This lecture is being recorded

18-452/18-750
Wireless Networks and Applications
Lecture 18: 5G

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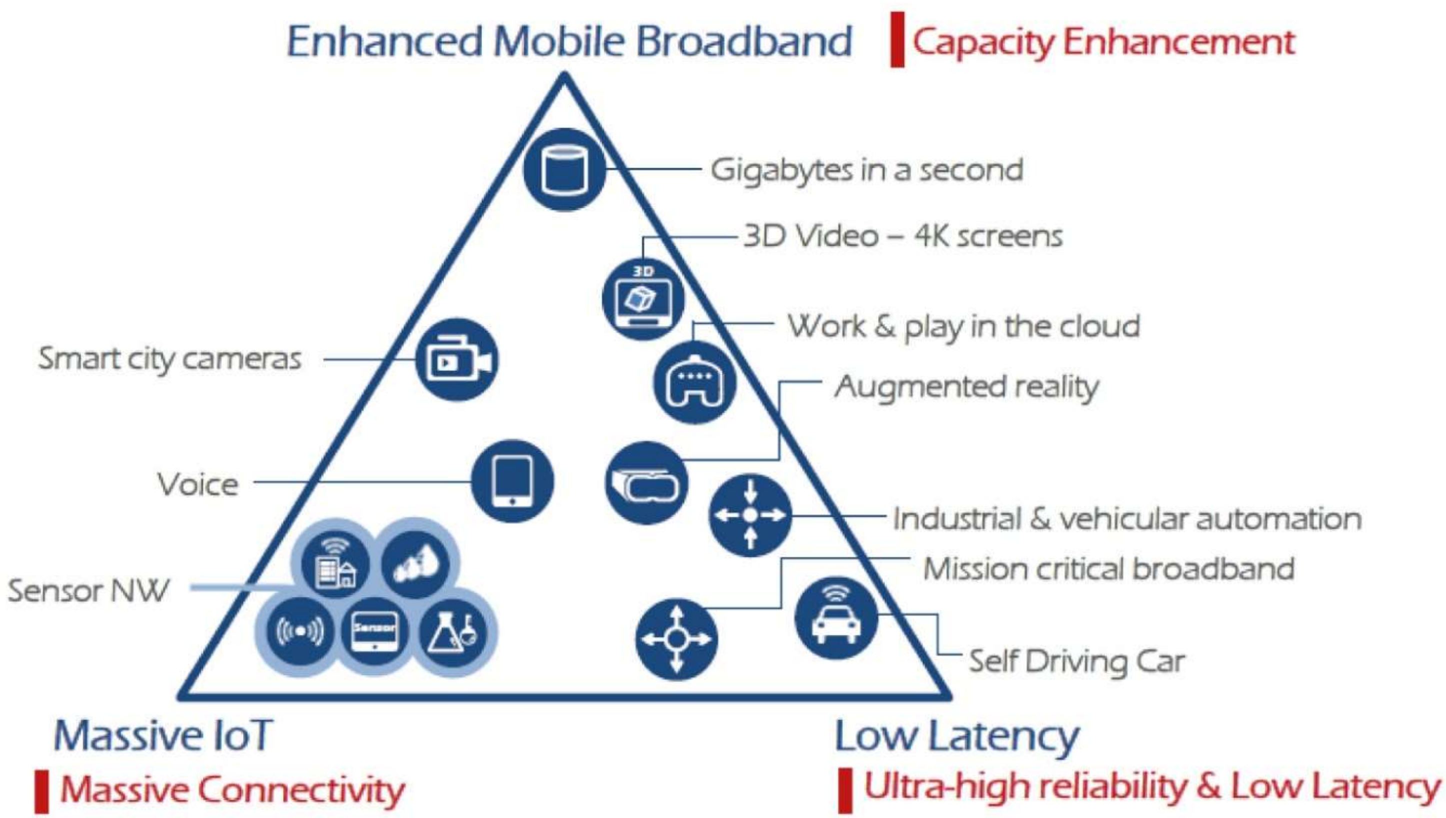
http://www.cs.cmu.edu/~prs/wirelessS22/

Overview 5G

- Goals and Motivation
- Architecture
- Managing heterogeneity
- Virtualization and cloud technology
- Cloud-RAN
- 5G campus networks

