



Προηγμένα Θέματα Ασύρματων και Κινητών Δικτύων

Διδάσκοντες

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Δομή Μαθήματος

- Εξελίξεις στο σχεδιασμό και την υλοποίηση κινητών δικτύων 4^{ης} Γενιάς με έμφαση στο σύστημα LTE (Long Term Evolution).
- Διαλέξεις σε βασικά ερευνητικά θέματα στην παραπάνω περιοχή και από προσκεκλημένους ερευνητές.
- Σύντομες παρουσιάσεις φοιτητών σε θέματα της επιλογής τους με σχετική καθοδήγηση.
- Τελική προφορική εξέταση.
- Εκτεταμένη χρήση του eclass (eclass.uoa.gr/courses/DI304/)



Πρόγραμμα Διαλέξεων

1. Εισαγωγή – Εξέλιξη κινητών/ασύρματων επικοινωνιών
2. Δίκτυα 4ης γενιάς (LTE, LTE-A)
3. Διαχείριση κινητικότητας σε δίκτυα LTE-A
4. Εξοικονόμηση ενέργειας σε δίκτυα LTE-A
5. Αντιμετώπιση παρεμβολών σε δίκτυα LTE-A
6. Διαχείριση πόρων σε προηγμένα ασύρματα/κινητά δίκτυα
7. Δίκτυο κορμού συστήματος LTE (Evolved Packet Core)
8. Επικοινωνία συσκευής-με-συσκευή σε δίκτυα LTE-A
9. Ποιότητα υπηρεσίας και εμπειρίας σε δίκτυα LTE-A
10. Software Defined Networking - Network Functions Virtualization
11. Ασφάλεια κινητών επικοινωνιών



Introduction to Wireless/Mobile Communications



Lecture Contents

Mobile
communications
evolution

A few words for
each lecture

Local area
communications
evolution (WiFi)

Metropolitan area
communications
evolution (WiMaX)

Typical
Transmission
methods and
access control





The beginning of mobile communications



It all started 100 years ago

Heinrich Hertz, 1857-1894

- Electromagnetic waves 1887



Reginald Fessenden 1866-1932

- Voice transmission over radio 1906



Guglielmo Marconi 1874-1937

- First radio 1897

Mobile Communications at the beginning of the 20th century

1910: Ericsson & wife Hilda



1924: First mobile radio telephone



Courtesy of Rich Howard

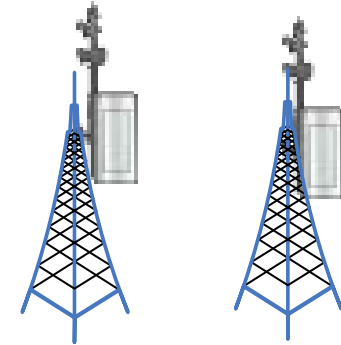


Cellular Networks Impact our Lives

More Mobile Connection



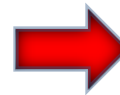
More Infrastructure Deployment



More Mobile Information Sharing

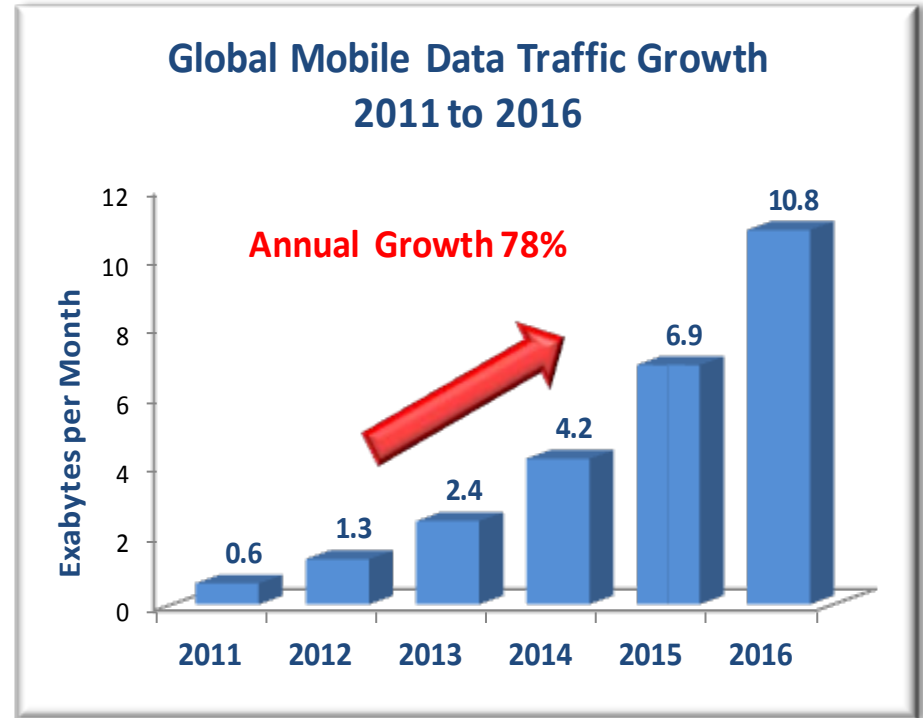


More Mobile Users



Mobile Data Tsunami Challenges Current Cellular Technologies

- Global growth **18 times** from 2011 to 2016
- AT&T network:
 - Over the **past five years**, wireless data traffic has grown **20,000%**
 - At least **doubling every year** since 2007
- Existing cellular technologies are inadequate
 - Fundamental redesign of cellular networks is needed



Source: CISCO Visual Networking Index (VNI) Global Mobil Data Traffic Forecast 2011 to 2016

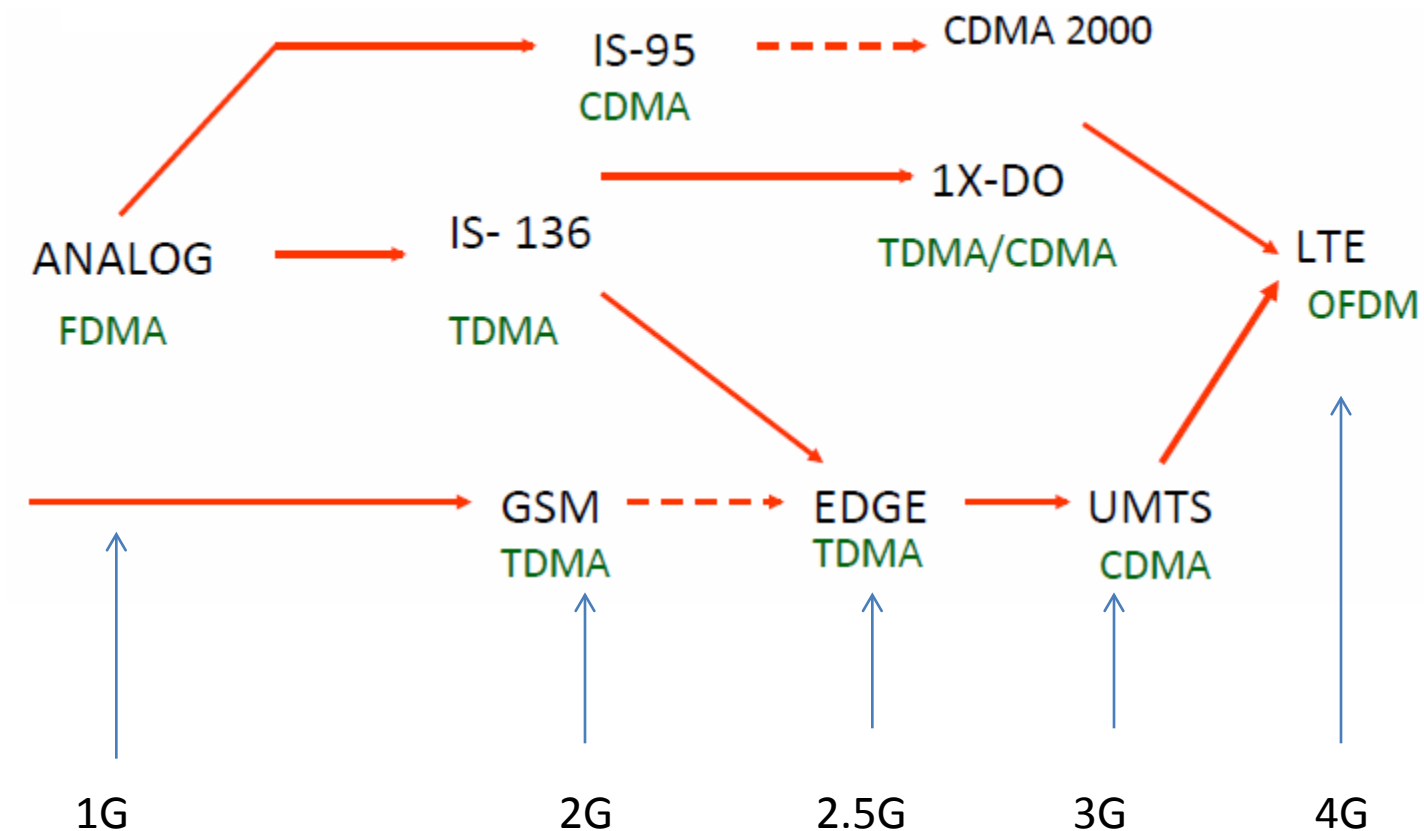


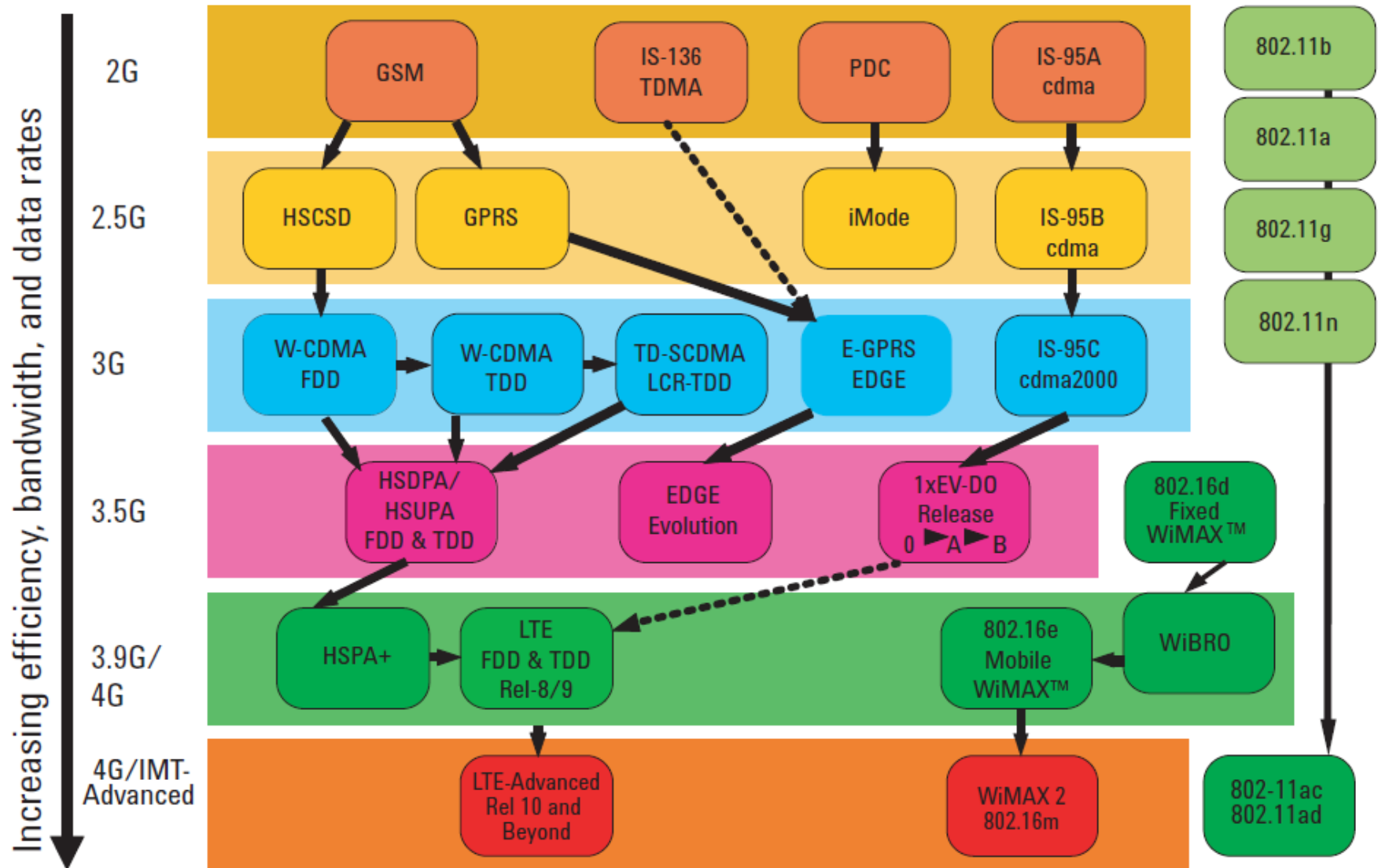
Cellular Network Generations

- It is useful to think of cellular Network/telephony in terms of *generations*:
 - **0G**: Briefcase-size mobile radio telephones
 - **1G**: *Analog* cellular telephony (end '70s)
 - **2G**: *Digital* cellular telephony (beg '90's)
 - **3G**: *High-speed* digital cellular telephony (including *video telephony*) (beg '00)
 - **4G**: IP-based “anytime, anywhere” voice, data, and multimedia telephony at *faster* data rates than 3G (beg '10)
 - **5G**: 10-times faster data rates, much more flexible in mobility, Internet of Things (IoT) support (cheap, low energy, massive number of devices) (beg '20)



Evolution of Cellular Standards

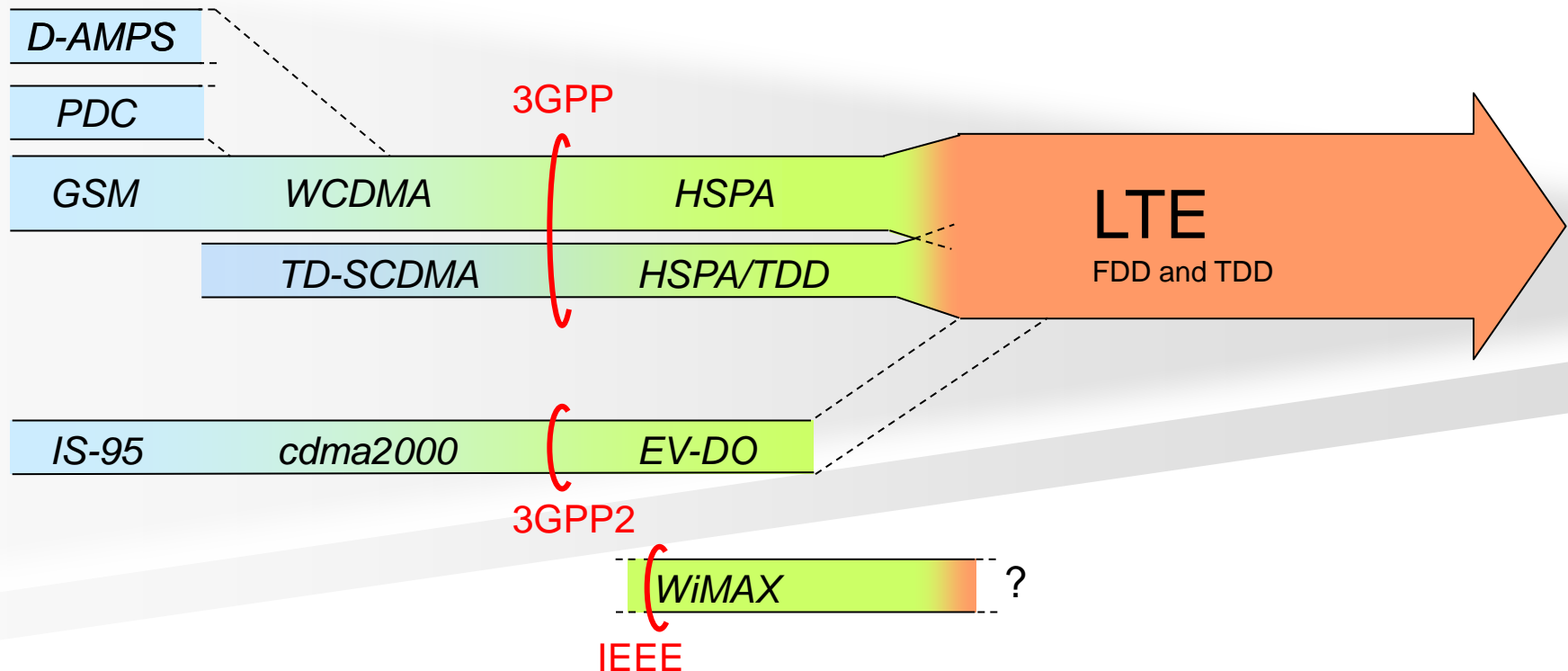






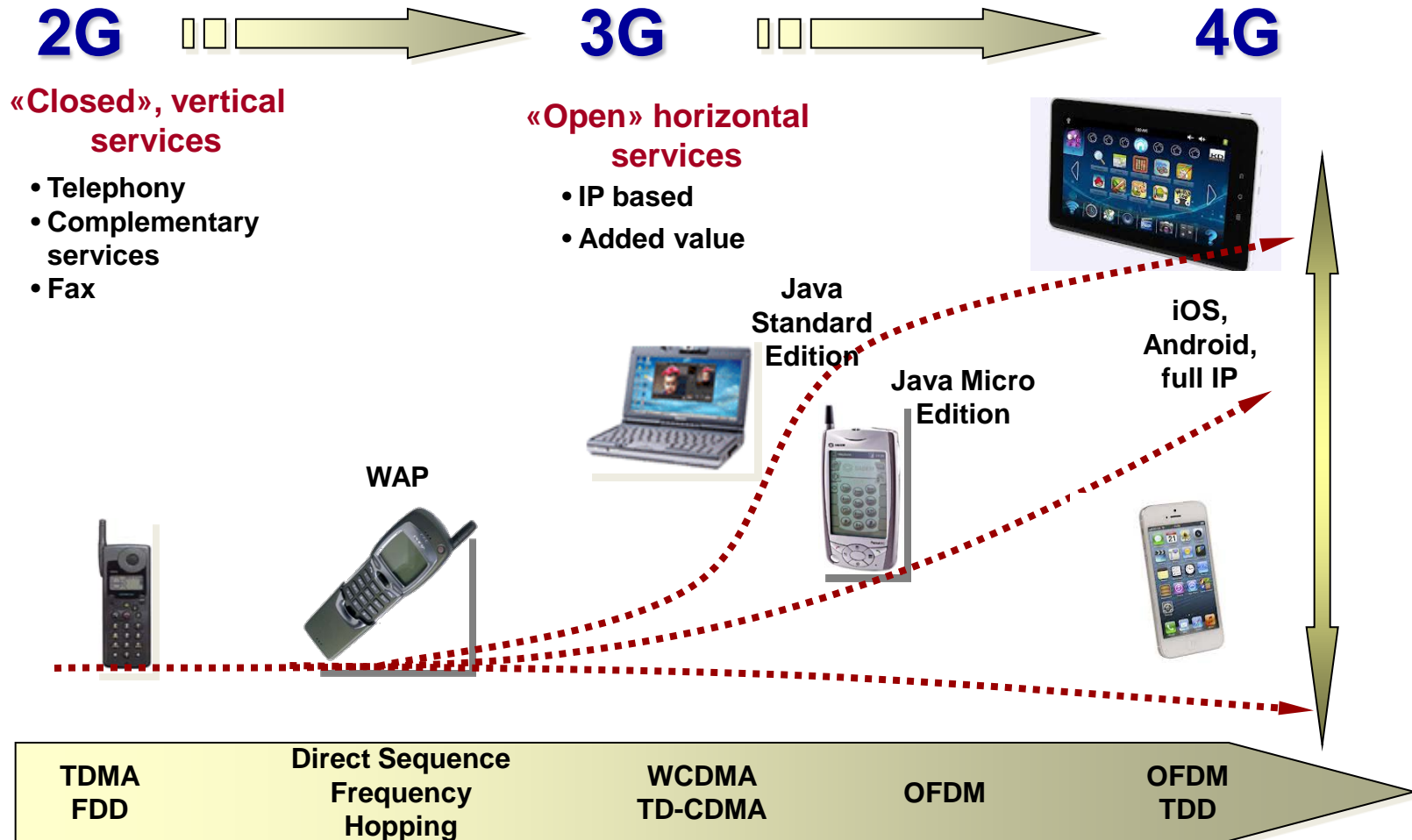
Global Convergence

- LTE is the major technology for mobile broadband communications
 - Convergence of 3GPP and 3GPP2 technology tracks
 - Convergence of FDD and TDD into a single technology track





