Link Layer: WiFi and 5G

CS204: Advanced Computer Networks

Nov 8, 2023

Agenda

- Introduction to wireless
  - Architecture Options
  - Wireless Link Characteristics
- WiFi
  - Challenges to design wireless link layers
  - WiFi's Approach
- Cellular
  - Basic Architecture
  - Critical Functions
  - Mobility

802.11 (Wi-Fi) MAC

- Basic Access Mechanism for Data Traffic
  - CSMA/CA
  - Binary exponential back-off

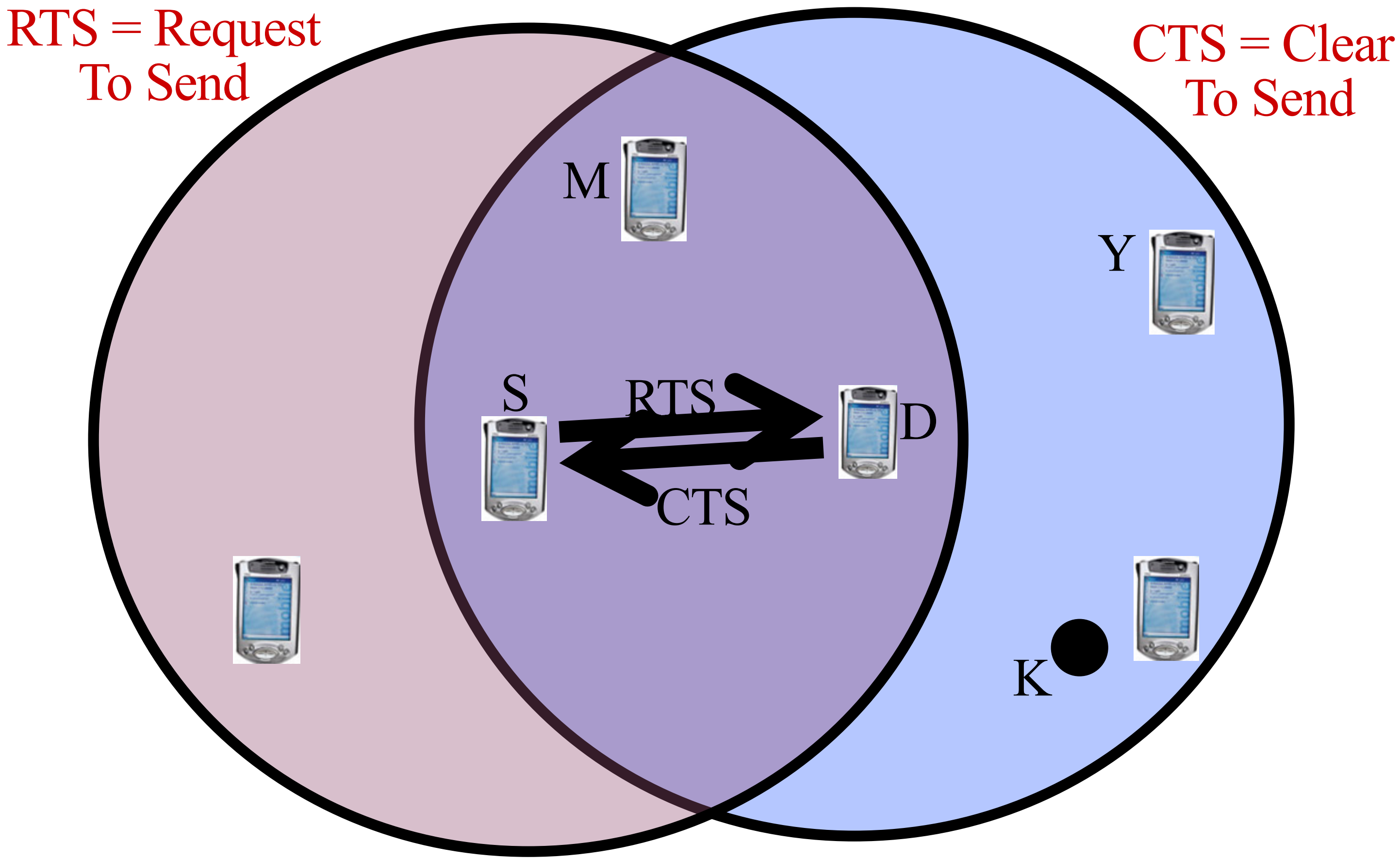
- Timing Intervals: SIFS, Slot Time, PIFS, DIFS, EIFS

- Distributed coordination function (DCF) Operation

DCF MAC

- Carrier sense multiple access with collision avoidance (CSMA/CA)
  - based on carrier sense function in PHY called Clear Channel Assessment (CCA)
  - CSMA/CA+ACK for unicast frames, with MAC level recovery
  - parameterized use of RTS/CTS to protect against hidden terminals
  - frame formats to support both infrastructure and ad-hoc networks

