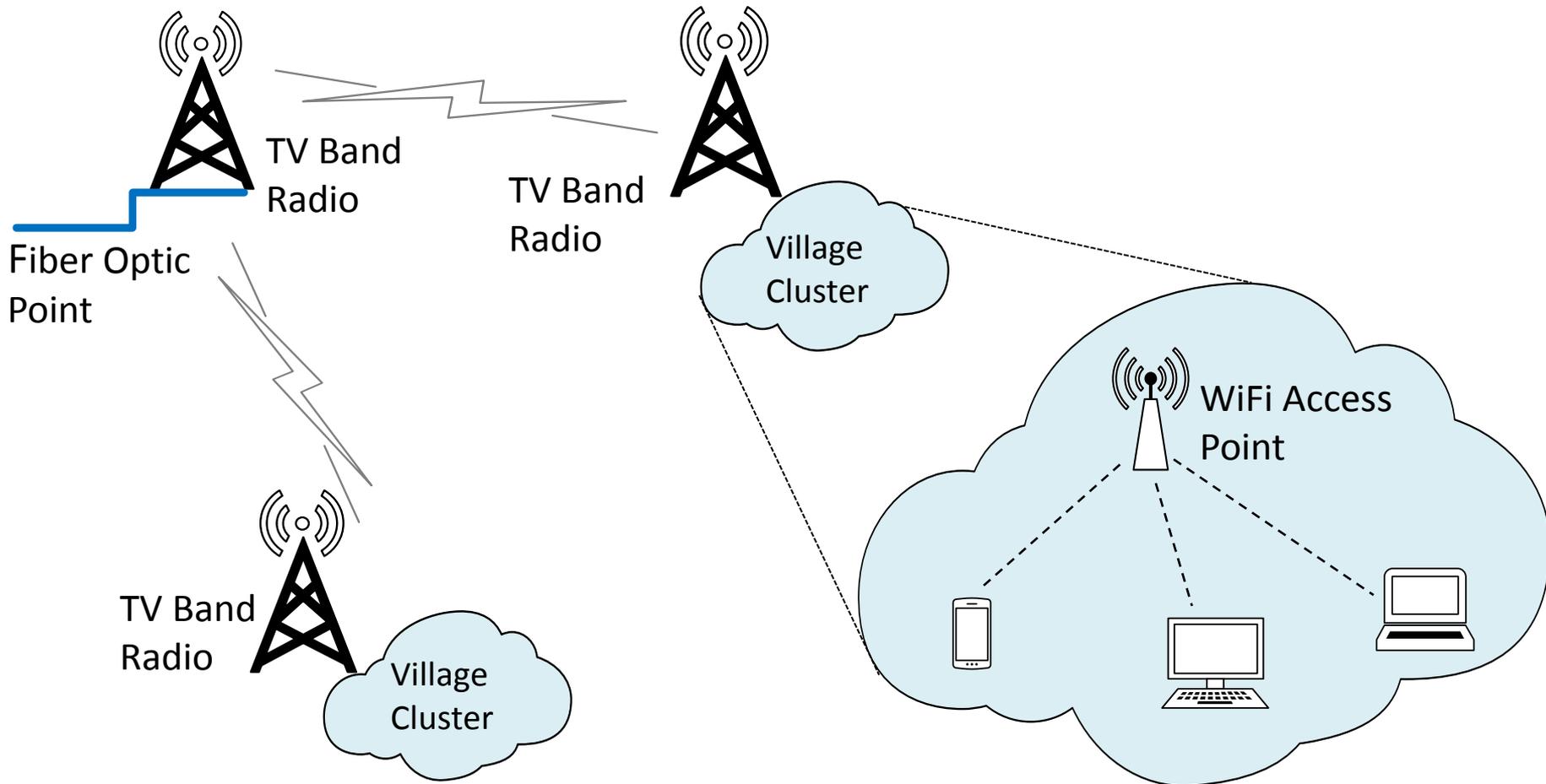
Topology 3: Middle-Mile Multi-Hop Network

←— — — — — — — — — —10-20 kms— — — — — — — — —→

TV Band BTS
Village Cluster

TV Band BTS
Village Cluster

Fiber Optic Point

TV Band BTS
Village Cluster

TV Band BTS
Village Cluster

TV Band BTS
Village Cluster

WiFi Access Point

WiFi Cluster within the Village
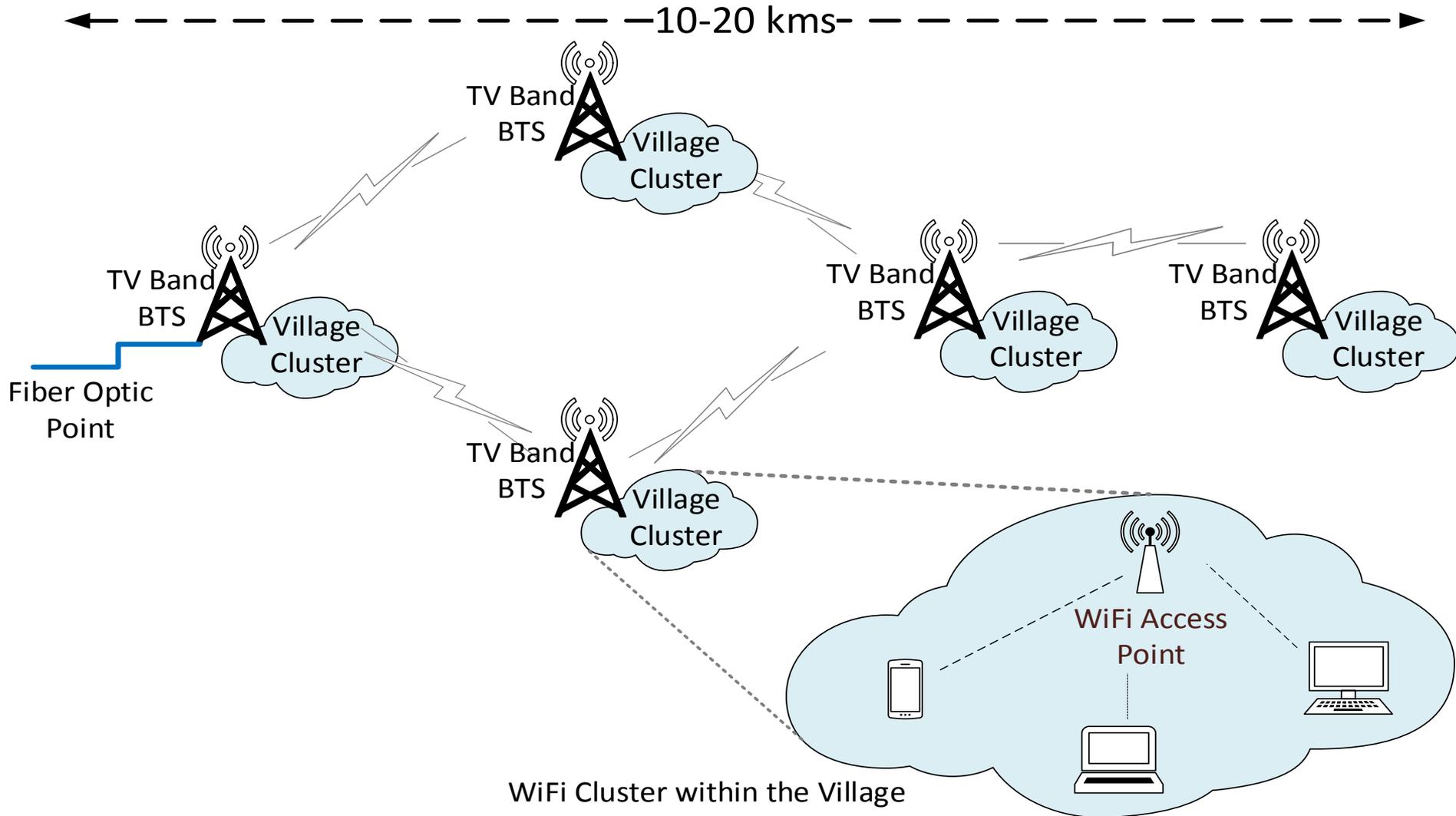
Registered Shared Access

- Orthogonal channels across operators

- Few shared channels across operators

- All Channels shared across operators
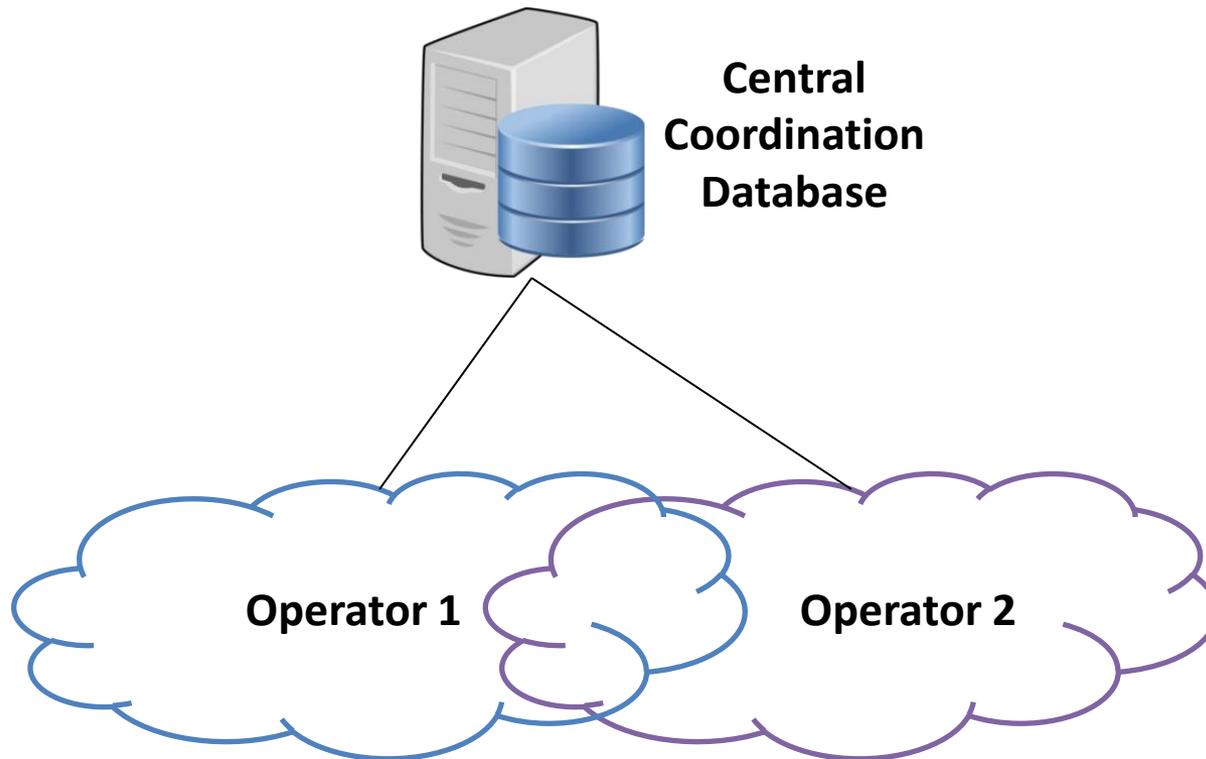
Central Coordination Database

Operator 1   **Operator 2**

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Generic Topology of Test-Bed

TV Band Radio

TV Band Radio

Fiber Connectivity

Access Points with
2.4 GHz & TV band antenna

TVWS link

2.4 GHz ISM link
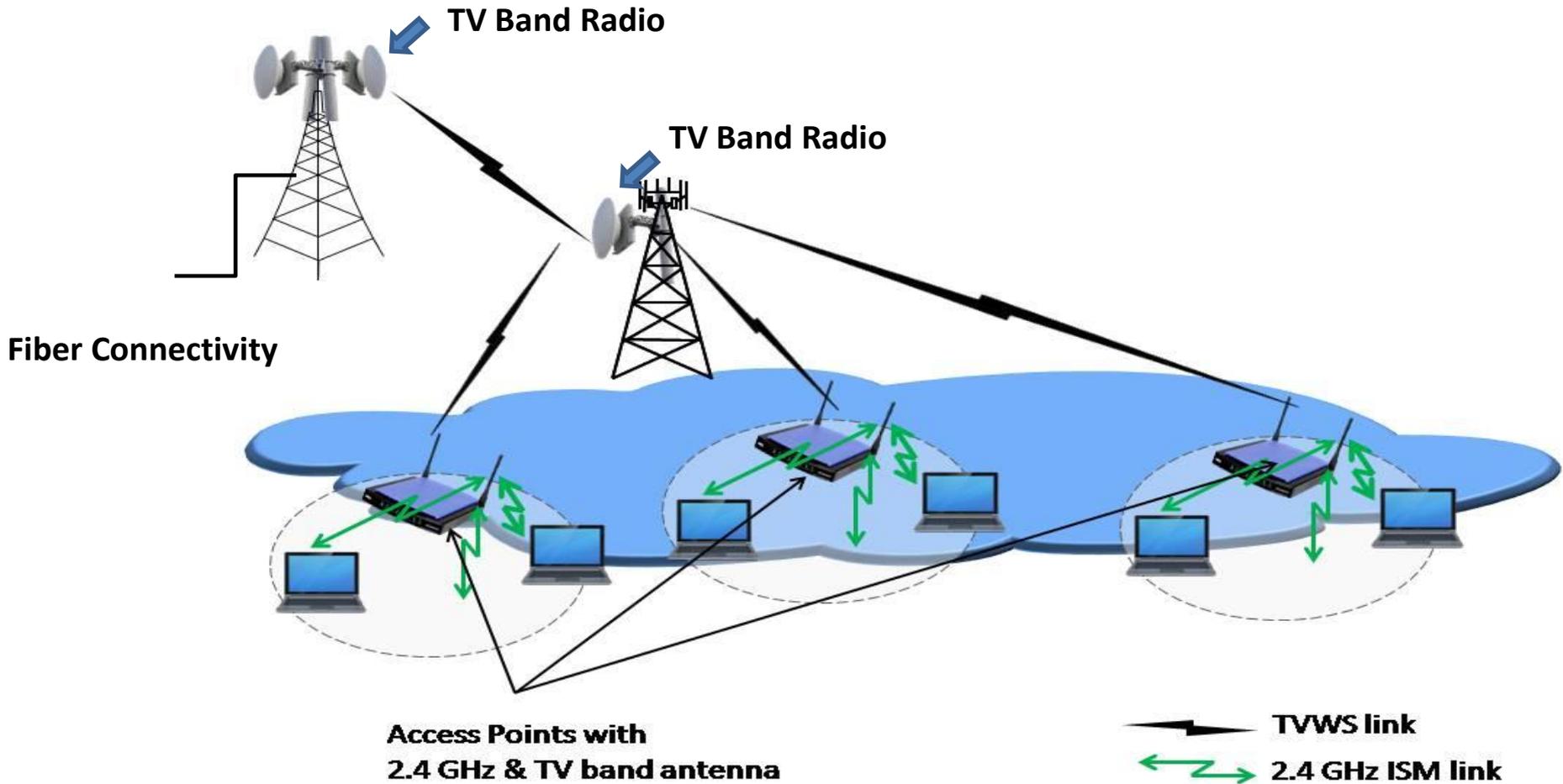
Equipment

- Base station and CPE based on 802.11 in 500 MHz with TDMA scheduling tested.

