5G Network Architecture

COS 597S: *Recent Advances in Wireless Networks*

Fall 2024

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Outline

Peterson, Sunay, Davie (PSD). *Private 5G: A Systems Approach*

- **Chapter 1: Introduction**
- Chapter 2: Architecture
- Chapter 3: Radio Transmission

Context: 3G, 4G, 5G Transitions

- 3G: the arrival of **broadband** (100 Kbit/second) data access

- **5G's promise:**

1. Transition from broadband → collection of **"edge services"**
   - Augmented Reality (extreme **capacity**)
   - Autonomous vehicles (ultra **high-availability**)
   - Internet of Things (**low-energy, high density**)

2. Broader **platform for innovation**
   - Like nascent Internet, design for apps we don't yet know
   - Disaggregated, virtualized, and software-defined

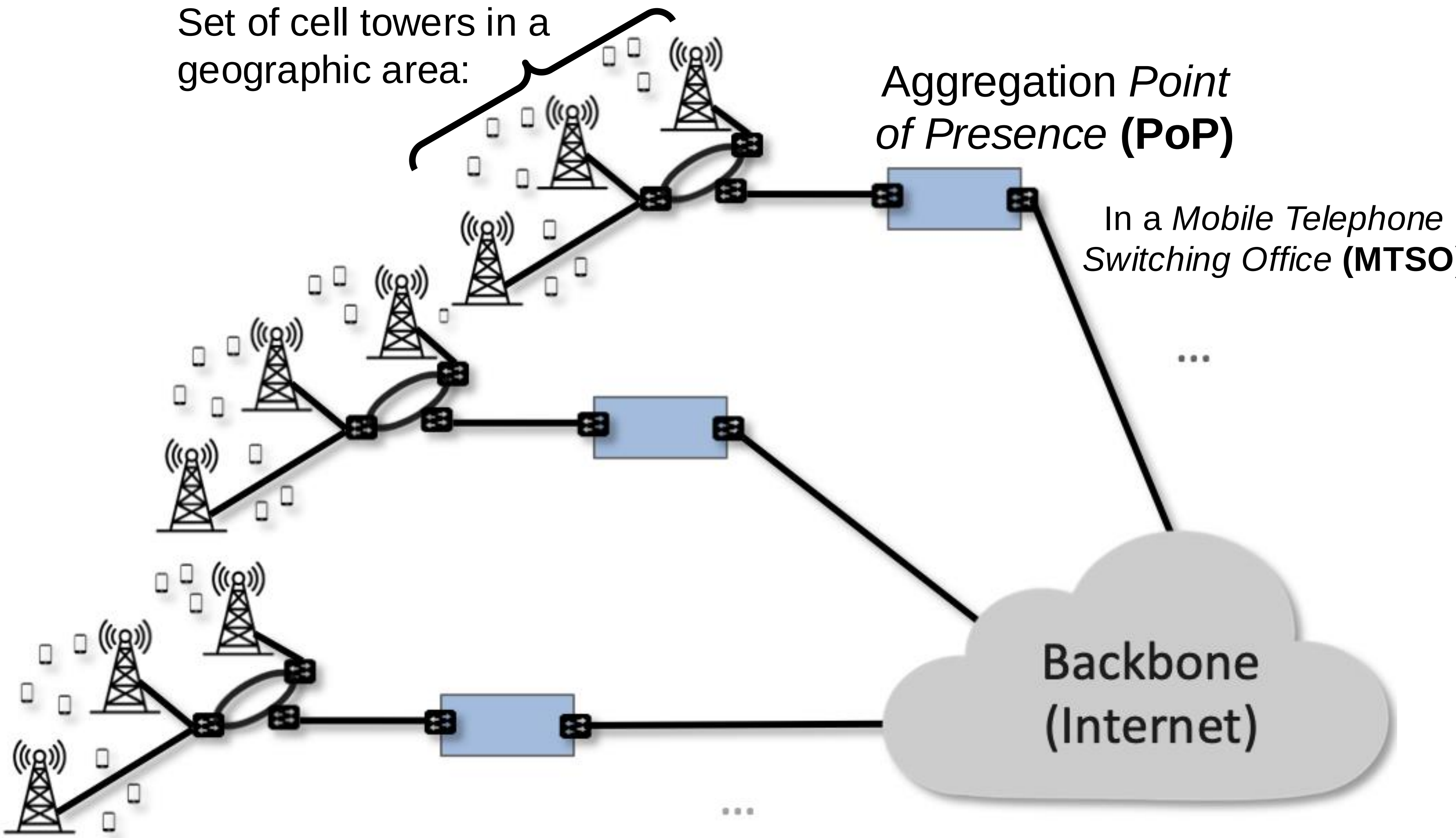
Standardization and Frequency Licensing

- ***3rd Generation Partnership Project*** (3GPP)
  - Release 15 demarcates 4G and 5G, Release 17 (ca. 2022)

- Unlike Wi-Fi, most spectrum in **government-licensed bands**
  - *Citizens Broadband Radio Service* (CBRS) **shared license band** at 3.5 GHz with **three-tier access** rules
    - Attractive for deploying a Private 5G network

  - New bands with novel radio characteristics in each:
    - ***FR2*** **millimeter-wave** band > 24 GHz
    - ***FR3*** **centimeter-wave** band *ca.* 7-20 GHz

Access Networks: The "Last Mile"



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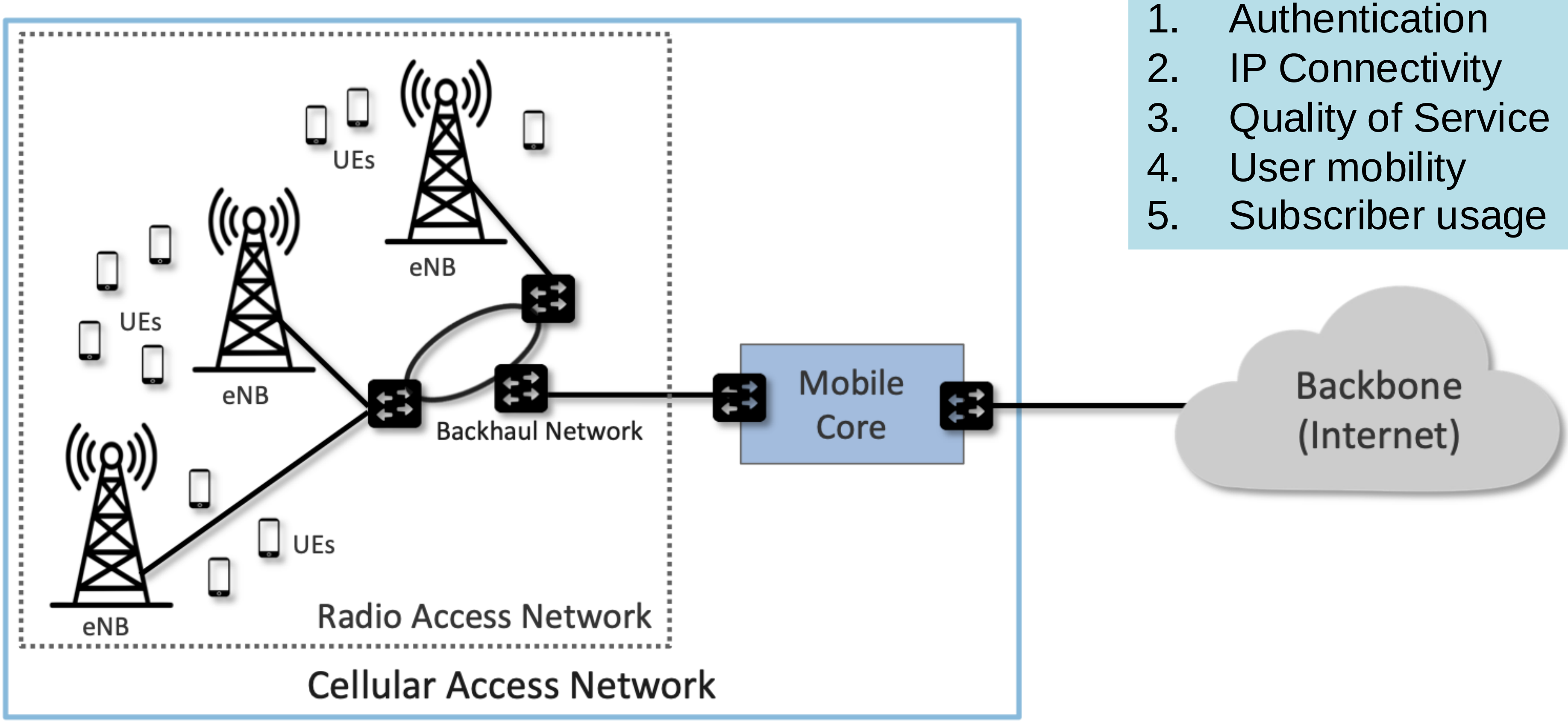
Mobile Cellular Network = RAN + Core

