Connecting the Unconnected in 5G and Beyond

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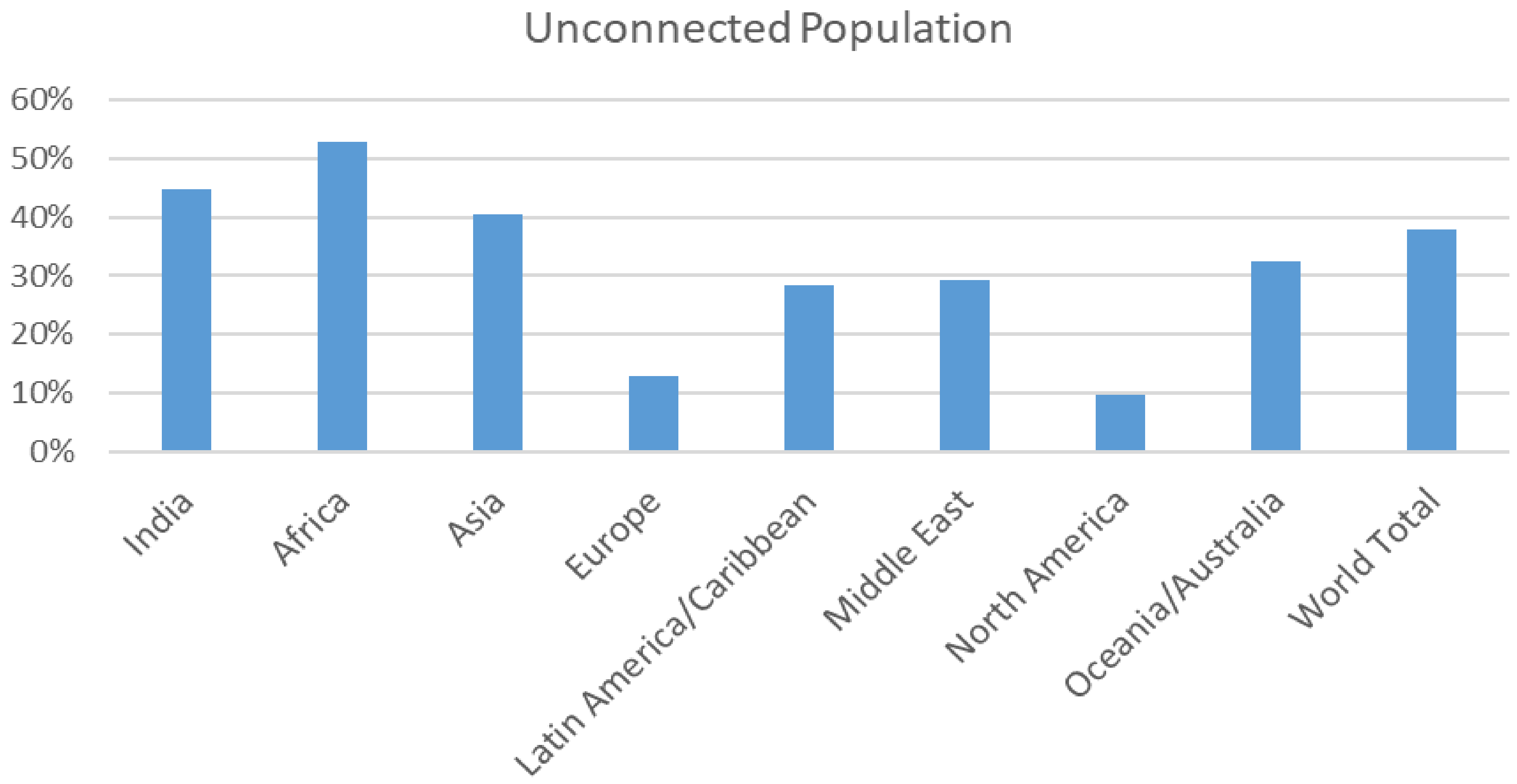
Agenda

- Status of Internet and Broadband Connectivity
- Key Challenges to Rural Broadband Connectivity
- Rural Broadband Requirements
- Rural Broadband Initiatives
- 5G Flow – Realizing Frugal 5G

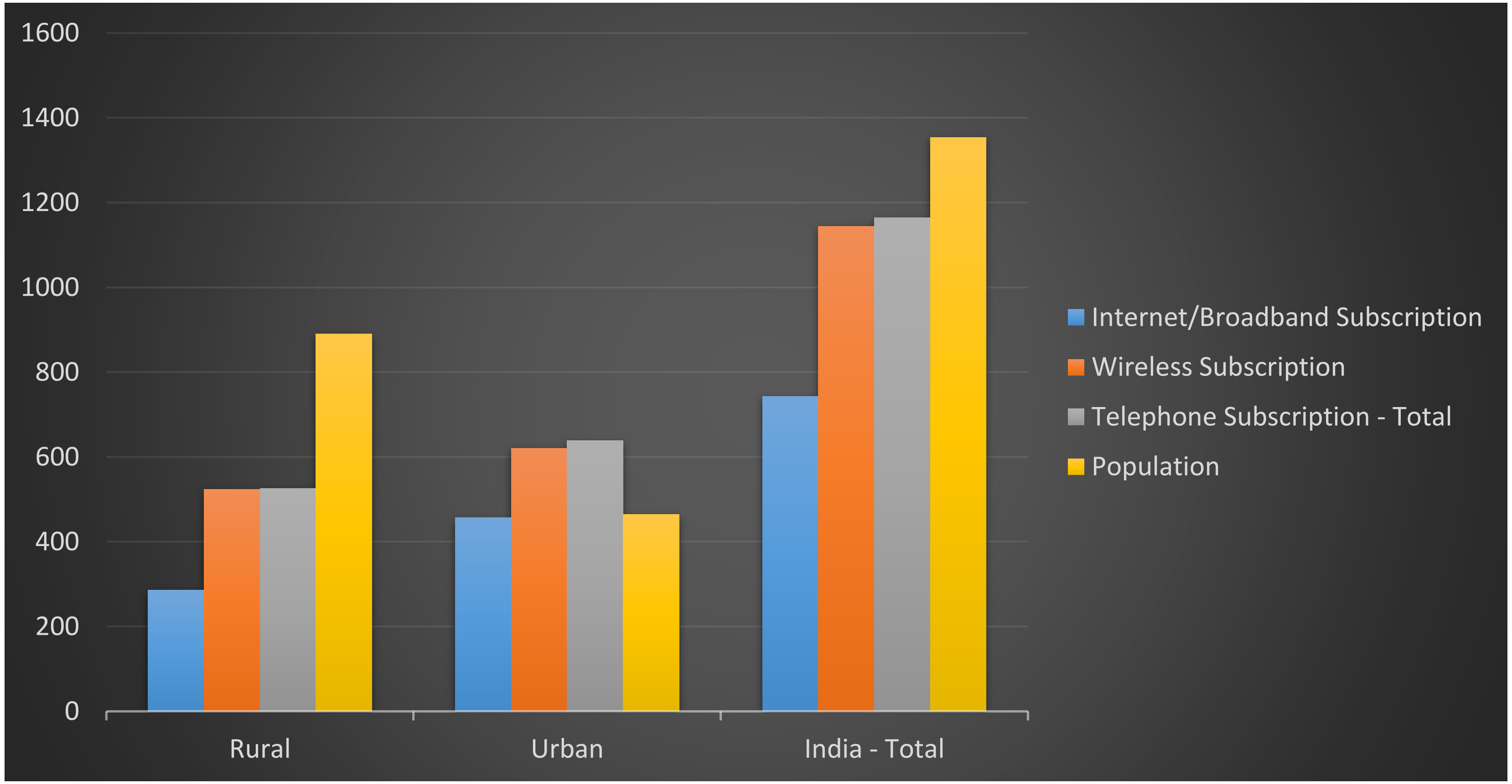
Internet Connectivity Status: Worldwide



~40% of the world population is unconnected - Majority in Developing World and in Rural Areas

Source: https://www.internetworldstats.com/ - October 2020

Internet/Broadband Penetration Status: India

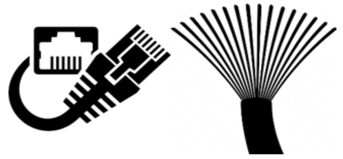


~610 million people (45%) do not have Broadband/Internet access

Source: Telecom Regulatory Authority India, October 2020 Report

Internet/Broadband Access- How is it enabled?

