SDN for 5G Wireless Networks: Research and Standardization Directions

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Abhay Karandikar
Director
Indian Institute of Technology Kanpur, India
director@iitk.ac.in
karandi@ee.iitb.ac.in

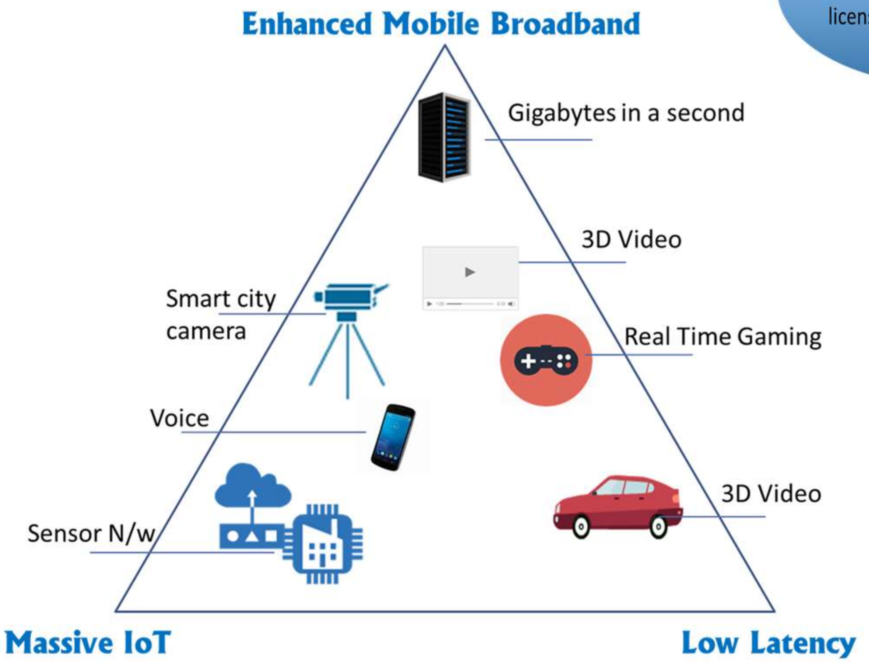
Pranav Jha
Senior Consultant
Indian Institute of Technology Bombay, India
pranavjha@ee.iitb.ac.in

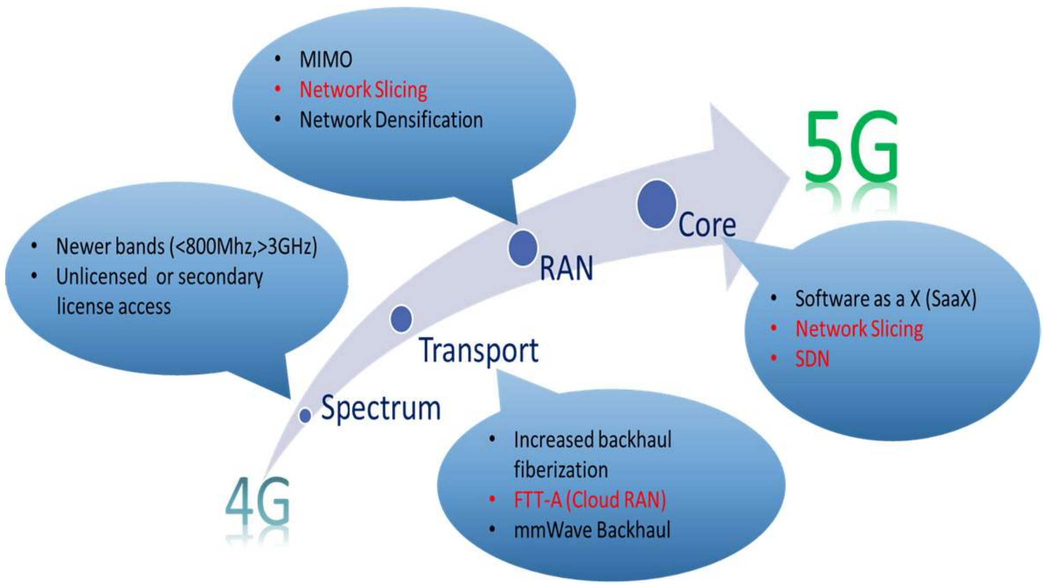
Agenda

- Introduction to 5G Wireless Communication Networks
- Introduction to SDN
- SDN and Wireless Networks
- Research in Wireless SDN
- SDN in 5G Standardization
- Frugal 5G - A Novel Use Case of SDN in Wireless Networks

Introduction to 5G Wireless Communication Networks

What is 5G?





Key Use Cases

- Ultra Reliable Low Latency Communications (URLLC)
- Massive Machine Type Communications (MMTC)
- enhanced Mobile Broad Band (eMBB)

***Courtesy**: International Telecommunication Union*

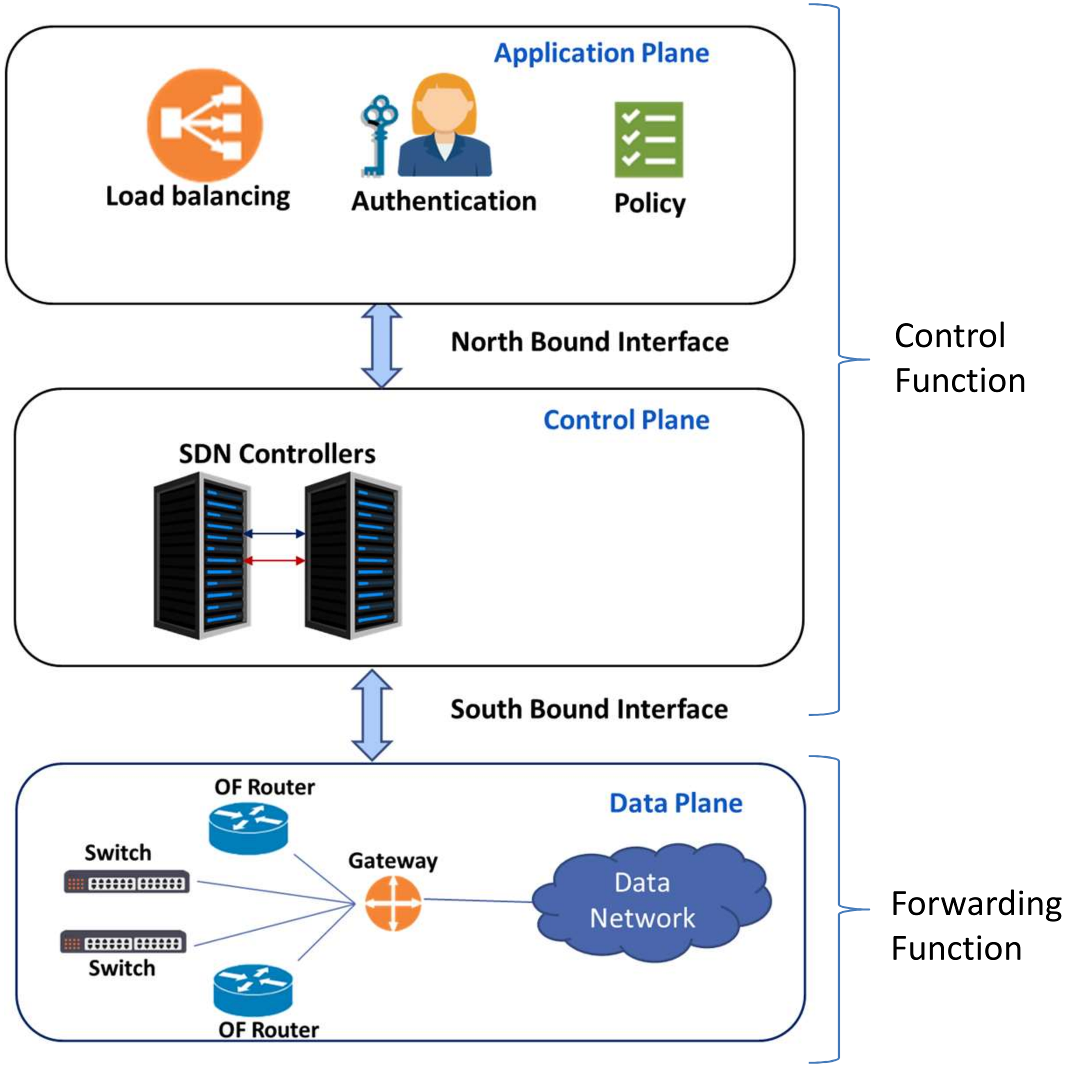
Introduction to SDN

Towards Software Defined Networking (SDN)