IEEE 802.11 with Omni Antenna



IEEE 802.11 with Omni Antenna

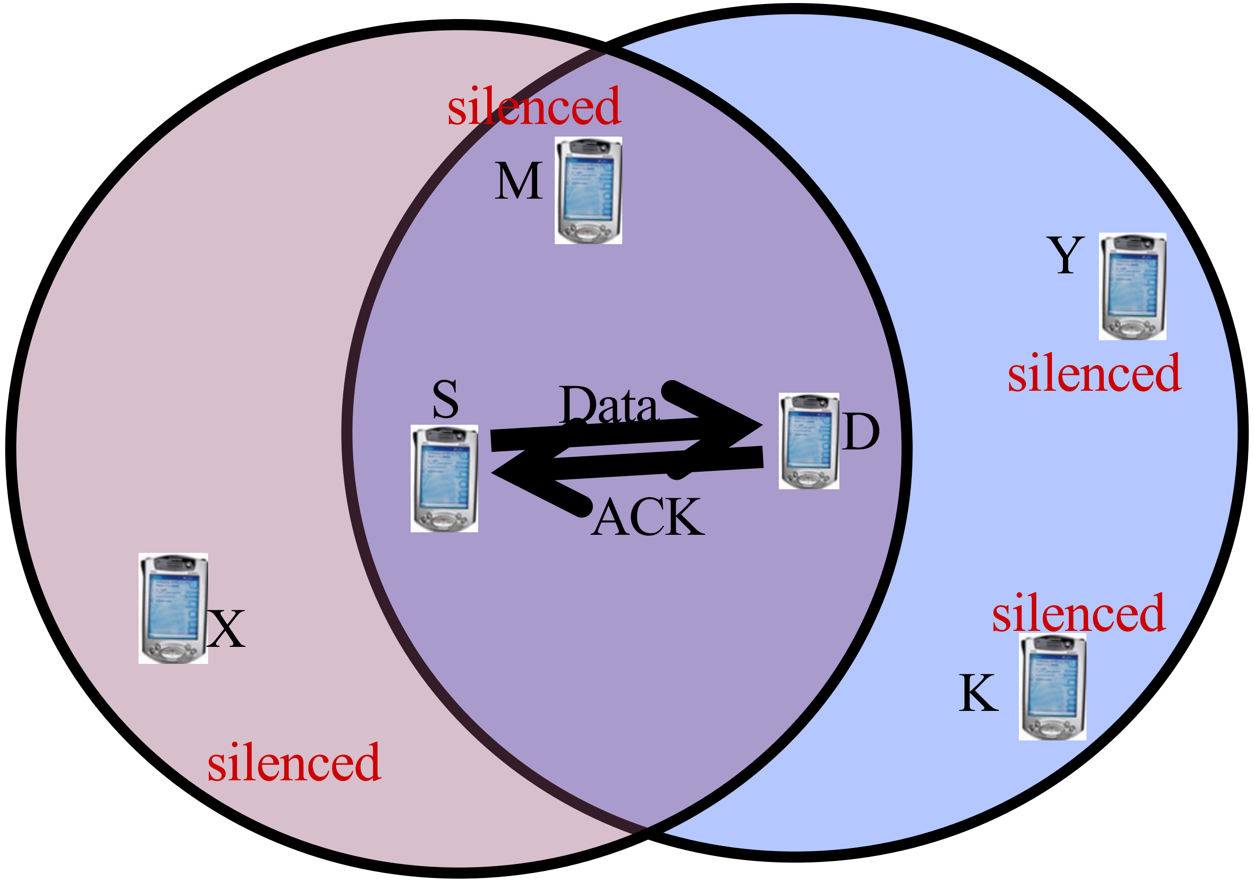
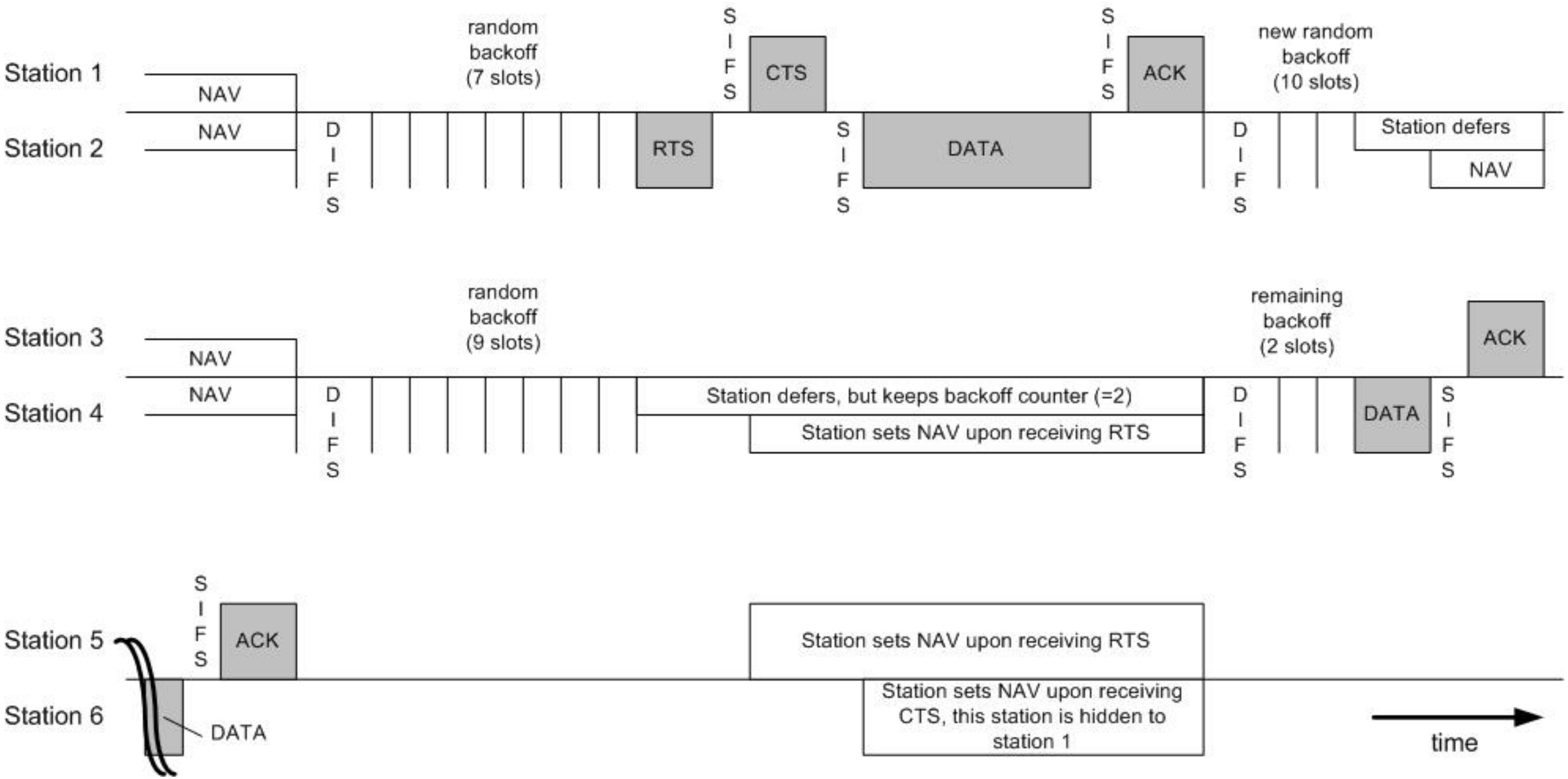
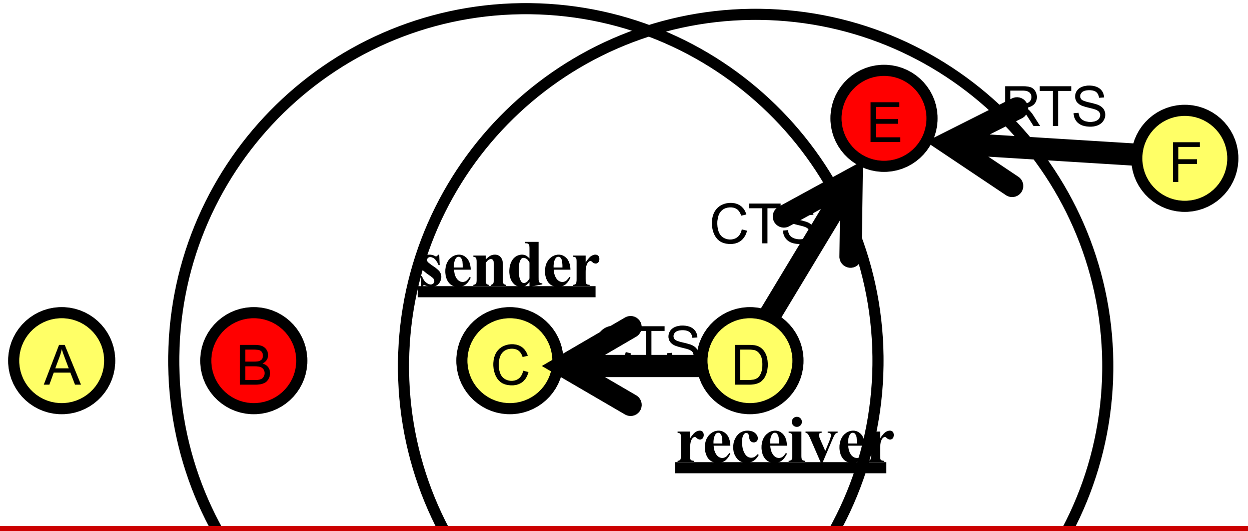


Illustration for DCF Operation



Does it solve hidden receivers?

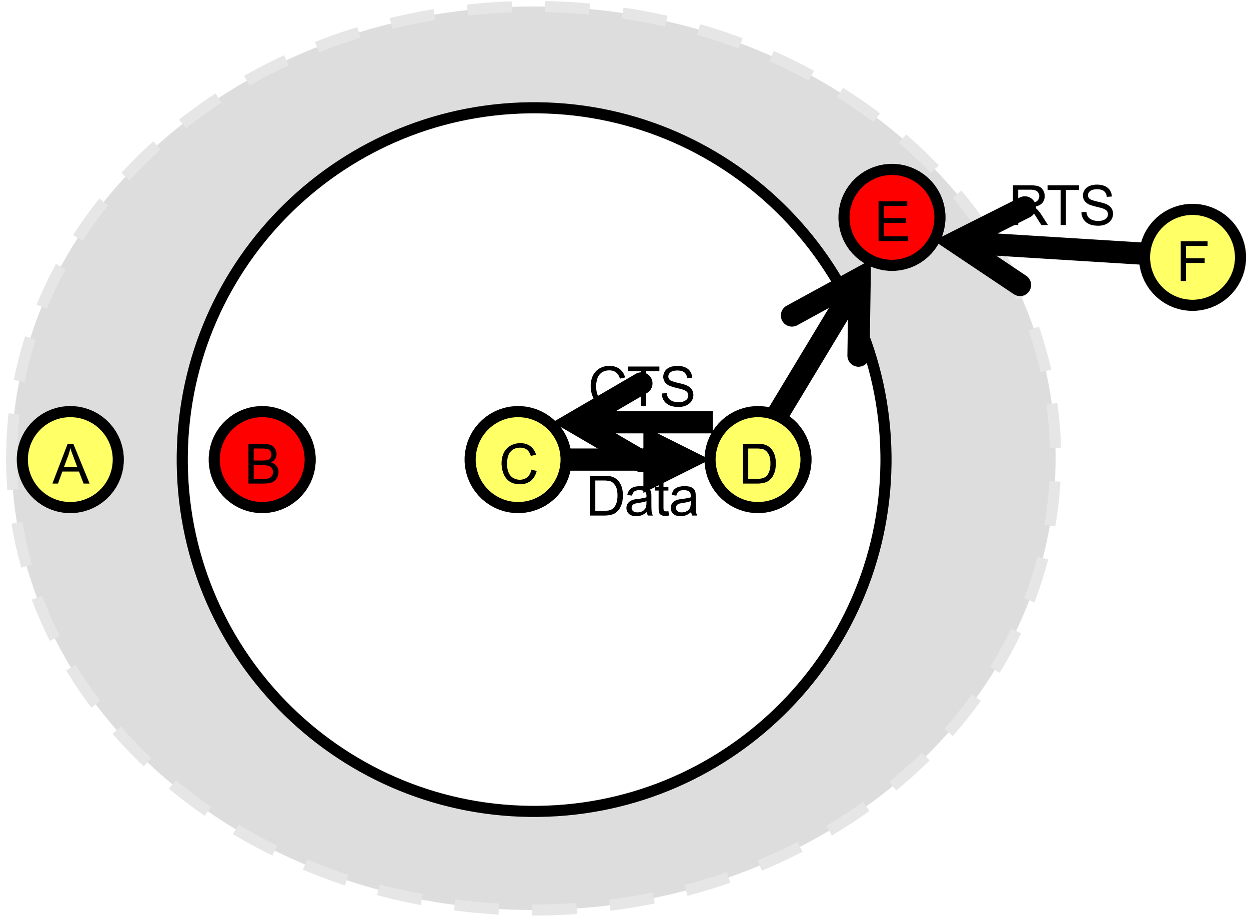
- Assuming carrier sensing zone = communication zone
- Case: C sends RTS to D, D replies CTS to C



E does not receive CTS successfully, nor RTS from C → Can later initiate transmission to D.
Hidden receiver problem @ E remains.

