ETSF15 Communication Systems and Networks

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# 4G mobile communication system LTE

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# Plan of lecture

- Some history of mobile networks—Past and future
- Idea of network structure
- EPC packet networks
- LTE radio channel
- What comes next?

# History of mobile systems

1st generation

- Analog transmission with no security
- Small regions (countries)
  - First NTT ('79), second NMT ('81)
  - NMT (Nordic), AMPS (NA+Aus), TACS (UK), TZ80x (NTT), DDI (Jap), Radiocom 2000 (Fr), RTMI (It)
  - NMT shut down 2007

# History of mobile systems

2$^{nd}$ generation

- Digital voice channel (10kb/s), Circuit switched
- News: SIM card, SMS
  - 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, IS-95B

# History of mobile systems

3rd generation

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

    Universal Terrestrial Radio Access Network

# History of mobile systems

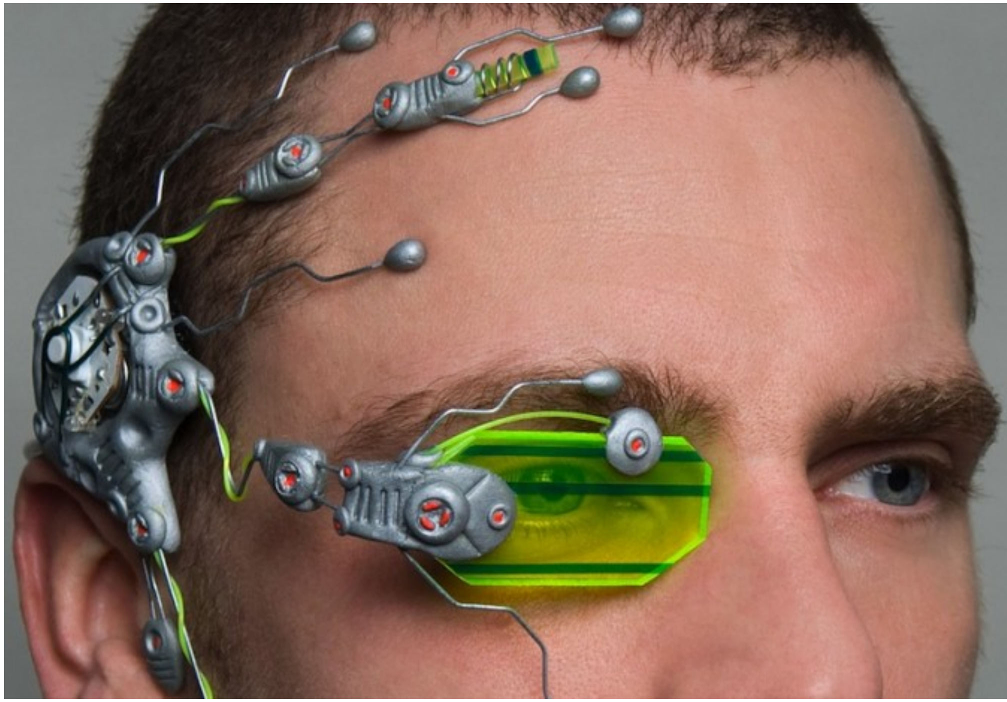
4th generation

- Packet switched data traffic (Voice over IP or 3G)
- 100Mb/s-1Gb/s
- Global: LTE
  - Dec 2009 (Stockholm and Oslo by TeliaSonera)
- News: Smartphones and apps
  - iPhone 2007

# History of mobile systems

5th generation

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

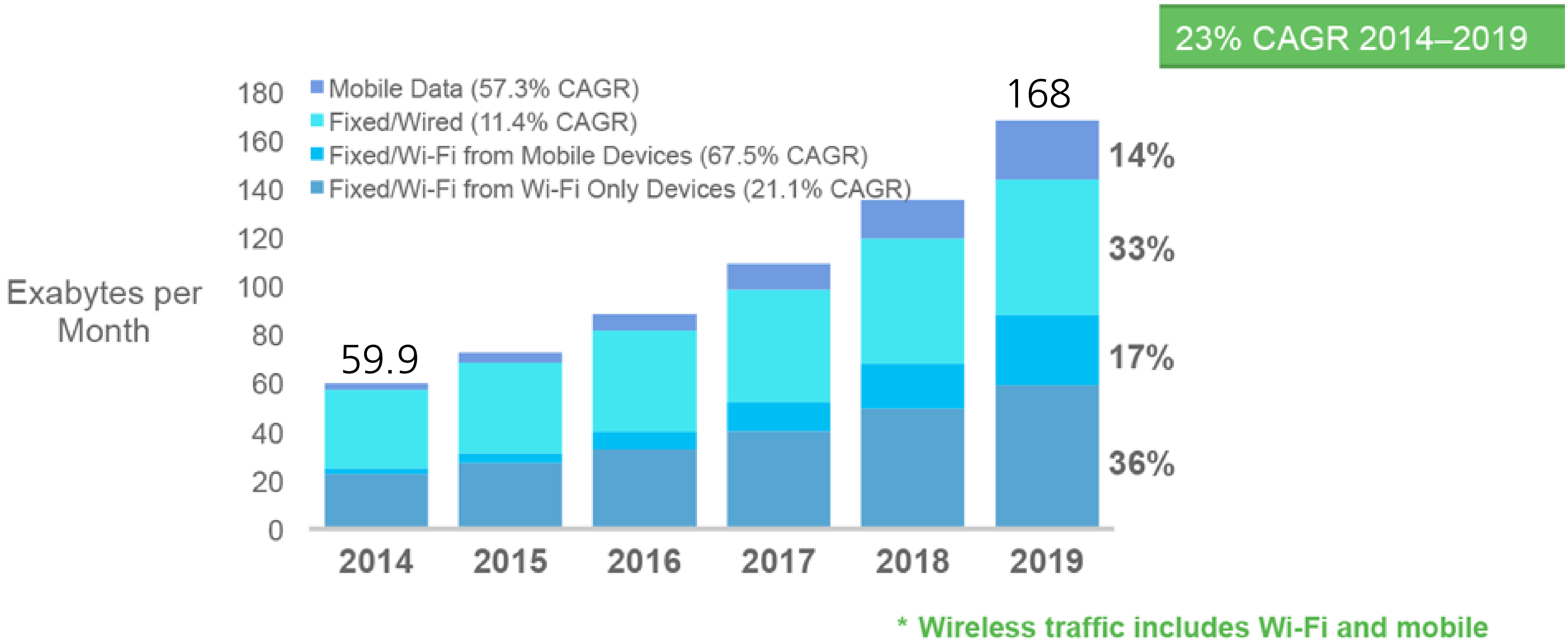


# Mobile traffic (CISCO VNI)

- Global mobile data traffic grew 69% in 2014
  - 1.5 EB in Dec '13 to 2.5 EB in Dec '14
- Global mobile devices and connections in 2014 grew to 7.4 billion (11.5 B in 2019)
  - 26% smart devices generate 80% of traffic
  - 4G devices generate 10 times more traffic than non-4G

# Total IP traffic

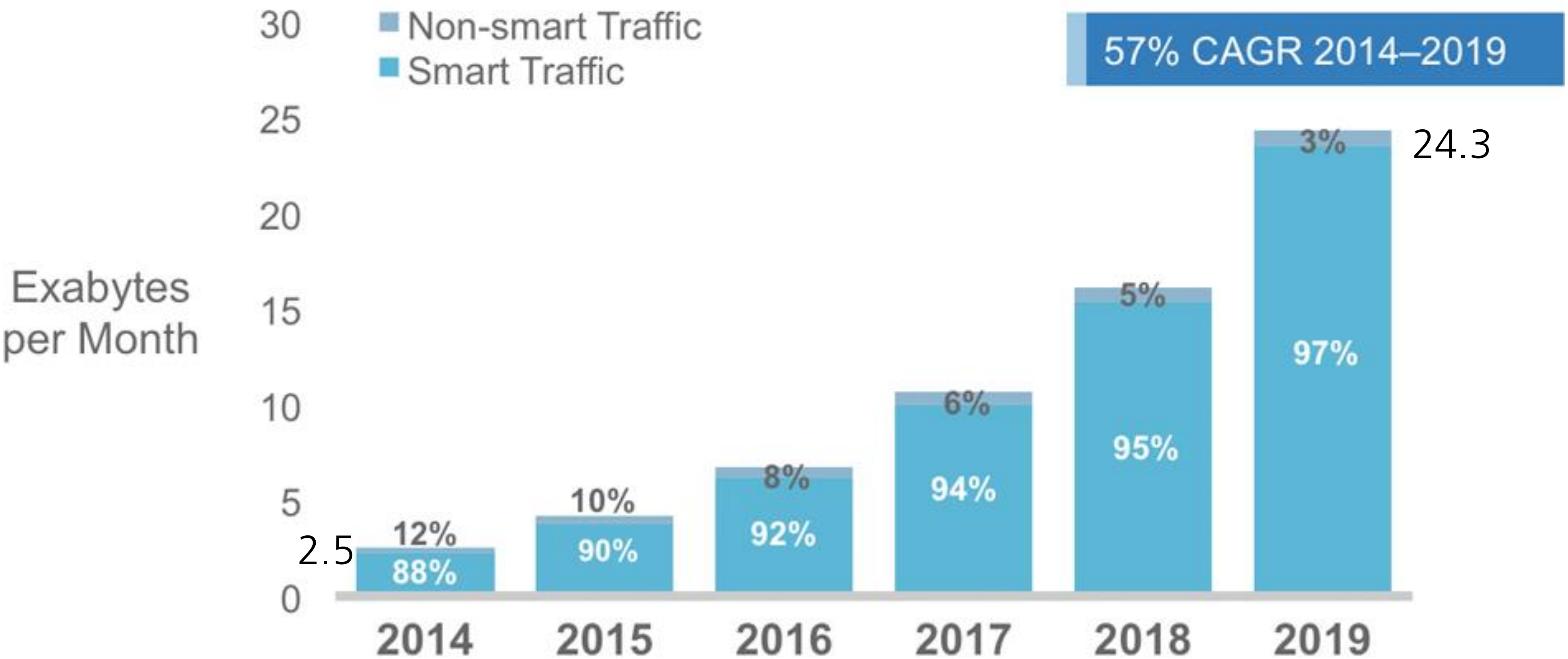
**Figure 22.** Global IP Traffic, Wired and Wireless