- Existing Communication Networks
  - Tightly coupled control and forwarding functions
    - Proprietary Interfaces
  - Distributed Intelligence and State
    - Distributed across a large number of network elements
- Tight Coupling between Control and Forwarding Functions
  - Reduces Modularity
  - Abets Vendor Monopoly and Lack of Interoperability
  - Throttles Innovation
  - Hampers independent evolution of forwarding and control plane function/entities
- Distributed intelligence and state
  - Leads to Suboptimal decisions

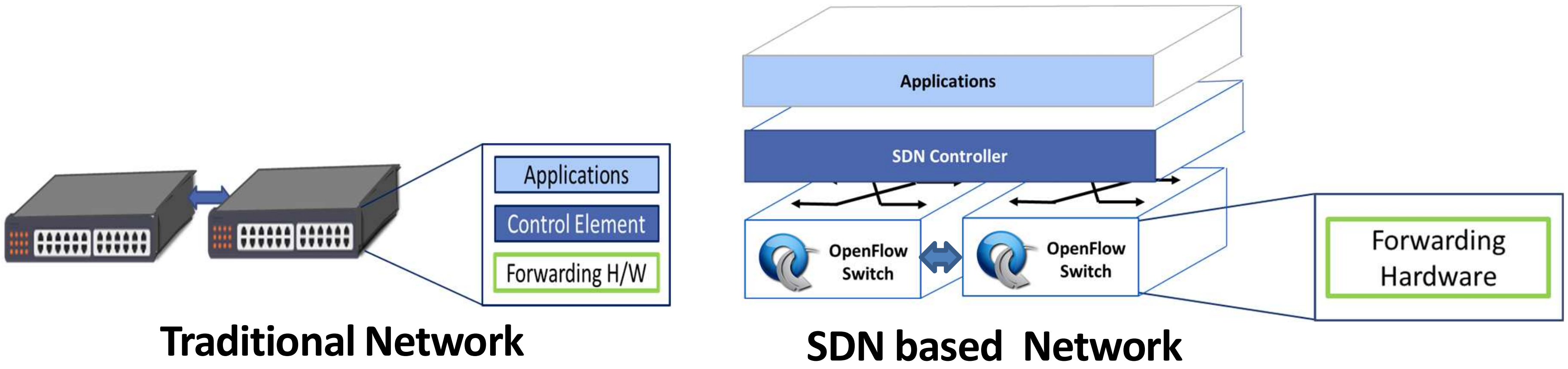
What is SDN?

- Separate Control and Forwarding functions
  - Separated through Open, Standardized interface
- Network divided into three planes
  - Forwarding/Data Plane
    - Forwarding Function/Elements
  - Control Plane
    - Configures forwarding elements
  - Applications Plane
    - Deals with Policies, Algorithms
      - Uniform policy enforcement
    - Exercises control over network resources



SDN Architecture

SDN v/s Traditional networks



- Traditional networks- de-centralized intelligence and state
  - suboptimal decisions due to fragmented view
  - Independent innovation at constituent planes not possible
- Software Defined Networks: intelligence and state logically centralized
  - Optimal decisions due to global view
  - Innovation can be carried out independently at each plane

What is SDN? Contd.

- Programmable Network
  - Application Provides policies, decisions to the Controller
    - Thru North bound interface
      - e.g., REST based interface
  - Controller configures Forwarding Elements
    - Thru South bound interface
      - e.g., OpenFlow, NETCONF
- Intelligence - logically centralized
  - Optimal decisions due to global view
- Independent Innovation possible for all three layers

SDN and Wireless Networks

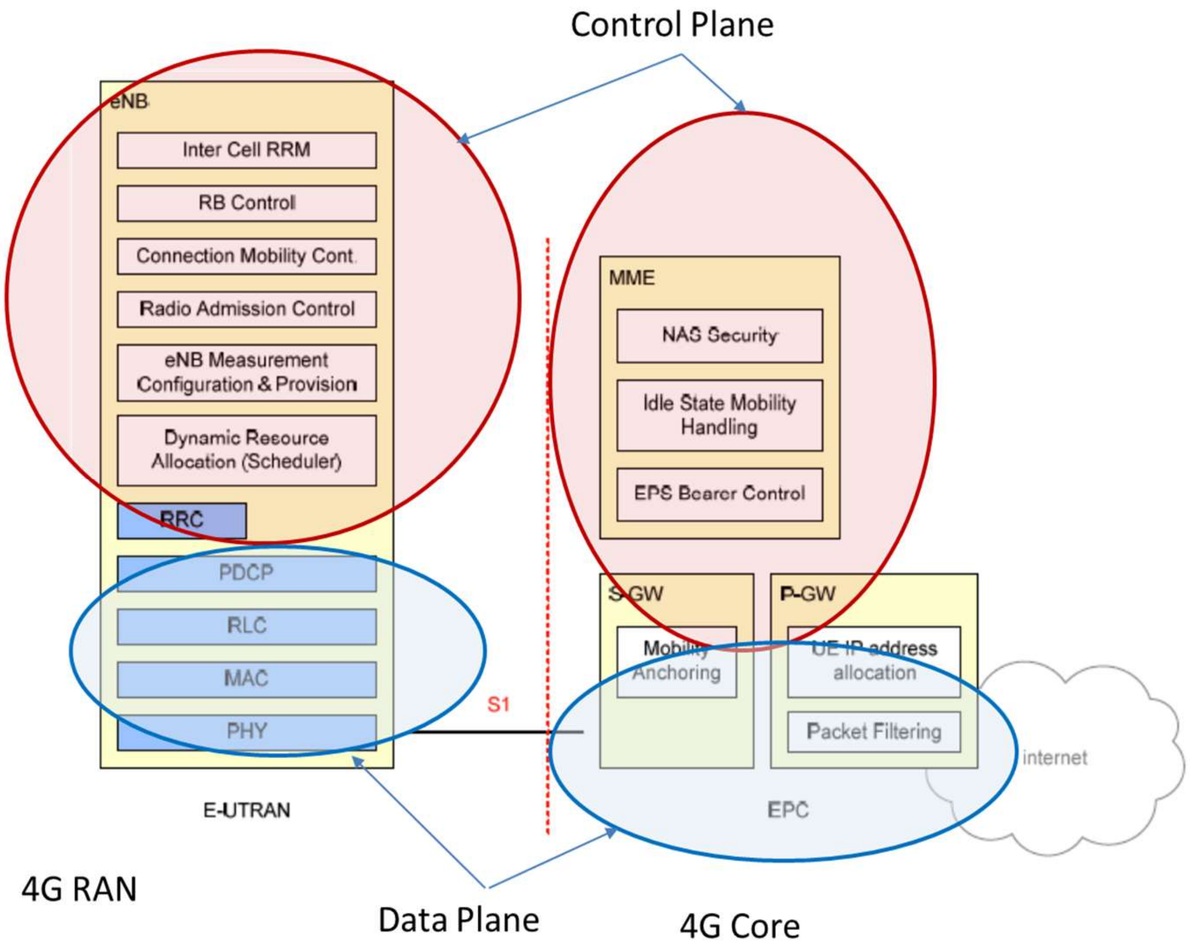
Wireless Networks : The need for SDN

- Similar problems as seen earlier
  - Tightly coupled Control and Data Planes
  - Distributed Intelligence
- Wireless communication specific issues
  - Existence of multiple Radio Access Technologies, e.g., LTE, WiFi
    - Independent Control and Management of RATs
    - Sub-optimal network performance
  - User Association and Mobility
    - Signal strength based User association to Network
    - Change in user association due to Mobility
    - Uneven load across network elements
  - Distributed Interference Management
    - Inefficient network utilization

3GPP LTE Architecture – Compatibility with SDN?