Evolution of terminals and services





Business model evolution

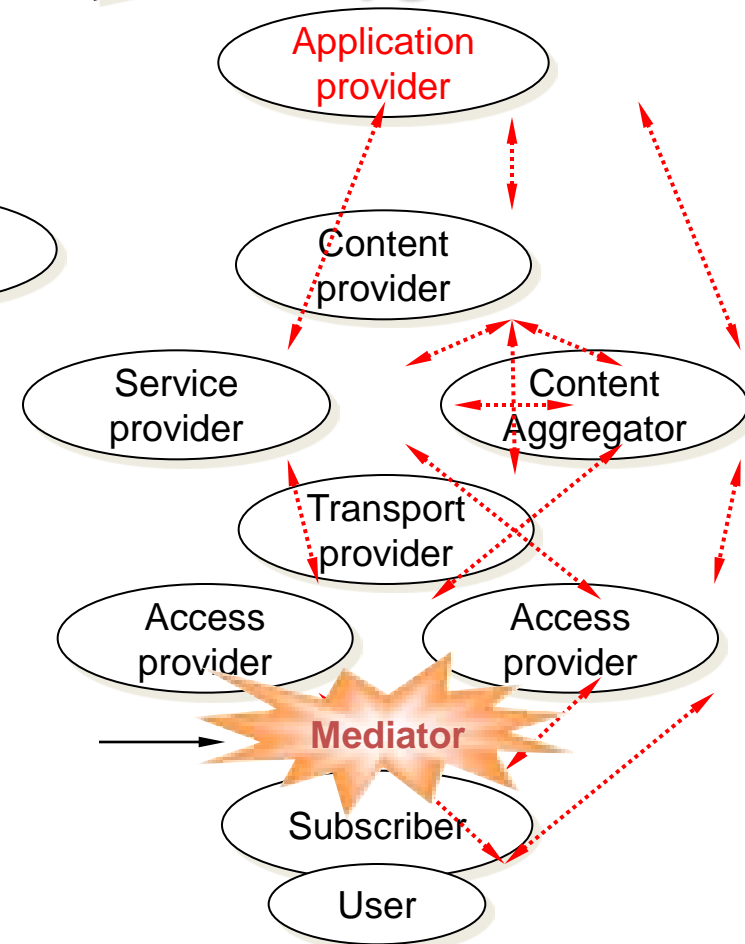
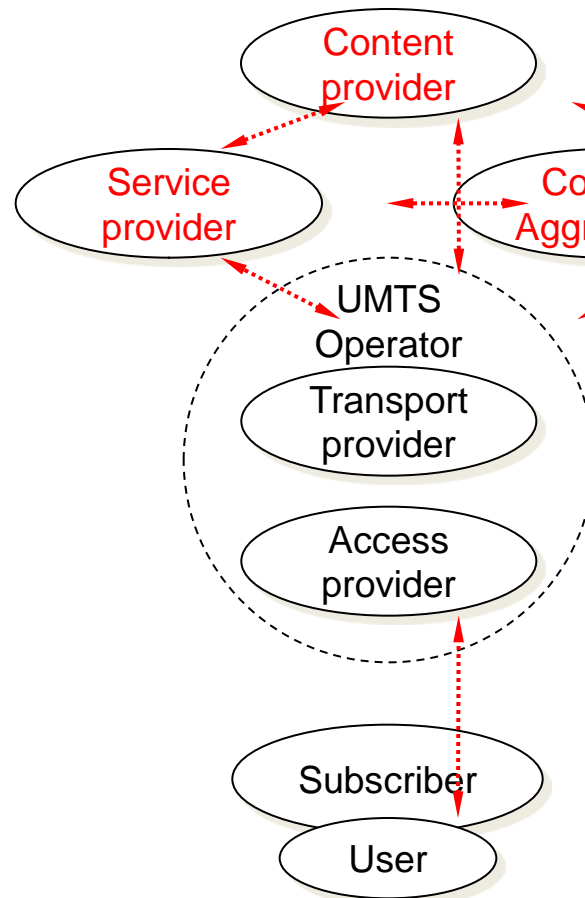
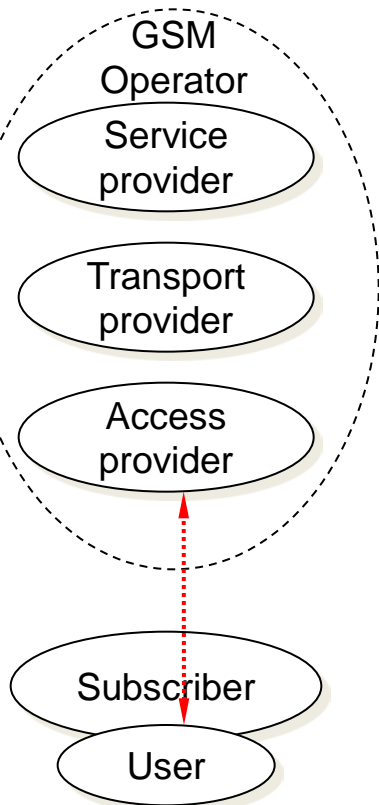
2G



3G

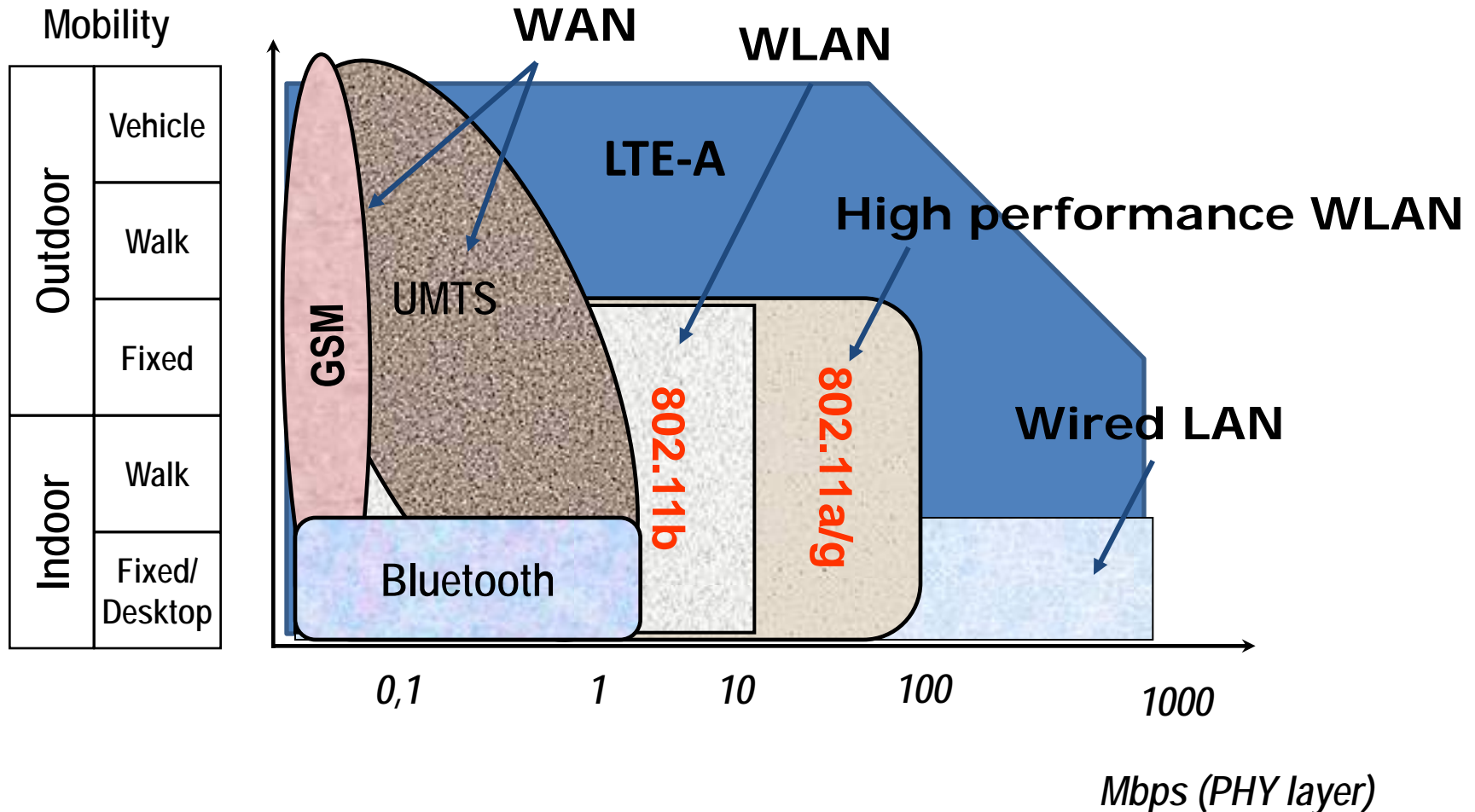


4G





Wireless Standards



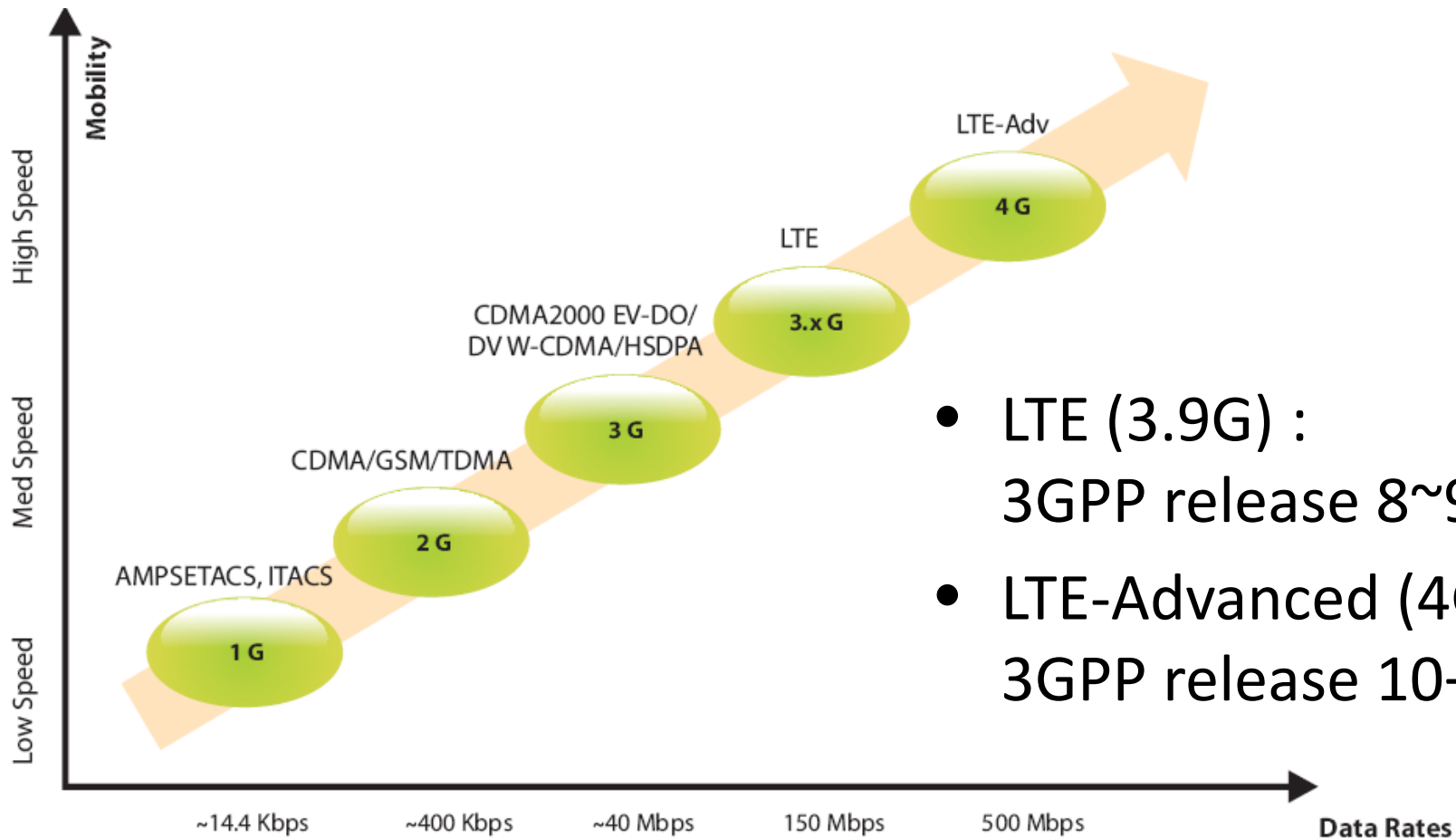


2. LTE/LTE-A Basics

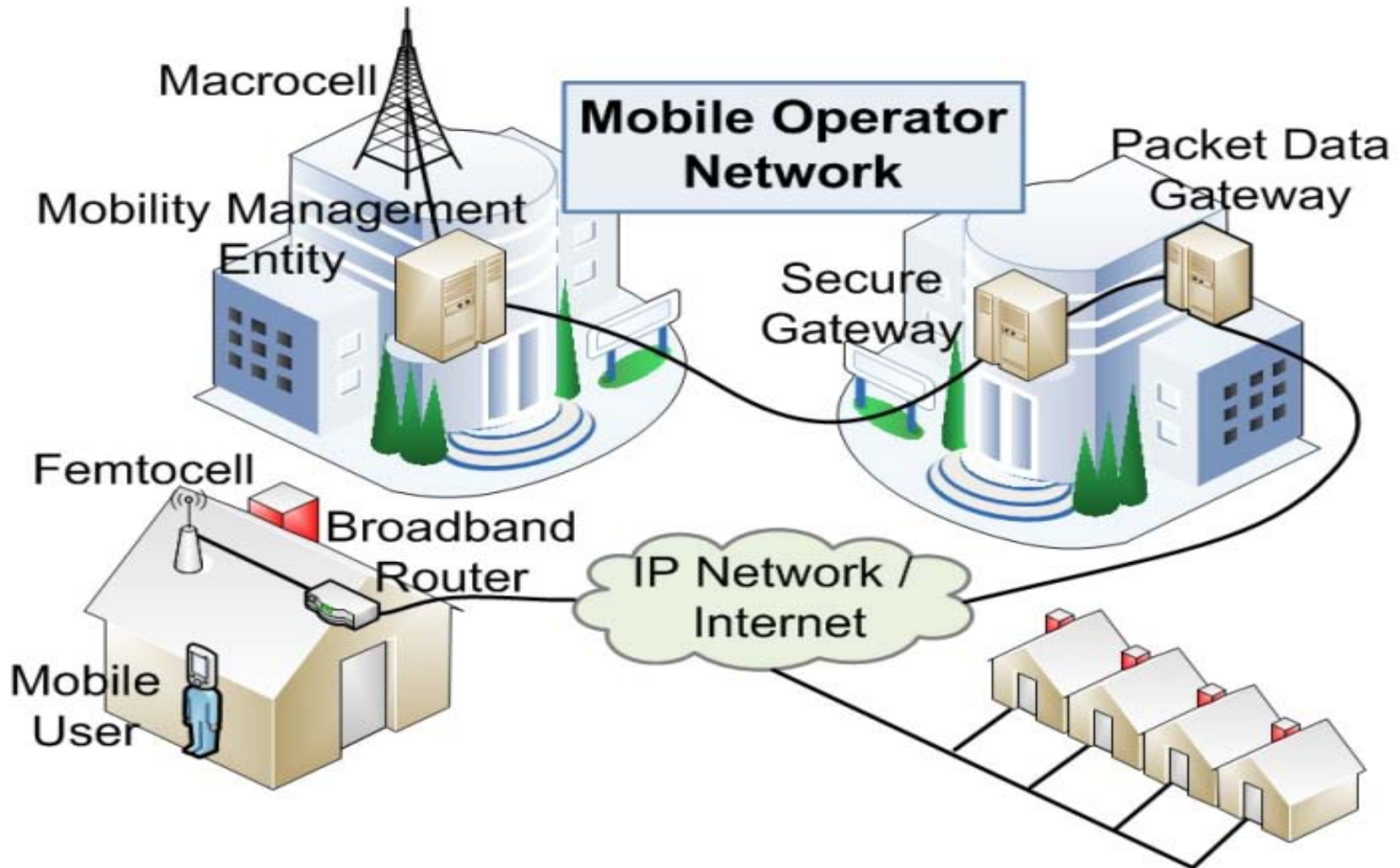
- Mobile standards evolution towards 4G
GSM->GPRS->UMTS->LTE->LTE-A
- Key features of Long Term Evolution (LTE)
- LTE architecture / components / functionality
- LTE transmission techniques
- LTE-Advanced enhancements



Evolution of Radio Access Technologies



3. Mobility Management in LTE-A Networks





Focus of the Lecture

- Motivation
- Support of femtocells in LTE-A
- Key aspects and **research challenges**
 - Cell search
 - Cell selection / Reselection
 - Handover decision
 - Handover execution
- **Handover decision** for femtocells in LTE-Advanced (LTE-A)
 - Handover decision **criteria** and context
 - Classification and **survey** of handover decision algorithms
 - Comparative **summary** and future research directions

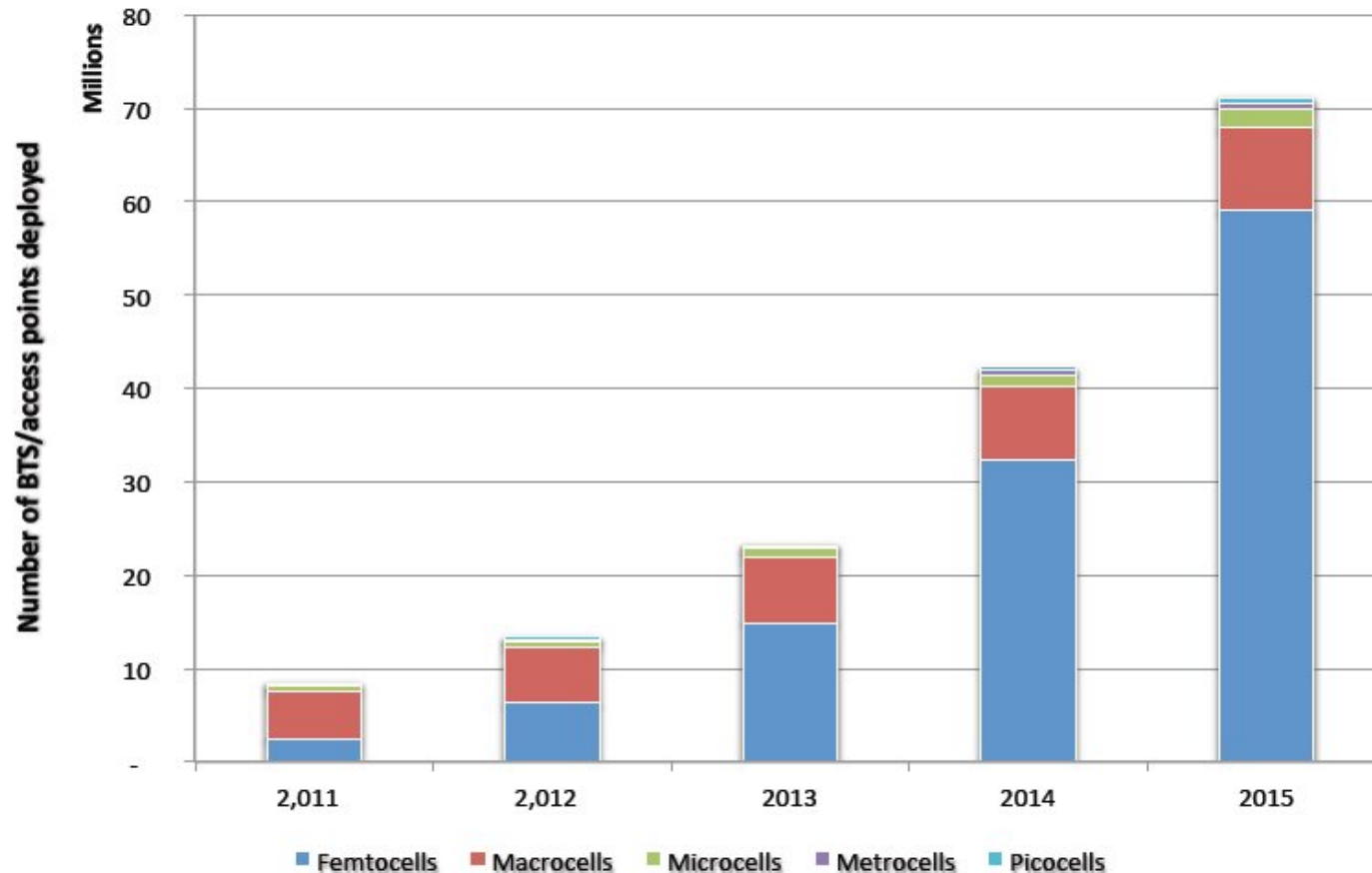


4. Energy Saving in LTE-A Networks

- The use of devices such as **smart phones, tablets** etc. , is widespread.
- Inevitably user expectations also rise in terms of **higher data rates**, instant internet connectivity and a much larger variety of applications to play with.
- Higher speed data transmission or reception requires **higher power consumption**; this in turn drains the battery quickly.
- To support battery-operated mobile devices, LTE has developed **energy-saving features** that allow mobile devices to operate for longer durations without having to recharge.



Huge increase of femtocells



Source: Informa Telecoms & Media

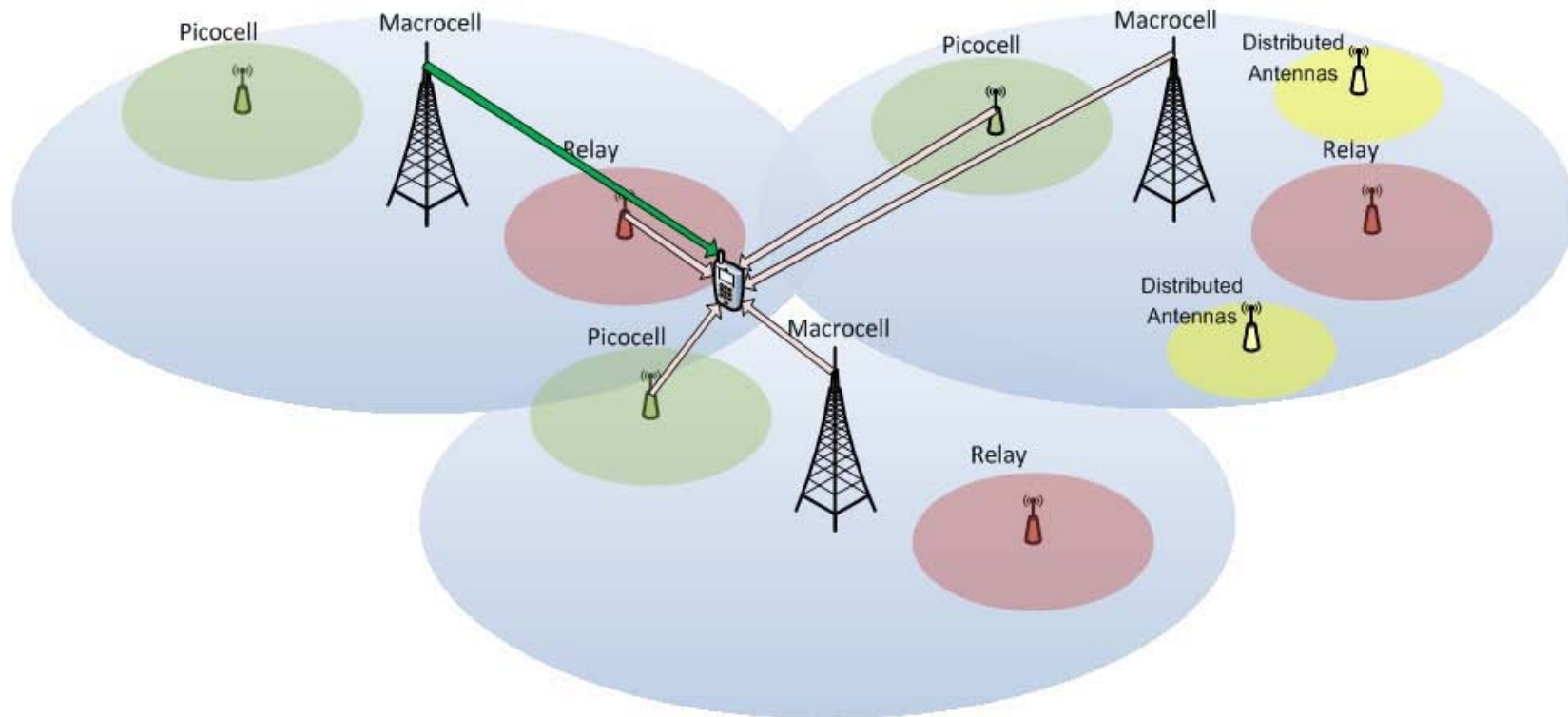


Focus of the Lecture

- Motivation
- Component-Level Energy Saving
 - **Energy consumption model** for component-level energy saving
 - **Opportunities** for component-level energy saving for femtocells
- System-Level Energy Saving
 - **Energy consumption model** for system-level energy saving
 - **Opportunities** for system-level energy saving for femtocells
 - Performance **comparison** of system-level energy saving approaches
 - Research **directions**

