Programmability in 5G (and beyond)

Anup Bhattacharjee

Part 1:
Introduction to 5G

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Contents

- Why 5G?
- What is 5G?

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5G


5G ?


THIS TOWER IN YOUR AREA IS A CRIME AGAINST US. DO NOT CONSENT
Dr. Barrie Trower is a former Royal Navy Microwave Weapons Expert. Find Him on Youtube. Snap this page !!
THEY HAVE CHOSEN THE MOST HARMFUL FREQUENCIES
DANGER
If You knew what these were? You would tear every single one of them!
UNSHIELDED MICROWAVES
QUIET WEAPONS FOR SILENT WARS
5-20 YEARS BEFORE ILLNESS PRESENTS. CHILDREN ARE MORE VULNERABLE TO THIS FORM OF RADIATION.
DANGER
MICROWAVE TOWER IN USE
I AM NOT A SCIENCE EXPERIMENT
TED TURNER. BILL GATES. PRINCE PHILLIP. AGENDA 21 (2030) AND MANY OTHERS WANT TO REDUCE HUMAN FERTILITY AND POPULATION. IE. YOU AND YOUR CHILDREN. (NOT THEIRS). THE MASONIC ORDERS & JESUITS ARE INVOLVED IN THIS. REALITY !! KABALISTS. THEY ARE THE VECTORS FROM WHICH EVIL FILTERS DOWN INTO SOCIETY FROM THOSE WHO MEET IN SECRET. ALL BASED ON LUCIFERIAN BELIEFS. TRUE CHRISTIANS ARE TARGETS NOW.
15 - 50 m
Frequency weapons (mod) 50 – 300 m
OUT OF LOTS OF POSSIBLE FREQUENCIES - FOR SOME REASON 5G WILL USE 60 HZ. KNOWN TO BE THE MOST HARMFUL TO HUMAN BEINGS. WHO DID THIS? WHY/
Unshielded Microwaves cause: glioma (brain cancer) presents after 4-49 years. Neurological disorders. Children are especially vulnerable to this form of rradiation. Who put this in your community? Planning. Council?. politicians? Who ever did this has committed a crime against you. Photograph this page !!! Share !
Find Dr Barrie Trower on his website and on youtube. Just type his name into net.

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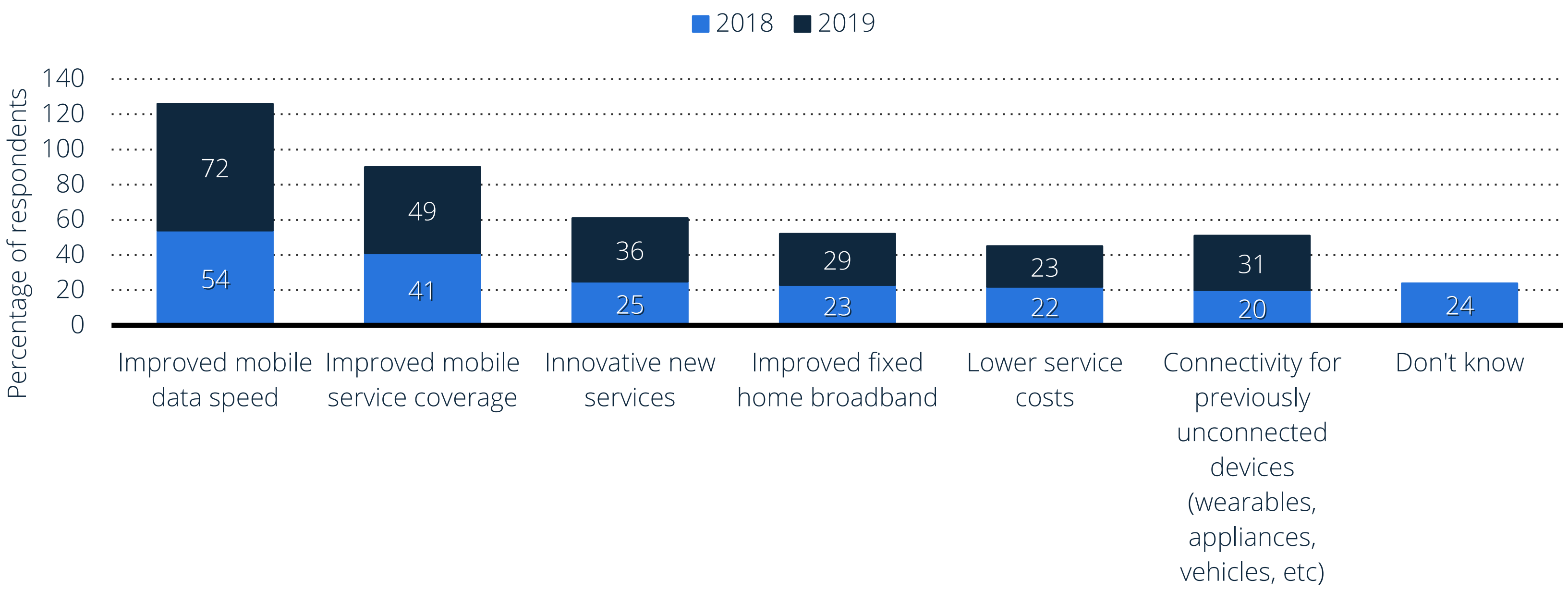
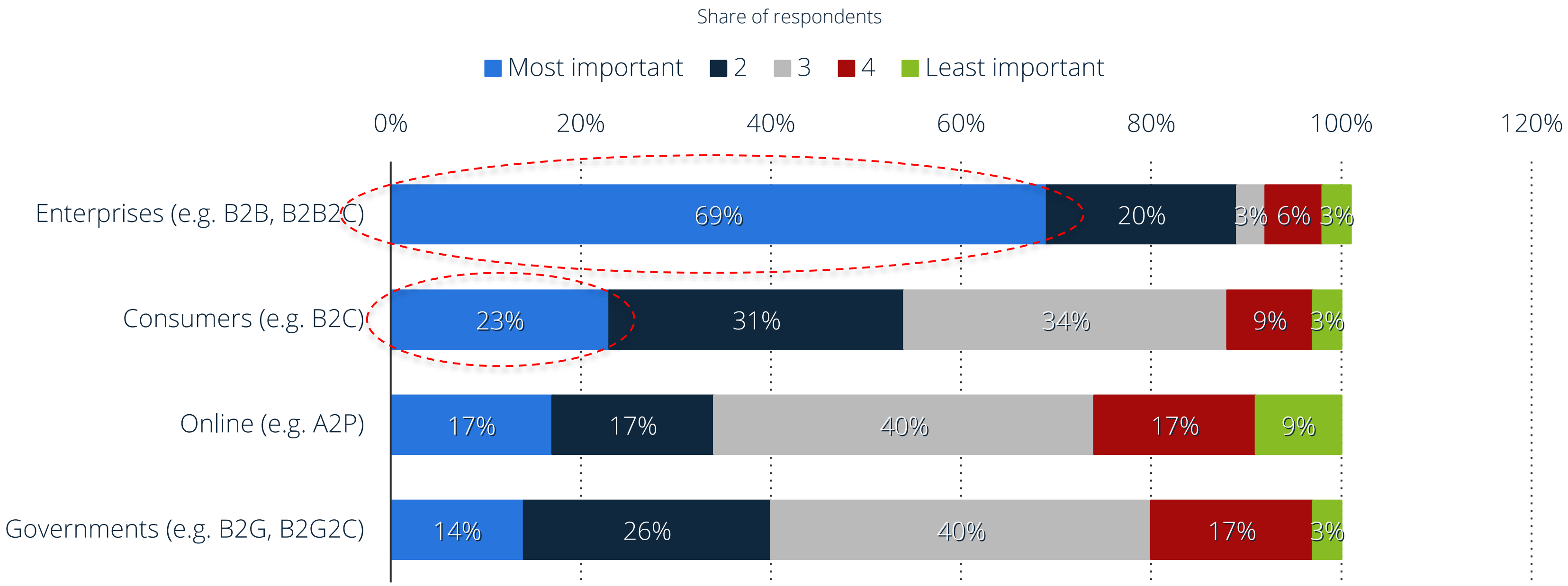
Consumer Expectations from 5G in 2018 and 2019



GSMA . (February 25, 2020). From what you know of 5G, what do you expect it will deliver?* [Graph]. In *Statista*. Retrieved November 30, 2022, from https://www.statista.com/statistics/1101091/5g-consumer-expectations/
Details: Worldwide; GSMA ; GSMA Intelligence; 2018 and 2019

Where will new operator revenues in 5G come from? (survey done in 2016)



GSMA . (February 28, 2017). Where will new operator revenues in 5G come from? [Graph].
In *Statista*. Retrieved November 30, 2022,
from https://www.statista.com/statistics/693366/5g-operator-revenue-sources/
Details: Worldwide; GSMA ; October 2016; 750 respondents; Telecom operator CEOs and other industry stakeholders

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Need for 5G

- Earlier network generations have been designed as general-purpose connectivity platforms with limited differentiation capabilities across use cases.

- Because of this, not all requirements could be met for all the use cases. Think of it like one size of shoe cannot fit everyone.

- In 5G, the aim is to be able to meet the use-case requirements for diverse use cases in different industries.

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Verticals in 5G

Diversity of requirements, associated to the different categories of usage, enables the <u>different industry sectors</u> to work with the Telecom Operator to tweak the network as per their requirements.

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Verticals in 5G

- The different industry sectors are referred to as "verticals", e.g.:
  - Automotive and other transport (trains, maritime communications),
  - Logistics
  - IoT and smart cities,
  - Discrete automation,
  - Electricity distribution,
  - Public Safety,
  - Health and wellness,
  - Media and entertainment.

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Different types of requirements in 5G Usage

- 5G aims to meet the requirements for the verticals by defining certain requirements as per use cases. Some of the interesting use cases:
- Enhanced Mobile Broadband (eMBB).
- Critical communications (CC) such as,
  - Ultra Reliable Low Latency Communication (URLLC).
  - Highly Reliable Low Latency Communication (HRLLC).
- massive IoT (mIoT).
- Vehicle to Everything (V2X).
- Flexible network operations.
- Interoperability with WLAN and unlicensed spectrum

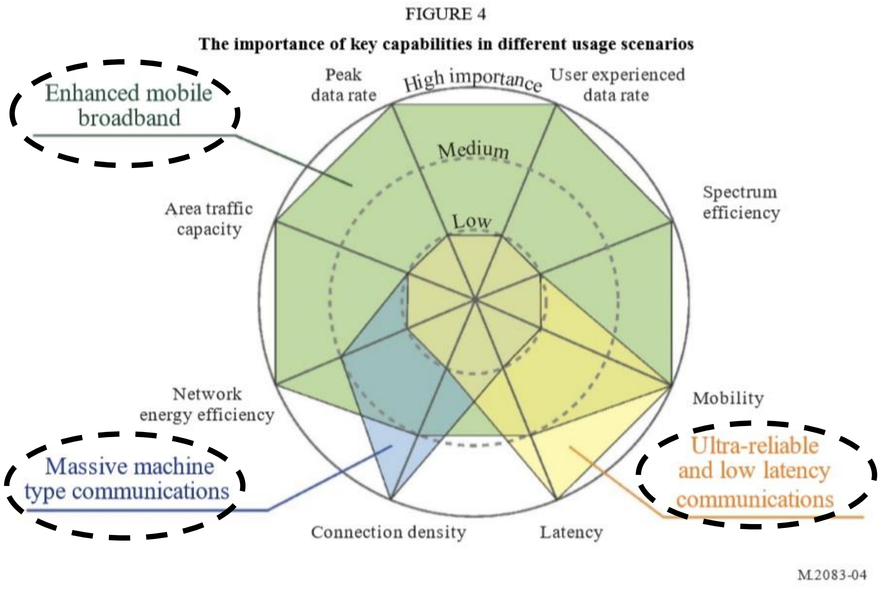
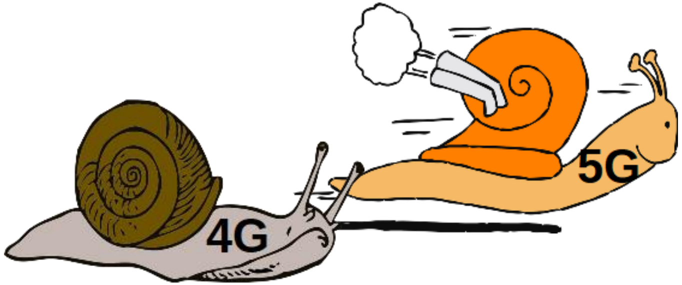


*Figure from IMT Vision

Enhanced Mobile Broadband (eMBB)

- This is the usual human type communication (mobiles) that we use in our day to day lives.

- Intention is to provide users with higher data rates across a wide coverage area.



- Uses in regular cellular communication, AR, VR, etc.

Enhanced Mobile Broadband (eMBB)

- The new requirements are higher than for 4G, are specified for data-rates, traffic/connection density, user mobility, etc.

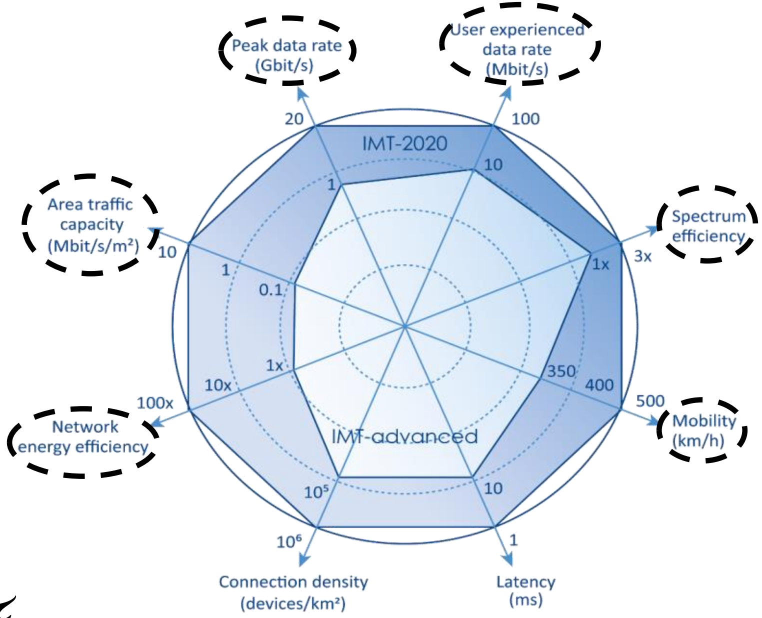
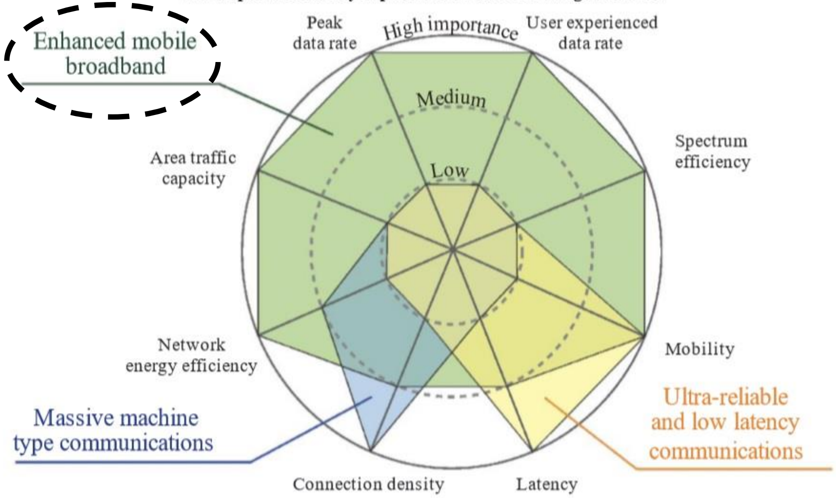


FIGURE 4

The importance of key capabilities in different usage scenarios



M.2083-04

*Figure from IMT Vision

Ultra Reliable Low Latency Communications (URLLC)

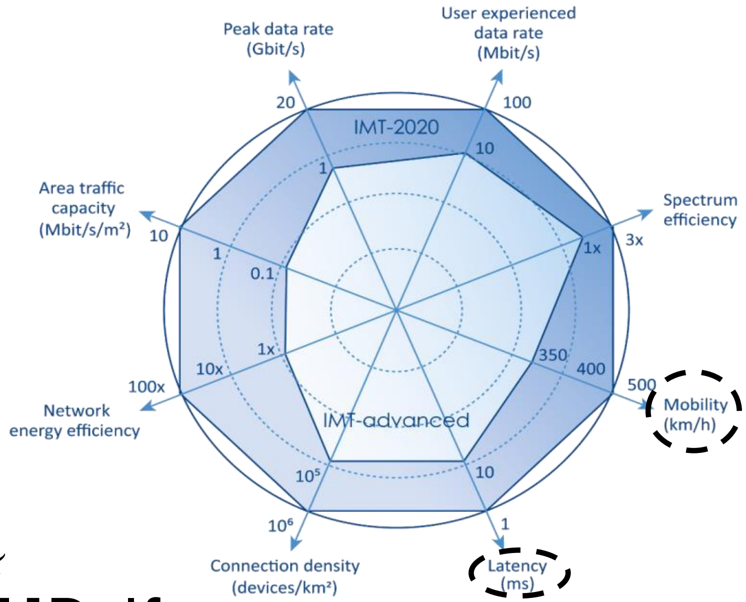
- This is for machine-type communication which will be used in mission critical systems.

- Will be used in applications that have stringent requirements on delay and reliability.

- Used in areas like tactile internet, smart factory, autonomous vehicles etc.