Source: Cisco VNI Global IP Traffic Forecast, 2014–2019

# Total Mobile traffic

**Figure 6.** Effect of Smart Mobile Devices and Connections Growth on Traffic

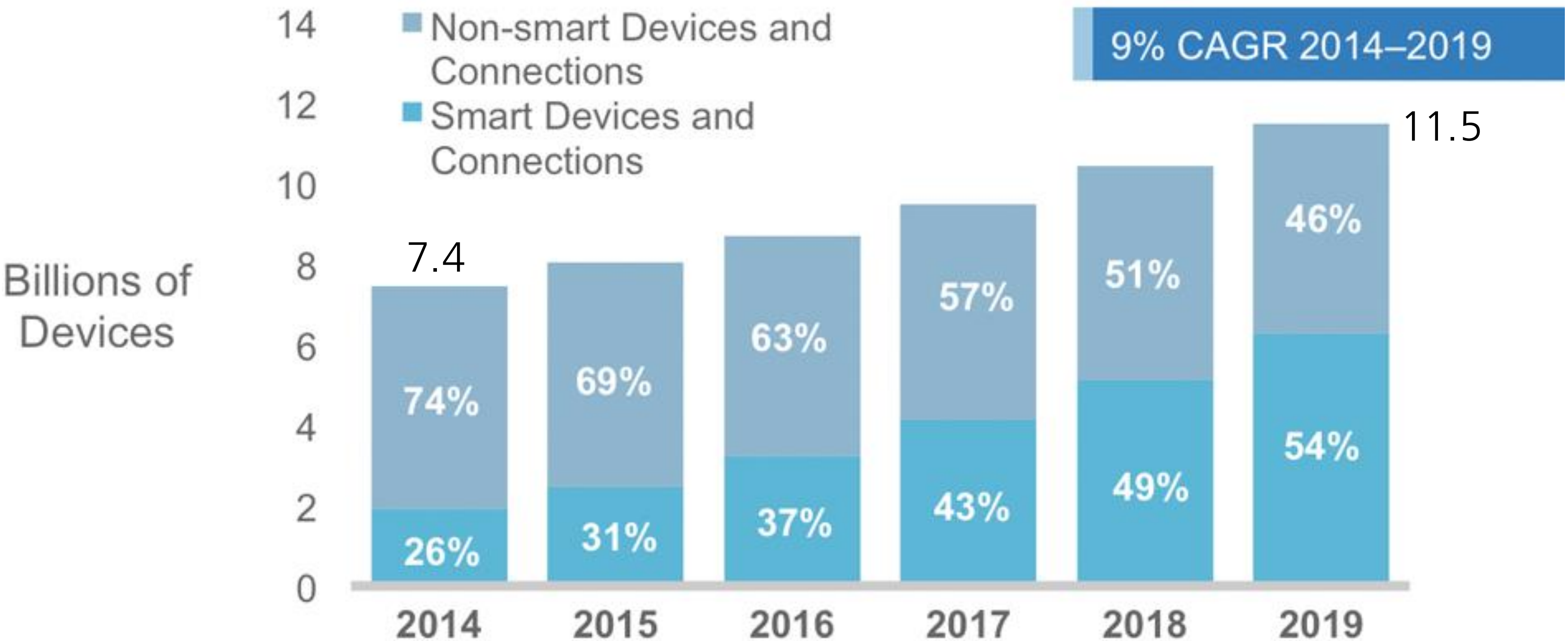



Percentages refer to traffic share.

Source: Cisco VNI Mobile, 2015

# Growth of devices

**Figure 4.** Global Growth of Smart Mobile Devices and Connections

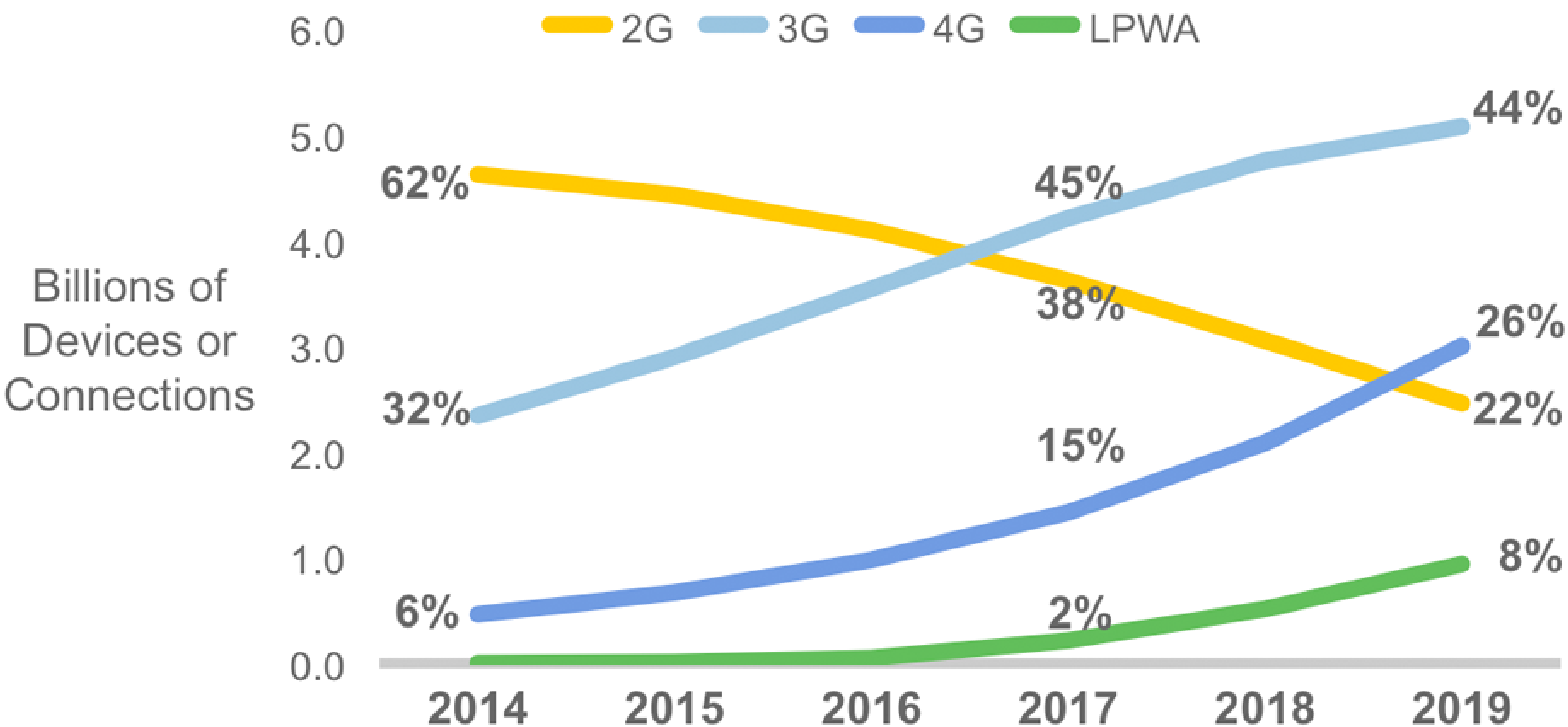



Percentages refer to device and connections share.

Source: Cisco VNI Mobile, 2015

# Growth of technology

**Figure 7.** Global Mobile Devices and Connections by 2G, 3G, and 4G




Percentages refer to device and connections share.