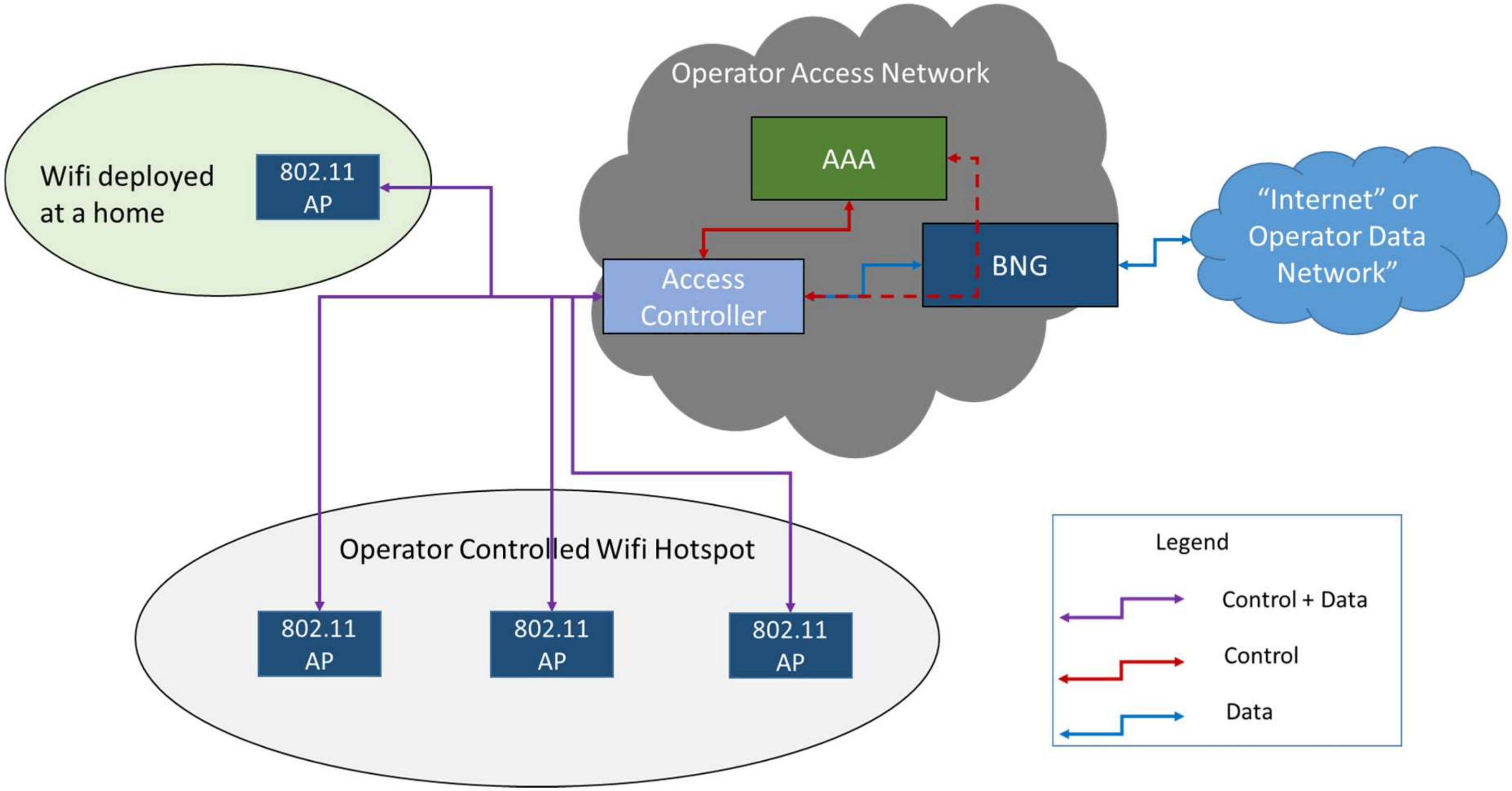
- 4G RAN
  - Control plane consists of RRC, RRM
  - Data plane consists of PDCP and lower layers
- 4G Core
  - MME
    - Control plane entity
  - SGW/PGW
    - Both data and control plane functionality

- **Issues ??**
- *Separation between the Control and Data Planes*
  - *neither open nor standardized*
- *Distributed Intelligence in RAN*



Courtesy: *3GPP TS 36.300, "Evolved Universal Terrestrial Radio Access Network (E-UTRAN); Overall description," 2017. [Online]. Available:http://www.etsi.org/deliver/etsi_ts/136300_136399/136300/13.02.00_60/ts_136300v130200p.pdf*

Existing Public WiFi Networks – Compatibility with SDN?



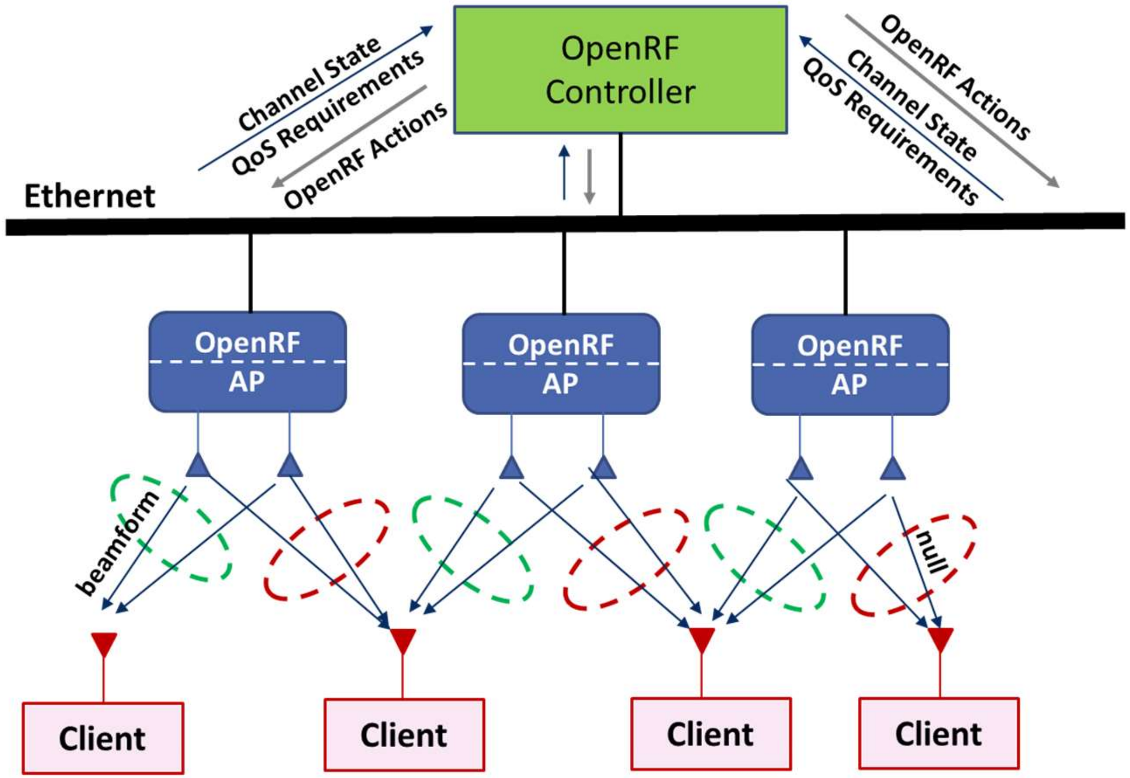
- Management and control of Access Points
  - Not compatible with SDN
  - Access Controllers - Typically integrated control and data plane nodes
- ***Separation between the Control and Data Plane***
  - ***Neither open nor standardized***