5. Interference Management in LTE-A

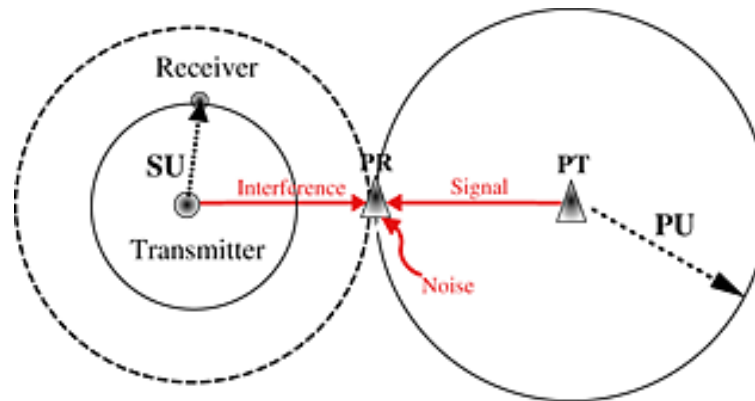
Heterogeneous environment - Different types of interference



The Interference problem in Femtocell-Overlaid LTE-A networks

During the interference management lecture we will deal with:

- The LTE-A **tools/technologies** that are related with the interference management
- The **state-of-the-art approaches** for interference management
- The interference management in **control channels**
- The relation between **interference and QoE**



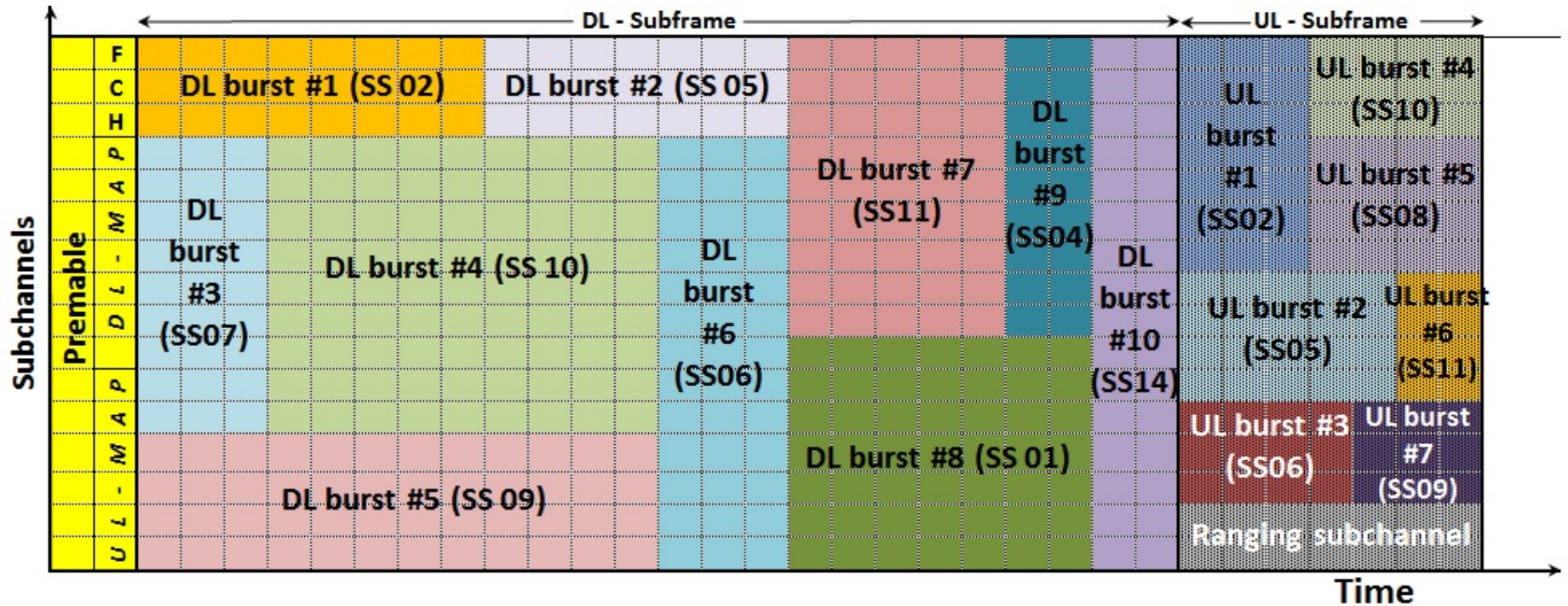


6. Radio/Resource Management in Modern Wireless/Mobile Networks (focus on LTE-A)

- Synchronous wireless networks important **characteristics**
 - Frequency band
 - MAC architecture
 - Transmission scheme
 - Modulation
- Multiple access schemes
 - Single Carrier
 - OFDM
 - OFDMA
 - SC-OFDMA
- Point-to-multipoint & mesh architectures



Typical RRM Problem

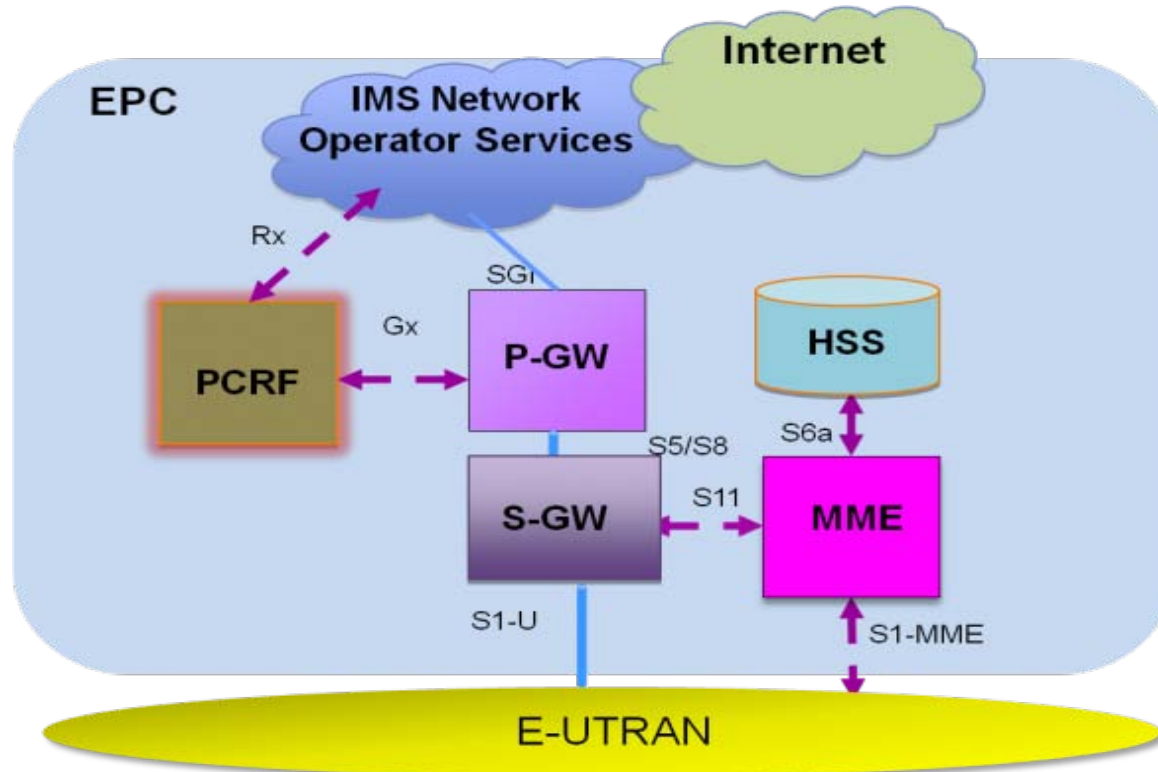




Resource Management – Theory vs reality

- How **QoS affects** scheduling & resource management
- **Importance of resource management** for wireless networks efficiency
- **Commonly used algorithms** for scheduling & resource allocation
- **Complexity** vs performance
- **Operator's** point of view
- **Customer's** (Public/Civil/Military/Industry) point of view
- Case study on **LTE**

7. Evolved Packet Core – The Core Network of LTE



MME (Mobility Management Entity)

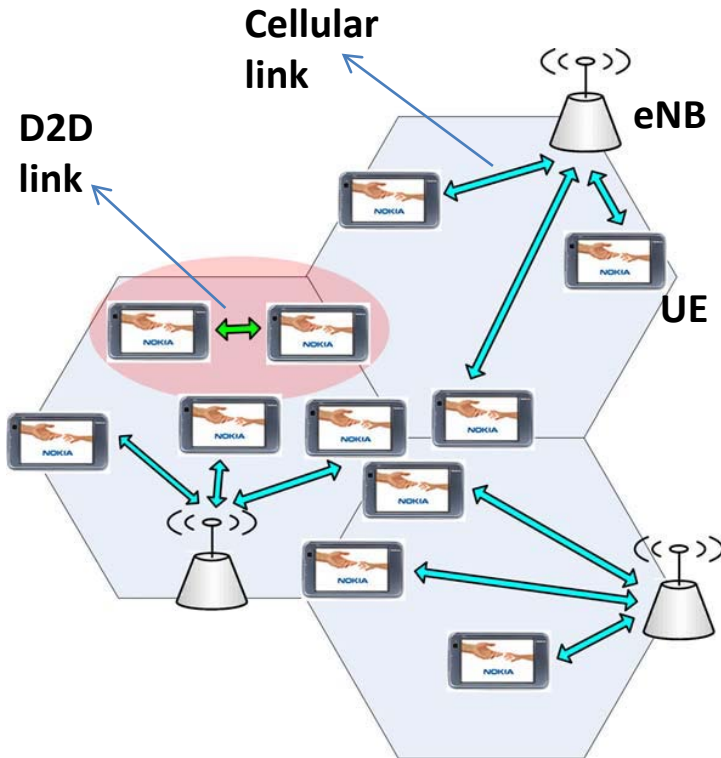
HSS (Home Subscriber Server)

S-GW (Serving Gateway)

P-GW (Packet Data Network Gateway)

PCRF (Policy and Charging Rules Function)

8. Device-to-Device Communications in LTE-A Networks



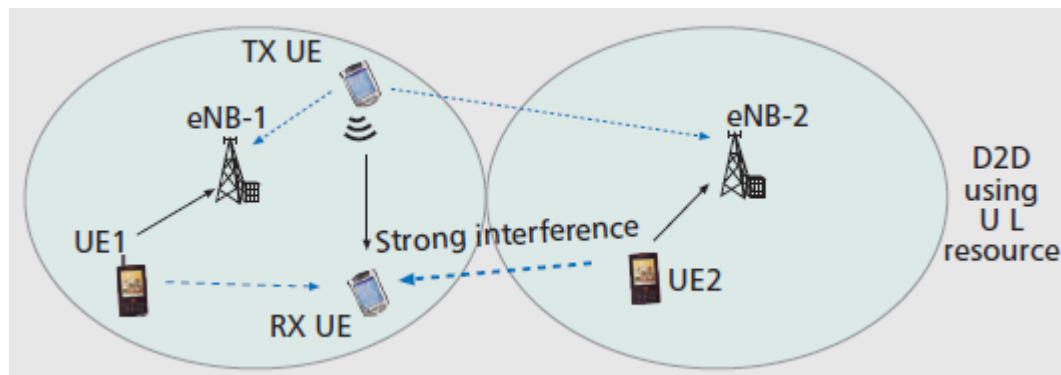
Why D2D?

- Higher **throughput**, lower **delays**, reduced **power consumption**
 - Increased **spectrum utilisation**
 - eNB **offloading** and network decongestion
 - All benefits of centralised eNB control (higher security etc.)
 - **New service** opportunities
 - Can be **transparent** to the user
- D2D is ideal for **short range data intensive** peer-to-peer communications, e.g. games, video streaming etc.

- Focus on:
- **Network-assisted** D2D links
 - Utilising **licensed** spectrum
 - **Direct** pair communication

Main research issues

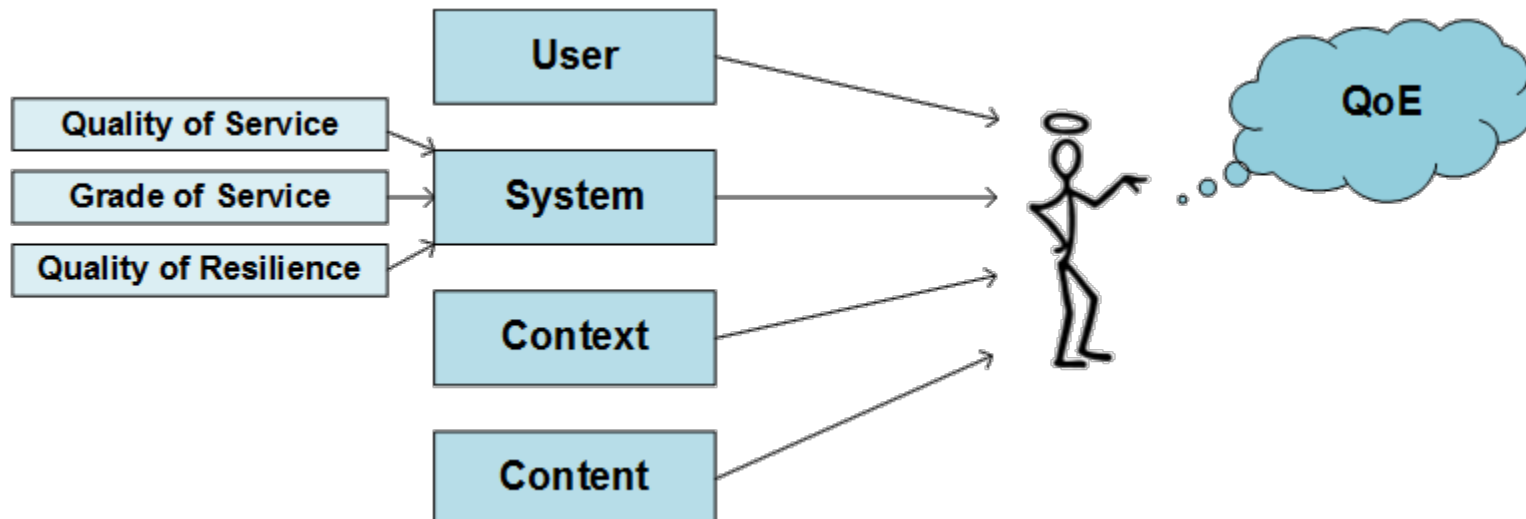
- Intra- and Intercell **interference mitigation** (co-existence of cellular & D2D links): Power control optimisation mechanism for D2D, Exploitation of proximity/neighbourhood information etc.
- Radio **resource management** (Resource Blocks allocation)
- Comparison between **cellular and D2D performance**
- D2D **session setup and management**
- Peer **device and service discovery** techniques



9. QoS vs QoE in LTE-A Networks

What is Quality of Experience (QoE)?

- The overall **acceptability** of an application or service, as perceived subjectively by the end-user.
- The degree of **your** delight or annoyance over a product, application or service.



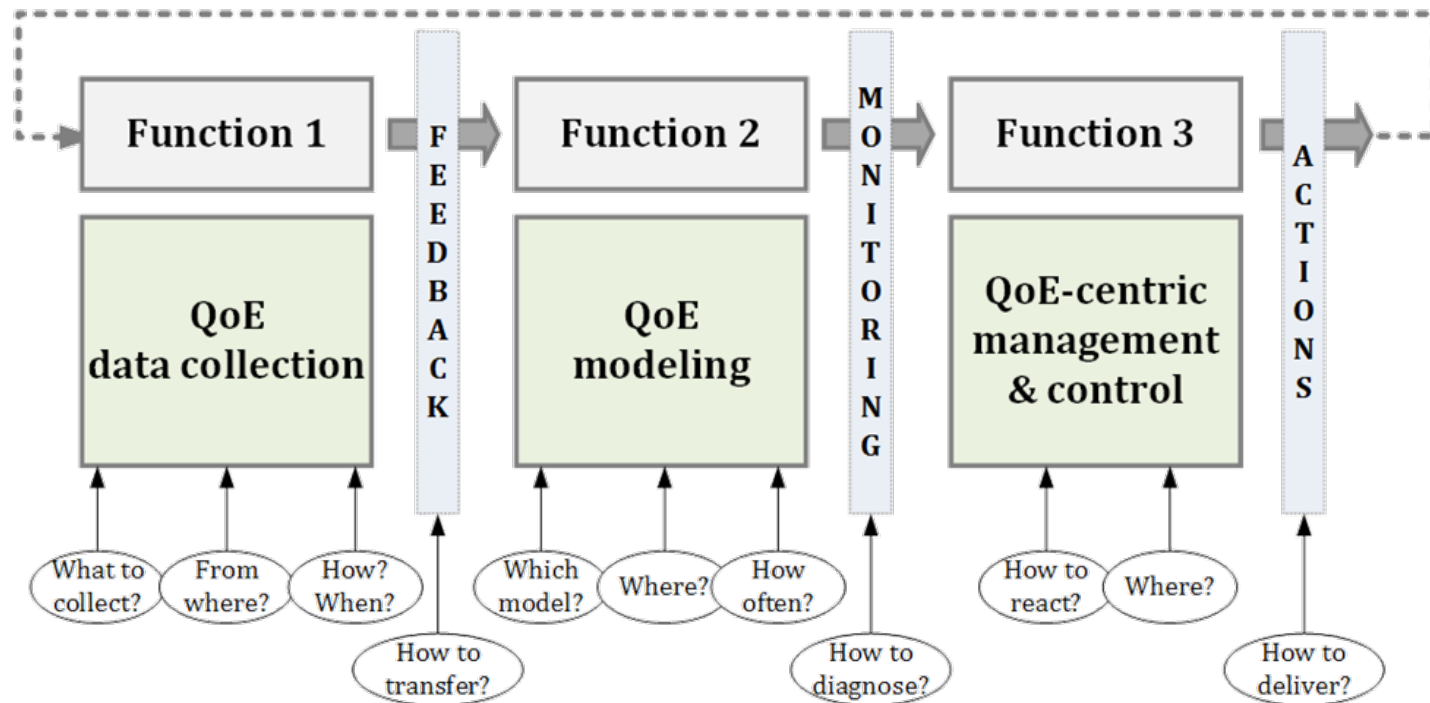


Learning objectives

- QoS in LTE-A
- QoS versus QoE
- Motivation behind QoE
- The QoE concept & its significance
- Major influence factors
- **QoE provisioning framework in LTE-A**
- Relationship between QoS and QoE
- How can it be measured? → **QoE modeling**
- How can it be controlled? → **QoE management**
- **Standardization**
- **Non-technical challenges** (legal, business, etc.)

QoE provisioning

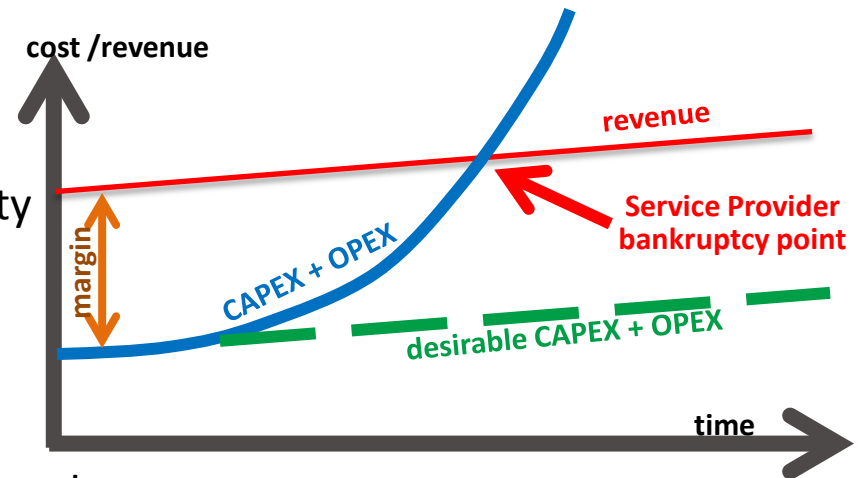
Goal: Optimize end-user QoE, while making efficient use of network resources & maintaining a satisfied customer base.



10. Software Defined Networking – Network Functions Virtualization

Today`s challenges

- Mobility, explosion of devices and traffic: huge capital investment.
- Network operators face an increasing disparity between costs and revenues
- Complexity: large and increasing variety of proprietary network hardware appliances
- Lack of flexibility and agility
- Launching new services is difficult and takes too long.



Two complementary solutions

Software Defined Networking

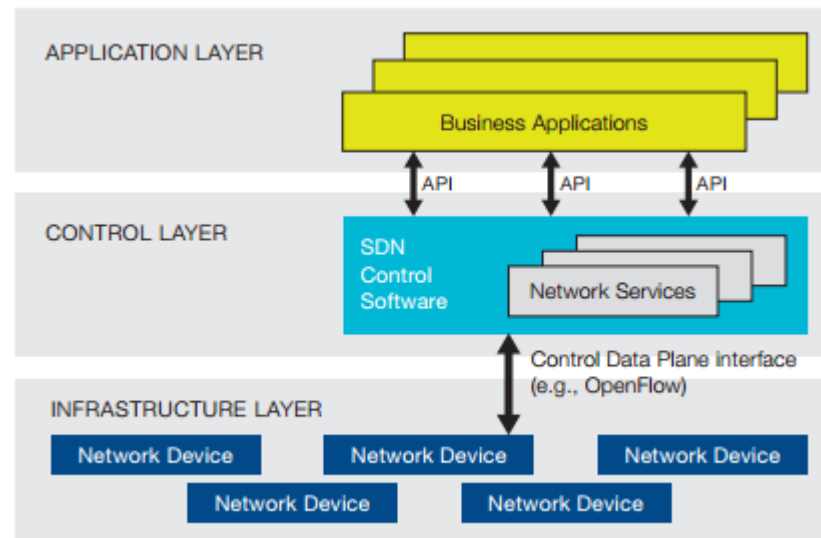
SDN is an approach to networking in which the **standardized networking protocols are replaced with centralized software applications** that may configure all the network devices.

Network Functions Virtualization

NFV aims to **virtualize the network functions** previously carried out by proprietary, dedicated hardware appliances, so they can run in software.

Why we need SDN/NFV?