5G Vision ITU
International Mobile Telecommunications



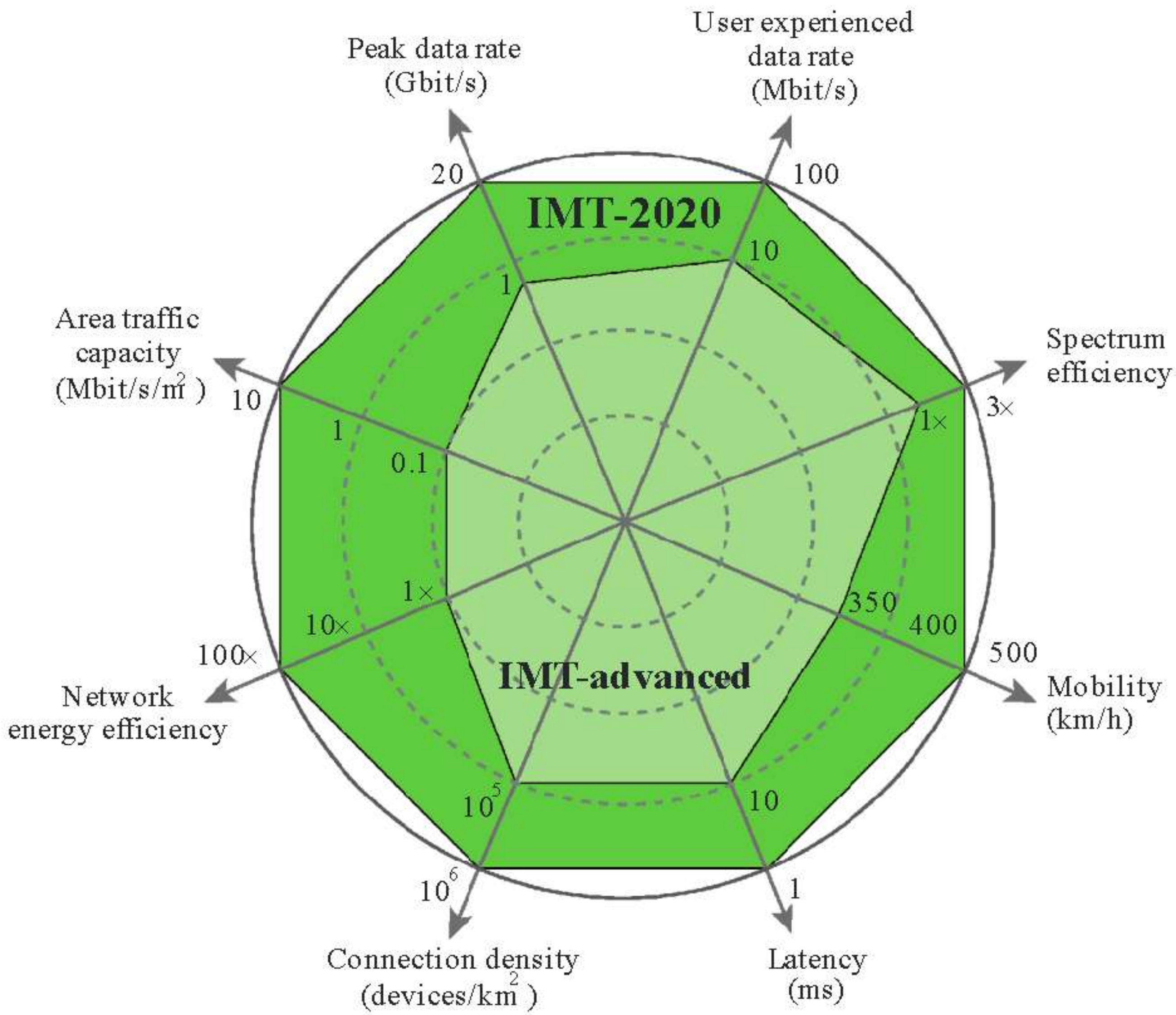
Faster 4G

Growing application domains

(Source: ETRI graphic, from ITU-R IMT 2020 requirements)

https://www.itu.int/dms_pubrec/itu-r/rec/m/R-REC-M.2083-0-201509-I!!PDF-E.pdf

Performance Goals ITU



5G technology
More of the same?

- Goal is 10+ fold increase in bandwidth over 4G
  - » Combination of more spectrum and more aggressive use of 4G technologies
- Very aggressive use of MIMO
  - » Tens to hundred antennas
  - » Very fine grain beamforming and MU-MIMO
- More spectrum: use of millimeter bands
  - » Low band: below 2Ghz, e.g., 660-850 MHz
  - » Mid band: below 6 GHz, new bands, e.g., 2.5-3.7 GHz
    - – https://www.cnn.com/2021/03/14/tech/5g-spectrum-auction-att-verizon-tmobile/index.html
  - » High band: mmWave, over 26 GHz, e.g., 25-39 GHz
    - – New bands - challenging but a lot of spectrum available

Is That Enough?

- Scaling up existing solutions attacks bandwidth challenges, but what about …
- Dealing with heterogeneity
  - » Widely different traffic loads
  - » Use of very different parts of the spectrum
- Dealing with increased complexity
  - » Multiple traffic classes, signaling protocols
  - » Diverse types of PHY processing
- Managing multiple deployment models and controlling costs
  - » Mobile users vs IoT vs low latency/high bandwidth
  - » Private cellular – 5G campus networks