Ultra Reliable Low Latency Communications (URLLC)

- Critical Communications (CC) and Ultra Reliable Low Latency Communications (URLLC):
  - require the support of very low latency and very high communications service availability (like industrial automation)



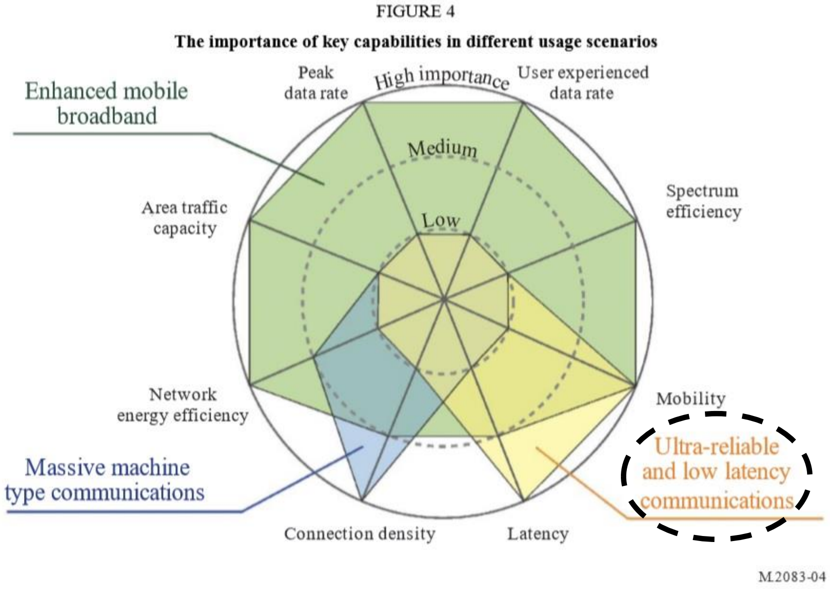


*Figure from IMT Vision

Massive Internet of Things (mIoT)

- This is the machine-type communication that will be used by applications that send sporadic data.

- Intention is to provide huge number of low-cost and low-powered devices with connectivity.

- Used in services like electricity meter, maintenance, etc.

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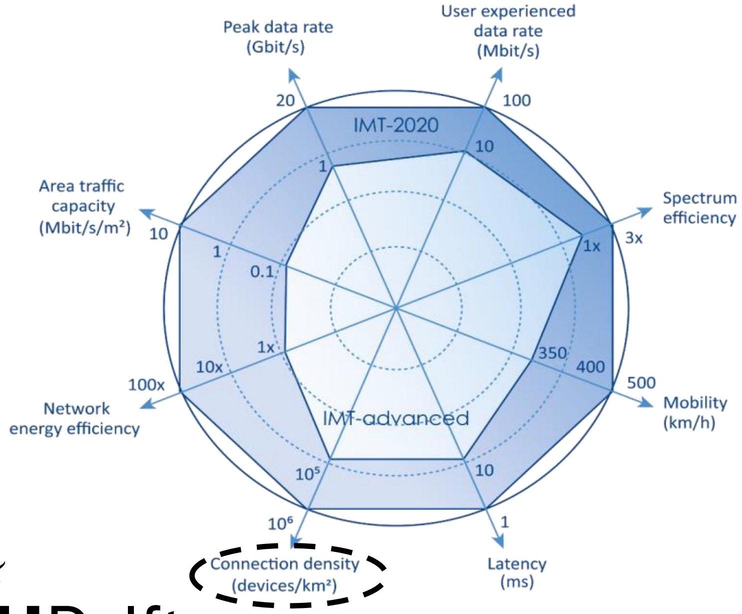
Massive Internet of Things (mIoT)

- This is the requirement for the case when a huge number of devices that send a small amount of data are connected.
- The requirement is to be able to support a very high traffic density of devices.



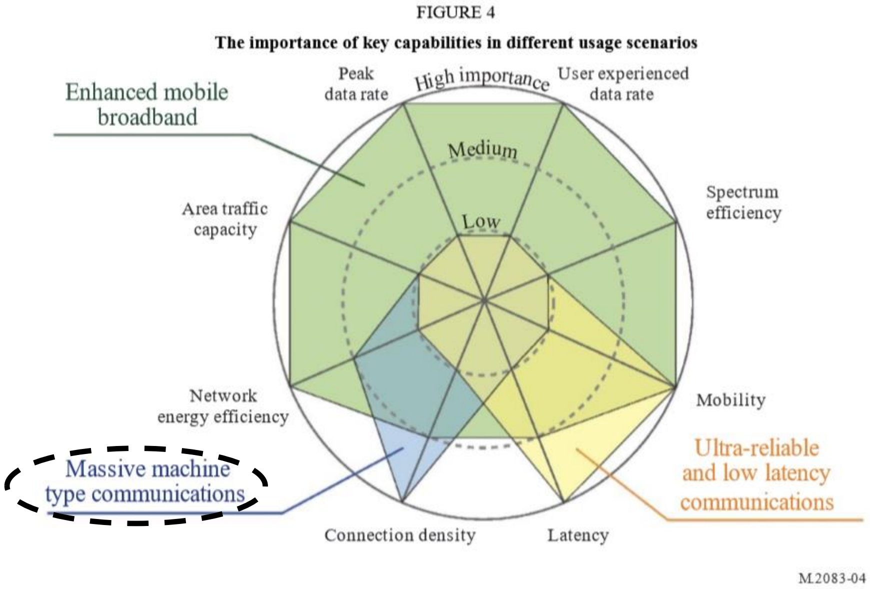


*Figure from IMT Vision

So how does 5G work?

- To understand the working of 5G, we can divide the network into the following parts:
  - The **Radio Access Network (RAN)**: This comprises of 5G macro and small cells (explained in further slides) to provide connection to the users.
  - The **Core Network (5GC)**: This part of the network is to act as a data network and mobile exchange to provide the users with internet, data and voice connections.

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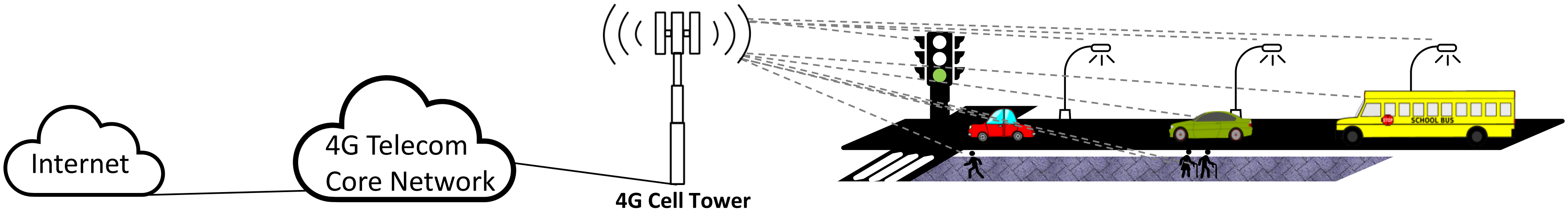
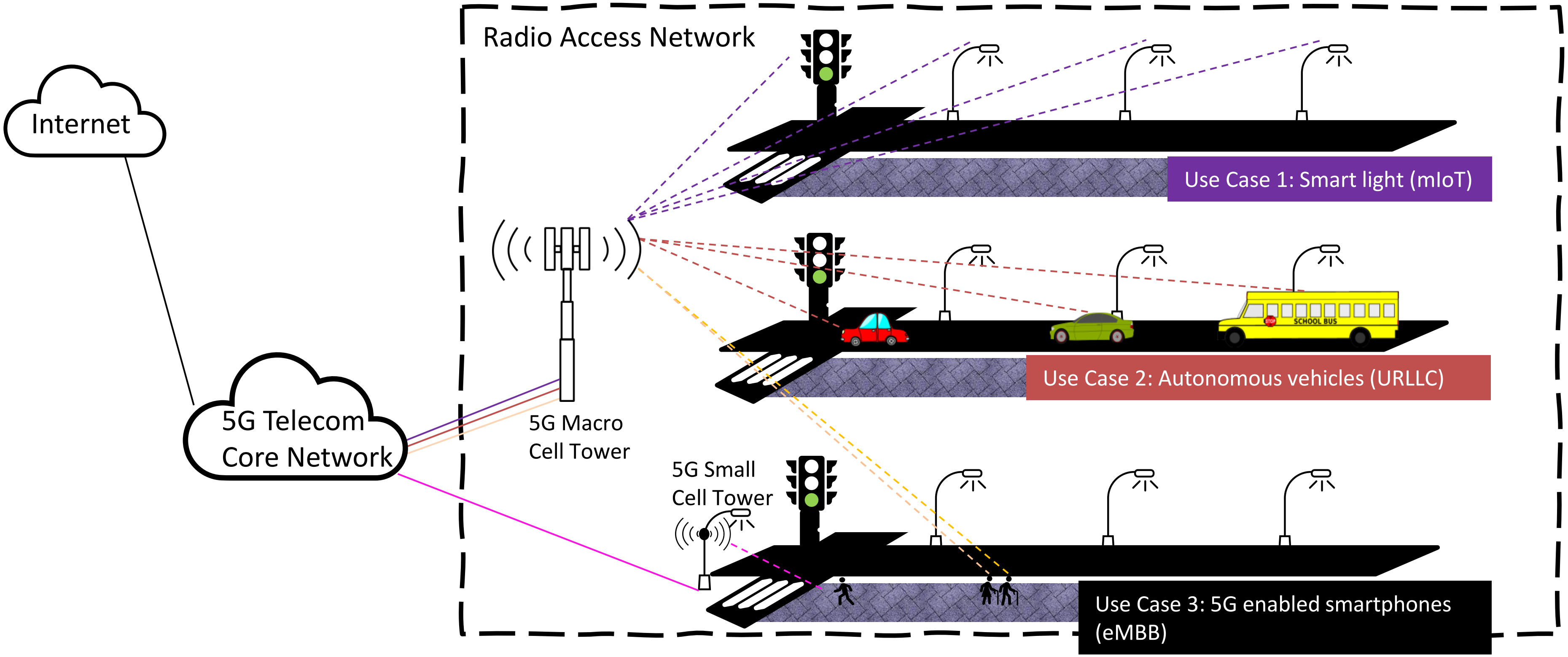
4G Network



5G Network



* The colours depict the virtual networks being constructed by the operator as per the use cases

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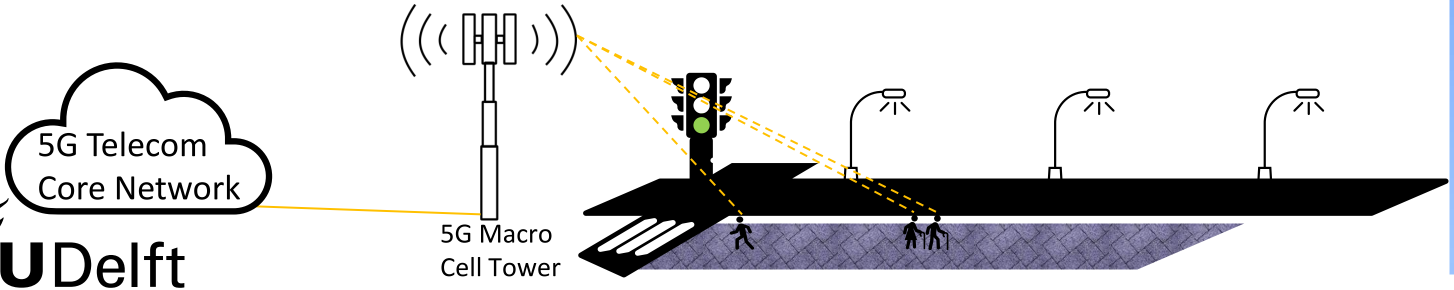
Radio Access Network (RAN)

- Macro-cells
  - These are like (same physical size) the traditional 3G/4G towers that we see, but with newer features like Multiple Input Multiple Output (MIMO) and massive MIMO (very large number of antenna elements).
  - MIMO and massive MIMO aim to provide a higher number of simultaneous connections to receive and send data that can be maintained. This results in increased network throughput compared to 3G/4G networks.



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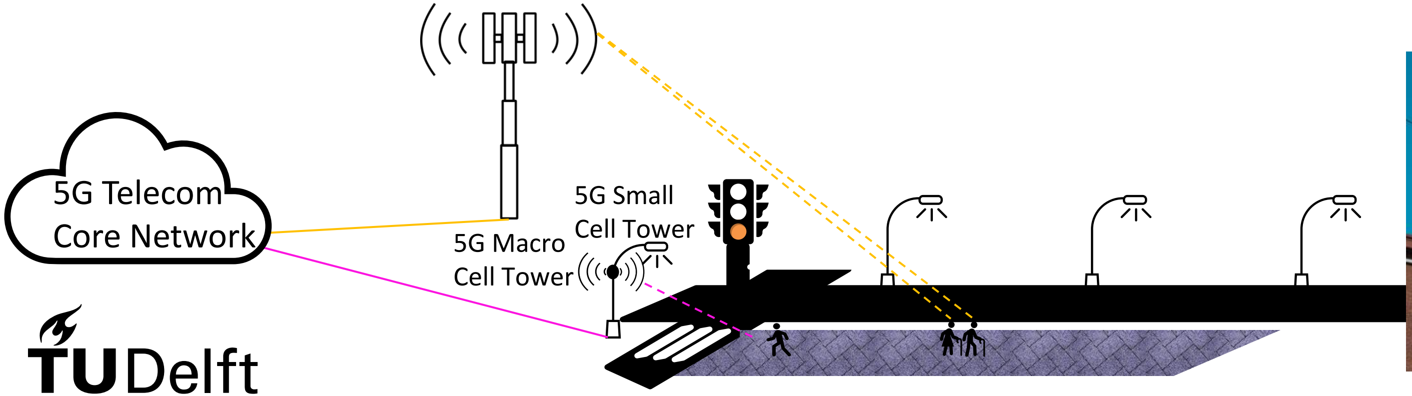
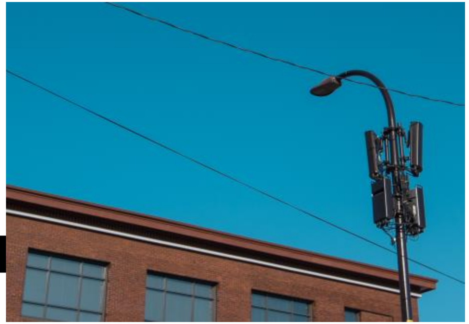
Radio Access Network (RAN)

- Small-cells
  - These are low-powered, short-range base stations to cover small geographical areas. Examples can be to provide indoor coverage or providing coverage from streetlights.
  - They are small with aim to reduce complexity (can also be wall mountable), which makes 5G rollout easier and faster.





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5G Core Network (5GC)

- The 5GC is responsible to provide users connected by the RAN with services like voice and data.

- In 5G, as explained in earlier slides, the main aim of the network is to meet the different use-case requirements of the various verticals.

- To achieve such a feat, 5G uses Network Function Virtualization (NFV) to make virtual networks using network slicing.

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5GC (contd.)

- Network slices can be understood as different network resources being provided to the users as per their requirement.

- For example, the slice requirement for
  - URLLC would be high reliability and low delay.
  - mIoT would be delay tolerant but a lot of low powered connections.
  - eMBB would be high data rates.

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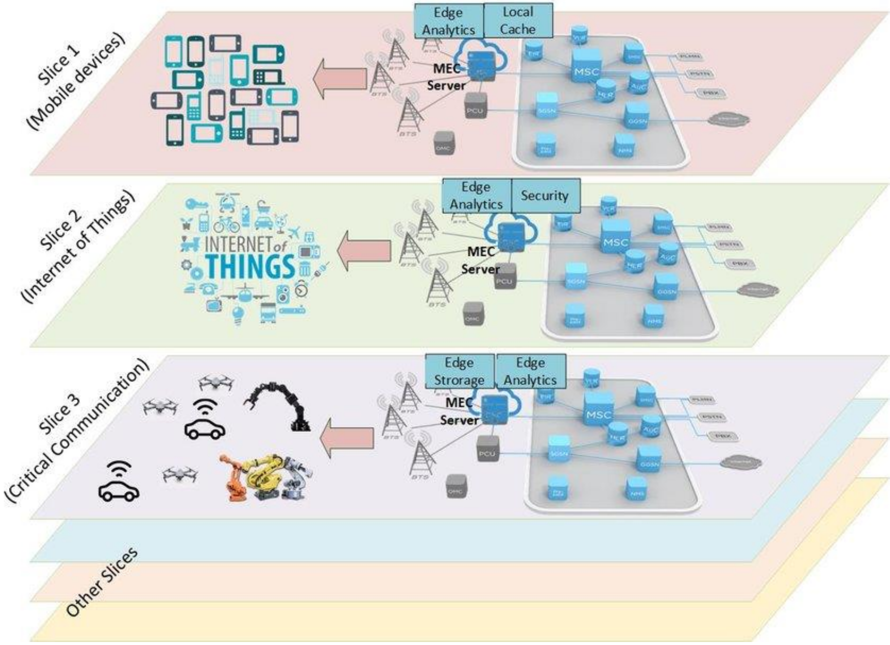
5GC (contd.)

- This ensures optimal network resource usage for operators and better user experience for customers when compared to 4G (where such a differentiation was not present).

- To sum it up, the users of different network slices do not interfere with performance of users from another slice (forming a virtual network for each slice).



Five Driving Forces of Multi-Access Edge Computing - Scientific Figure on ResearchGate. Available from: https://www.researchgate.net/figure/Use-of-Network-Slicing-and-MEC-in-different-5G-applications_fig3_328039848[accessed 24 Jul, 2020]

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Part 2:
Open Source in Cellular Networks

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Making our own cellular network?

Are only network operators able to make a cellular network?

Can we make our own cellular network?

Do we need a lot of money?

