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# Cellular mobile networks (4G/5G, in Sweden)

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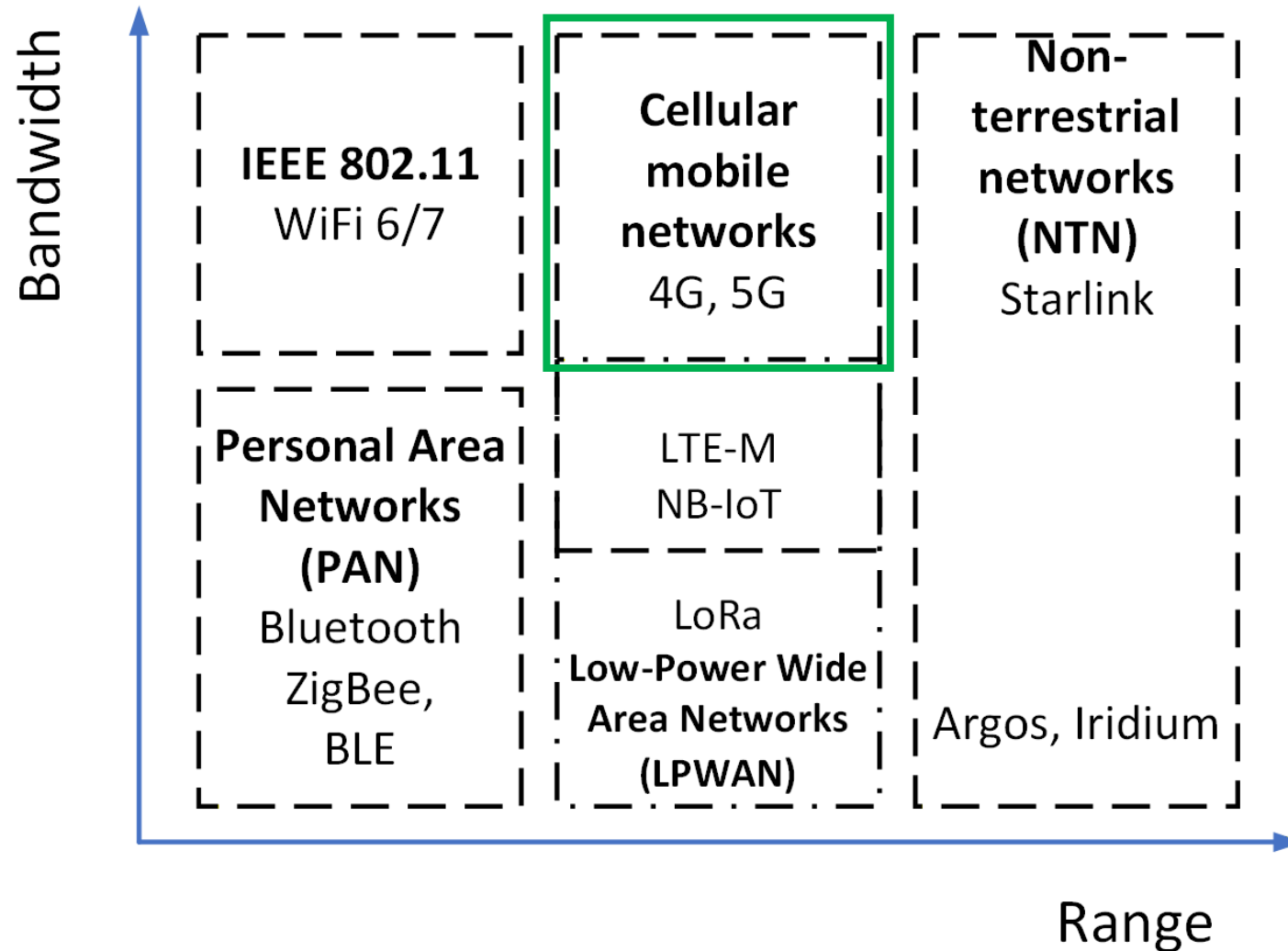


# Literature

- "5G Wireless Access: an Overview", Ericsson White Paper, 1/28423-FGB1010937, 2020.
  - Pages 1-6
- A. Checko et.al, "Cloud RAN for Mobile Networks – A technology overview", IEEE Communication Surveys & Tutorials, 2015.
  - Sections I + II

**Note:** This lecture is to a large extent new compared with previous years. Therefore, concepts and technologies that are presented here may not be visible in the old exams.

# Today's lecture



# Today's scenario: Helsingborg West Harbour

Your task is to help Helsingborg West Harbour with their project on self-driving trucks. The trucks will move containers within the harbour area. The trucks will be controlled by a software application placed in a back-end server. The software application will send instructions to the trucks about their path trajectory, so that the trucks' movements are optimized.

The trucks will continuously send information about their current position to the software application. As a fall-back solution, the trucks will have their own internal collision-avoidance mechanism so that they do not collide into each other or other things.

Your task is to propose a complete network system design for this self-driving application. The image shows Helsingborg West Harbour.



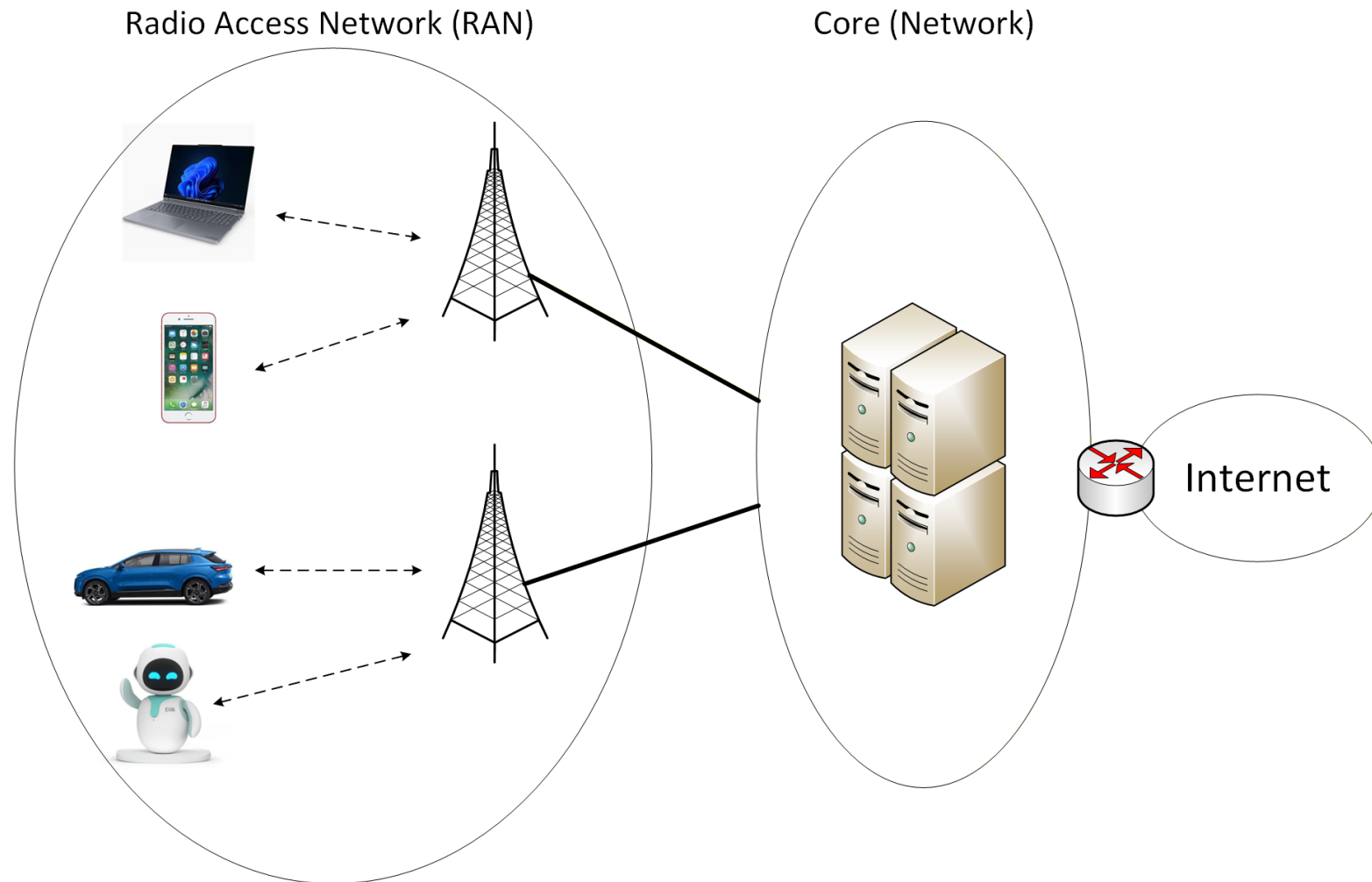
# Cellular Mobile Networks – Basic concepts