5G Key Technologies

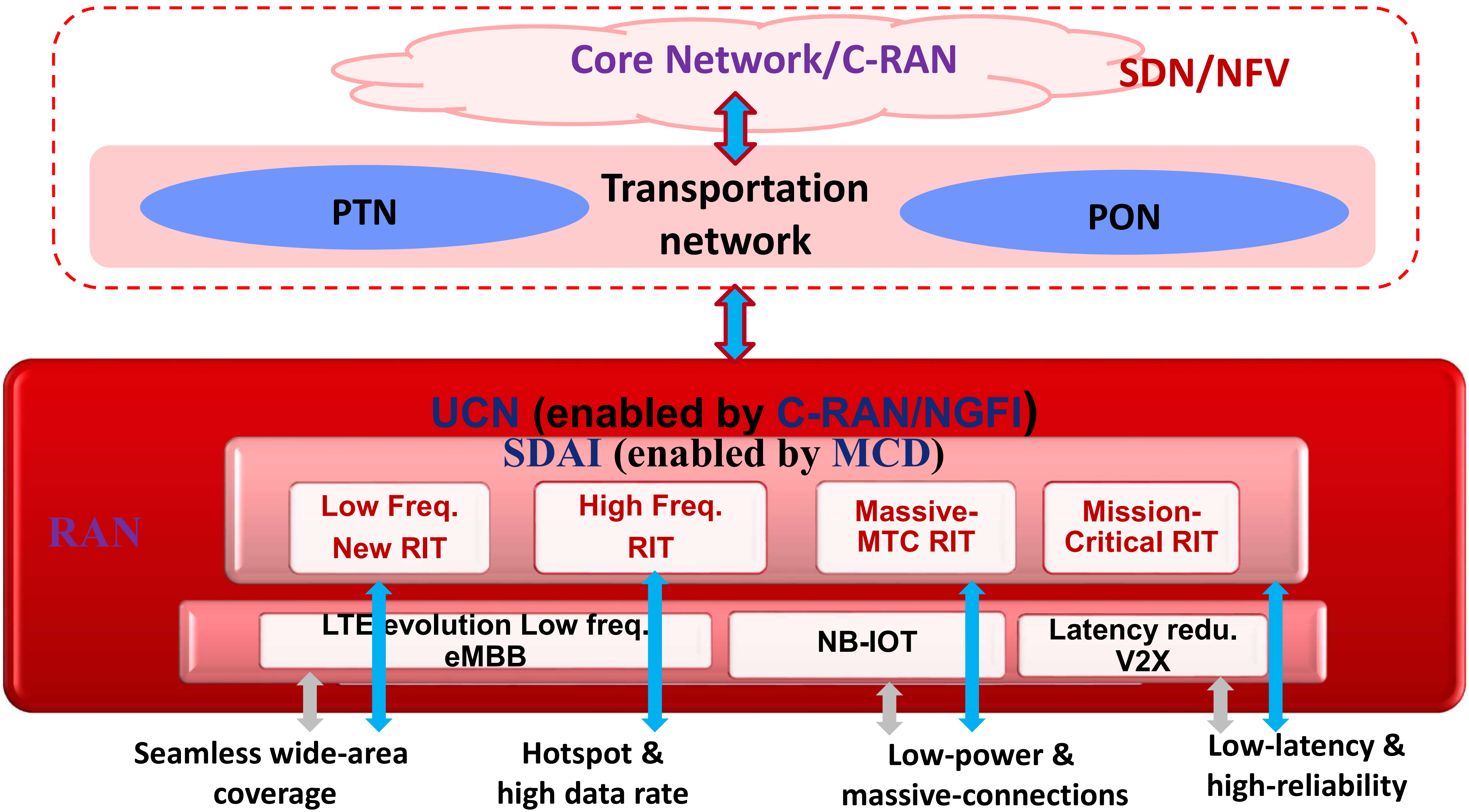


Figure based on: https://www.itu.int/en/ITU-T/gsc/Documents/GSC-20/Session-6/GSC20_Session6_5G_Chih_IEEE.ppt