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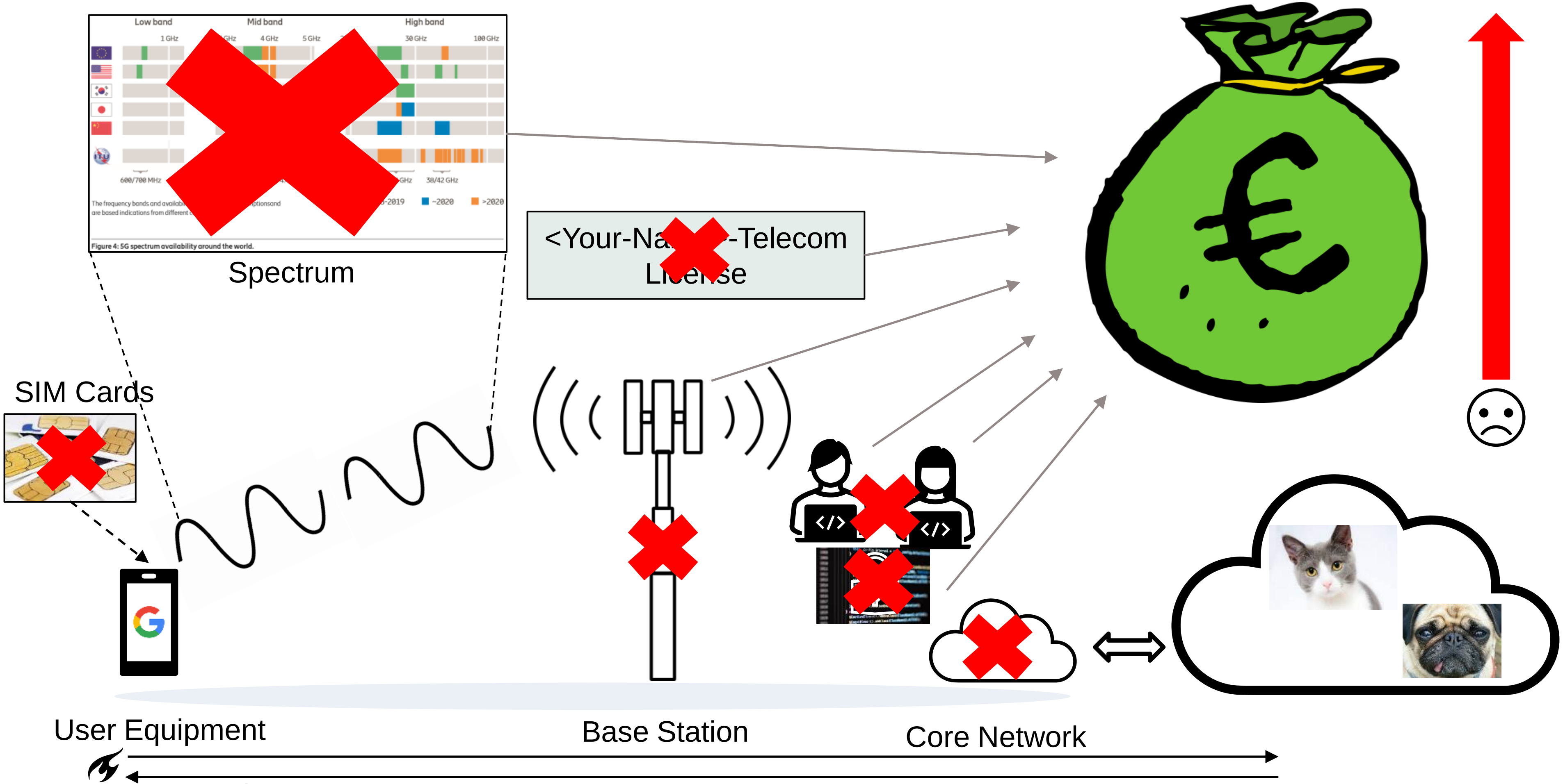
Low band
Mid band
High band
1 GHz
4 GHz
5 GHz
30 GHz
100 GHz
600/700 MHz
38/42 GHz
~2020
>2020
Figure 4: 5G spectrum availability around the world.
Spectrum
<Your-Na
-Telecom
SIM Cards
User Equipment
Base Station
Core Network

Open-Source Telecom Networks

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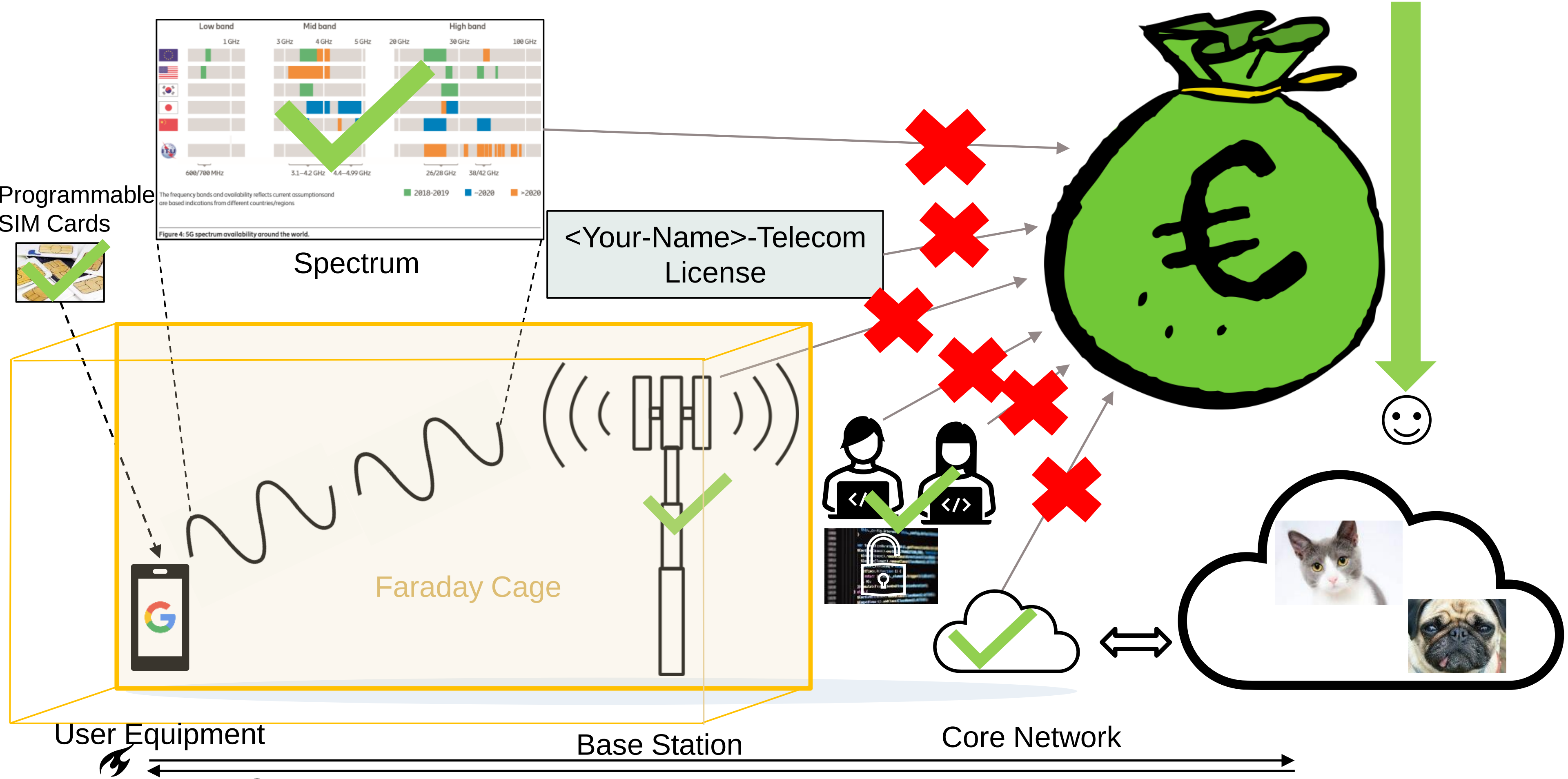
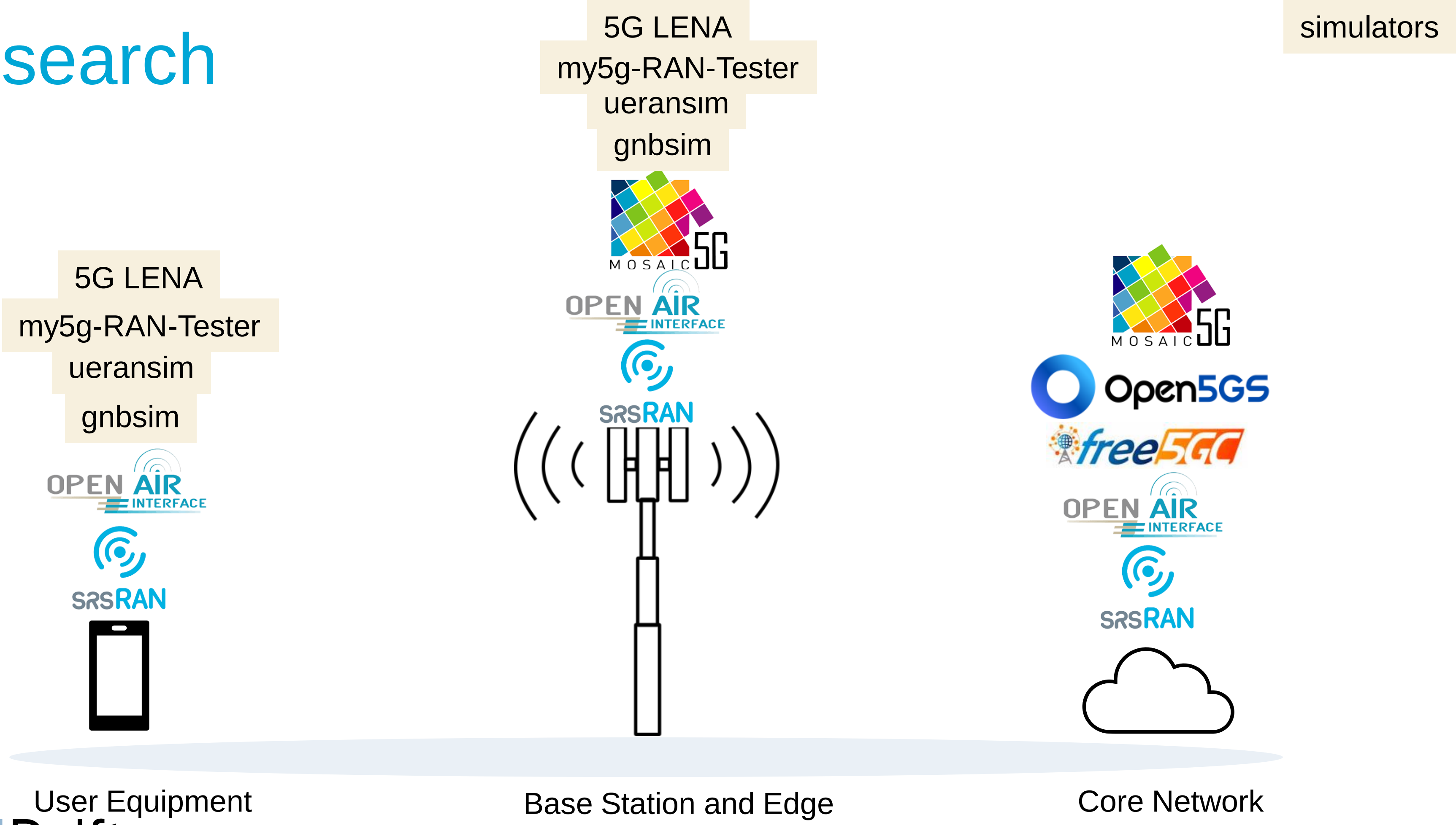
Why open source?


Low band
Mid band
High band
Programmable
SIM Cards
Spectrum
<Your-Name>-Telecom
License
Faraday Cage
User Equipment
Base Station
Core Network

Where is open source being used?

Research



simulators
5G LENA
my5g-RAN-Tester
ueransim
gnbsim
5G LENA
my5g-RAN-Tester
ueransim
gnbsim
MOSAIC 5G
OPEN AIR INTERFACE
SRSRAN
MOSAIC 5G
Open5GS
free5GC
OPEN AIR INTERFACE
SRSRAN
OPEN AIR INTERFACE
SRSRAN
User Equipment
Base Station and Edge
Core Network

Industry

- Open source reduces CapEx and OpEx.

- Many companies are seriously considering open source for private telecom networks.

- Initiatives from industry to incorporate open-source technologies into the network to
  - Prevent vendor lock-in
  - Easier entry for newly established telco companies
  - Promote softwarisation of network components

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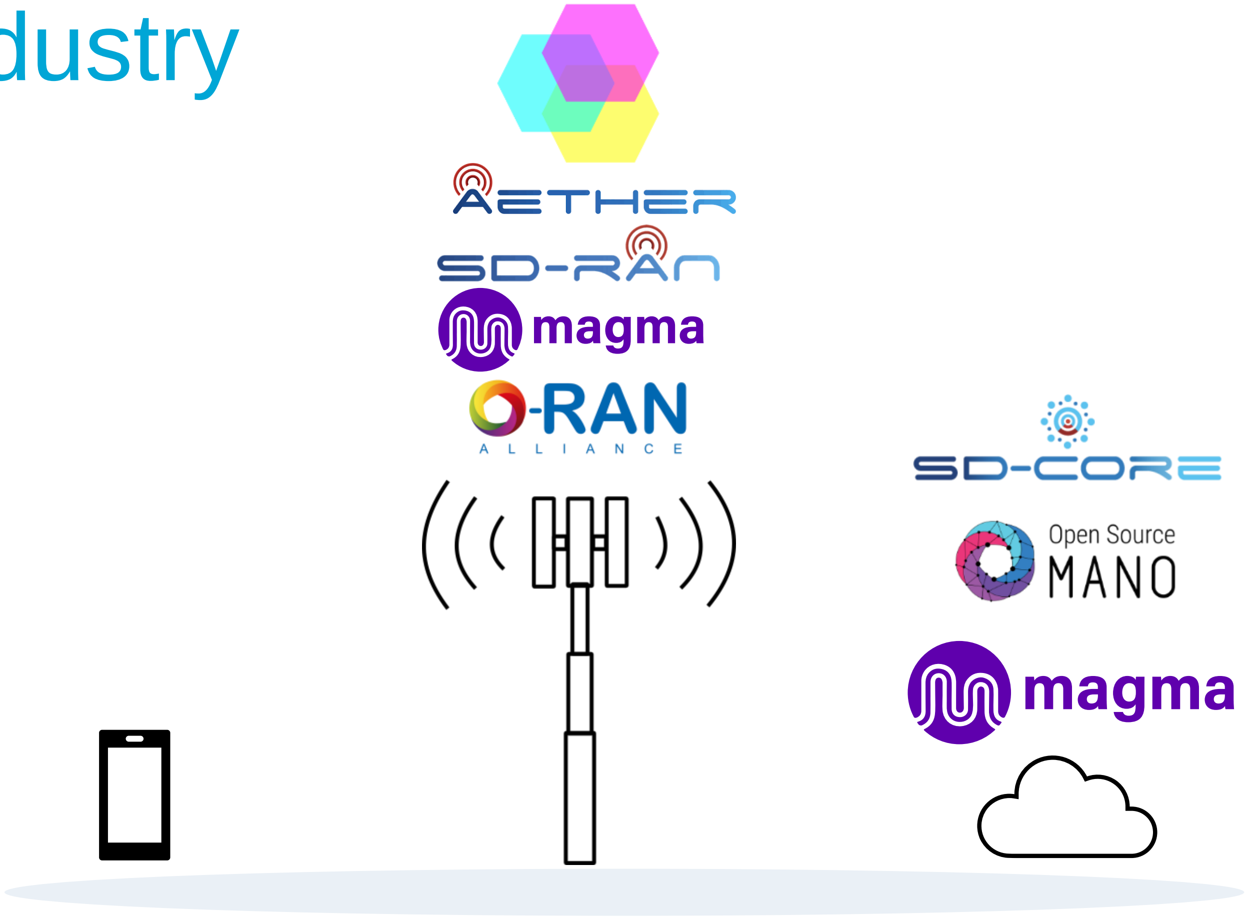
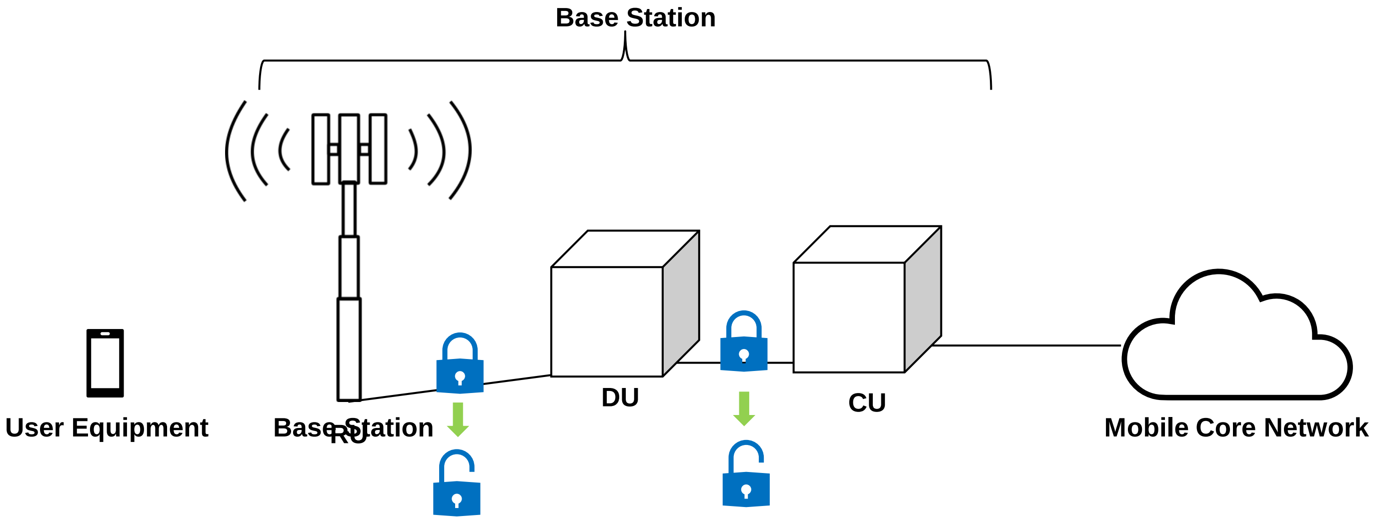
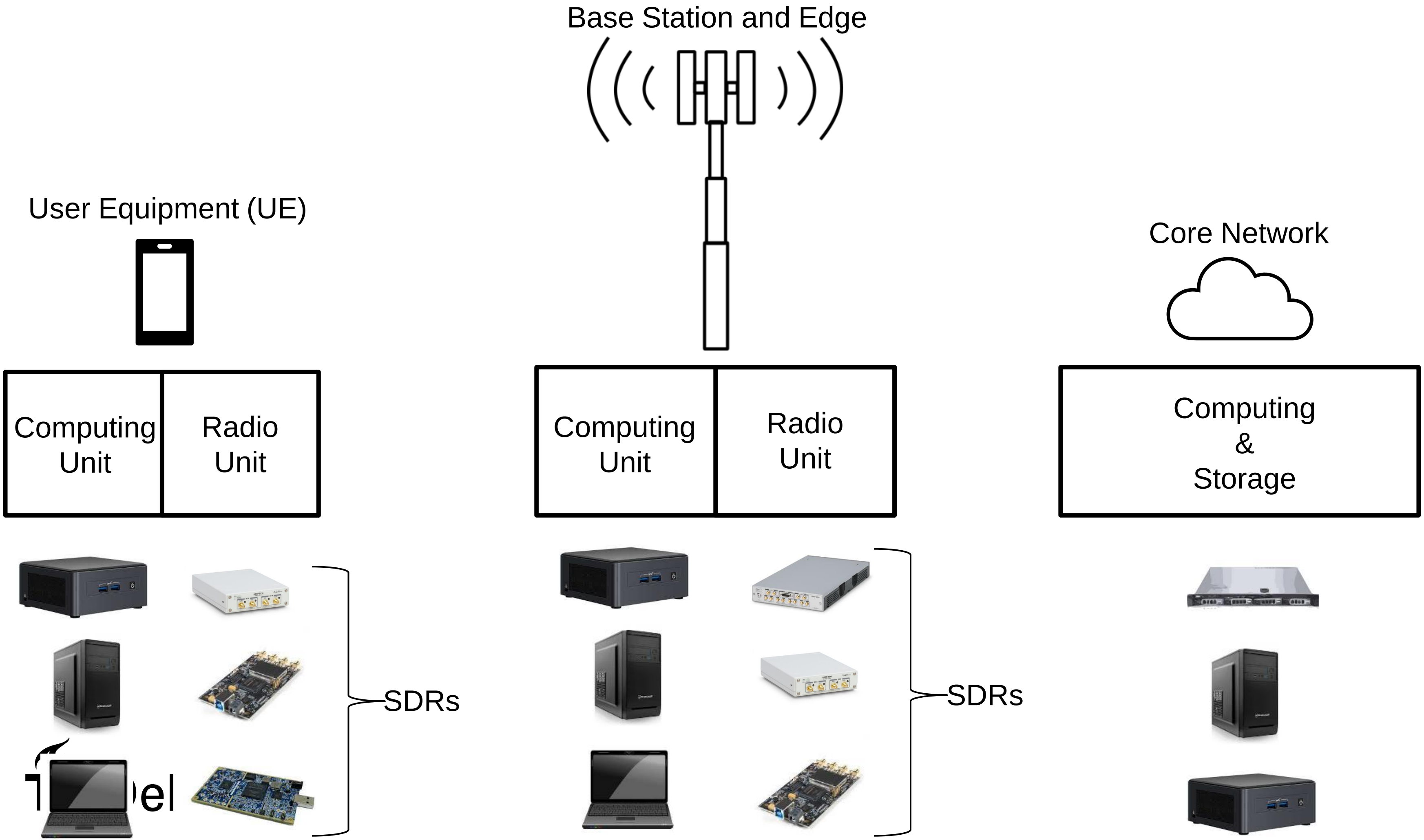
Industry



