Connecting the Unconnected in 5G and Beyond

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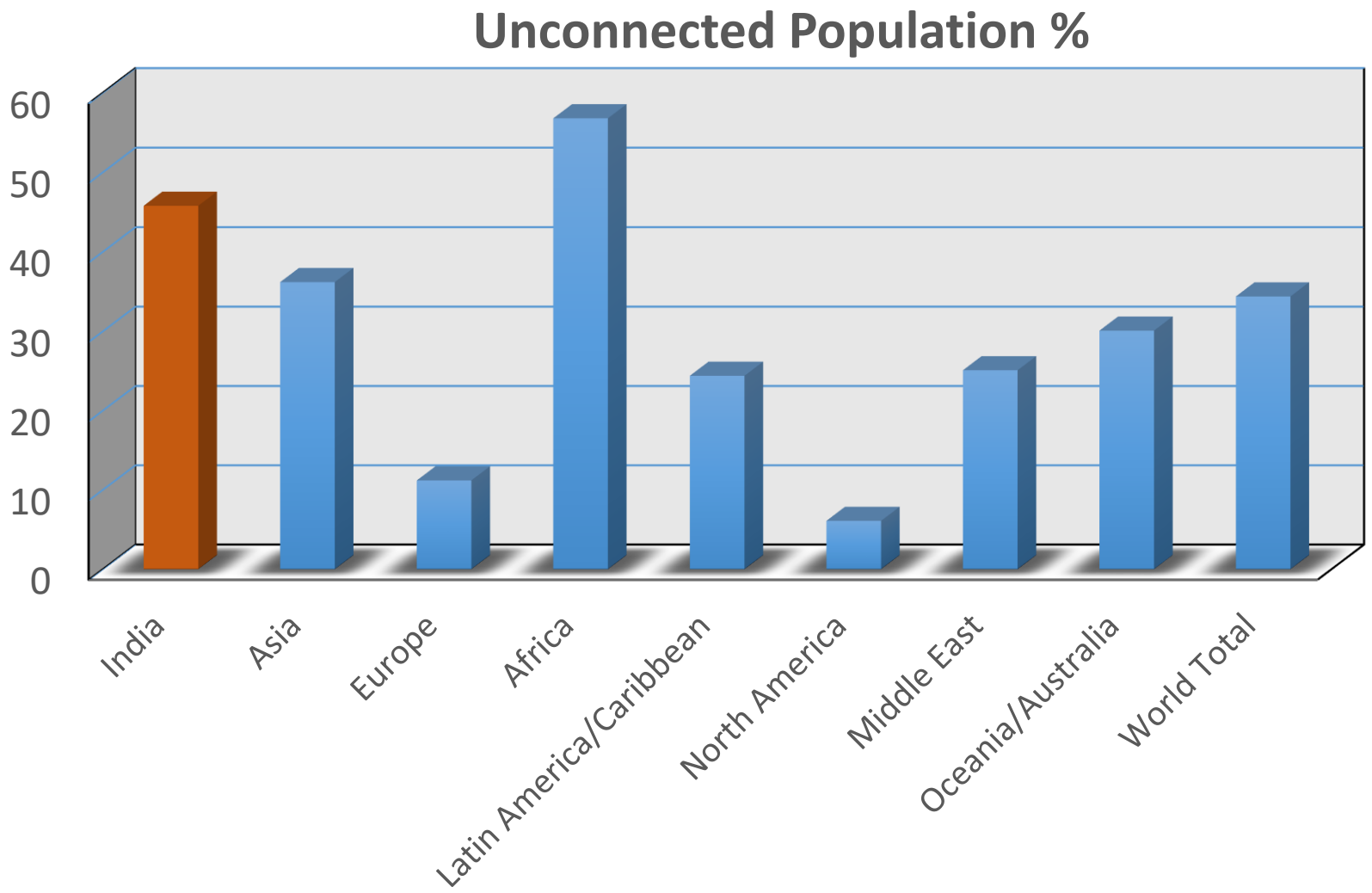
Agenda

- Status of Internet and Broadband Connectivity
- Key Challenges to Rural Broadband Connectivity
- Use Cases and Requirements
- Rural Broadband Standardization Initiatives
  - 5Gi (LMLC)
  - IEEE P2061
- Frugal 5G (IEEE P2061) Architecture
- 5G Flow - Realizing Frugal 5G

Internet Connectivity Status: Worldwide



~34 % of the World Population is Unconnected - Majority in Developing World and in Rural Areas

Source: https://www.internetworldstats.com/stats.htm/

Internet/Broadband Penetration Status: India

Population

~ 1399 M

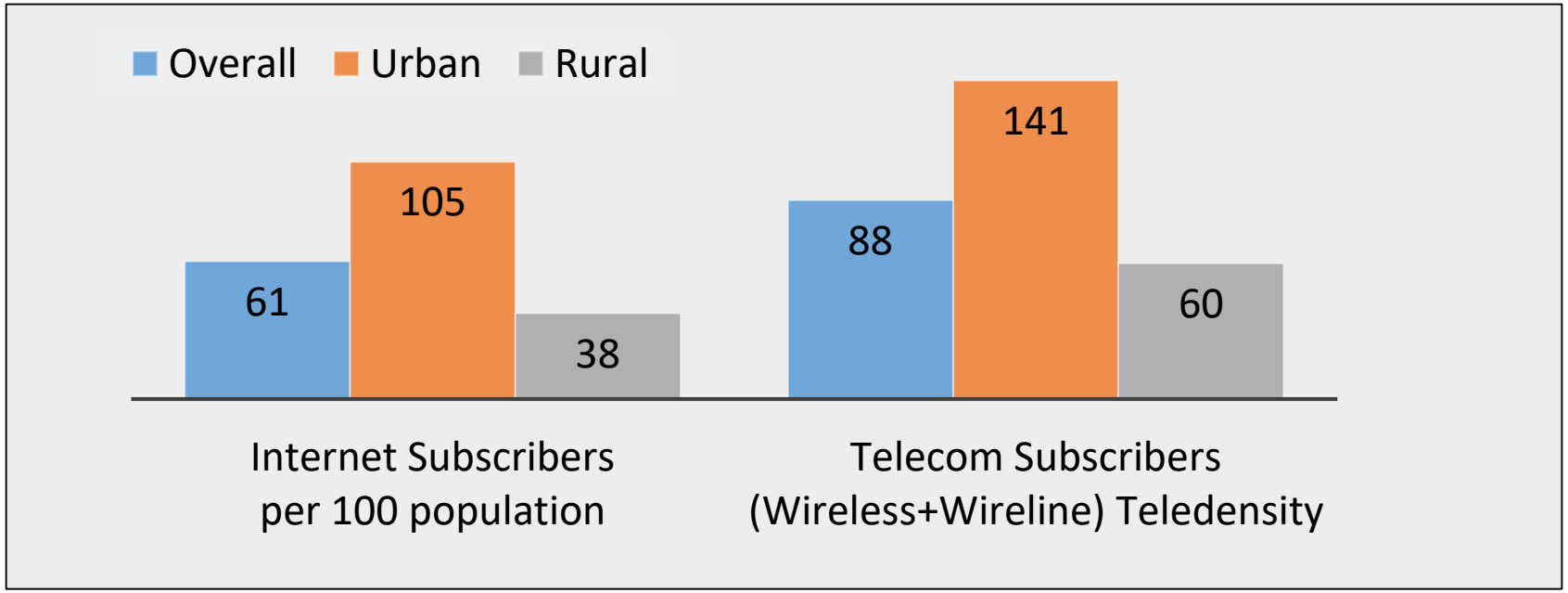
Wireless Subscribers

~ 1181 M

Broadband Subscribers

~ 793 M

Rural vs. Urban



Source: Telecom Regulatory Authority of India, The Indian Telecom Services Performance Indicators, April – June, 2021

The Pandemic Reinforced the Need for Improved Connectivity

JANUARY 19, 2021

When internet comes home: E-learning in Indian villages during COVID-19

As learning went digital due to COVID-19, a group of teachers working in India's villages took internet to people's homes, making education more inclusive.

