Ontwikkelingen in het Radio Access Network (RAN) voor Next-Gen mobiele netwerken

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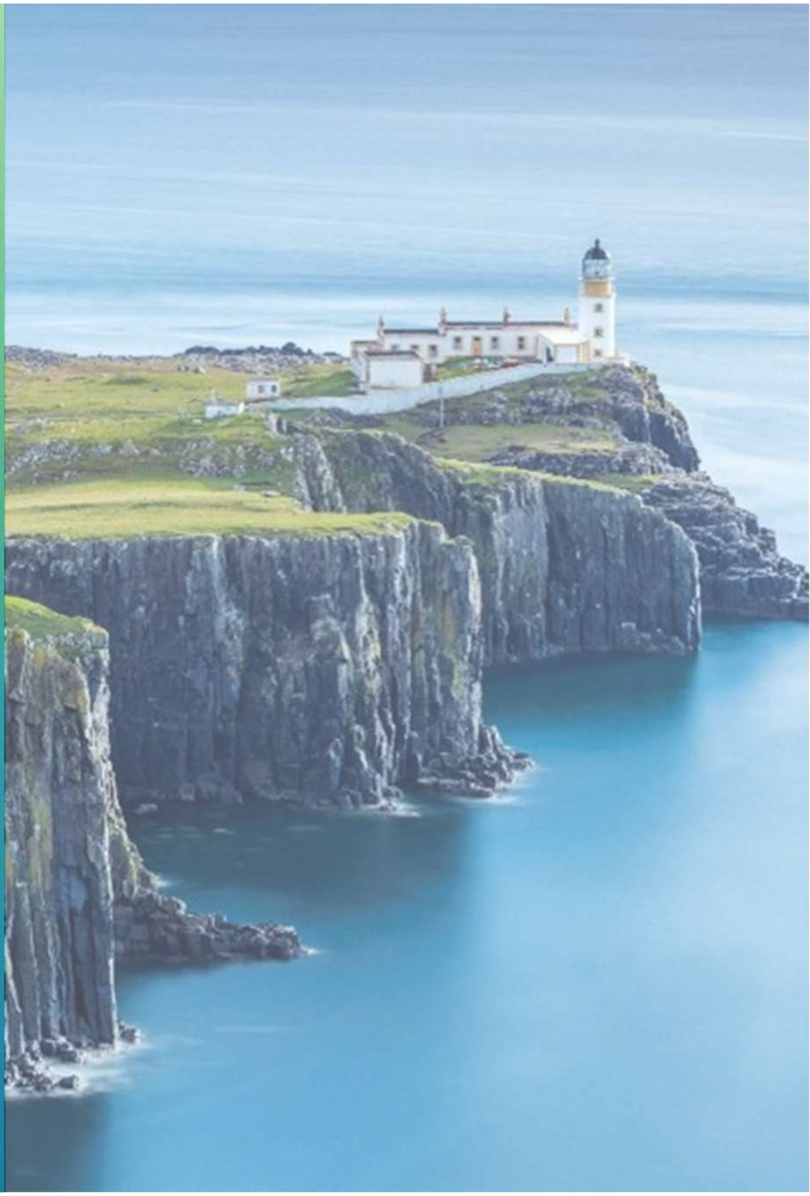
KIVI mini-seminar

(on-line)



A vision on developments in the mobile communications network in 5G, 6G and beyond

Outline

Part I: Functional enhancements and architecture evolution

- Massive MIMO (M-MIMO)
- Edge computing - user plane offload
- Carrier aggregation, EN-DC
- Device-to-device communication
- Multi-antenna communication (user plane established through multiple cells)
- XR/AR/VR; IMS data channel
- ISAC
- Cell-Free Networks
- "Elevated RAN" – RAN for the transport layer

Part II: General aspects of advanced mobile communication networks

- Frequency allocation in 5G and 6G
- Cloud-native deployment
- Envisaged advanced use cases
- 4G -> 5G NSA --> 5G SA --> 6G
- Open RAN (O-RAN)
- Exposure from 6G RAN

Q&A

All abbreviations will be explained!

Part I
Functional enhancements and architecture evolution

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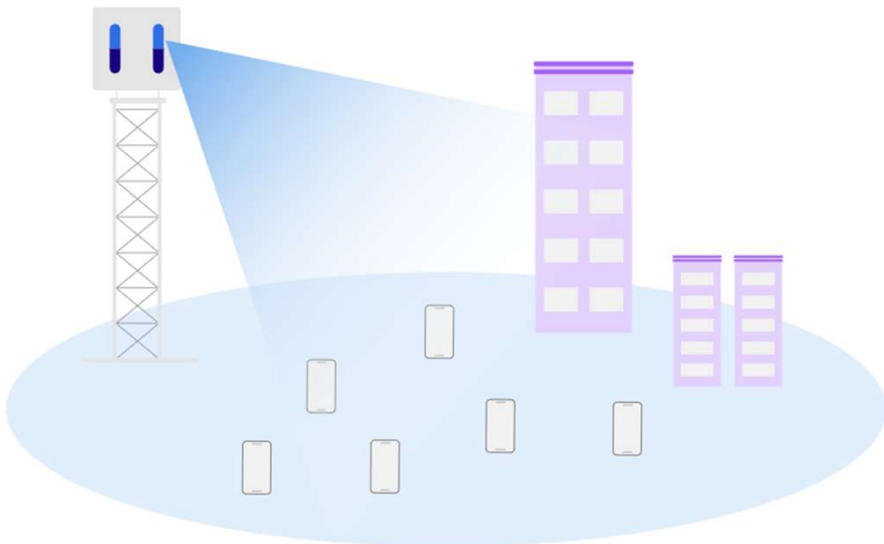
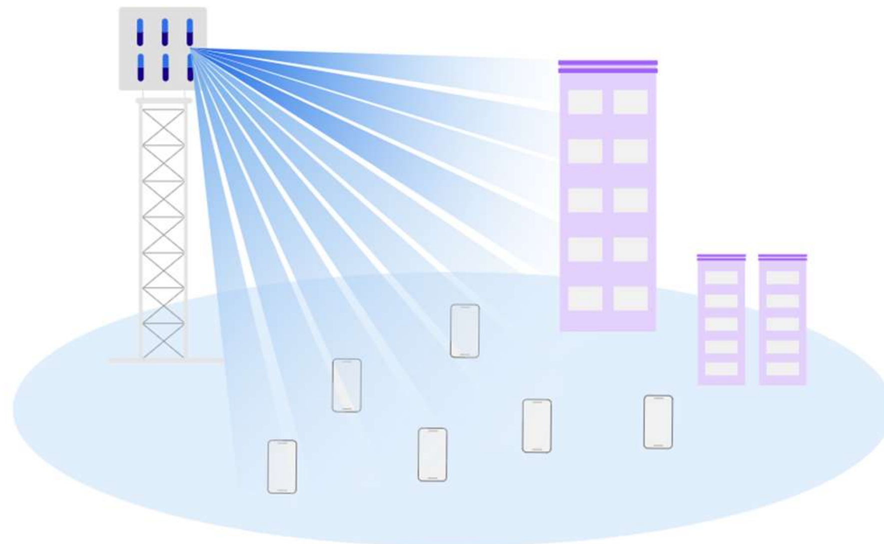
Massive MIMO
The raw facts

- Traditional antennas send and receive signal in a defined 3D space; typically a horizontal sector of 120º and vertical angle of 30º - 60º; signal is sent through a single main lobe
- Signal energy is spread over the entire 3D space; so, the signal is *also* transmitted in a direction where the signal does not reach the intended receiver
- Multiple-input and multiple-output (MIMO) is a technique whereby an antenna transmits through “beams”; signal is transmitted into the direction of the intended receiver
- This leads, among others, to improved Signal-to-Noise Ratio (SNR) and less interference
- A MIMO antenna (or Massive MIMO, M-MIMO) is divided in a multitude of antenna elements (8, 16, 32, 64, 128...)

Legacy antenna



M-MIMO antenna



M-MIMO:

- Mobile devices are served through individual beams
- Higher frequency -> shorter wavelength -> smaller antenna element -> larger number of antenna element built into a M-MIMO antenna
- Higher number of antenna elements leads to increased number of simultaneous beams and allows for more accurate direction of the beams

M-MIMO in 5G and 6G

- M-MIMO is used in contemporary 5G networks, typically using 3.5 GHz
- For 6G, eXtreme MIMO (X-MIMO) is targeted for the 7 – 24 GHz range
- M-MIMO (X-MIMO) allows for accurate positioning of the mobile device
- M-MIMO in 6G may use up to 1024 antenna elements
  - At higher frequency
  - And hence shorter signal reach

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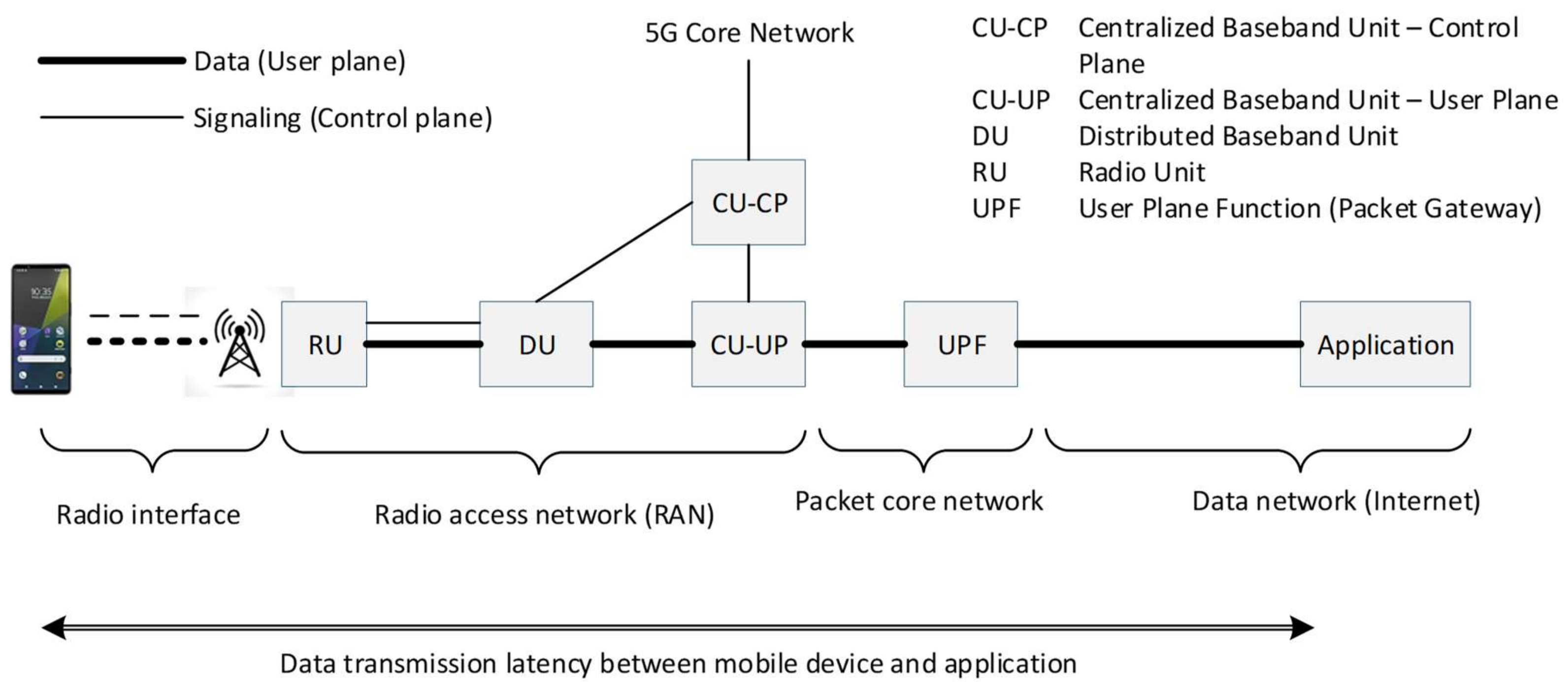
Edge computing

Conceptual view on data transmission between mobile device and application

Data traverses the RAN and the packet core network towards the application



The problem

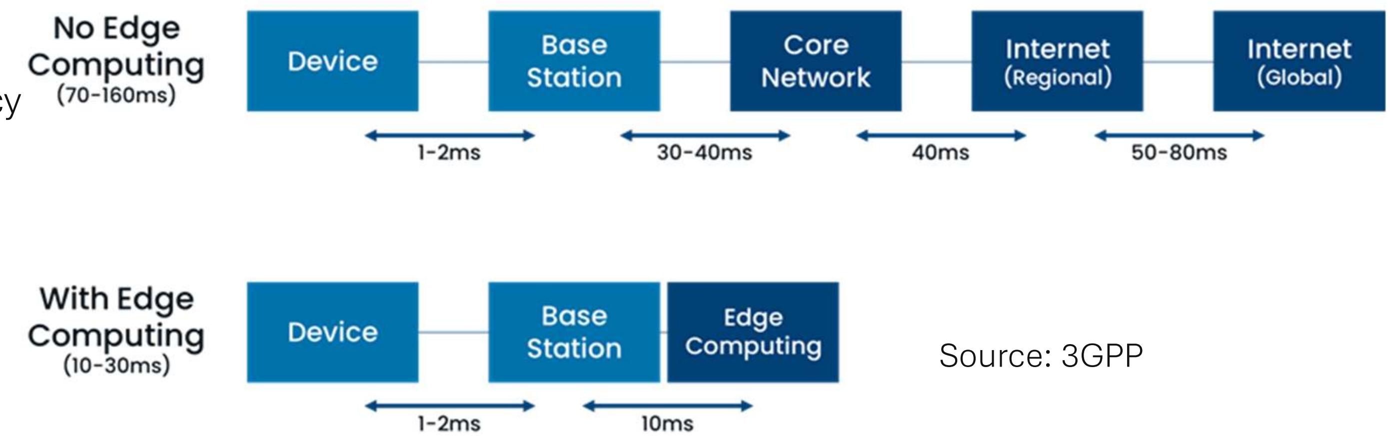
For certain applications, the latency between (mobile) device and application may be too large, impacting the functioning of the application

The solution

Place the application *close* to the edge of the network; as close as possible to the radio base station

The limit

The speed of light! In other words, further improvement may be possible



Source: 3GPP

Specification: 3GPP TS 23.558

Edge application areas

Industrial applications: Short latency for real-time control of factory plant

- Intelligent factory
- Industrial Internet of Things (IoT)