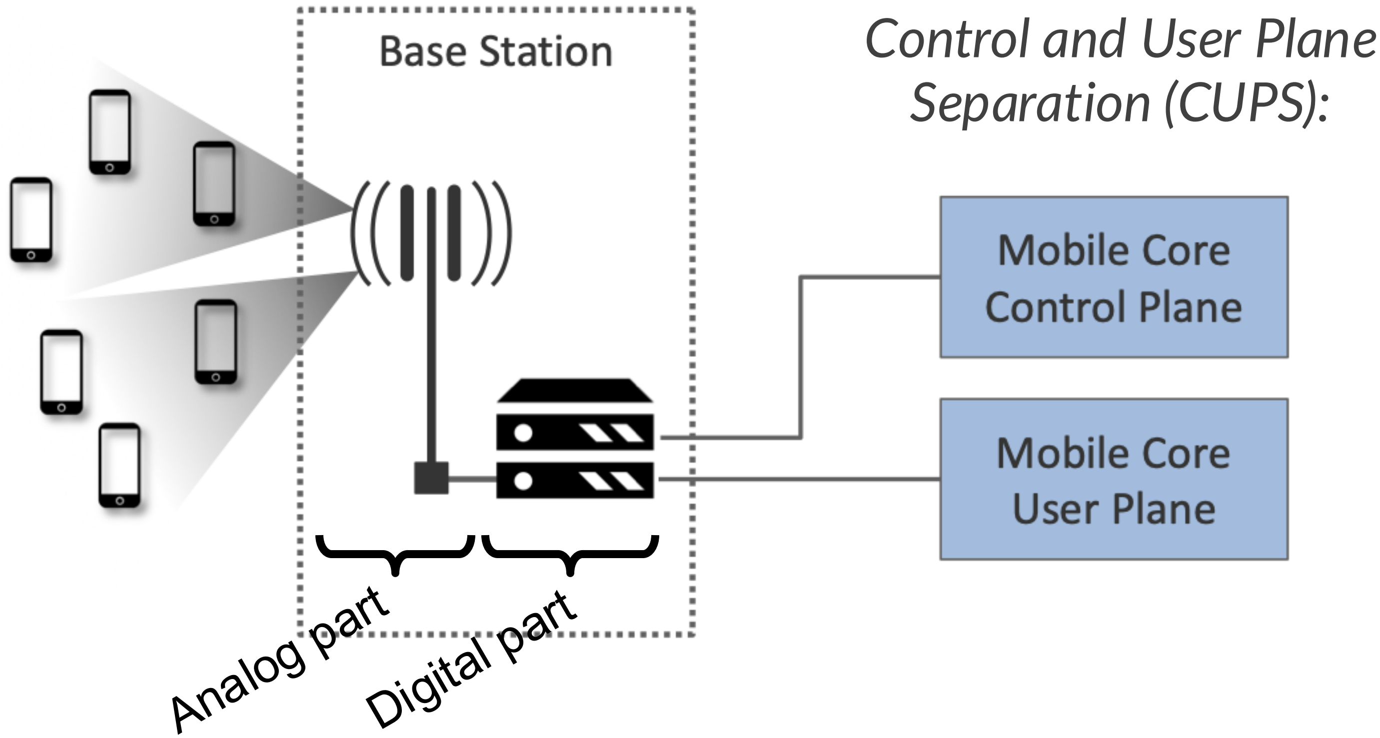
Core Functionality

1. Authentication
2. IP Connectivity
3. Quality of Service
4. User mobility
5. Subscriber usage

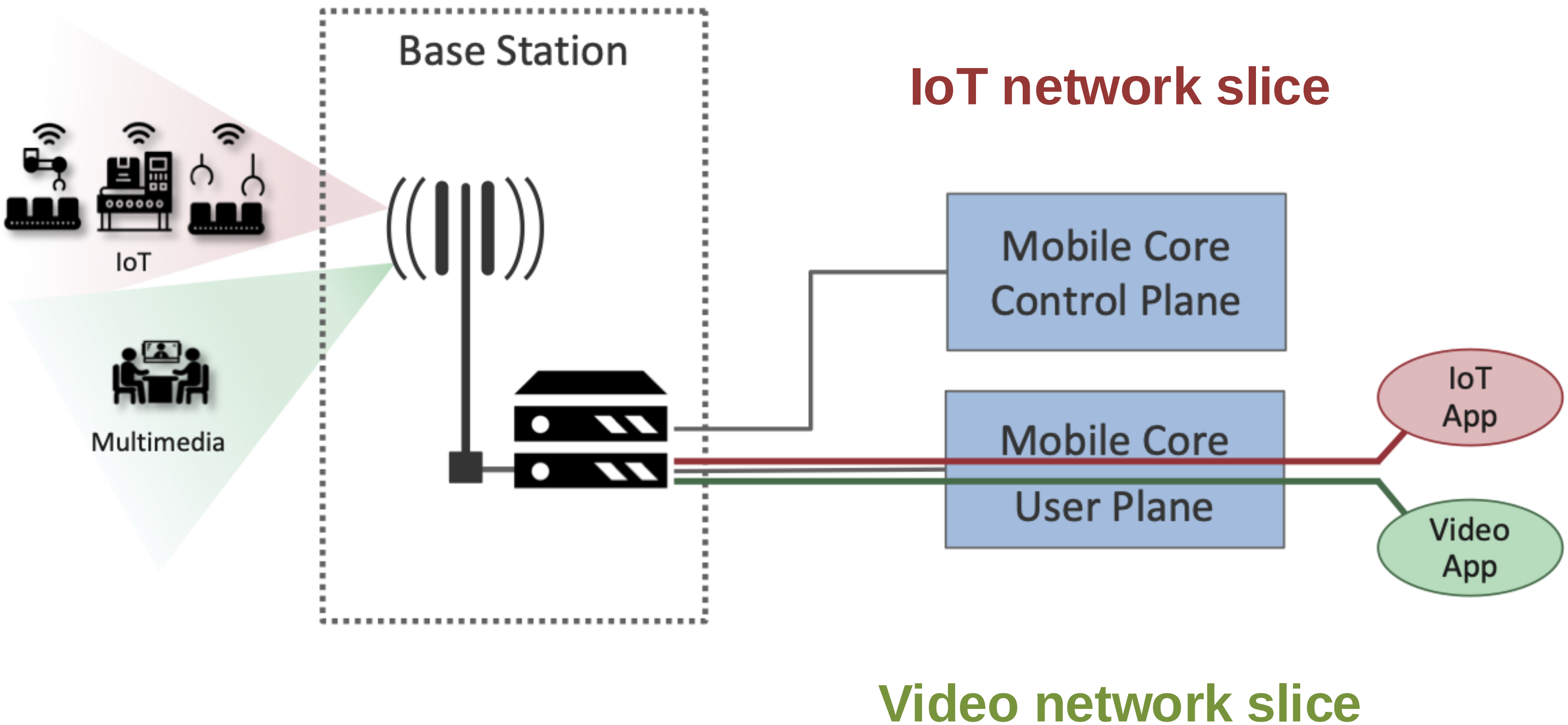


Significant opportunity to open and disaggregate the RAN and Mobile Core

RAN and Mobile Core in More Detail



The Network Slice: a “Wireless VLAN”



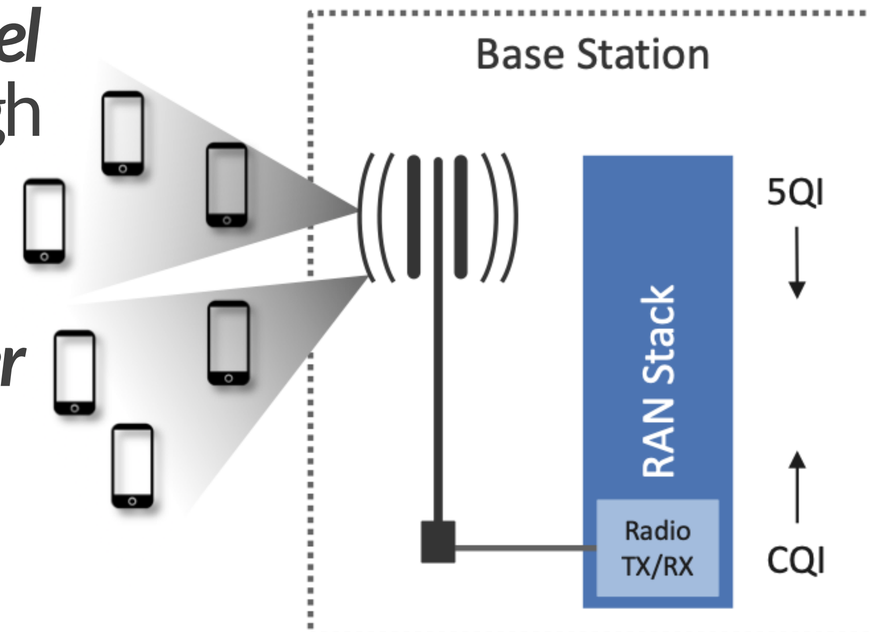
Need: To implement slicing end-to-end, across radio, RAN, mobile core

The Core/High-RAN View of the Radio Spectrum