by SMITA AGARWAL | 4 min read

COVID-19
A wake-up call for Indian Internet Service Providers

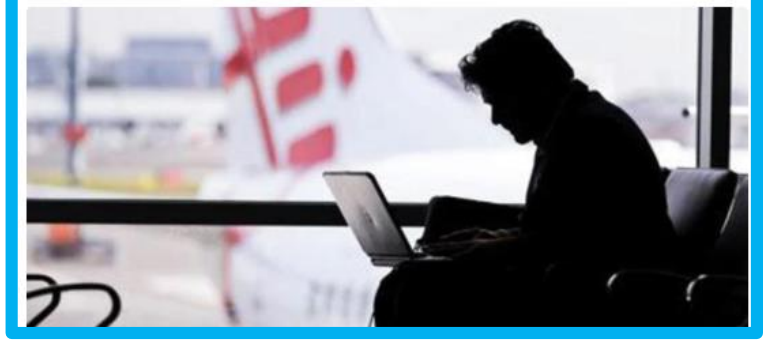
INDIAN STUDENTS EXCLUSIVE

QS I-GAUGE

INDIA NEWS

India's internet consumption up during Covid-19 lockdown, shows data

Data from the department of telecommunications showed that between March 22 and March 28, Indians consumed an average of 307,963 TB or 307 petabytes (PB) of data.



Business Standard SPECIAL ON CORONAVIRUS

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Connectivity for corona crisis

Prime Minister Narendra Modi's call for COVID-19 Solution Challenge on MyGov is a welcome effort towards involving private sector in times of a national crisis

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Covid-19 pandemic risks a lost generation in India as digital divide widens

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Explained | Increase in digital connectivity but there are many who are still left out

Priscilla Jebaraj

NEW DELHI, NOVEMBER 15, 2021 01:45 IST
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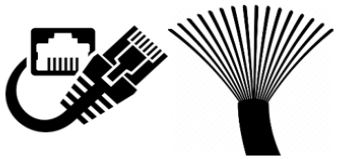
Internet/Broadband Access- How is it enabled?

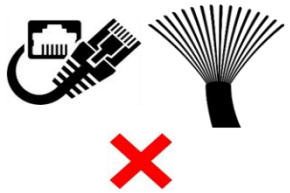
Developed Countries



Mostly enabled through wired communication infrastructure, Fiber and DSL

Developing Countries

Cellular Technology - Primary broadband access mechanism



Fiber/DSL Infrastructure - Inadequate

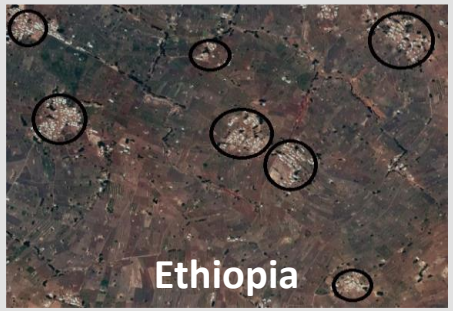
Challenges in using Cellular Technology in Rural Areas

- Focus on urban usage scenarios
- Limited support for rural connectivity requirements in specs.
- No compelling commercial reasons to target rural areas

Connecting the Unconnected - Challenges

Sparsely Populated Rural Settlements

Remote and difficult to reach regions



Rural Settlements*

High CAPEX & OPEX

Spectrum cost

Cost of backhaul

Low Average Revenue per user

Scarcity of Resources

Uninterrupted electric power supply from the grid

Access Constraints

Right of way

Relevance of Content

Most content on internet is in English and a handful of other languages

Challenges of Manageability

Unavailability of trained manpower

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

Use Cases for Rural Connectivity

Rethinking 5G Requirements for Rural Areas

- Affordability
- No/Limited need for high mobility
- Large coverage area support
- Clustered service provision
- Energy efficient solutions
- Localized communication and local content generation/storage
- Ease of manageability

Rural Broadband Standardization Initiatives

5Gi (LMLC)

- Augmenting IMT-2020 for rural broadband
- TSDSI RIT approved as an IMT 2020 technology

IEEE P2061 - Frugal 5G Networks

- Architecture for a Low Mobility and Energy Efficient Network for Affordable Broadband Access

IMT-2020 Rural eMBB – Original Test Configuration

- Essentially Models: Connectivity to High-speed Vehicular Traffic in Rural Areas in Economically Developed Countries
- Not Suitable for “Connecting the Unconnected”

IMT-2020 – Original Rural – eMBB Test Configuration used in ITU		
Parameters	Config A	Config B
Carrier Frequency	700 MHz	4 GHz
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) • 500km/h for evaluation of mobility in high-speed cases • Uniform User distribution	

Source: ITU M.2410 and 2412

IMT-2020 Rural eMBB – LMLC Configuration

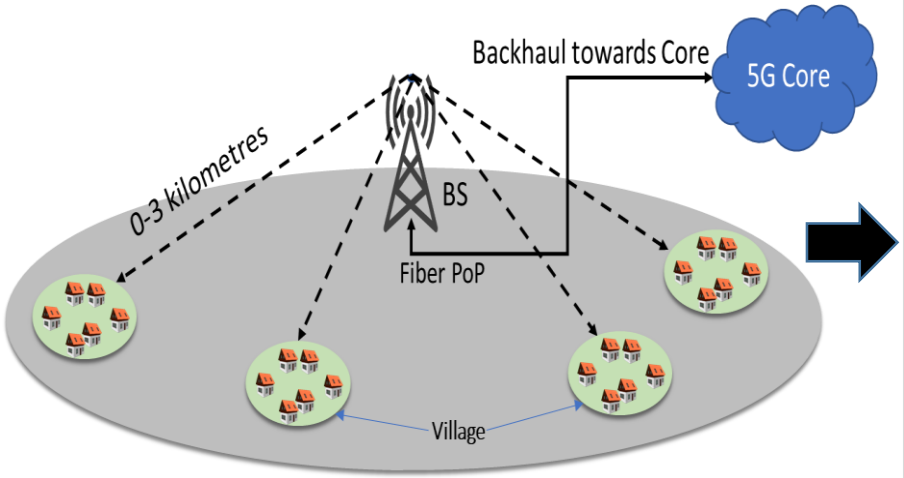
- 5G based cellular connectivity around a fiber PoP
  - Vicinity of village cluster
- Large coverage area
- Focus on low mobility users
  - No support for high-speed mobility

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., Journal of Indian Institute of Science, April 2020

5Gi Journey: Requirement -> Innovation -> Standard

Courtesy : "A Case for Large Cells for Affordable Rural Cellular Coverage", Saidhiraj Amuru, Radha Krishna Ganti et al.