Public sector: vast amount of data collected and to be processed

- Autonomous vehicles
- Transport sector

Enterprise networks: Keeping sensitive data on-premises

Residential applications: edge processing of application data

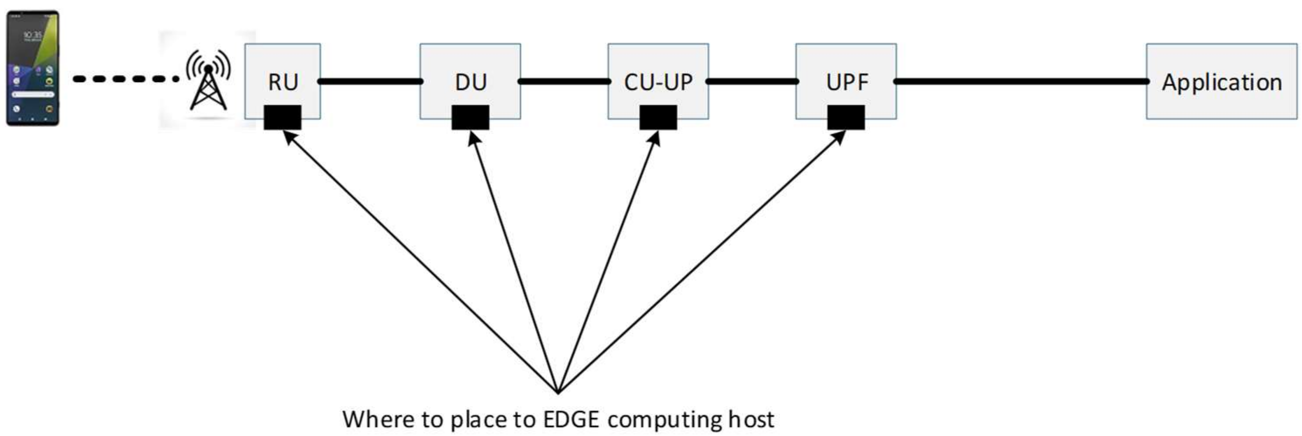
- Offloading device processing
- Voice calls augmented with AR/XR/VR

The challenge – where to place the edge computing platform

- Placing edge computing platform very close to network edge
  - Technically more challenging – more impact on RAN architecture
  - Very short latency
  - More frequent handover needed, when served device moves location; application processing to be transferred in real-time to other computing host in the RAN
- Placing edge computing platform in (slightly more) central location
  - Less impact on network architecture
  - Larger latency than placing edge computing close to the network edge
  - Fewer handovers needed

A technical consideration

- DU, CU-UP and UPF are likely candidates for placing EDGE computing host
- RU unlikely candidate for placing EDGE computing host
  - However, Open RAN (O-RAN) might introduce capability for EDGE-like computing in or near the RU
- "In-network Computing“ is the concept of data processing embedded in the fabric of the network (routers, switches)



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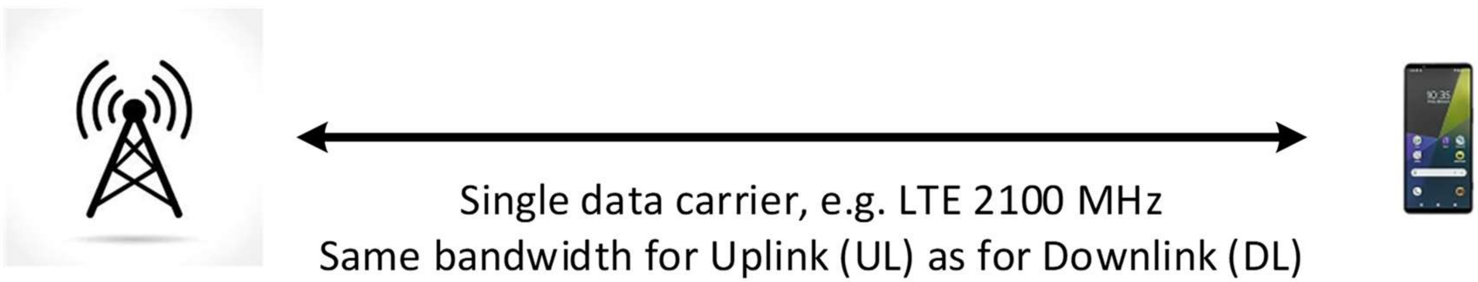
Traditional data transmission through the radio access network

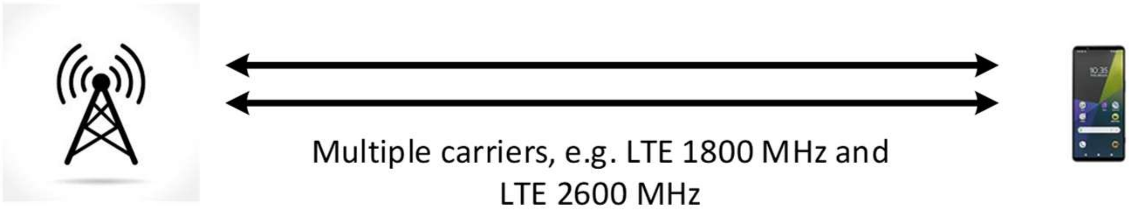
- Single data carrier
- Same bandwidth for uplink and downlink
- Frequency Division Duplex (FDD) and Time Division Duplex (TDD)



Increasing bandwidth for a single data connection

Carrier Aggregation

- Combining multiple LTE carriers for increased bandwidth
- Different UL bandwidth than DL bandwidth
  - DL bandwidth requirement often higher than UL bandwidth requirement
- Allows for flexible usage of different frequency bands; increased efficiency of available frequency bands

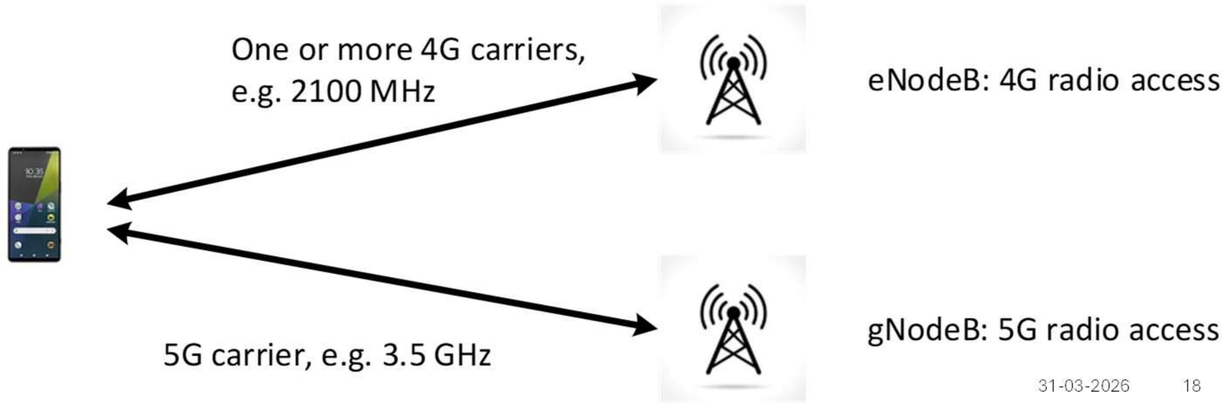


EN-DC: Multi-technology carrier aggregation

- E-UTRAN-NR Dual Connectivity (EN-DC)
- E-UTRAN = 4G radio access network
- NR (New Radio) = 5G radio access network
- A mobile device connects to 4G radio (eNodeB) for mobility, session management and data connectivity
- The mobile device increases data throughput by combining the 4G data connection with 5G data connection, through gNodeB

Legend

NodeB	= 3G antenna
eNodeB	= 4G antenna
gNodeB	= 5G antenna



Reflection on EN-DC

- A Mobile Network Operator (MNO) that operates a 4G network (4G radio + 4G core network) can introduce 5G radio to augment the data transmission --> higher data rates possible
- The core network remains 4G; 5G radio is used for increased data transmission only
- Currently, 4G radio (LTE) is combined with 5G radio at 700 MHz or 5G radio at 3.5 GHz; a next step is to combine 4G radio with 5G at 6 GHz (when license is available)
- When 5G core network is introduced, a pure 5G radio access can be deployed

Situation in The Netherlands: 4G core network & 4G radio access network, augmented with 5G radio access (5G Non-standalone, NSA; see a later slide)

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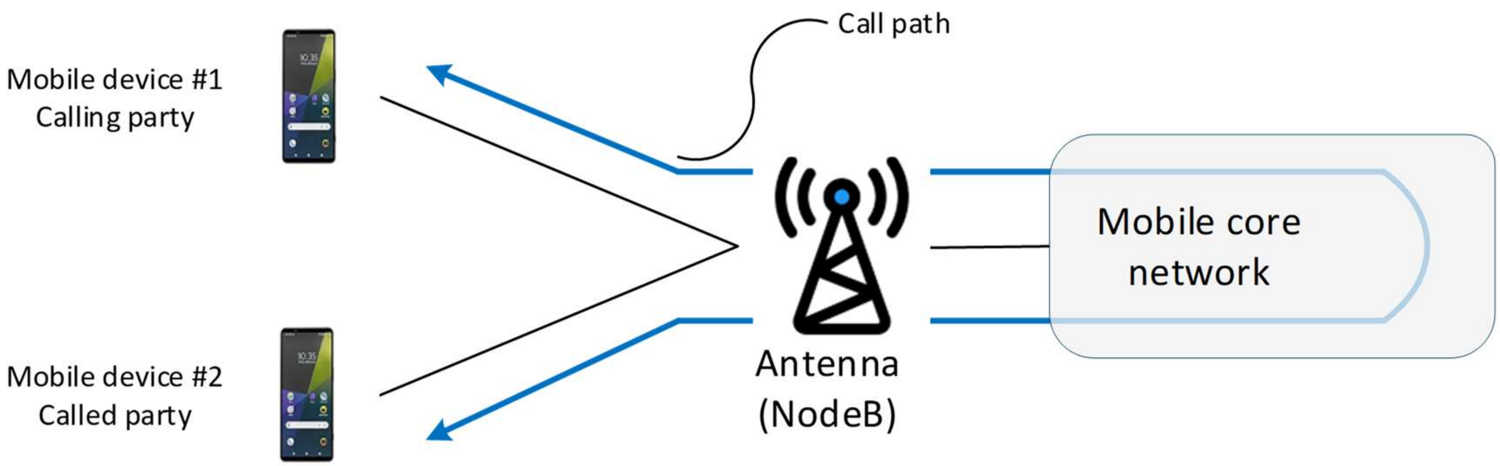
Call routing - the current approach

- Call routing (control plane signaling and media transfer) is routed through the mobile core network
- Mobile devices engaged in a voice call have full and independent flexibility for changing location, incl. handover to other antenna

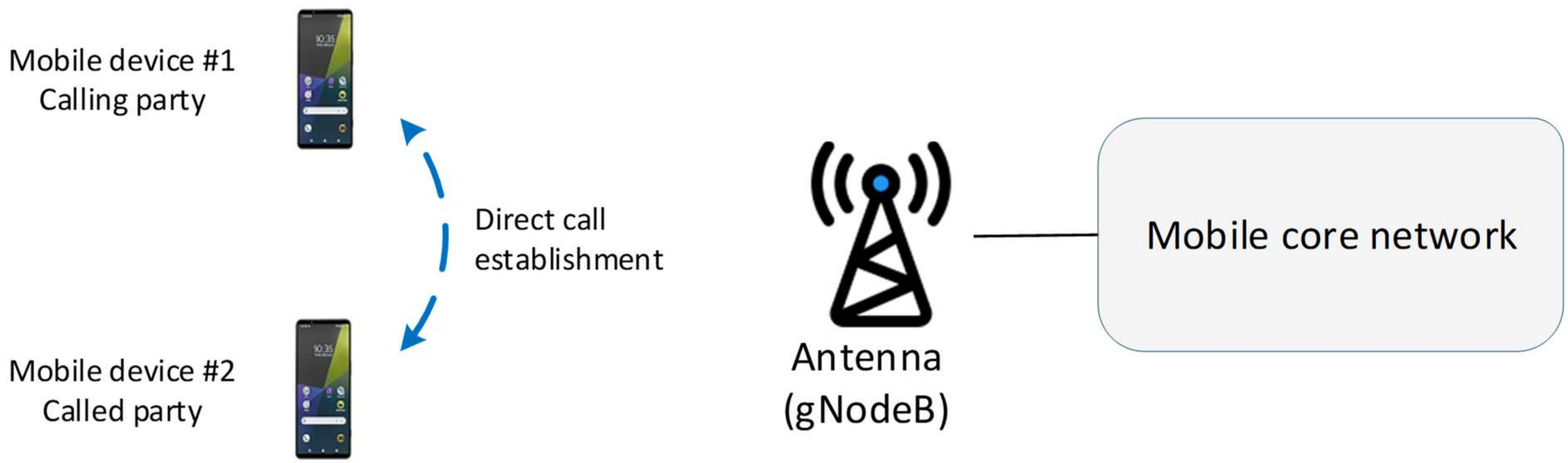


Proximity Services

- The 5G mobile network introduces Proximity Services (ProSe), also referred to as Device-to-Device communication
- Devices may exploit their “proximity” for establishing a communication session
- Rationale: offload the radio access network and offload the core network
- Remote locations: communication establishment without mobile communication network

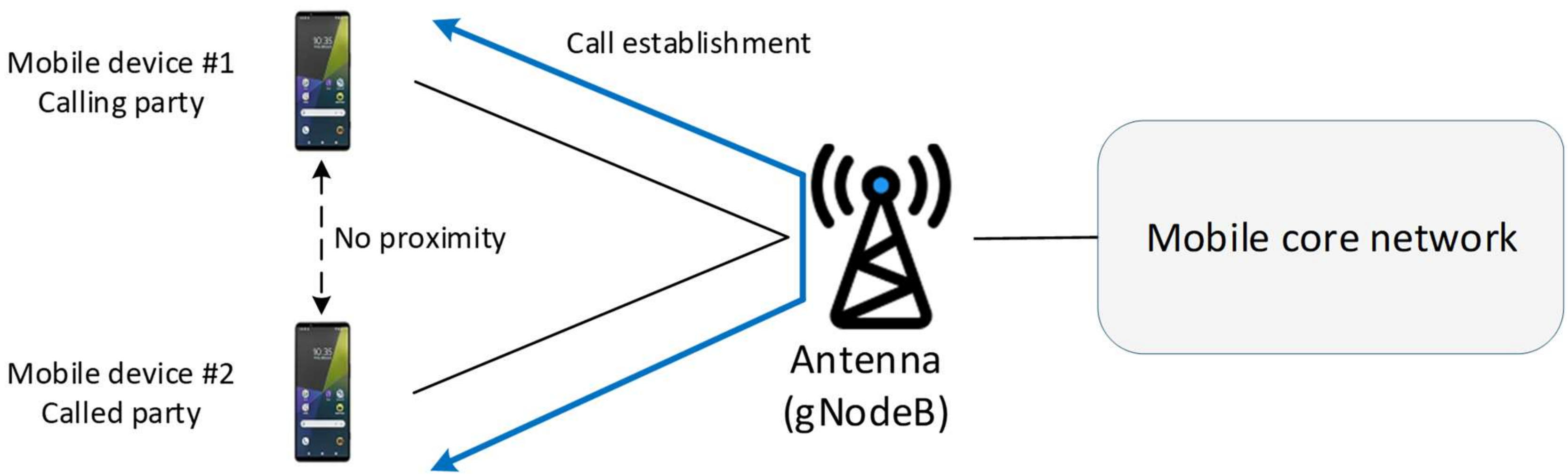
ProSe scenario 1: Device-to-Device communication

