SVEUČILIŠTE U ZAGREBU

Fakultet elektrotehnike i računarstva

Master Programme

Computing

Advanced Architectures of Telecommunication Networks

Lecture 10: 5G Mobility Management.

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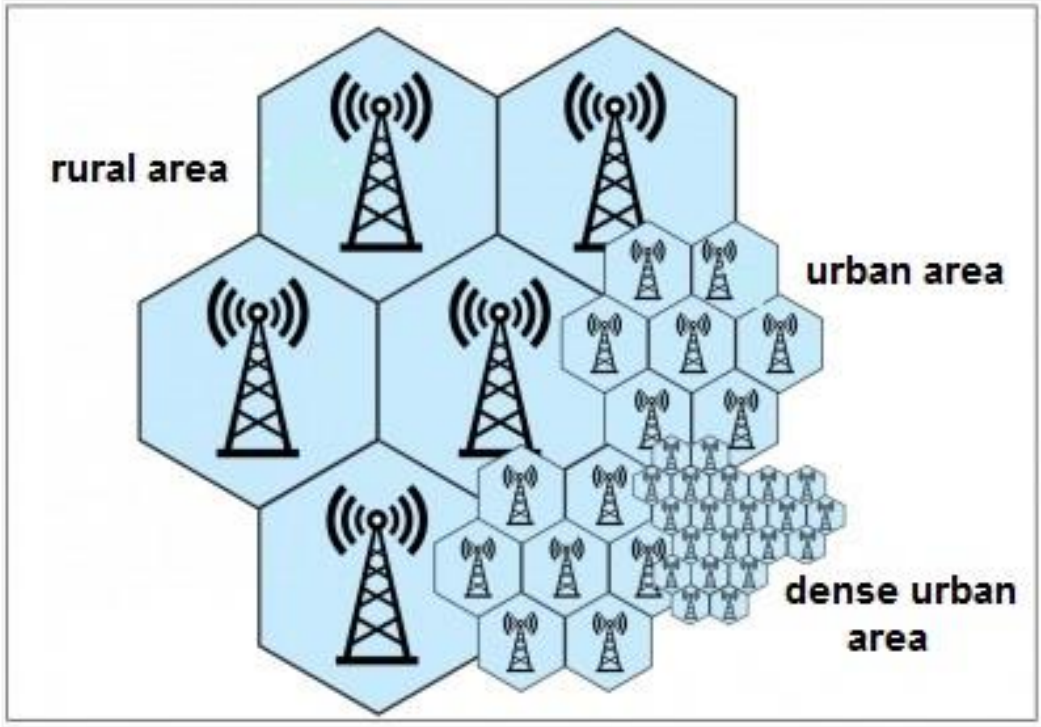
Outline

- Mobile network fundamentals
- Connecting the 5G RAN and 5G Core
- Mobility Management procedures
  - Network discovery and selection
  - Registration and Mobility
  - Reachability

Mobile network fundamentals

Radio networks

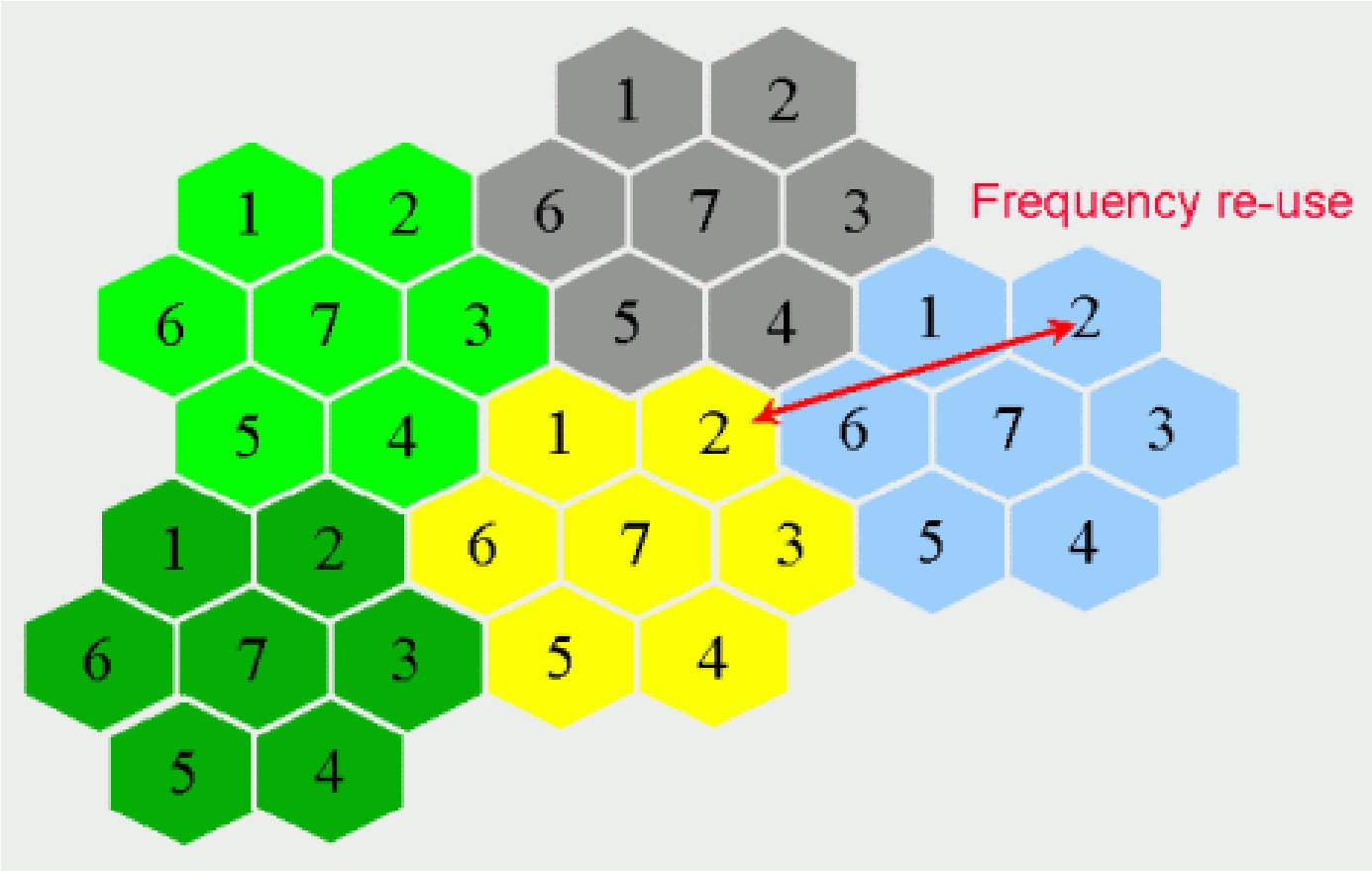
The radio network part of mobile networks (cellular networks) consists of several radio base stations, each serving wireless transmission and reception of digital information in one or several “cells”



- Cells can range in size from tens and hundreds of meters to tens of kilometers
  - size and the outline of the cell are controlled by various factors: base station and terminal power levels, antenna configurations, frequency bands (radio signals using lower frequencies normally propagate over longer distances than those using higher frequencies if the same power level is used.)
  - the environment has a significant effect on the cell size: smaller cells in case of buildings, mountains, hills, or forests as compared to a surrounding area that is fairly flat and mostly uninhabited