Config A
- 700 MHz
- ISD 1.732km
- 120/500 km/h

Config B
- 4 GHz
- ISD 1.1732km
- 120/500 km/h

Existing rural models 3G, 4G, 5G

Config C (LMLC)
- 700 MHz
- ISD 6 km
- 3/30 km/h

New model 5G

3GPP 5G Standard + Indian Enhancements

To address Indian needs

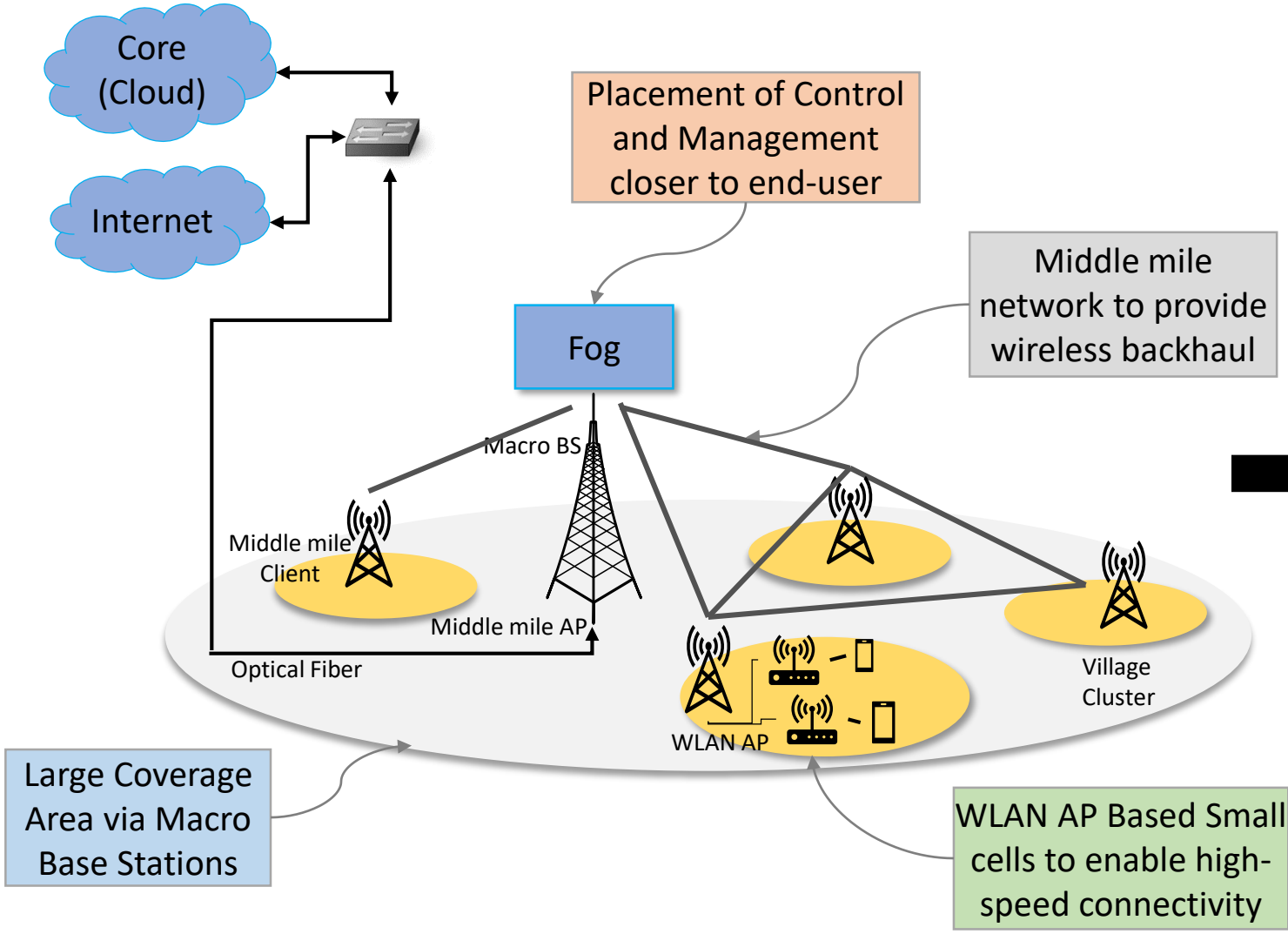
Technical studies and finalization done in TSDSI

India Requirement

TSDSI's Low Mobility Large Cell (LMLC) Requirement incorporated as a mandatory Requirement at ITU in Q3 2017

TSDSI RIT (5Gi) approved as a IMT2020 Technology in (M.2150) in Feb 2021

IEEE P2061 - Frugal 5G Networks

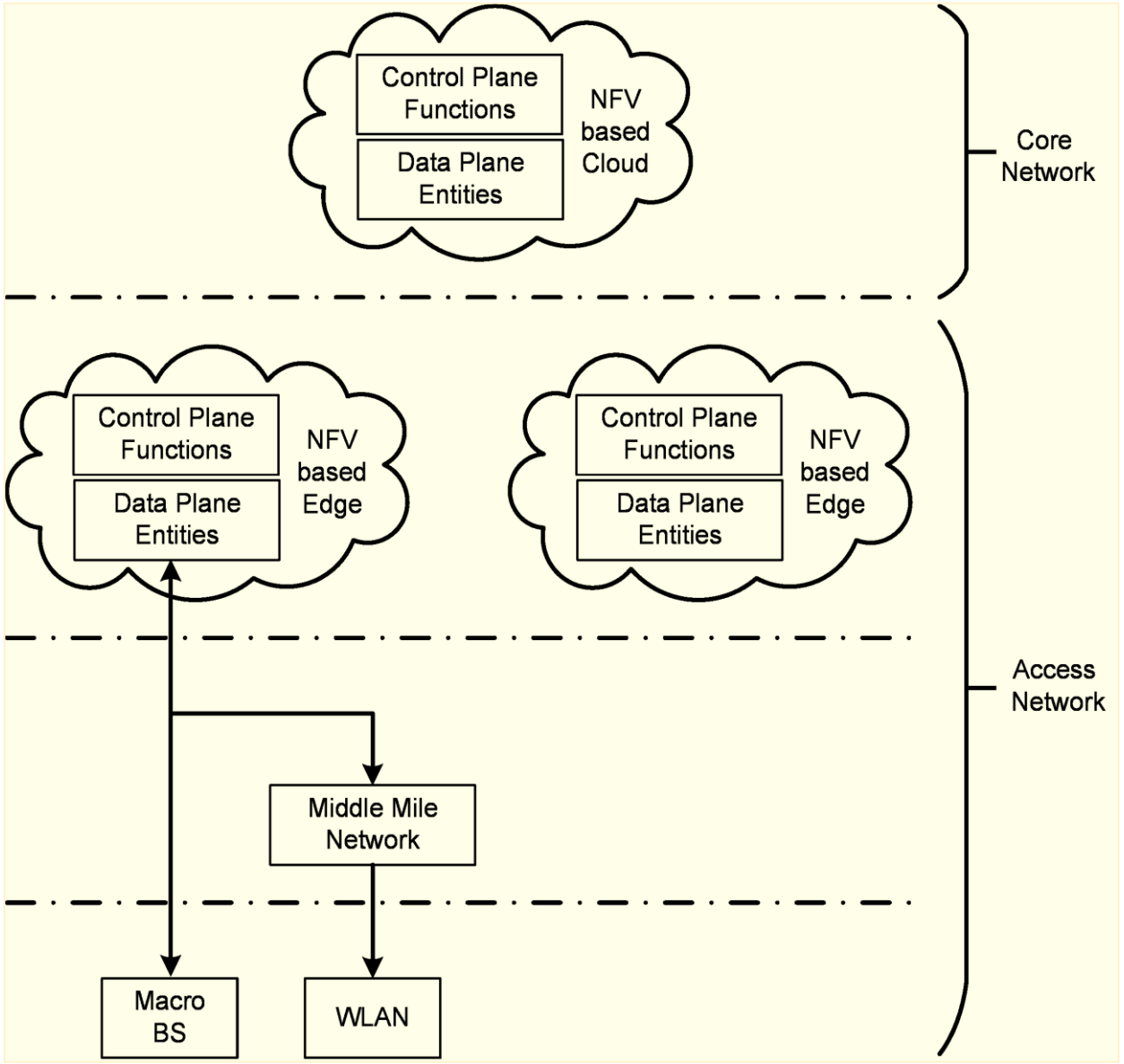


Frugal 5G Networks (IEEE P2061)

