

UiO : Faculty of Mathematics and Natural Sciences
University of Oslo

Department of Informatics
Networks and Distributed Systems (ND) group

IN3230/4230

Wireless Communications - II

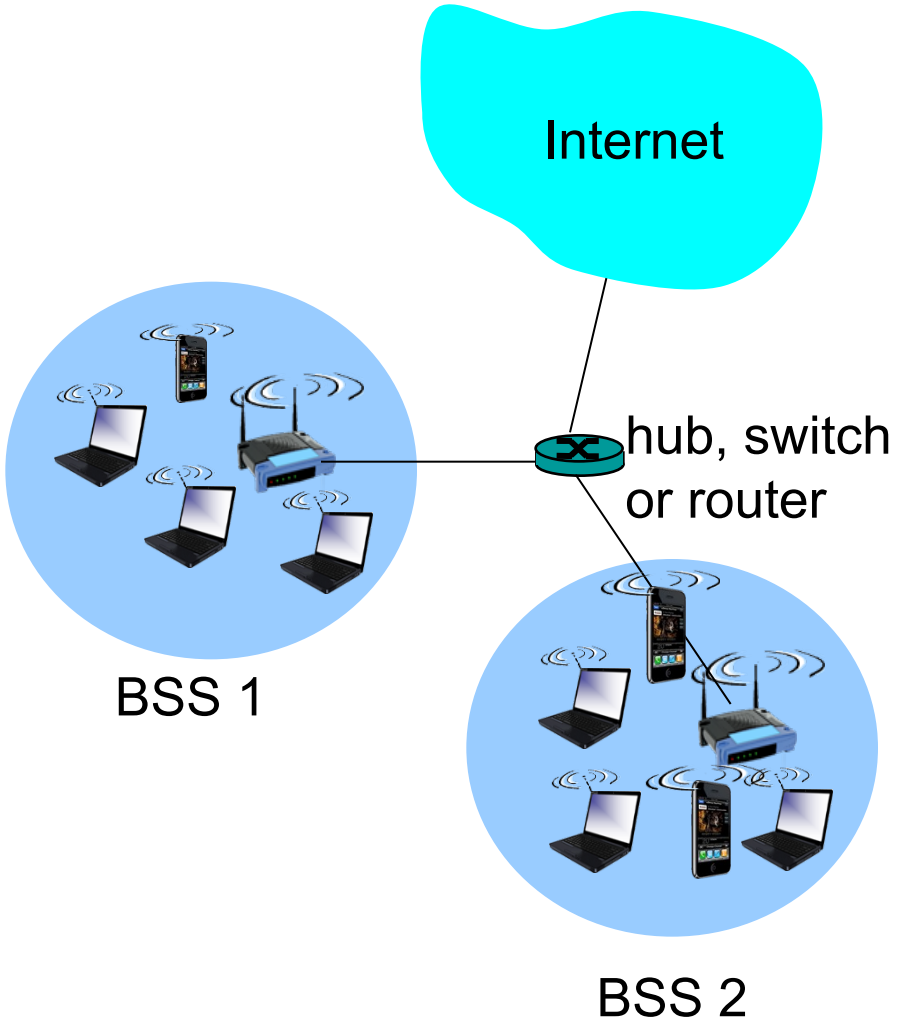


Özgü Alay
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Outline

- Wireless Systems - Short Range
  - Wifi
  - Bluetooth
- Mobile Broadband Networks
  - Building Blocks
  - Performance
  - Operations

Wireless LAN Architecture



- wireless host communicates with access points (AP)
- The owner of the AP becomes the operator
- Basic Service Set (BSS) in infrastructure mode contains:
  - wireless hosts
  - access point (AP): base station
  - ad hoc mode: hosts only

802.11: Channels, association

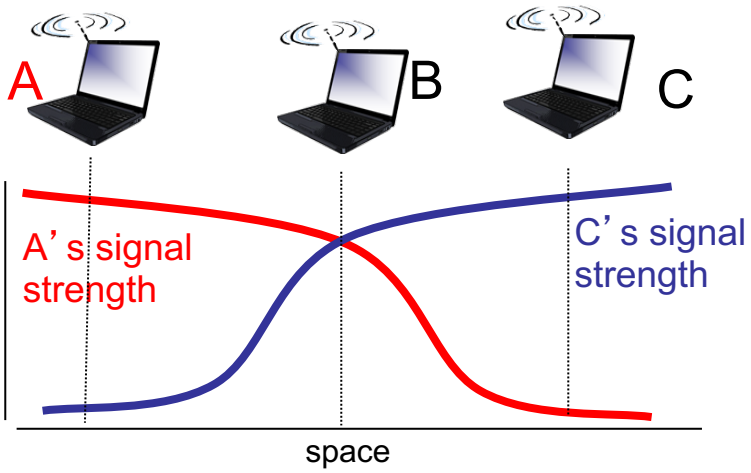
- spectrum divided into channels at different frequencies
  - AP admin chooses frequency for AP
  - interference possible: channel can be same as that chosen by neighboring AP!
- arriving host: must associate with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - then may perform authentication
  - then typically run DHCP to get IP address in AP's subnet



BSS

Wireless network characteristics (1)

Multiple wireless senders and receivers create additional problems (beyond multiple access):

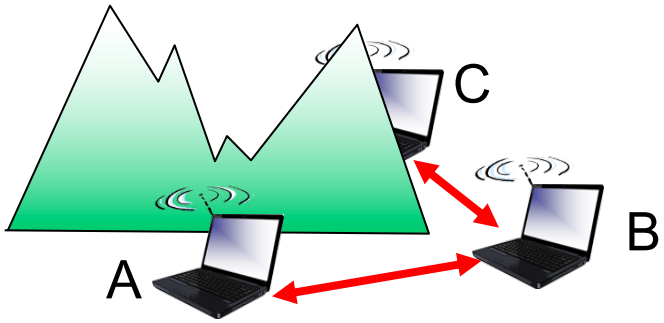


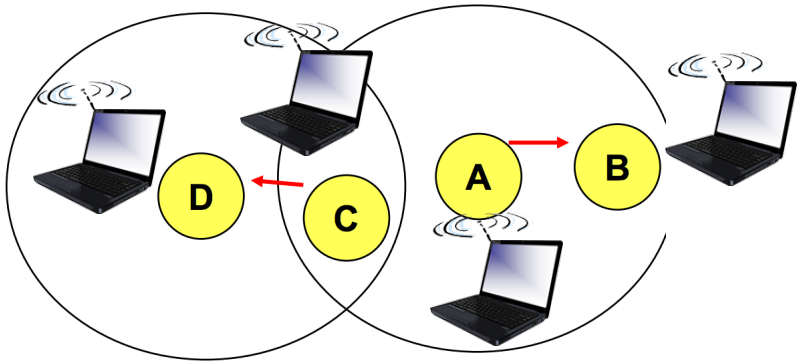
Signal attenuation:

- B, A hear each other
- B, C hear each other
- A, C can not hear each other interfering at B

Wireless network characteristics (2)

Multiple wireless senders and receivers create additional problems (beyond multiple access):





Hidden terminal problem

- B, A hear each other
- B, C hear each other
- A, C can not hear each other means A, C unaware of their interference at B

Exposed terminal problem

- C wants to send D, A wants to send B
- When A transmits to B, C waits
- But D is outside of the range of A, so the wait is unnecessary

Carrier Sense Multiple Access (CSMA)

- Listen Before Talk (LBT):
  - channel idle: transmit entire frame
  - channel busy: defer transmission
    - 1-Persistent CSMA: retry immediately when channel becomes idle
    - P-Persistent CSMA: retry immediately with probability p when channel becomes idle
    - Non-persistent CSMA: retry after random interval

What happens if two senders do this?

- Human analogy: don't interrupt others!
  - Politicians are sometimes 1-Persistent…

- Collisions
  - sender 1 may not immediately see 2's transmission (propagation delay)
  - entire frame transmision time wasted

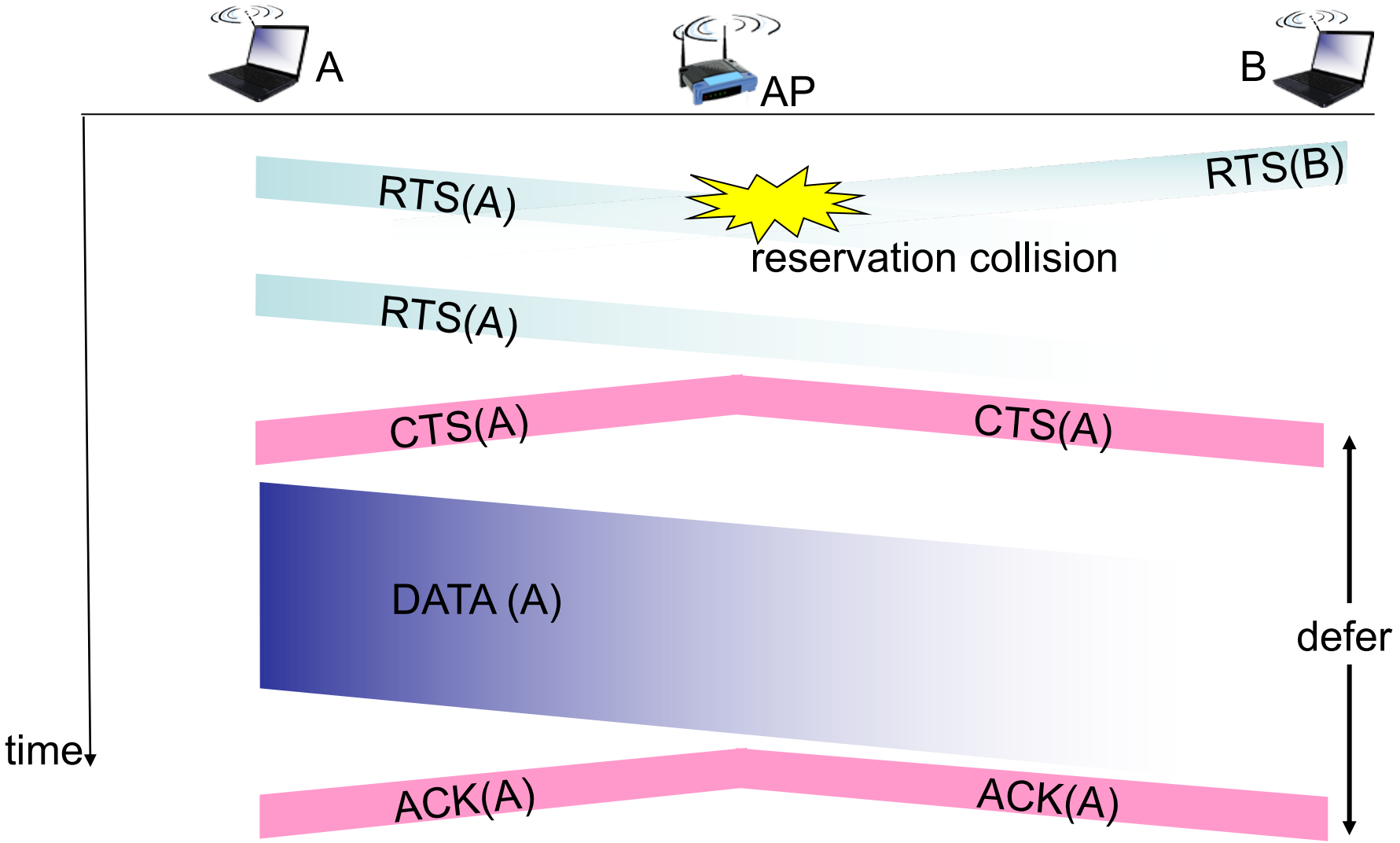
Avoiding collisions

Idea: allow sender to "reserve" channel rather than random access of data frames: avoid collisions of long data frames

- sender first transmits *small* request-to-send (RTS) packets to BS using CSMA
  - RTSs may still collide with each other (but they're short)
- BS broadcasts clear-to-send CTS in response to RTS
- CTS heard by all nodes
  - sender transmits data frame
  - other stations defer transmissions

avoid data frame collisions completely using small reservation packets!