Frequency re-use

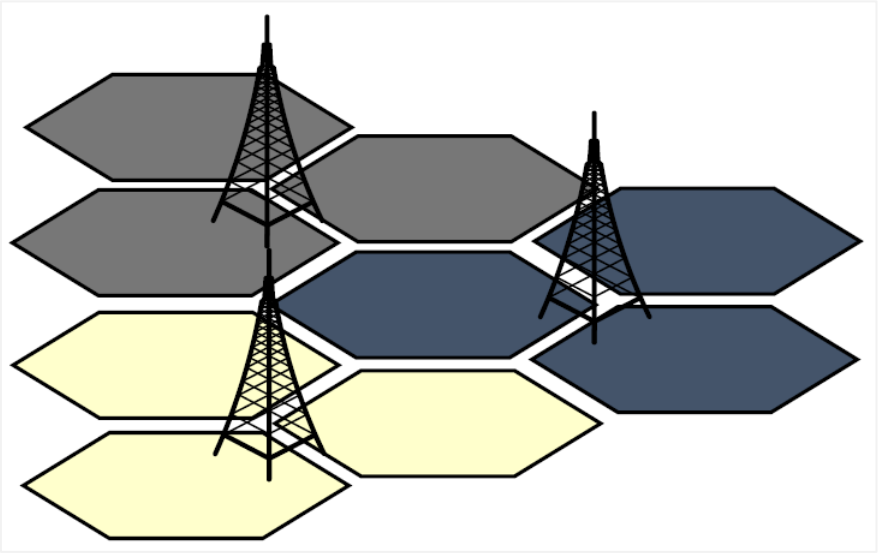
Example: the total amount of frequencies is divided in 7 sets of frequencies. Each set is used in another cell. The cluster of 7 cells is repeated to cover the complete geographic area



source: https://www.telecomabc.com/c/cellular.html

Base station positioning

- one base station can serve multiple cells (depends on antenna configuration and planning)
- The same frequencies can be used in multiple cells, as long as there is no interference



- Base stations: located at sites carefully selected to optimize the overall capacity and coverage of the mobile services.
  - In areas where many users are present (e.g., city center), base station sites are located more closely to each other → more (but smaller) cells
  - Less populated areas (e.g., countryside) → cells are normally made larger to cover a large area with as few base stations as possible

Key principles of Mobility Management

Main goal: keep track of the UE as it moves among cells

1. Ensure that the network can “reach” the user, for example to notify the user about incoming messages and calls

2. Ensure that a user can initiate communication toward other users or services such as Internet access

3. Ensure that connectivity and ongoing sessions can be maintained as the user moves, within or between access technologies.

Mobility Management

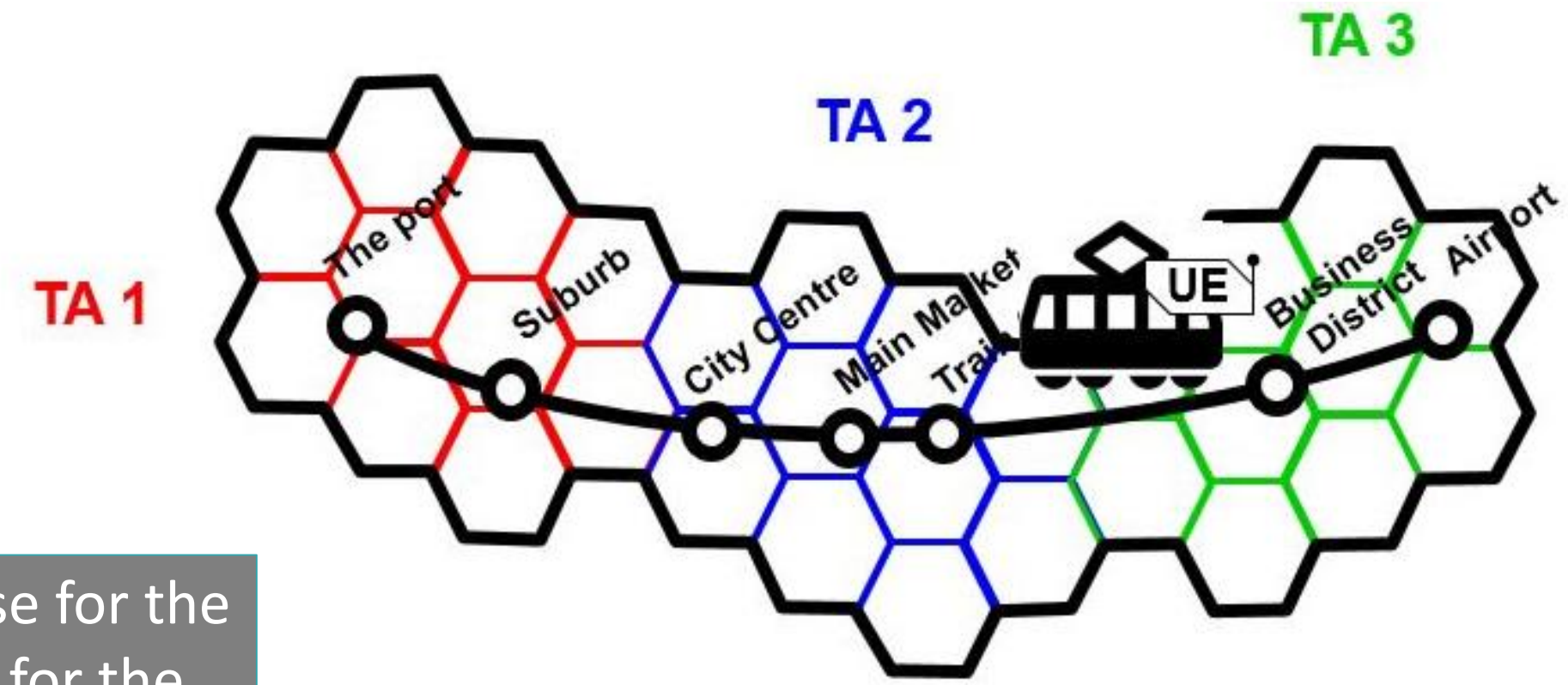
- a UE initially attaches to the network via a registration procedure and may move among cells
- UEs are tracked while connected to the network - when the user moves, the call must be transferred from one base station to another (**handover**).
- It is not practical to keep track of a UE in idle mode every time it moves between different cells (would cause too much signaling!) nor to search for a UE across the entire network for every terminating event (e.g. an incoming call).
- Cells are therefore grouped together into **Tracking Areas (TA)**, and one or more Tracking Areas may be assigned to the UE as a **Registration Area (RA).**

Tracking Area (TA) and Registration Area (RA)

- **Tracking Area:** a collection of radio cells that together cover a larger geographical area
- **Registration Area:** a set of Tracking Areas, specifically grouped for a particular UE.
- If a UE moves within its Registration Area, it does not have to perform an update
- when a UE needs to be paged, the paging message will be sent out in all the cells of the Registration Area
  - As long as the UE moves within its limits, it will not need to perform any mobility updates to the 5G Core Network – this can mean a considerable saving on the signalling resources that otherwise would need to be used!

Tracking Area (TA) and Registration Area (RA)

Registration Area: a UE-specific list of Tracking Areas reflecting its mobility pattern



Example: RA comprised of TA1 + TA2 + TA3

RA is used as a base for the network to search for the UE and for the UE to report its location!

source: https://apistraining.com/tracking-area-5g/

Tracking Area (TA) and Registration Area (RA)

- a UE will only perform a mobility update signalling procedure when it leaves its RA
- when re-selecting to a cell outside its current RA, a UE sends a "*Registration Request*" message → Registration Type parameter set to "Mobility Update".
- UEs used for human communication (smartphones, tablets, laptops, etc) will predominantly have Registration Areas set to one Tracking Area, as Mobility Patterns of people tend to be quite random, but devices moving along pre-defined routes (e.g., sensor on a tram) will probably end up with personalized Registration Areas.