1. **Virtualization:** Use network resource without worrying about where it is physically located, how it is organized, etc.
2. **Orchestration:** Should be able to control and manage thousands of devices with one command.
3. **Programmable:** Should be able to change the network behavior on the fly.
4. **Automation:** To lower OPEX by minimizing manual involvement



SDN/NFV Benefits

1. Reduced operator CAPEX and OPEX through reduced equipment costs
2. Reduced time-to-market to deploy new network services
3. Greater flexibility and agility to evolve services
4. Openness to the virtual appliance market and pure software entrants



11. Security in Mobile Communications

- Security **architectures** for mobile networks
- Security **services** provided
 - User Identity **Confidentiality**
 - User and Network **Authentication**
 - **Keying** material generation
 - User data and signaling confidentiality and **integrity** protection
- Network domain security **services** designed for future networks
- Security **Weaknesses** and Vulnerabilities
- Possible **Attacks** and their Impact



12-13. Student's Presentations

- Each student will do a 10-15' presentation in one of these areas
- Paper presentation or comparison of two papers
- Assistance and supervision during preparation
- Questions from audience
- 60% of the final grade

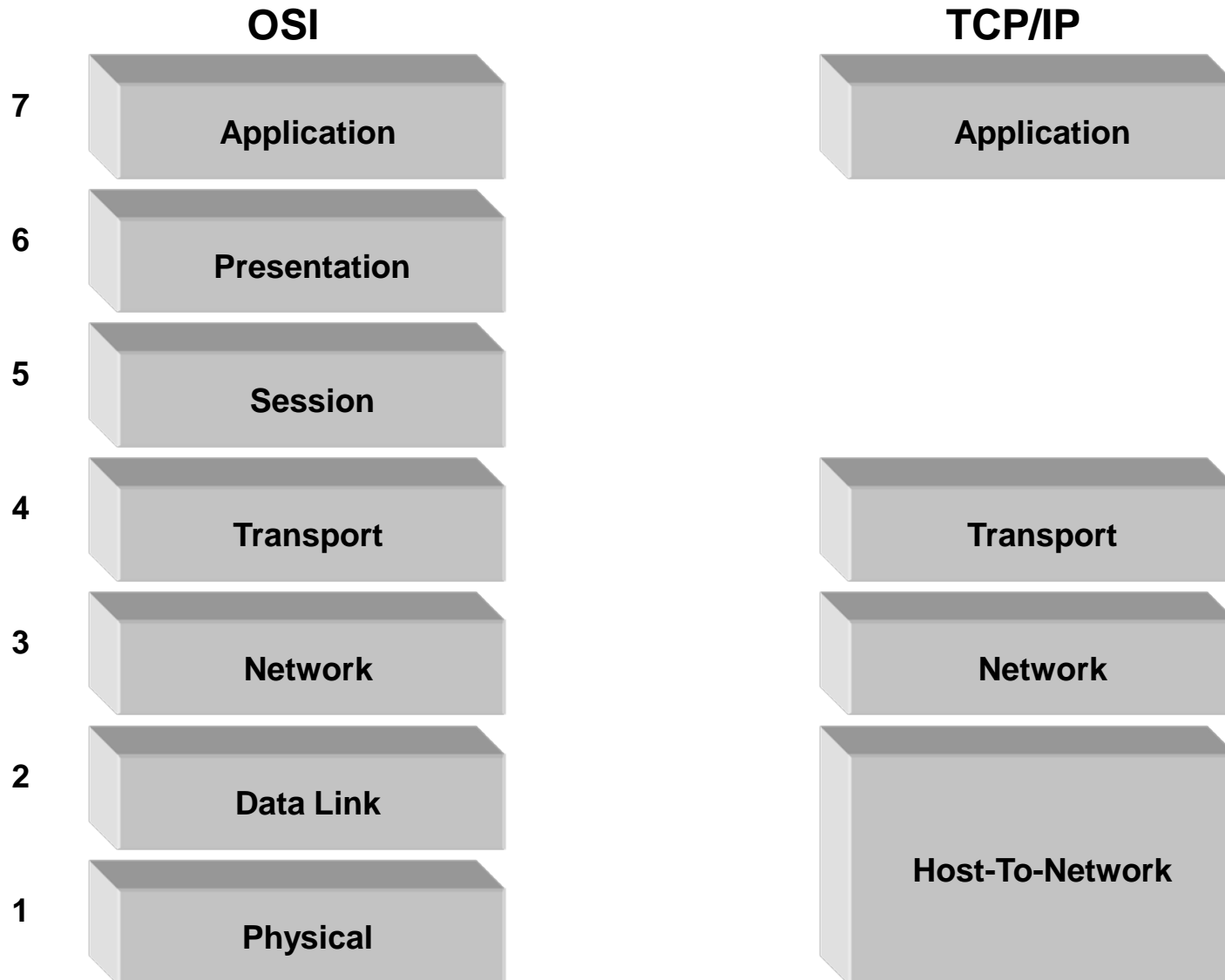


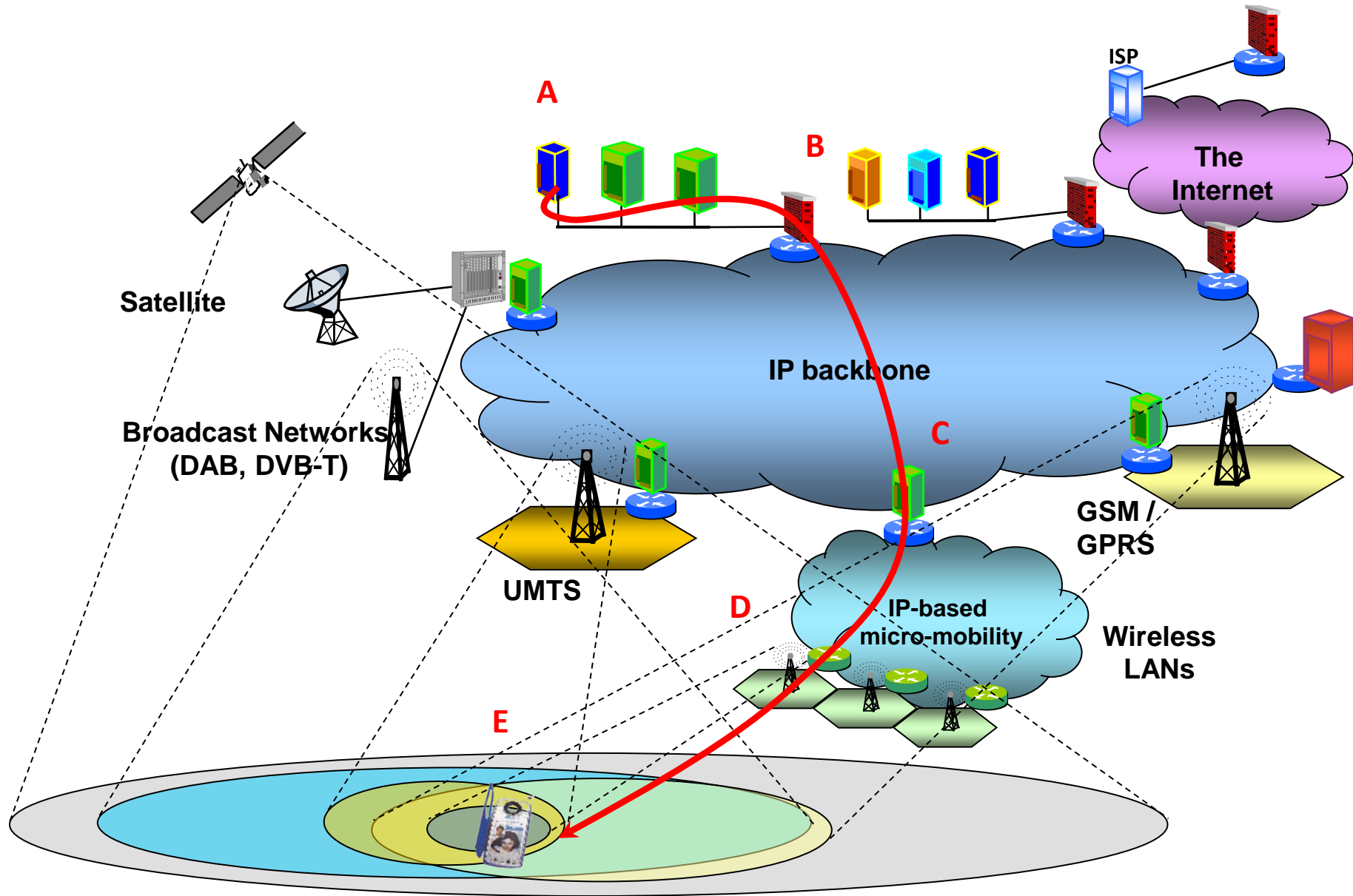
From Aloha & wired networks to synchronous wireless networks

- Introduction to access techniques and spectrum exploitation
- More than a Century of wired communications ↔ few decades of wireless communications
- Spectrum has more difficulties than wire
- Great evolution in microelectronics helps
- How we deal those difficulties during the evolution of wireless networks (standards 802.11, 802.16 etc)
- 4G wireless networks are quite mature but
- There are still many challenges and research opportunities



TCP/IP Reference Model







A



E

HTTP

HTTP

TCP

TCP

IP

IP

IP

IP

IP

Ethernet

Ethernet

Ethernet

Ethernet

Ethernet

Ethernet

802.11 MAC

802.11 MAC

Coaxial

Coaxial

Fiber-Optic

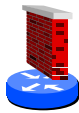
Fiber-Optic

Coaxial

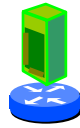
Coaxial

802.11 PHY

802.11 PHY



B



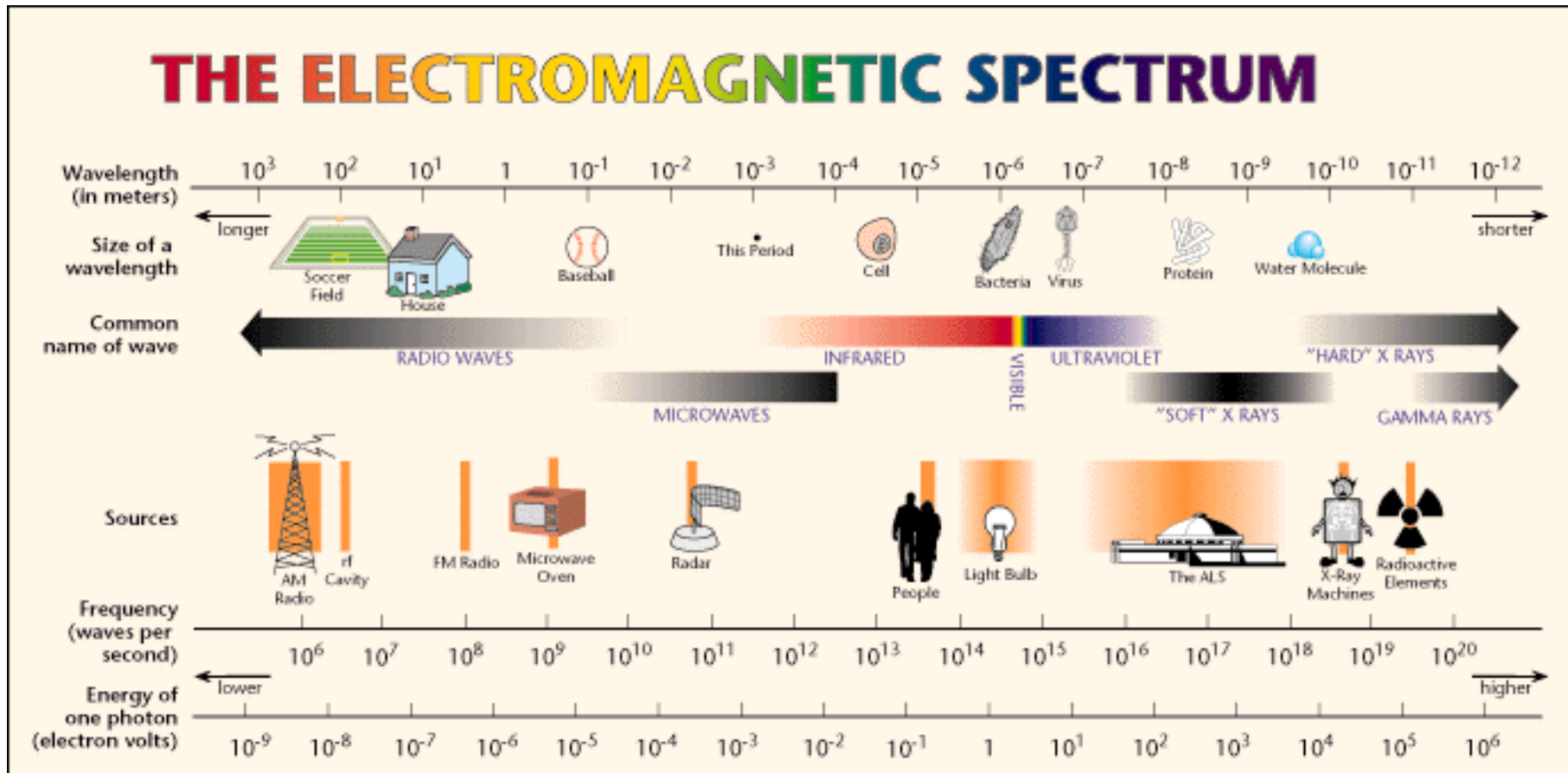
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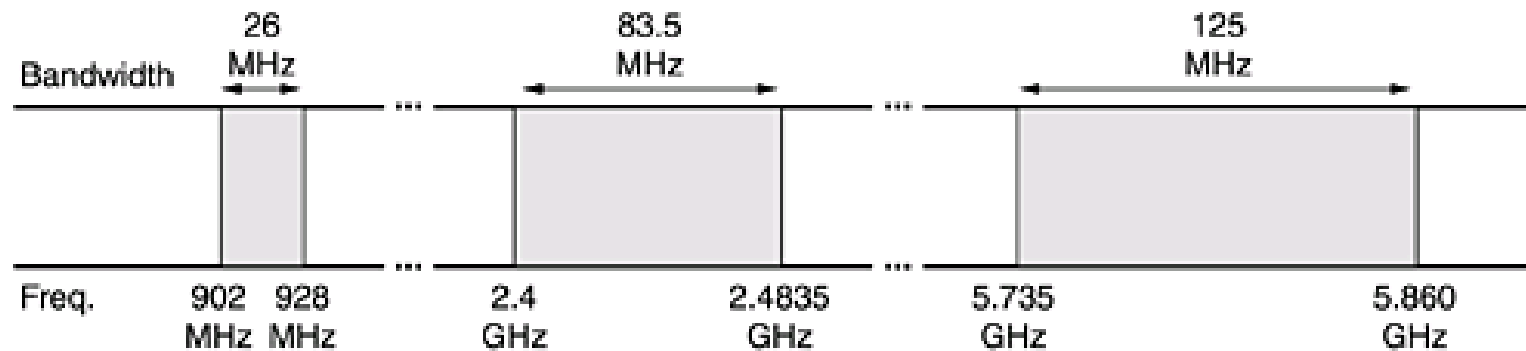
D



Electromagnetic Spectrum



ISM Band (Industrial Scientific Medical)



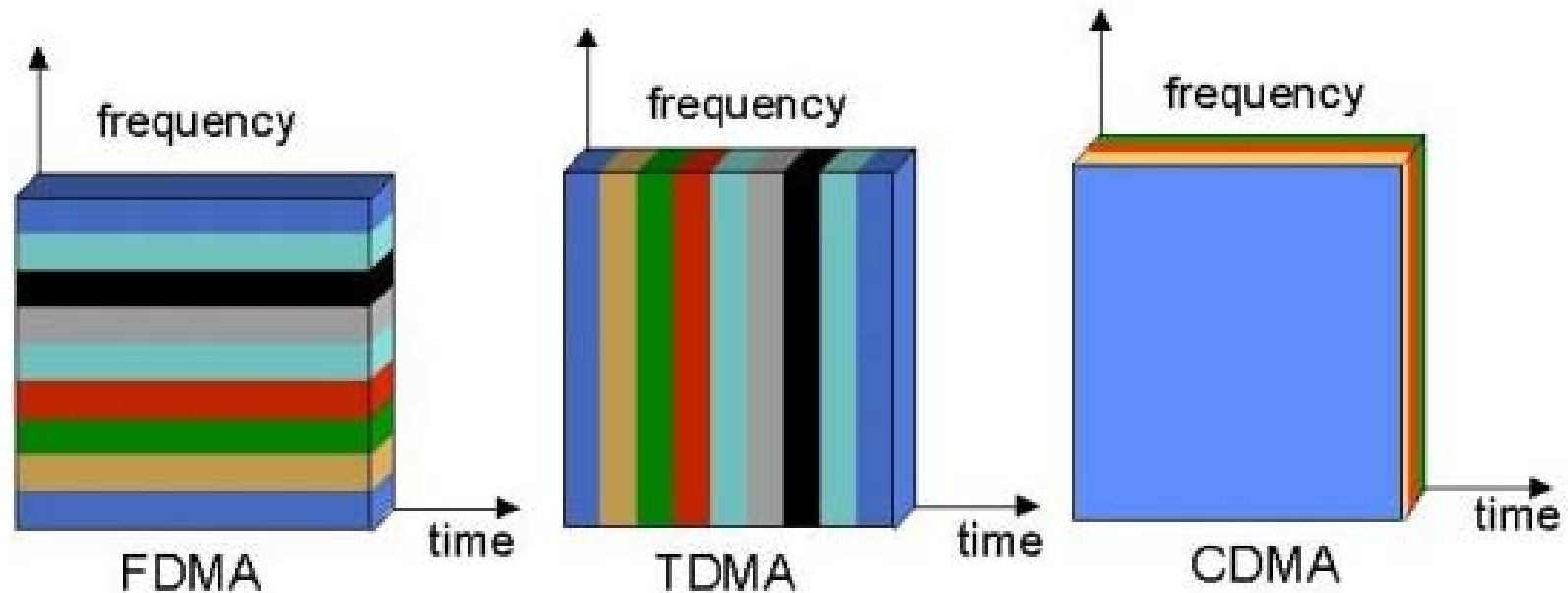
- Unlicensed, free to use
- Mainly used for WLANs



The Multiple Access Problem

- The base stations need to serve many mobile terminals at the same time (both downlink and uplink)
- All mobiles in the cell need to transmit to the base station
- Interference among different senders and receivers
- So we need multiple access scheme, to control transmissions from/to mobile terminals

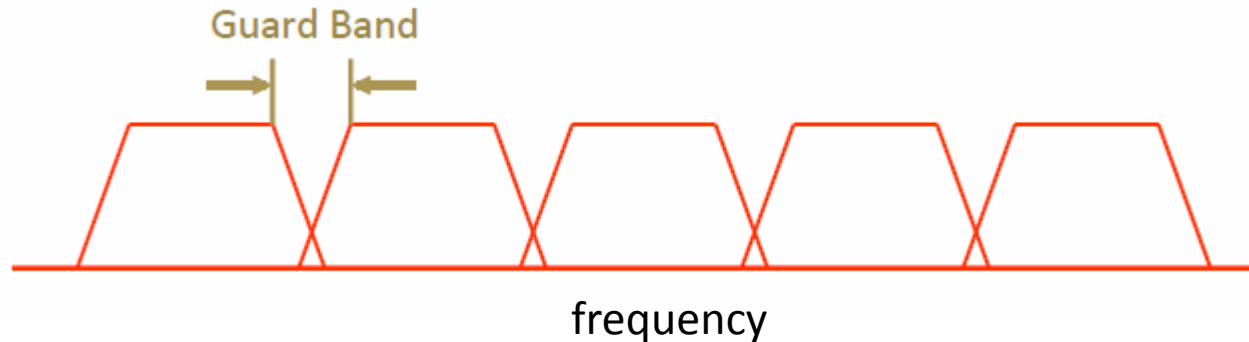
Multiple Access Schemes



3 orthogonal Schemes:

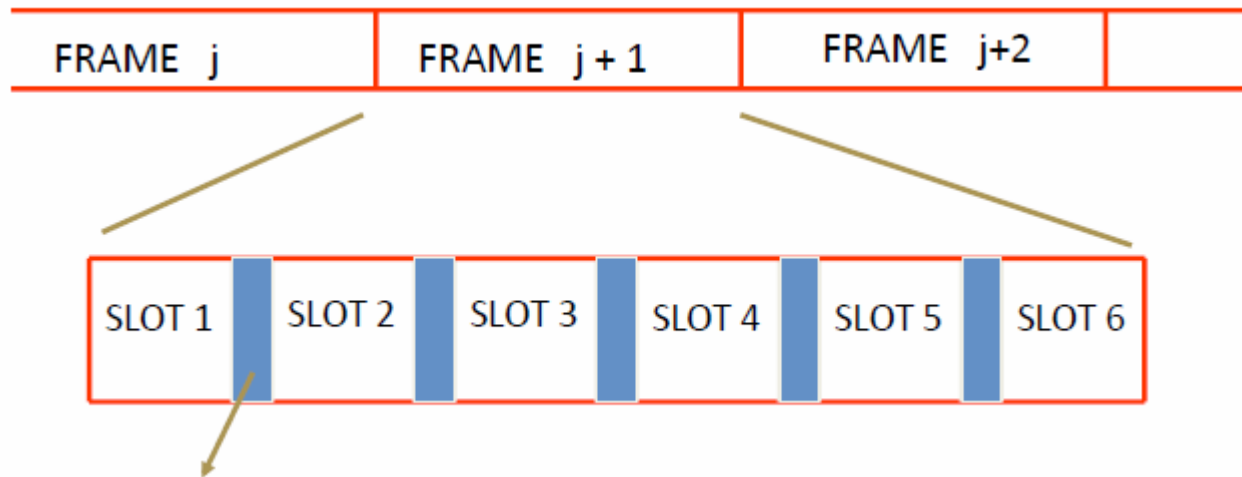
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

Frequency Division Multiple Access



- Each mobile is assigned a **separate frequency** channel for the duration of the call
- Sufficient **guard band** is required to prevent adjacent channel interference
- Usually, mobile terminals will have **one downlink** frequency band and **one uplink** frequency band
- Different cellular network protocols use **different frequencies**
- Frequency is a **precious and scarce resource**. We are running out of it