- Direct communication between two mobile devices
- No involvement by the core network
- Mobile devices have to “discover” each other



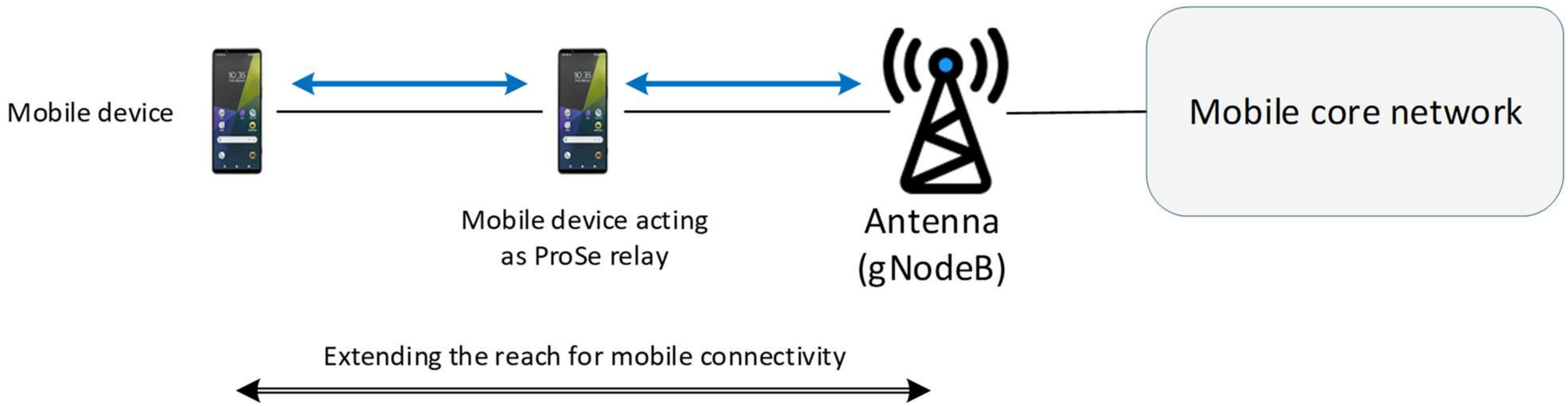
ProSe scenario 2: Device-to-Device communication with NodeB relay

- Call establishment follows a path through the antenna (gNodeB)
- Involved mobile devices have radio connectivity to the same antenna



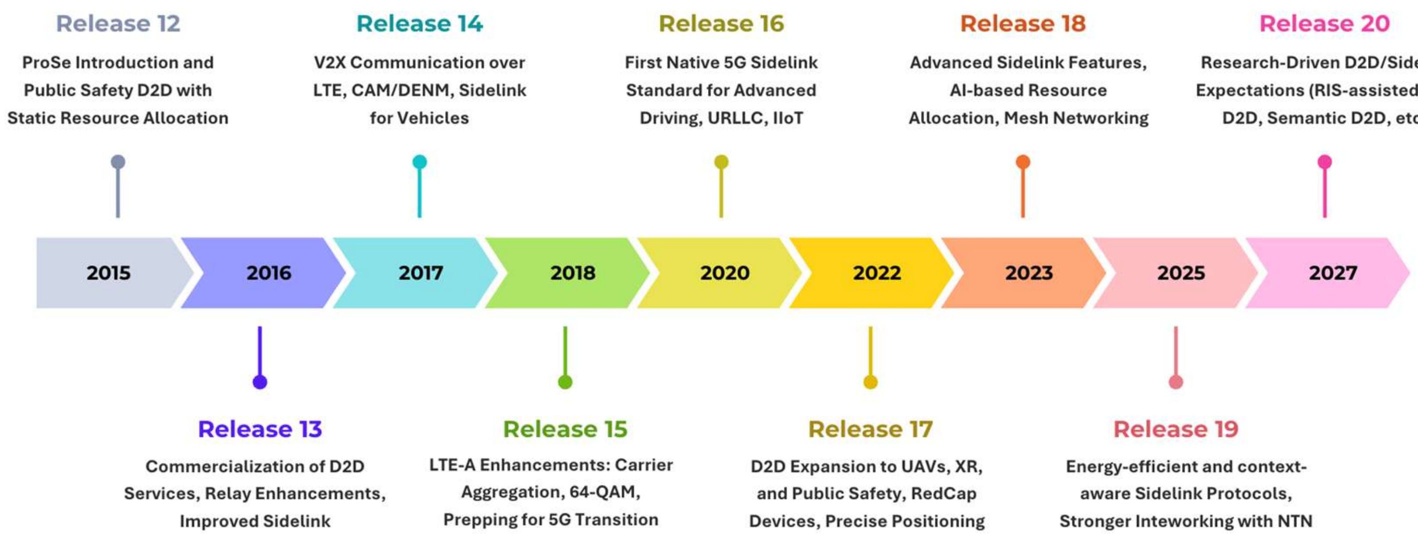
ProSe scenario 3: Device-to-Device communication with mobile device relay

- A mobile device may take the role of ProSe Relay
- Other device(s) may establish radio connectivity to the antenna *through* the Relay device
- Effectively, the reach of the mobile connectivity is extended



Device-to-device communication - a reflection

- D2D is introduced in 5G – work is ongoing in 6G
- Challenges: spectrum management, interference, mobility
- Co-existence with advanced radio techniques (M-MIMO, Cell-Free)



Source: Fasihi and Mark

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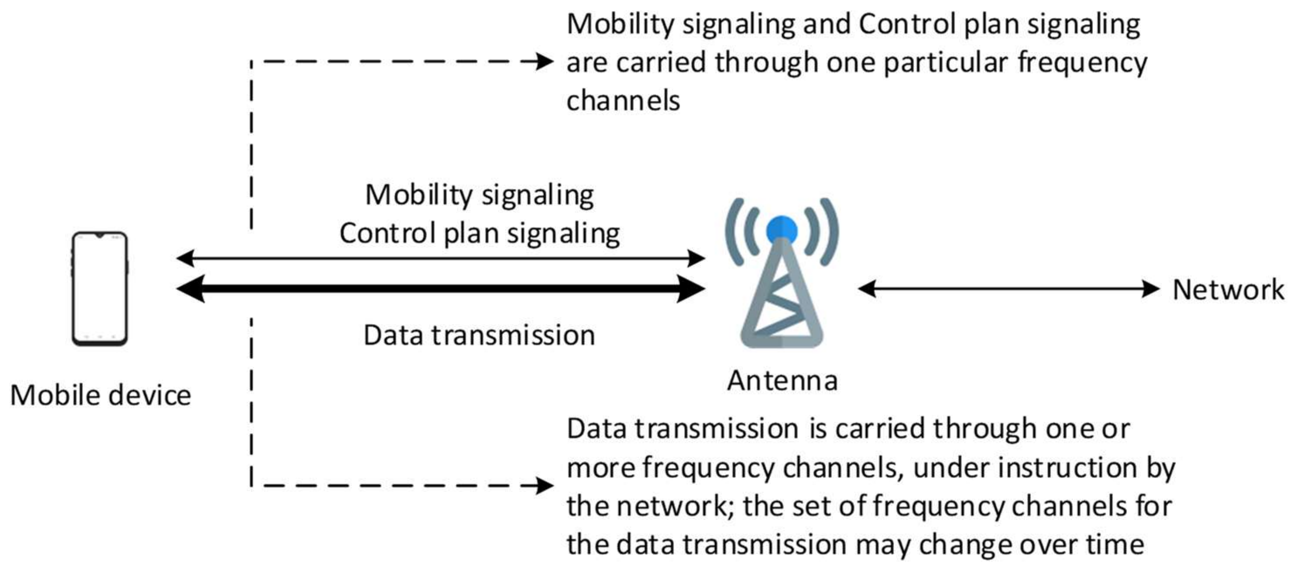
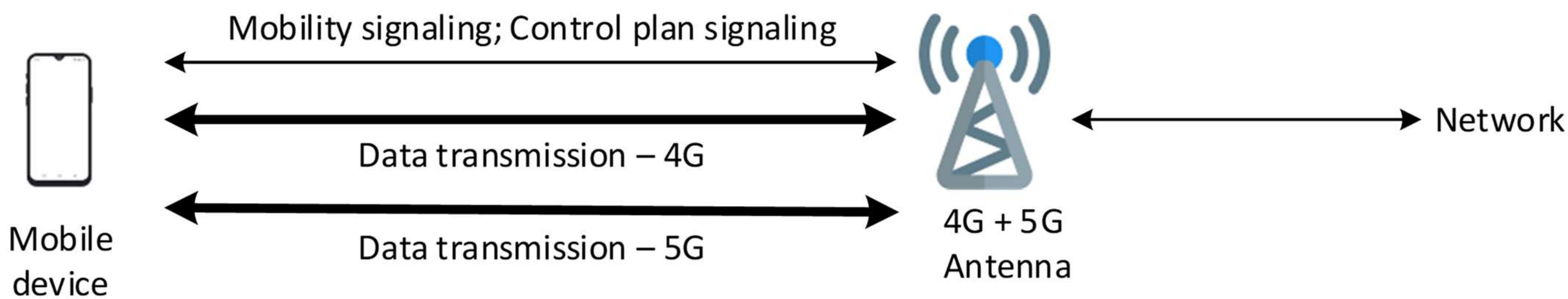
Antenna connectivity – the “traditional method"

- User Equipment (UE) has radio connectivity to one antenna
- Radio connectivity comprises (i) Mobility signaling and Control plane and (ii) data transmission
- Mobility connection and data transmission are placed on specific frequency channel
- UE hands over to other antenna when needed



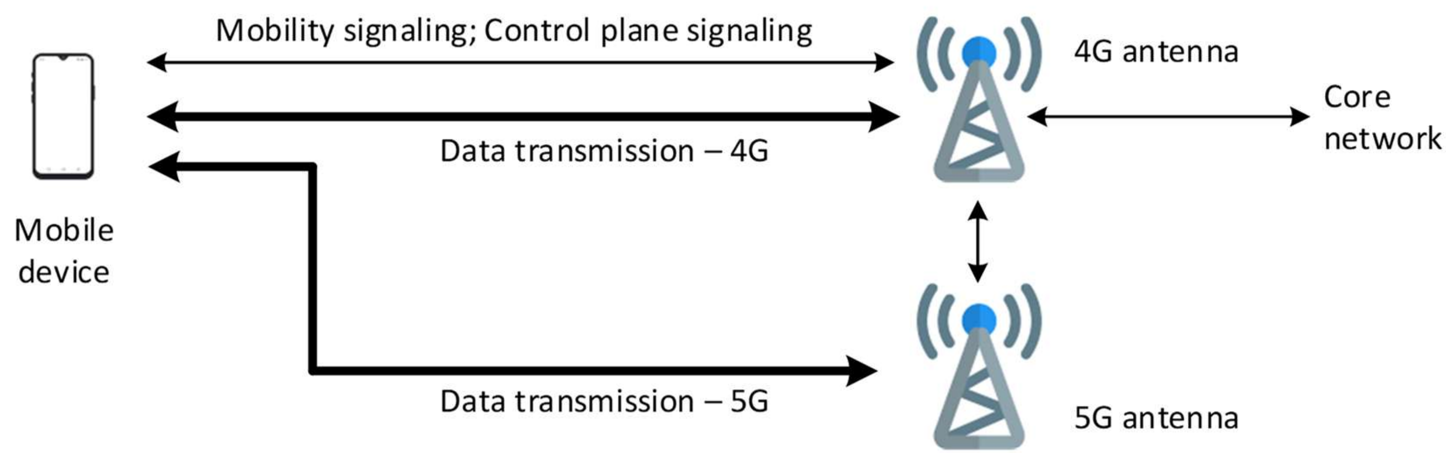
Combining 4G radio connectivity with 5G radio connectivity

- Next step: combine 4G data transmission with 5G data transmission
- Antenna is adapted for supporting 4G radio connectivity and 5G radio connectivity
- Operator has (some) flexibility in deciding which frequency bands / channels are used for the data transmission



Multi-antenna data transmission

- EN-DC (E-UTRAN-NR Dual Connectivity) over multiple antenna's
- Efficient usage of available frequency spectrum of neighbouring cells
- Partial offload of traffic to other cell



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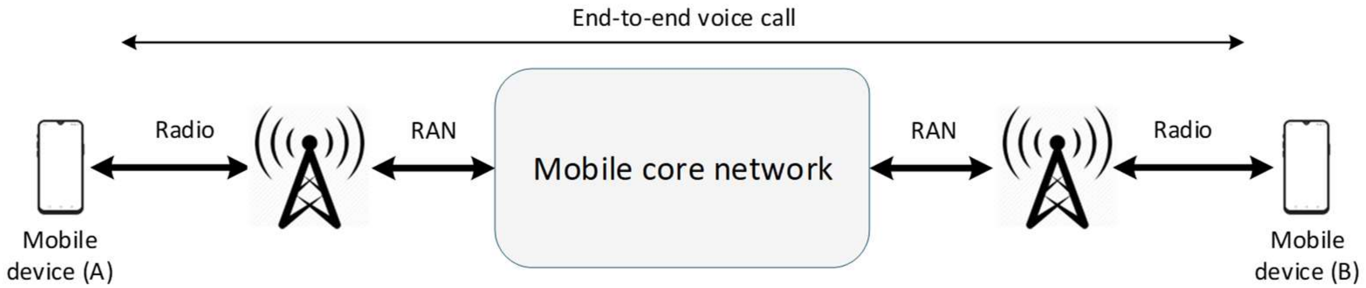
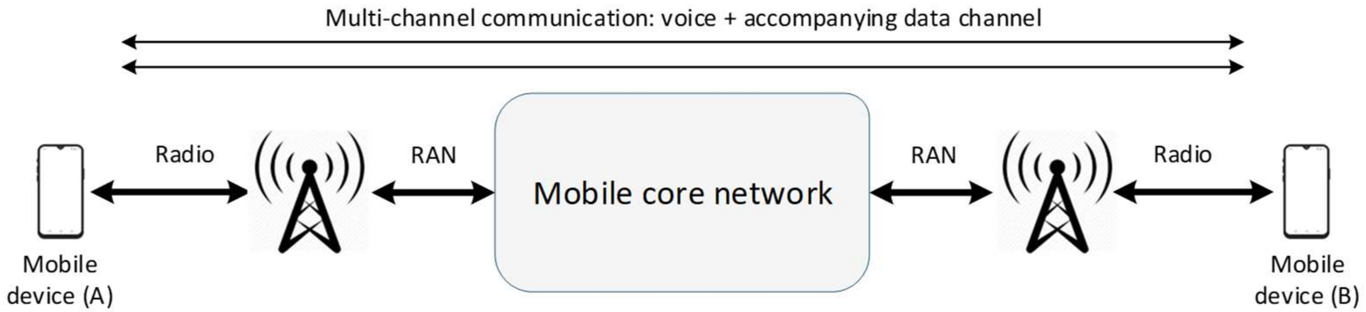
Enriched communication
Combining voice with data channel