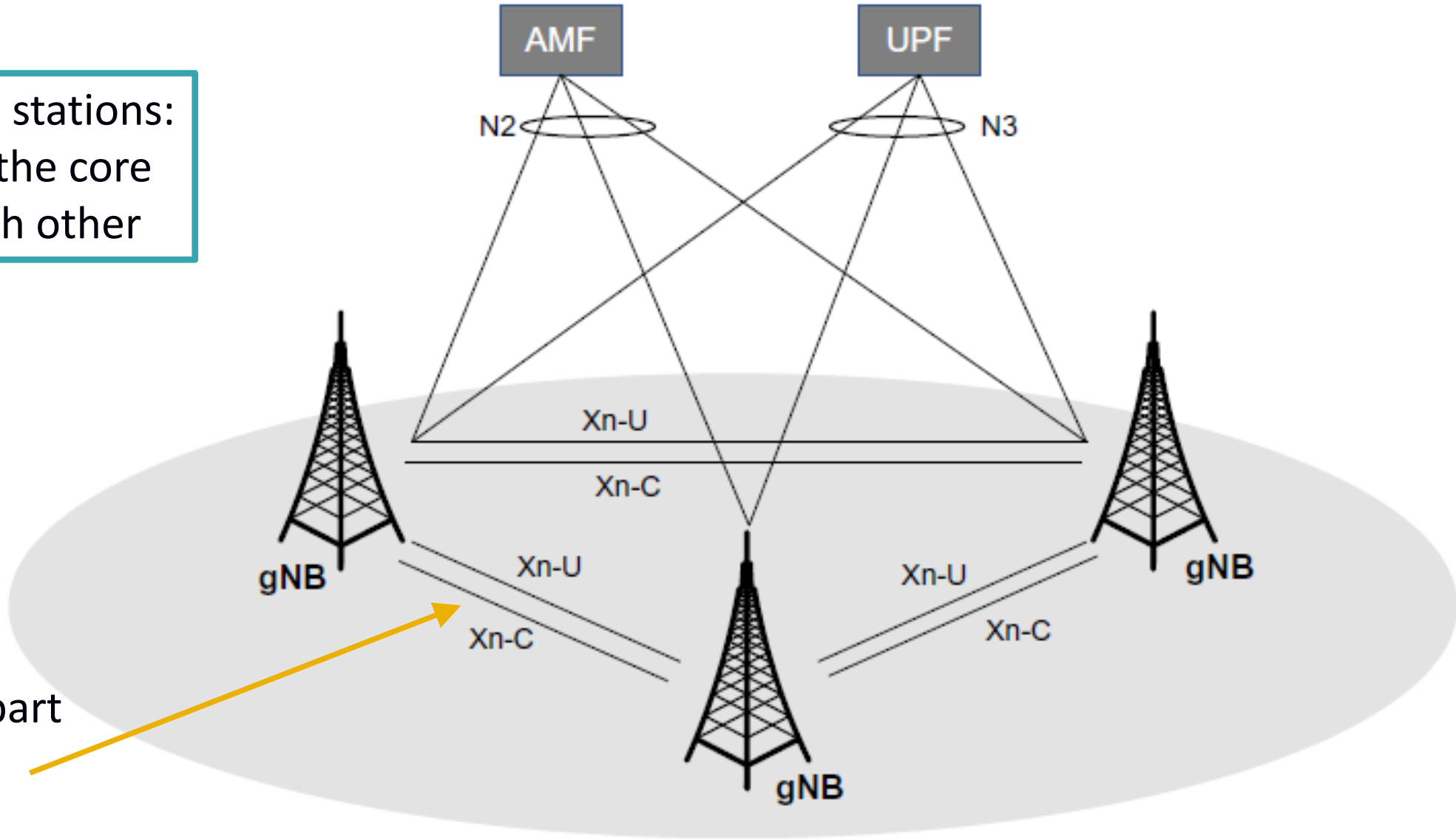
Connecting the 5G RAN and 5G Core

5G Access Network (*reminder*)

- 5G Radio Access Network (5G-RAN) or Next Generation RAN (NG-RAN) or New Radio (NR)
- An NG-RAN node is either:
  - a gNB, for NR radio access, or
  - an ng-eNB, for LTE radio access

5G radio network architecture

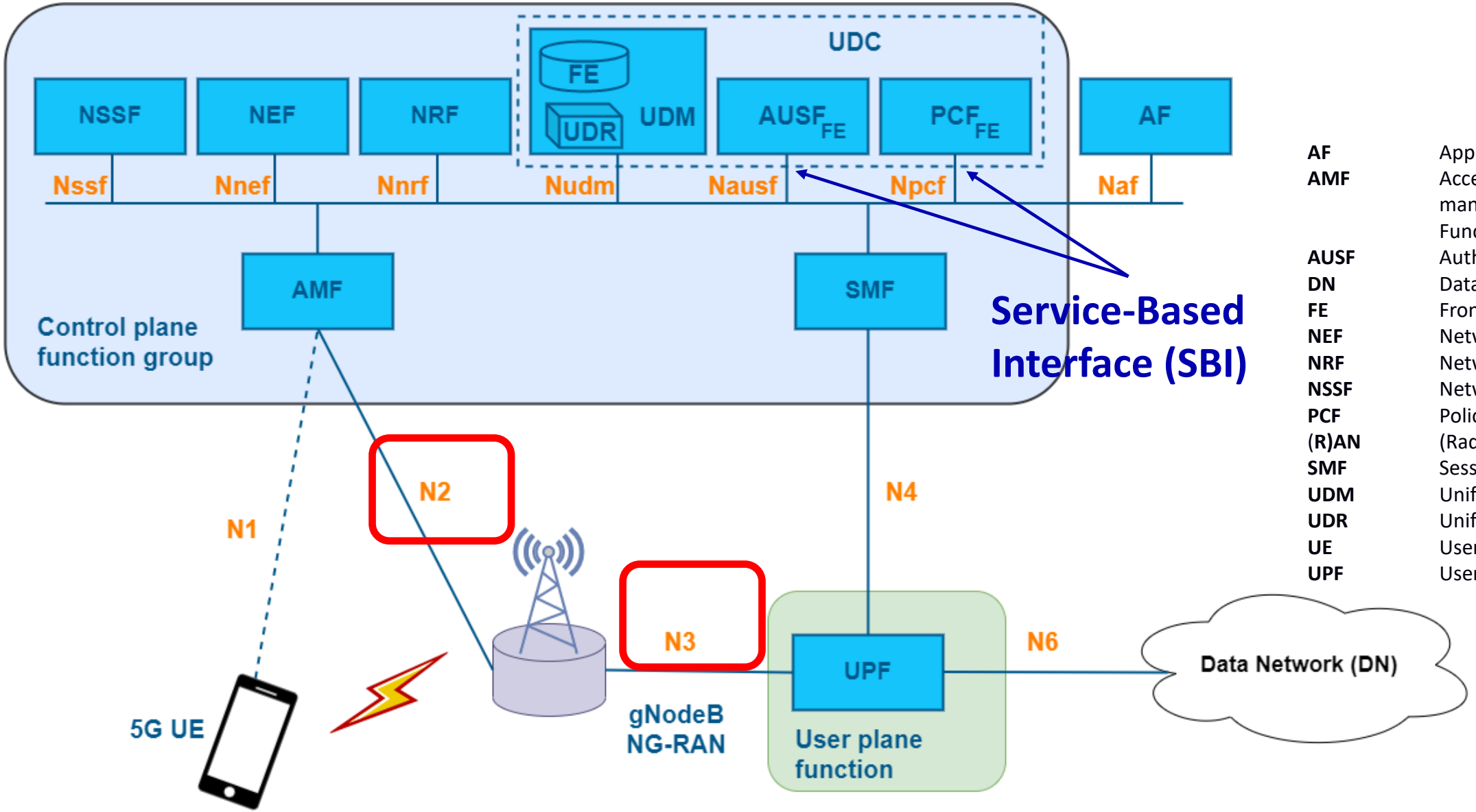
Multiple radio base stations: connected both to the core network and to each other



Base stations communicate via a signaling interface part (Xn-C) and a data transfer part (Xn-U)

source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

5G Service-Based Architecture (SBA) (*reminder*)



AF	Application Function
AMF	Access and Mobility management Function
AUSF	Authentication Server Function
DN	Data Network
FE	Front End
NEF	Network Exposure Function
NRF	Network Repository Function
NSSF	Network Slice Selection Function
PCF	Policy Control Function
(R)AN	(Radio) Access Network
SMF	Session Management Function
UDM	Unified Data Management
UDR	Unified Data Repository
UE	User Equipment
UPF	User Plane Function

AMF (Access and Mobility Management Function)