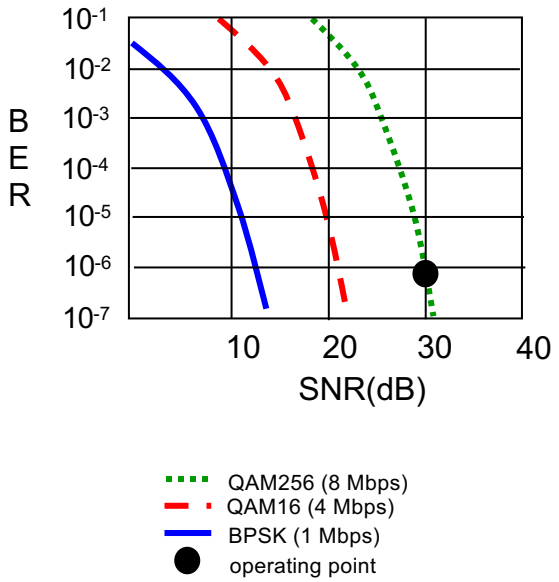
Collision Avoidance: RTS-CTS exchange



802.11: advanced capabilities

Rate adaptation

- base station, mobile dynamically change transmission rate (physical layer modulation technique) as mobile moves, SNR varies



1. SNR decreases, BER increase as node moves away from base station

2. When BER becomes too high, switch to lower transmission rate but with lower BER

IEEE 802.11 Wireless LAN

802.11b
- 2.4 GHz range
- up to 11 Mbps

802.11a
- 5 GHz range
- up to 54 Mbps

802.11g
- 2.4 GHz range
- up to 54 Mbps

802.11n: MIMO
- 2.4/5 GHz range
- up to 600 Mbps

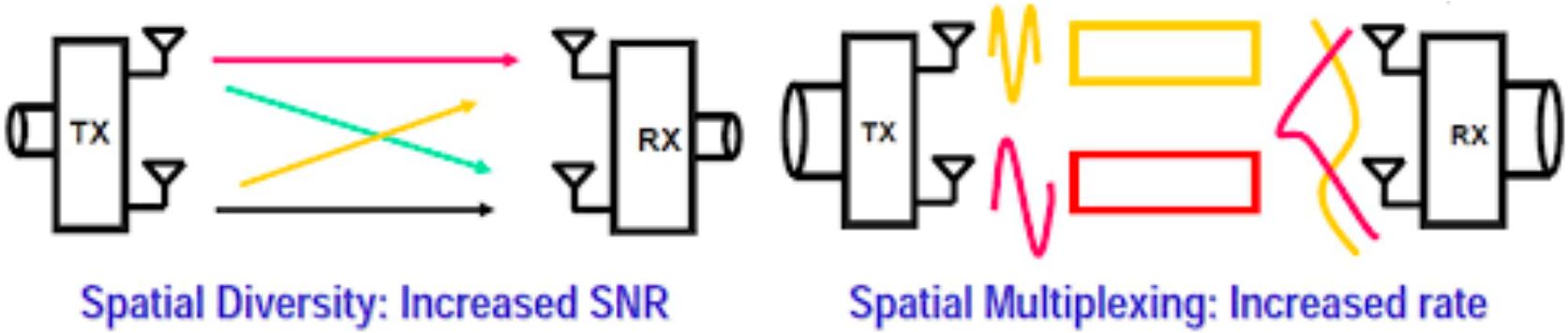
802.11ac: MU-MIMO
- 5 GHz range
- up to 3.2 Gbps

802.11ad: mmWave
- 2,4/5/60 GHz range
- up to 7 Gbps

Recap on different Types of MIMO

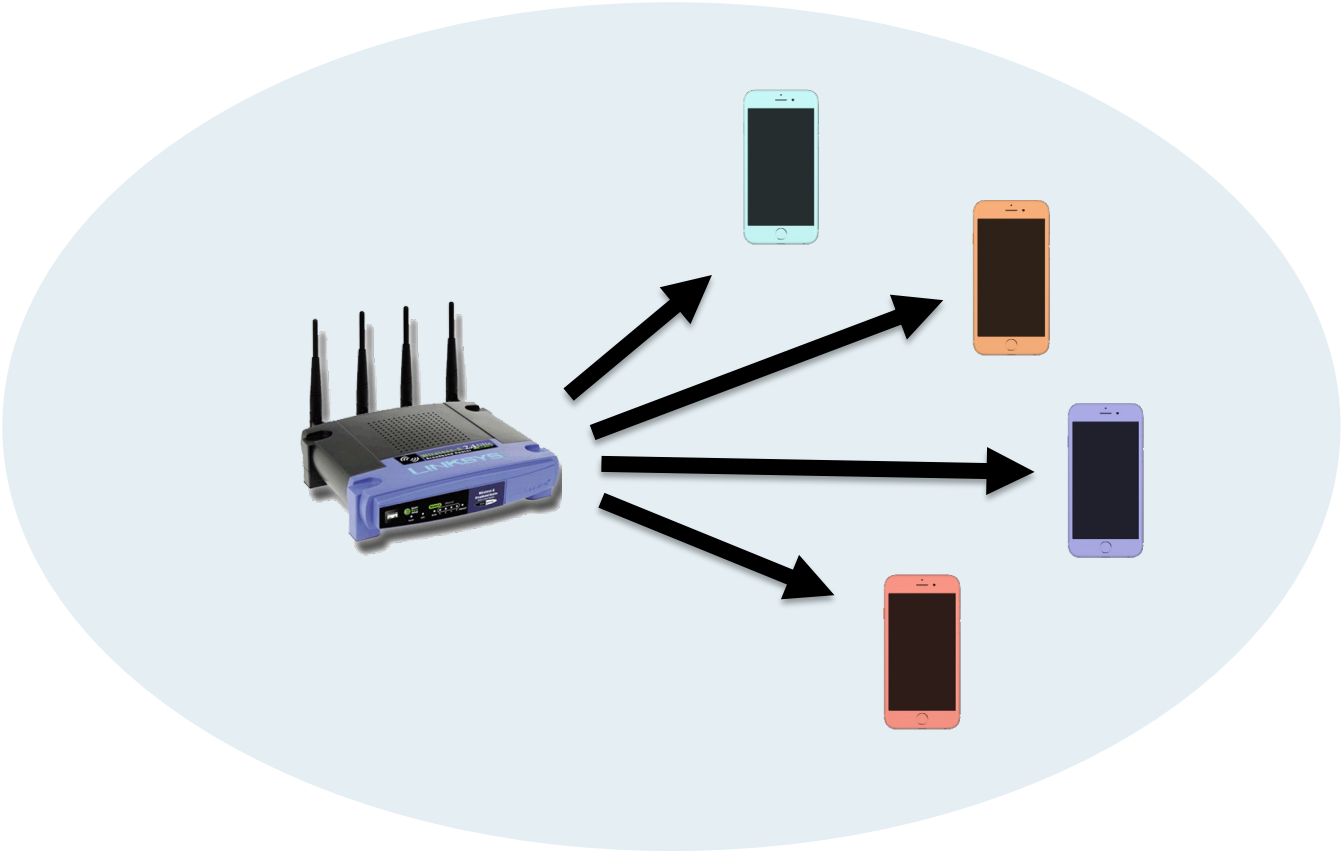
- **Space Time Transmit Diversity (STTD)** - The same data is coded and transmitted through different antennas, which effectively doubles the power in the channel. This improves Signal Noise Ratio (SNR) for cell edge performance.

- **Spatial Multiplexing (SM)** - SM delivers parallel streams of data by exploiting multi-path. It can double (2x2 MIMO) or quadruple (4x4) capacity and throughput. SM gives higher capacity when RF conditions are favorable and users are closer to the base station.



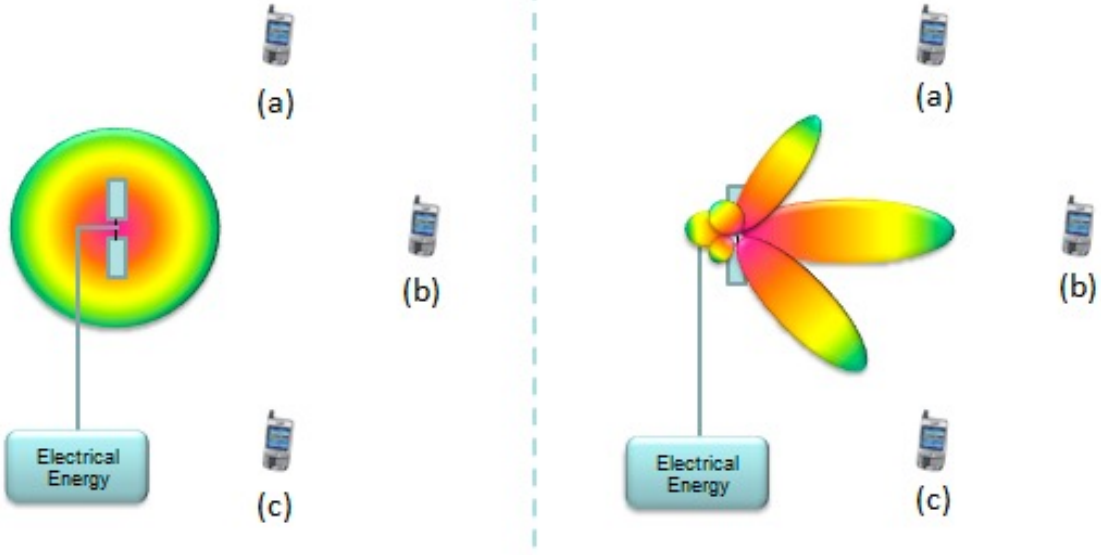
802.11n MIMO

- The 802.11n standard enables spatial multiplexing, improving data rates and link robustness
- Transmission to each of them sequentially—underutilizing the spatial resources available at the access point.



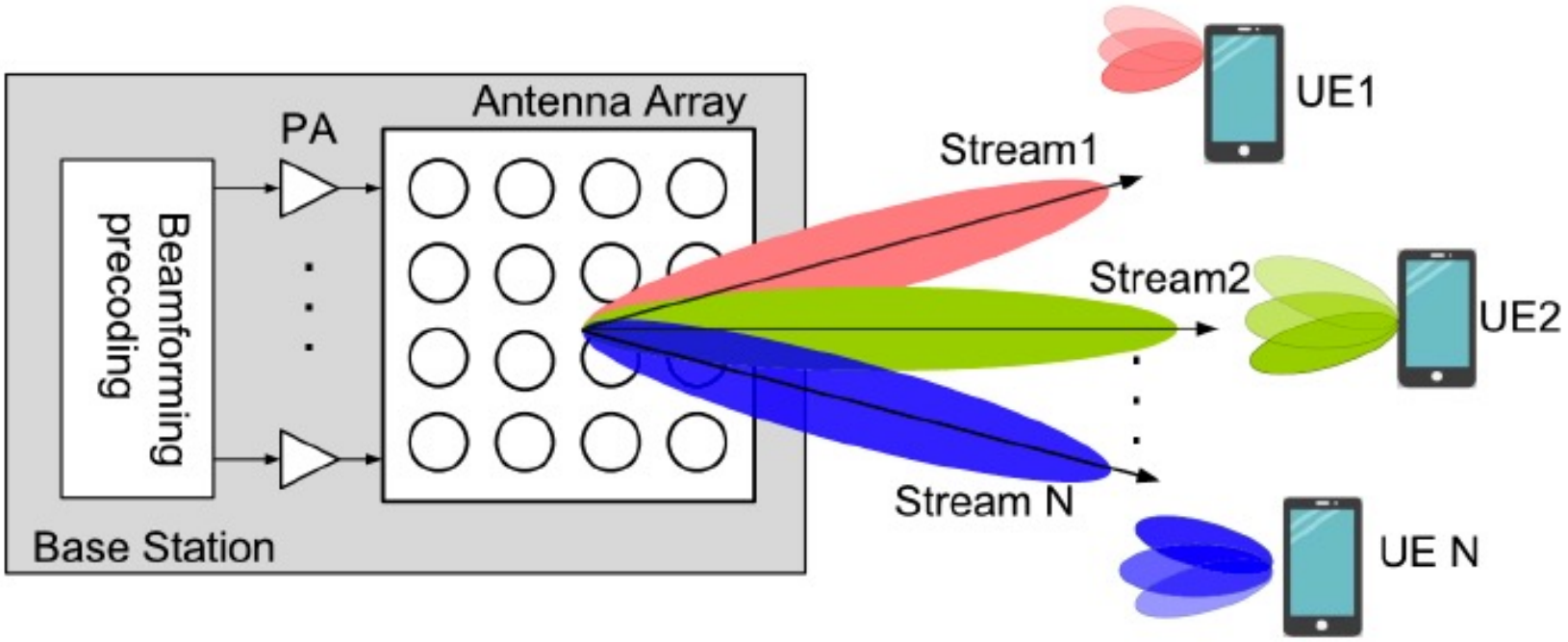
Recap on MIMO Beamforming

- **Beamforming** is a signal processing technique used for directional signal transmission or reception.
- Elements of an antenna array is combined in such a way that signals at particular angles experience constructive interference while others experience destructive interference.