User Equipment | Base Station and Edge | Core Network



Base Station	Central Unit (CU)	Oversees communication and control between user devices and the network
	Distributed Unit (DU)	Specializes in packet and data processing
	Radio Unit (RU)	Dedicated to the management of radio signal communication


Base Station and Edge
User Equipment (UE)
Core Network
Computing Unit
Radio Unit
Computing Unit
Radio Unit
Computing & Storage
SDRs
SDRs

Software Defined Radio (SDR)

- Has a reconfigurable RF front end compared to the traditional implementations done in analog hardware.

- Used for rapid prototyping and testing in development of radio functions.

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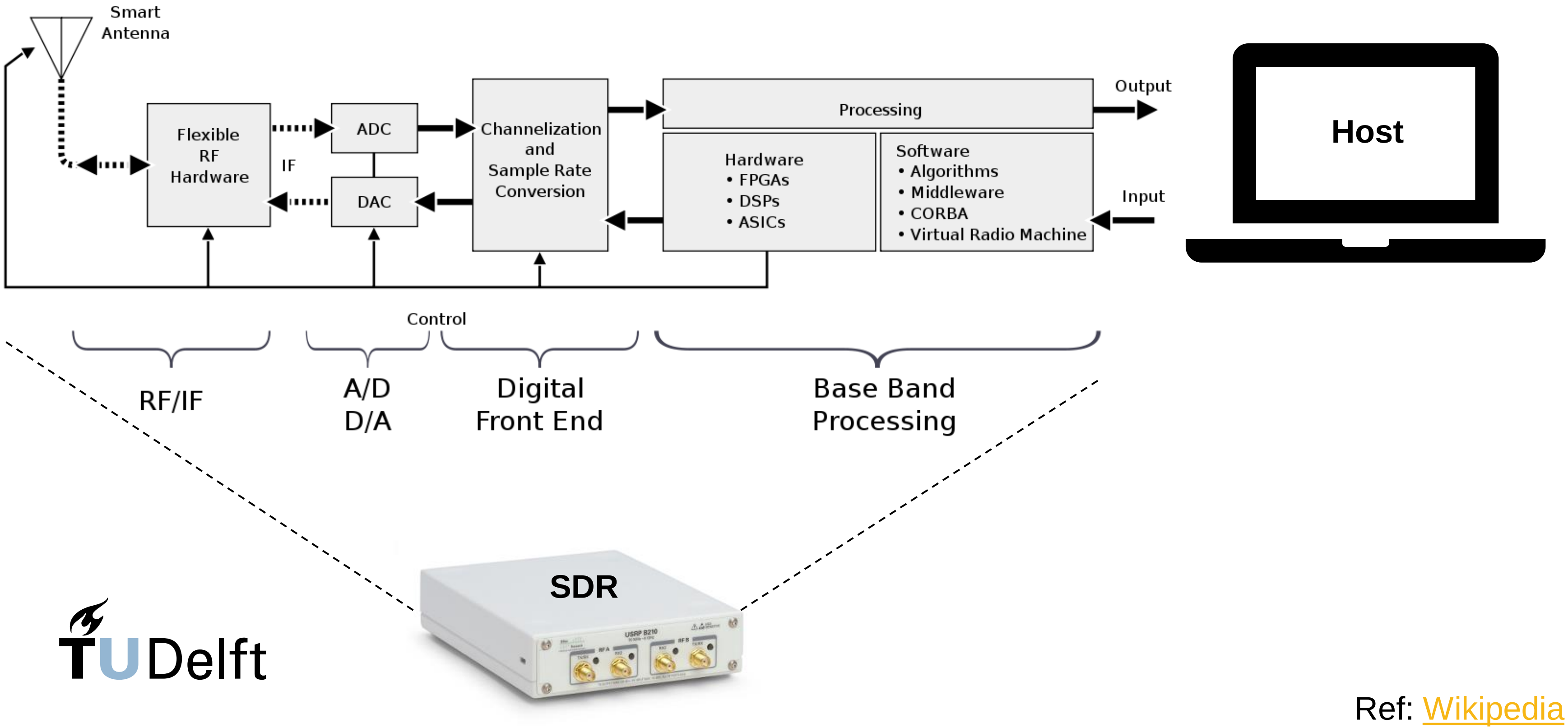
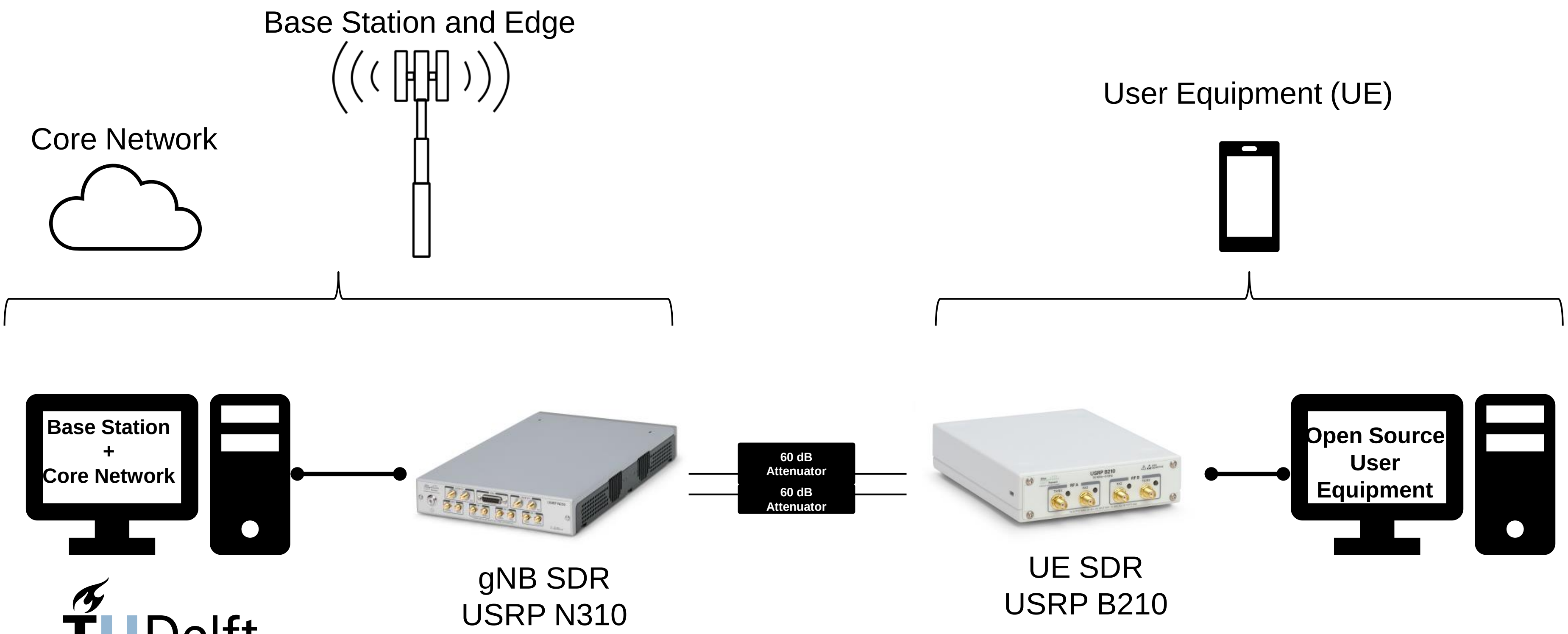
Software Defined Radio (SDR)



Ref: Wikipedia

Example Setup 4G



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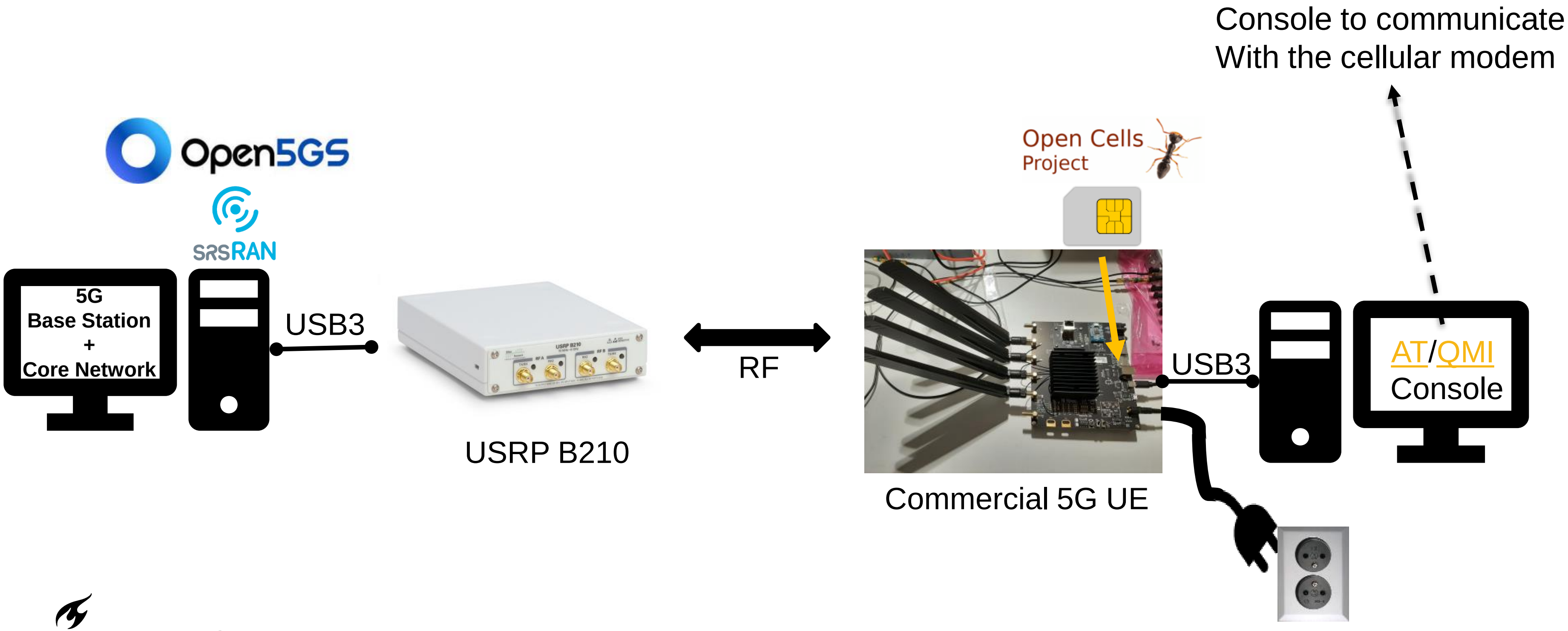
Example Setup 5G