- interacts with the radio network (N2 interface) and end user devices (N1 interface) through signaling
- interacts with other NFs via service-based interfaces
- involved in most signaling flows in the 5G network
- signaling connection towards devices:
  - supports device registration and authentication (via the Authentication Server Function, AUSF)
  - enables devices to move between different radio cells in the network
  - supports reaching and activating devices that are in idle mode

AMF (Access and Mobility Management Function)

- AMF does NOT handle session management, but forwards all session management-related signaling messages between the devices and the SMF (Session Management Function)
  - SMF: manages the end user (or actually *device*) sessions. This includes establishment, modification and release of individual sessions, and allocation of IP addresses per session → **refer back to Lecture 10!**

SMF (Session Management Function)

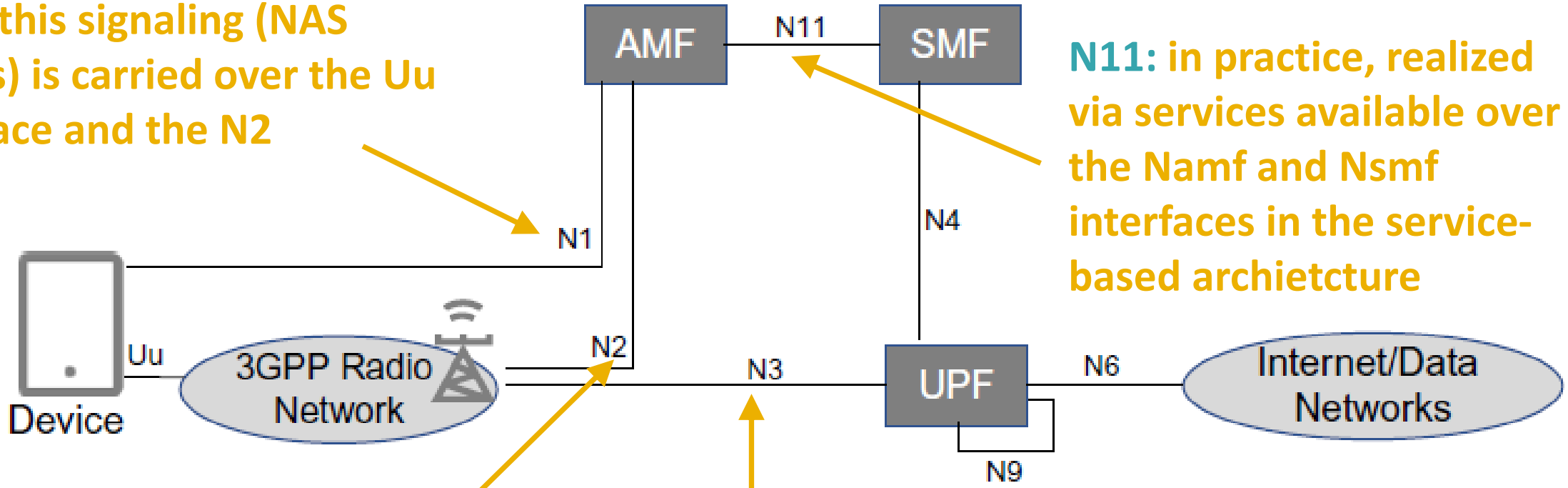
- establishment, modification and release of individual sessions, and allocation of IP addresses per session
- selects and controls the different UPF (User Plane Functions) in the network over the **N4 network interface**.
  - includes configuration of the traffic steering and traffic enforcement in the UPF for individual sessions - provides Quality-of-Service parameter values to the UPF for QoS enforcement of data flows, for example limitations of available data rate
  - controls charging functionality (based on traffic usage reports generated by the UPF)

UPF (User Plane Function)

- IP anchor point for data sessions
- connects to external IP networks
- performs packet routing/forwarding and packet inspection
- enforces policy rules and QoS (bitrate enforcement, redirection)
- reports traffic usage (important for charging!)

Connecting the 5G RAN and 5G Core

N1 is only a logical interface – in practice, this signaling (NAS messages) is carried over the Uu air interface and the N2 interface



N11: in practice, realized via services available over the Namf and Nsmf interfaces in the service-based archietcture

N2 signling is based on the NGAP protocol (*NG Application Protocol*)

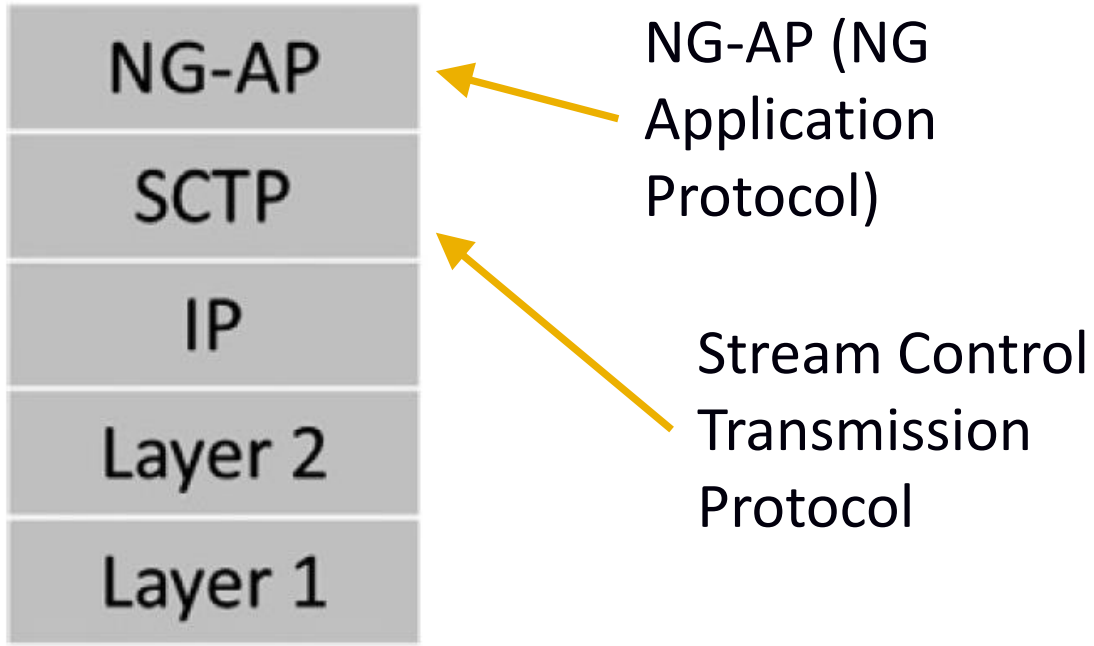
N3 data transfer based on the GTP-U protocol

source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

Key interfaces between 5G RAN and 5G core

N2 interface:

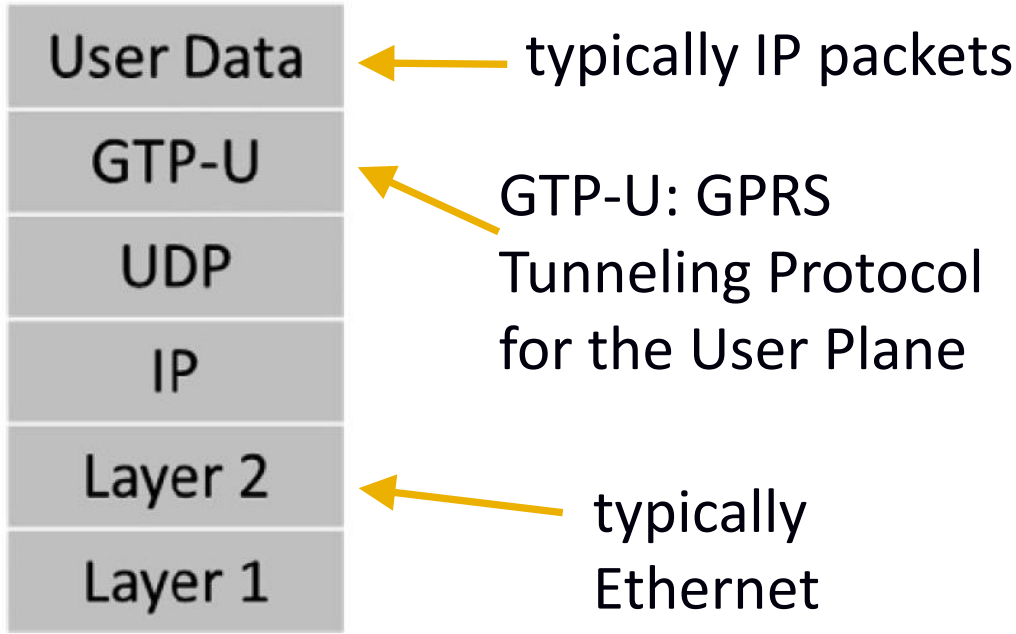
between AMF and 5G RAN
(**SIGNALING**)



