

UiO : Faculty of Mathematics and Natural Sciences
University of Oslo

Department of Informatics
Networks and Distributed Systems (ND) group

IN3230/4230

Wireless Communications - II

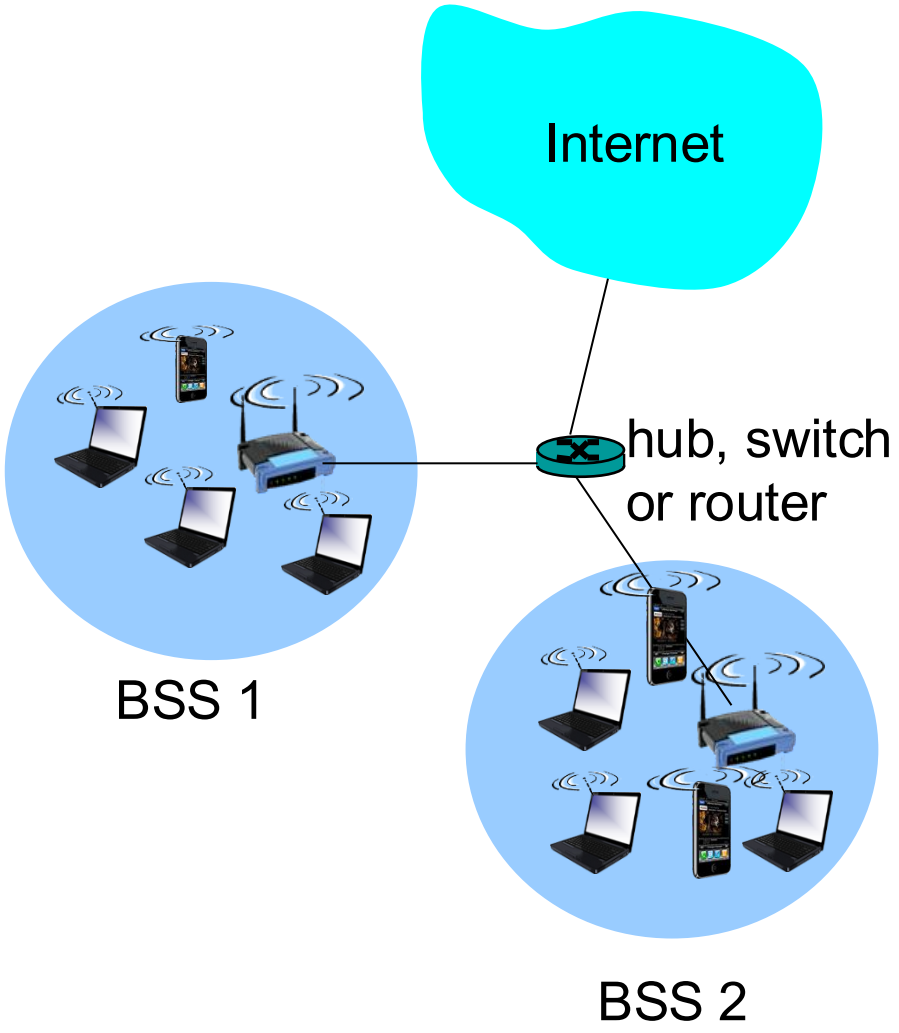


Özgü Alay
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Outline

- Wireless Systems - Short Range
  - Wifi
- Mobile Broadband Networks
  - Building Blocks
  - Performance
  - International Roaming
  - 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 (legacy)

- 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!
  - Modern: *Adjust channels in real time based on the environment*

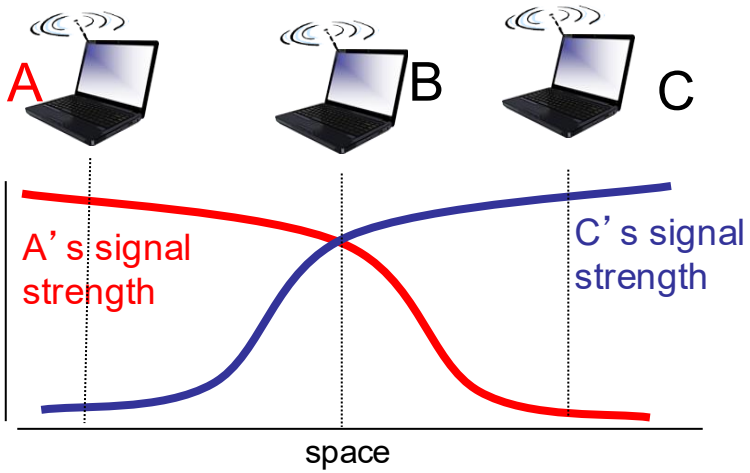
- arriving host: must associate with an AP
  - scans channels, listening for *beacon frames* containing AP's name (SSID) and MAC address
  - selects AP to associate with
  - then may perform authentication
  - then typically run DHCP to get IP address in AP's subnet
  - Modern: *Active scanning by broadcasting Probe Requests frames and receiving Probe Response frames*



BSS

Wireless network characteristics (1)

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

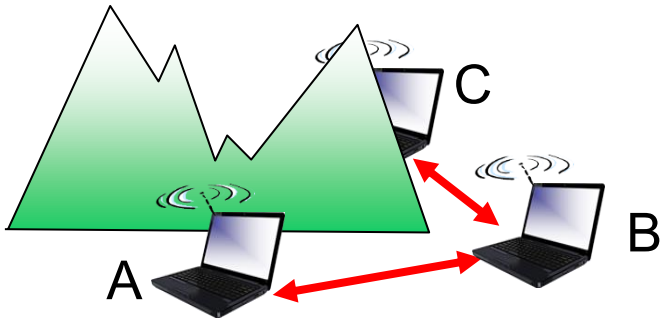


Signal attenuation:

- 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

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

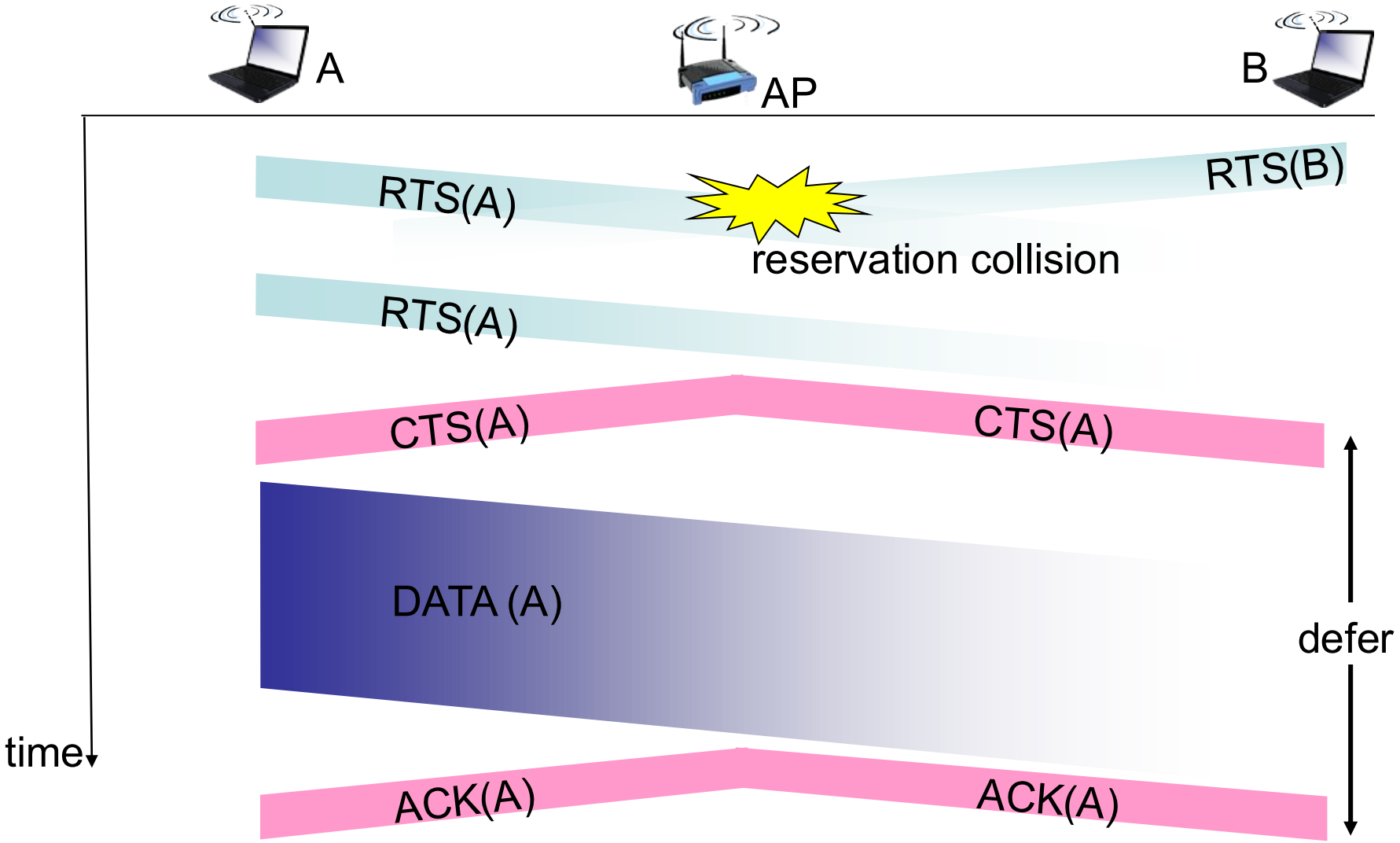
Avoiding collisions

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!

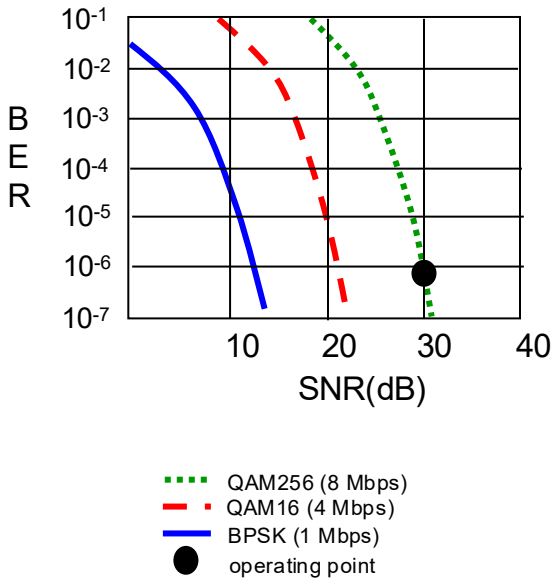
Collision Avoidance: RTS-CTS exchange



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

Standard	Generation	Frequency Band	Max Data Rate	Key PHY / MAC Features	Primary Application
802.11a / b / g	Wi-Fi 1 / 2 / 3	2.4 / 5 GHz	11 / 54 Mbps	OFDM (11a/g), 20 MHz channels	Legacy Web & Basic WLAN

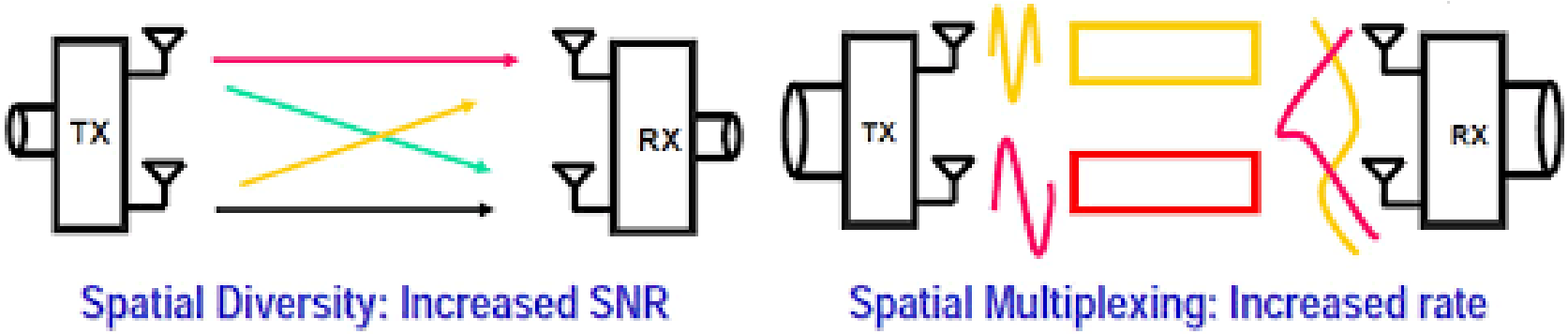
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Recap on different Types of MIMO