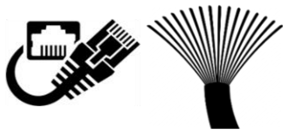
Developed Countries



Mostly enabled through wired communication infrastructure, Fiber and DSL

Developing Countries

Cellular Technology - Primary broadband access mechanism



Fiber/DSL Infrastructure - Inadequate

Challenges in using Cellular Technology in Rural Areas

1. Existing/Emerging Cellular Technology Standards

- Focused on urban usage scenarios
  - Key Targets for 5G : 20 Gbps rate, 1 ms latency, 500 km/h mobility
- Challenges and Characteristics of Rural Connectivity
  - Not factored in specification and design
- Variations in use cases across regions, countries, continents ignored

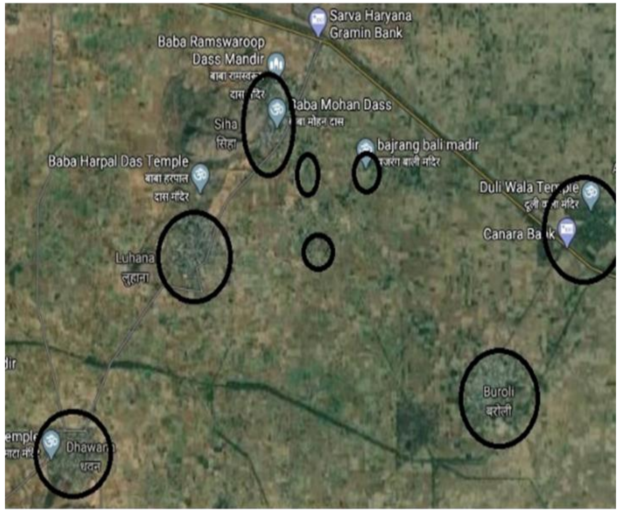
2. Operators Roll our networks in urban/semi-urban areas

- No compelling commercial reason for them to target rural areas

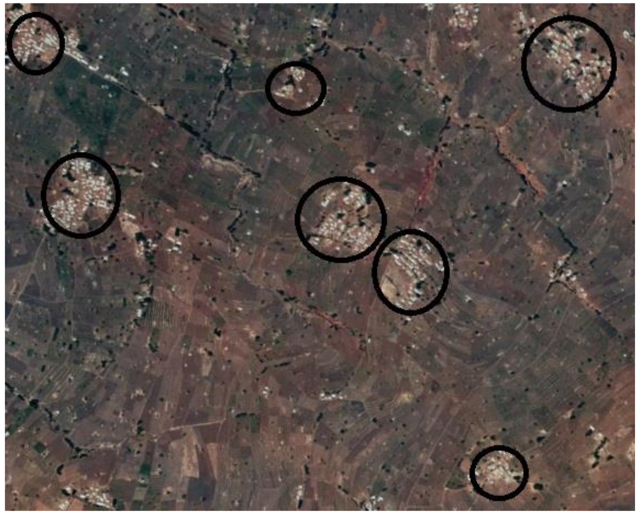
Connecting the Unconnected – Challenges

- Sparsely Populated (as shown in the figure)
  - Not typical to Africa or India
  - Other continents and countries similar
- Remote and Difficult to Reach Regions
  - Not all but a significant %
- High CAPEX & OPEX
  - Spectrum Cost
  - Cost of Backhaul

Rural Settlements



India



Ethiopia

Source: Google Earth
(Circles denote habited areas, Rest of the areas have no population)

Connecting the Unconnected – Challenges contd.

- Scarcity of Resources
  - Uninterrupted Electric Power Supply from the grid
- Low Average Revenue per user
- Access Constraints
  - Right of Way
- Challenges of Manageability
  - Unavailability of Trained Manpower
- Relevance of Content
  - Most Content on Internet is in English and a handful of other Languages

Rethinking 5G Requirements for Rural Areas

- Low cost Solution
  - Low Cost Backhaul Solutions
    - Wireless backhaul instead of Fiber
  - Lower Spectrum Cost
    - Unlicensed Spectrum wherever possible
- Limited Mobility Support
  - High-Speed Mobility Not Required
    - Small no of vehicles in Rural Areas
    - Slow moving vehicles
  - Fixed Access is the Key
- Large Coverage Area Support
- Energy Efficient Solution

Frugal 5G Networks (IEEE P2061)

Frugal 5G Networks (IEEE P2061)

Refers to the vision of providing broadband access to rural areas by addressing these requirements and challenges

Source: Khaturia M, Jha P and Karandikar A, "Connecting the Unconnected: Towards Frugal 5G Network Architecture and Standardization", IEEE Communication Standards Magazine, June 2020.