(note: same protocol stack also used between base stations)

N3 interface:

between 5G RAN and UPF
(**DATA**)



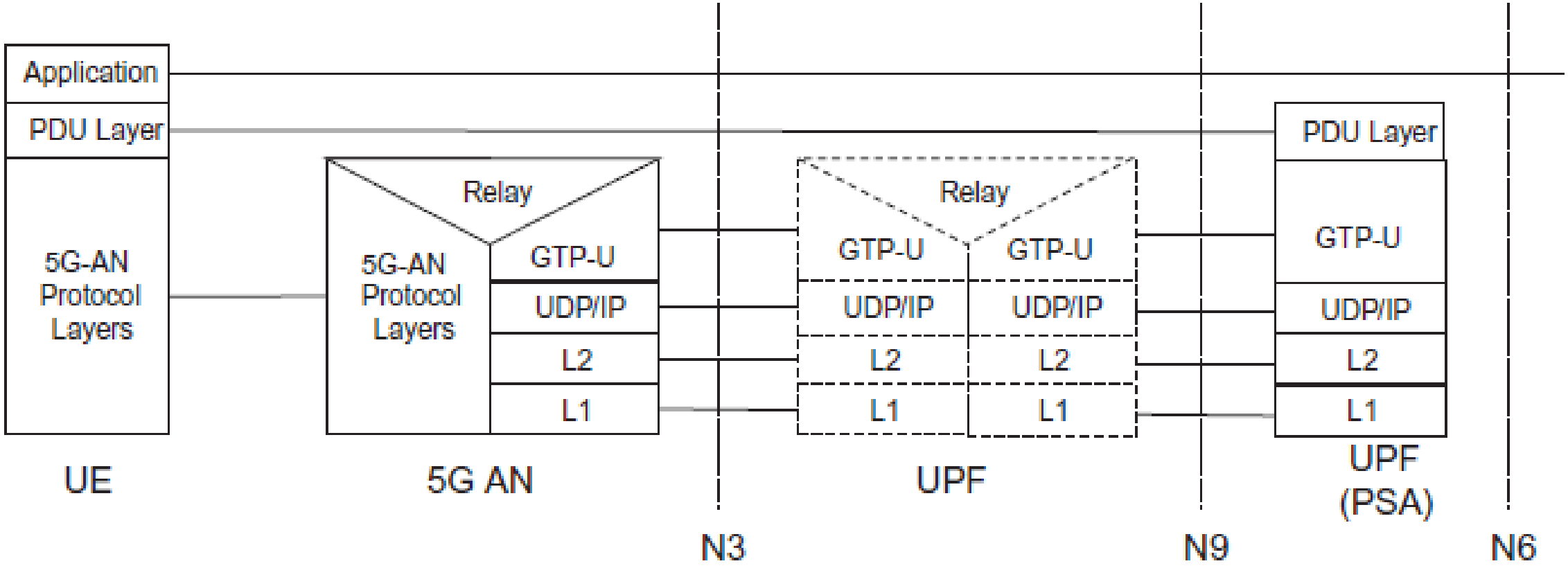
Connecting the 5G RAN and 5G Core: N2 signaling interface

Signaling procedures supported over N2:

- N2 interface configuration
- Signaling for a specific UE/device
  - forwarding of messages between the device and the core network → based on the NAS protocol ("Non-Access Stratum"). Individual NAS messages are either managed by the AMF or the SMF.
  - signaling related to modification of stored data for a specific device → referred to as the **UE context**
  - signaling related to management of events such as handovers between radio cells or access networks and paging of devices that are in idle mode.

source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

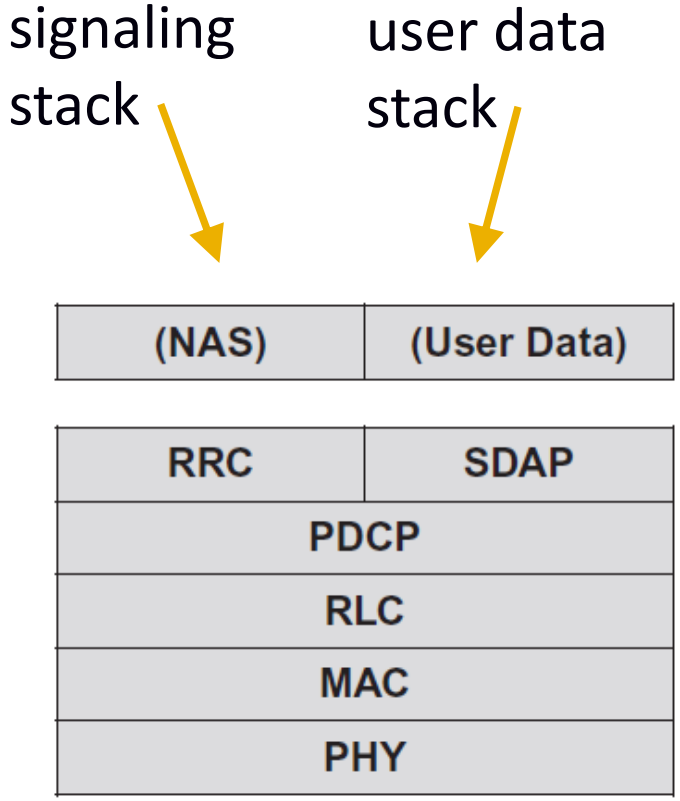
Connecting the 5G RAN and 5G Core: User Plane protocol stack



source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

Air interface between devices and base stations

- **PHY**: physical layer (actual radio transmission using OFDM modulation)
- **MAC** (Medium Access Control layer): layer 2 transport
- **RLC** (Radio Link Control): can provide a reliable transport for selected transmissions
- **PDCP** (Packet Data Convergence Protocol): provides encryption
- **RRC** (Radio Resource Control): broadcasting of system information, delivery of encryption keys, mobility signaling, management of radio bearers, paging of terminals who are in idle mode. (also transparently carries NAS signaling between the Core Network and the devices → N1 interface)
- **SDAP** (Service Data Adaptation Protocol): carries packets