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

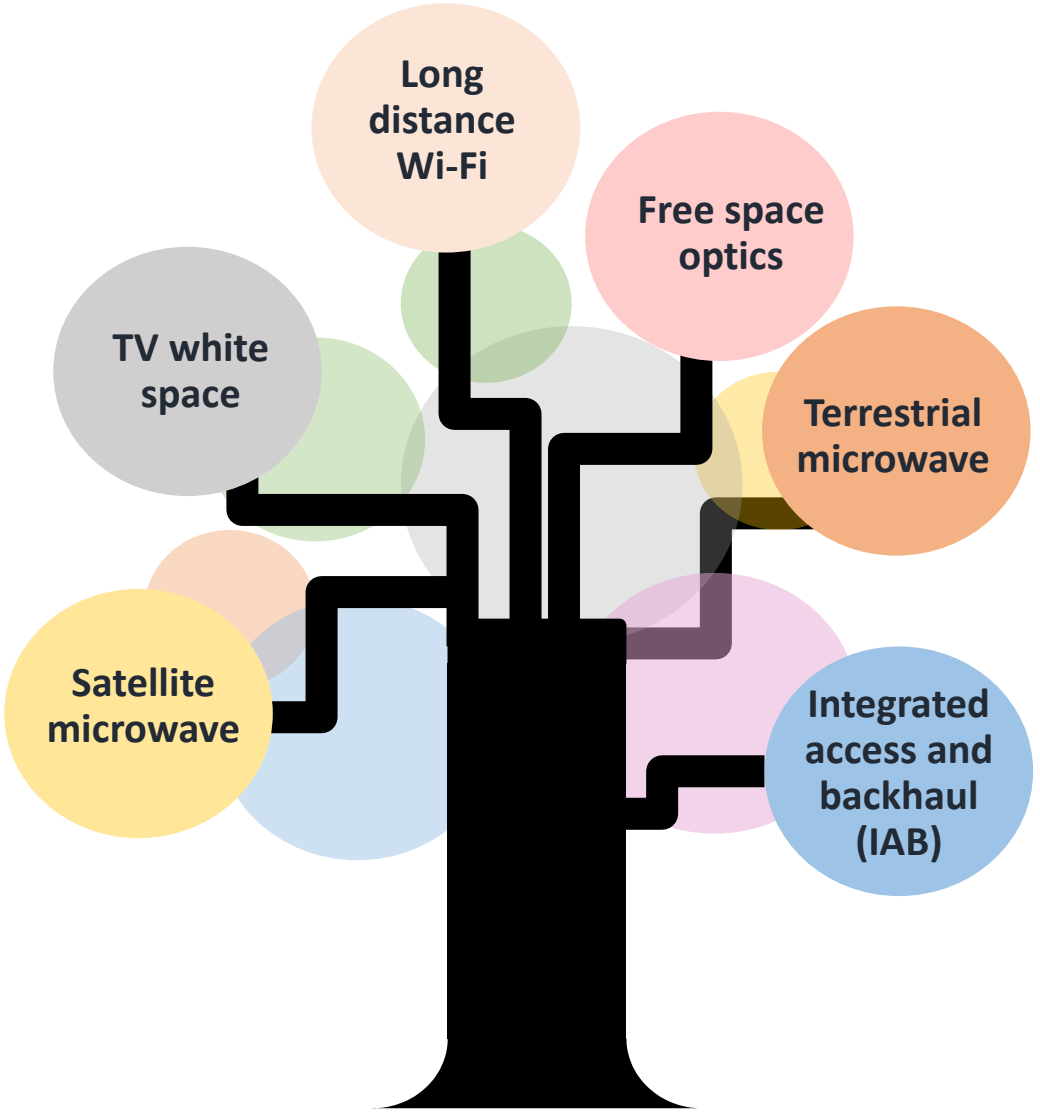
Source: Khaturia M, Jha P and Karandikar A, IEEE Communication Standards Magazine, June 2020

IEEE P2061- Frugal 5G Conceptual View

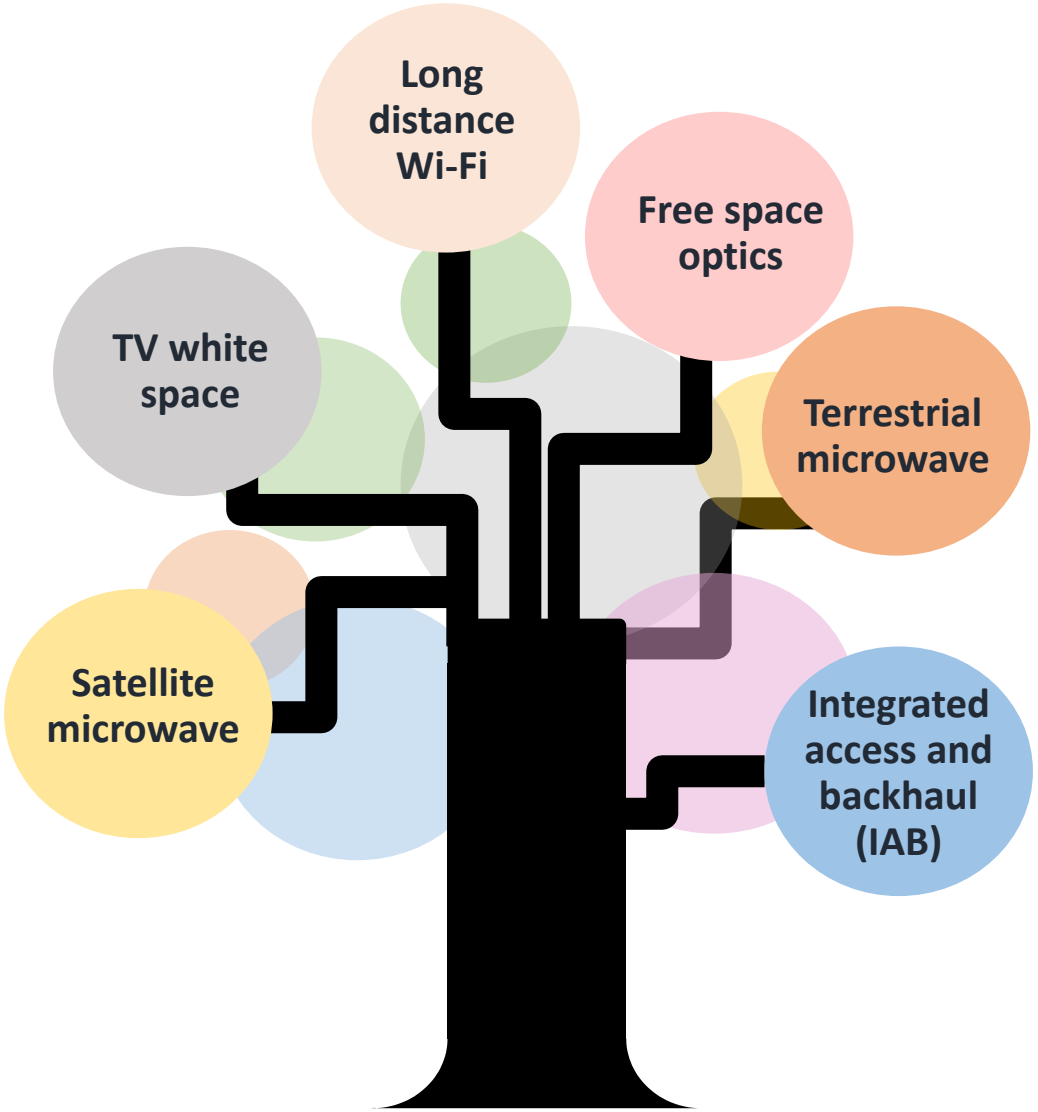


Usage of Virtual Network Functions	Makes the system cost-effective
Intelligence at the Edge	Enables local communication & reduces resource usage
SDN based Unified Control	Efficient service delivery, independent evolution and development of control/data plane entities