Source: Cisco VNI Mobile, 2015

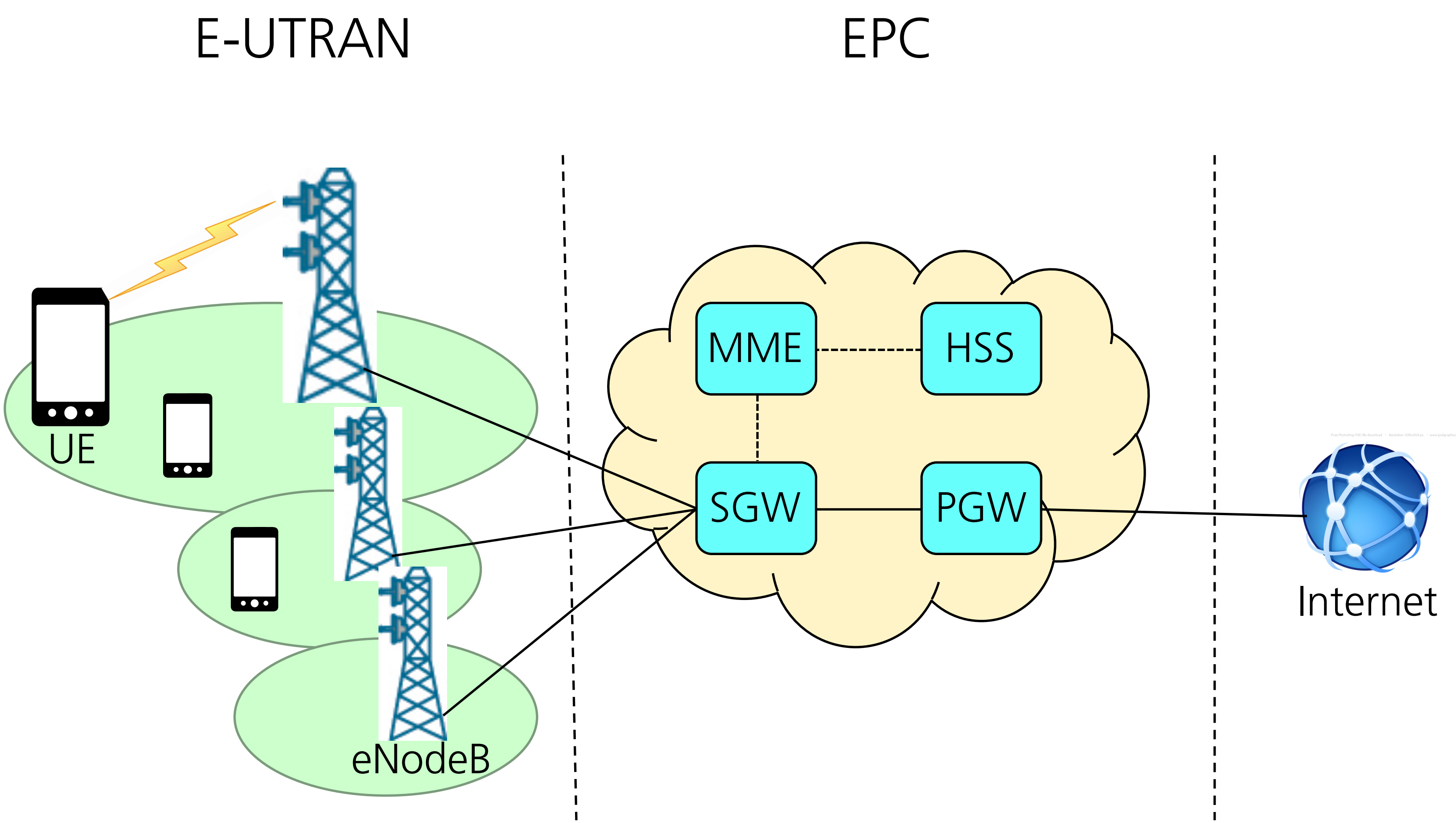
# 4G – LTE
## Long Term Evolution

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).

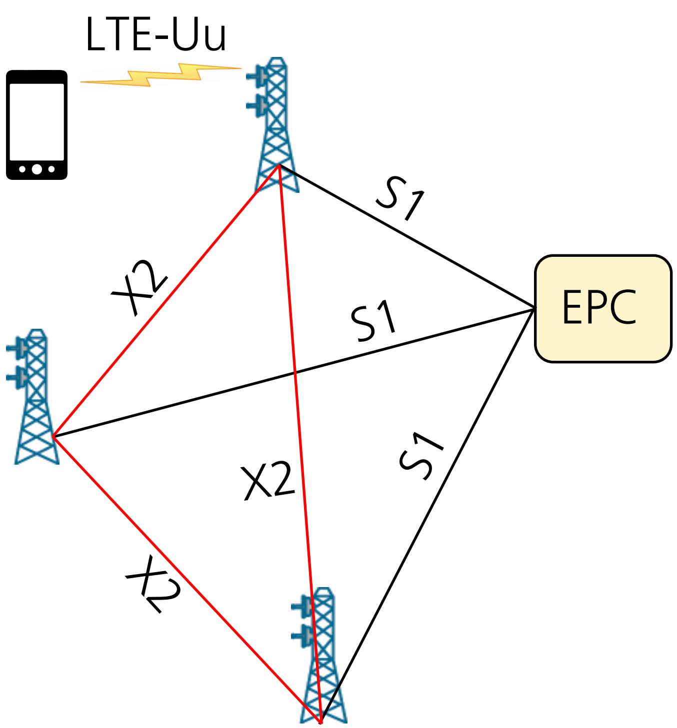
# EPS (Evolved Packet System)



# 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 and security
  - And acounting
- User mobility
  - When to change eNB and how to transfer data in the network
- Cost efficient use of infrastructure

# EPS interfaces




EPC <-> eNB

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

eNB <-> eNB

- X2 interface
- Coordination and positioning

eNB <-> UE

- LTE-Uu or EUTRAN-Uu

# E-UTRAN

## Evolved Universal Terrestrial Radio Access Network

RAN responsible for

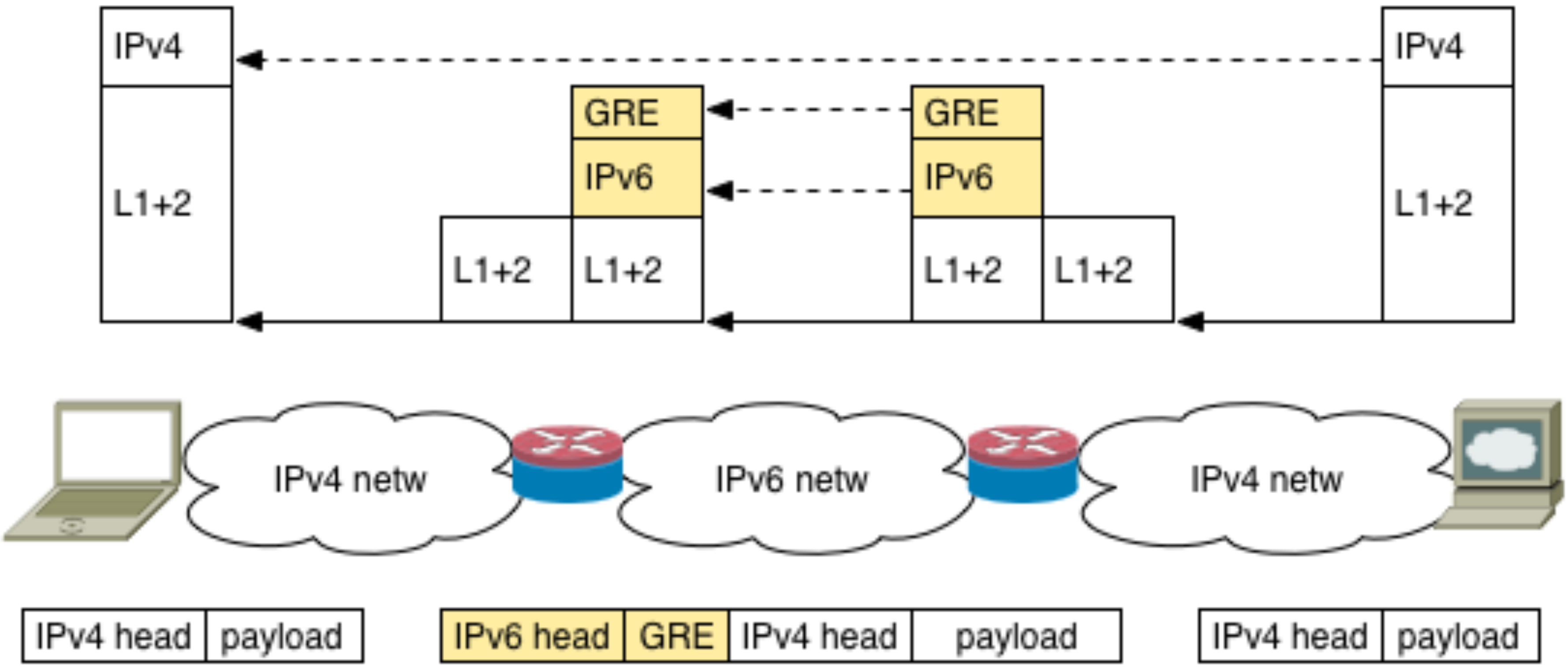
- Resource management
  - Scheduling and dynamic resouce allocation
- Compression
  - IP head compression reduces overhead
- Security
  - Encryption of data
- Positioning
  - UE physical position
- Connection to EPC
  - User and control plane

# Protocol stack

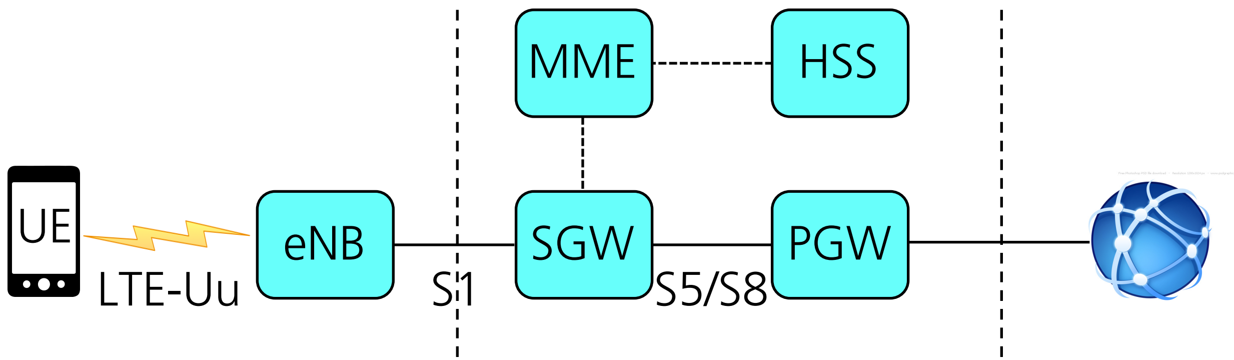
- S1 often tunneled over the fix network architecture
- A tunnel is a way to send packets over other types of network. E.g.
  - IPv4 over IPv6 and vice versa
  - IP over IPsec
- GTP: GPRS Tunneling Protocol