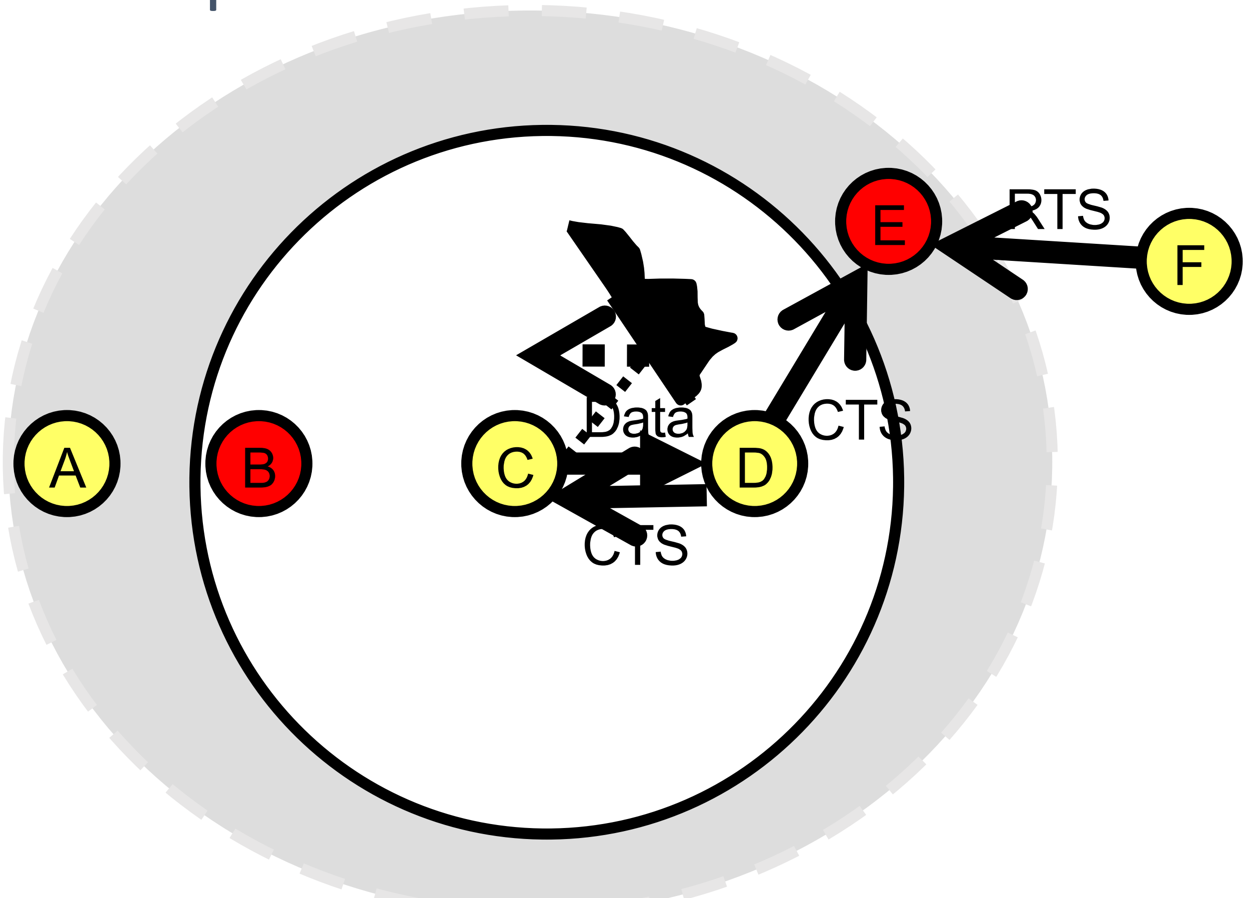
Increase carrier sense range?

- E knows C is sending, but cannot hear what C sends
- E will defer on sensing carrier → no collision!



Barriers/obstructions?

- E doesn't hear C (during DATA transmission) → Carrier sensing does not help



WiFi Mobility Approach

Client-initiated solution

- Client decides that link to its current AP is poor
- Client uses scanning function to find another AP
- Client sends Re-association Request to new AP
- if Re-association Response is successful
  - then client has roamed to the new AP
  - else client scans for another AP
- if AP accepts Re-association Request
  - AP indicates Re-association to the Distribution System
  - Old AP may be notified thru distribution system

WiFi Scanning

- Scanning required for many functions
  - finding and joining a network
  - finding a new AP while roaming
  - initializing an ad hoc network
- 802.11 MAC uses a common mechanism
  - passive or active scanning
- Passive scanning
  - by listening for Beacons
- Action Scanning
  - probe + response