# Cellular mobile network generations (in Sweden), the short version

- 2G: GSM
  - Only for telephony, GPRS add-on for data communication.
  - Frequency bands: 900 MHz, 1.8 GHz
- 3G: UMTS
  - For both telephony and data communication
  - Frequency bands: 900 MHz, 2.1 GHz
- 4G: LTE
  - Internet access, telephony is an application (IP telephony).
  - Frequency bands: 450, 800, 900 MHz, 1.8, 2.6 GHz
- 5G
  - Beyond ordinary Internet access.
  - Frequency bands: 700 MHz, 3.4-3.8 GHz, (26 GHz)

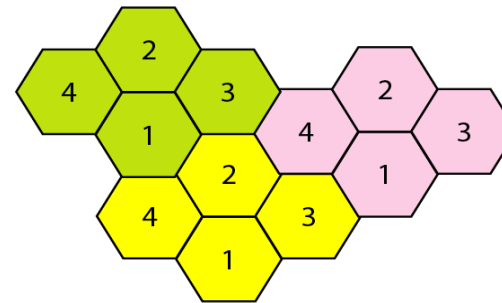
# Basic network architecture

A cellular network consists of a **Radio Access Network (RAN)** and a **Core**.

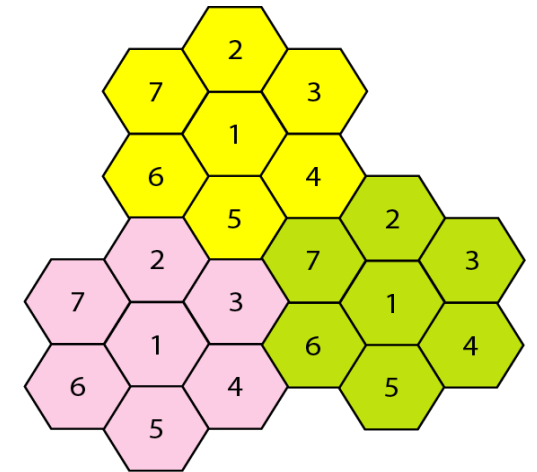


# Cells and frequencies

- A cellular mobile network is geographically divided in cells.
- Each cell is controlled by a base station (several cells can be controlled by the same base station)
- Each cell gets a frequency range. The frequency ranges are distributed so that interference between cells is minimized.
- **Higher frequency bands can provide higher capacity, but with a shorter radio range (i.e. smaller cells).**



a. Reuse factor of 4



b. Reuse factor of 7

# Licensed frequency bands

- All cellular mobile networks operate on **Licensed frequency bands**.
- The licensed frequency usage is in each country controlled by an authority, in Sweden it is the Swedish Post and Telecom Authority (PTS).
- PTS have auctions for licensed frequency band.
  - The winner of an auction controls a specific frequency band.
- **A mobile operator either owns a licensed frequency band, or rents capacity from another operator.**
- For 4G/5G, there is a **licensed frequency band specifically aimed for private networks**. An organization can apply for a license in this band for a **limited geographic area**.
  - For example: LTH/EIT has a license for the south part of LTH campus. Ericsson AB has a license for Brunnshög.

# Addressing in Mobile cellular networks

Mobile cellular networks use **International Mobile Subscriber Identity (IMSI)** to uniquely identify each subscriber. IMSI is a 15 digits number, stored in a 64-bit field.

- The first set of digits is the **Mobile Country Code (MCC)**, which defines the country a subscriber primarily operates within. This is always either two or three digits.
  - Example: MCC for Sweden is 240.
- The second set of digits is the **Mobile Network Code (MNC)**, which identifies the specific MNO a subscriber is associated with. This is between one and three digits.
- The final set of digits is the **Mobile Subscription Identification Number**, which is unique to the subscriber. (This is typically nine or ten digits.)

# Radio Access Networks (in 4G/5G)

The Radio Access Network (RAN) manages the connections between the connected devices, called User Equipment (UEs), and the network.

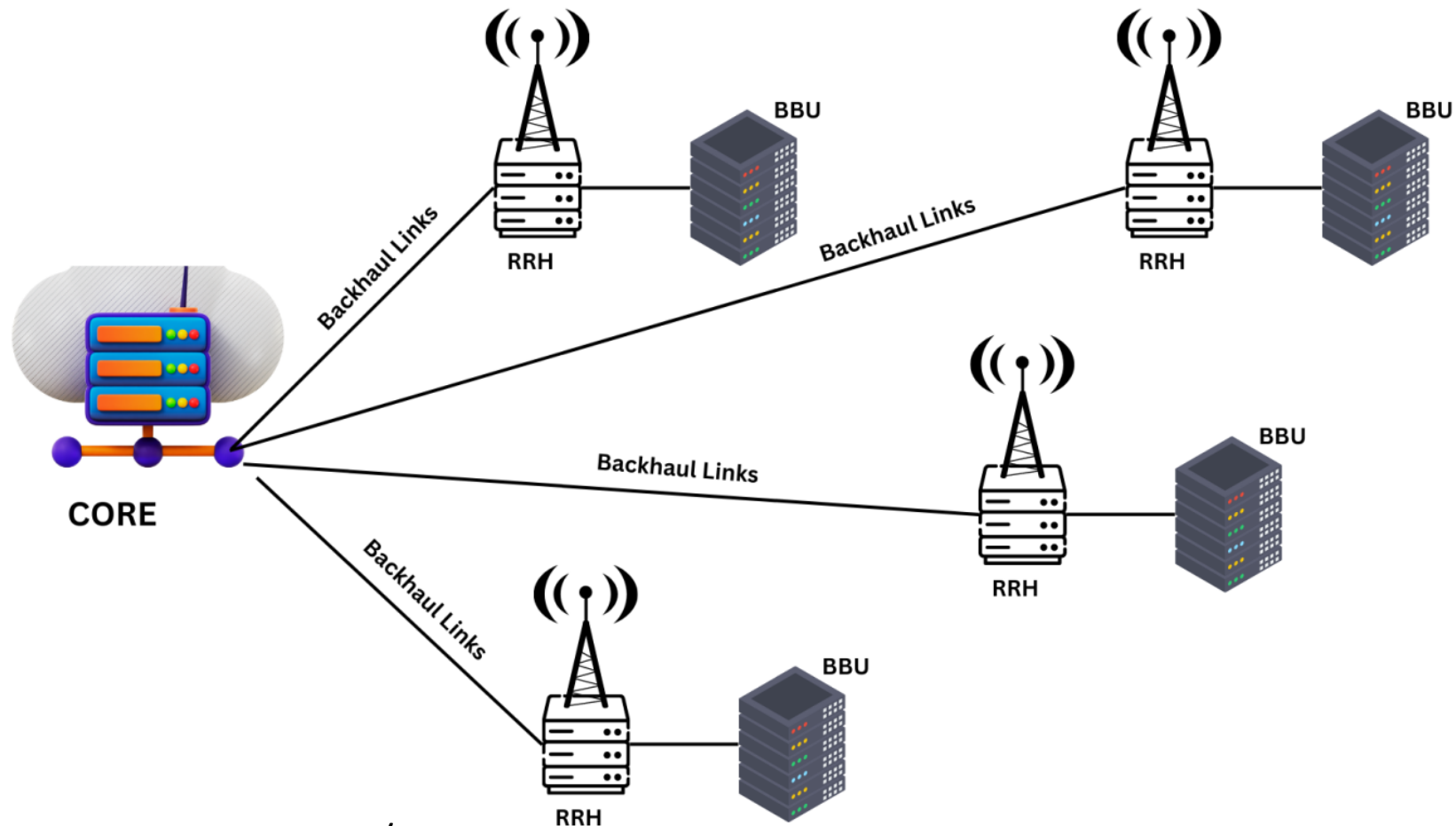
The connection between a UE and the network includes several lower layers communication protocols that are not part of this course.

