ETSF15 Communication Systems and Networks

Stefan Höst

LTE

Long Term Evolution

4G mobile communication system

LUND UNIVERSITY

Plan of lecture

- Some history of mobile networks—Past and future
- EPS: Idea of network structure
- EPC: Packet networks
- LTE (E-UTRAN): Radio channel
- What comes next?

1st generation

- Analog transmission with no security
- Small regions (countries)
  - First NTT ('79), second NMT ('81)
  - NMT (Nordic), NTT (Jap),
    AMPS (NA+Aus), TACS (UK),
    Radiocom 2000 (Fr), RTMI (It)
  - NMT shut down 2007

2nd generation

- Digital voice channel (10kb/s), Circuit switched
- News:
  - SIM card (Subscriber Identification Module)
  - SMS: First 3 December 1992: “Merry Christmas”
- Larger regions (continents)
  - GSM (Eur), IS-136 (N+S Am+Aus),
    IS-95 (NA+Asia), PDC (Jap)
  - GSM 1991

2.5 generation => Data channels

- HSCSD, GPRS, EDGE (E-GPRS), IS-95B

3rd generation

- Packet switched for voice and data
- 144kb/s – 3Mb/s
- Global
  - CDMA2000 (2000)
  - UMTS (2001)
- News:
  - UTRAN

    Universal Terrestrial Radio Access Network

4^{th} generation

- Packet switched data traffic (Voice over IP or 3G)
- 100Mb/s-1Gb/s
- Global:
  - LTE (Long Term Evolution)
  - Feb 2007 First demo (Ericsson)
  - Dec 2009 first commercial (Stockholm and Oslo)
- News: Smartphones and apps
  - iPhone 2007

5^{th} generation

- Packet switched data traffic
- 1-100Gb/s
    - 1Gb/s / user
- ≈2020
- News: Small cells, home cell, IoT (M2M), Car2Car, Massive MIMO, heterogeneous, etc

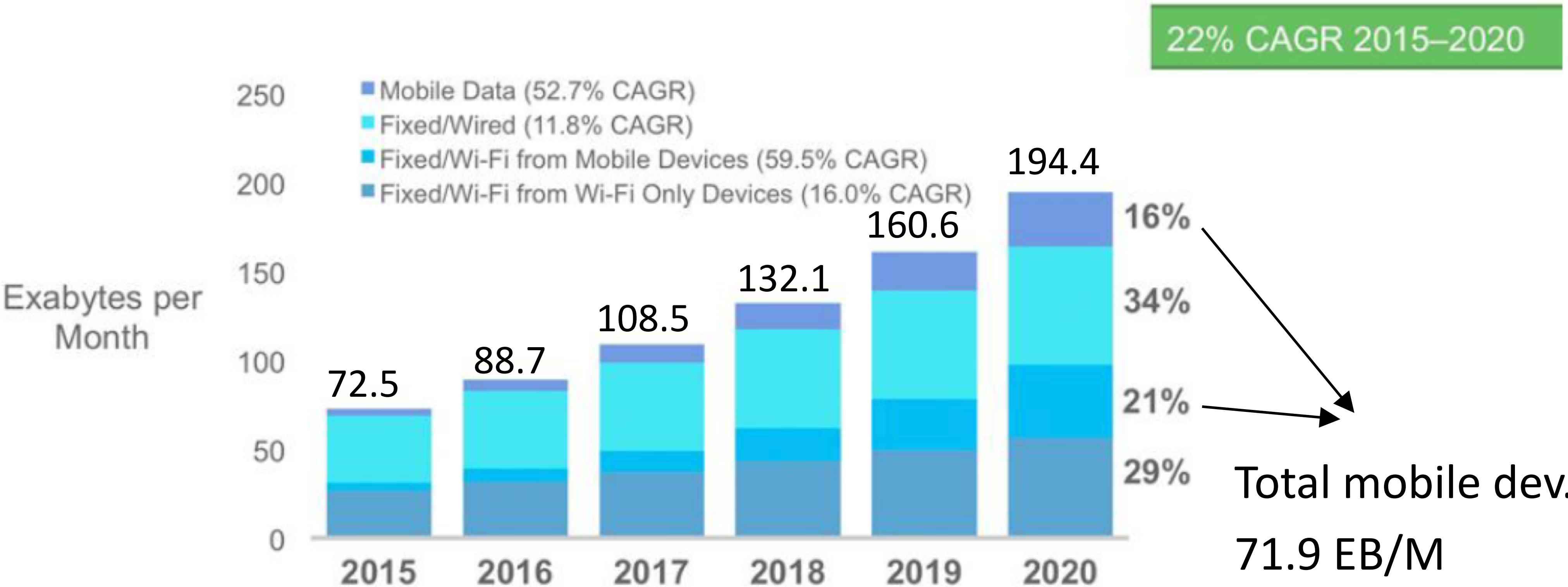
https://www.youtube.com/watch?v=Fq2A6bi_sDE

Mobile traffic (CISCO VNI 2016-2021)

- Global mobile data traffic grew 63% in 2016
  - 4.4 EB in Dec ’15 to 7.2 EB in Dec ’16
  - 18 fold growth over last 5 years
- Global mobile devices and connections in 2016 grew to 8.0 billion (estimated 11.6 billion in 2021 – 1.5/capita)
  - 45% smart devices generate 81% of traffic in 2016
    - 86% in 2021
  - 26% 4G connections generate 69% data in 2016
    - 53% 4G in 2021 will generate 79% traffic
    - 0.2% 5G (25 million)

Total IP traffic

Figure 25. Global IP Traffic, Wired and Wireless*

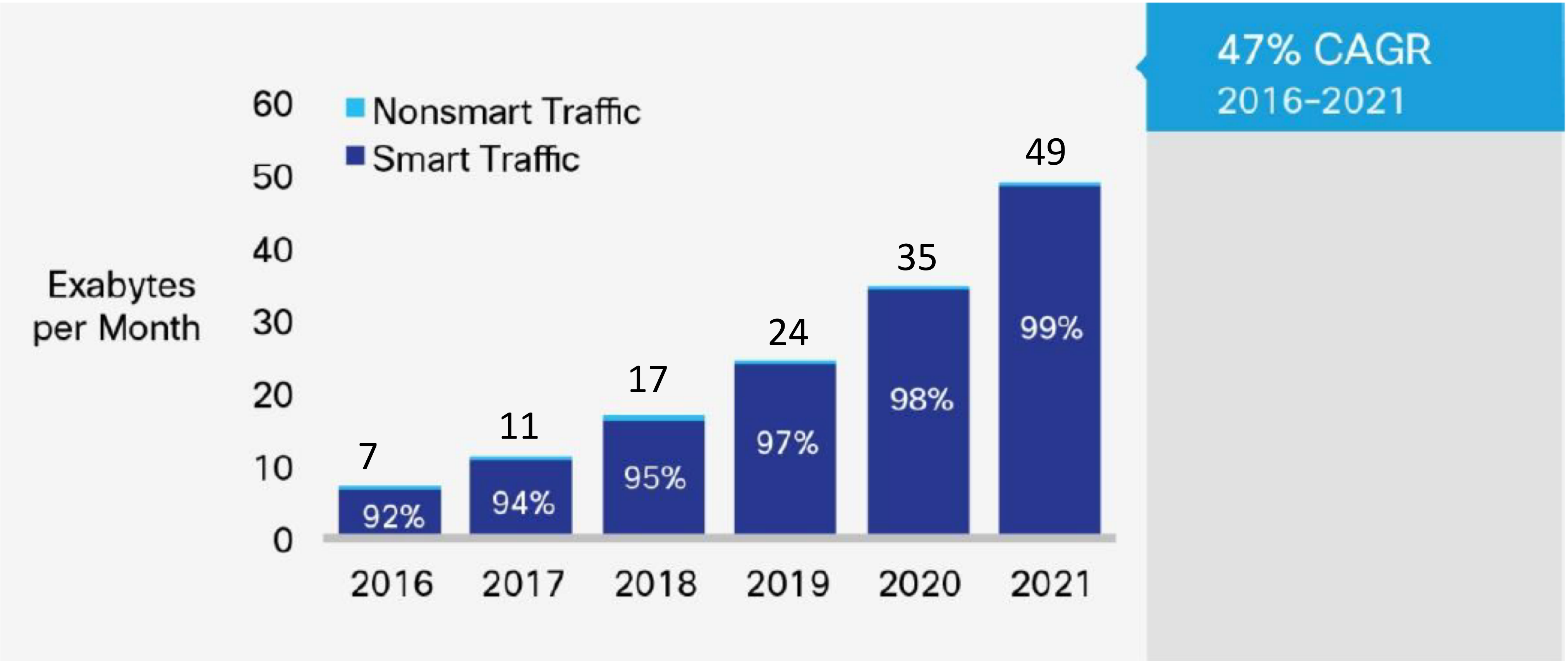


Total mobile dev.
71.9 EB/M
(≈ total of 2015)

* Wireless traffic includes Wi-Fi and mobile.
Source: Cisco VNI Global IP Traffic Forecast, 2015–2020

Total Mobile traffic

Figure 8. Effect of Smart Mobile Devices and Connections Growth on Traffic

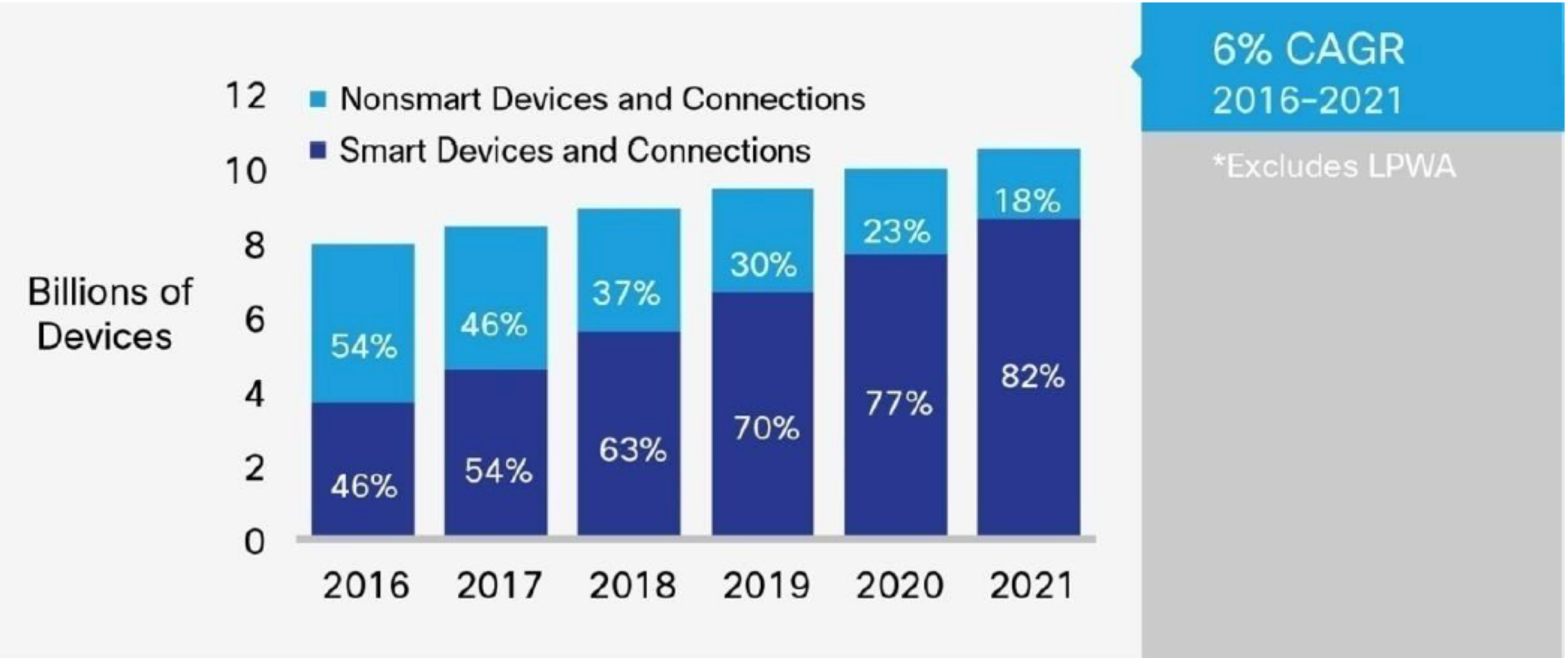


Note: Percentages refer to traffic share.