Time Division Multiple Access



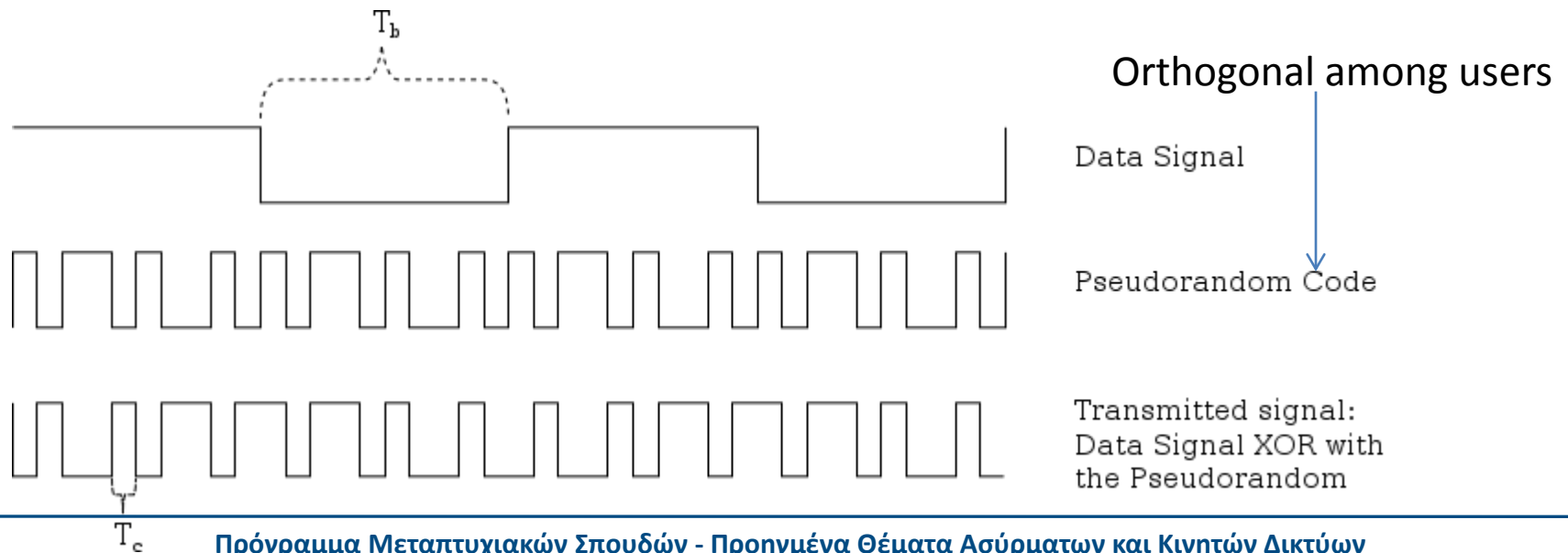
Guard time – signal transmitted by mobile terminals at different locations do not arrive at the base station at the same time

- Time is divided into slots and only **one mobile terminal transmits during each slot**
 - Like during the lecture, only one can talk, but others may take the floor in turn
- Each user is given a specific slot. No competition in cellular network
 - Unlike Carrier Sensing Multiple Access (CSMA) in WiFi



Code Division Multiple Access

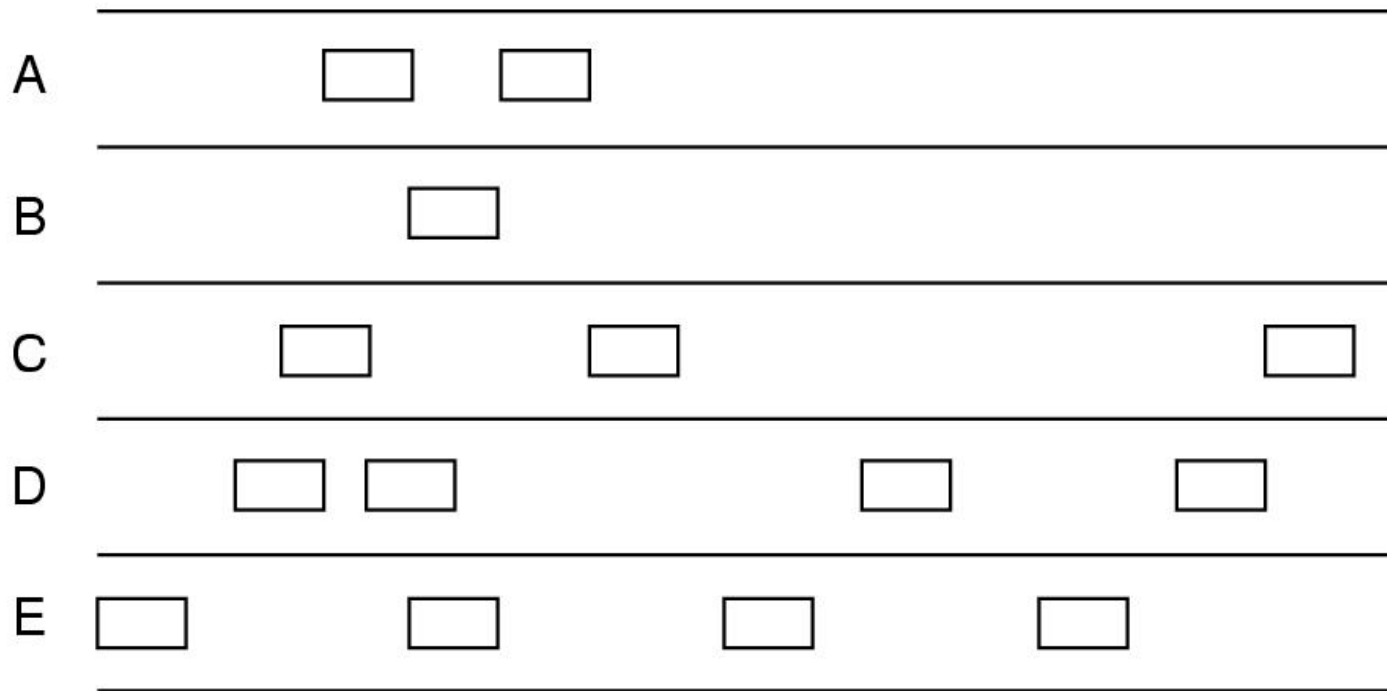
- Use of **orthogonal codes** to separate different transmissions
- Each symbol of bit is transmitted as a larger number of bits using the user specific code – Spreading
 - Bandwidth occupied by the signal is much larger than the information transmission rate
 - But all users use the same frequency band together





ALOHA

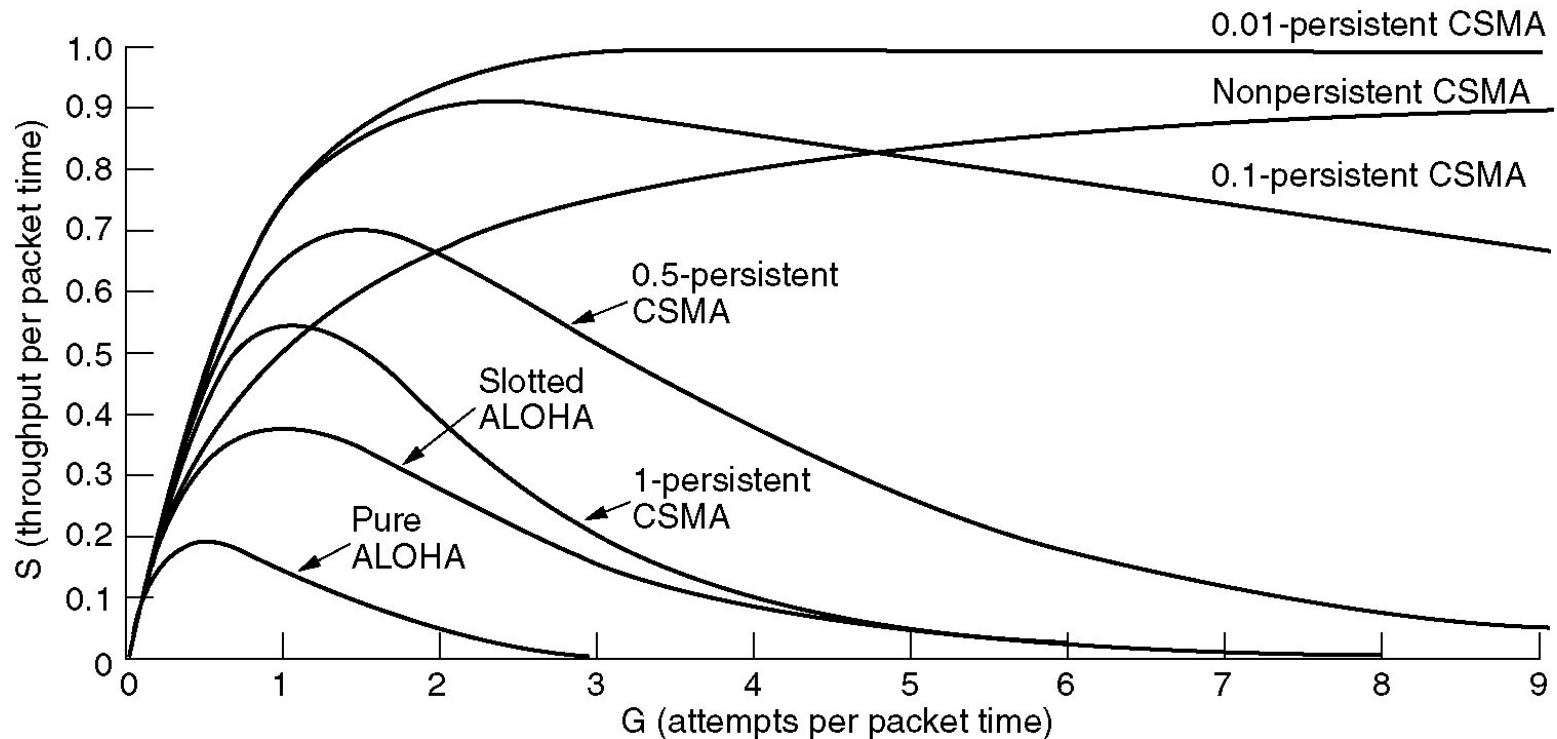
User



Time →



A comparison of simple protocols

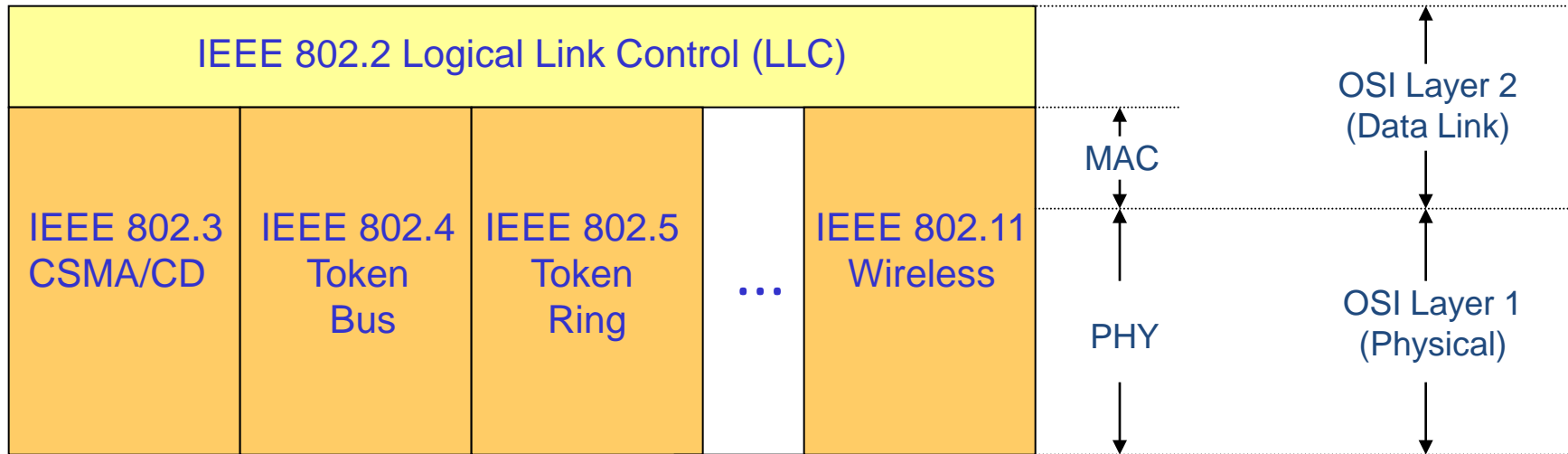




- Based on IEEE 802.11 standard and its amendments (a,b,g,n,...)
- Simple but efficient especially for light/medium traffic
- Cheap to implement and operate
- Constantly upgraded to be up to date
- Follows the evolution in wireless communications



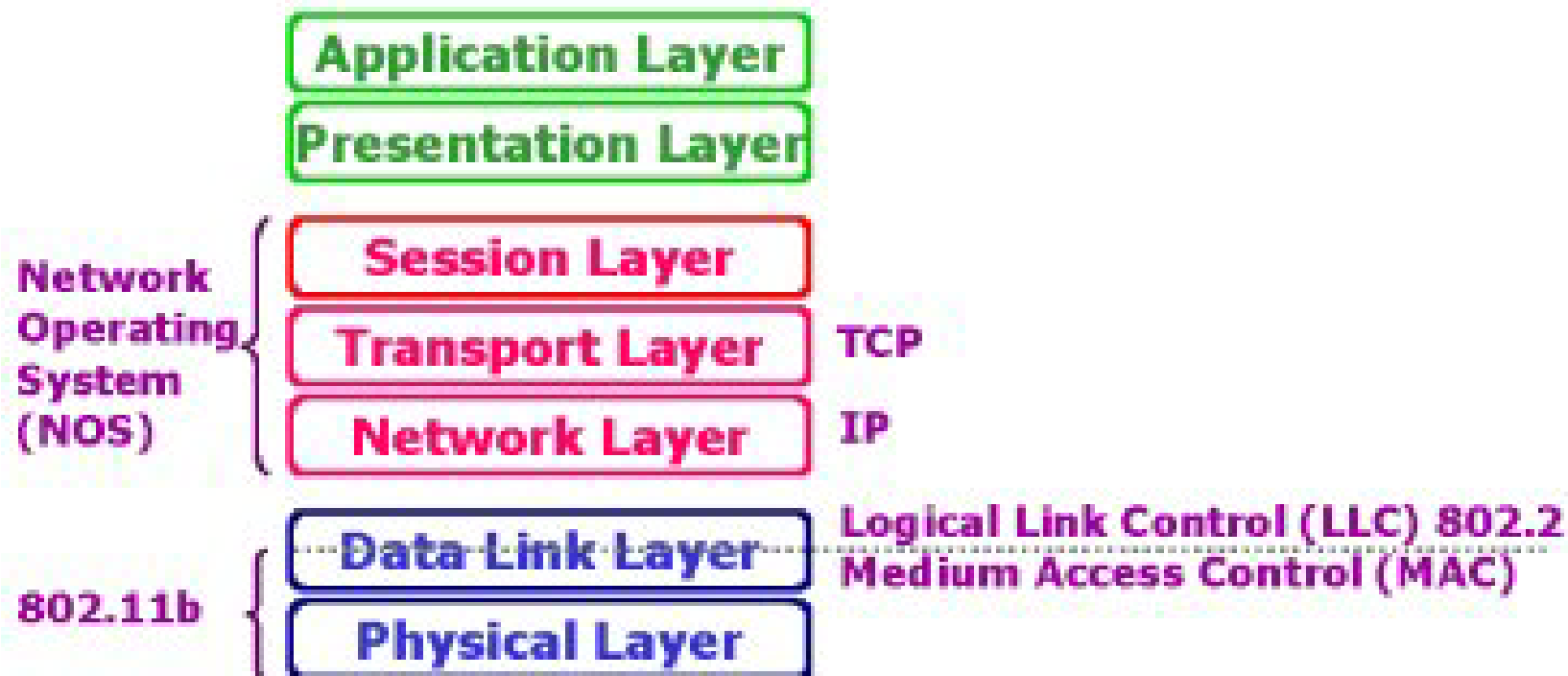
802.X Family of Standards





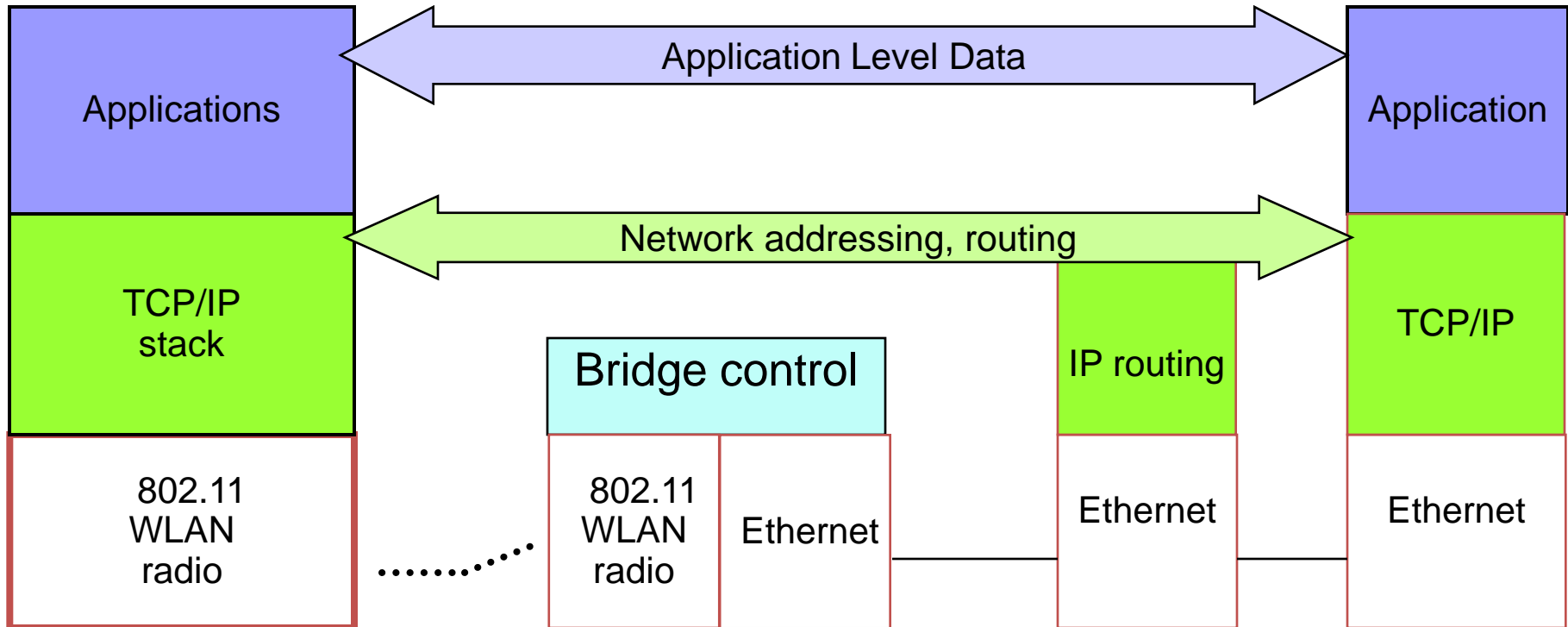
802.11 OSI Protocol Stack

OSI Reference Model





802.11 – Ethernet Wireless Extension





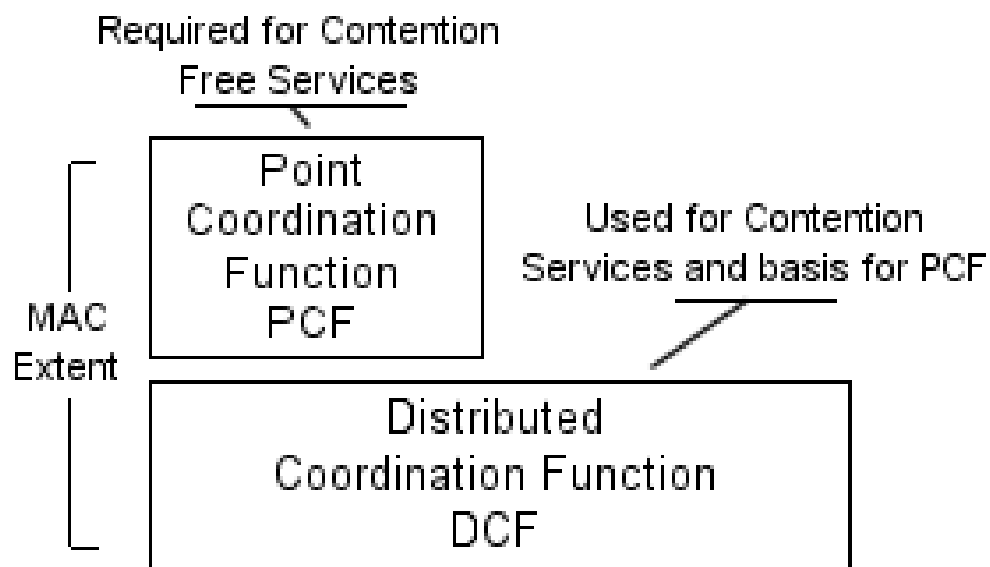
Access Modes

Distributed Coordination Function (DCF)

- Mandatory
- Basic access mode
- Contention-based

Point Coordination Function (PCF)

