Προηγμένα Θέματα Ασύρματων και Κινητών Δικτύων

Διδάσκοντες

Νίκος Πασσάς (passas@di.uoa.gr)

Σπύρος Ξεργιάς (xergias@di.uoa.gr)

Δομή Μαθήματος

- Εξελίξεις στο σχεδιασμό και την υλοποίηση κινητών δικτύων 4ης 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)

Metropolital 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

Guglielmo Marconi 1874-1937

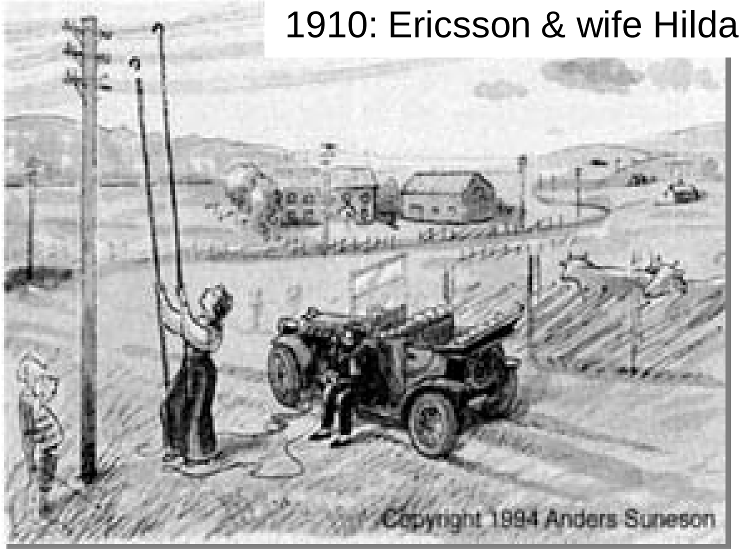
- First radio 1897

Reginald Fessenden 1866-1932

- Voice transmission over radio 1906

Mobile Communications at the beginning of the 20th century

1910: Ericsson & wife Hilda



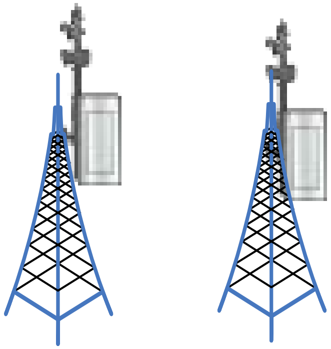
1924: First mobile radio telephone

Courtesy of Rich Howard

Cellular Networks Impact our Lives

More Mobile Connection

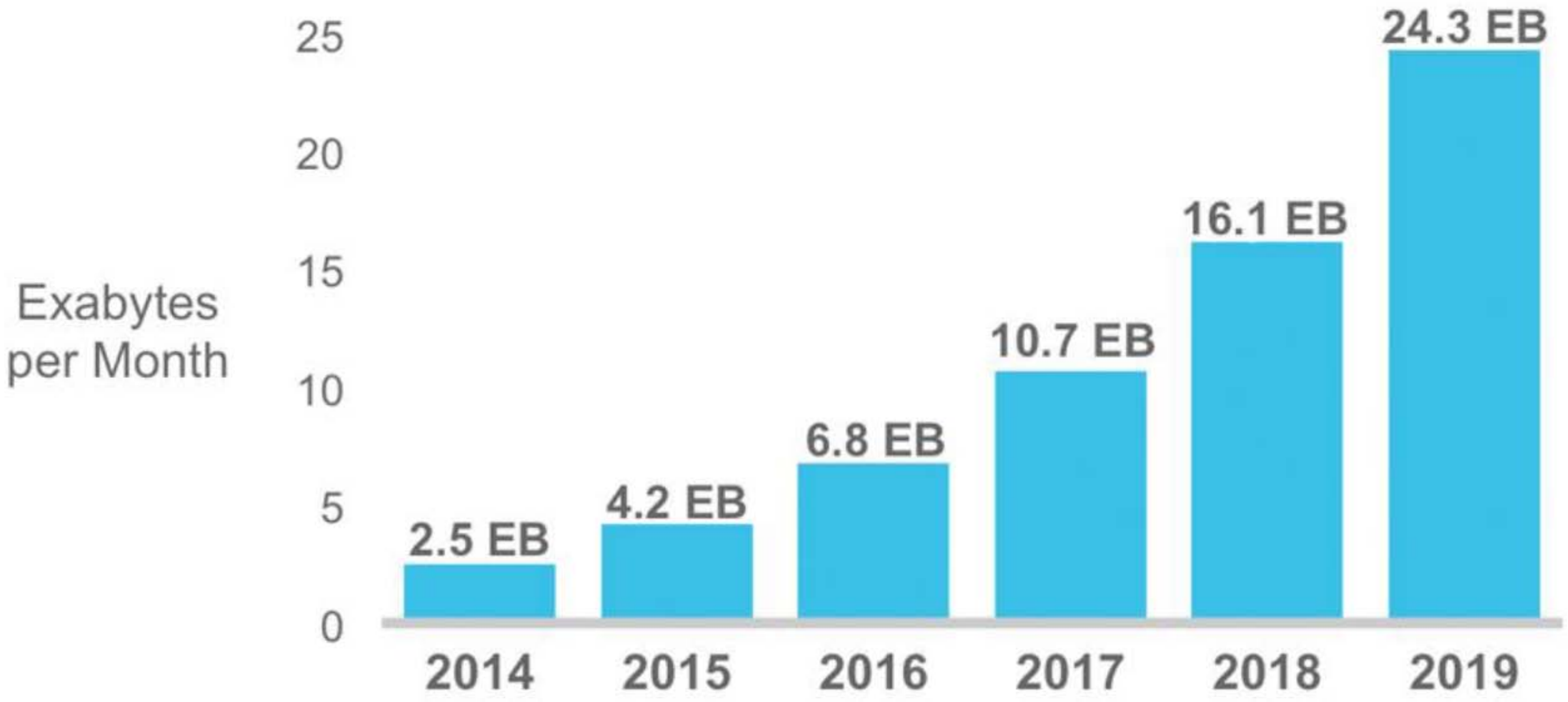
More Infrastructure Deployment



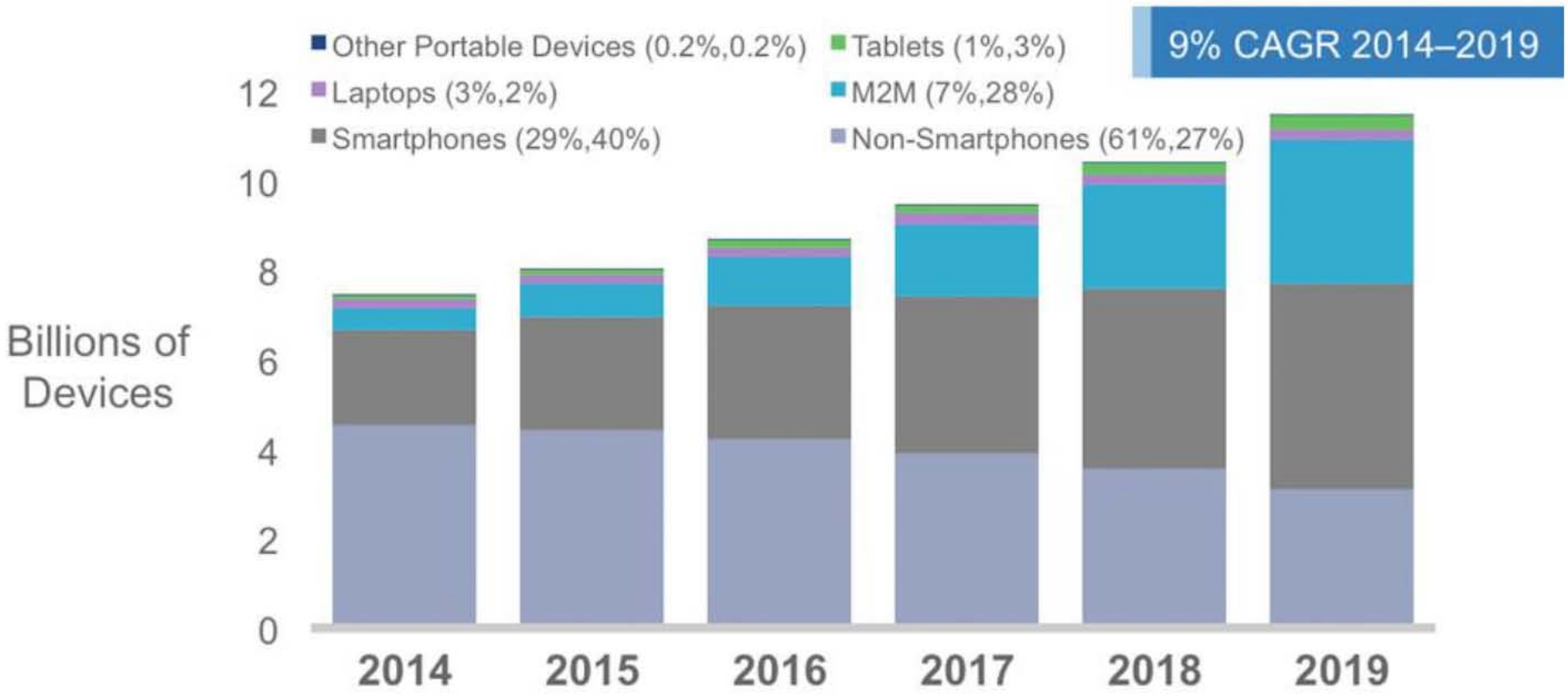
More Mobile Users

More Mobile Information Sharing

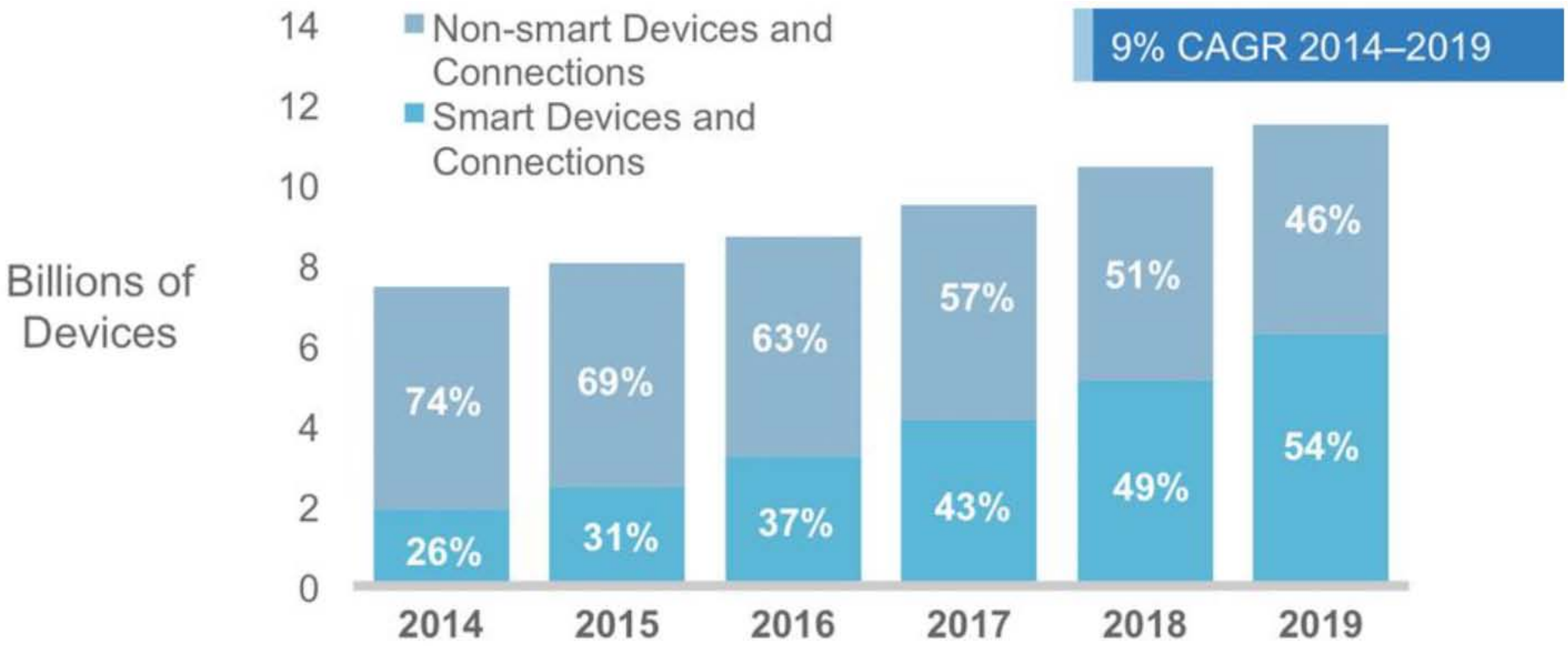
Exabytes per Month of Mobile Data Traffic