All processing and radio communication is performed by two main types of entities:

- **Baseband Units (BBUs)**, handle the digital processing of information between the radio tower and the mobile devices. It enables voice and data transmission through processing. This involves interpreting and managing the baseband frequencies. The BBUs are connected to the Core.
- **Radio Units (RUs) or Remote Radio Heads (RRHs)** handles the radio channel communication between the UE:s and the network. An RU is managed by a BBU.

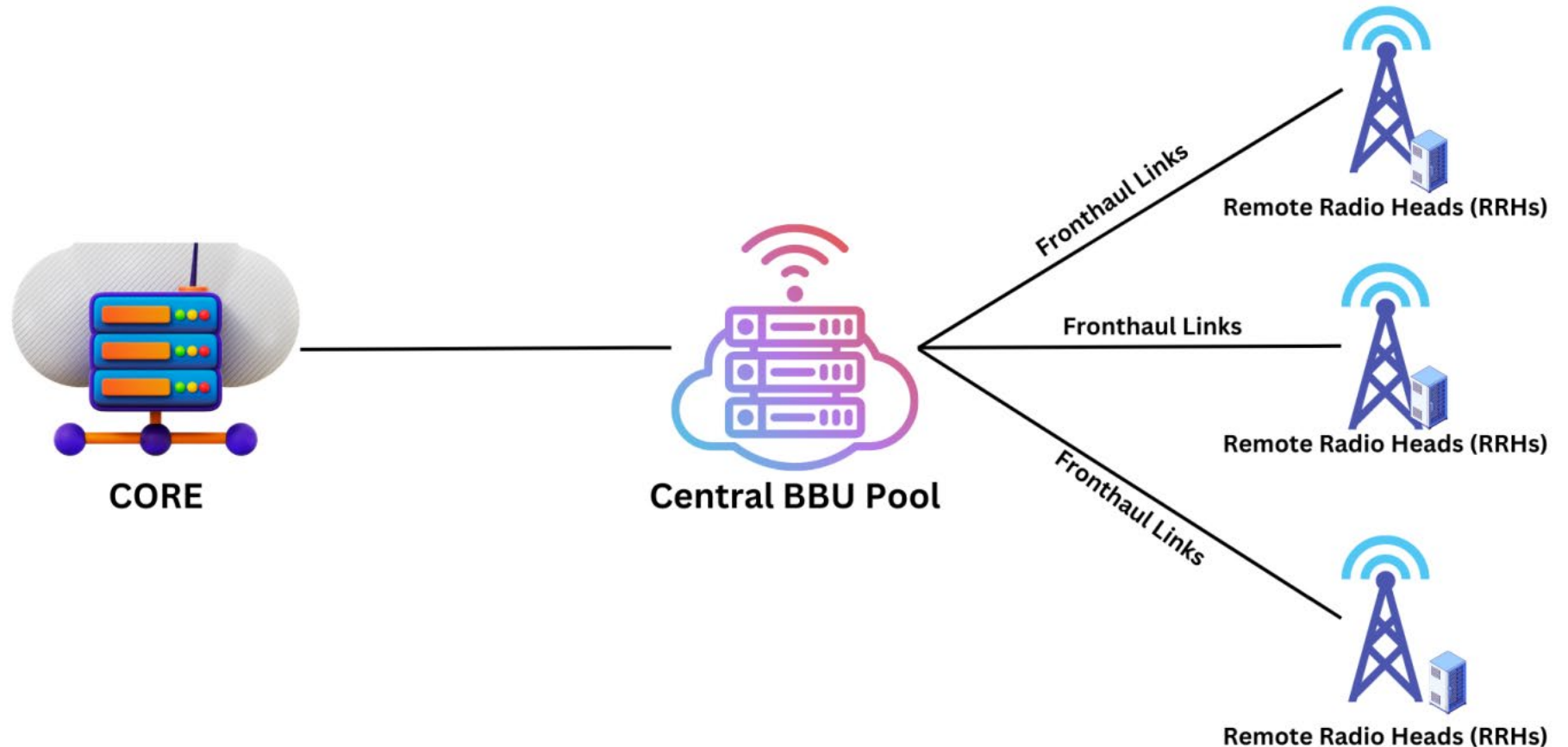
# Traditional RAN architecture: Distributed RAN (D-RAN)

In a Distributed RAN (D-RAN) architecture, each base station is connected with the core and perform all RAN processing within in its own cell (cells).



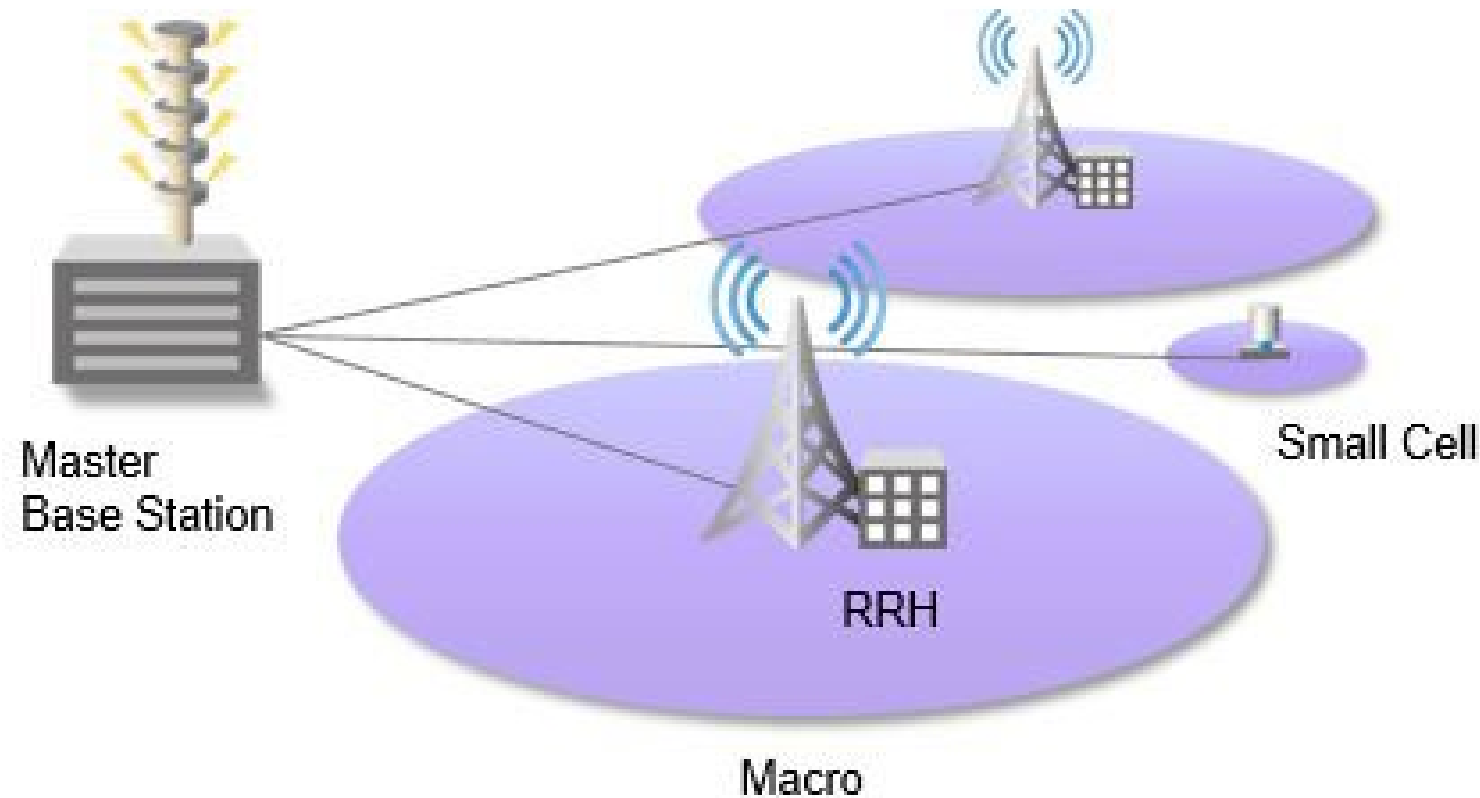
# Modern RAN architecture: Centralized RAN (C-RAN)

In a Centralized RAN (C-RAN) architecture, sometimes referred to as Cloud RAN, the BBUs are centralized and pooled together in a single location. The BBUs are then connected to RRHs at the cell sites through high-capacity, low-latency fronthaul connections.