- **Goal:** **Share the radio spectrum** that hundreds of gNBs provide to thousands of UEs
  - Two important pieces of information:

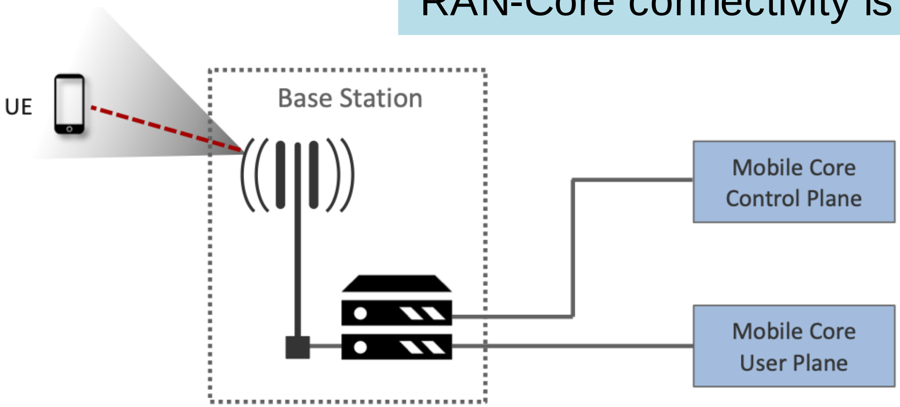
1. Lower RAN passes up ***Channel Quality Indicator*** (**CQI**) to High RAN and Core

2. Core passes ***5G QoS Identifier*** (**5QI**) down to the radio

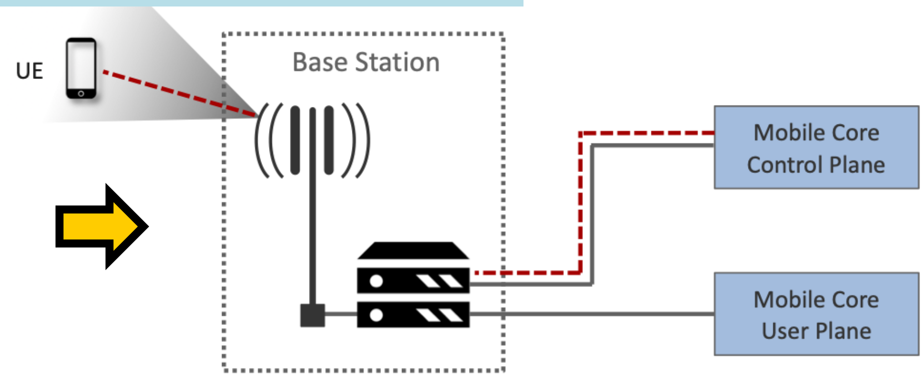


Radio Access Network: UE Connection Establishment

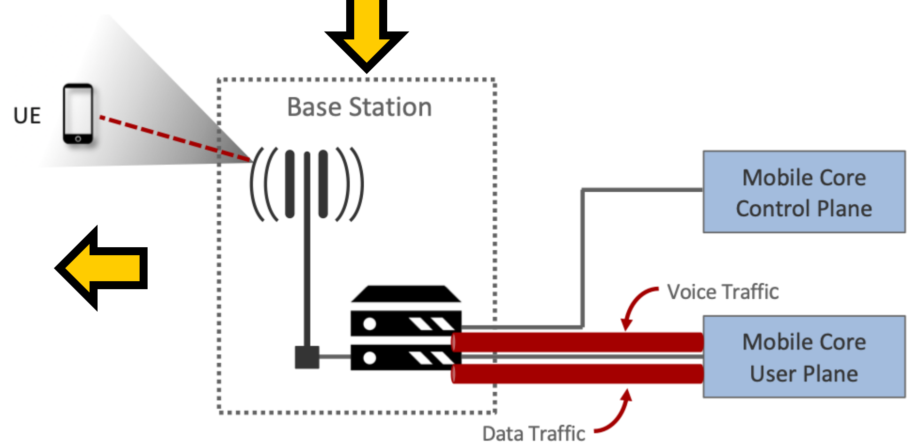
RAN-Core connectivity is **IP based** (starting with 4G)