Research in 5G SDN

Some Examples

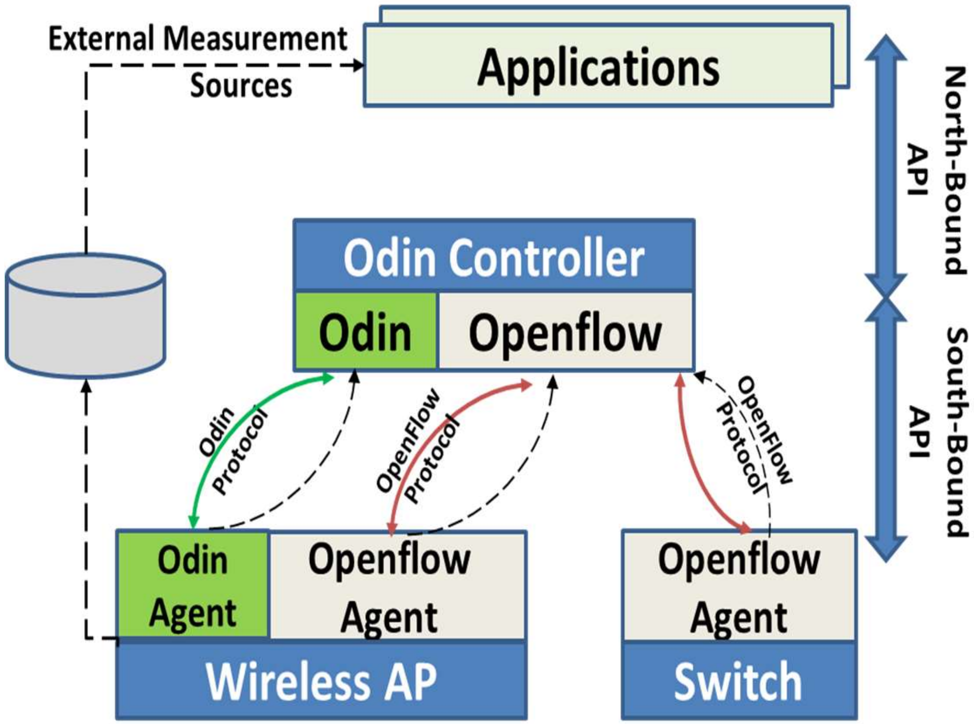
SDN based interference management for WLAN - OpenRF

- Interference an issue for WLANs
  - Clients may receive interfering signals from neighbouring Access Points (APs)
- OpenRF
  - SDN based scheme for Interference management
  - Controller to manage multiple Access Points
- Controller - AP Interface
  - Modified OpenFlow protocol
  - interference control information supplied to APs



Courtesy: *S. Kumar, D. Cifuentes, S. Gollakota, and D. Katabi, "Bringing Cross-Layer MIMO to Today's Wireless LANs," ACM SIGCOMM Computer Communication Review, 2013.*

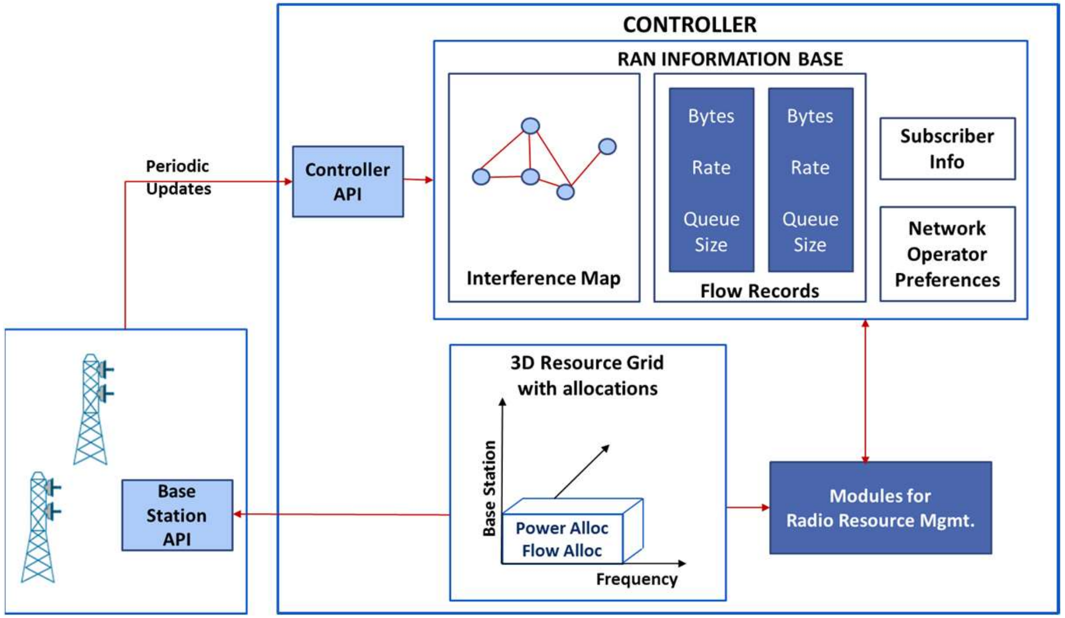
SDN based Load Balancing in WiFi Networks - ODIN



- Concept of virtual APs
  - One virtual AP for each client (UE)
  - Instantiated on physical AP and associated with Client
- Virtual AP is moved across physical APs along with the movement of Client
  - No handover overheads
- Enables centralized control of load balancing and mobility

Courtesy: *J. Schulz-Zander, L. Suresh, N. Sarrar, A. Feldmann, T. Huhn, and R. Merz, "Programmatic Orchestration of WiFi Networks," USENIX Annual Technical Conference, 2014*

SDN for Cellular RAN - SoftRAN



- Abstracts base stations in a geographic area as a large base station
  - Comprising of a controller and physical base stations
  - Controller maintains global view of the network
- Network state maintained in the form of database
- Decisions affecting other BSs made at controller
  - e.g. Handover, Transmit power
- Decisions not affecting neighbours made locally
  - e.g. RB Allocation

Courtesy:A. Gudipati, D. Perry, L. E. Li, and S. Katti, "SoftRAN: Software Defined Radio Access Network," ACM SIGCOMM workshop on Hot topics in software defined networking, 2013.*

SDN based end-to-end Architectures for 5G Wireless Networks

MobileFlow:

- Comprises of forwarding elements and a Controller
  - Mobile Flow Controller(MFC)
  - Mobile Flow Forwarding Elements (MFFE)
- Mobile Flow Controller and Applications used to steer traffic thru MFFEs
- Backward compatible with 4G core networks

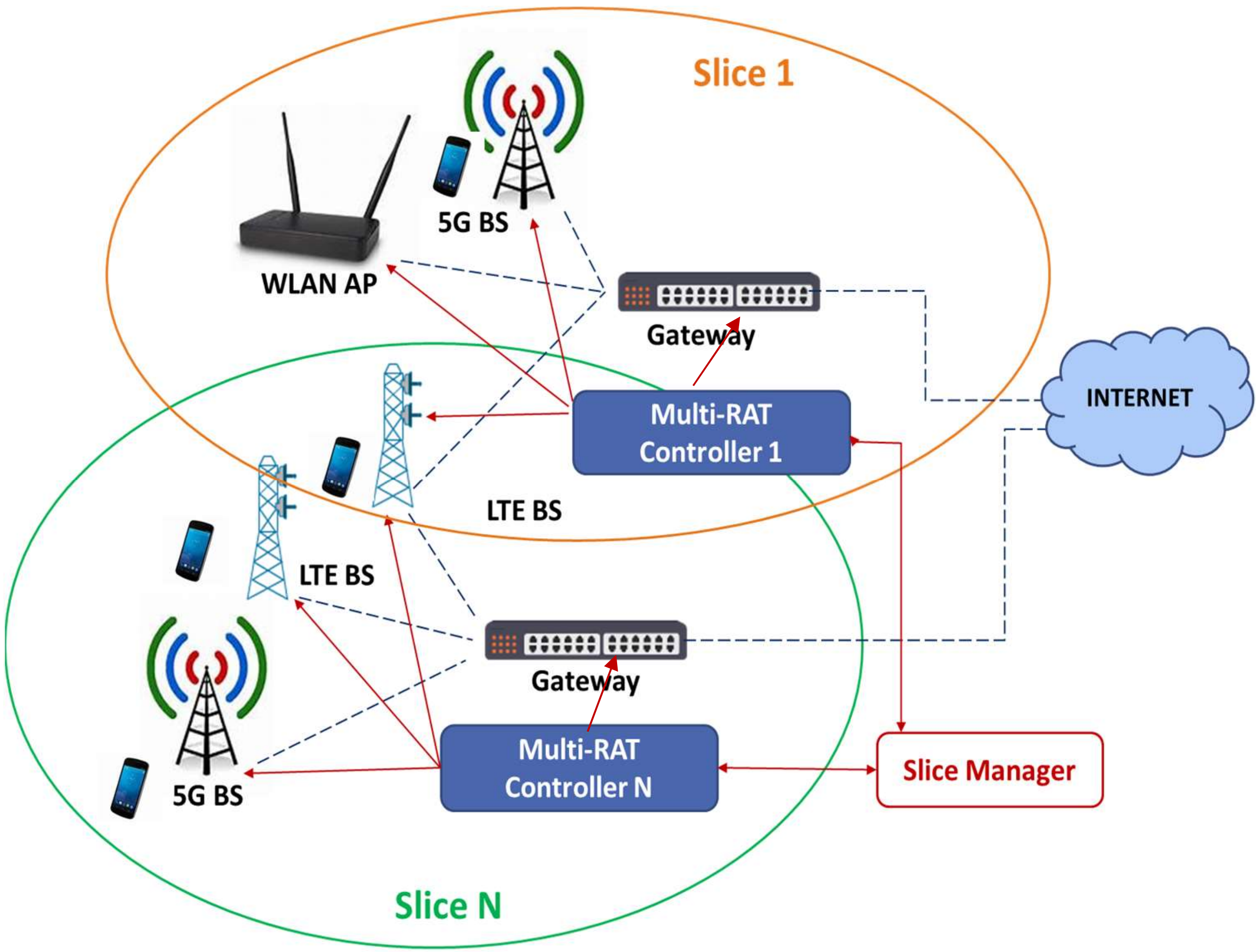
SoftAir:

- Supports control of multiple RATs
- Data plane
  - Software-defined base stations in the RAN
  - Software-defined switches for core
- Network Controller to control and manage the data plane entities
- Usage of OpenFlow as the interface between Control Plane and Data Plane

Courtesy: *Kostas Pentikousis, Yan Wang, and Weihua Hu, "MobileFlow: Toward Software-Defined Mobile Networks," IEEE Communications Magazine • July 2013.*
Ian F. Akyildiz, Pu Wang,Shih-Chun Lina, "SoftAir: A software defined networking architecture for 5G wireless systems" ComputerNetworks 85 (2015).

SDN based architecture for multi-RAT networks

- Separate data plane and control plane entities
  - Separated through a programmable interface
- Base Stations and Gateways are data plane entities
- Single controller for end-to-end Multi-RAT network control
  - Enables a unified view of the network
- Usage of Network Slice as a means to achieve control plane scalability



SDN based Wireless Network Architectures – Key Takeaways

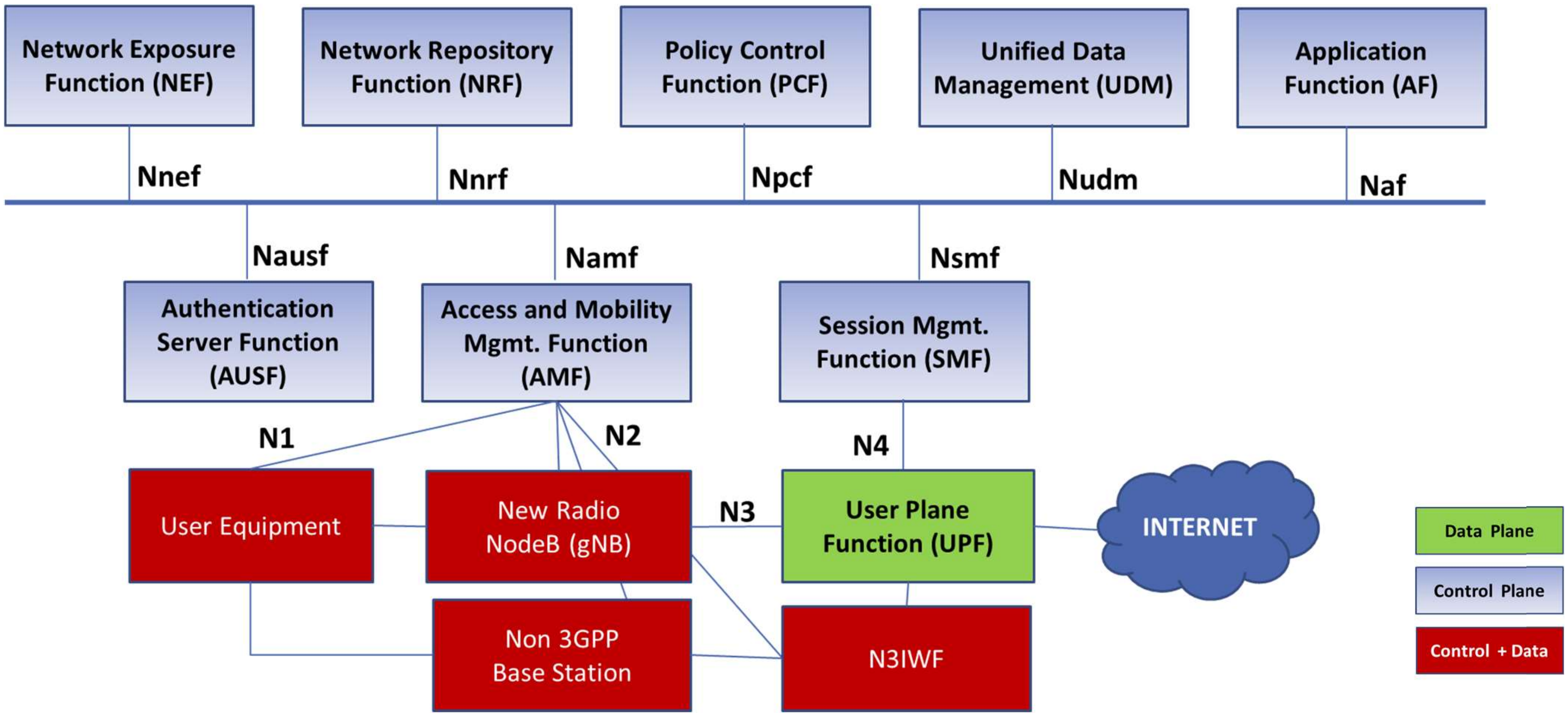
- Effective Interference Management
  - OpenRF
- Better Mobility Management & Load Balancing
  - ODIN for WLAN
- Efficient Radio Network Utilization
  - SoftRAN for Cellular Networks
- Unified Control and Management
  - Reduced Signaling Overheads and Efficient E2E Network Utilization
  - MobileFlow, SoftAir, Our work
- May bring additional advantages
  - Admission Control etc.

SDN based Standardization for 5G

3GPP 5G standardization

- SDN and NFV
  - Key technologies for 3GPP 5G standards
- Specifies components as Network Functions
- Data Plane and Control Plane Functions separated thru standardized interface
  - Both in Core and Radio Access Network (RAN)
- Control Plane Functions in Core Network (CN)
  - Access & Mobility Management Function (AMF)
  - Session Management Function (SMF)
  - …
- Forwarding Plane Function in Core Network
  - User Plane Function (UPF)

3GPP 5G Network Architecture – Impact of SDN and NFV



3GPP System Architecture : Courtesy TS 23.501

3GPP 5G Network Architecture viz-a-viz 4G Architecture

- 5G explicitly leverages
  - Software Defined Networking
    - Data Plane & Control Plane Functions separated through standard interface
- Only partially used in 4G and earlier systems
- What does it facilitate in 5G?
  - Open, standardized separation between the Data Plane and the Control Plane functions
  - Independent scalability
  - Independent evolution
  - Flexible Deployments
  - Interesting Use Cases like Network Slicing

3GPP 5G standardization - Network Slicing

- Network Slicing
  - Splits a single physical network in multiple virtual networks
  - A slice provides differentiated treatment to data flows
- Network slice is defined end-to-end
  - consists of RAN as well as CN part
- Different slices (virtual networks)
  - Support different usage scenarios
  - One slice may support eMBB, the other one mMTC