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Mobile Internet

~ 3.5 billion

Smartphone users

~ 31 billion

Interconnected
devices in 2020

114.9 billion in 2019

Mobile app download

Mobile Network Architecture Evolution

2G → **3G** → **4G/5G**

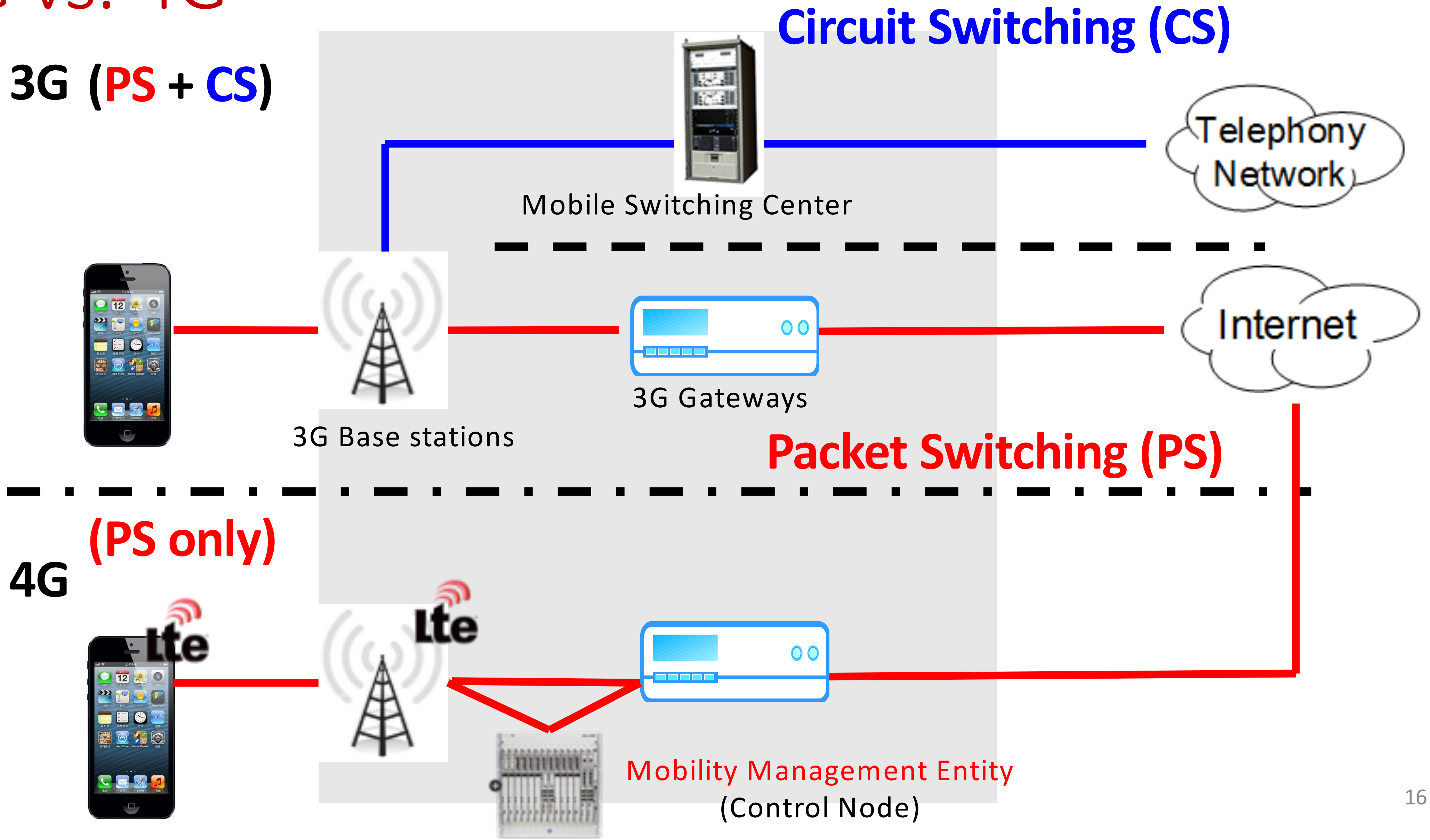
2G
- Circuit-switching for voice

3G
- Circuit-switching for voice
- Packet-switching for data

4G/5G
- Packet-switching for everything
- IP-based

Telecomm Infrastructure → **IP-based Internet**

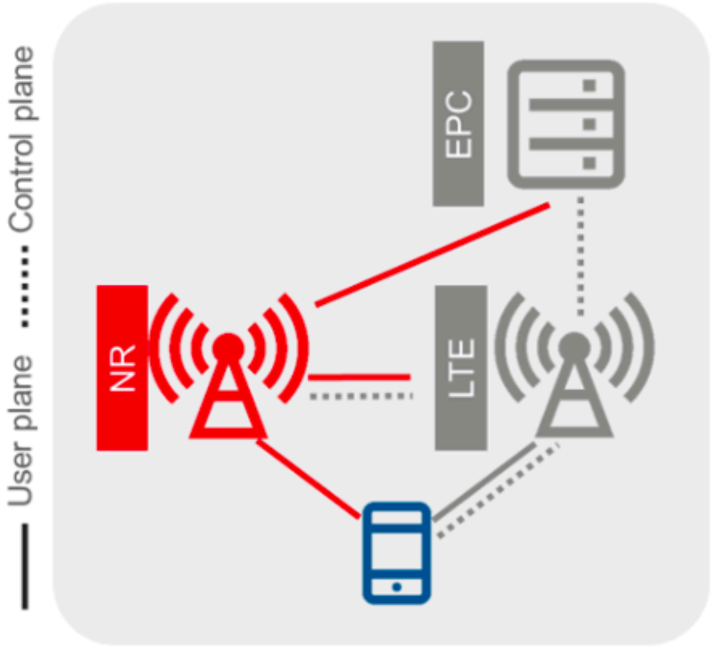
3G vs. 4G

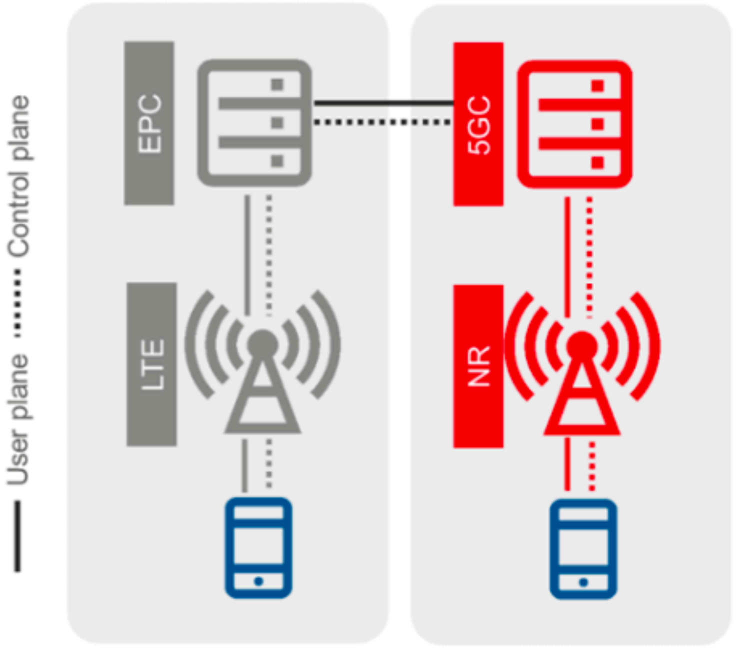


Circuit Switching (CS)
3G (PS + CS)
Telephony Network
Mobile Switching Center
Internet
3G Gateways
3G Base stations
Packet Switching (PS)
(PS only)
4G
lte
lte
Mobility Management Entity
(Control Node)

From 5G NSA (Non-Standalone) to SA

- 5G NSA: 4G architecture and protocol with 5G radio (current 5G)
  - Recall – PHY Innovation drives network design
  - That said, the following description will focus on 4G LTE
    - Even 5G SA shares similar design philosophy

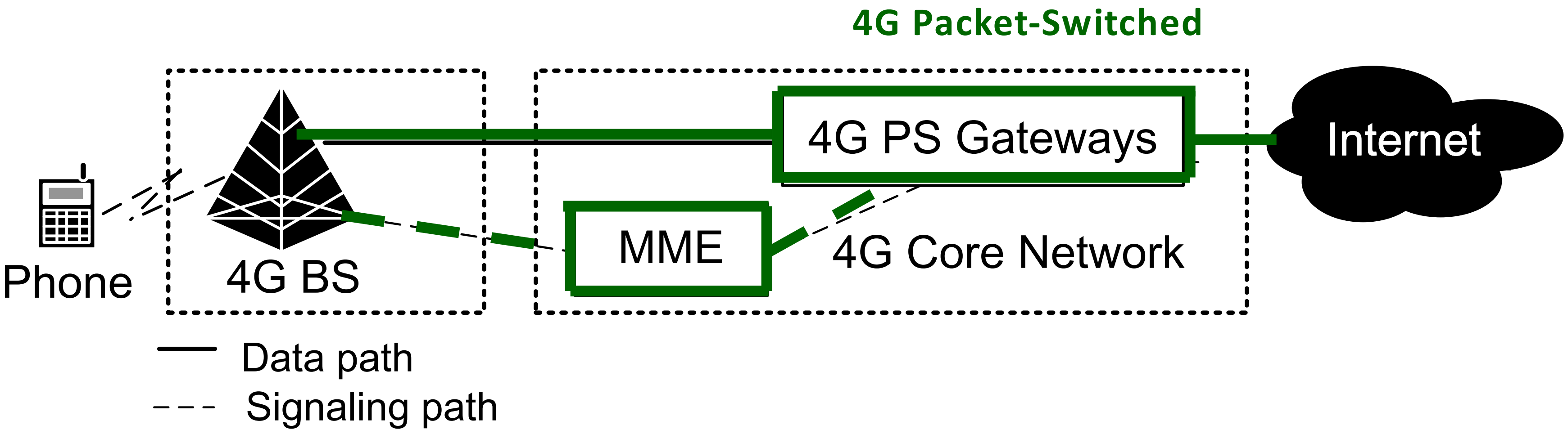




4G LTE Network Architecture

Main components:

- MME (mobility management entity): mobility support
- PS gateway: IP routers
- BS (base station): radio access
- User device: clients requesting for 4G access



Operations on Network Planes

Two main planes in operation in parallel:

- **Data plane**: data content delivery
- **Control plane**: signaling functions for control

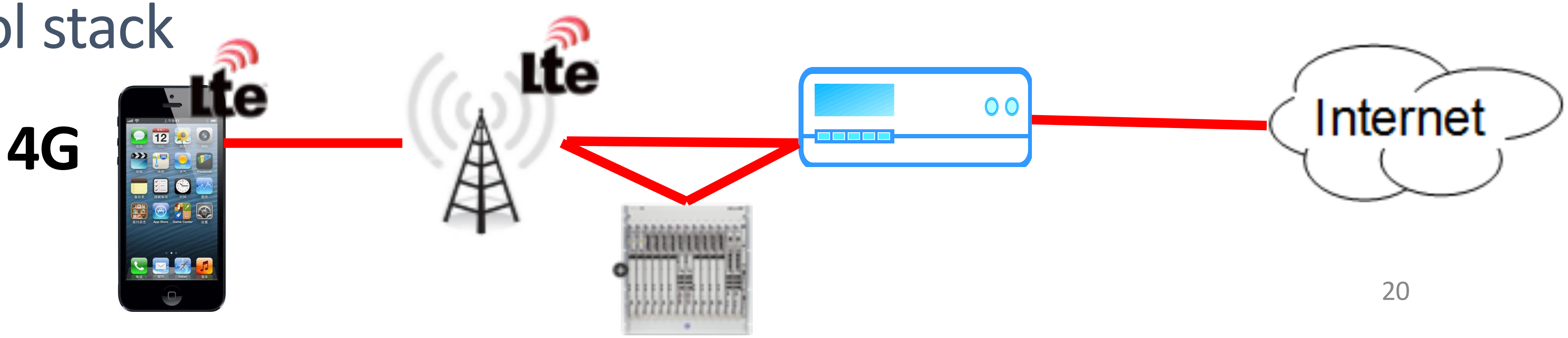
There is an additional plane that works with the above two planes:

- **Management plane**: configurations, monitoring

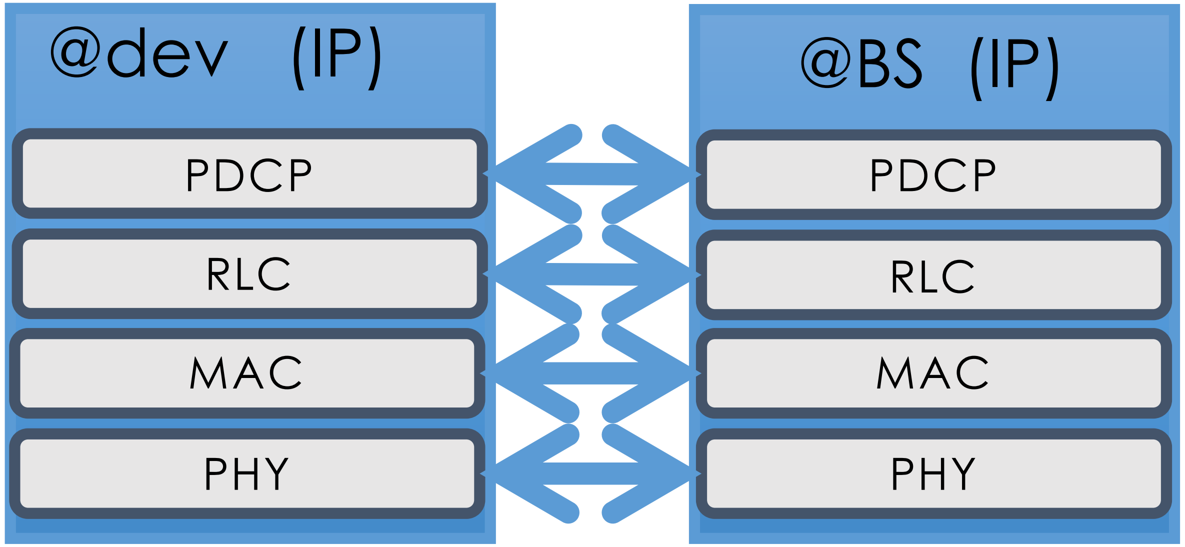
Control Plane Features

- Control plane regulates:
  - Radio resource allocation
  - Mobility management
  - Connectivity
  - Security management, …

- Control-plane signaling message is free of charge
- Control-plane is always offered highest serving priority
- Layered protocol stack