- Standards WiFi access points for hot-spots

- Also implemented PAWS

Network Topology of UHF TV Band Pilot at Palghar

Paragoan Tower

Maswan Tower

Khamloli Village

500 m

700 m

5.5 km

7.2 km

Khamloli Tower

2.5 km

Tower at Dhuktan Hill

600 m

2.3 Km

1.2 km

550 m

Optical fiber

Dhuktan Village

Bahadoli Village

Dowli Pada at Dhuktan

Ganje Tower

6.7 km

Haloli Tower

3.9 km

Point to Point TV UHF Band Links

Khamloli Tower
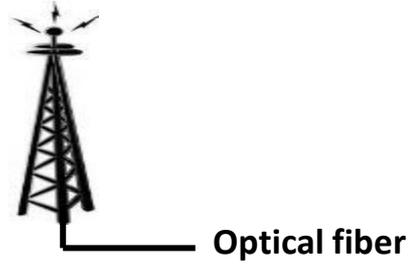
Optical fiber

UHF Band
Omni Antenna
(500-520 MHz)
Connecting Four GBTs

KHAMLOLI TOWER

Point to Point TV UHF Band Links

Khamloli Tower

Optical fiber

3.9 Km

Haloli Tower

UHF Band
Omni Antenna
(500-520 MHz)

UHF Band Yagi Antenna
Connecting Khamloli Base
Station
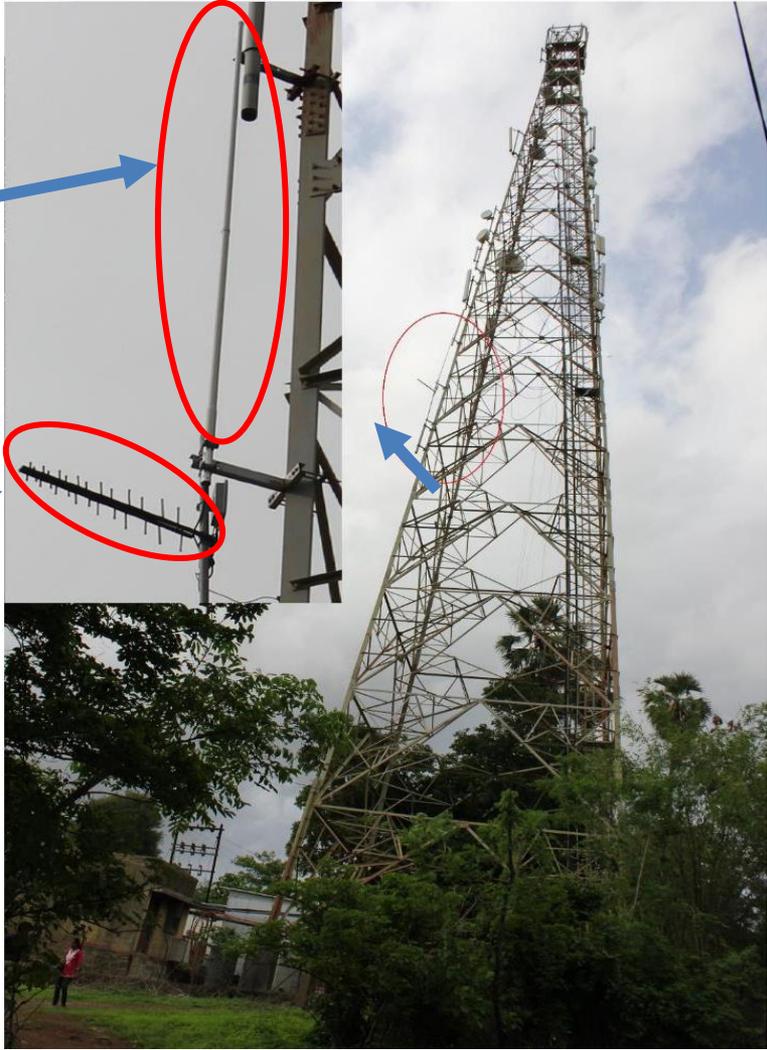
HALOLI TOWER

Point to Point TV UHF Band Links
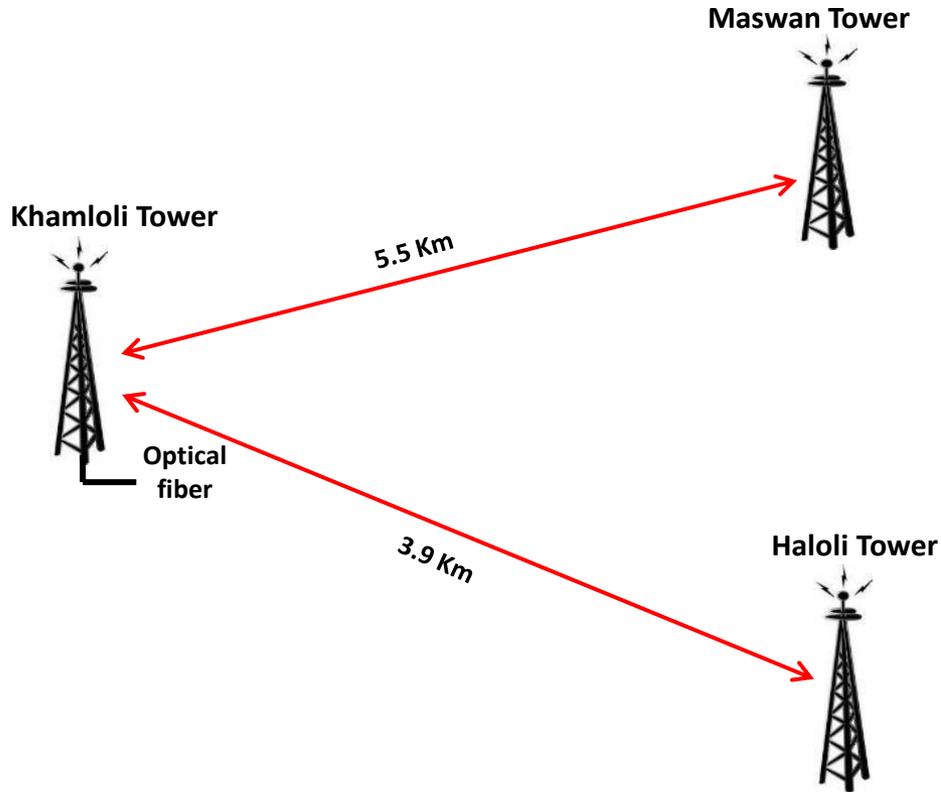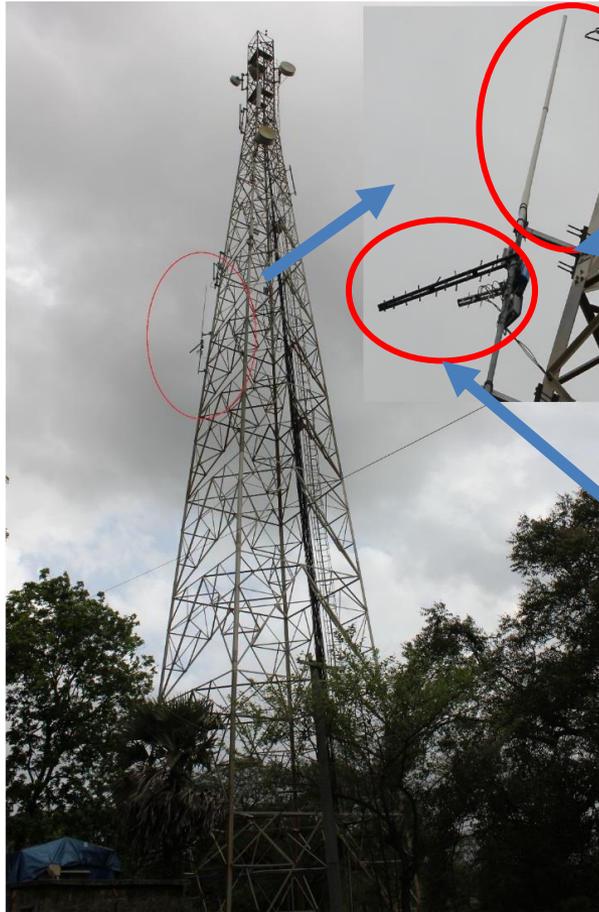
UHF Band Omni Antenna (500-520 MHz)

UHF Band Yagi Antenna Connecting Khamloli Base Station

MASWAN TOWER

Point to Point TV UHF Band Links

UHF Band
Omni Antenna
(500-520 MHz)

UHF Band Yagi
Antenna
Connecting
Khamloli Base
Station
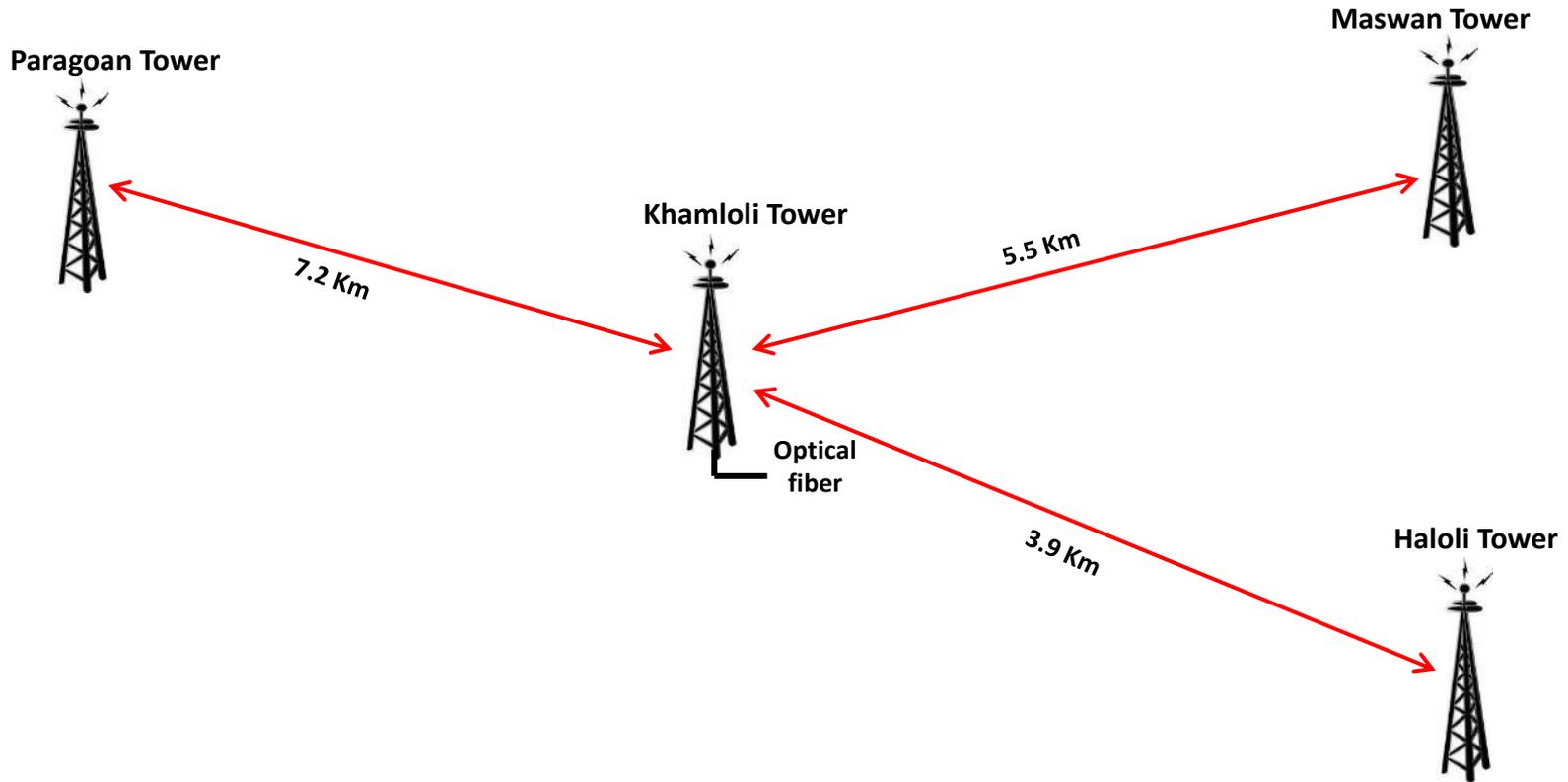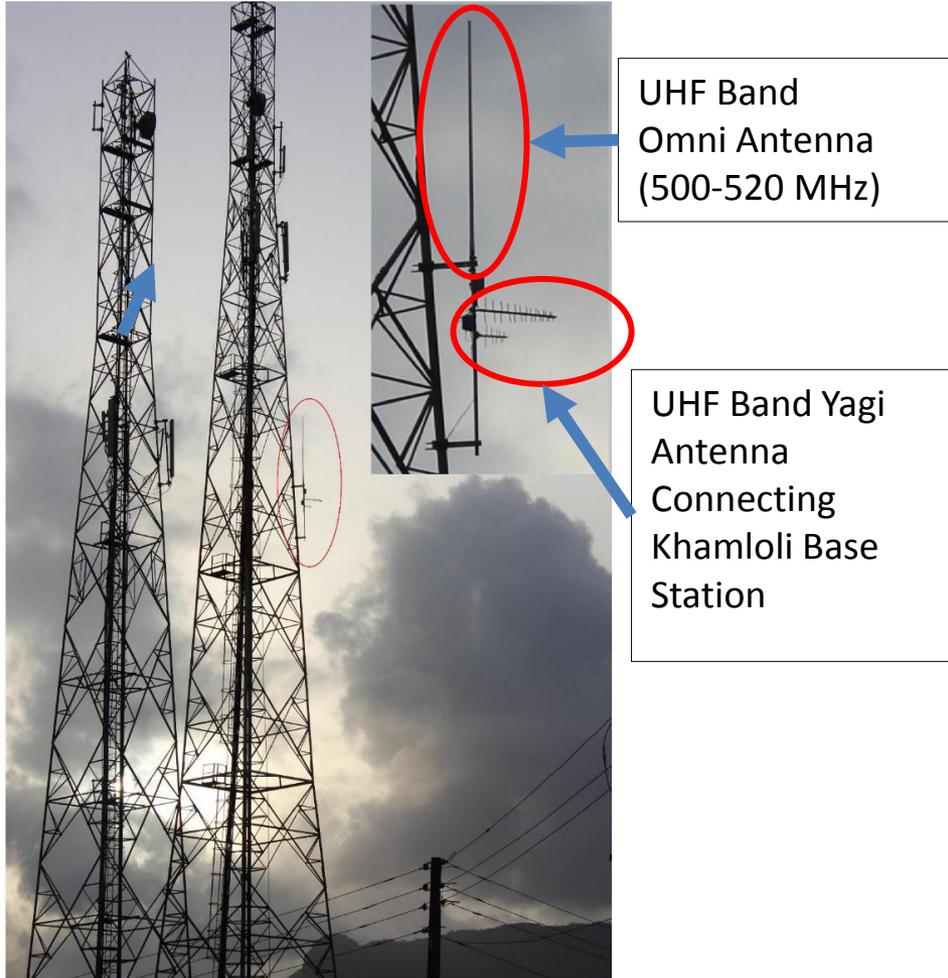
PARGAON TOWER