IEEE P2061 - Middle Mile Technologies

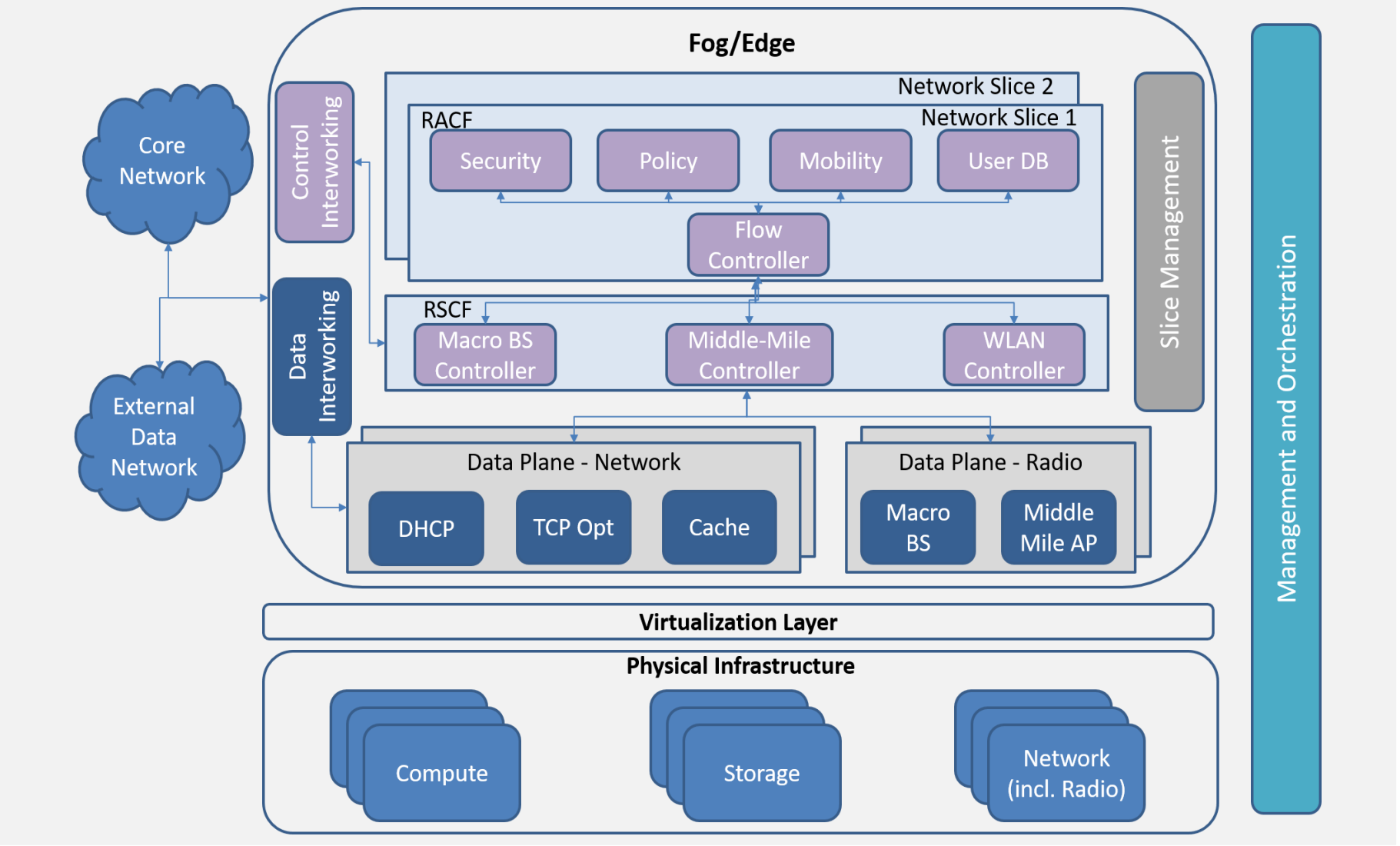


IEEE P2061 - Middle Mile Technologies



Long distance Wi-Fi (IEEE 802.11n/ac/ax)	Unlicensed spectrum 2.4-5.8 GHz (+ 6 GHz band)	Cost effective and easily deployable
TV white space (IEEE 802.22, 802.11af)	Unused channels in VHF/UHF TV band	Geographical database based regulation
Free space optics	Spectrum available in THz (785-1550 nm)	High directivity and sensitive to weather conditions
Terrestrial microwave	Spectrum: licensed between 6 GHz to 30 GHz	Multiband antenna and boosters for higher capacity
Satellite microwave	GEO: placed at high altitude MEO/LEO: nearer to earth	High throughput satellite (HTS): multi-spot-beam technology
Integrated access and backhaul (IAB)	Licensed 5G Spectrum	Beam Forming and integrated with 5G system