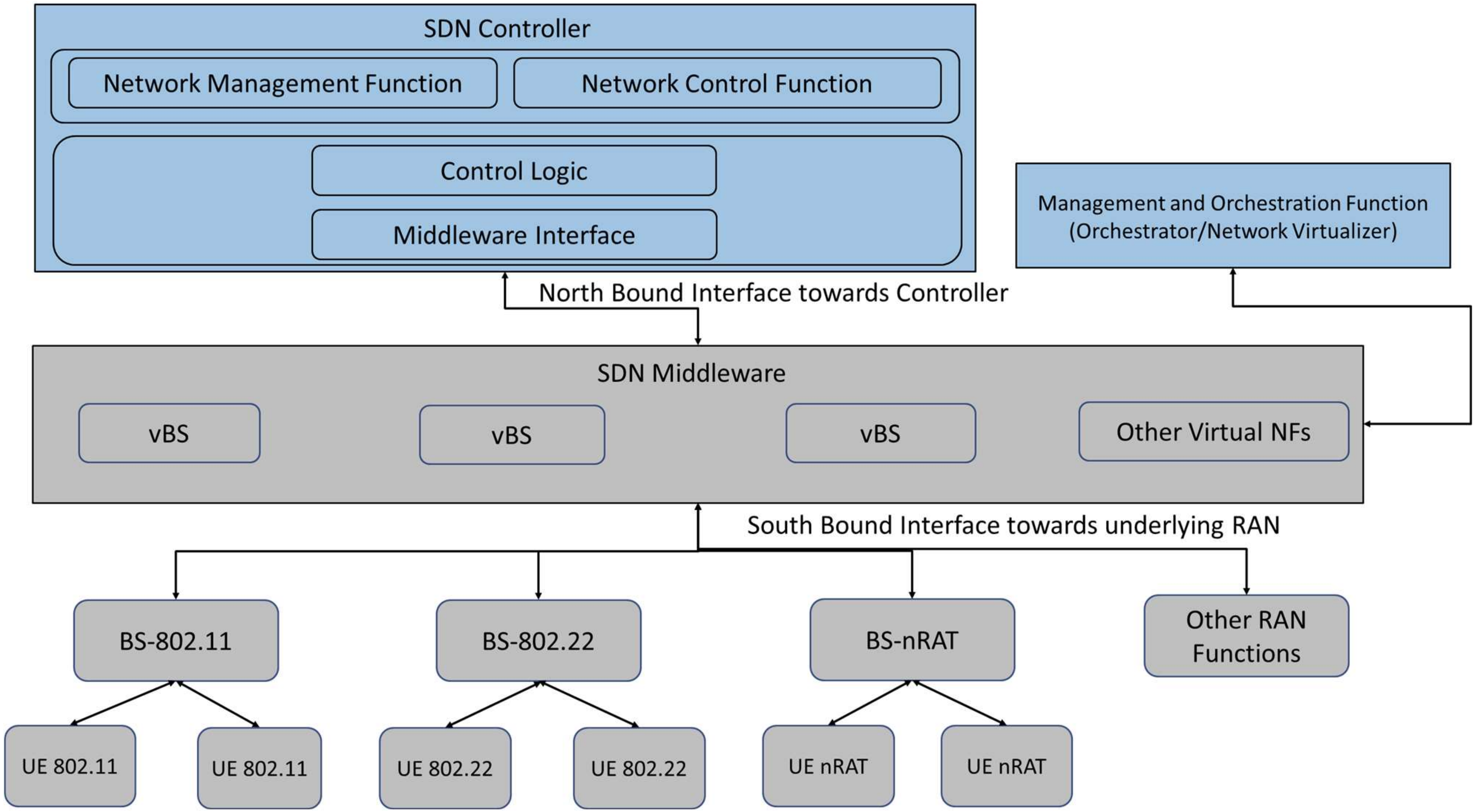
IEEE - Standardization Activities for 5G SDN

Project No.	Name	Scope
P1915.1	SDN and NFV Security	Specifies security framework, models, analytics, and requirements for SDN and NFV based environment
P1916.1	SDN and NFV Performance	Specifies performance framework including models, terminology and analytics for optimized system operations
P1917.1	SDN and NFV Reliability	Specifies a framework to build and operate SDN/NFV service delivery infrastructure that satisfies reliability expectations of operators, content providers etc.
P1921.1	Bootstrapping Procedures	Introduces automation in networking by means of an SDN bootstrapping procedure

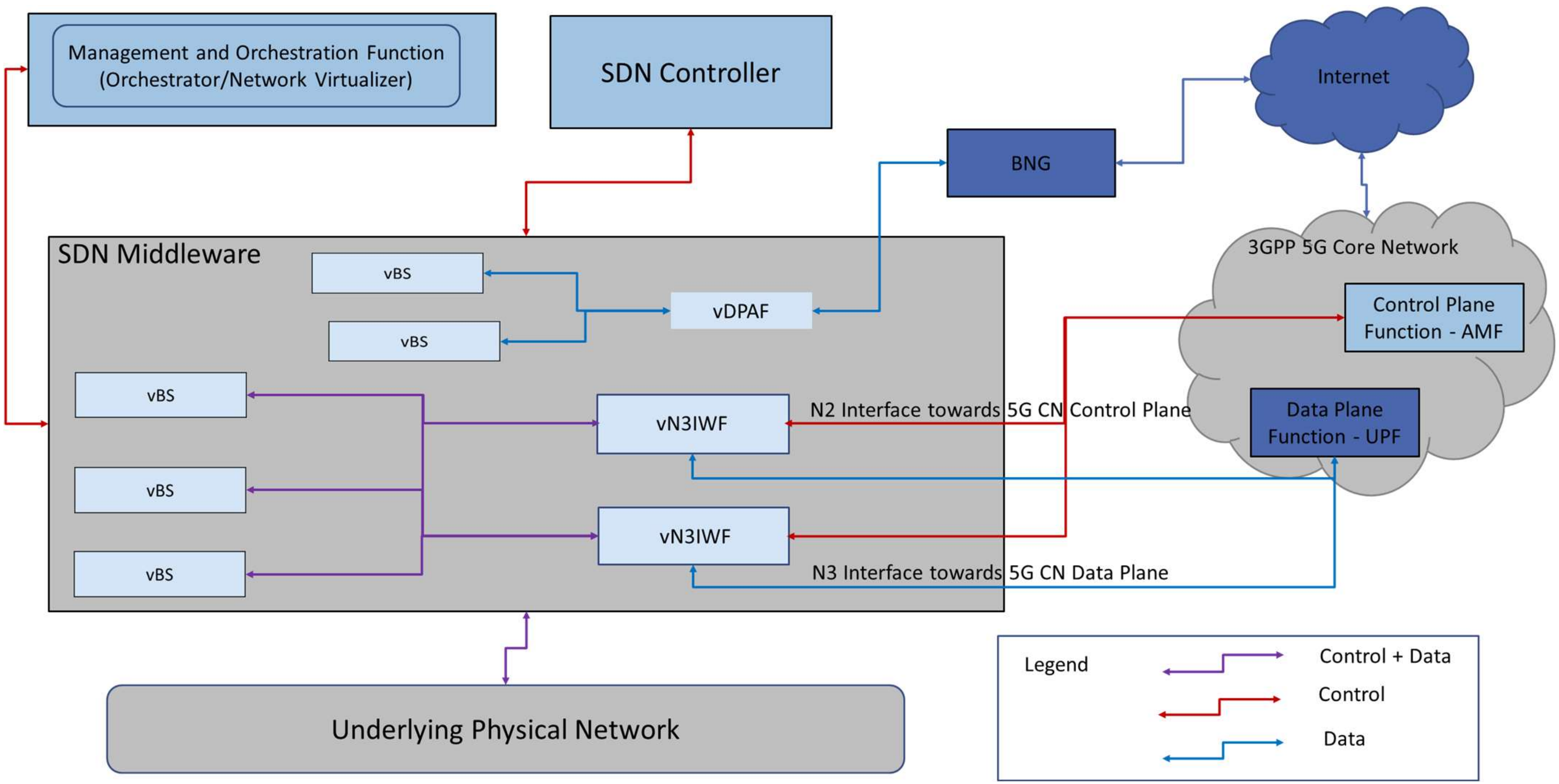
IEEE 5G SDN standardization Activities-P1930.1

- Recommended Practice for
  - SDN based Middleware to facilitate
    - Control and Management of Wireless Access Network
- Specifies
  - An SDN based Architecture for control and management of Multi-RAT Radio Access Network
  - An SDN based Middleware
    - For vendor independent management and control of Wireless Networks
      - especially IEEE 802.11 APs and IEEE 802.22 Base Stations
    - Aims to achieve interoperability across equipment from different vendors
    - Supports a unified interface with the 5G Core Network

IEEE 5G P1930.1 – SDN based RAN Architecture



IEEE 5G P1930.1 – SDN based RAN Architecture



Frugal 5G - A Novel Use Case for SDN

Broadband/Internet Penetration Status: Worldwide

	2010	2015	2016	2017 (E)
Population (in billions)	7.1	7.3	7.5	7.6
Mobile cellular subscriptions (in billions)	5.3	7.2	7.5	7.7
Unique mobile subscribers* (in billions)	3.2	4.6	4.79	5
Mobile Broadband subscriptions (in billions)	2.02	3.30	3.86	4.22
Individuals using the Internet (in billions)	1.09	3.15	3.39	3.58
Fixed broadband subscribers (in millions)	526	842	917	979