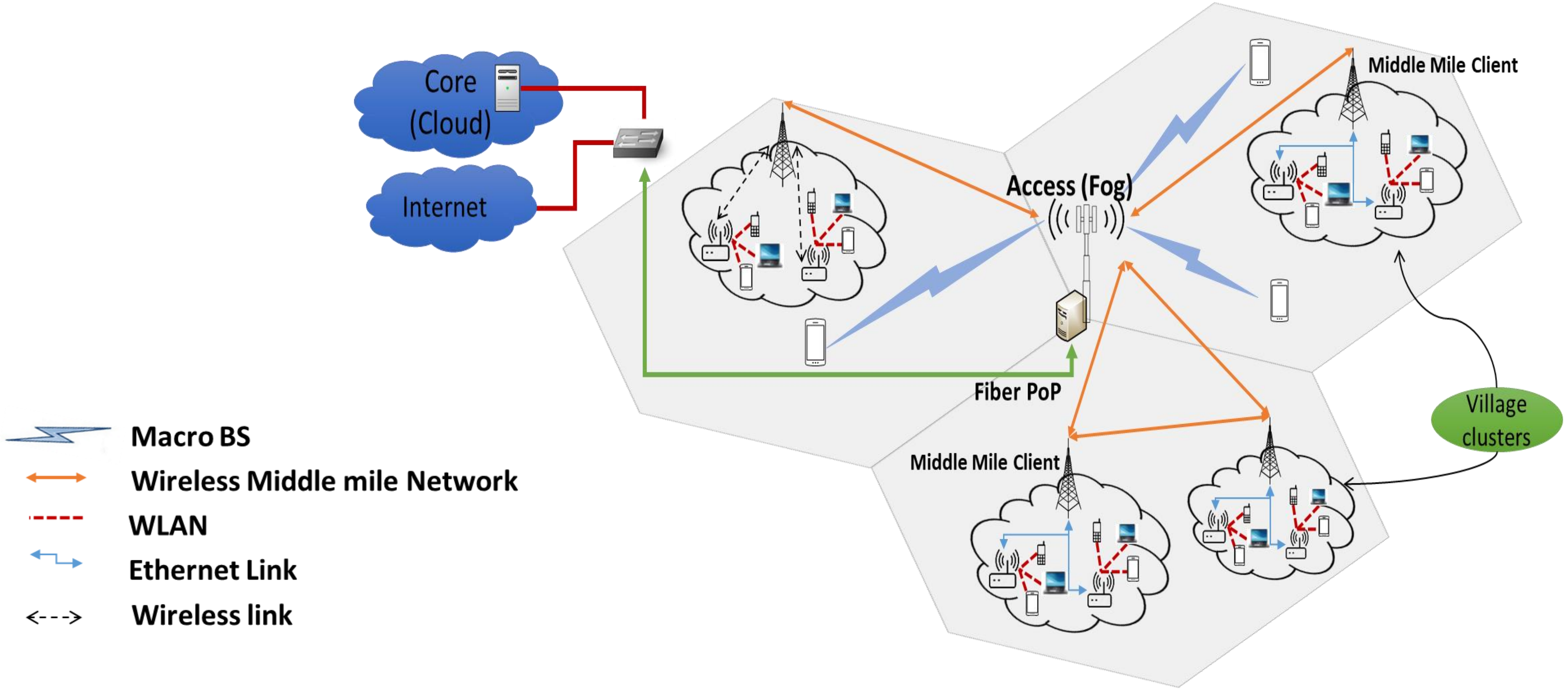
Network Architecture - Features

Large Coverage Area Cells to provide ubiquitous connectivity

Small Cells (WiFi Hotspots) as high speed access points

Wireless Middle Mile Network to backhaul data

Point to point wireless links to connect the nodes in villages



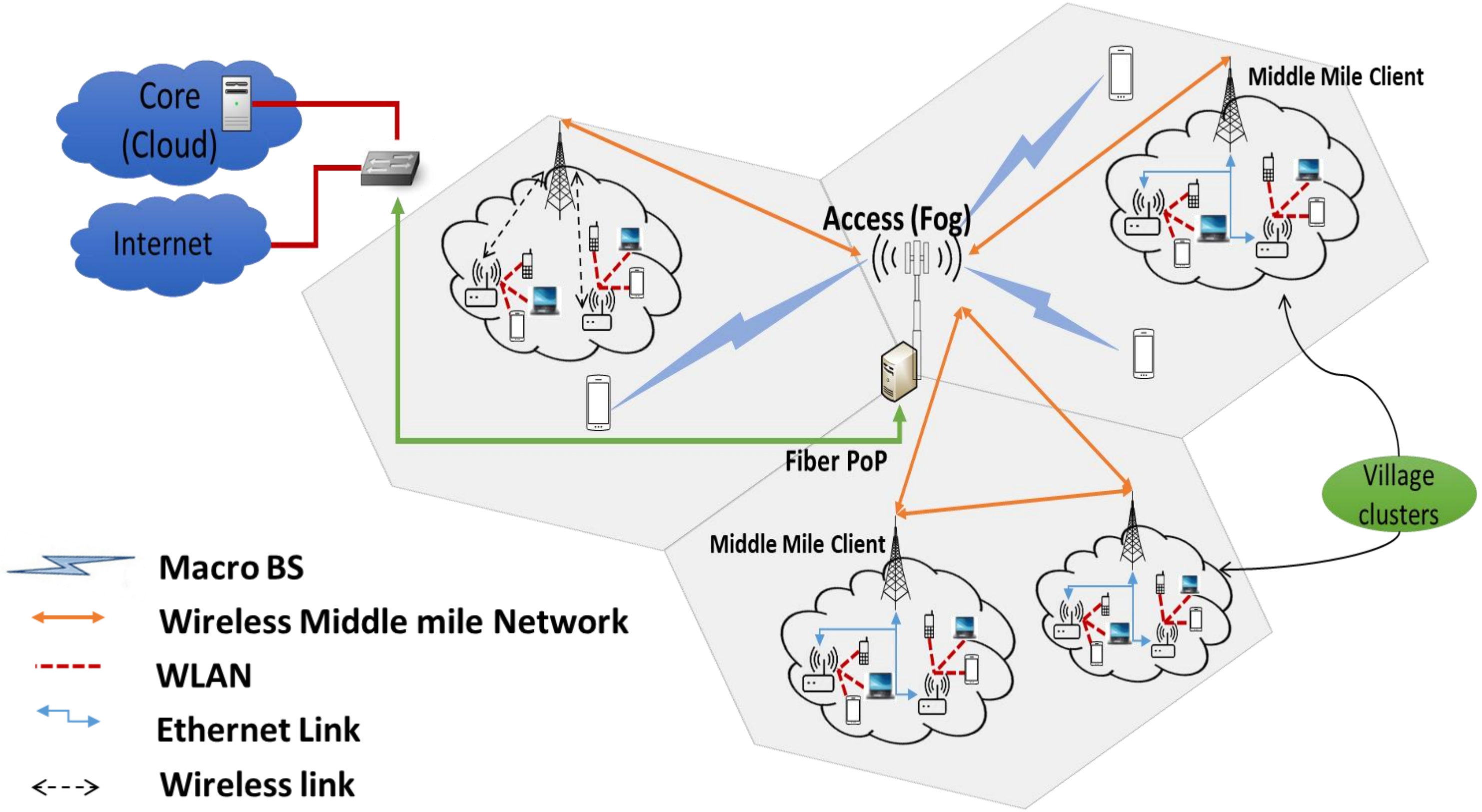
Source: Khaturia M, Jha P and Karandikar A , "Connecting the Unconnected: Towards Frugal 5G Network Architecture and Standardization", IEEE Communication Standards Magazine, June 2020.

IEEE P2061Network Architecture

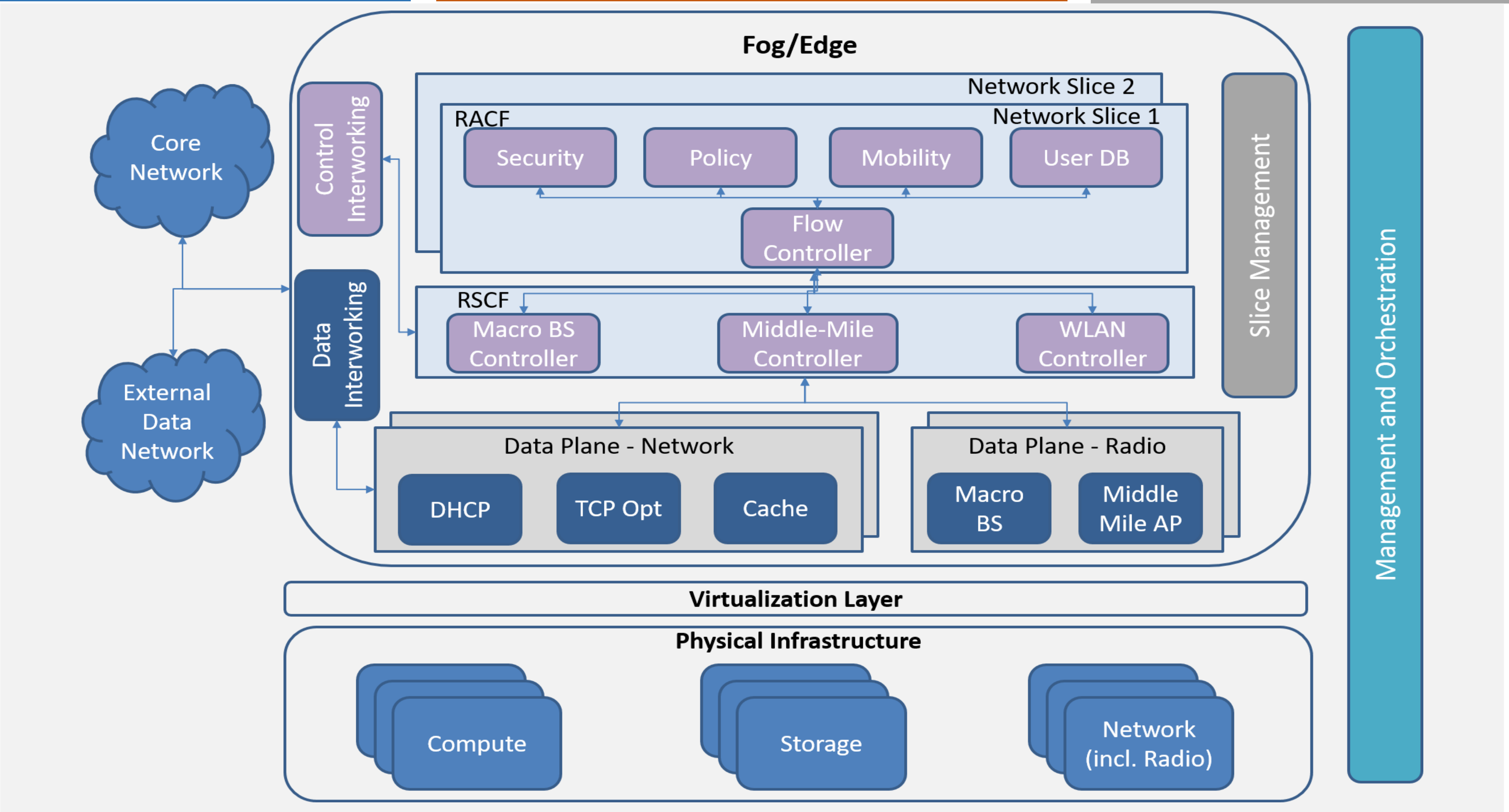
SDN based unified control - Efficient service delivery, Independent Evolution and Development of control/data plane entities