Frugal 5G Architecture – Fog/Edge Components

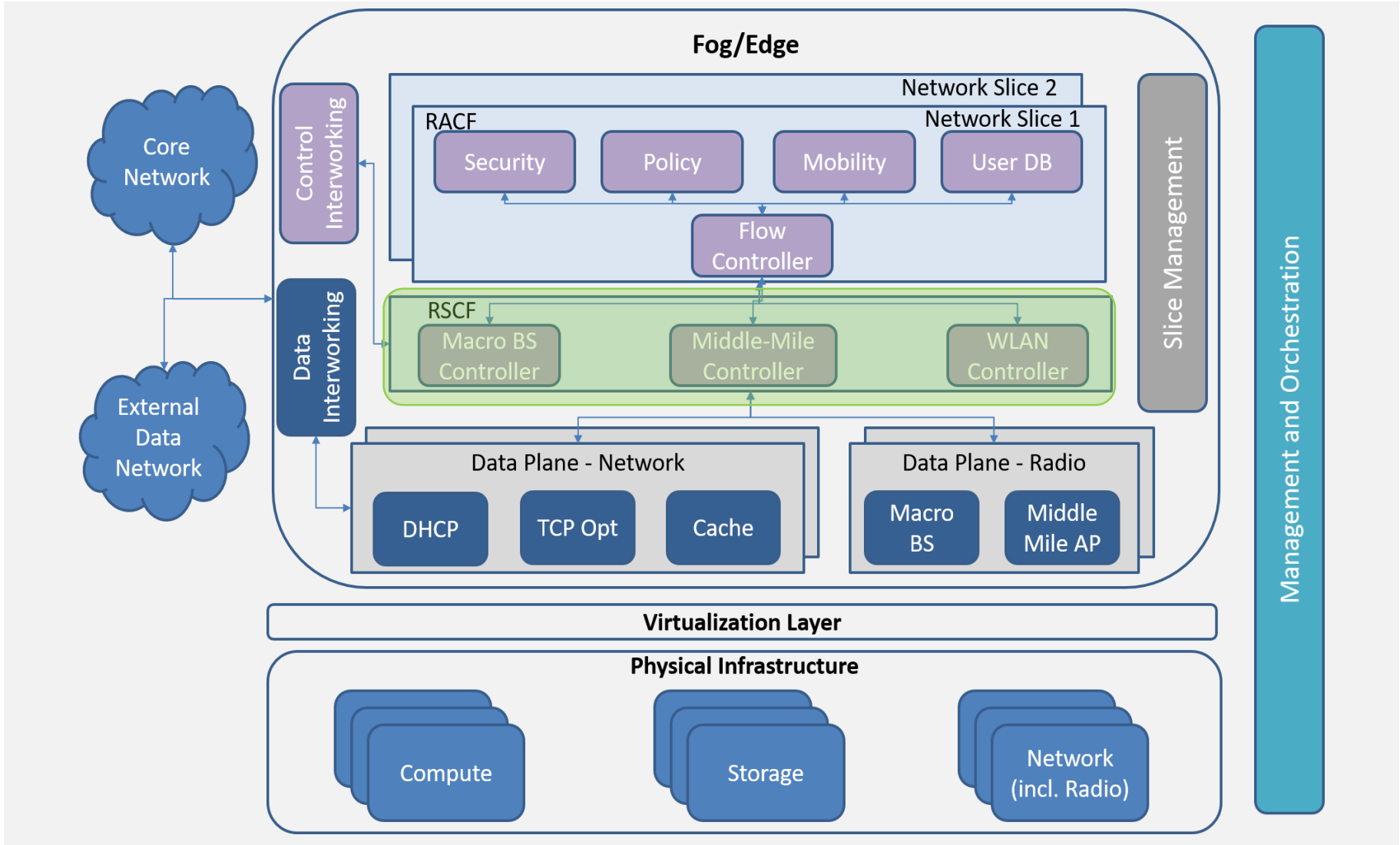


Cloud based Core Network: Overall control of the network

Fog/Edge: Hierarchical SDN based control of the multi-RAT network

Synchronization of network functions over fog & cloud to avoid inconsistencies

Frugal 5G Architecture – Fog/Edge Components



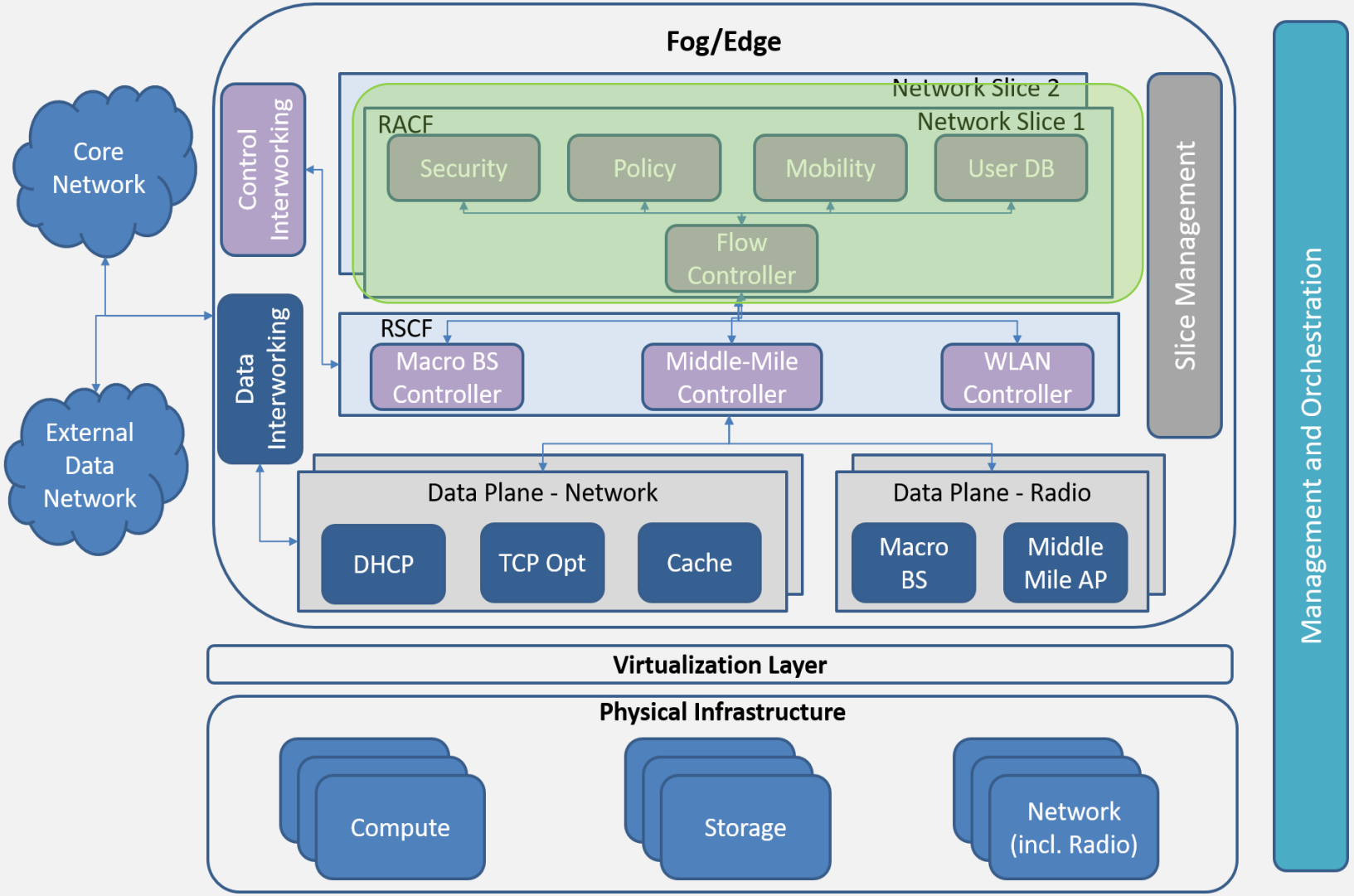
RAT Specific Control Functions (RSCF)

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

Enables unified control of multi-RAT network

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

Frugal 5G Architecture – Fog/Edge Components



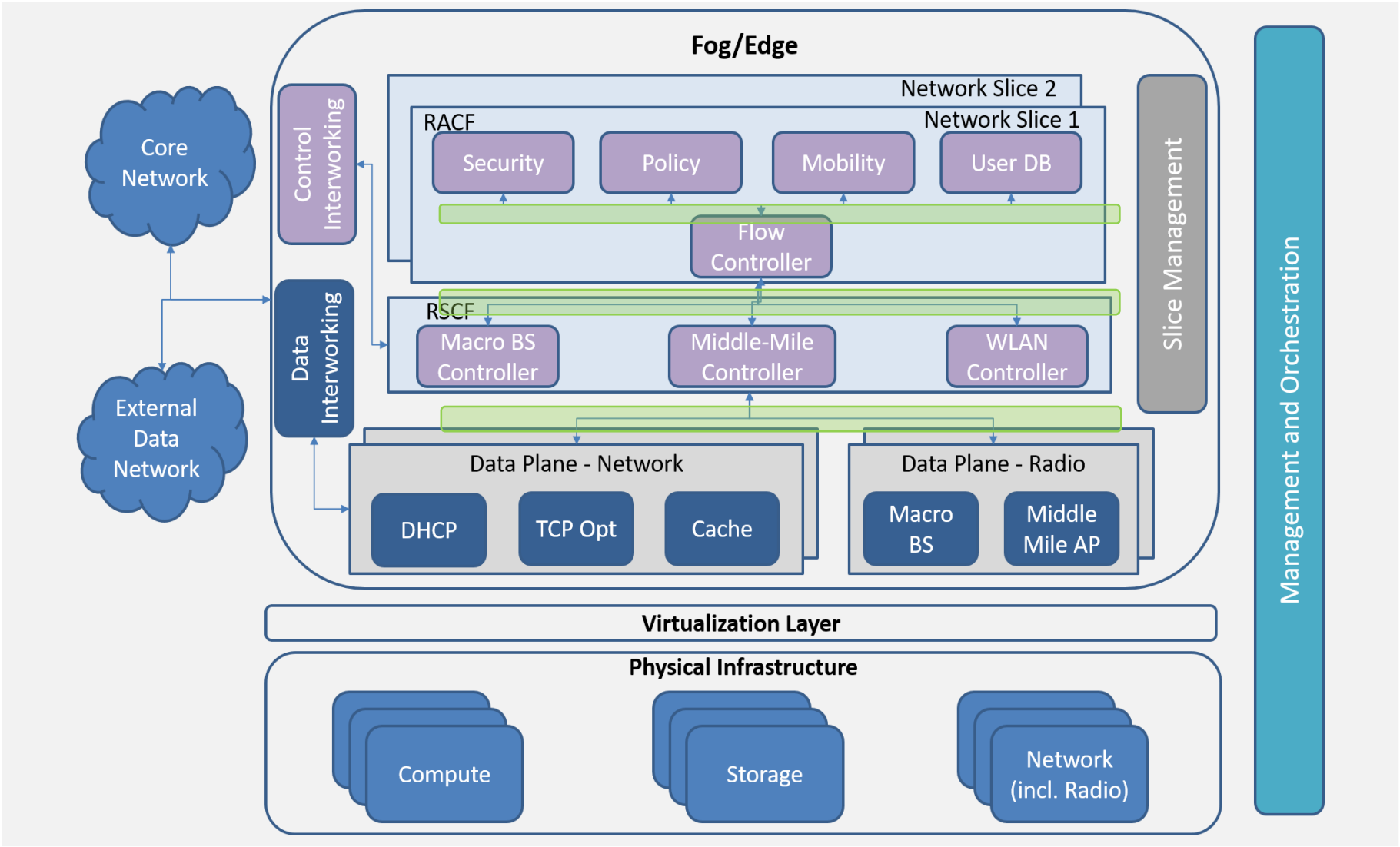
RAT Agnostic Control Functions (RACF)

RACFs operate over abstract resources provided by RSCFs

Flow controller analyses individual traffic flows and acts on it with help from other RACFs

RACFs enable localized communication under individual fog element

Frugal 5G Architecture – Fog/Edge Components



Interfaces

Interface between two RACFs : Service based Interface

Interface between Flow controller & RSCFs : NETCONF and OpenFlow (Modified)

Interface between RSCFs & the Corresponding Data Plane Entities : Similar to E1AP/F1AP (3GPP), CAPWAP (IETF)….