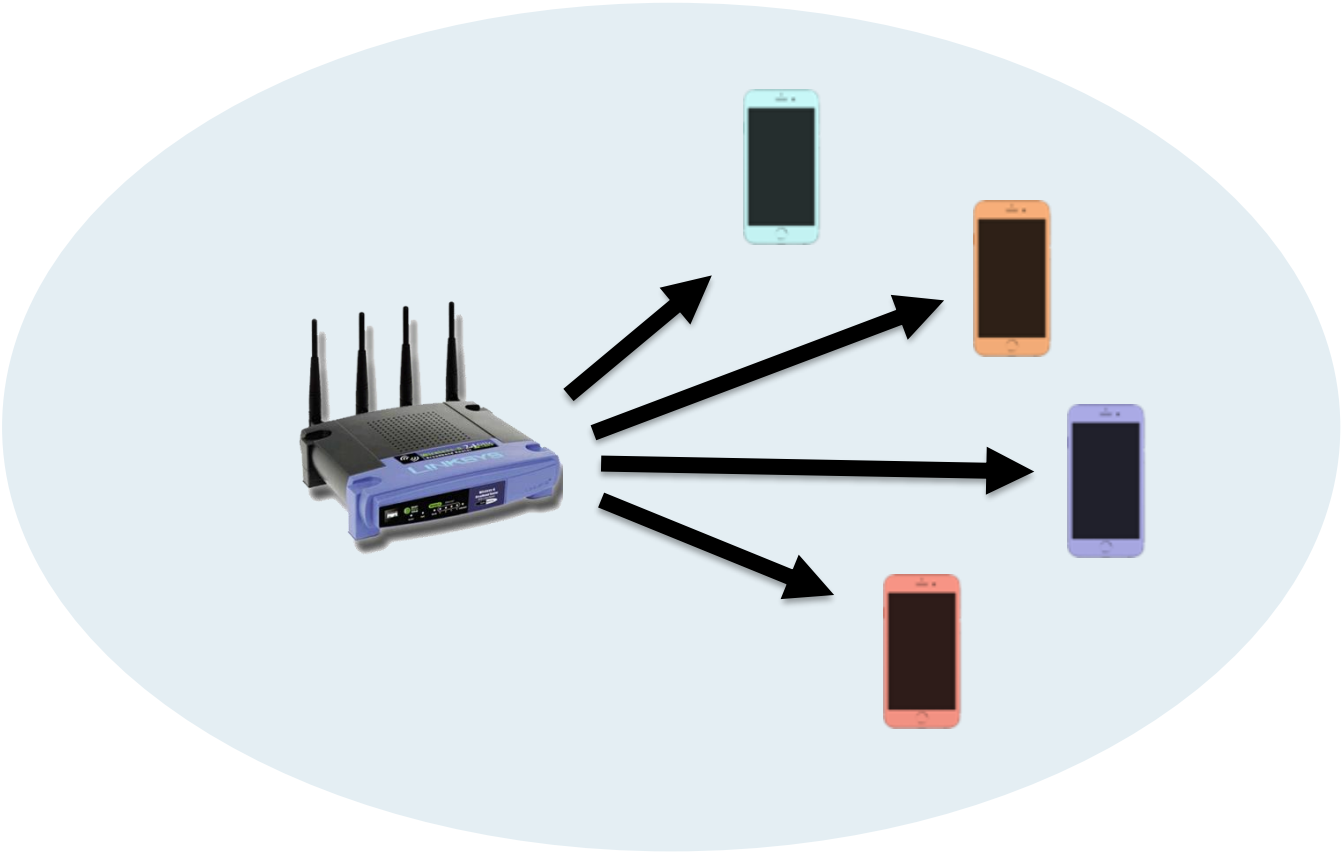
- **Space Time Transmit Diversity (STTD)** - The same data is coded and transmitted through different antennas, which effectively doubles the power in the channel. This improves Signal Noise Ratio (SNR) for cell edge performance.

- **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.

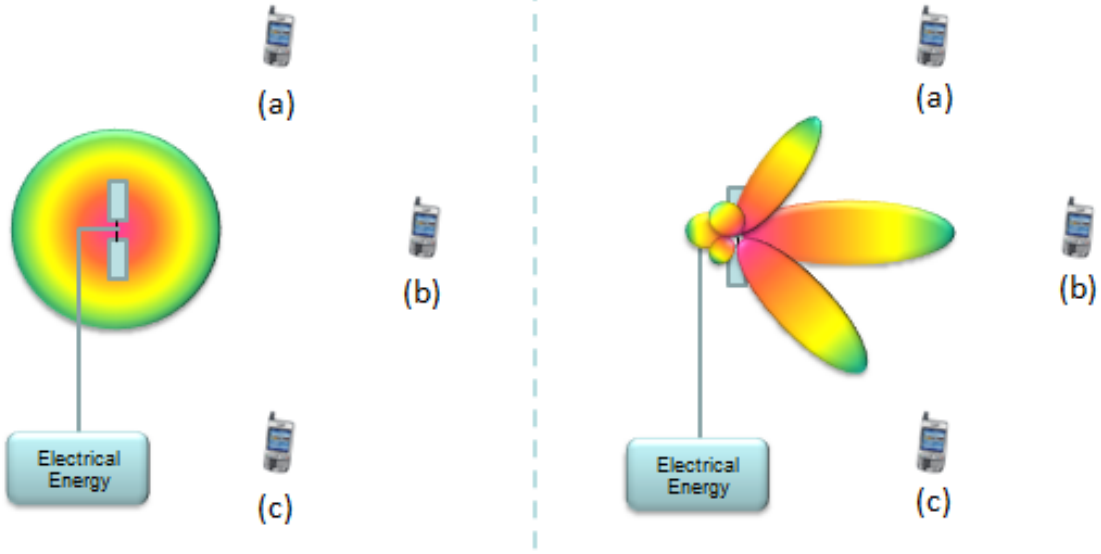


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802.11ac	Wi-Fi 5	5 GHz	Up to 6.9 Gbps	**DL MU-MIMO**, 256-QAM, 80/160 MHz channels	High-Density Video Streaming

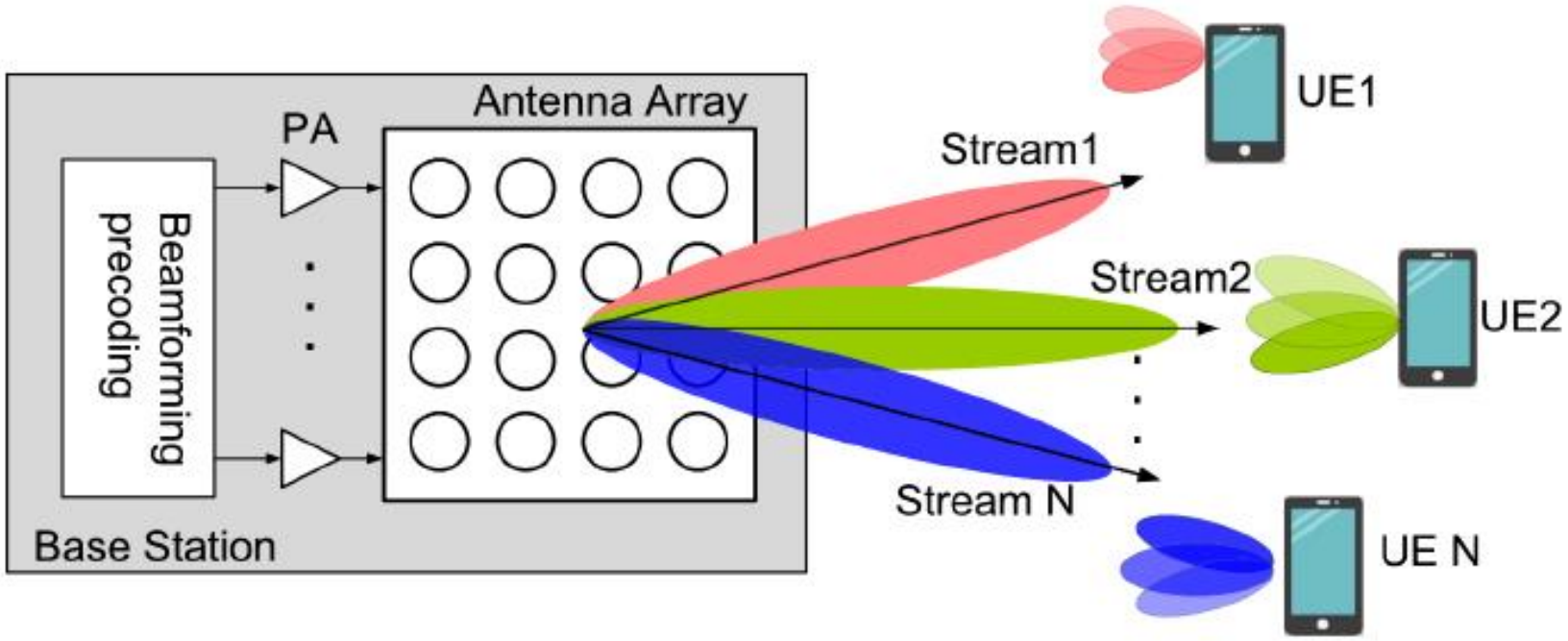
Recap on MIMO Beamforming

- **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.



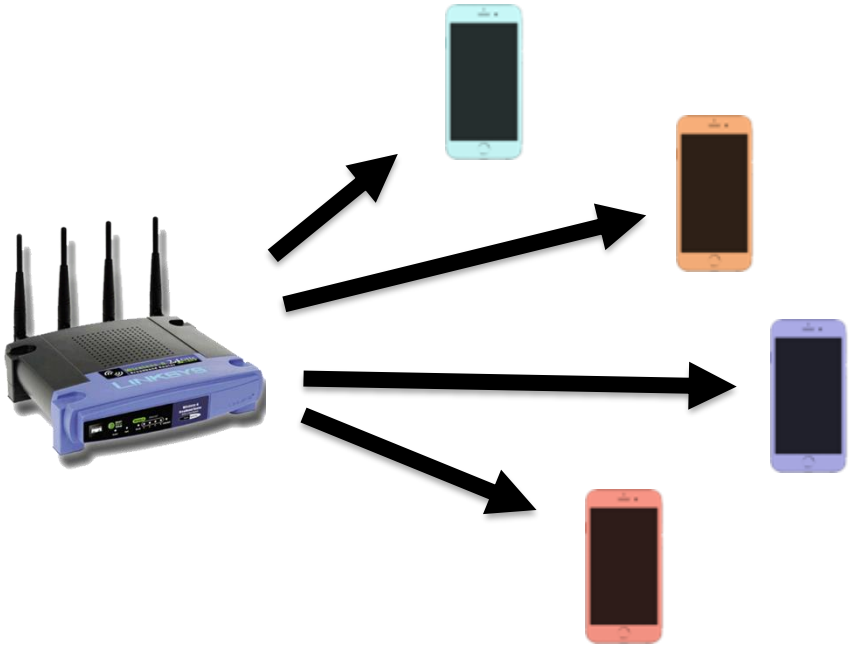
< Case 1 > < Case 2 >

Beamforming and Steering



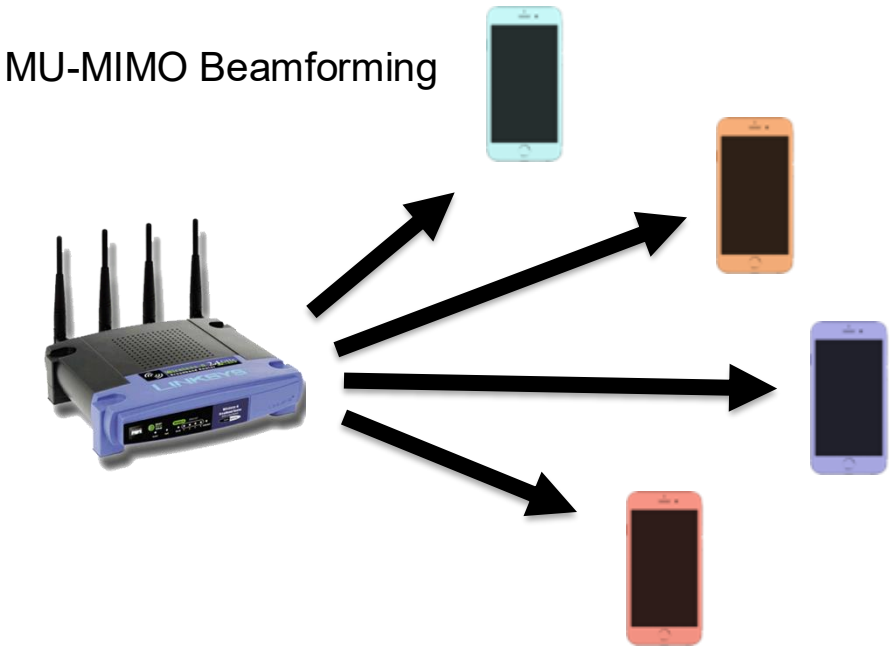
802.11ac MIMO Beamforming

- 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

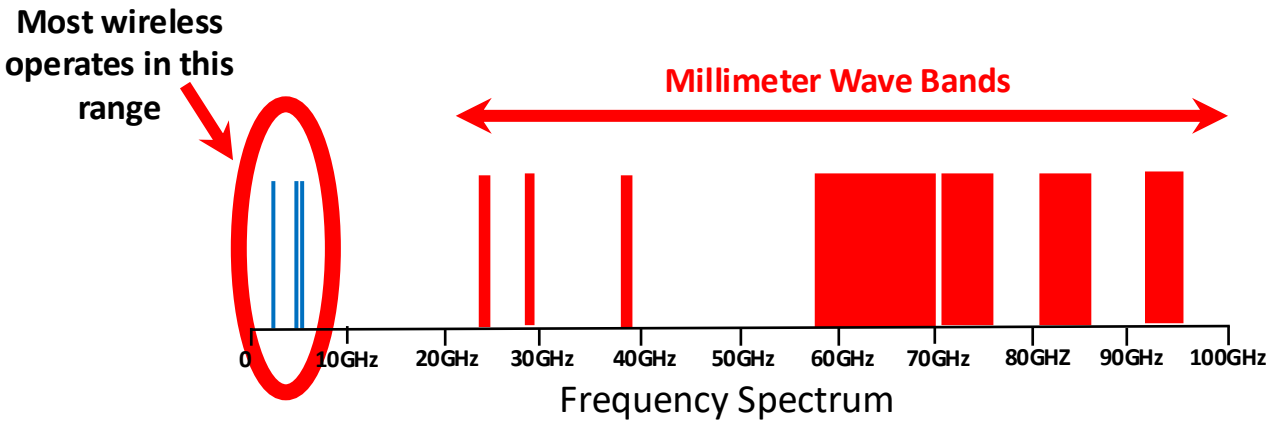
- Multi-user beamforming allows full utilization of available spatial resources by allowing simultaneous transmissions to multiple stations on the same channel.
- And while fantastic, the increased spectral efficiency doesn't come for free….



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802.11ad / ay	mmWave Wi-Fi	60 GHz	7 to 40+ Gbps	**Beamforming**, Channel Bonding (8.64 GHz)	Uncompressed Video, VR, Backhaul

How does mmWave work?