# C-RAN: More flexible network design

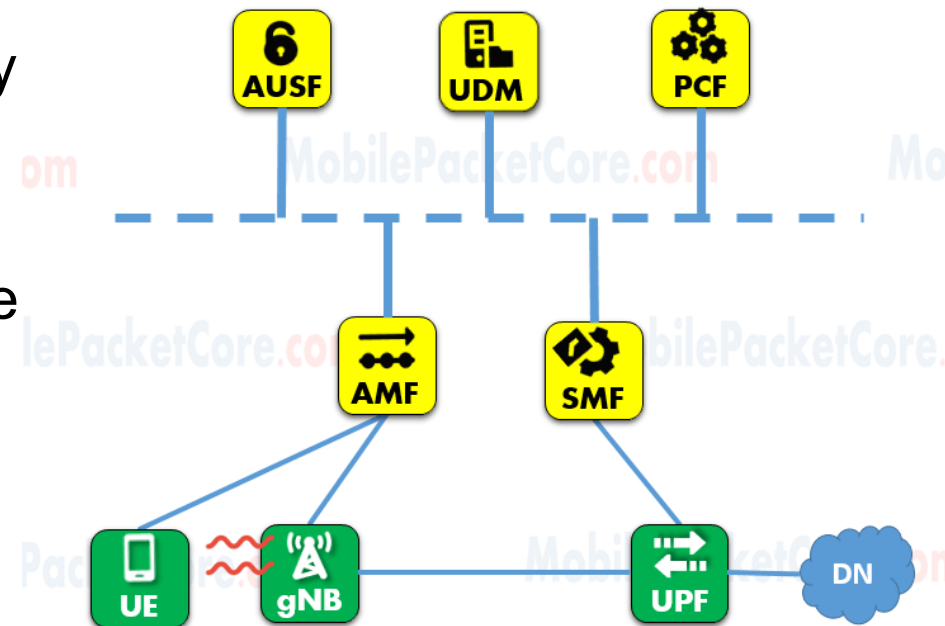
Separating the base station logic and processing into the two parts, BBU and RRH, allows for a more flexible network architecture.



# The Core network

The mobile core network is the central control and processing engine of a cellular mobile network system, responsible for managing subscriber authentication, routing data traffic, and handling mobility.

- In **4G**, the core network (Evolved Packet Core, EPC) has several computing nodes performing specific functions. One node acts as the gateway to the rest of the Internet.
- In **5G**, the core network (5G Core, 5GC) is completely software-based and built to run in the cloud. 5GC is built on a Service-Based Architecture (SBA), implementing IT network principles and a cloud-native design. Each network function (NF) within the 5GC offers services through APIs.



# The core and the RAN

- The core is based on software, and there is one core per mobile operator.
- The mobile operator's network covers a whole country.
- Therefore, the core is not geographically close to all parts of the RAN.
- The image shows an example, where a 5G connected UAV is managed by AI placed in the cloud.
- The UAV is flying in Luleå, and the 5G core is placed either in Luleå (case 1) or in Kista (case 2).

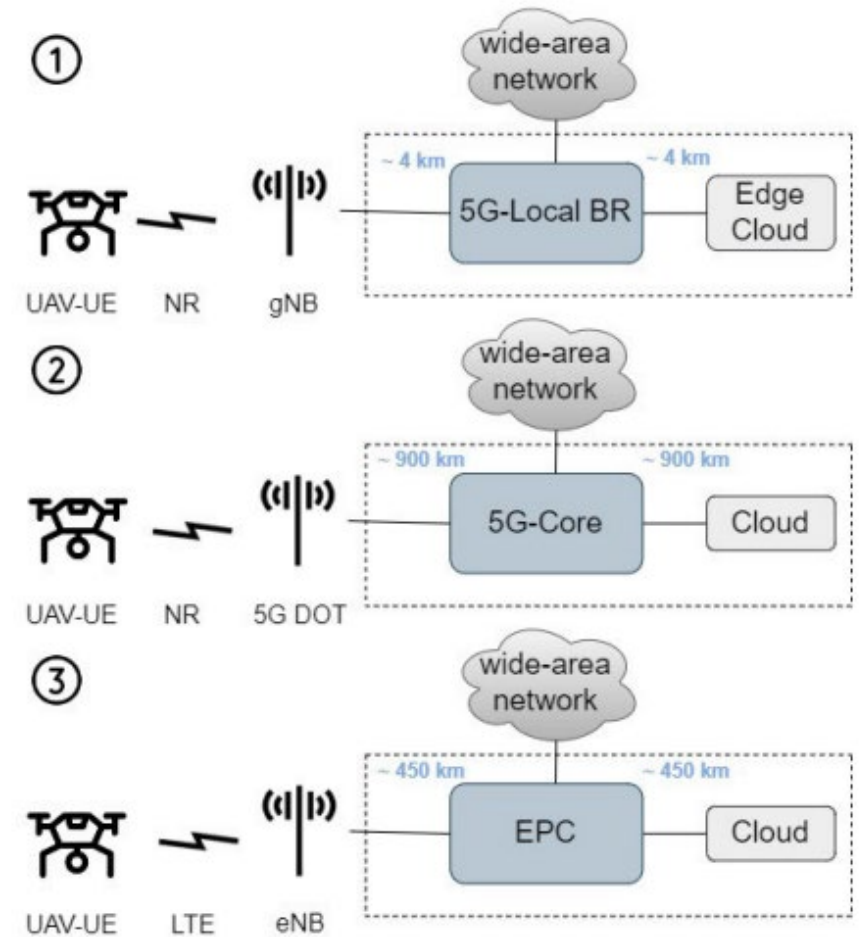


**FIGURE 2.** Three different network topologies for the used experimental setup.

# Information flow

The information flow in a cellular network is separated into a **Data plane** and a **Control Plane**.

- The Data plane handles the user data transmission.
- The user equipment (UE), nodes in the RAN and nodes in the core network uses the Control plane for signalling messages for controlling the user sessions.
- **The separation between a Data plane and a Control plane is different from the Internet protocols, where protocol control information is placed in the header of each data packet.**