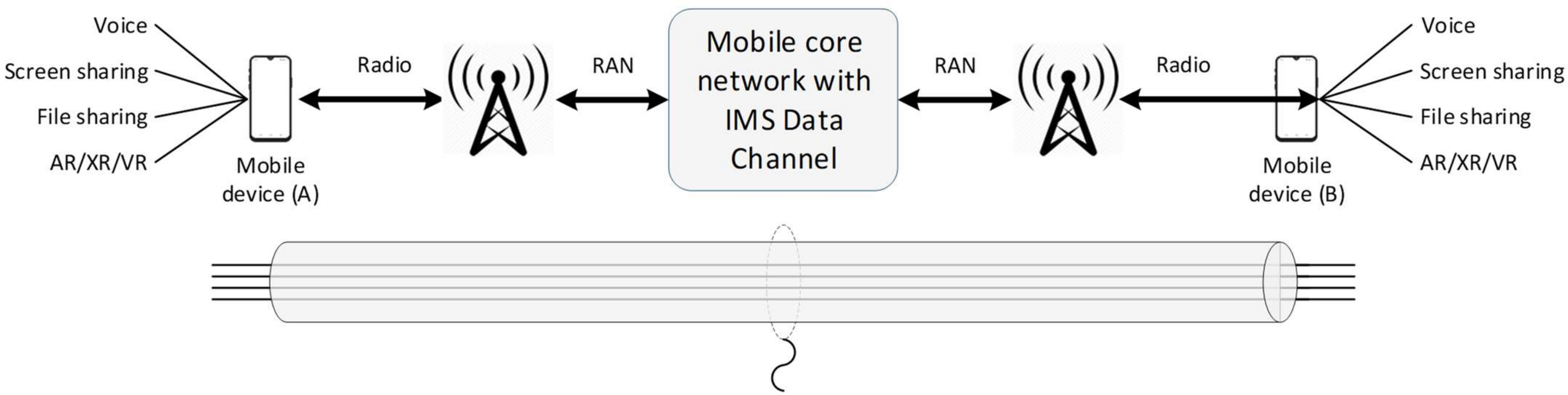
- Single-channel communication: voice
- Multi-channel communication: enriched communication
- Data channel established along with voice channel





Multifaceted communication

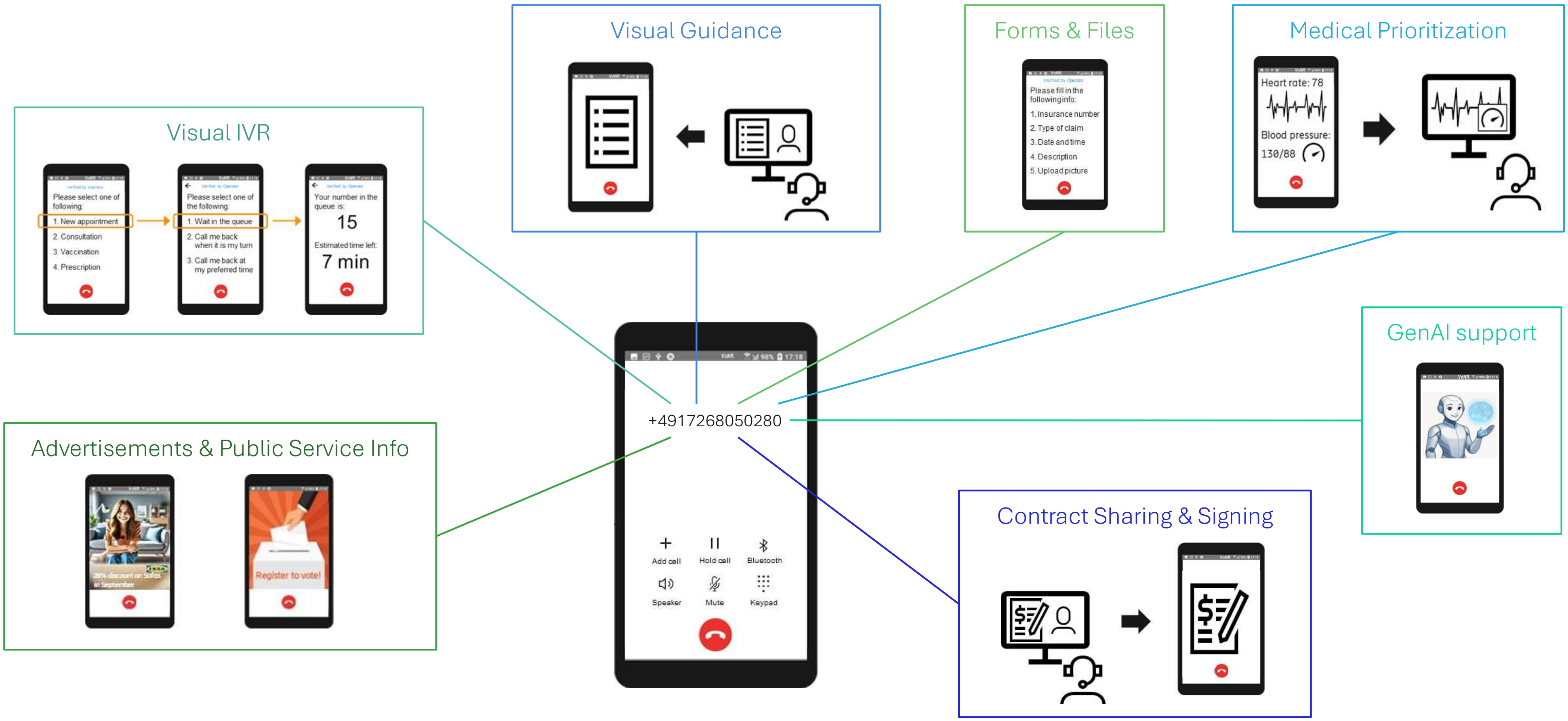
- Enterprise communication (B2B, B2C)
- Consumer application
- Parallel communication channels established end-to-end through RAN and core network, with differentiated transmission characteristics (QoS)



Multiple, parallel data connections

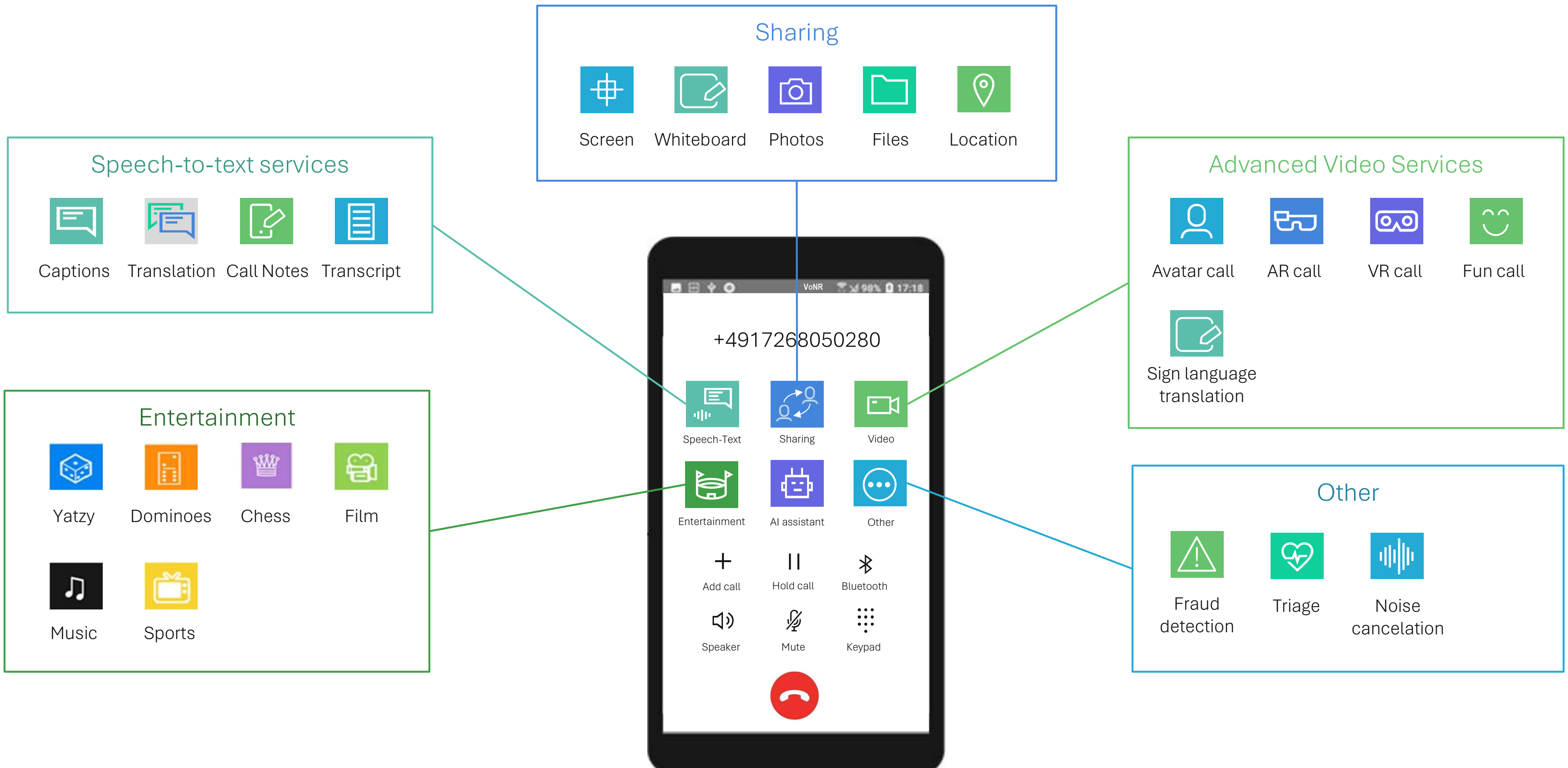
New calling cases for businesses

Use case examples



New calling cases for consumers

Use case examples



Reflection on enriched communication (with IMS data channel)

- Taking business-to-business, business-to-consumer and consumer-to-business communication to the next level
- Providing rich end-user experience
- Is IMS Data Channel based enriched communication better than Over-the-Top (OTT) service (Whatsapp, Signal etc.)?
  - from technology point of view yes
  - It's an operator service, so subject to regulation, security, privacy, safety

- IMS Data Channel may work alongside OTT applications

IMS: IP Multimedia Subsystem; 3GPP TS 24.229

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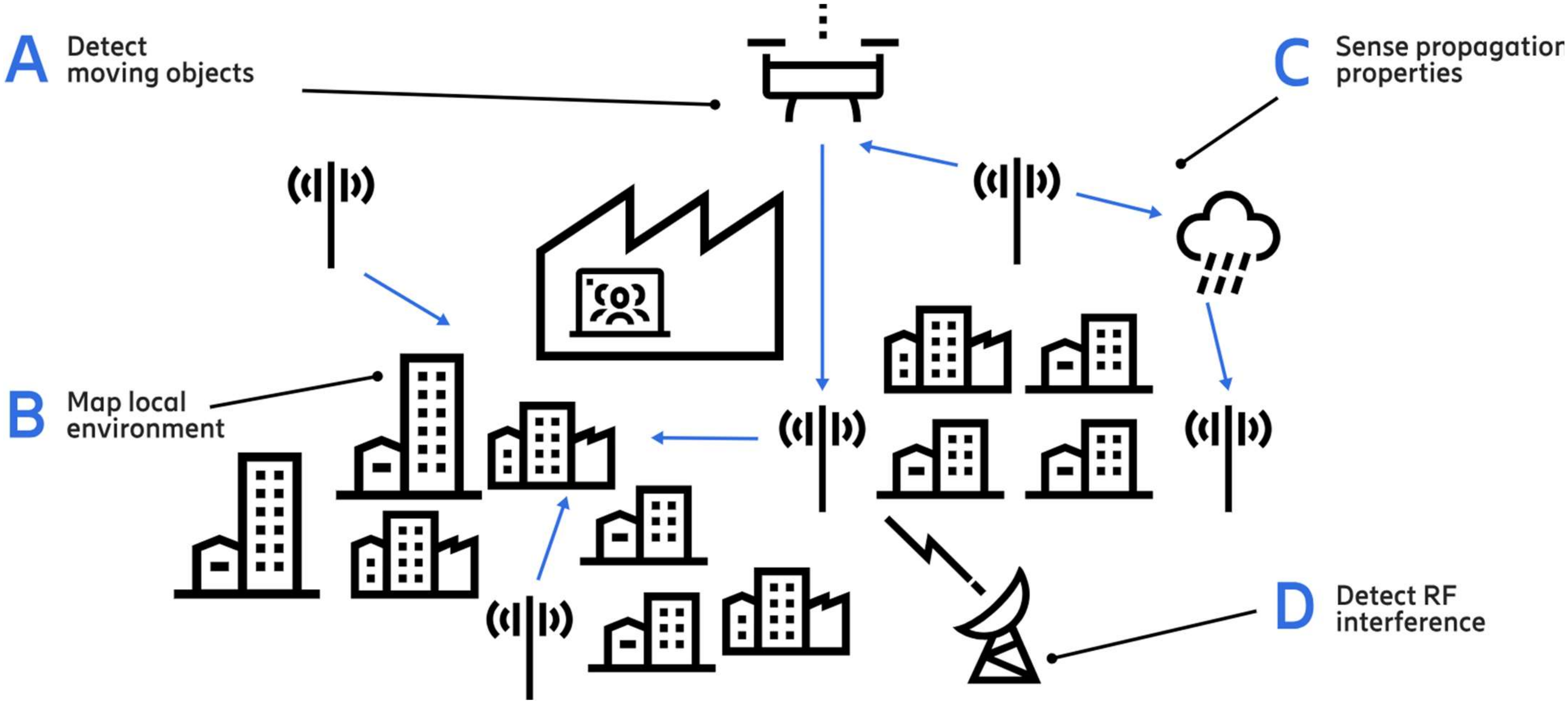
Integrated Sensing and Communication (ISAC)
(previously known as Joint Communication and Sensing, JCAS)

- One of the pillars of 6G!
- ISAC integrates sensing and spatial location of passive objects into the mobile communication network; in this manner, ISAC expands the network's functionality beyond communication
- ISAC integrates cellular mobile communication with RADAR
- Efficient usage of radio spectrum; the same spectrum is used for communication and sensing
- RADAR works at 72 GHz; ISAC can be used as low as 3.5 GHz (laboratory testing ongoing)