Frugal 5G Qualitative Analysis

Requirements for Rural area networks	Supporting features in the Frugal 5G network
Affordability	• Low-cost WLAN and middle mile network nodes in the clusters • Middle mile network can utilize unlicensed spectrum • Multi-operator sharing of resources using NFV and SDN • Flexible edge access network control to utilize underlying resources efficiently
Connectivity in clusters	Deployment of high-speed WLAN in clusters to provide connectivity
Low power consumption	• Low power WLAN and middle mile network nodes which are able to work using renewable energy sources (supplements grid based supply)
Localized communication and storage	Edge access network availability near to the users provides • Local storage in the edge cache • Path for local communication without involving core network

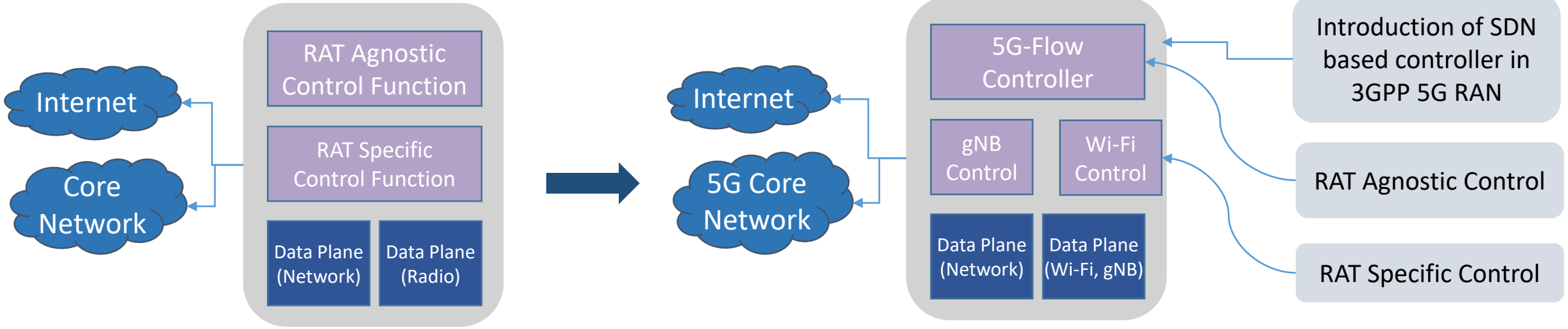
5G-Flow: Realizing Frugal-5G Architecture

Technology Selection

- Macro BS : 3GPP 5G NR based gNB
- WLAN : IEEE 802.11 based Wi-Fi APs

Applying Frugal 5G Framework

- RAT Agnostic Control : SDN based controller
- RAT Specific Control : Existing radio protocol stack



Frugal 5G Network (Edge Component)

5G-Flow: Implementing Frugal 5G concepts

Source: Khaturia M, Jha P and Karandikar A, Journal of Computer Networks (2021)

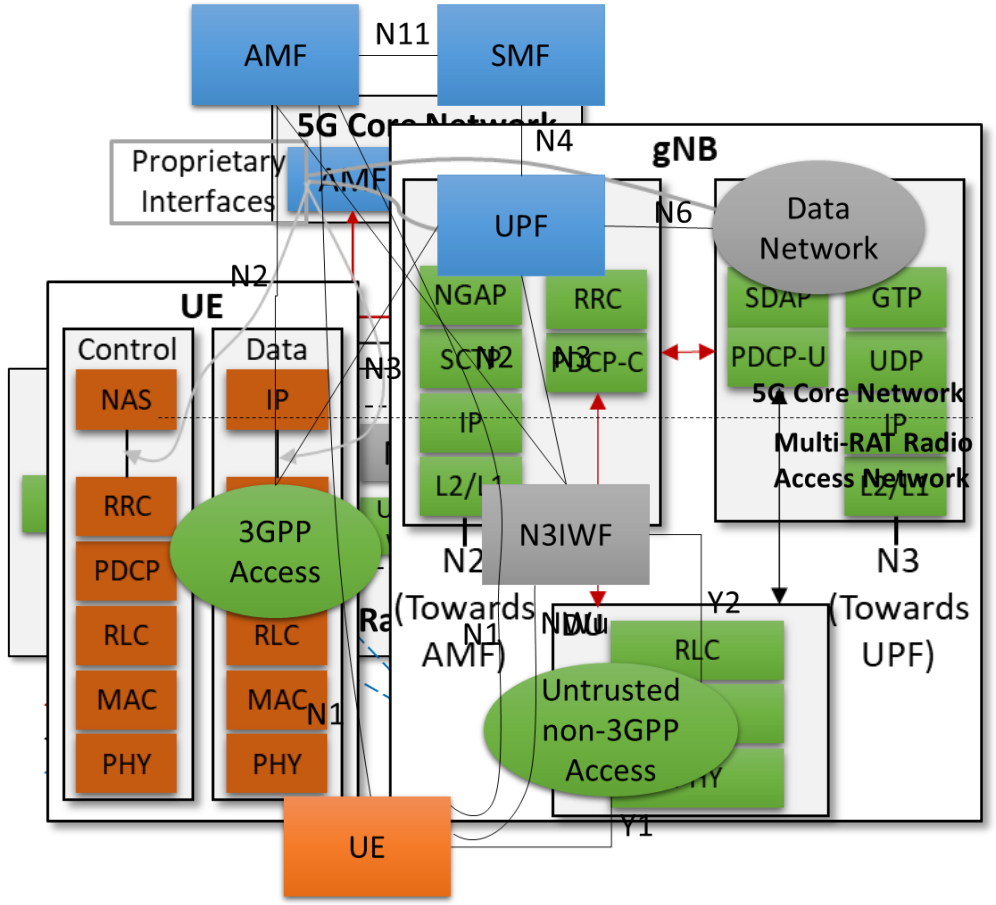
5G-Flow: Realizing Frugal 5G Architecture