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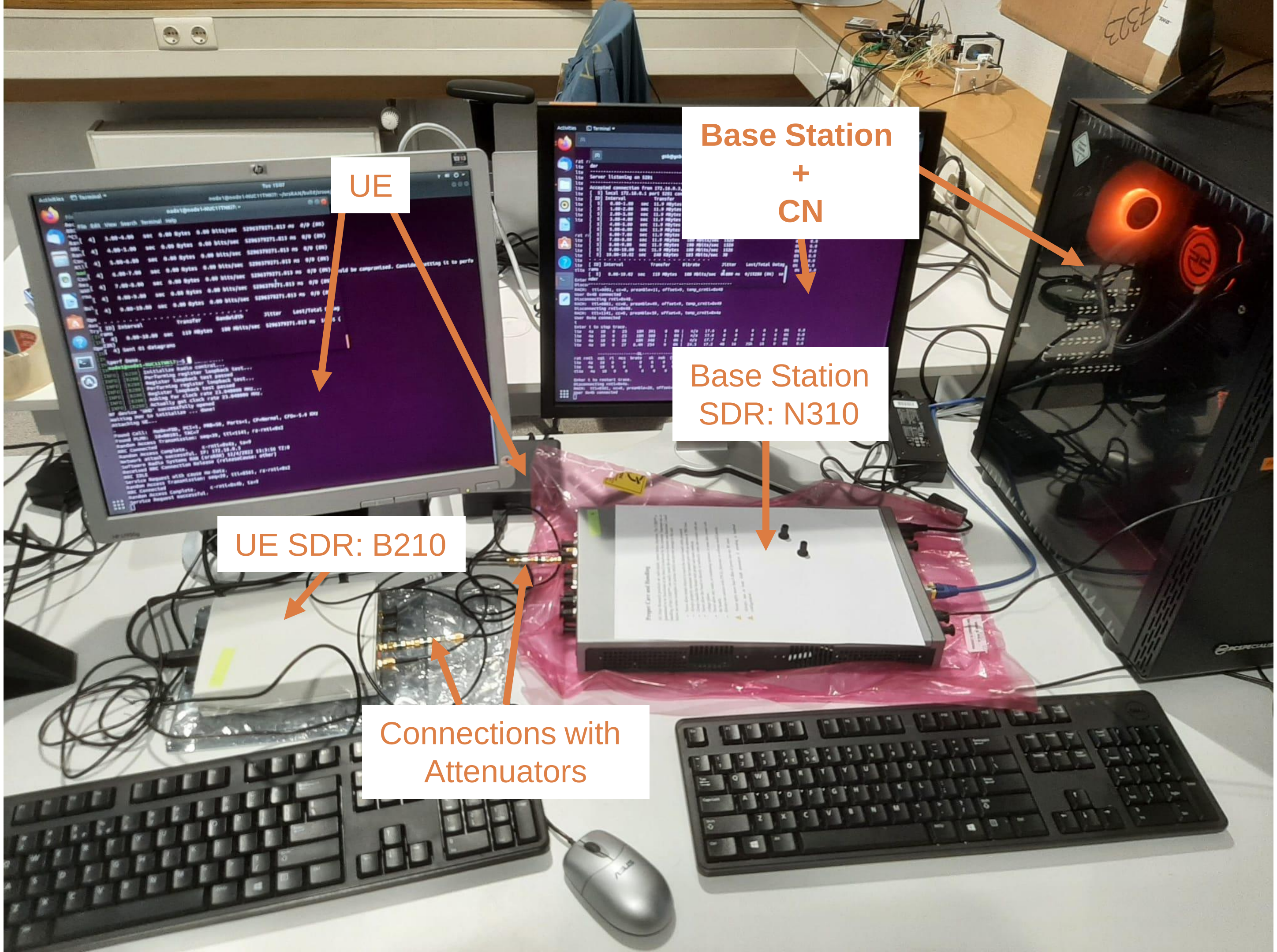
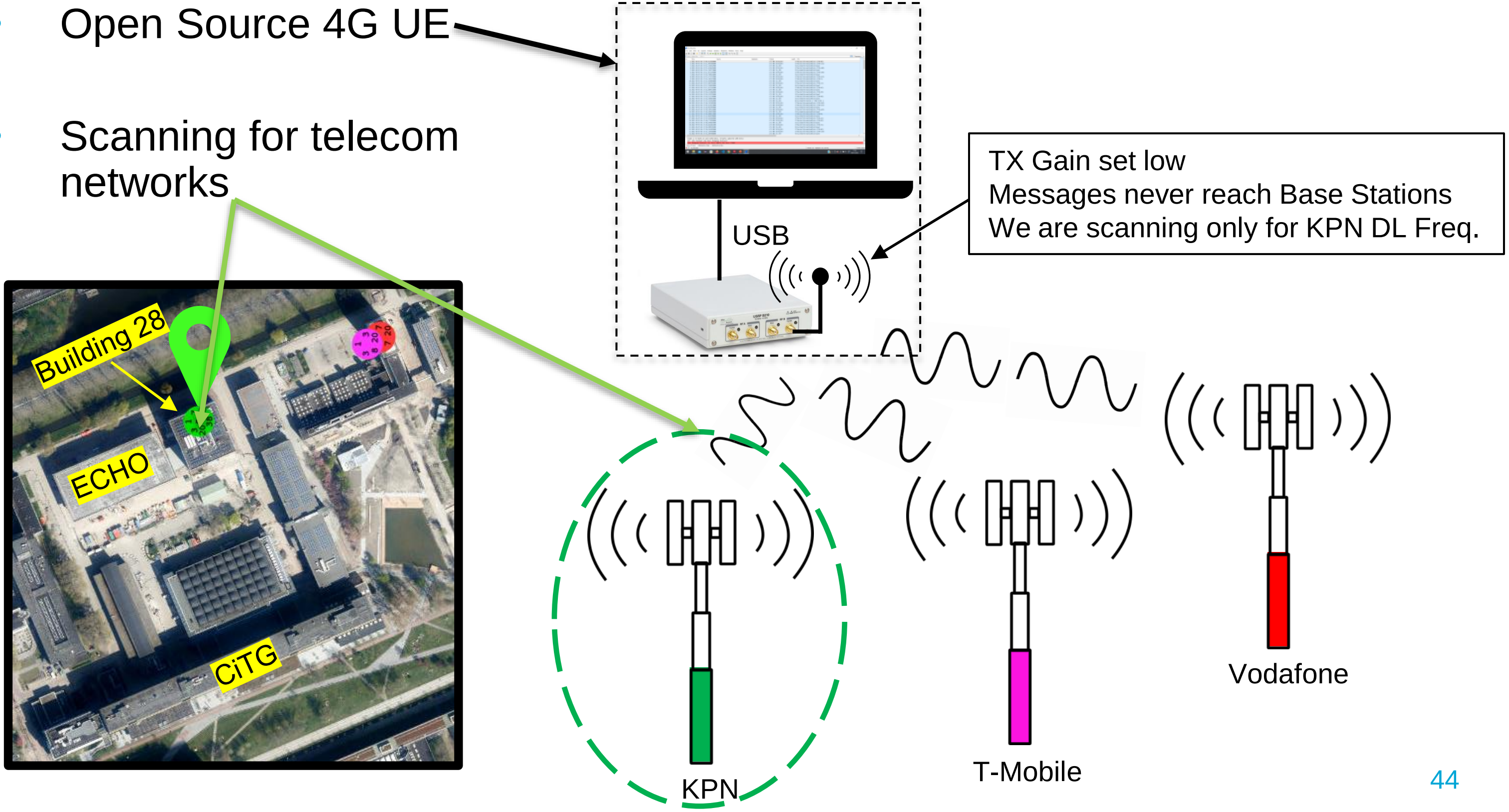
4G



UE
Base Station
+
CN
Base Station
SDR: N310
UE SDR: B210
Connections with
Attenuators

Demo: Cell Scan with 4G Open-Source UE

- Open Source 4G UE
- Scanning for telecom networks



What to expect?

- We use an open-source UE (laptop and SDR).
- We have used the srsRAN for open-source UE.
- The open-source UE only listens for a specific set of frequencies corresponding to a Mobile Network Operator (here KPN).
- We look for the PLMN (identifier for KPN) in the messages received from the Base Station of KPN.
- This is found in the message SystemInformationBlock-1 (SIB1).

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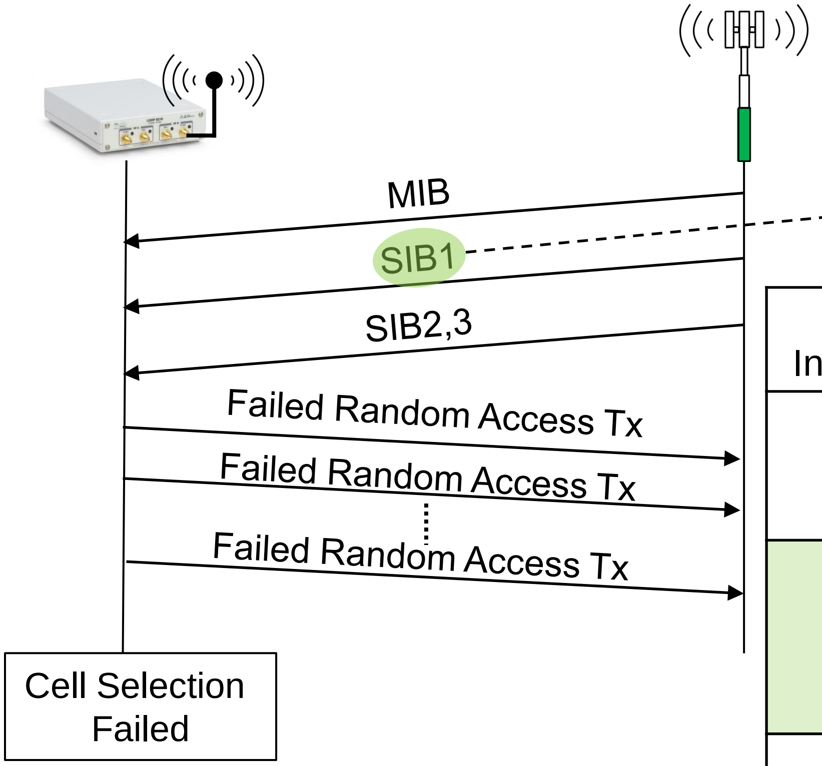
We look at the received SIB1 downlink message to see the mobile network operator identifier (here KPN).



PLMN Id: 20408 (KPN)

System Information(SI)	Full Name	Details
MIB	Master Information Block	Contains information of LTE cell that helps to receive further downlink messages
SIB1	System Information Block 1	Initial Cell Selection and access, System Information (SI) Scheduling
SIB2	System Information Block 2	Cell reselection, handover, random access information
SIB3	System Information Block 3	Intra Frequency Cell Reselection

```
anup@tud266678:~$ sudo srsRAN/build/srsue/src/srsue /home/anup/.config/srsran/ue.conf
Active RF plugins: libsrsran_rf_uhd.so libsrsran_rf_zmq.so
Inactive RF plugins:
Reading configuration file /home/anup/.config/srsran/ue.conf...

Built in Release mode using commit ce8a3cae1 on branch master.

Opening 1 channels in RF device=default with args=default
Supported RF device list: UHD zmq file
Trying to open RF device 'UHD'
[INFO] [UHD] linux; GNU C++ version 7.5.0; Boost_106501; UHD_3.15.0.HEAD-0-gaea0e2de
[INFO] [LOGGING] Fastpath logging disabled at runtime.
Opening USRP channels=1, args: type=b200,master_clock_rate=23.04e6
[INFO] [UHD RF] RF UHD Generic instance constructed
[INFO] [B200] Detected Device: B210
[INFO] [B200] Operating over USB 3.
[INFO] [B200] Initialize CODEC control...
[INFO] [B200] Initialize Radio control...
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Performing register loopback test...
[INFO] [B200] Register loopback test passed
[INFO] [B200] Asking for clock rate 23.040000 MHz...
[INFO] [B200] Actually got clock rate 23.040000 MHz.
RF device 'UHD' successfully opened
Waiting PHY to initialize ... done!
Attaching UE...
.
.
.
Found Cell:  Mode=FDD, PCI=274, PRB=50, Ports=2, CP=Normal, CFO=1.7 KHz
Found PLMN:  Id=20408, TAC=31501
Could not find Home PLMN Id=20409, trying to connect to PLMN Id=20408
Random Access Transmission: seq=10, tti=2091, ra-rnti=0x2
Random Access Transmission: seq=26, tti=2111, ra-rnti=0x2
Random Access Transmission: seq=23, tti=2131, ra-rnti=0x2
Random Access Transmission: seq=3, tti=2151, ra-rnti=0x2
Random Access Transmission: seq=15, tti=2171, ra-rnti=0x2
Random Access Transmission: seq=21, tti=2191, ra-rnti=0x2
Random Access Transmission: seq=22, tti=2211, ra-rnti=0x2
Random Access Transmission: seq=5, tti=2231, ra-rnti=0x2
Random Access Transmission: seq=12, tti=2251, ra-rnti=0x2
Random Access Transmission: seq=3, tti=2271, ra-rnti=0x2
```

1. srsRAN UE starts with the given conf file

2. srsRAN UE initializes USRP B210 SDR

3. srsRAN UE does the attach procedure to find cells and then connect to the best one.

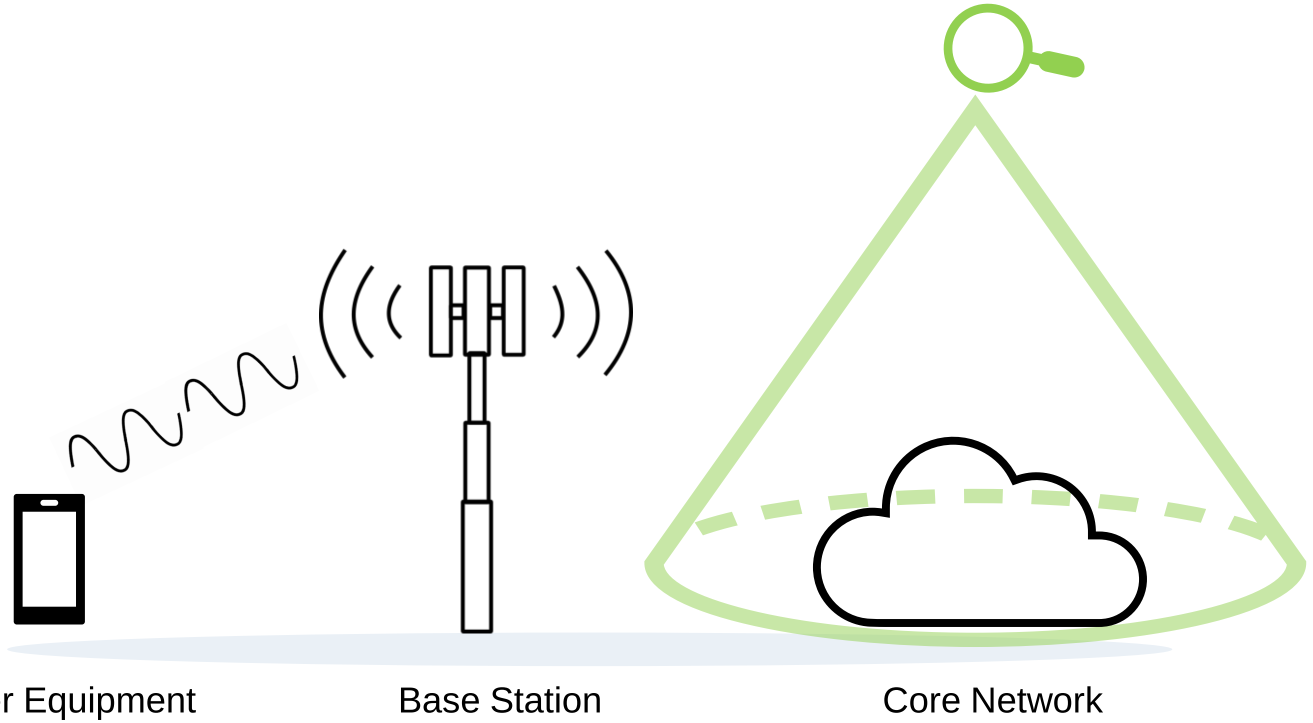
4. Since TX power is very low it can never successfully do an attach procedure.

```
▸ Frame 2: 52 bytes on wire (416 bits), 52 bytes captured (416 bits)
  DLT: 149, Payload: udp (User Datagram Protocol)
▸ User Datagram Protocol, Src Port: 48879, Dst Port: 57005
▾ MAC-LTE BCH PDU (18 bytes, on DL-SCH transport)
  ▸ [Context (RNTI=65535)]
    [Transport channel: DL-SCH (4)]
  ▾ LTE Radio Resource Control (RRC) protocol
    ▾ BCCH-DL-SCH-Message
      ▾ message: c1 (0)
        ▾ c1: systemInformationBlockType1 (1)
          ▾ systemInformationBlockType1
            ▾ cellAccessRelatedInfo
              ▾ plmn-IdentityList: 1 item
                ▾ Item 0
                  ▾ PLMN-IdentityInfo
                    ▾ plmn-Identity
                      ▾ mcc: 3 items
                        ▾ Item 0
                            MCC-MNC-Digit: 2
                        ▾ Item 1
                            MCC-MNC-Digit: 0
                        ▾ Item 2
                            MCC-MNC-Digit: 4
                      ▾ mnc: 2 items
                        ▾ Item 0
                            MCC-MNC-Digit: 0
                        ▾ Item 1
                            MCC-MNC-Digit: 8
                      cellReservedForOperatorUse: notReserved (1)
              trackingAreaCode: 7b0d [bit length 16, 0111 1011  0000 1101 decimal value 31501]
              cellIdentity: 0fdb70d0 [bit length 28, 4 LSB pad bits, 0000 1111  1101 1011  0111 0000  1101 .... decimal value 16627469]
              cellBarred: notBarred (1)
              intraFreqReselection: allowed (0)
              .... ..0. csg-Indication: False
            ▸ cellSelectionInfo
              freqBandIndicator: 20
            ▸ schedulingInfoList: 3 items
              si-WindowLength: ms40 (6)
              systemInfoValueTag: 7
```

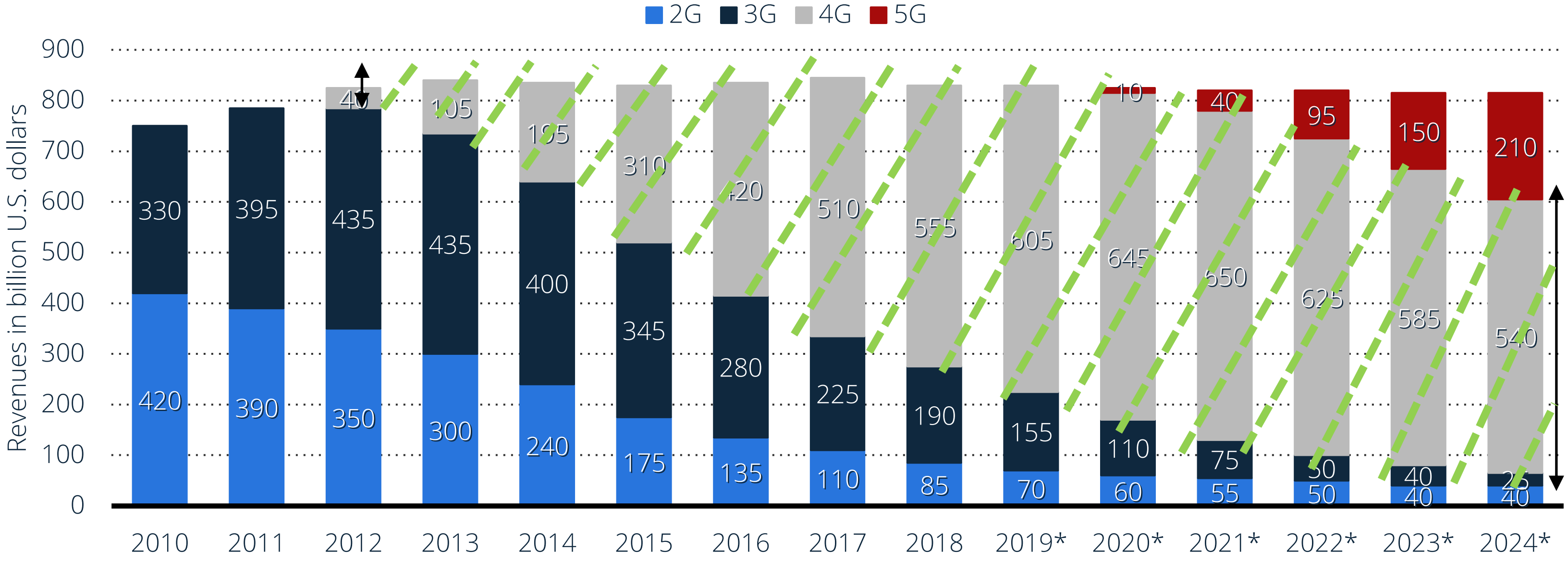
srsRAN UE found the KPN cell.
20408 corresponds to KPN.

Programmability in Telecom networks

What role does SDN play in this field?