ISAC: a functional overview



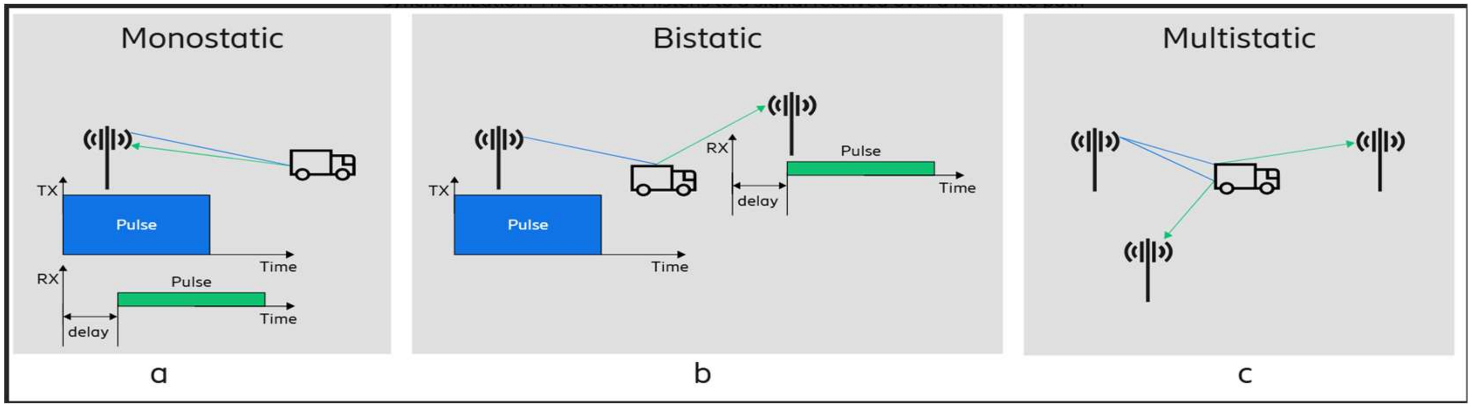
Topological options (not exhaustive)

Monostatic sensing systems use the same antenna for signal transmission and (reflected) signal reception

Bistatic sensing systems avoid self-interference by using different nodes as transmitters and receivers

Multistatic sensing systems combine multiple bistatic sensing links

Different topologies have different level of spectrum efficiency



Some (more) real-world examples

- Uncrewed Aerial Vehicle (UAV; drone) detection
- Autonomous driving, self-driving vehicles
- ISAC antenna mounted on vehicle or on UAV (object detection)
- Smart factory
- Vehicle detection at road junctions (eliminating the need for detection cables embedded in the road)

And some observations

- ISAC applies the M-MIMO principle: (narrow) radio signal beams in all directions
- An antenna that employs ISAC is probably applying more power on signal transmission (in order to get reflection from all objects in the 3D space)
- The waveform that is used must be optimized for dual functionality: communication and sensing
- And hence impact on mobile terminals
- Complex antenna design
- Legislation; protecting the data that is obtained through the sensing

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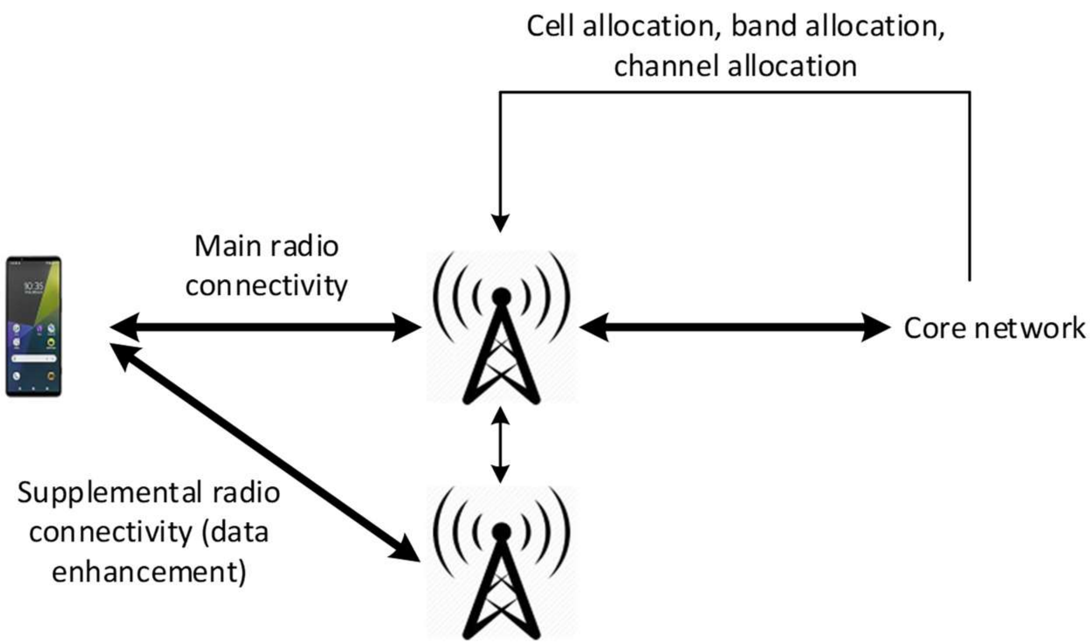
Cell-free networks?
Indeed!

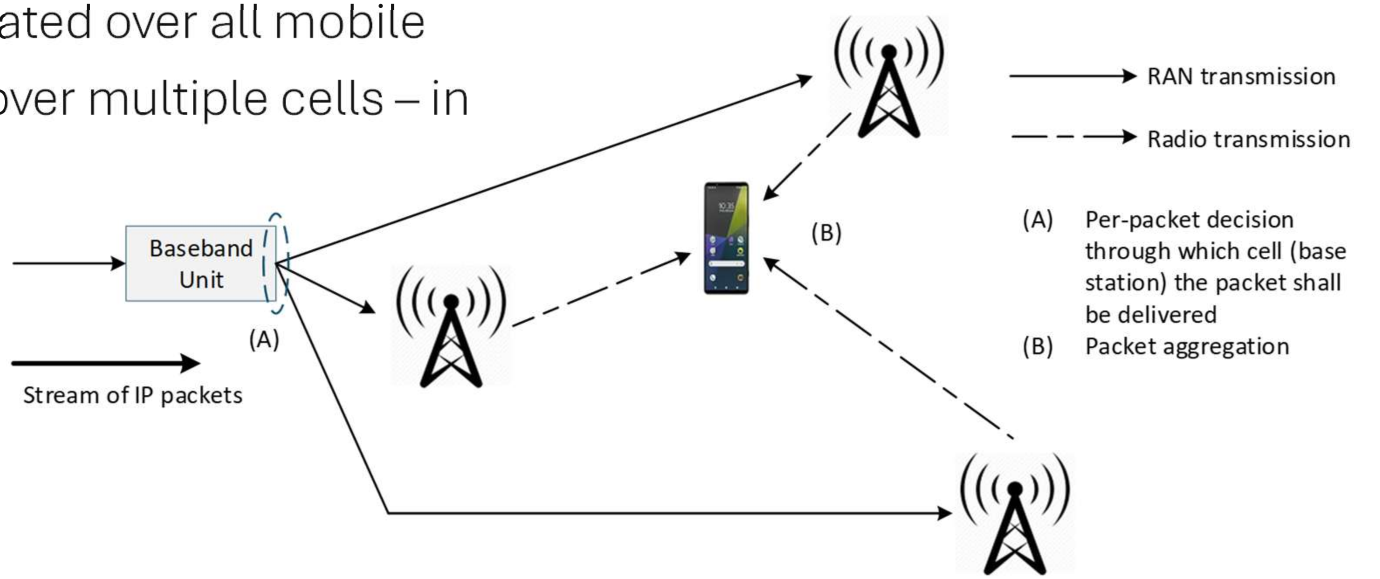
State of the art

- At any moment, a mobile device has radio connectivity to (i) one antenna for mobility & control plane and (ii) one or more antennas for data transmission
- The RAN is, under instruction from the core network, continuously determining to which antenna(s) a subscriber
- Continuous allocation of air space to users



New concept: Mobile terminal served by multiple antennas
Per-packet cell selection

- Rationale: increased spectrum efficiency
- Allocation of cell to mobile terminal, for data transmission, becomes a continuous function
- Transmission load aggregated over all mobile terminals can be shared over multiple cells – in geographic vicinity
- Combined with M-MIMO

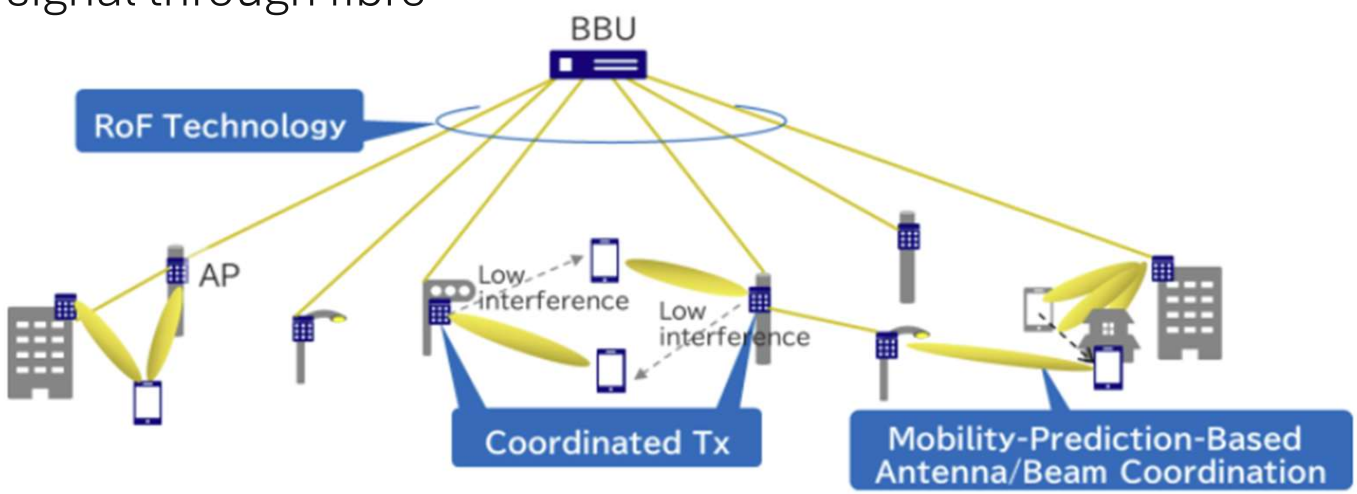


Why Cell-Free?

- Mobile terminal no longer bound to one cell - the geographic area becomes “the cell”
- Resilient connectivity
- Improved power efficiency
- Higher data throughput

Fundamental for Cell-Free: Radio over Fibre (RoF)

- Cell-Free M-MIMO requires large number of Base Stations (antennas)
- Accurate coordination needed between the cooperating Base Stations
- One Baseband Unit (BBU) can serve large number of Access Points (AP), by transmitting the radio signal through fibre
- APs can become low(er) cost devices



Muraoka, Shikida et al.

Evaluation on cell-free networks

- Cell-Free networks is a candidate technology for 6G
- Substantial research still needed
- High(er) proliferation of RAN infrastructure, with more complex RAN planning
- But promising capabilities – so worth the research!

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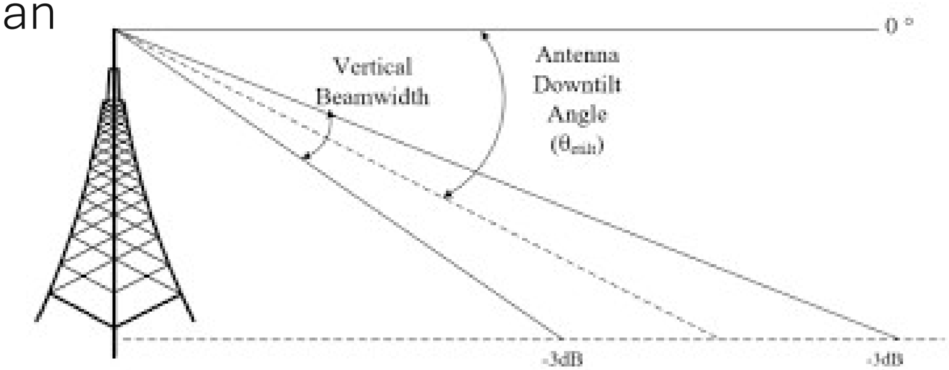
A fresh look at the RAN architecture

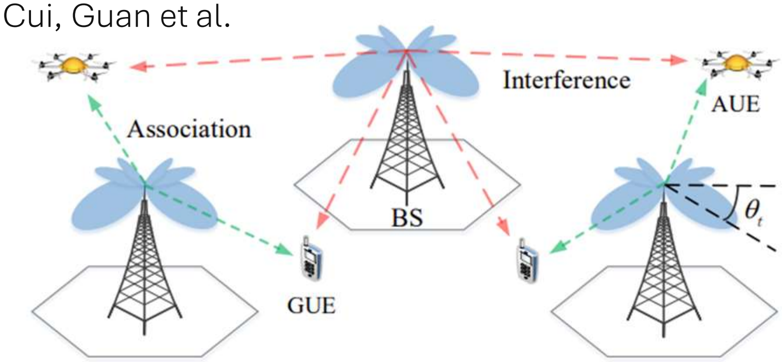
- RAN (GSM/GPRS) --> UTRAN (3G) --> E-UTRAN (4G)
- UTRAN = Universal Terrestrial Radio Access Network
- Antennas are generally <u>down-tilted</u>
- Radio coverage is required near ground level (i.e. terrestrial), serving people, devices, vehicles etc.
- For high-rise buildings, selected antennas can have horizontal reach or uptilt
  - In combination with in-building radio access (micro cells)



The landscape (or rather "airscape")

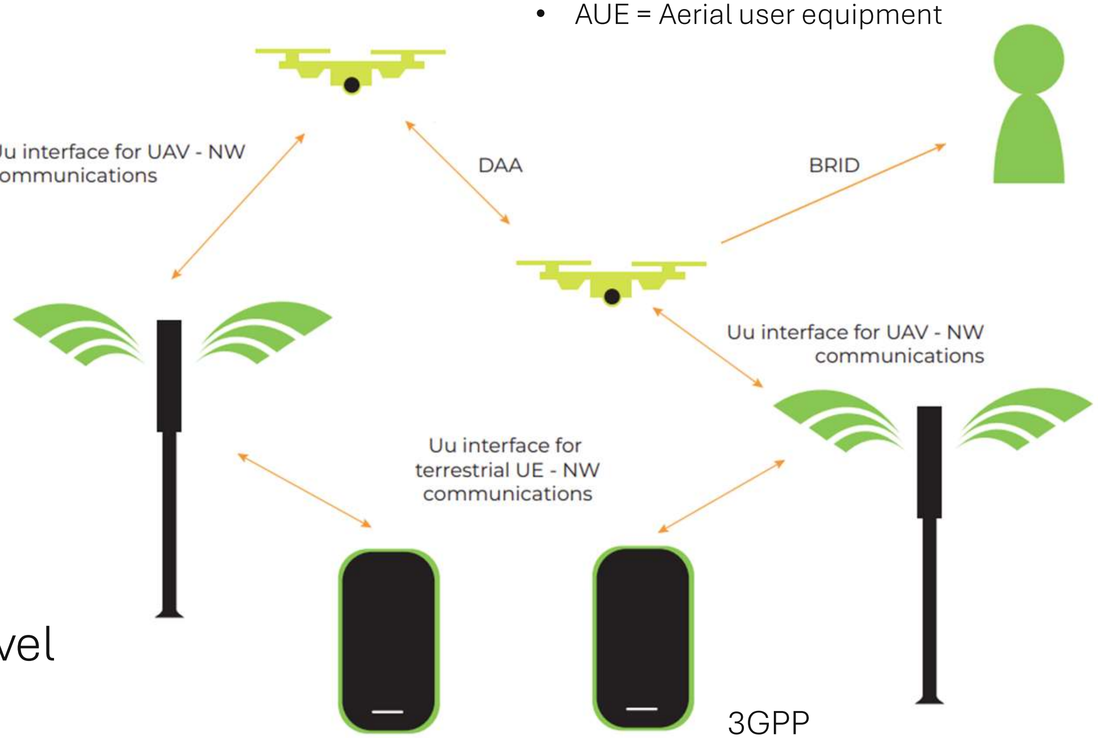
The challenge: using 3GPP mobile network for the "transport layer"

Cui, Guan et al.