- Optional
- Contention-free
- Lower delay variance



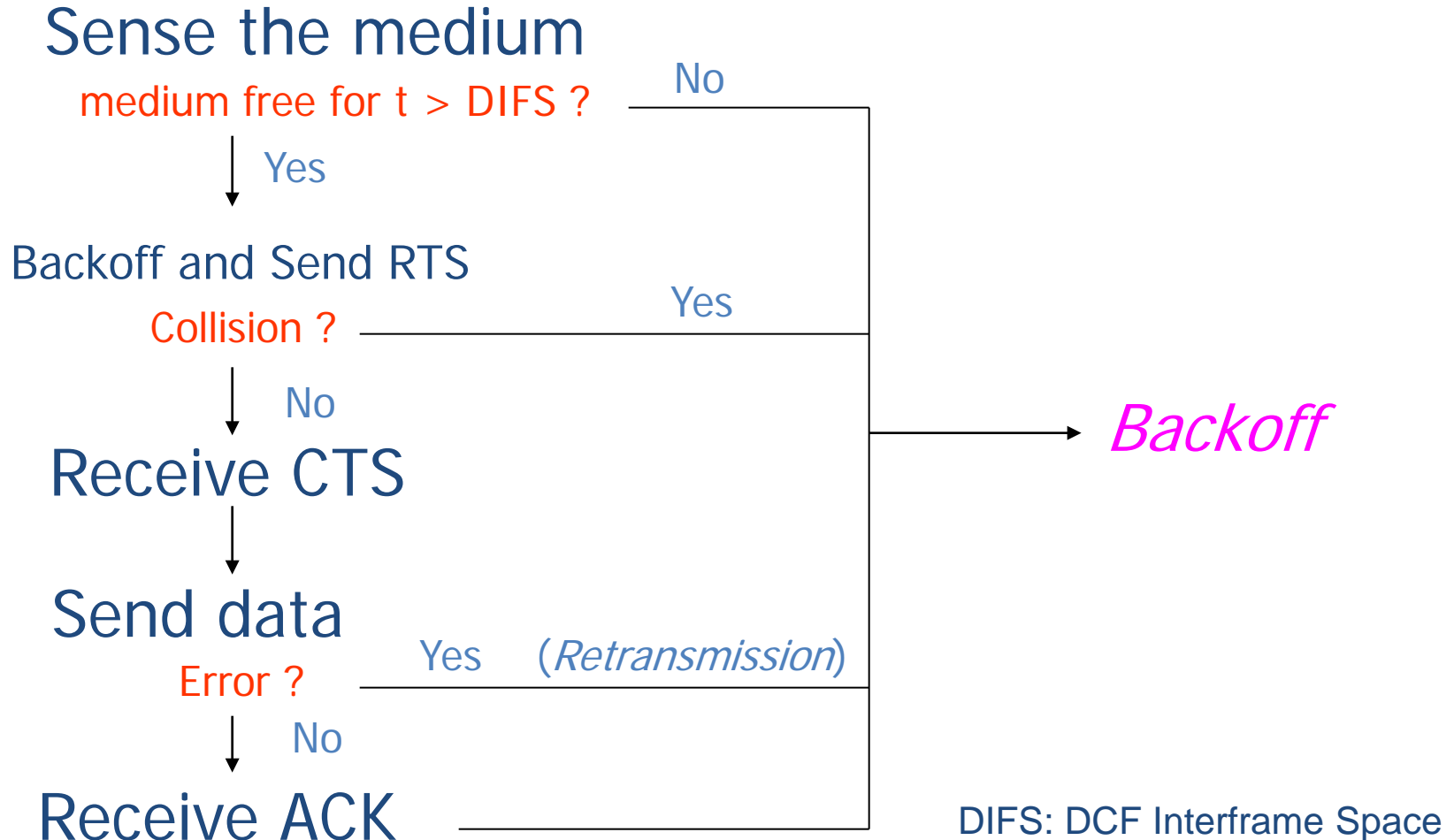


Distributed Coordination Function

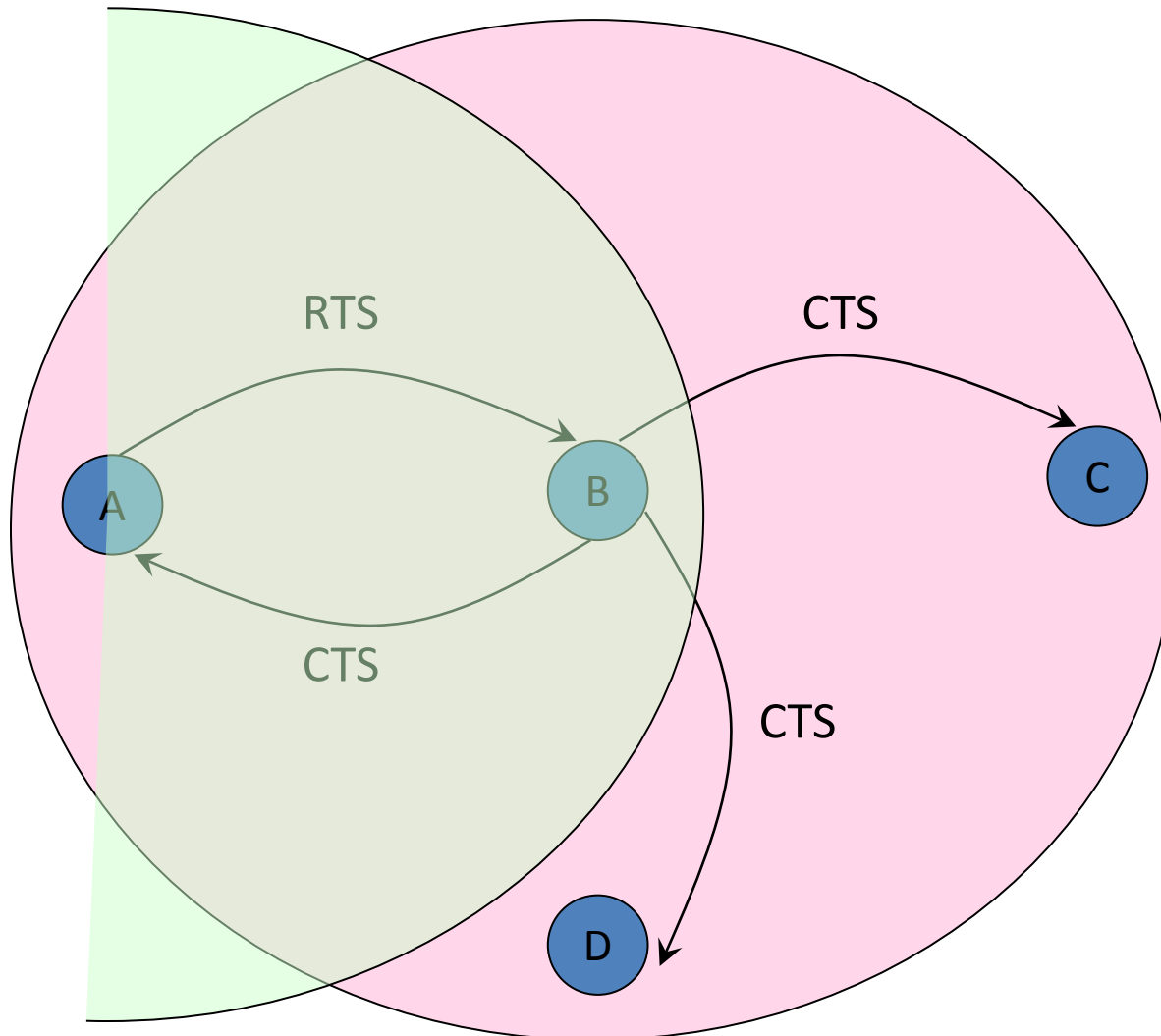
- CSMA/CA based protocol
 - Listen before talk
 - Collision Avoidance instead of Collision Detection
 - Different than CSMA/CD used in wired Ethernet (why ??)
- Uses acknowledgment for all transmission
- Data correction through retransmissions
- 4-way handshake (RTS/CTS/Data/Ack) for «Virtual Carrier Sensing»
- Handles hidden terminal problem

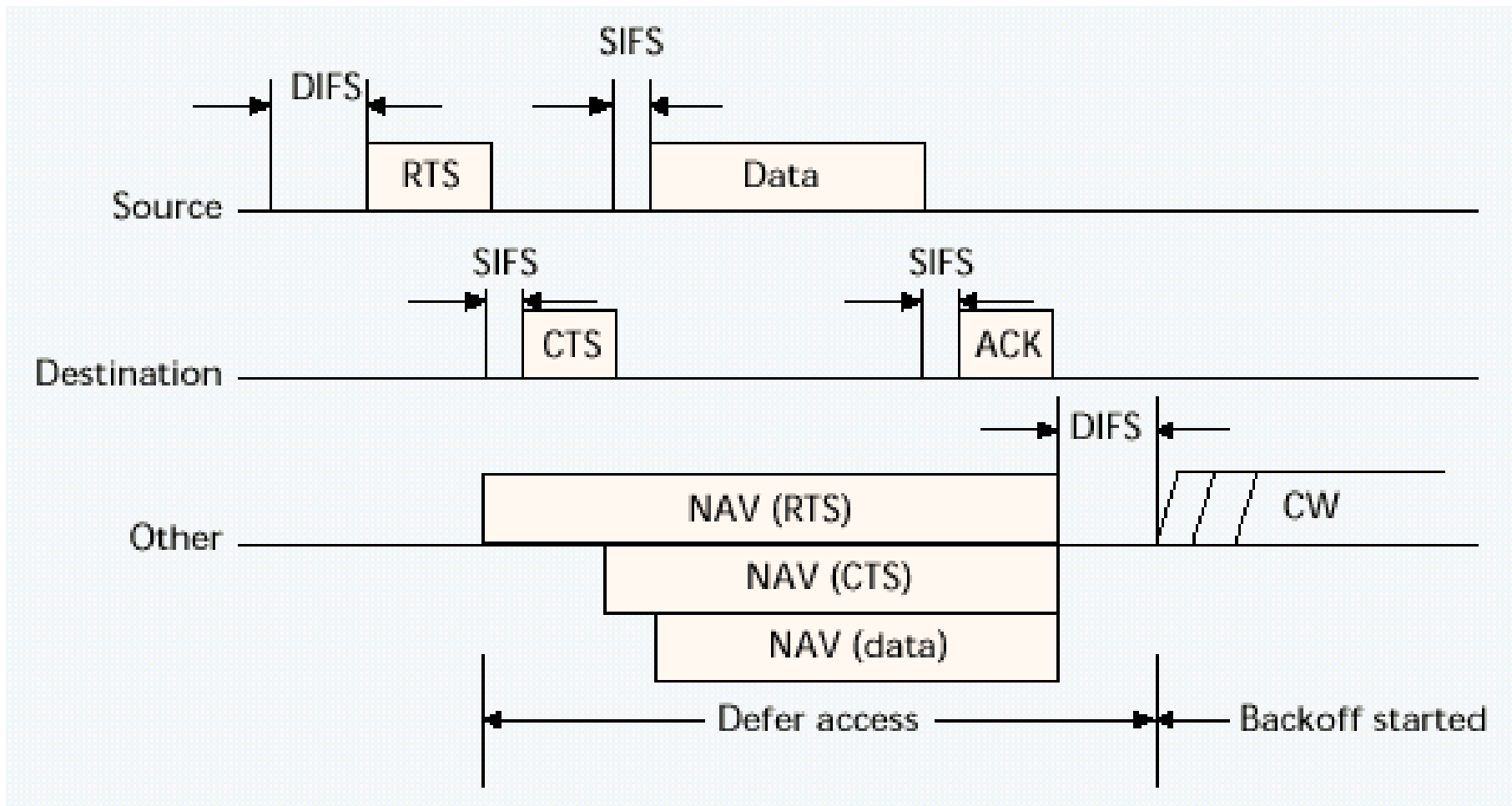


Distributed Coordination Function



Collision avoidance in node B

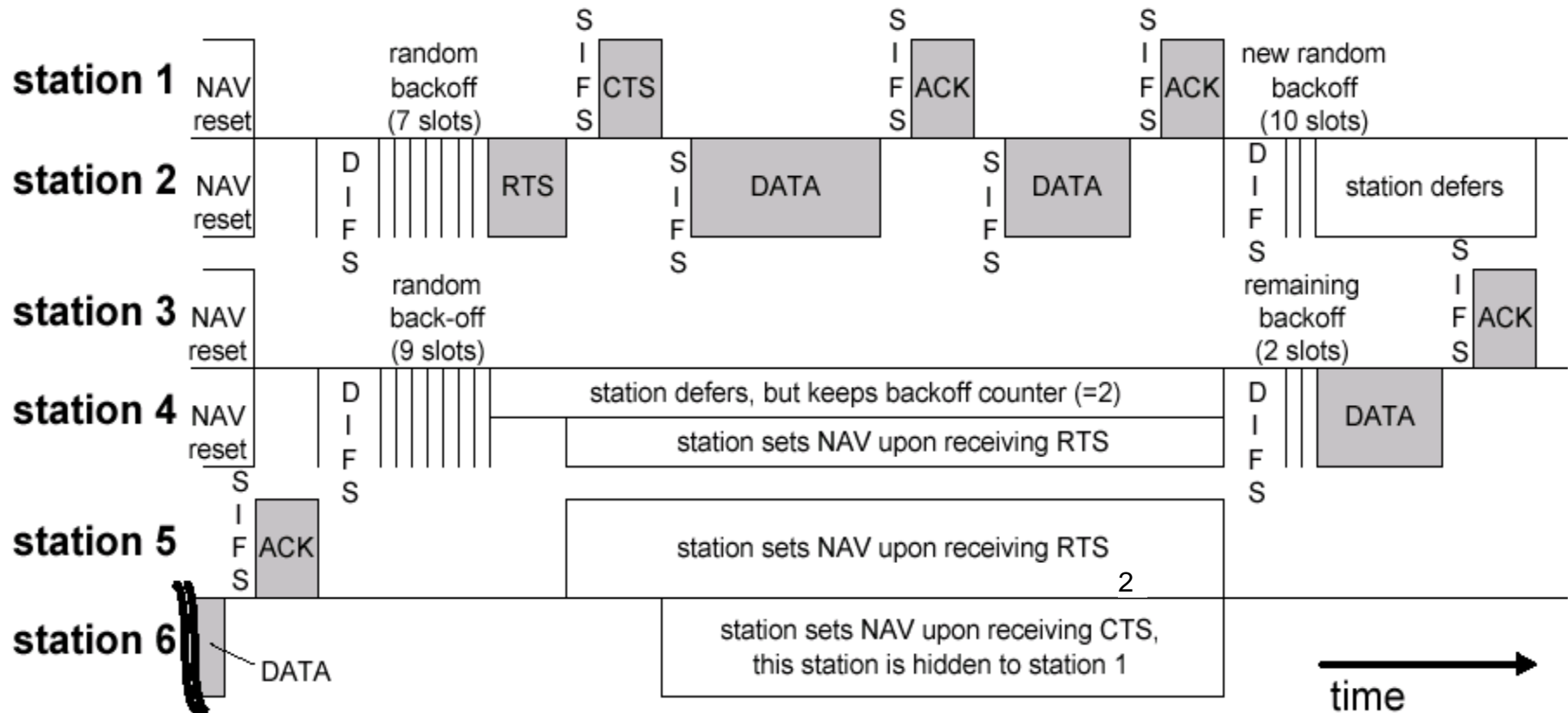




- Always $SIFS < DIFS$
- Power saving through the NAVs



Example of DCF Transmission





Disadvantages of DCF

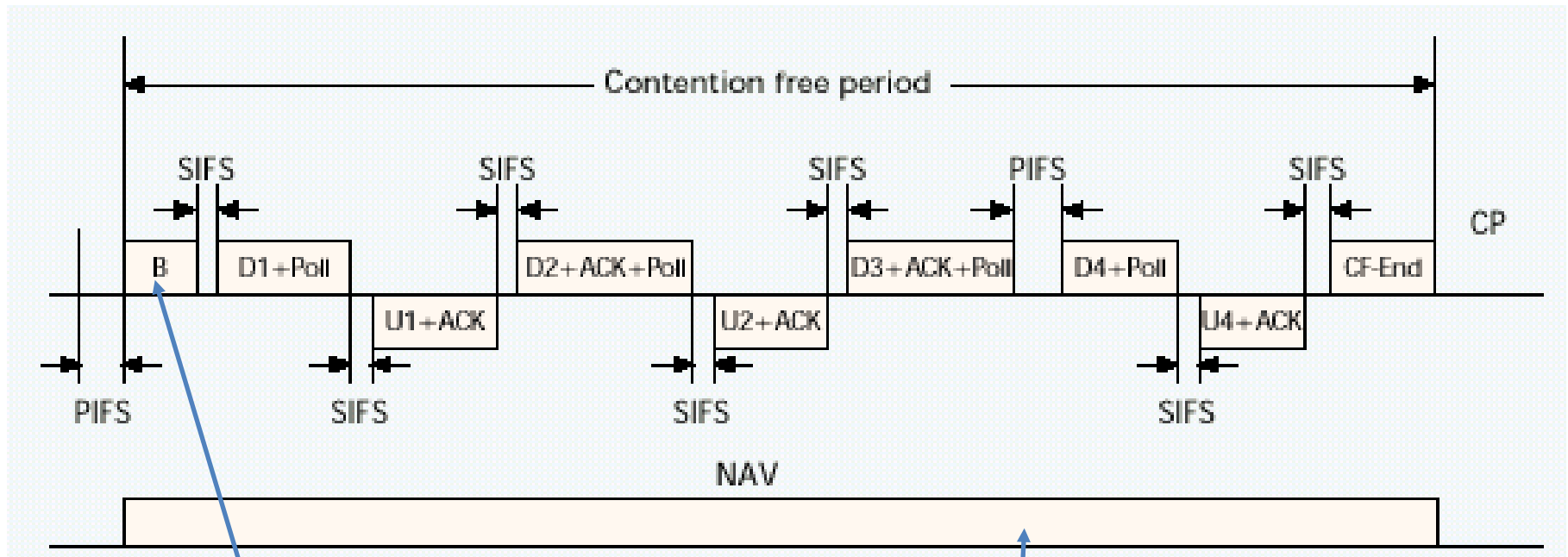
- Unpredictable number of **collisions**
- Unpredictable **delays**
- Unpredictable **throughput**
- Equal opportunities for transmission (**no priorities**)

And one advantage

- Low delays and good performance in **light traffic** load conditions



Point Coordination Function



Synchronization beacon

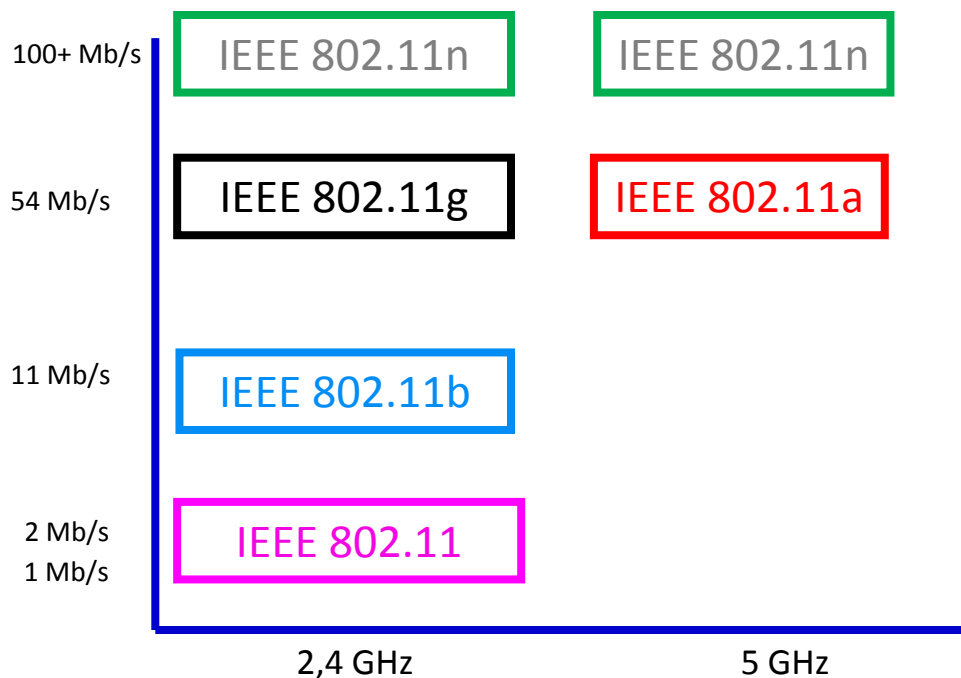
Variable duration of
Contention Free Period



Disadvantages of PCF for QoS

- ✓ Terminals cannot transmit their **requirements** to the AP
- ✓ The AP cannot **stop a transmission** to transmit the synchronization beacon *
- ✓ Polling does not include **time to reserve** the channel *

* Maximum packet (MPDU) allowed 4095 bytes = 32760 bits
= 32,76 msec (για κανάλι 1Mbps)



	802.11a	802.11b	802.11g	802.11n
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS	OFDM	OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of spatial streams (MIMO)	1	1	1	1 to 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

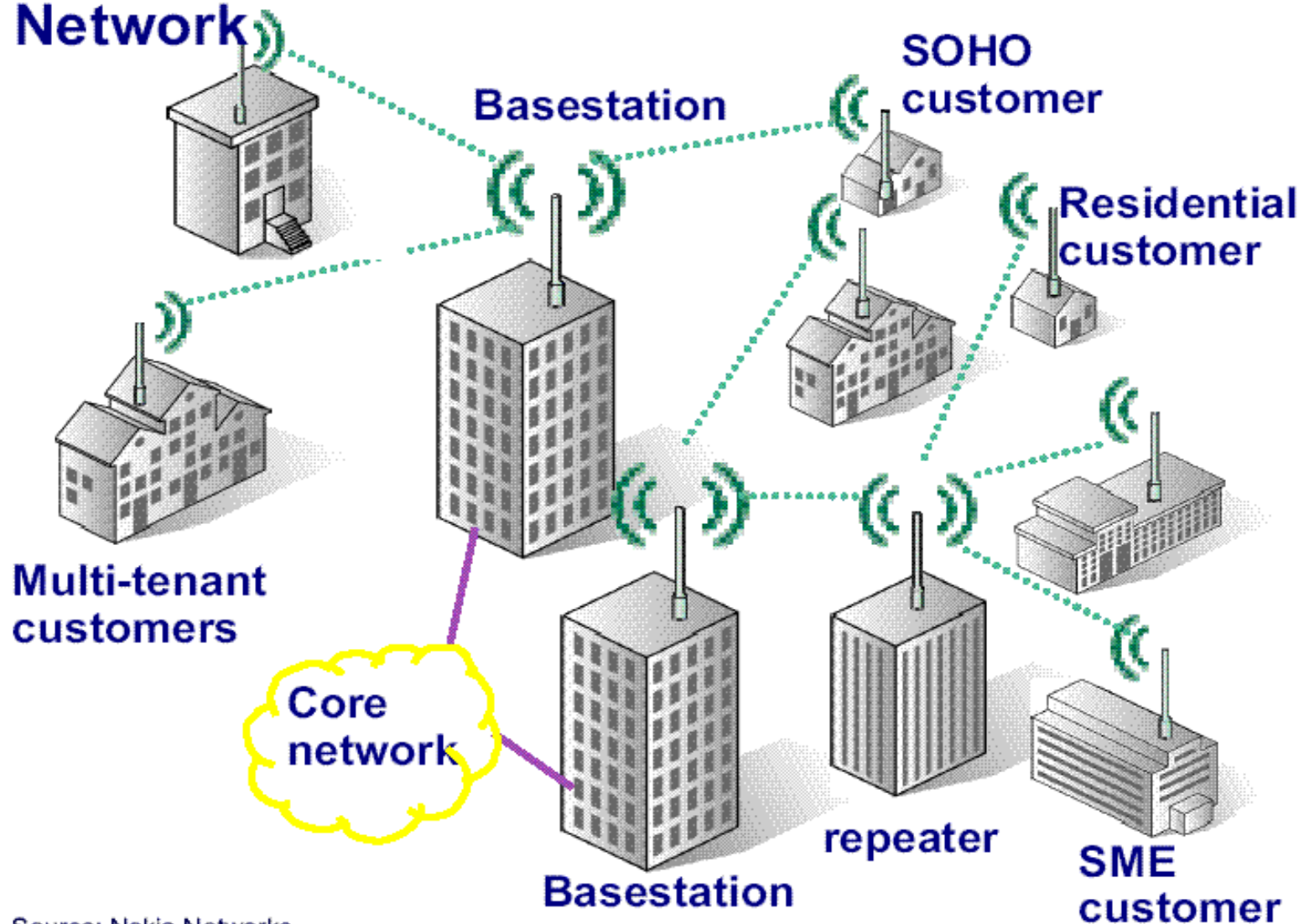


IEEE 802.16 WiMaX

"Air Interface for Fixed Broadband
Wireless Access Systems"