Source: Cisco VNI Mobile, 2017

Growth of devices

Figure 7. Global Growth of Smart Mobile Devices and Connections (Excluding LPWA)

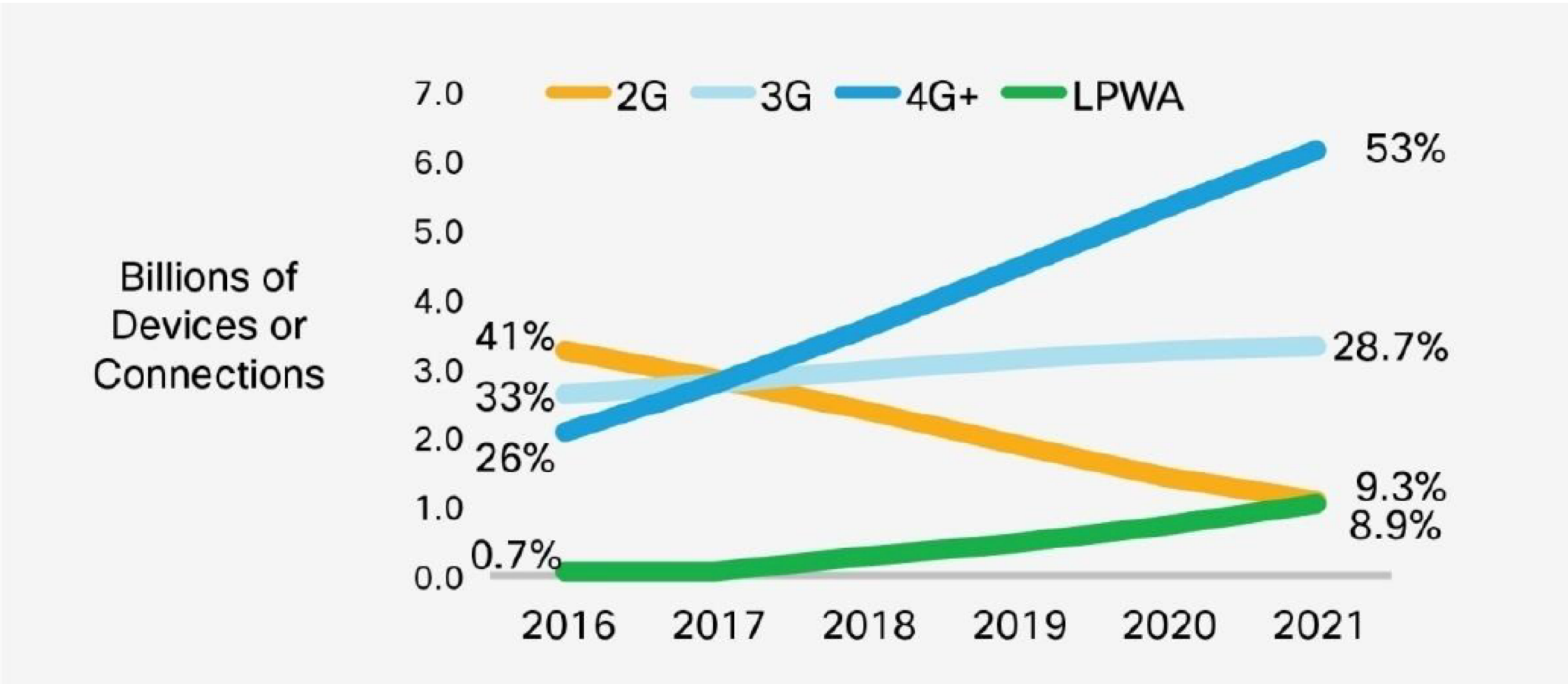


Note: Percentages refer to device and connections share.

Source: Cisco VNI Mobile, 2017

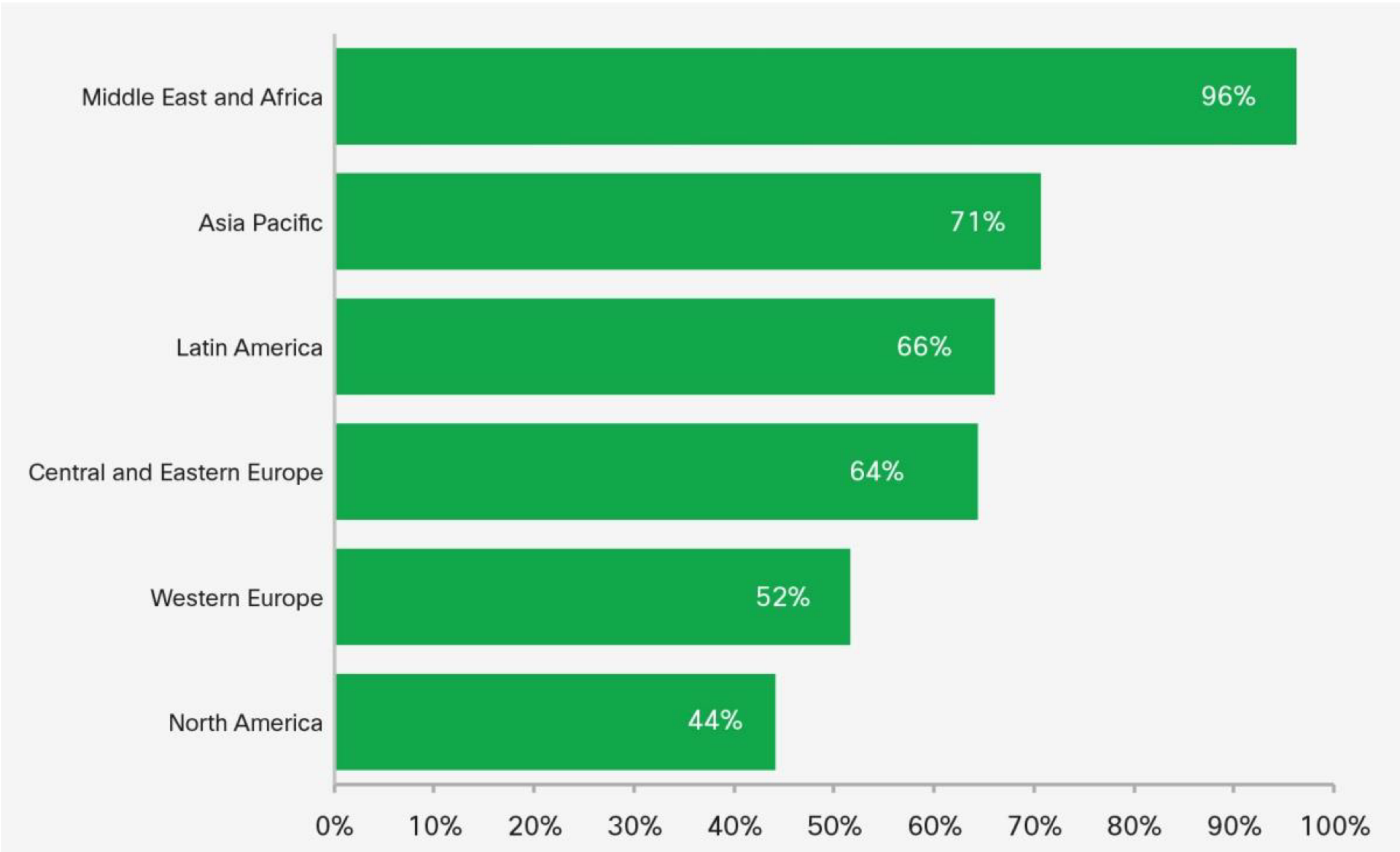
Growth of technology

Figure 12. Global Mobile Devices and Connections by 2G, 3G, and 4G+



Note: Percentages refer to device and connections share.