Point to Point TV UHF Band Links

UHF Band Yagi Antenna Connecting Khamloli Base Station
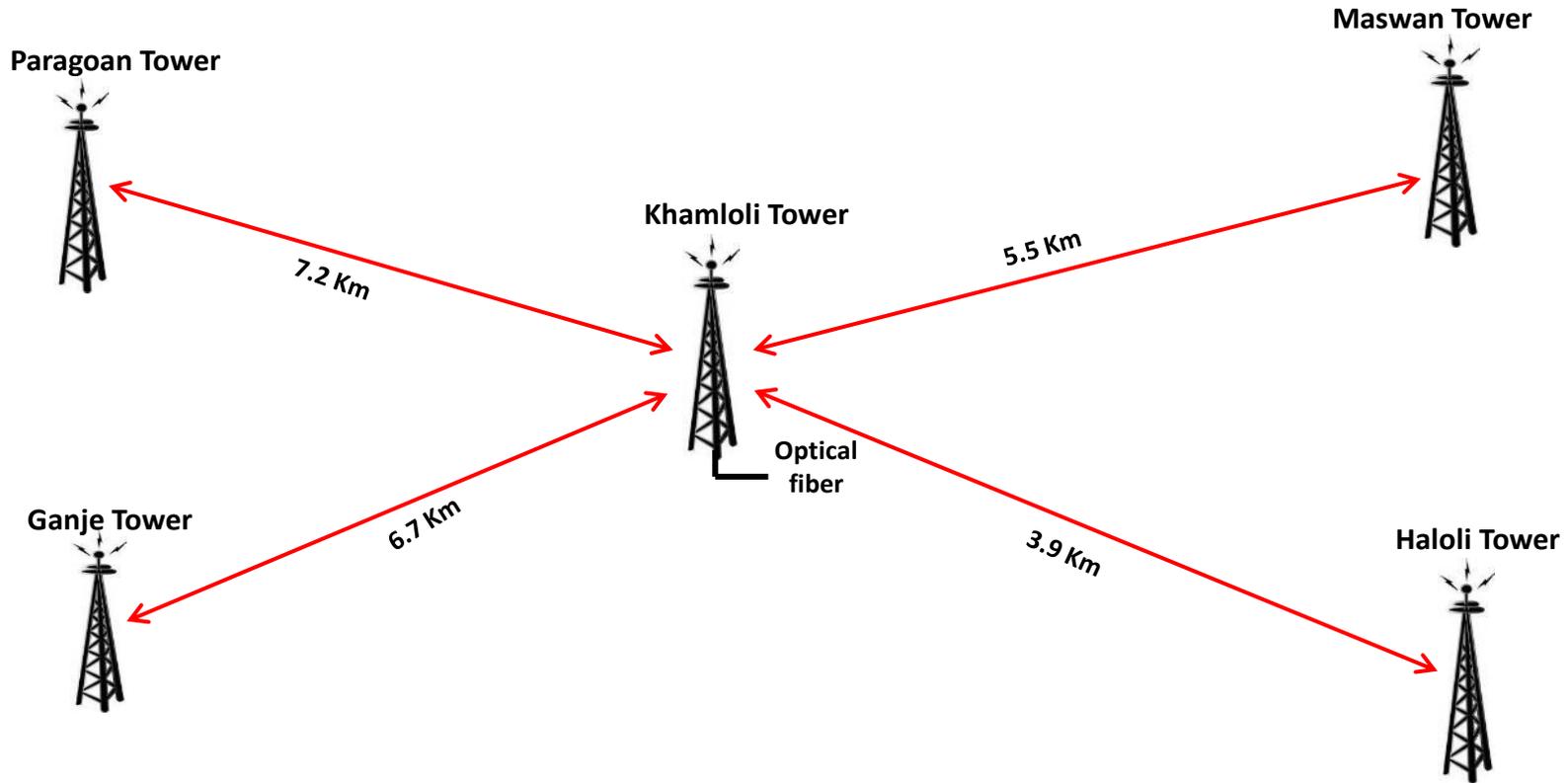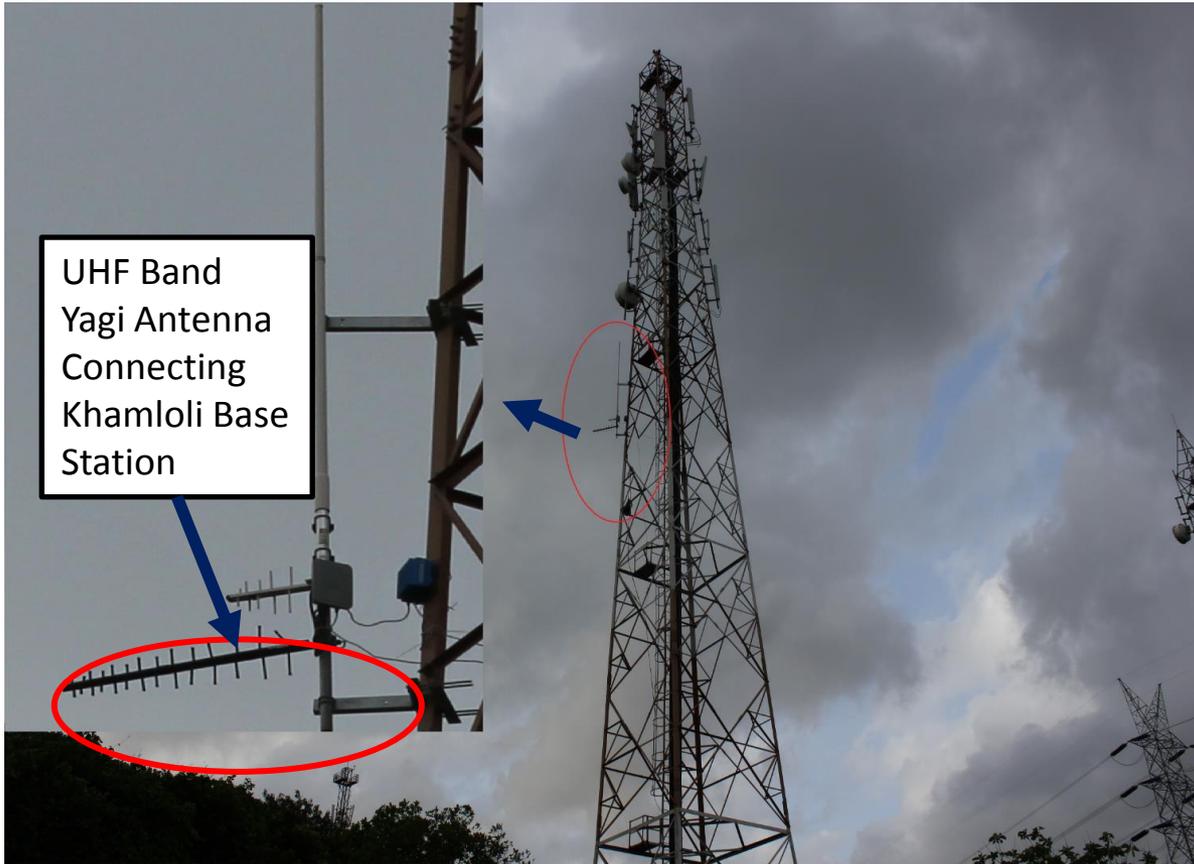
GANJE TOWER

Multi-Hop UHF TV Band Link

Khamloli Tower

2.5 Km

First Hop

Tower at Dhuktan Hill

Optical fiber

10 m
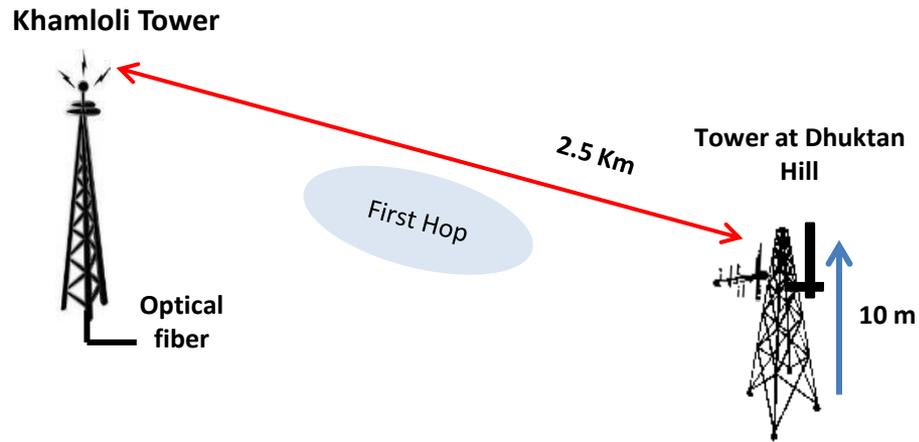
UHF Band Yagi Antenna: for the First Hop
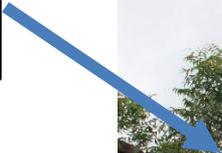
UHF Band Omni Antenna: for the Second Hop

Outdoor boxes for Adaptor, PoE, LAN Cable, Switch

TVWS Radio for the Antennas
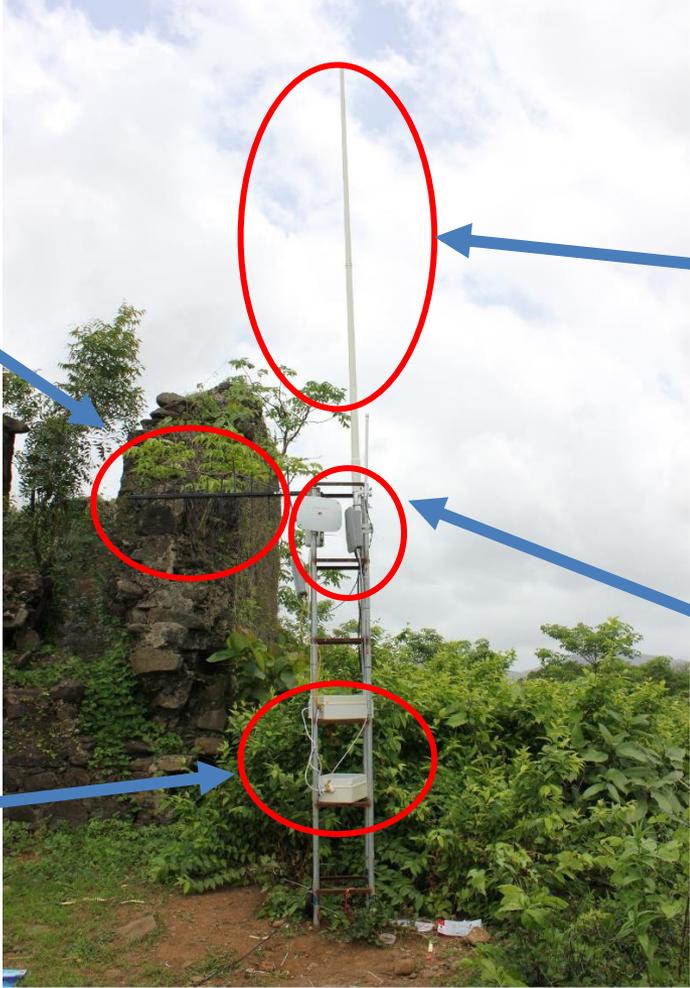
Tower at Dhuktan Hill

