



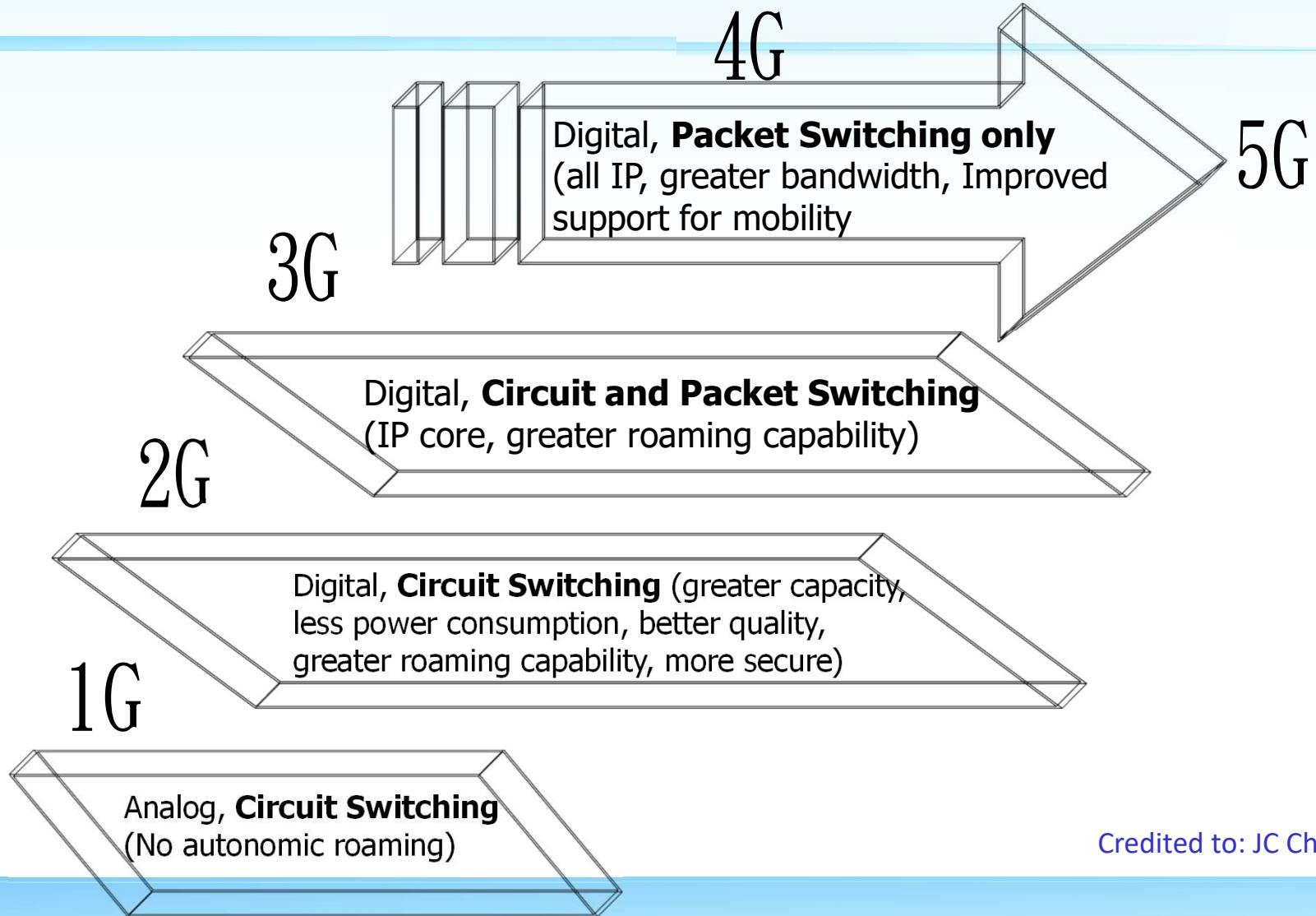
# Enabling Technologies for 5G Networks

**Professor Chien-Chao Tseng**

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National Yang Ming Chiao Tung University  
[cctseng@cs.nctu.edu.tw](mailto:cctseng@cs.nctu.edu.tw)



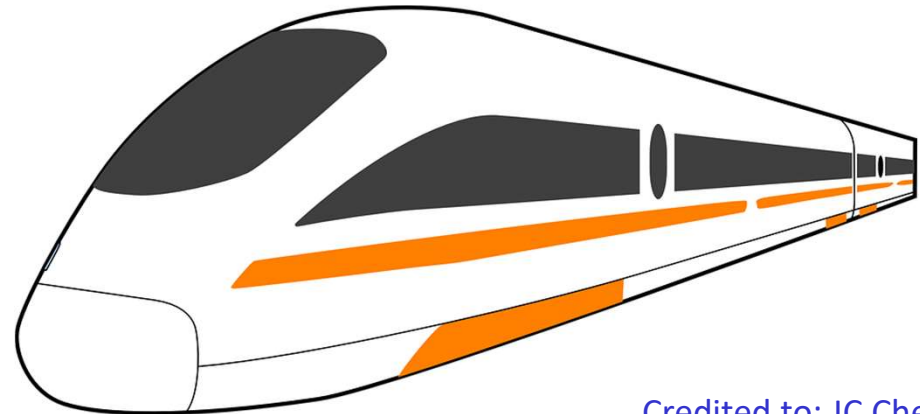
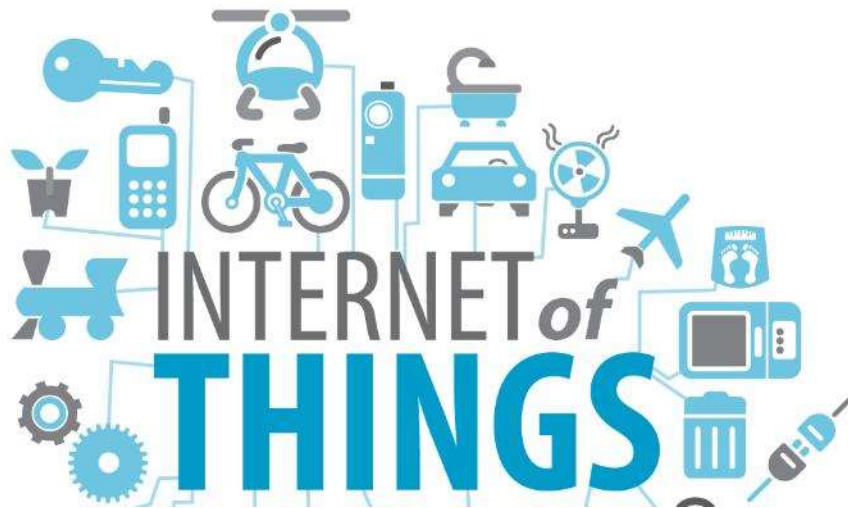
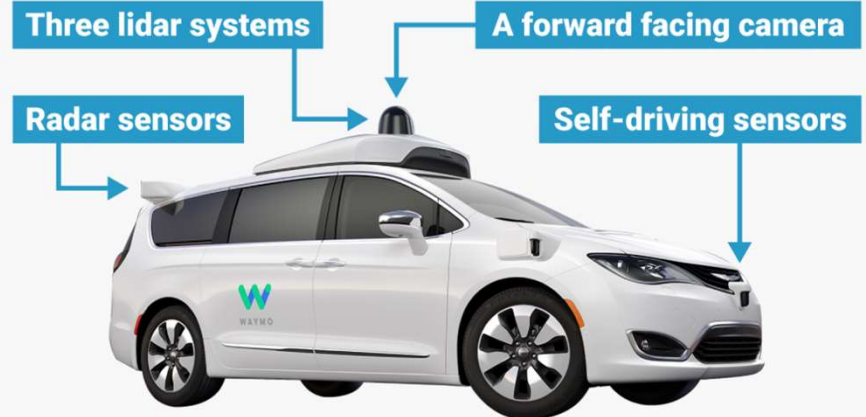
## Evolution from 1G to 4G