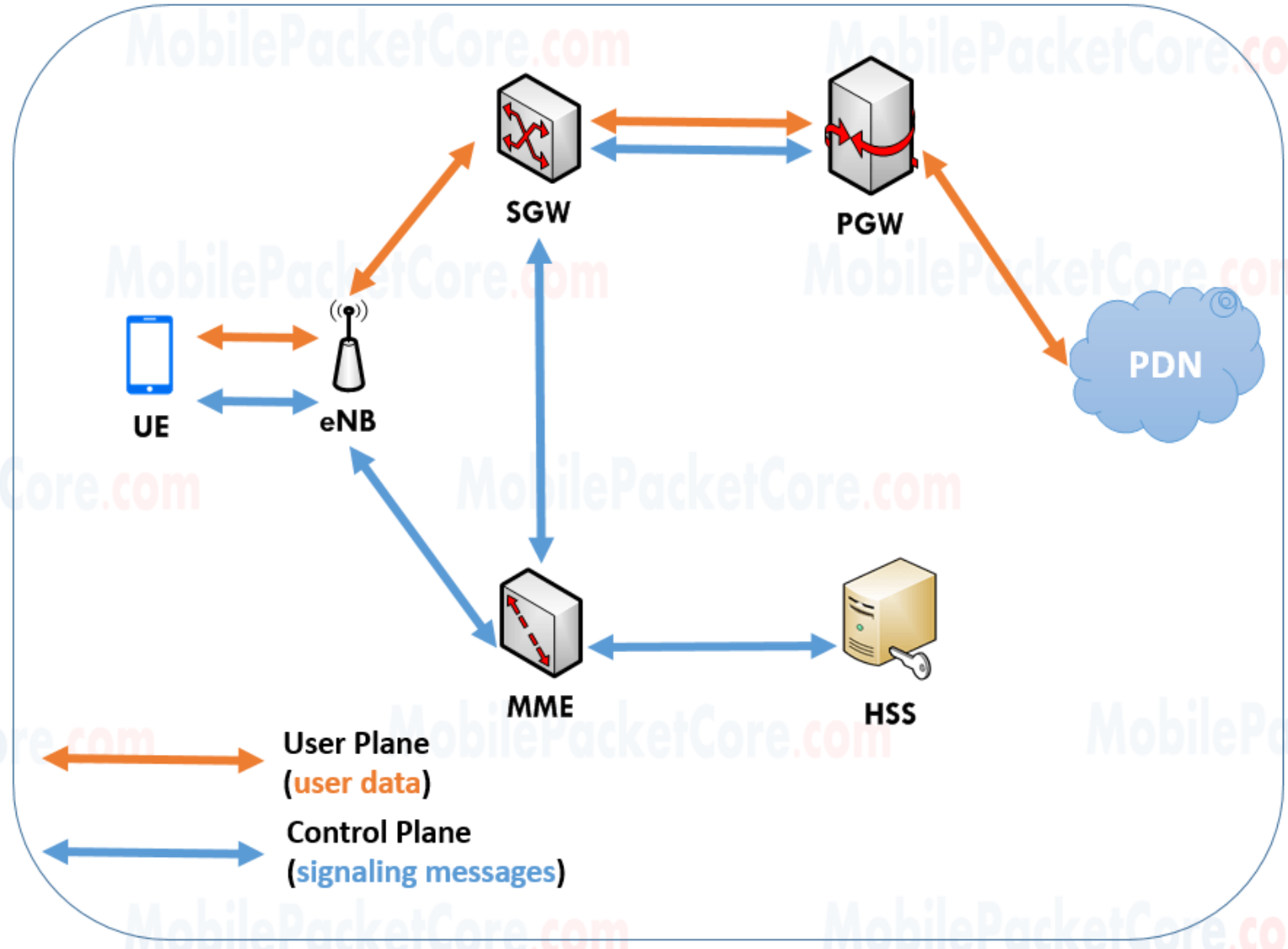
# Information flow - Illustration

The image illustrates the general information flow in a 4G network.

eNodeB (eNB) is the basestation that the user connects to. It belongs to the RAN.

MME (Mobility Management Entity), HSS (Home Subscriber Server), SGW (Serving Gateway) and PGW (PDN Gateway) belong to the 4G Core, called the Evolved Packet Core (EPC).

PDN corresponds to the Internet.

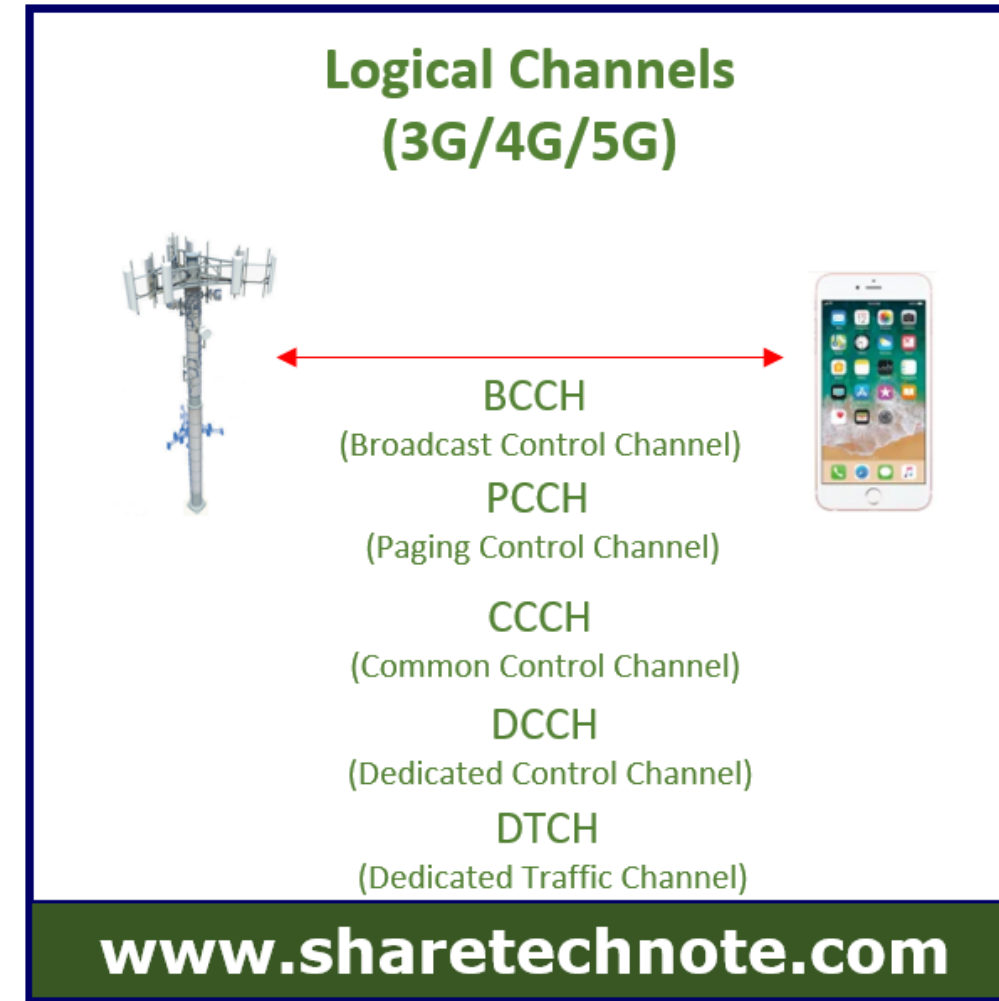


# Logical (radio) channels

The communication between the UE and the base station is wireless. Therefore, the data sent between the UE and the base station is transmitted on one of several uplink and downlink **logical channels**.

There are two main types of channels:

- **Control channels** for transferring control plane information.
- **Traffic channels** for transferring user plane information.



# Node association procedure: RACH

The **Random Access Channel (RACH) procedure** is the node association procedure in 4G and 5G, where an UE establishes initial time-synchronized uplink communication with a base station.

During the RACH procedure, the network checks that the UE is allowed to enter the network, i.e there is a user authentication procedure.

Only UEs with a valid subscription can enter the network. The UE's physical address (IMSI) is used in this process.