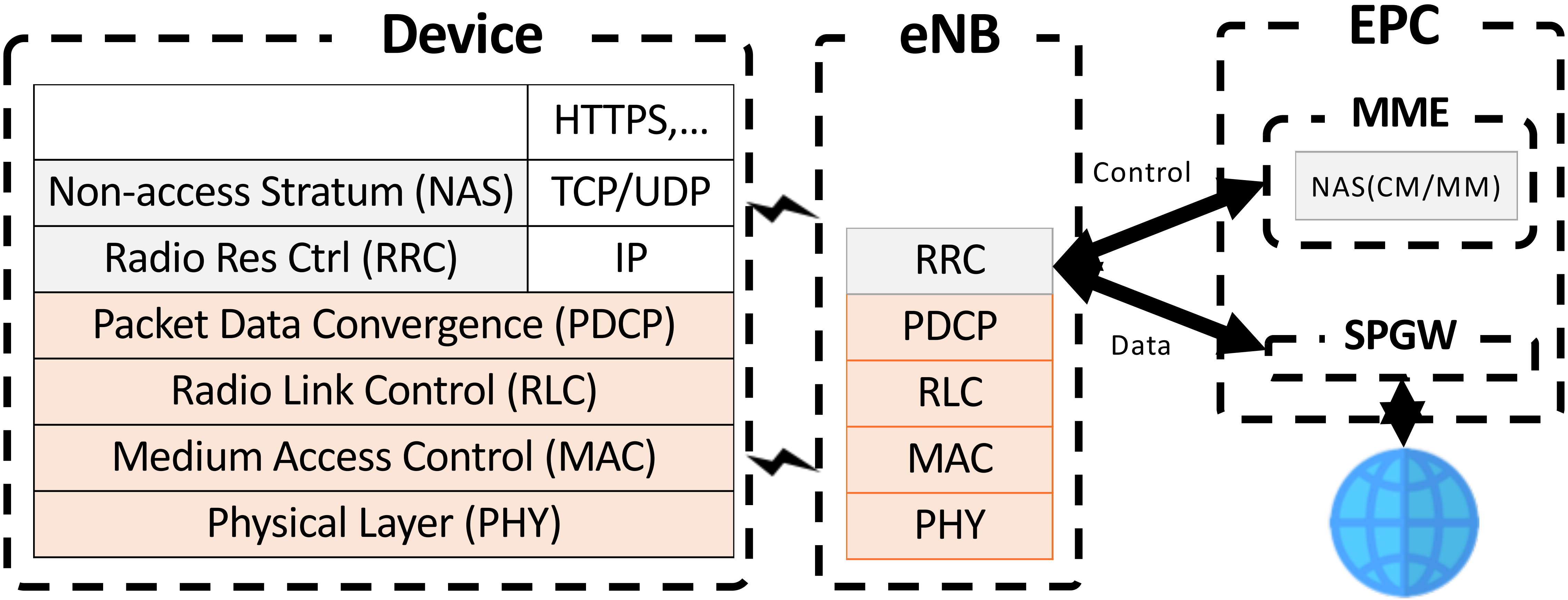


Data-Plane Protocols: IP + Lower layers

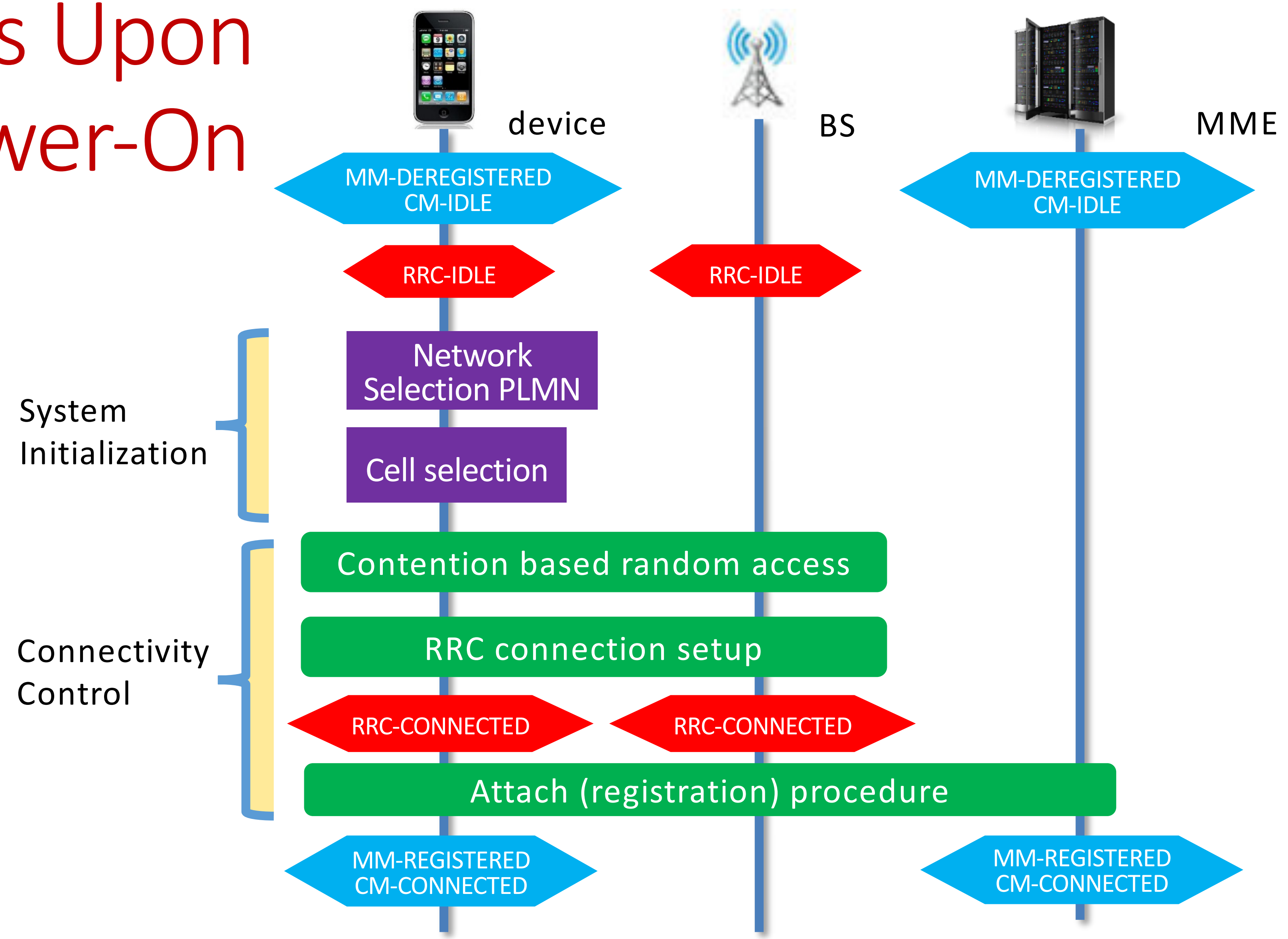


- **Packet Data Convergence Protocol (PDCP)** – header compression, radio encryption
- **Radio Link Control (RLC)** – Readies packets to be transferred over the air interface
- **Medium Access Control (MAC)** – Medium access