- Transport layer: layer above earth surface for uncrewed aerial vehicles (UAV)
- UTRAN is not designed for providing "coverage" other than near ground level

- BRID = Broadcasting UAV ID
- GUE = Ground user equipment
- AUE = Aerial user equipment



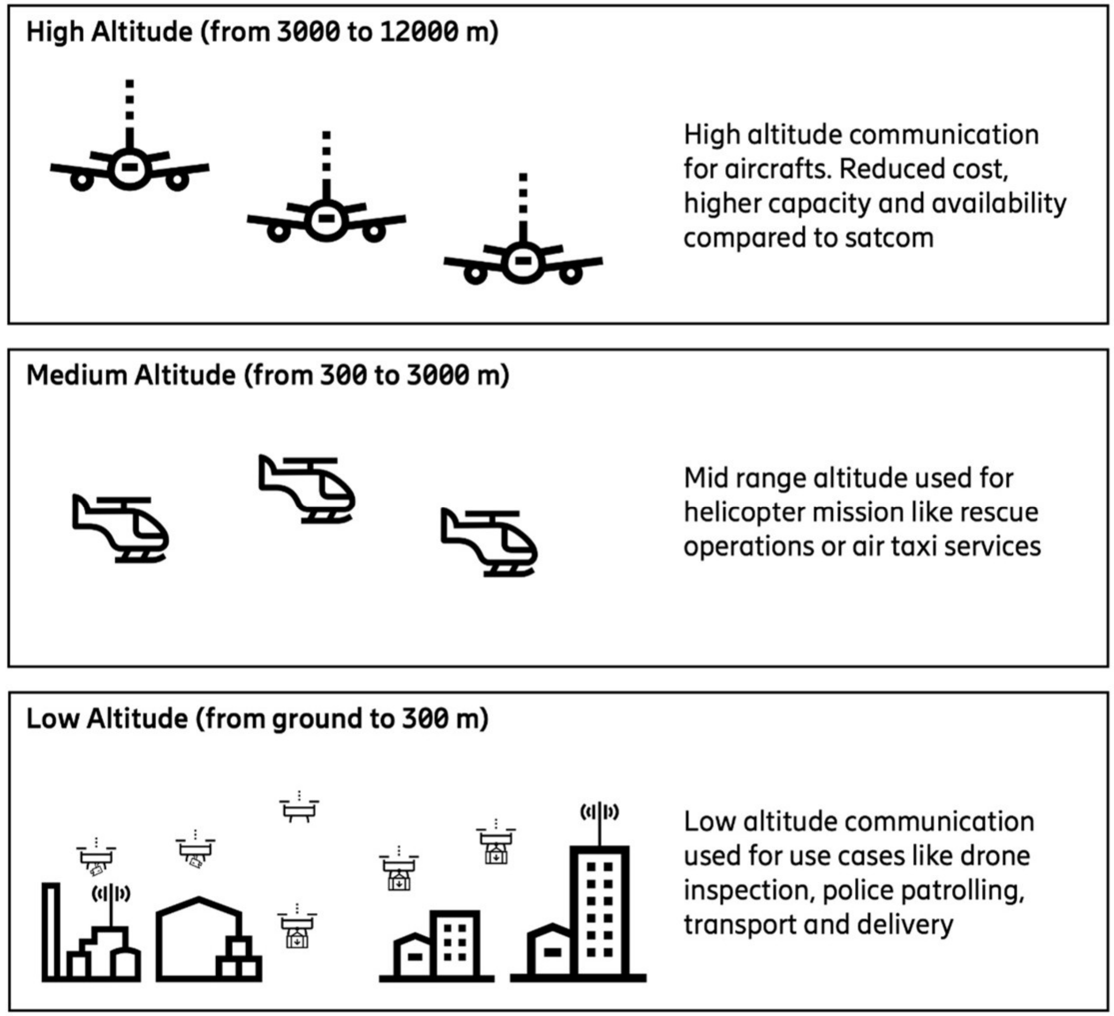
3GPP

Some challenges

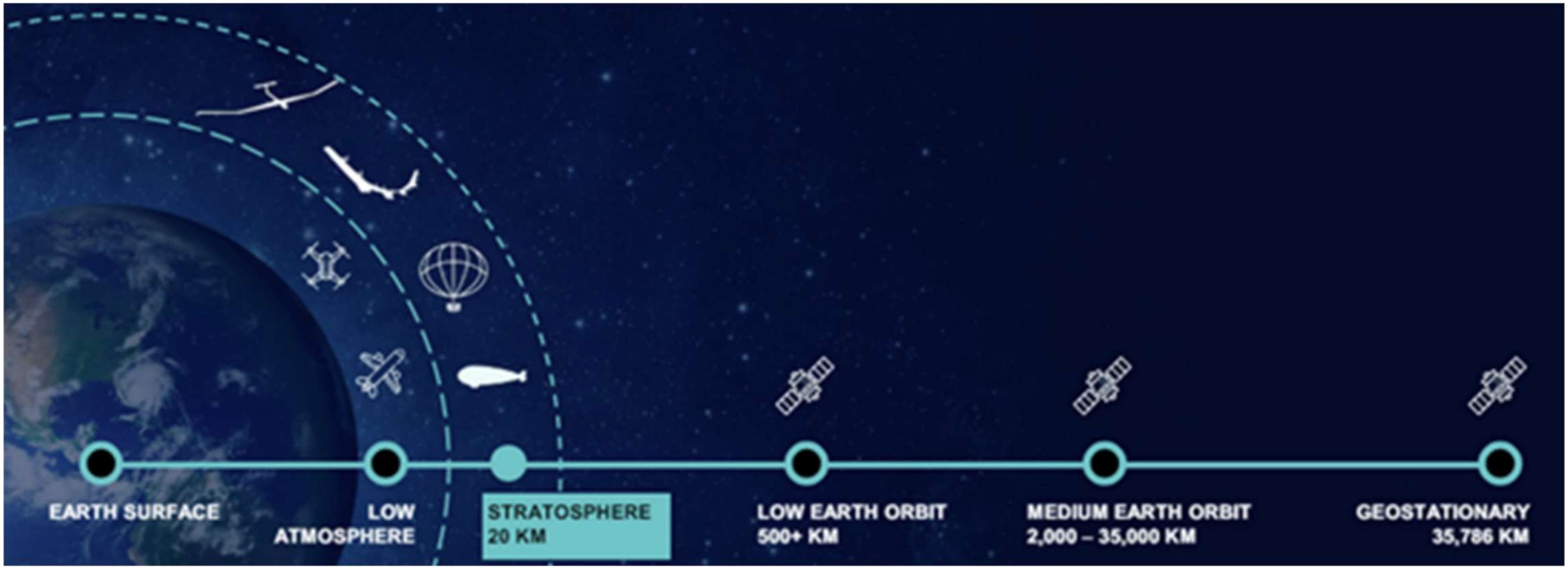
- Reaching UAVs at high(er) altitude would require “beaming into the air”
- Uptilted beaming at 4.2 GHz might cause interference with aircraft
- A device at high(er) altitude has Line of Sight (LoS) to a large number of base stations, including base stations at large distance from the device; the RAN is not intrinsically designed for these scenario’s

Digital Airspace

- Low altitude (< 300m)
  - Existing RAN *may* be used with some adjustments
- Medium altitude (300m – 3,000m)
  - High-rise antennas (up to 300m)
  - Dedicated RAN
  - Tested by Teracom, Sweden
- High altitude (3,000m – 12,000m)
  - Air-to-ground antennas



High-altitude platform systems (HAPS)
Communication enablement at 20km altitude



HAPS Alliance

HAPS in a nutshell

- Cell-tower in the air
- Bridging the gap between terrestrial RAN and Satellite communication
- Acting as cellular mobile network antenna, beaming towards earth surface
- Moving away from the traditional Mobile Network Operator (MNO) model; a HAPS may be operated by a private company, by a government, a regional / global communications services provider
- Using HAPS for UAVs might mitigate the observed dilemma of “random cell usage”
- Research on HAPS is ongoing!

Part II
General aspects of advanced mobile communication networks

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Frequencies in use in 5G mobile network
Frequency range group #1 (FR1)

- Ranging from band "n1“ to "n110“
- FR1 spans 450 MHz – 7.125 GHz
- Both FDD (Frequency division duplex) and TDD (Time division duplex) are used
- Asynchronous frequency budget: supplemental downlink (SDL) and supplemental uplink (SUL) for increasing data throughput in one direction
- Channel bandwidth between 5 MHz and 100 MHz
- Band n28 (700 MHz) and band n78 (3.5 GHz) commonly used in NL
- Next 5G FR1 spectrum to be auctioned in NL (no date set yet) is the n104 band, also known as “Upper 6G” (U6G) band, spanning 6.425 GHz – 7.125 GHz

Frequencies in use in 5G mobile network
Frequency range group #2 (FR2)

- Ranging from band "n257“ to "n263“; TDD only
- FR2 spans 24.25 GHz – 71.00 GHz
- Channel bandwidth between 5 MHz and 400 MHz, except for n263
- Channel bandwidth between 100 MHz and 2 GHz, for n263
- Designated to be used for high-speed, high-capacity and low-latency applications (including micro cells)
- Sometimes referred to as “mmWave” (although it’s strictly better to reserve the term “mmWave” for the frequency range 30 GHz - 300 GHz)
- Japan and USA are reported to have 5G FR2 operational

And frequency bands for 6G?
Frequency Range #3 (FR3)

- FR3 = 7.125 GHz to 24.25 GHz – nicely positioned between FR1 and FR2
  - Offering good balance between coverage and capacity
- FR3 currently more favoured for 6G than sub-Terahertz (90 GHz - 300 GHz)
- FR1 and FR2 may also be used for 6G

- A mix of frequency bands will be used:
  - Outdoor: predominantly FR1
  - Indoor, enterprise, industrial, transports, special applications: predominantly F2 and (potential) FR3

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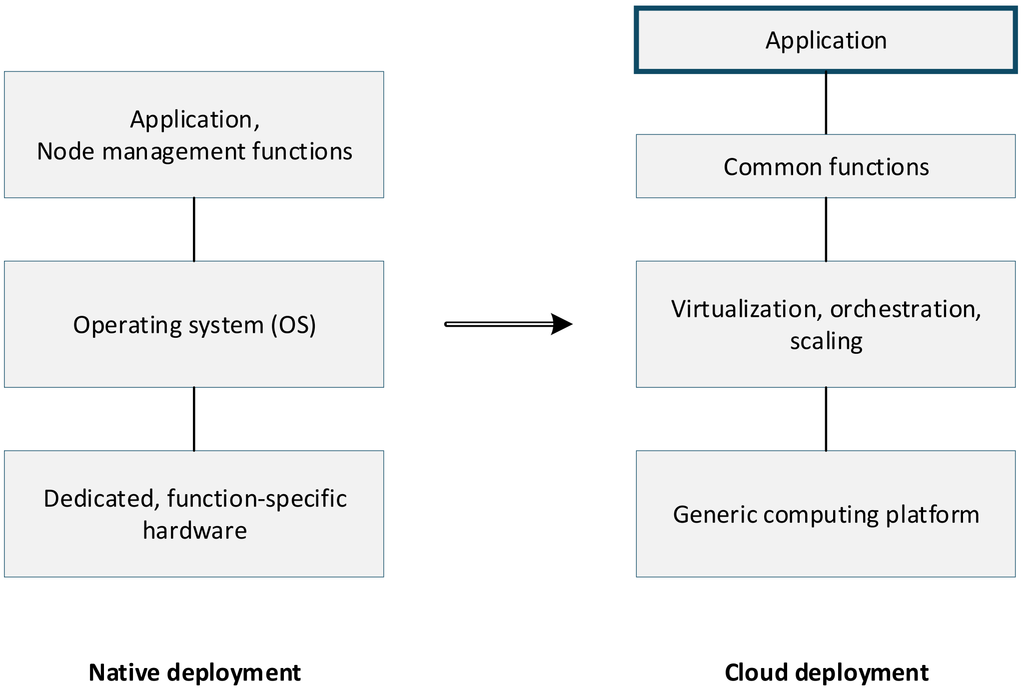
The cloud paradigm

Traditional deployment scenario for mobile networks

- Geographically distributed network functions (switch, location server, media gateway)
- Network functions deployed on dedicated hardware
- Rigid deployment and dimensioning