Mobile service revenues worldwide from 2010 to 2024, by technology (in billion U.S. dollars)



Statista. (June 12, 2019). Mobile service revenues worldwide from 2010 to 2024, by technology (in billion U.S. dollars) [Graph]. In *Statista*. Retrieved November 30, 2022, from https://www.statista.com/statistics/1015977/mobile-service-revenues-by-technology-worldwide/
* Details: Worldwide; 2010 to 2018

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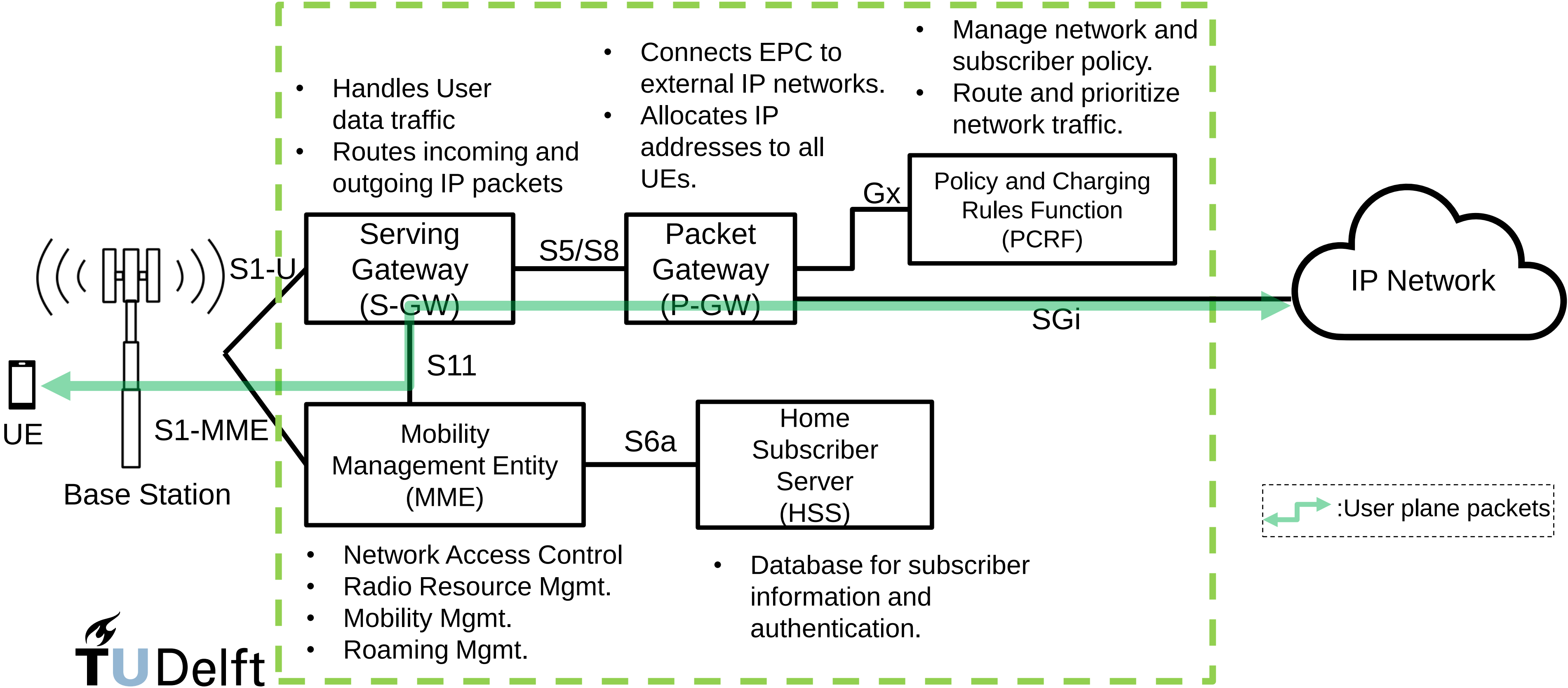
Core Network Architecture for 4G before Control and User Plane Separation (CUPS)



Evolved Packet Core (EPC) without CUPS

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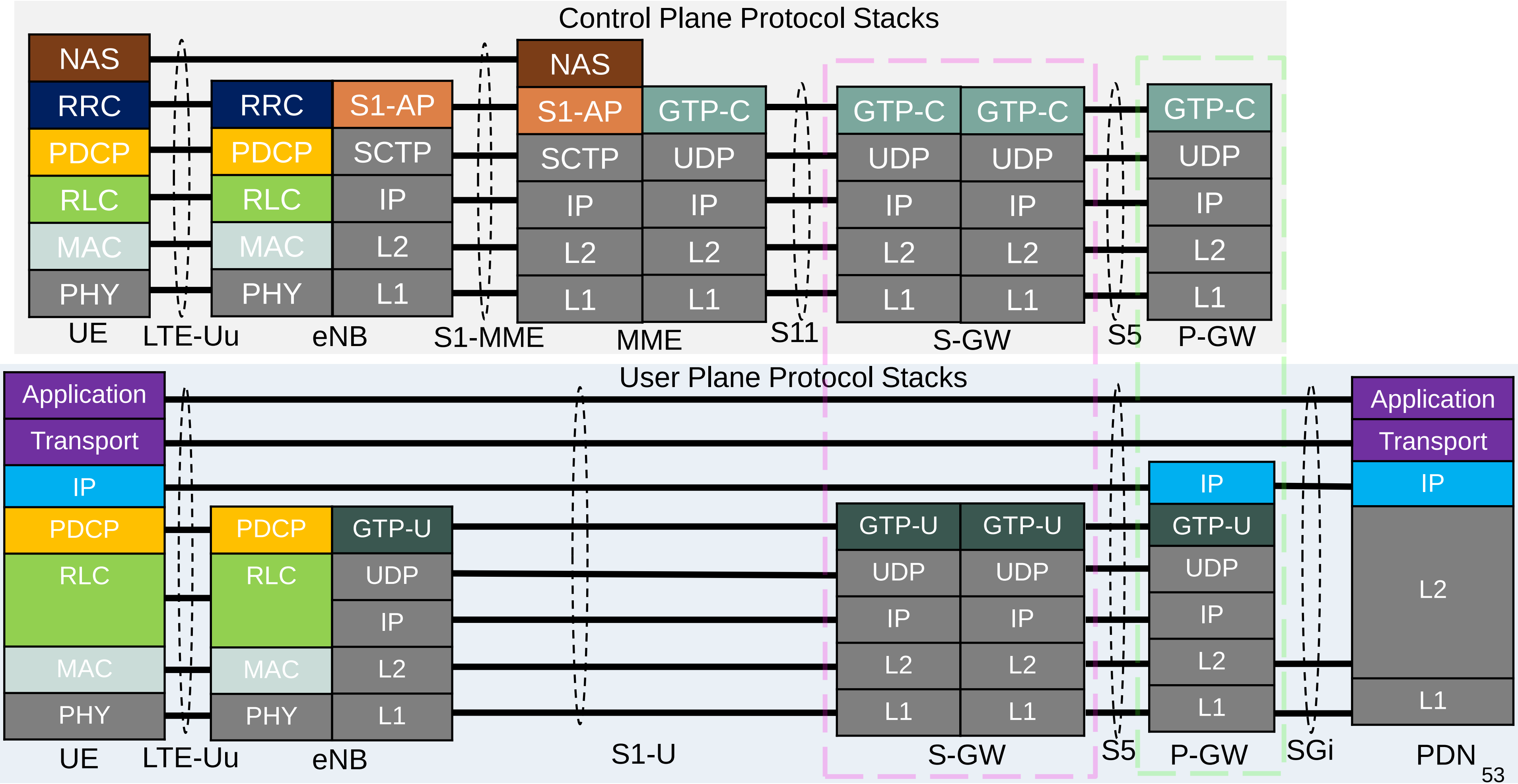
Protocol stack

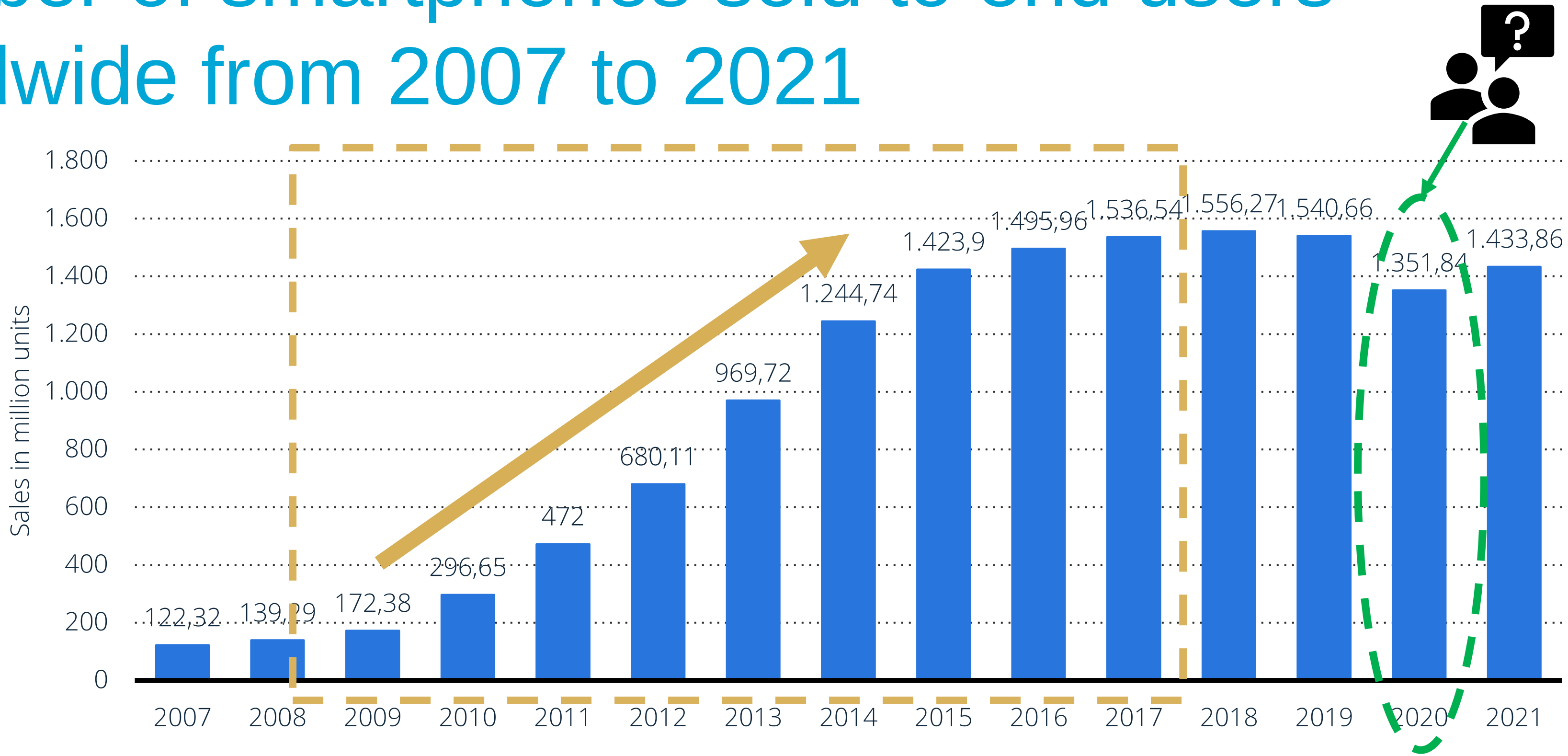
Source: Netmanias



Quick look at protocol stack components

Layer	Summary
Physical Layer (PHY)	Handles information RX/TX over the air interface.
Medium Access Control (MAC)	Responsible for mapping of logical and transport channels.
Radio Link Control (RLC)	Responsible for error correction, concatenation, segmentation and reassembly of RLC SDUs.
Packet Data Convergence Protocol (PDCP)	Does header compression and decompression of IP data, ciphering and deciphering of both user plane and control plane data.
Radio Resource Control (RRC)	Maintenance of point-to-point radio bearers for both data and signal.
Non-Access Stratum (NAS)	Control plane signalling between UE and MME.
S1 Application Protocol (S1-AP)	Control plane signalling between RAN and Core Network.
GPRS Tunnelling Protocol – Control (GTP-C)	Control plane signalling between the Core Network.
GPRS Tunnelling Protocol – User (GTP-U)	In User Plane to carry user data traffic.

Number of smartphones sold to end users worldwide from 2007 to 2021



Gartner. (March 2, 2022). Number of smartphones sold to end users worldwide from 2007 to 2021 (in million units) [Graph].
In *Statista*. Retrieved November 30, 2022,
from https://www.statista.com/statistics/263437/global-smartphone-sales-to-end-users-since-2007/
Details: Worldwide; Gartner; 2007 to 2021

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With More Users Comes More Responsibilities

- Rapid increase in the sales of 4G compatible UEs led to higher interest in content-rich multi-media services.
  - Leading to a requirement of large volume data support.

- Strong consumer demand for user experience improvements:
  - Lower latency
  - Higher speed

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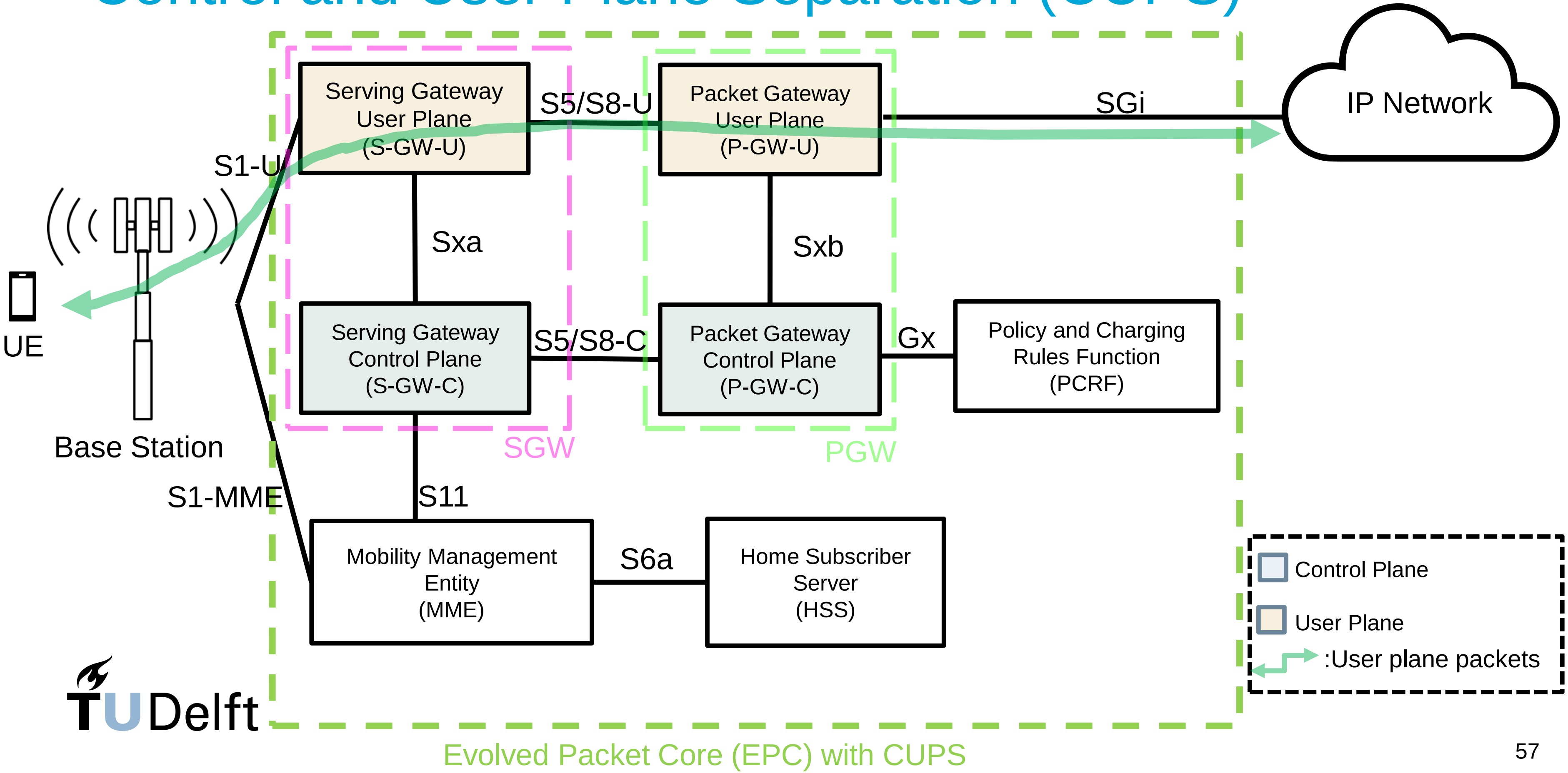
Core Network Architecture for 4G after Control and User Plane Separation (CUPS)