Credited to: JC Chen



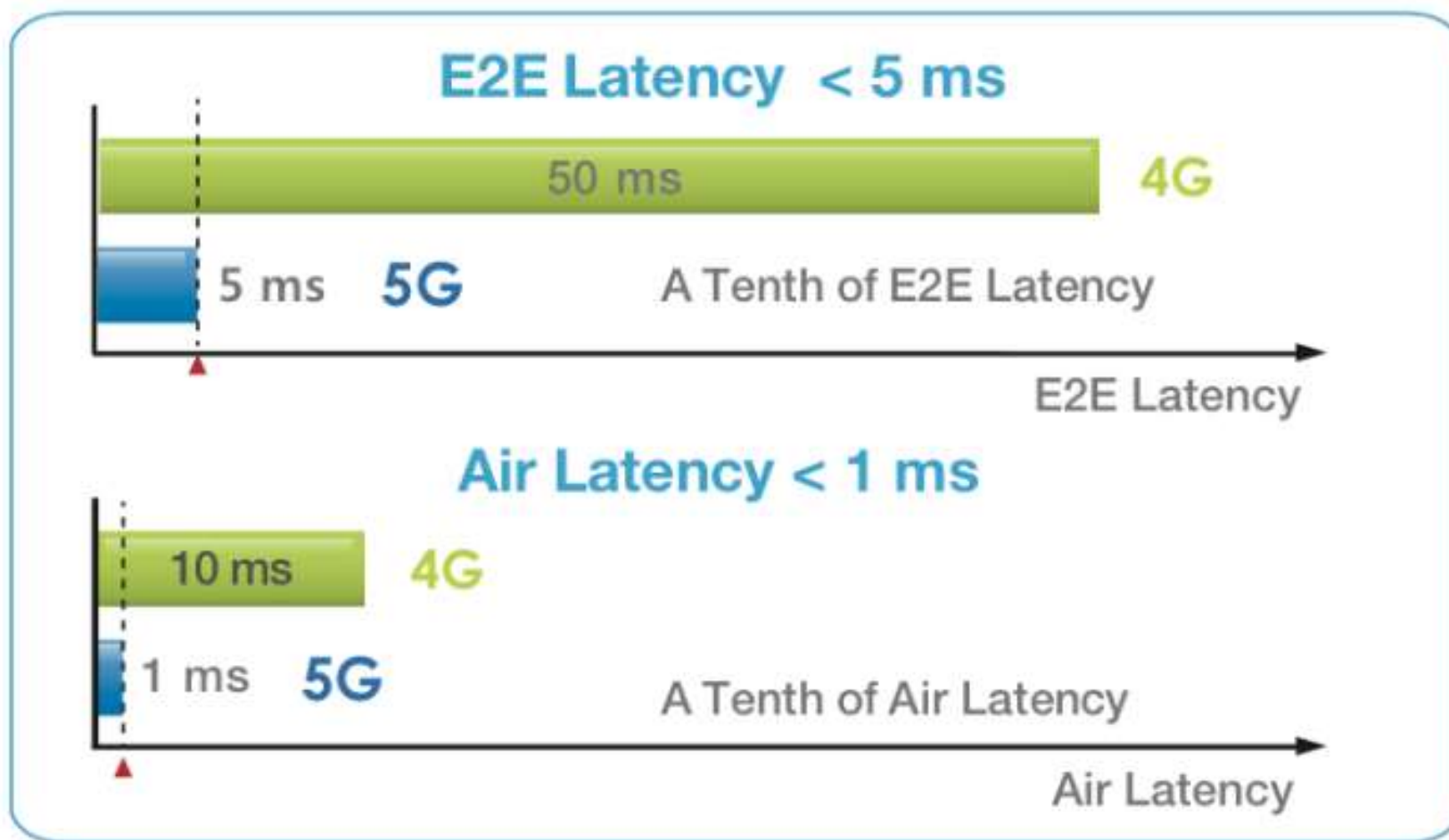
## More and more applications



Credited to: JC Chen



## Lower and lower latency

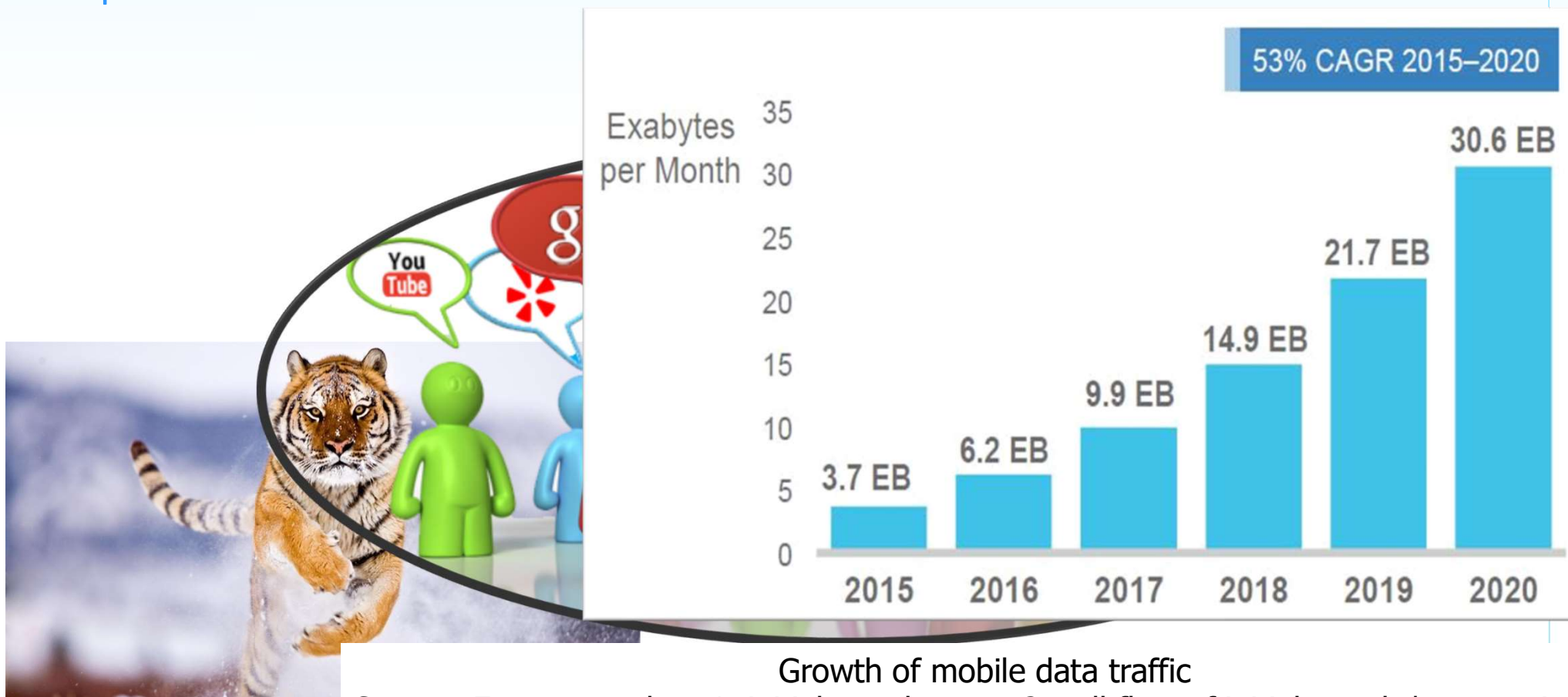


Credited to: JC Chen



# More and more data transmitted

- Explosive multimedia and social services

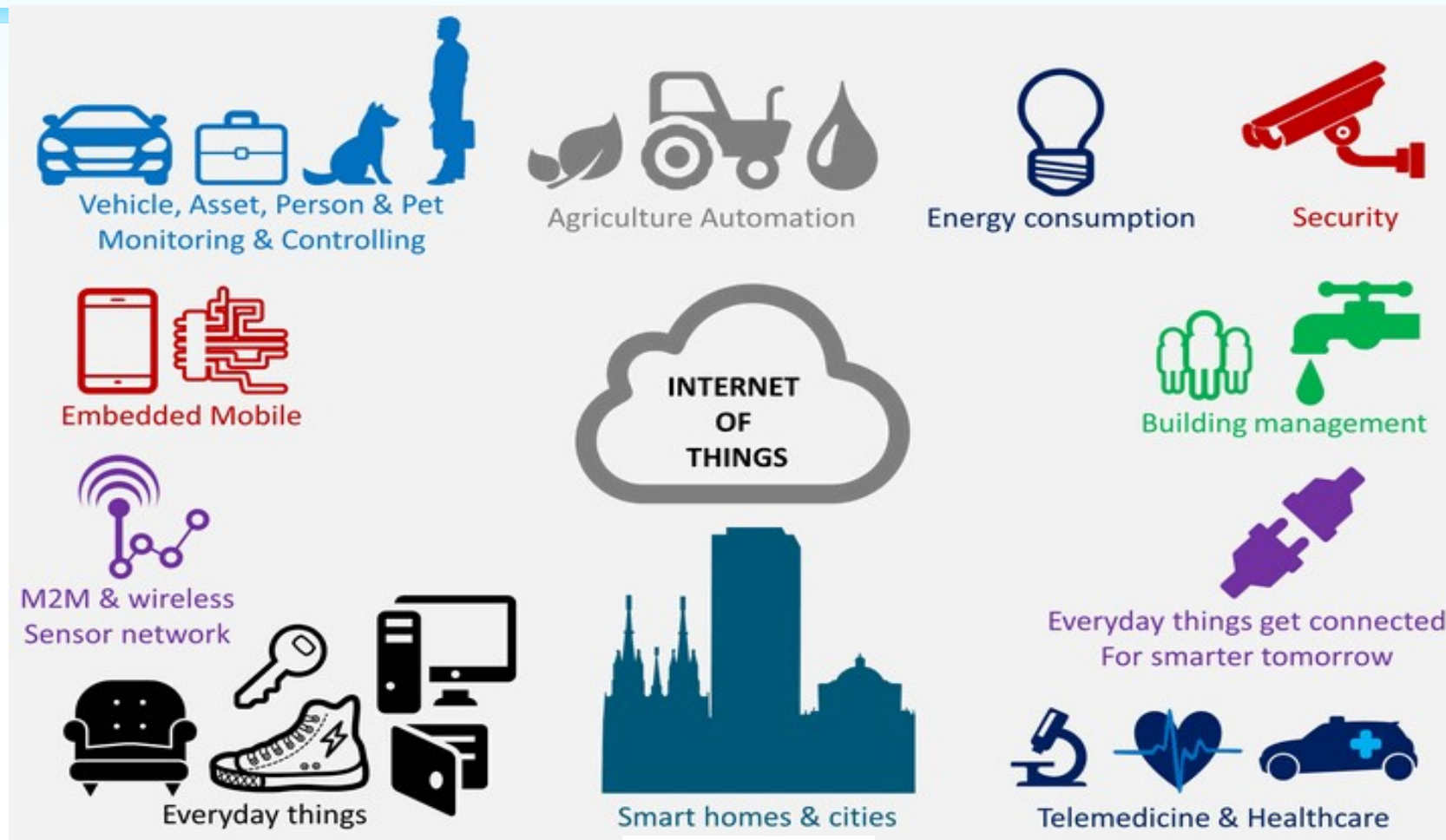


Source: Emm procedure 1. initial attach - part 2. call flow of initial attach | netmanias





# Not Just Smartphones Anymore

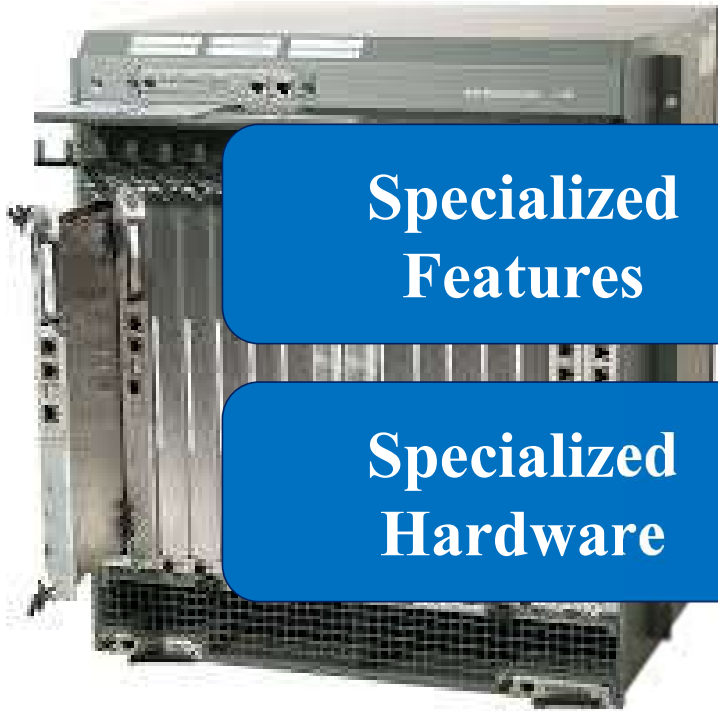


IoT use cases

Source: Ericsson mobility report, June 2016

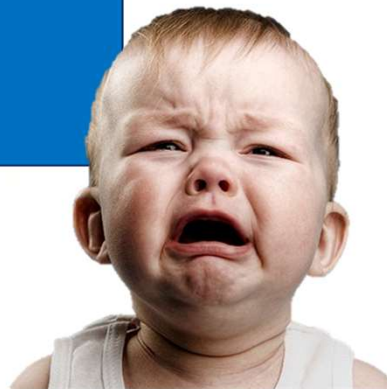


# All Proprietary Hardware



**Specialized  
Features**

**Specialized  
Hardware**



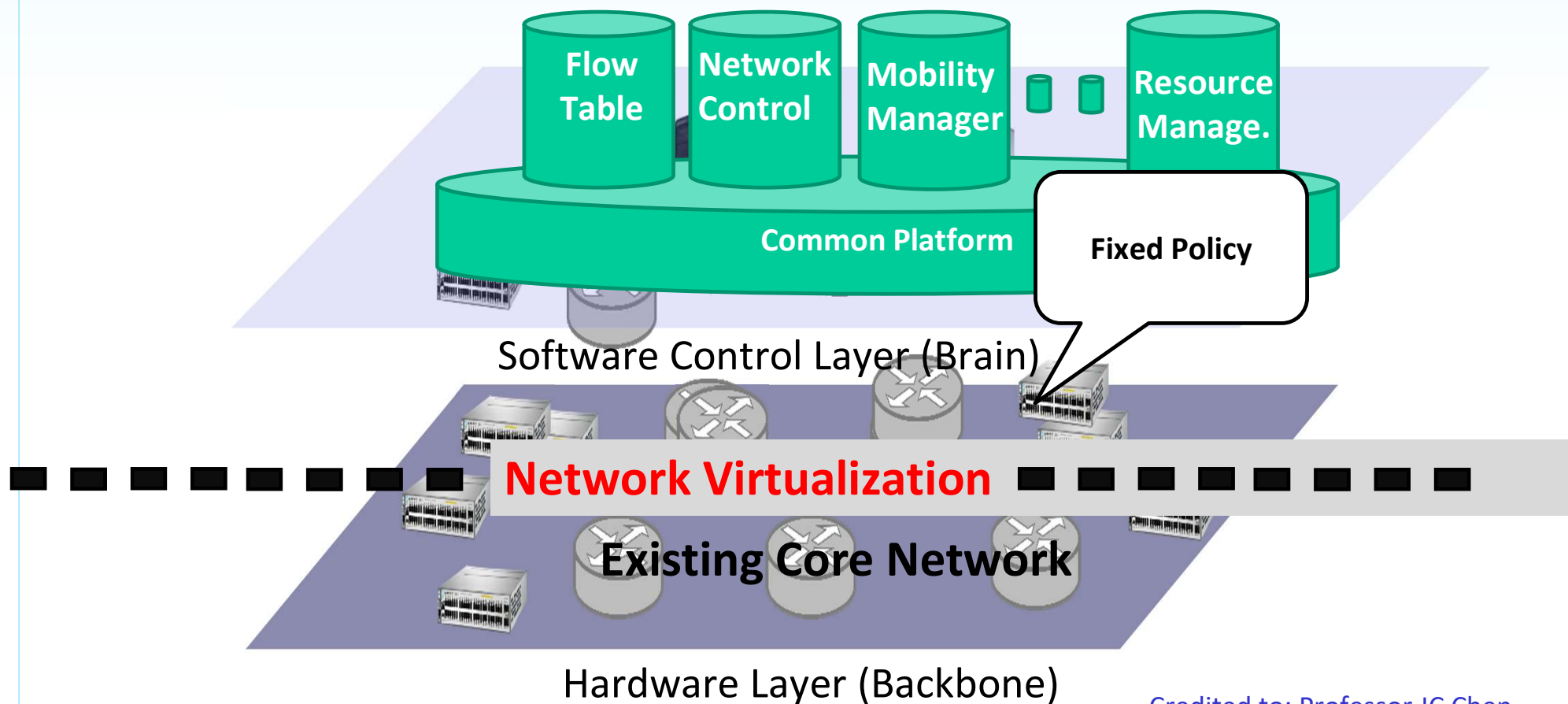
**High cost**  
**Limits innovation**  
**Not flexible**

Source: Flexi Network Server from Nokia Siemens Networks



# Network Function Virtualization (NFV) – Core Network

- Virtualized Network Functions (VNFs)