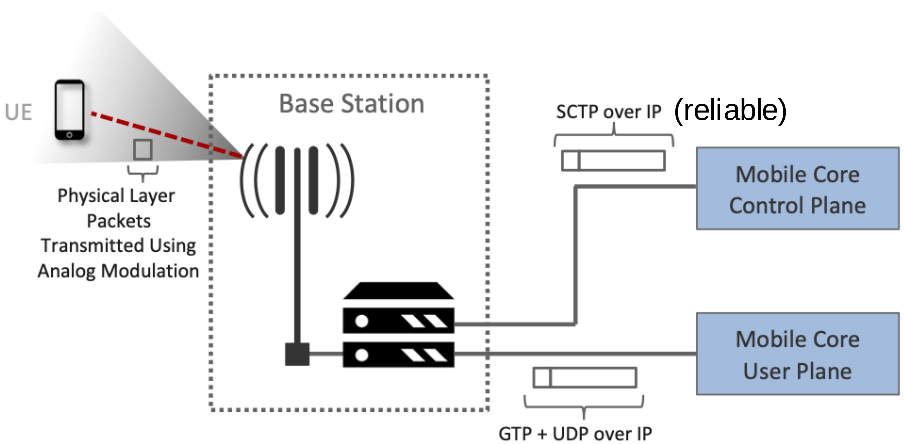
1) Establish wireless channel (“*radio bearer*”)



2) Establish ”3GPP Control Plane” connectivity with core

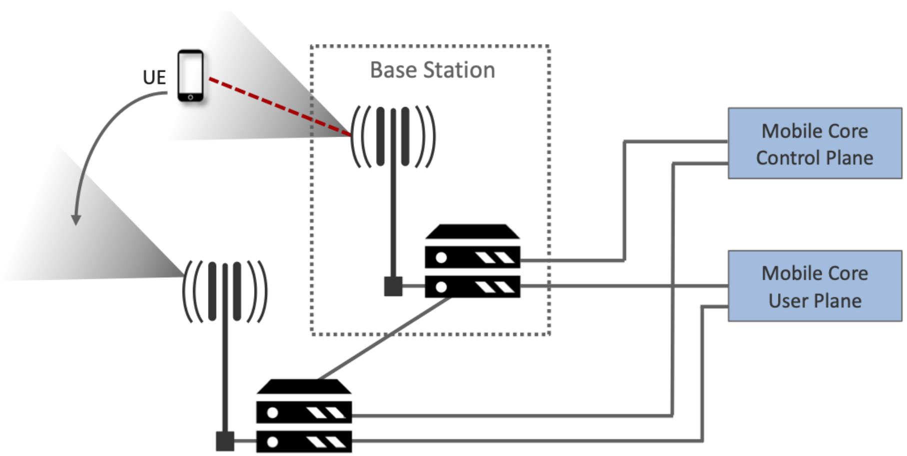


3) Establish *tunnels* from UE to core user plane

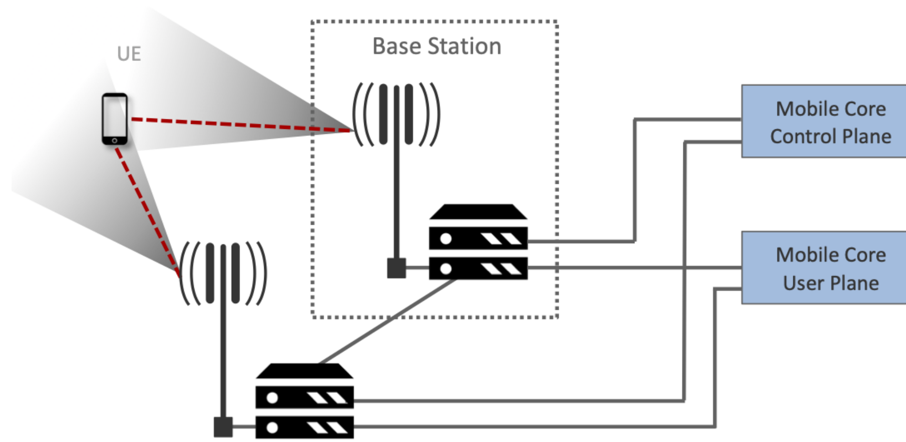


4) Forwarding control traffic and data traffic over tunnels

Radio Access Network: Handover and Carrier Aggregation



Coordinating UE **handovers**
with neighboring base stations



Wireless **multi-point transmission**
to UE from multiple eNBs

- **Handovers** use **direct** inter-Base Station links

Radio Access Network: Handover and Carrier Aggregation

- **Takeaway:** Base Station is a **highly specialized forwarder**
  - **Downlink,** fragments IP datagrams into physical-layer units and **schedules** them
  - **Uplink,** assembles bits to datagrams, GTP-tunnels to core
  - Makes **switching decisions** (forward to UE, handover, use multiple paths)
    - A **planning process** potentially spanning a metro area

Mobile Core

- **Basic service:** provide Internet connectivity to UEs, **and:**
  - Ensure UEs are **authenticated**
  - Deliver **service quality levels** to UEs
  - Track UEs to base stations for **mobility**