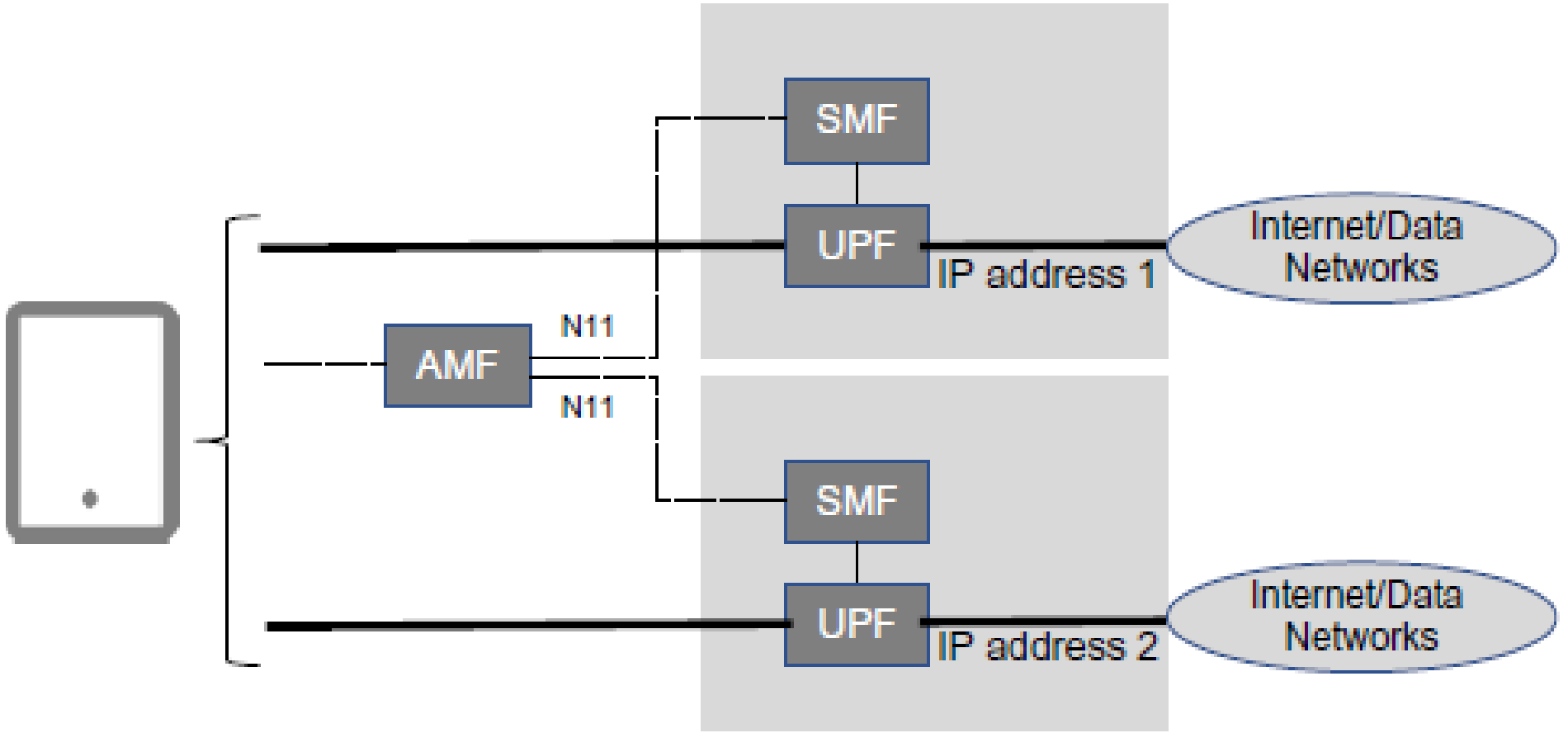
Connecting the 5G RAN and 5G Core – Key concepts

- one gNB (5G radio base station) can be connected to multiple AMFs → supports load balansing, network slicing
- each UE device is always associated with a single AMF
- one device can be utilizing data sessions managed by more than one SMF
  - allows for simultaneous connections to multiple logical networks with different treatment, policies, and rules for routing of user data (more in the next lecture – Network slicing!)

source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

Example: multiple service connections from one UE

Example: one device served by a single AMF, but has sessions established with two SMFs, each with its own UPF (User Plane Function).

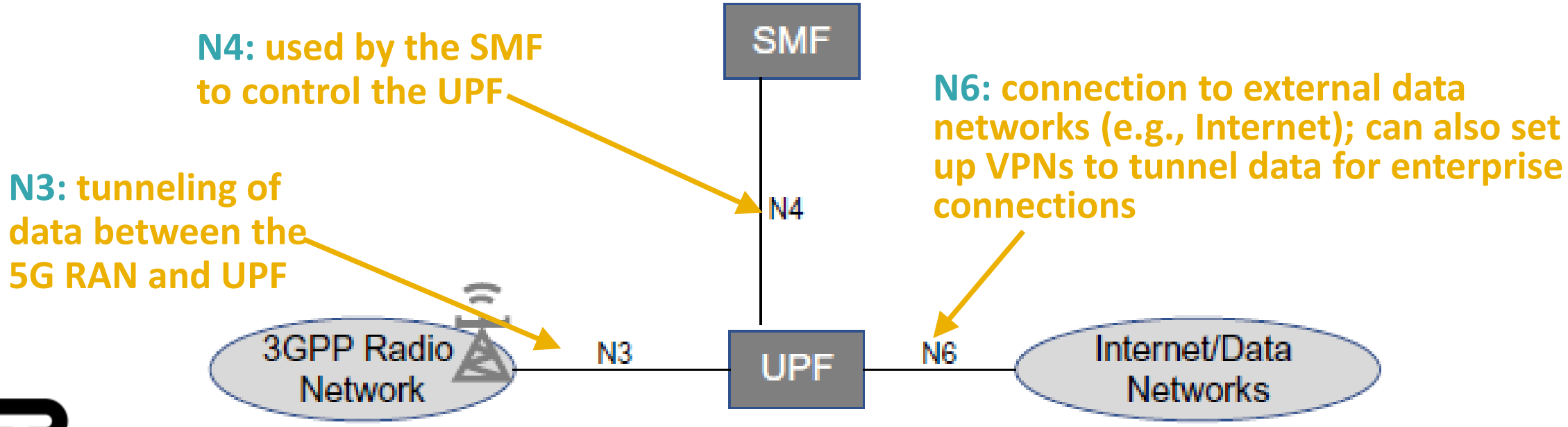


A UE can have multiple PDU Sessions active at the same time (e.g., one PDU Session to IMS for voice calls and one to the Internet)

source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

Mobility and data connectivity

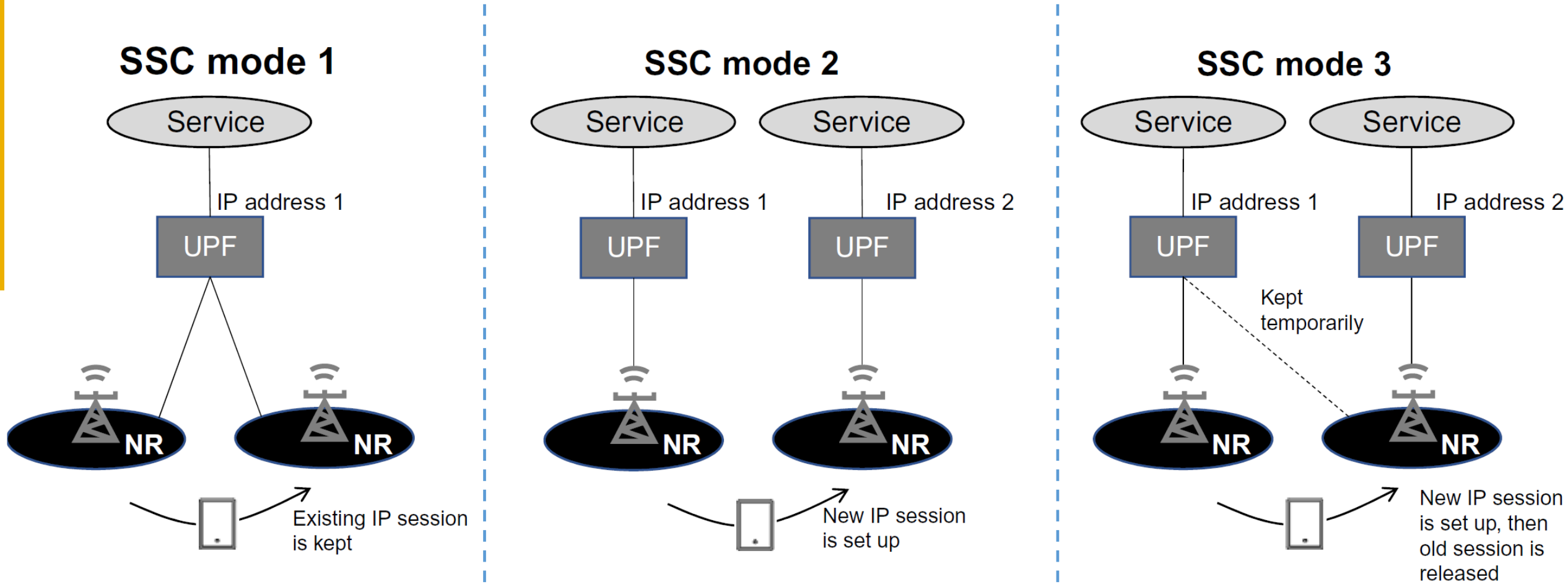
- user data is handled in the UPF (User Plane Function)
- IP routing is done on the tunnel header IP address instead of the end user IP address
- UPF maintains a stable IP anchor point even though the device is moving in the network (across different cells and base stations)