Multi-Hop UHF TV Band Link

Khamloli Tower

2.5 Km

First Hop

Optical fiber

Tower at Dhuktan Hill

10 m

Second Hop

1.2 Km
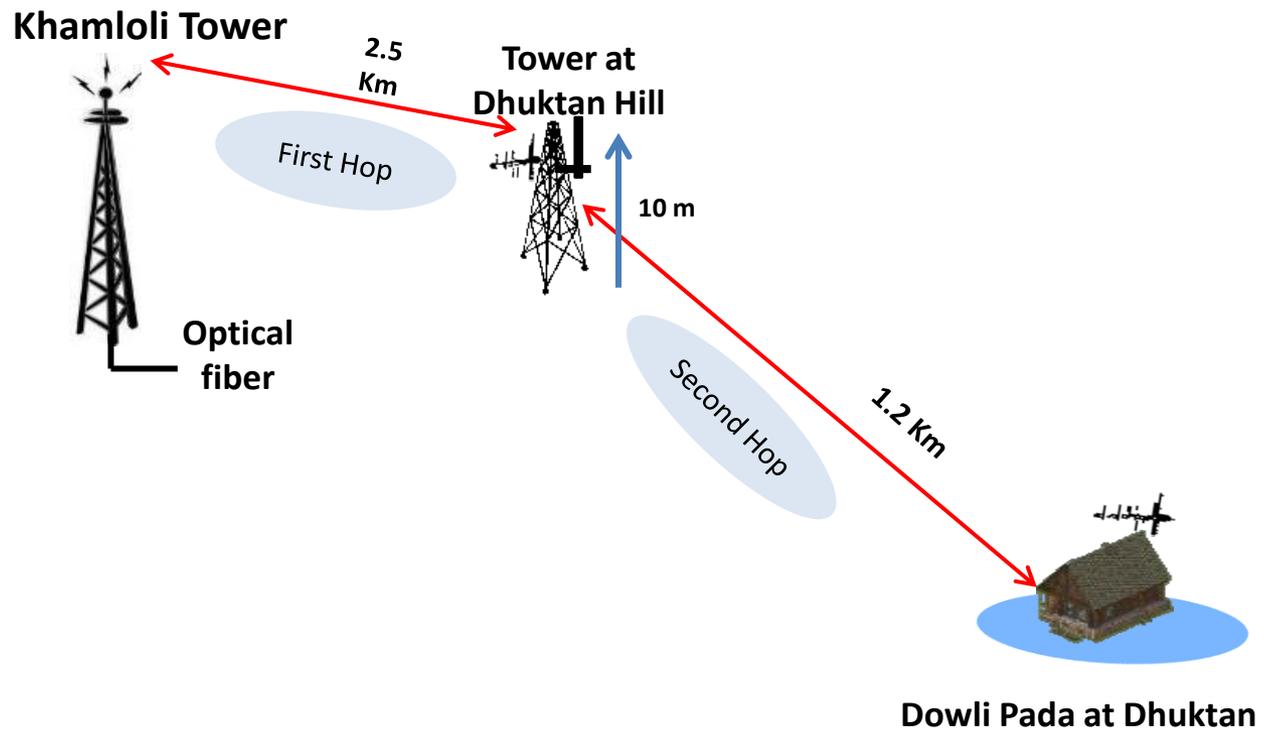
Dowli Pada at Dhuktan

UHF Band Yagi Antenna: Two hops away from Khamloli Base Station

Wi-Fi AP for Hot Spot

Dowli Pada at Dhuktan

Point to point TV Band Links Backhauling Wi-Fi APs

Khamloli Tower

Optical
fiber

500 m

**Khamloli
Village**

Outside view

TV UHF Band Yagi Antenna
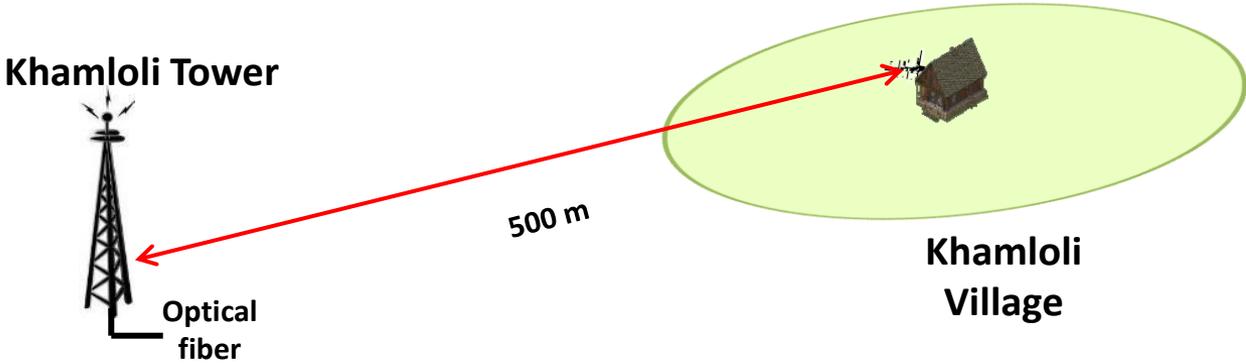
CPE 1 at Khamloli

TV UHF Band CPE

Wiring Box

WiFi AP 1
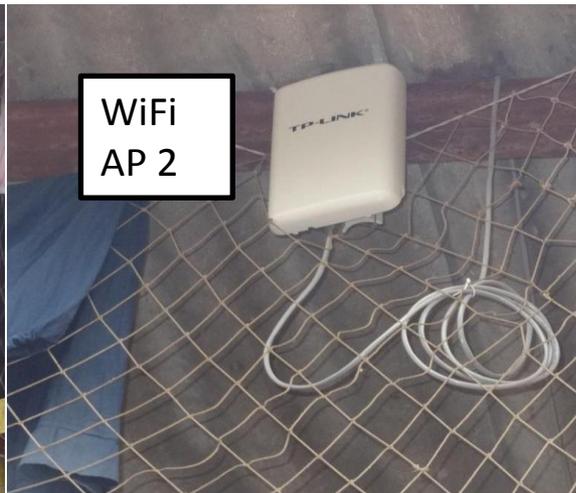
WiFi AP 2

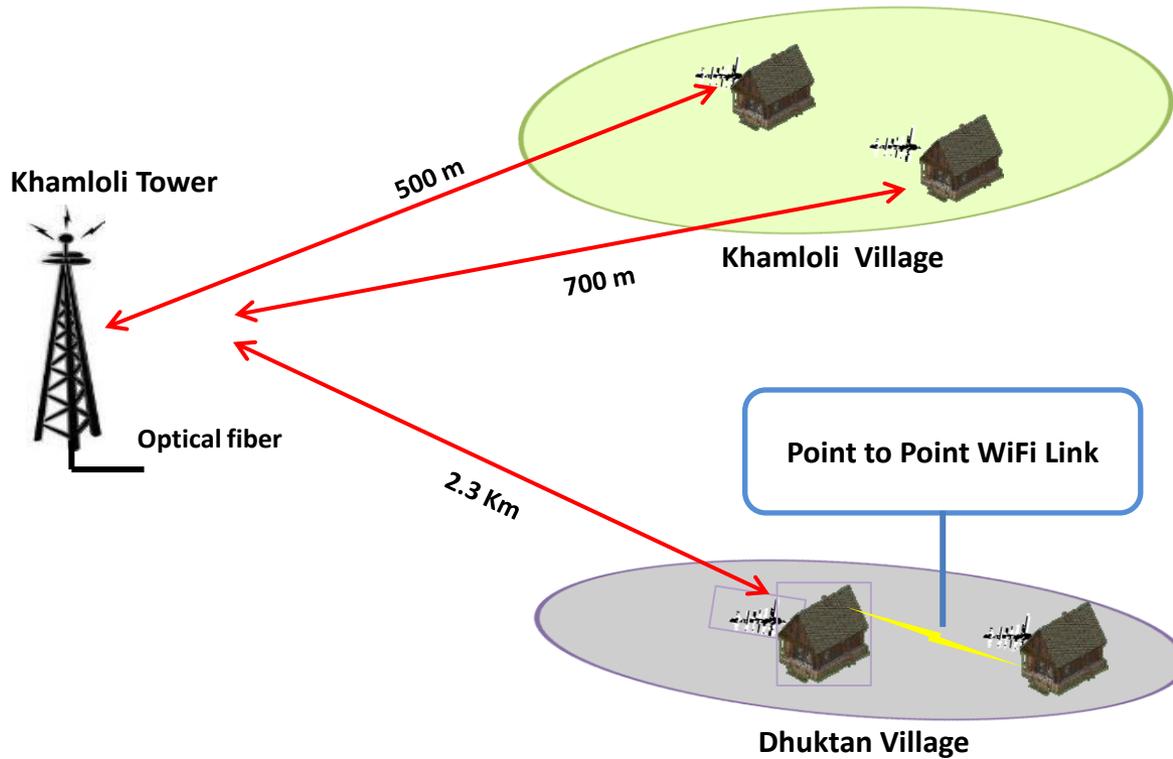# Point to point TV Band Links Backhauling Wi-Fi APs