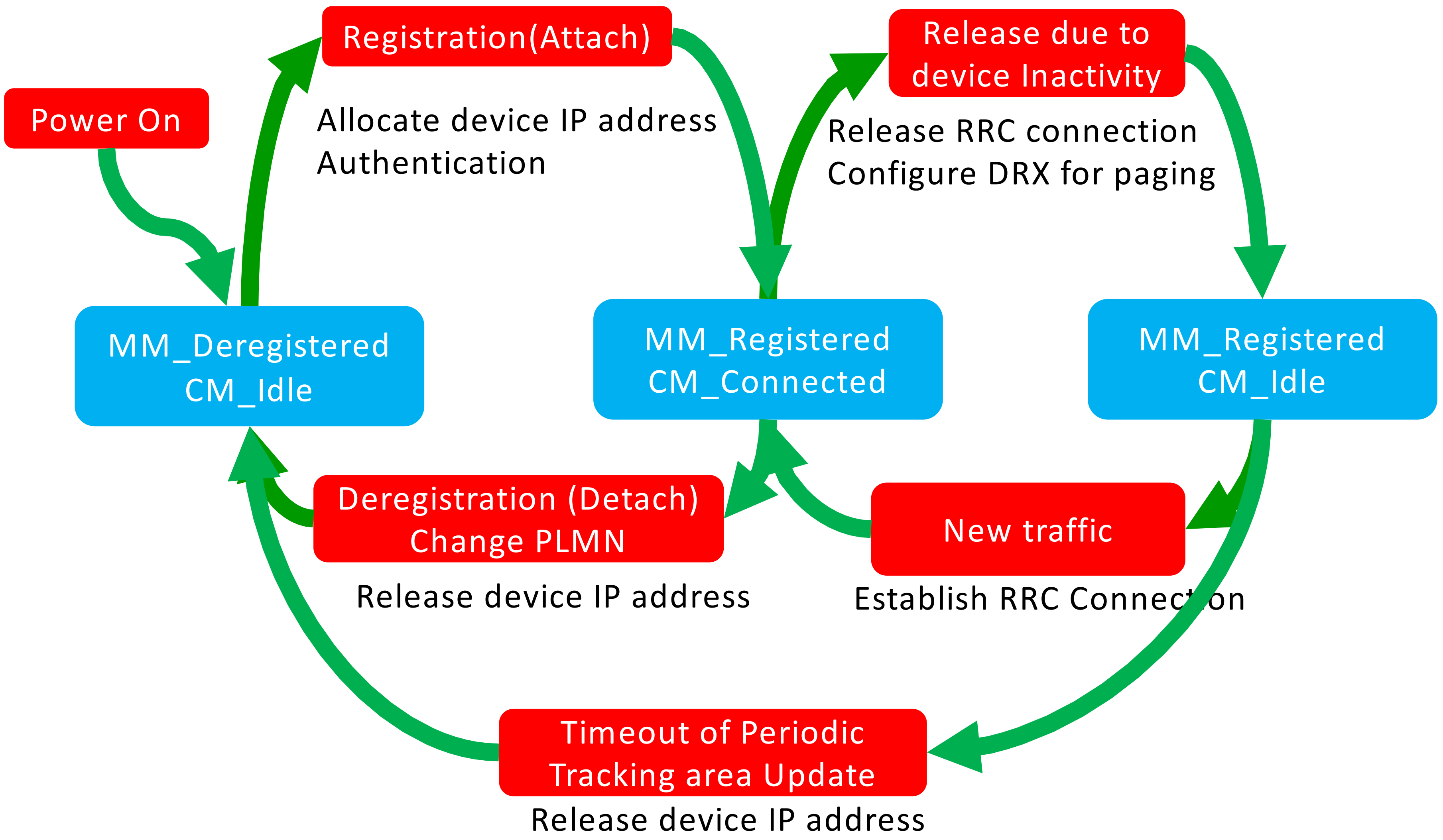
Putting These Together



Procedures Upon Device Power-On

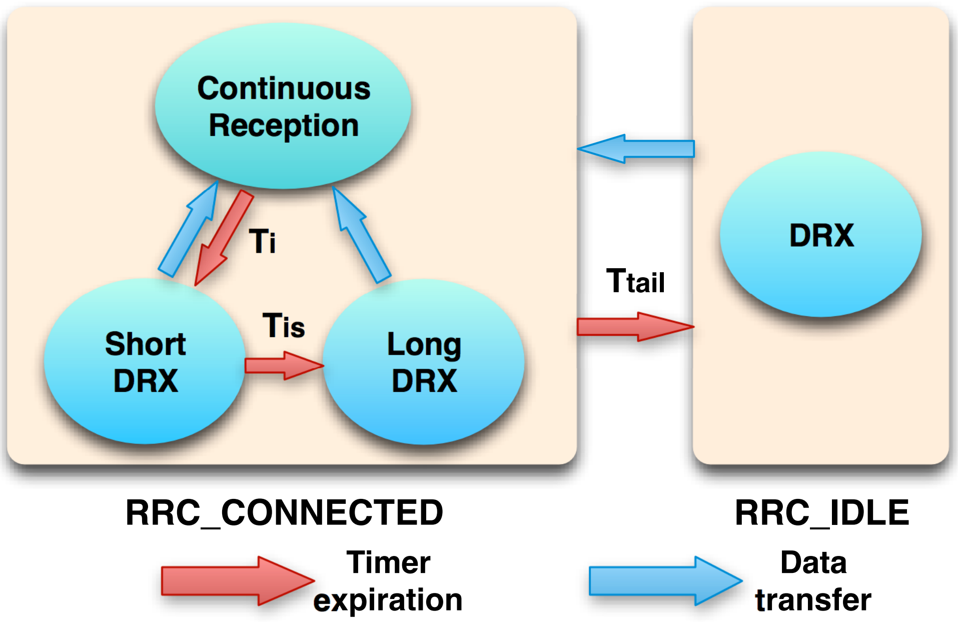


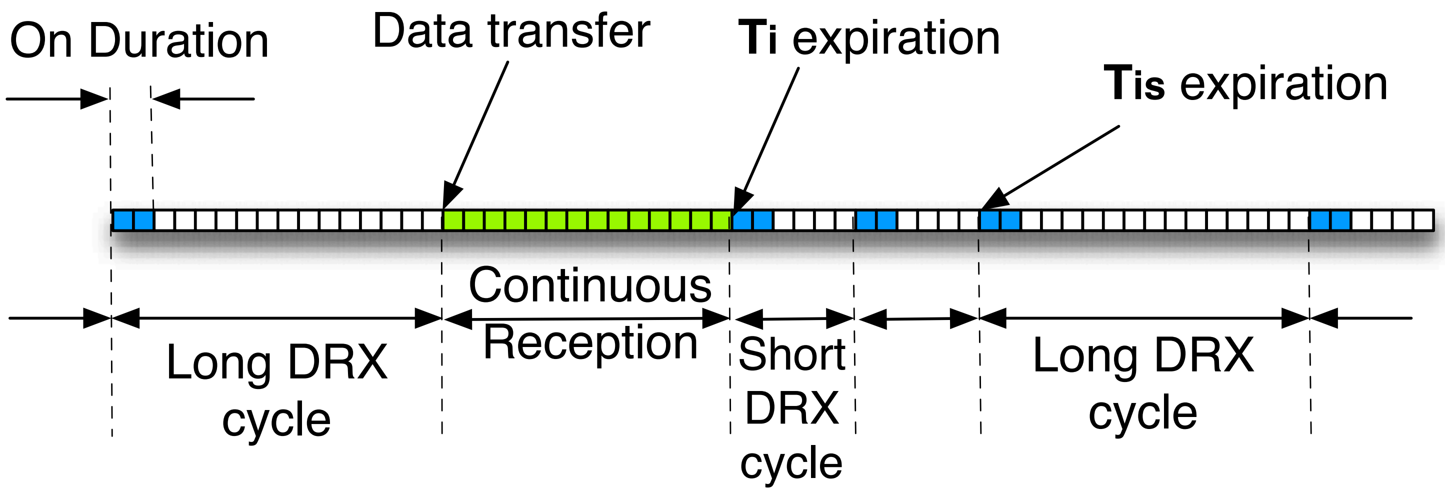
Control Plane State Transitions



Power Management via RRC in LTE

- Device RRC finite state machine
- 2 states: IDLE, CONNECTED
- Discontinuous reception (DRX): monitor a subframe per DRX cycle; receiver sleeps in other sub-frames



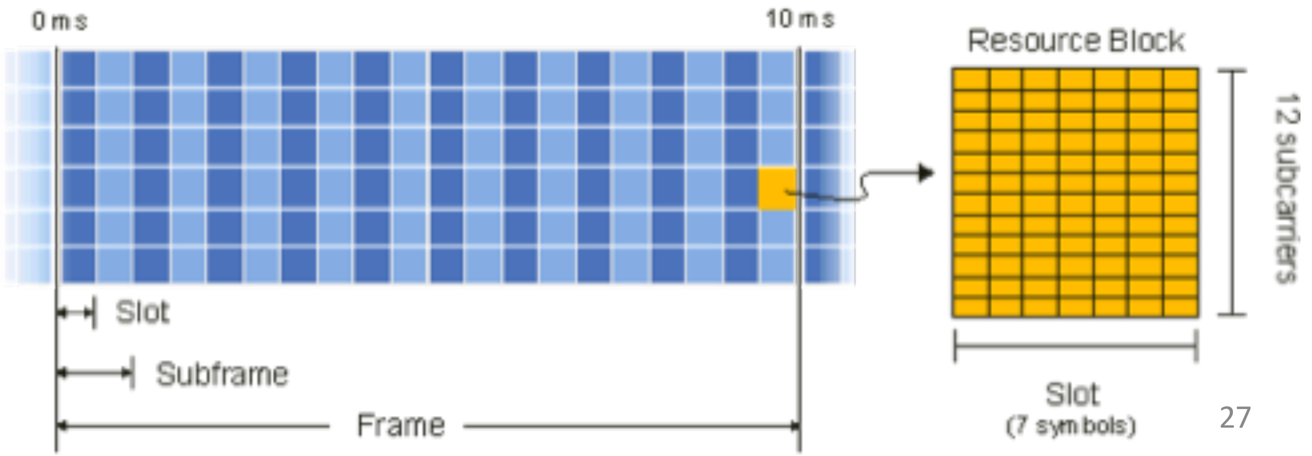


Data Delivery Path

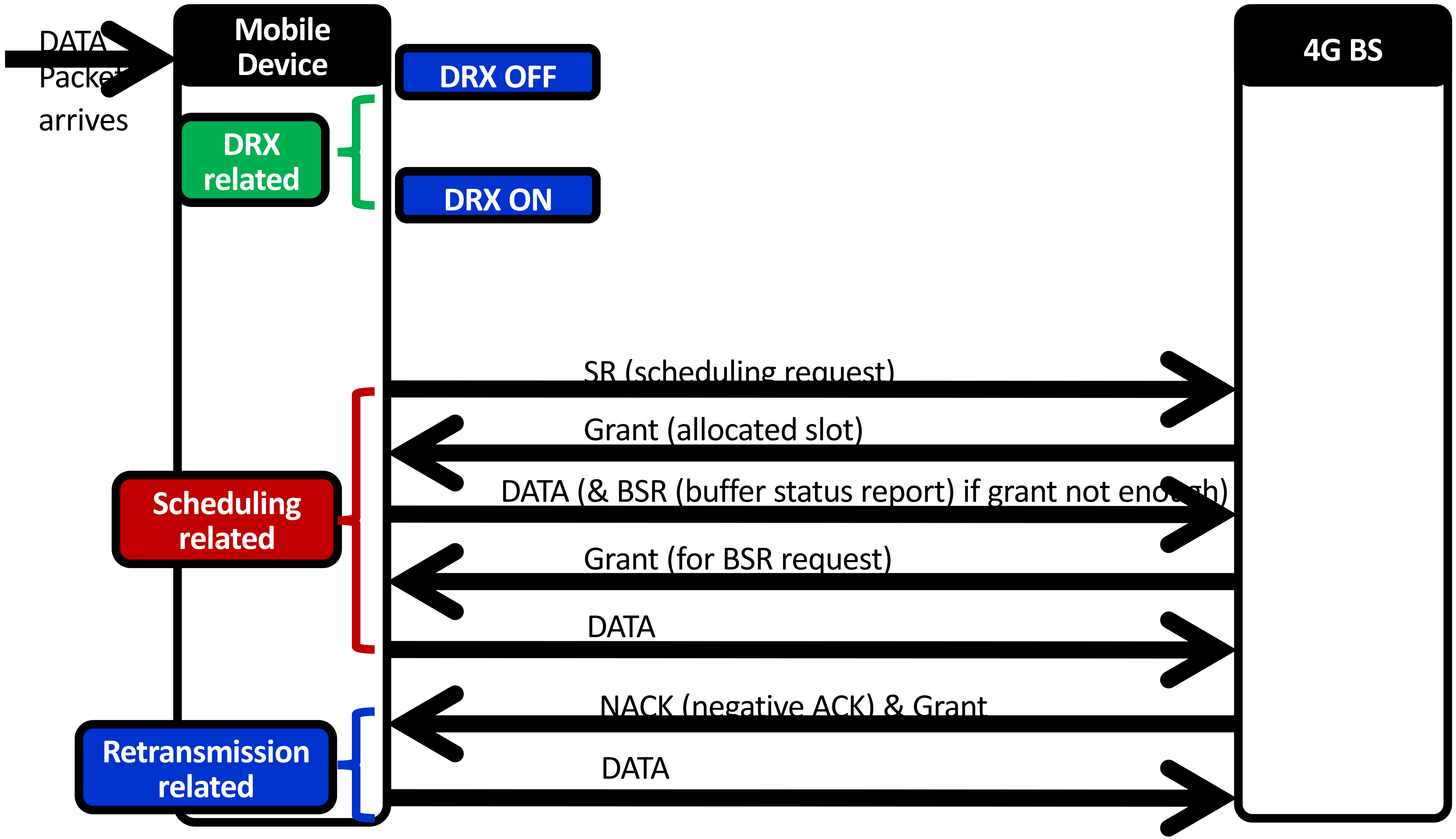
- Simple IP based forwarding
- Data packets do not traverse control-plane elements (like MME)
  - Control plane packets also need to go through data plane protocols as well
  - However, much higher priority for control plane packets