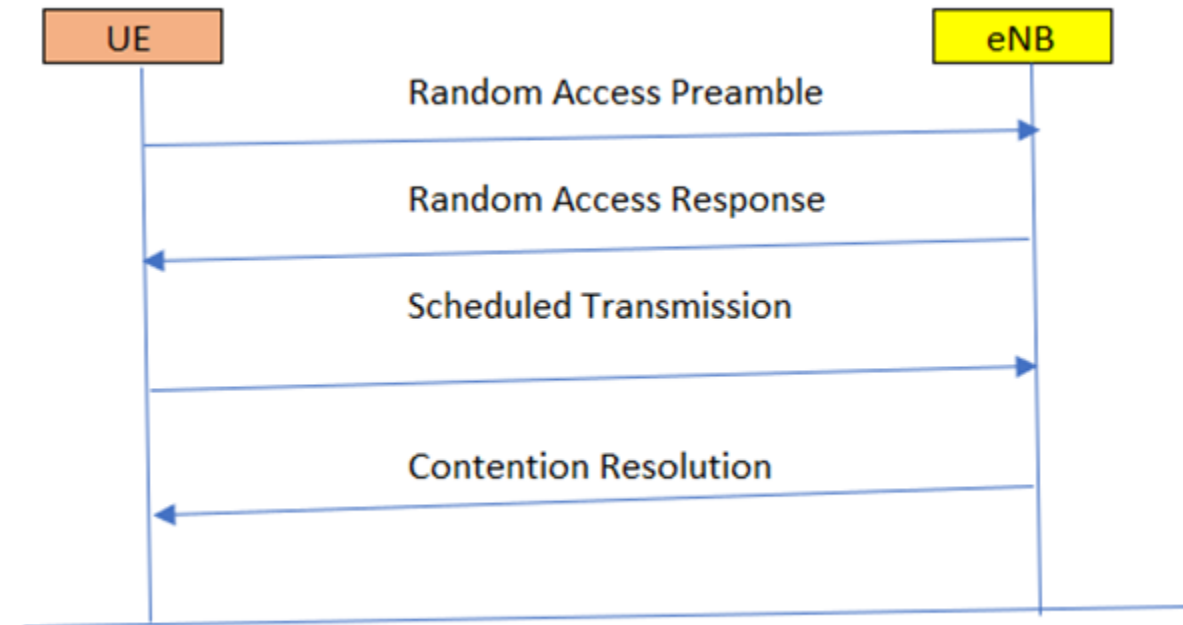


Fig 2: Contention Based Random Access

# Mobility management

Mobility management is a crucial part in cellular mobile networks, ensuring **seamless connectivity** and **efficient resource utilization** as **users move** across different network areas.

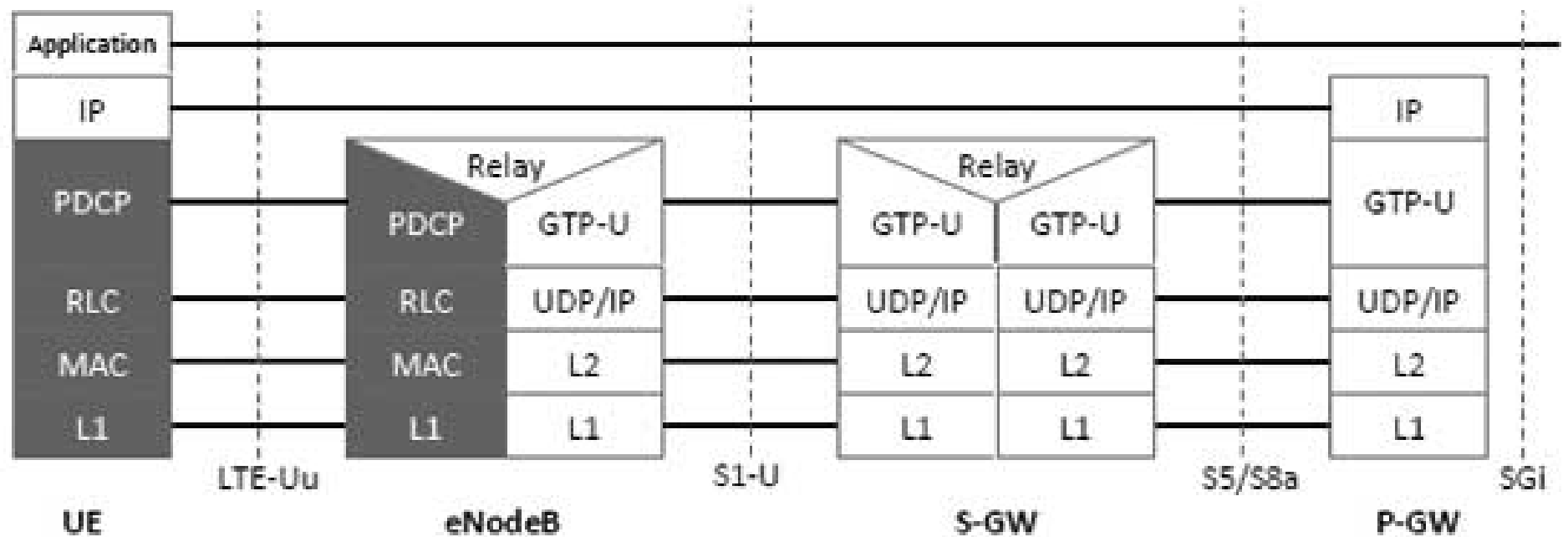
Core mobility functions:

- **Location management:** The network continuously track and know the location of all connected devices, also idle devices, so that all devices are connected to the closest base station. This is performed via specific radio channels (control channels) and continuous control messages.
- **Handoff (Handover) Management:** Core network functions for handover ensure that ongoing user sessions seamlessly are transferred from one base station to another without dropping the connection. The handover management functions are also used for **roaming**, that is, the transfer of sessions between different cellular networks (different operators).

# GPRS Tunneling Protocol (GTP)

**GPRS Tunnelling Protocol (GTP)** is a group of IP-based communications protocols used to carry data packets within both 4G and 5G networks (and previous 2G and 3G networks). (The image shows the network entities in a 4G network).

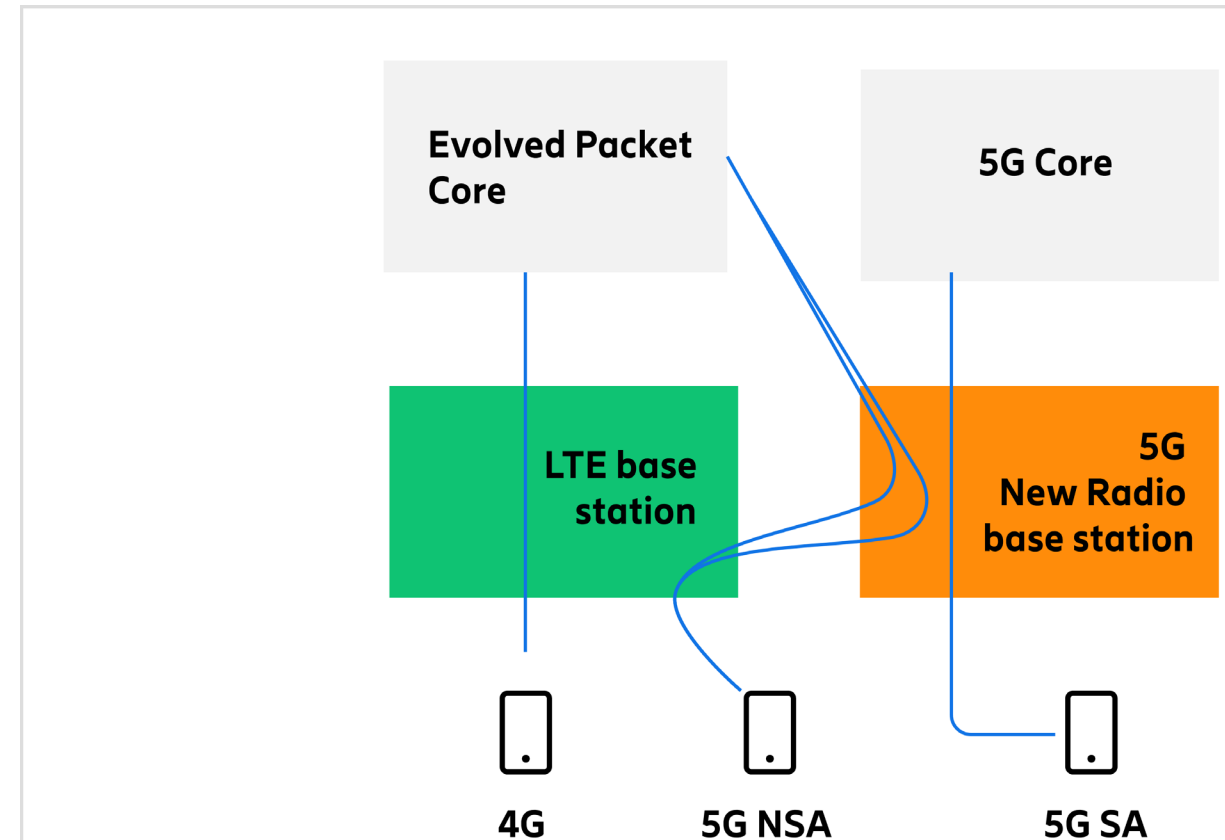
GTP ensures that a user device can keep the same IP address when the user move between cells.