- A **differentiator,** versus Wi-Fi

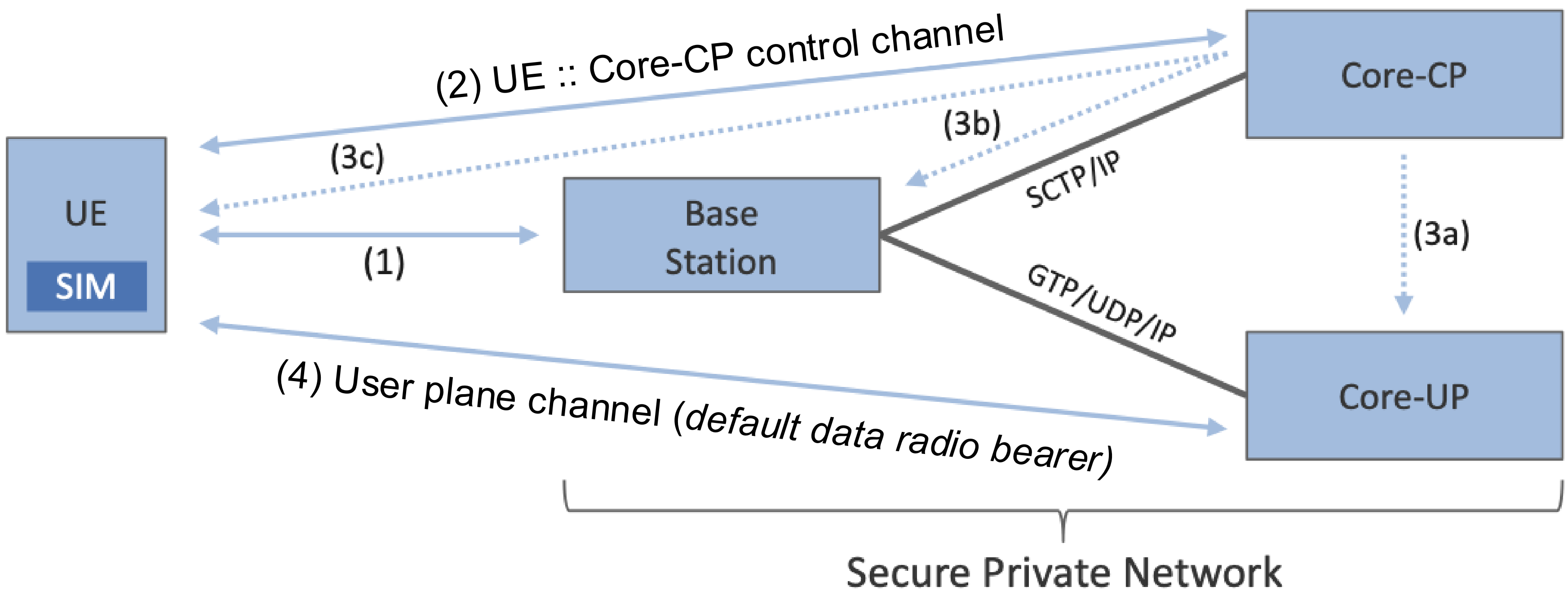
Mobile Core: Security Architecture

- Base station trusts secure private network connection to core

- UE has a SIM card that uniquely identifies the subscriber
  - SIM card identifier: 64-bit **IMSI** (*International Mobile Subscriber Identity*)
    - **MCC:** Mobile Country Code (3-digit decimal)
    - **MNC:** Mobile Network Code (2 or 3-digit decimal)
    - **ENT:** Enterprise Code (3-digit decimal number)
    - **SUB:** Subscriber (6-digit decimal number)

- MCC/MNC pair: *Public Land Mobile Network (PLMN)* identifier

Mobile Core: Establishing Secure Control and User Plane Channels

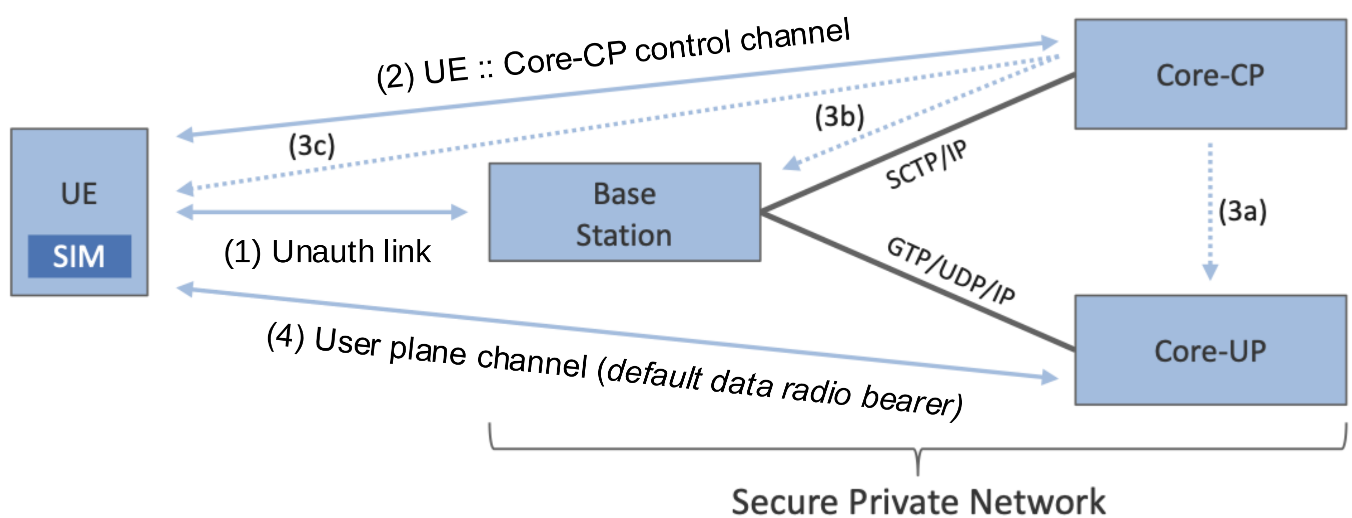


Step (3): Core-CP tells UP to assign UE an IP; Core-CP distributes symmetric key to UE

Understanding Roaming in More Detail

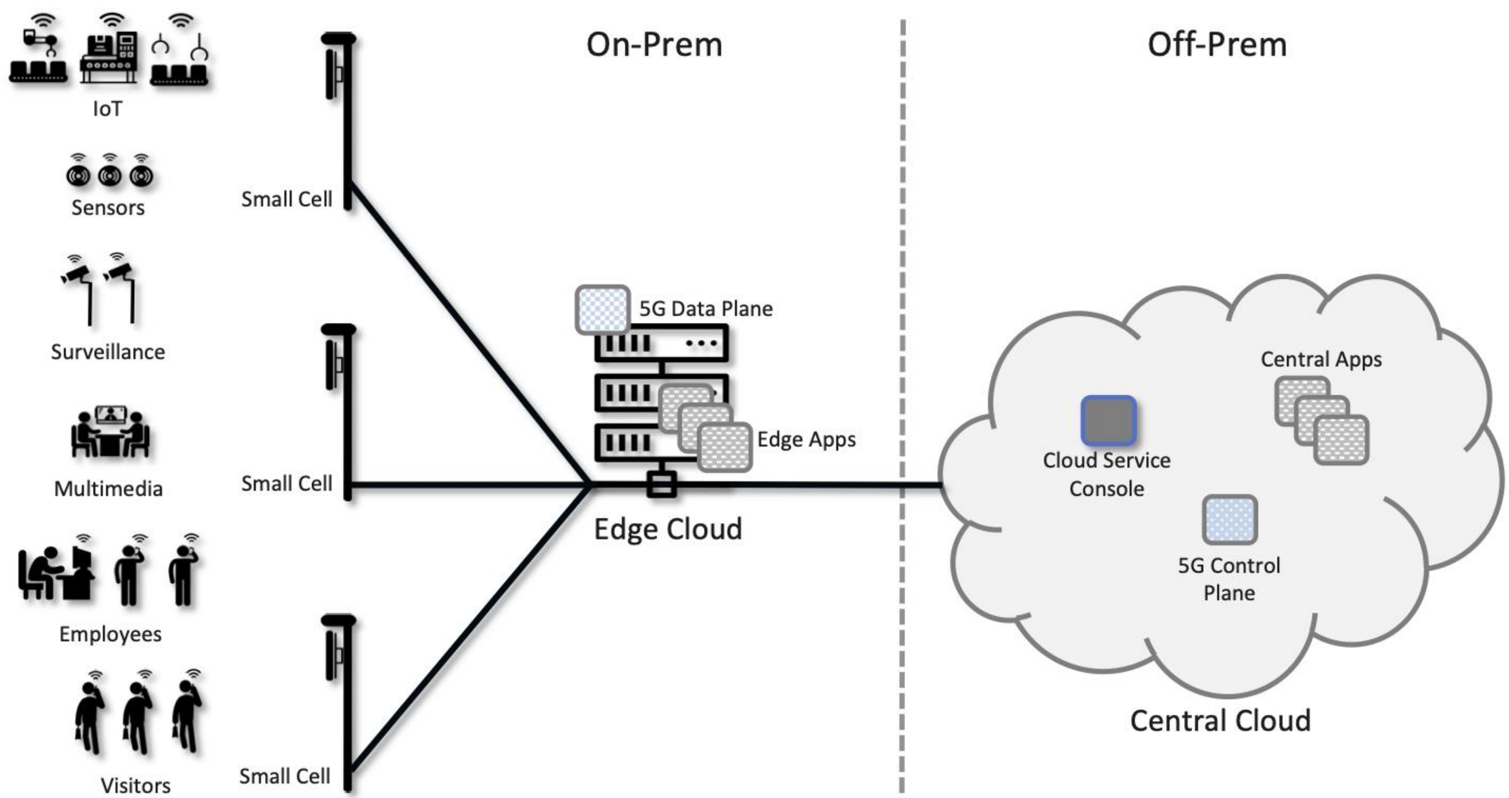
- Base Stations **detect UE presence** via unauthenticated link **(1)**
  - Communicate among themselves to make **handover decision**