Service and Session Continuity (SSC) modes

- When a PDU Session is established, a PDU Session Anchor (PSA) UPF is selected (e.g., close to the UE's location) that remains as the IP anchor point for the PDU Session.
- If UE moves far away, that PSA UPF may no longer be optimally located → other UPFs closer to the UE's new location that could act as PSA UPF!
- Changing PSA UPF however requires the change of UE IP address → may or may not cause a problem for applications/services running on the UE.
  - Some applications/services require IP address continuity in order to run smoothly, while others may handle IP address changes
  - To address different IP address continuity requirements, 3 different Service and Session Continuity (SSC) modes defined → **SSC mode 1, SSC mode 2, SSC mode 3**

Service and Session Continuity (SSC) modes



source: Rommer et al, „5G Core Networks: Powering Digitalization", 2020

Service and Session Continuity (SSC) modes

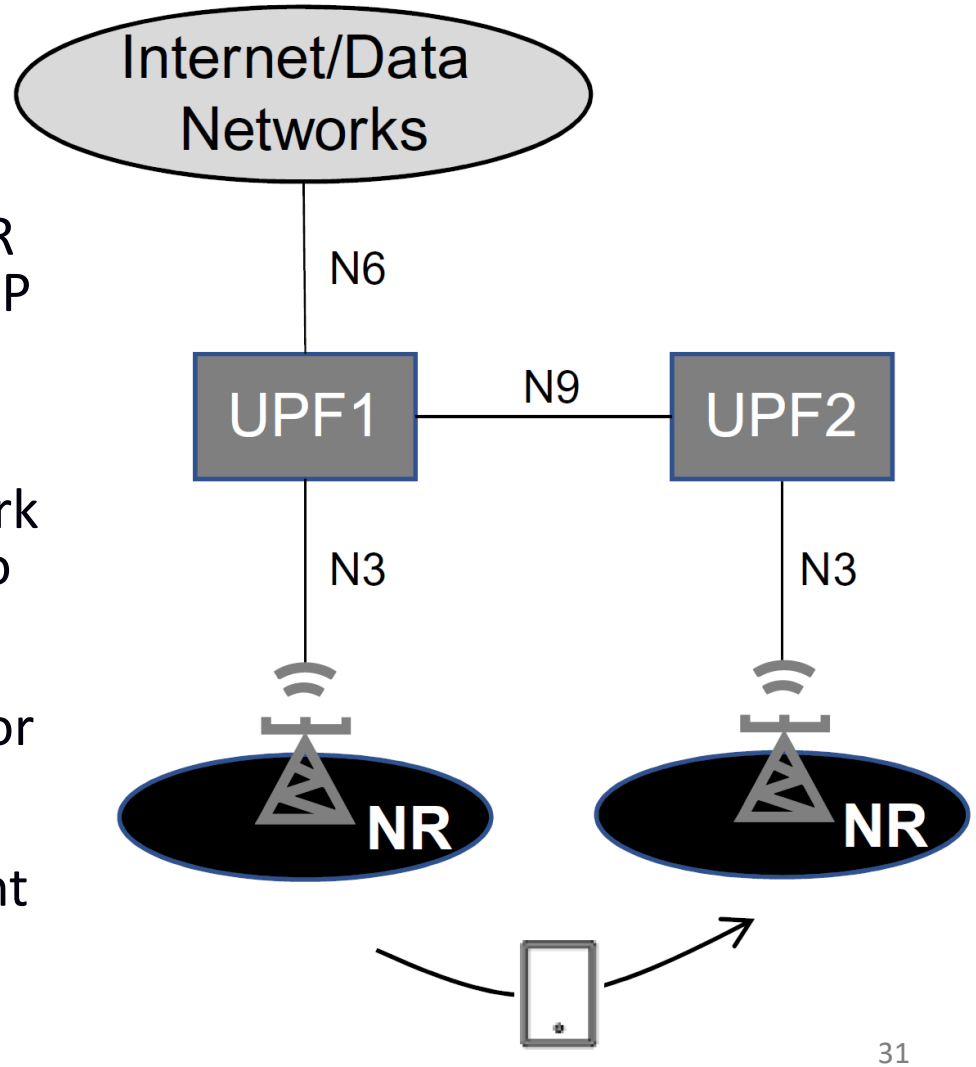
- **SSC mode 1**: the IP address is maintained regardless of movements in the network. The same IP anchor point (UPF) is accessible and can be used across the network.
- **SSC mode 2**: The network will release and trigger the device to re-establish new sessions as the device moves around in the network.
  - When the device requests a new session, the network can select a new UPF more suitable to the service → e.g., a UPF that is located closer to where the device is currently located.
  - causes short interruption of the service
- **SSC mode 3**: first establish a new session and connection to the new UPF before releasing the session and connection anchored in the old UPF (“*make-before-break*”)

IP mobility when interconnecting 2 UPFs

Enables full mobility while keeping a stable IP anchor point across the network-

Example:

- A device attaches over a radio cell in the left-hand NR coverage area. UPF1 will be selected to serve as the IP anchor for the device, connecting to the Internet or another data network
- The device then moves to another part of the network → radio base stations cannot connect to UPF1 due to limitations in the transport network configuration.
- SMF allocates UPF2 to serve as a termination point for the new N3 interface and connect back to UPF1.
- No change to the IP address of the device or the point of interconnect!