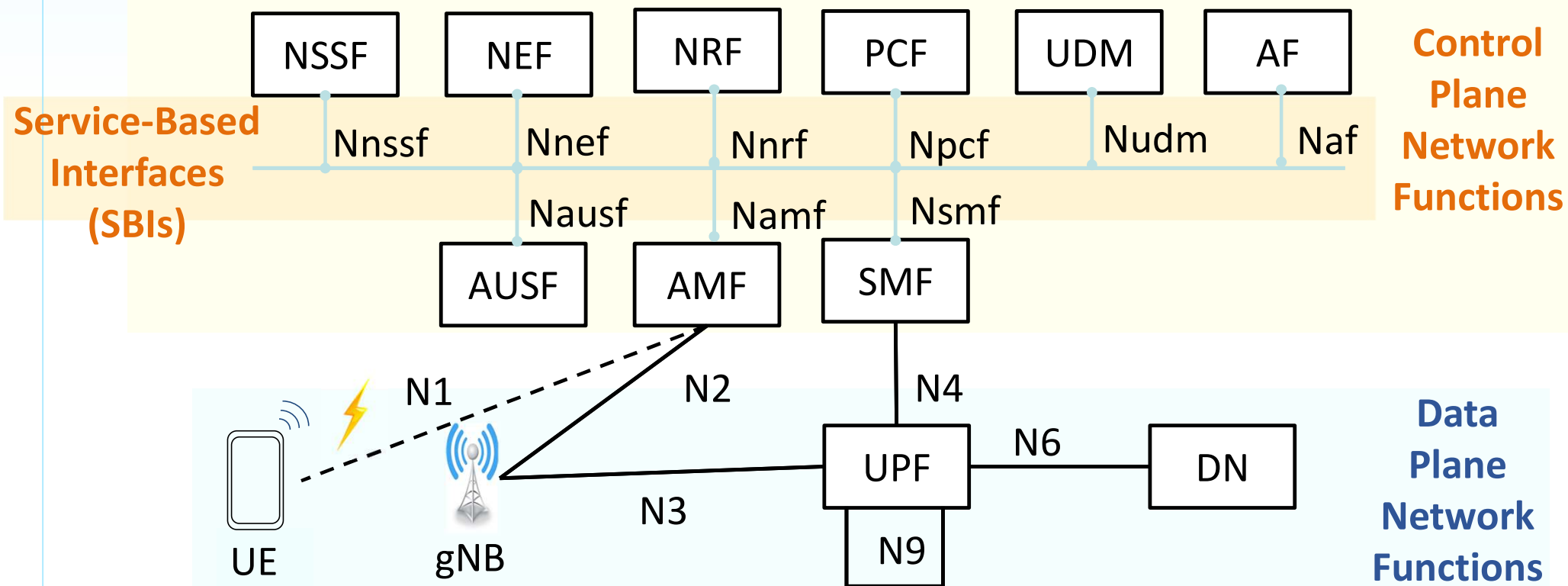
Credited to: Professor JC Chen





# 5G Service Based Architecture

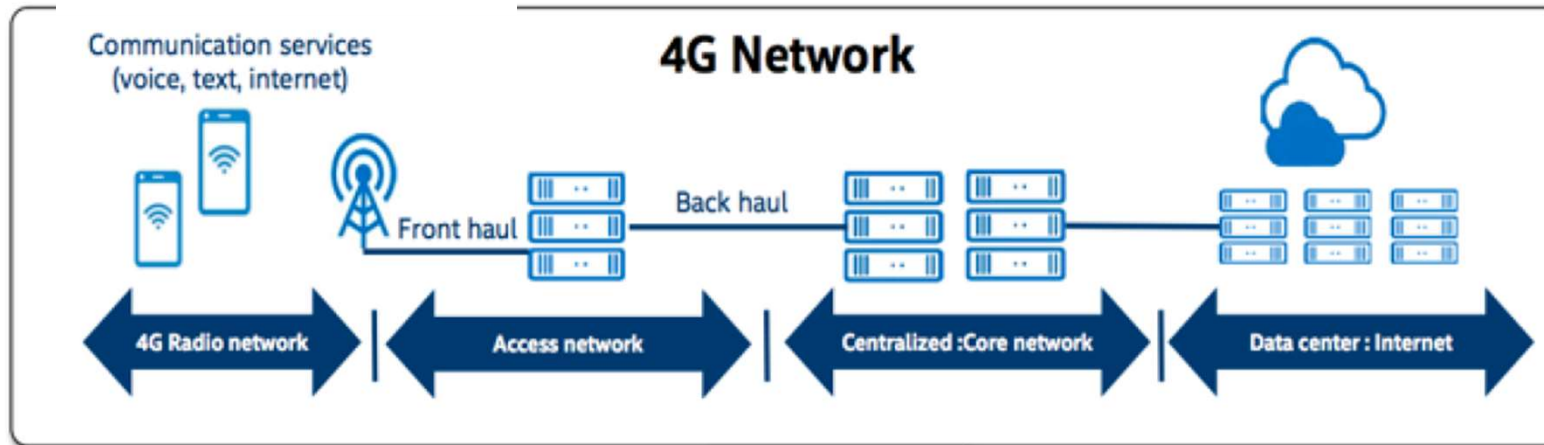
★ SDN, NFV and Cloud Native



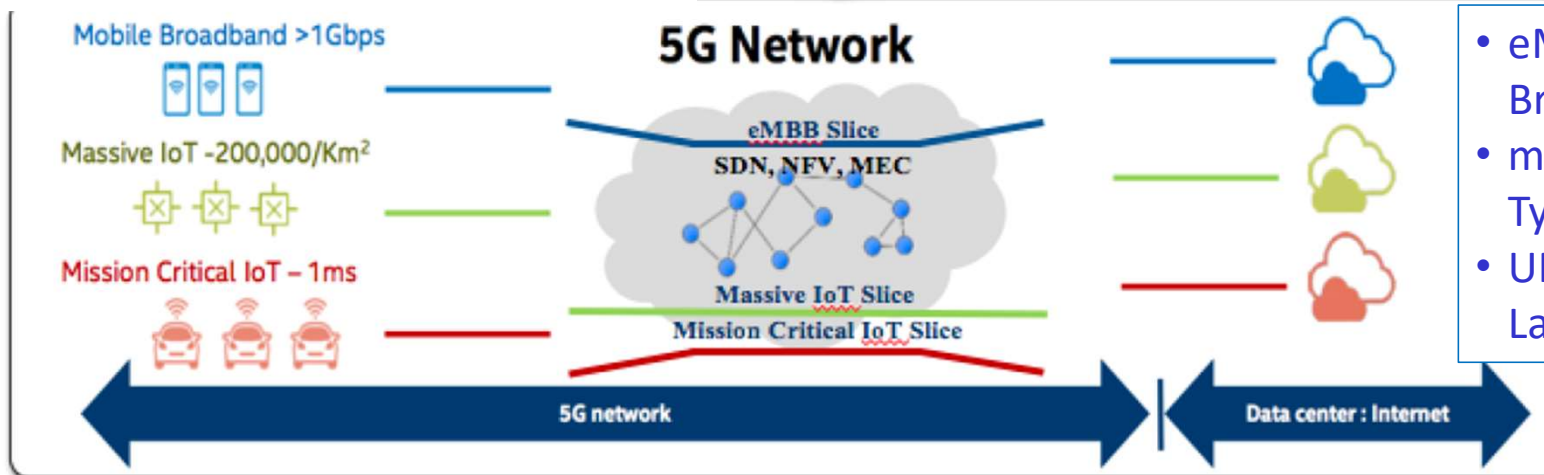


One size fits it all!

## 5G Services and Network Slicing



Slices tailored to applications!



- eMBB: enhanced Mobile Broadband
- mMTC: massive Machine Type Communications
- URLLC: Ultra Reliable Low Latency Communications

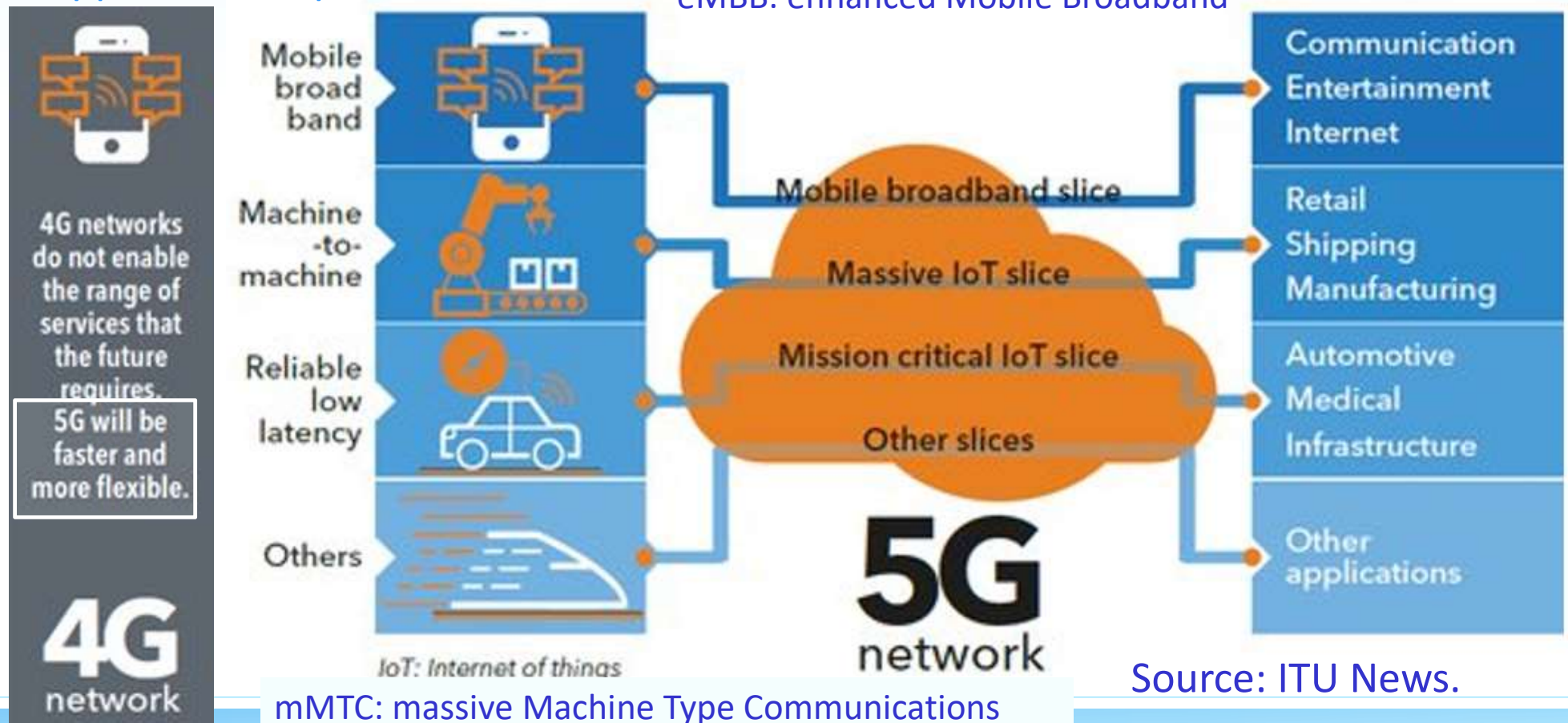
Source: .iotsolutionprovider.com



# 5G Network Slicing

- Enable service providers to build virtual **end-to-end networks** tailored to application requirements

eMBB: enhanced Mobile Broadband



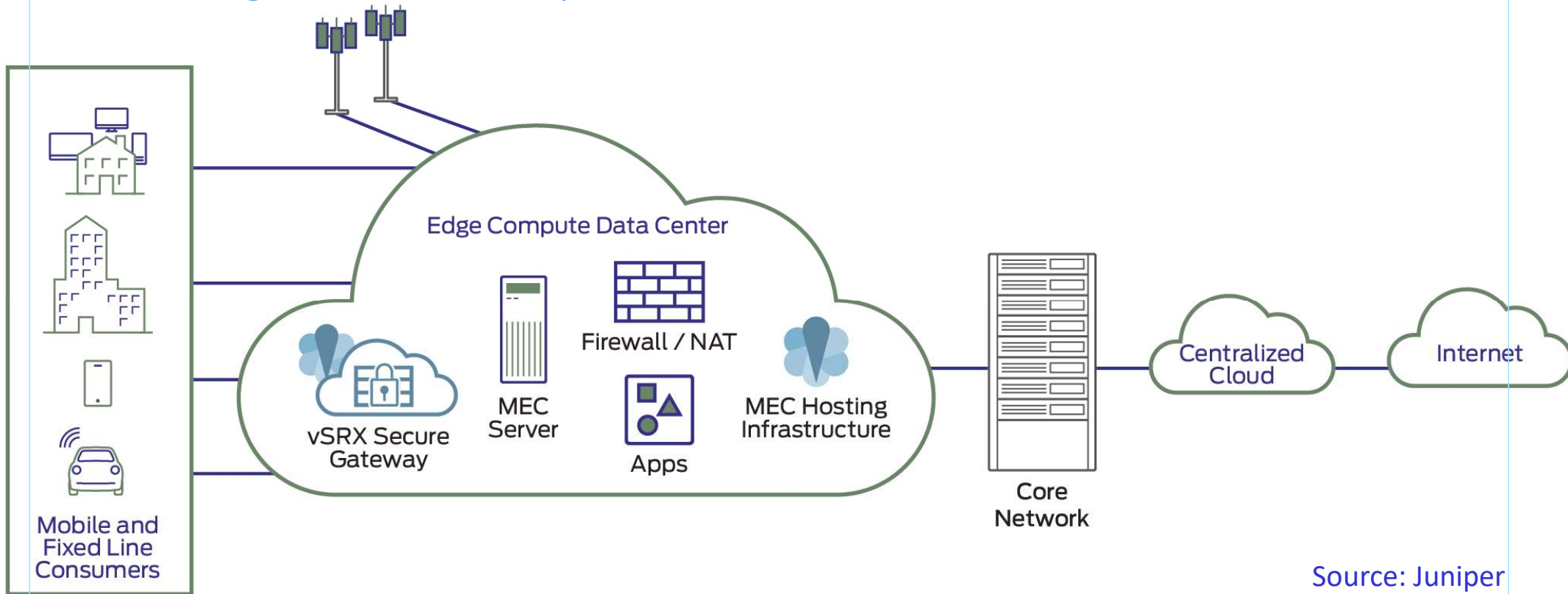
Source: ITU News.

mMTC: massive Machine Type Communications  
URLLC: Ultra Reliable Low Latency Communications



# 5G Multi-Access Edge Computing

- Bringing computing near users
- Offloading traffic from transport networks and core



Source: Juniper



# 5G MEC-Cloud Architecture

- 5G MEC-Cloud Architecture



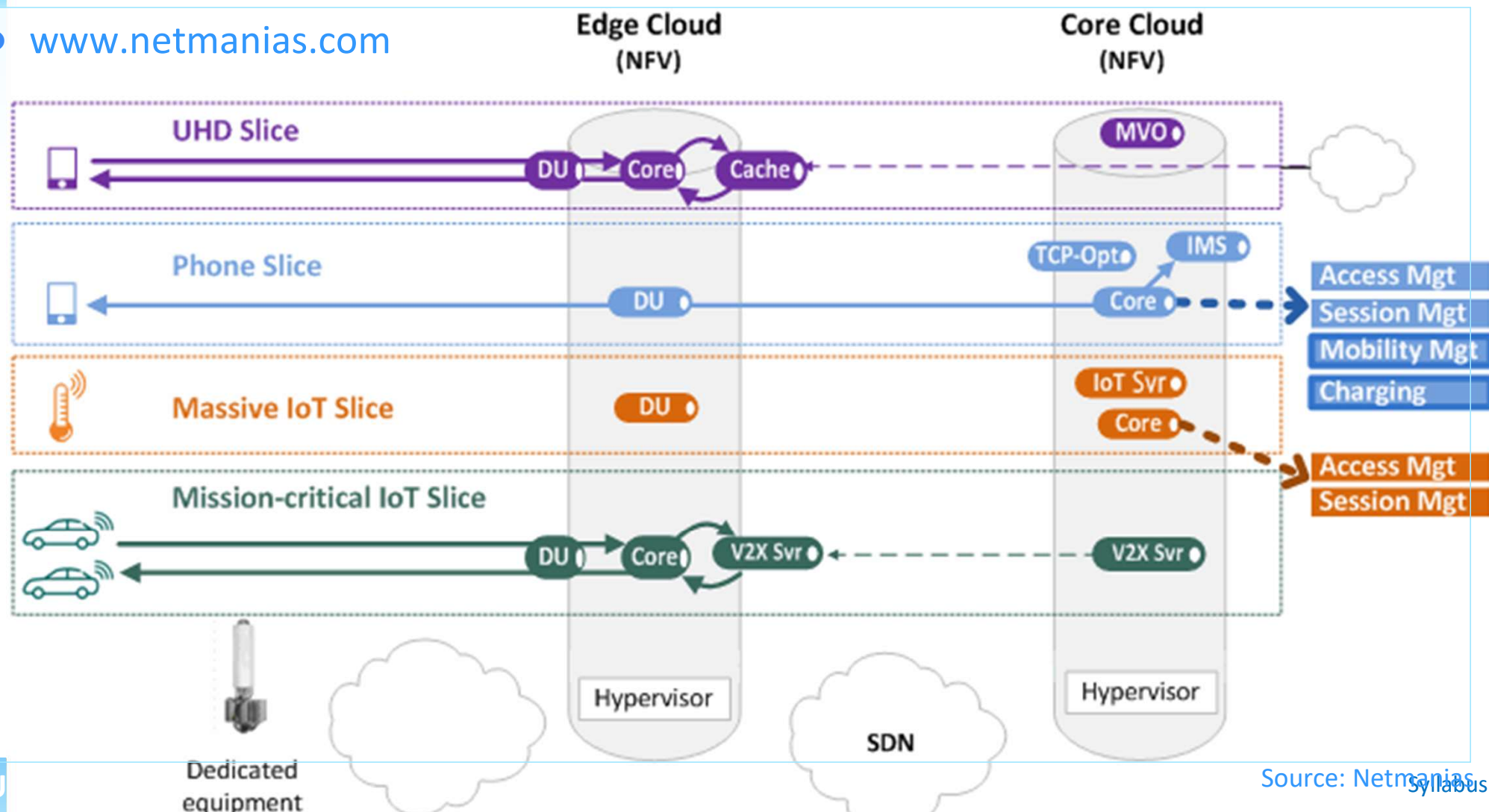
Source: Aaron Yi Ding (TU Delft), MEC and Cloud Security, Wiley 5G Ref  
<http://homepage.tudelft.nl/8e79t/files/pre-print-book2019.pdf>





# SDN/NFV/Cloud/MEC/Network Slicing for 5G

- [www.netmanias.com](http://www.netmanias.com)