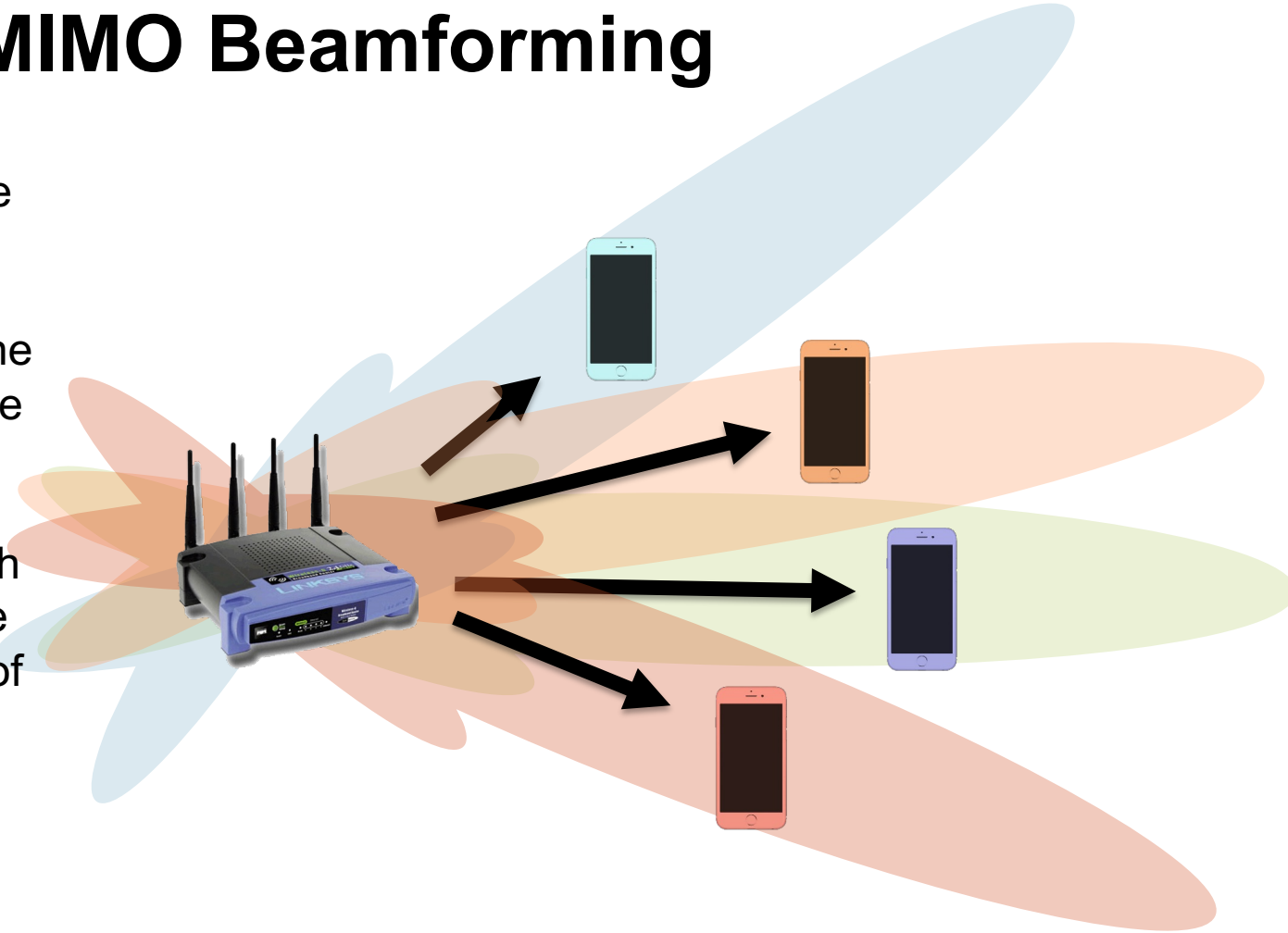
< Case 1 > < Case 2 >

Beamforming and Steering



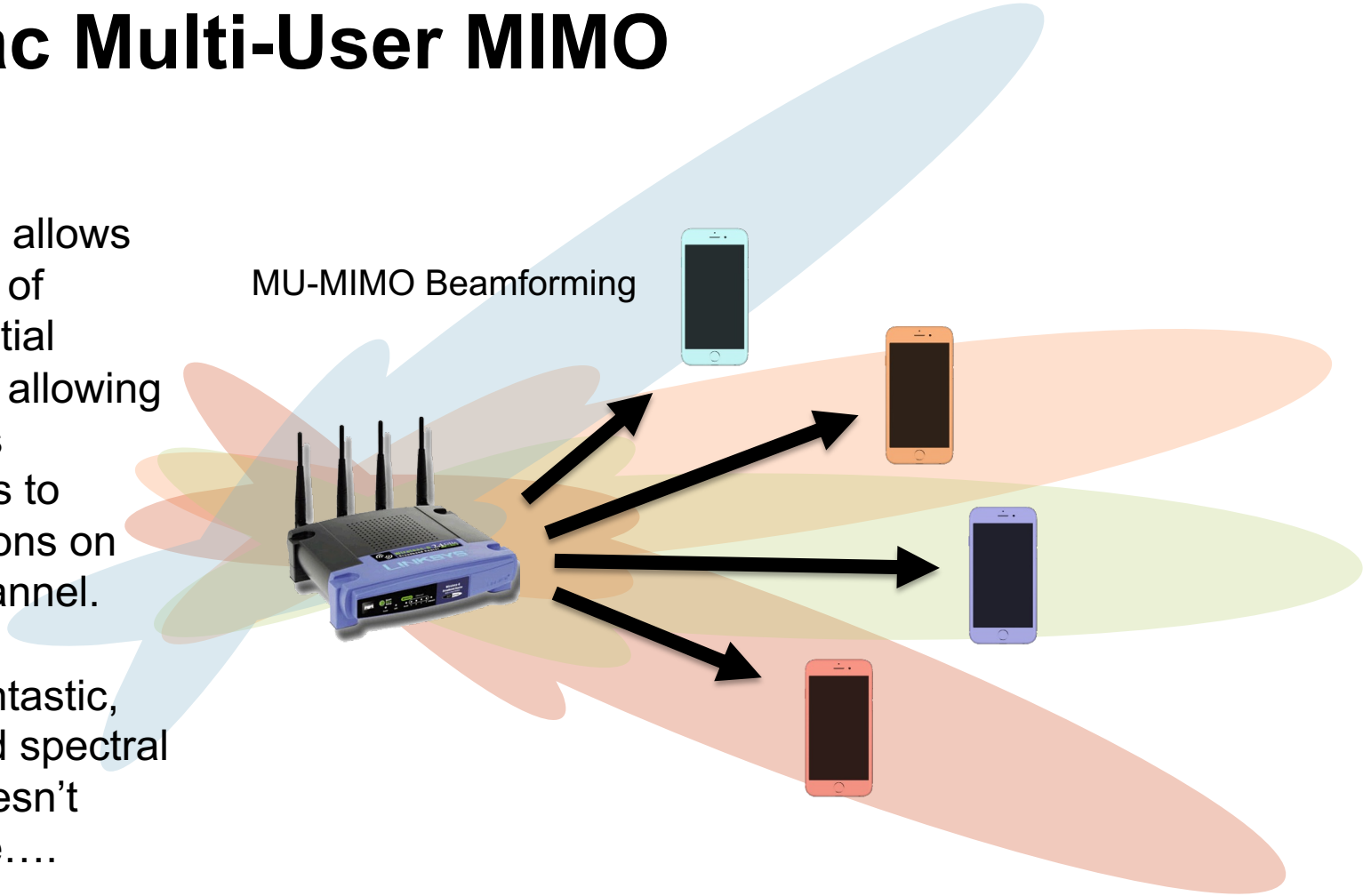
802.11ac MIMO Beamforming

- We can increase the link SNR by coherently beamforming with the antennas at the base station
- Still limited to communications with one station at a time on a small number of spatial streams, resulting in an underutilization of spatial resources.

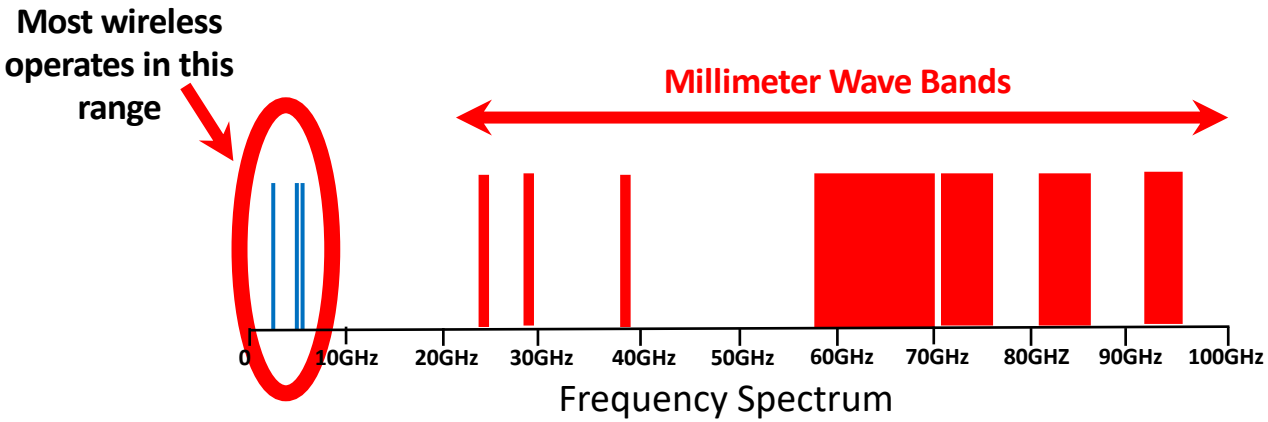


802.11ac Multi-User MIMO

- Multi-user beamforming allows full utilization of available spatial resources by allowing simultaneous transmissions to multiple stations on the same channel.
- And while fantastic, the increased spectral efficiency doesn't come for free….



How does mmWave work?

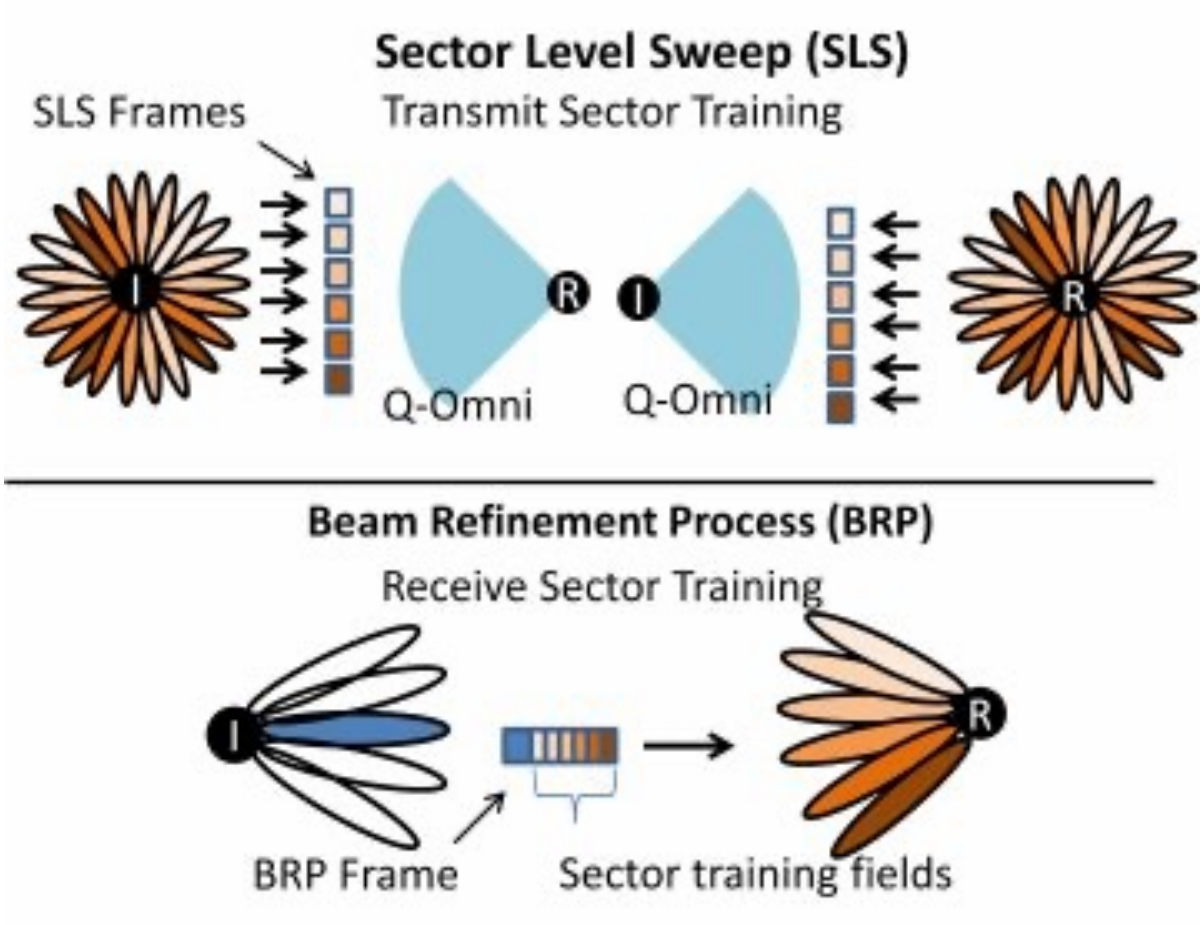


mmWave: High attenuation -> beamforming

Challenge: Beam alignment



802.11ad mmWave



Beamforming Training in 802.11ad

Summary of new 802.11 technologies

	802.11n	802.11ac	802.11ad
Throughput	600 Mbps	3.2 Gbps	Up to 7 Gbps
Coverage	Home, 70 m	Home, 30 m	Room, <5m
Freq. Band	2.4/5 GHz	5 GHz	2.4/5/60 GHz
Antennas	4 x 4 MIMO	8 x 8 MIMO	>10 x 10 MIMO
Applications	Data, Video	Video	Uncompressed Video

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Bluetooth

- Bluetooth is a wireless technology standard for exchanging data over short distances from fixed and mobile devices, and building personal area networks
- In 1994 Bluetooth was developed by Ericsson.
- It is named after a Danish king, whose nickname was Bluetooth because he brought the Danish tribes together.