Summary Statistics for the Telecom Market, 2010-2017

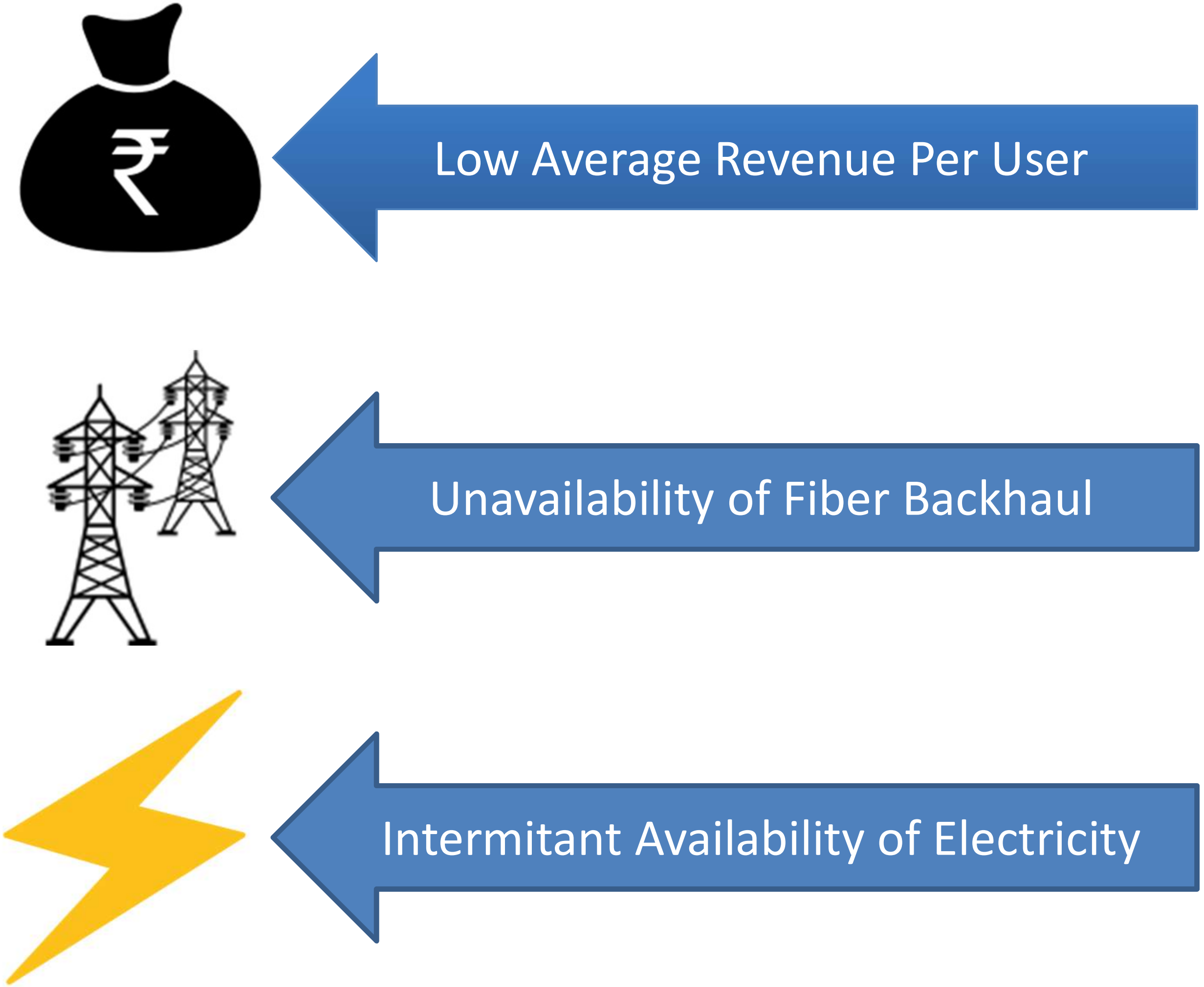
Region	Total Population No. of Inhabitants (millions)	Total no. of people unconnected by mobile (millions)	Total no. of people unconnected by Internet (millions)	% of the Internet-unconnected Population
Africa	1,060.67	583.41	738.58	17.8%
Americas	1004.65	282.52	334.81	8.1%
Arab States	314.95	121.97	239.77	5.8%
CIS	283.09	61.92	113.55	2.7%
Europe	635.55	136.08	140.50	3.4%
Asia-Pacific	4,132.64	1,470.02	2,572.98	62.2%
Total	**7,399.96**	**2,615.76**	**4,140.18**	**100.0%**

Location of Individuals using & not using Internet, 2016

Around half of the global population is unconnected

Source: International Telecommunication Union

Challenges in connecting Rural Areas in a country like India



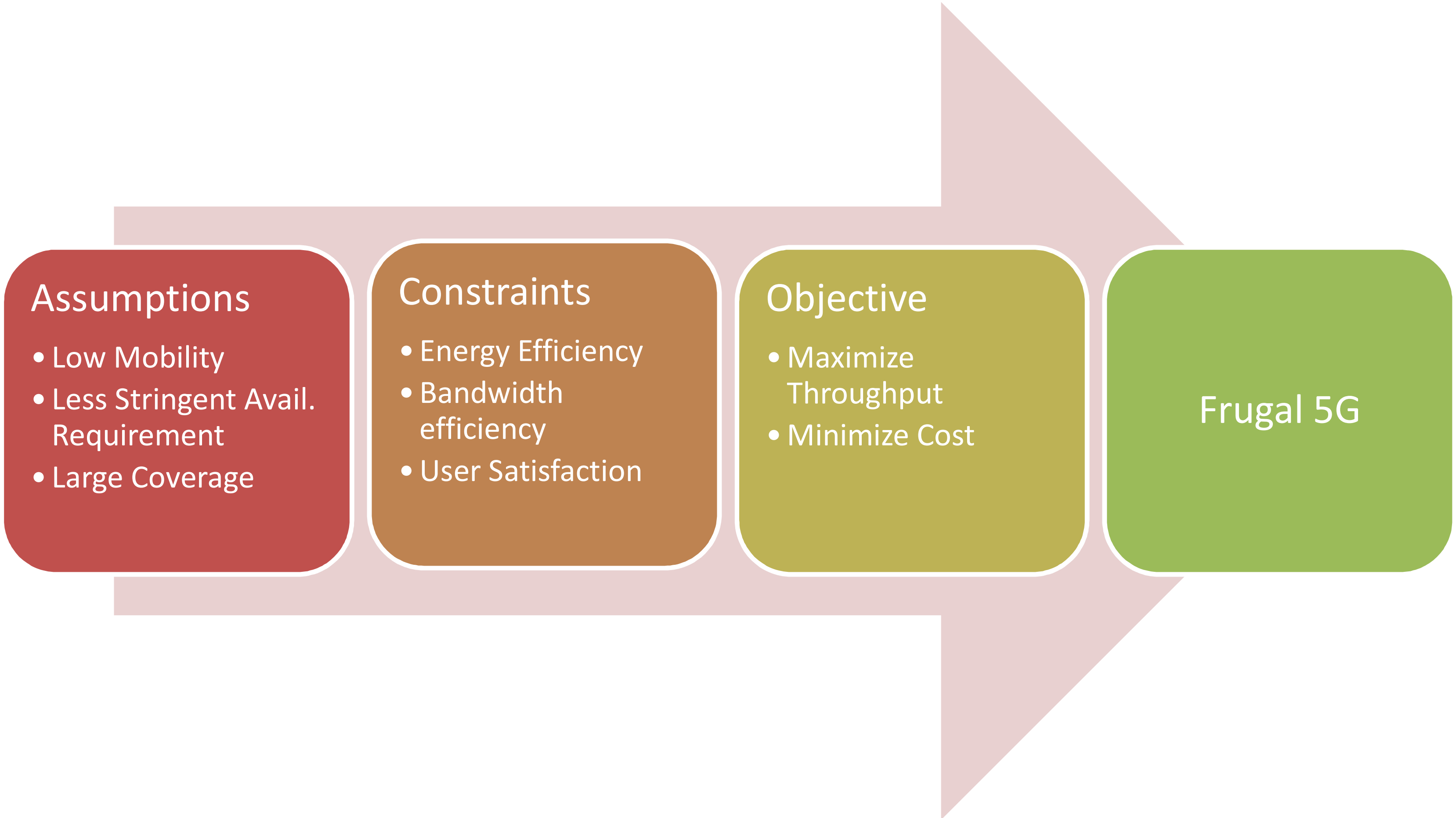
Rural Broadband Connectivity - Rethinking 5G Requirements

- Low cost solution
  - Low Device costs
    - Simpler Hardware and RF Design reducing the device costs
  - Low cost Connectivity / backhaul solutions
    - Using wireless backhaul/middle mile instead of fiber
  - Lower spectrum cost
    - Efficient usage of spectrum
    - Using network sharing options to share spectrum across Radio Access Technologies (RATs) across operators
- Limited mobility support
  - Mobility is required but not very high speed
  - Fixed primary access is the key

Rural Broadband Connectivity - Rethinking 5G Requirements contd.