Usage of Virtual Network Functions - makes the system cost-effective

Intelligence at the edge - Enables local communication & reduces resource usage



IEEE P2061 Architecture – Fog/Edge Components

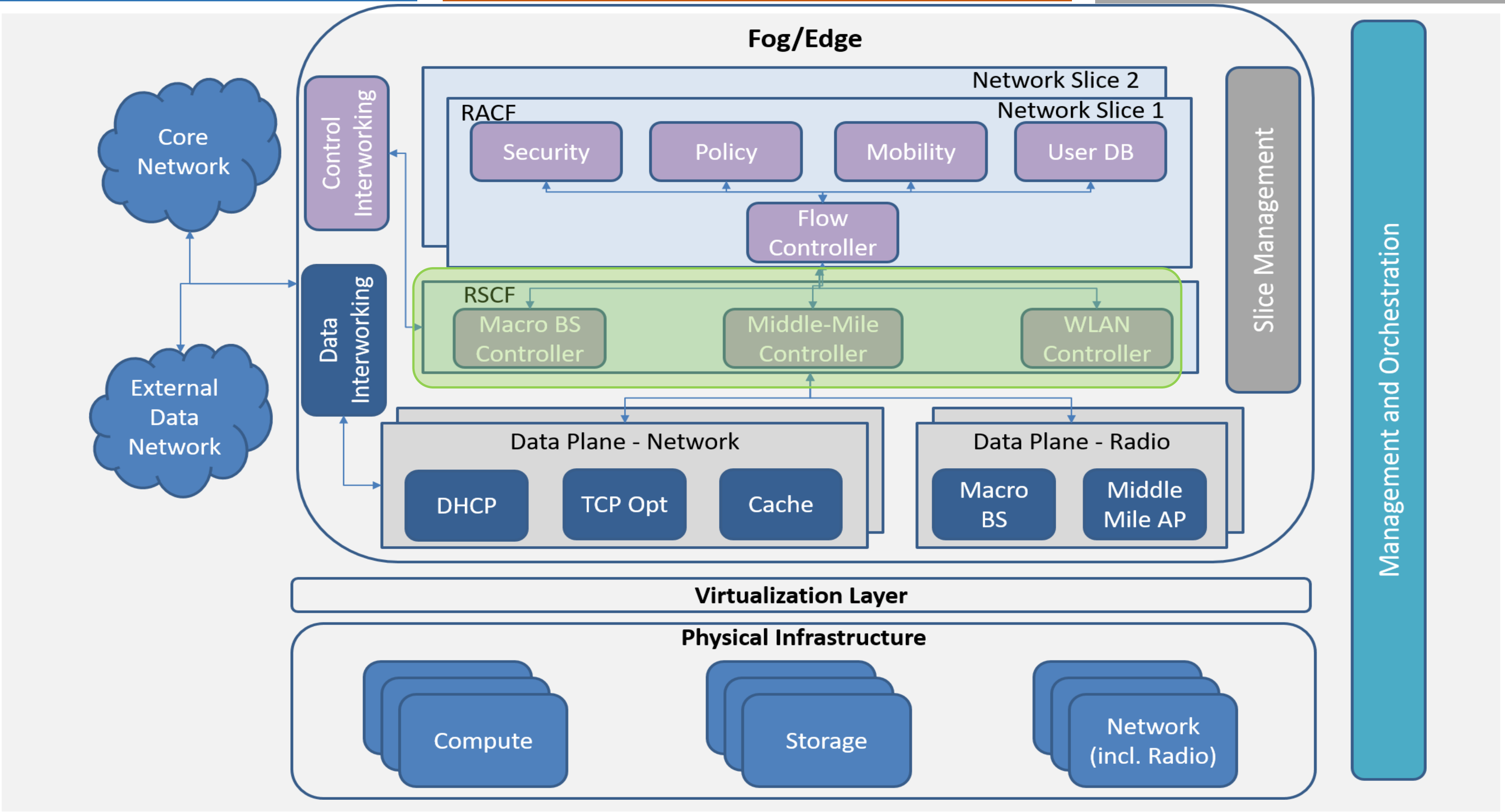


Core Network (CN): Responsible for overall control of the network; Standard Core : 5G