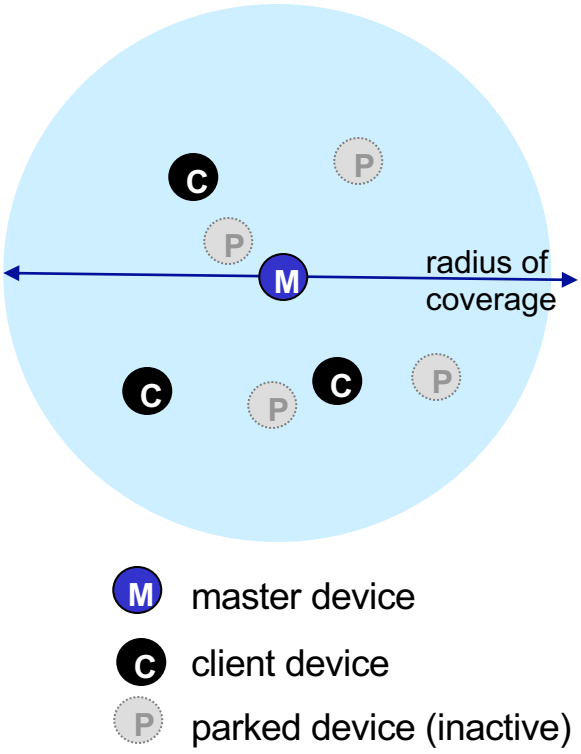






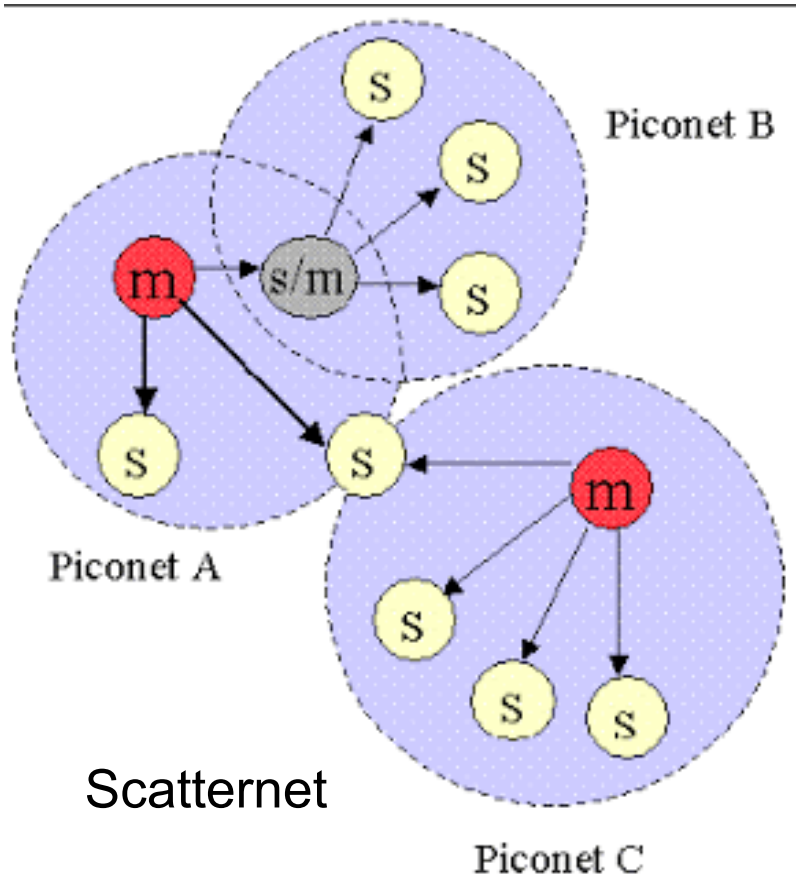
Personal area networks: Bluetooth

- less than 10 m diameter
- replacement for cables (mouse, keyboard, headphones)
- ad hoc: no infrastructure
- 2.4-2.5 GHz ISM radio band, up to 3 Mbps
- master controller / clients devices:
  - master polls clients, grants requests for client transmissions



How it works?

- A master Bluetooth device can communicate with a maximum of seven devices in a piconet (an ad-hoc computer network using Bluetooth technology)
- The devices can switch roles, by agreement, and the slave can become the master
- The connection of two or more piconets form a scatternet, in which certain devices simultaneously play the master role in one piconet and the slave role in another.



Pairing

- Pairing is a bonding procedure that allows you to avoid entering access information each time two devices establish a connection.
- If Secure Connection is enabled, devices will pair automatically the first time they connect (a password, or passkey, must be successfully exchanged).
- When you pair two devices, they generate and store a common link key so that you do not need to enter the passkey.



Communication

- Bluetooth devices automatically detect and connect to one another and up to eight of them can communicate at any one time.
- They don't interfere with one another because ,they operate at different frequencies.
- If two devices want to talk, they pick a channel randomly and, if that's already taken, randomly switch to one of the others (a technique known as spread-spectrum frequency hopping).
- To minimize the risks of interference from other electrical appliances (and also to improve security), pairs of devices constantly shift the frequency they're using.

Technical Specification

- Classes (4.0)
  - Class 1 (100mW, 100m range)
  - **Class 2 (2.5mW, 10m range)**
  - Class 3 (1mW, 1m range)
- RF
  - ISM band between 2.4-2.485GHz
  - Frequency hopping over 79 channels, 1600 hops/second

Bluetooth Version

Version	Data rate	Feature
1.2	721 kb/s	
2.0 + EDR	3 Mb/s	Enhanced Data Rate (EDR)
3.0 + HS	24 Mb/s	High-Speed
4.0	1 Mb/s (BLE)	Bluetooth Low Energy (BLE)
5.0	2 Mb/s	Improve range and increase data rates

WiFi vs. Bluetooth

	Bluetooth	Wifi
Specifications authority	Bluetooth SIG	IEEE, WECA
Year of development	1994	1991
Bandwidth	Low (Up to 2 Mbps)	High (Up to 8 Gbps)
Hardware requirement	Bluetooth adaptor on all the devices connecting with each other	Wireless adaptors on all the devices of the network, a wireless router and/or wireless access points
Cost	Low	High
Power Consumption	Low	High
Frequency	2.4 GHz	2.4, 5, 60 GHz
Security	It is less secure	It is more secure
Range	10 meters	100 meters

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Mobile Broadband (MBB) Networks

- Mobile cellular networks (e.g. 3G/4G)
  - Underpins a lot of vital operations of the modern society
    - Extended coverage
    - Mobility
    - Security



Mobile Broadband Networks

similarities to wired Internet

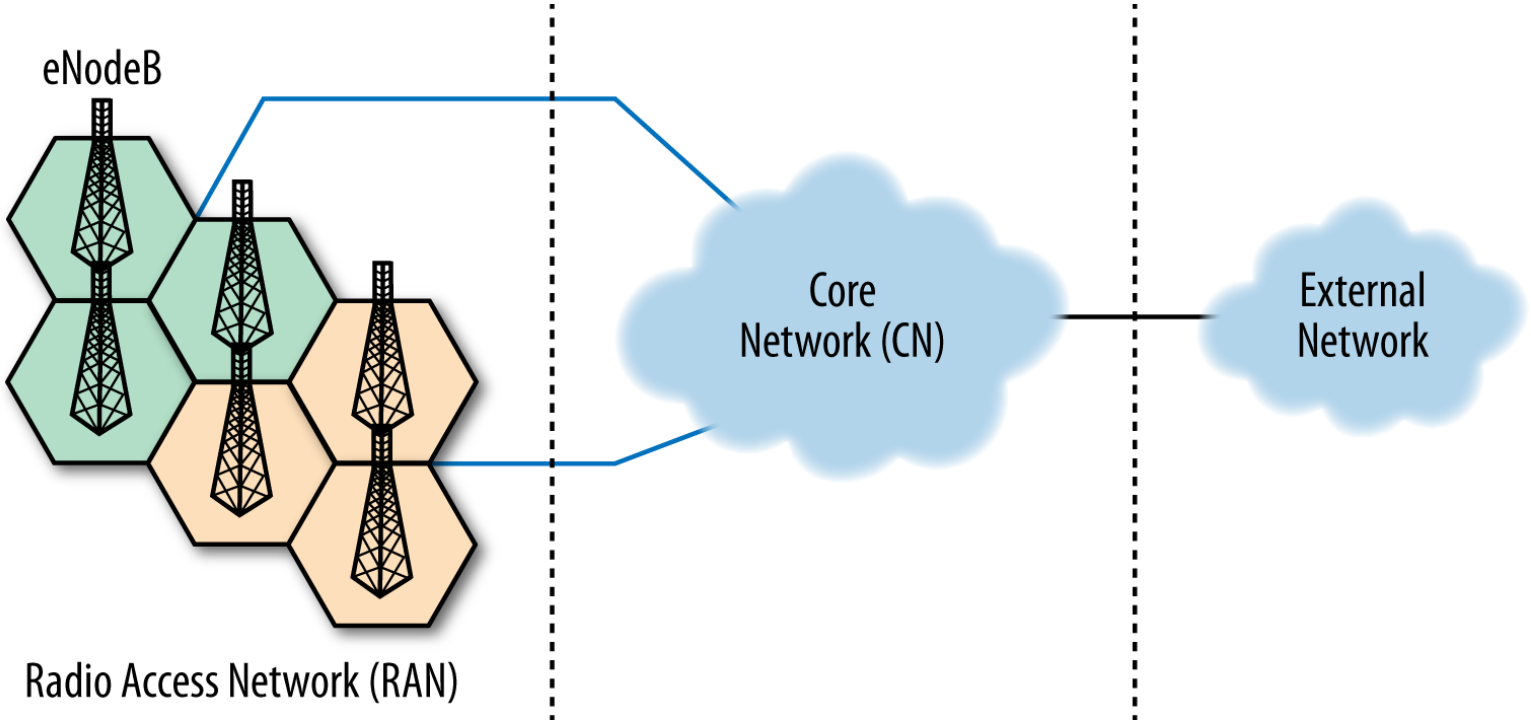
- edge/core distinction, but both below to same carrier
- global cellular network: a network of networks
- widespread use of protocols we've studied: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling
- interconnected to wired Internet