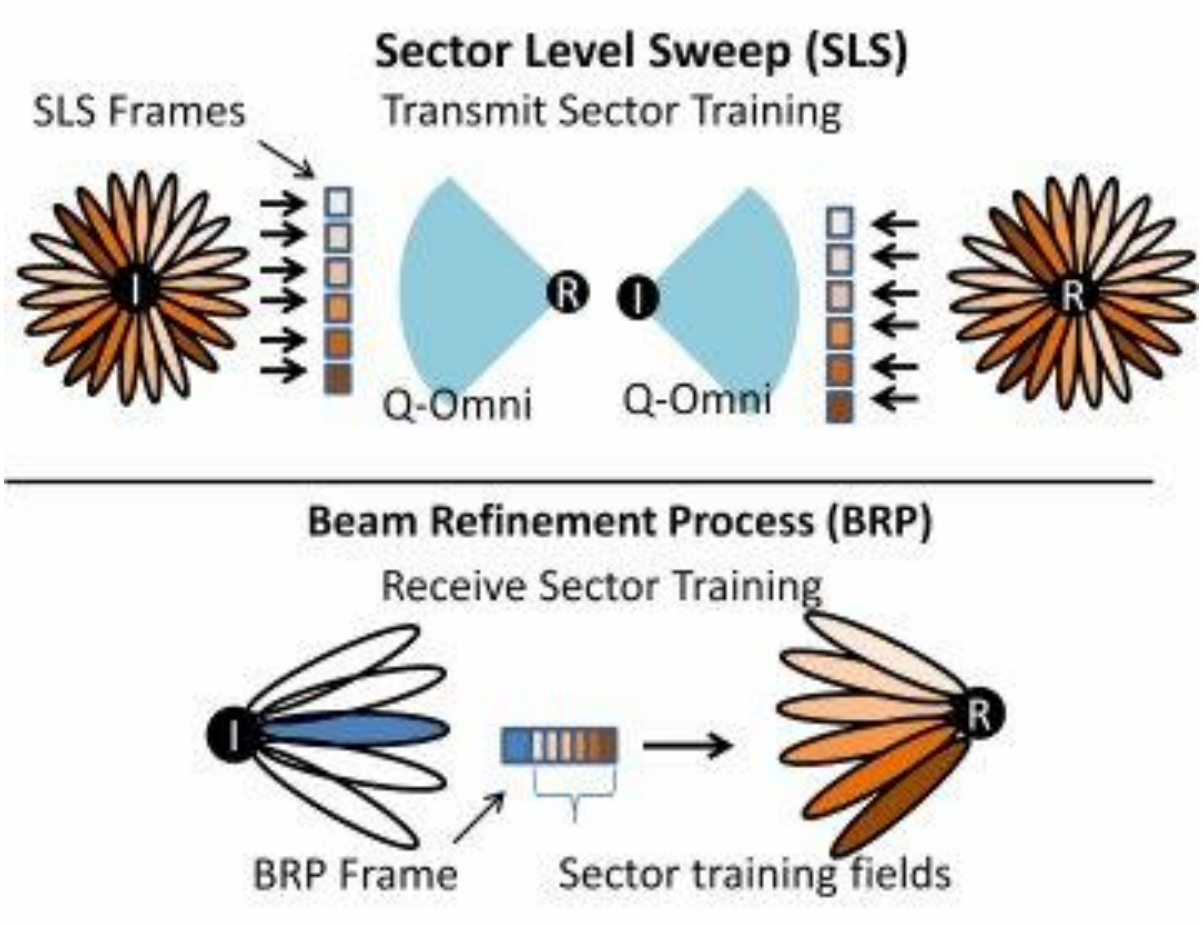


mmWave: High attenuation -> beamforming

Challenge: Beam alignment



802.11ad mmWave



Beamforming Training in 802.11ad

IEEE 802.11 Wireless LAN

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802.11ax	Wi-Fi 6 / 6E	2.4 / 5 / 6 GHz	Up to 9.6 Gbps	OFDMA (RUs), TWT (IoT power save), 1024-QAM, 6 GHz Band	Dense IoT & Campus Networks

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- Mobile Broadband Networks
  - Building Blocks
  - Performance
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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

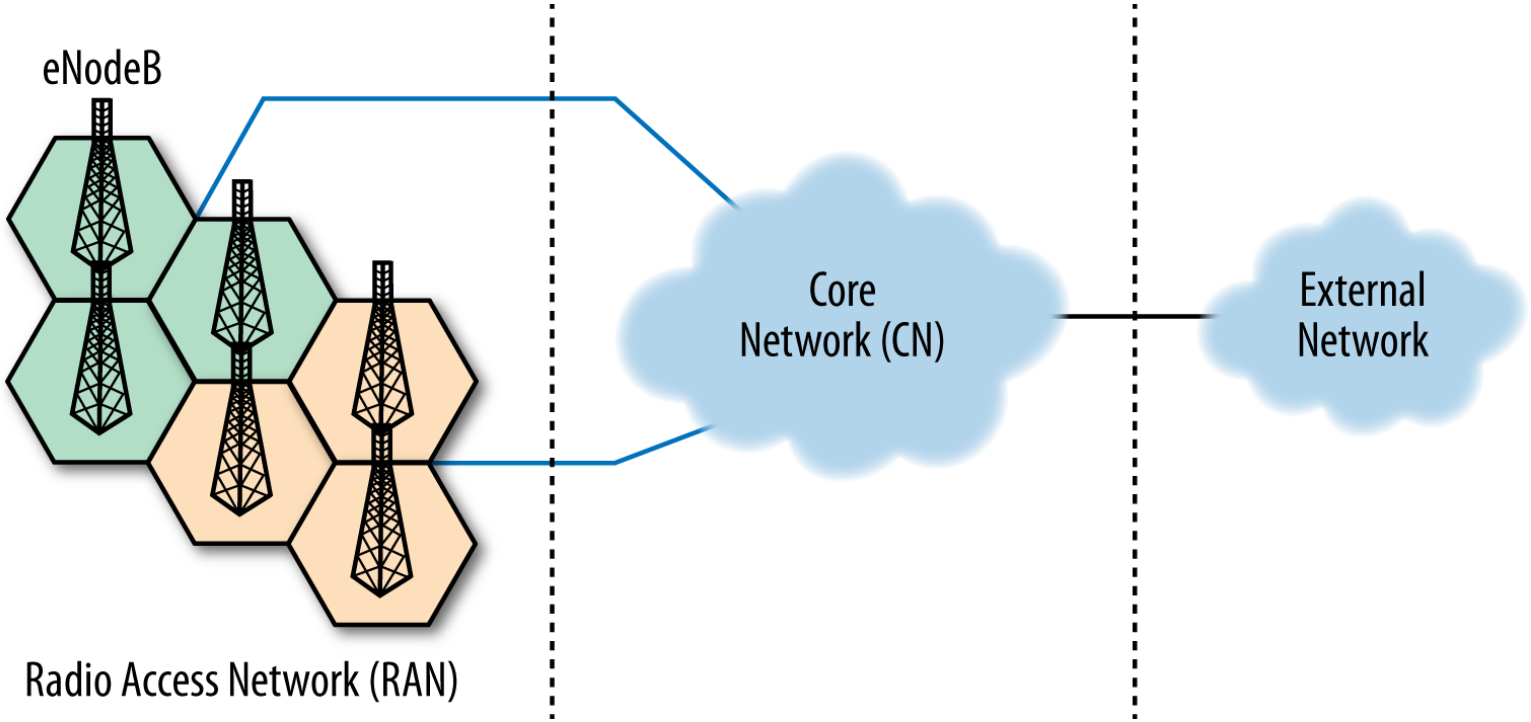
- edge/core distinction, but both below to same carrier
- global cellular network: a network of networks
- widespread use of protocols we've studied: HTTP, DNS, TCP, UDP, IP, NAT, separation of data/control planes, SDN, Ethernet, tunneling
- interconnected to wired Internet

differences from wired Internet

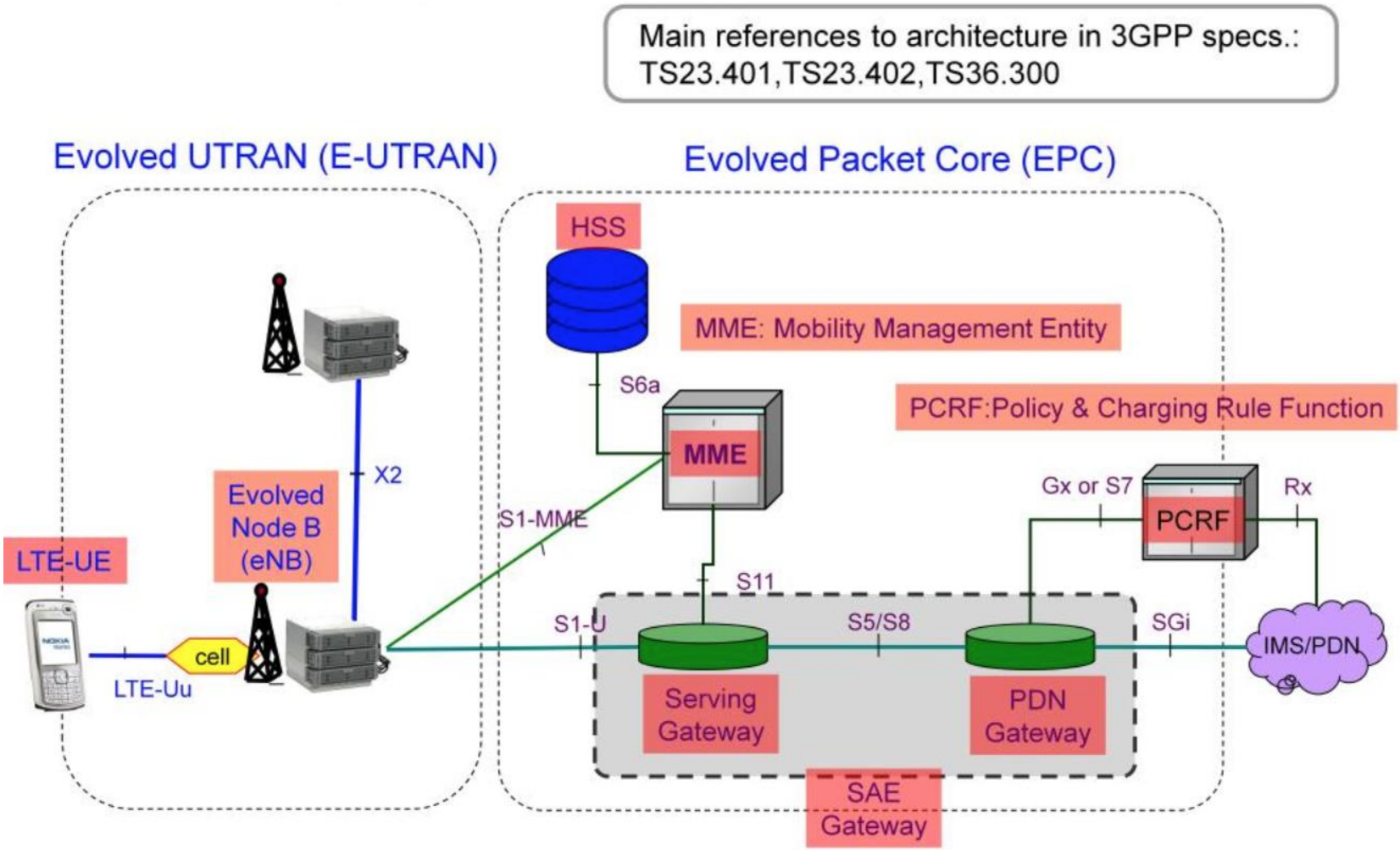
- different wireless link layer
- mobility as a 1st class service
- user "identity" (via SIM card)
- business model: users subscribe to a cellular provider
  - strong notion of "home network" versus roaming on visited nets
  - global access, with authentication infrastructure, and inter-carrier settlements

Macro View

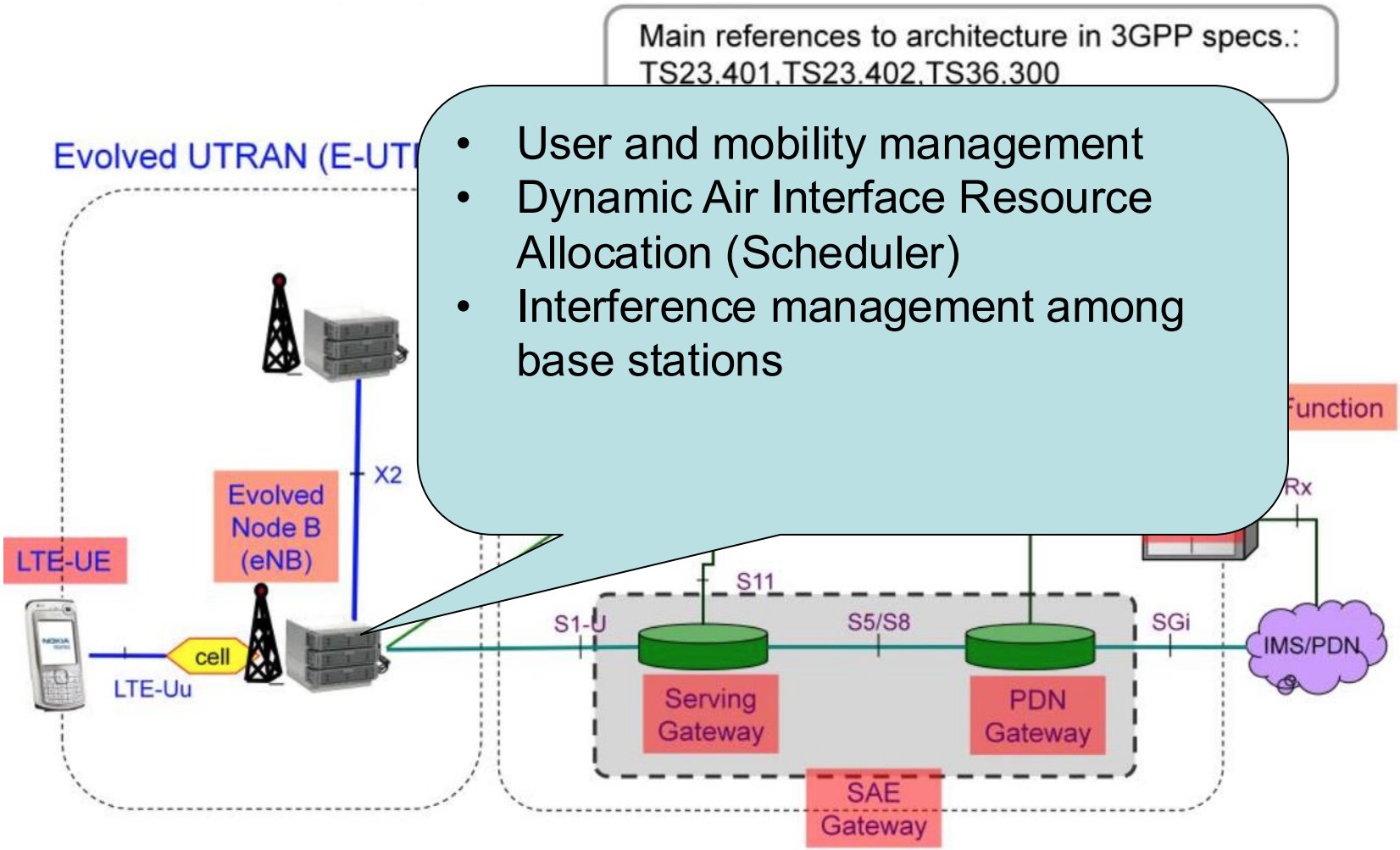
- Building Blocks of MBB Networks
  - Radio Access Network
  - Core Network