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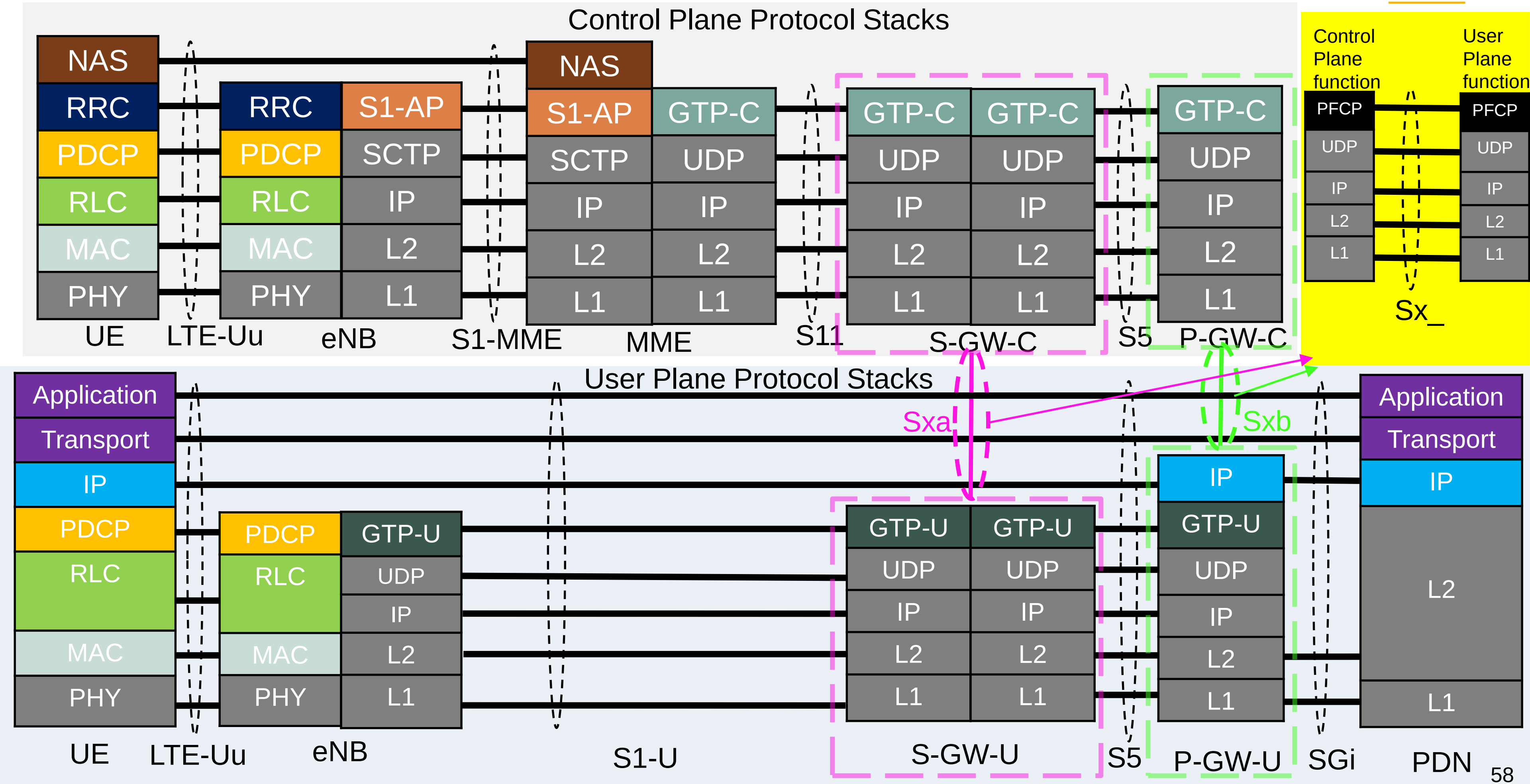
Protocol stack

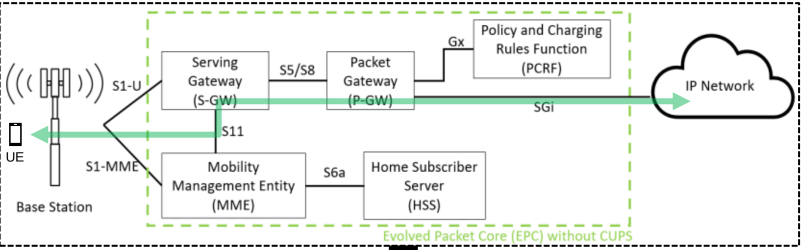
Source: Netmanias, 3GPP



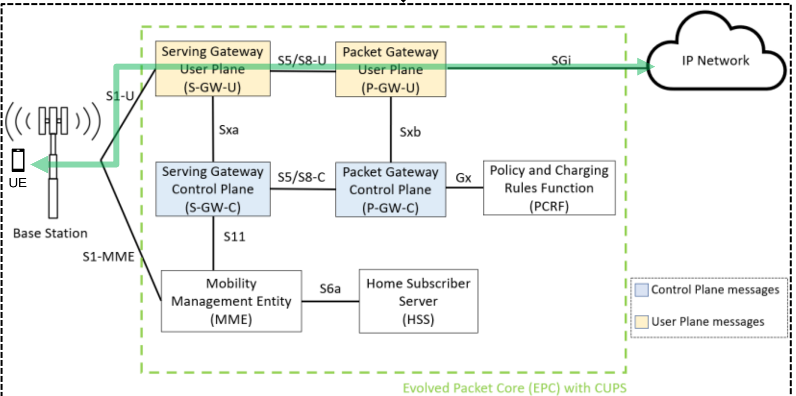
Advantages of CUPS

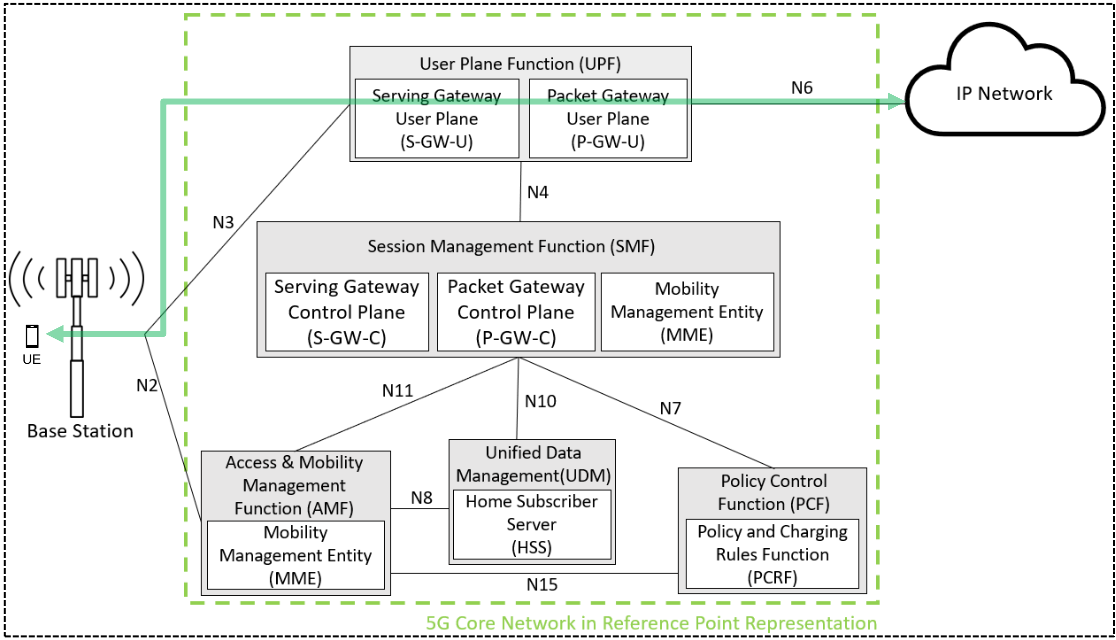
- Reduced Latency for applications.
- Flexibility for having specific User Planes (UPs) for specific UE applications.
- Independently scale UP and CP as per requirements of the network.

4G CUPS to 5GC



EPC with CUPS



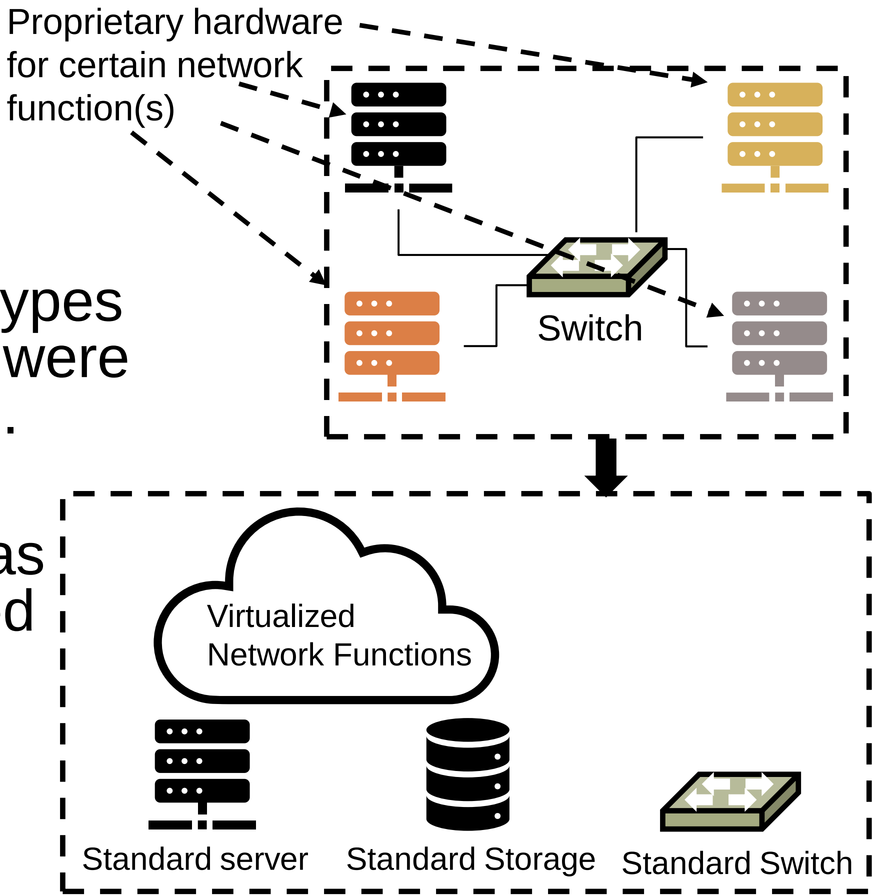


EPC Functions to new 5G CN functions

:User plane packets

5G CN: Network Function Virtualization (NFV)

- Virtualizing network infrastructure.
- Takes out the previous types of implementations that were on proprietary hardware.
- Network Functions run as software on standardized hardware.



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Advantages of NFV

- Faster time to deployment.
- Flexibility of scaling up and down network resources.
- Efficient use of resources.
- Reduced CapEx and OpEx.
- Move out of dependence on proprietary technology and towards a broader software community (f.e. open source).
- Enables Network Slicing.

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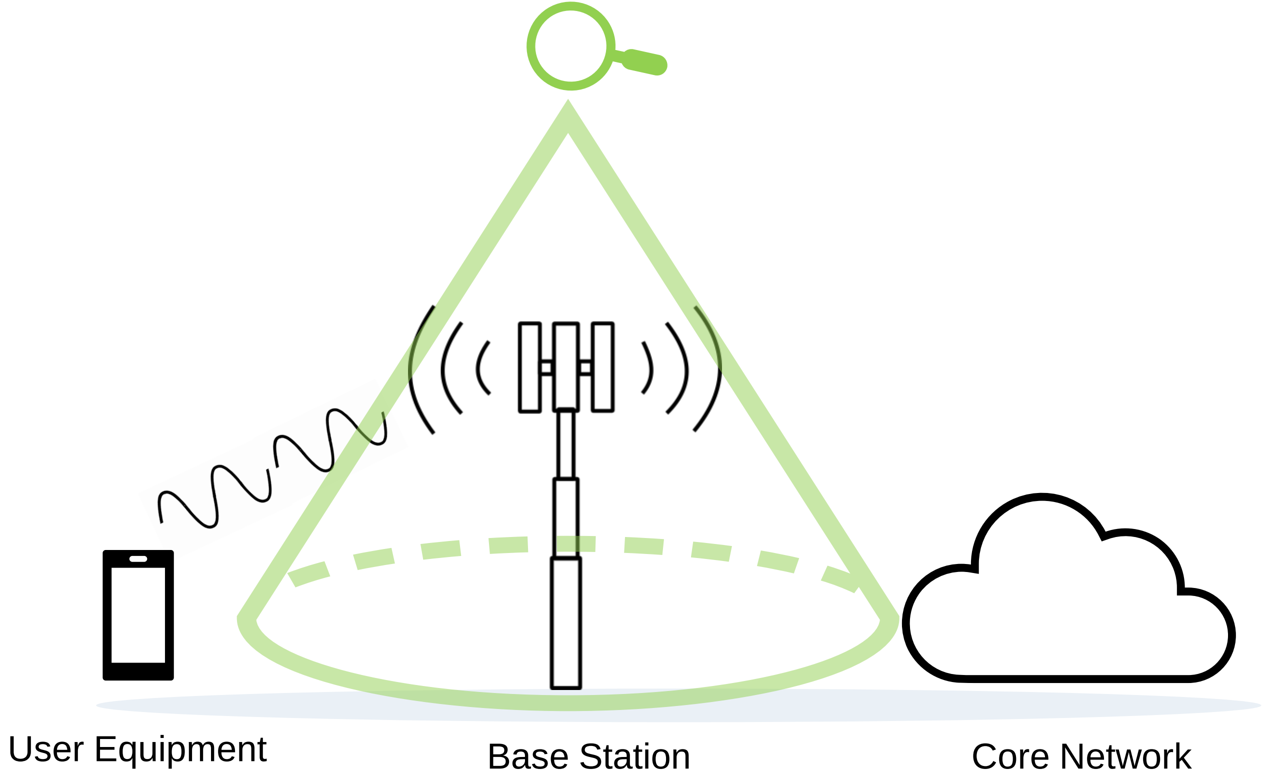
Does SDN play any role in Radio Access Networks (RAN) especially Base Station for 5G?



RAN Disaggregation

- We saw the disaggregation in the Core Network of 4G and how it carries on to 5G, but what about the Radio Access Network (RAN)?

- In 5G similar principles seen in the Core Network are also used for the RAN (especially the base station).

- The intention is to have an open and virtualized RAN from the operator perspective.

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SDN role in 5G RAN Disaggregation: Motivation

Open and Virtualized network can:

- Optimise deployment.
- Move more functionality to software.
- Avoid vendor lock-in.
- Better resource utilisation and cost saving.
- Support for customized networks.

Disaggregation of RAN takes place in 3 tiers across two dimensions.

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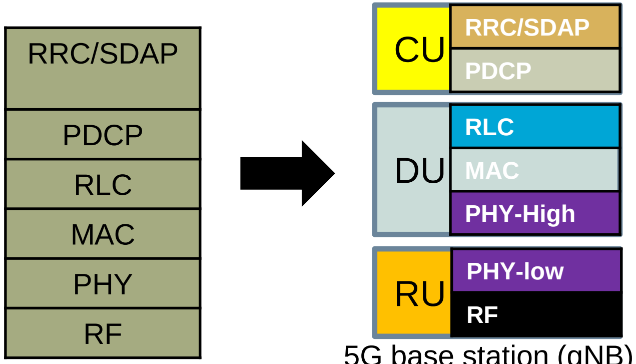
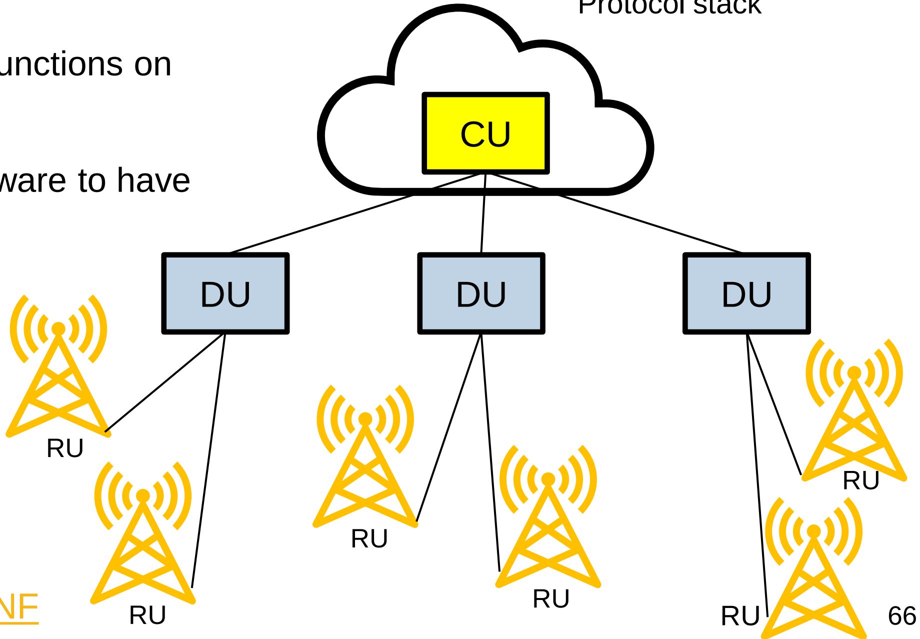
Tier 1 Horizontal: CU-DU-RU disaggregation

- Split Ran-protocol to realize independent components separately:
  - CU: Central Unit: centralize packet processing functions in geographically centralized telco edge cloud locations.
  - DU: Distributed Unit: realize baseband processing functions on commodity hardware.
  - RU: Radio Unit: radio functions on specialized hardware to have geographical coverage.
  - Could be multiple ways:
    - CU and DU+RU
    - CU+DU and RU
    - CU+DU+RU



5G base station (gNB) Protocol stack

5G base station (gNB) Disaggregated Protocol stack



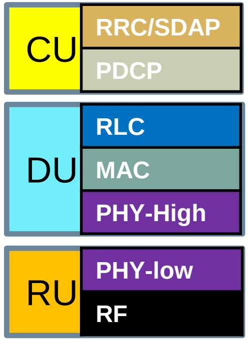
Source: ONF

Quick look at protocol stack components

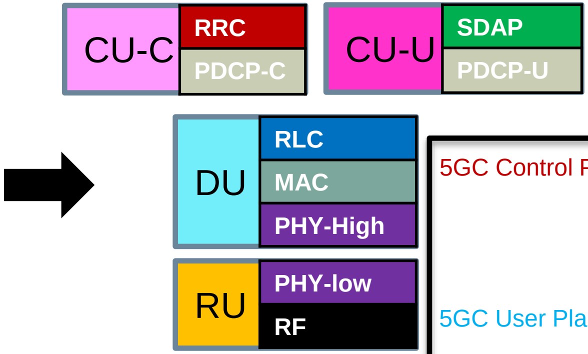
Layer	Summary
Service Data Adaption Protocol (SDAP)	Responsible for mapping related to QoS between 5GC and data radio bearer.