differences from wired Internet

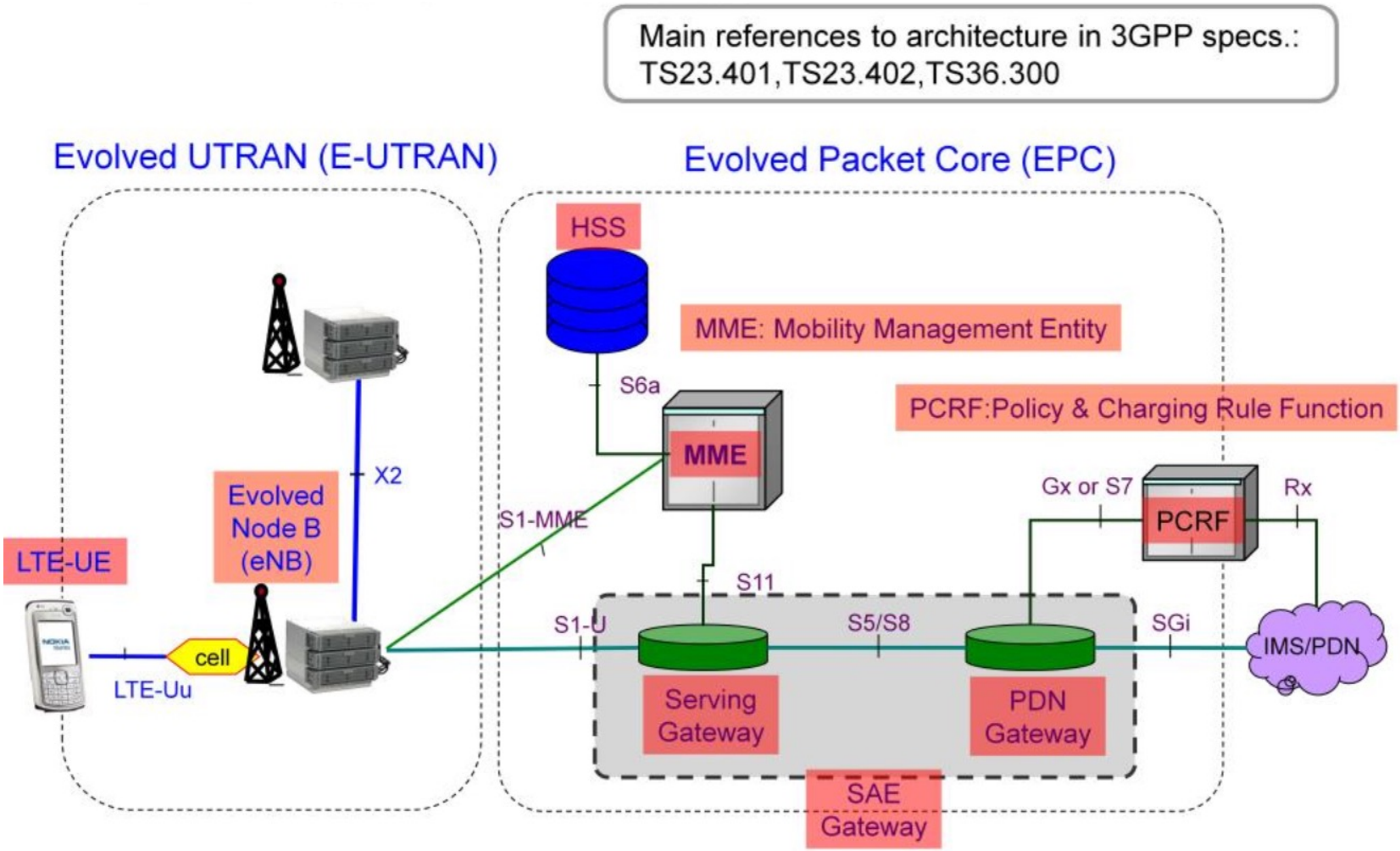
- different wireless link layer
- mobility as a 1st class service
- user "identity" (via SIM card)
- business model: users subscribe to a cellular provider
  - strong notion of "home network" versus roaming on visited nets
  - global access, with authentication infrastructure, and inter-carrier settlements

Macro View

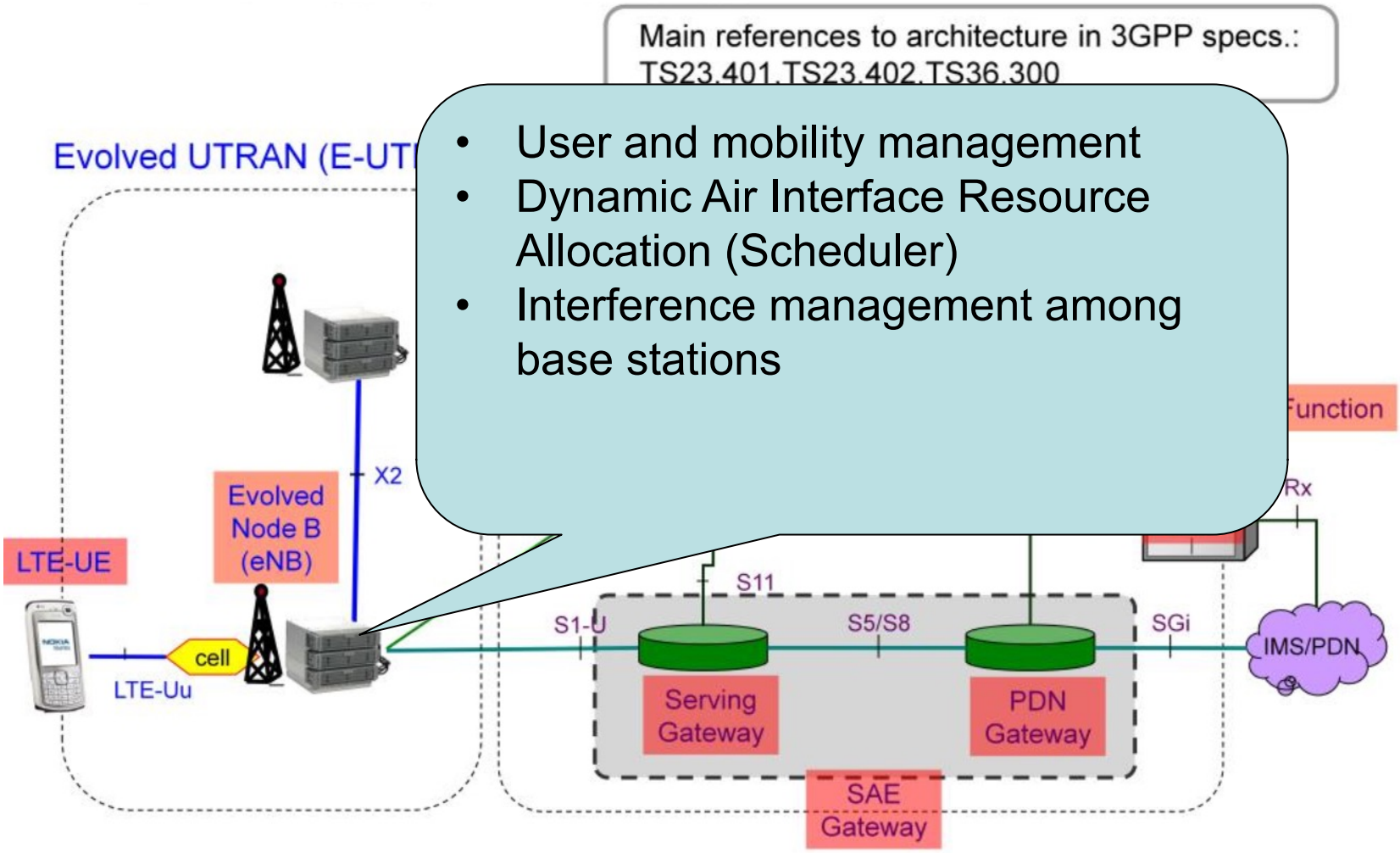
- Building Blocks of MBB Networks
  - Radio Access Network
  - Core Network