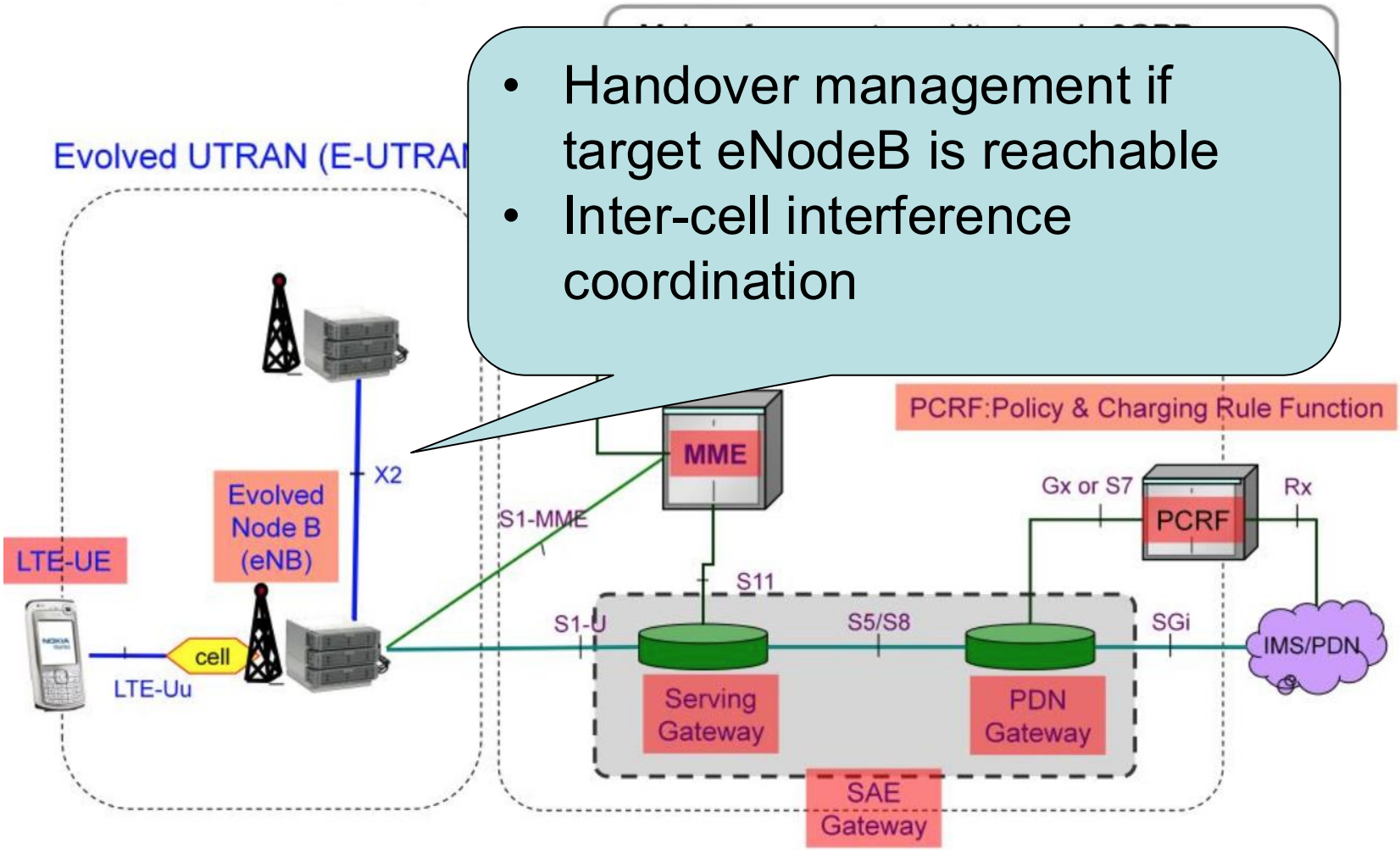
Closer look to LTE



Closer look to LTE



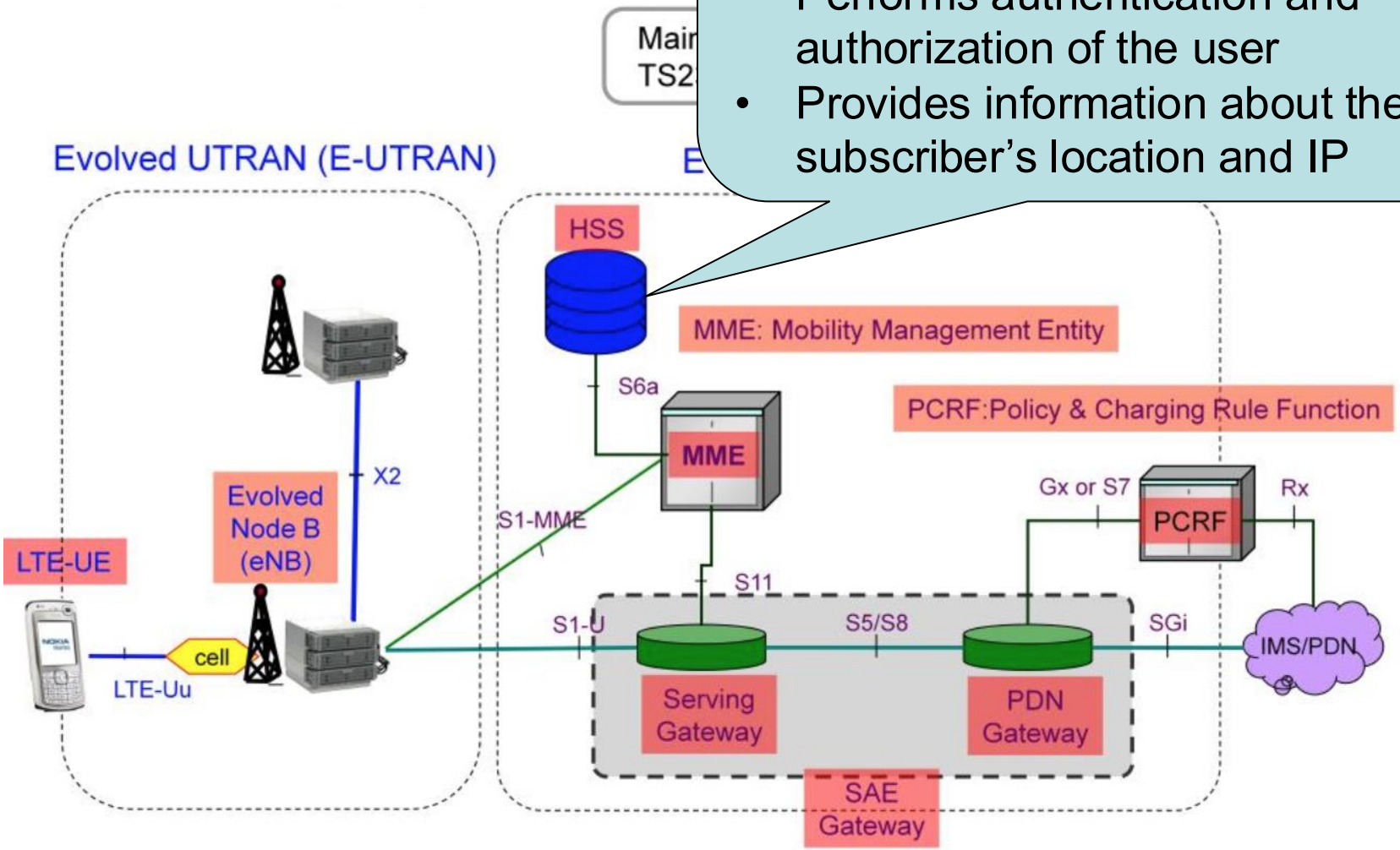
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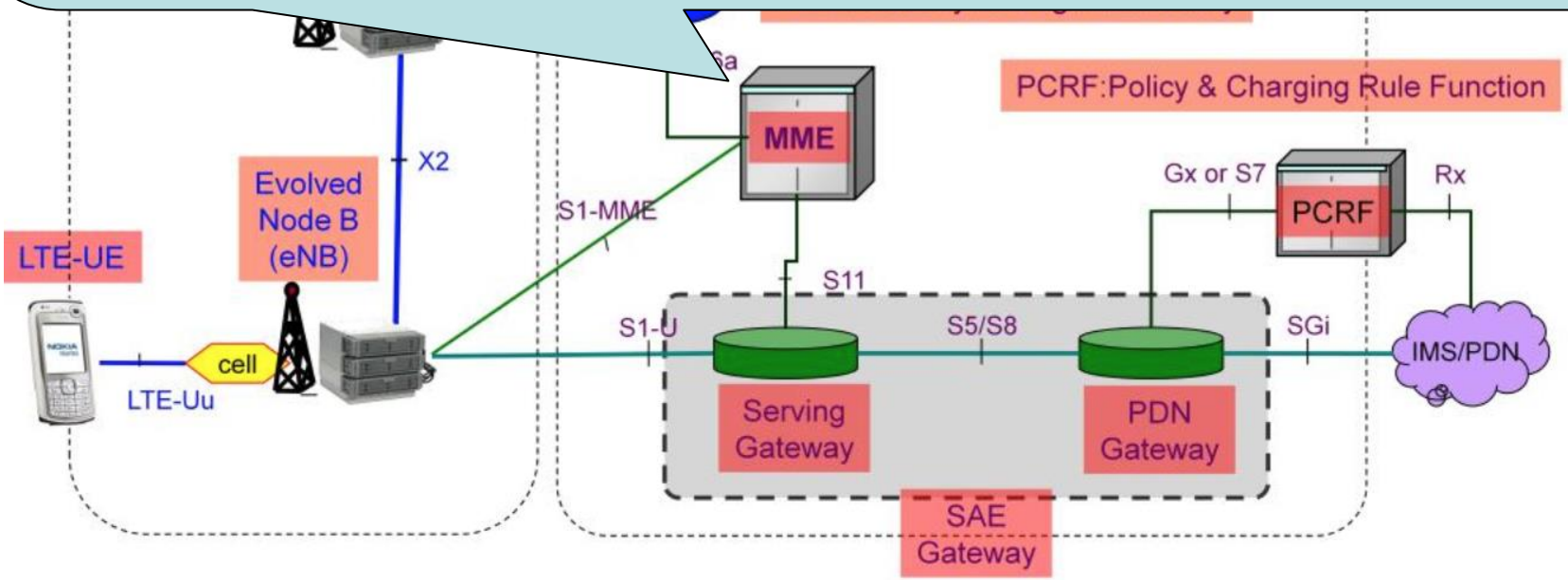
- Handover management if target eNodeB is reachable
- Inter-cell interference coordination

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

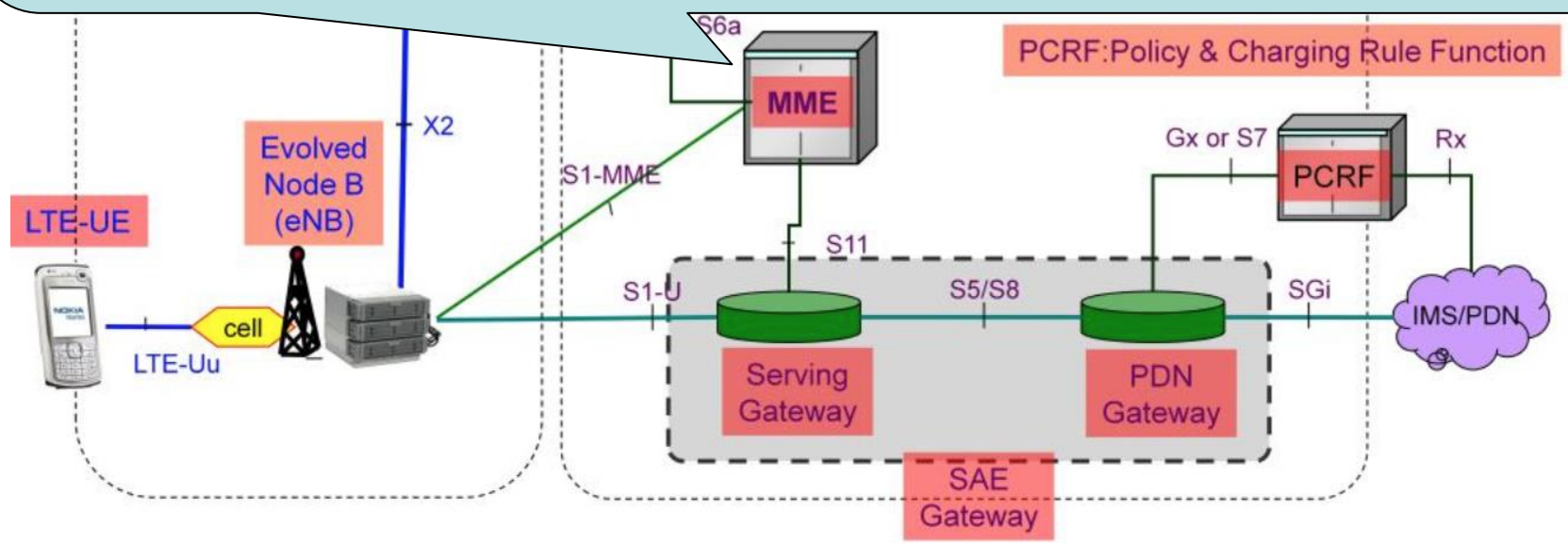


- **Mobility Management**: One of the most complex functions MME performs. Providing seamless inter-working has multiple use cases such as Inter-eNB and Inter-RAT, among others.
- **Radio Resource Management**: MME works with the HSS and the RAN to decide the appropriate radio resource management strategy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