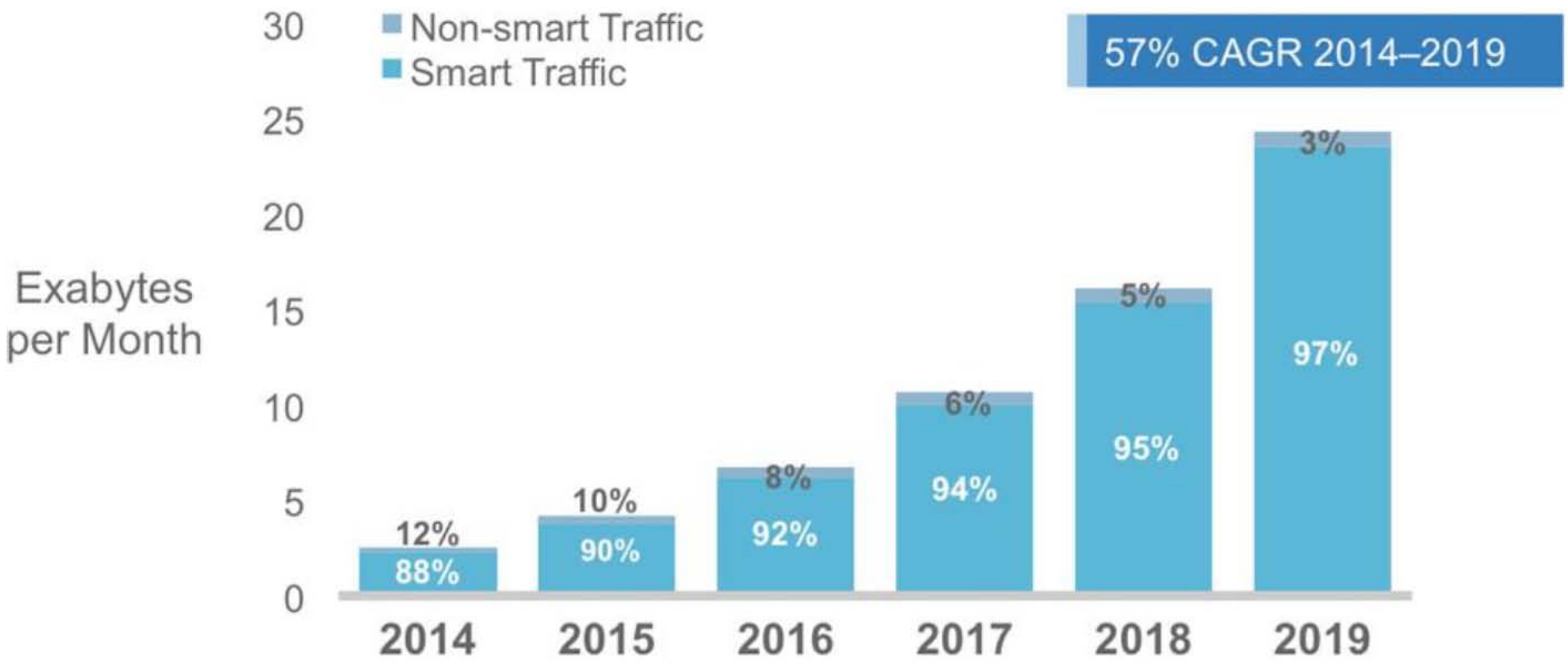
Global mobile devices



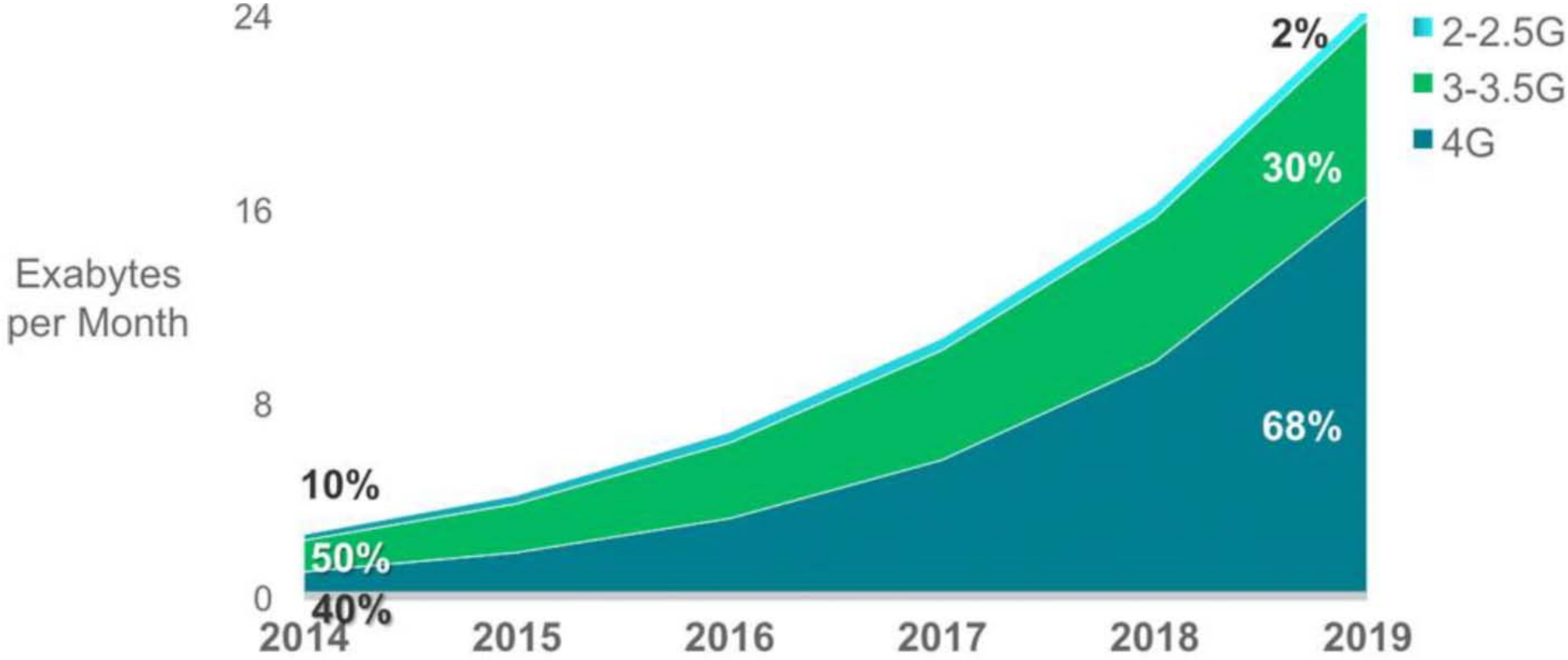
Growth of smart devices



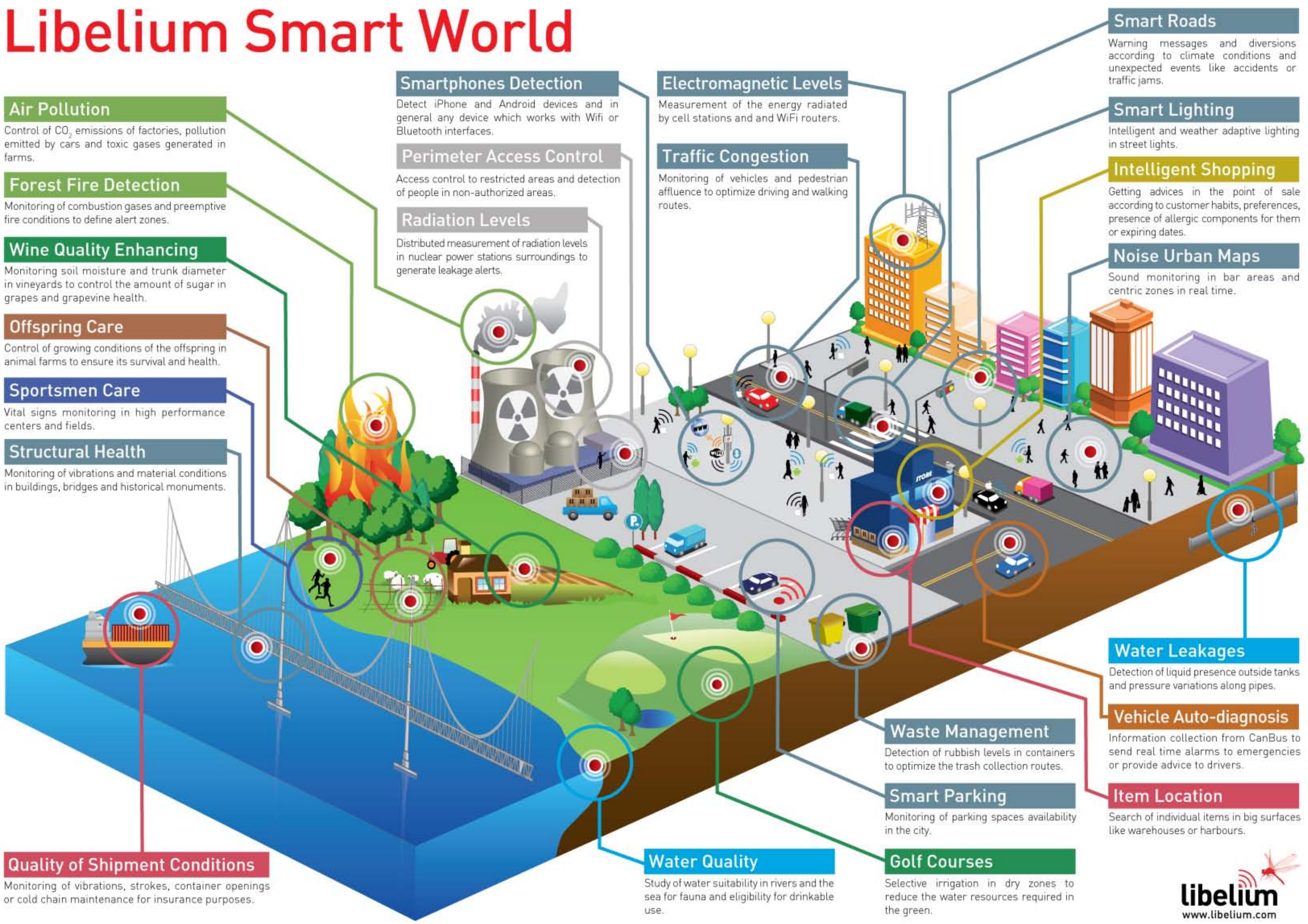
Growth of smart traffic



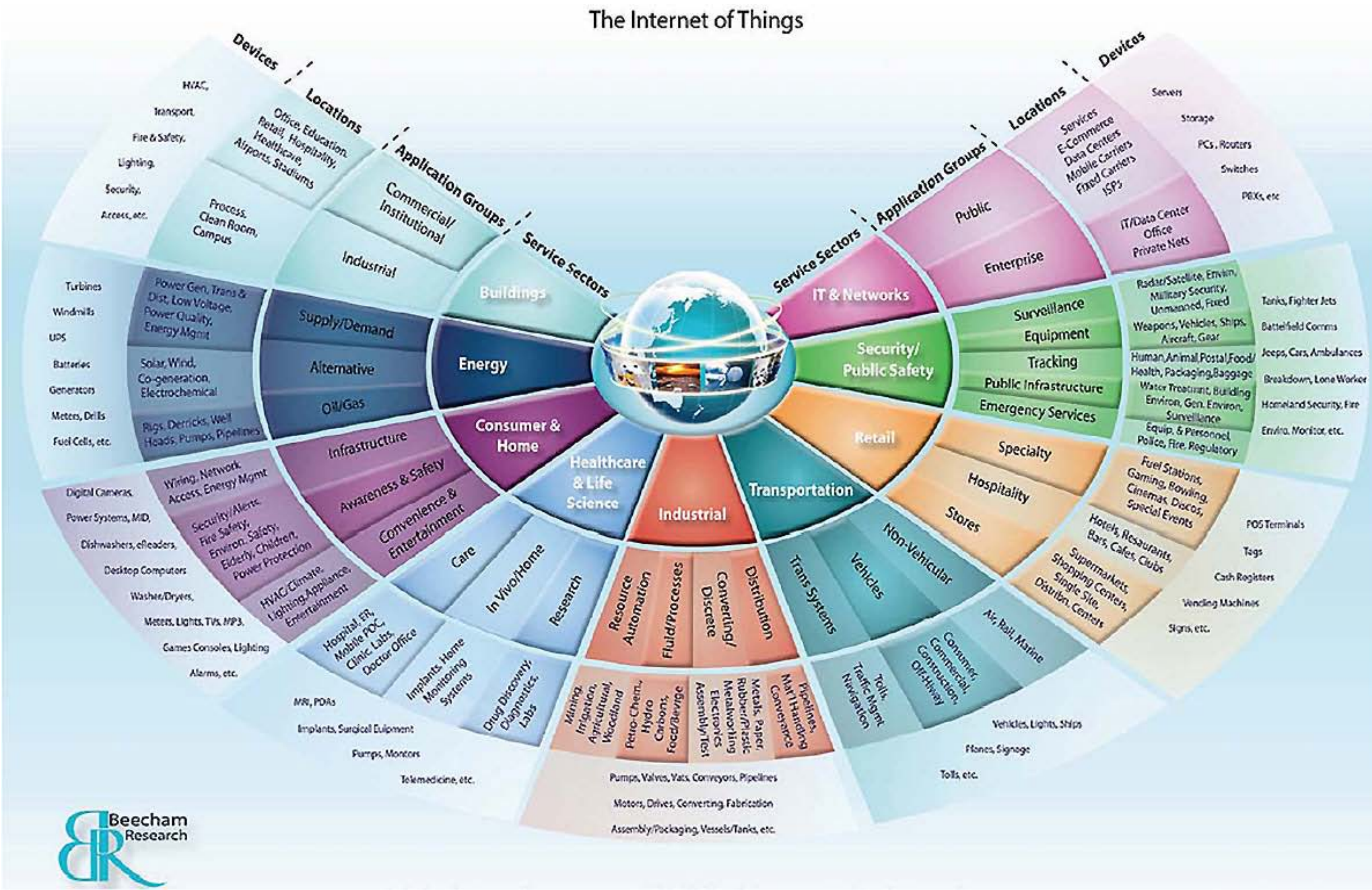
Global mobile traffic



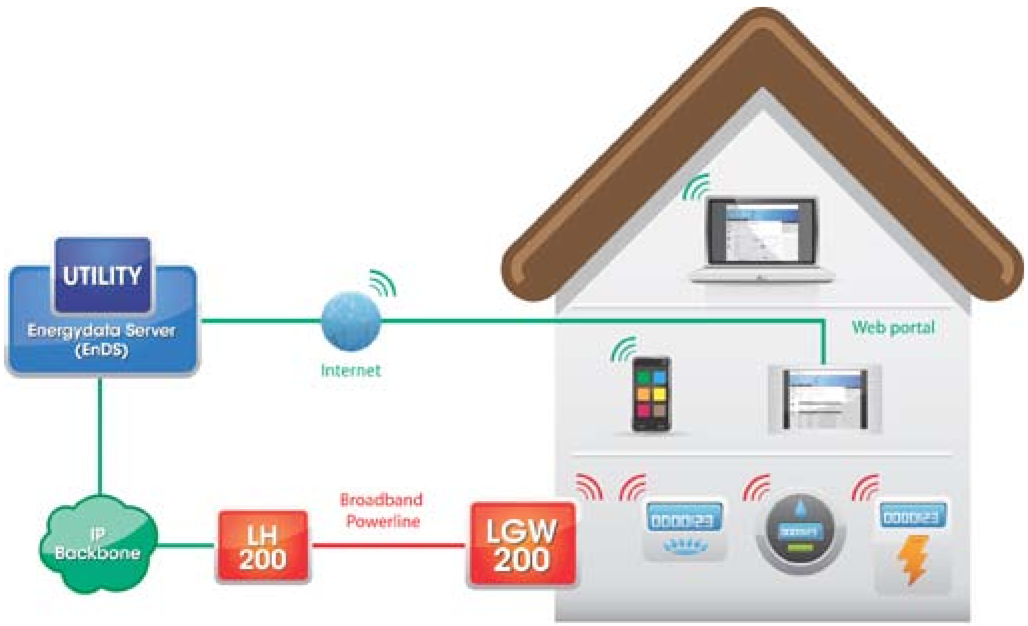
Internet of Things (IoT)



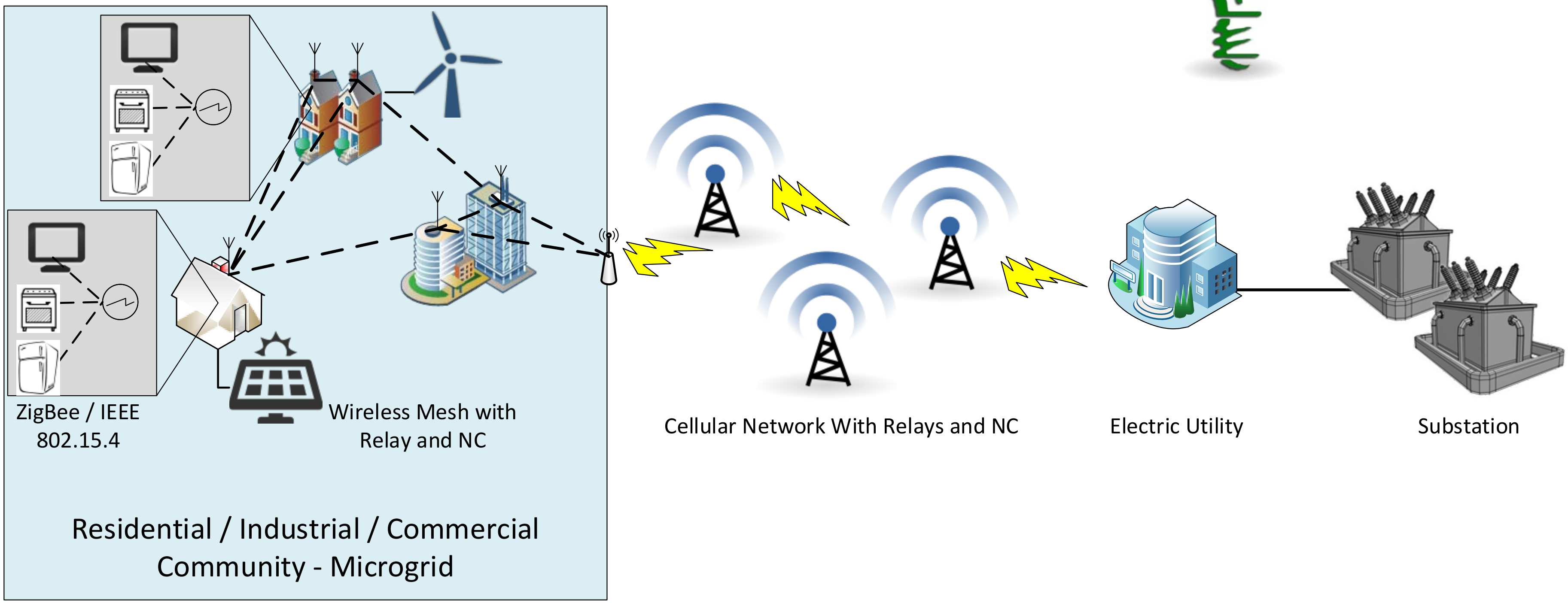
Internet of Things (IoT)



Smart Energy

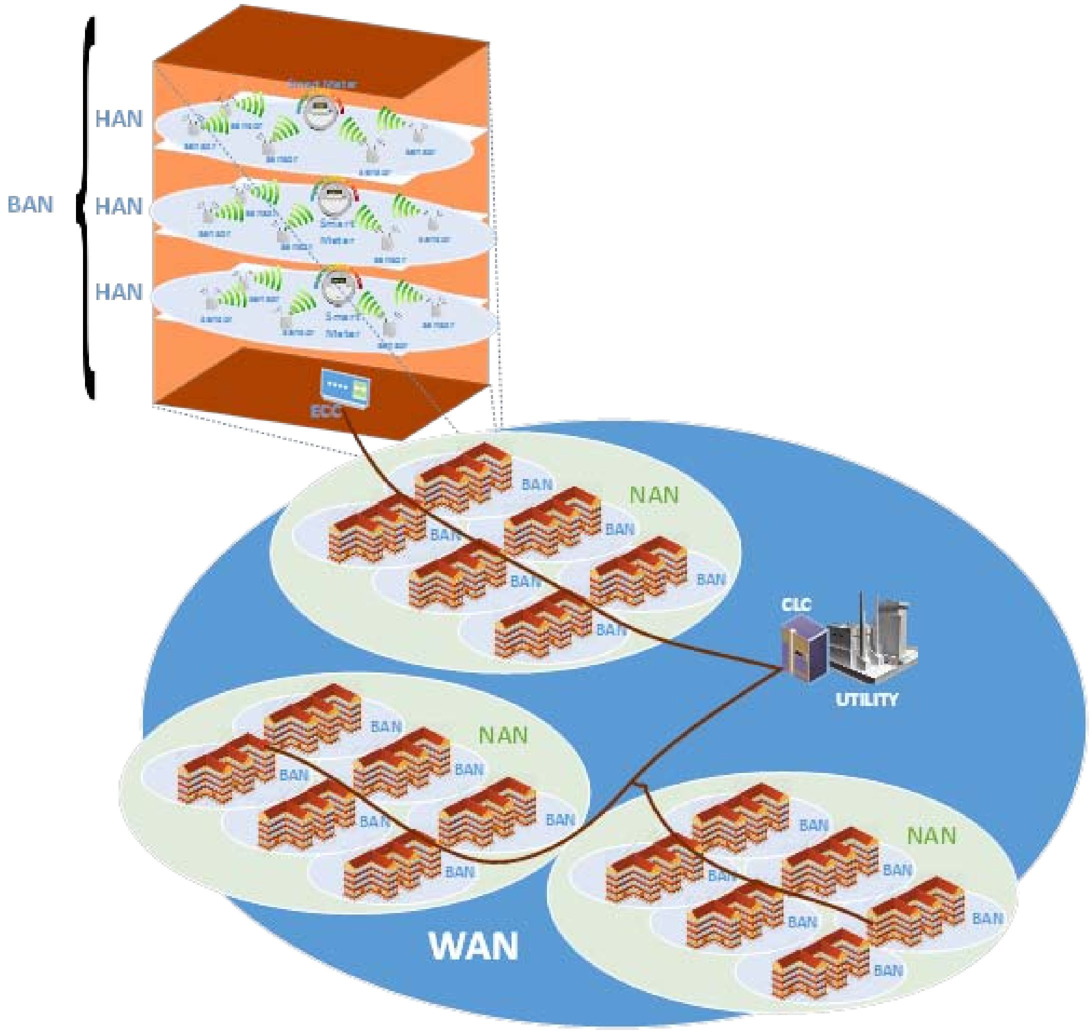


Reference architecture

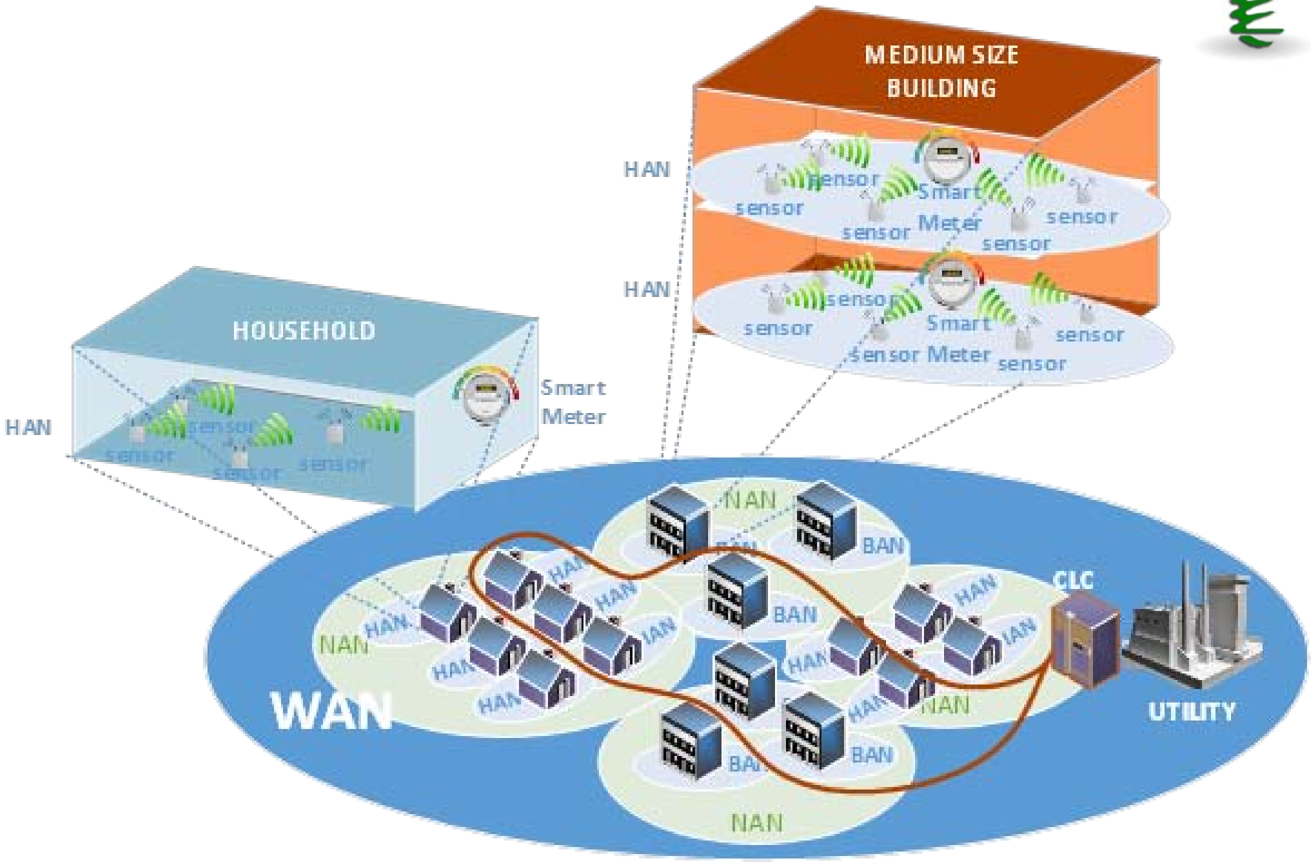


http://gain.di.uoa.gr/smart-nrg/

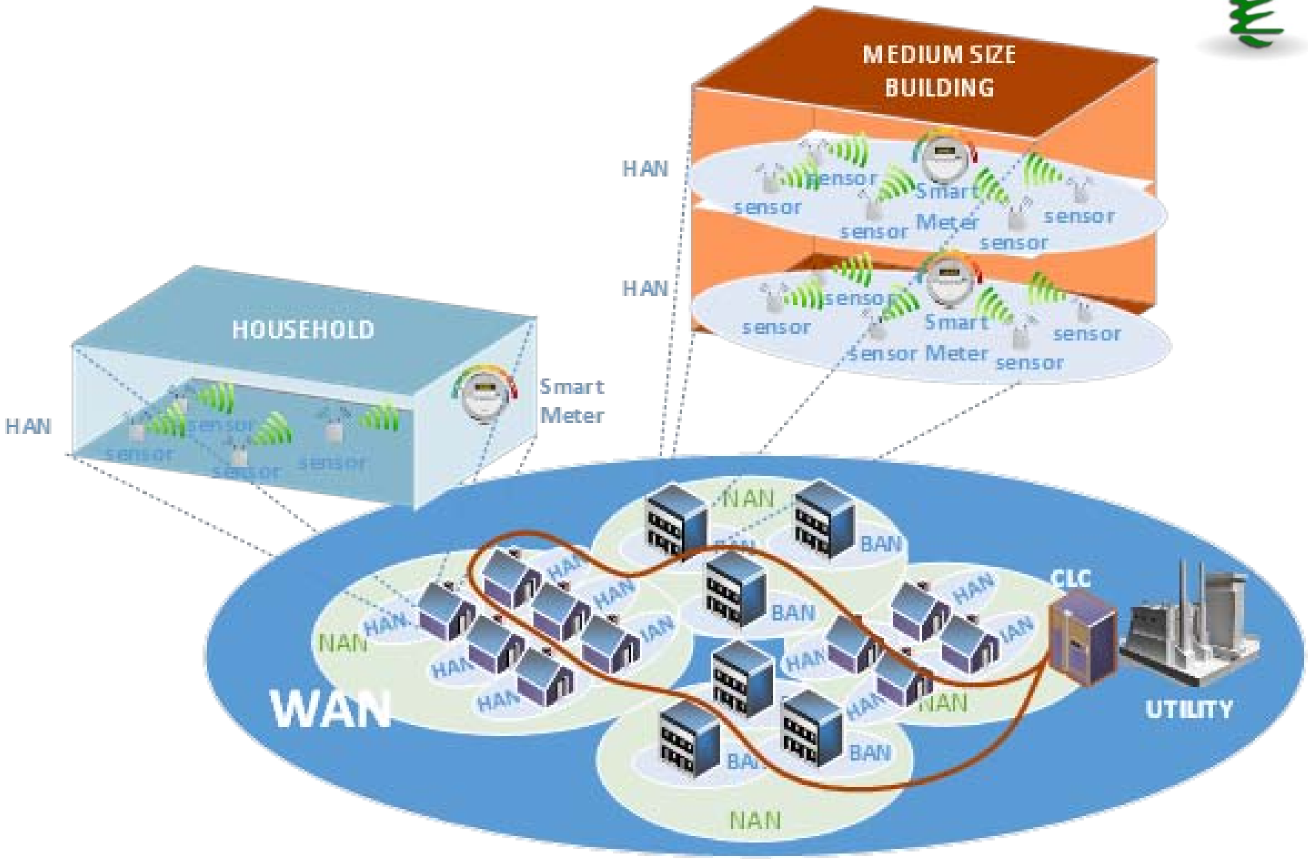
Dense urban scenario



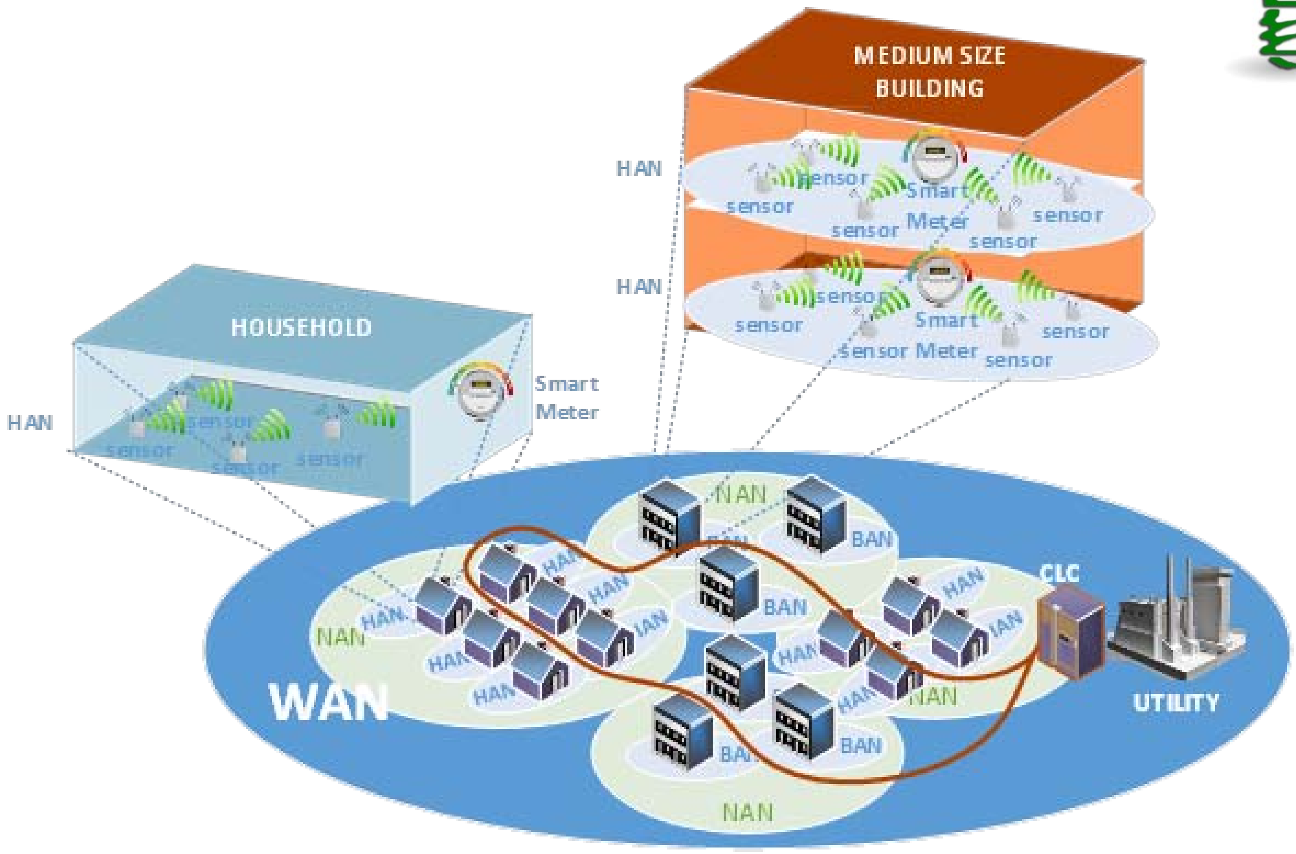
Dense rural scenario



Dense rural scenario



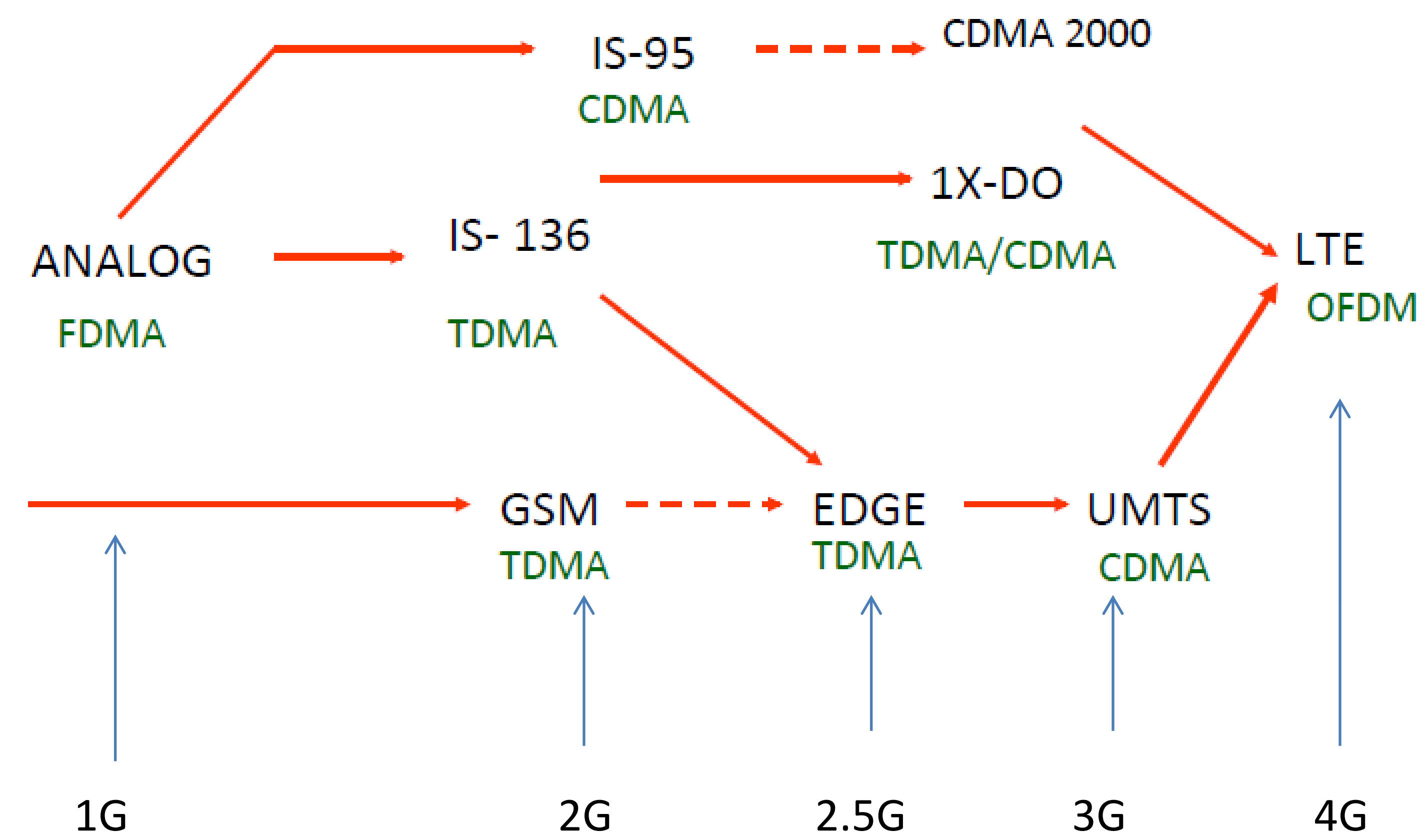
Industrial scenario

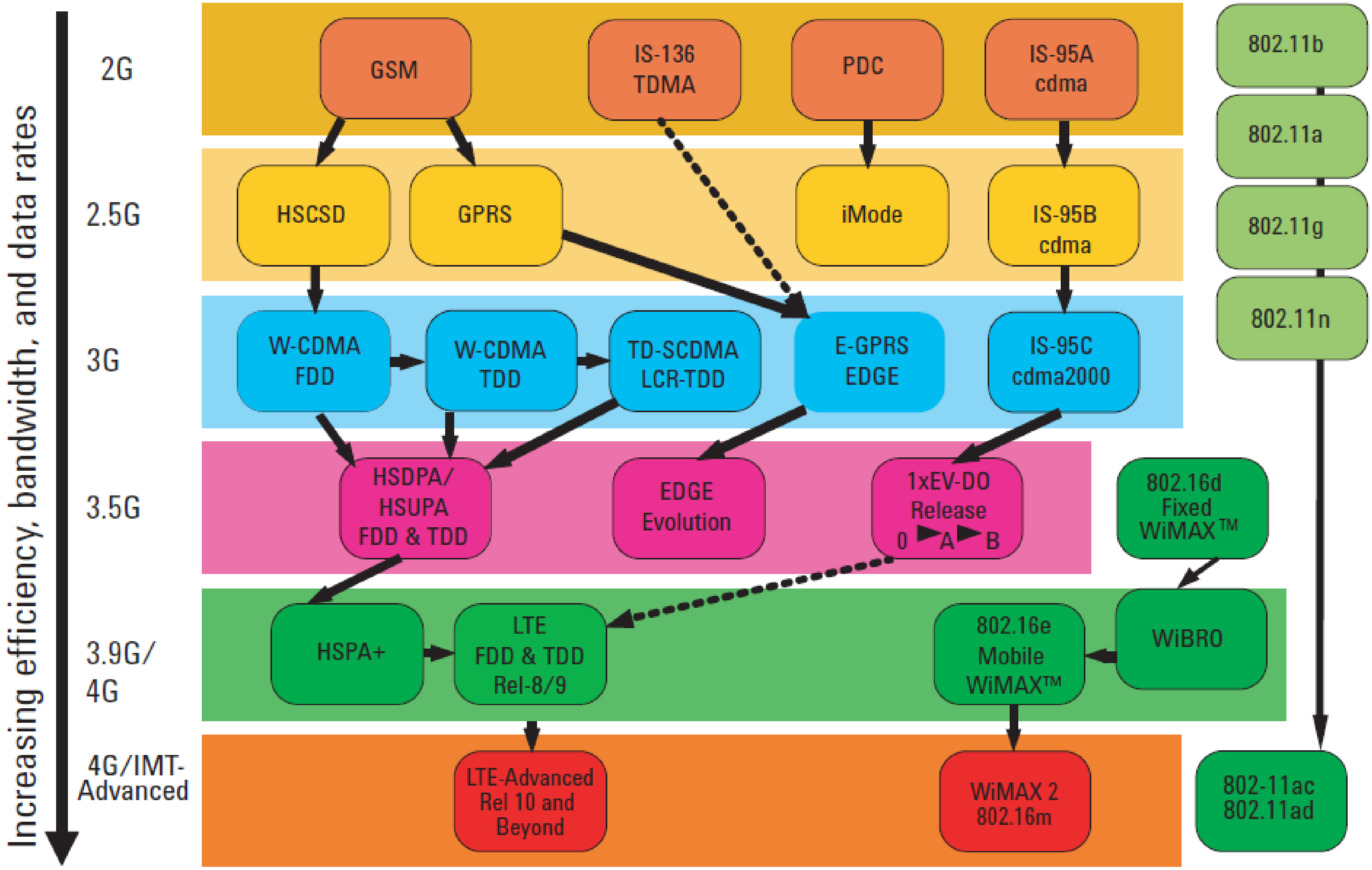


Cellular Network Generations

- 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)