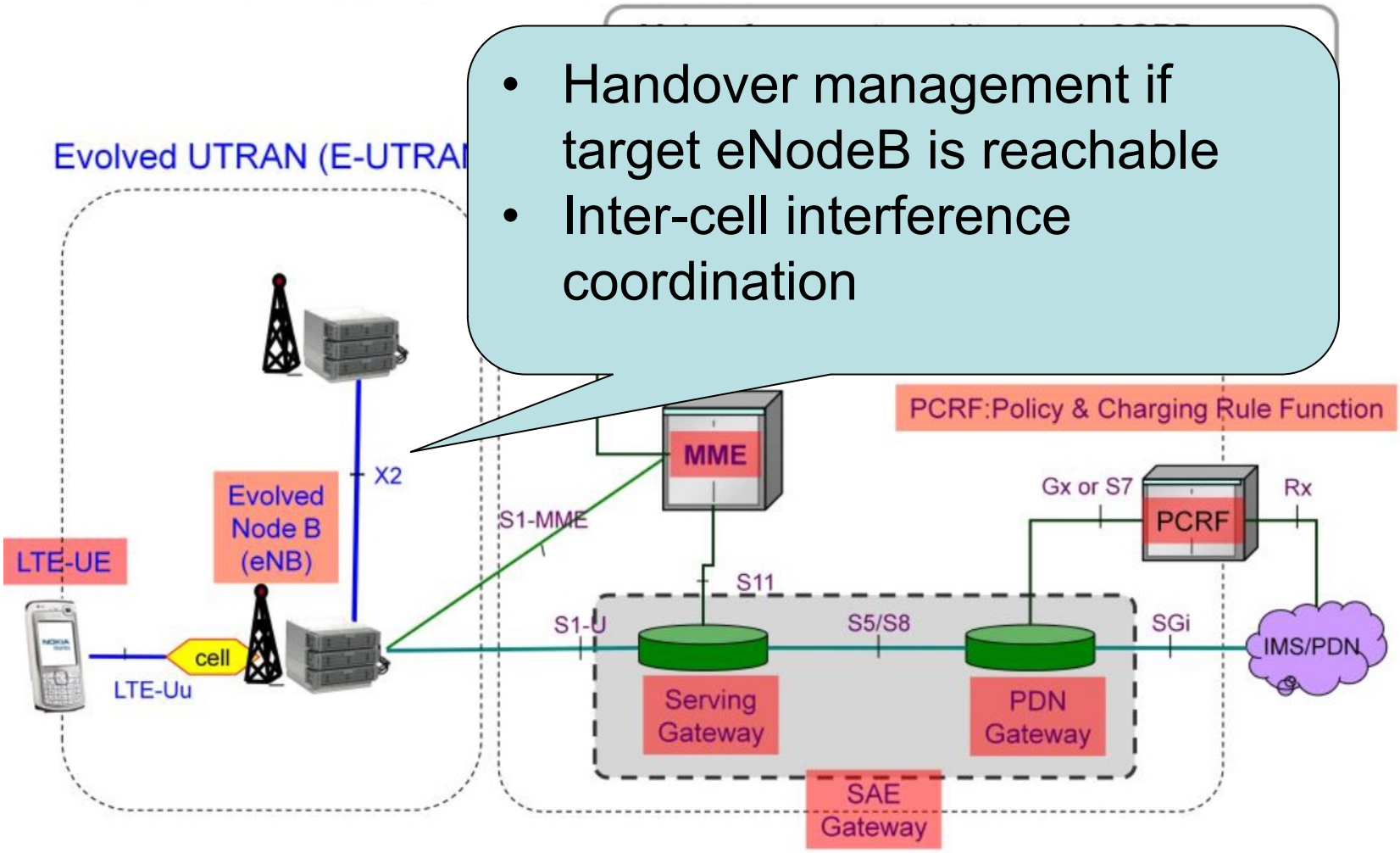
Closer look to LTE



Closer look to LTE



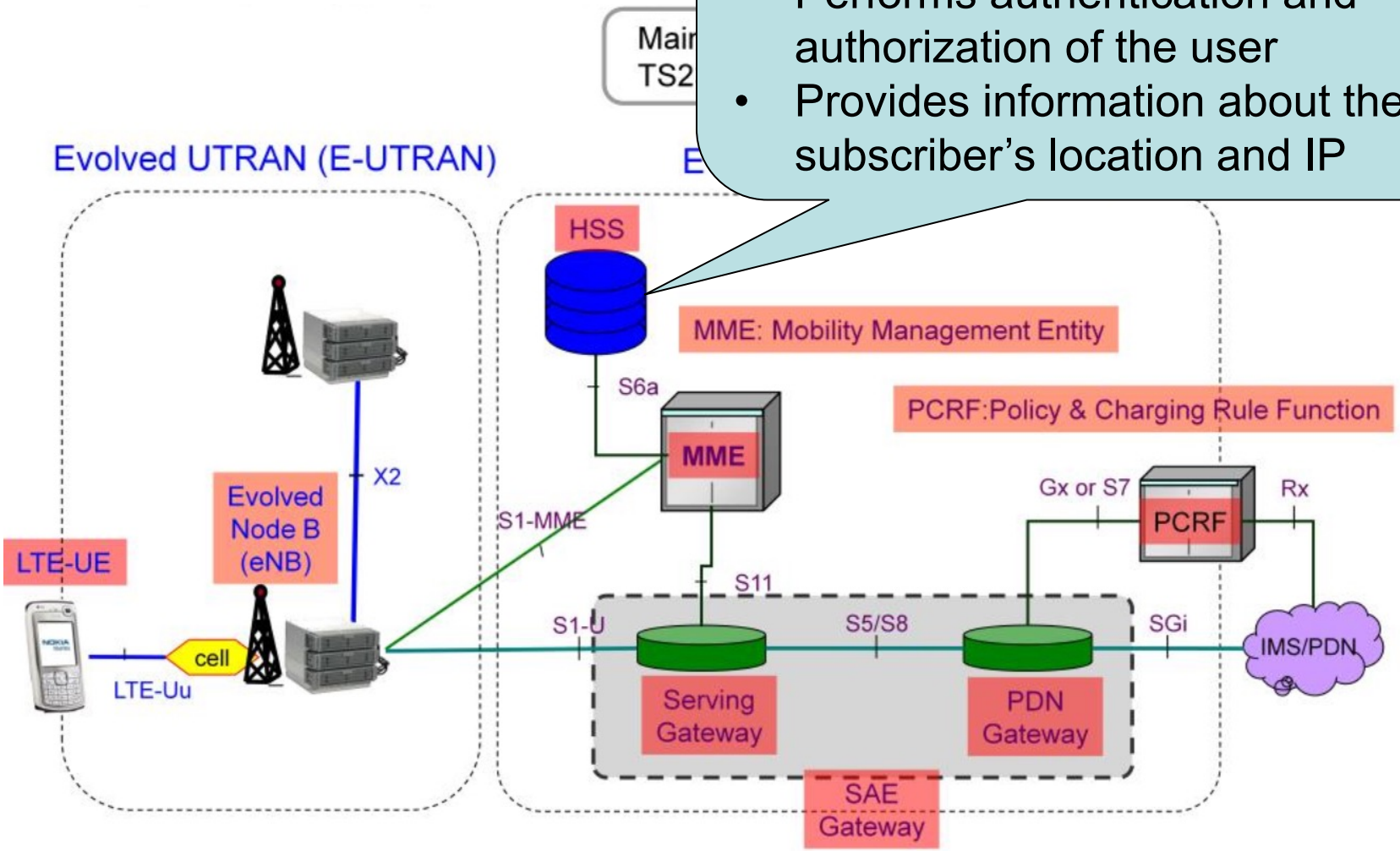
Closer look to LTE



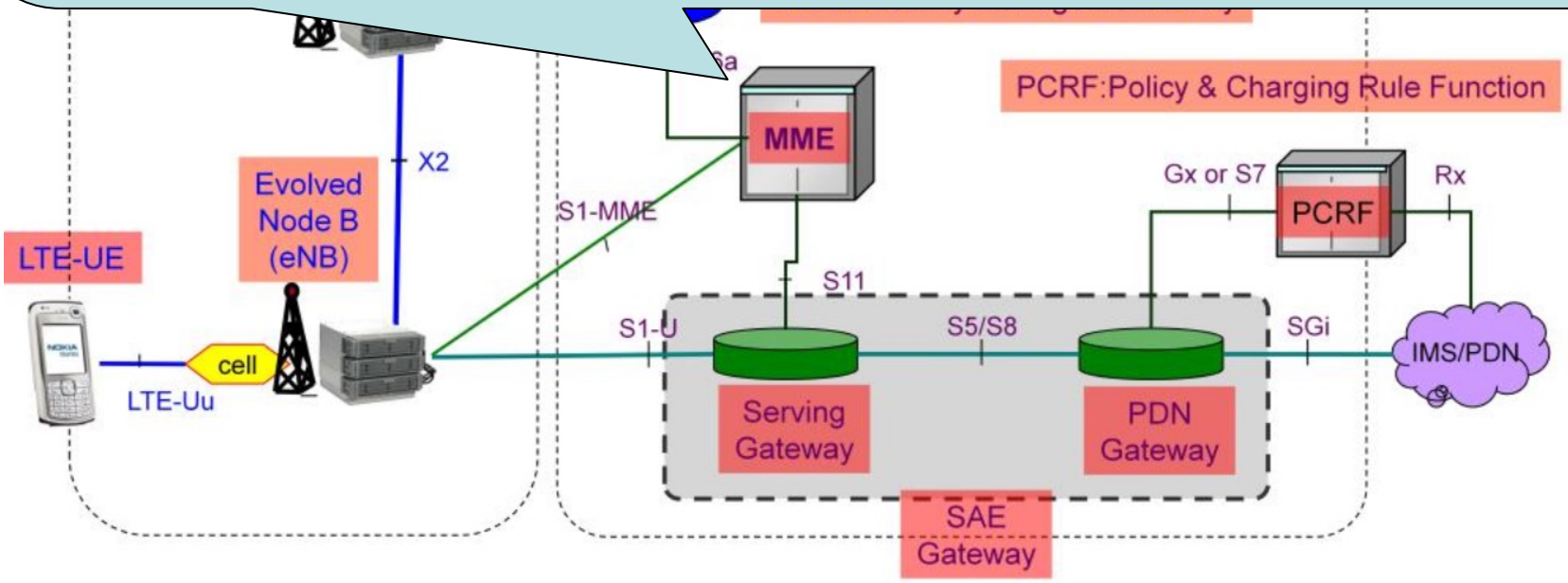
- Handover management if target eNodeB is reachable
- Inter-cell interference coordination

Closer look to LTE

- Central database that contains the subscription related about all the network operators
- Performs authentication and authorization of the user
- Provides information about the subscriber's location and IP

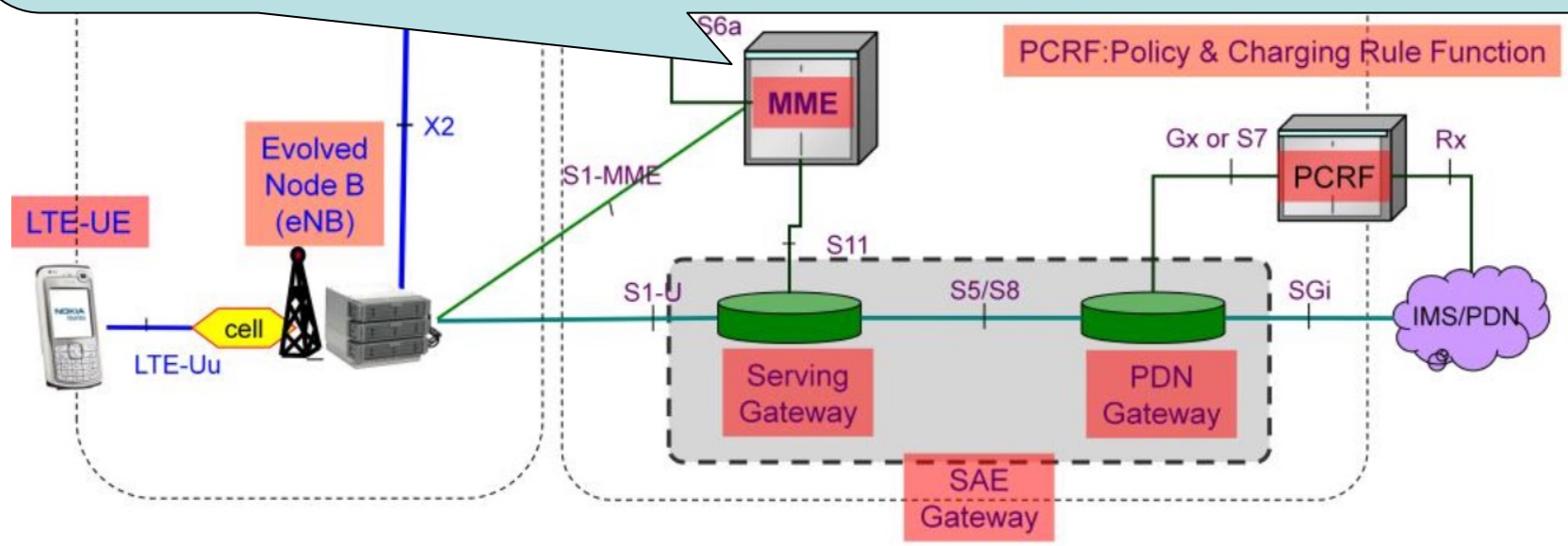


- **Mobility Management**: One of the most complex functions MME performs. Providing seamless inter-working has multiple use cases such as Inter-eNB and Inter-RAT, among others.
- **Radio Resource Management**: MME works with the HSS and the RAN to decide the appropriate radio resource management strategy (RRM) that can be UE-specific.
- **UE Reachability**: MME manages communication with the UE and HSS to provide UE reachability and activity-related information.

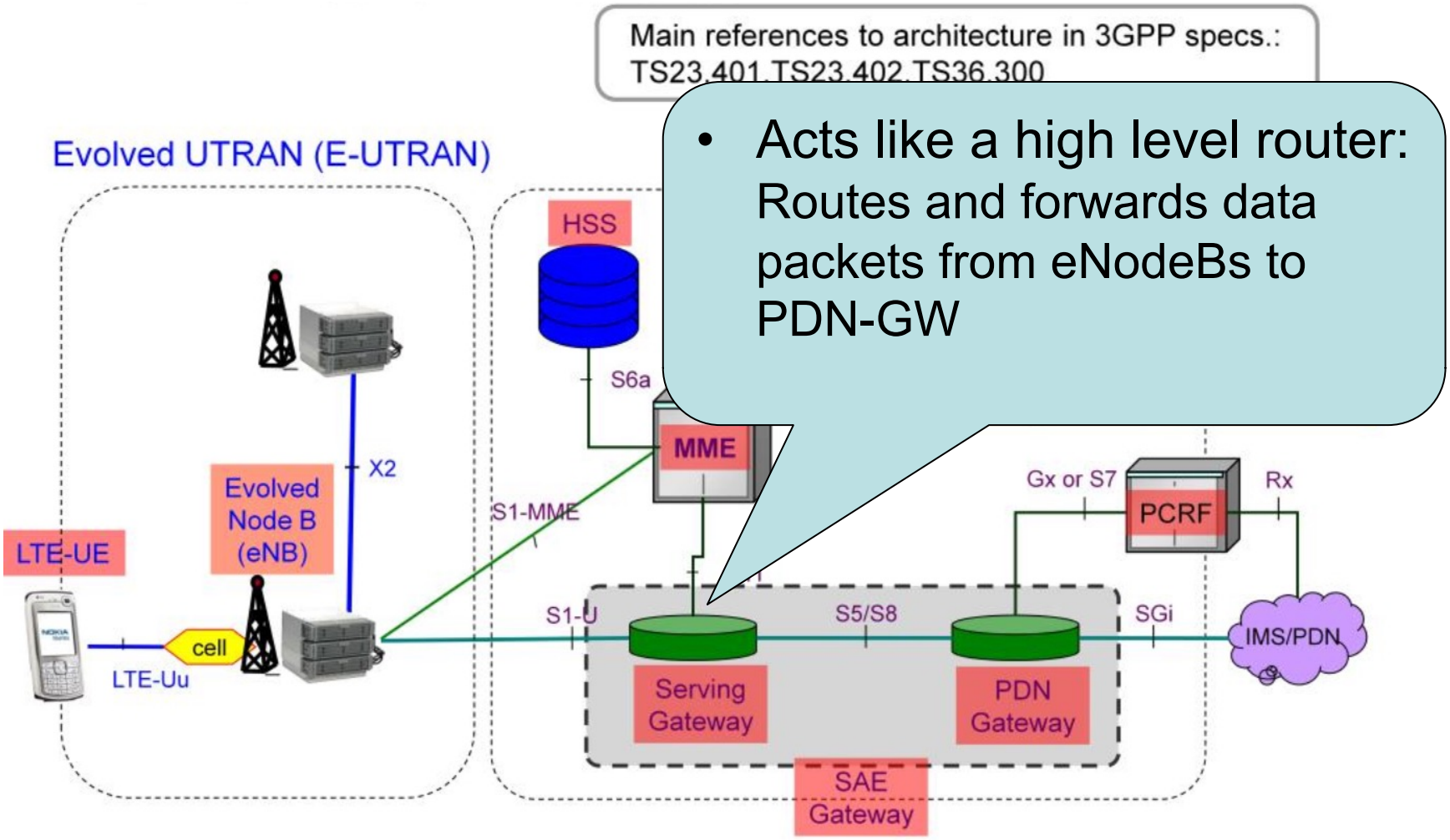


Closer look to LTE

- **Roaming Management**: MME supports outbound and inbound roaming subscribers from other LTE/EPC systems and legacy networks.
- **Lawful Intercept**: Since MME manages the control plane of the network, MME can provide the whereabouts of a UE to a law enforcement monitoring facility.