Data Delivery

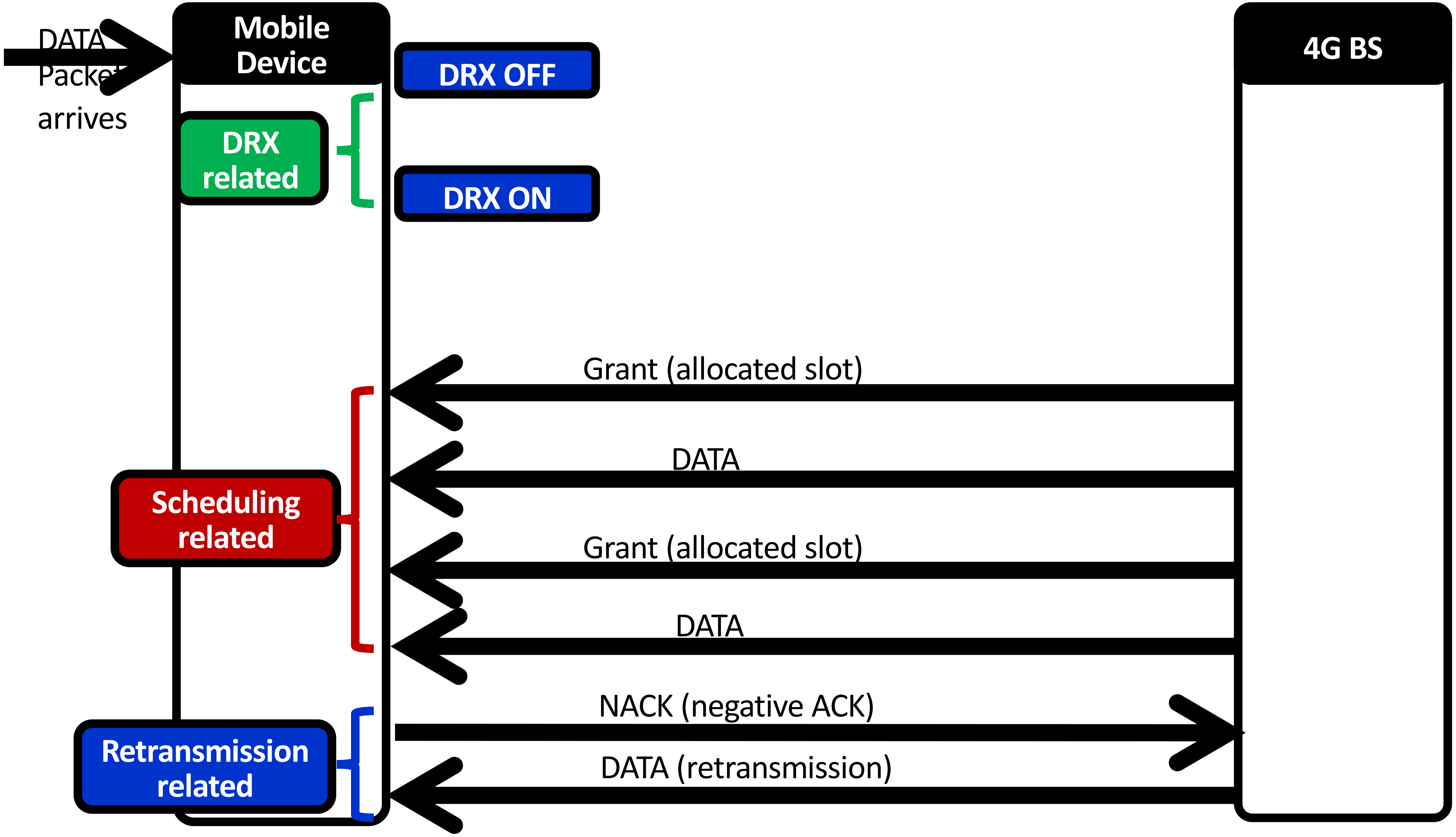
- Recall in WiFi: random access-based plus RTS-CTS
  - Would that be a good idea for cellular?
  - No, considering the number of users, and the licensed band
- Mobile Network: Access control through *scheduling*
  - Every node notifies the base station for resource (Resource block)



Step-by-Step Operation: Uplink data delivery



Step-by-Step Operation: Downlink data delivery



Voice Services in LTE

- How to provide “carrier grade” voice over IP-based 4G LTE?
  - Recall, we no longer have circuit switch in 4G
- Two solutions:
  - #1. **VoLTE** (Voice over LTE): deliver voice **directly in packets (over IP),**
    - but with higher delivery quality
  - #2. **CSFB** (Circuit-Switched Fallback): leverage **CS** in legacy 3G network to deliver voice

Mobility in Mobile Networks

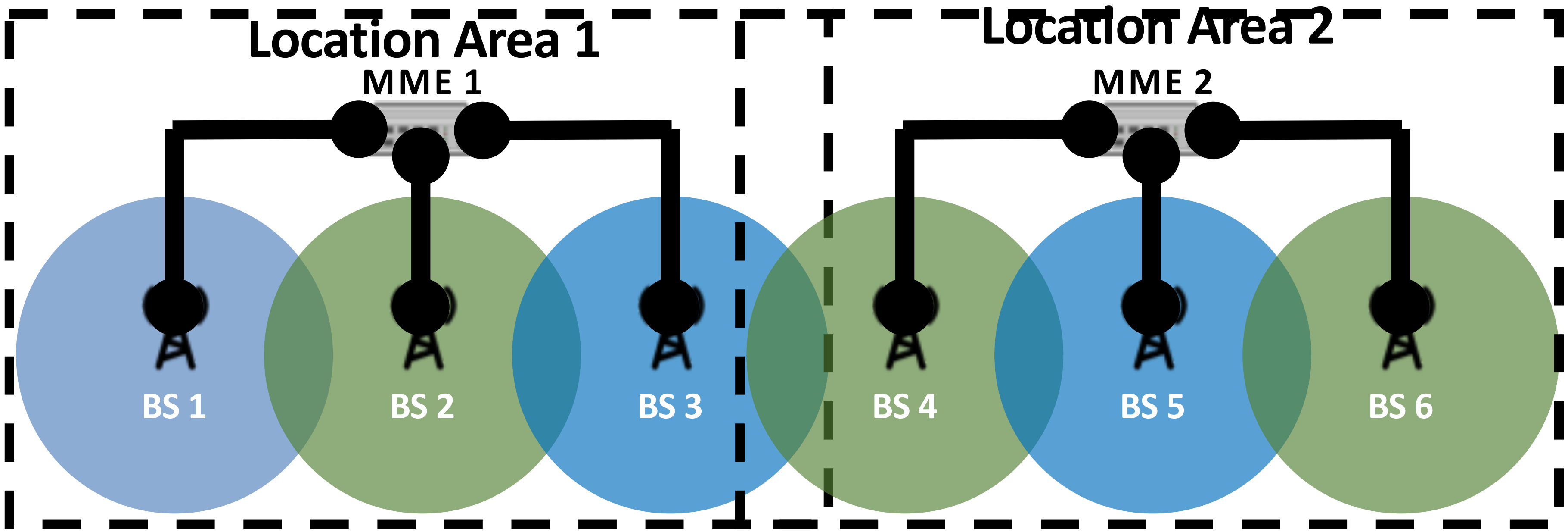
- **Mobility support**: a fundamental service to the evolving Internet
  - Seamless network service to mobile users ***everywhere***

- Cellular network is the ***only*** deployed infrastructure with working solution to **wide-area** mobility support

- We will see
  - Which mobility functions are standardized, which are not?
  - Challenges and guidelines for mobility management