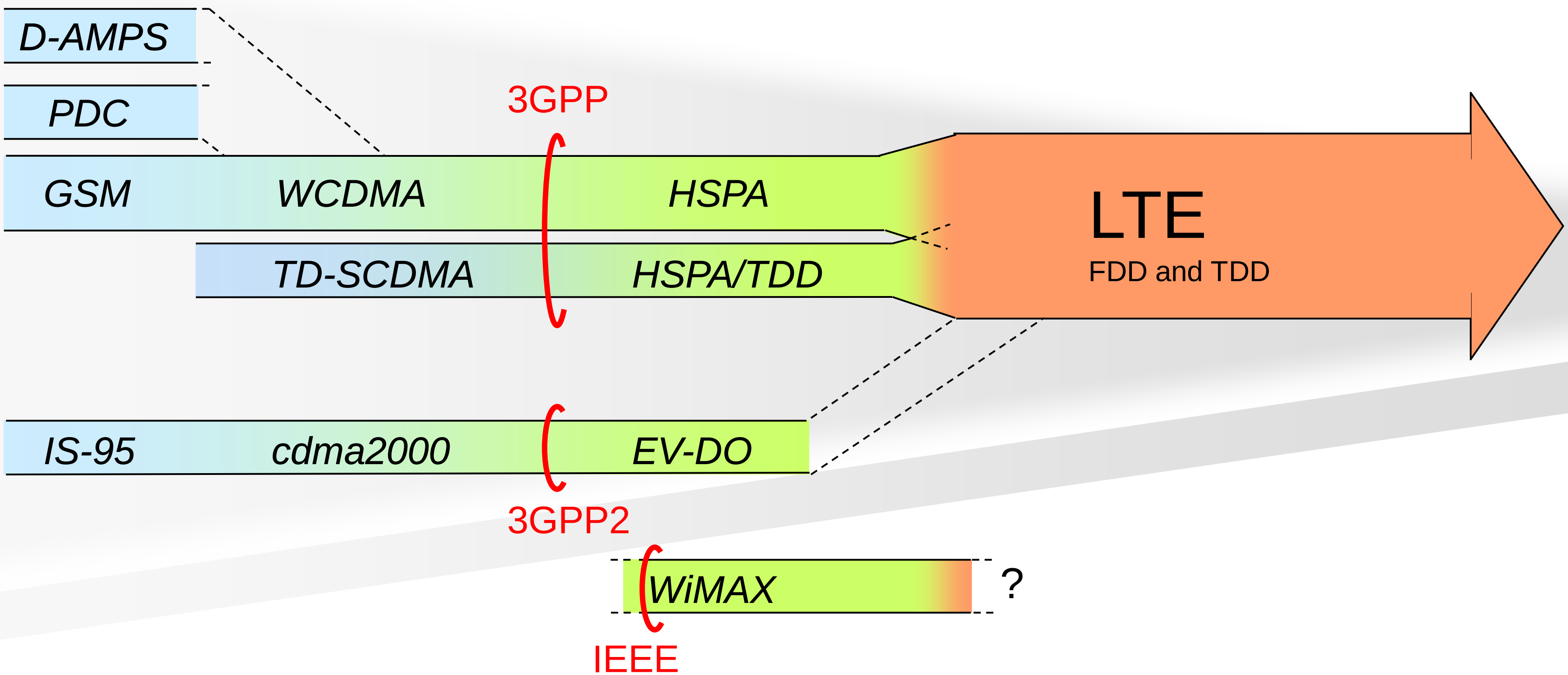
Evolution of Cellular Standards



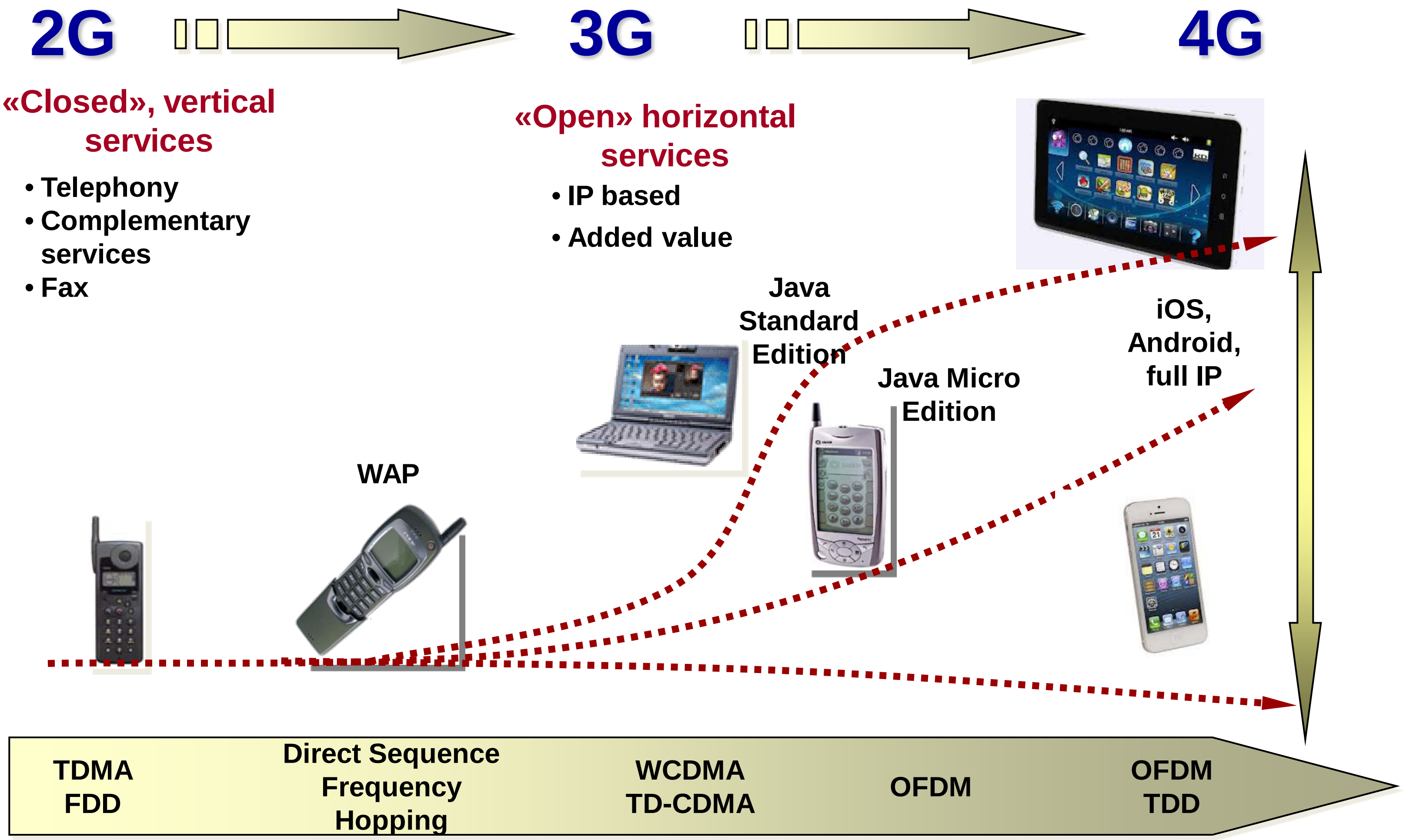

Increasing efficiency, bandwidth, and data rates
2G
2.5G
3G
3.5G
3.9G/
4G
4G/IMT-
Advanced
GSM
IS-136
TDMA
PDC
IS-95A
cdma
HSCSD
GPRS
iMode
IS-95B
cdma
W-CDMA
FDD
W-CDMA
TDD
TD-SCDMA
LCR-TDD
E-GPRS
EDGE
IS-95C
cdma2000
HSDPA/
HSUPA
FDD & TDD
EDGE
Evolution
1xEV-DO
Release
0 A B
802.16d
Fixed
WiMAX™
HSPA+
LTE
FDD & TDD
Rel-8/9
802.16e
Mobile
WiMAX™
WiBRO
LTE-Advanced
Rel 10 and
Beyond
WiMAX 2
802.16m
802.11b
802.11a
802.11g
802.11n
802-11ac
802.11ad

Global Convergence

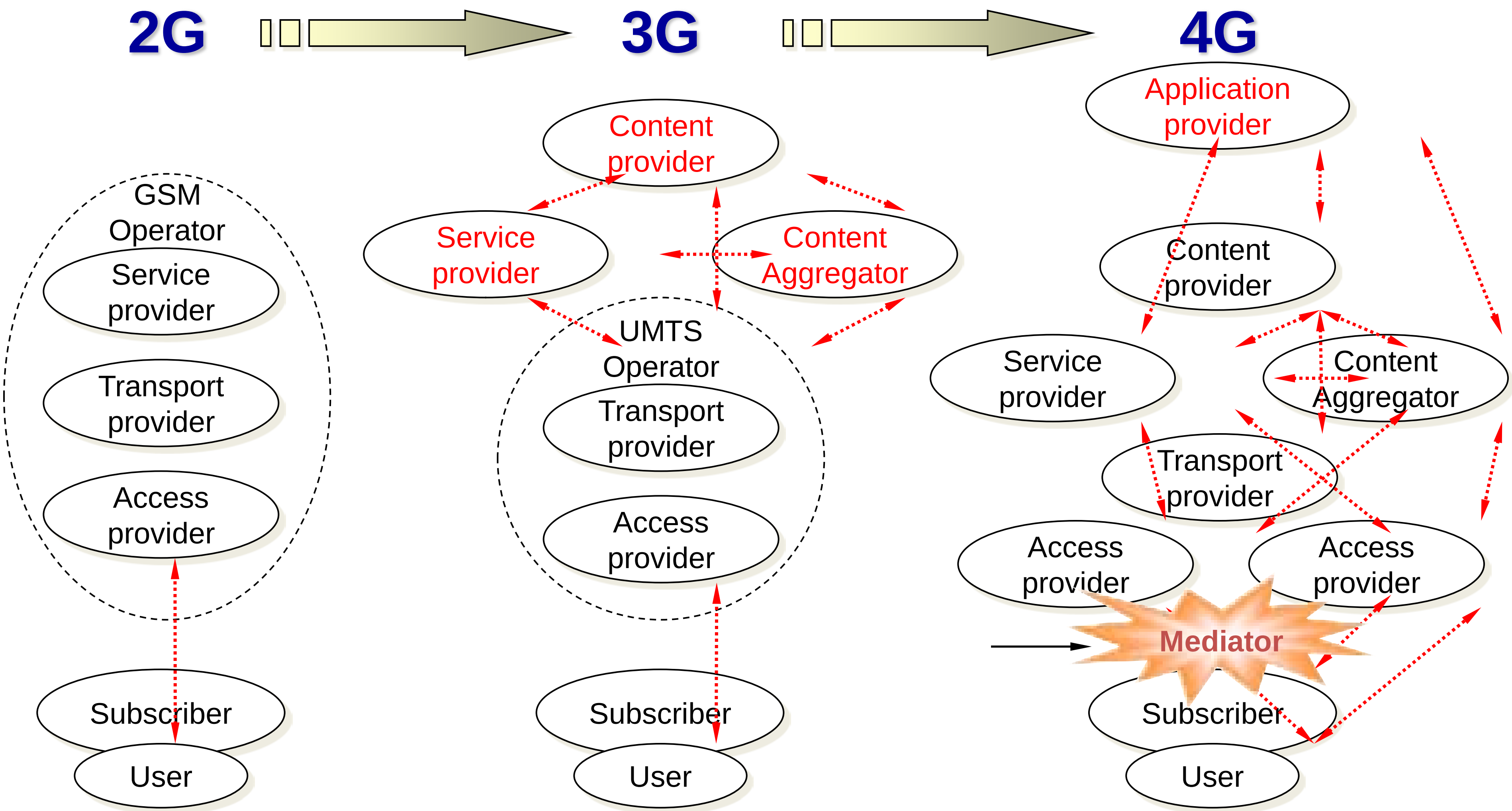
- LTE is the major technology for mobile broadband communications
  - Convergence of 3GPP and 3GPP2 technology tracks
  - Convergence of FDD and TDD into a single technology track



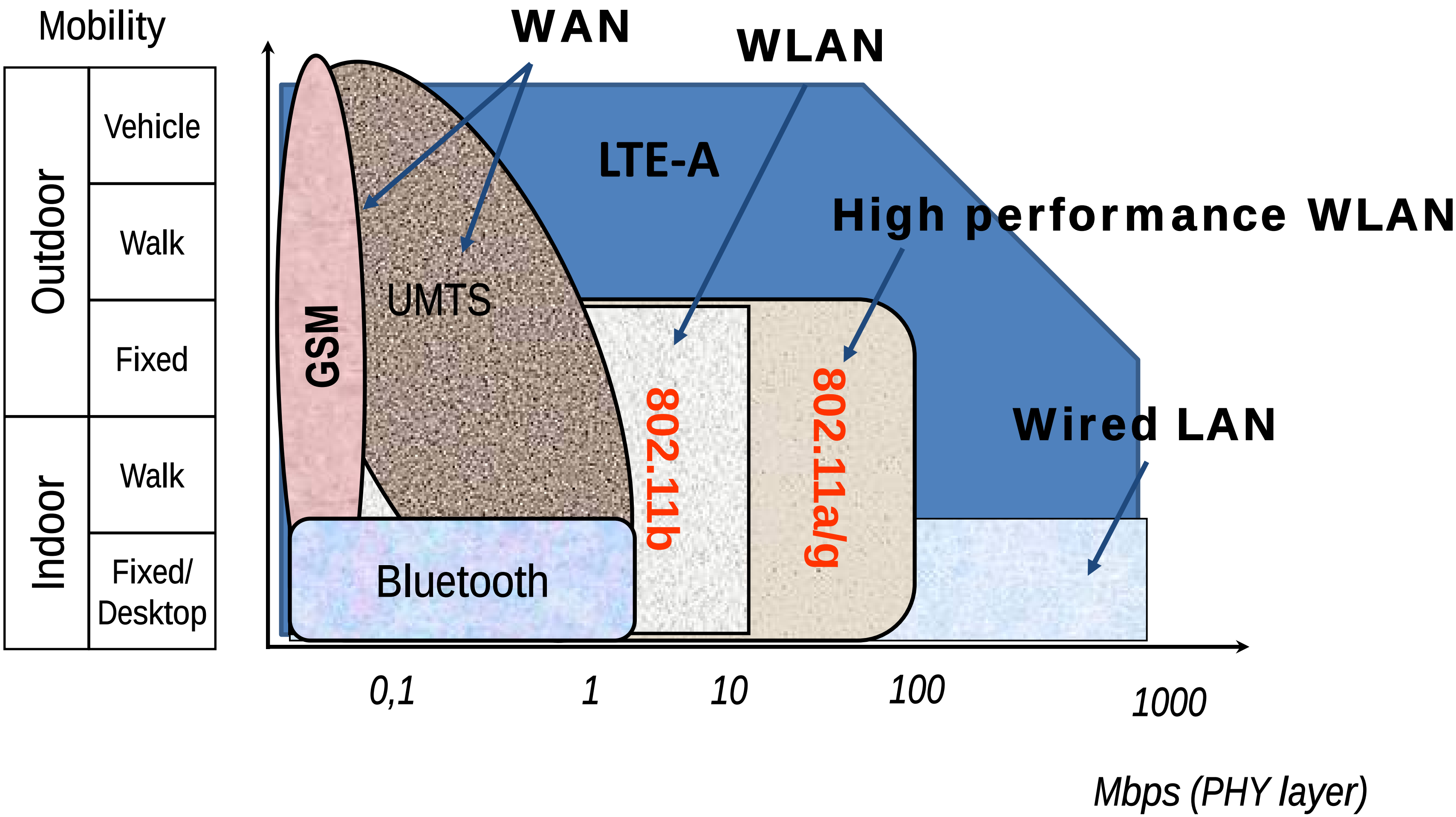
Evolution of terminals and services



Business model evolution



Wireless Standards

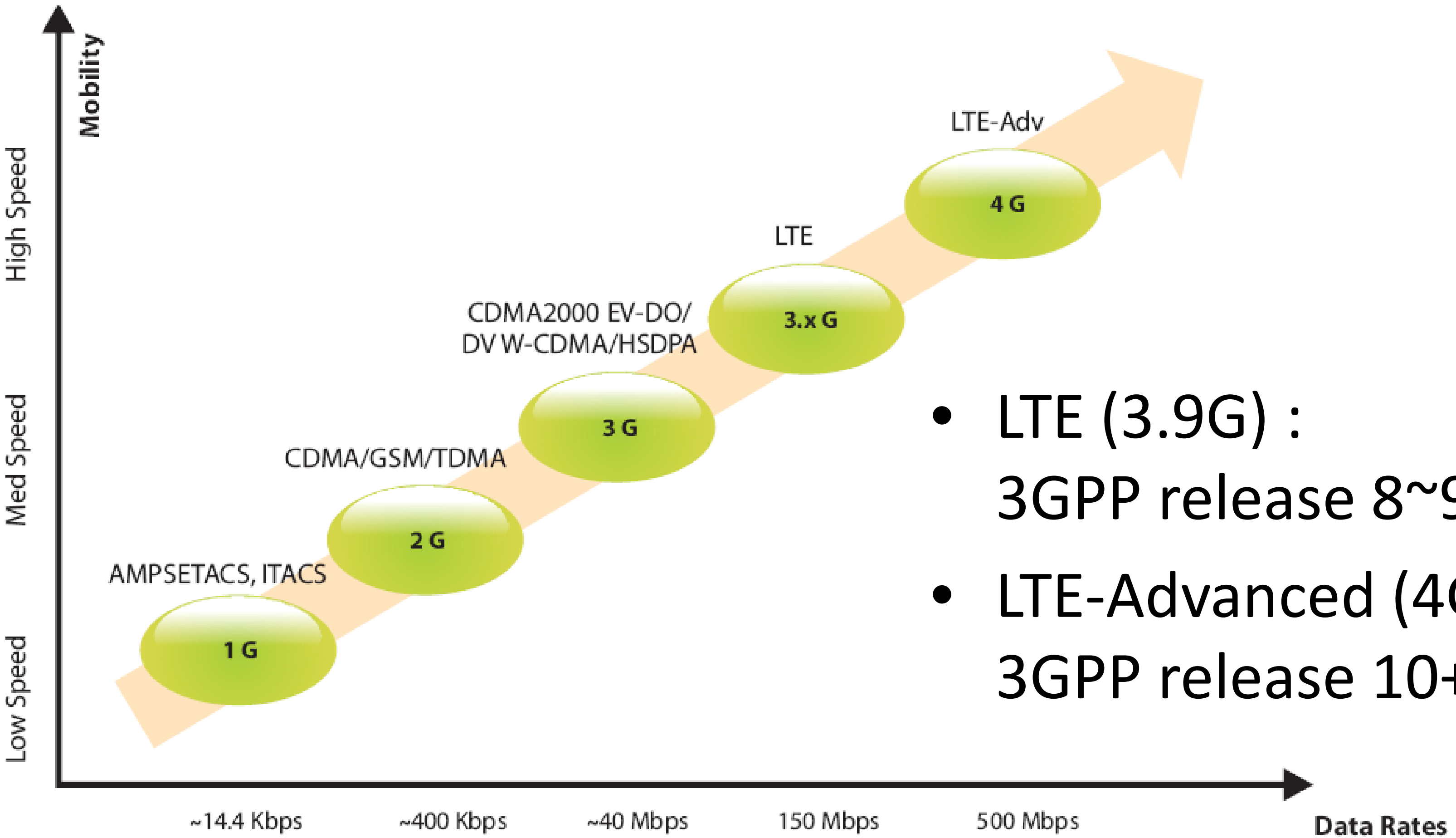


2. LTE/LTE-A Basics

- Mobile standards evolution towards 4G

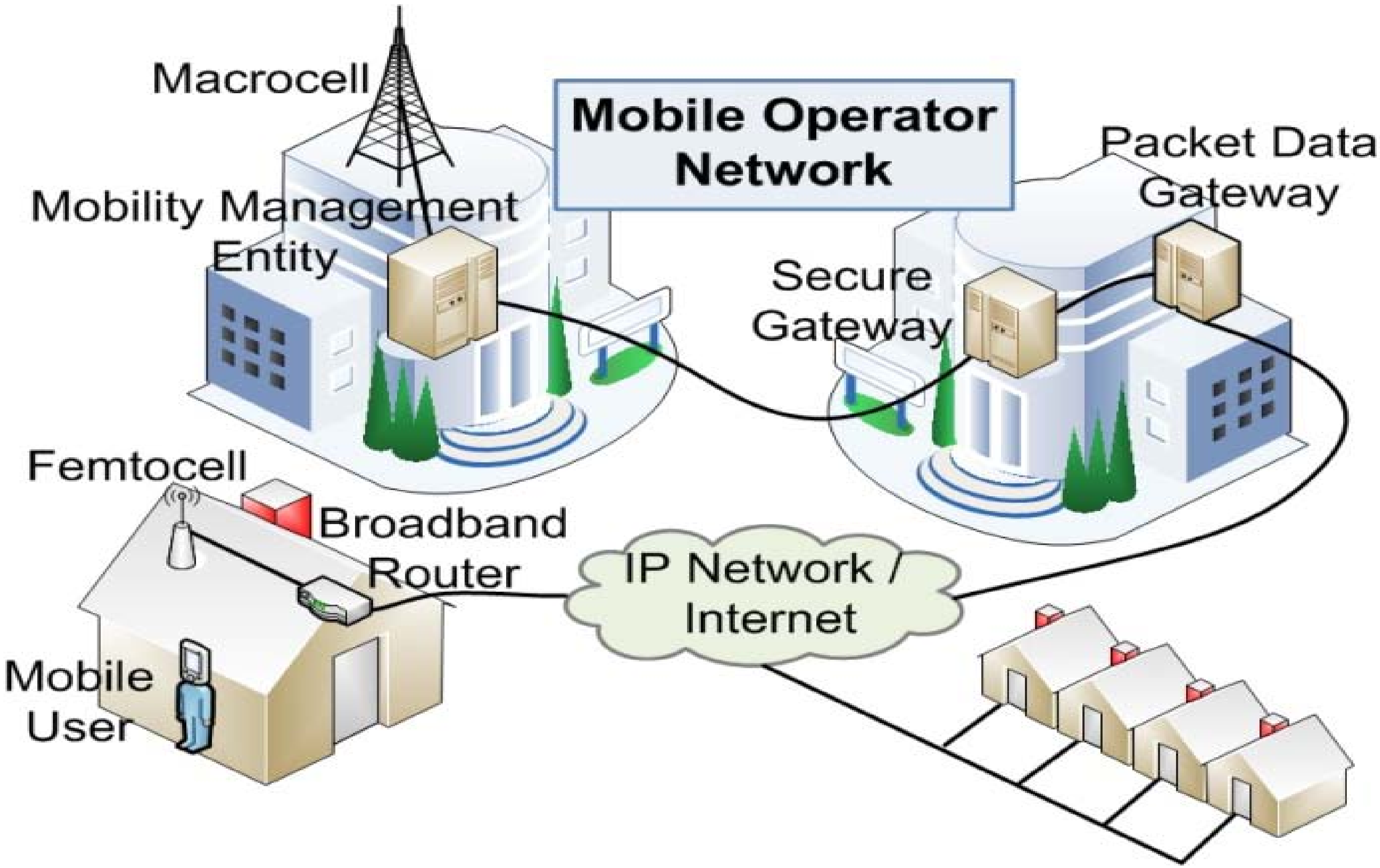
  GSM->GPRS->UMTS->LTE->LTE-A
- Key features of Long Term Evolution (LTE)
- LTE architecture / components / functionality
- LTE transmission techniques
- LTE-Advanced enhancements