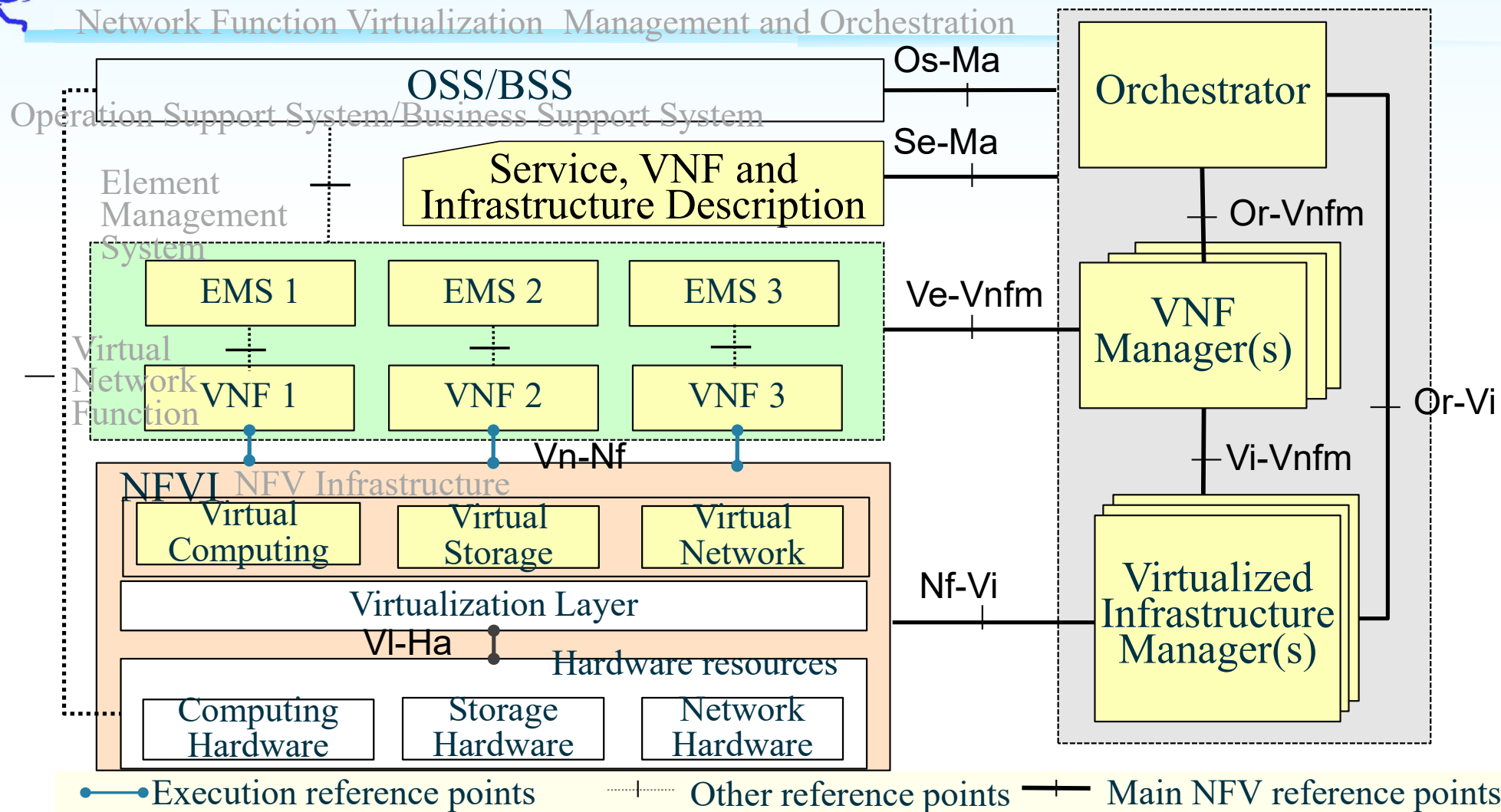




European Telecommunications Standards Institute

# ETSI NFV-MANO Reference Architecture

Network Function Virtualization Management and Orchestration





# Open Networking Foundation (ONF) and Exemplar Platforms

**Professor Chien-Chao Tseng**

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[cctseng@cs.nctu.edu.tw](mailto:cctseng@cs.nctu.edu.tw)



## ONF – Operator Led Consortium



With 13+ additional operators at 'Innovator' level

**Collaborating to Address a Common Problem**

**Operators need cloud-like economics and agility**

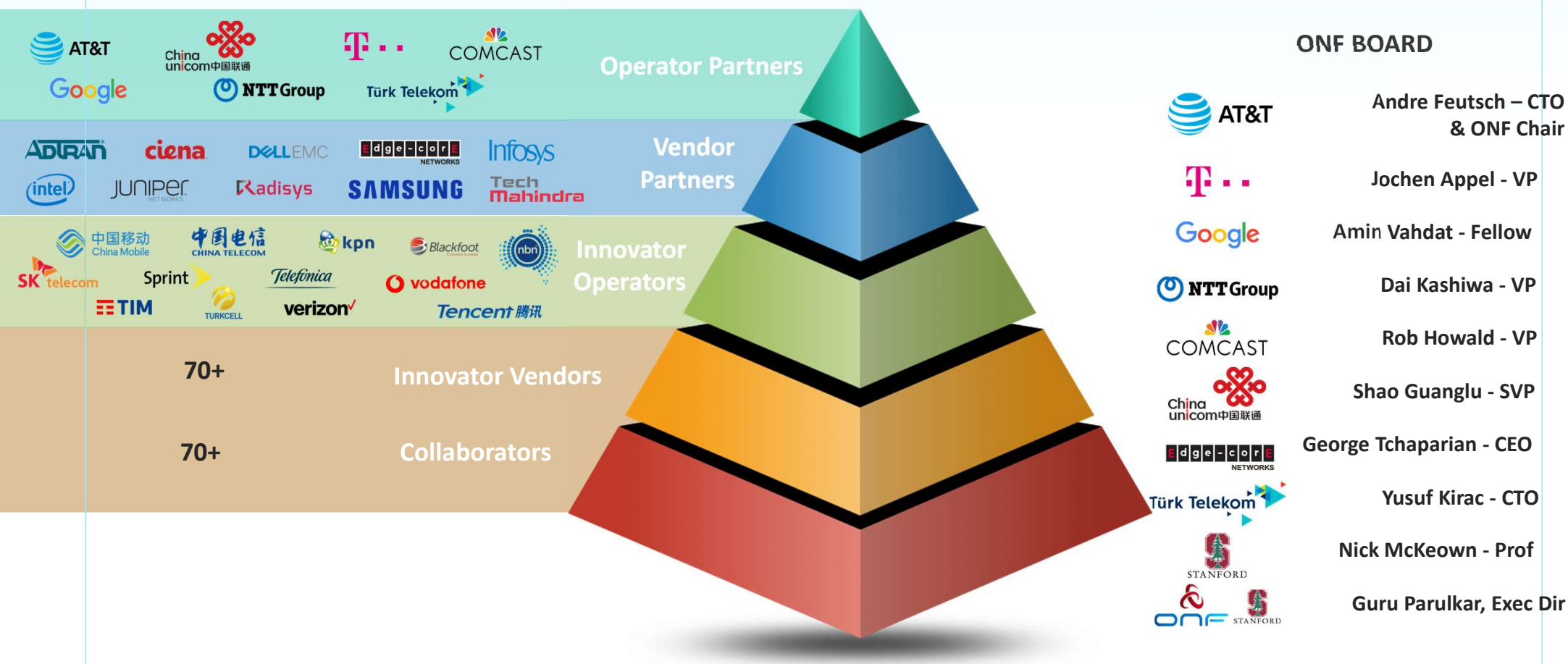
Incumbent vendors have not been providing open tools & cloud-like building blocks

Source: Timon Sloane, VP Marketing & Ecosystem, Open Networking Foundation



# Operator Led - Curated Open Source Community

- Partners committed to disaggregation, open source and SDN/NFV/Cloudification



# Collaborators

MEF



metaswitch





# Central Office Re-architected as a Datacenter (CORD)



Large number of COs



Evolved over 40-50 years



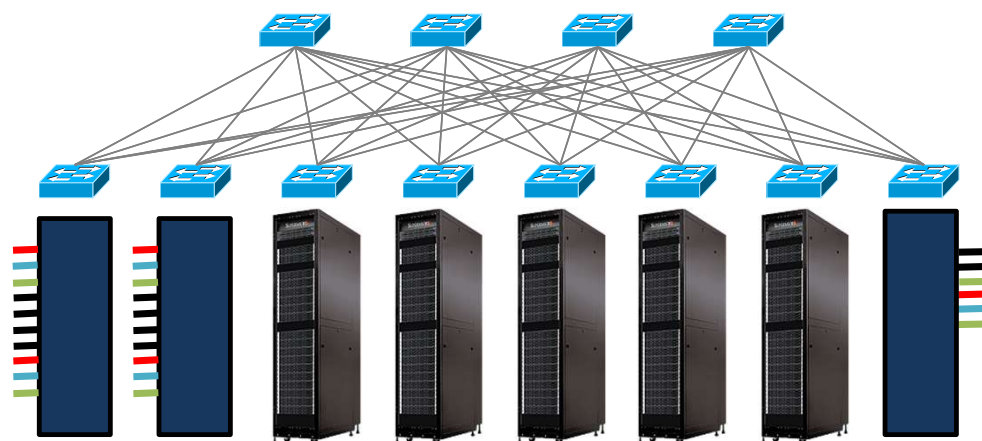
300+ Types of equipment  
Huge source of CAPEX/OPEX

SDN + NFV + Cloud

Open Source Software

+

Commodity Hardware  
(Servers, White-Box Switches,  
I/O Blades)



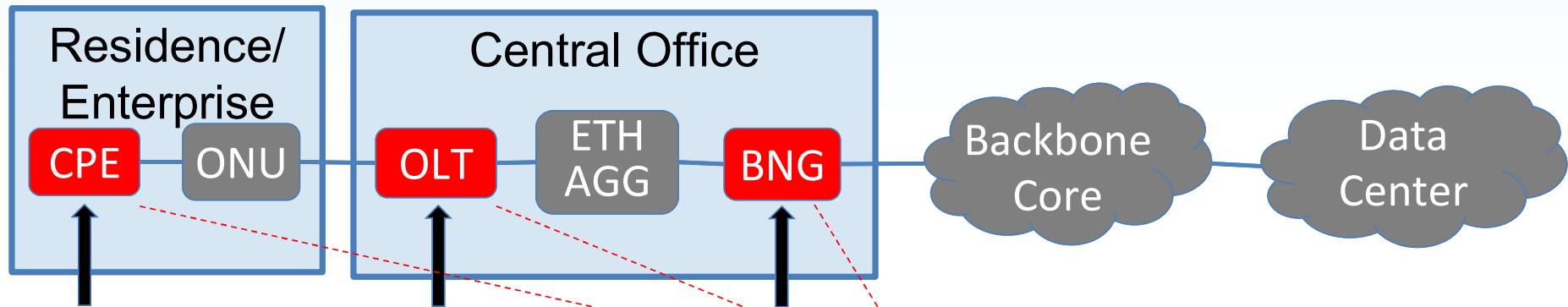
Source: Open Networking Foundation





# Traditional Residential Access

- Optical Network Terminologies



NAT  
DHCP  
VoIP  
Firewall  
Parental  
Control  
...

Authorization  
Physical Connect  
Point  
...

QoS  
VPN  
GRE Tunneling  
MPLS Tunneling  
Q-in-Q Termination  
...

**Devices to be Virtualized**

## Acronyms

- CPE – Customer Premises Equipment
- ONU – Optical Network Unit
- OLT – Optical Line Termination
- ETH AGG – Ethernet Aggregate Switch
- BNG – Broadband Network Gateway

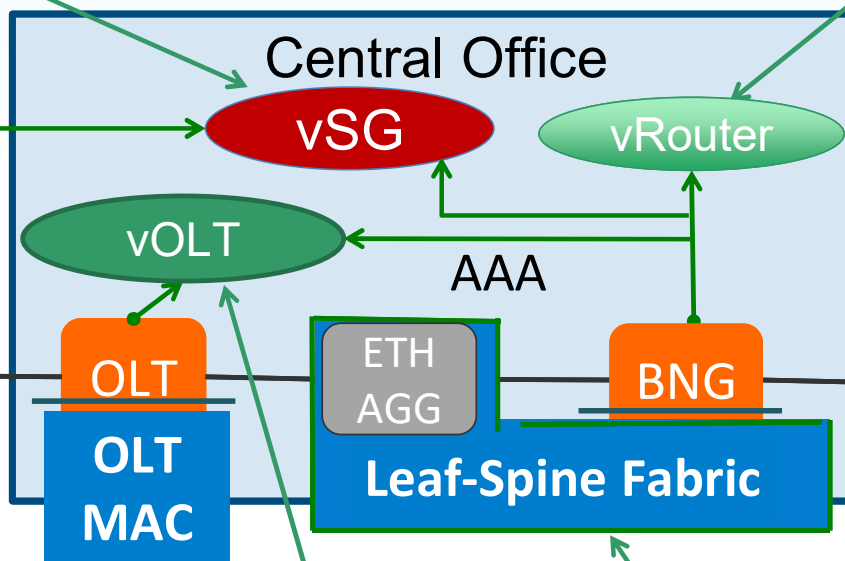
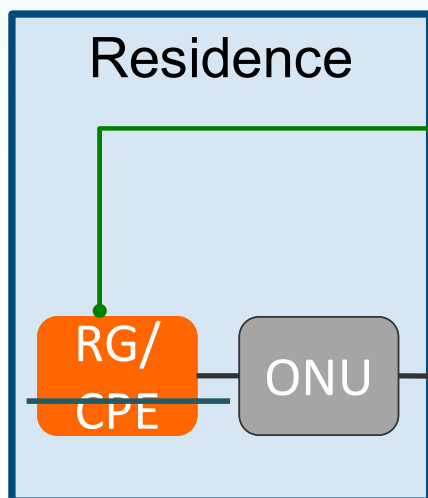


# Residential CORD (R-CORD) –

## Disaggregated Residential Access

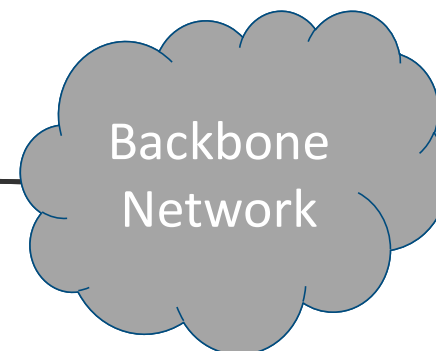
### Virtual Subscriber Gateway

- DHCP
- NAT
- ...