# 5G development

5G has evolved from LTE (4G), in different releases.

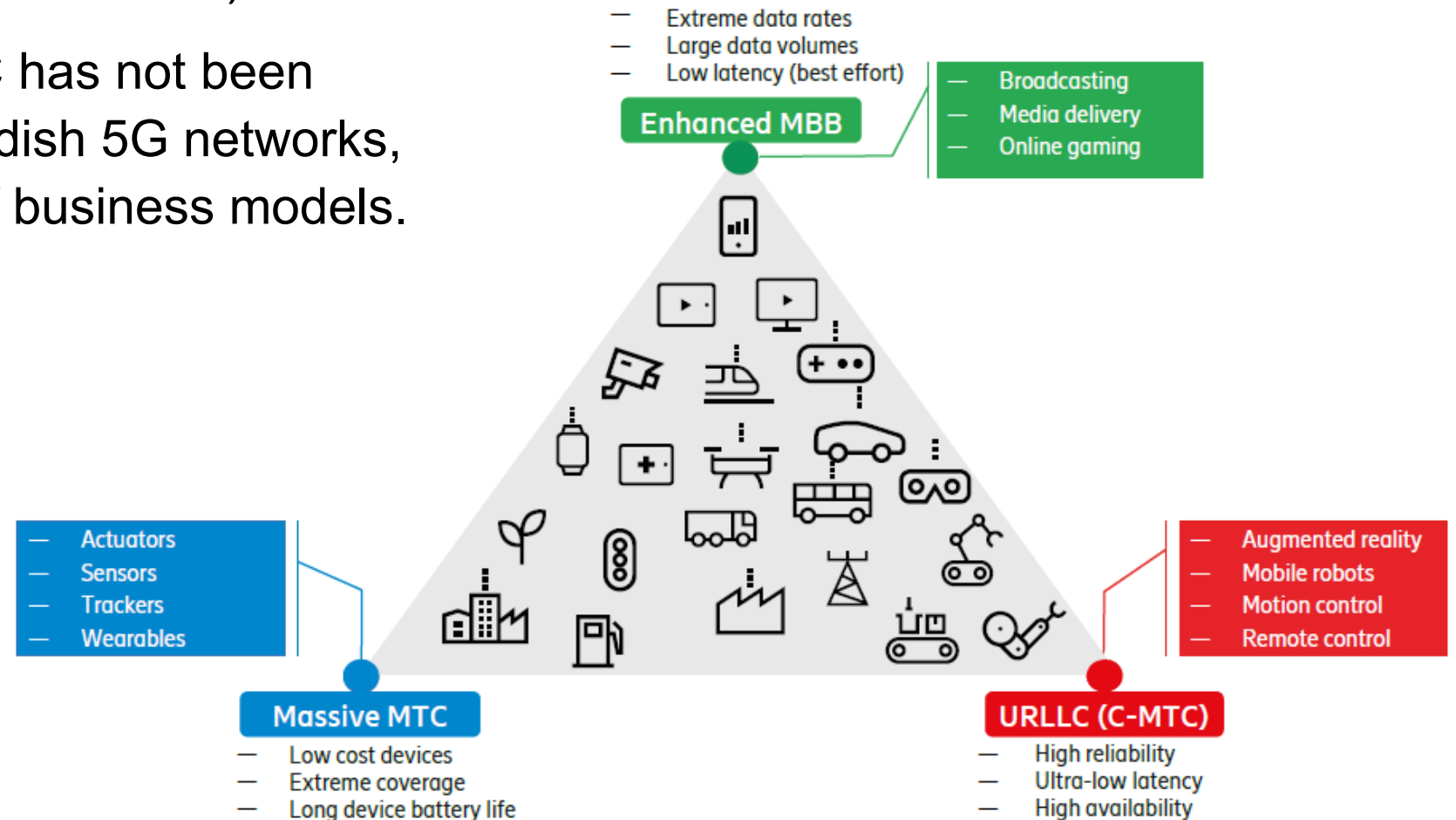
- In the first releases, 5G was based on the 4G core, using a new radio access network, called 5G New Radio (5G NR).
  - This technology is called **5G Non-Standalone-Access** (5G NSA)
- In the later releases, 5G has its own core, called 5G Core (5GC).
  - This technology is called **5G Standalone-Access** (5G SA)
- This means that 4G and 5G can operate in parallel in the same network infrastructure.
- A cell phone usually have both 4G and 5G access.



# 5G application scenarios

5G is developed for ordinary Internet access (**eMBB**), but also for other application scenarios (**URLLC** and **mMTC**).

**Note:** So far, URLLC has not been deployed in the Swedish 5G networks, mainly due to lack of business models.



# 5G Application scenarios in more detail

- **Enhanced Mobile broadband (eMBB)** relates to **high requirements for bandwidth**, such as high-resolution video streaming, virtual reality, and augmented reality. In order to achieve 100-fold capacity increase over 4G systems, more aggressive physical layer technologies improving the spectral efficiency and exploiting the unexplored spectrum are needed.
- **Massive Machine Type Communication (mMTC)** supports the **access of a large number of machine-type devices (Internet of things)**. mMTC-based services, such as sensing, tagging, metering, and monitoring, require high connection density and better energy efficiency.
- **Ultra-Reliable Low Latency Communication (URLLC)** is for **use cases with stringent requirements on reliability and latency** (down to a few milliseconds) such as autonomous vehicles, cloud robotics and real-time coordination and control of machines and processes.

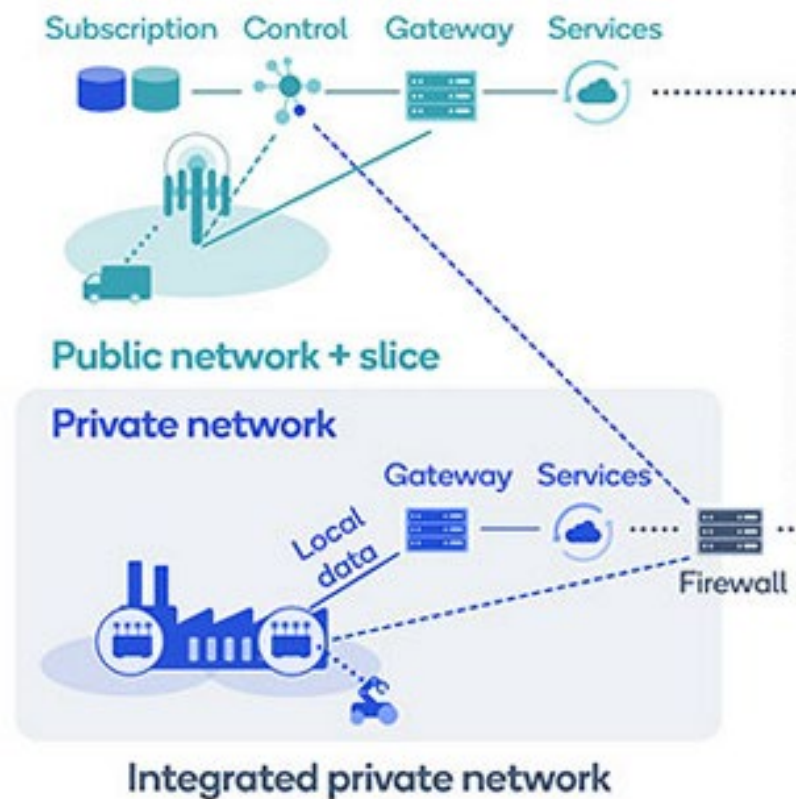
# Private 4G/5G networks

- All 4G/5G networks are managed by mobile operators, where users buy a subscription to a network. Therefore, these networks are called Public networks (compare with Public cloud services).
- However, the 4G and 5G technologies also allow for so called **Private networks**.
- A private network is a dedicated, secure cellular network built exclusively for a single organization within a defined geographic area (compare with Private cloud services).
- There are two main types of Private 4G/5G networks:
  - Integrated private network
  - Independent private network

**Note:** A Private 4G/5G network solution is expensive and only suitable for very specific types of scenarios, for example in the military or in very limited areas.