Hierarchical SDN based control of the multi-RAT network

Synchronization of network functions over fog & cloud to avoid inconsistencies

IEEE P2061 – RAT Specific Control Functions

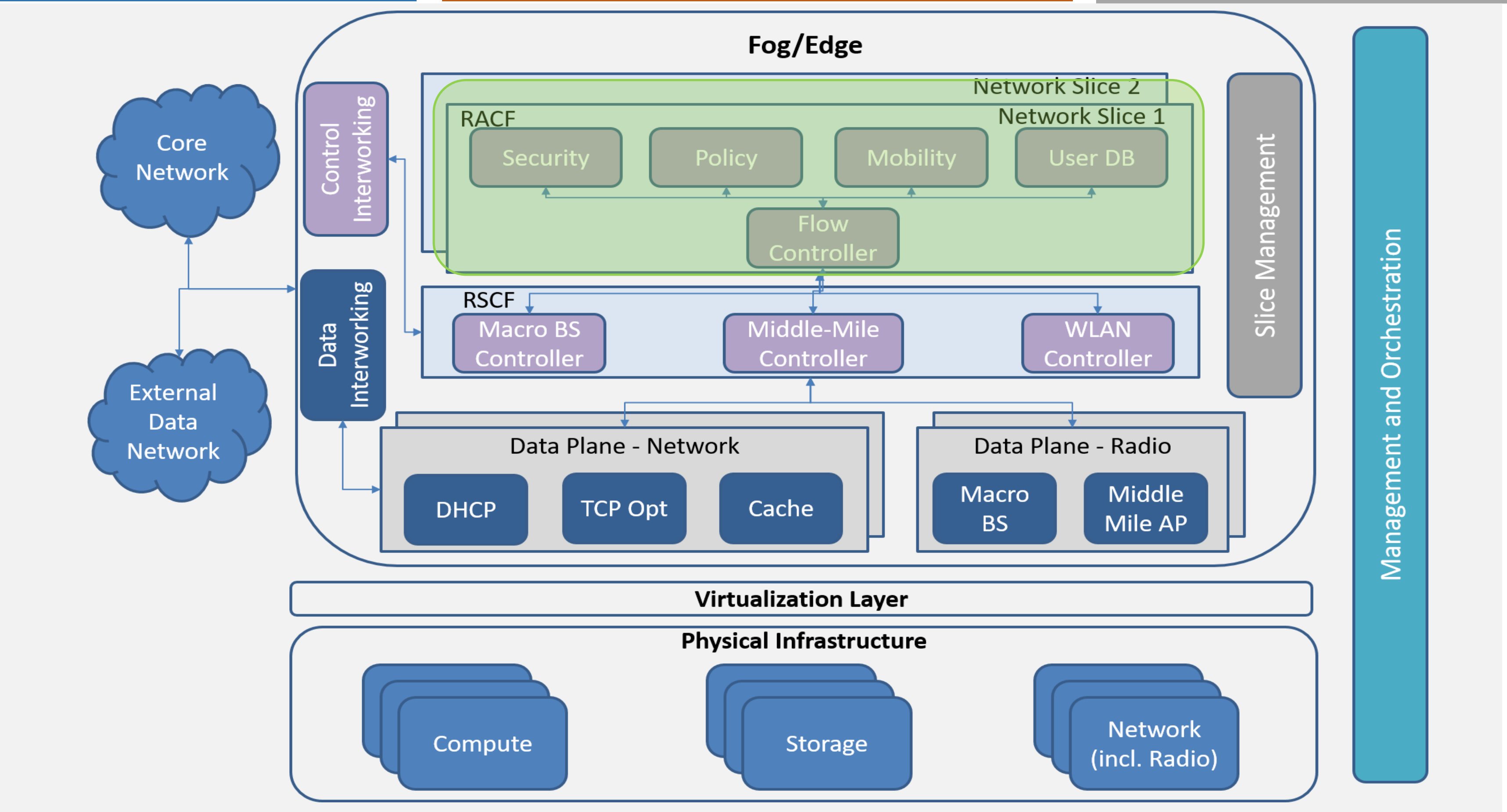


Provides an abstract view of underlying RAN to higher level control entities

Enables unified control of multi-RAT network

Enables RAN virtualization and Network Slicing

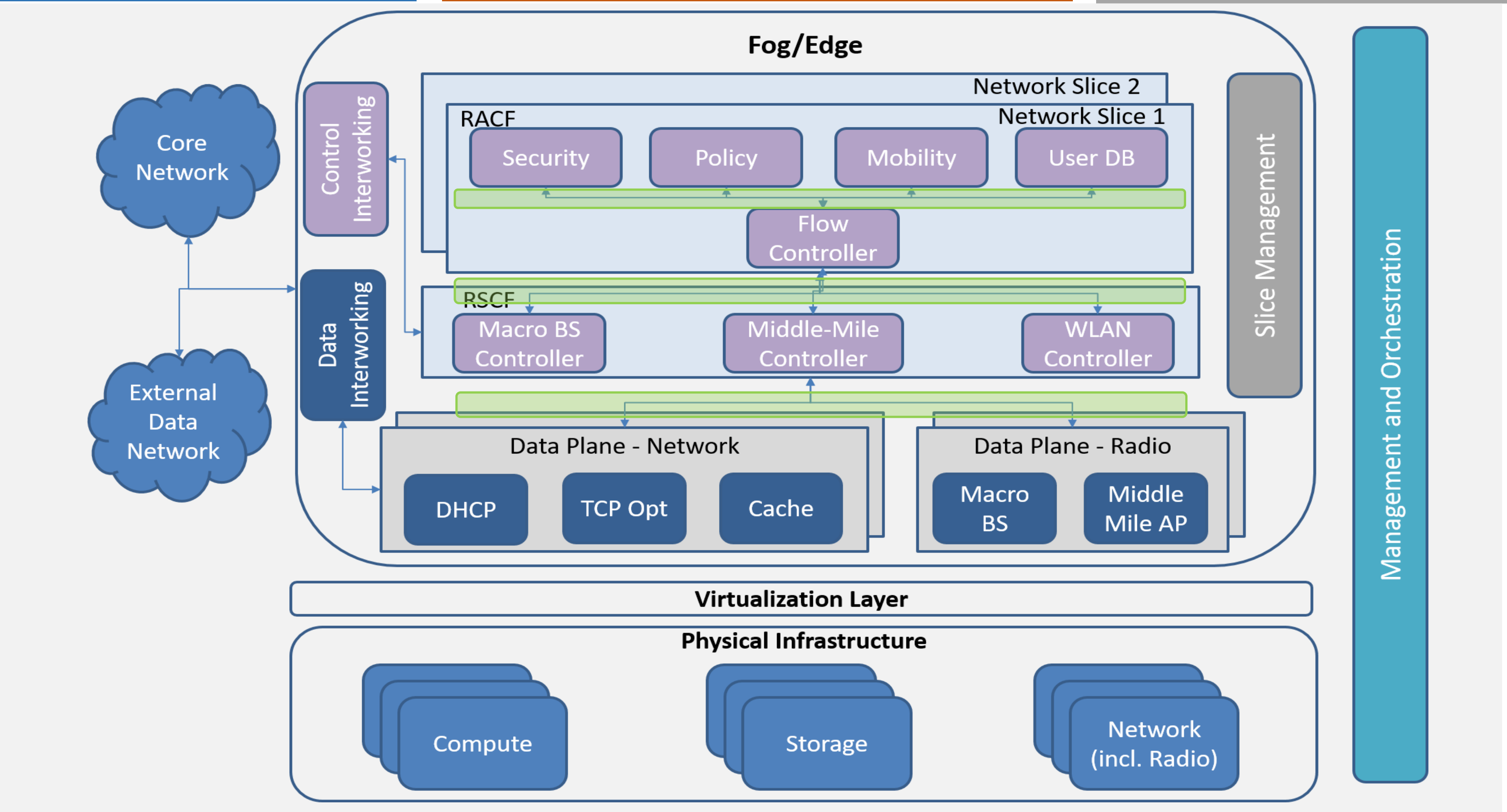
IEEE P2061 – RAT Agnostic Control Functions



Flow controller

- Operates over abstract resources provided by RSCFs
- Analyses individual traffic flows and acts on it with help from other RACFs
- Enables localized communication under individual fog element

IEEE P2061 Architecture – Interfaces



Interactions between RACFs : Service based Interface

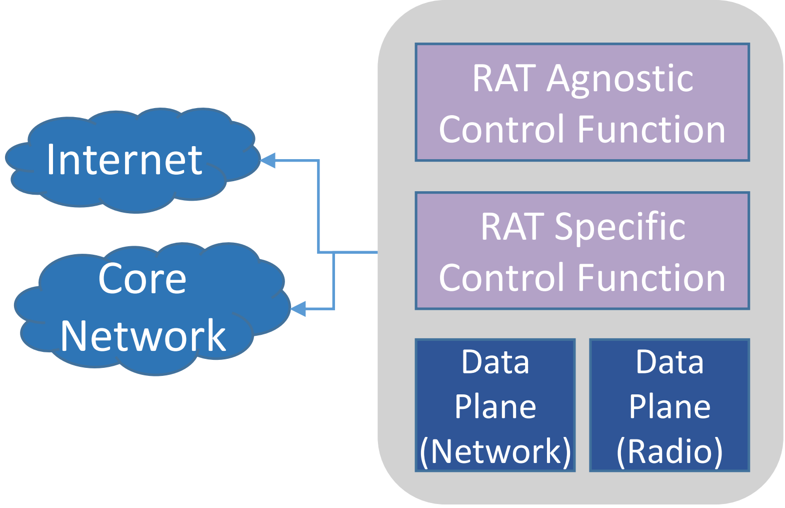
Flow controller & RSCFs : OpenFlow (Modified)