Khamloli Tower

500 m

700 m

Khamloli Village

Optical fiber
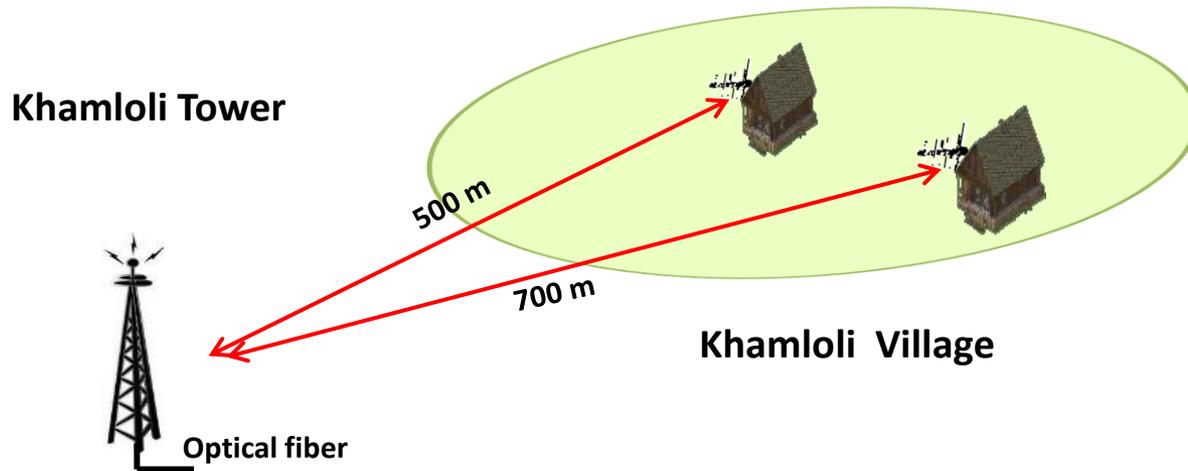
TV UHF Band CPE

WiFi AP

CPE 2 at Khamloli

Point to point TV Band Links Backhauling Wi-Fi APs

Khamloli Tower

Khamloli Village

500 m

700 m

Optical fiber

2.3 Km

Point to Point WiFi Link
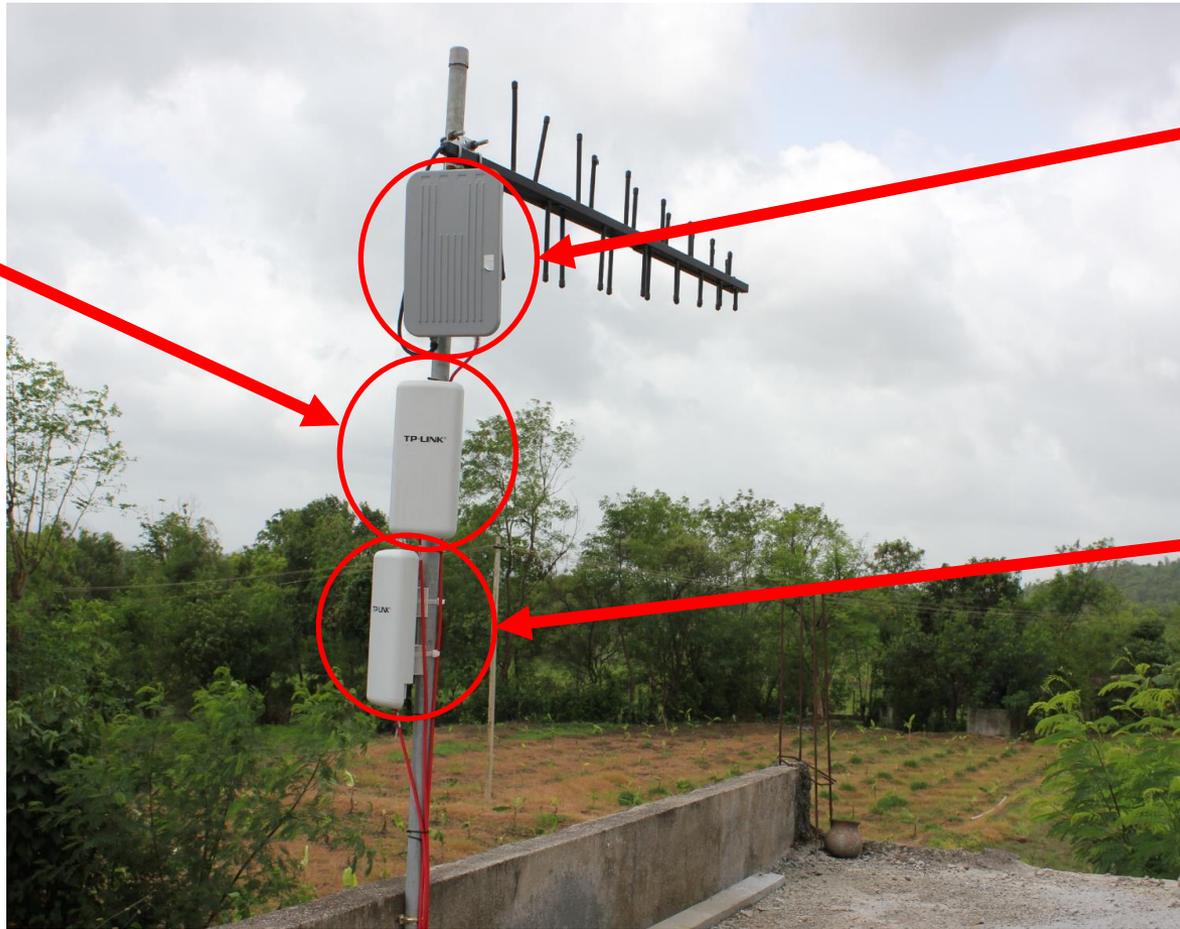
Dhuktan Village

Wi-Fi AP for Point to Point Link to Dhuktan Gram Panchayat

TVWS Radio with UHF Band Yagi Antenna

Wi-Fi AP for Creating Hot Spot

CPE at Dhuktan Village

Kiosk at
Dhuktan
(Set up by IIT
Bombay and
PUKAR)

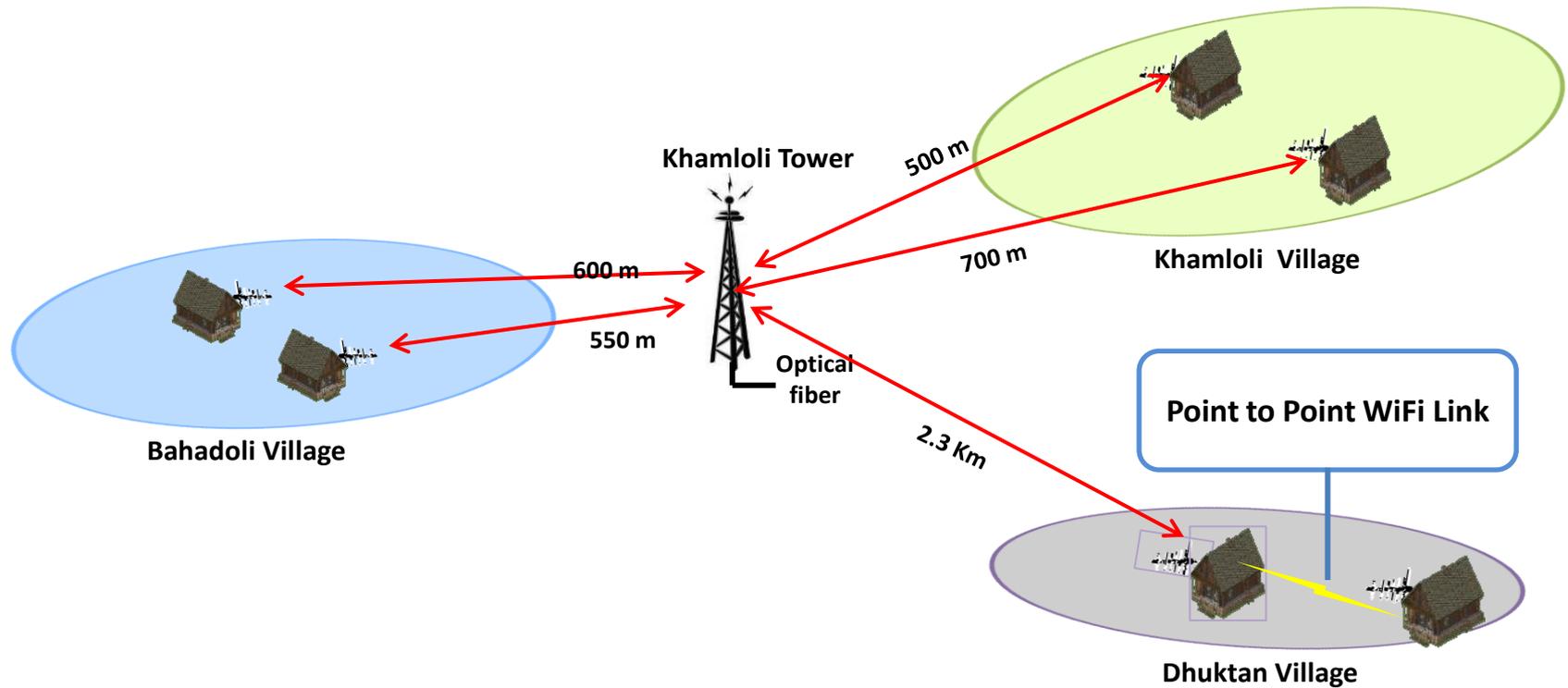# Point to point TV Band Links Backhauling Wi-Fi APs
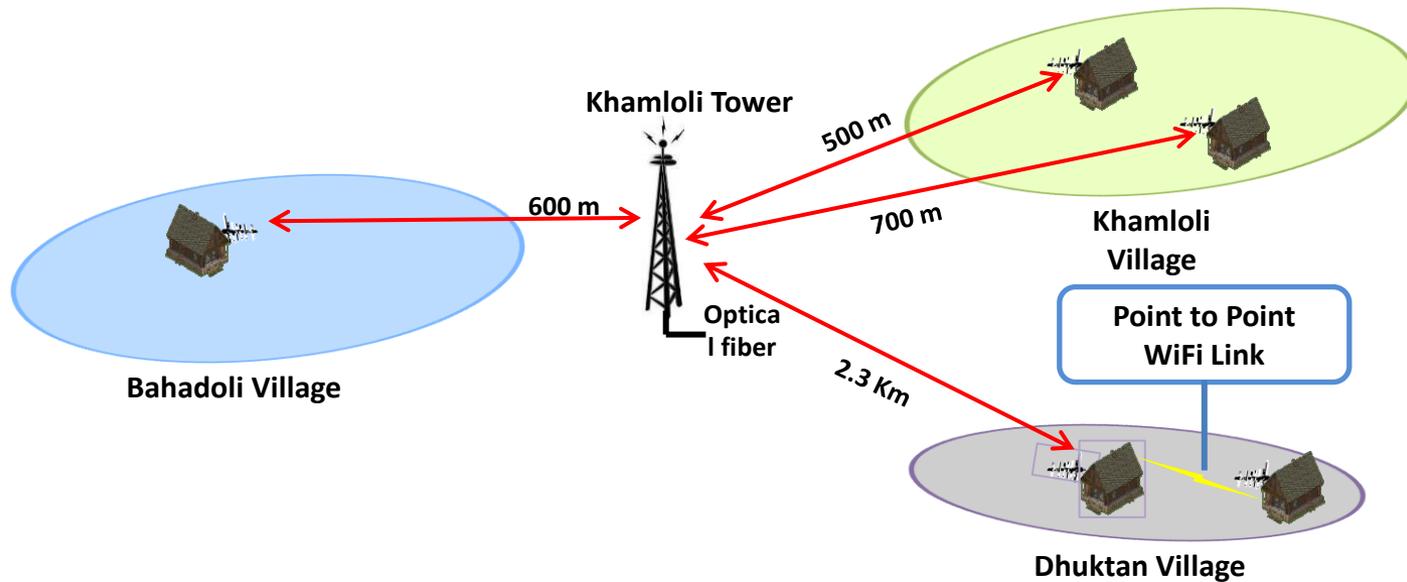
UHF Band Antenna Connected to Khamloli Base Station

CPE 1 at Bahadoli Village

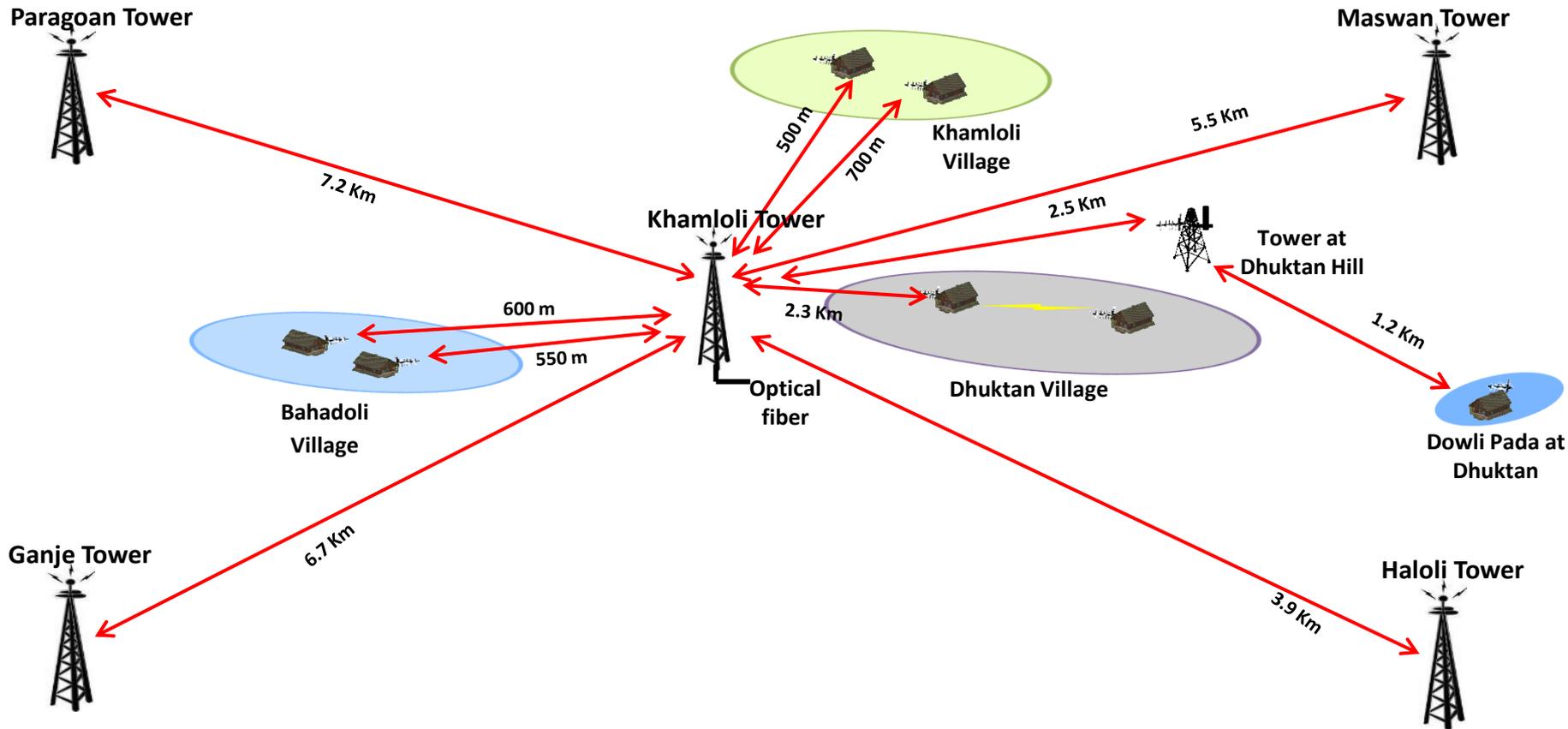# Point to point TV Band Links Backhauling Wi-Fi APs

Khamloli Tower

500 m

Khamloli Village

600 m

700 m

550 m

Optical fiber

Bahadoli Village

2.3 Km

Point to Point WiFi Link

Dhuktan Village

UHF Band Antenna Connected to Khamloli Base Station

CPE 2 at Bahadoli Village

Kiosk at Bahadoli (Set up by IIT Bombay and PUKAR)