Tier 2 Vertical: CUPS of CU

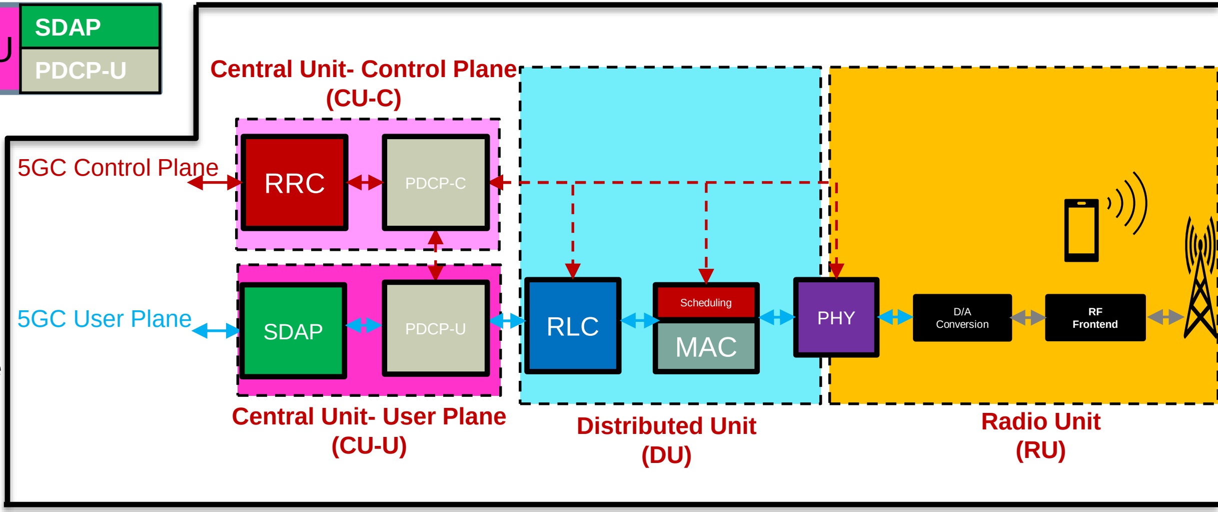
- Focus on Control and User Plane Separation (CUPS) of CU.
- CU becomes:
  - CU-C: Control Plane part of CU: Contains RRC protocol and Control-plane part of PDCP protocol.
  - CU-U: User Plane part of CU: Contains SDAP protocol and User-plane part of PDCP protocol.



5G base station (gNB) Disaggregated Protocol stack



Disaggregated 5G base station (gNB) with CU-C and CU-U disaggregated Protocol stack



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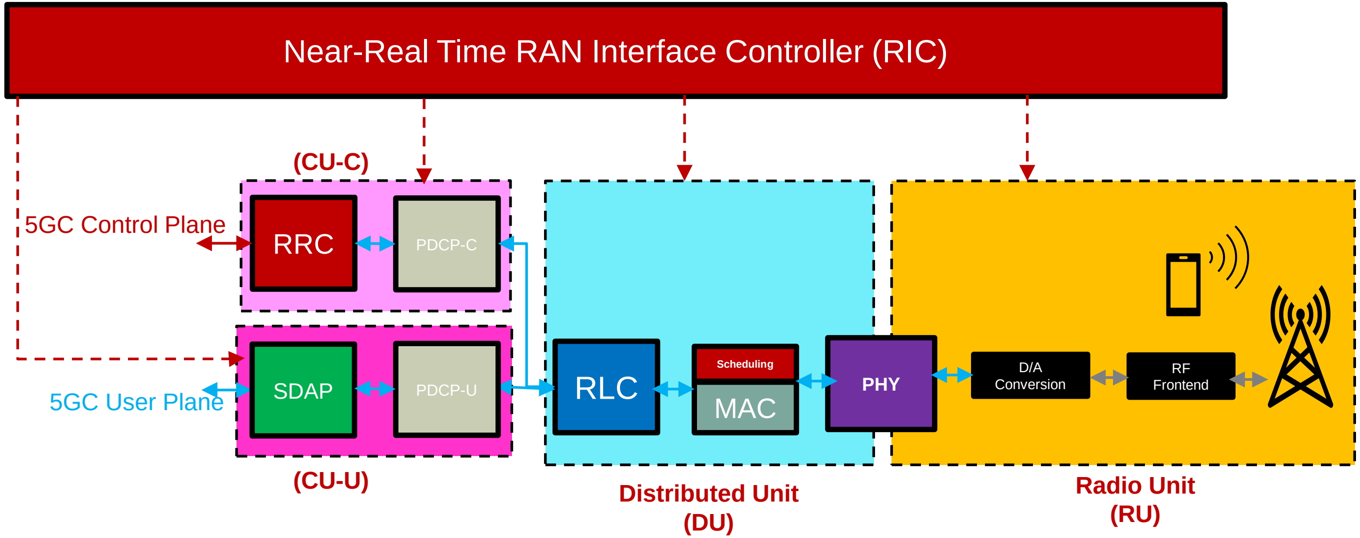
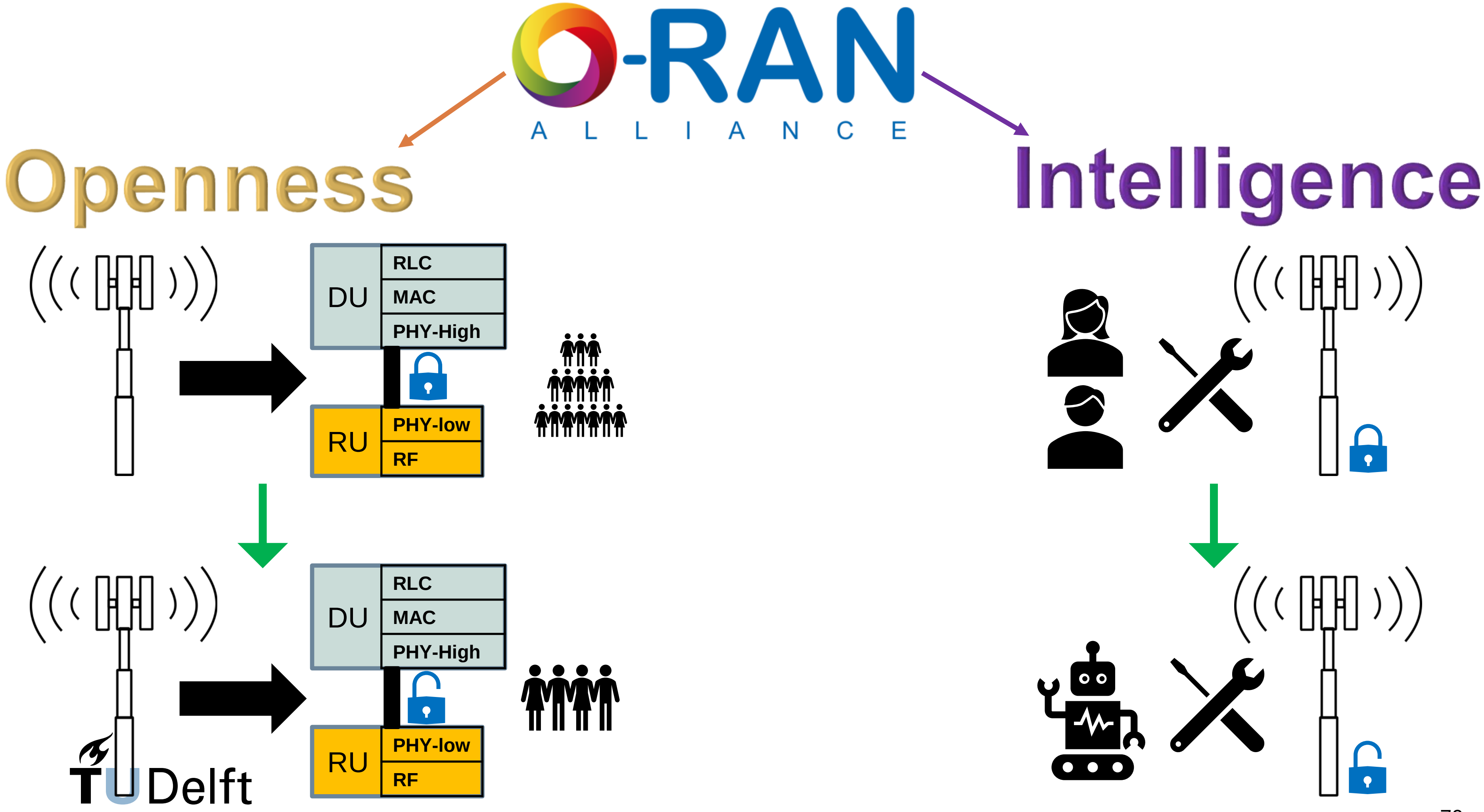
Source: ONF

Tier 3 Vertical: Software Defined RAN Control

- Even with the previous 2 tiers of RAN Disaggregation issues still remain:
  - Increasing deployment complexity due to network densification, various spectrum bands etc.
  - Radio Resource Management (RRM) control distributed across base stations is not optimal.
- Intention is to take the control part of RRM and decoupling it from underlying stack for better system performance.



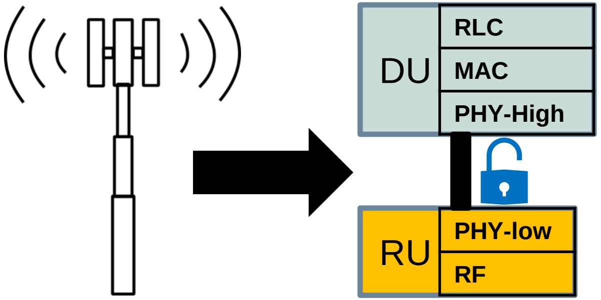
Source:ONF

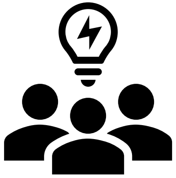

O-RAN
ALLIANCE
Openness
Intelligence
DU
RLC
MAC
PHY-High
RU
PHY-low
RF
DU
RLC
MAC
PHY-High
RU
PHY-low
RF
TUDelft

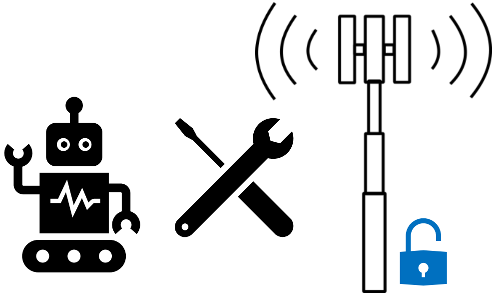
O-RAN
A L L I A N C E

Openness

Intelligence

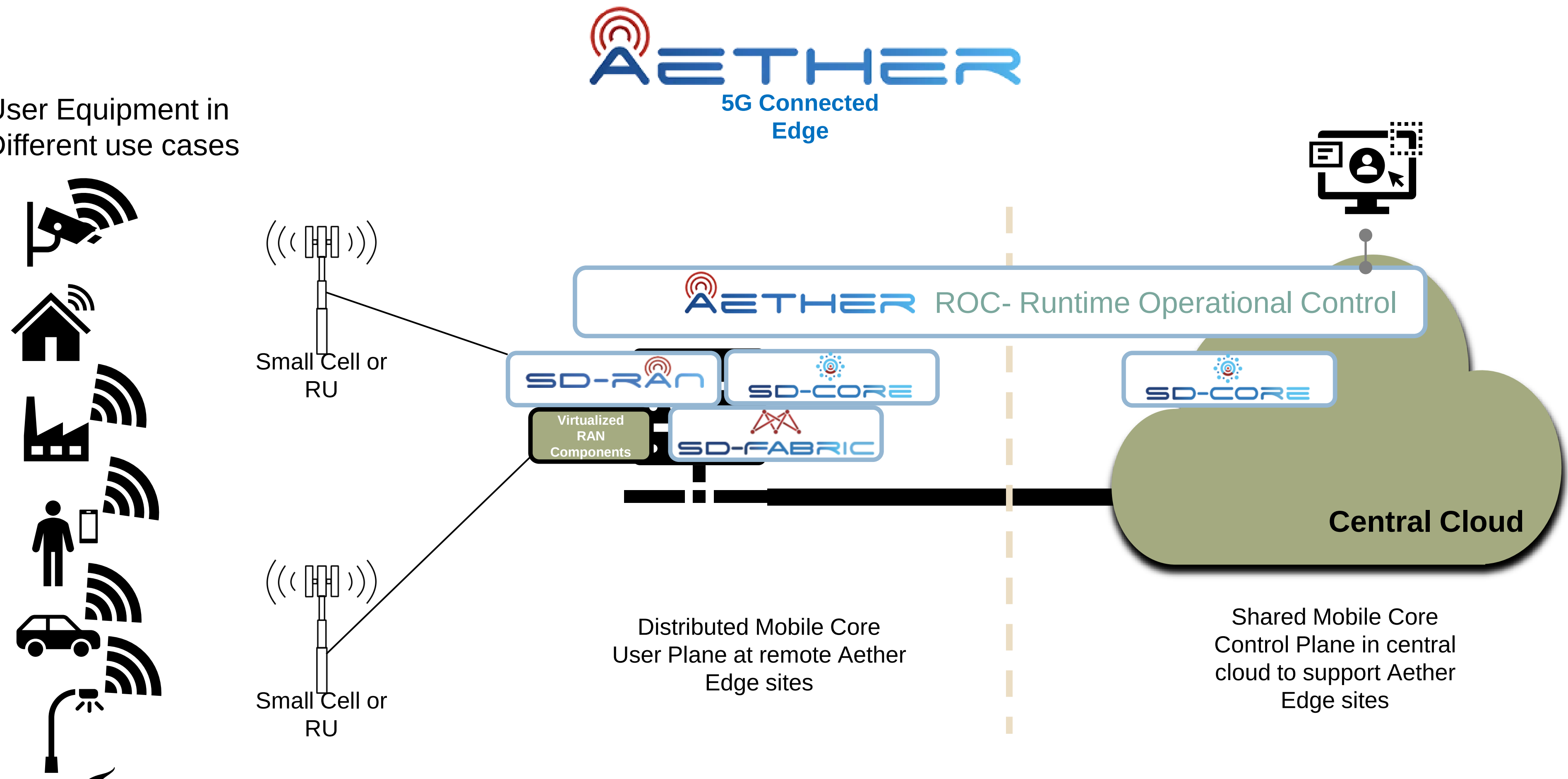






- Open Interfaces -> Open Source and Open Whitebox Network Elements
- Focus on: RAN Interface Controller (RICs), Protocol Stack, PHY Layer Processing and Virtualization

User Equipment in
Different use cases



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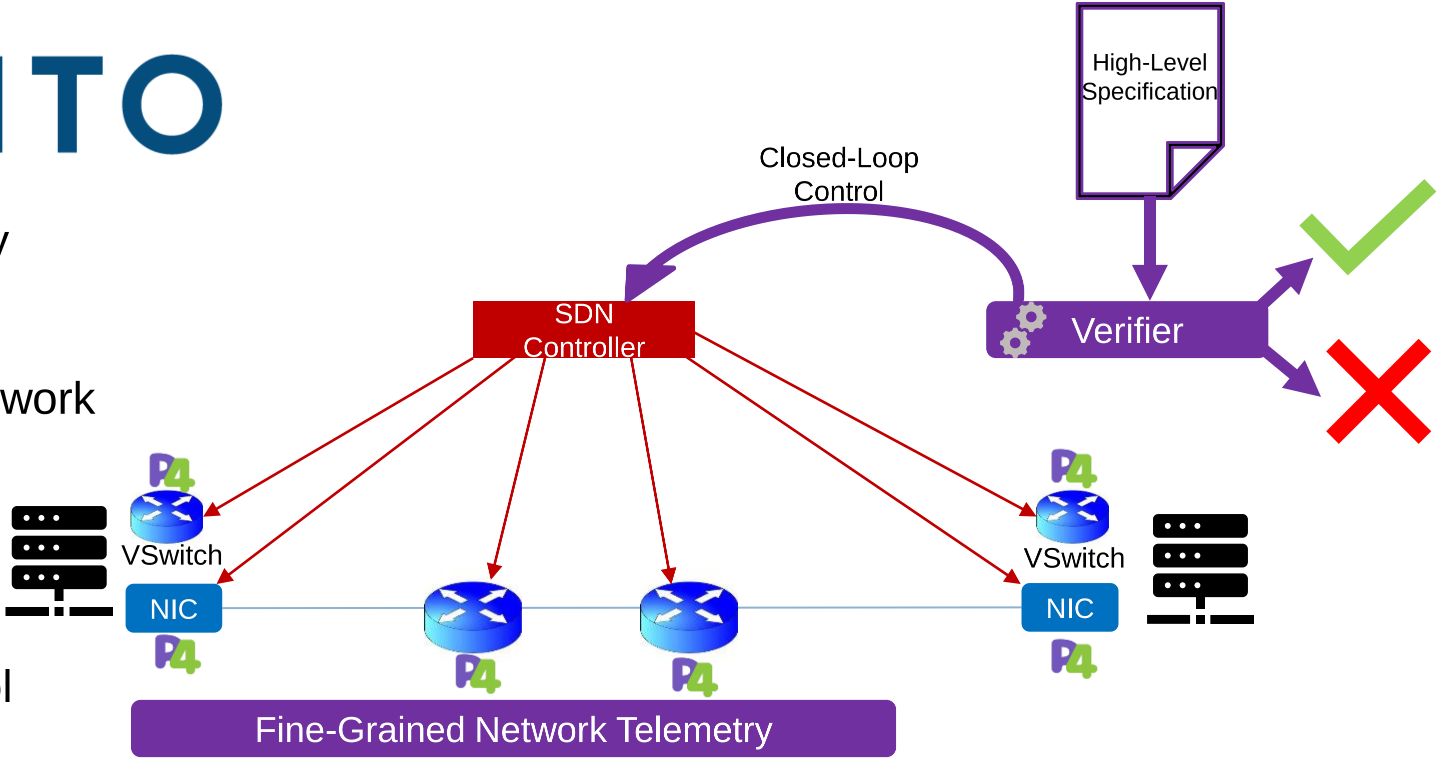
Source: Aether

Provide tools to deploy customized network functionality for:

- Deep and wide network visibility
- Verification
- Closed-loop control



Source: Project Pronto