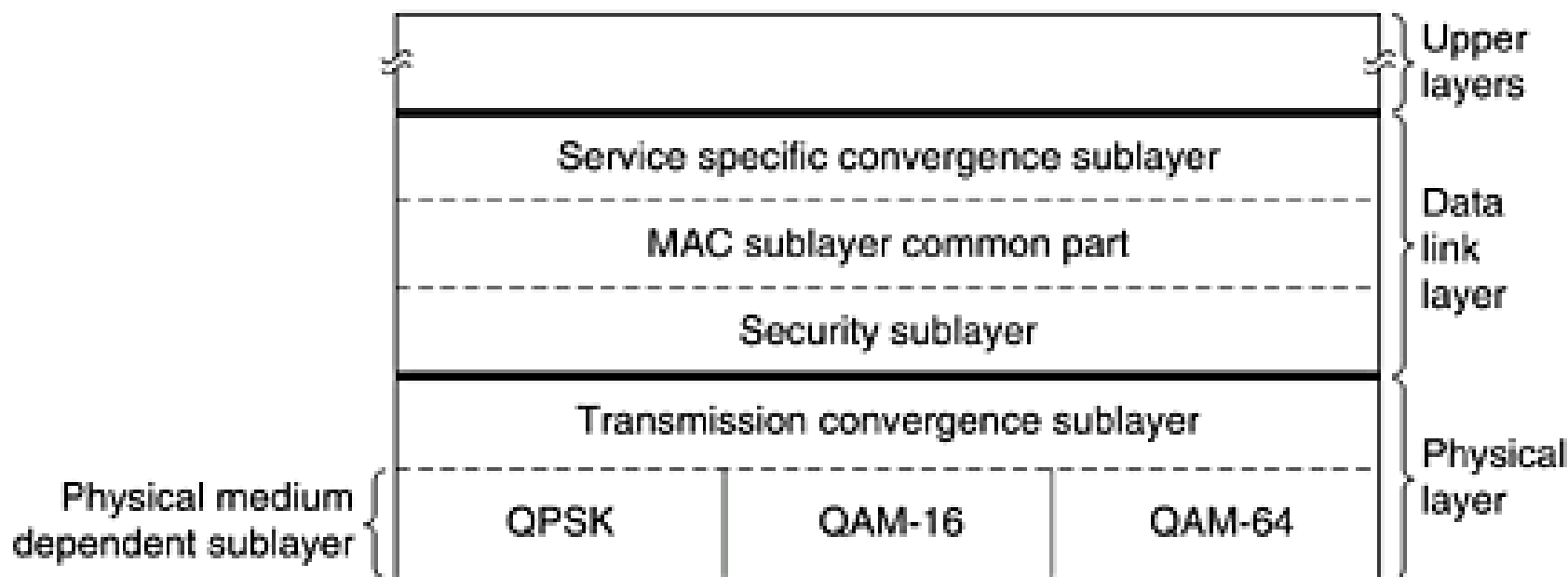


WirelessMAN: Wireless Metropolitan Area Network



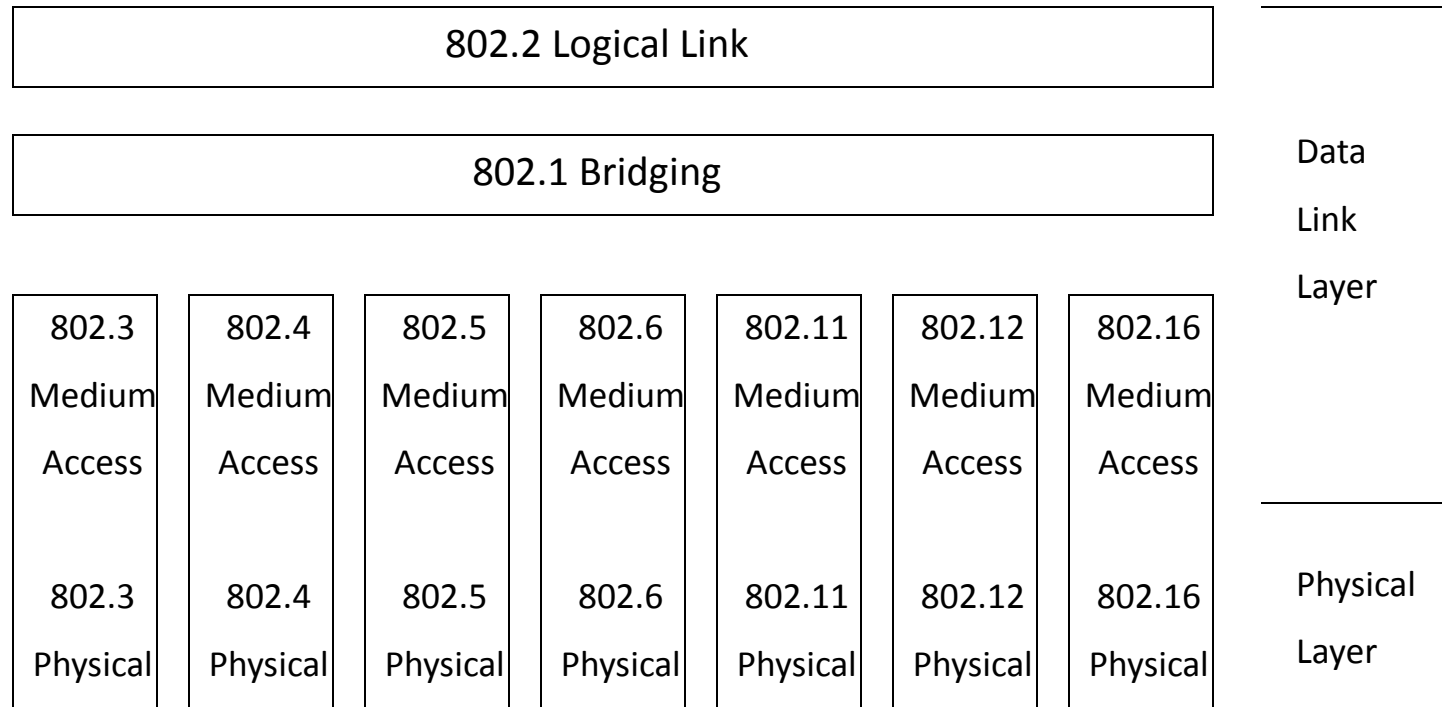
Source: Nokia Networks

WiMaX Layers



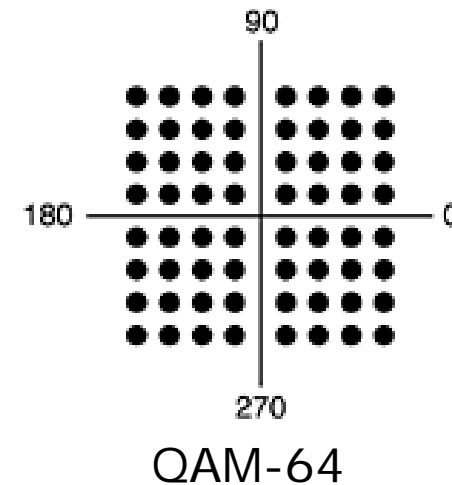
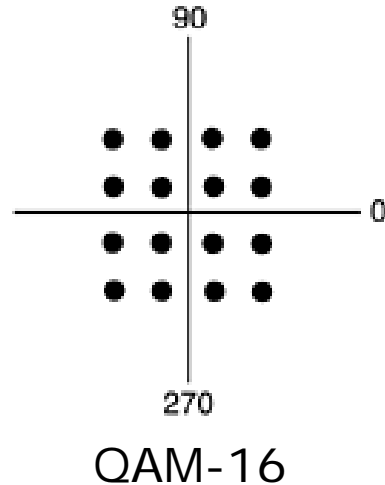
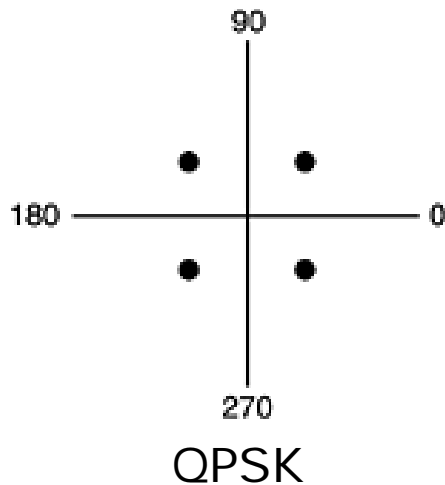


The 802 Family

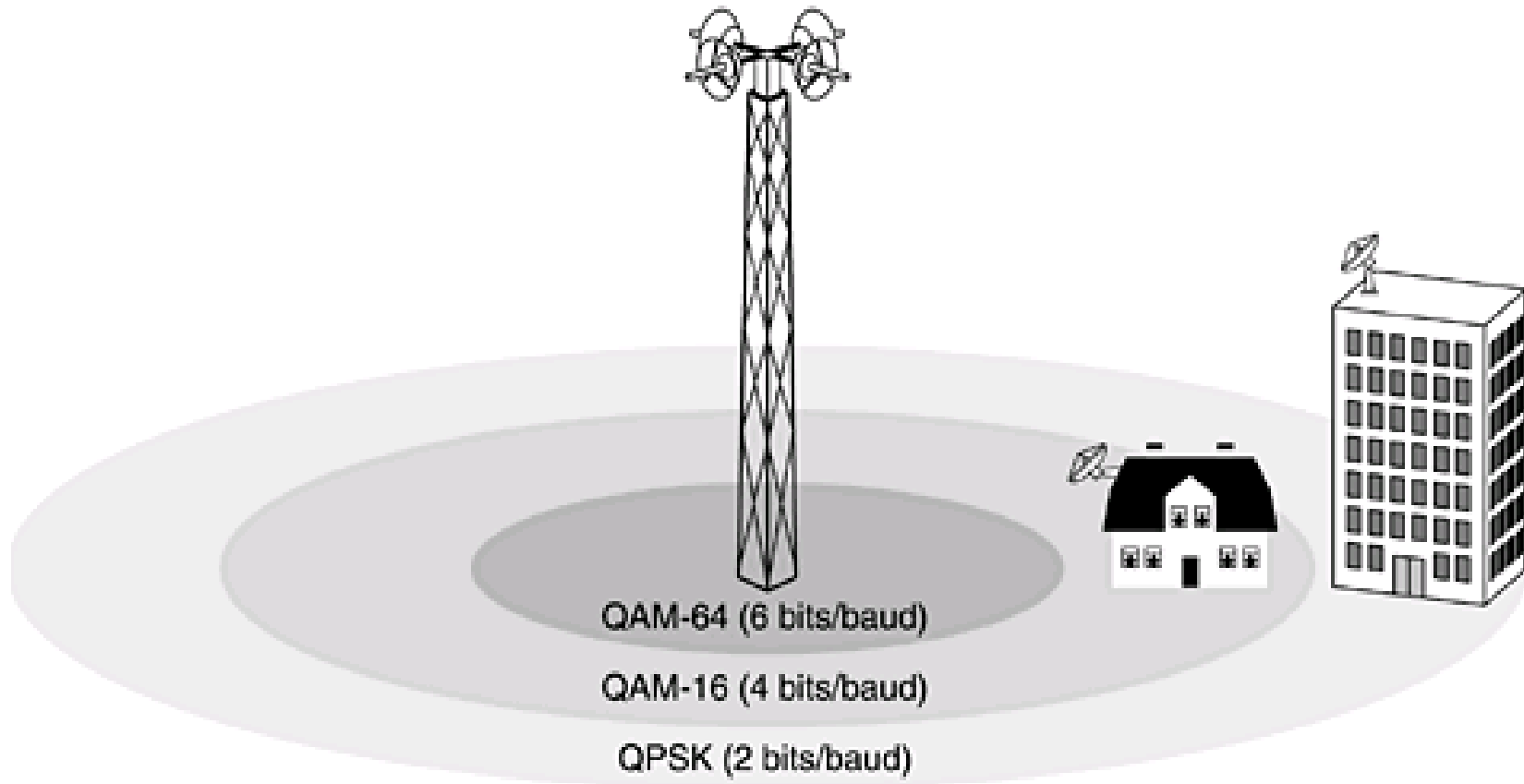


Multiple modulations

- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



Adaptive modulation



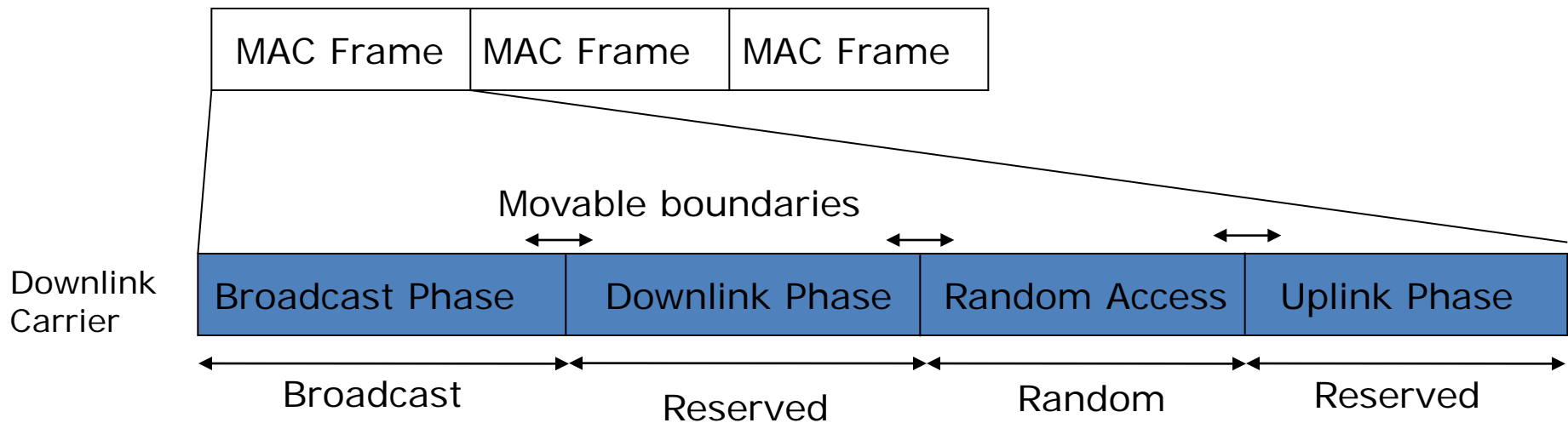


Adaptive modulation in WiMaX

Modulation	FEC Coding Rate	<u>Uncoded</u> Burst Rate (Mbps)	End to End Ethernet Throughput (Mbps)
BPSK	$\frac{1}{2}$	6	5.7
BPSK	$\frac{3}{4}$	9	8.6
QPSK	$\frac{1}{2}$	12	11.4
QPSK	$\frac{3}{4}$	18	17
16QAM	$\frac{1}{2}$	24	22.4
16QAM	$\frac{3}{4}$	36	33
64QAM	$\frac{2}{3}$	48	43.2
64QAM	$\frac{3}{4}$	54	48.1



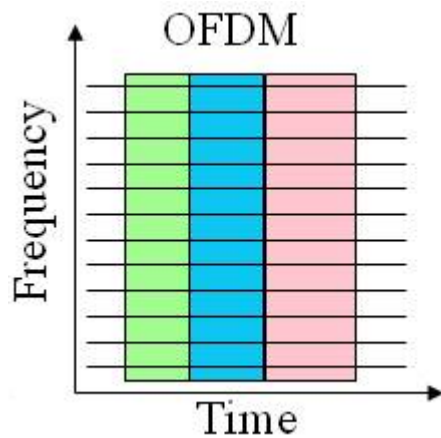
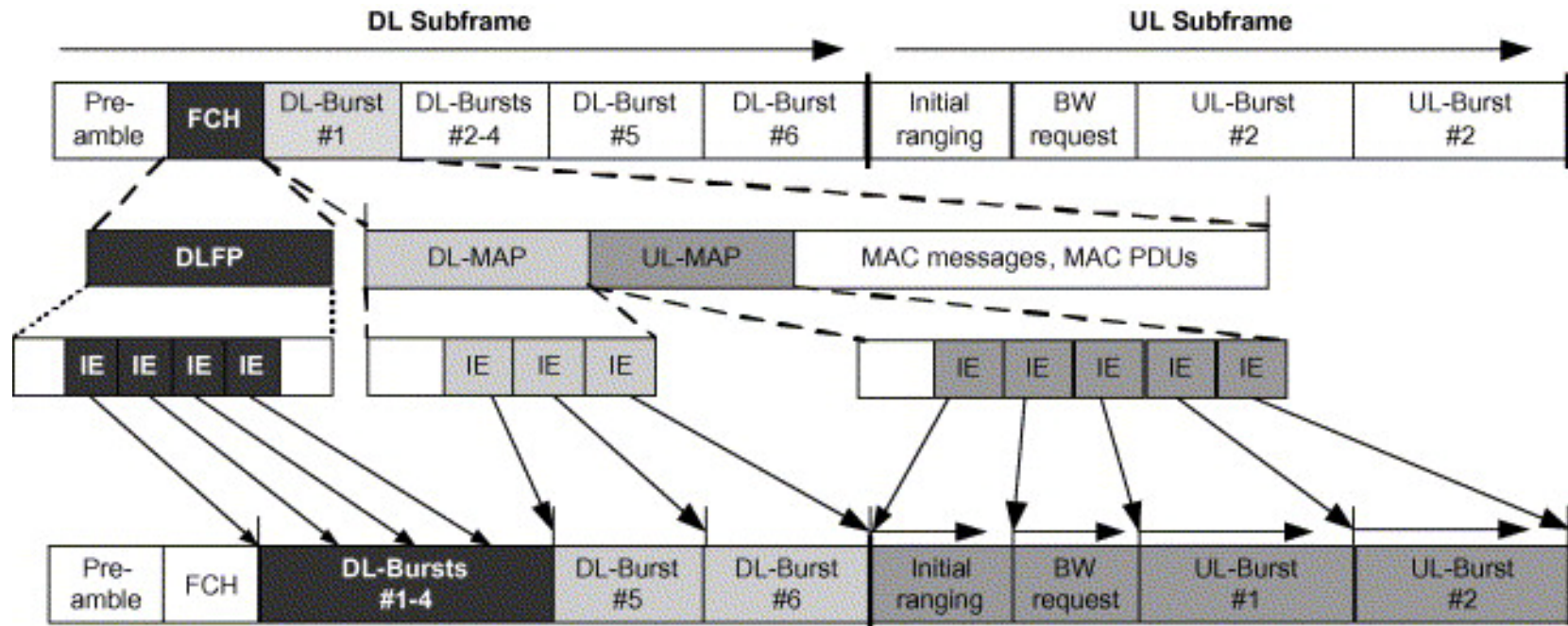
Time Division Duplexing (TDD)





Media Access Control (MAC)

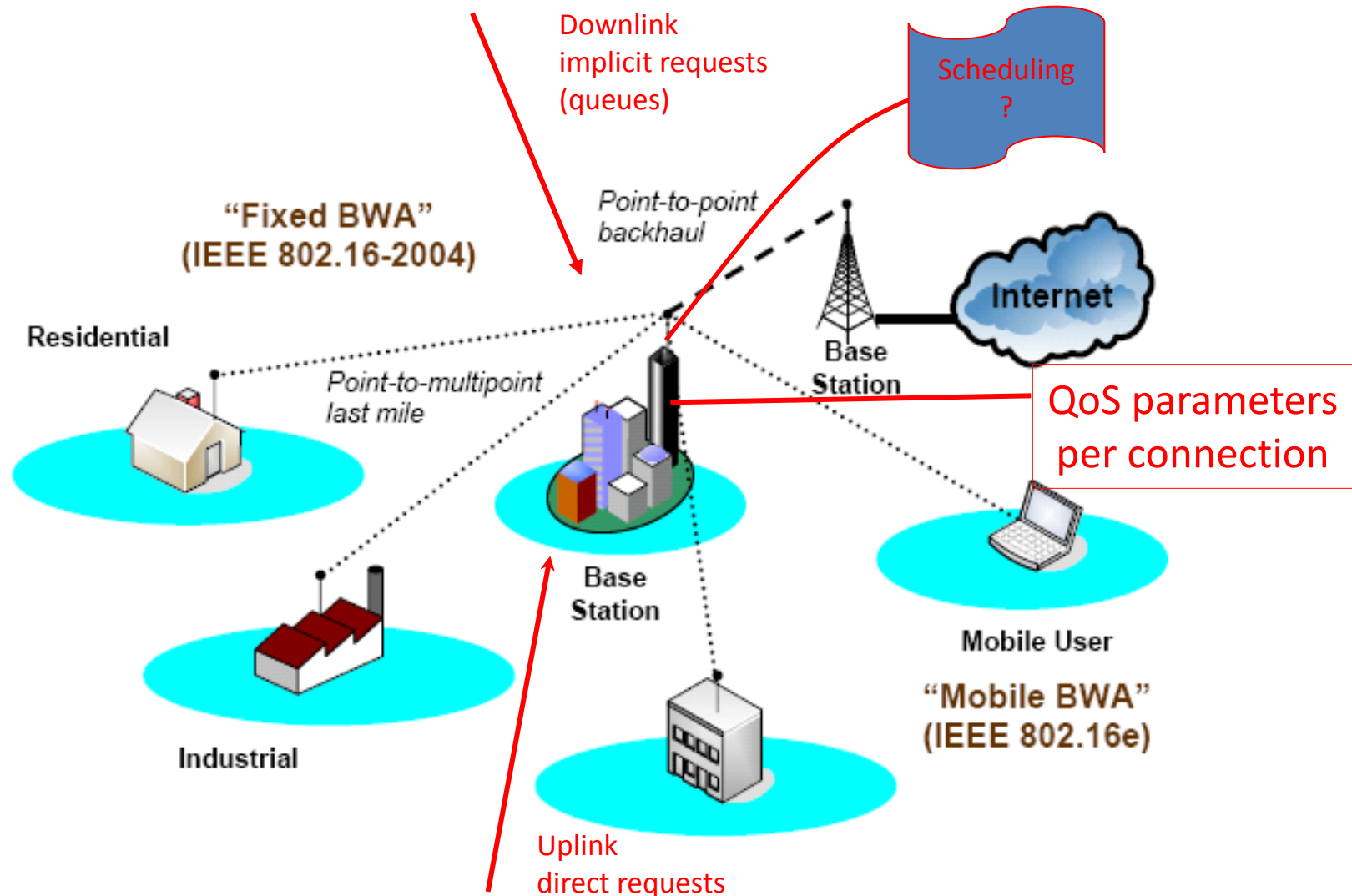
- Connection oriented μετάδοση
 - Connection ID (CID)
 - Uni-directional
- Channel access:
 - UL-MAP
 - Includes reservation information for the uplink
 - Who transmits (to the Base Station) and when
 - DL-MAP
 - Includes reservation information for the downlink
 - Who receives (from the Base Station) and when
 - UL-MAP and DL-MAP are transmitted at the beginning of each time frame (broadcasting).