# Example of tunneling

## IPv4 over IPv6 using GRE (Generic Routing Encapsulation)



# IP packets in EPC (User plane)



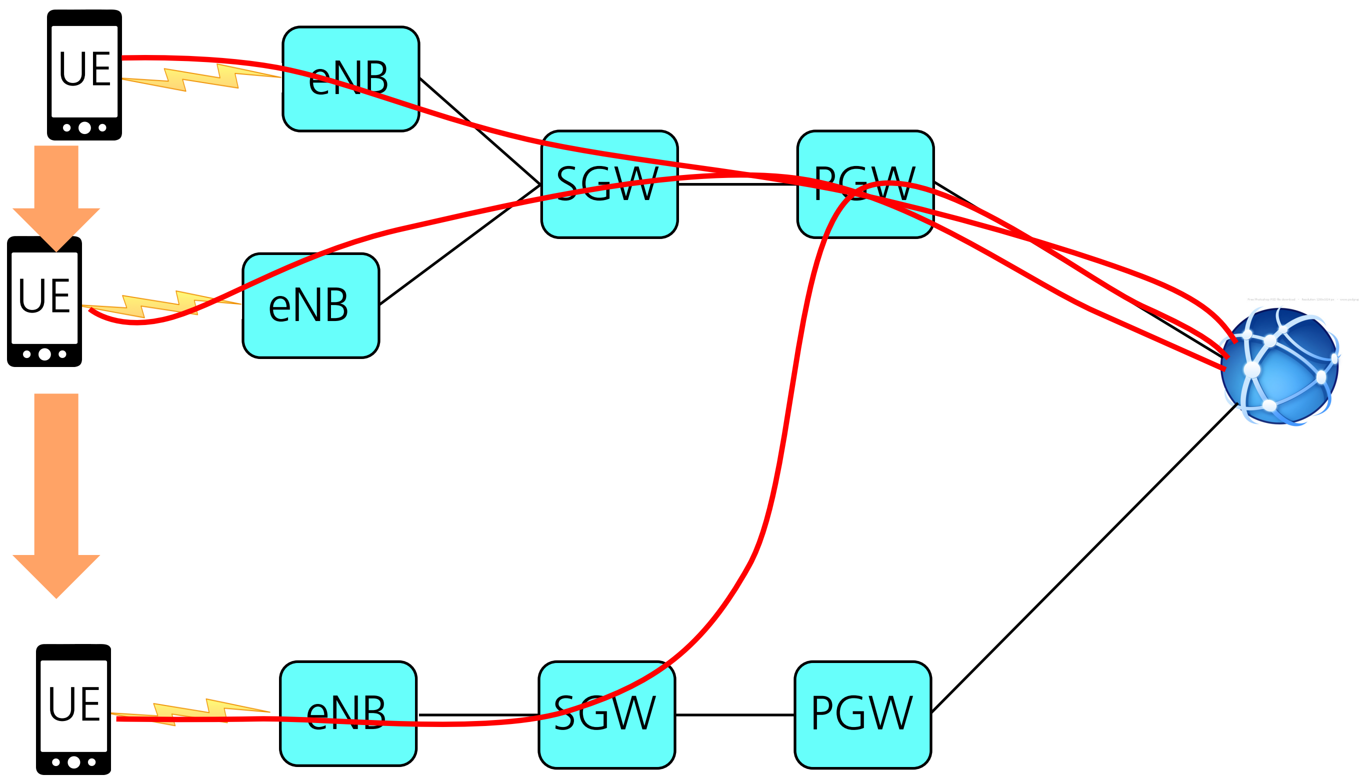

**PGW**

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

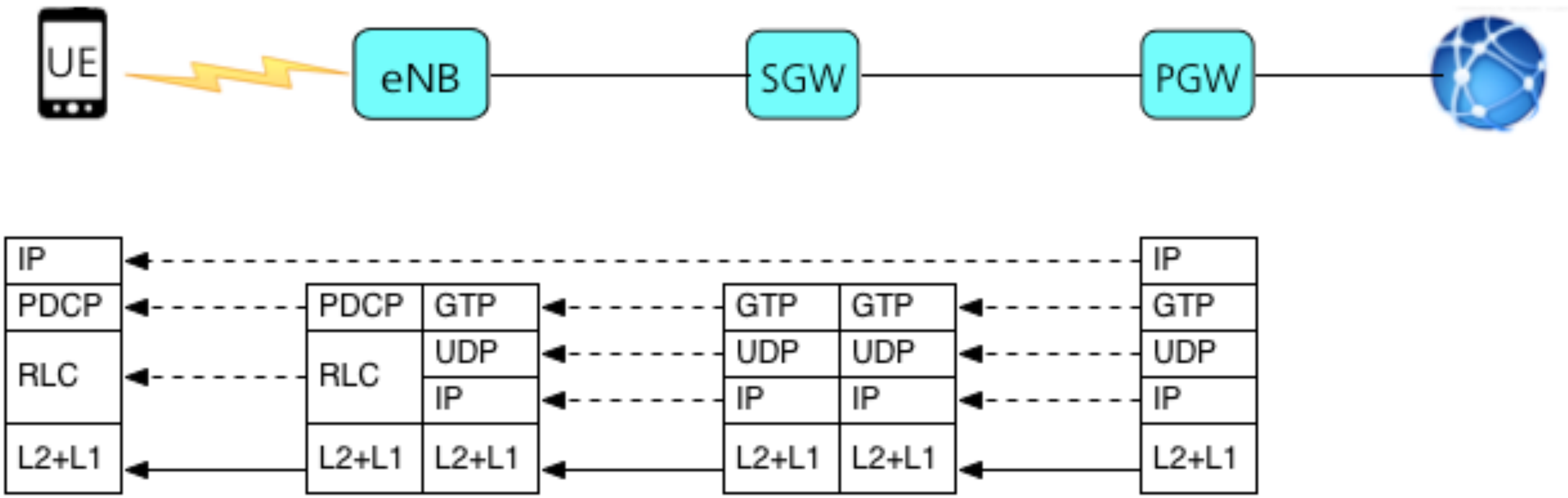
**SGW**

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

# IP packets in EPC (User mobility)



# Protocol stacks (User plane)




GTP: GPRS Tunneling Protocol

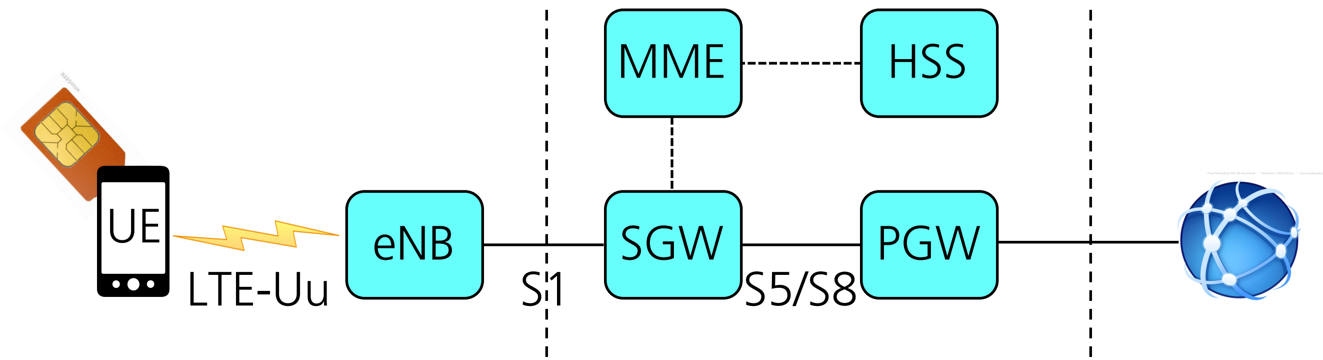
PDCP: Packet Data Convergence Protocol

(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

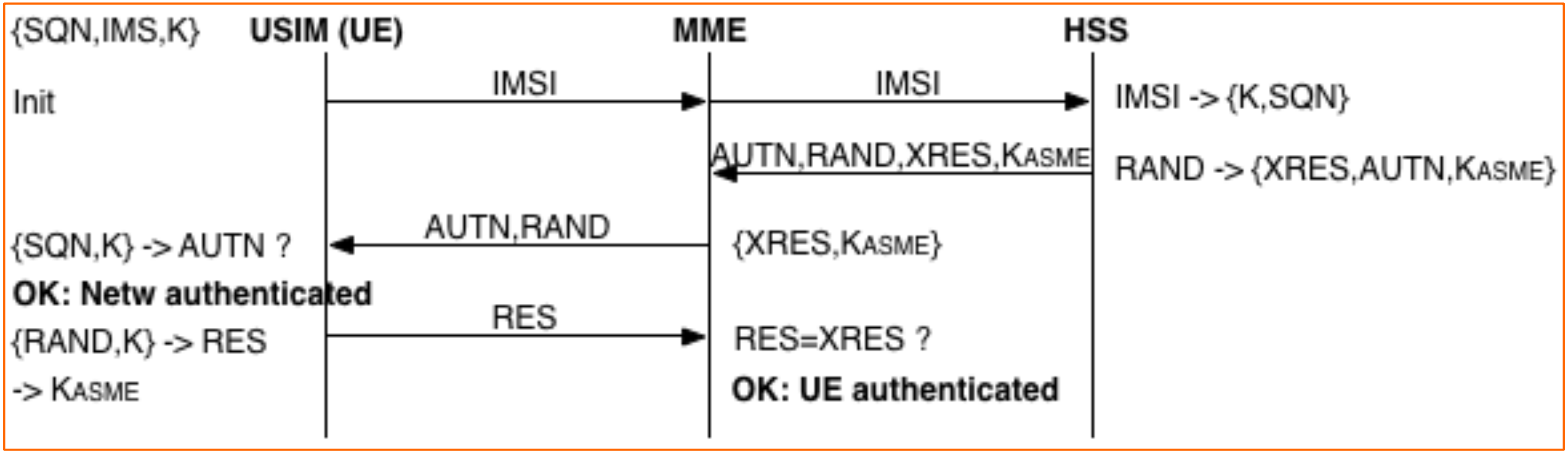