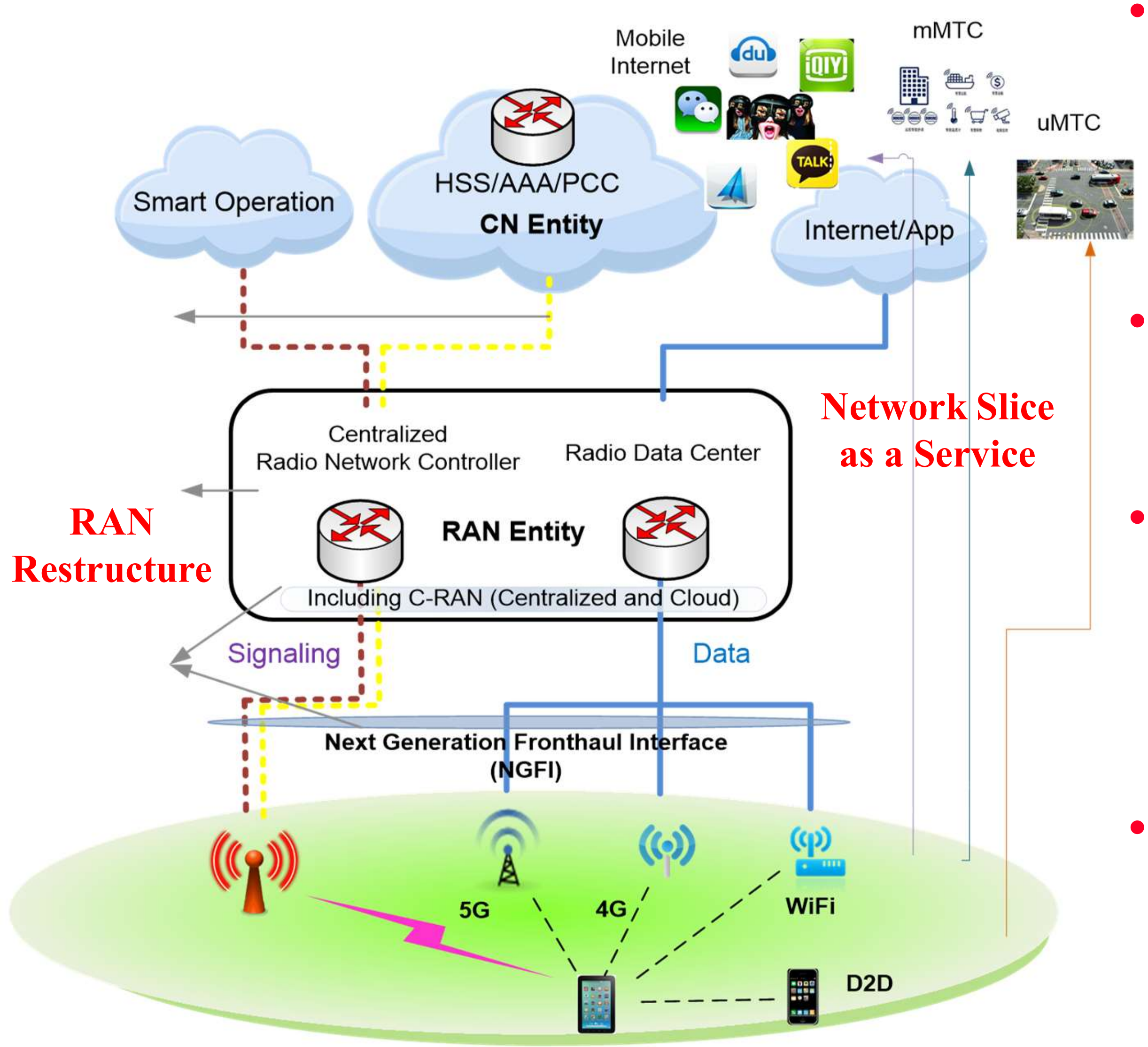
Acronyms

- RIT: Radio Interface Technology
- UNC: User-centric network (data)
  - » Optimize user (device) performance, e.g., interference mitigation
- NGFI: Next-Generation Fronthaul Interfaces
  - » Interface for exchanging signal information between baseband processing in C-RAN (IQ sample) and remote radio units
  - » Used in C-RAN to minimize impact of interference, …
- SDAI: Software-Defined Air Interface (control)
  - » Interface to manage PHY and link level: frame structure, waveform, multiple access, duplex mode, antenna configuration, ..
- MCD: Multi-level Centralized and Distribute protocol stack:
  - » Coordinates decision making across the system (cell, UE)
- PTN: Packet Transport Network
- PON: Passive Optical Network

Technology Discussion

- The basestations have support for diverse front ends and antennas
  - » Responsible for generating/transmitting baseband signal
  - » Needed to deal with diversity of frequency bands, traffic loads
- All other processing is done in a "cloud RAN"
  - » Responsible for both the sent/received data stream and for RAN control
- Standard protocols to coordinate between basestations and C-RAN:
  - » MCD stack for control of PHY and cellular protocol functions using SDIA interface
  - » UNC for RF signal data transfer based on NGFI interface

Cloud RAN (C-RAN)



- **Aggressively move radio processing to the cloud**
  - » **Network control, signaling protocols**
  - » **Radio signal processing**
- **All processing to commodity platforms instead of custom HW**
- **Use of modern cloud and network technologies**
  - » **Virtualization, NFV, SDN (later)**
  - » **Could be outsourced to cloud providers**
- **Also:**
  - » **Home Subscriber Service**
  - » **Authentication, Authorization, Accounting (RADIUS)**
  - » **Policy Charging Control**

Figure based on: https://www.itu.int/en/ITU-T/gsc/Documents/GSC-20/Session-6/GSC20_Session6_5G_Chih_IEEE.ppt

Why C-RAN? Standard Cloud Arguments

- Cheap compute resources
  - » Economy of scale of operating large data centers
- Elastic resource pool
  - » Size of the resource pool can adapt to the traffic load
  - » Multiplexing of resources with other users/applications
- Flexible allocation of resources across applications
  - » Relative load of different traffic classes, frequency bands
- Ability to outsourcing cloud management
  - » Can be delegated to specialized cloud providers
  - » Reduces infrastructure investment
- Virtualization offers isolation of services

C-RAN Challenges

- Transfer of signal data between basestations and C-RAN requires a lot of bandwidth
  - Supported by the NGFI interface
- Processing of the signal data is latency sensitive
  - Latency bounds are much tighter than for typically workloads
  - Need to be able to adapt to channel conditions
  - May need additional support in the cloud infrastructure
- RAN control needs to be driven by information obtained from signal data
  - Adjust transmit powers, antennas, …