- Energy efficient solutions
  - Lowering system energy consumption
  - Support for operation in power saving mode
  - To enable working off non-conventional energy sources
- Large coverage area support
  - Support for large cells to reduce CAPEX and OPEX
- Less stringent availability requirements

SDN based Broadband Wireless Network for Rural Connectivity – Frugal 5G

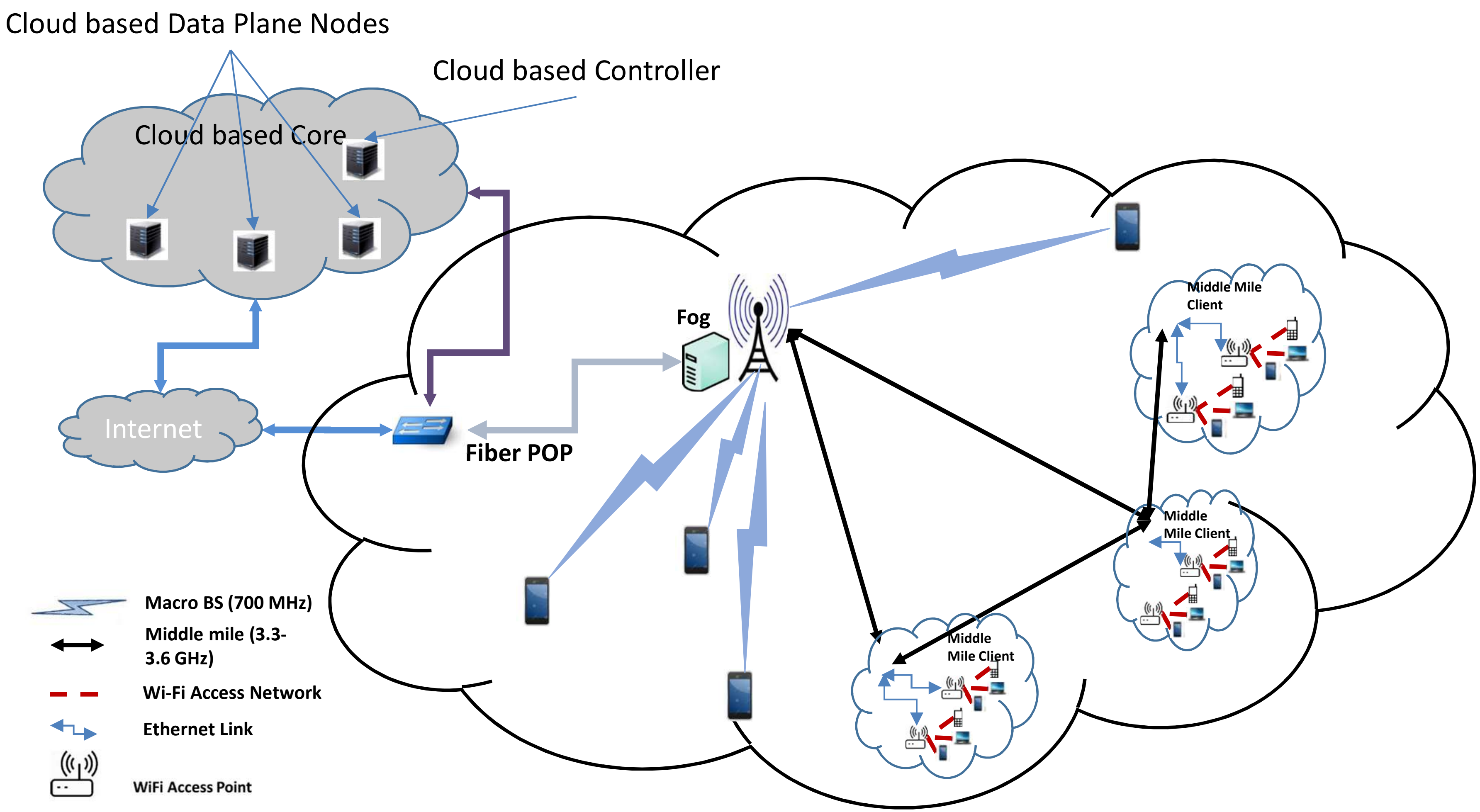


- Aimed at providing affordable primary broadband connectivity to rural areas
- Standardization of reference architecture initiated under IEEE - P2061

Frugal 5G – Key Features

- Large Coverage Area Cells to provide ubiquitous connectivity
- Small Cells (WiFi Hotspots) as access points for high speed data connectivity
  - WiFi devices are very low cost devices
- Wireless Middle Mile Network to backhaul the data from WiFi Hotspots to Fiber POP
  - Point to point wireless links to connect the nodes in villages
- SDN based control and management of the network
  - Local (Fog/Edge) as well as Global (Cloud-based) Controllers

Frugal 5G – Proposed System Architecture



References

1. https://www.mckinsey.com/industries/telecommunications/our-insights/the-road-to-5g-the-inevitable-growth-of-infrastructure-cost
2. R. Alvizu, G. Maier, N. Kukreja, A. Pattavina, R. Morro, A. Capello, and C. Cavazzoni, “Comprehensive Survey on T-SDN: Software-Defined Networking for Transport Networks,” IEEE Communications Surveys & Tutorials, 2017.
3. I. T. Haque and N. Abu-Ghazaleh, “Wireless Software Defined Networking: A Survey and Taxonomy,” IEEE Communications Surveys & Tutorials , 2016.
4. S. Kumar, D. Cifuentes, S. Gollakota, and D. Katabi, “Bringing Cross-Layer MIMO to Today’s Wireless LANs,” ACM SIGCOMM Computer Communication Review, 2013.
5. J. Schulz-Zander, L. Suresh, N. Sarrar, A. Feldmann, T. Huhn, and R. Merz, “Programmatic Orchestration of WiFi Networks,” USENIX Annual Technical Conference, 2014.
6. A. Gudipati, D. Perry, L. E. Li, and S. Katti, “SoftRAN: Software Defined Radio Access Network,” ACM SIGCOMM workshop on Hot topics in software defined networking, 2013.
7. V. G. Nguyen, A. Brunstrom, K. J. Grinnemo, and J. Taheri, “SDN/NFV-Based Mobile Packet Core Network Architectures: A Survey,” IEEE Communications Surveys and Tutorials, 2017.

References (Contd.)

8. K. Pentikousis, Y. Wang, and W. Hu, “Mobileflow: Toward software-defined mobile networks,” IEEE Communications Magazine, 2013.
9. I. F. Akyildiz, P. Wang, and S. C. Lin, “SoftAir: A software defined networking architecture for 5G wireless systems,” IEEE Computer Networks, 2015.
10. A. Nayak, A. Roy, P. Jha, and A. Karandikar, “Control and Management of Multiple RATs in Wireless Networks: An SDN Approach” arXiv preprint arXiv:1801.03819, 2018.
11. A. Checko, H. L. Christiansen, Y. Yan, L. Scolari, G. Kardaras, M. S. Berger, and L. Dittmann, “Cloud RAN for Mobile Networks - A Technology Overview,” IEEE Communications Surveys and Tutorials, 2015.
12. P. Yang , N. Zhang , B. Yuanguo , L. Yu ,X. S. Shen, “Catalyzing cloud-fog interoperation in 5G wireless networks: An SDN approach”, IEEE Networks ,2017.
13. 3GPP TS 23.501, “System Architecture for the 5G System,” 2017. [Online]. Available:https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3144.
14. https://standards.ieee.org/develop/project/1930.1.html

Questions ??

THANK YOU