# USIM card

## 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:



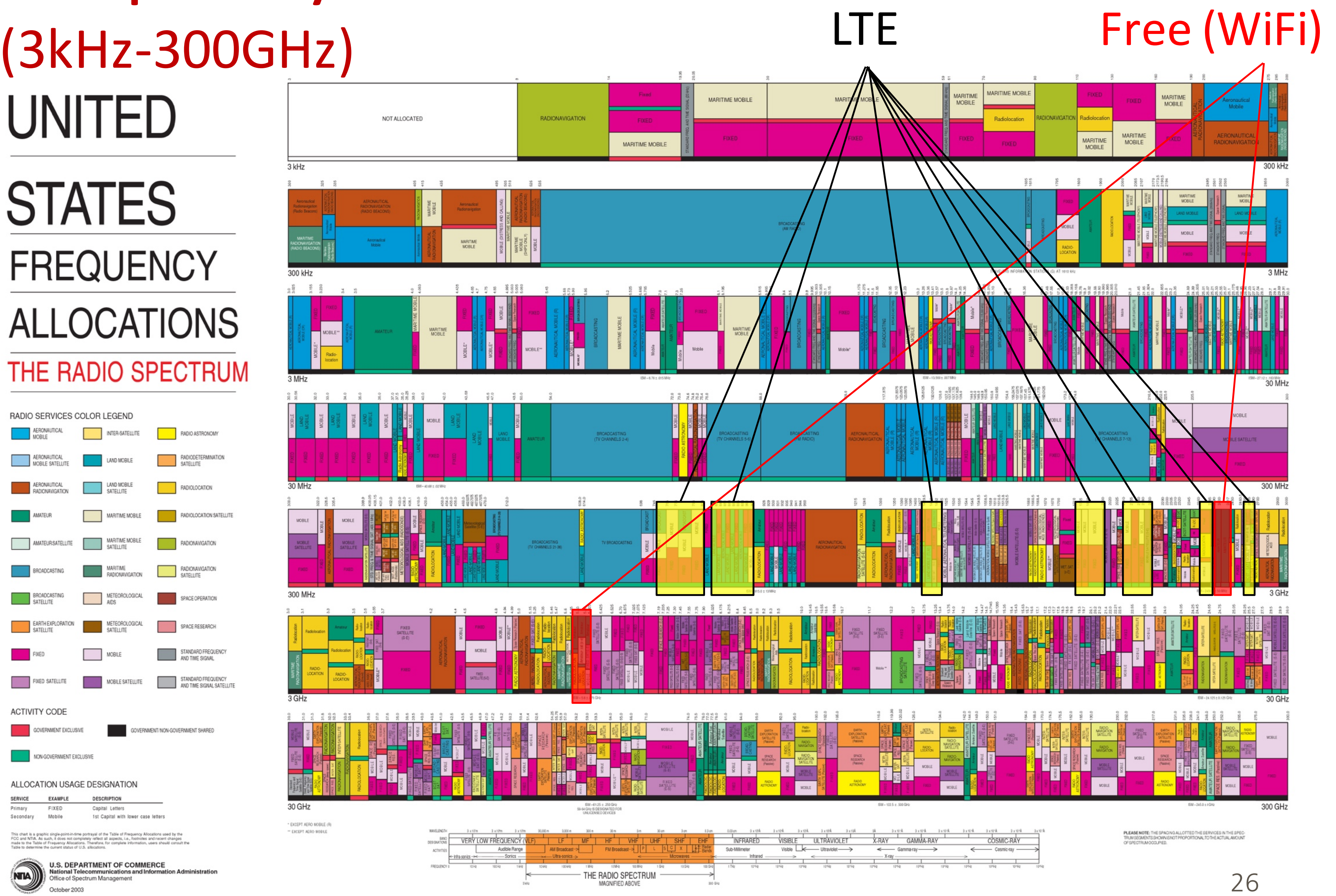

$K_{ASME}$ is used for encryption of messages

# The radio channel

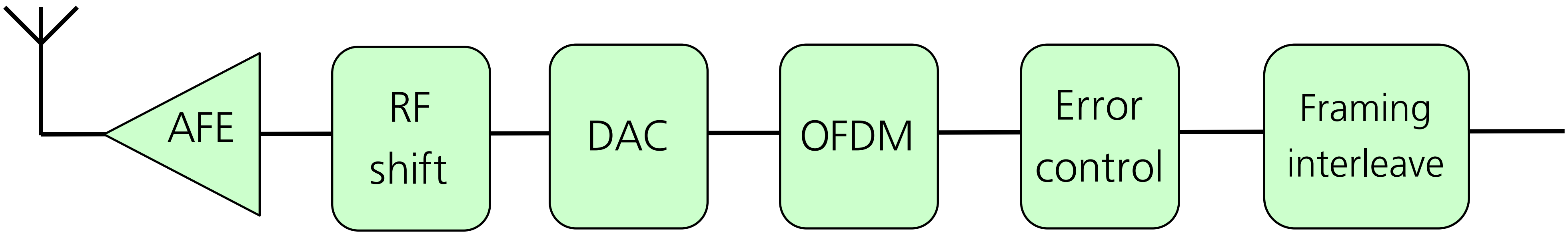
- Licensed frequency bands (slots of 20 MHz)
  - In 0.5-4 GHz
- Cost in order of Billions $
- Alternative: FDD and TDD
  - Most common FDD
- Efficient transmission
  - UE low power => long(er) battery life

    => very low power at receiver

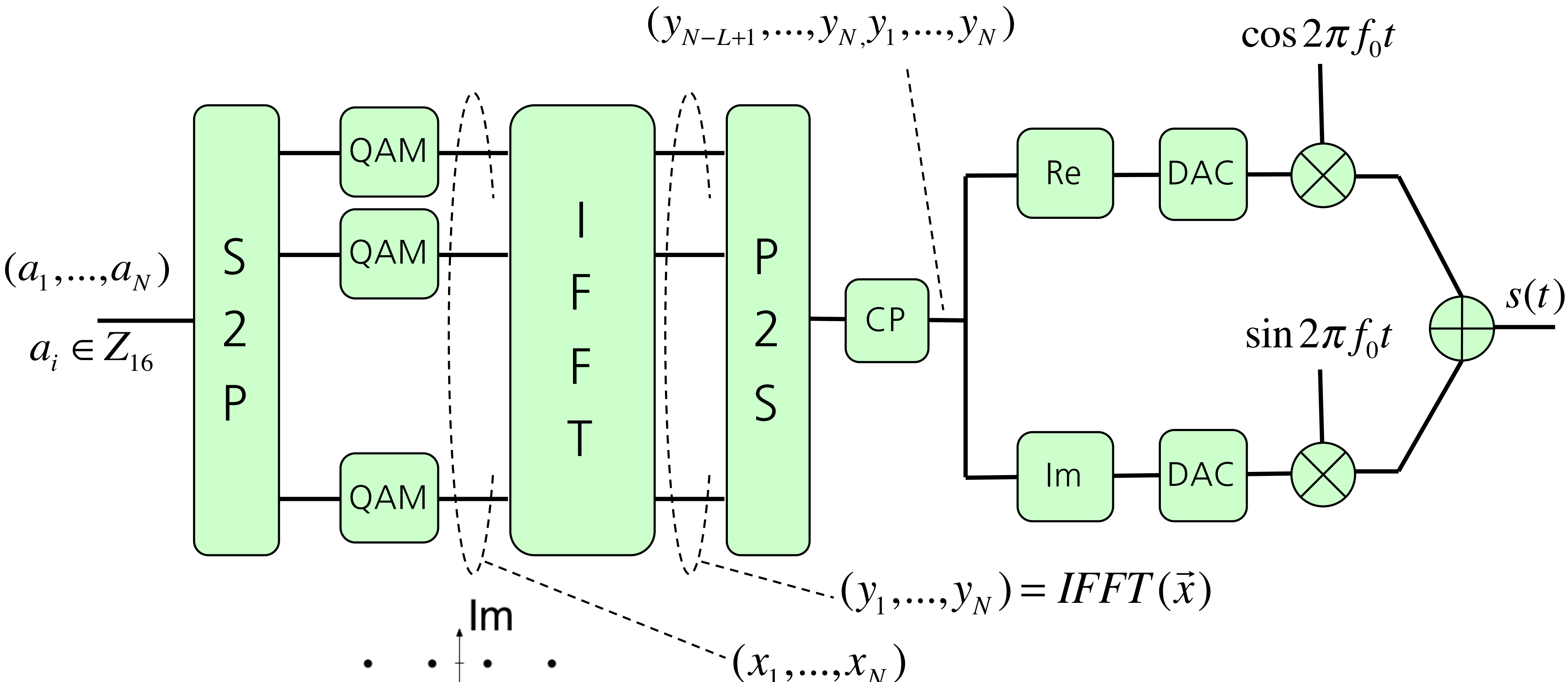
# Frequency allocation (3kHz-300GHz)



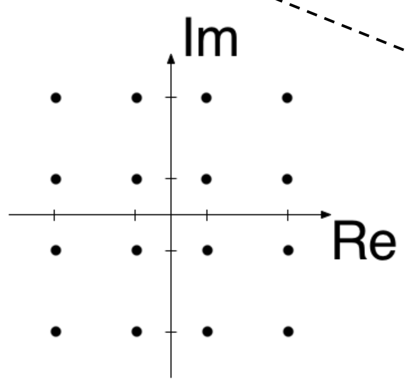
# eNodeB structure (physical layer)