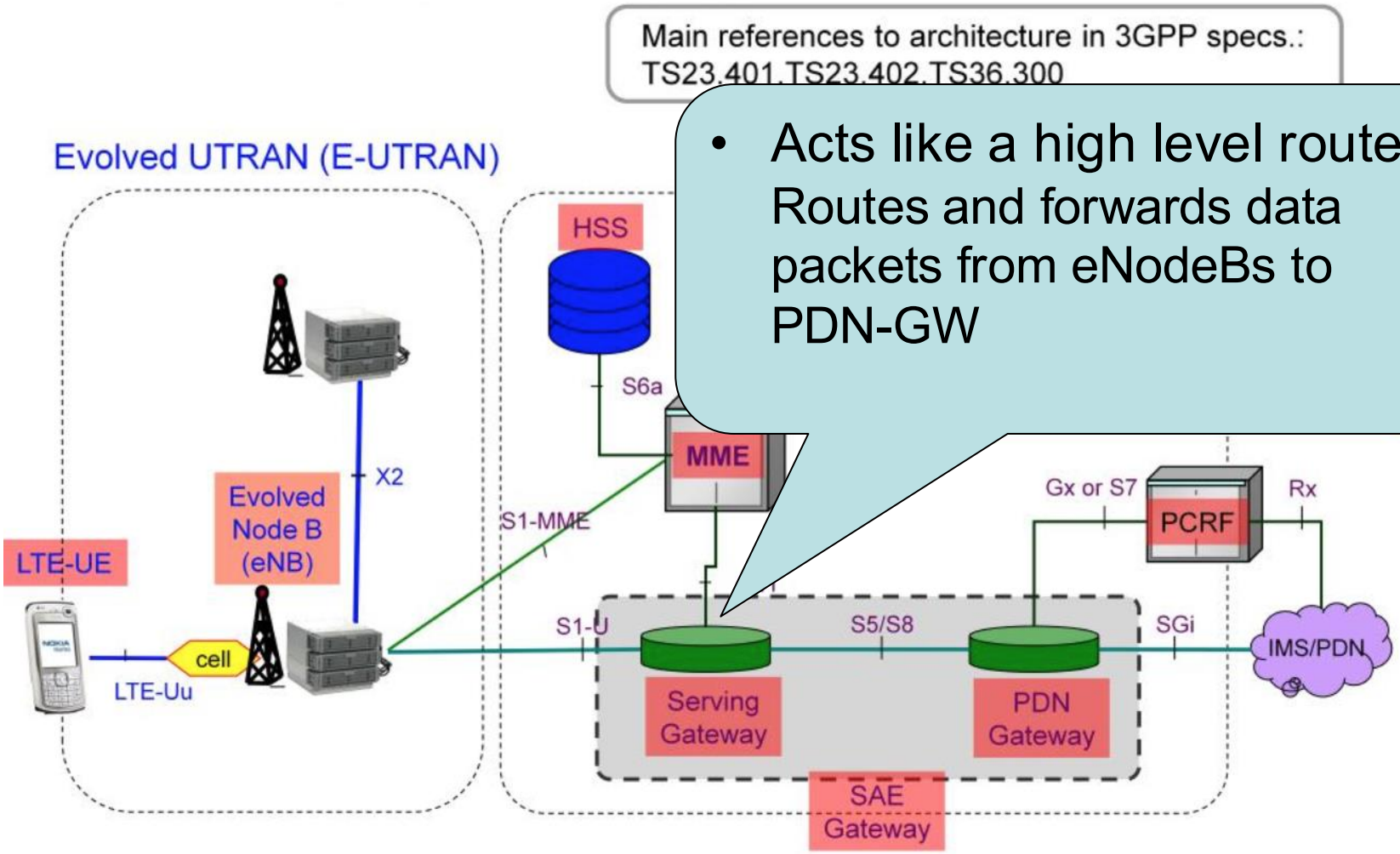


Closer look to LTE

- **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.



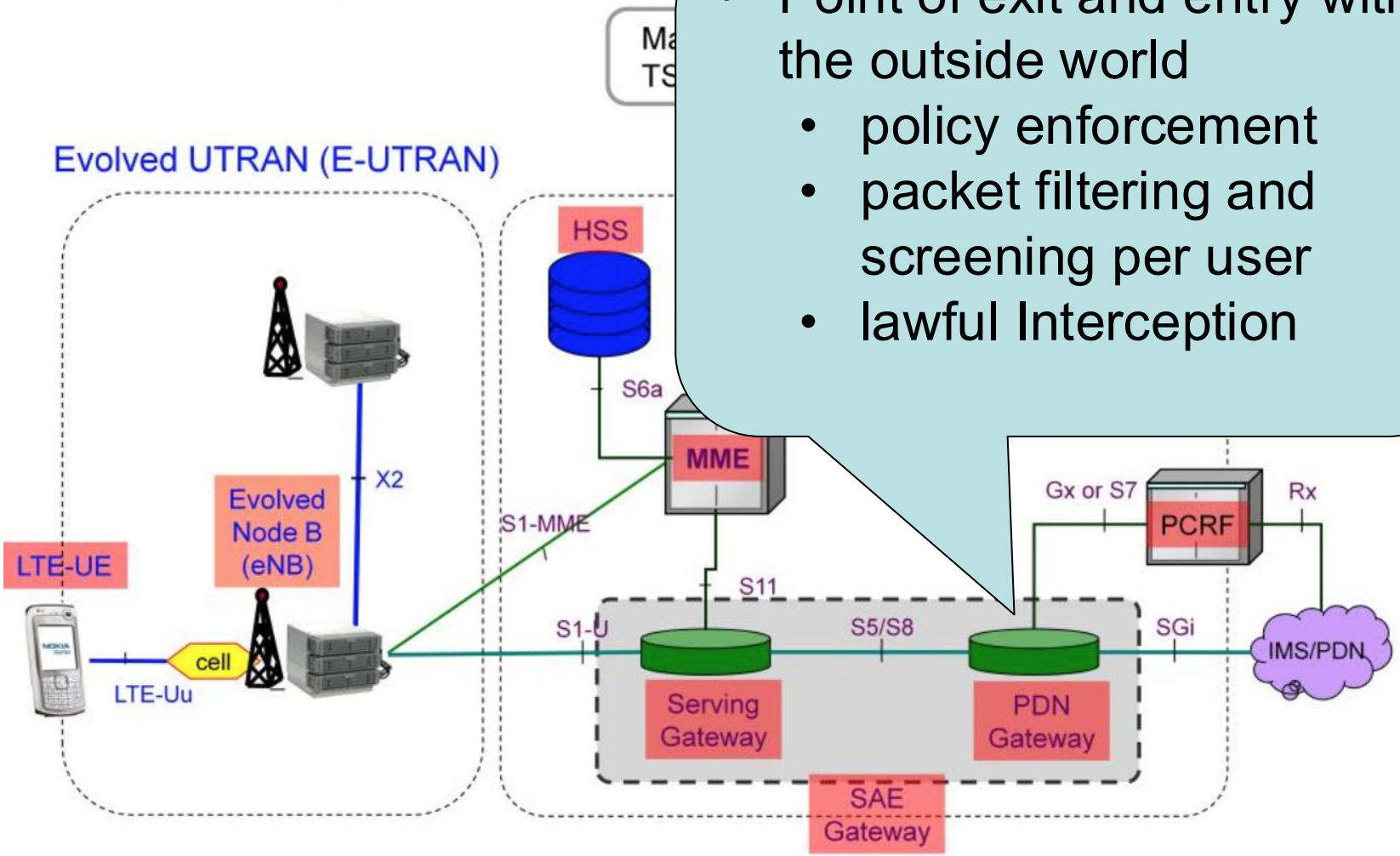
Closer look to LTE



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

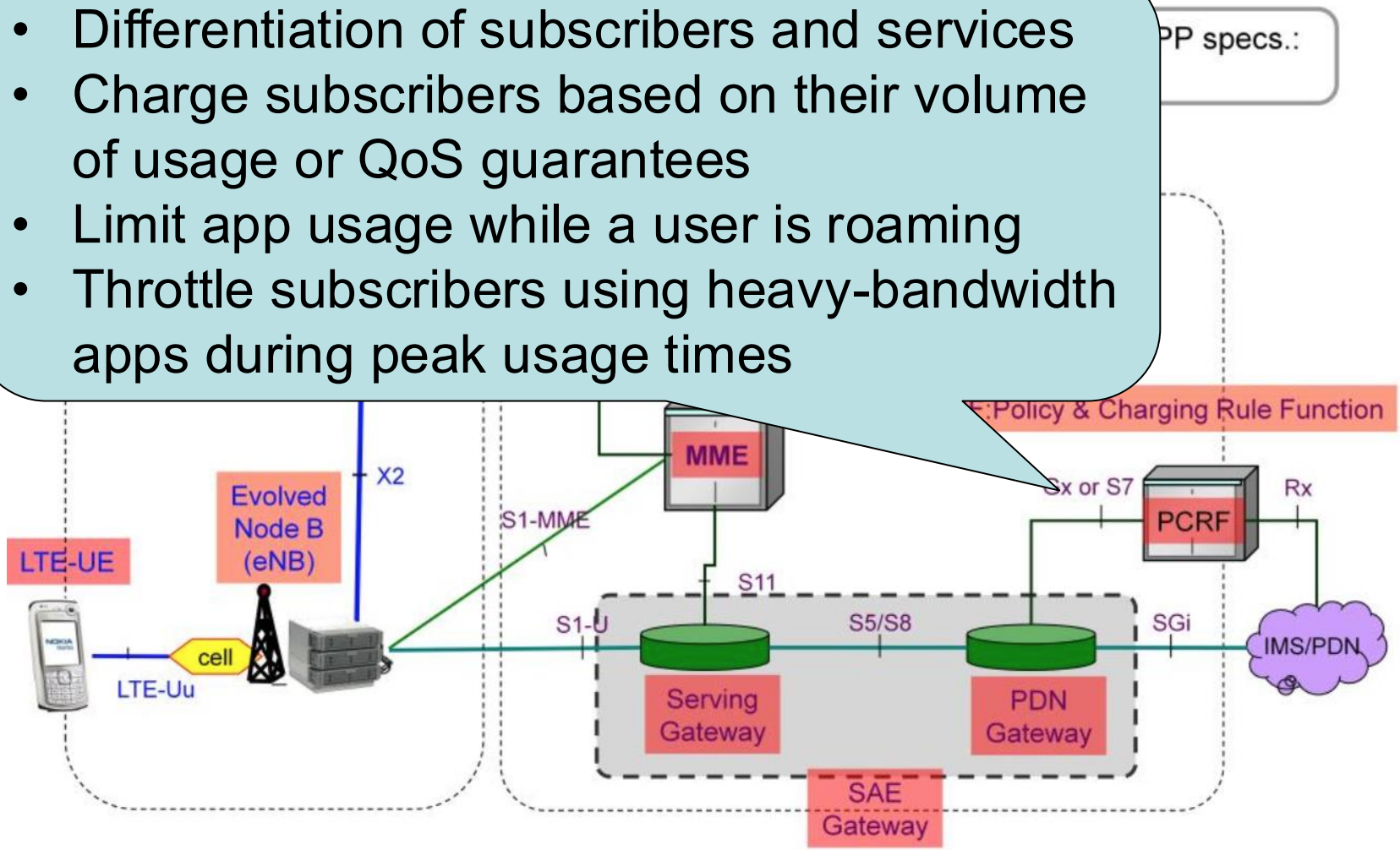
Closer look to LTE

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

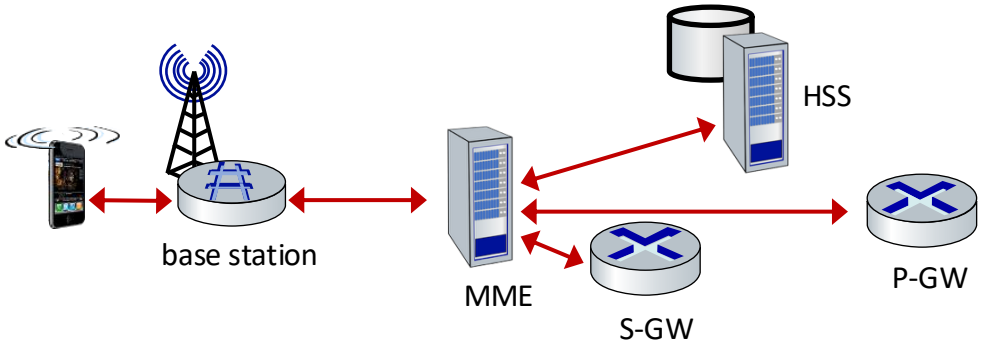


Closer look to LTE

- 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

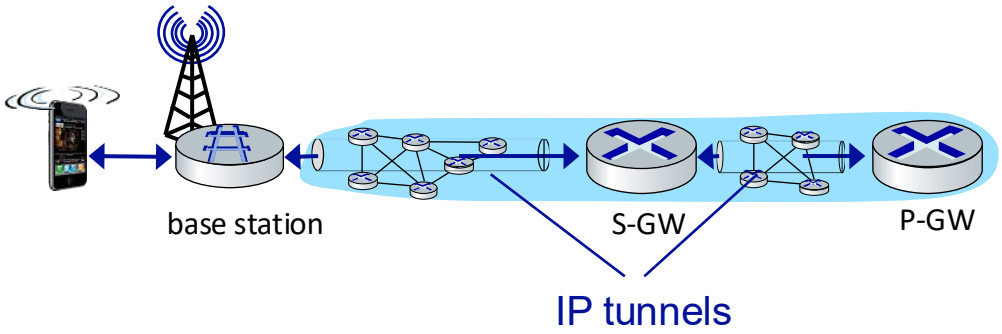


LTE: data plane control plane separation



control plane

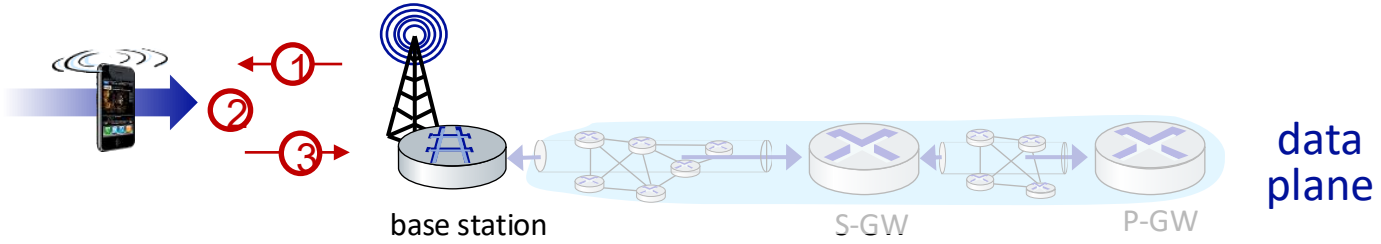
- new protocols for mobility management , security, authentication