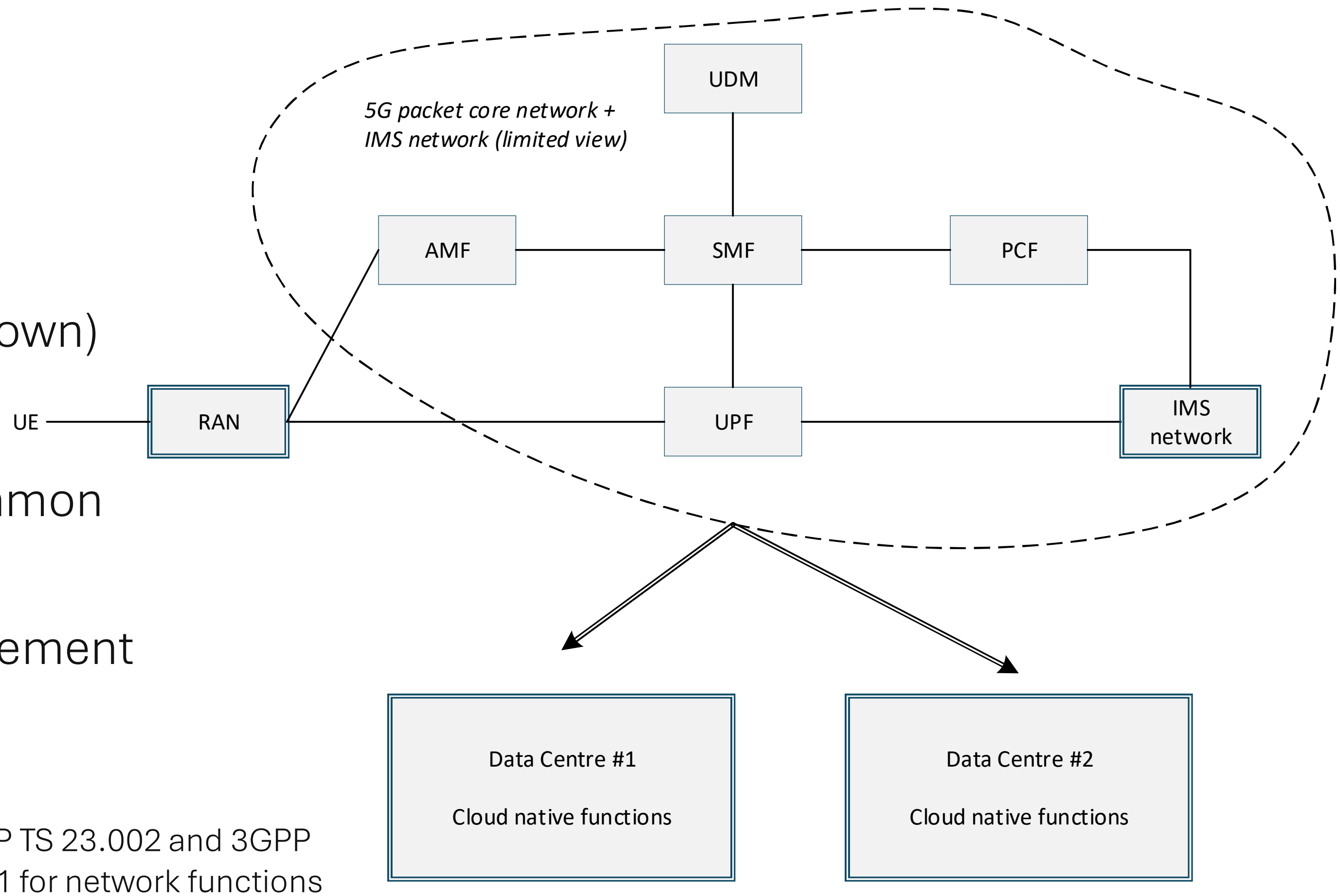
The cloud paradigm

- Network functions deployed on generic computing platform
- Network functions centrally located (data centres)
- Flexible deployment and dimensioning



Shifting mobile communication networks to the cloud

- Flexible and adaptive deployment of network functions
- Automated scaling (up, down) of network functions
- Common hardware, common execution environment, common network management

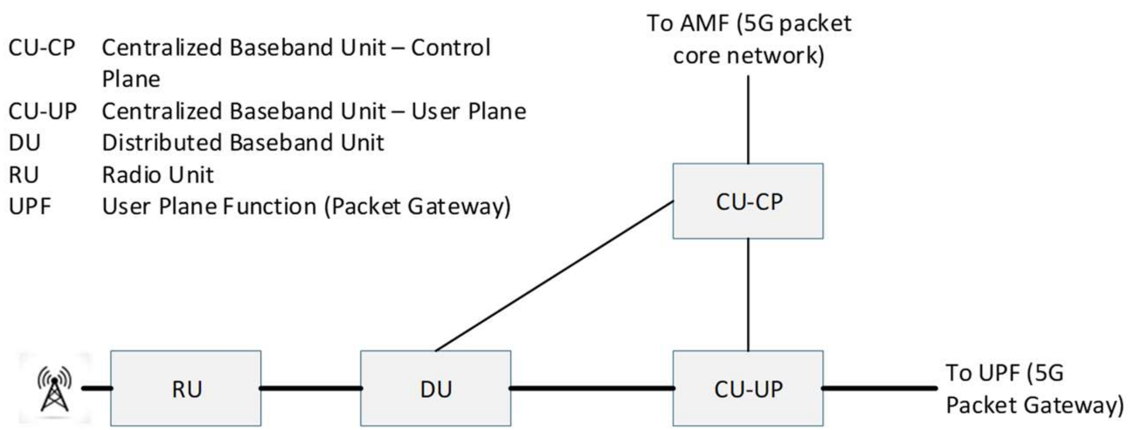


See 3GPP TS 23.002 and 3GPP TS 23.501 for network functions

Cloud deployment also for the RAN?

- Yes, RAN functional components will also be placed in the cloud
- Envisaged sequence of cloudifying the RAN

1) CU-UP – essentially control service logic
2) CU-UP – data transmission (data tunnel for mobile IP access)
3) DU – 3GPP RAN-specific functions
4) RU – not likely at the moment - very specialized and critical radio functions



Evaluation of cloudifying the RAN

- A RAN built on cloud principles benefits from the operational cost optimization that cloud deployment brings
- The envisaged 5G advanced and 6G network features, including AI-driven RAN, require high degree of adaptability in the RAN
- Cloudifying the CU-UP and the UPF (packet gateway) may provide synergies, especially in the context of edge computing and enterprise gateway (on-premises packet gateway)
- More on cloud RAN in the section on Open RAN (O-RAN)

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Envisaged use cases vs raw capacity

- Should we get excited about the “raw capacity claims” of 6G, such as
  - 10 to 100 times faster (data transmission speed to handheld mobile) than 5G; peak of 1 Tb/s
  - 100 - 1000 times lower data transmission latency compared to 5G; target 1μs
  - Spectrum above 100 GHz
  - A factor 10 - 100 more energy efficient compared to 5G
- More important are the possible (envisaged) use cases that can be accomplished
- This section provides an overview of envisaged use cases

Envisaged use cases and use case groups

- Smart factory: on-premises & inter-premises private communication (using licensed or unlicensed spectrum); high frequency (especially in-door)
- Fixed-wireless access: providing communication capability to remote areas (with satellite acting as complementing technology)
- Transportation: intelligent road transportation, railways
- Healthcare & wearables: wireless operation rooms, remote surgery, AI-supported Image guided therapy (IGT), remote patient monitoring
- Integration with Non-terrestrial networks (NTN): ubiquitous connectivity on ground level, medium altitude, low atmosphere, stratosphere

Envisaged use cases and use case groups (continued)

- Power networks: applying intelligent (centralized / distributed) control of *energy sources* (such as solar panels, wind turbines), *energy consumers* (such as car chargers, household equipment) and energy storage systems (such as batteries, electric cars) in order to optimize energy generation, energy transportation and energy storage
- AI-driven network operation: optimizing the effectiveness of the mobile communications network
- Critical communications: ensuring reliable (99.999 % aka "five nines") communication systems for emergency, disaster relief
- Remote learning: high-speed data access for remote locations
- Ad hoc networks: adapting the network topology / radio coverage as and when needed in designated locations (e.g. events that attract large number of people)

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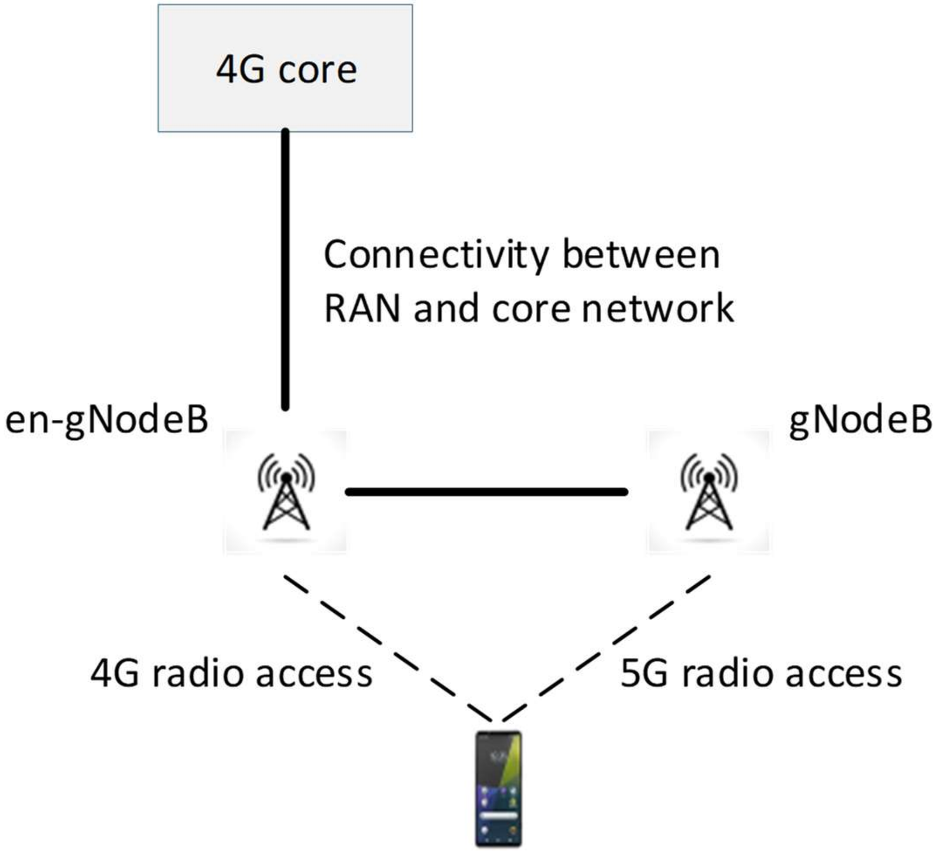
The journey from 4G to 5G to 6G
Introduction of the 5G network

- The 5G network is introduced in two stages:
  - Stage 1: 5G Non-Standalone (5G NSA): enhancing 4G core network + 4G radio access network with 5G radio access
  - Stage 2: 5G Standalone (5G SA): combination of 5G core network and 5G radio access network
- 5G NSA allows operators to introduce 5G radio capability without having to upgrade the core network to 5G
- Advanced 5G features require, however, 5G SA

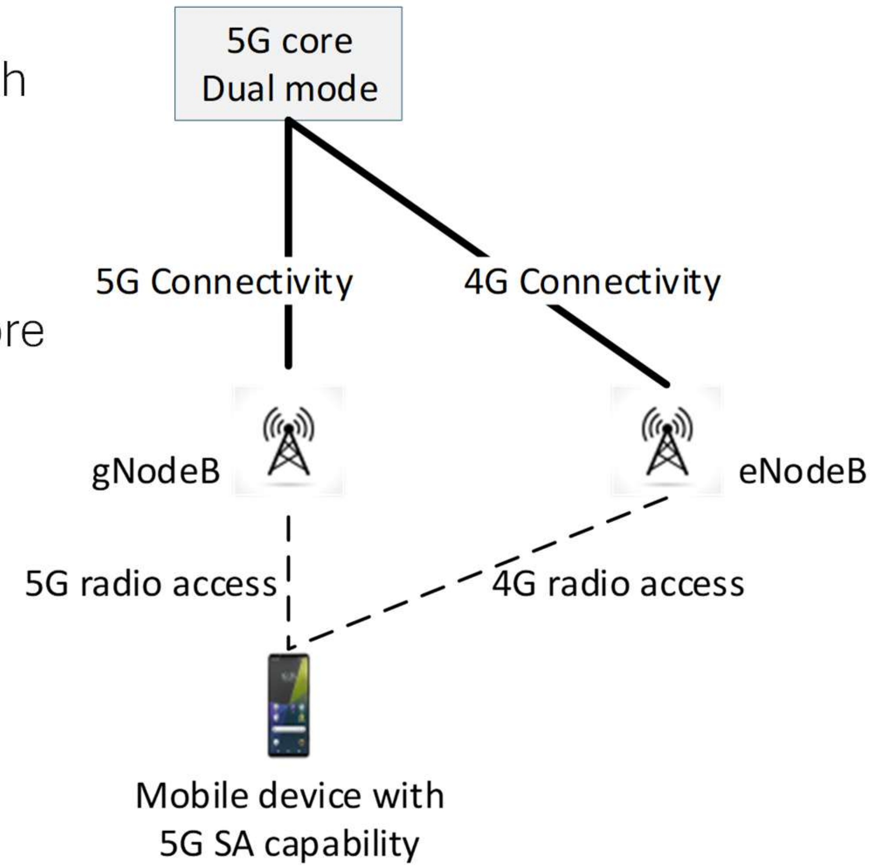
5G Non-Standalone

- 4G radio access (en-gNodeB) used for network access, authentication, mobility
- 4G radio access also used for data transmission
- 5G radio access (gNodeB) augments the 4G radio access; data connectivity uses 5G spectrum in combination with 4G spectrum
- Core network is 4G



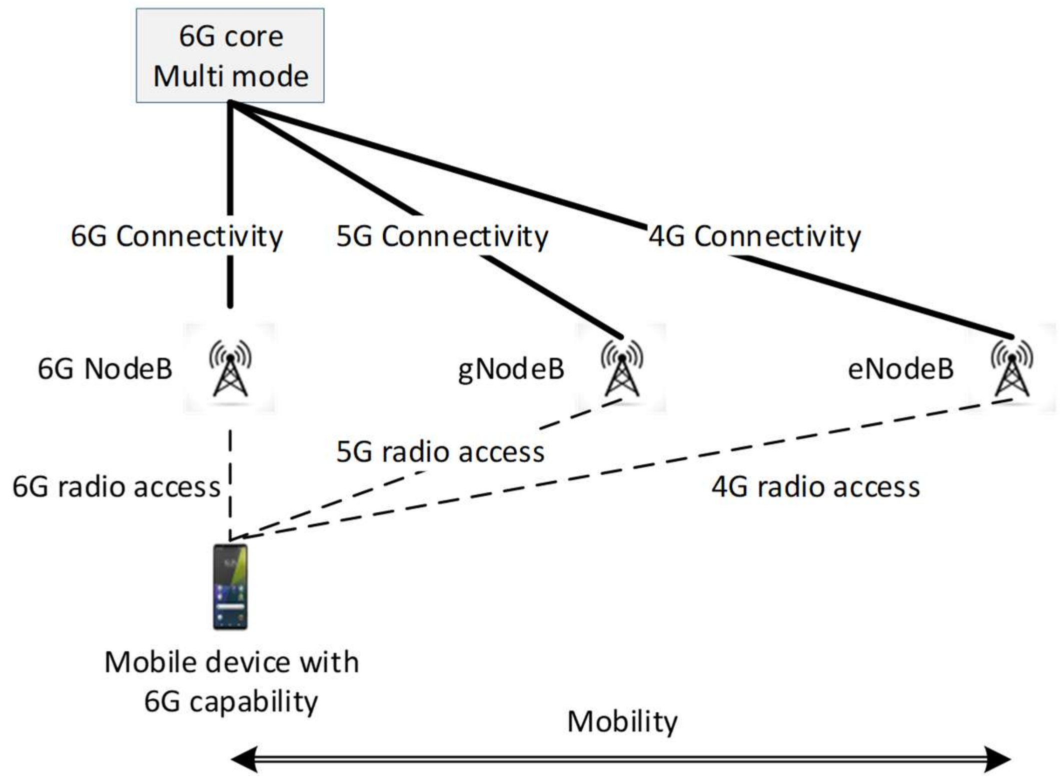
5G Standalone

- Mobile device attaches to 5G core network: both radio and core network are 5G
- Mobile device may do an access transfer to 4G radio; mobile device remains attached to 5G core
- Seamless mobility – data tunnel remains anchored in the 4G-5G dual mode packet gateway
- 5G SA is the target scenario for 5G deployment; access transfer to 4G when 5G access not available – preferably limited cases