Mobile data traffic growth in 2016



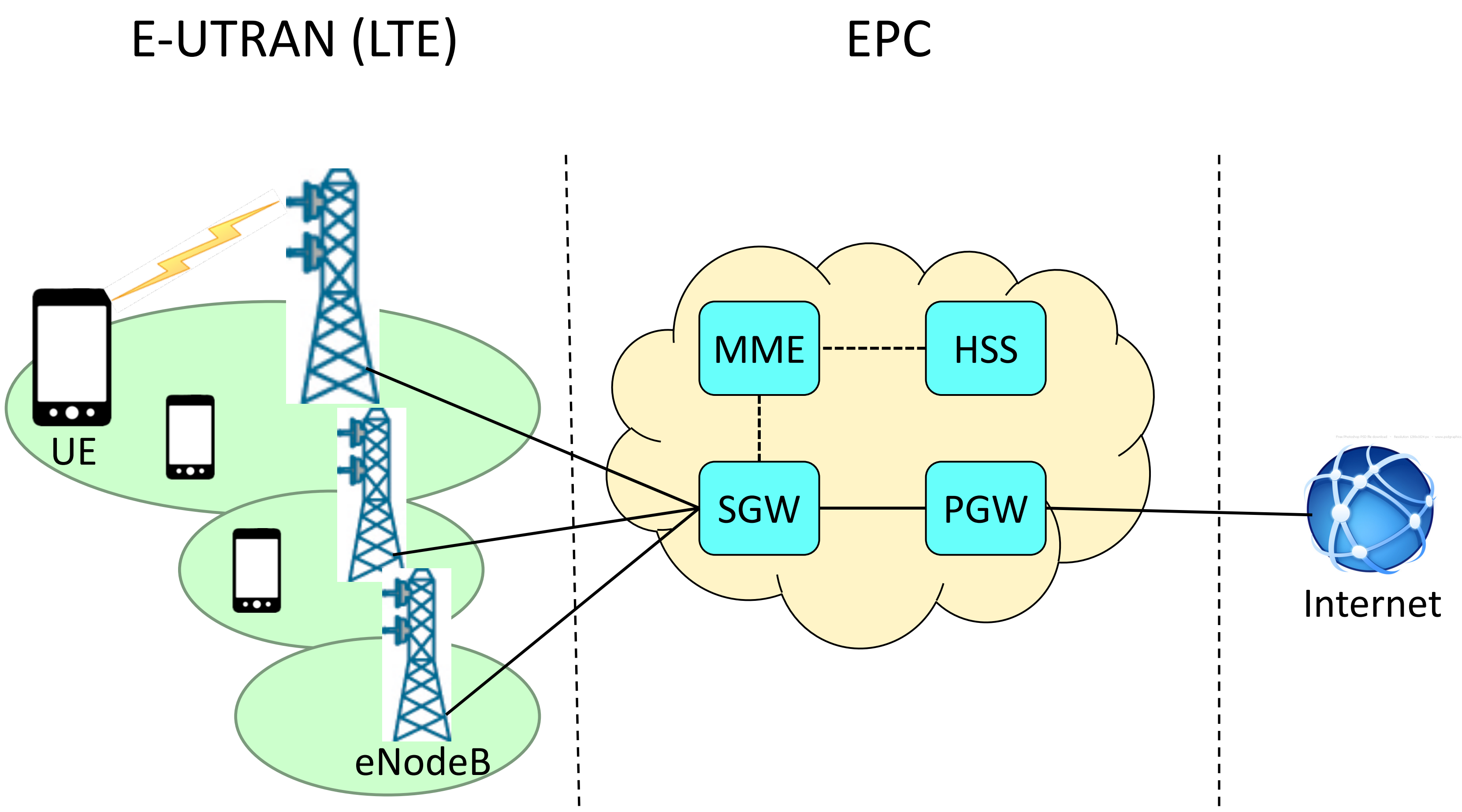
4G – LTE
Long Term Evolution

Standardized by 3GPP

(3rd Generation Partnership Project)

- Radio Access Networks (RAN)
- Service & Systems Aspects (SA)
- Core Network & Terminals (CT)
- GSM EDGE Radio Access Networks (GERAN).

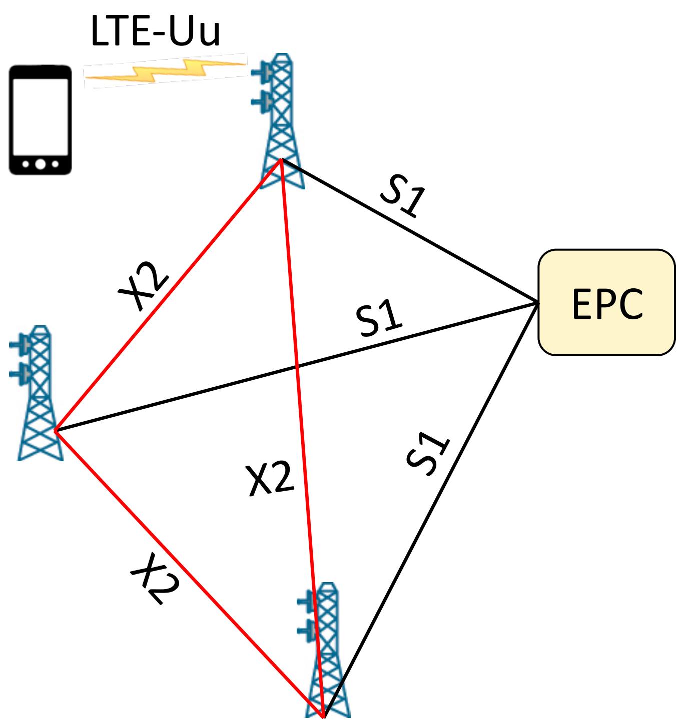
EPS (Evolved Packet System)



EPS challenges

- High speed radio link
  - Bandwidth is extremely expensive. Squeeze out all bits you can
- Access to Internet
  - How to send IP packets
- Authentication, security and accounting
- User mobility
  - Handover between eNBs
  - How to transfer data in the network
- Cost efficient infrastructure

EPS interfaces



EPC <-> eNB

- S1 interface
- Split in S1-MME and S1-U
- No centralised node

eNB <-> eNB

- X2 interface
- Coordination and positioning
- Synchronisation

eNB <-> UE

- LTE-Uu or E-UTRAN-Uu

E-UTRAN
Evolved Universal Terrestrial Radio Access Network

RAN responsible for

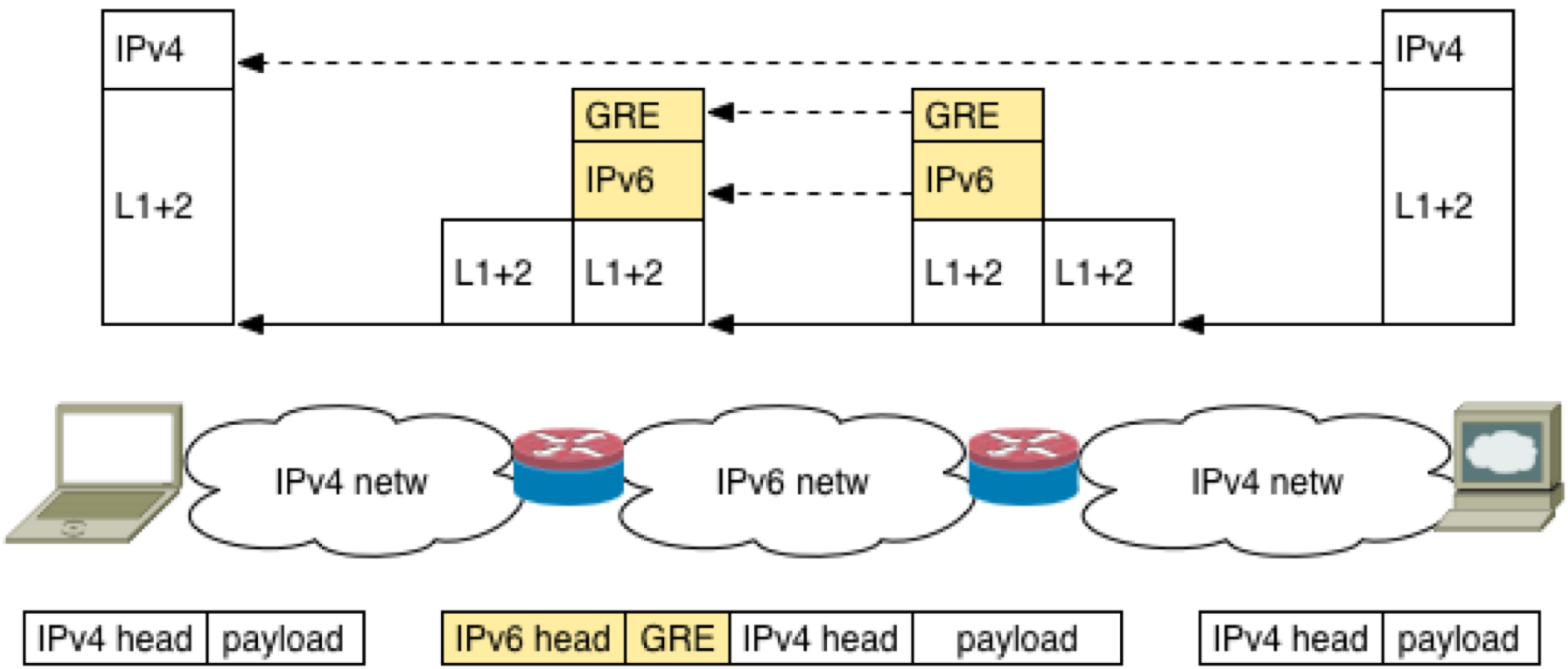
- Resource management
  - Scheduling and dynamic resource allocation
- Compression
  - IP head compression reduces overhead
- Security
  - Encryption of data
- Positioning
  - UE physical position
- Connection to EPC
  - User and control plane

Protocol stack

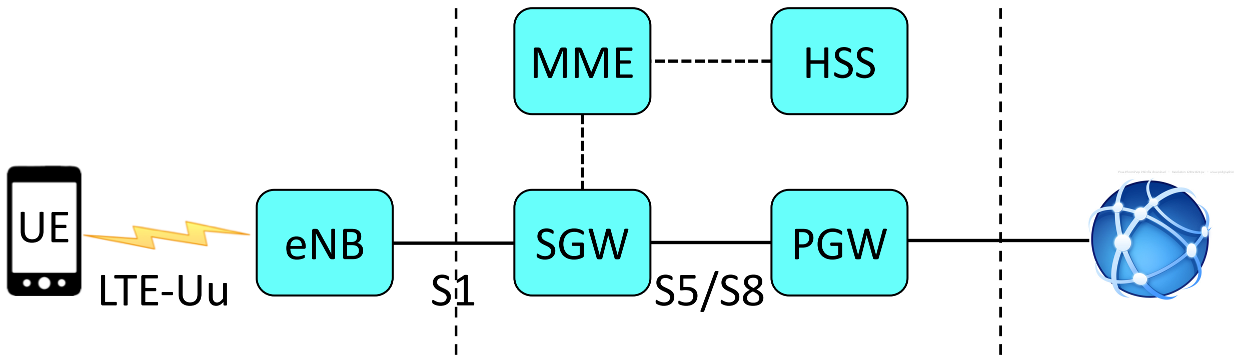
- S1 often tunneled through the fix network architecture
- A tunnel is a way to send packets over other types of network, e.g.
  - IPv6 over IPv4 and vice versa
  - IP over IPsec
- GTP: GPRS Tunneling Protocol

Example of tunneling

IPv4 over IPv6 using GRE (Generic Routing Encapsulation)



IP packets in EPC (User plane)