QoS - Priorities
Uplink → problem ?



Bandwidth request and allocation





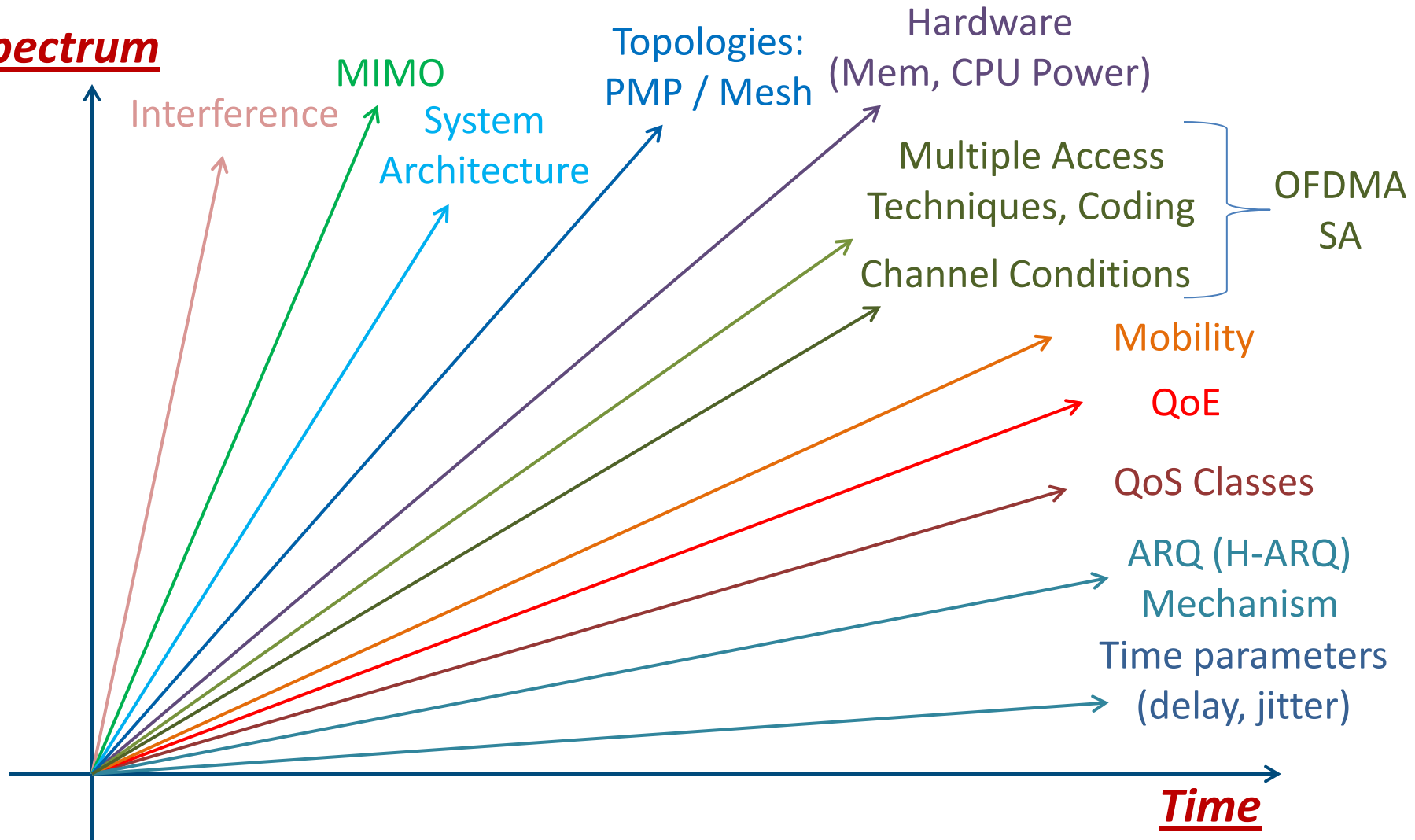
Extensions in 802.16e

- Mobility support
- Orthogonal time division multiple access (OFDMA)



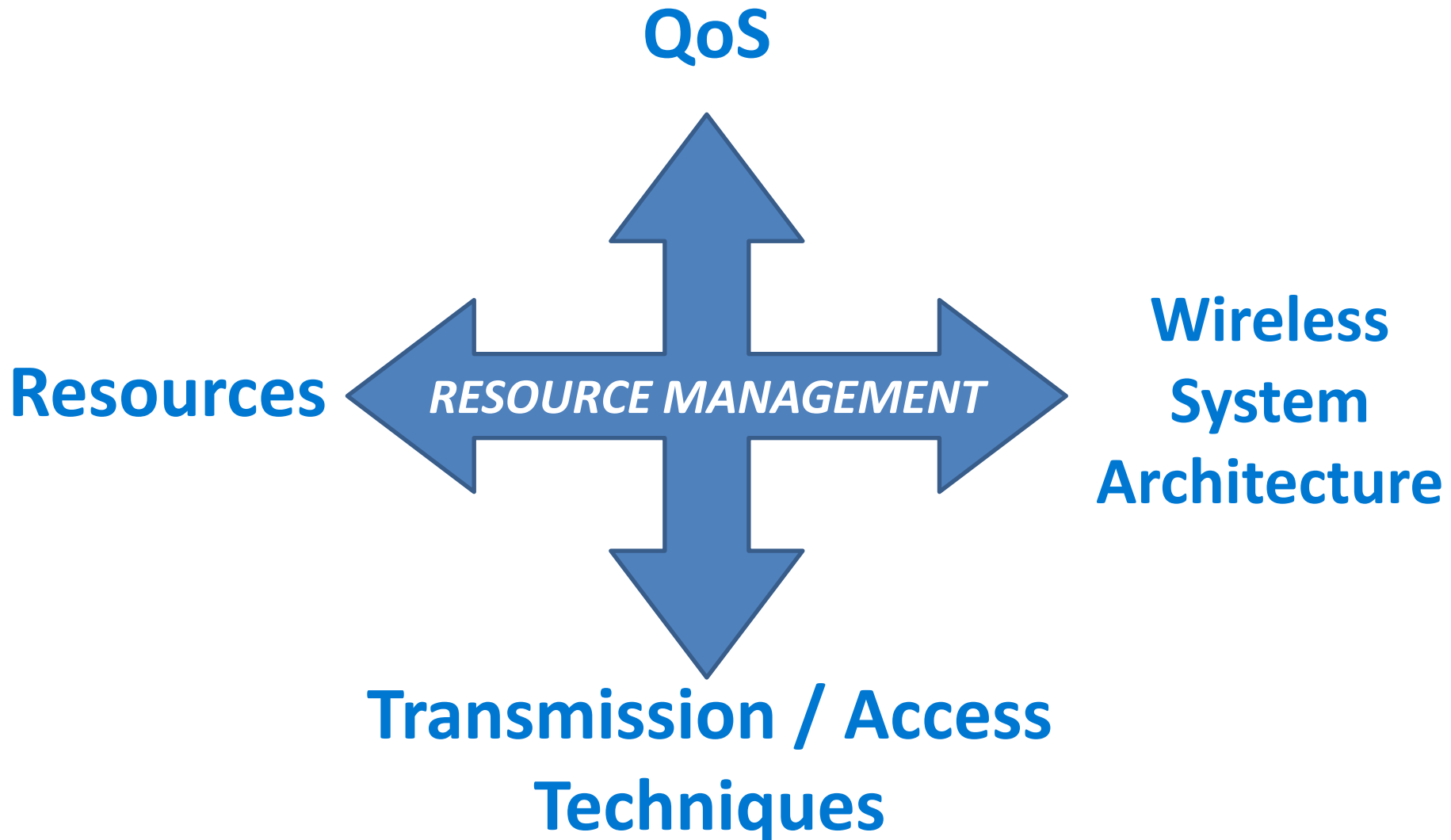
Dimensionize Resource Management

Spectrum





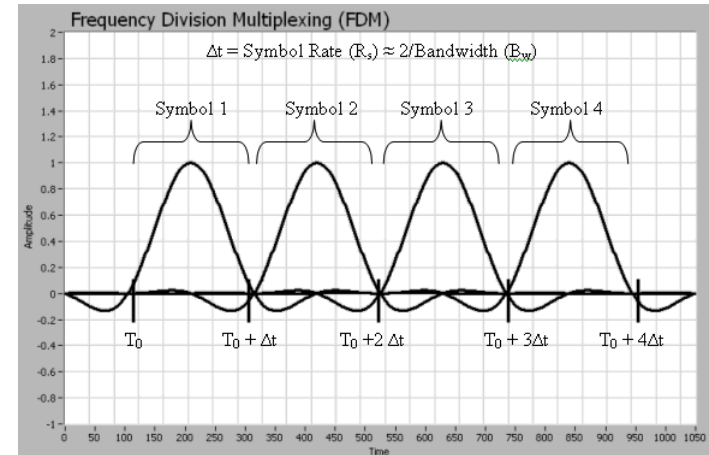
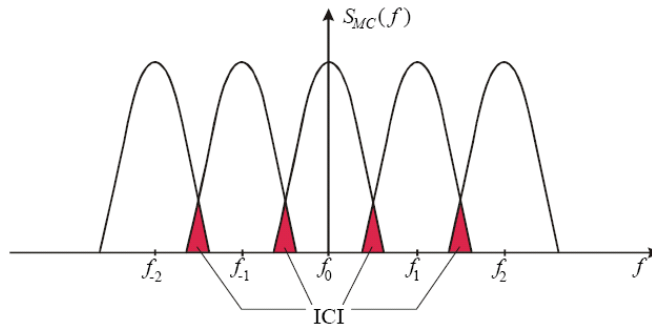
Scheduler/RA's role



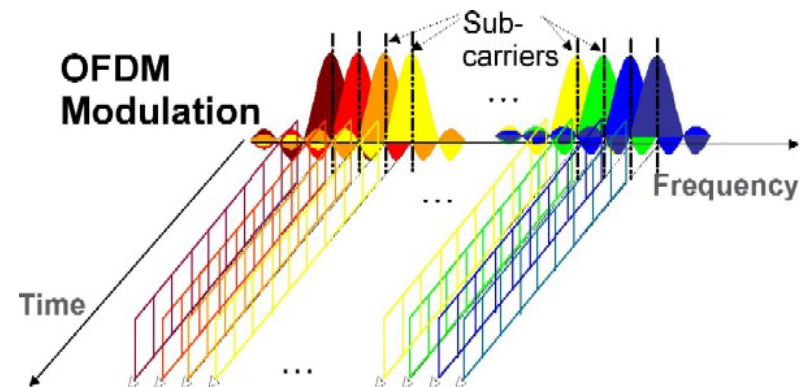
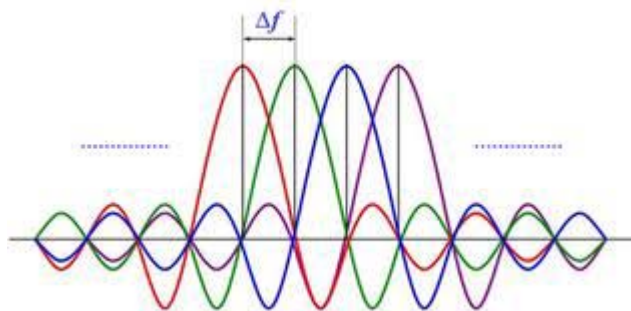


OFDM: Orthogonal Frequency Division Multiplexing

Traditional FDM



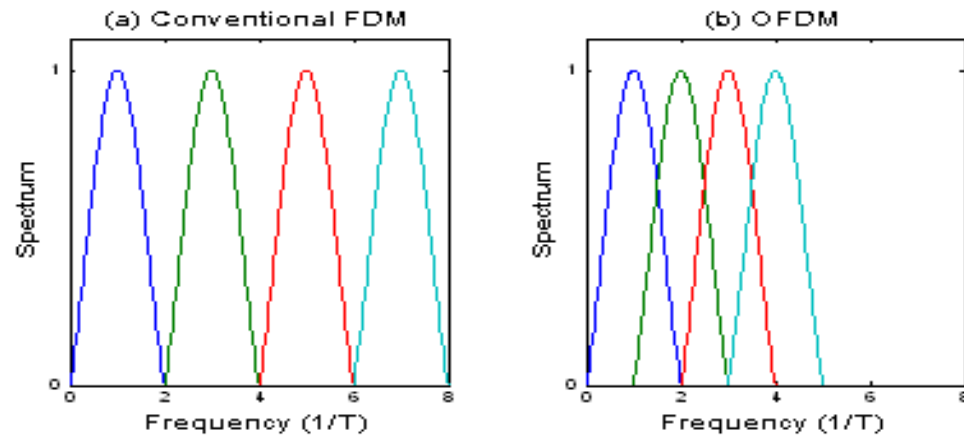
OFDM



OFDM pros and cons

Pros

- Spectral **efficiency**
- **Robust** against narrow-band co-channel **interference**
- Higher **throughput** in the same frequency band (more subcarriers)

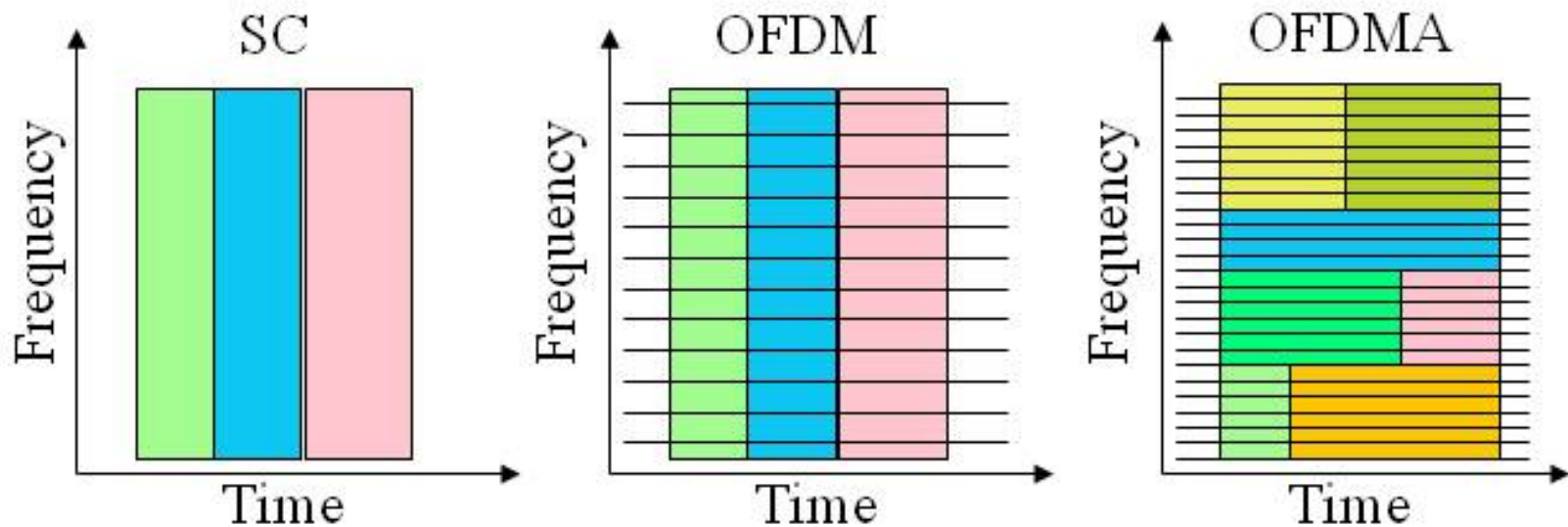


Cons

- It is more sensitive to **carrier frequency offsets**
- More **energy requirements** due to high peak-to-average power ratio (PAPR)

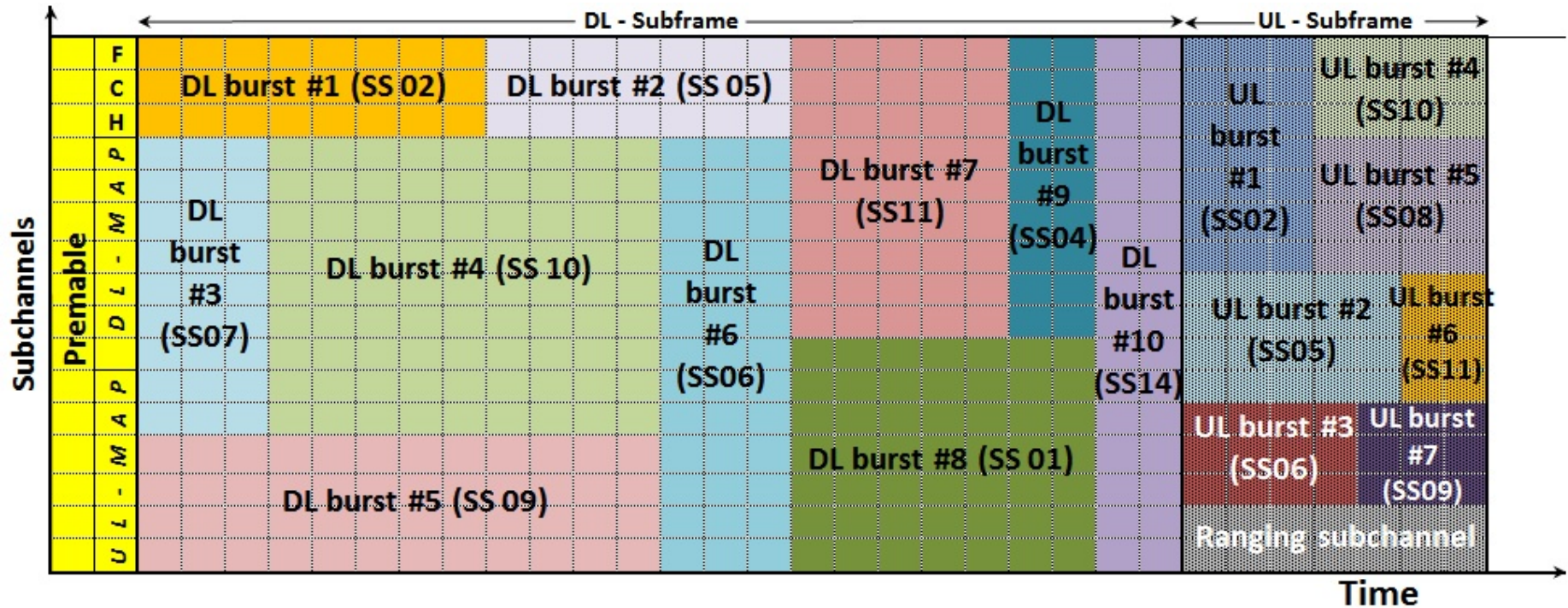


SC/OFDM/OFDMA



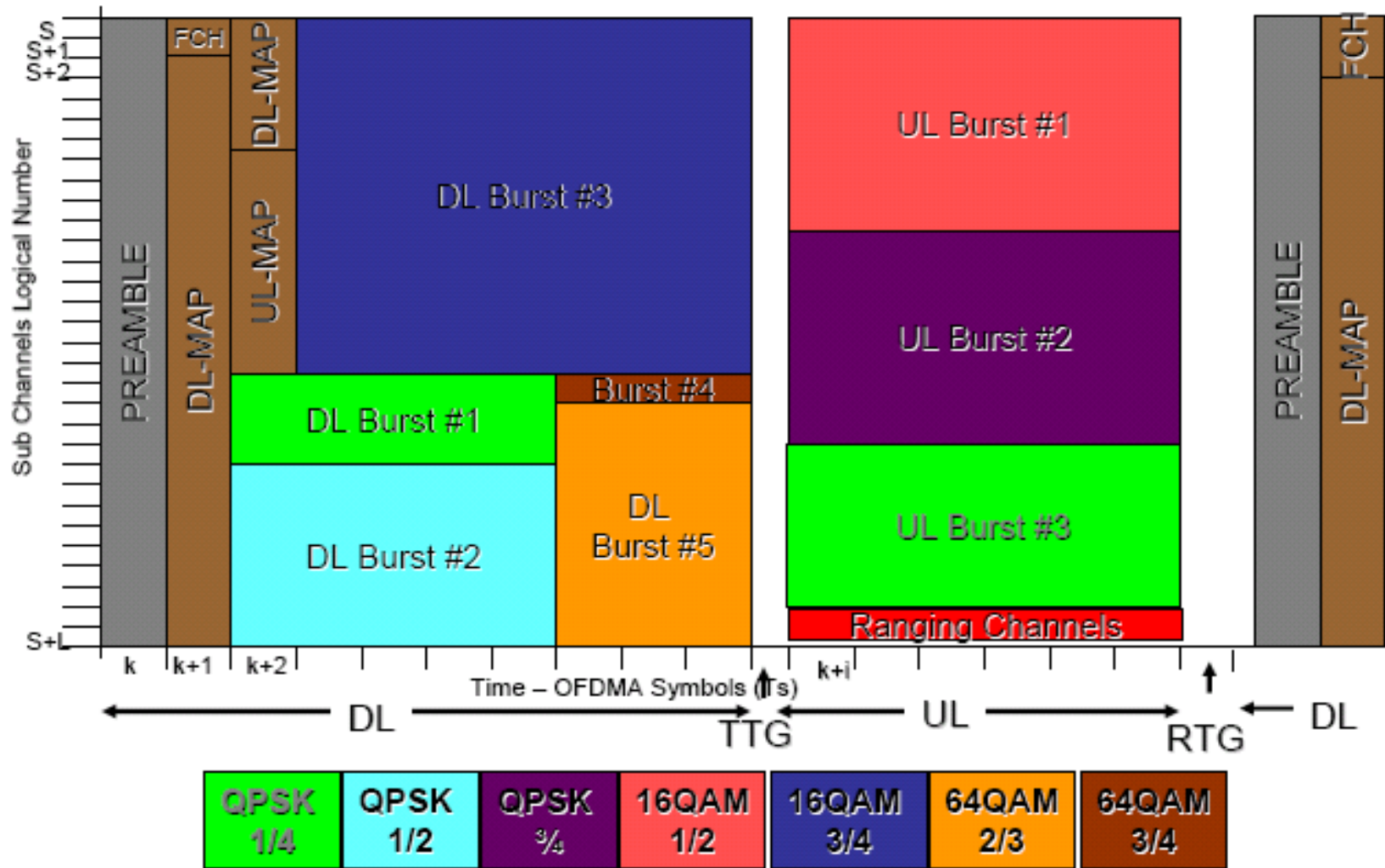


OFDMA/TDD structure





OFDMA/TDD structure





Advantages of OFDMA

- More **flexible allocation** of the available spectrum.
- Avoid transmission in **low quality carriers** (e.g., due to interference).
- **Lower maximum transmission power** for users.
- Higher overall **throughput**.
- Allows **simultaneous transmissions** from several users.
- Lower **delay variance**.
- Averaging interferences from **neighboring cells**, by using different carriers when possible.

Disadvantage

- Considerably **complex** in design and implementation



Thank you for your attention