### Virtual BNG

- VLAN termination
- DHCP
- QoS



- RG – Residential Gateway
- CPE –Customer Premises Equipment
- ONU – Optical Network Unit
- OLT – Optical Line Termination
- ETH AGG – Ethernet Aggregate Switch
- BNG – Broadband Network Gateway

Virtual OLT  
manages and  
abstracts PON

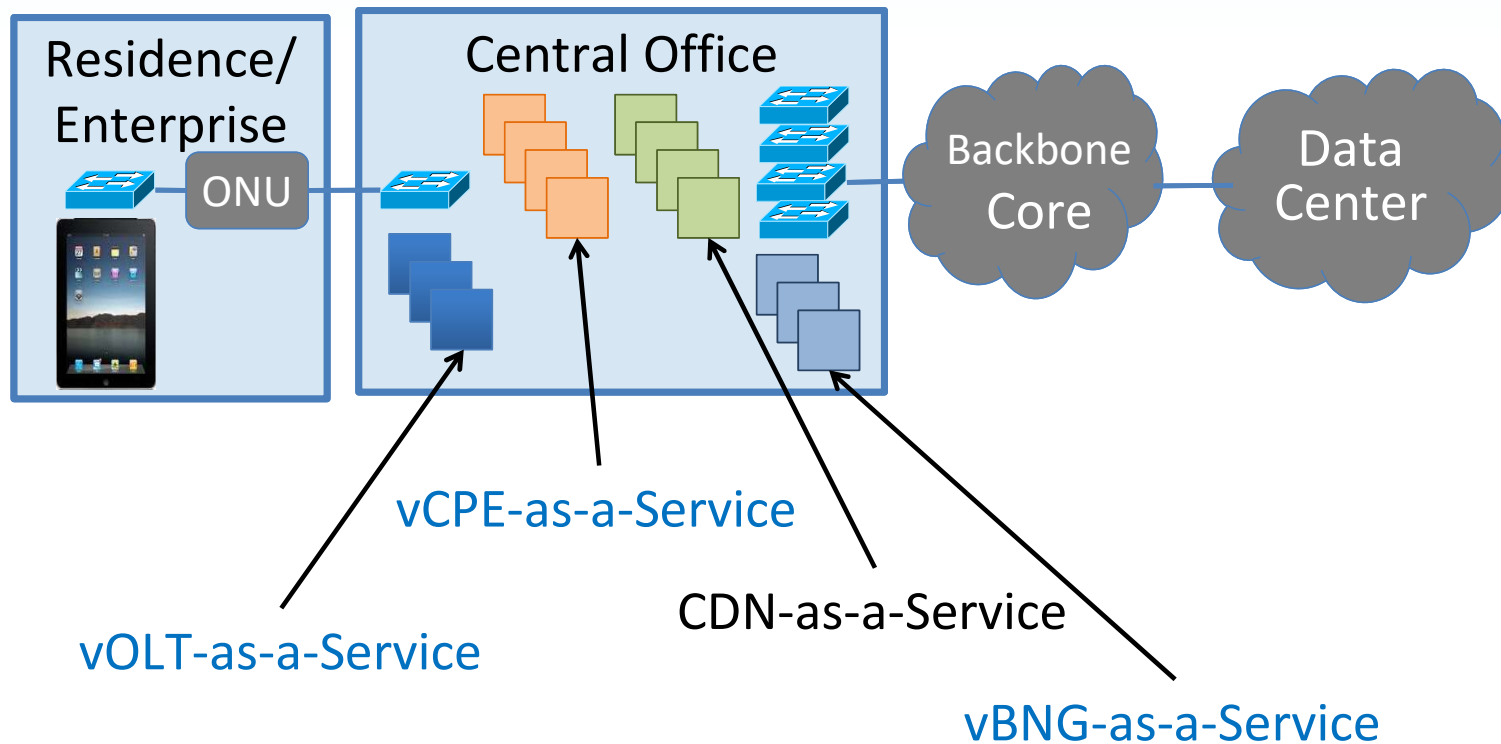
Fabric provides

- Eth aggregation
- Routing



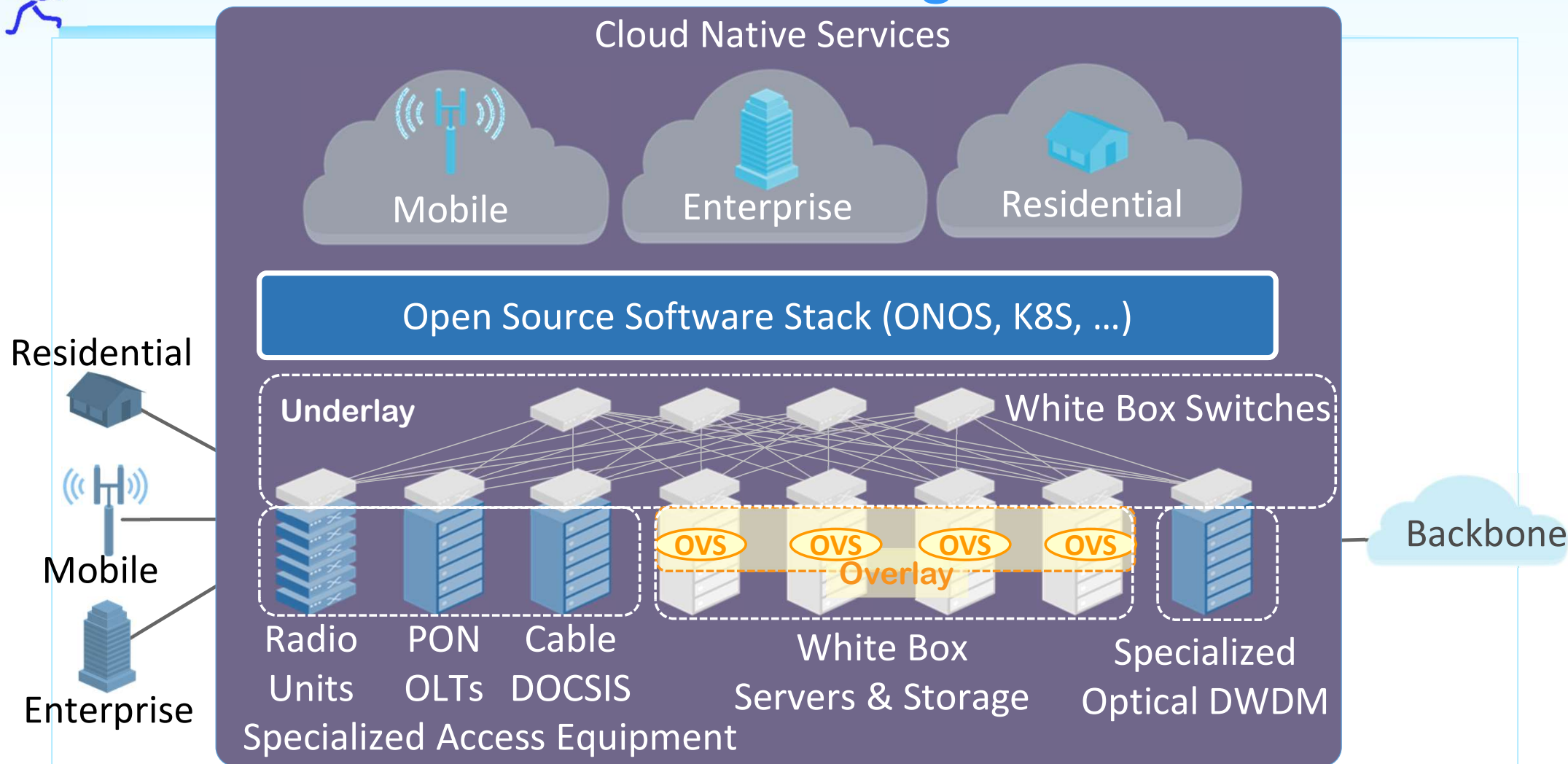
## Telco Central Office – After (R-CORD)

- vCPE+ vOLT + vBNG (+ CDN, ...)