data plane

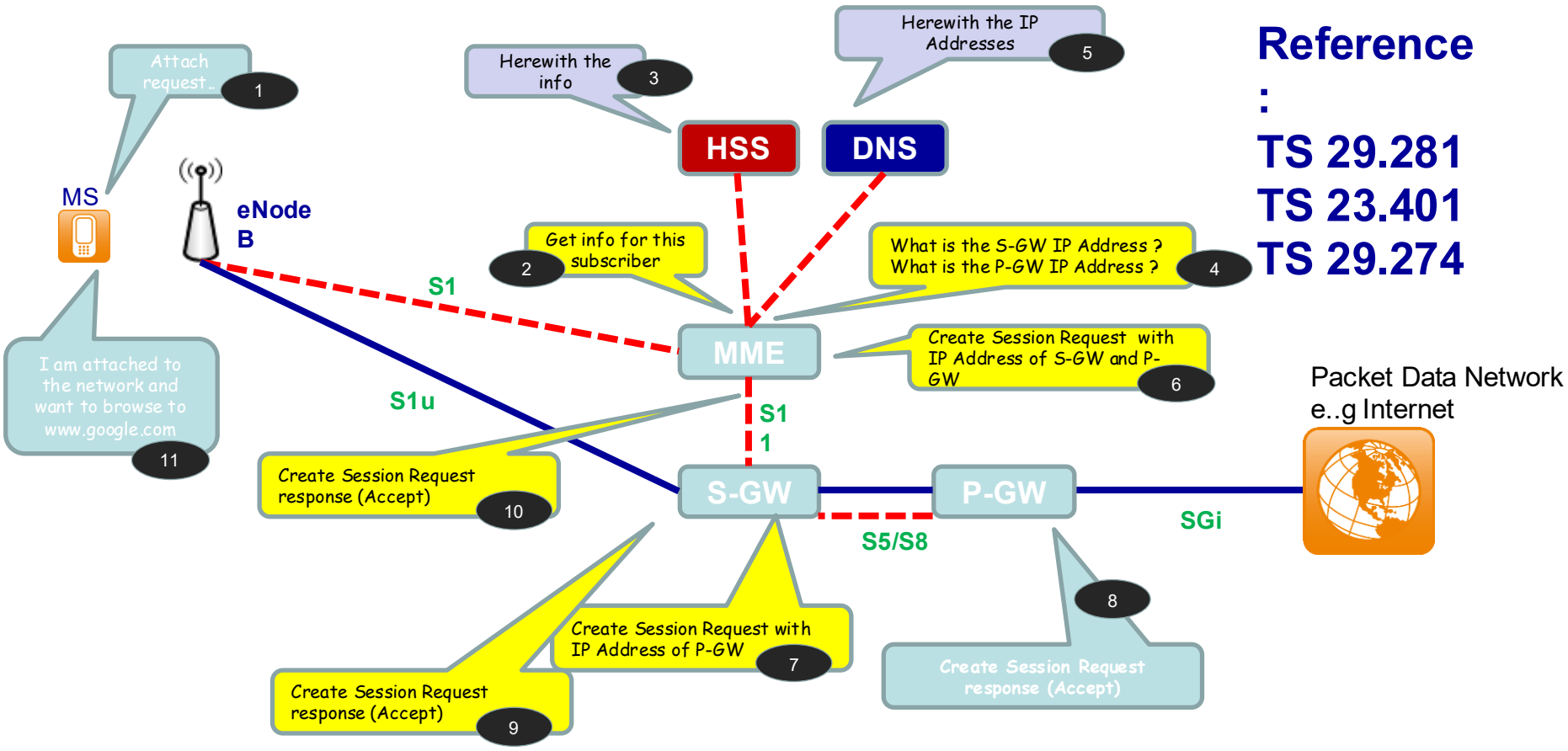
- new protocols at link, physical layers
- extensive use of tunneling to facilitate mobility

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)

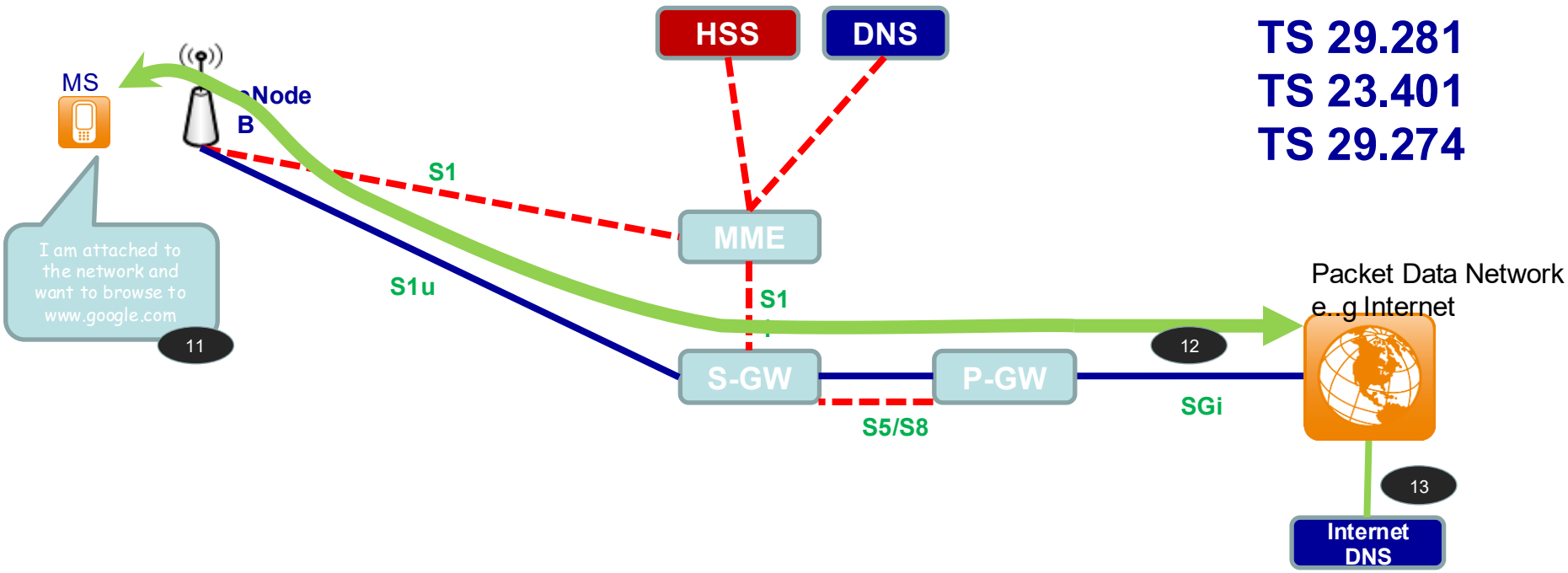
A Simplified Data Flow with 4G…(1/2)



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

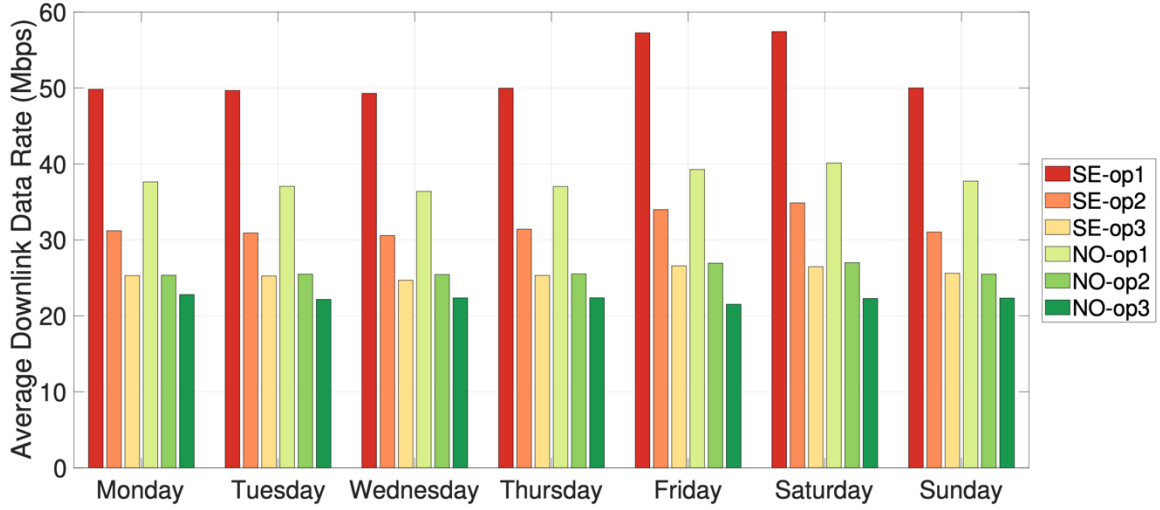
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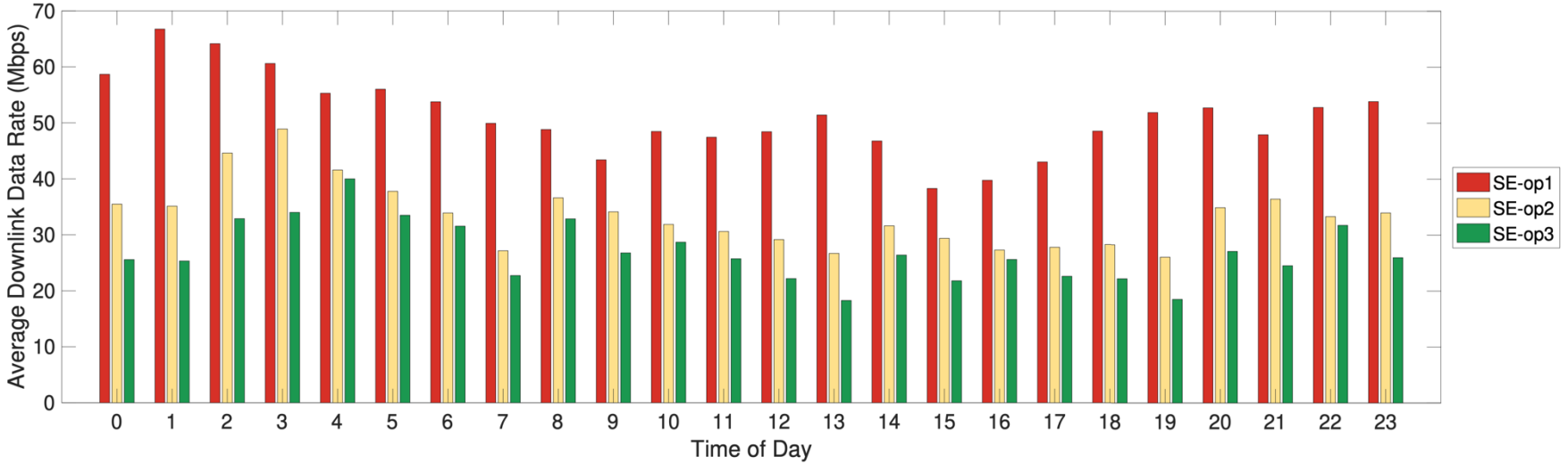
MONROE – Mobile Broadband Measurement Platform

- Coverage in 4 European Countries (Norway, Sweden, Spain, Italy)
- A set of 100 nodes equipped with Ethernet, WiFi and 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).