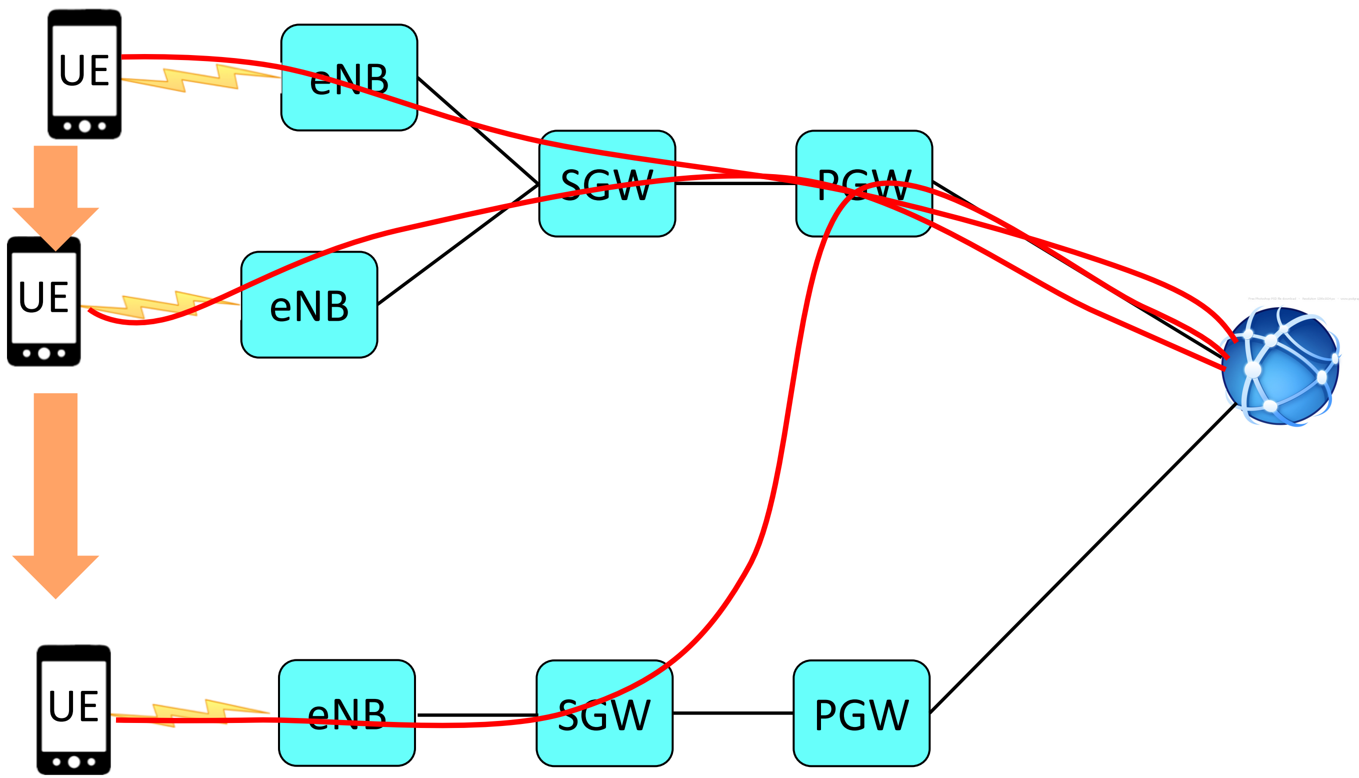
PGW

- IP edge for user
- IP address allocation to UE
- QoS filtering
- Mobility anchor
  - Does not change during session. Preserves the IP addr

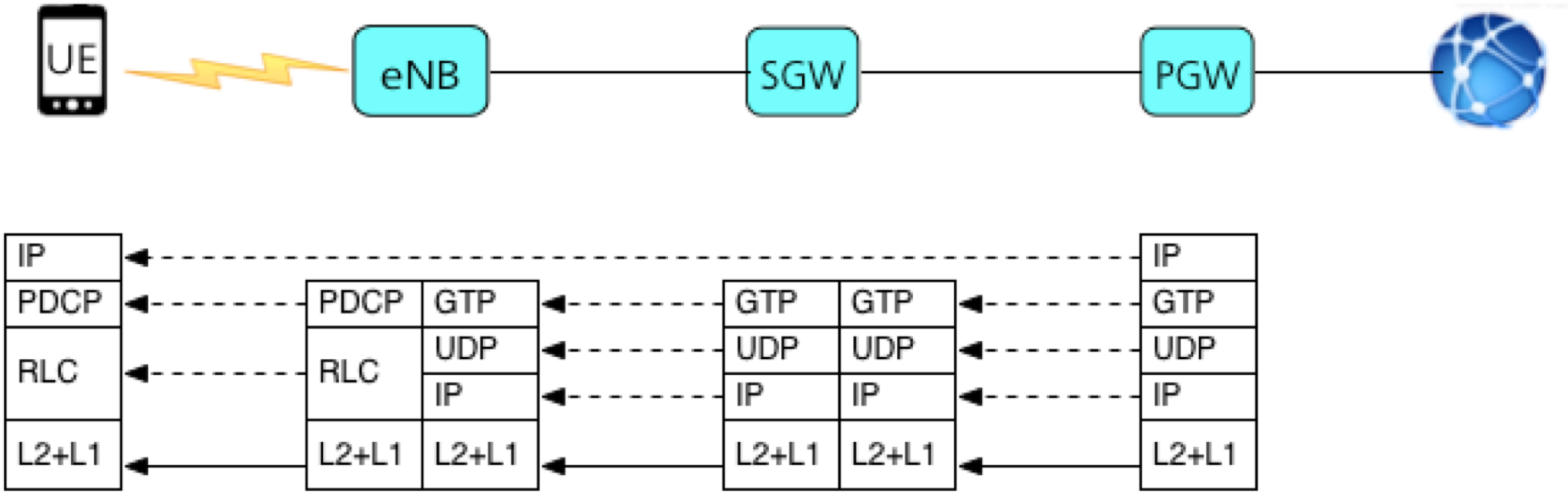
SGW

- Collecting charging info
- Local anchor towards eNB
  - Can change due to mobility

IP packets in EPC (User mobility)



Protocol stacks (Data plane)



GTP: GPRS Tunneling Protocol

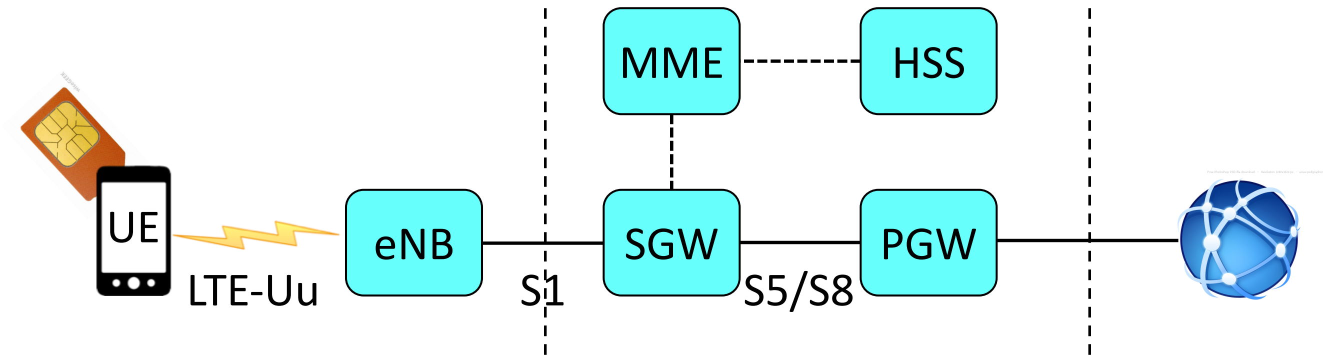
PDCP: Packet Data Convergence Protocol

(IP<->Radio, Header compression, security)

RLC: Radio Link Control

(Segmentation, reordering)

Control plane in EPC



MME

(Mobility Management Entity)

- Communicates with eNB and SGW
- Manage tunnels and encryption

HSS

(Home Subscriber Server)

- Subscriber data base
- SIM card key exchange
- AAA
  - Authentication, Authorization and Accounting

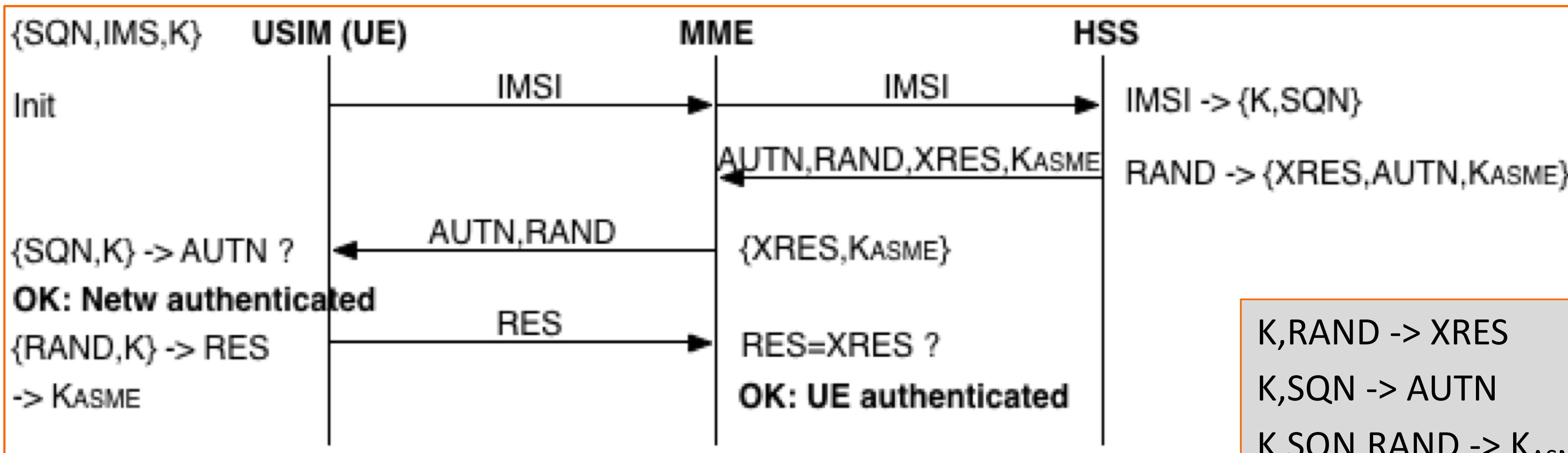
USIM card

UMTS Subscriber Identity Module

The USIM card is an application on a smart card and contains:

- IMSI (International mobile subscriber identity) 15 digits
- Authentication key K and sequence number SQN

Authentication process:



K,RAND -> XRES

K,SQN -> AUTN

K,SQN,RAND -> K_{ASME}

K_{ASME} is used for encryption of messages

The radio channel

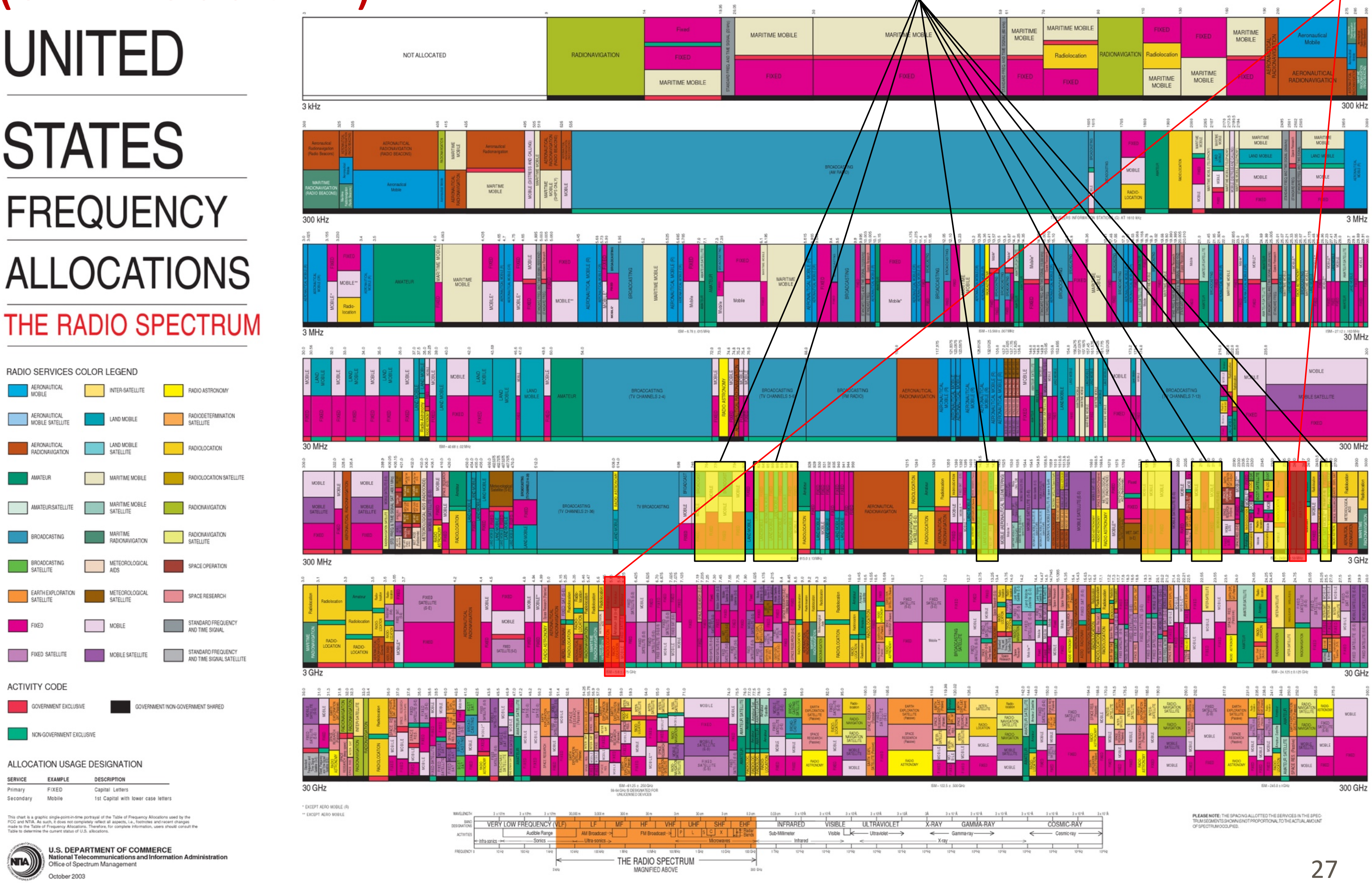
- Licensed frequency bands (slots of 20 MHz)
  - In 0.5-4 GHz
- Cost in order of Billions $
- Alternative: FDD and TDD
  - Most common FDD
- Efficient transmission
  - UE low power => long(er) battery life

    => signal very low power at receiver

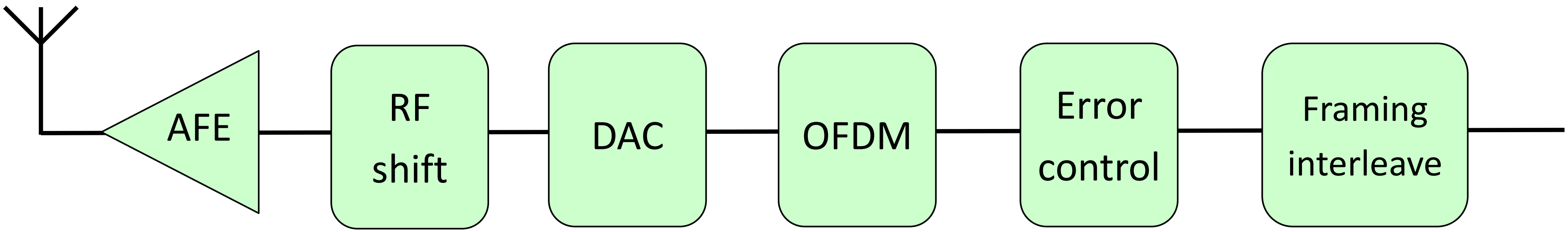
Frequency allocation
(3kHz-300GHz)

LTE

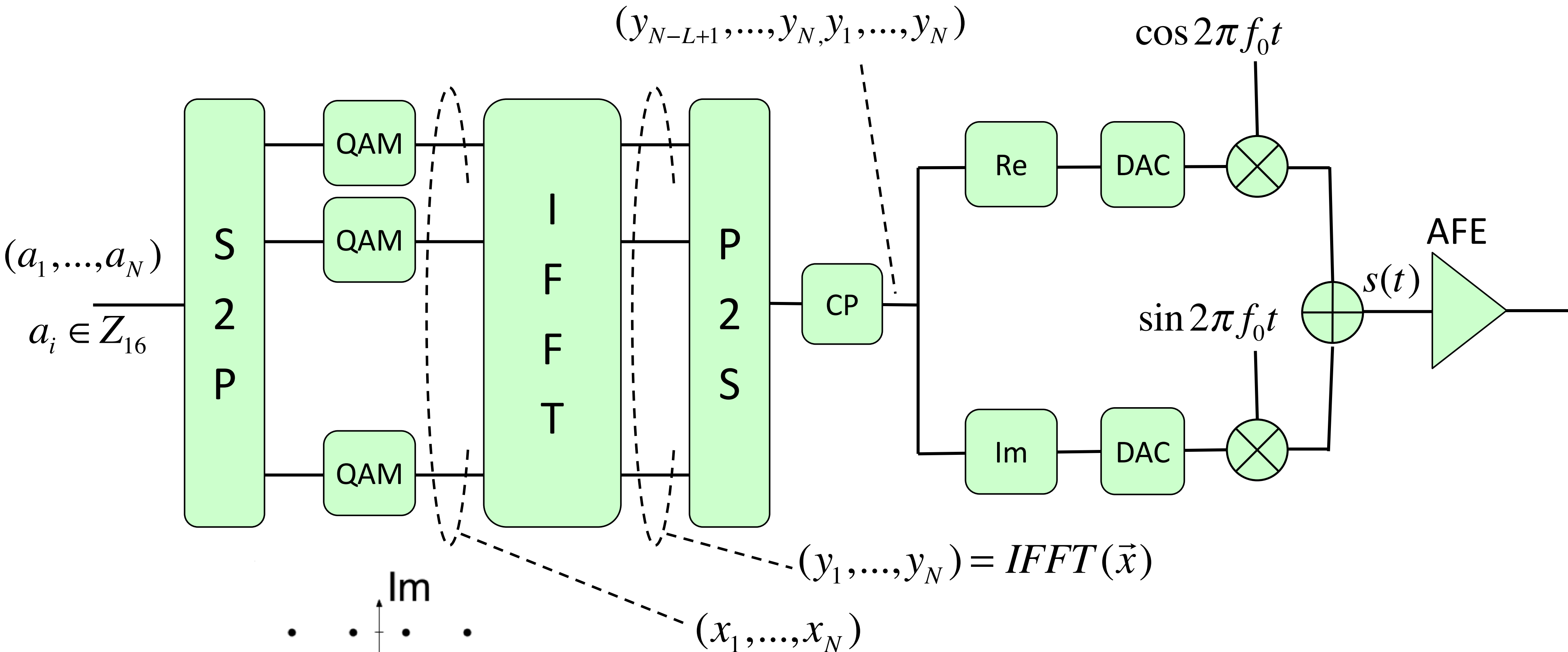
2.4/5.8 GHz
Free (WiFi)



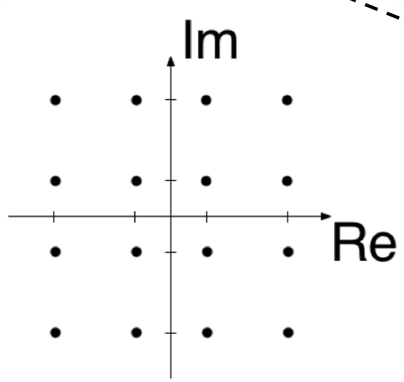
eNodeB structure (physical layer)



OFDM
Orthogonal Frequency Division Multiplexing



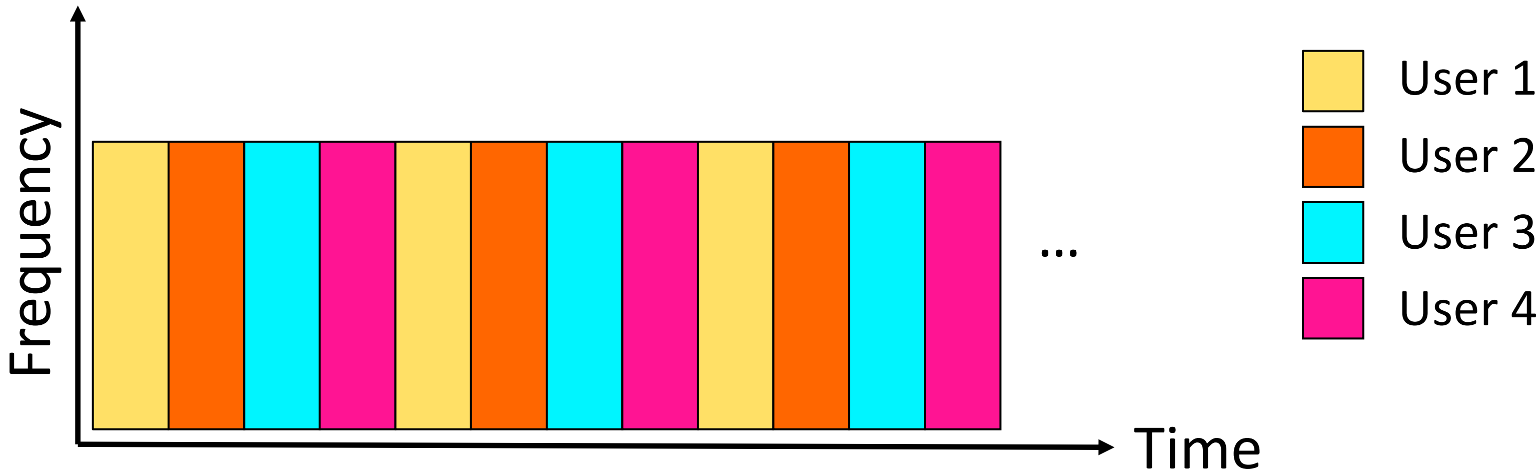
16-QAM mapping:



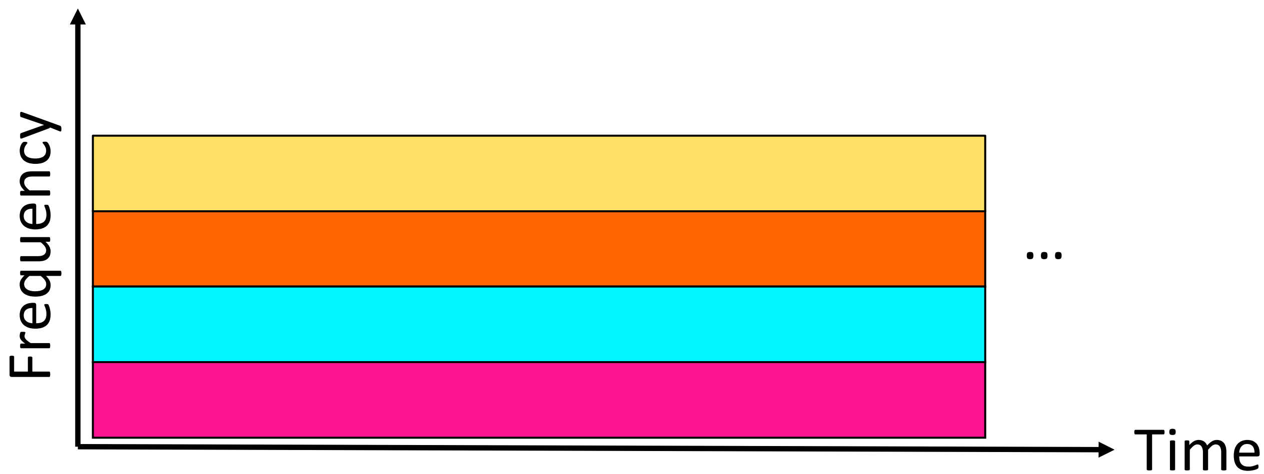
Can be used with M=4, 16, 64 or 256

Time-frequecy multiple access

TDMA:

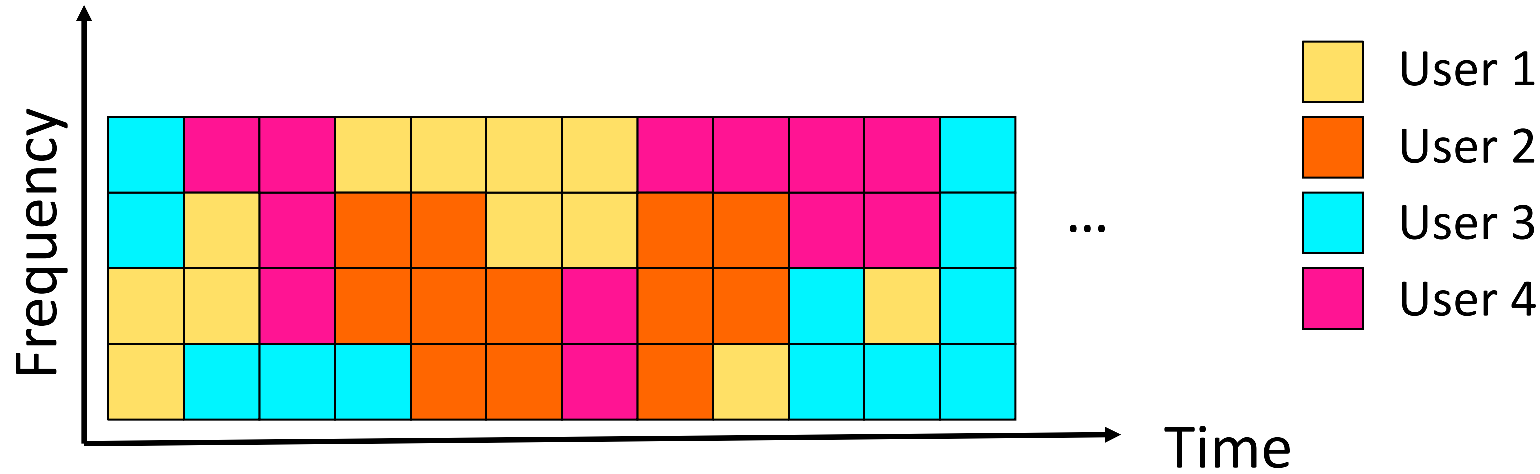


FDMA:



Time-frequecy multiple access

OFDMA:



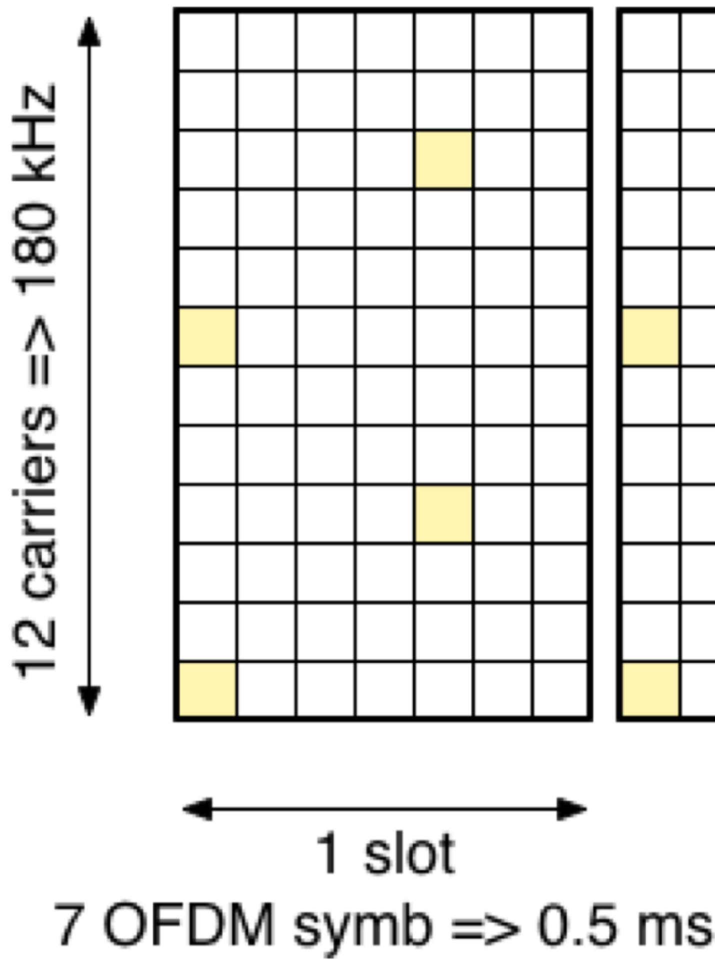
In LTE

- A Resource Element (RE) is one carrier over one OFDM symbol

  This is the least time-frequency resolution

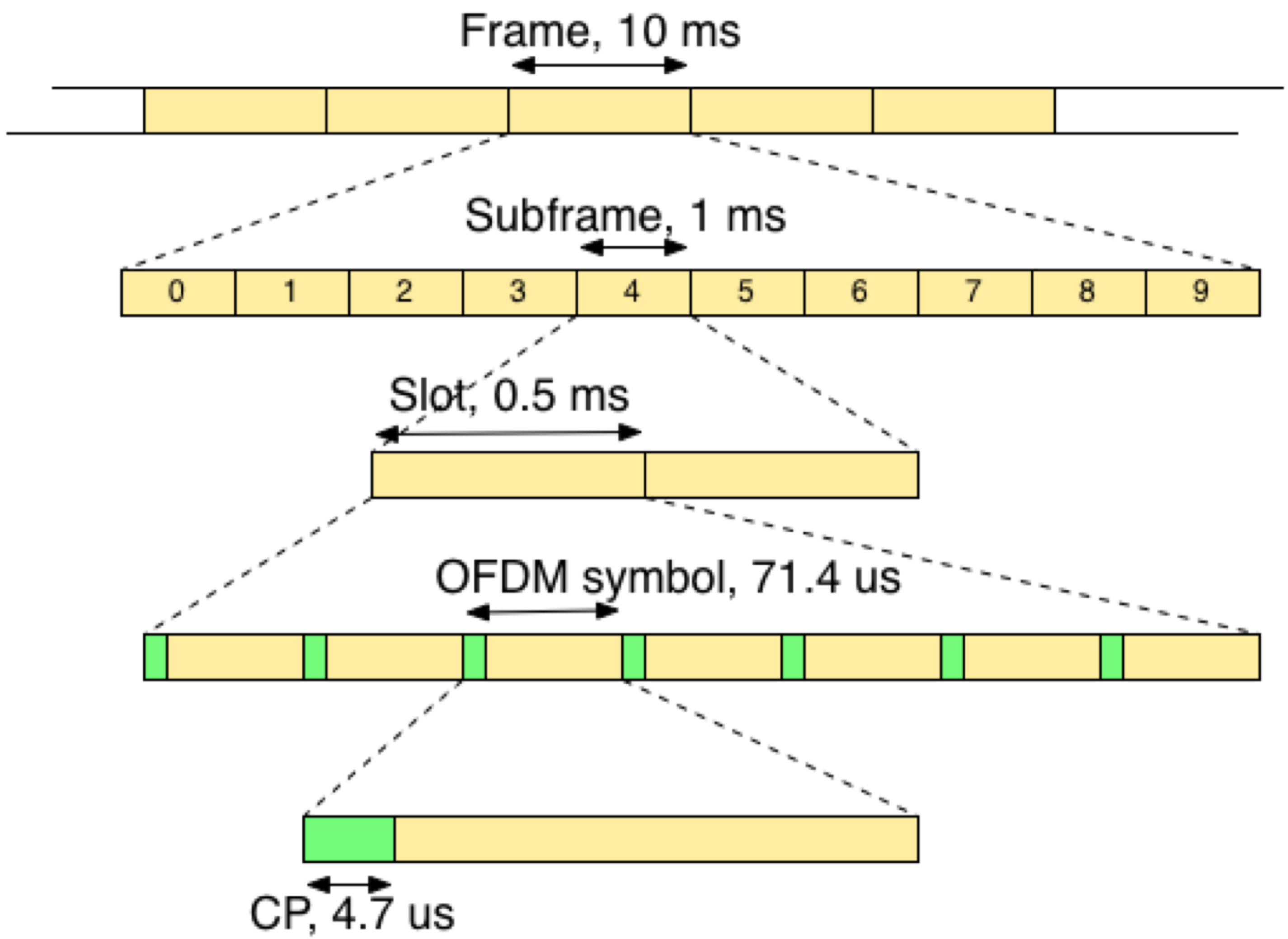
  - 15 kHz X 71.4 us

Resource block (RB)



A pair of RB (sub-frame) is the least assigned resource

Frame structure in time



Resource allocation in frequency

BW [MHz]	1.4	3	5	10	15	20
N	128	256	512	1024	1536	2048
#alloc RB (in Freq)	6	12	25	50	75	100
#used carrier	72	144	300	600	900	1200
Oversampling	1.78	1.78	1.71	1.71	1.71	1.71
Max Rate [Mb/s]	6	12	25	50	75	100