- On handover, **Core-CP re-triggers** setup functions **(3)**
  - Meanwhile, Core-UP buffers data (a mixed blessing!)



Operating the Network: Managed Cloud Service

- **Operationalization:** how network operators activate and manage the components of the network
  - **Example-** Aether:



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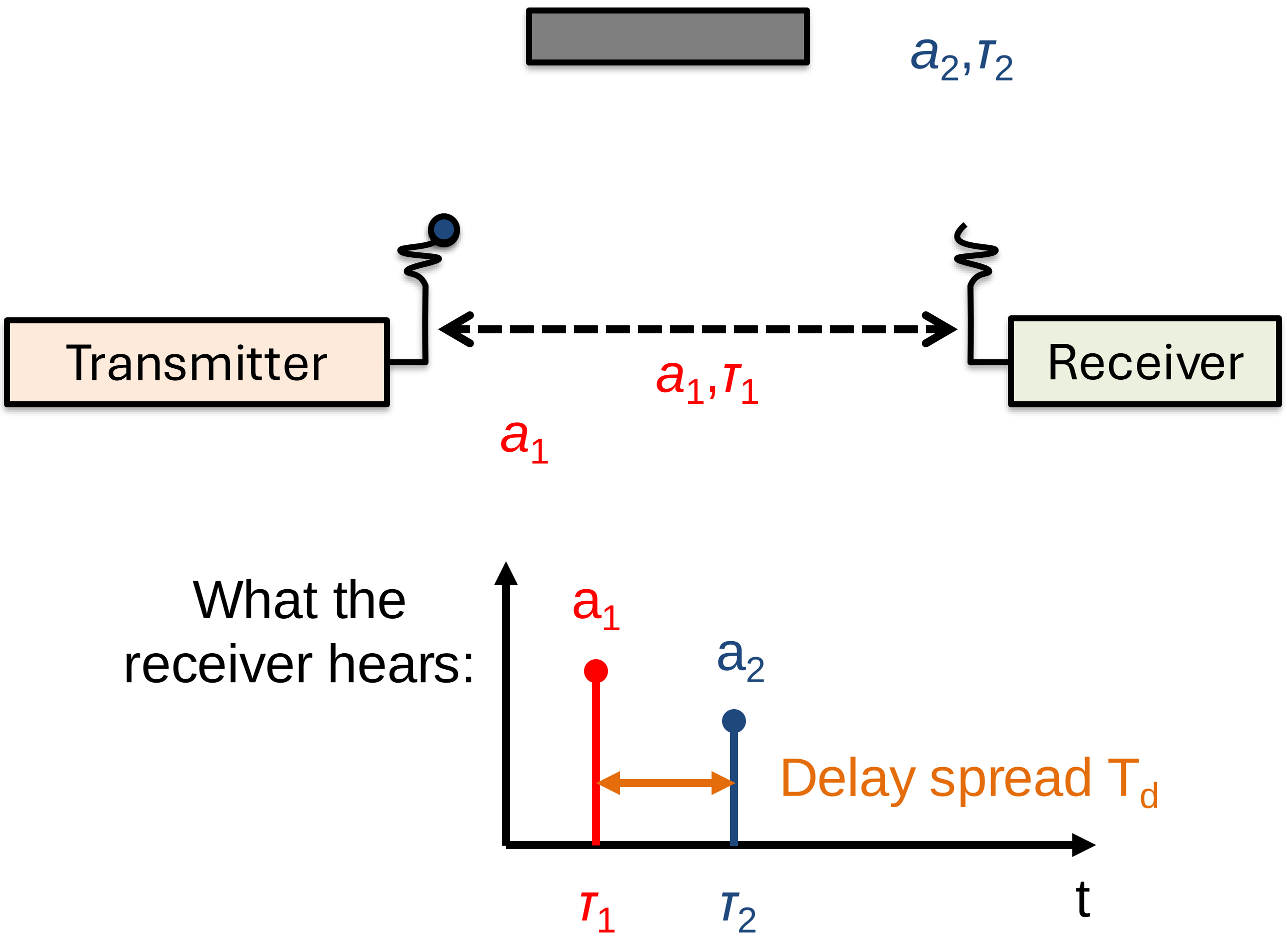
Wireless Challenges, Cellular Goals

- Wireless has **challenges** that don't arise in wired networks:
  - **Interference**, environmental **reflections** and **absorption**

- Cellular networks aim for **quality of service** (not best effort)
  - Maximize overall network **spectral efficiency** (*i.e.* bits/second/Hz delivered by network)

  - **Reservation based** strategy
    - Supports **high utilization** (compare Wi-Fi contention-based strategy)

Challenge: Wireless Multipath Propgation



Attenuation of i^{th} path: a_i
Time delay of i^{th} path: $\boldsymbol{\tau}_i$

Challenge: Channel Coherence Time

- **A change** in **path length difference** of wavelength / 2 transitions from **constructive** to **destructive** interference
  - Receiver movement of **wavelength/4:** ***coherence distance***
  - **Duration of time** that transmitter, receiver, or objects in environment take to move a coherence distance: ***channel coherence time*** T_c
    - Walking speed (2 mph) @ 2.4 GHz: ≈ 15 milliseconds
    - Driving speed (20 mph) @ 1.9 GHz: ≈ 2.5 milliseconds
    - Train/freeway speed (75 mph) @ 1.9 GHz: < 1 millisecond