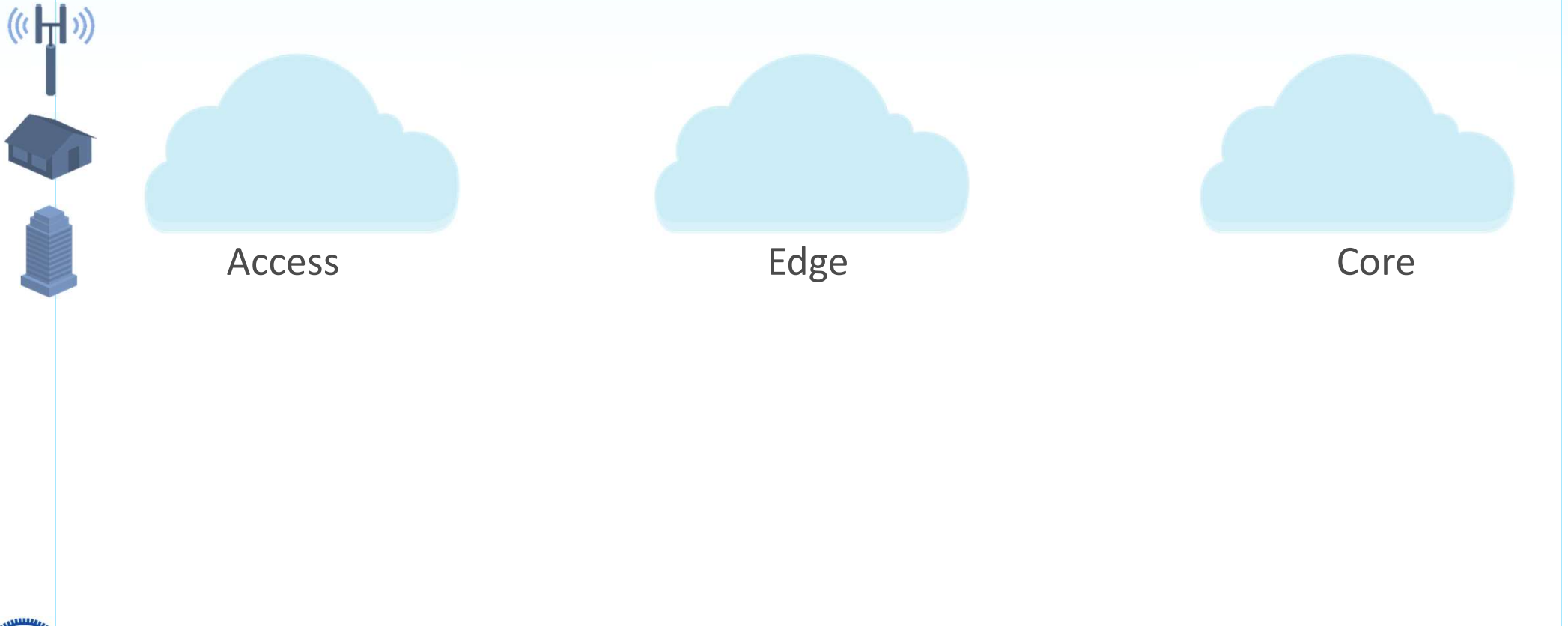




# CORD – Next Generation Edge Cloud Platform

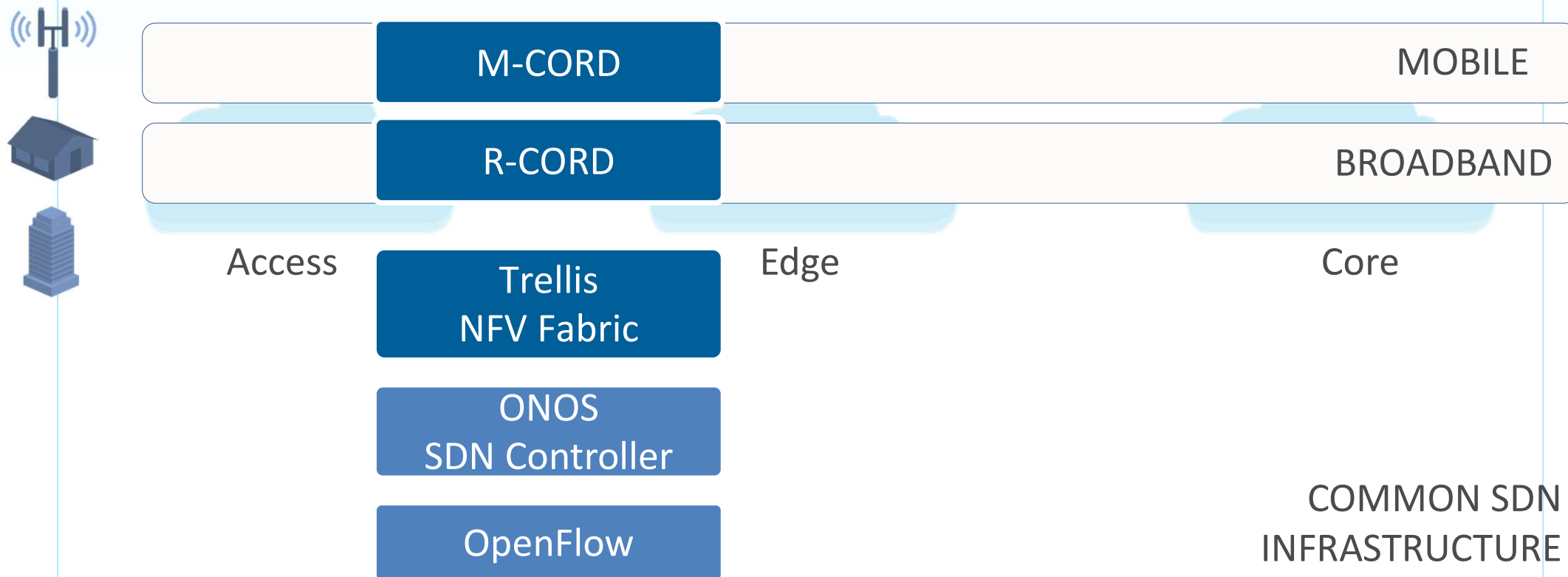


# ONF's Interconnected Set of Curated Open Source Projects



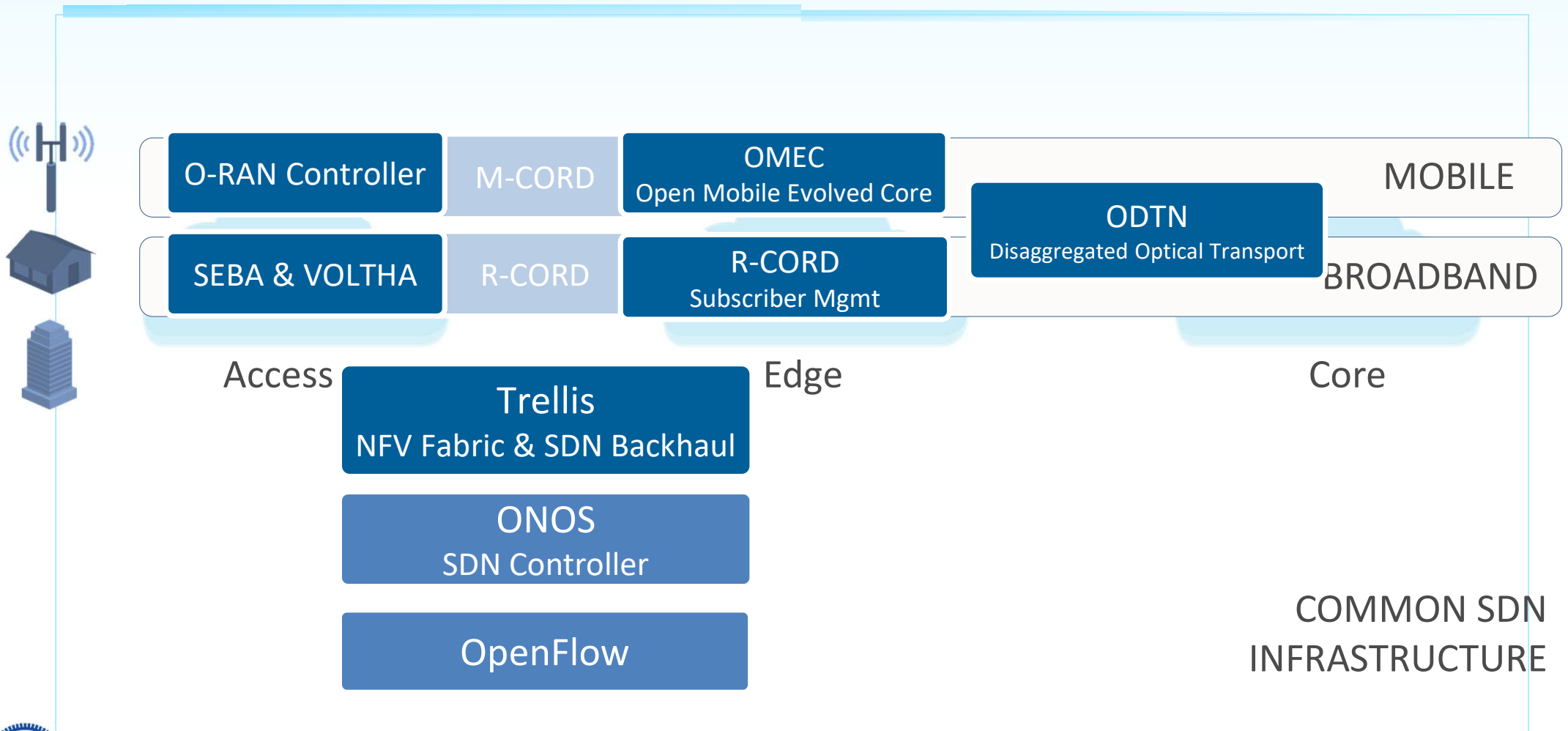


# ONF's Interconnected Set of Curated Open Source Projects



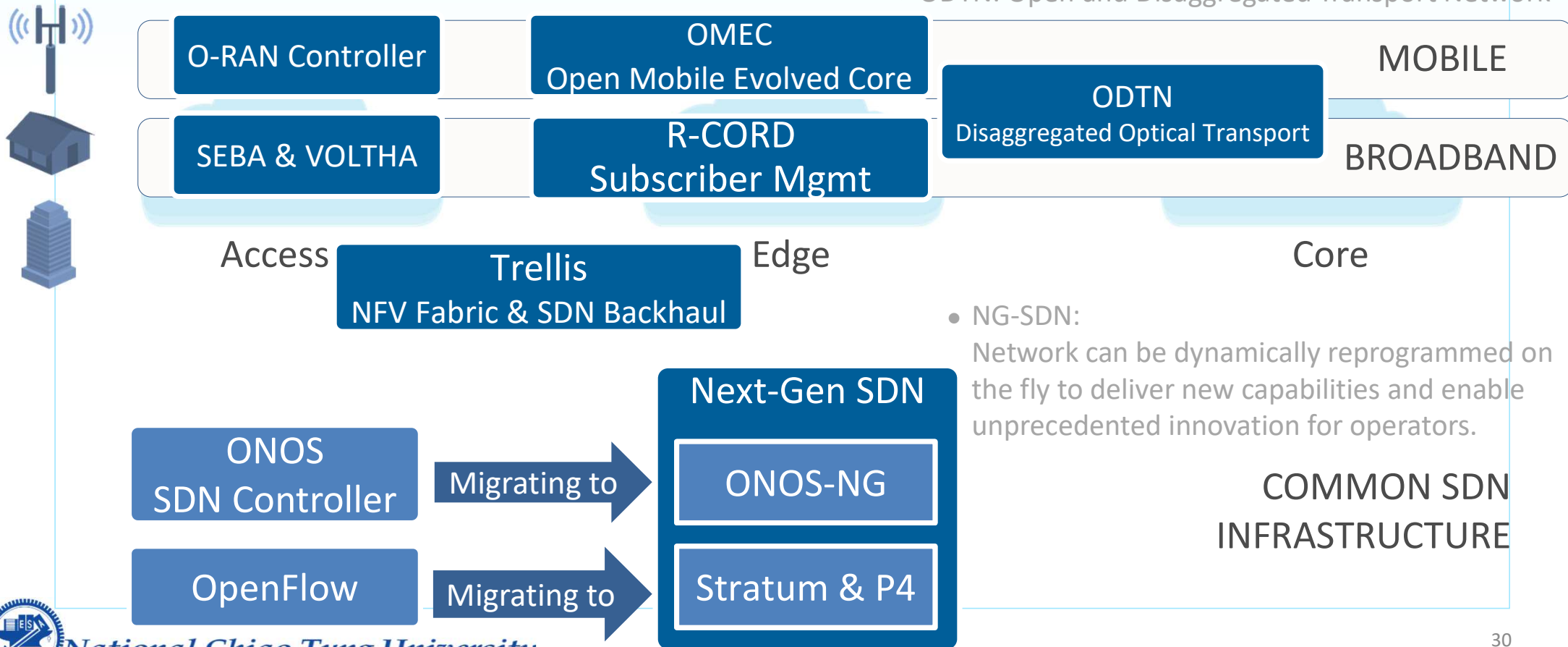


# ONF's Interconnected Set of Curated Open Source Projects



# ONF's Interconnected Set of Curated Open Source Projects

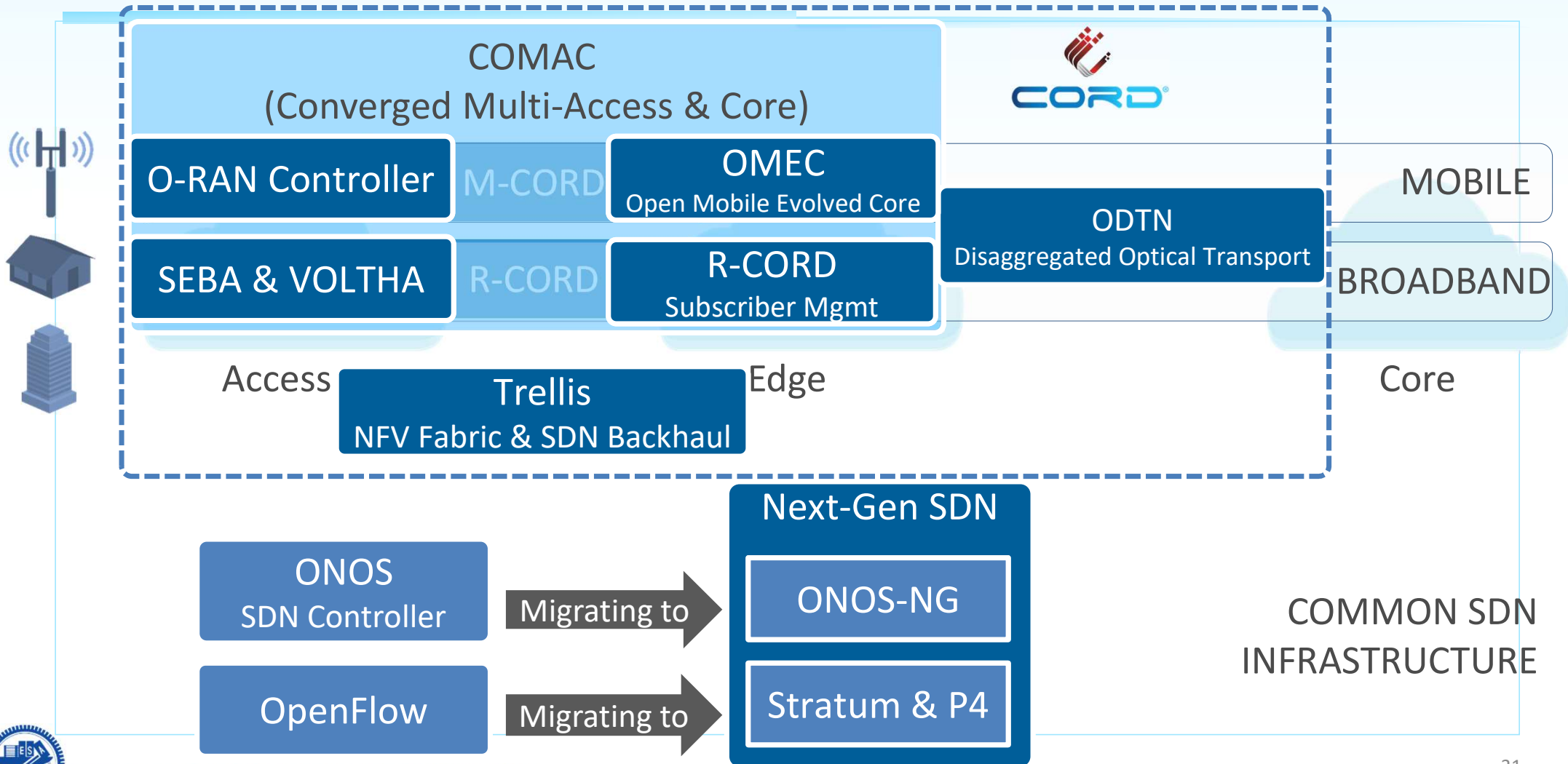
- O-RAN: Open Radio Access Network
- SEBA: SDN Enabled Broadband Access
- OMEC: Open Mobile Evolved Packet Core
- ODTN: Open and Disaggregated Transport Network



- NG-SDN:  
Network can be dynamically reprogrammed on the fly to deliver new capabilities and enable unprecedented innovation for operators.

COMMON SDN  
INFRASTRUCTURE

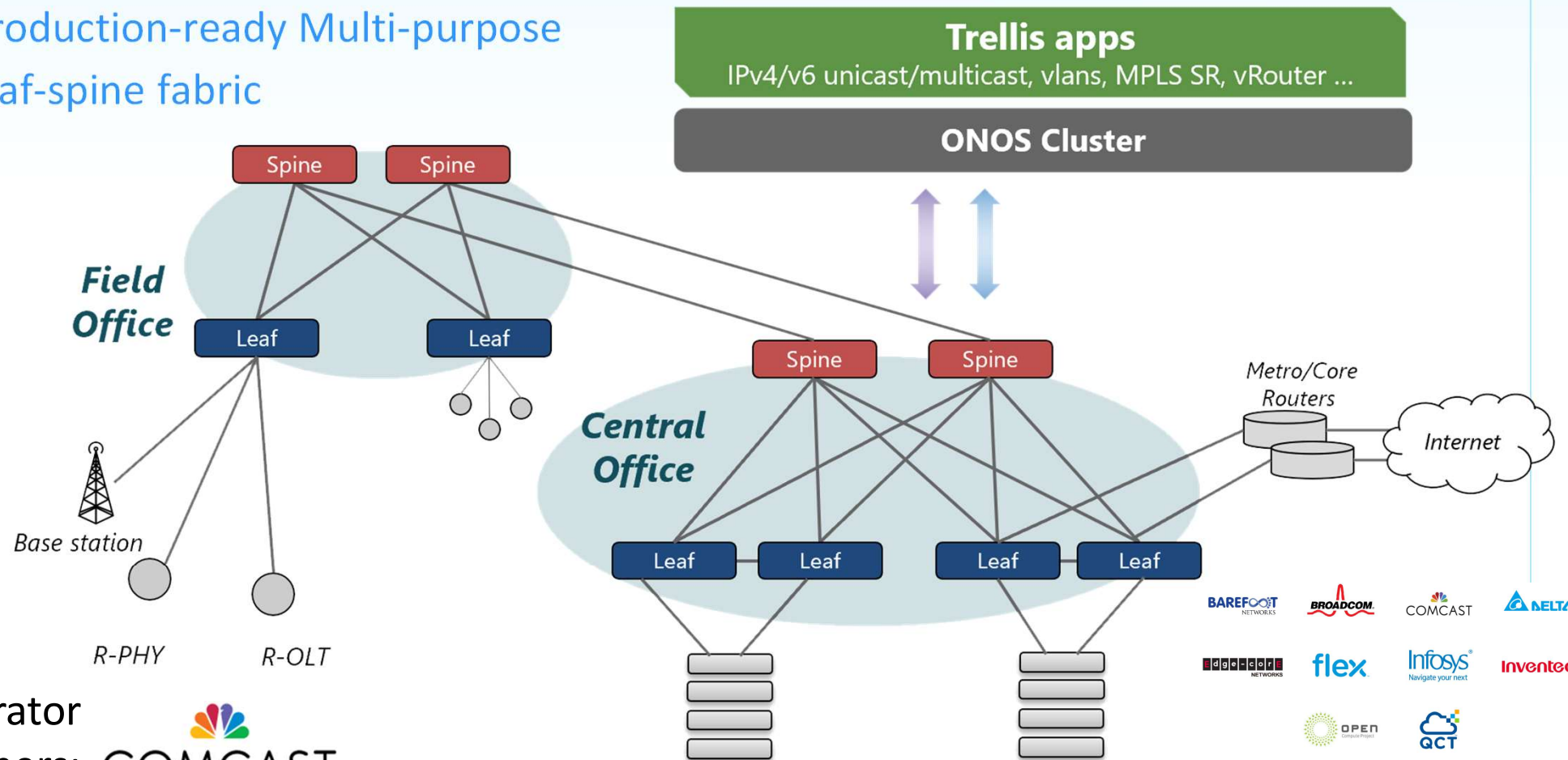
# ONF's Interconnected Set of Curated Open Source Projects