Network Topology of UHF TV Band Pilot at Palghar

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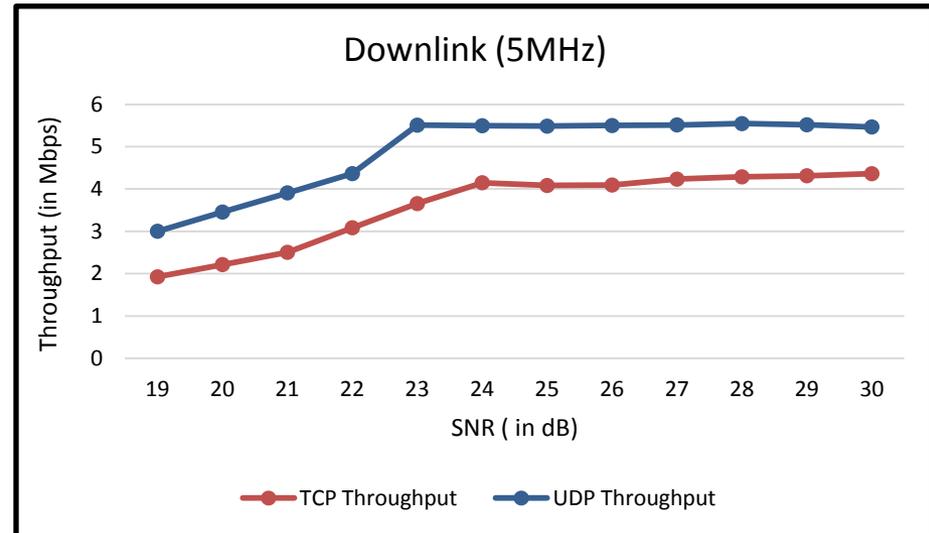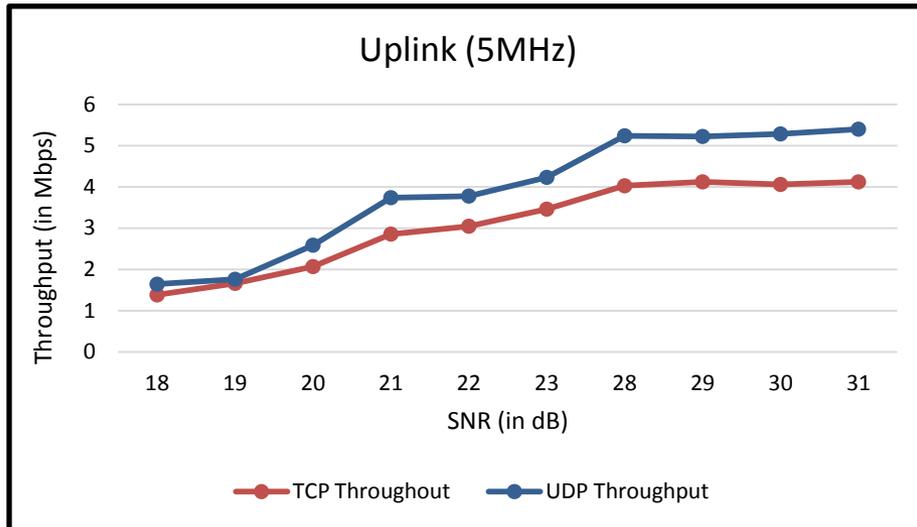
Elevation profile between Dhuktan and Khamloli

| Min, Avg, Max | Elevation: 5, 14, 30 m | | | |
| Range Totals: | Distance: 2.28 km | Elev Gain/Loss: 25.4 m, -25 m | Max Slope: 4.2%, -5.3% | Avg Slope: 1.8%, -2.8% |

Khamloli   Dhuktan

Base Station: Khamloli (at 30m)
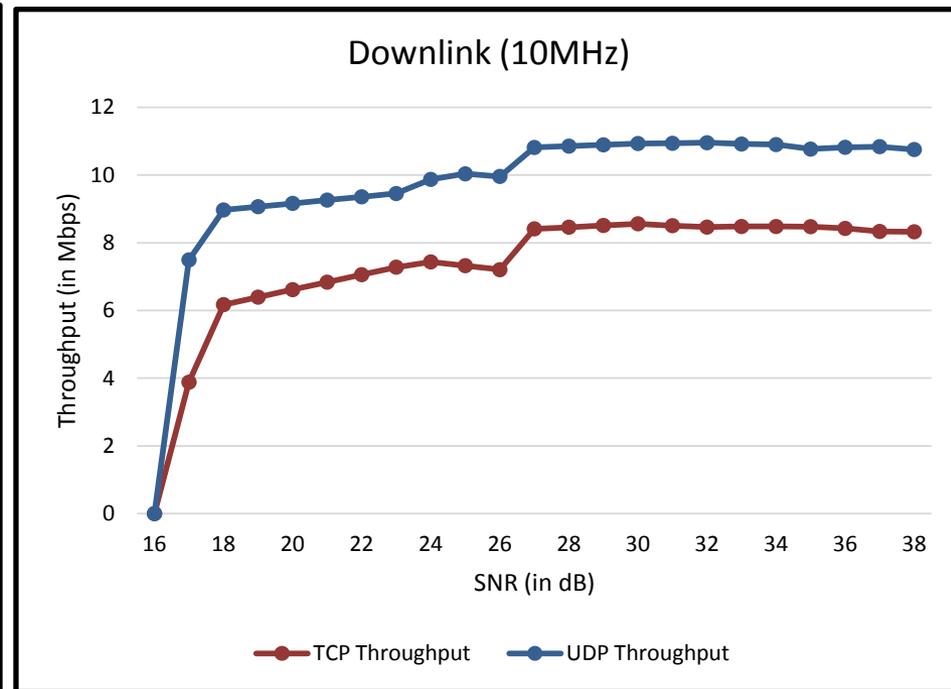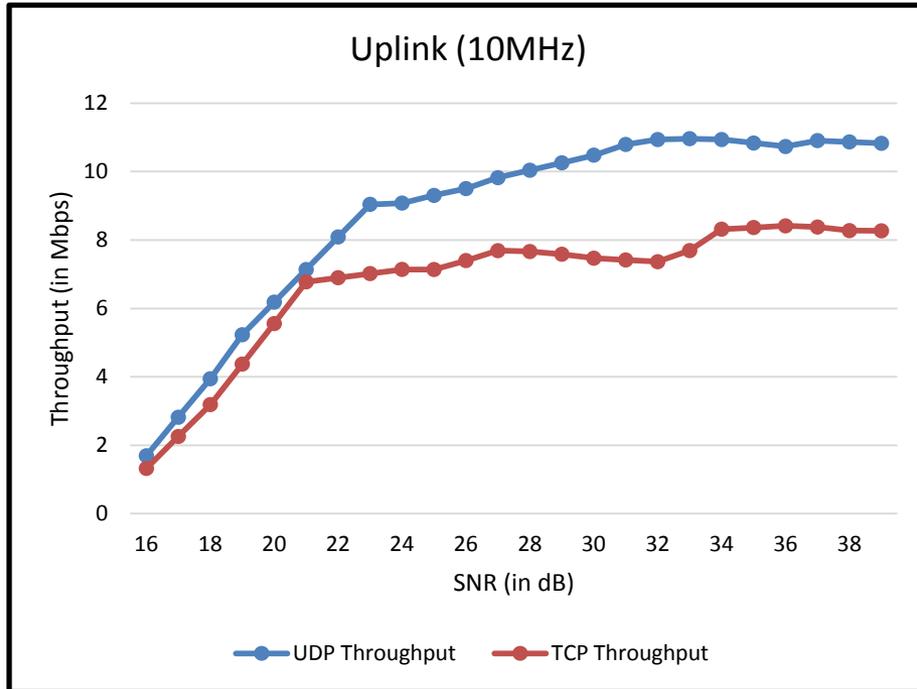**Client: Dhuktan (at 3m)**
Distance between base station and client: 2.3 km

Throughput vs SNR (Bandwidth = 5 MHz) at Dhuktan

Transmit Power Range = 0 – 27 dBm
Theoretical SNR Range (Okumara Hata Path Loss Model)= 16 - 43 dB
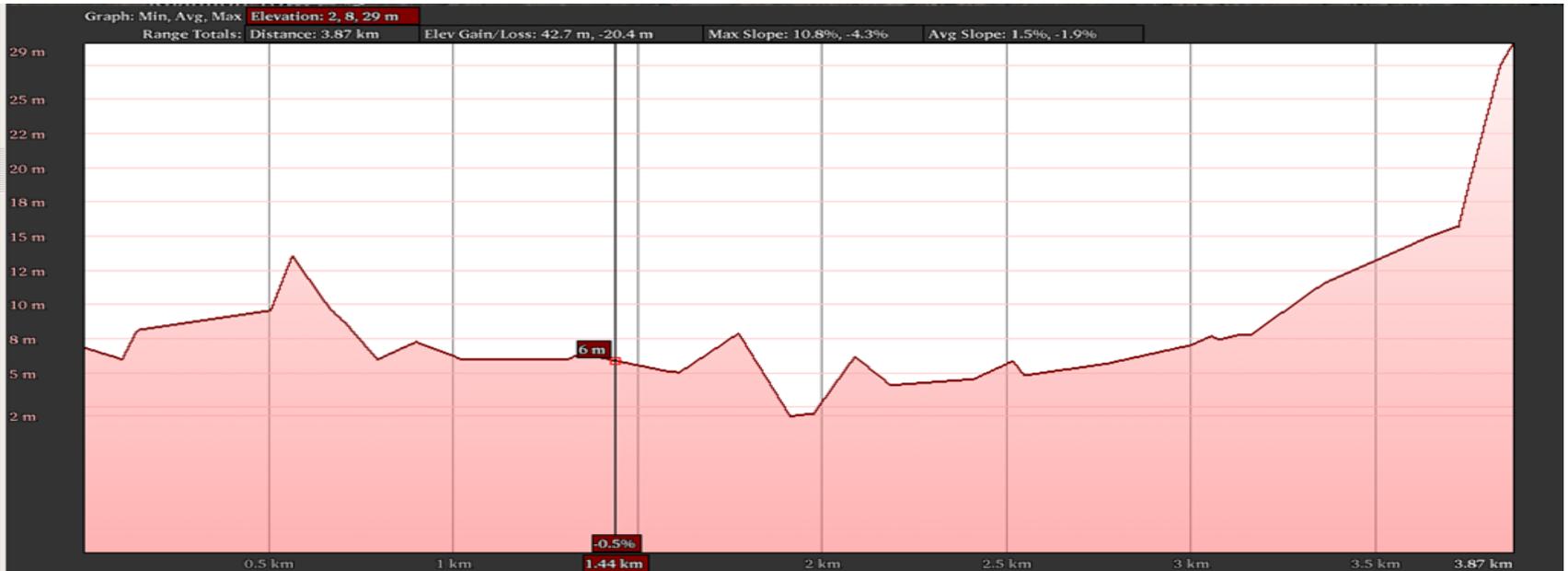
Throughput vs SNR (Bandwidth = 10MHz) at Dhuktan

Transmit Power Range = 0 – 27 dBm
Theoretical SNR Range (Okumara Hata Path Loss Model)= 16 - 43 dB

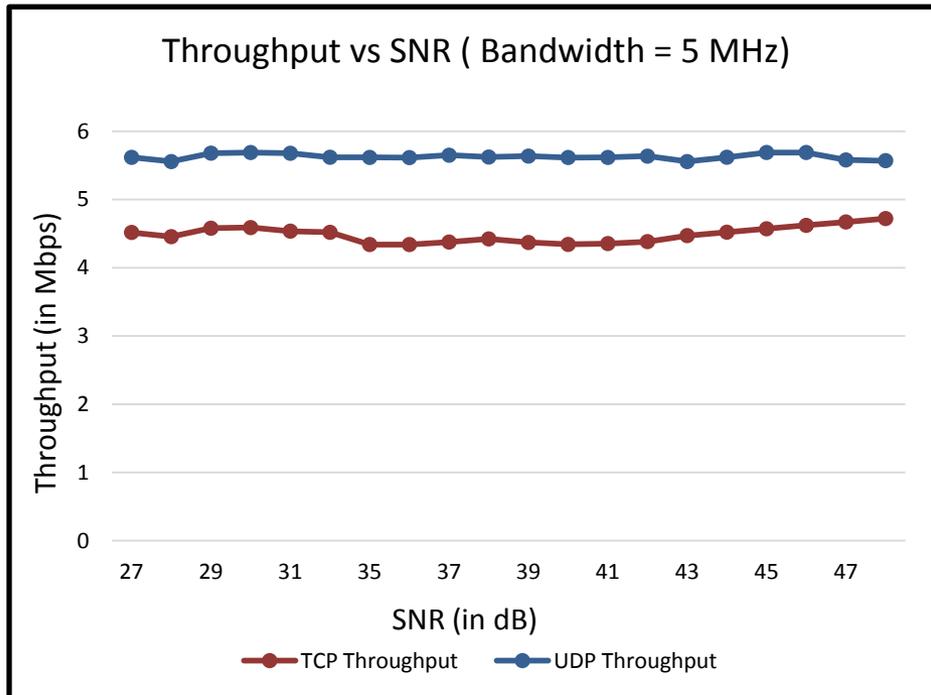# Elevation profile between Haloli and Khamloli