Frequency Reuse

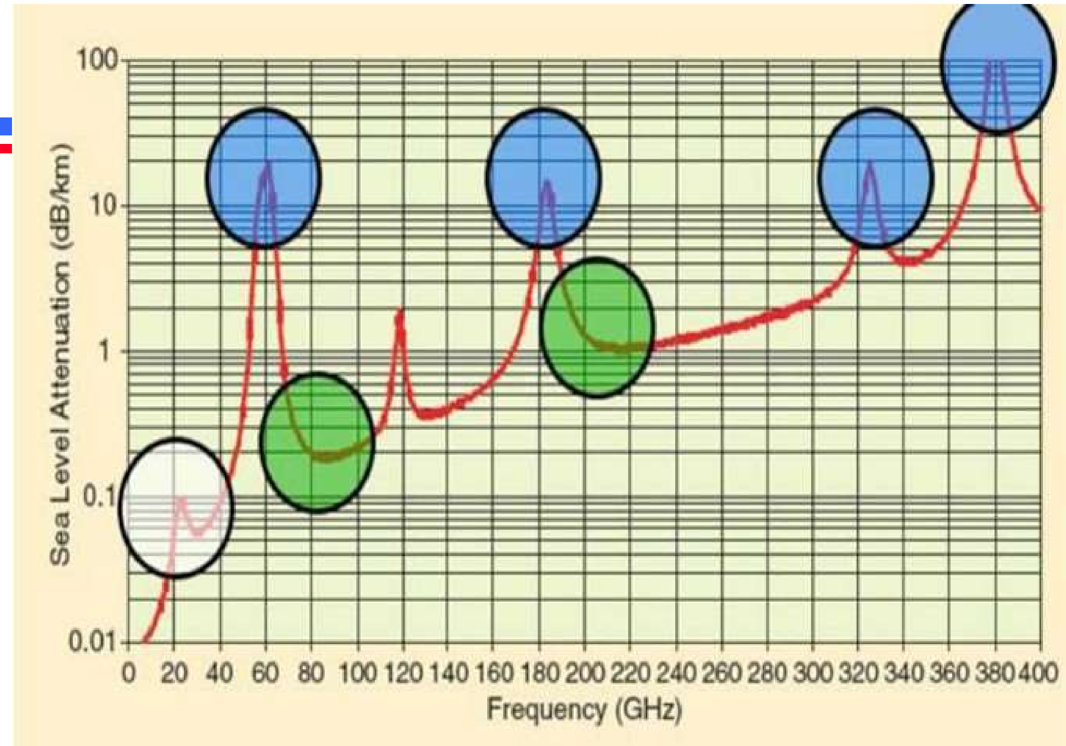
- Frequency reuse across cells has become increasingly aggressive:
  - » Initially, macro cells with relatively static distribution of frequencies across cells
  - » Next, introduction of micro, pico, etc. cells that are selectively deployed and can reuse frequencies more aggressively
  - » Finally, more aggressive reuse using coordinated interference mitigation across cells
- Drive for frequency reuse is economics
- Goal: no cell designs, where frequencies are dynamically assigned and used "everywhere"
  - » Very carefully limit interference during reuse

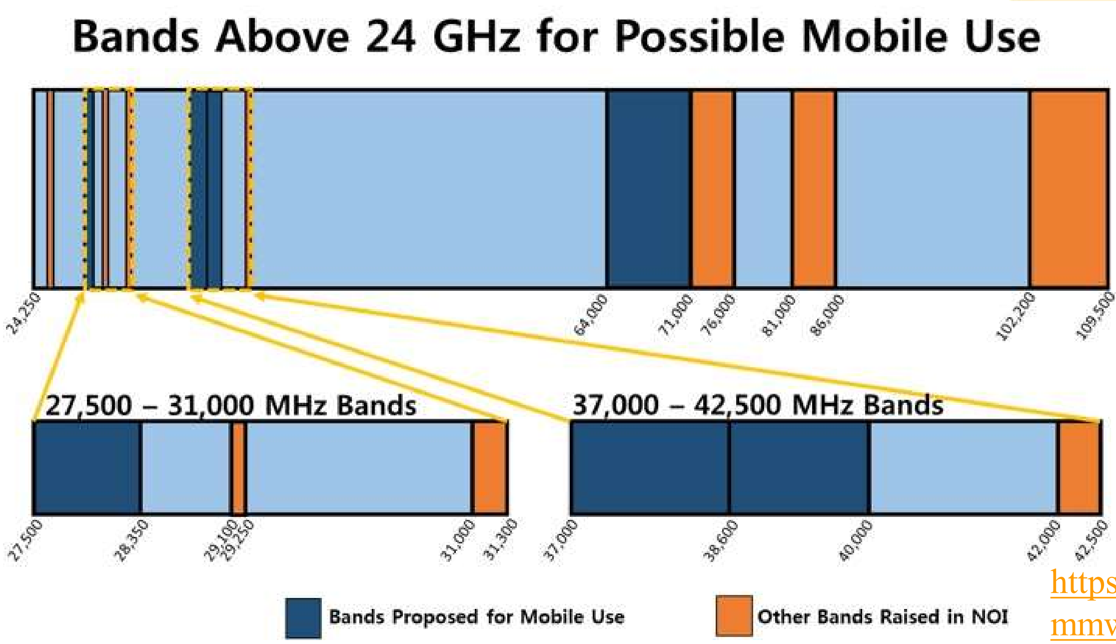
mmWave Offers Significant More Capacity

- There is a lot of spectrum available!
  - » See next slide for the fine print
- Need to use beam forming to achieve reasonable range for mmWave
  - » Possibly using large number of antennas (10s .. 100)
  - » Technology similar to that discussed for 802.11ad
  - » Challenges include establishing sessions, mobility, ..
- Best solution likely involves coordination between stations with “cm-wave” technologies
  - » ~GHz technologies are used for coverage
  - » mmWave is used for high capacity when needed

mmWave is Hard to Use

- Some mmWave frequencies are hard to use because of atmospheric absorption
  - » E.g., 60GHz!