Evolution of Radio Access Technologies



- LTE (3.9G) : 3GPP release 8~9
- LTE-Advanced (4G): 3GPP release 10+

3. Mobility Management in LTE-A Networks



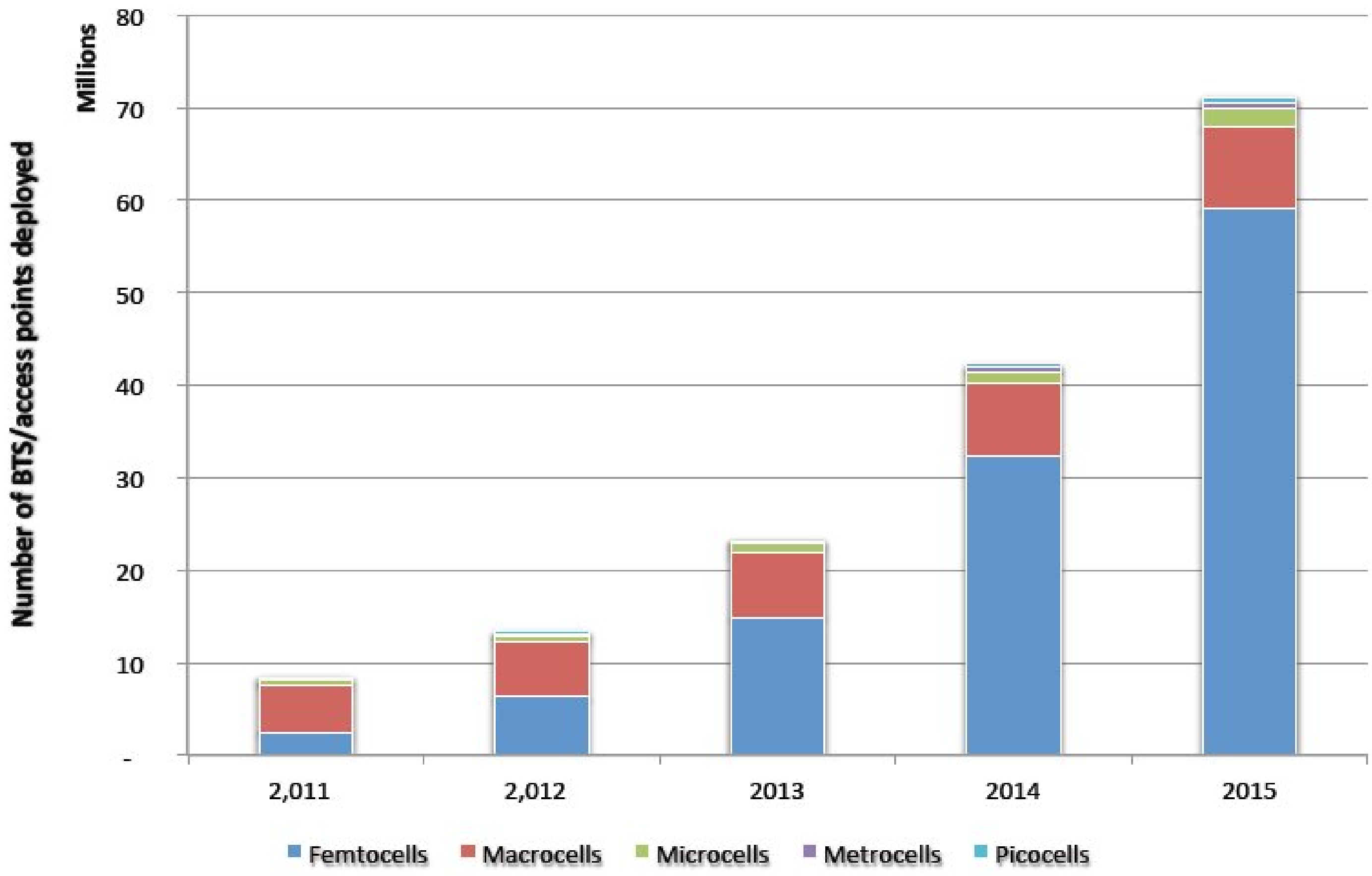
Focus of the Lecture

- 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



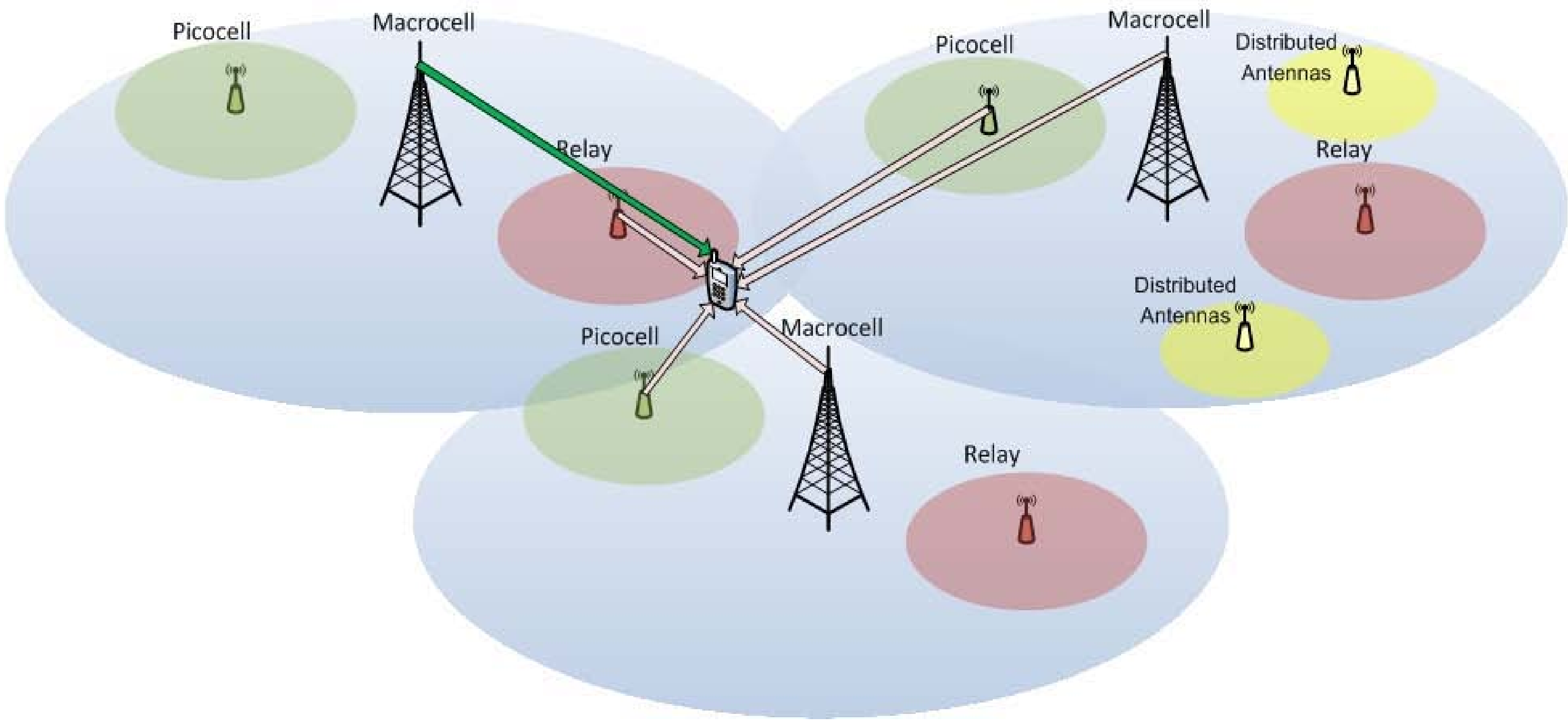
Source: Informa Telecoms & Media

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

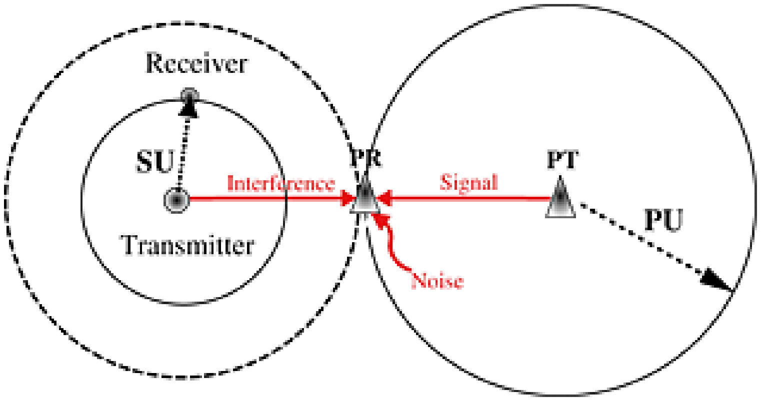
Heterogeneous environment - Different types of interference



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



INTERFERENCE PROBLEM IN FEMTOCELLS

- Co-channel Interference
- Uncertainty of Placement due to User-Deployment
- Degradation to and from other Femtocell and Macrocell Basestations

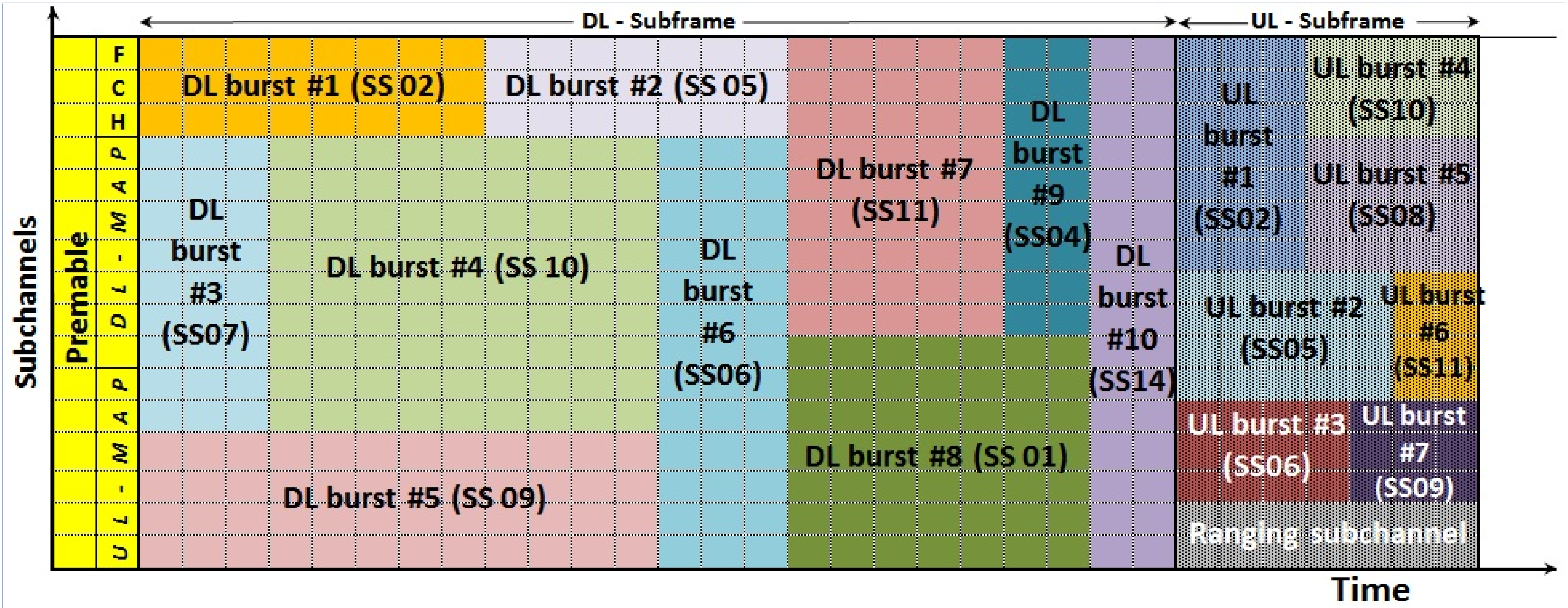
INTERFERENCE SCENARIOS

#	Source		Victim	Type
1.	Macrocell UE	→	Femtocell BS	Cross-Tier
2.	Macrocell BS	→	Femtocell UE	Cross-Tier
3.	Femtocell UE	→	Macrocell BS	Cross-Tier
4.	Femtocell BS	→	Macrocell UE	Cross-Tier
5.	Femtocell 'A' UE	→	Femtocell 'B' BS	Co-Tier
6.	Femtocell 'A' BS	→	Femtocell 'B' UE	Co-Tier

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

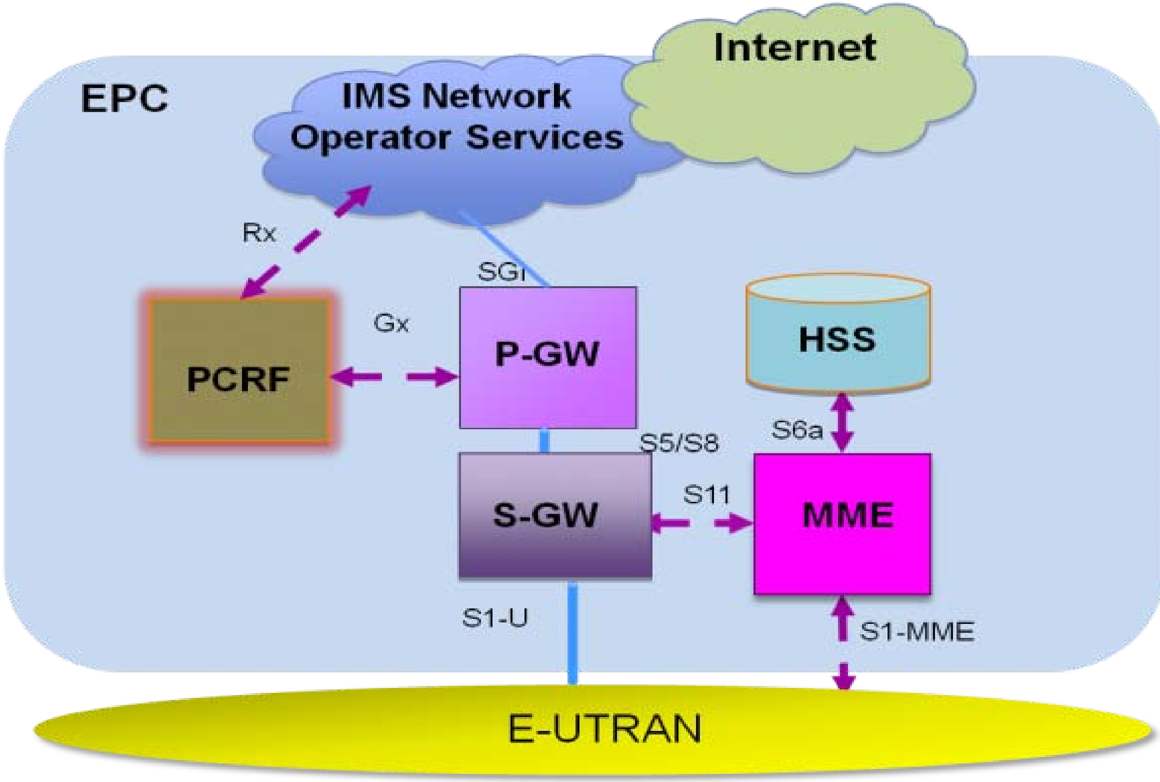
Typical RRM Problem



Resource Management – Theory vs reality

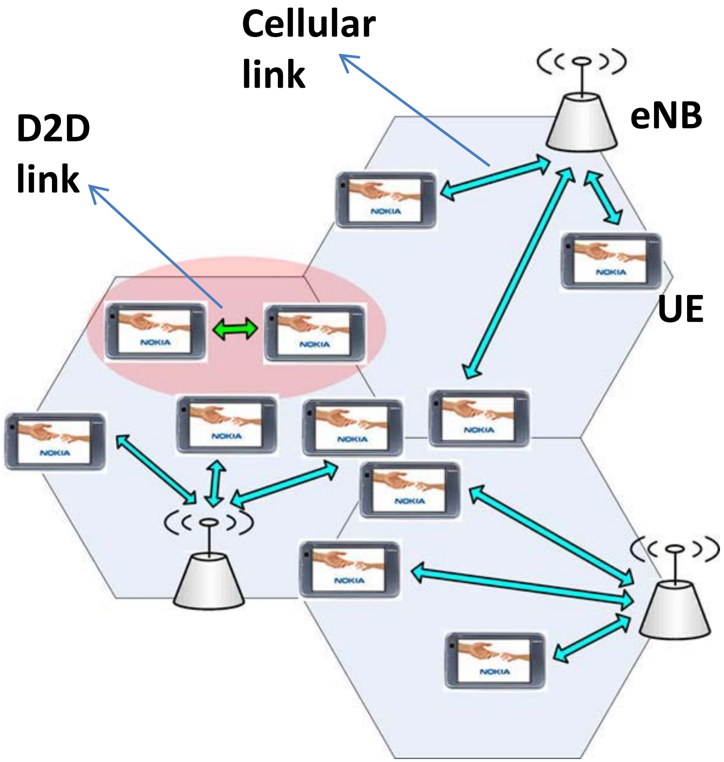
- How QoS affects scheduling & resource management
- Importance of resource management for wireless networks efficiency
- Commonly used algorithms for scheduling & resource allocation
- Complexity vs performance
- Operator’s point of view
- Customer's (Public/Civil/Military/Industry) point of view
-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

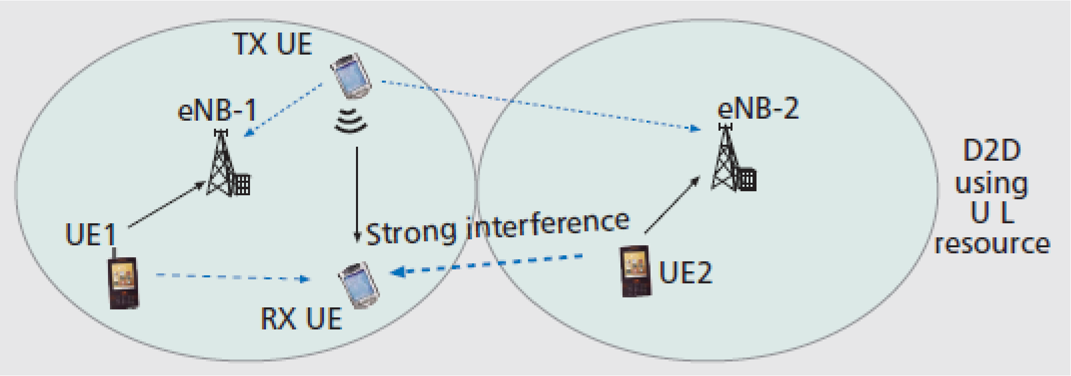
- Higher throughput, lower delays, reduced power consumption
- Increased spectrum utilisation
- eNB offloading and network decongestion
- All benefits of centralised eNB control (higher security etc.)
- New service opportunities
- Can be transparent to the user

➢ 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

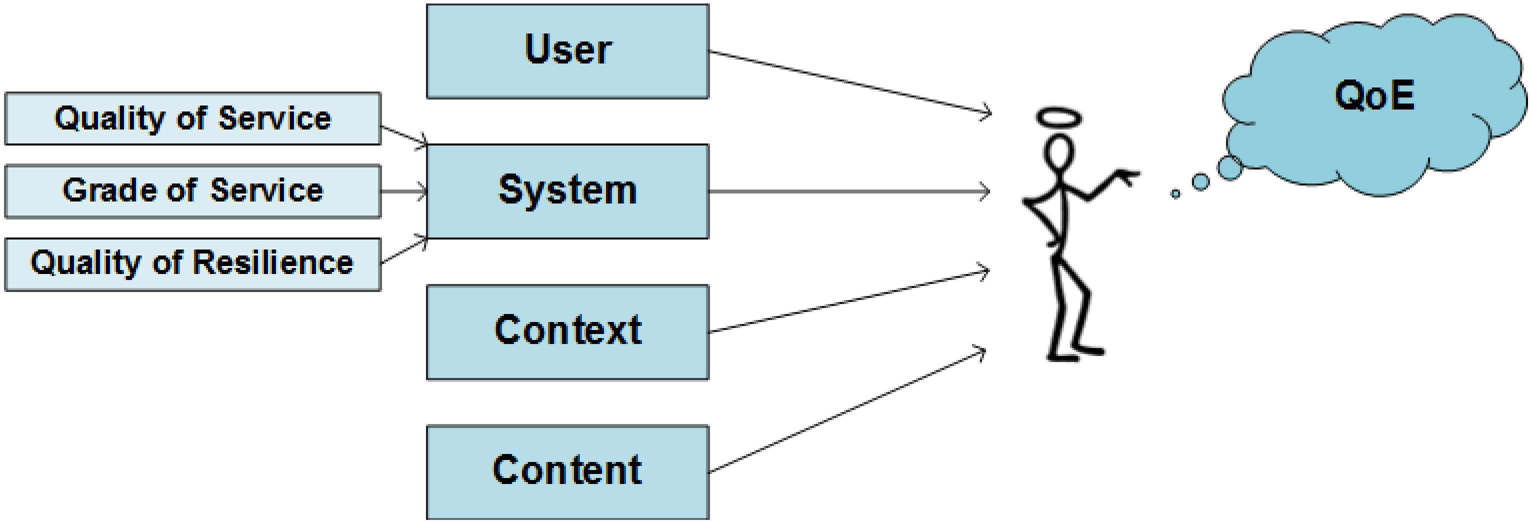
- Intra- and Intercell interference mitigation (co-existence of cellular & D2D links): Power control optimisation mechanism for D2D, Exploitation of proximity/neighbourhood information etc.
- Radio resource management (Resource Blocks allocation)
- Comparison between cellular and D2D performance
- D2D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

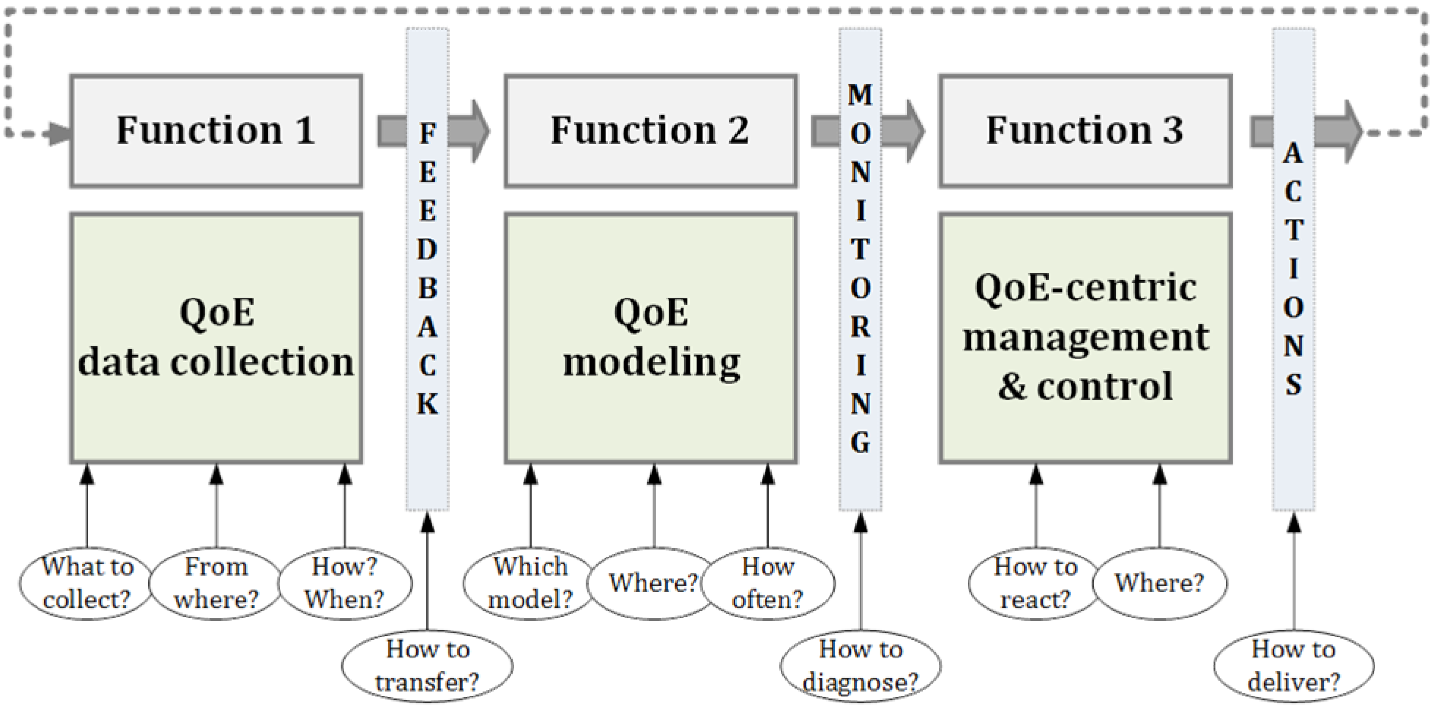


Learning objectives

- 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

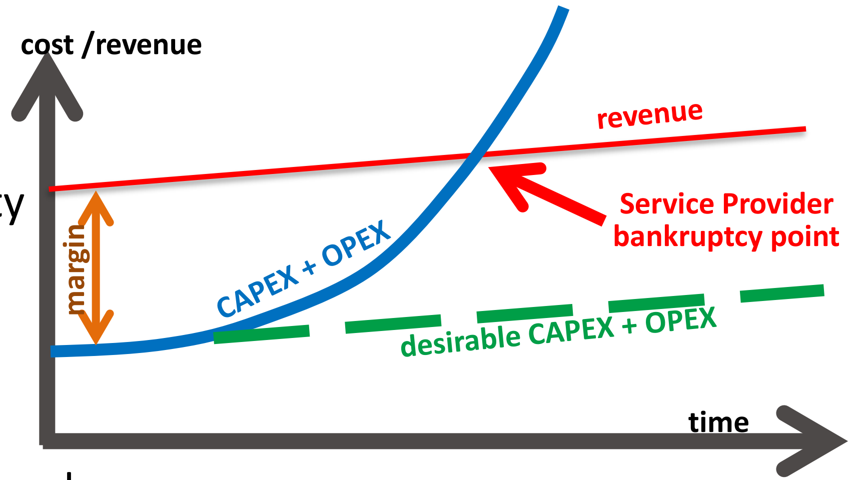
Goal: Optimize end-user QoE, while making efficient use of network resources & maintaining a satisfied customer base.