Khamloli   Haloli

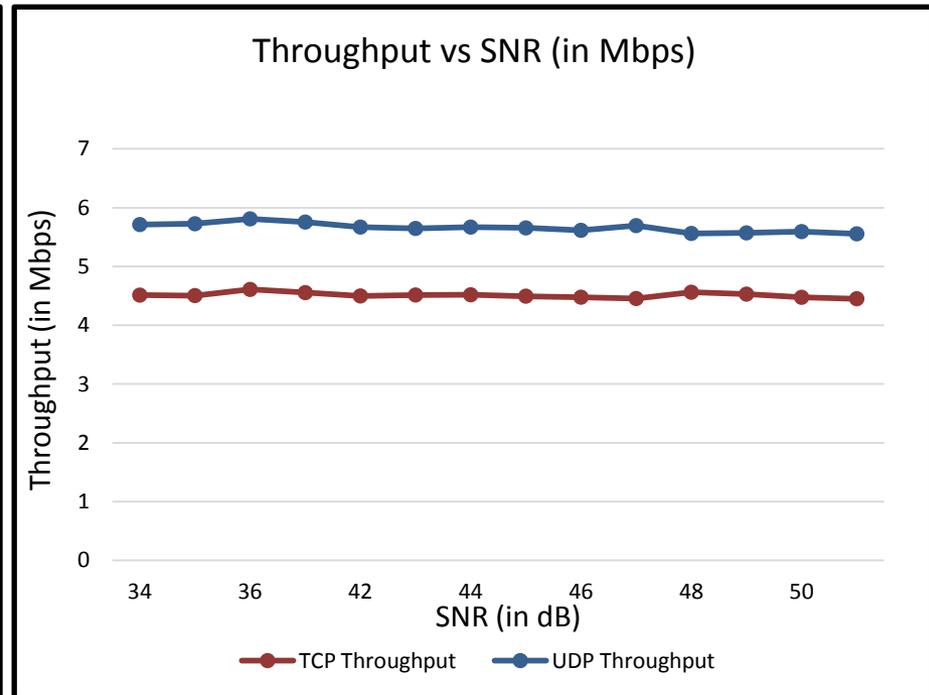**Base Station: Khamloli (at 30m)**
Client: Haloli (at 30m)
Distance between base station and client: 3.9 km

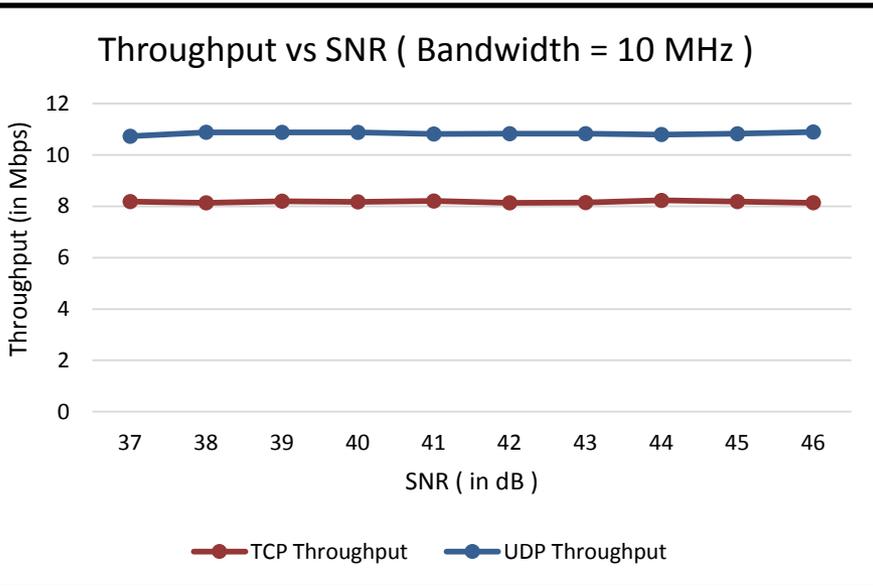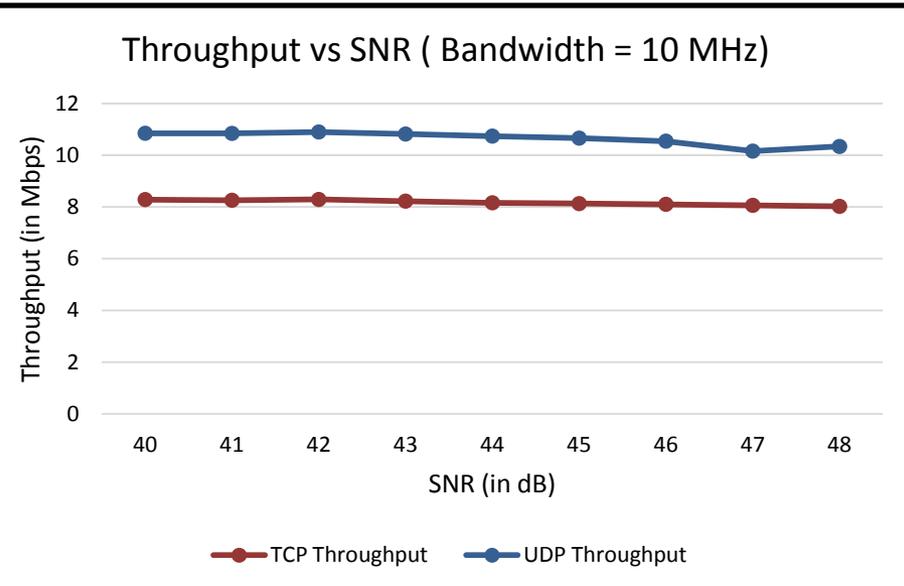# Throughput vs SNR (Bandwidth = 5 MHz) at Haloli

Transmit Power Range = 0 – 27 dBm
Constant throughput achieved due to constant MCS setting - 64 QAM

Throughput vs SNR (Bandwidth = 10 MHz) at Haloli

Uplink

Throughput vs SNR (Bandwidth = 10 MHz)

Downlink

Throughput vs SNR (Bandwidth = 10 MHz)

Transmit Power Range = 0 – 27 dBm
Constant throughput achieved due to constant MCS setting - 64 QAM

Elevation profile between Pargaon and Khamloli

Khamloli   Pargaon
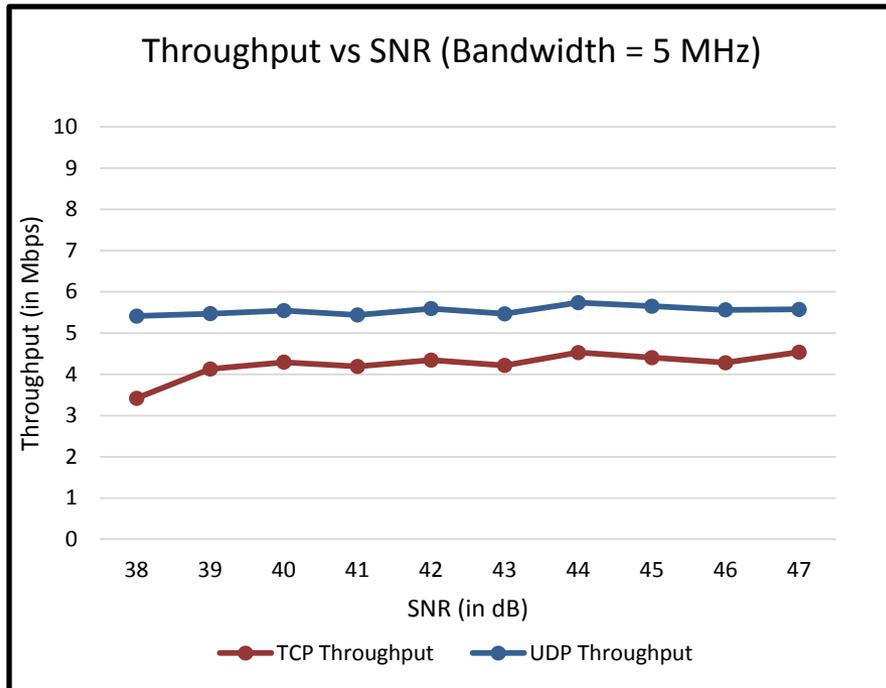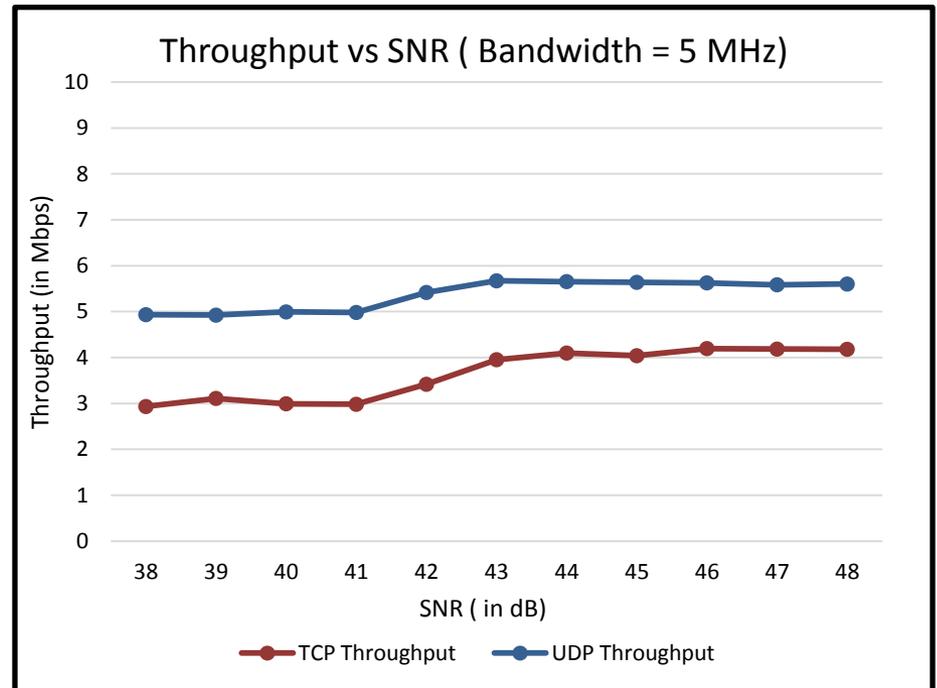
Base Station: Khamloli (at 30m)
Client: Pargaon(at 30m)
Distance between base station and client: 7.2 km

Throughput vs SNR (Bandwidth = 5 MHz) at Pargaon

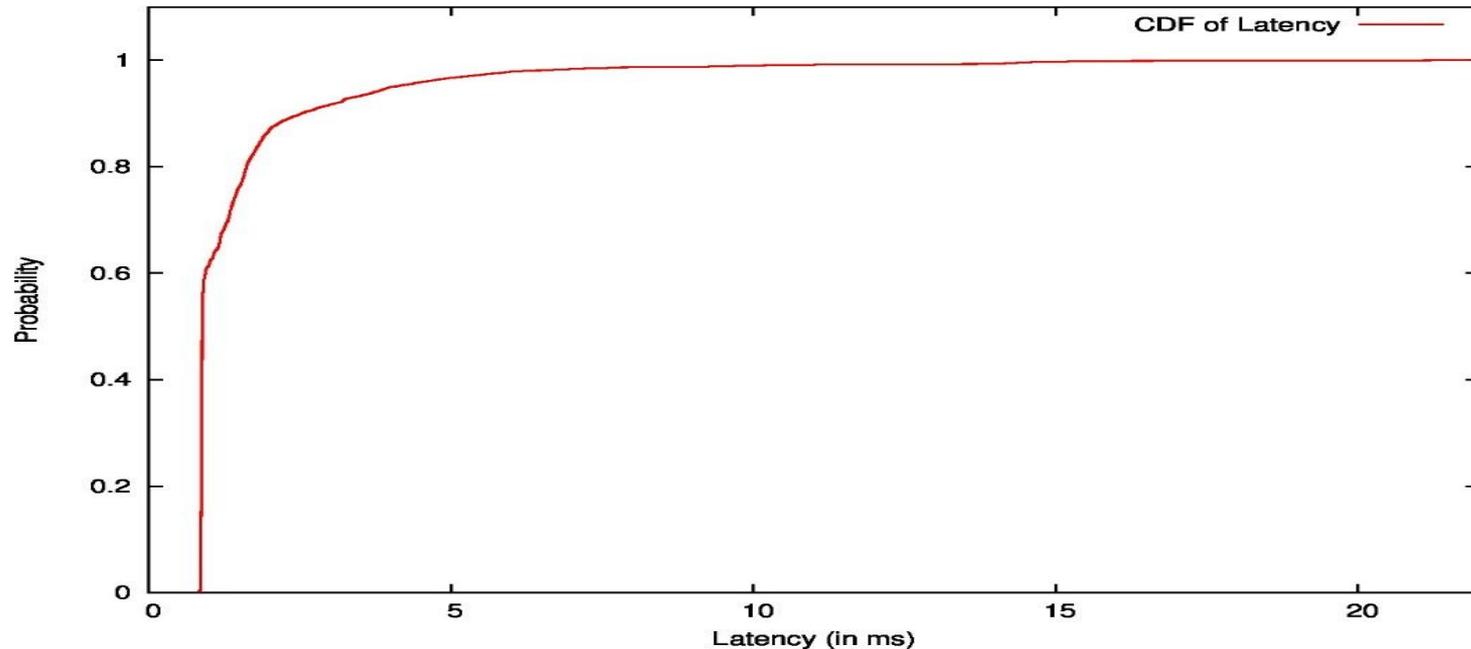Uplink — Throughput vs SNR (Bandwidth = 5 MHz)

Downlink — Throughput vs SNR (Bandwidth = 5 MHz)

Transmit Power Range = 0 – 27 dBm
Constant throughput achieved due to constant MCS setting - 64 QAM