# Trellis

- Production-ready Multi-purpose leaf-spine fabric

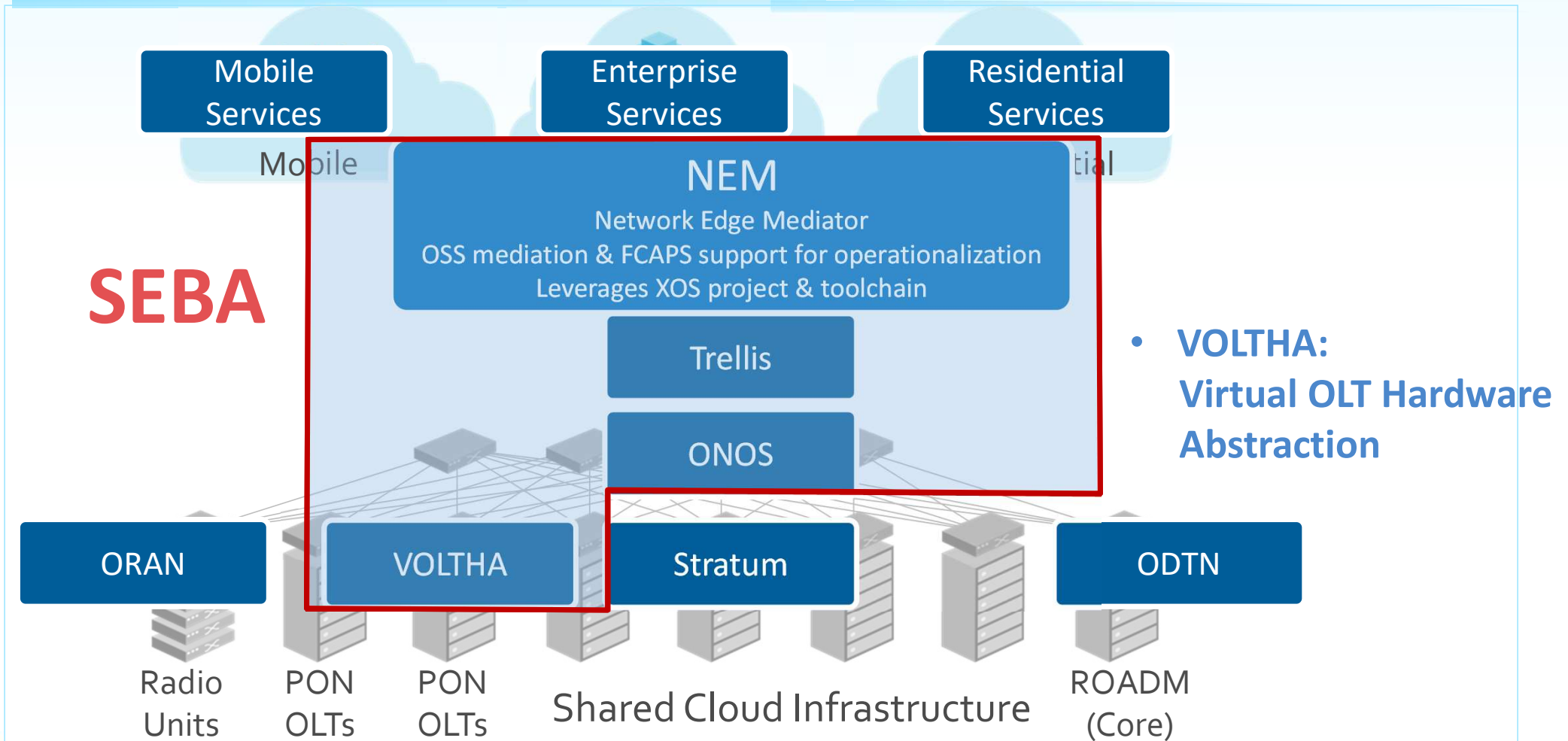


Operator  
Partners: COMCAST



Source: ONF

# SEBA Built on CORD – SDN Enabled Broadband Access





# SD-Fabric

## Cloud Managed Edge Cloud Fabric as a Service

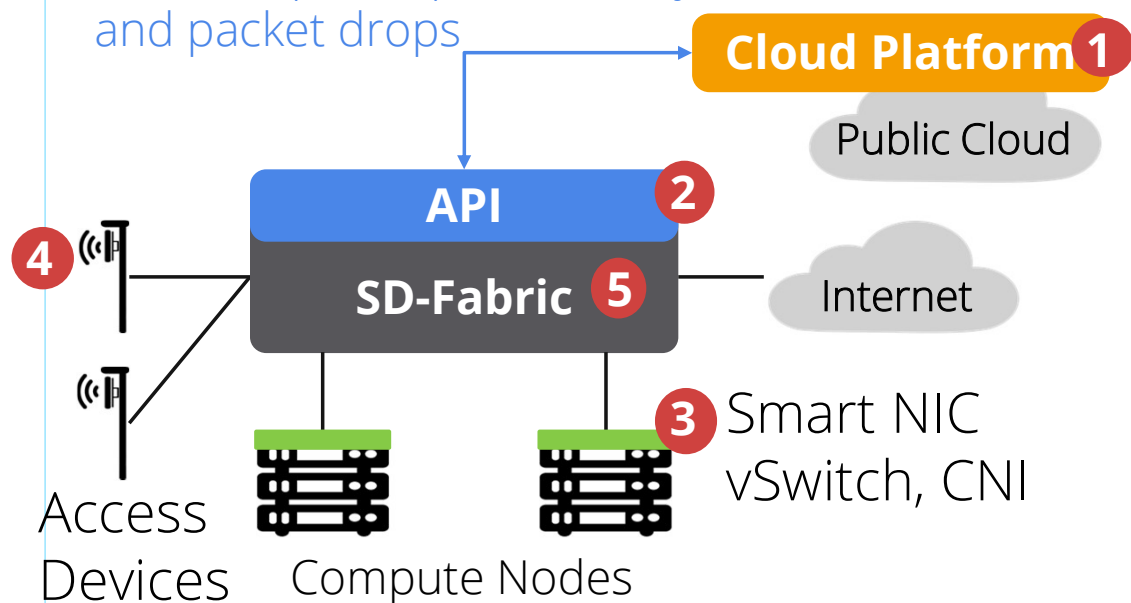
### Control APIs

- Network slicing and QoS management
- Path selection (redirecting)
- Access control (blocking)

### Telemetry APIs

- Monitor queue, path, latency and packet drops

<https://opennetworking.org/sd-fabric/>



- 1 Cloud-managed network fabric as a service  
Integrated with CI/CD, logging, monitoring, alert
- 2 API driven  
Programmable throughout the stack  
Visible throughout the network
- 3 Tighter Integration of servers and networks
- 4 Initially focus on 5G workload
- 5 One big router. One big UPF

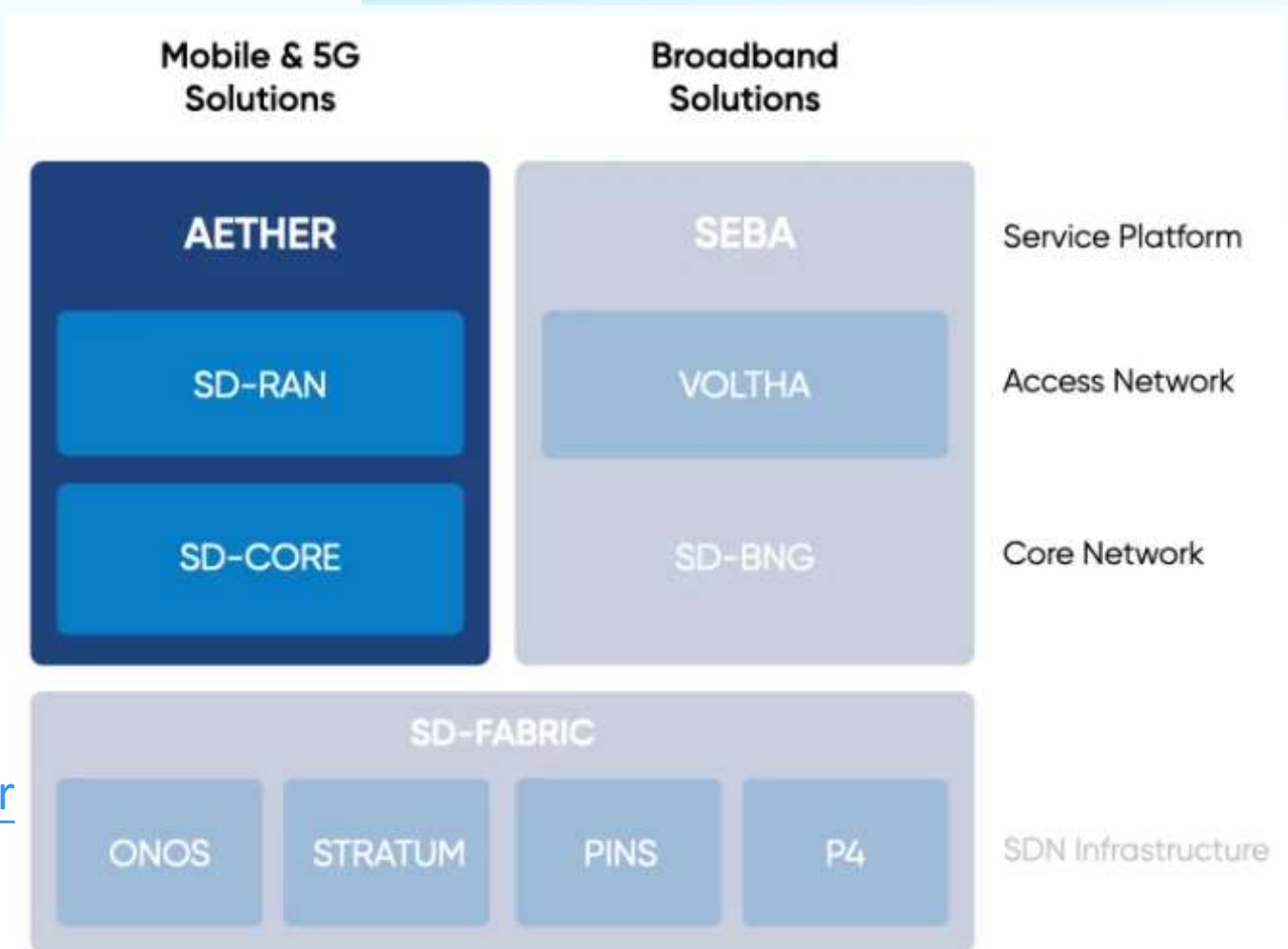




# ONF Mobile Projects

- Aether
  - SD-RAN
  - SD-CORE
  - SD-Fabric

<https://opennetworking.org/onf-mobile-projects/>

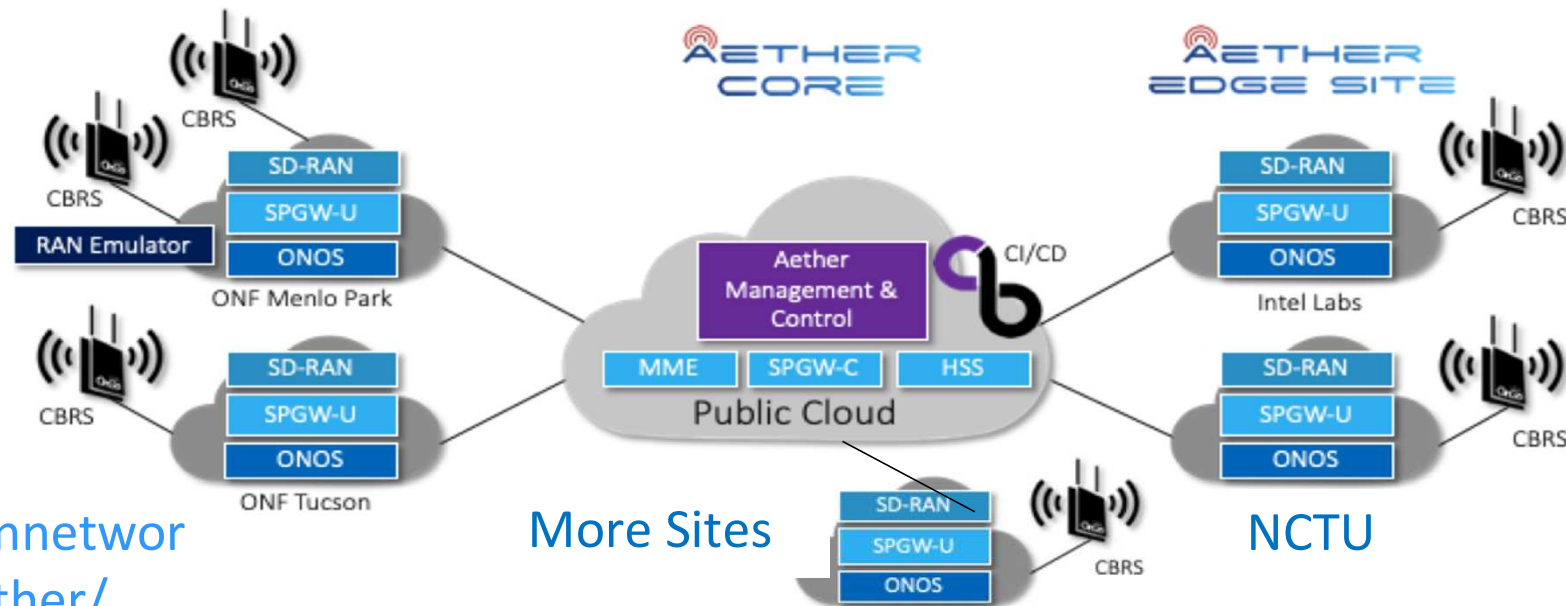




# Aether



- First open source enterprise 5G/LTE Edge-Cloud-as-a-Service Platform
  - Delivers mobile connectivity and edge cloud services for distributed enterprise network
    - with provisioning and management from a central cloud
  - Connected-Edge platform for enabling enterprise digital transformation