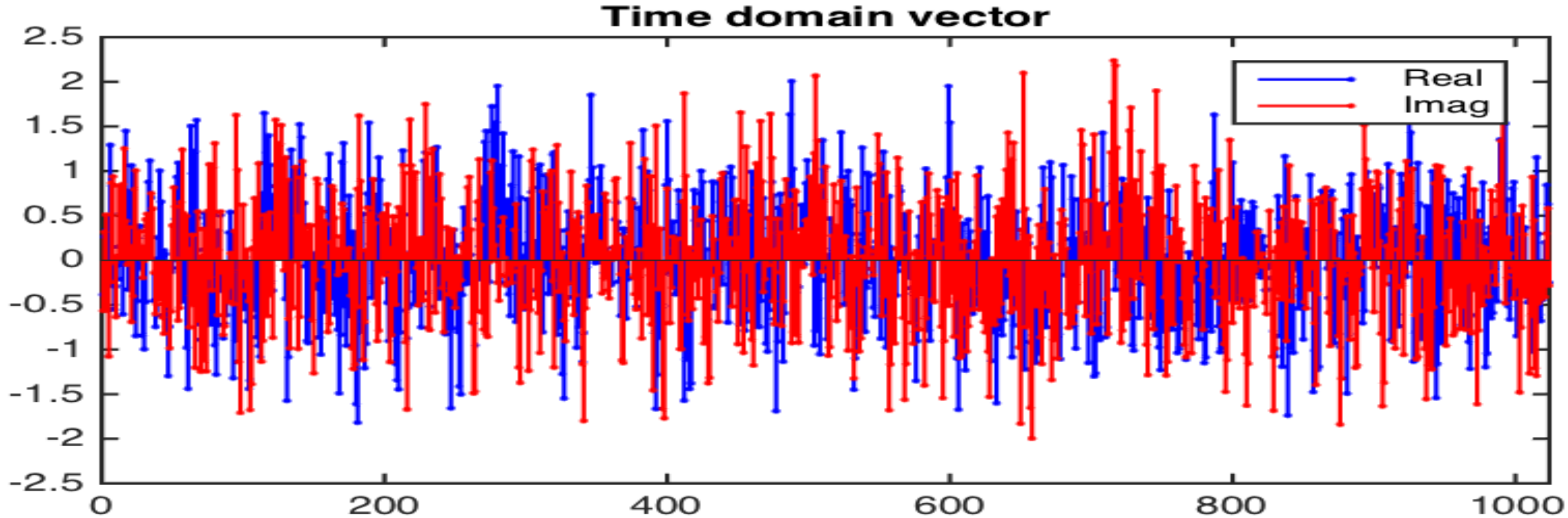
Max Rate is for 64-QAM, i.e. 6 bit/carrier

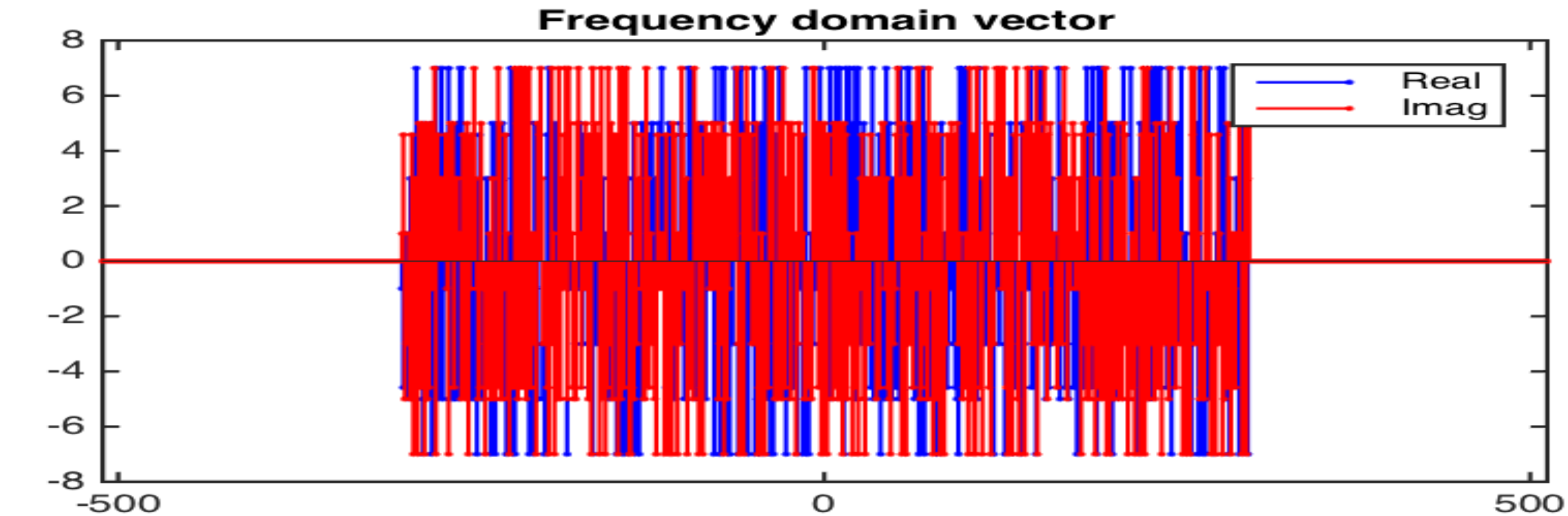
Then $R = \# carrier \cdot 6 \cdot 7 \cdot 2 \cdot 10 \cdot 100$ [b/s]

Impact of control signals and error control is not included

Example

One OFDM symbol for BW=10 MHz and 64-QAM

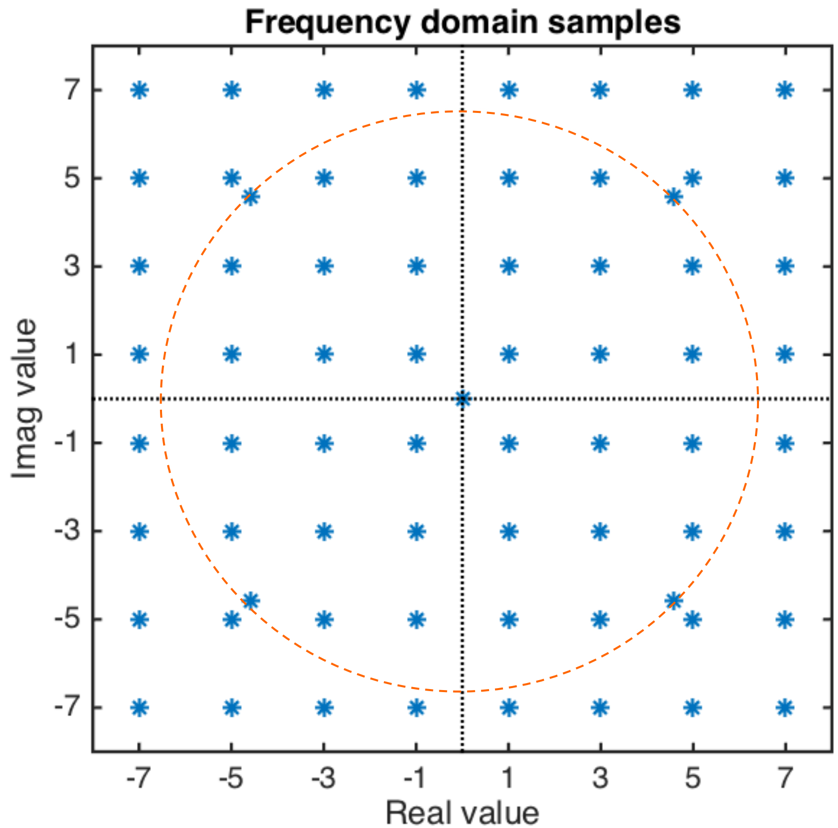




Example

One OFDM symbol for BW=10 MHz and 64-QAM

Plot of (all) frequency domain samples as I-Q

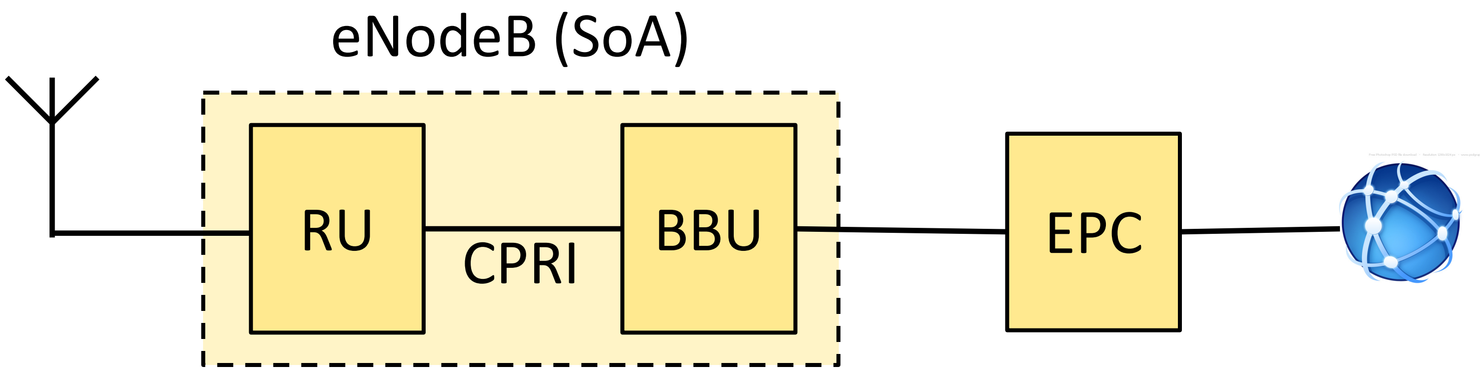


4G mobile networks

- Packet Network: EPC
  - Data plane: PGW & SGW
  - Control plane: MME & HSS
  - In core network
- Access Network: LTE (E-UTRAN)
  - Up to 20 MHz bandwidth (=> 100 Mbps)
  - OFDM signaling

What comes next 1

C-RAN



Radio unit (RU)

- BB samples to RF signal
  - Digital/analog conversion
  - Mixing to RF
  - AFE

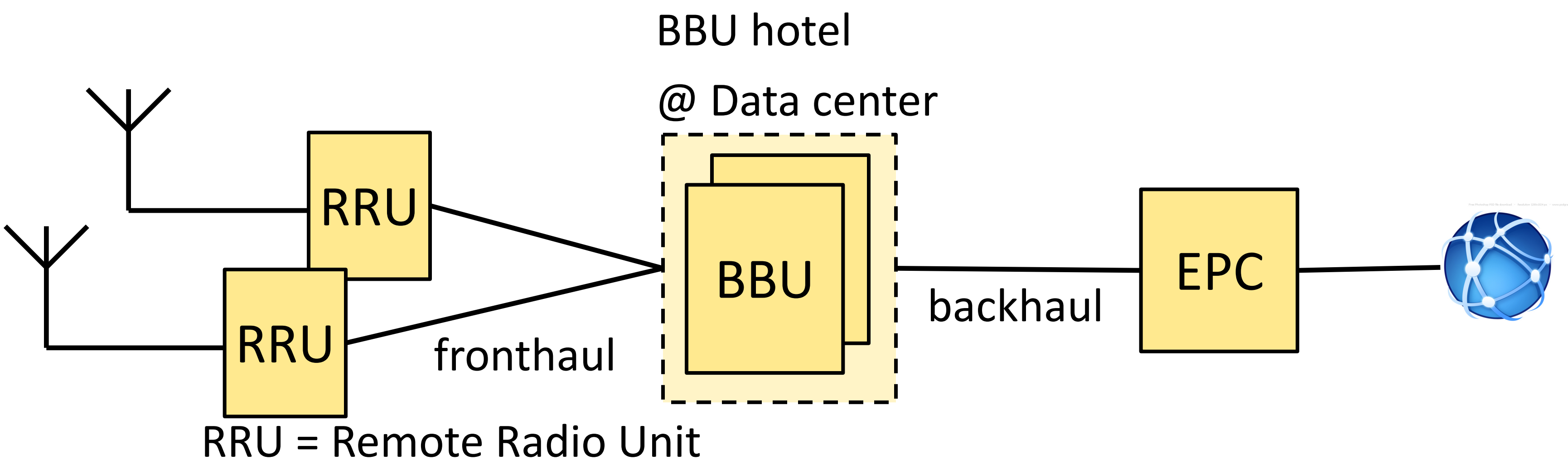
Baseband unit (BBU)