CDF of Latency at Ganje Node
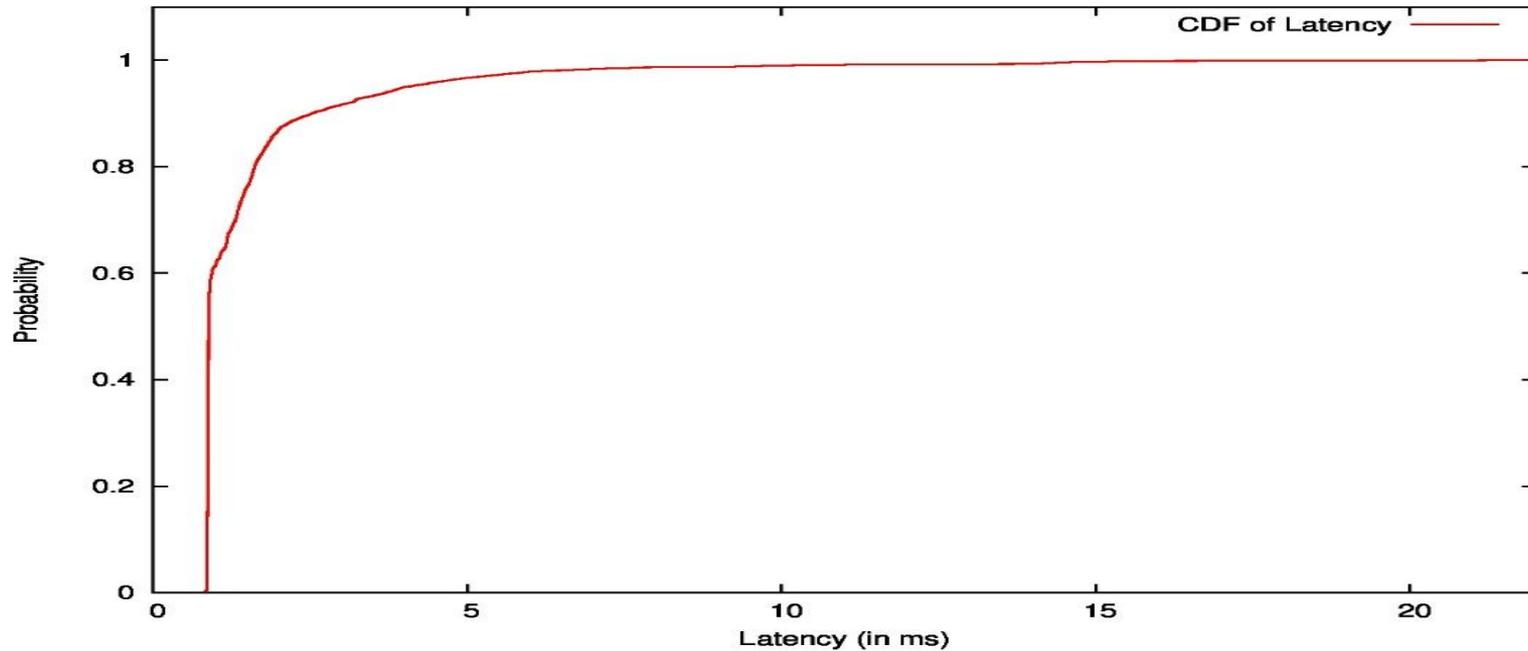## (BW=5Mhz, Tx Power= 27dBm)

Base Station: Khamloli (at 30m)
Client: Ganje (at 30m)
Distance between base station and client: 6.9 km

CDF of Latency at Dhuktan Node
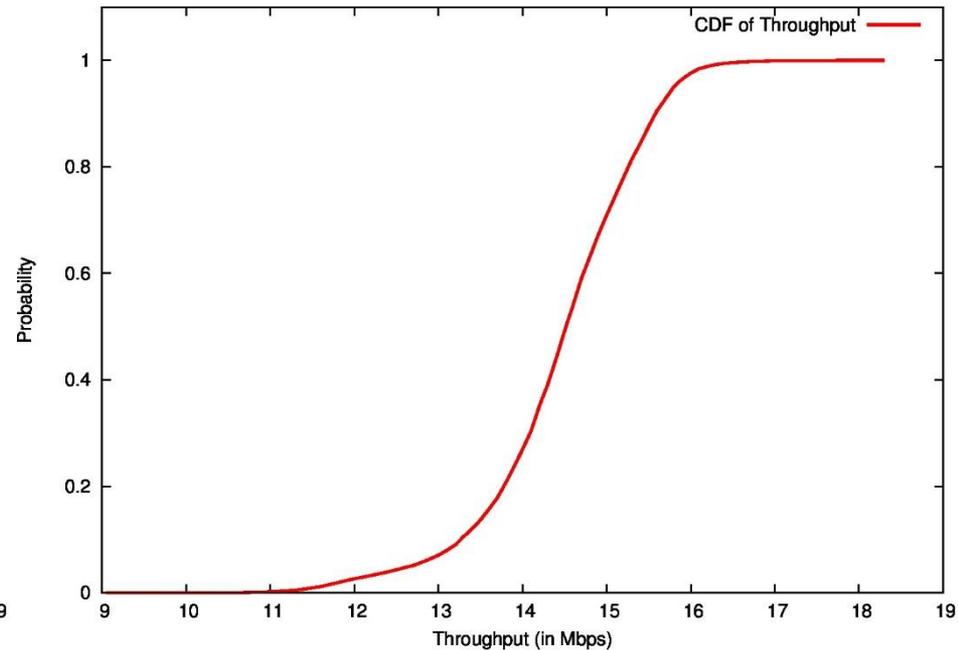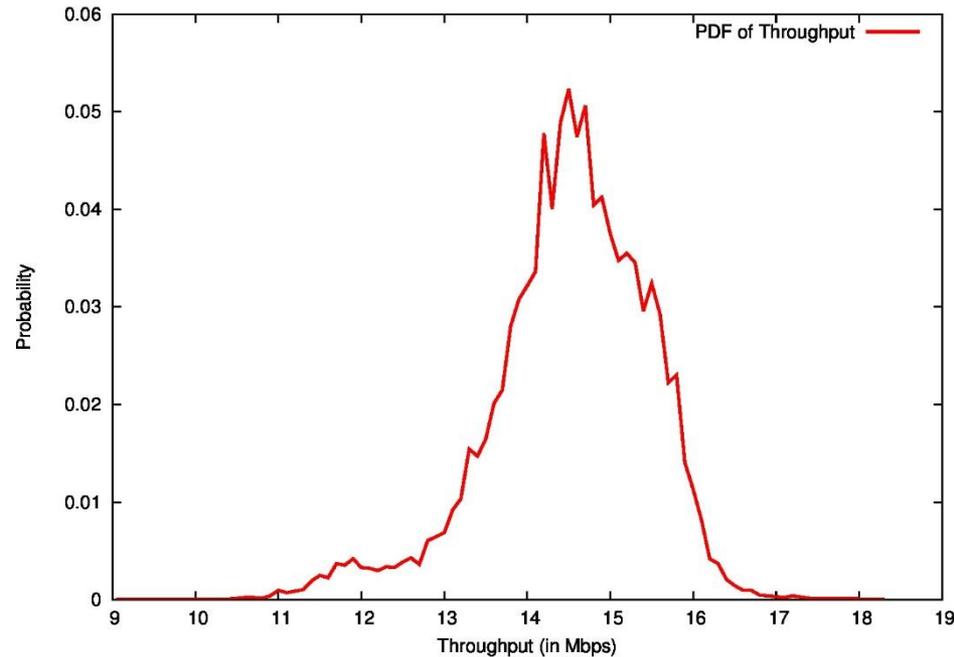## (BW=20Mhz, Tx Power= 27dBm)

Base Station: Khamloli (at 30m)
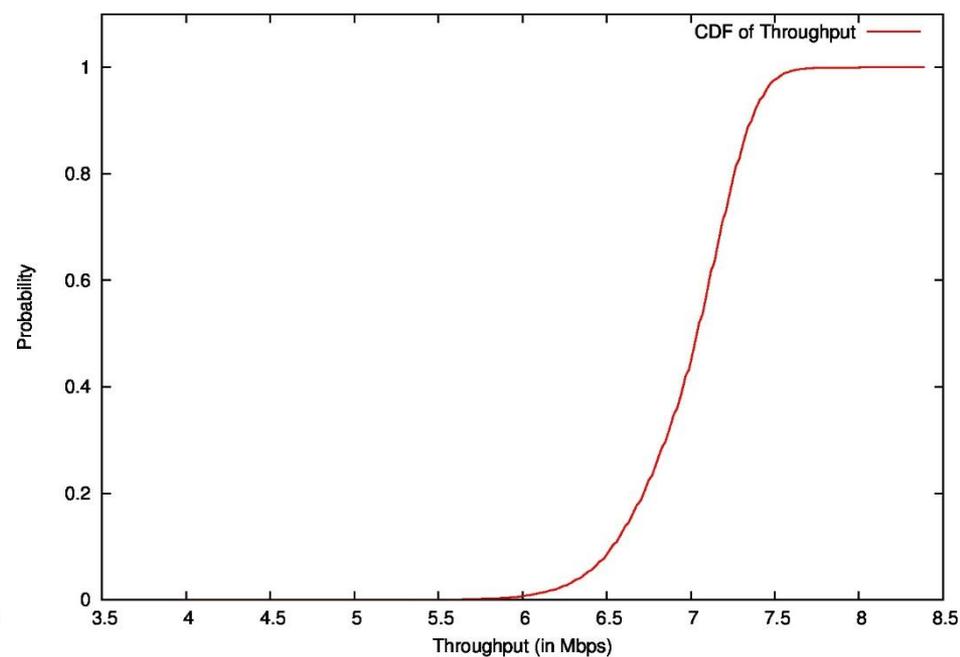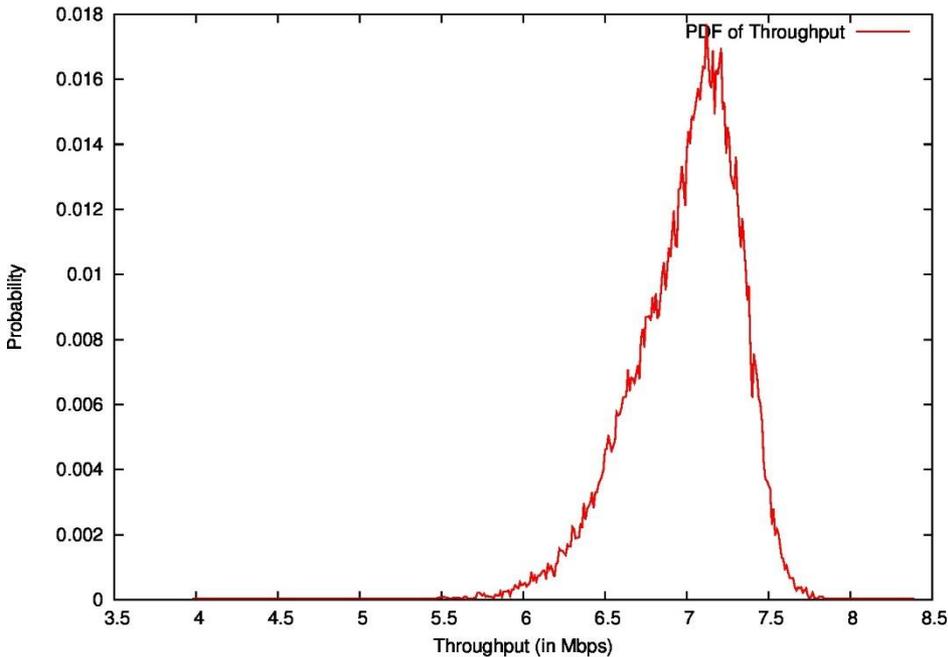**Client: Dhuktan(at 3m)**
Distance between base station and client: 2.3 km

PDF & CDF of the UDP Throughput at Dhuktan Node

Base Station: Khamloli (Height=30m)
Client: Dhuktan (Height=3m)
Distance between base station and client: 2.3 km

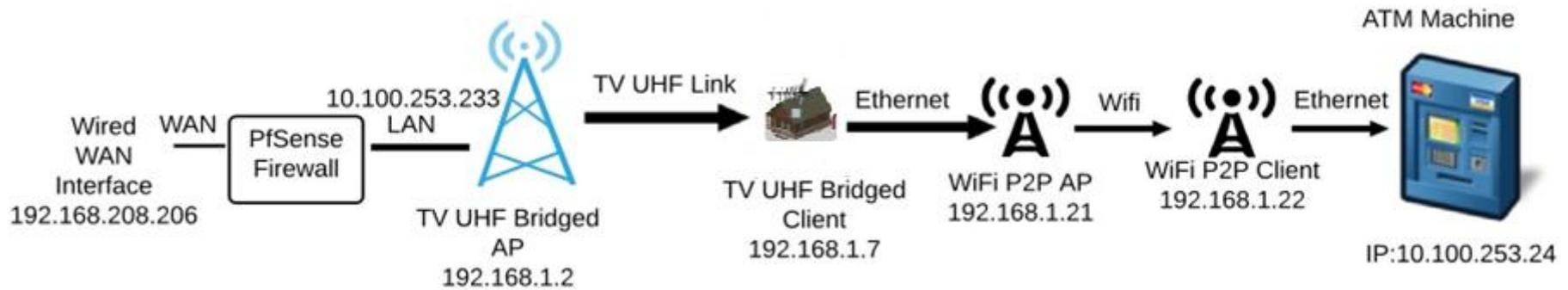# PDF & CDF of the UDP Throughput at Ganje Node (BW=5MHz, Tx Power=27dBm)

Base Station: Khamloli (at 30m)
Client: Pargaon(at 30m)
Distance between base station and client: 7.2 km

Network Configuration for ATM at Dhuktan Gram Panchayat

Summary of Test-Bed

- Test-Bed
  - 10 WiFi hotspots backhauled using TVWS radios
  - One two hop link
  - 4 point to point near LoS links
  - 60 Tablets with villagers
  - Two kiosks
  - Secure VPN for ATM deployment

- Results
  - UDP throughput of 11 Mbps on 10 MHz bandwidth over ~3 km Non LoS
  - Latency of 1 ms

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Conclusions

- About 100 MHz unused in UHF band in India
- Primary broadband is the crying need
  - Affordable broadband can be provided using TV white spaces
- Results of the test-bed encouraging
- Future Directions
  - Multi-operator co-existence
  - SDN enabled policy based radio

Thank You!