# Integrated Private 4G/5G network

- In an integrated Private 4G/5G Network, capacity in a public network is reserved for a single organization.
- The capacity reservation technique is called **Network Slicing**.
- This means that **the private network is controlled by the core in the public network**.



# Example: 5G tele-operated wheel-loader

Volvo CE has tele-operated heavy wheel-loaders that are remote-controlled over an integrated private 5G network.



Source: <https://www.volvoce.com/global/en/news-and-events/news-and-stories/2021/volvo-ce-tests-worlds-first-high-lift-tele-operation-over-5g/>

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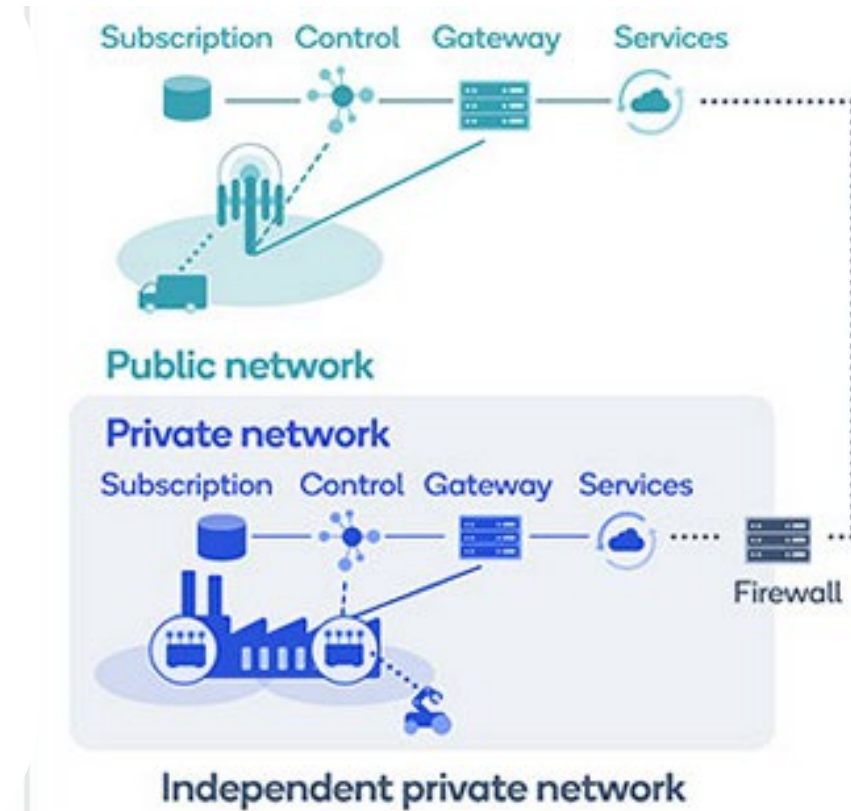
# Example: Boliden mines

An integrated private 5G network has been installed in the Boliden mine in Kankberg, to facilitate trials of remote-controlled and self-driving vehicles and machines in harsh environments.



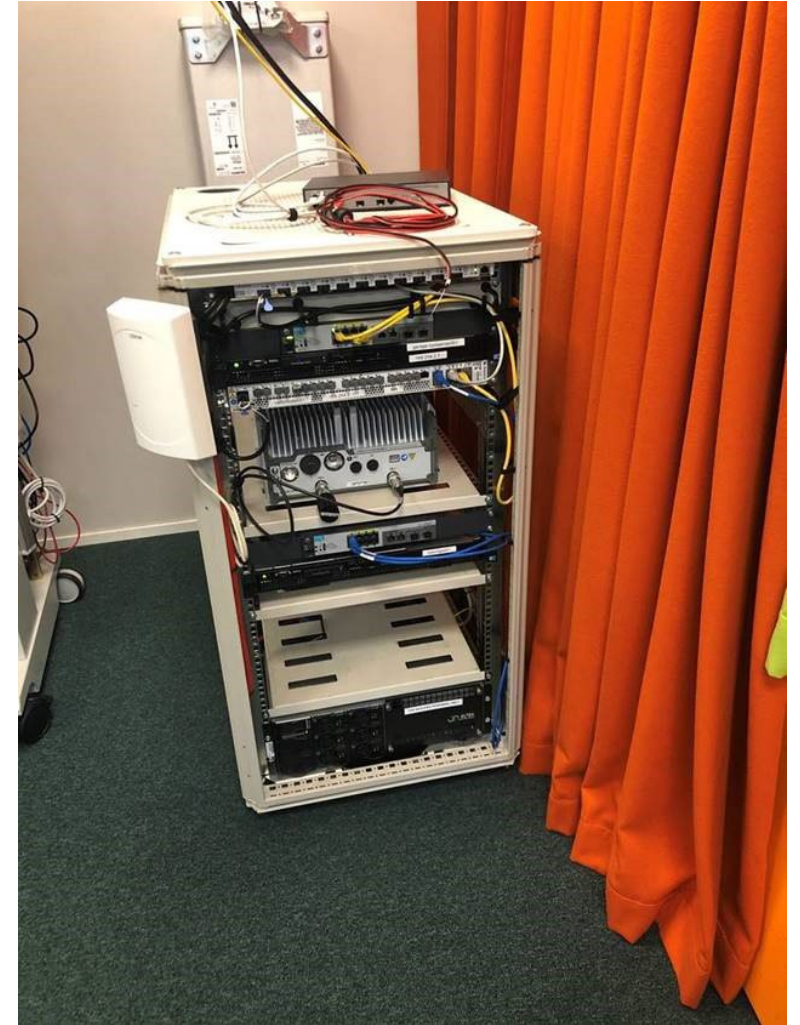
# Independent Private 4G/5G Network

- An independent private 4G/5G network is a **privately owned 4G/5G network with its own core**.
- In Sweden, there is a licensed frequency band for private networks.
- The private operator needs permission from PTS to use this licenced frequency band.
- Also, the **private operator must buy all equipment for the RAN and the core**.



# Example: The 5G lab at LTH

- A **private independent 5G network** for research and education at the the Dept. of Electrical and Information Technology.
- The network equipment, including radio units and a BBU, is on loan from Ericsson in Lund.
- The network uses an open-source core network, called Open5Gs, which runs in a server cluster managed with Kubernetes.
- The department has a license for a private 5G network within the south part of the LTH campus.



# Cellular mobile networks?

Your task is to help Helsingborg West Harbour with their project on self-driving trucks. The trucks will move containers within the harbour area. The trucks will be controlled by a software application placed in a back-end server. The software application will send instructions to the trucks about their path trajectory, so that the trucks' movements are optimized.

The trucks will continuously send information about their current position to the software application. As a fall-back solution, the trucks will have their own internal collision-avoidance mechanism so that they do not collide into each other or other things.

Your task is to propose a complete network system design for this self-driving application. The image shows Helsingborg West Harbour.



# Helsingborg Harbour - Suggested solution – 4G/5G

## **Scenario conditions and requirements:**

- This is an outdoor scenario in Helsingborg.
- Each truck will continuously receive instructions from a back-end server, and continuously send location information to the server.
- The dialogue between a truck and the back-end server is time-critical, which means that this is a time-critical application.

## **System design:**

- Since this is an outdoor scenario in the city of Helsingborg, the 4G/5G coverage should be good.
- We can connect each truck over 4G/5G.
- The trucks communicate with the back-end server over the Internet (i.e the back-end server is not connected to 4G/5G). We can use a private or a public cloud solution for the back-end server.

**Note:** The back-end server may not be logically "close" to the harbour even if it is physically placed there.



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