What about 6G
Provisional - architecture not defined yet

- 6G Non-Standalone not foreseen - 6G data transmission shall be used in combination with 6G access & registration
- Access transfer to 5G and 4G may be implemented – the 6G core shall be “multi mode”, supporting 4G access, 5G access and 6G access
- 6G access in combination with 5G NSA undefined at the moment



A reflection on 6G introduction

- Backwards compatibility required; operators will (have to) continue to support 4G and 5G
- For industrial applications, 6G-only networks may be deployed (with mobile devices supporting 6G only)
- The 6G RAN architecture is largely undefined, but key findings from 4G network operation and 5G network operation will form guiding principles for the 6G RAN architecture definition
- Yet unknown whether 6G introduction will initially be in designated locations only, e.g. urban areas, or nation wide – this will depend, among others, on the envisaged use cases

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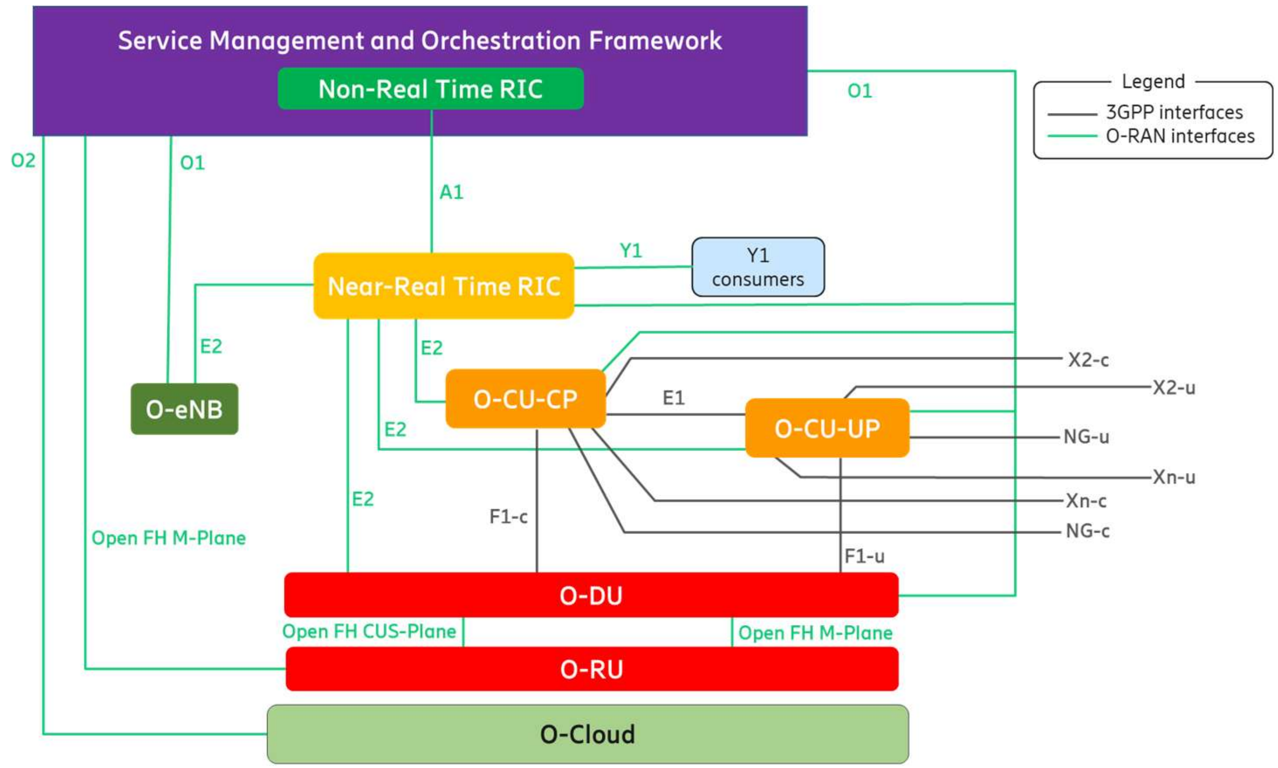
Open RAN (O-RAN)

- O-RAN is a new initiative on RAN definition
- O-RAN is defined by the O-RAN Alliance (https://www.o-ran.org/)
- O-RAN defines RAN architecture for:
  - Open intra-RAN interfaces
  - Application (“applet”) execution within the RAN
  - RAN operation exposure
- O-RAN defined functionality & capability that complements the 3GPP RAN

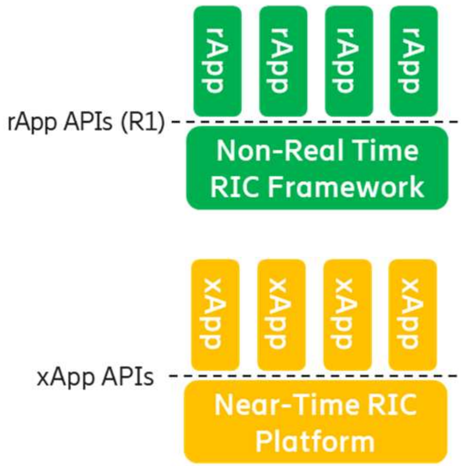
O-RAN architecture

- Essential components:
  - Near-Real Time RIC
  - Non-Real Time RIC
- RAN Intelligent Controller (RIC)
- Existing 3GPP RAN functions:
  - RU, DU, CU-UP, CU-CP (see previous slides)
- O-RAN is built on cloud principles



RAN Intelligent Controller

- Flexible service logic execution environment
- Non-Real Tim RIC:
  - rApps
  - > 1s latency
  - Interacting with O-RAN functions
- Near-Real Time RIC:
  - xApps
  - 10ms – 1s latency
  - Controlling CU and DU
  - Very close to fundamental radio processing



A reflection on O-RAN

- O-RAN is in early stage
- Real-Time RIC (xApps) may be difficult to realize
- Complex 6G use cases, e.g. ISAC and distributed MIMO, may require or benefit from Non-Real Time RIC
- O-RAN, and especially the RIC, may be a necessary component for AI-driven RAN

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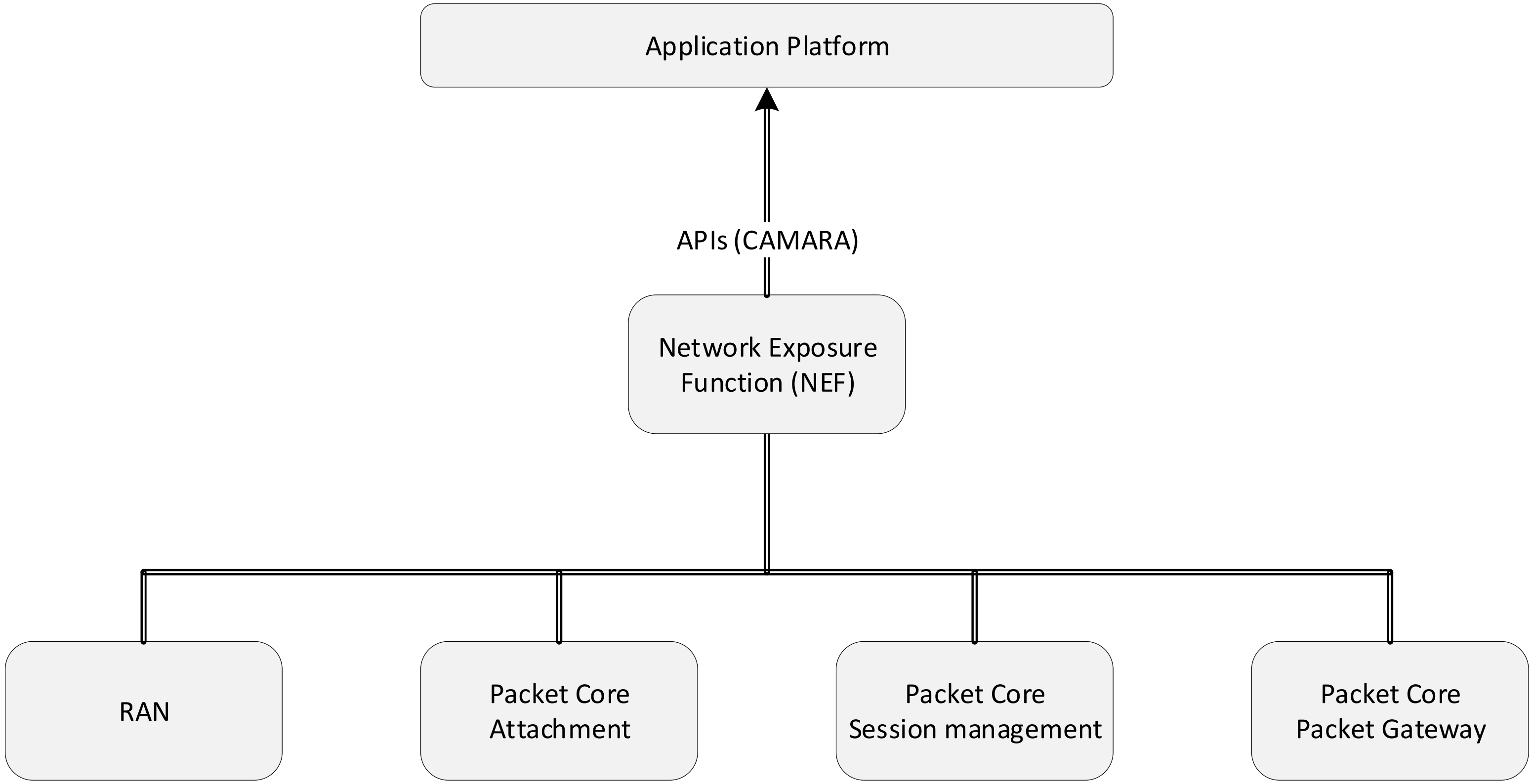
Exposing network capability

Exploiting the capability of the mobile communications network

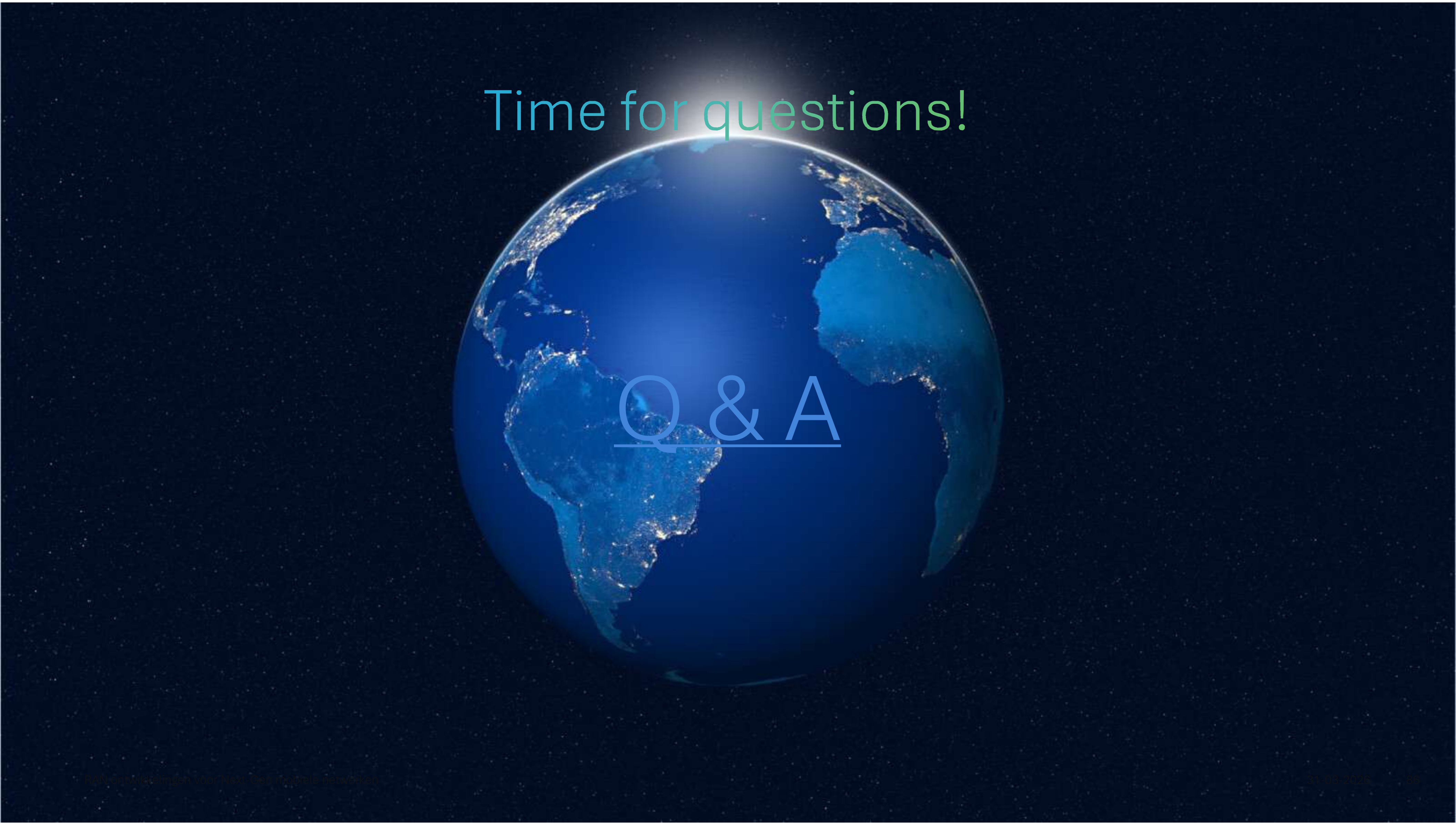


Capability exposure

- Network functions in the 3GPP communications network, including RAN and Packet Core, may exposure capability to external applications
- Capability exposure is governed by the Network Exposure Function (NEF)
- NEF has functional connection with the various core network functions and exposes capability
- Capability exposure APIs are defined by CAMARA
- CAMARA aims to hide "tele complexity“
- An operator may deploy applications (on the application platform) that utilize network capability

Exposure from the RAN?

- RAN capability exposure envisaged to be done through the O-RAN framework
- The Near-realtime RIC and the Non-Realtime RIC collect operational information and provide the information to external application (through a platform like NEF)


Time for questions!
Q & A