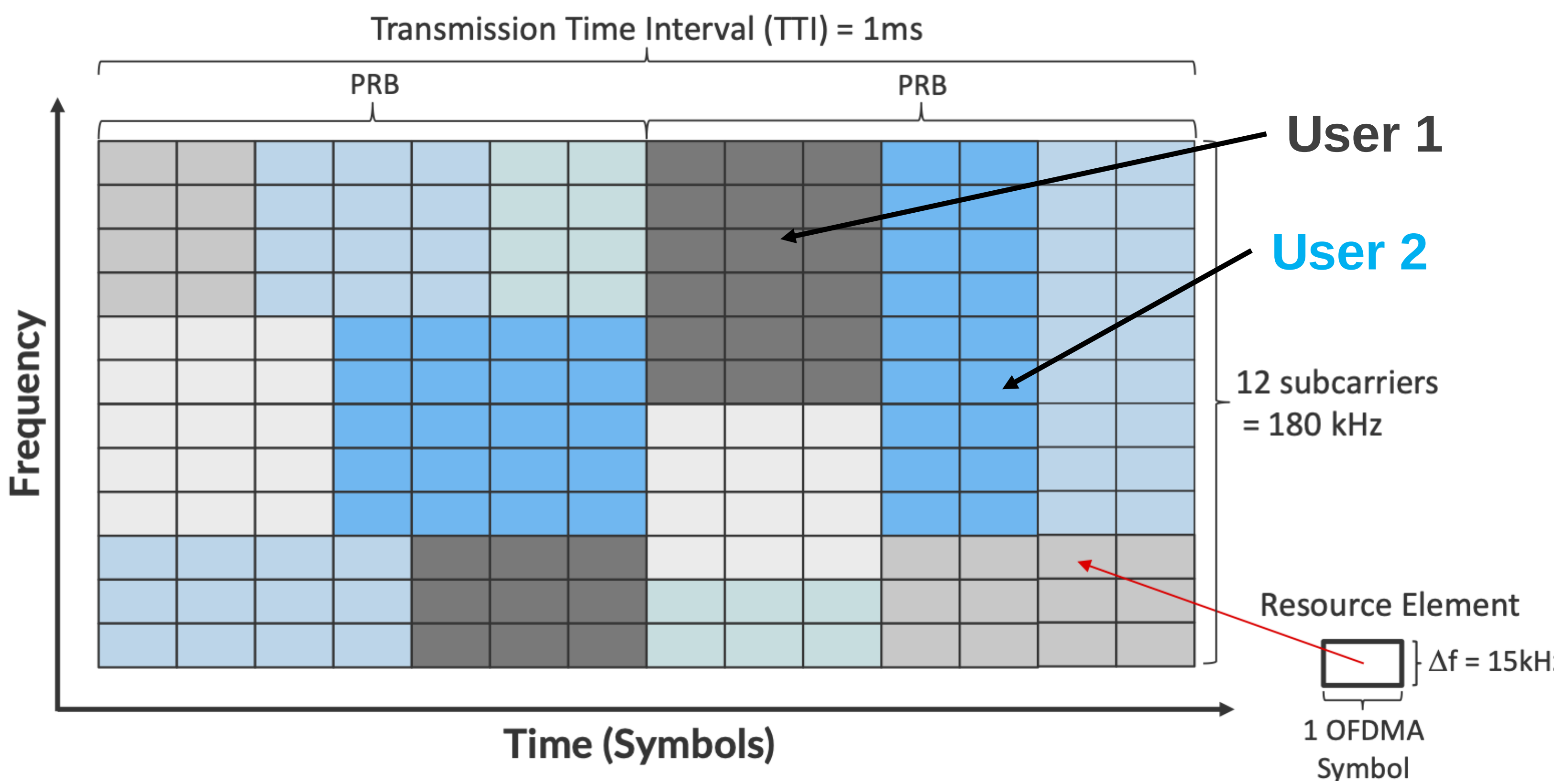
Channel Quality Feedback

- **Wireless channels** from Base Station to UEs determine **resource allocation**
  - Wireless channel **changes quickly**

- Transmitter needs ***channel quality information*** (**CQI**) **feedback** from receivers at rate $\propto$ to user **mobility**
  - Feedback data stream **consumes network capacity**

- A perennial problem, challenge, and target of research and development!

Sharing the Wireless Medium: 4G

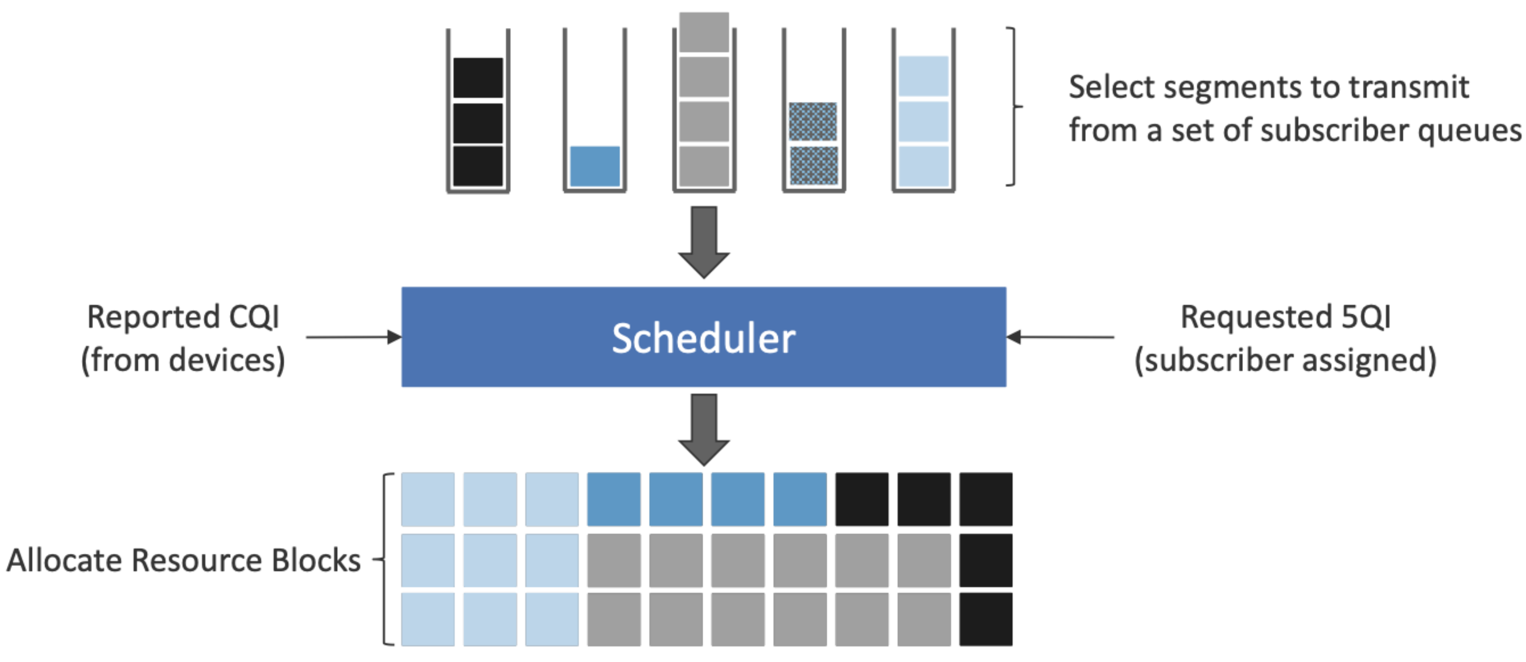


- Using CQI, **scheduler** allocates users for each **TTI** with *Physical Resource Block* (**PRB**) granularity