# OFDM
## Orthogonal Frequency Division Multiplexing



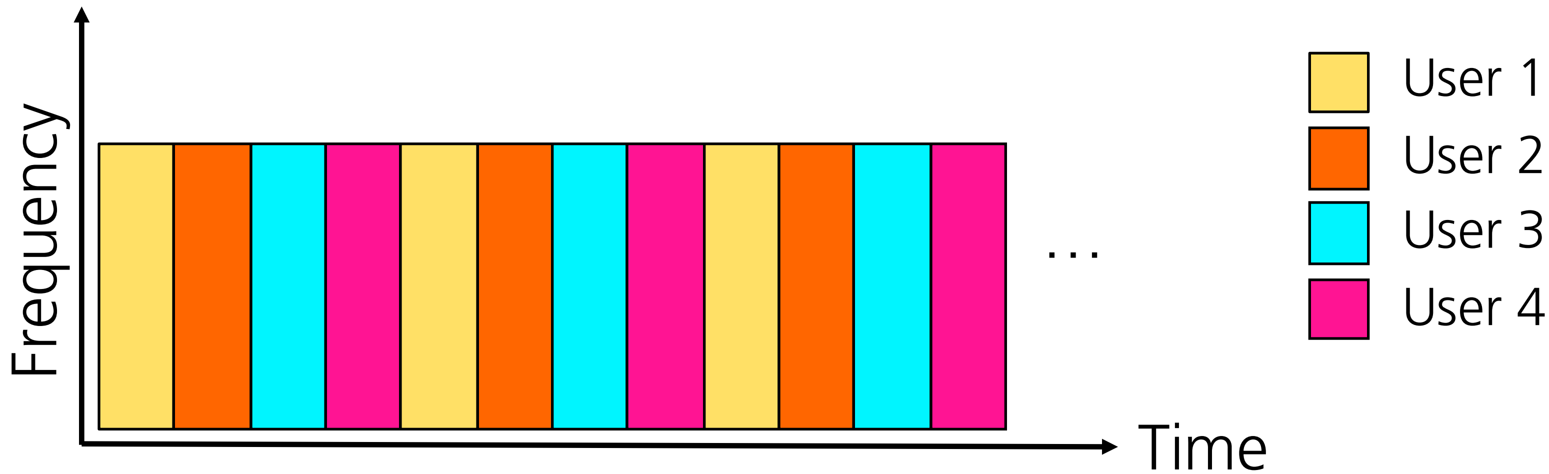

16-QAM mapping:



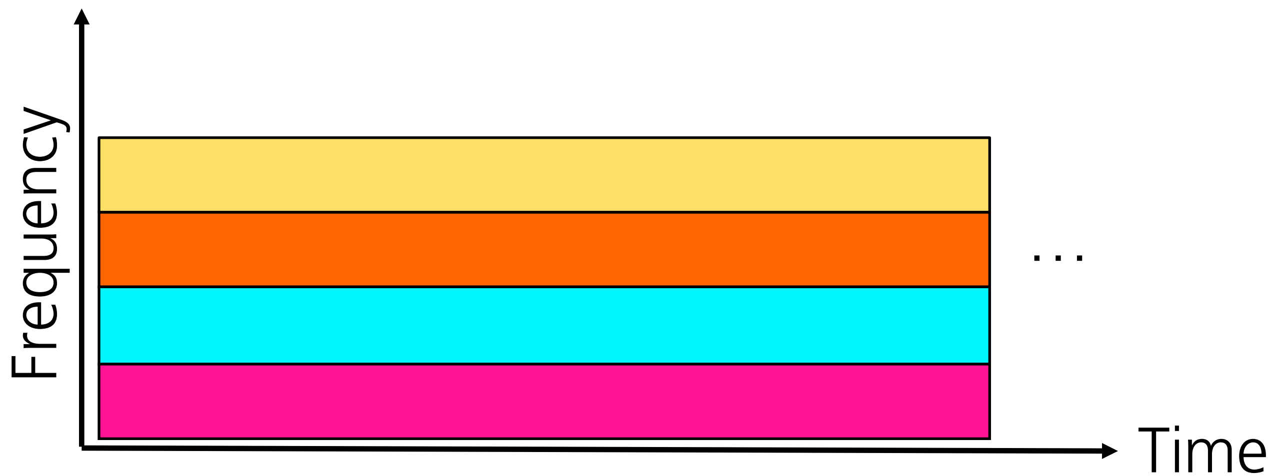

Can be used with M=4, 16, 64 or 256

# Time-frequecy multiple access

TDMA:

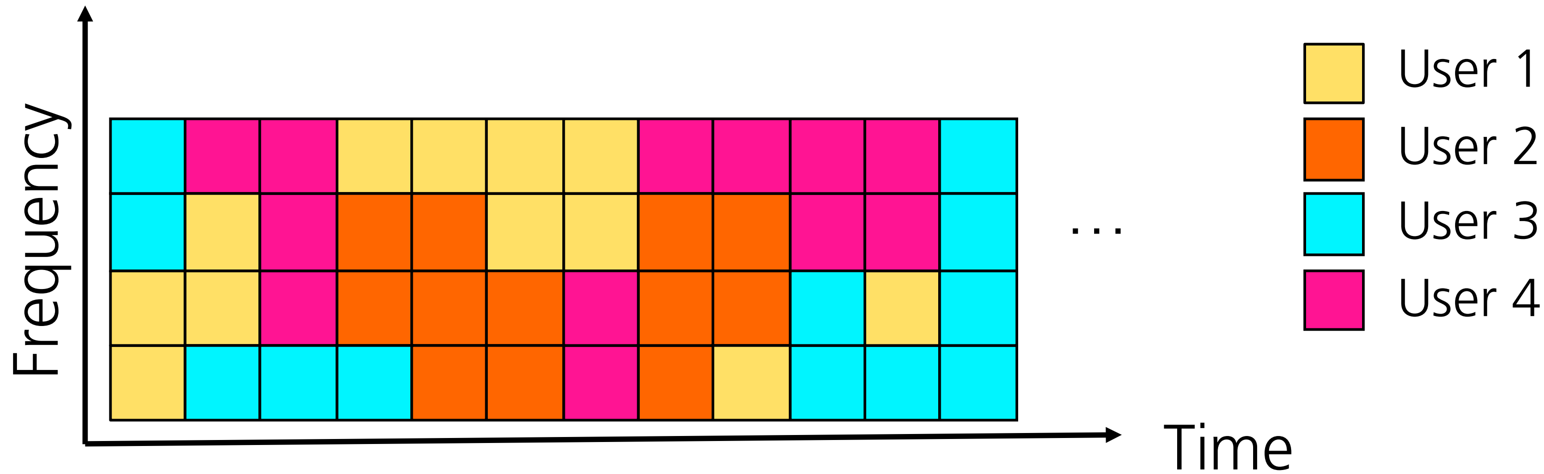



FDMA:



# Time-frequecy multiple access

OFDMA:



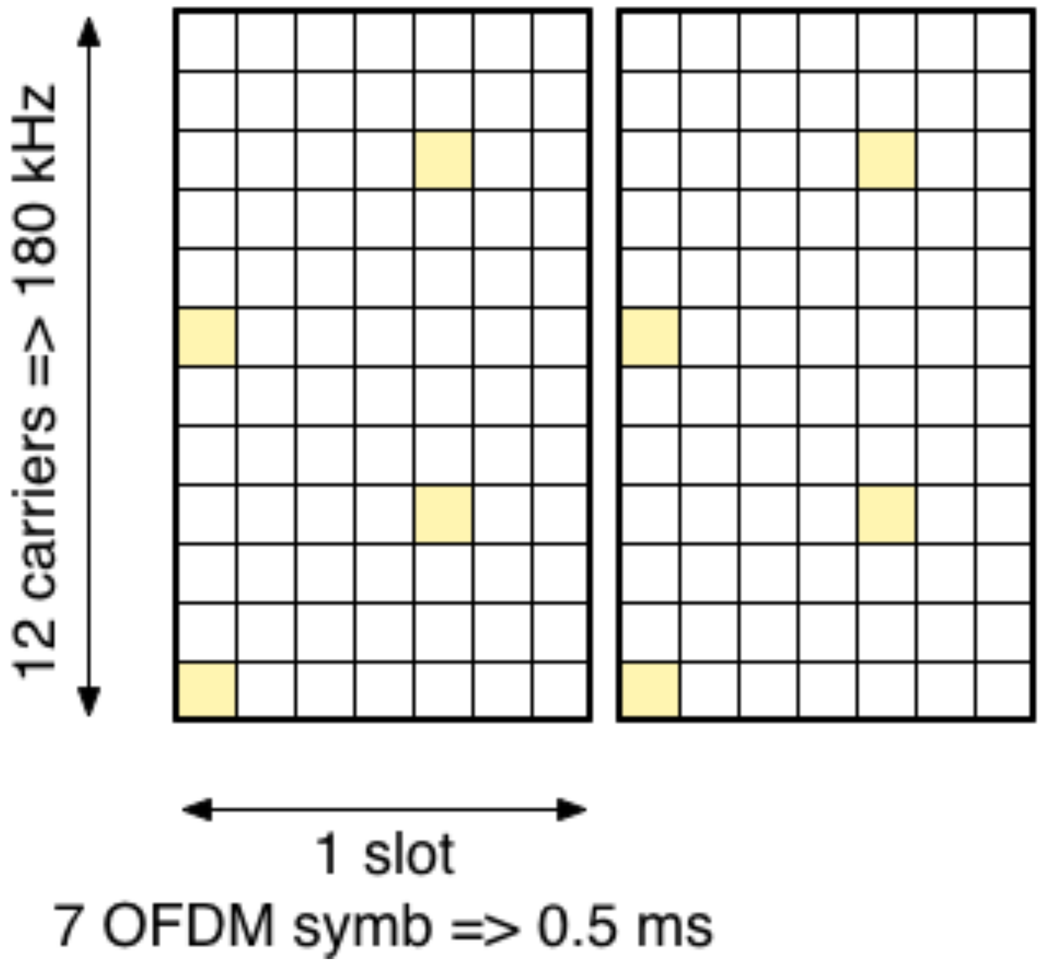

In LTE

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

  This is the least time-frequency resolution

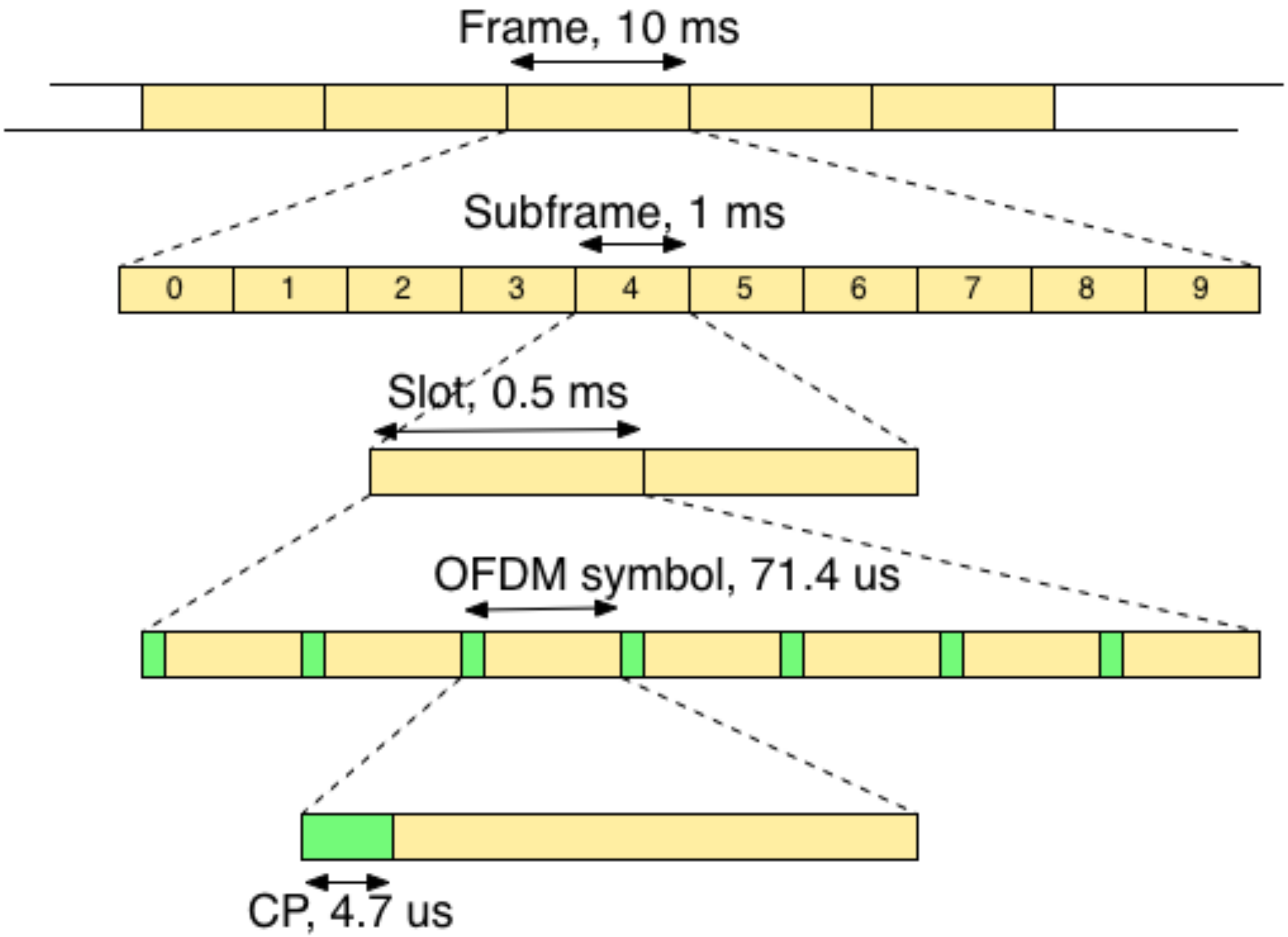
  - 15 kHz X 71.4 us

# Resource block (RB)




A pair of RB (subframe) 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 |

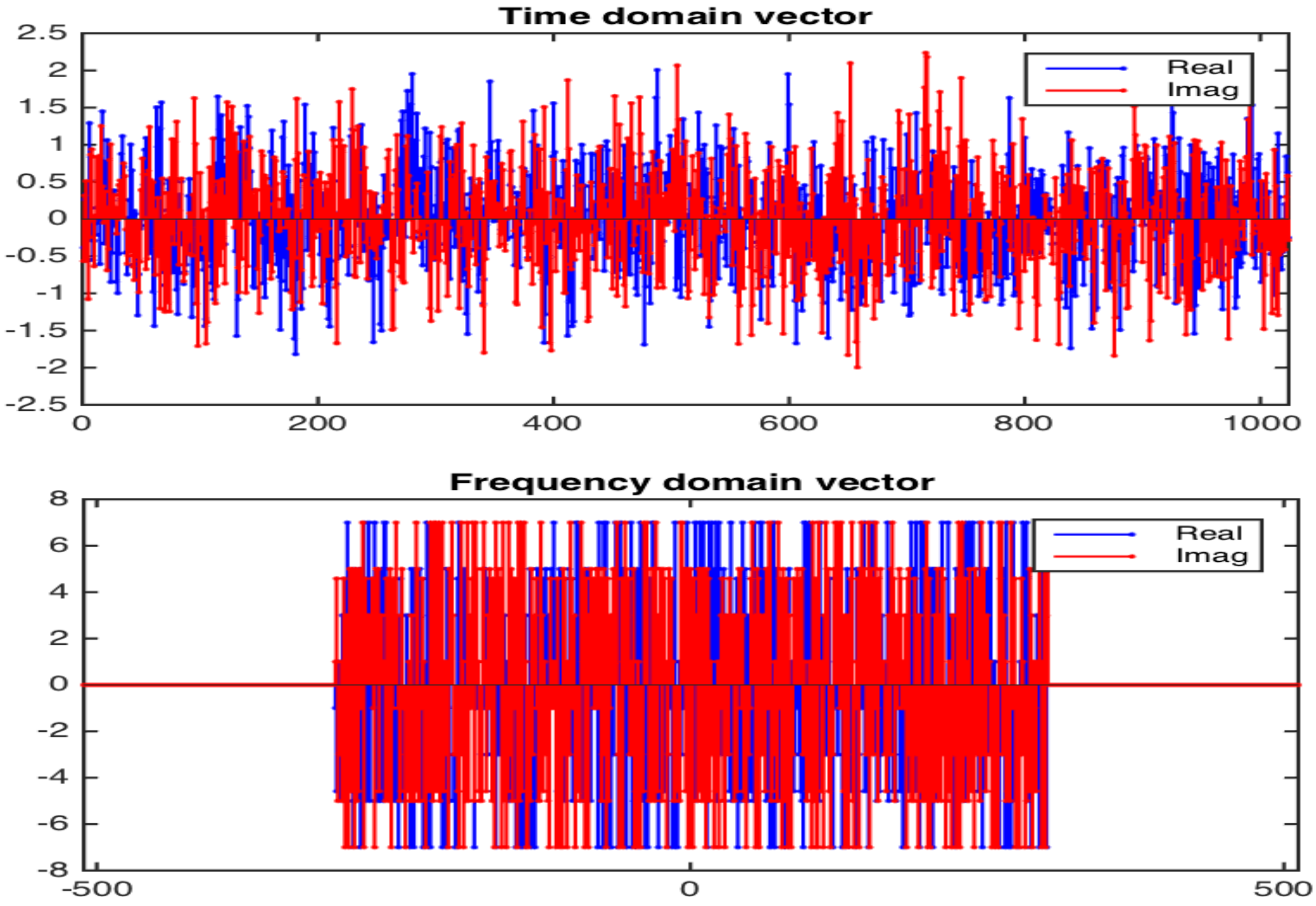
Max Rate is for 64-QAM, i.e. 6 bit/carrier

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

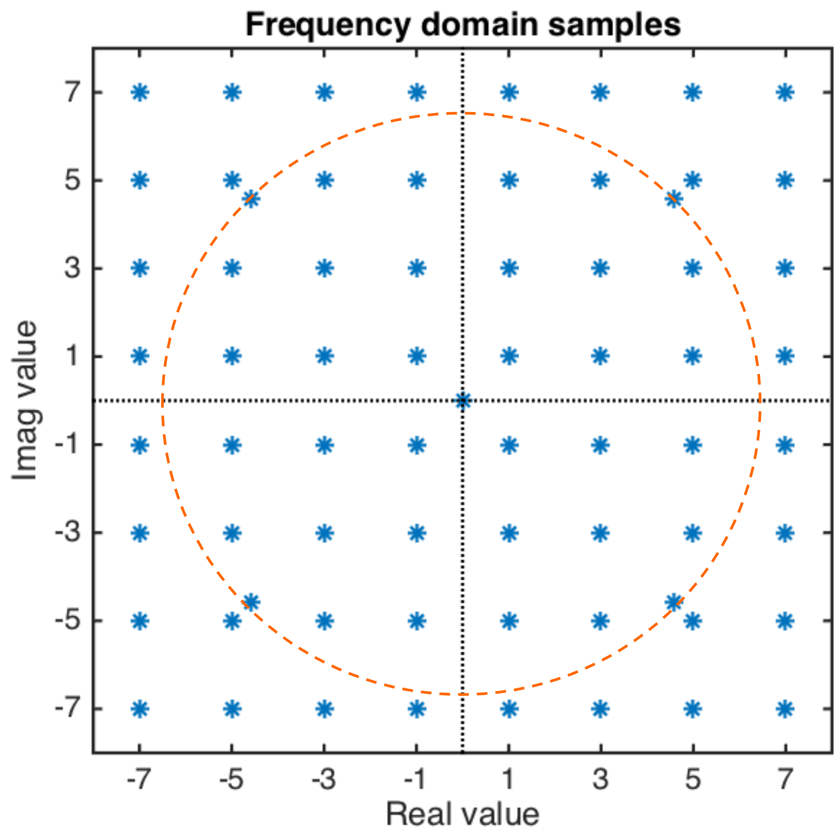
## One OFDM symbol for BW=10 MHz and 64-QAM