- Binary data to BB samples
  - QAM mapping
  - IFFT
  - Coding

What comes next 1
C-RAN

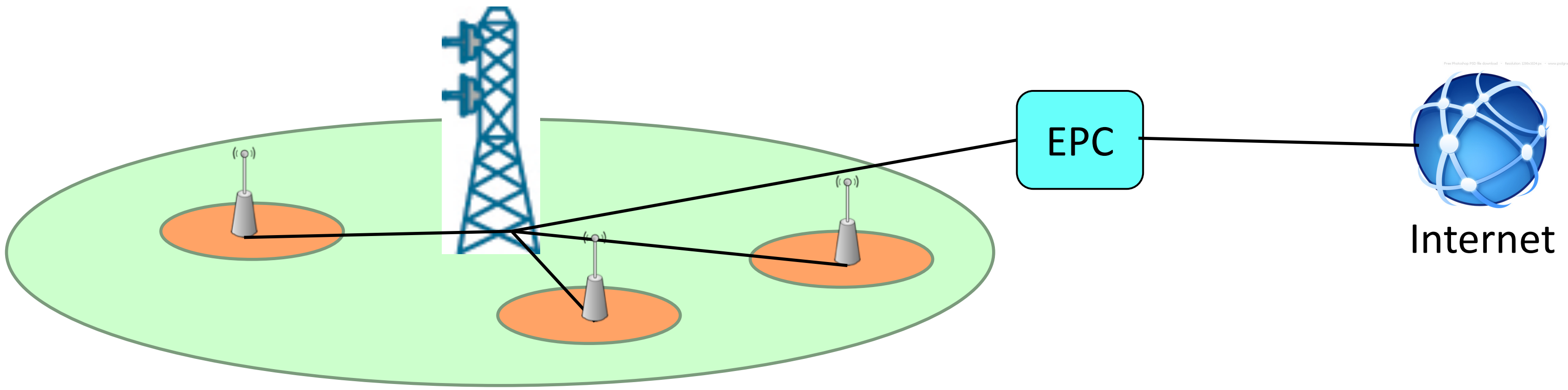
To utilize recourses better split BBU and RU in network

- Use CPRI to transmit BB samples between BBU and RRU



Problem: Data rate expansion in transmission of radio samples approximately a factor 10.
Need compression

What comes next 2
Small cells



- Small cells work in
  - Short distance (low power)
  - High data rate (few users)
- In public places, offices, shopping malls, etc
- Even plans for small cells in homes
  - Instead of, or combined with, WiFi?

Problems

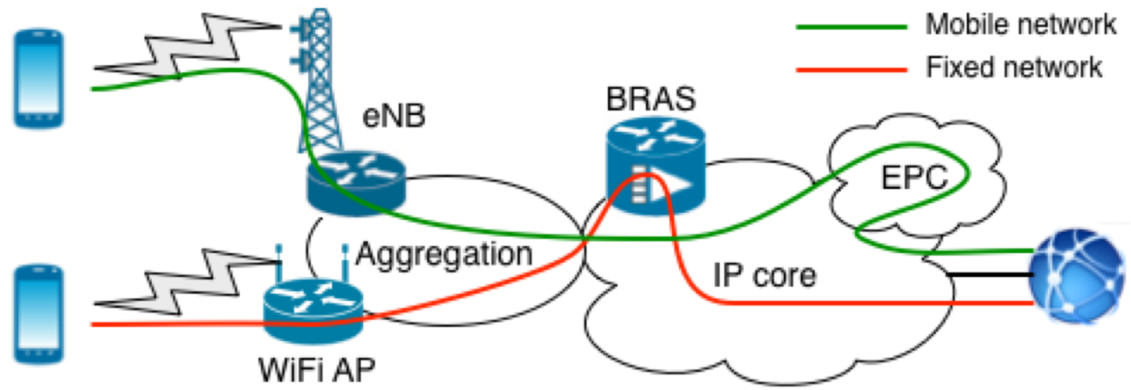
- How to backhaul/fronthaul
- How can they be part of coordination?
- In-door / in-home solutions

What comes next 3
Converged network

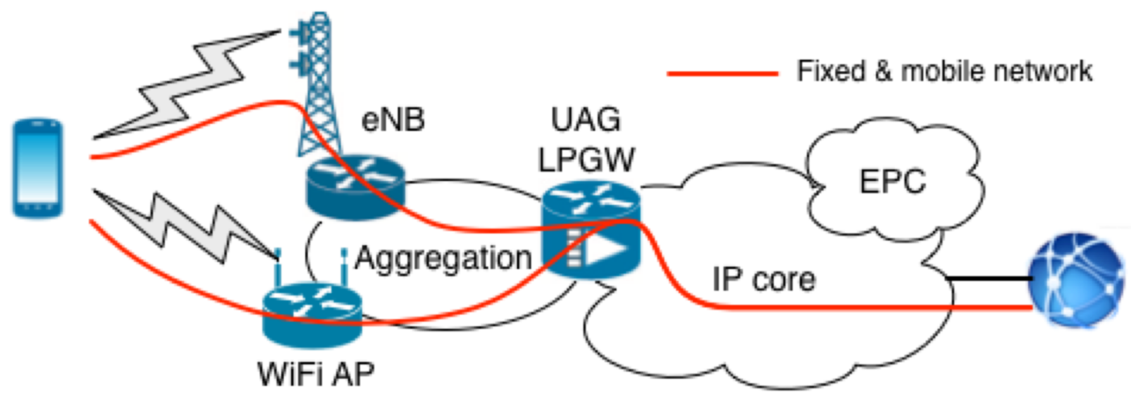
- Users becomes more mobile
  - When price and rate differences diminish most users don’t care about choice of connection
- Convergence:
  - One network, many access technologies
  - Flexible network
  - One Authentication (and pricing)
  - Seamless handover between networks, e.g. LTE-WiFi
  - Dual connections and traffic off-loading
  - All units everywhere
- Problem:
  - Partly new network structure (e.g. where is the IP edge?)

What comes next 3
Converged network

Fixed or mobile network (separated, SoA)

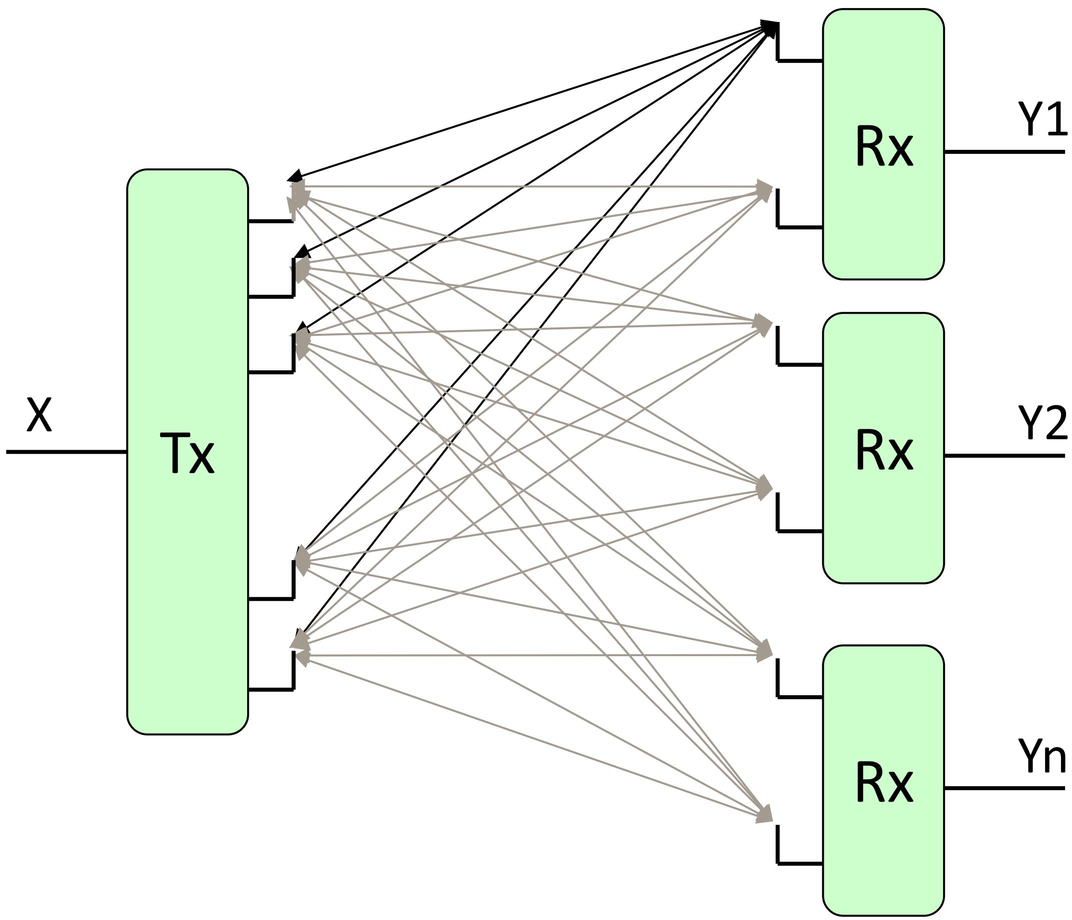


Fixed and mobile network (converged network)



Massive MIMO

MIMO: Multiple-in Multiple-out antennas



- High capacity
- Pinpoint users or equipment
- Efficient signalling

Problems:

- Synchronisation
- Backhaul/fronthaul

What comes next 4

5G

- Roughly a factor of 10 in performance
  - 10 times faster, bandwidth, Data rate, etc
  - 10 times battery life (for low power devices, IoT, 10 years)
  - 1000 times traffic volume
  - Small cells everywhere
- Everything is connected
  - IoT, M2M, Car2Car
- New services
  - Cloud computing, VR, AR, Tactile Internet, Self driving cars, Skynet, …
- Expected to launch tests latest 2020
- Problems:
  - Backhaul/fronthaul, RAN sync, Energy efficiency, latency, stability, handover between networks, etc