Sharing the Wireless Medium: 5G

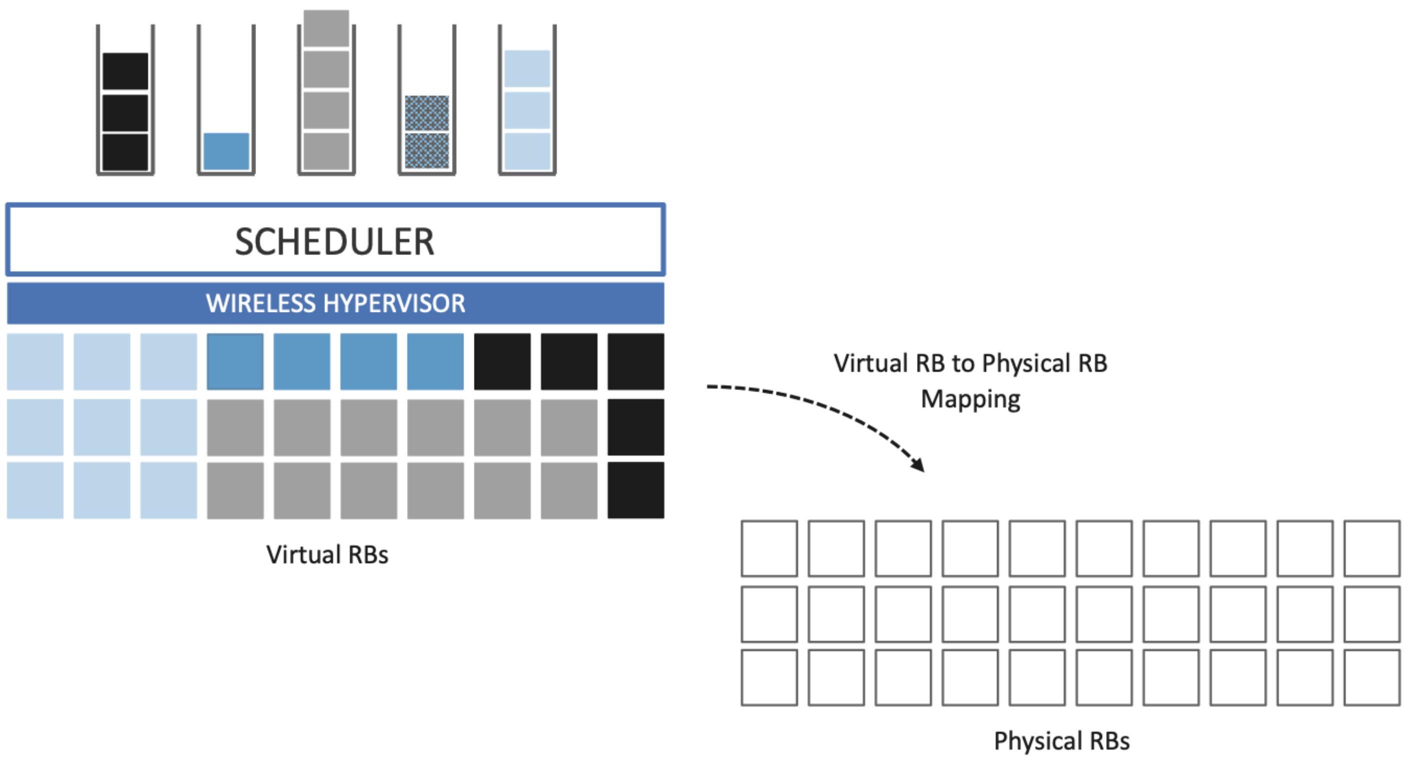
- 5G allows **flexibility** in **resource element size**
  - **Better match** range/capacity to diverse frequency bands

- Scheduler now works with **resource blocks**



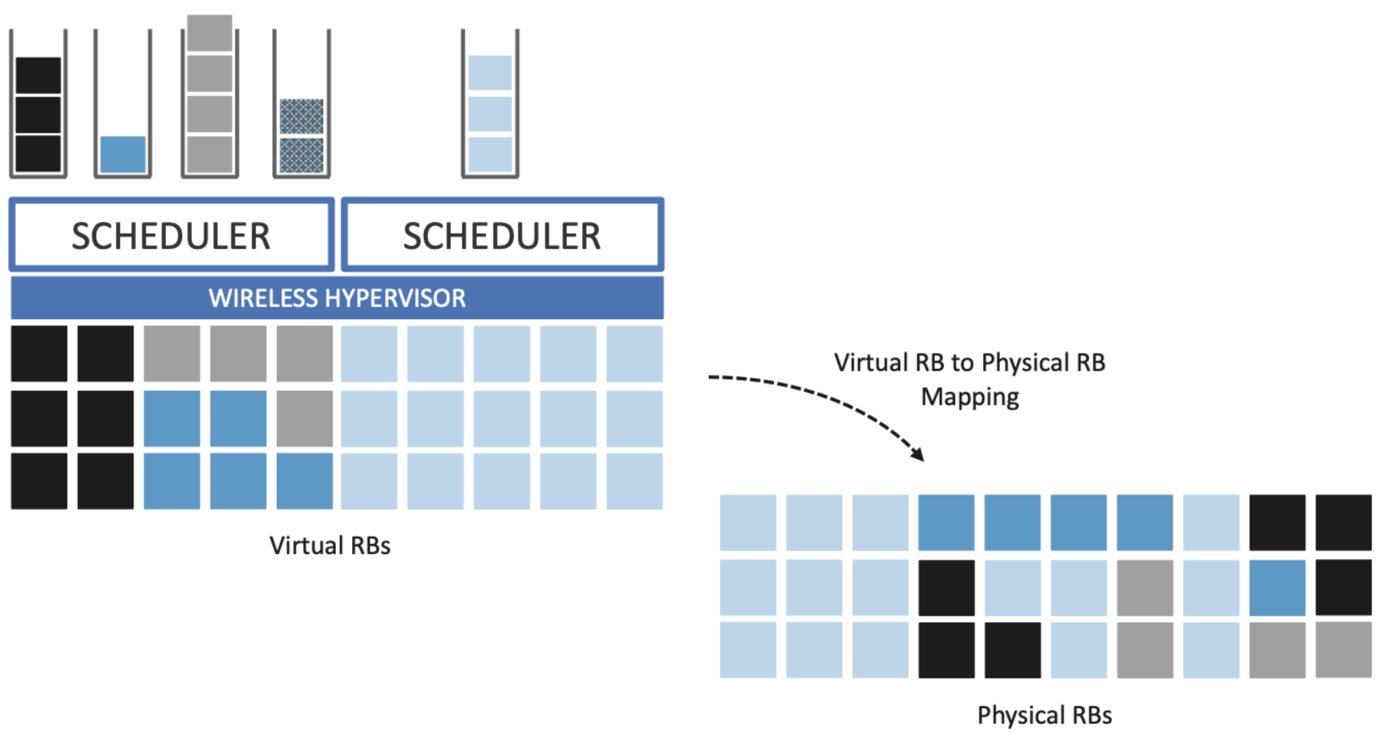
Virtualizing Resource Block Allocation

- **Different applications** may prefer **different schedulers**
- First, add a **layer of indirection (virtualization)** between scheduler and resource blocks:



Virtualized Scheduler (Slicing)

- **Slicing:** Define **multiple virtual RB sets** of varying sizes
  - e.g. low-latency IoT slice
  - e.g. high-availability public safety slide



Conclusions

- These **basic mechanisms** have great **promise for enabling tomorrow's applications:**

1. Enhanced Mobile Broadband (eMBB)
2. Ultra-Reliable Low-Latency Communications (URLLC)
3. Massive Internet of Things (MIoT)
4. Vehicle to Infrastructure/Vehicle (V2X)
5. High-Performance Machine-Type Communications (HMTC)

Up next:

Paper Discussion: Zipper (HW)

Balasingam, Kotaru, Bahl. "Application-Level Service Assurance with 5G RAN Slicing"