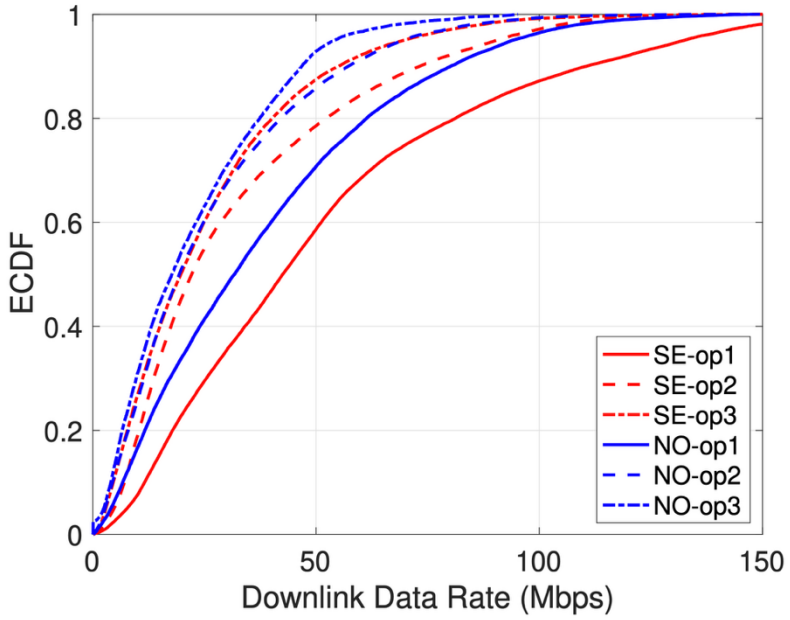


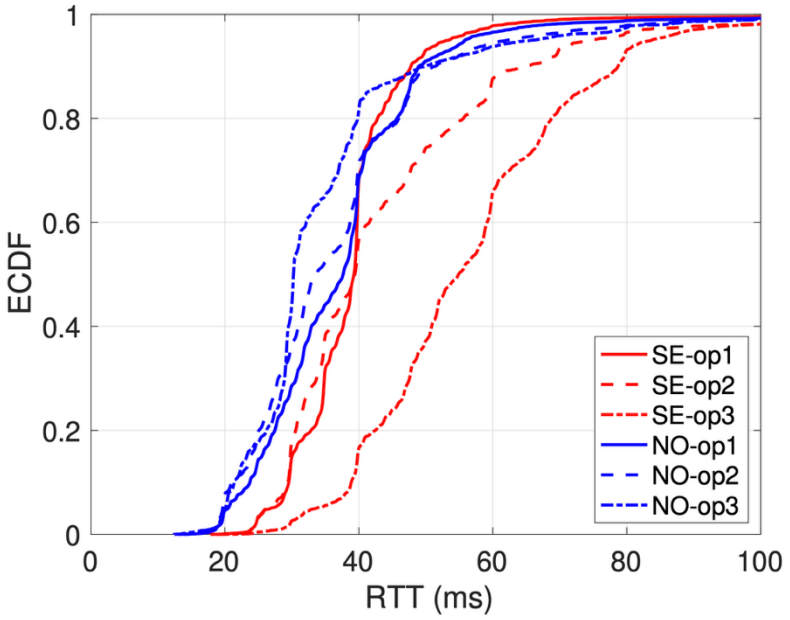
Hourly and Daily Patterns





LTE performance: Data rate and RTT





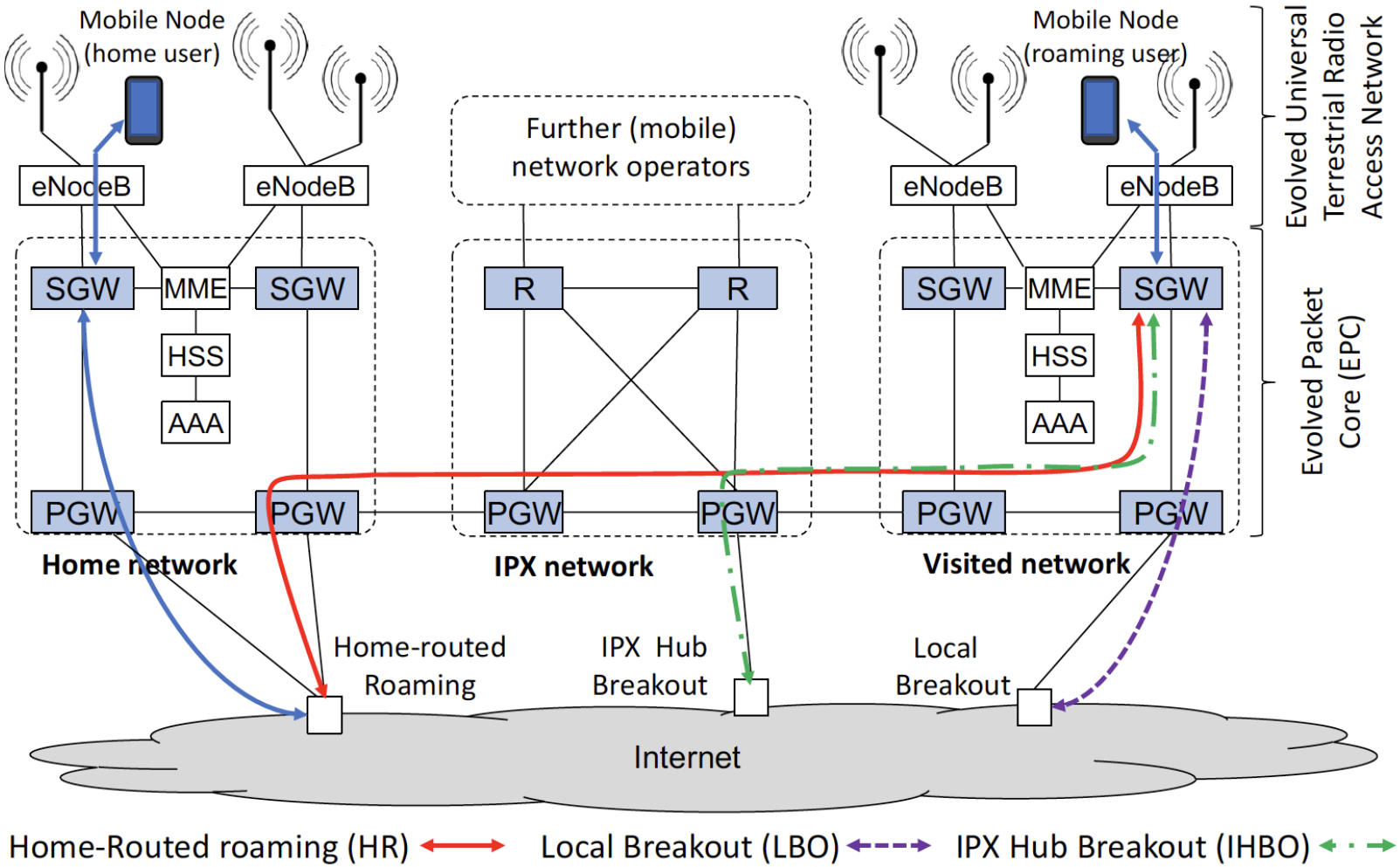
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Free roaming in Europe



Roaming Infrastructure



Internet access options for a mobile node at home (left) and when roaming (right).

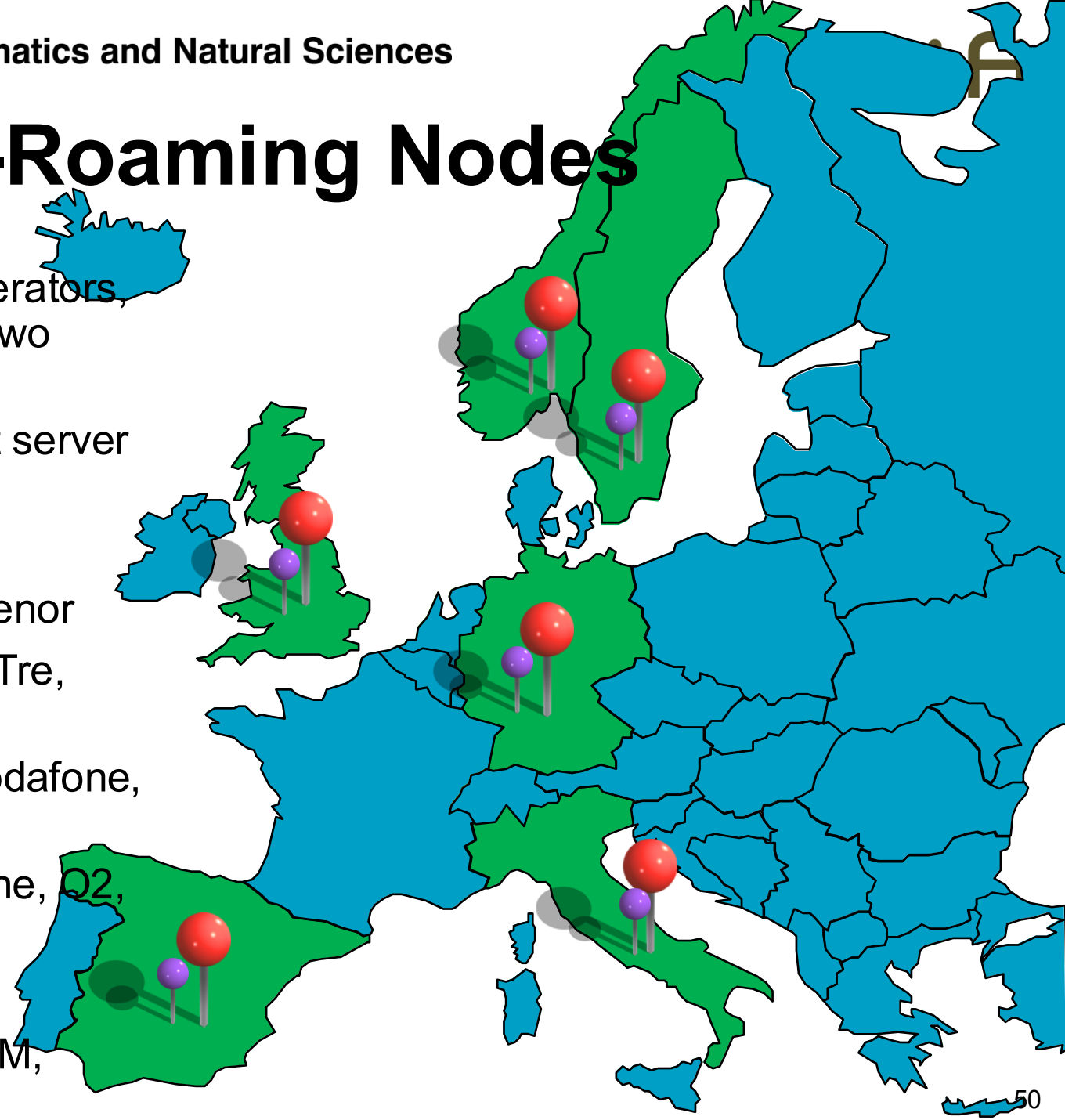
Roaming Models

- Home Routed (HR):
  - The IP address of the roaming user is provided by the home network.
  - All traffic to and from the mobile user is routed through the home network, for which a GTP tunnel is set up between the SGW of the visited network and the PGW of the home network (red path in the figure).
- Local BreakOut (LBO):
  - When LBO is used, the IP address of the roaming user is provided by the visited network.
  - The GTP tunnel is terminated at the PGW of the visited network and IP-based services can be accessed directly from there (purple path in the figure).
- IPX Hub Breakout (IHBO):
  - The IP address of the roaming user is provided by the IPX network. The GTP tunnel from the SGW in the visited network terminates at a PGW in the IPX network (green path in the figure).
  - There may be multiple PGWs so that latency and resource usage can be reduced by selecting one geographically close to the visited network.

MONROE-Roaming Nodes

- 6 countries, 16 operators, each country has two nodes
- One measurement server per country

- **Norway**: Telia, Telenor
- **Sweden**: Telenor, Tre, Telia
- **Spain**: Orange, Vodafone, Movistar
- **Germany**: Vodafone, O2, T-Mobile
- **UK**: Vodafone, EE
- **Italy**: Vodafone, TIM, WIND

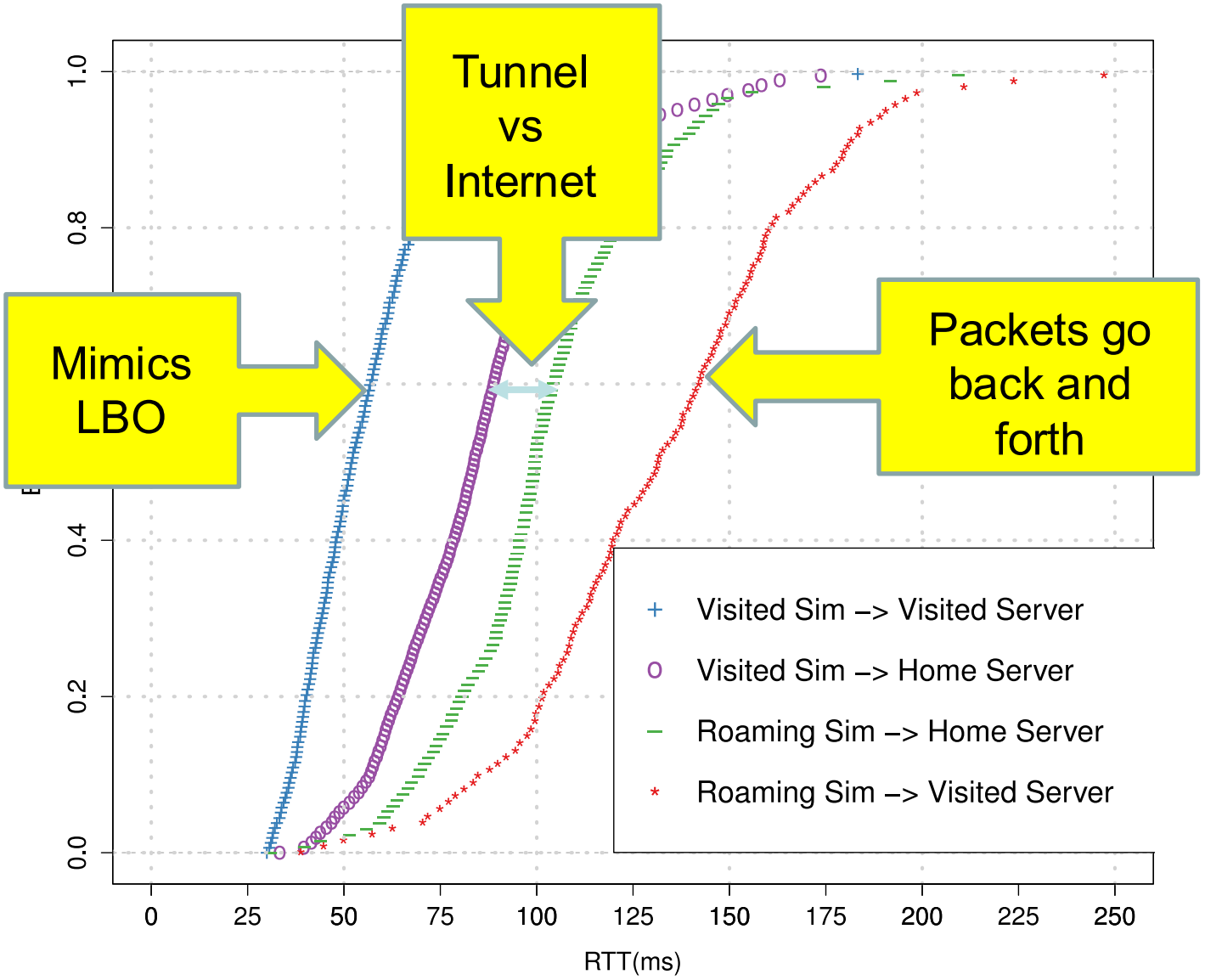


Roaming Configuration

- Home Routed (HR) Roaming was used by all 16 MNOs!