Desired Network Characteristics

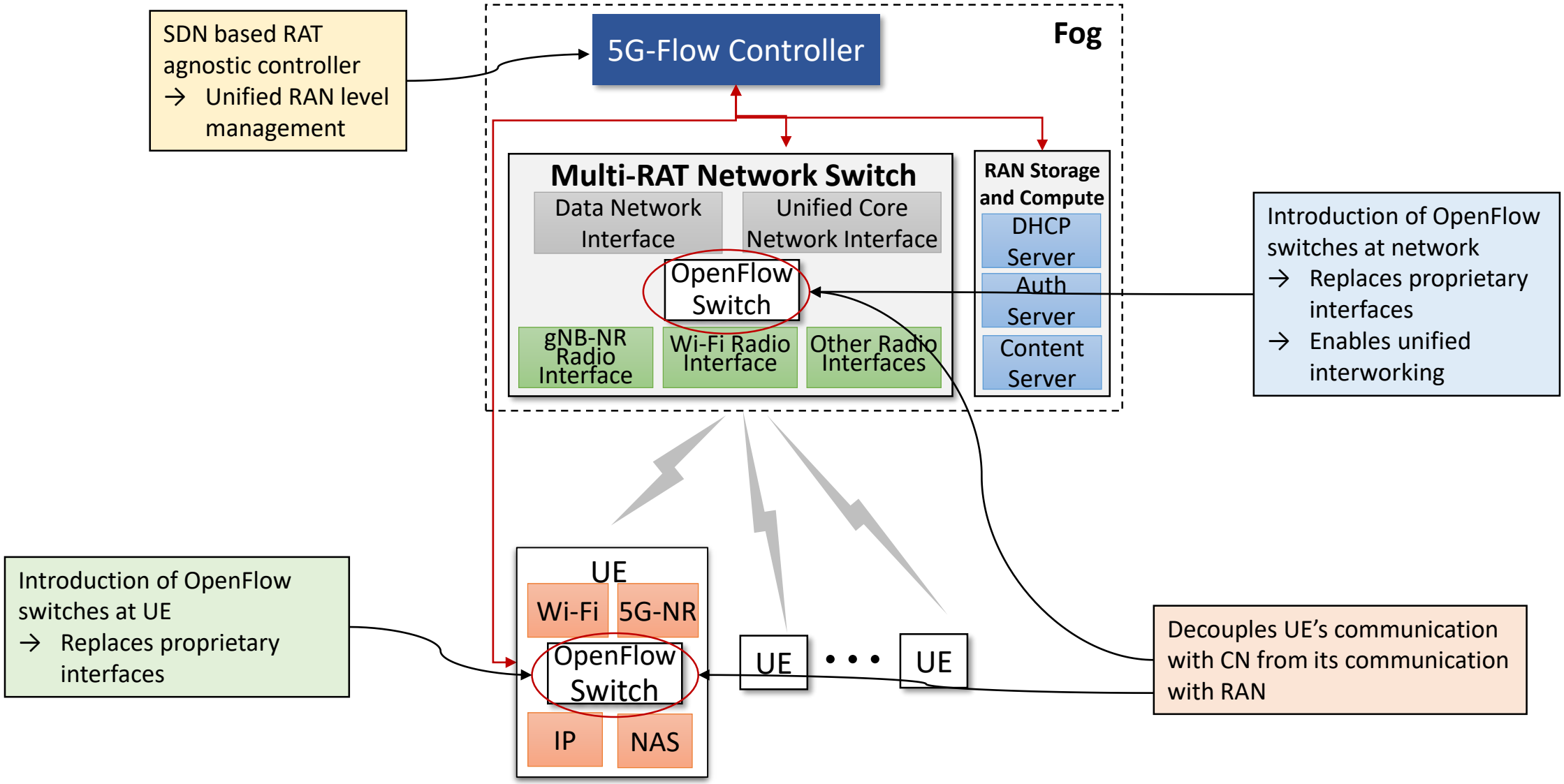
1. Unified multi-access control at the edge
2. Unified Interface towards Core Network
3. Flexible Network Deployment
4. Localized Communication Support

3GPP 5G Implementation Challenges

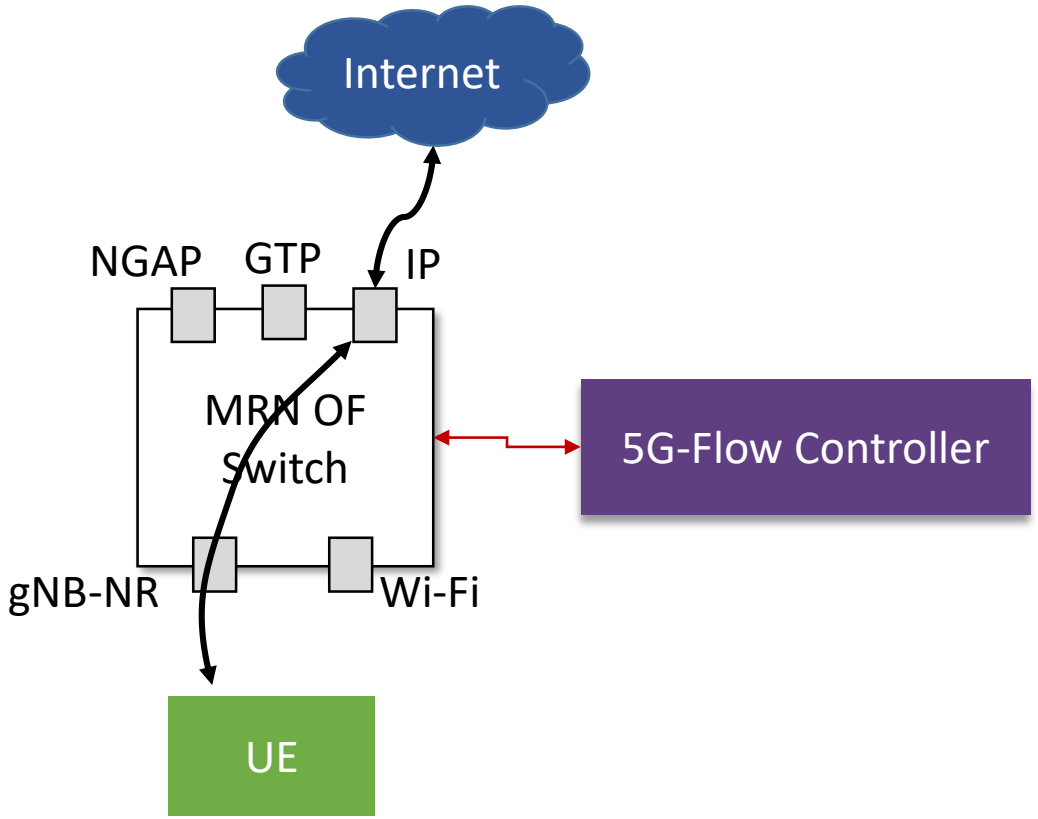
1. **Multi-RAT Unification at Core Network**
   - Frugal 5G proposes unification at edge
2. **Tight and proprietary coupling between Radio and CN protocol stacks**
   - RAT specific inter-working functions



5G-Flow Network: Architecture Overview



5G-Flow Capabilities - Direct Connectivity to Internet



Existing cellular technologies, e.g., LTE/5G NR requires support of Core Network (CN)

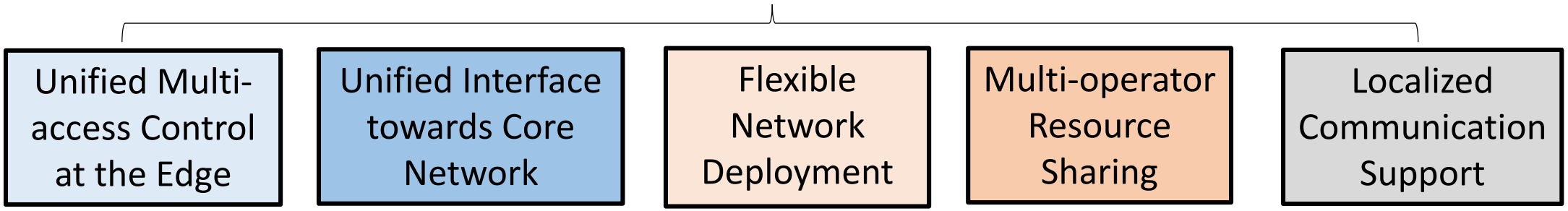
- Can not work in a standalone manner without CN

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

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 which supports:



- Ongoing/Future work
  - Our group leading P2061 Standardization: Expected to complete in 2022
  - Detailed cost analysis of IAB based Frugal 5G network
  - Implementation of 5G-Flow network

THANK YOU

LMLC Requirement Accepted @ ITU

eMBB

Indoor Hotspot eMBB

- Config A 4GHz
- Config B 30GHz
- Config C 70GHz

Dense Urban eMBB

- Config A 4GHz (1 layer)
- Config B 30GHz (1 layer)
- Config C 4/30GHz (2 layers)

Rural eMBB

- Config A 700MHz ISD 1.732 km 120/500 Km/h
- Config B 4GHz ISD 1.732 km 120/500 Km/h

- LMLC 700 MHz ISD 6Km 30 Km/h

MMTC

Urban Macro MMTC

- Config A ISD 500m
- Config B ISD 1.732 Km

URLLC

Urban Macro URLLC

- Config A 4 GHz
- Config B 700 MHz

In addition, for the Rural-eMBB test environment, the average spectral efficiency value should meet the threshold values for the LMLC evaluation configuration with ISD of 6 Km and evaluation configuration A & B with ISD of 1.732 Km

Low Mobility Large Cell Requirement accepted as Mandatory IM2020 Usage Scenario (M.2083) @ WP5D Mtg# 28 Oct ‘17