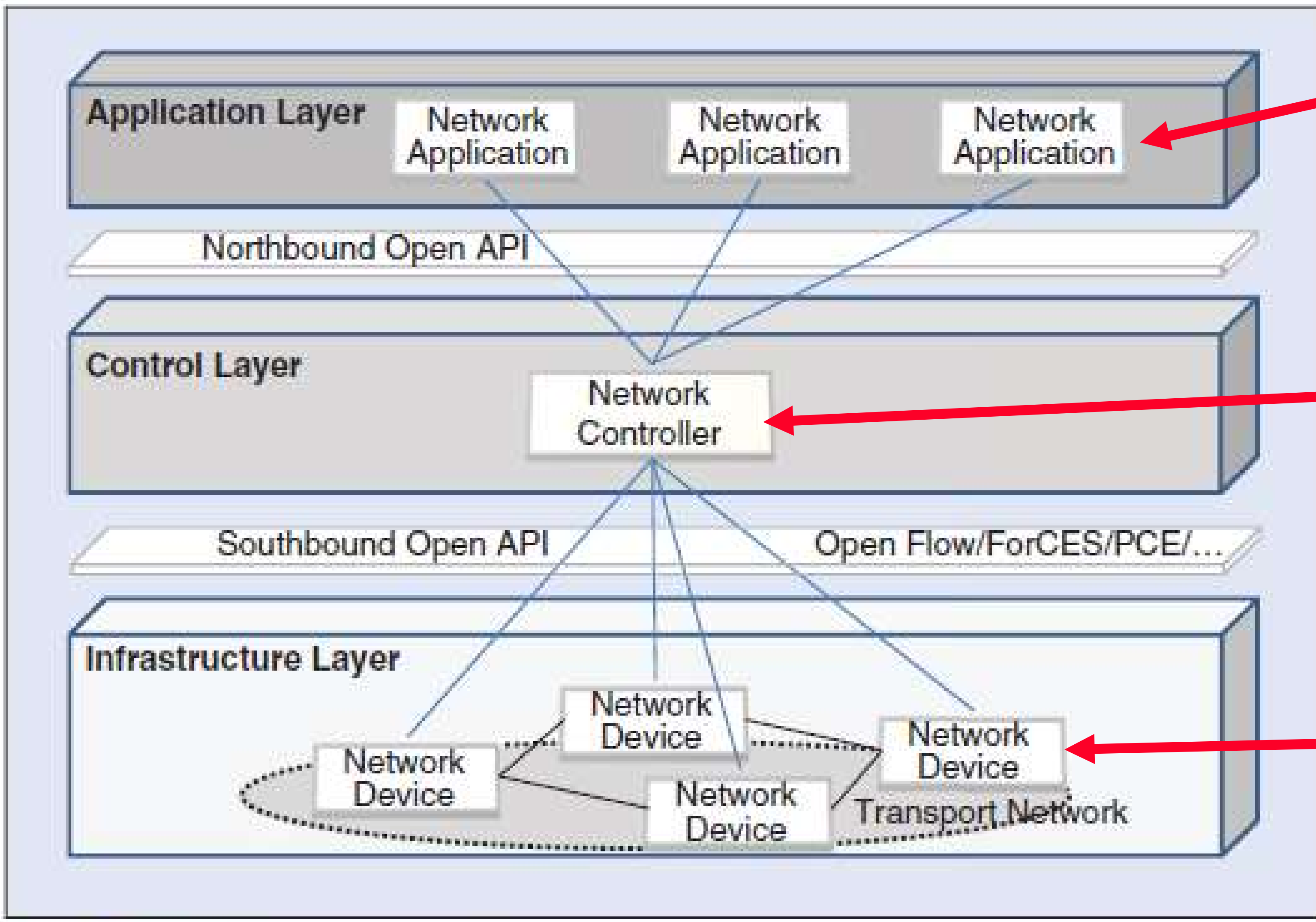
- Cellular operators measurements studies to identify frequencies that are commercially viable
  - » 28, 38, and 73 GHz look promising

https://www.ni.com/en-us/innovations/white-papers/16/mmwave--the-battle-of-the-bands.html#section-1236278719

Use New Network Technologies in Core Network

- Software Defined Networking (SDN)
  - Centralized control of the network
  - Provides more fine grain control over resources, e.g., bandwidth management, …
- Network Function Virtualization (NFV)
  - Cellular operators run a lot of “middleboxes” that provide value added services to users
  - Traditionally supported using custom hardware but increasingly supported by “Virtual Network Functions” running on commodity servers
  - Enabler for moving computing to clud
- Network slicing using virtualization
  - Flexible way of sharing a single infrastructure between several network operators and their clients

SDN concept



Network Management Applications

Centralized Control

Dumb Network Devices

P. Demestichas, "5G on the horizon: key challenges for the radio-access network." *Vehicular Technology Magazine, IEEE* (2013)