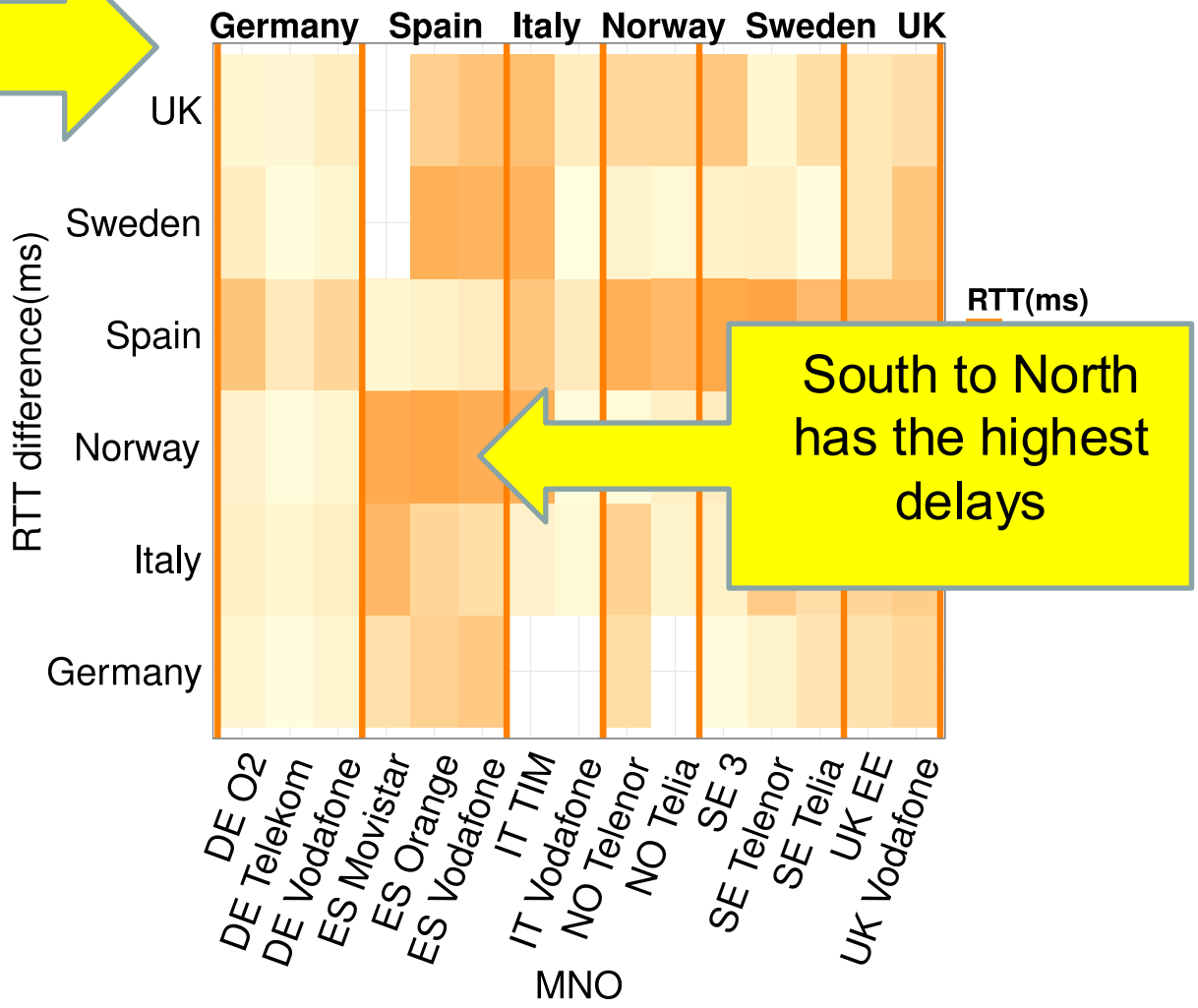
- Why all traffic is sent back to home network?
  - HR provides the home operators with all the accounting and billing information
  - Operators want to have near real-time view of the customer traffic for accounting reasons
  - More complex debugging if HR is not used, who is responsible if there is a problem?

Delay penalty of home-routed roaming



Dela of home-routed roaming geog

Germany is in a good position being in central Europe



RTT difference between the roaming SIM and the visited SIM

Outline

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

Mobile Virtual Network Operators (MVNO)

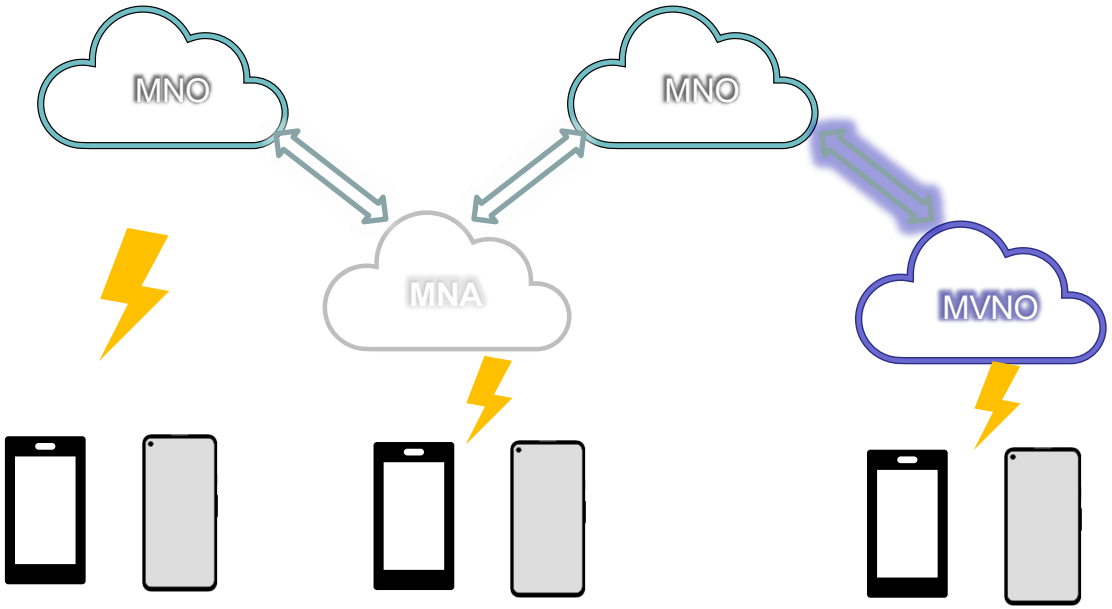
- MVNO is an entity that offers mobile network services to end-users, but does not own nor operate fully a cellular network. MVNOs lack of ownership of radio spectrum resources.
- In order to operate, an MVNO needs to have agreements in place to access the network of at least one MNO.

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):

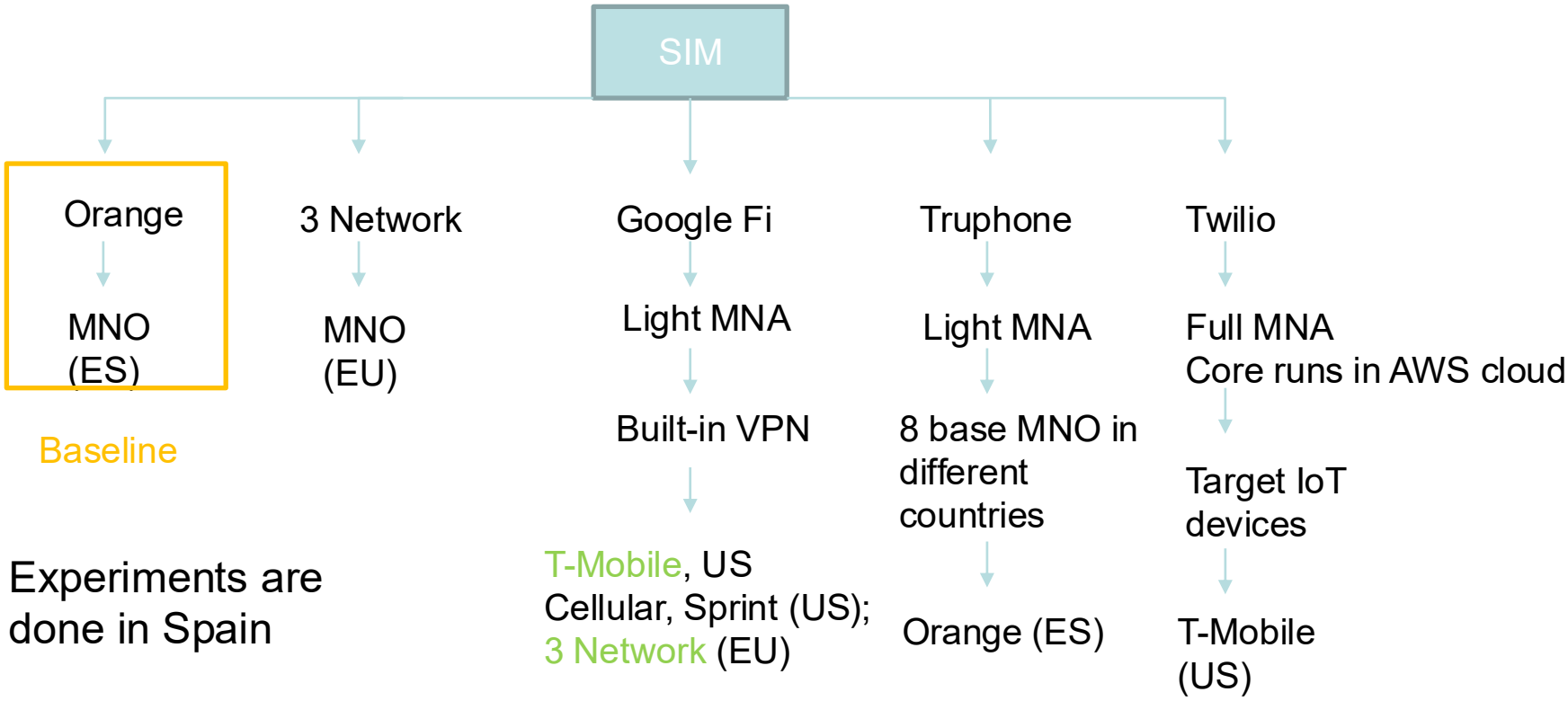
- MNAs rely on the infrastructure of Mobile Network Operators (MNO) to provide services. However, instead of relying on a single base MNO (like Mobile Virtual Network Operator (MVNO)), MNAs can multiplex clients across multiple MNOs.
- MNAs operations benefit from the extensive global network infrastructure in multiple countries.



Mobile Ecosystem Summary

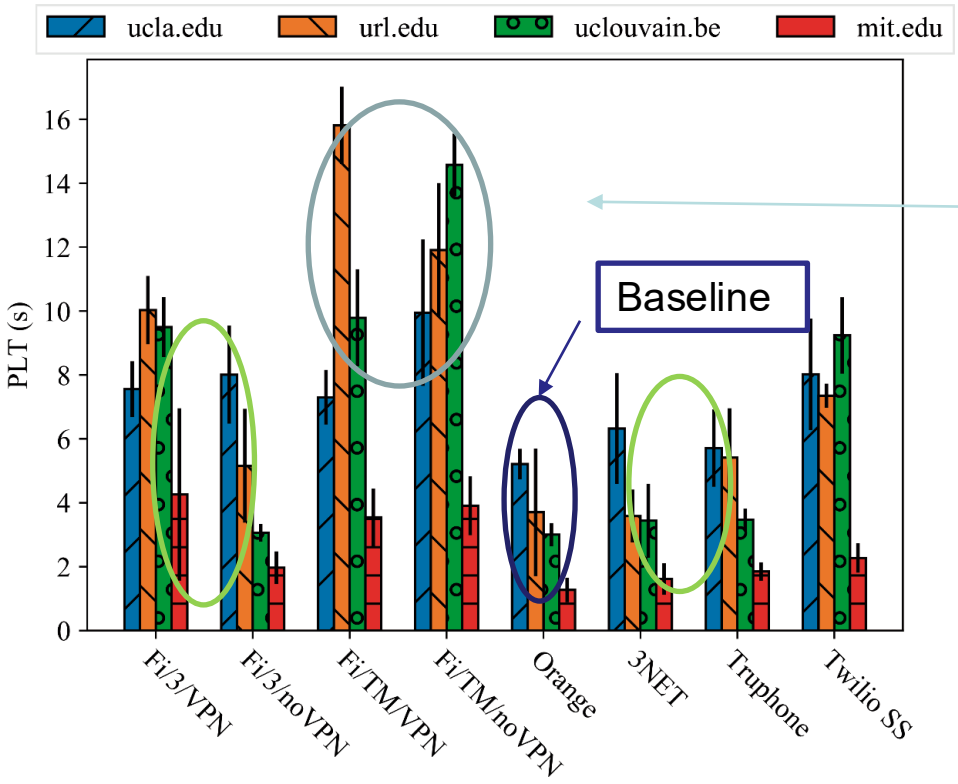
@HOME	Traditional MNO	Light MVNO	Full MVNO	Light MNA	Full MNA	Thick MNA
Sales	MNO	Light MVNO	Full MVNO	Light MNA	Full MNA	MNA
Core	MNO	Base MNO	Full MVNO	Base MNO	Full MNA	MNA / Base MNO
Radio	MNO	Base MNO	Base MNO	Base MNO	Base MNO	Base MNO

Experimental Setup



Experiments are done in Spain

Web Performance



For US breakout, large penalties accessing EU Webpages

Name	Breakout
Fi/TM/VPN	USA
Fi/TM/noVPN	USA
Fi/3/VPN	USA
Fi/3/noVPN	UK
Truphone	Europe
Twilio_SS	USA
Orange	Spain
3NET	UK

FI/3/NoVPN & Truphone have close performance to Orange

Low delay in CDN does not eliminates the differences in the PLT for the different configuration

Page Load Time (PLT): LoadEventStart – NavigationStart

https://developer.mozilla.org/en-US/docs/Web/Performance/Navigation_and_resource_timings