RSCFs & the Corresponding Data Plane Entities : Similar to E1AP/F1AP(3GPP)

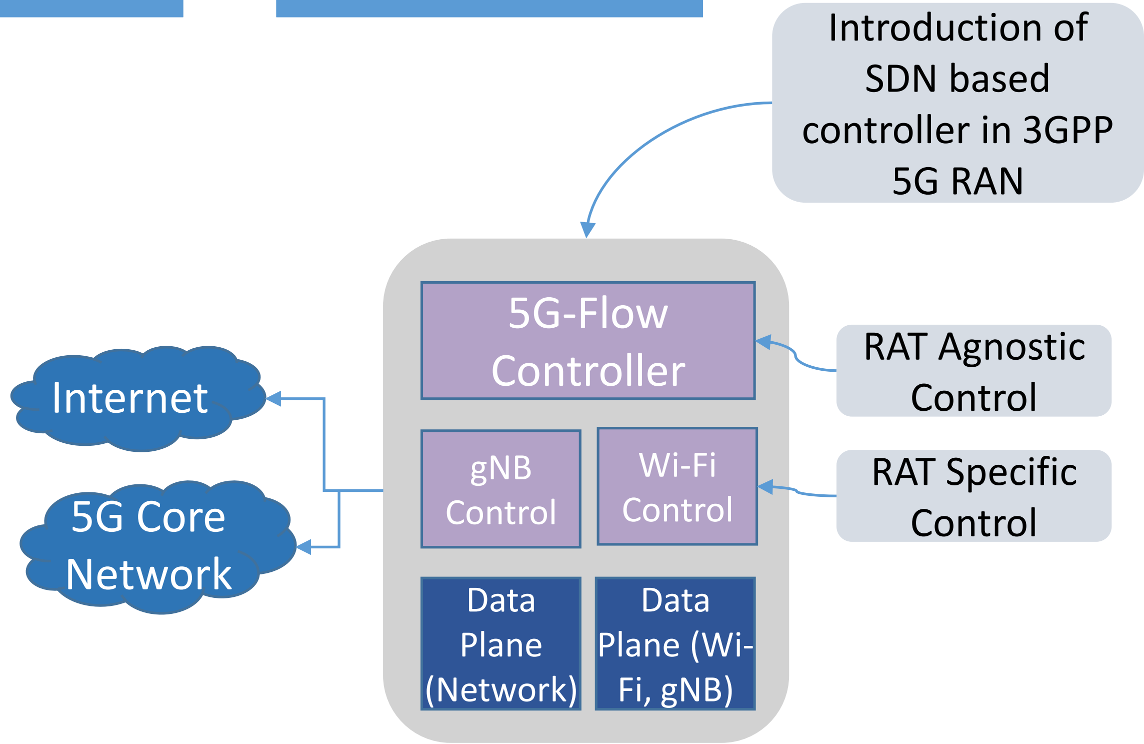
5G-Flow: Realizing Frugal-5G Architecture using 3GPP 5G

Desired Network Characteristics:

- SDN Based Unified Access Control at Edge
- Direct Internet Connectivity from RAN (w/o Core)
- Local Communication Support



Frugal 5G Network (Edge Component)

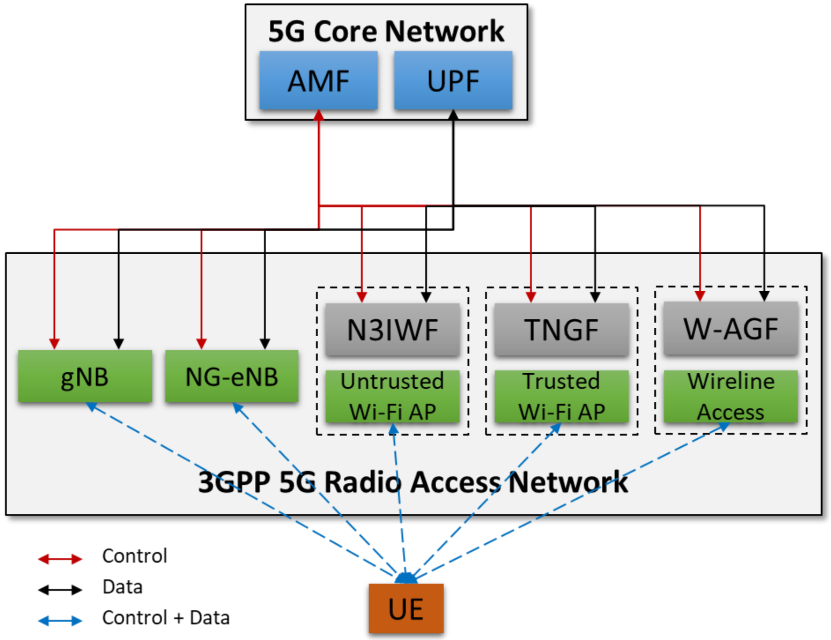


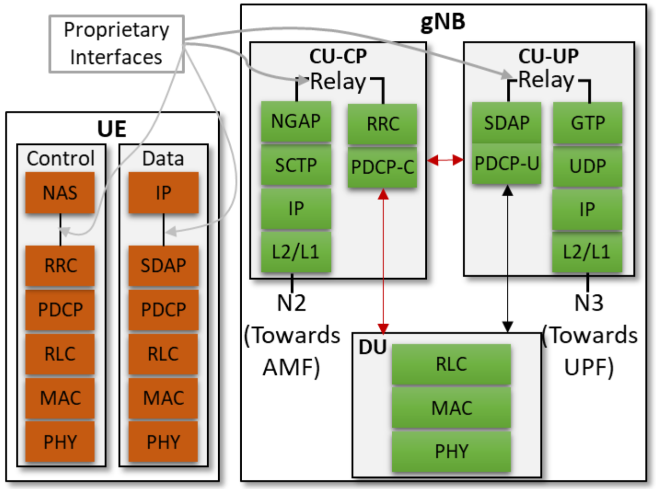
5G-Flow: Implementing Frugal 5G concepts at 3GPP 5G RAN

Source: Khaturia M, Jha P and Karandikar A, "5G-Flow: Flexible and Efficient 5G RAN Architecture Using OpenFlow." arXiv preprint arXiv:2010.07528 (2020).