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

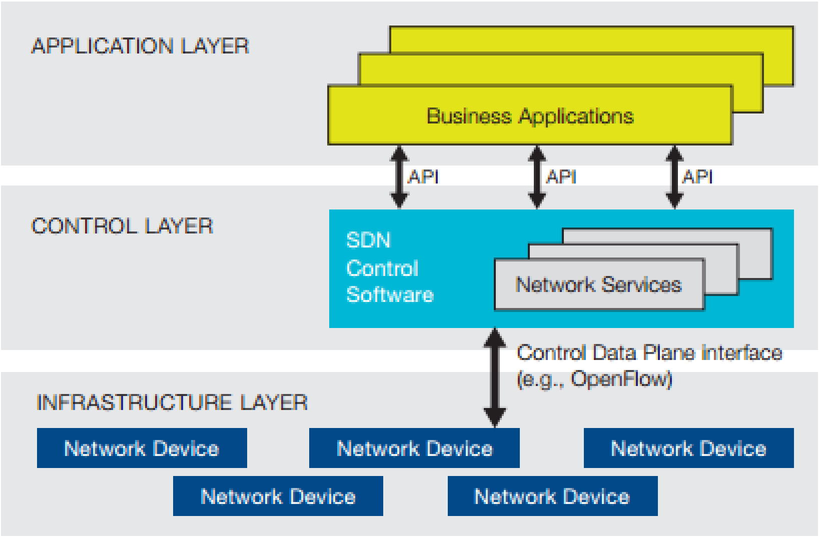
SDN is an approach to networking in which the standardized networking protocols are replaced with centralized software applications that may configure all the network devices.

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?

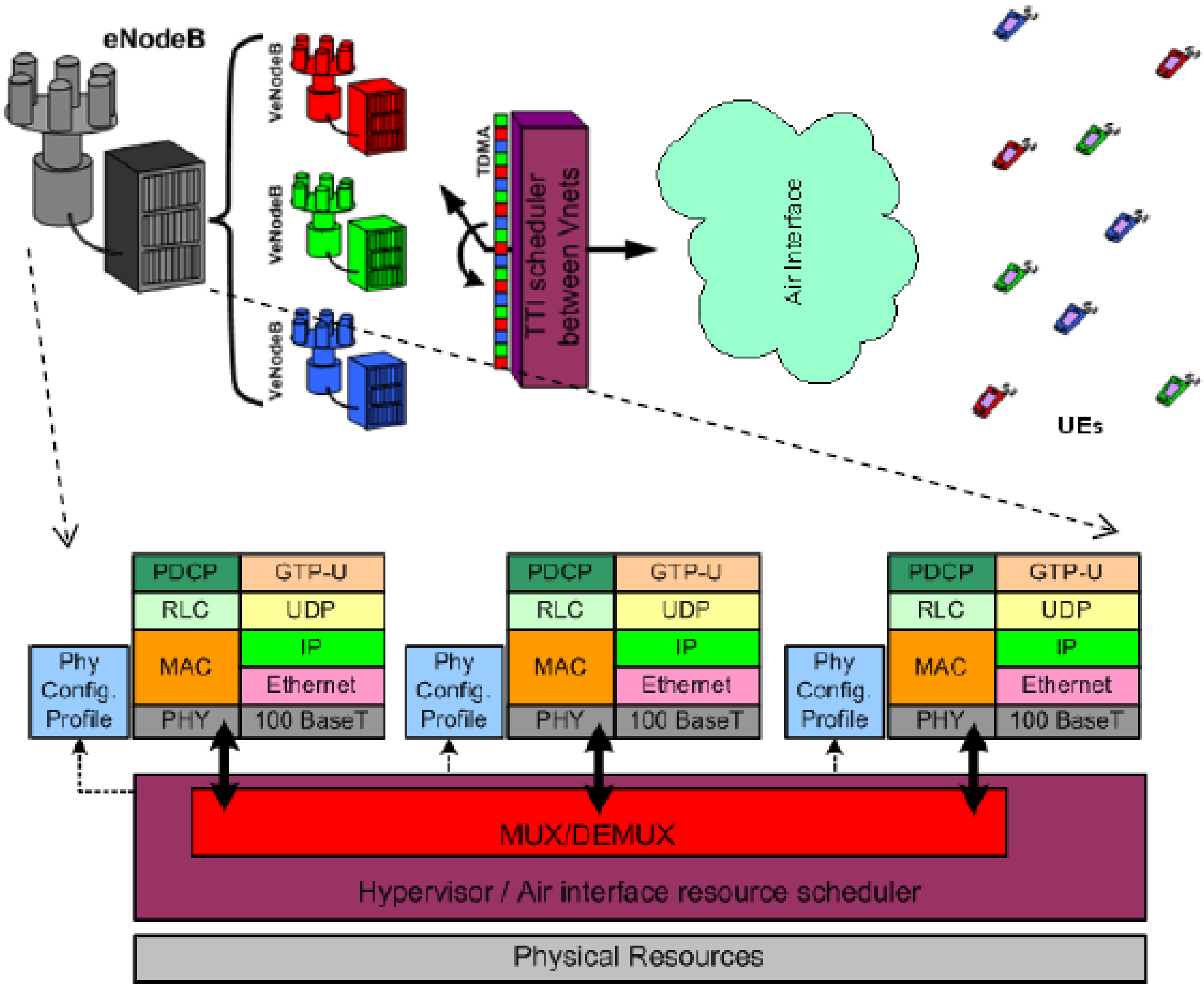
1. **Virtualization**: Use network resource without worrying about where it is physically located, how it is organized, etc.
2. **Orchestration**: Should be able to control and manage thousands of devices with one command.
3. **Programmable**: Should be able to change the network behavior on the fly.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

Virtualizing eNBs



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

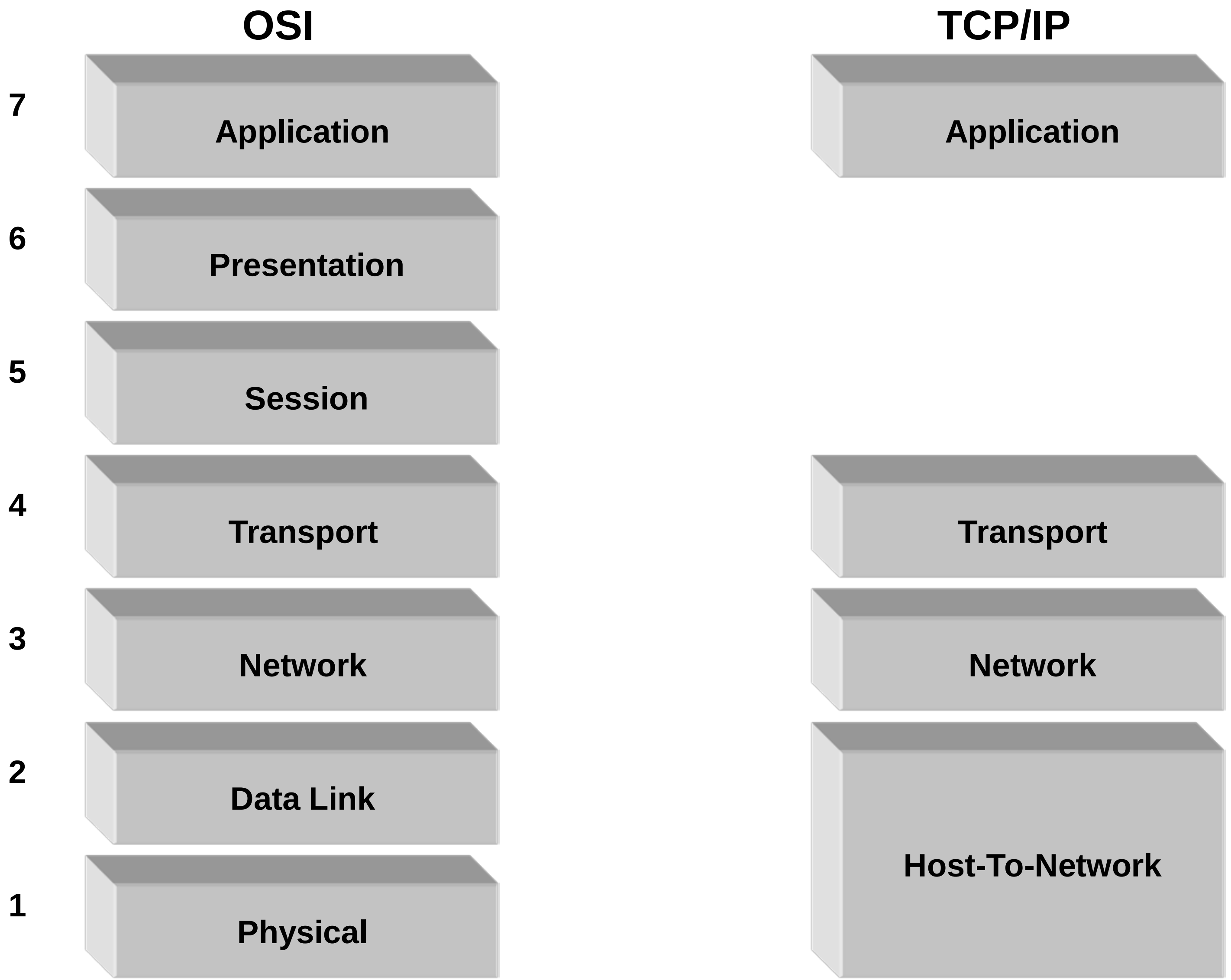
12-13. Student's Presentations

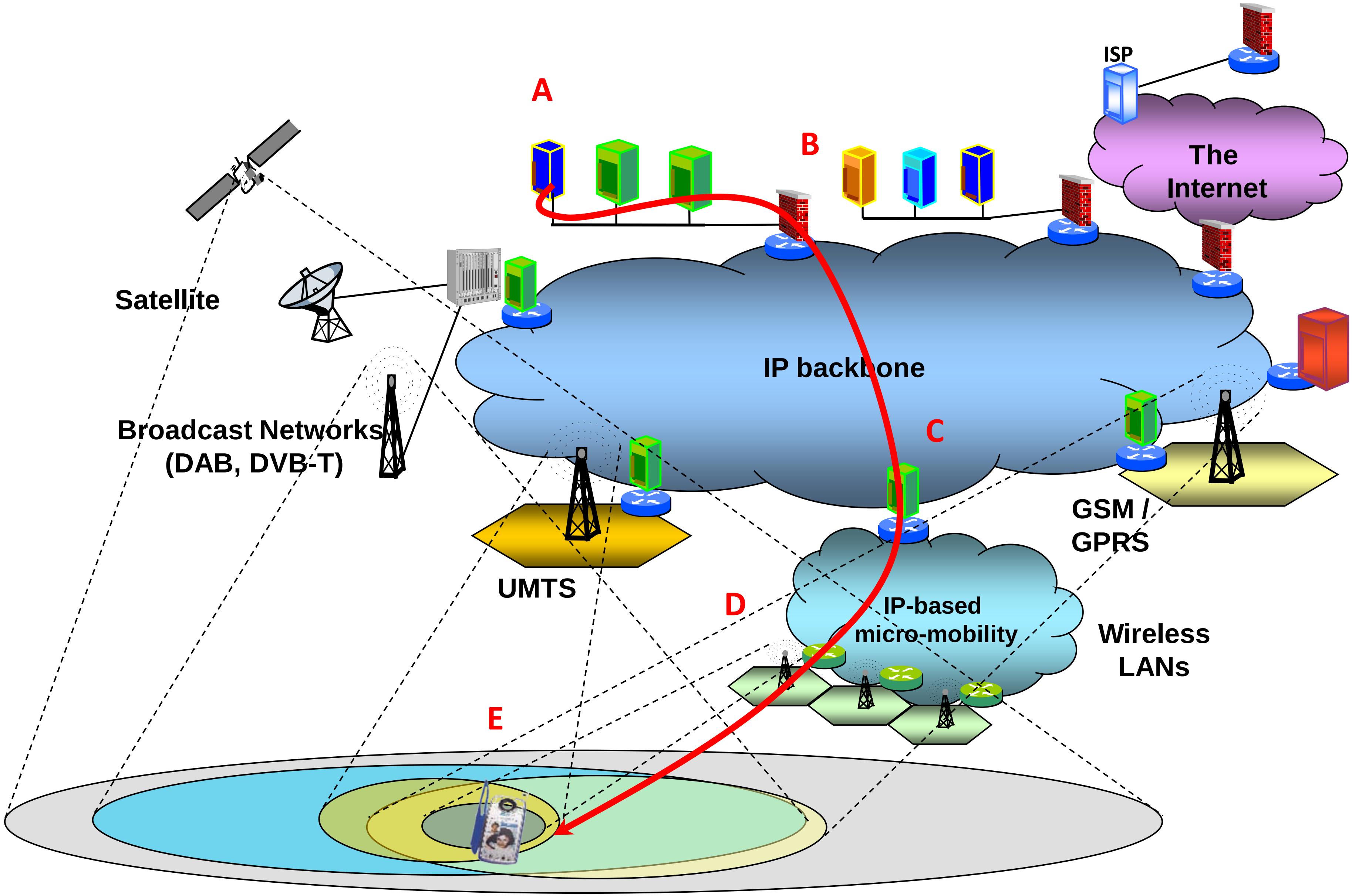
- Each student will do a 10-15' presentation in one of there areas
- Paper presentation or comparison of two papers
- Assistance and supervision during preparation
- Questions from audience
- 60% of the final grade

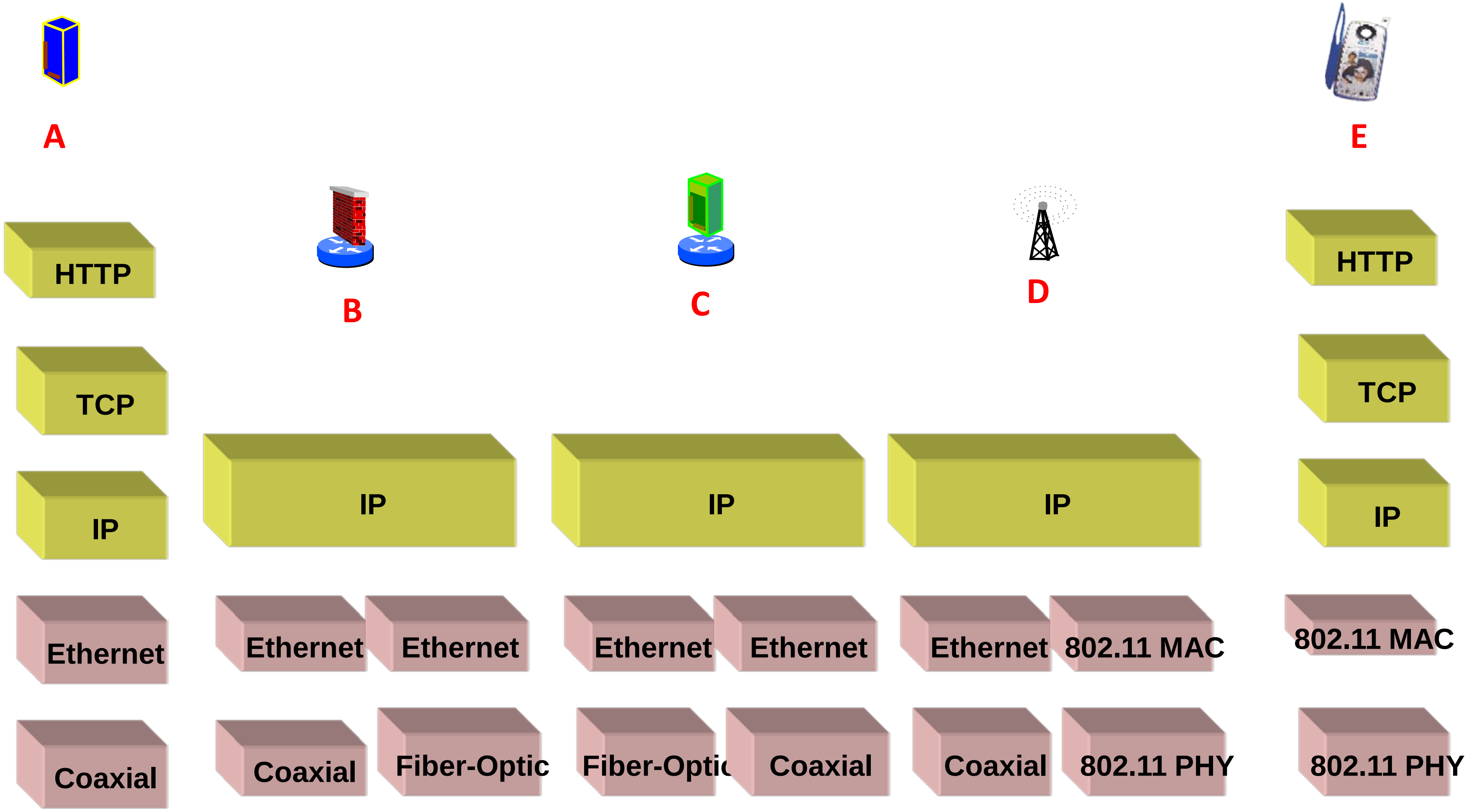
From Aloha & wired networks to synchronous wireless networks

- **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**

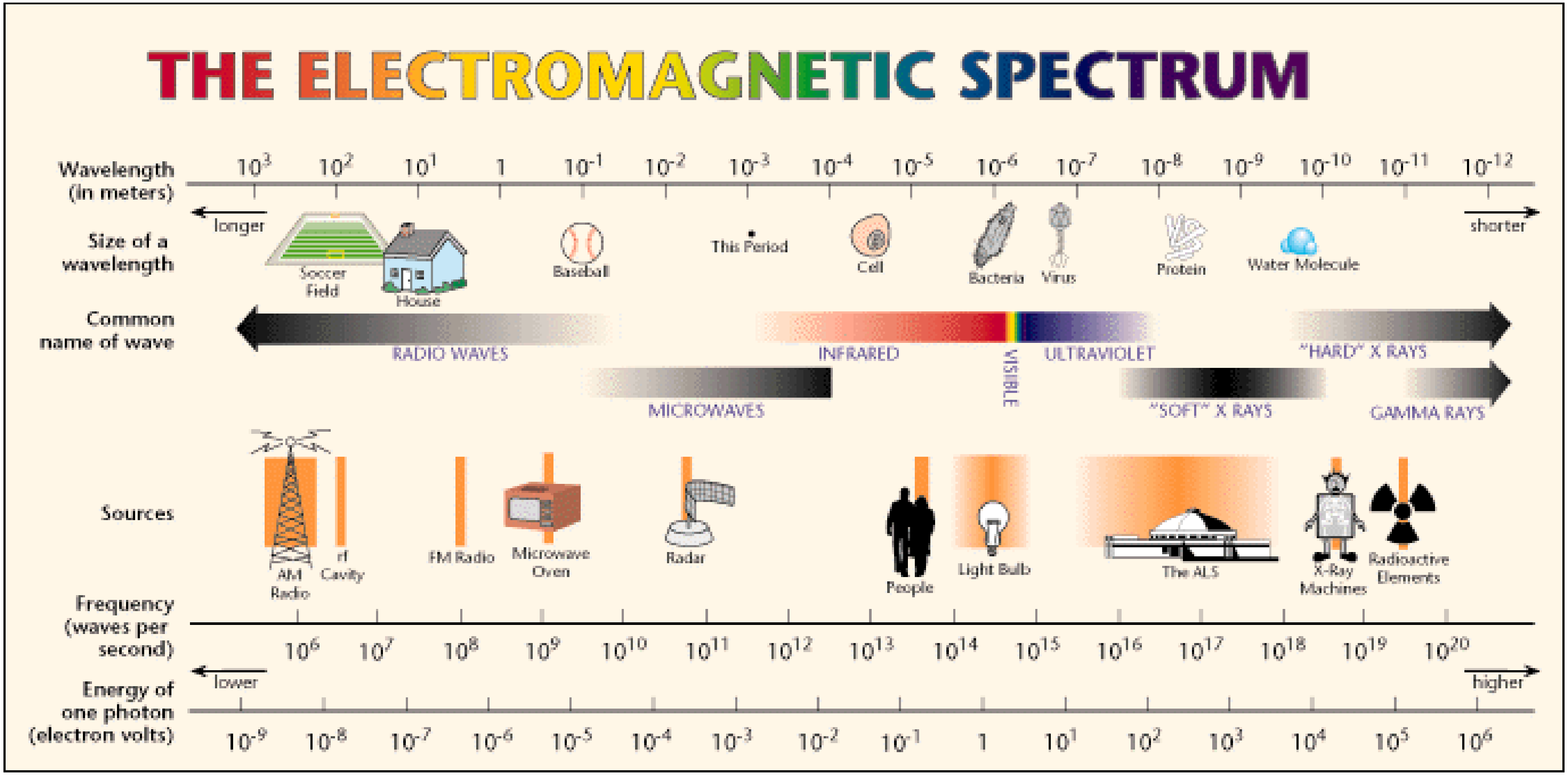
TCP/IP Reference Model



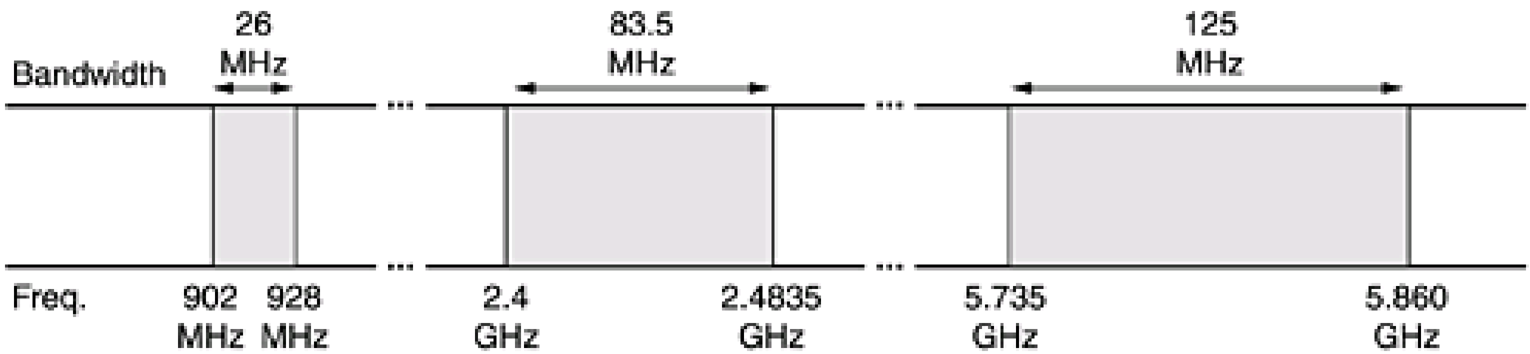

ISP
A
B
The Internet
Satellite
IP backbone
Broadcast Networks
(DAB, DVB-T)
C
GSM /
GPRS
UMTS
D
IP-based
micro-mobility
Wireless
LANs
E