5G Mobility Management (5GMM) procedures

- Network discovery and selection
- Registration and Mobility
- Reachability

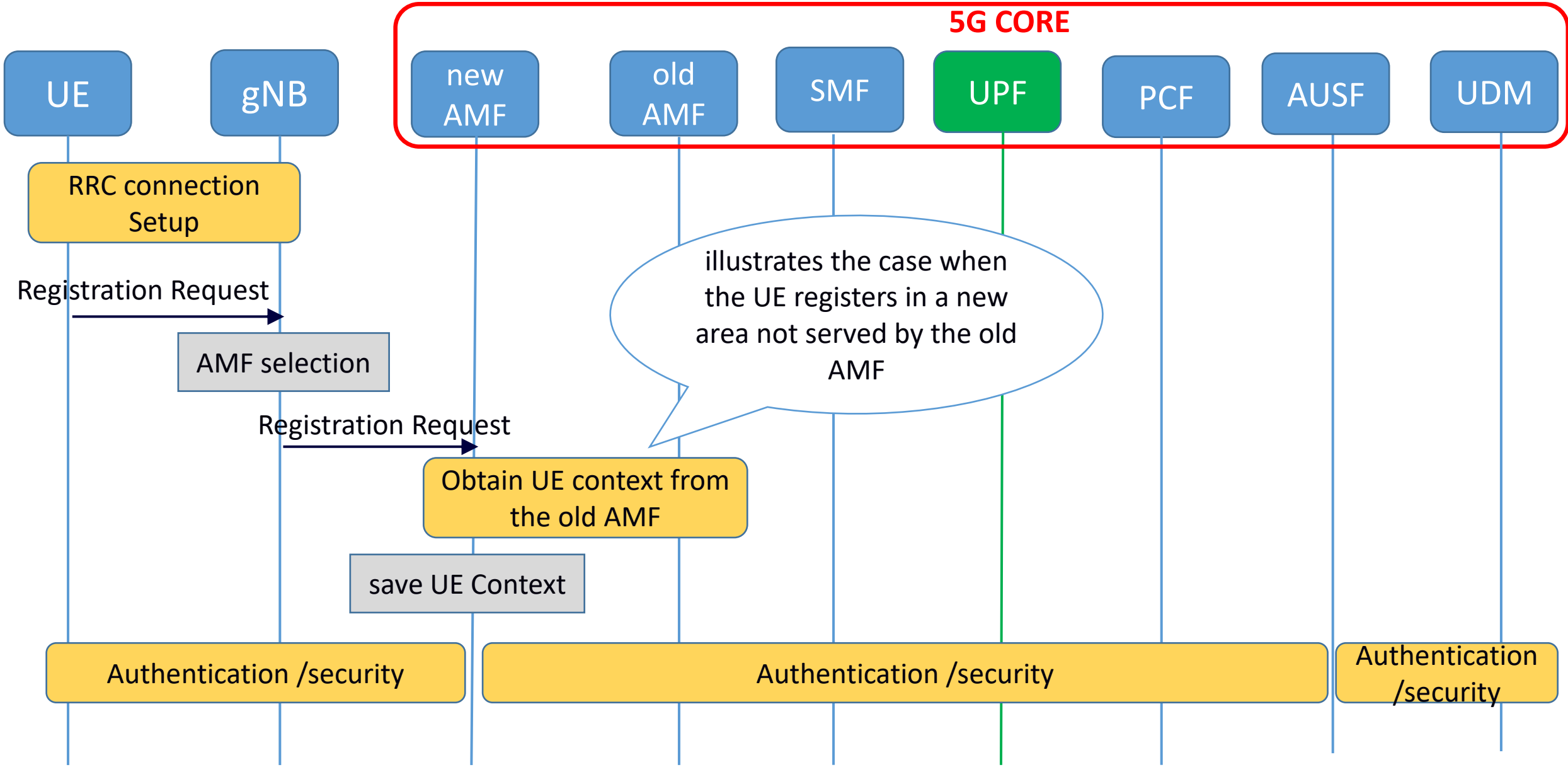
Network discovery and selection

1. UE selects a network and a 5G access network
2. UE selects a cell and establishes a RRC connection to the 5G RAN (gNB)
3. Based on the content (e.g. selected network, Network Slice information) provided by the UE in establishing the RRC connection, the gNB selects an AMF and forwards a UE NAS MM message to the AMF in the 5GC (using N2)
4. UE completes a registration procedure, and now has a NAS MM connection to the AMF
    - further communication between the UE and other entities in 5GC use this NAS connection

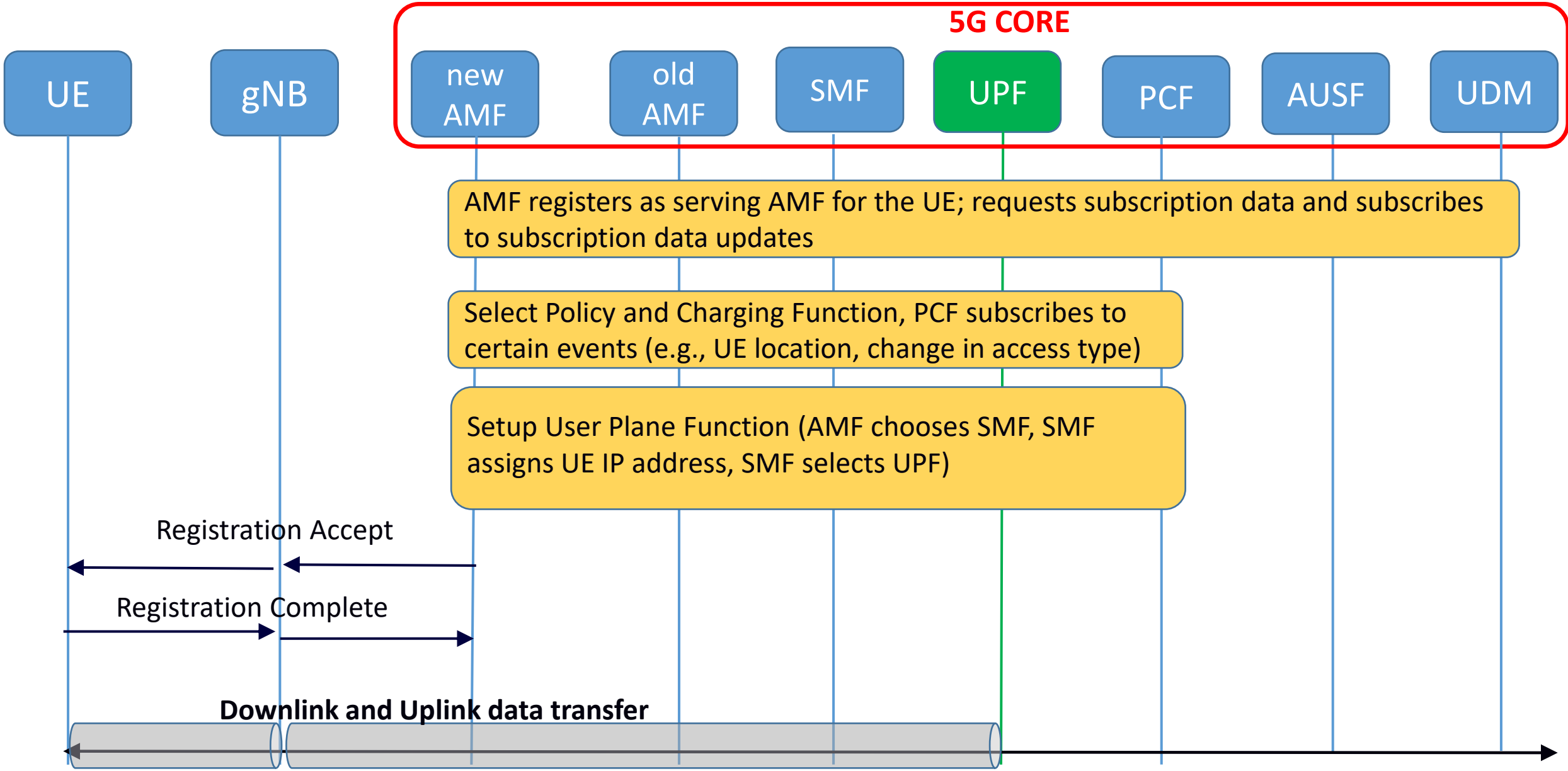
Registration procedure

- **Initial Registration**: used by the UE to connect to the network after power-on.
- **Periodic Registration**: used by the UE that is in CM-IDLE state to show to the network that the UE is still there. The periodicity is based on a time value received from the AMF.
- **Mobility Registration**: used by the UE in case it moves out of the Registration Area, or when the UE needs to update its capabilities or other parameters that are negotiated in Registration procedure with or without changing to a new TA.
- **Emergency Registration**: used by the UE when it wants to register for emergency services only.

5G registration procedure (simplified)



5G registration procedure (simplified)



Registration and mobility

- When a UE is in idle mode, it is not practical to keep track of the device every time it moves between different cells → would cause too much signaling
- The gNB broadcasts Tracking Area (TA) identity in each cell; the UE compares this information with the one or more TAs it has previously stored as part of the assigned Registration Area (RA).
  - If the broadcasted TA is not part of the assigned RA, the UE starts a Registration procedure update → informs the network it is in a different location.
  - Example: when a UE that was previously assigned a RA with TAs 1 and 2 moves into a cell that is broadcasting TA 3, the UE will notice this is not part of its RA → UE performs a Registration update procedure and informs the network about the new TA it has entered. The network assigns the UE a new RA

Reachability

- When a UE is in idle state and the network needs to reach the UE (e.g., to send down-link traffic), the **network pages the UE in the RA**.
- The size of the TAs/TA lists is a compromise between the number of Registration updates and the paging load in the system.
  - The smaller the TAs, the fewer the cells needed to page the UEs but on the other hand, there will be more frequent Registration updates.
  - The larger the TAs, the higher the paging load in the cells, but there will be less signaling for Registration updates due to UEs moving around.

Summary of *idle* mobility procedure

- A Tracking Area consists of a set of cells
- The Registration Area is a list of one or more Tracking Areas (TA list)
- The UE performs Registration update due to mobility when moving outside its Registration Area (TA list)
- The UE in idle state also performs periodic Registration update when a periodic Registration update timer expires.