Existing 3GPP 5G Architecture - Limitations

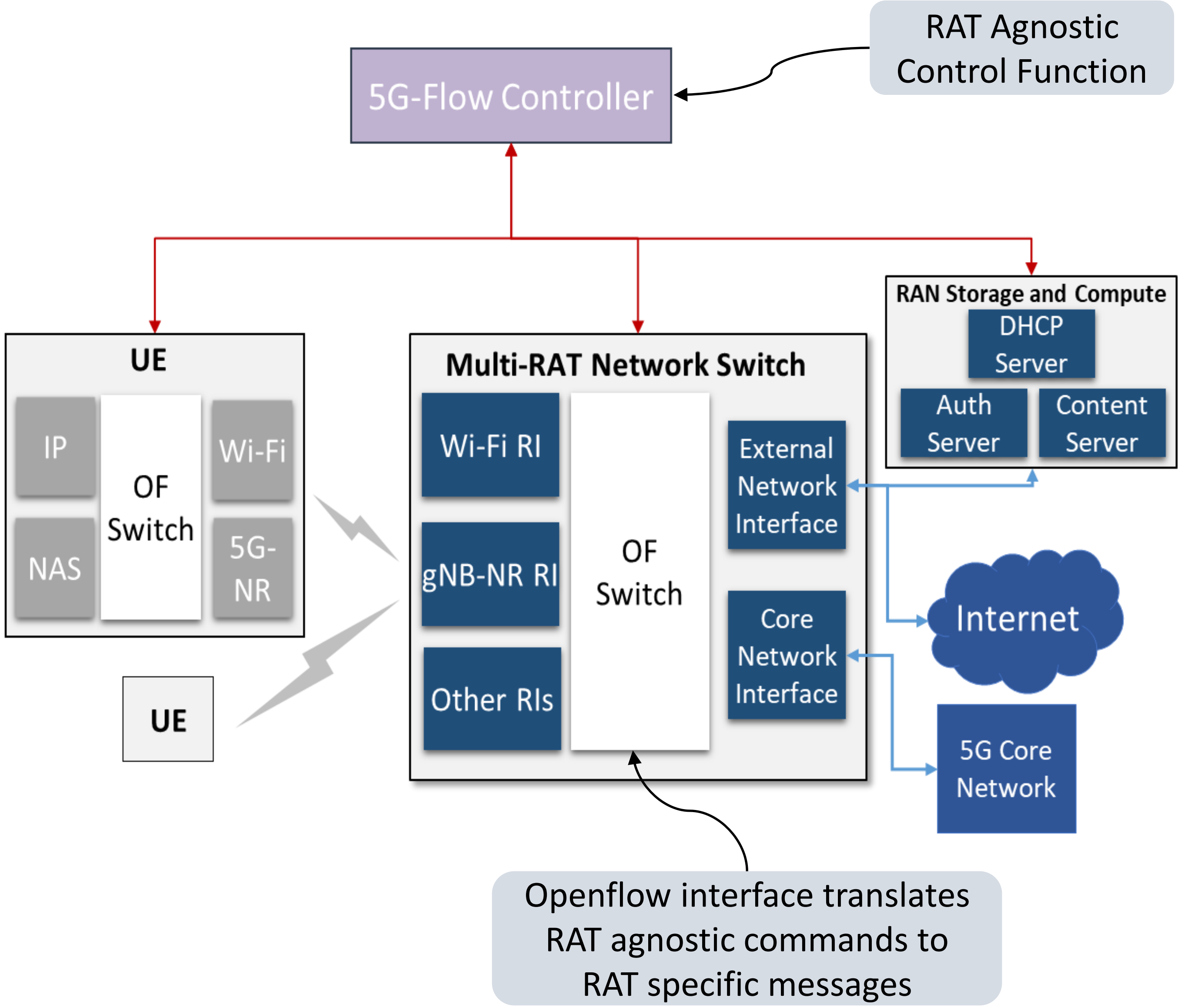
- Fragmented Decision Making in RAN
  - gNB, eNB, Wi-Fi APs …
  - Controlled and Managed Separately
- Unified Core but RAT Specific Inter-working functions
  - gNB, eNB, N3IWF, TNGF, W-AGF
  - Management Overhead
  - Non Optimal Multi-RAT Access
- Tight & Proprietary Coupling between Radio & CN Protocol Stacks in RAN
  - Leads to RAT Specific CN Interworking Function
  - Loss of Flexibility - Not possible to Connect 5G RAN to 4G Core
- Concurrent Multi-RAT Access for UE
  - Managed @Core - Access Traffic Steering, Switching & Splitting
  - Optimal Management of Multi-RAT Access Not Possible
    - RAN level information absent at Core





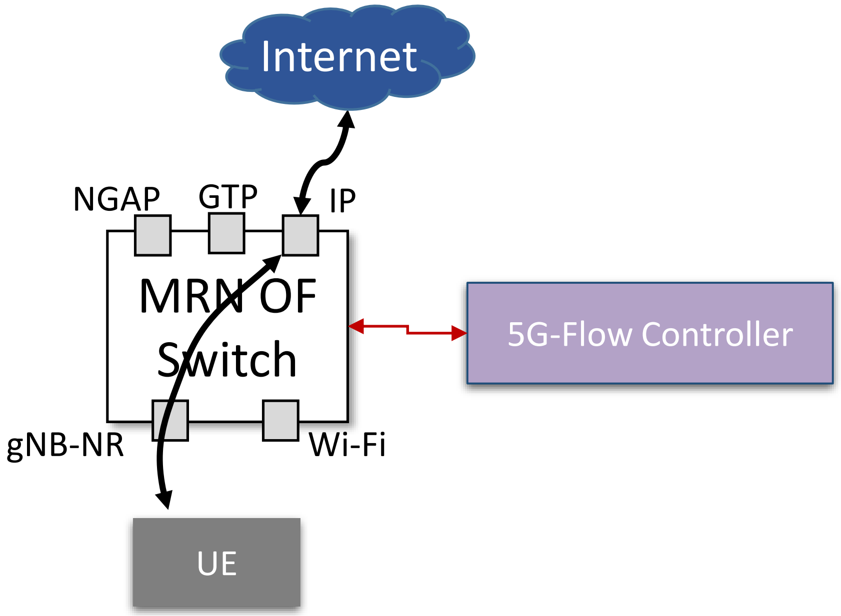
5G-Flow – Unified Multi-RAT RAN

- Logically Centralized Multi-RAT RAN Control
  - Light-weight OF (5G-Flow) Controller for Unified Control
- Decoupled Protocol Stacks at RAN Nodes and UE
  - CN and Radio Interface Stacks Decoupled
- OF-Switch based Unified Multi-RAT RAN Data Plane
  - Protocol Stacks used as Interfaces of an OF Switch
  - Even NAS Signaling Exchange treated as data passing through an OF-Switch



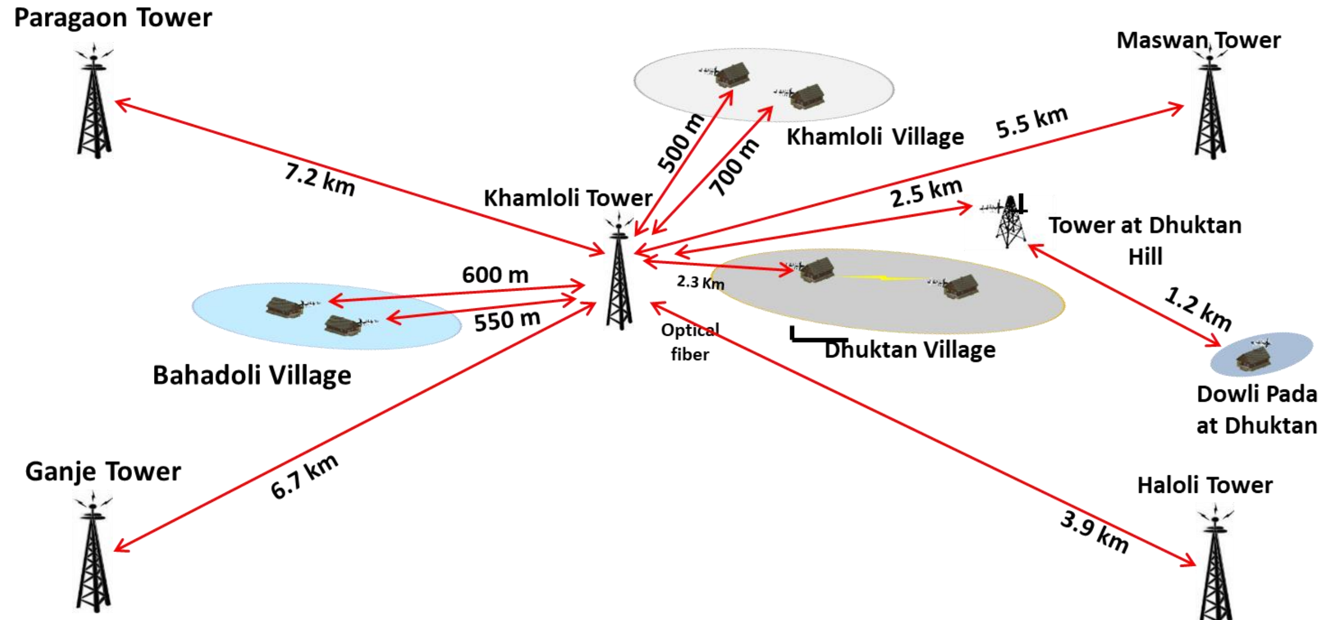
5G-Flow Capabilities - Direct Connectivity to Internet