A
E
B
C
D
HTTP
TCP
IP
Ethernet
Coaxial
IP
Ethernet
Ethernet
Coaxial
Fiber-Optic
IP
Ethernet
Ethernet
Fiber-Opti
Coaxial
IP
Ethernet
802.11 MAC
Coaxial
802.11 PHY
HTTP
TCP
IP
802.11 MAC
802.11 PHY

Electromagnetic Spectrum



ISM Band (Industrial Scientific Medical)

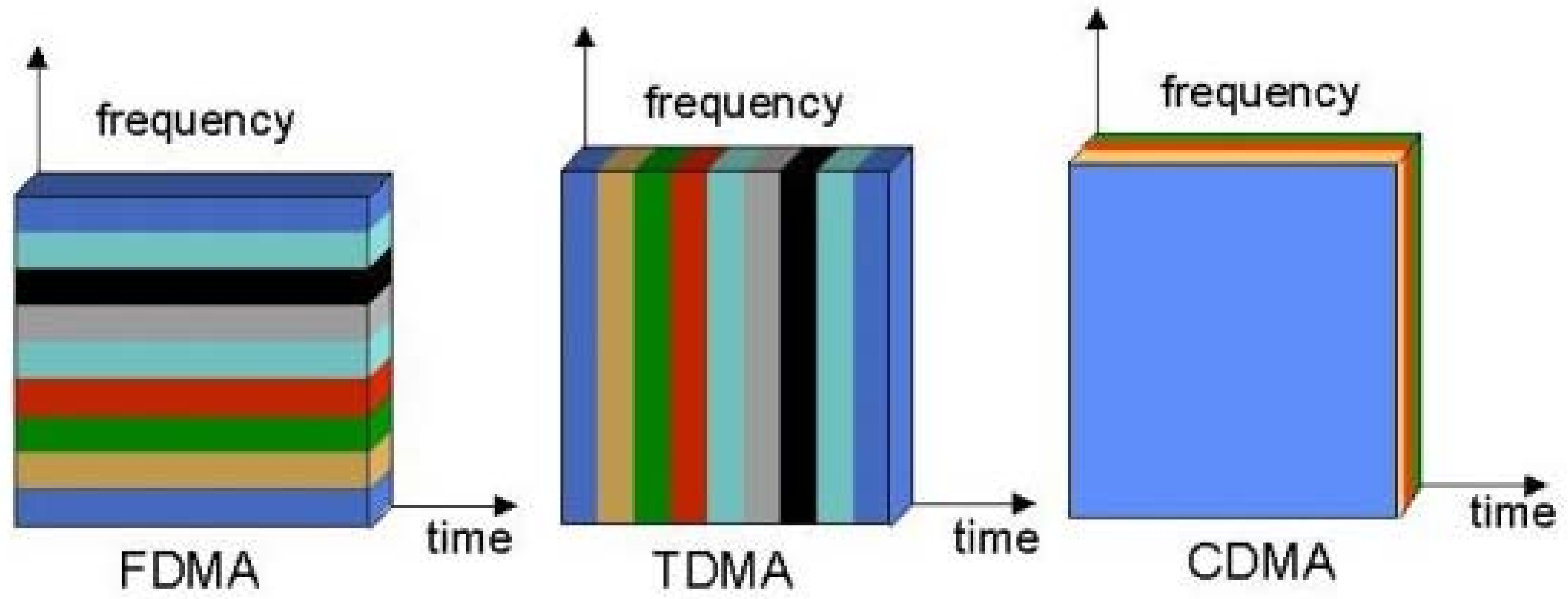


- Unlicensed, free to use
- Mainly used for WLANs

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

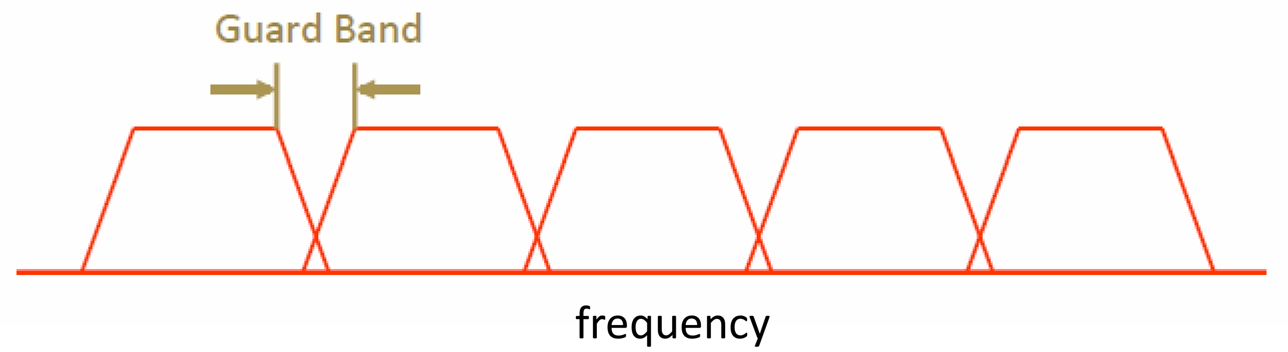
Multiple Access Schemes



3 orthogonal Schemes:

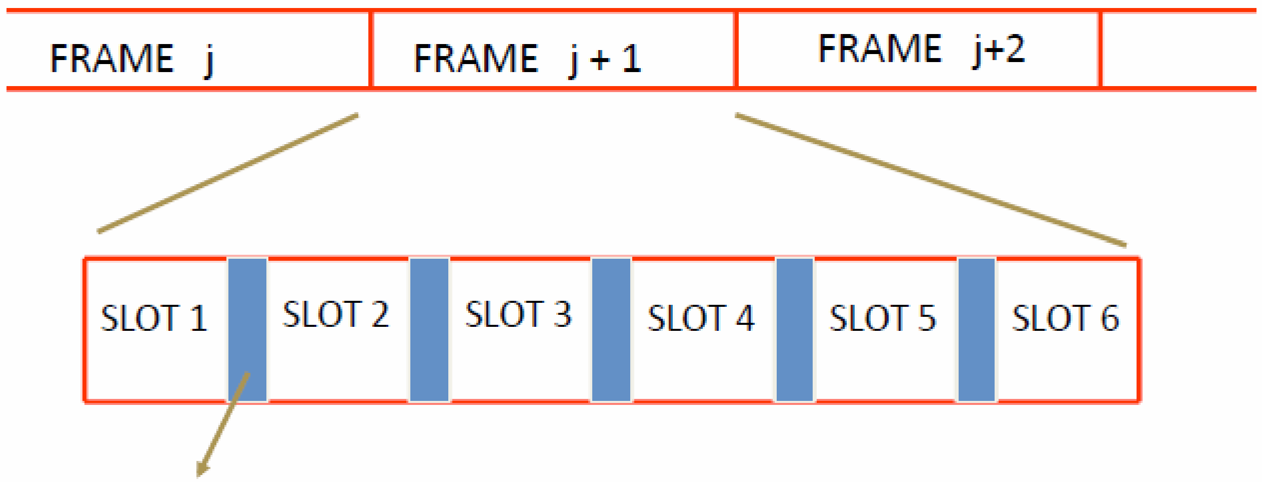
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

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 scare resource. We are running out of it

Time Division Multiple Access

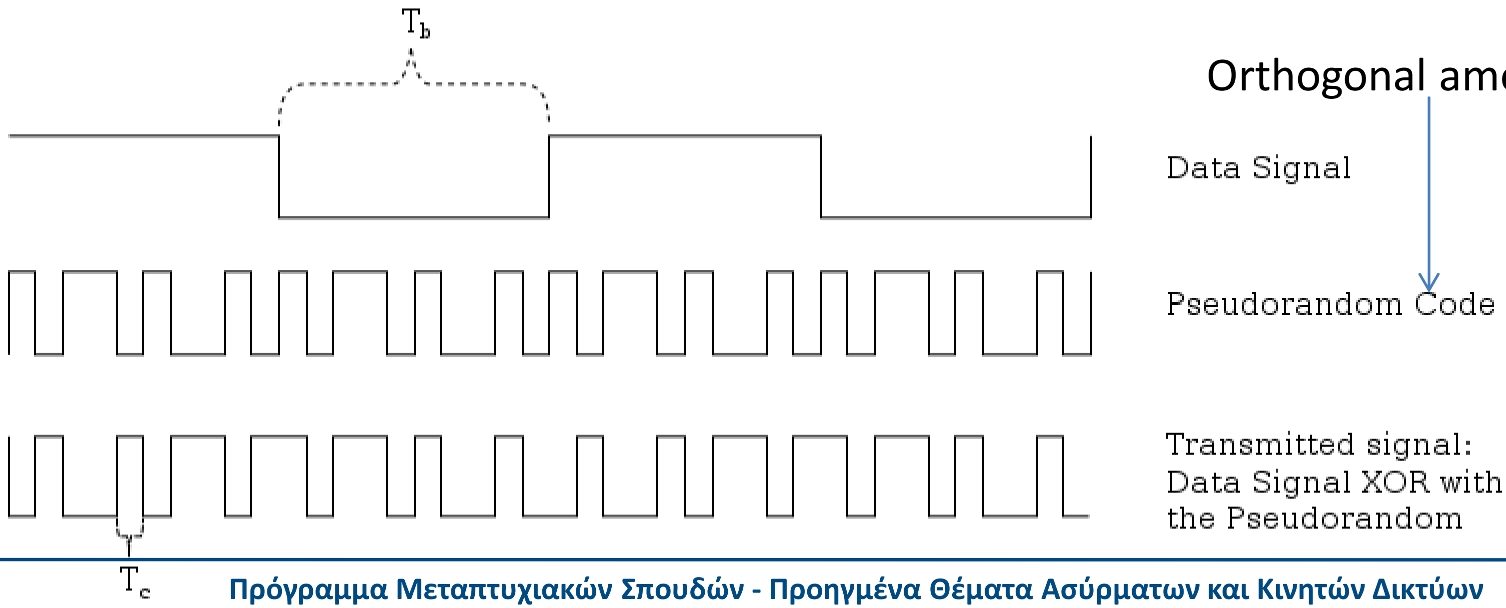


Guard time – signal transmitted by mobile terminals at different locations do no arrive at the base station at the same time

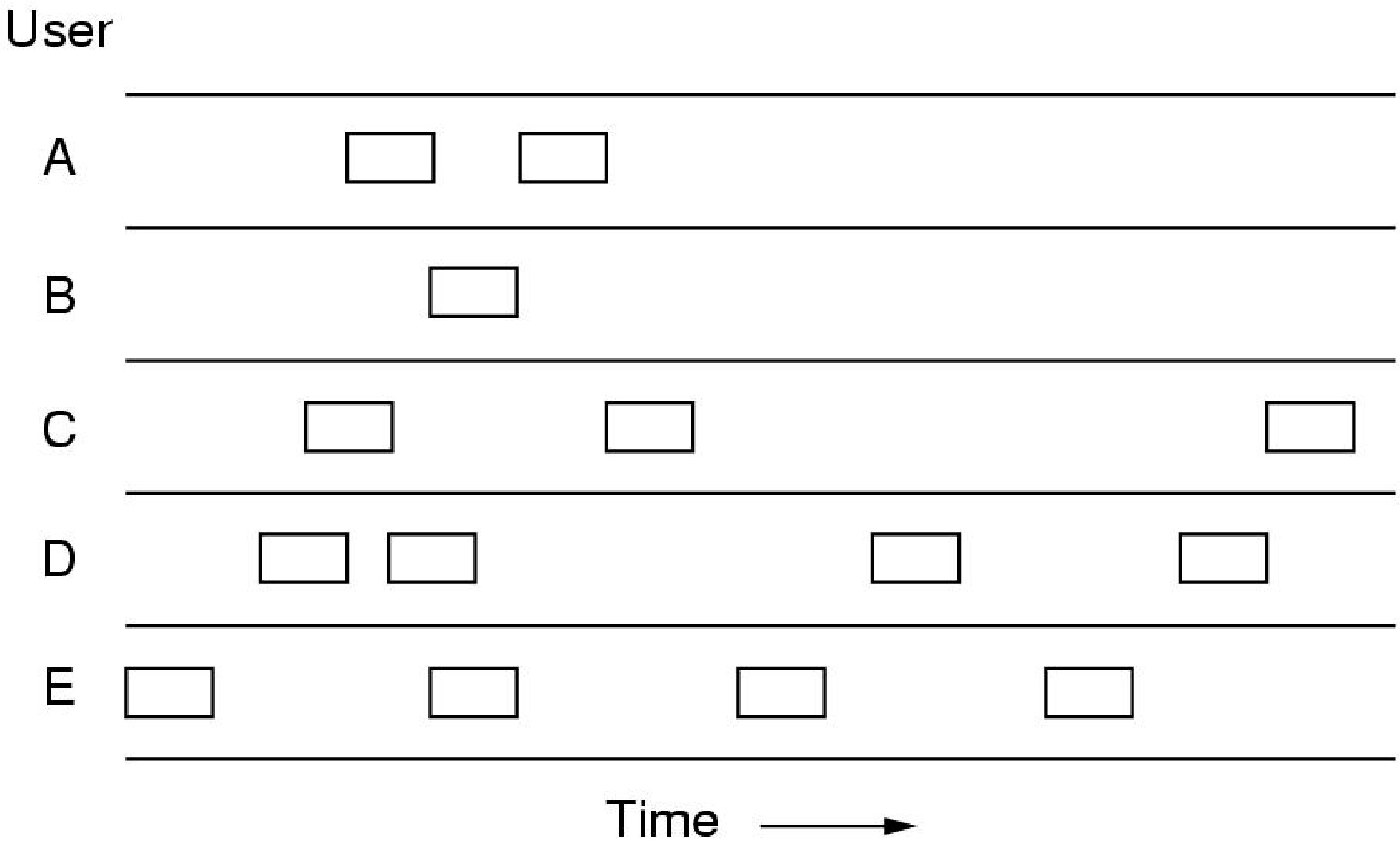
- Time is divided into slots and only one mobile terminal transmits during each slot
  - Like during the lecture, only one can talk, but others may take the floor in turn
- Each user is given a specific slot. No competition in cellular network
  - Unlike Carrier Sensing Multiple Access (CSMA) in WiFi

Code Division Multiple Access

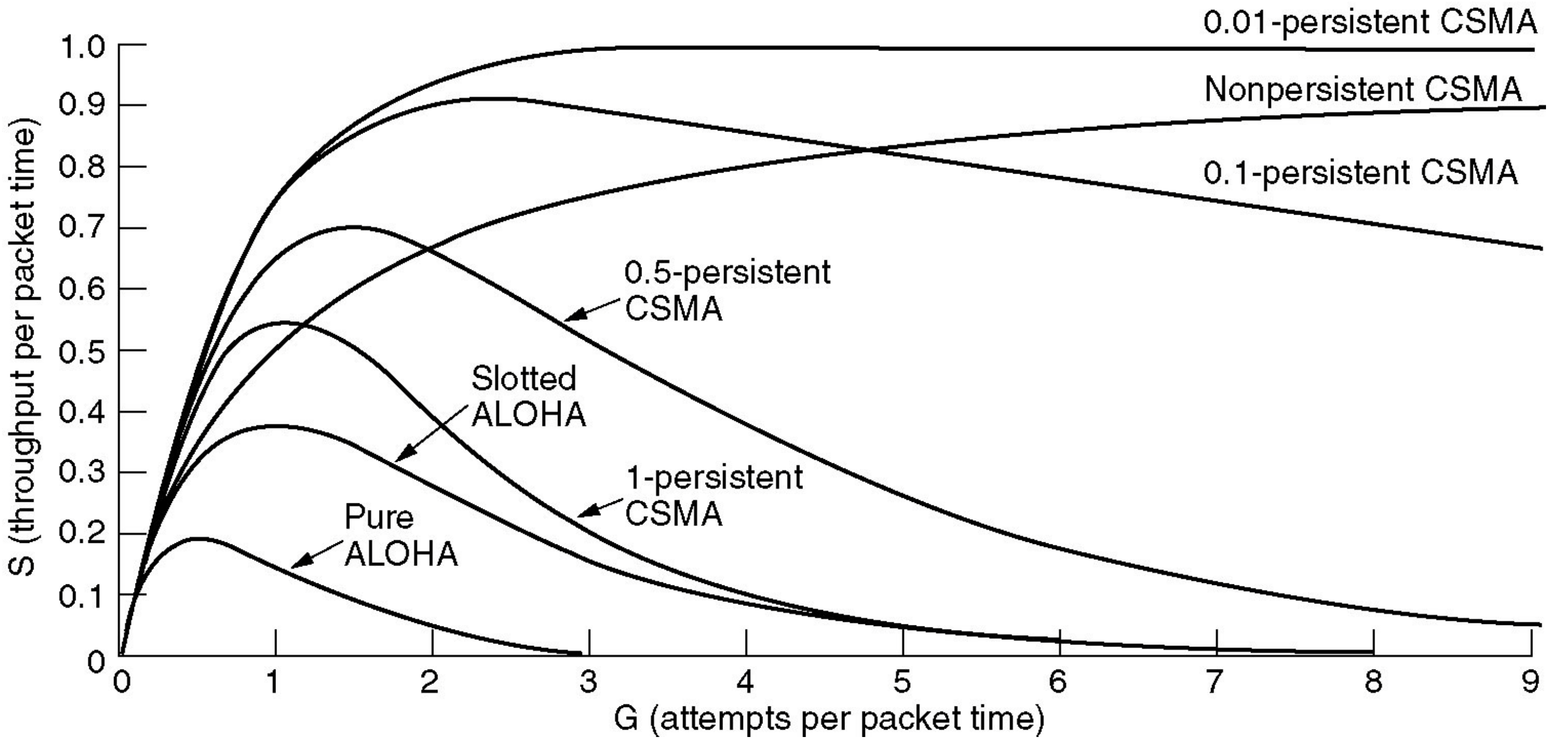
- Use of orthogonal codes to separate different transmissions
- Each symbol of bit is transmitted as a larger number of bits using the user specific code – Spreading
  - Bandwidth occupied by the signal is much larger than the information transmission rate
  - But all users use the same frequency band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



ALOHA

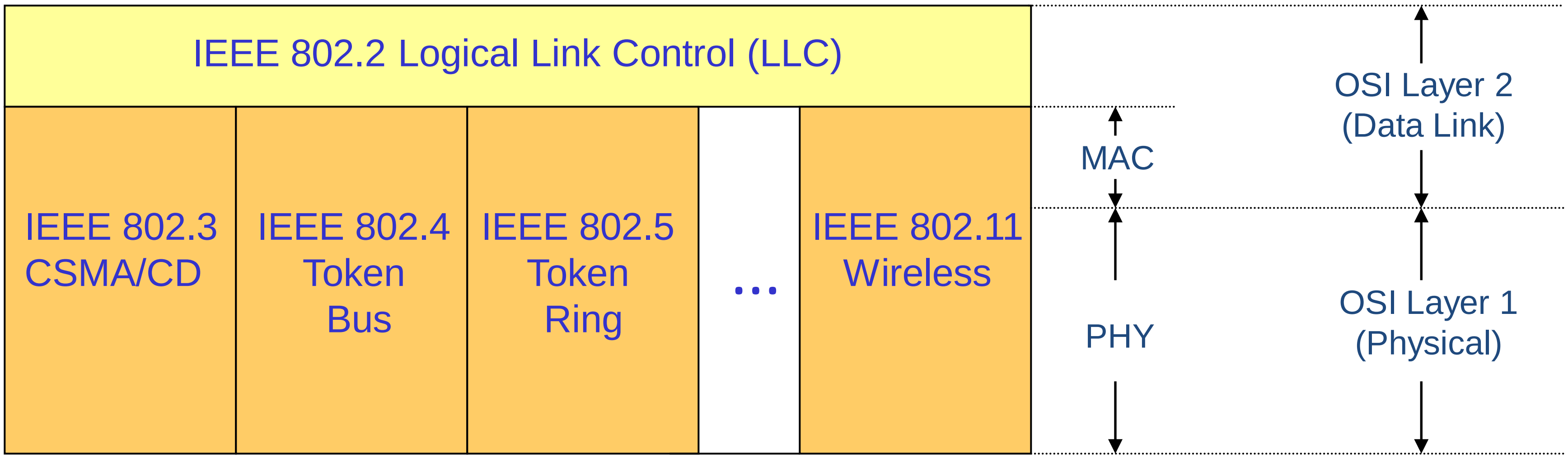


A comparison of simple protocols

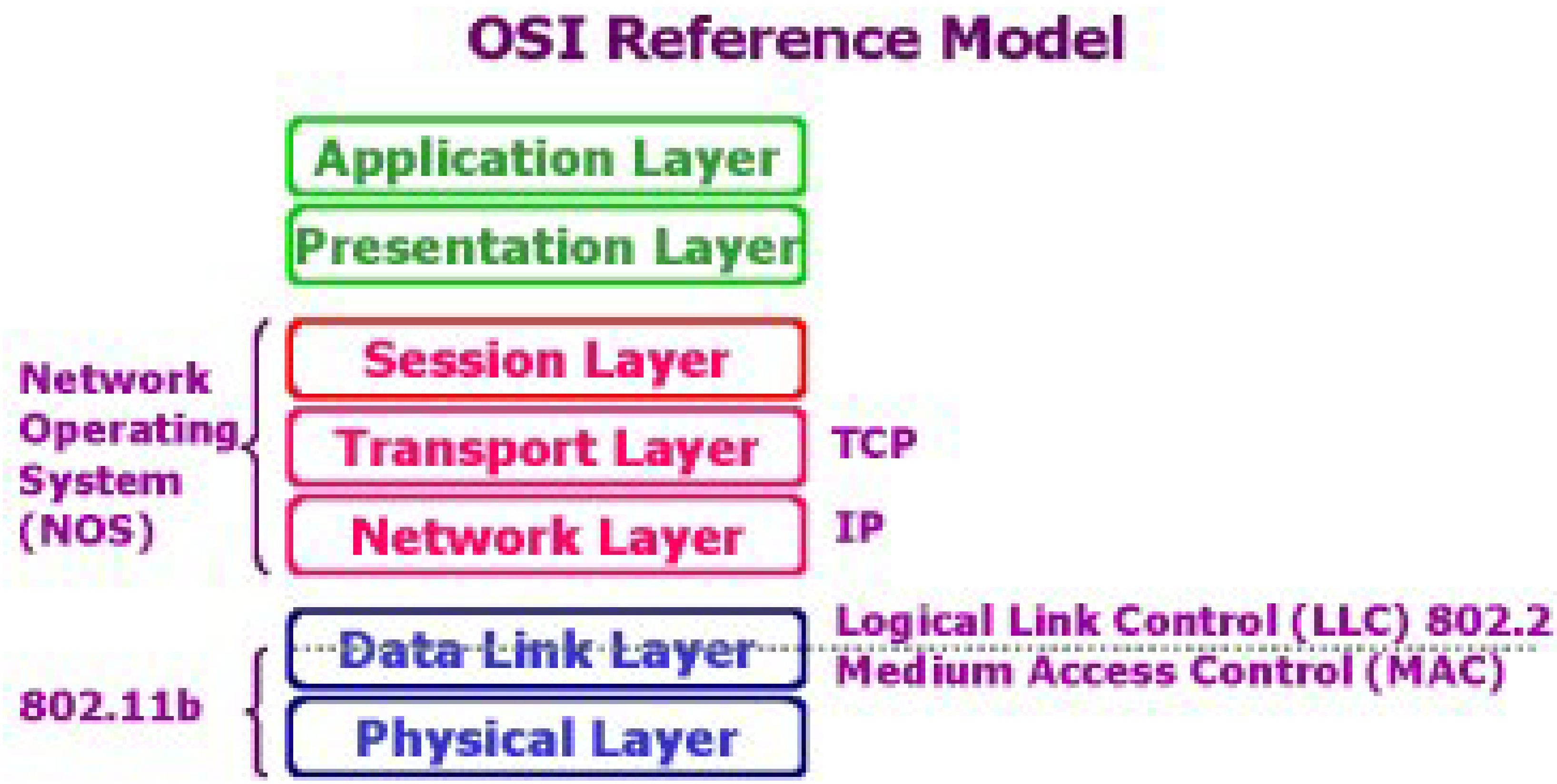


- Based on IEEE 802.11 standard and its amendments (a,b,g,n,…)
- Simple but efficient especially for light/medium traffic
- Cheap to implement and operate
- Constantly upgraded to be up to date
- Follows the evolution in wireless communications