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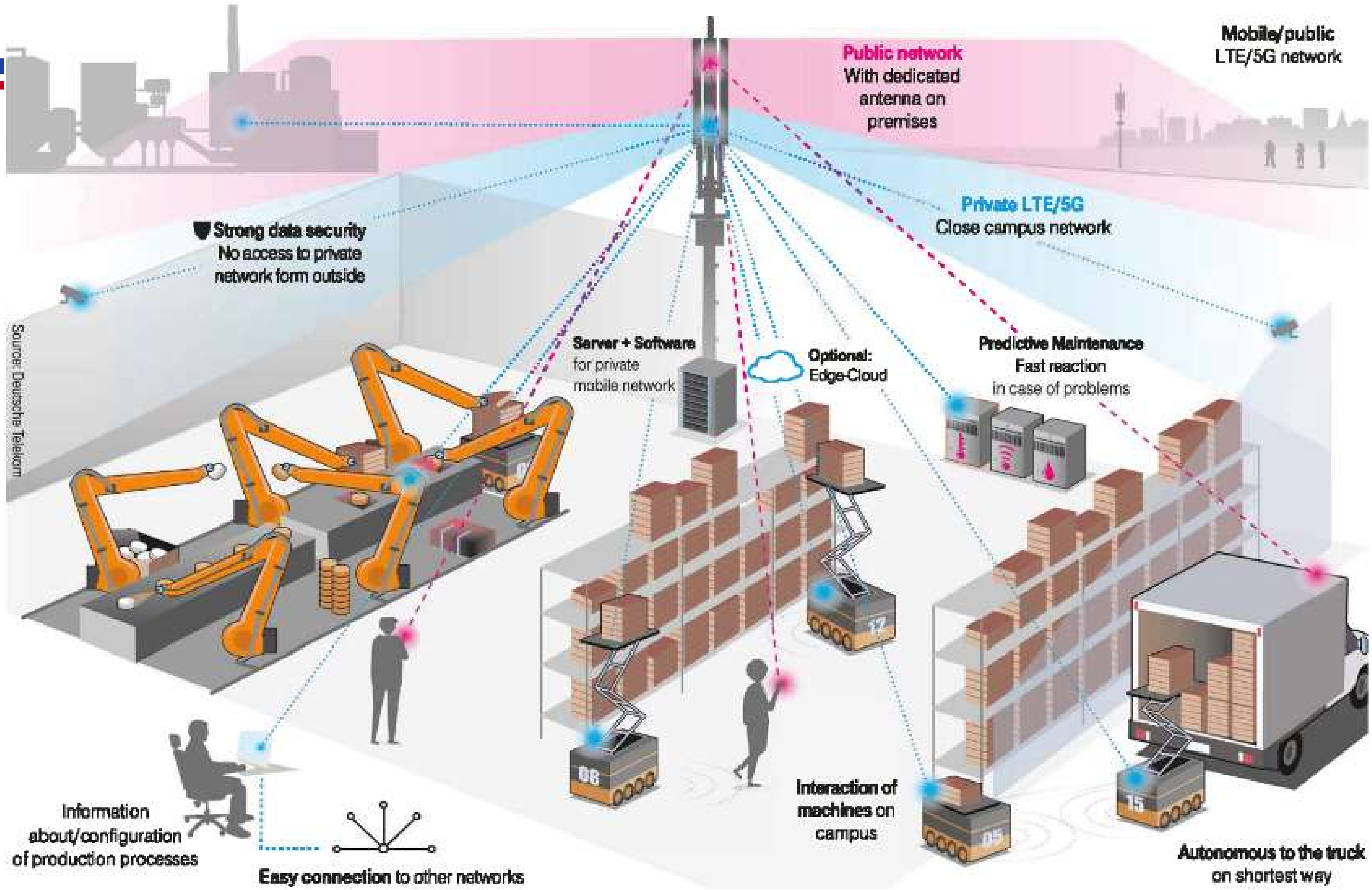
SDN Overview

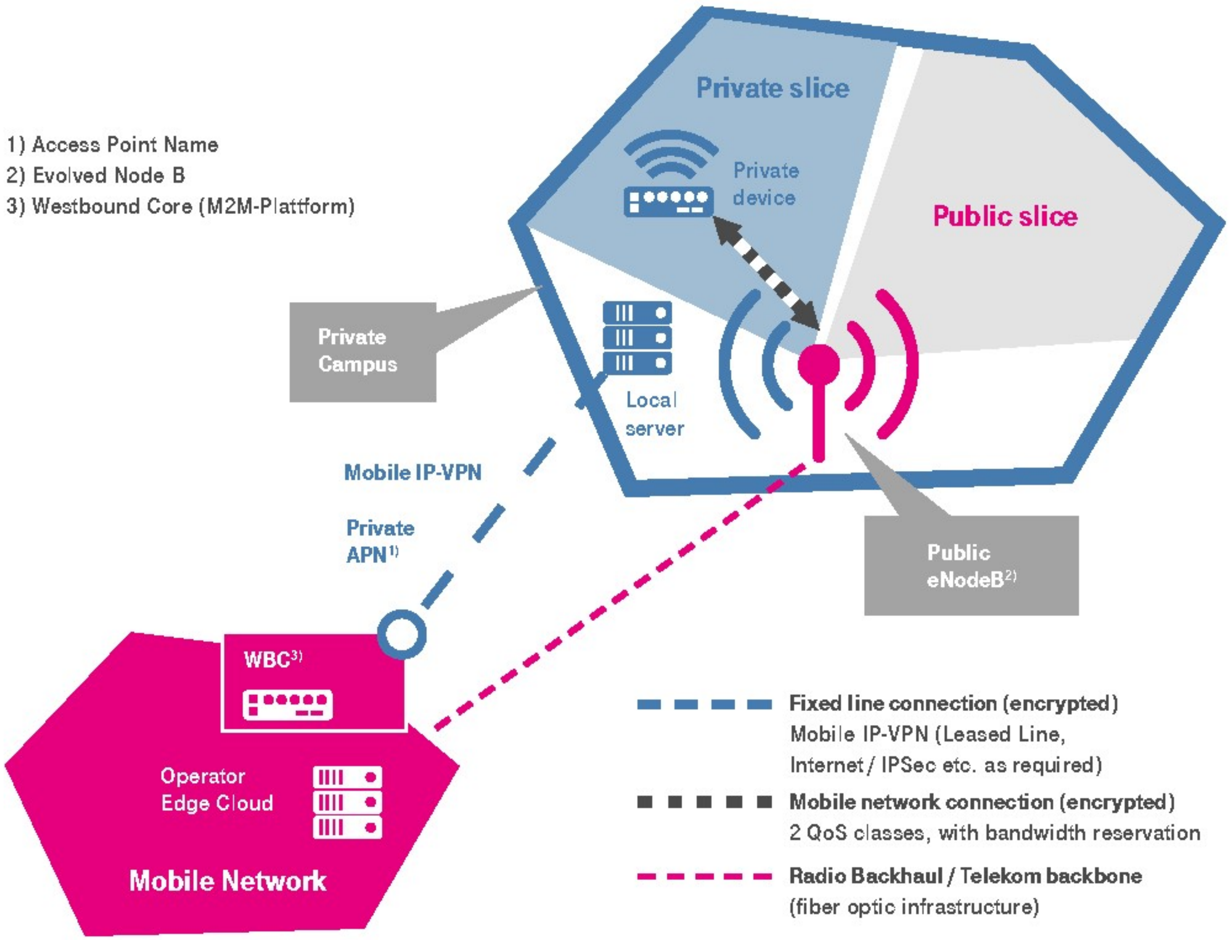
- The control plane and data forwarding plane are separated
- A centralized controller maintains a complete view of the network resources
- Network applications manage resources, control network functions
  - Routing, managing QoS, traffic engineering, etc.
  - Obtain network view through northbound interface
- Uses southbound interface to collect network state and send instructions to devices
  - Protocol is called Openflow for today's IP protocols