# Example

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

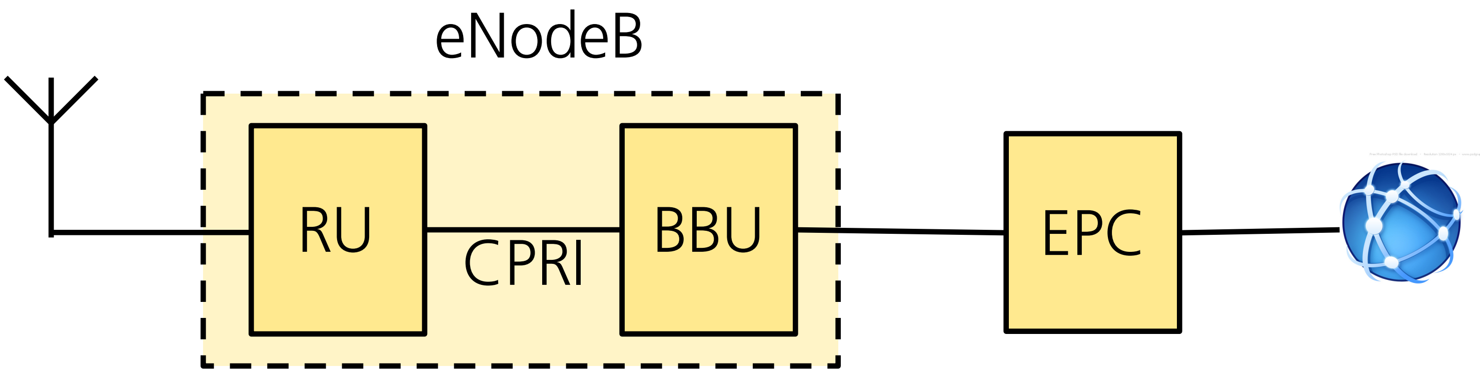
Plot of (all) frequency domain samples as I-Q



# 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
## BBU hoteling




Radio unit (RU)

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

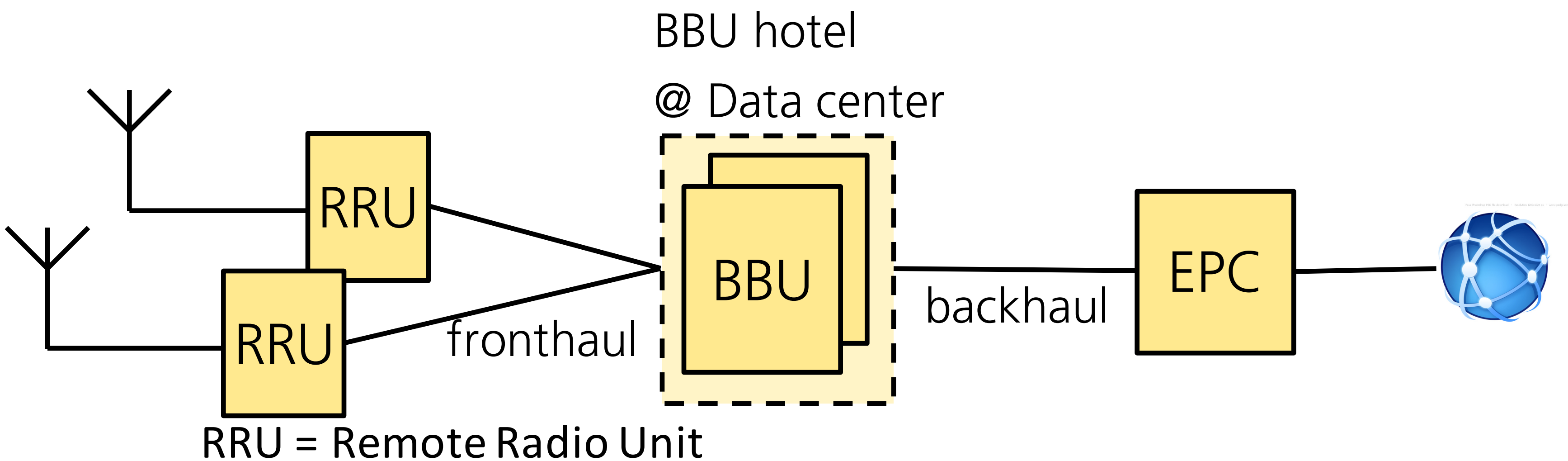
Baseband unit (BBU)

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

# What comes next 1
## BBU hoteling

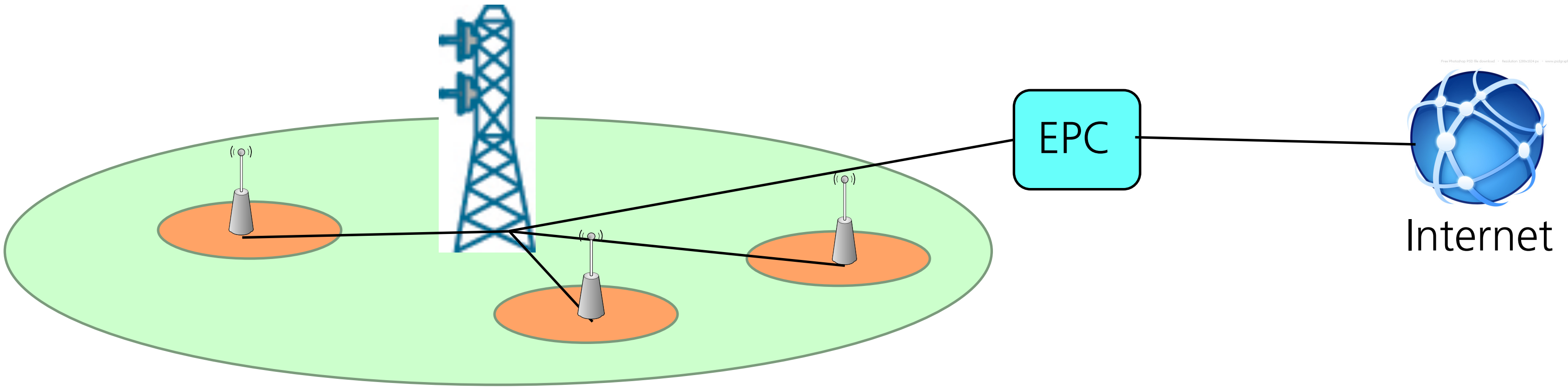
To utilize recourses better split BBU and RRU in network

- Use CPRI to transmit BB samples between BBU and RRU




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

# 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 or together with WiFi?

Problems

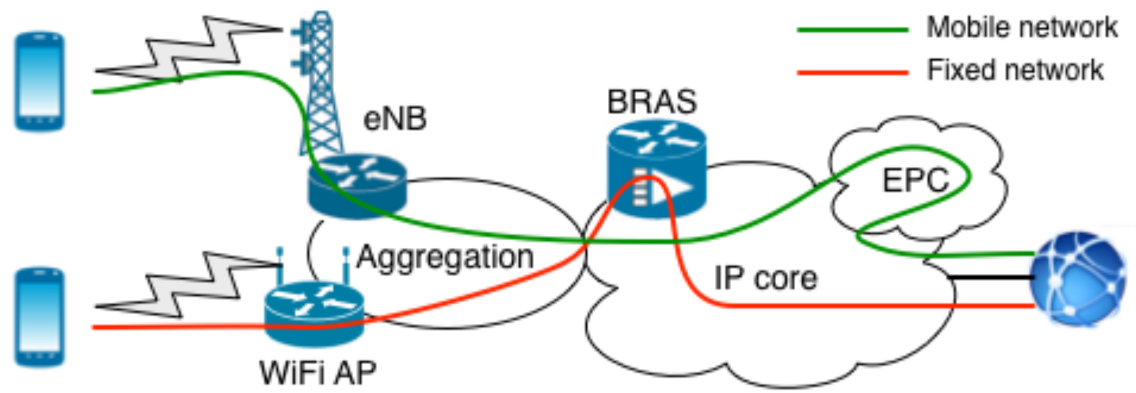
- How to backhaul/fronhaul
- Can they be part of coordination?
  - Pico cell: with coordination
  - Femto cell: no coordination

# What comes next 3
## Converged network

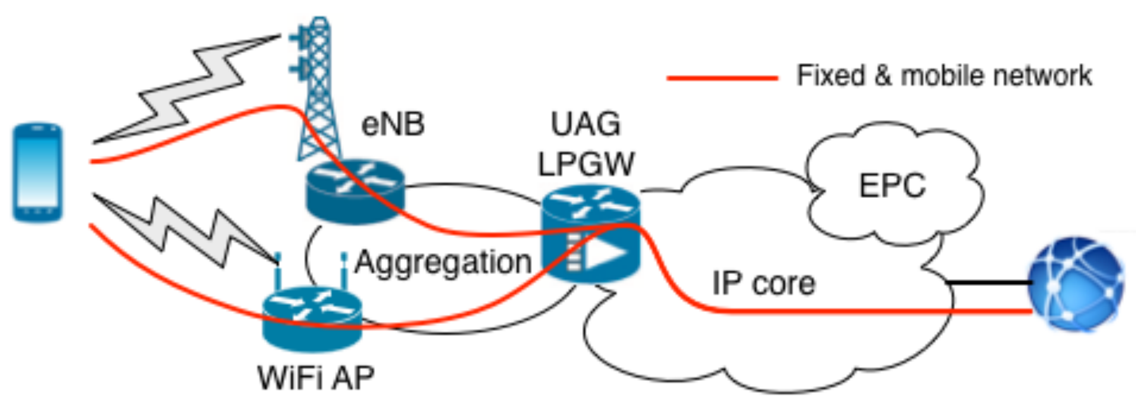
- Users becomes more mobile
  - When price and rate differences diminish most user will not care about choice of connection
- Convergence:
  - One network, many accesses
  - Flexible network
  - One AAA (and pricing)
  - Handover between e.g. LTE-WiFi
  - Dual connections and traffic off-loading
  - All units everywhere
- Problem:
  - Partly new network structure (e.g. common IP edge)

# What comes next 3
## Converged network

Fixed or mobile network (separated, SoA)




Fixed and mobile network (converged network)



# What comes next 4
## 5G

- Roughly a factor of 10 in performance
  - 10 times faster, bandwidth, Data rate, etc
  - 10 battery life (for low power devices)
  - 1000 times traffic volume
  - 10 times harder (at least)
- Small cells everywhere
- M2M; Everything is connected
  - Car2Car, IoT, Skynet, …
- Expected to launch latest 2020
- Problems:
  - Backhaul/fronthaul, RAN sync, Energy efficiency, etc