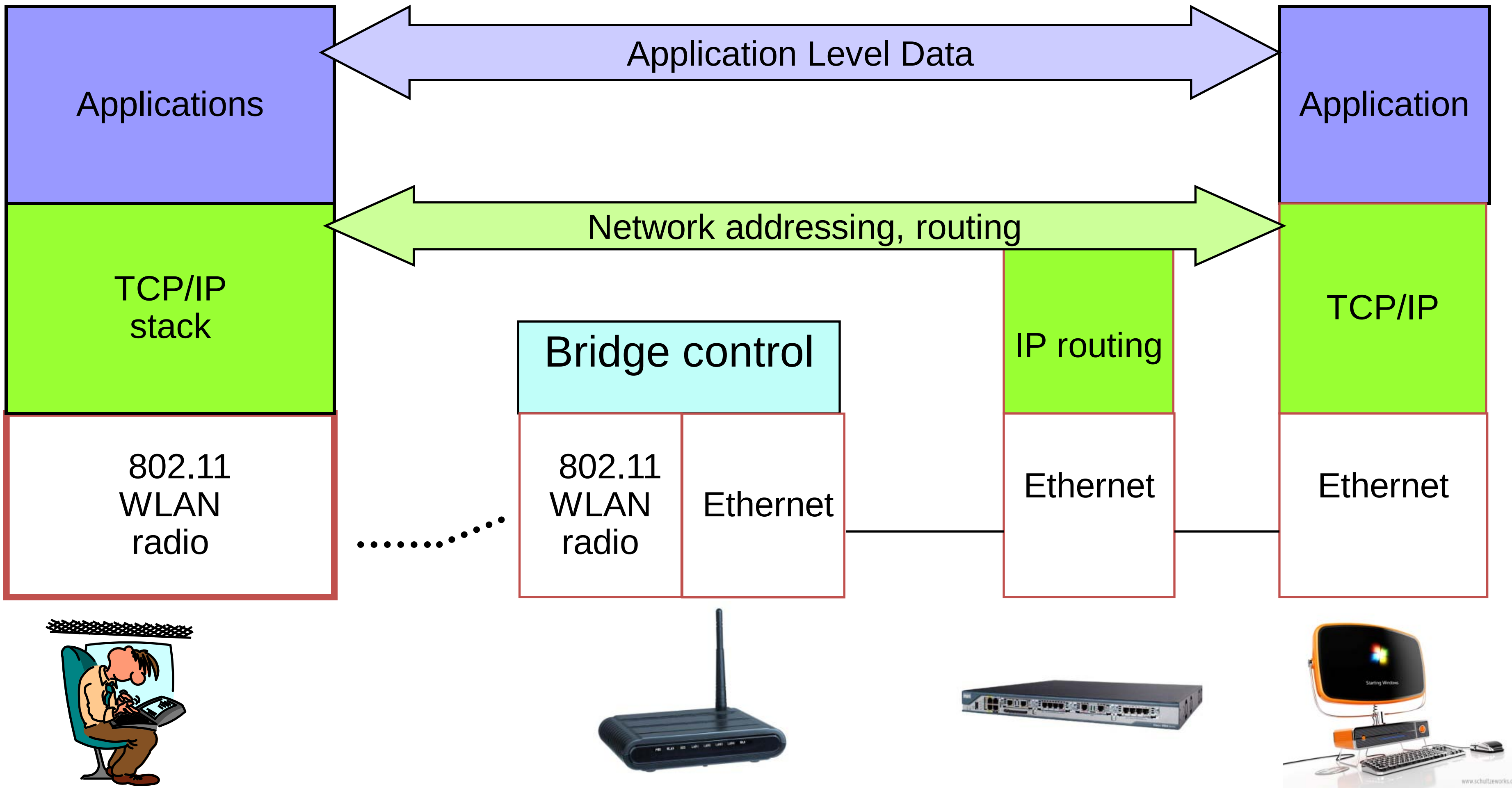
802.X Family of Standards



802.11 OSI Protocol Stack



802.11 – Ethernet Wireless Extension



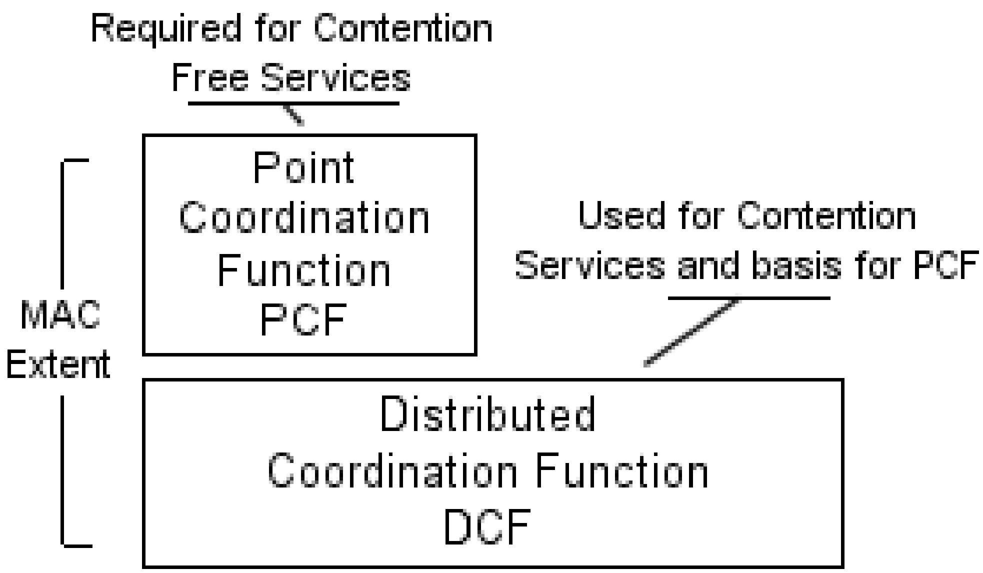
Access Modes

Distributed Coordination Function (DCF)

- Mandatory
- Basic access mode
- Contention-based

Point Coordination Function (PCF)

- Optional
- Contention-free
- Lower delay variance

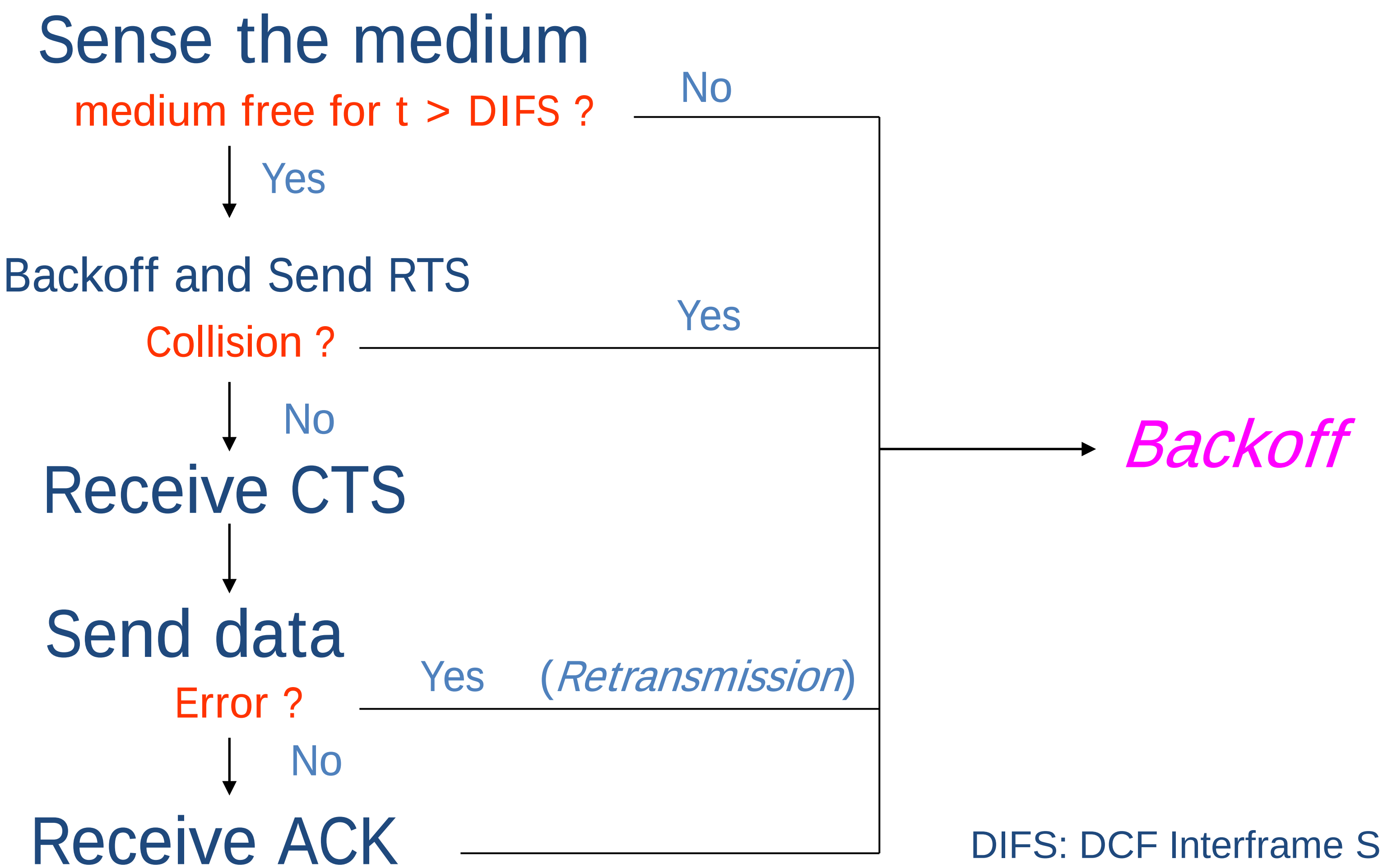


Distributed Coordination Function

- CSMA/CA based protocol
  - Listen before talk
  - Collision Avoidance instead of Collision Detection
  - Different than CSMA/CD used in wired Ethernet (why ??)

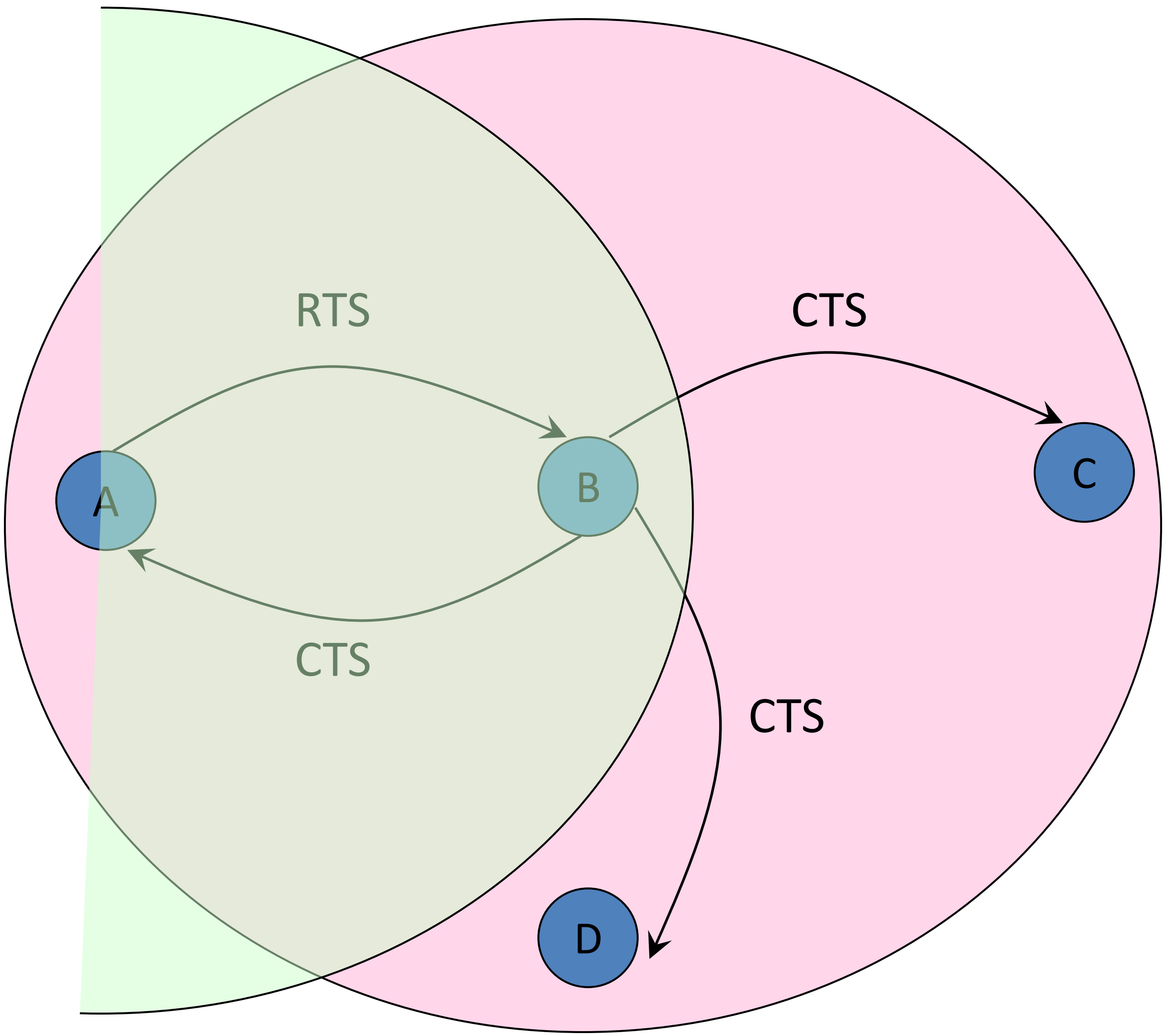
- Uses acknowledgment for all transmission
- Data correction through retransmissions
- 4-way handshake (RTS/CTS/Data/Ack) for «Virtual Carrier Sensing»
- Handles hidden terminal problem

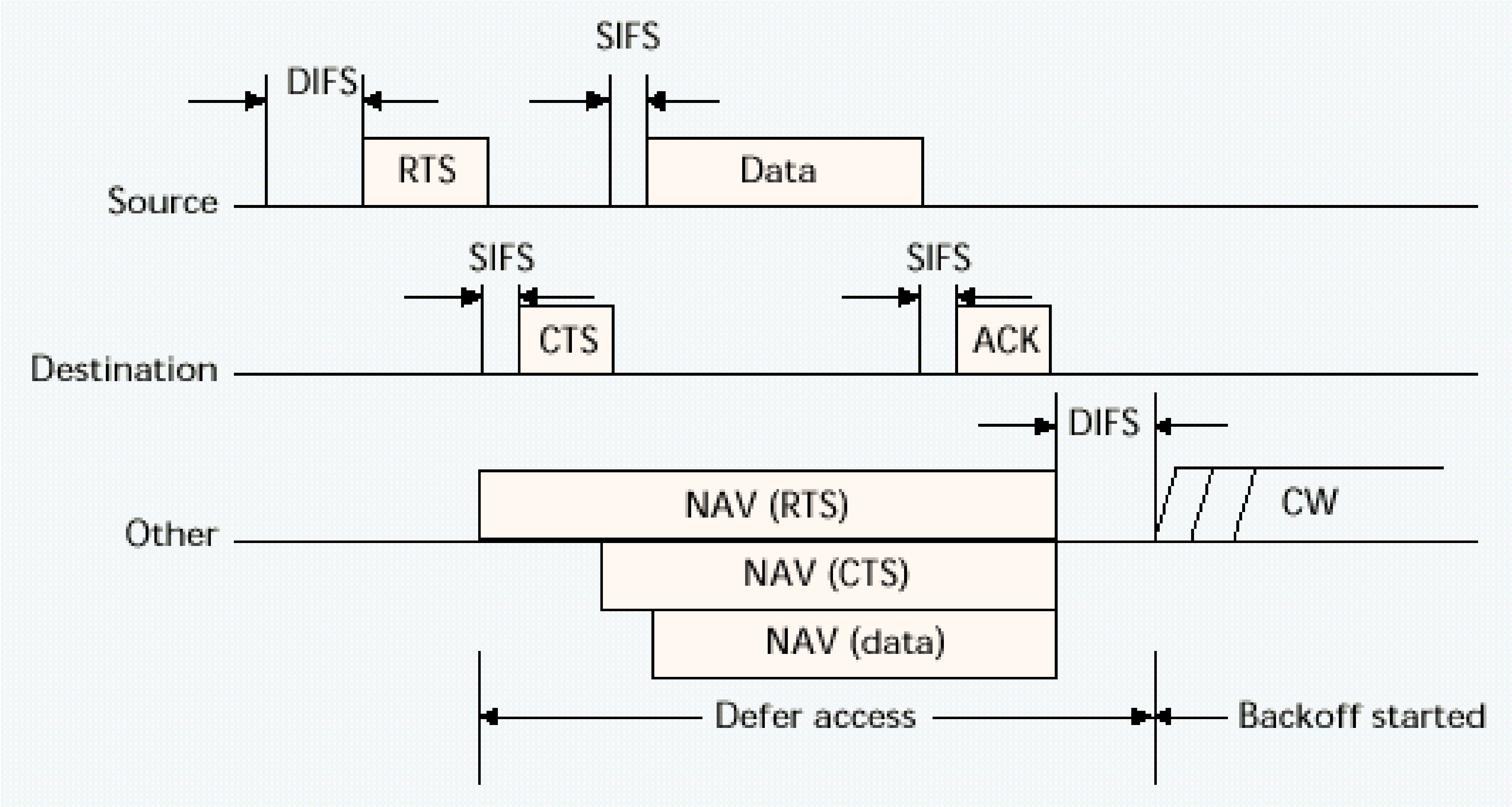
Distributed Coordination Function



DIFS: DCF Interframe Space

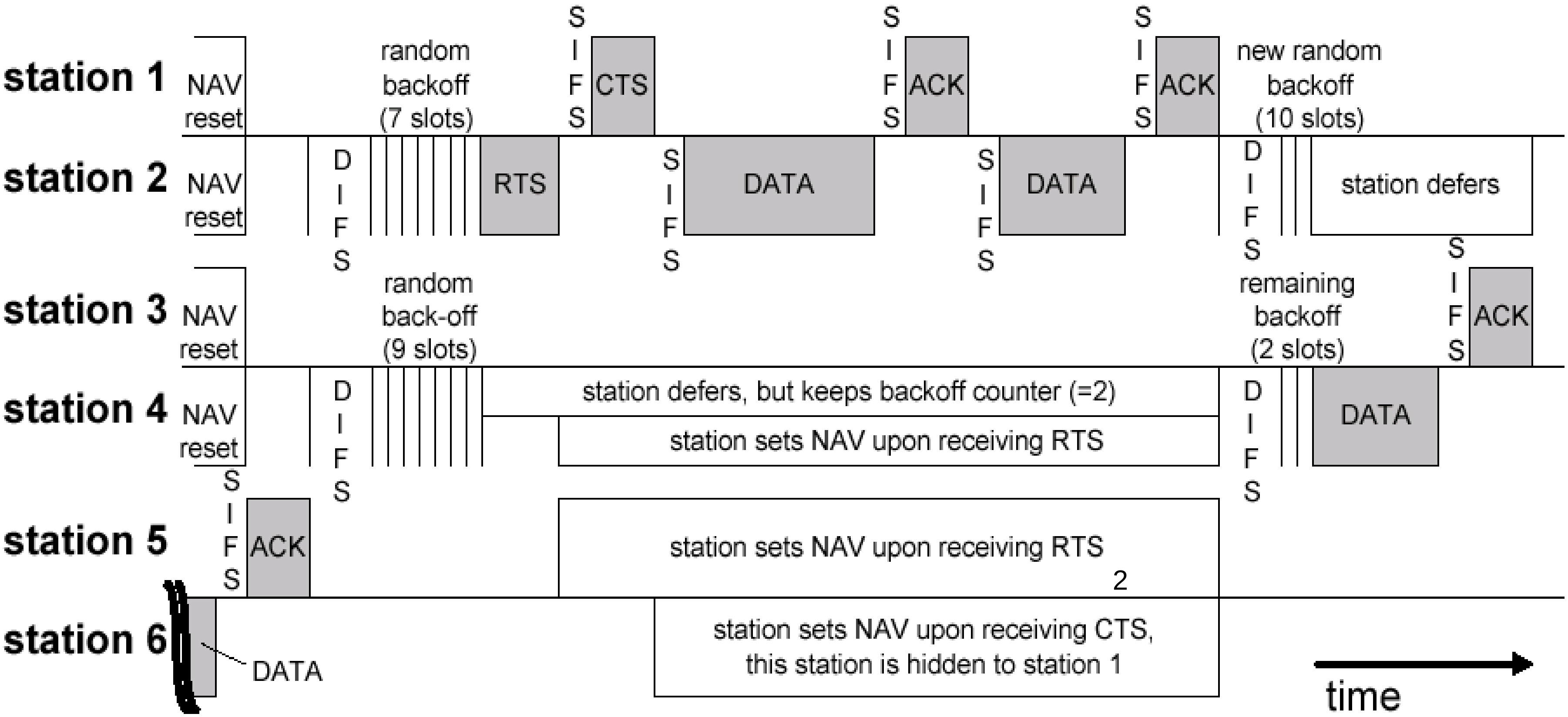
Collision avoidance in node B





- Always SIFS<DIFS
- Power saving through the NAVs

Example of DCF Transmission



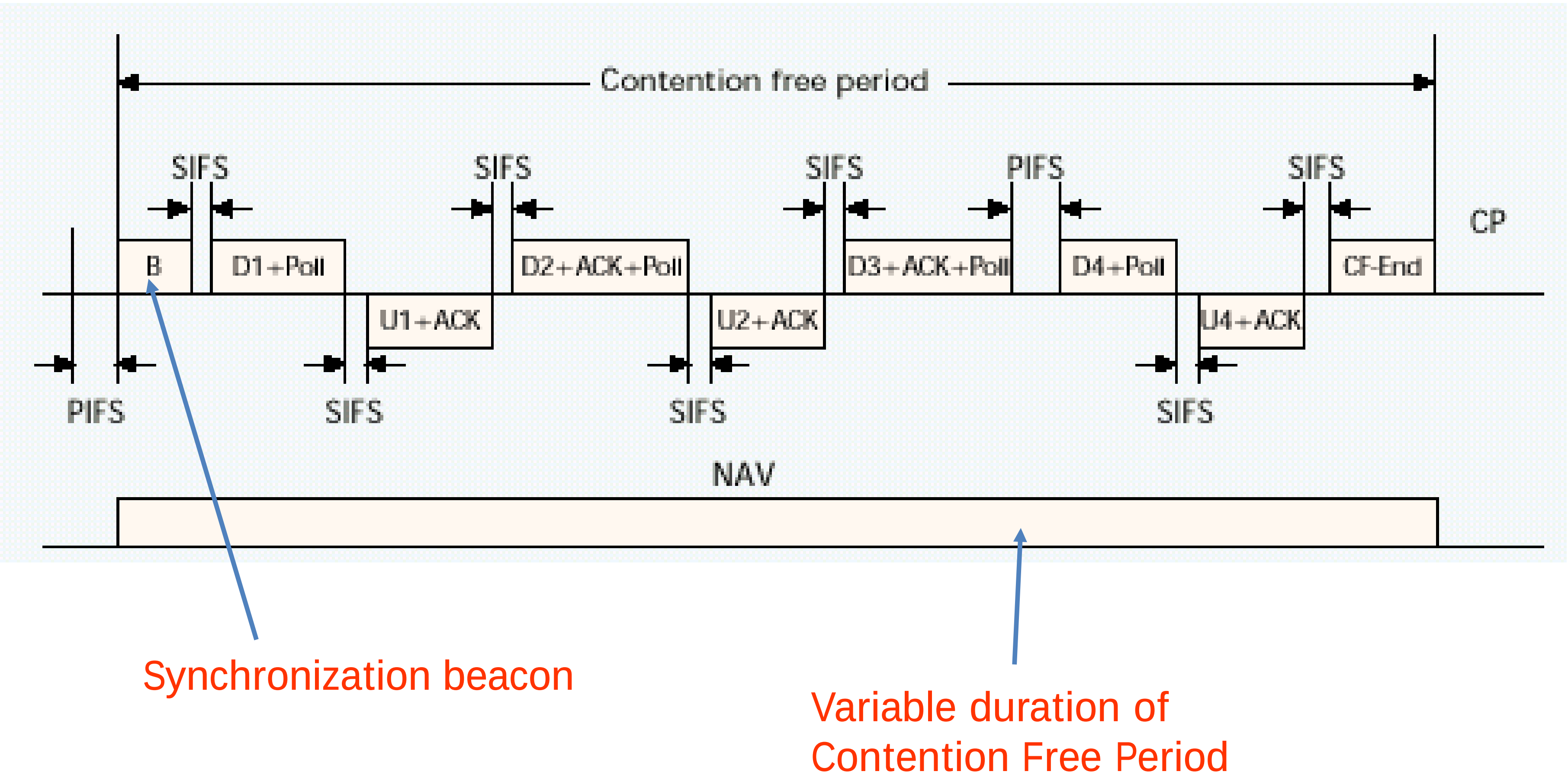
Disadvantages of DCF

- 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



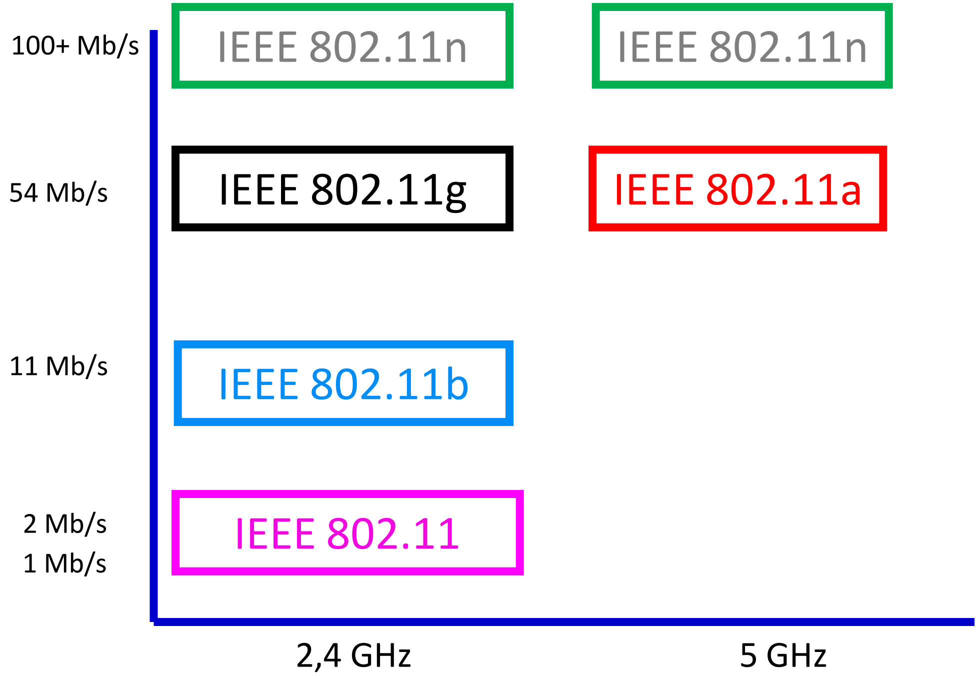
Disadvantages of PCF for QoS

✓ 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)