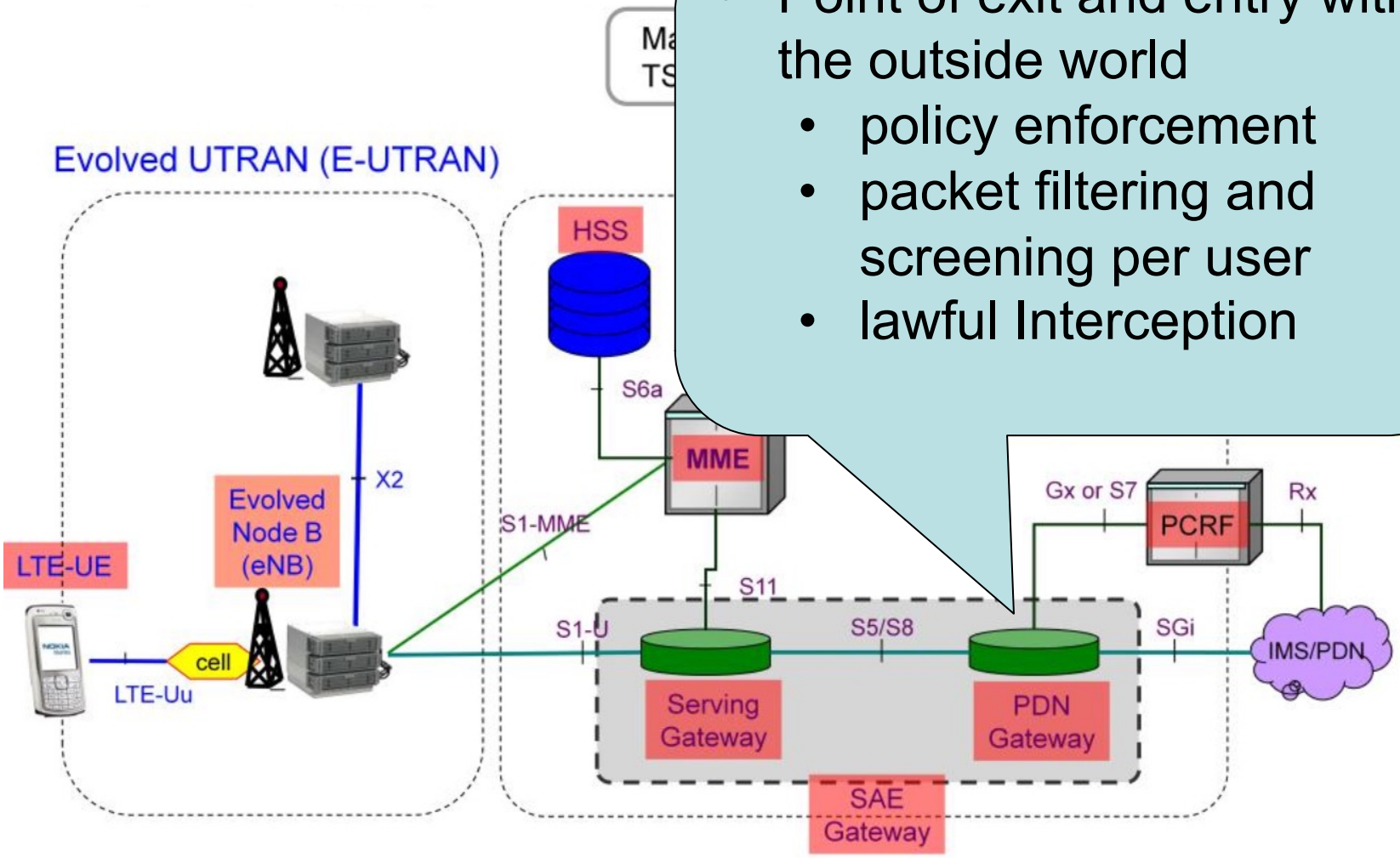
Closer look to LTE



- Acts like a high level router: Routes and forwards data packets from eNodeBs to PDN-GW

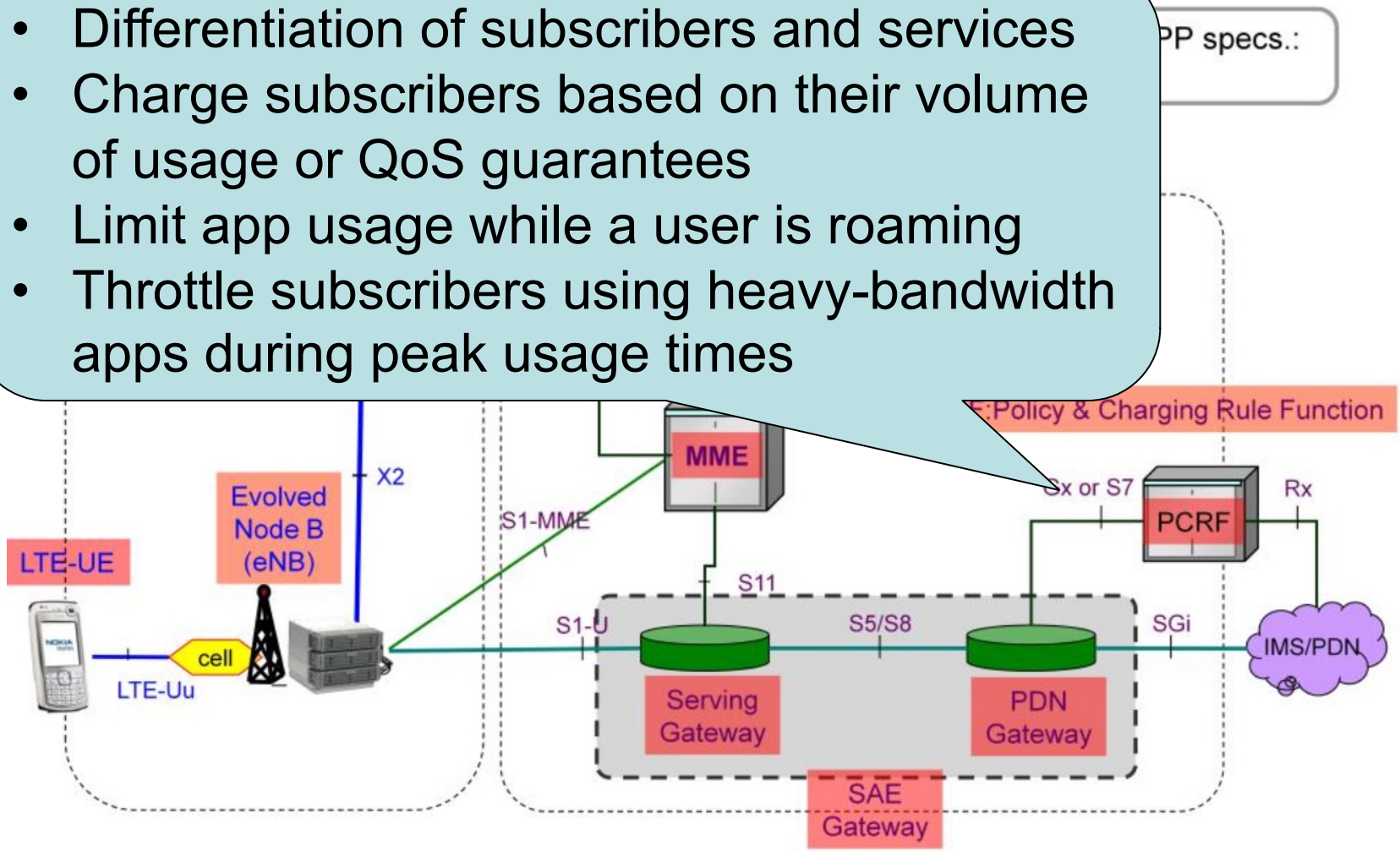
Closer look to LTE

- Point of exit and entry with the outside world
  - policy enforcement
  - packet filtering and screening per user
  - lawful Interception

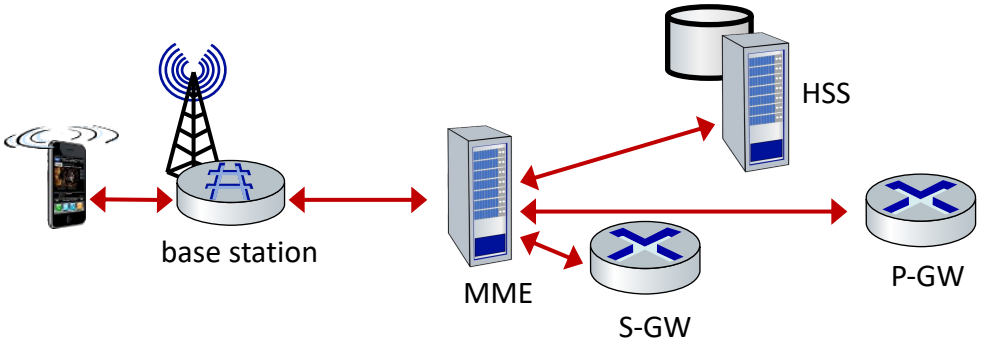


Closer look to LTE

- Differentiation of subscribers and services
- Charge subscribers based on their volume of usage or QoS guarantees
- Limit app usage while a user is roaming
- Throttle subscribers using heavy-bandwidth apps during peak usage times

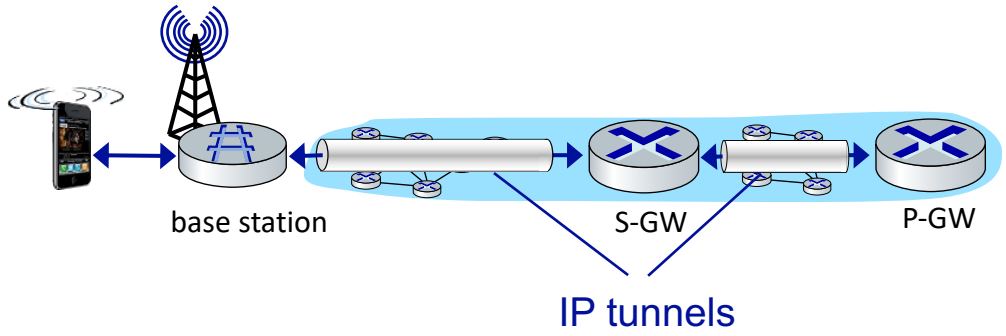


LTE: data plane control plane separation



control plane

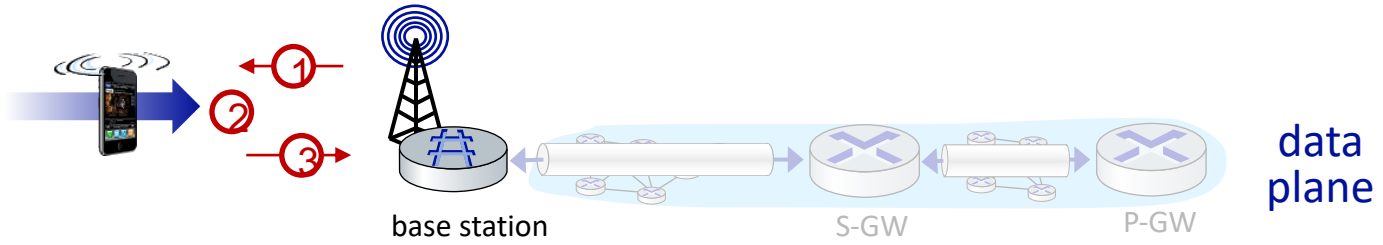
- new protocols for mobility management , security, authentication



data plane

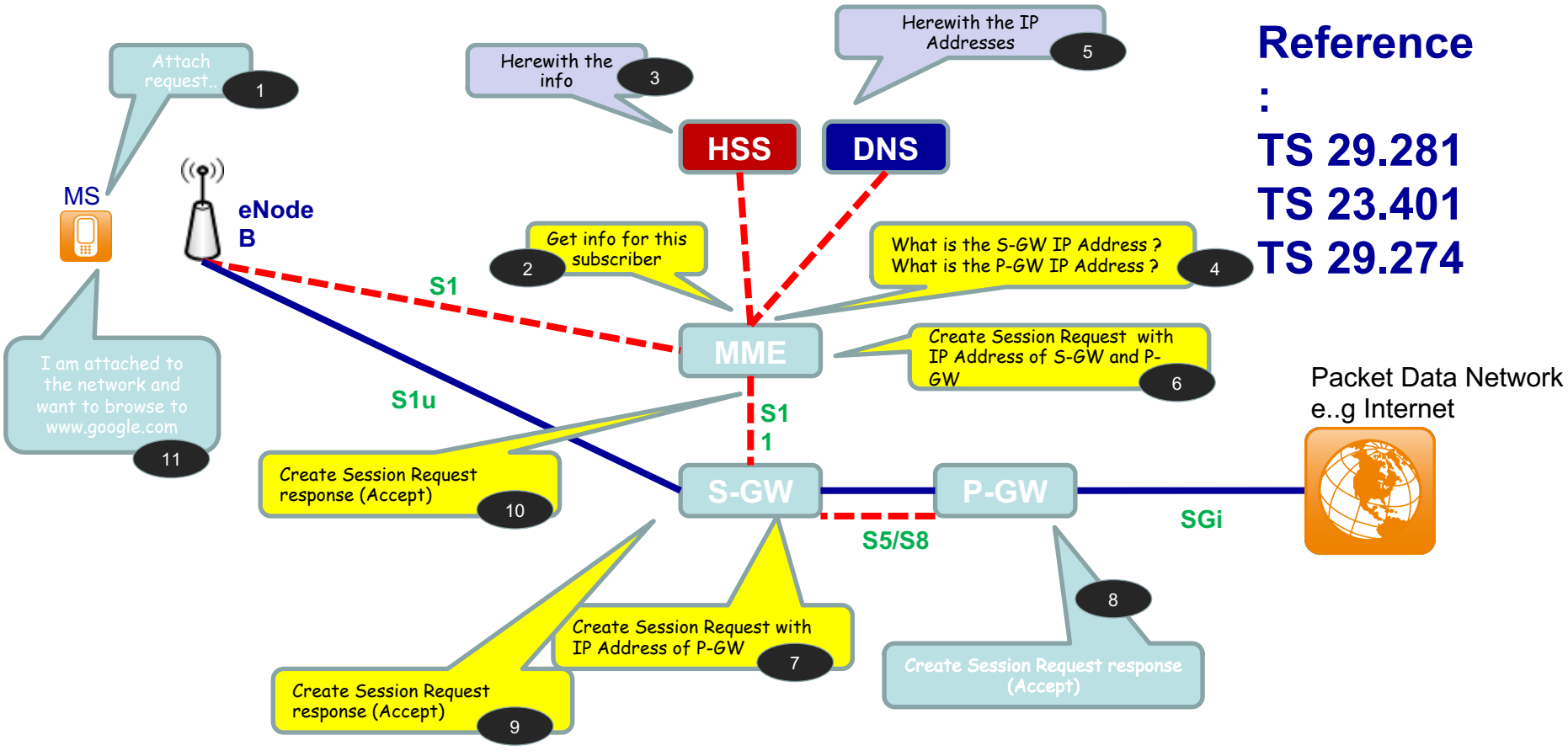
- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