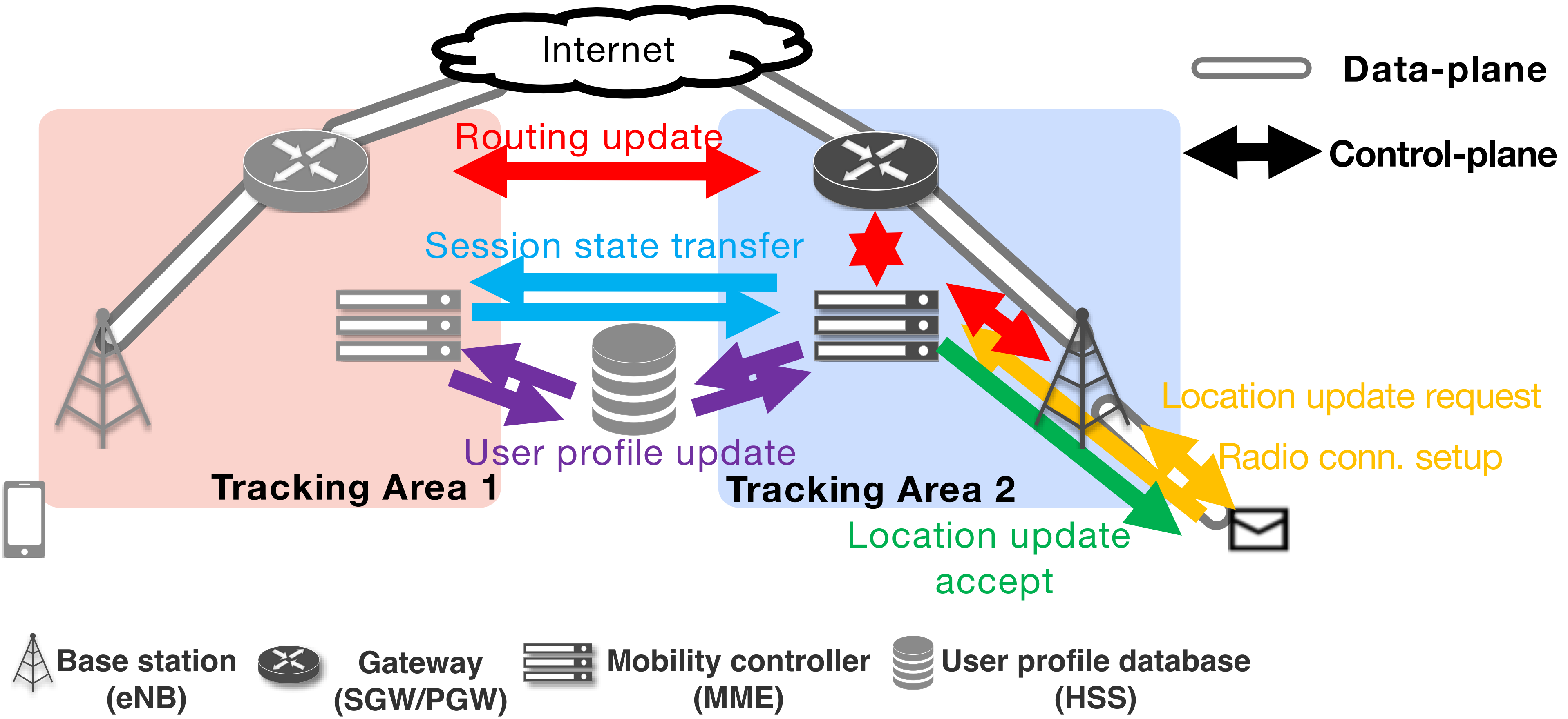
Mobility in Cellular Network since 2G

- **Low-level base station (BS)**: connect mobile device
  - A BS can have multiple cells (sectors), each covering geographical area
- **High-level controller**: MME for each **location area**
  - Track user location, allocate IP, configure data forwarding path



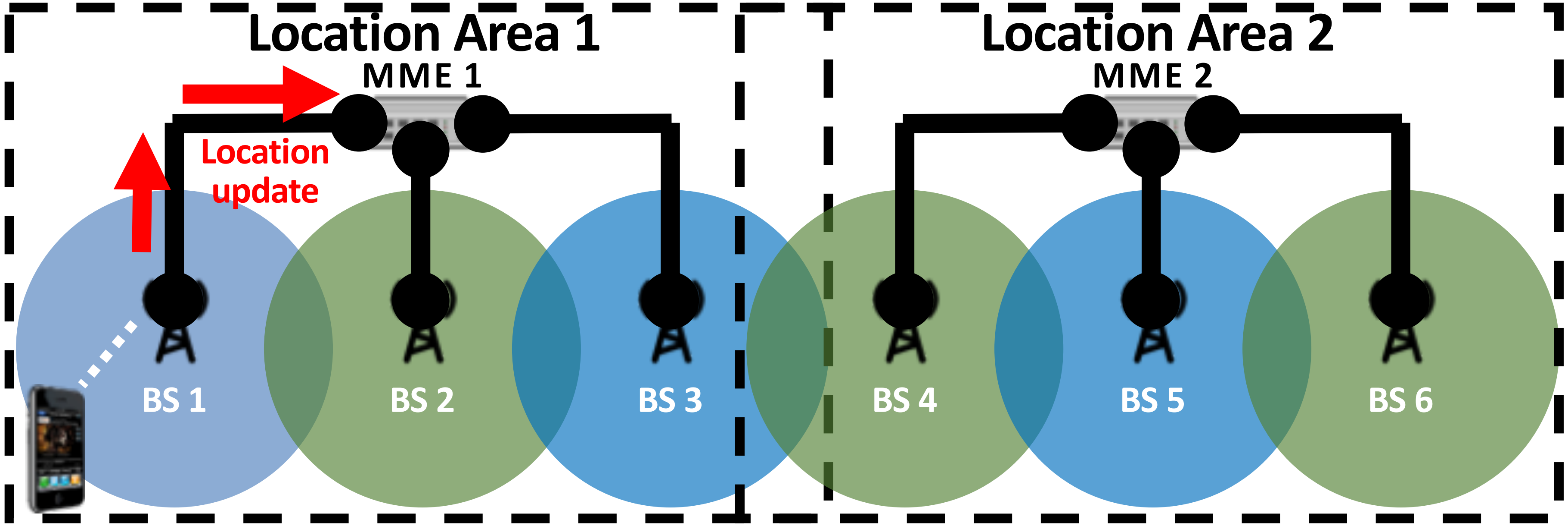
Mobility Support in 4G LTE

- Span on multiple network nodes
- Involve multiple control procedures



2-Tier Mobility Support

- Low-level: Device associates to a BS
  - Association to BS ≠ active connectivity to BS
    - **Idle-state**: the device disconnects from the BS
    - **Active-state**: the device connects to the BS (e.g., for data transfer)
- High-level: the device registers to the controller
  - The network knows **where** the user is



Low Level Handoff (Handover)

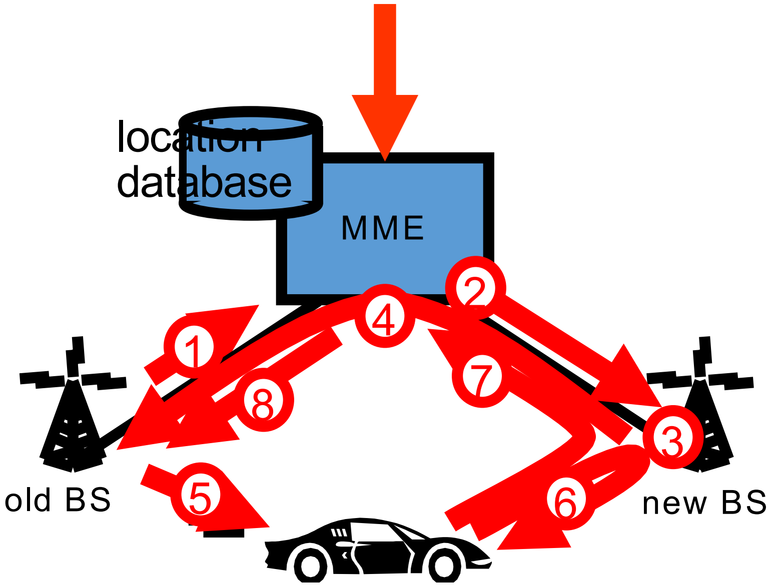
- **Handoff**: mobile device changes its association from the old BS to the new BS
  - One of the basic functions for cellular mobility support
  - Not equivalent to mobility
    - Handoff can happen without mobility (e.g., radio link downgrade)

- Two categories of handoff
  - **Idle-state handoff**: initiated by mobile device
  - **Active-state handoff**: initiated by the old BS
    - Seamless voice/data delivery should be guaranteed

Idle-State Handoff

1. Old BS broadcasts handoff parameters to device
   - Measurement threshold, preference, speed-dependent scaling factors, etc.
2. Mobile device measures the signal strengths of neighboring BSes
   - Signal strengths are averaged to tolerate transient radio variation
3. With the measurement results, mobile device decides the new BS to associate with

Active-State Handoff



1. Old BS informs MME of impending handoff, provides list of 1+ new BSSs
2. MME sets up path (allocates resources) to new BS
3. new BS allocates radio channel for mobile
4. new BS signals MME, old BS: ready
5. old BS tells mobile: perform handoff to new BS
6. mobile, new BS signal to activate new channel
7. mobile signals via new BS to MME: handoff complete. MME reroutes data/call

8 MME-old-BS resources released

Details on Active-State Handoff

- Initiated by old BS, assisted by the mobile device