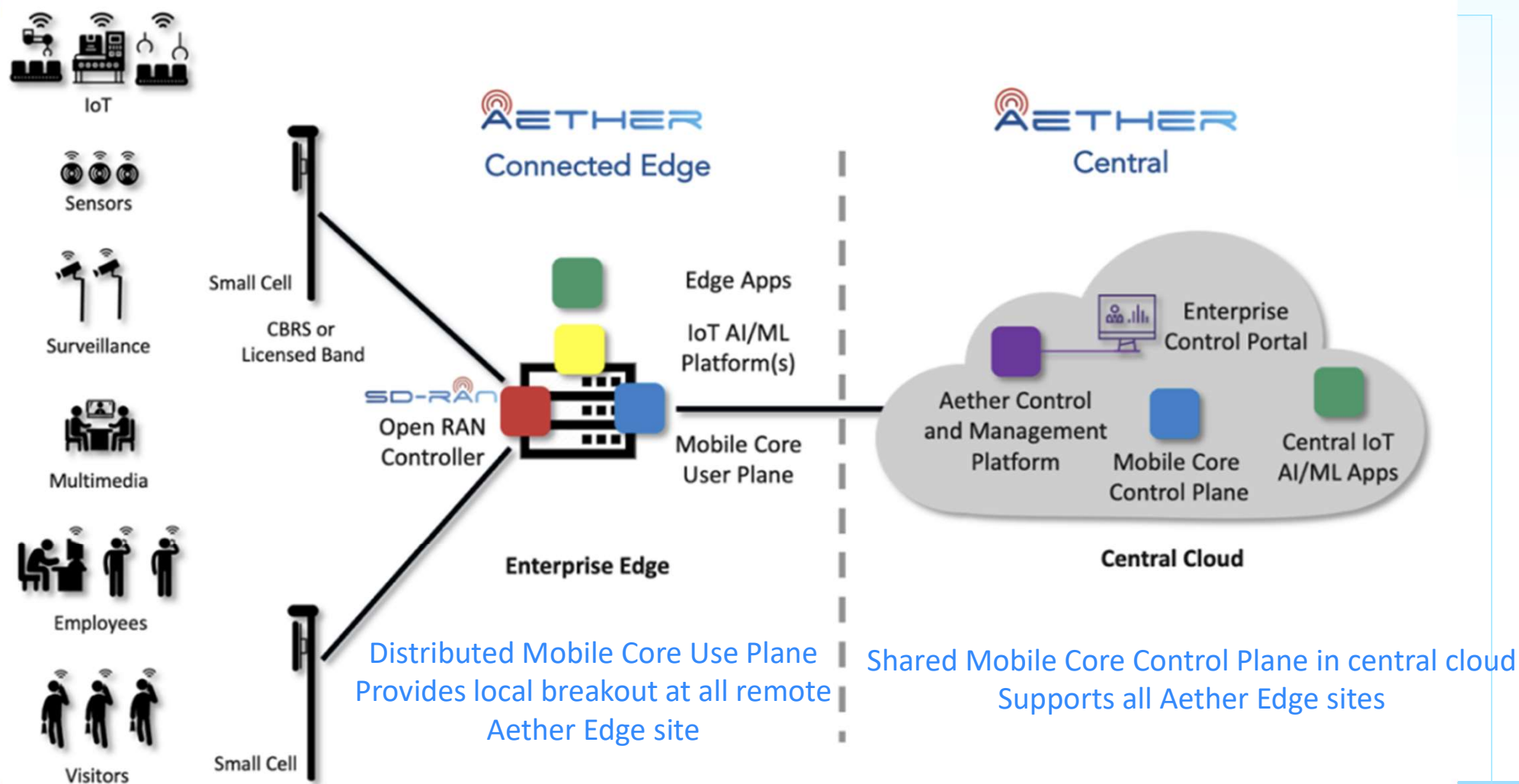
<https://opennetworking.org/aether/>

# Aether Connected Edges



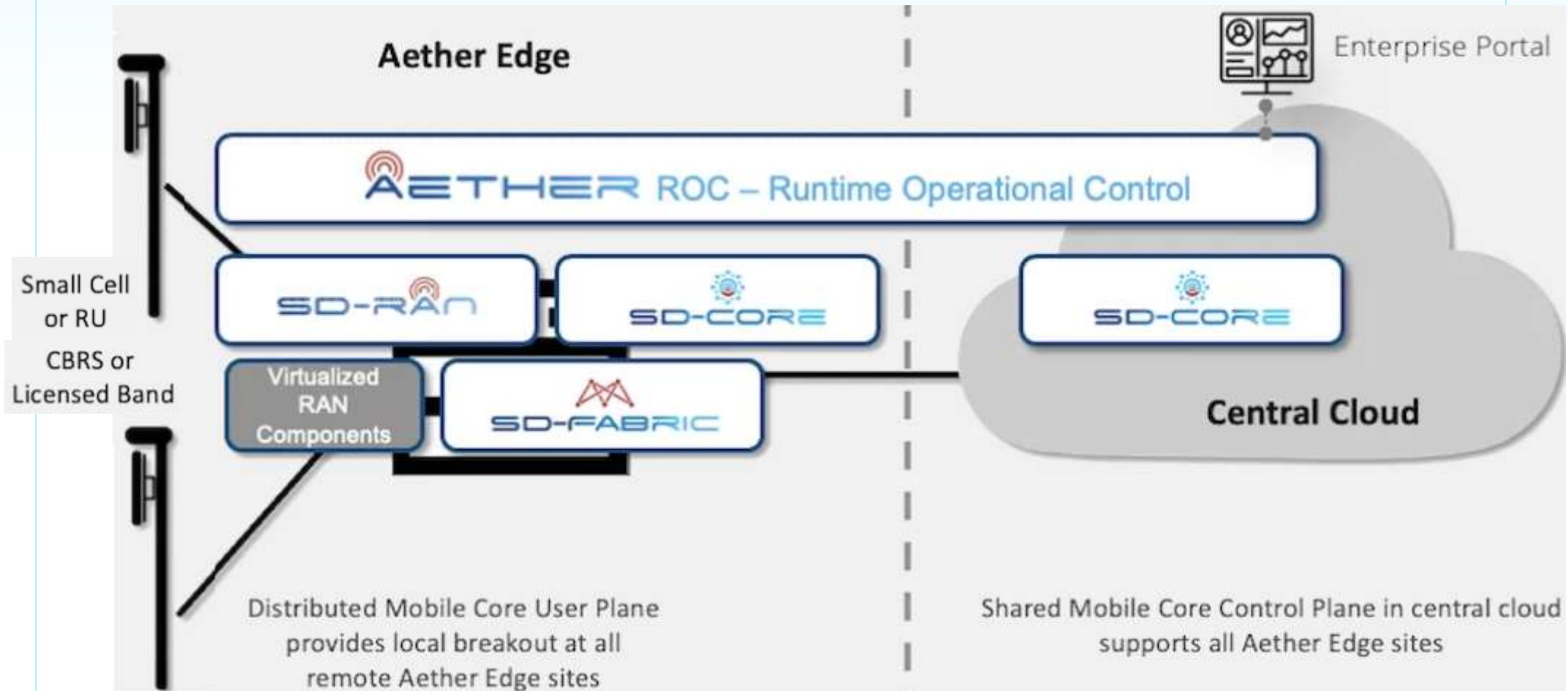


# Aether Software Architecture



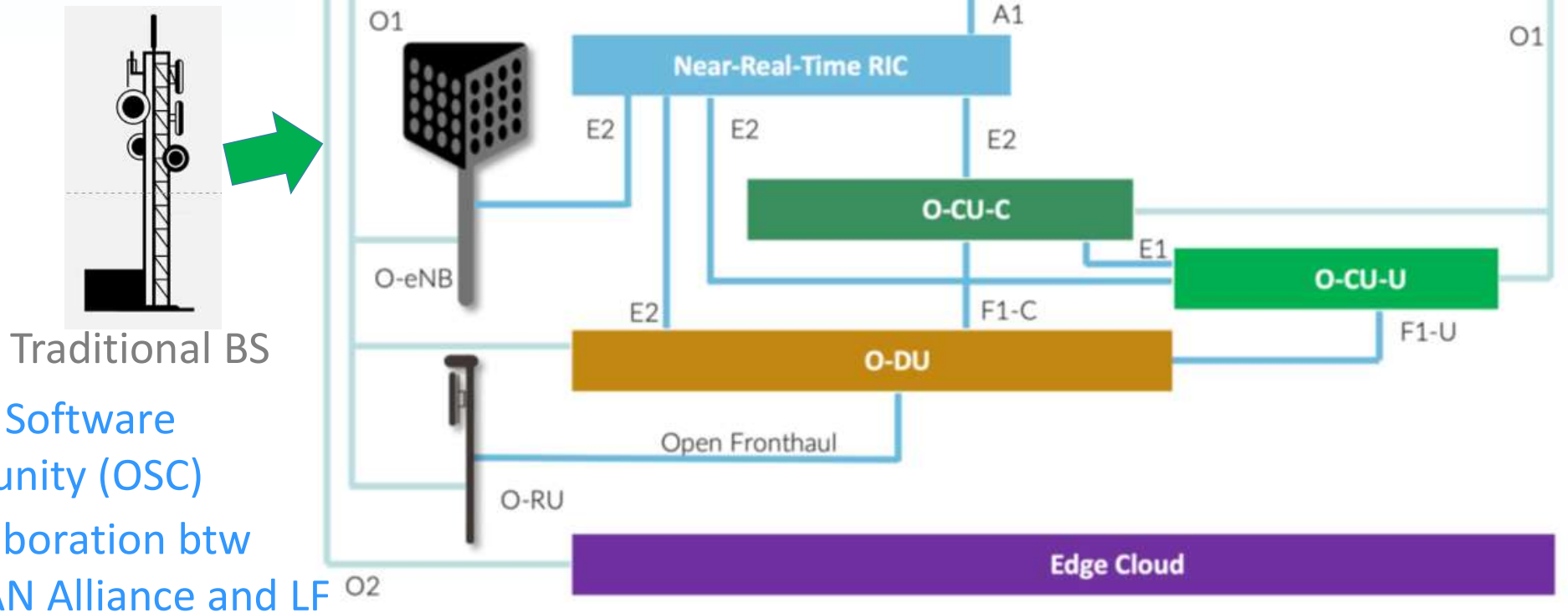


# Aether Architecture and Subprojects





# O-RAN Software Architecture



- O-RAN Software Community (OSC)
  - Collaboration btw O-RAN Alliance and LF

Mission: “Open and Intelligent Software for the Radio Access Networks”



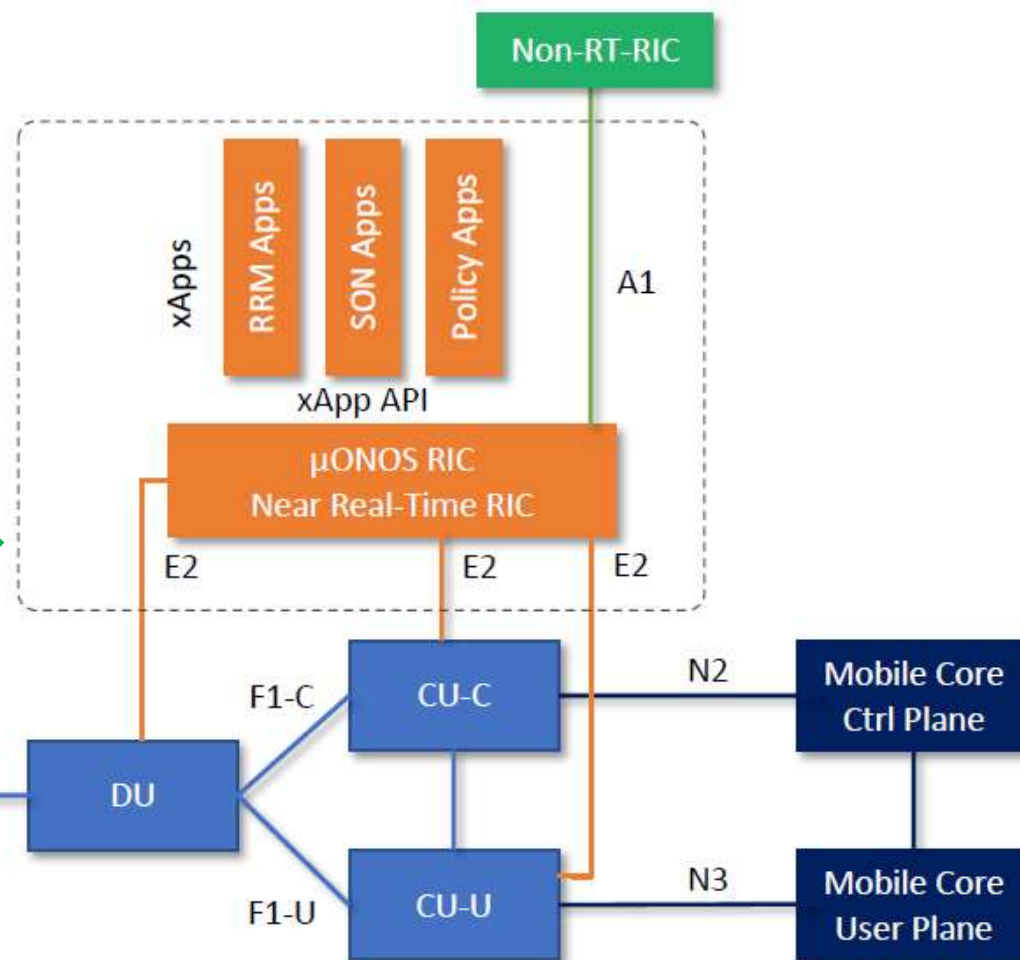
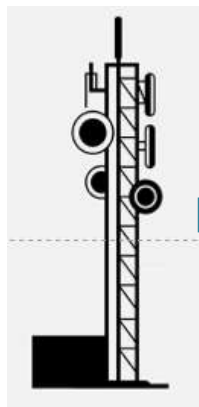


# SD-RAN



- ONF exemplar platform for 3G
  - Consistent with O-RAN archi
  - Cloud-native
  - Built on ONF's operator-app
    - ONOS
    - Aether
- Near RT-RIC
  - $\mu$ ONOS RIC
- xAPPs
  - Handover
  - Load Balancing

Developing  
Near RT-RIC and  
exemplar xAPPs



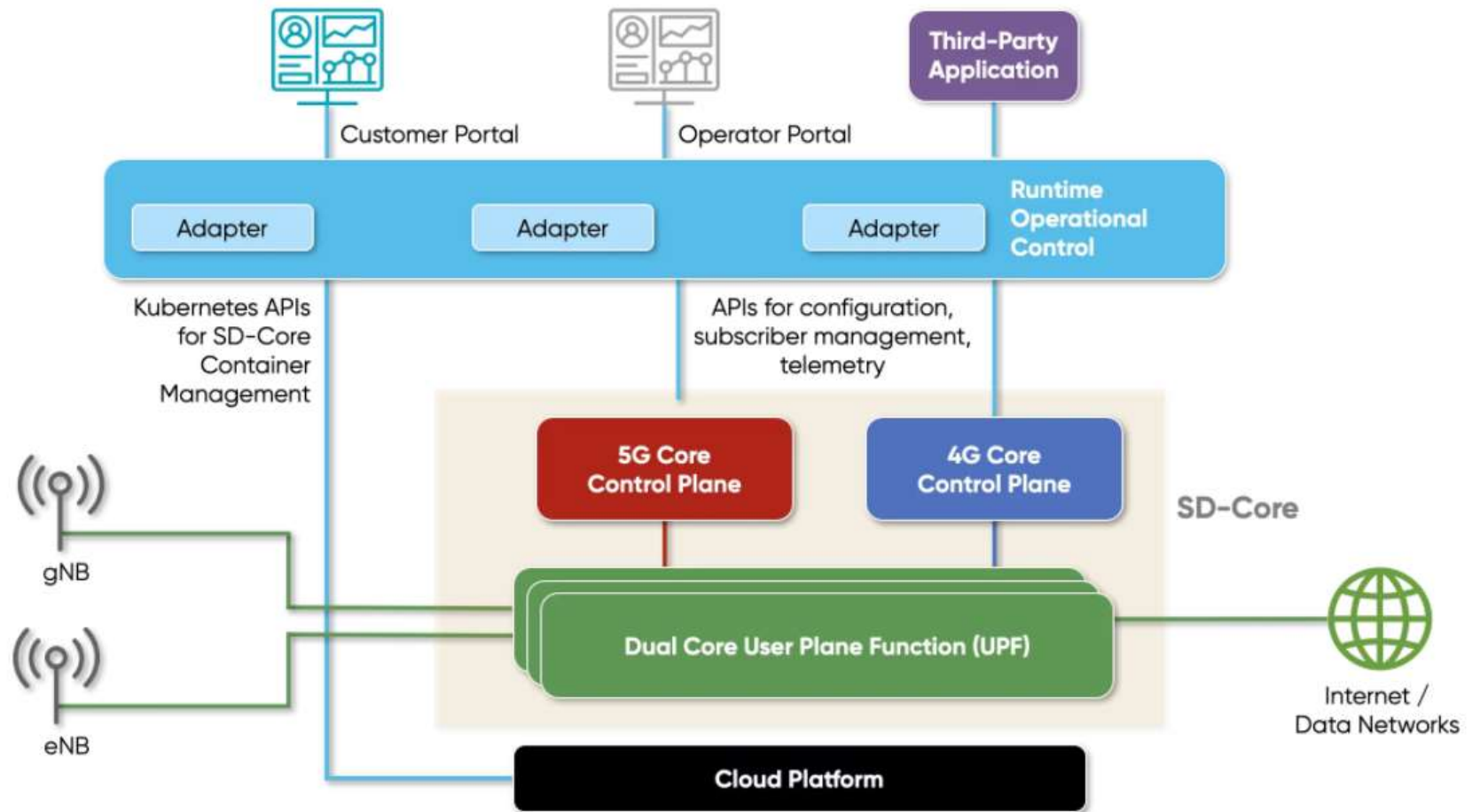
<https://opennetworking.org/sd-ran/>





# SD-CORE

- A 4G/5G disaggregated mobile core optimized for public cloud deployment



<https://opennetworkworking.org/sd-core/>