5G Campus Networks



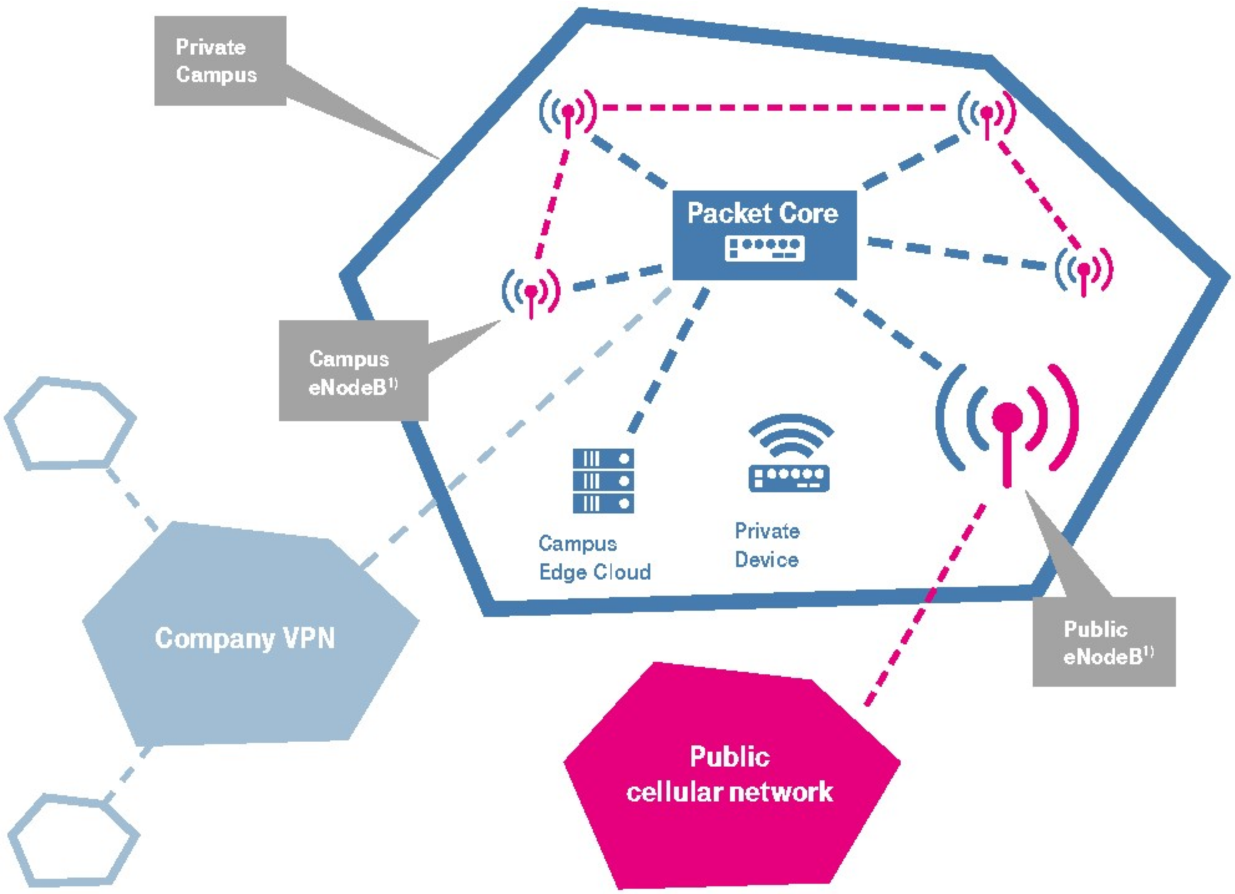
- Private cellular service for diverse applications
- Outsourcing of all wireless networking
- Different deployment models

Private Campus Connectivity



- Create a private slice with isolated resources from public networks
  - » Separates traffic of employees and others
- Can include radio infrastructure on the campus
- Can provide high quality of service

Dedicated Mobile Networks



- Can be used by both employees and others on campus
- Uses on site radio infrastructure
- Provides superior performance