- Existing Cellular Technologies, e.g., LTE/5G NR requires support of Core Network
  - Can not work in a standalone manner without CN
- 5G-Flow Network Architecture allows Usage of Cellular Technologies (5G NR…) without involving CN
  - UE's connectivity with RAN is decoupled from it's connectivity with CN
  - 5G-Flow controller sets up the flow entry and creates radio bearer at RAN to enable direct connectivity with Internet



Learnings from Our Palghar Testbed (Maharashtra, India)

- TV UHF band (470-590 MHz)
  - Largely Underutilized in India
- TV UHF band for Backhaul
  - Covers Large distances
  - Non-line-of-sight links can be formed
  - Low Power consumption
    - 5–10 W in our testbed
    - Can be powered via Solar Energy
  - Throughput - 6-15 Mbps in 5MHz
- Wi-Fi for Access in Villages
  - Cost Effective
  - Easy to Manage



Source: Kumar et al., "Toward enabling broadband for a billion plus population with TV white spaces," IEEE Communications Magazine, July 2016.

IMT-2020 Rural eMBB – Original Test Configuration

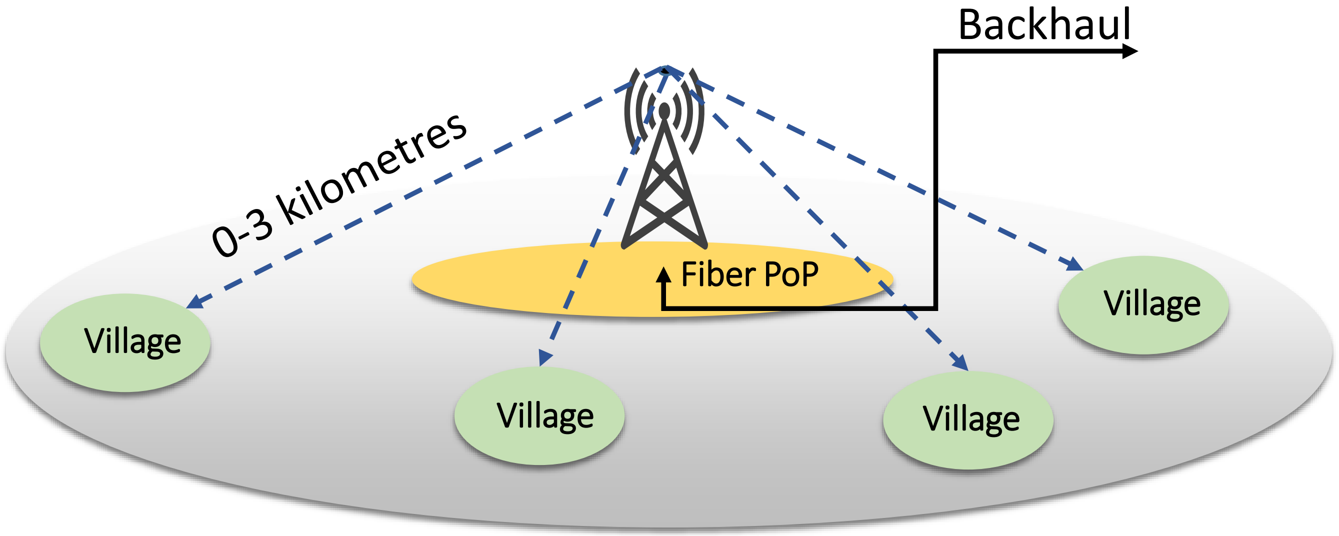
- Cell Radius - ~1 km
- Caters to High-Speed Vehicles
  - 120 km/hour
- Mobility KPI
  - High-speed Vehicular Traffic - Up to 500 km/hour
- Essentially Models
  - Connectivity to High-speed Vehicular Traffic In Rural Areas in Economically Developed Countries

IMT-2020 – Original Rural – eMBB Test Configuration used in ITU		
Parameters	Config A	Config B
Carrier Frequency	700 MHz	4GHz
Inter-Site Distance (ISD)	1732 meters	1732 meters
Bandwidth	20 MHz (DL+UL)	Up to 200 MHz (DL+UL)
BS Tx power	49 dBm	
BS Antenna Height	35 meters	
User Equipment (Device) Distribution	50% outdoor vehicles (120km/h) and 50% indoor (3km/h) 500 km/h for evaluation of mobility in high-speed cases Uniform User distribution	

Source: ITU M.2410 and 2412

LMLC - Augmenting IMT-2020 for Rural Broadband

- A Fiber PoP terminates at the village cluster
- 5G based Cellular Connectivity around a Fiber PoP
- Large Coverage Area
- Focus on Low Mobility Users
- No Support for High-speed Mobility
  - Unlike Original Rural Broadband use cases of IMT-2020 & IMT-Advanced
- A new Channel Model
  - Valid for a cell radius of 20 km



IMT-2020 – LMLC Test Configuration for Rural Broadband		
Parameters	Config A (Original)	LMLC - Config C
Carrier Frequency	700 MHz	700 MHz
Inter-Site Distance (ISD)	1732 meters	6000 meters
User Equipment (Device) Distribution	50% indoor, 50% outdoor (in-car) Randomly and uniformly distributed	40% indoor, 40% outdoor (pedestrian), 20% outdoor (in-car) Randomly and uniformly distributed
BS Tx power	49 dBm	
BS Antenna Height	35 meters	
User Equipment (Device) Speeds of interest	50% outdoor vehicles (120km/h) and 50% indoor (3km/h) 500 km/h for evaluation of mobility in high-speed cases	Indoor users: 3 km/h; Outdoor users (pedestrian): 3 km/h; Outdoor users (in-car): 30 km/h

Source: Amuru et al., "A Case for Large Cells for Affordable Rural Cellular Coverage", Journal of Indian Institute of Science, April 2020

Summary

- Rural Broadband and Digital Empowerment require challenges to be addressed through technology innovations
- Proposed an architecture (Frugal 5G) for rural broadband network; Implemented Frugal 5G using 3GPP 5G Network
  - Unified Access Control
  - Direct Internet Connectivity from RAN (w/o Core)
  - Integration of Middle-mile and Access Network
  - Local Communication Support
    - End-to-end data path may be fully contained within a single edge/fog element
    - Reduced end-to-end latency
- Our group leading P2061 Standardization
  - Ongoing; Expected to complete in early 2022

THANK YOU