LTE data plane: associating with a BS



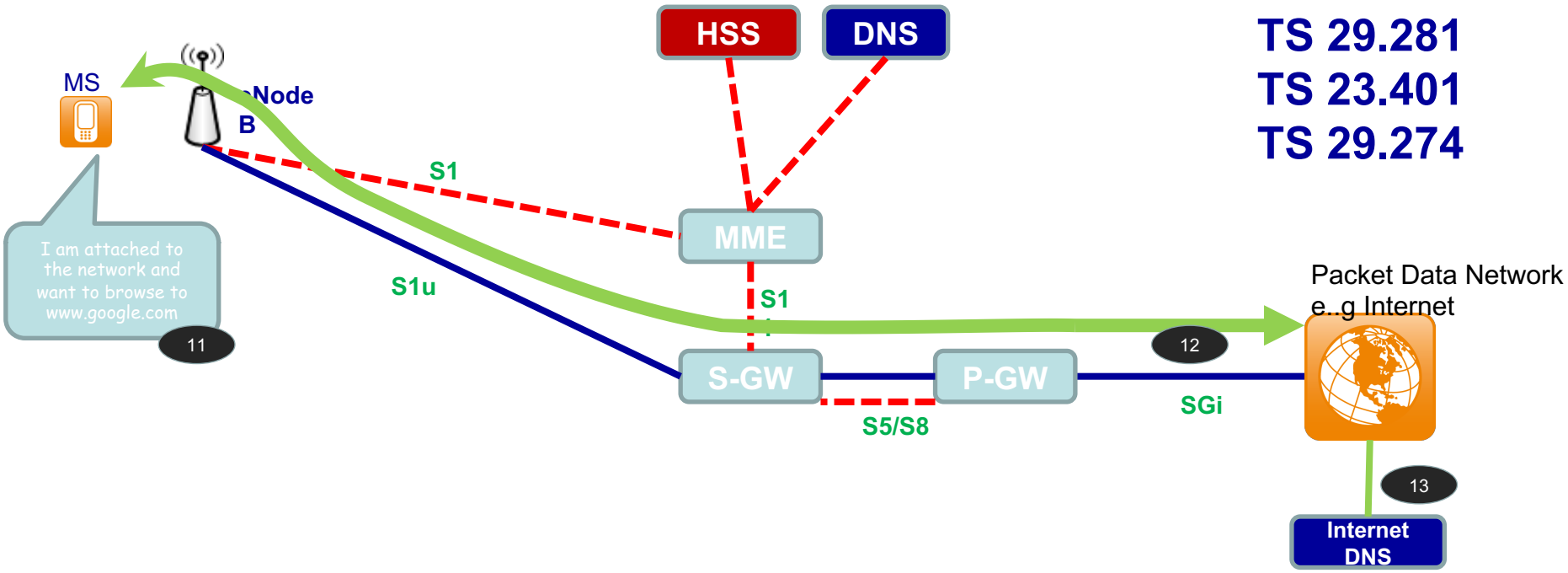
1. BS broadcasts primary synch signal every 5 ms on all frequencies
   - BSs from multiple carriers may be broadcasting synch signals
2. mobile finds a primary synch signal, then locates 2nd synch signal on this freq.
   - mobile then finds info broadcast by BS: channel bandwidth, configurations; BS's cellular carrier info
   - mobile may get info from multiple base stations, multiple cellular networks
3. mobile selects which BS to associate with (*e.g.,* preference for home carrier)

A Simplified Data Flow with 4G…(1/2)



Reference :
TS 29.281
TS 23.401
TS 29.274

A Simplified Data Flow with 4G… (2/2)



What defines the mobile operator performance?

- Deployment
- Configuration
- Subscription
- Number of users
- Mobility

- How do we define mobile performance?

Outline

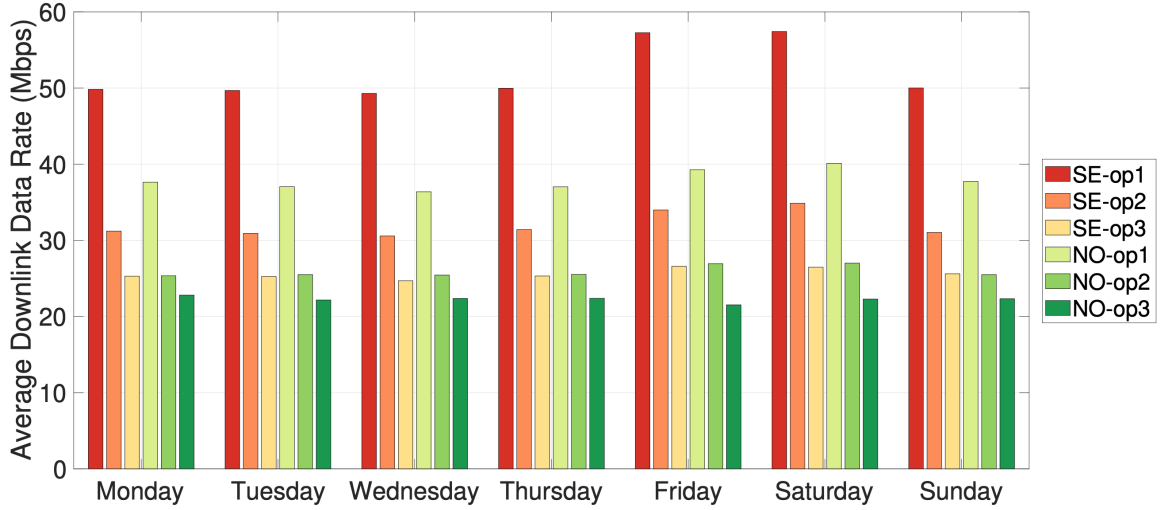
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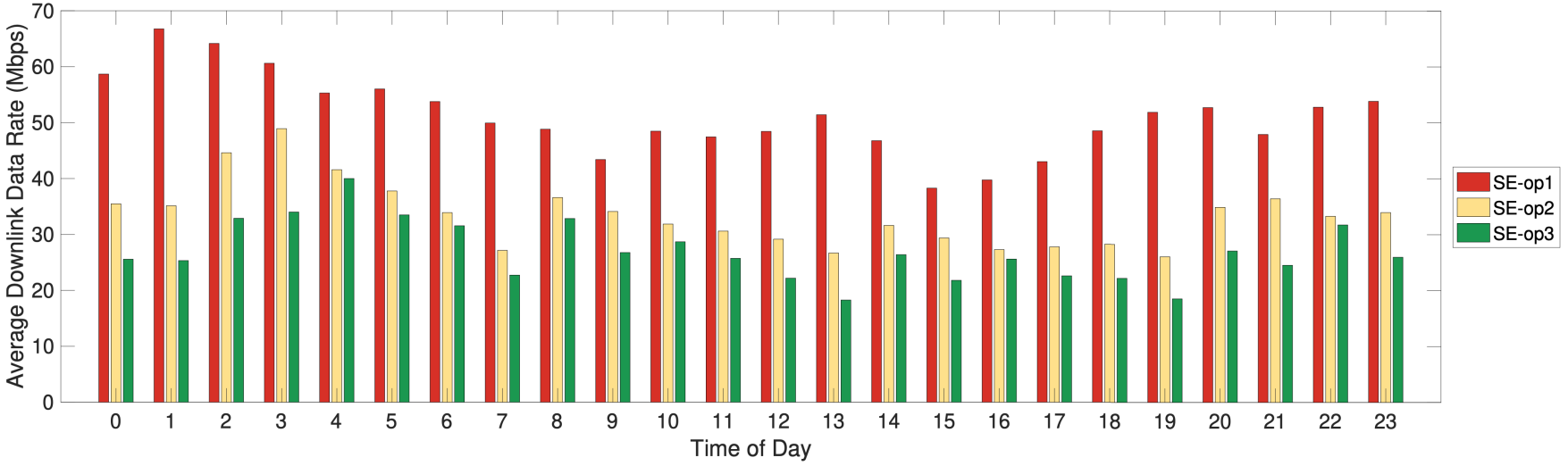
MONROE – Mobile Broadband Measurement Platform

- Coverage in 4 European Countries (Norway, Sweden, Spain, Italy)
- A set of 100 nodes equipped with Ethernet, WiFi and 3G/4G interfaces with commercial MBB subscriptions.
- Under mobility (e.g., on-board of trains or buses) or in stationary scenarios (e.g., in laboratories, or hosted by volunteers in homes).

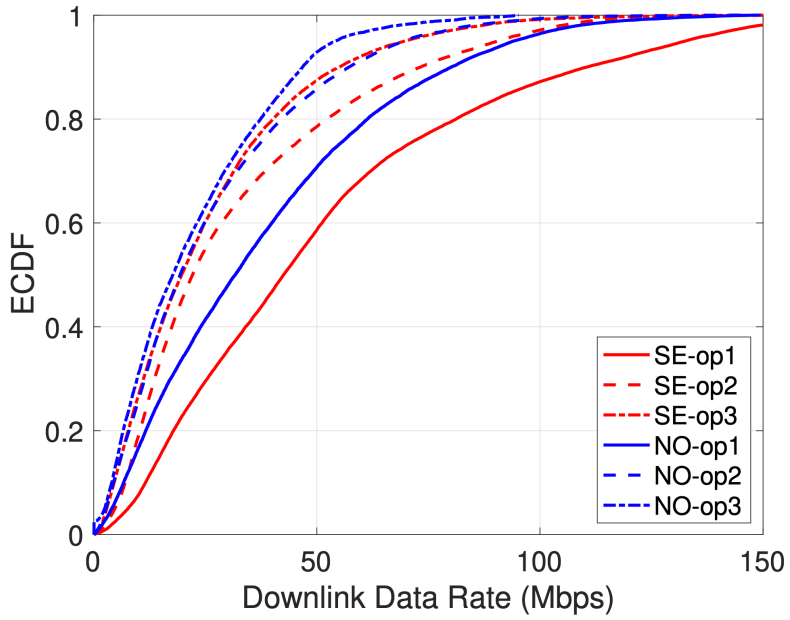


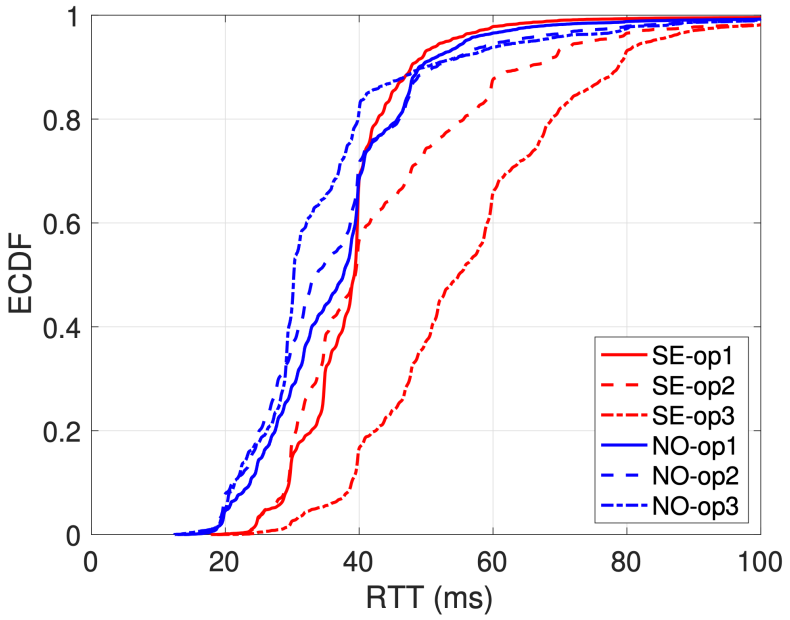
Hourly and Daily Patterns





LTE performance: Data rate and RTT





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  - Operations

Mobile Virtual Network Operators (MVNO)

- MVNO is an entity that offers mobile network services to end-users, but does not own nor operate fully a cellular network. MVNOs lack of ownership of radio spectrum resources.
- In order to operate, an MVNO needs to have agreements in place to access the network of at least one MNO.

MVNO Models

- A "light" MVNO is a service provider that has its own customer support, marketing, sales and distribution operations, and has the ability to set its tariffs independently from the retail prices set by the host MNO.
- The “full” MVNO have a core network implementation operating essentially the same technology as a mobile network operator, only missing their own radio network. They run their own core network and rely on at least one host MNO who can offer access to the radio resources.
- Mobile Network Aggregator (MNA): Some full MVNOs exploit more than one single MNO, establishing the MNA operating model. Aggregating multiple MNOs allows the MNA's customers to dynamically change the MNO they are attached to based on the different factors, such as policy, coverage, performance, etc.