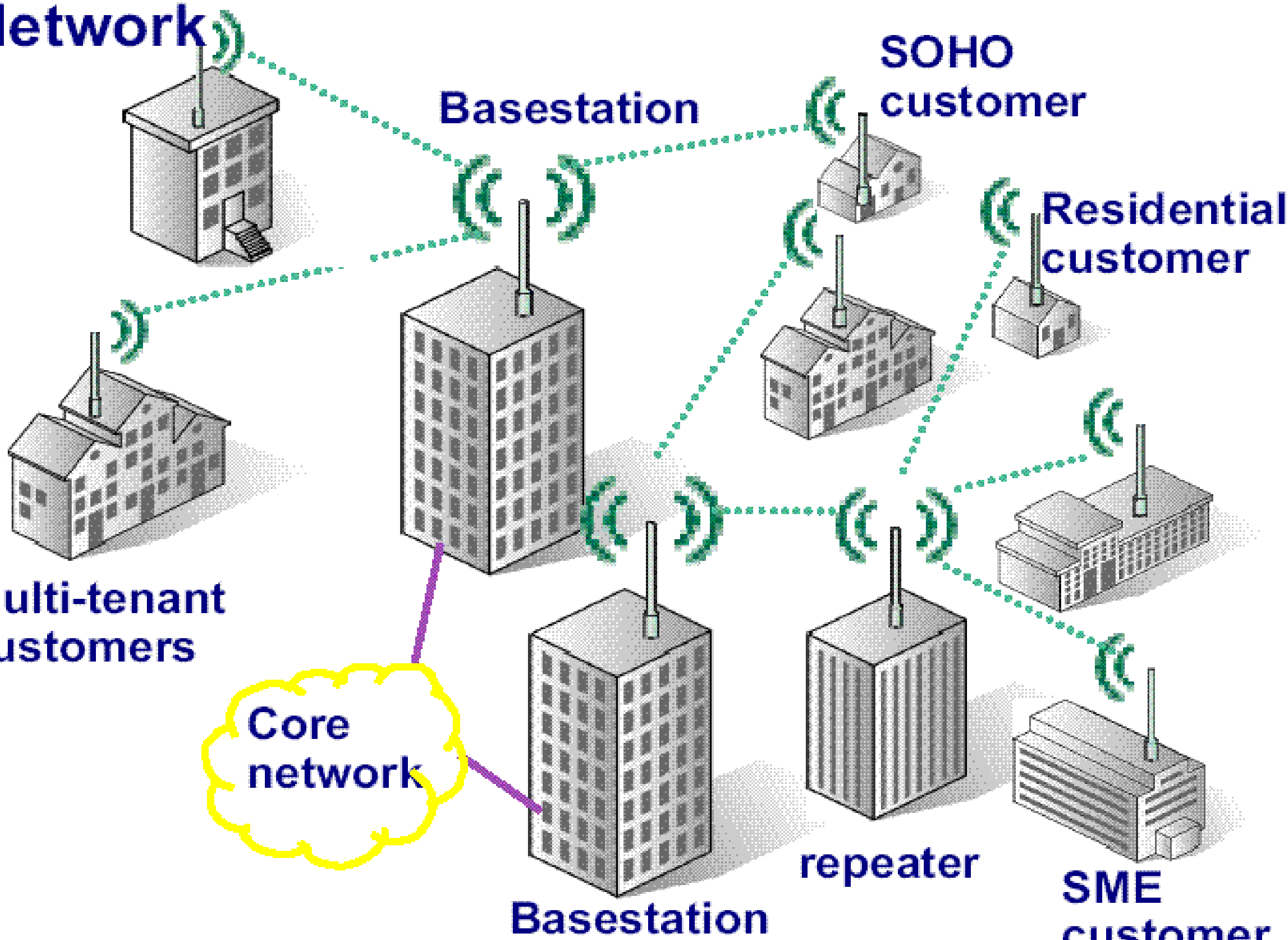


	802.11a	802.11b	802.11g	802.11n
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS	OFDM	OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of spatial streams (MIMO)	1	1	1	1 to 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

IEEE 802.16
WiMaX

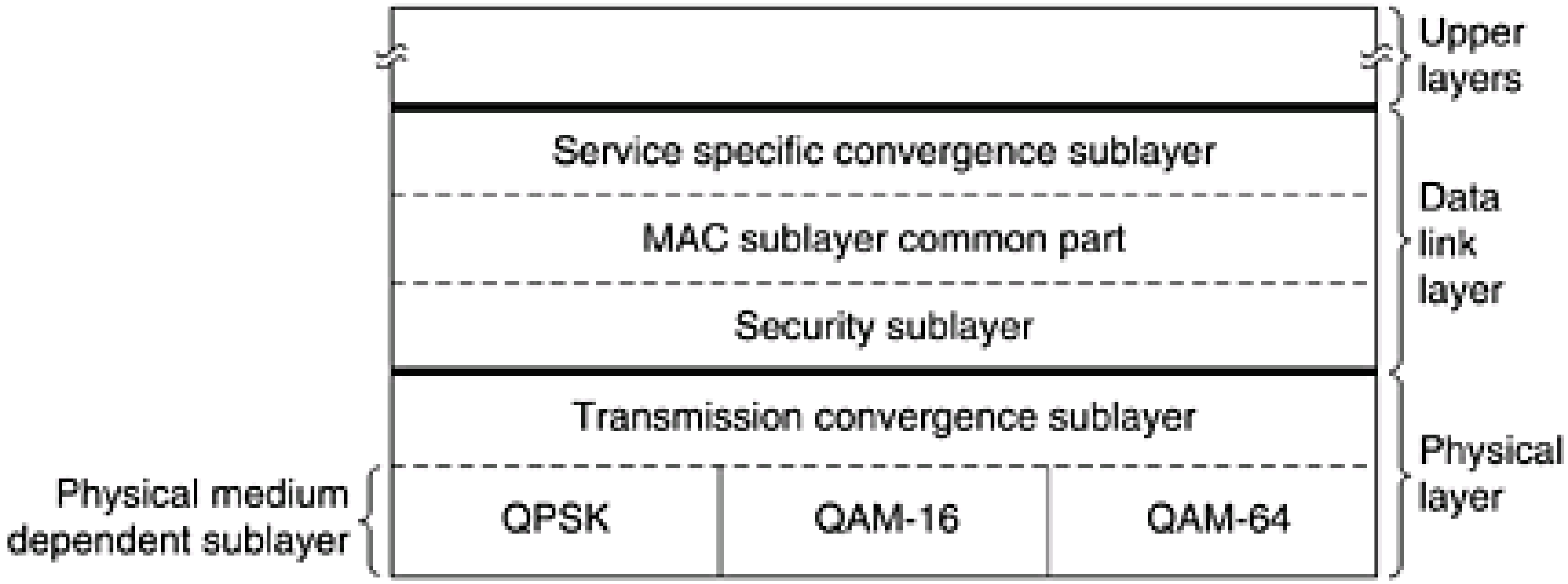
"Air Interface for Fixed Broadband Wireless Access Systems"

WirelessMAN: Wireless Metropolitan Area Network

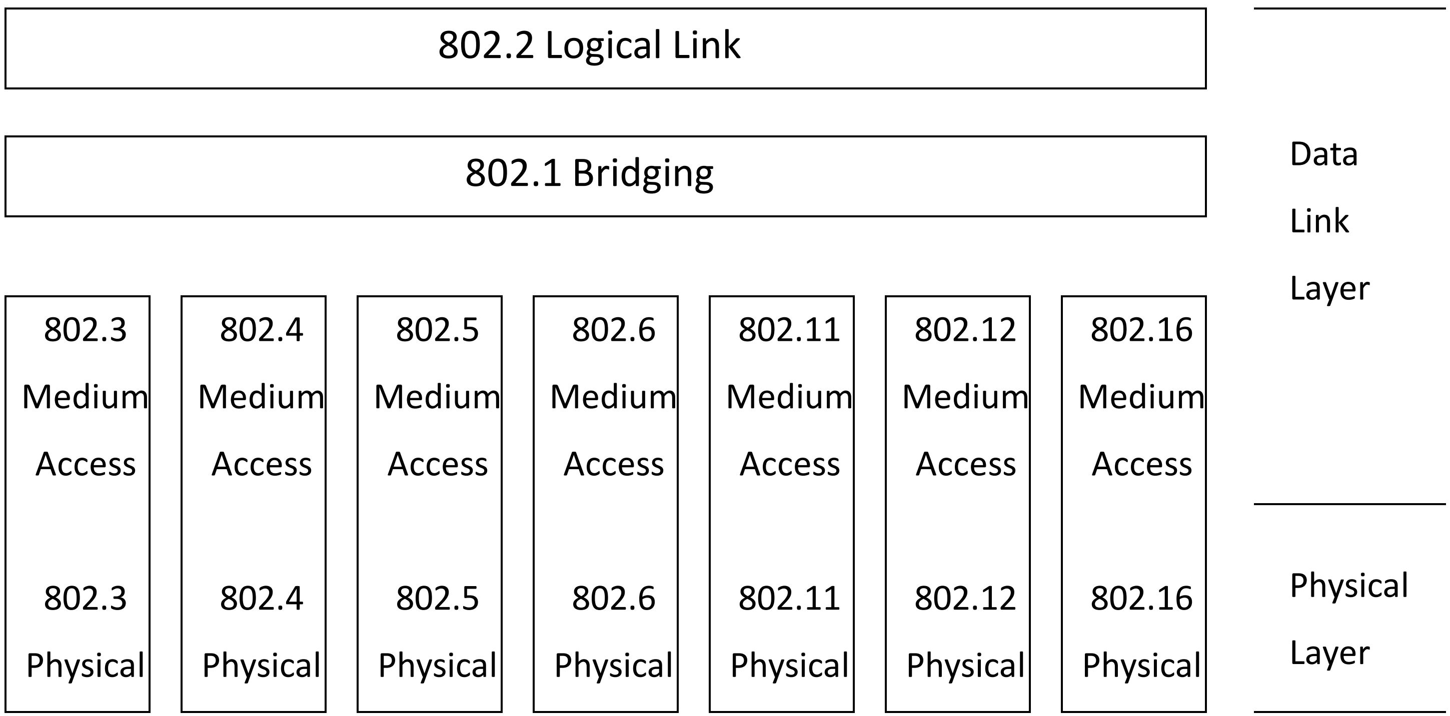


Source: Nokia Networks

WiMaX Layers

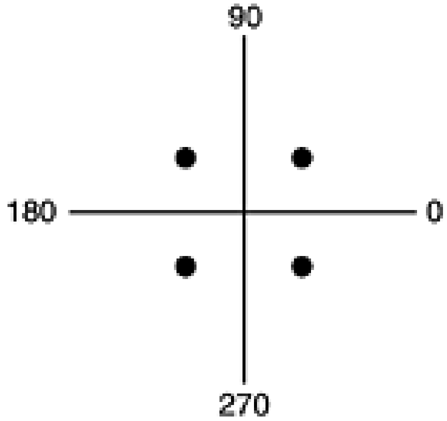


The 802 Family

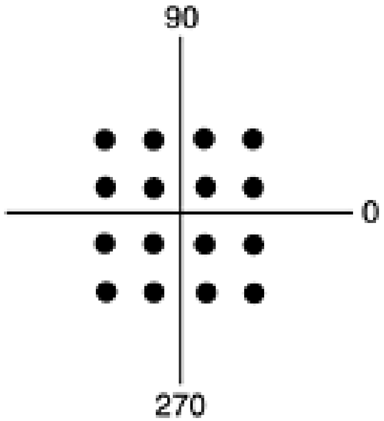


Multiple modulations

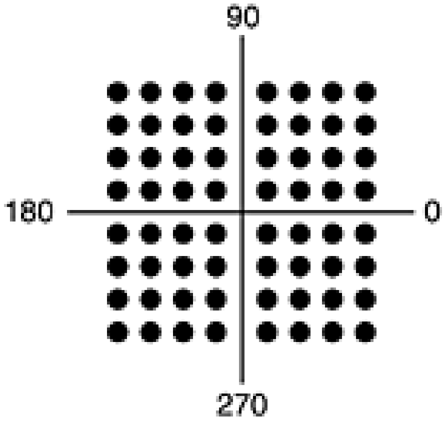
- QPSK (Quadrature Phase Shift Keying) = 4 phase shifts, 1 amplitude level, 2 bits/symbol
- QAM-16 = 4 phase shifts, 4 amplitude levels, 4 bits/symbol
- QAM-64 = 4 phase shifts, 16 amplitude levels, 6 bits/symbol



QPSK

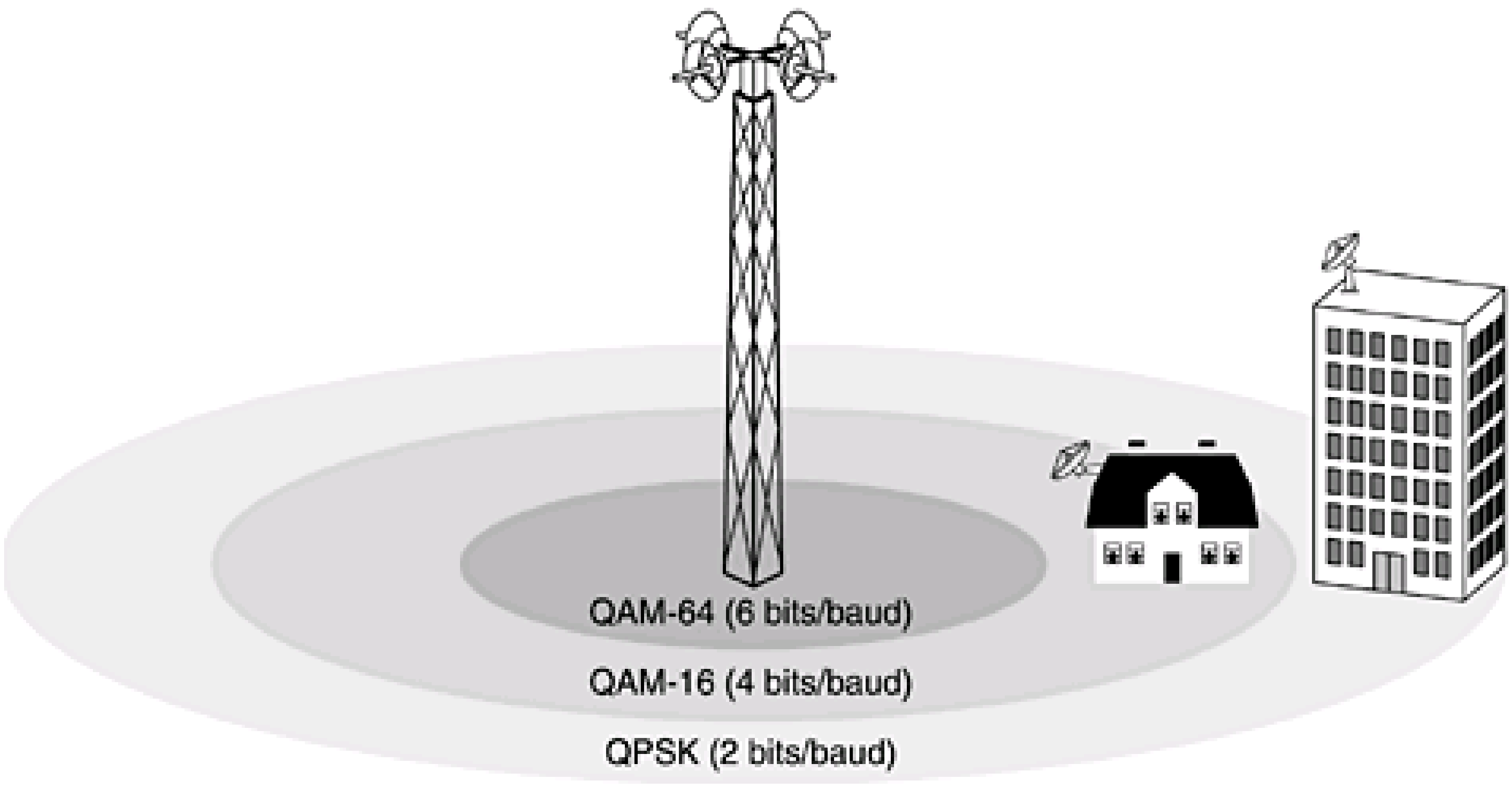


QAM-16



QAM-64

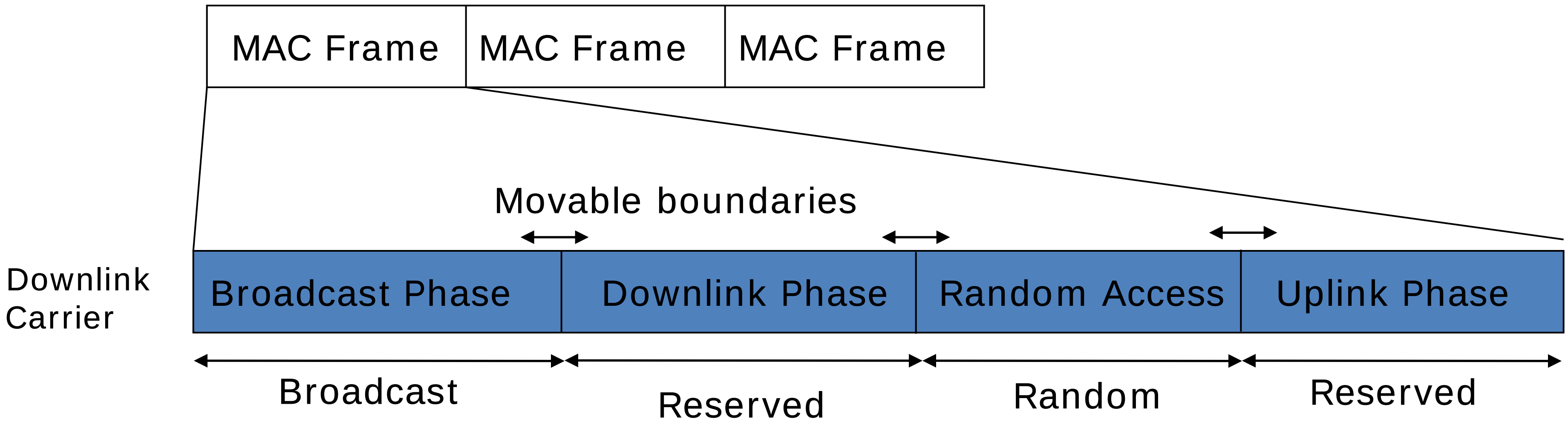
Adaptive modulation



Adaptive modulation in WiMaX

Modulation	FEC Coding Rate	Uncoded Burst Rate (Mbps)	End to End Ethernet Throughput (Mbps)
BPSK	½	6	5.7
BPSK	¾	9	8.6
QPSK	½	12	11.4
QPSK	¾	18	17
16QAM	½	24	22.4
16QAM	¾	36	33
64QAM	2/3	48	43.2
64QAM	¾	54	48.1

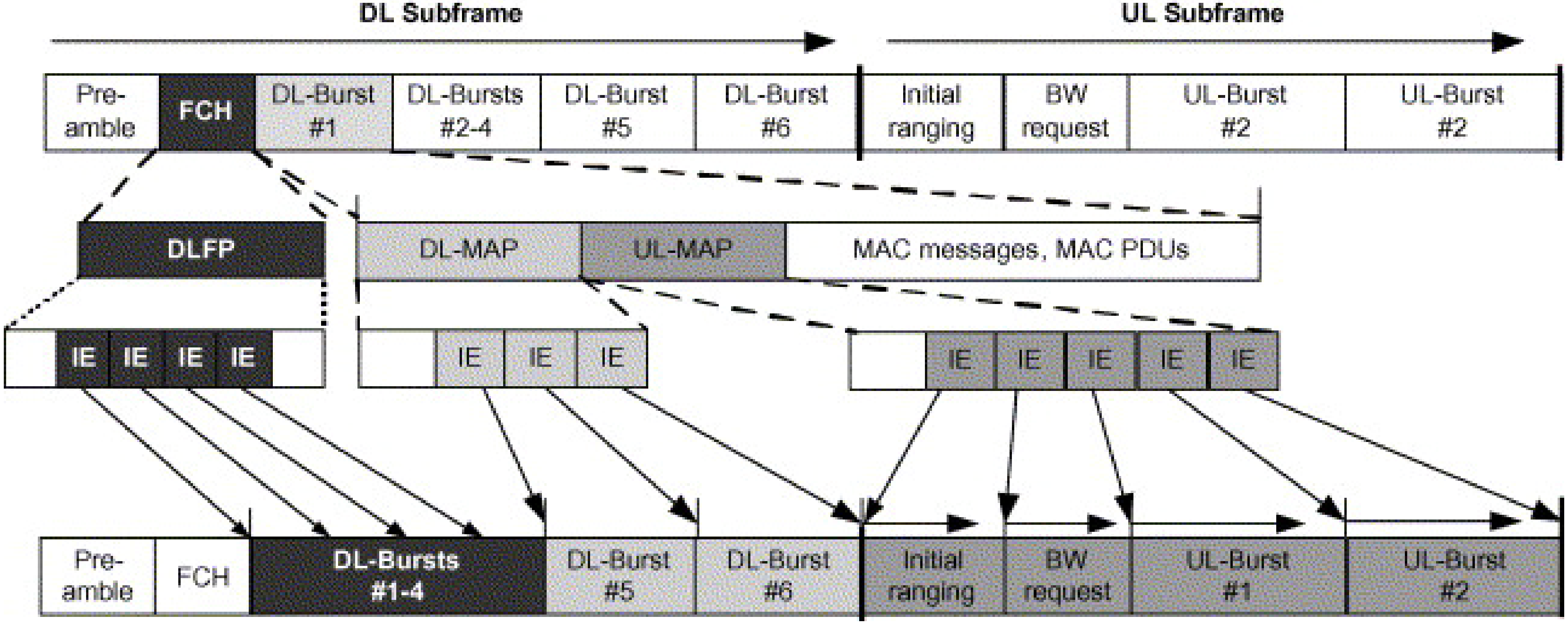
Time Division Duplexing (TDD)

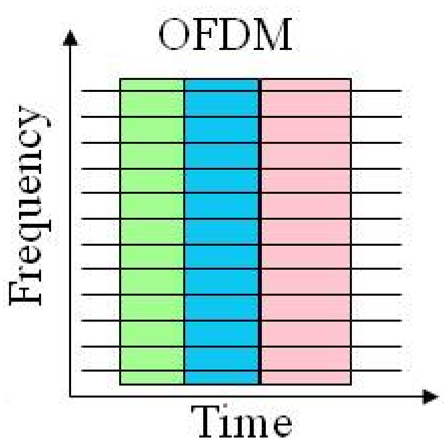


Media Access Control (MAC)

- Connection oriented μετάδοση
    - Connection ID (CID)
    - Uni-directional

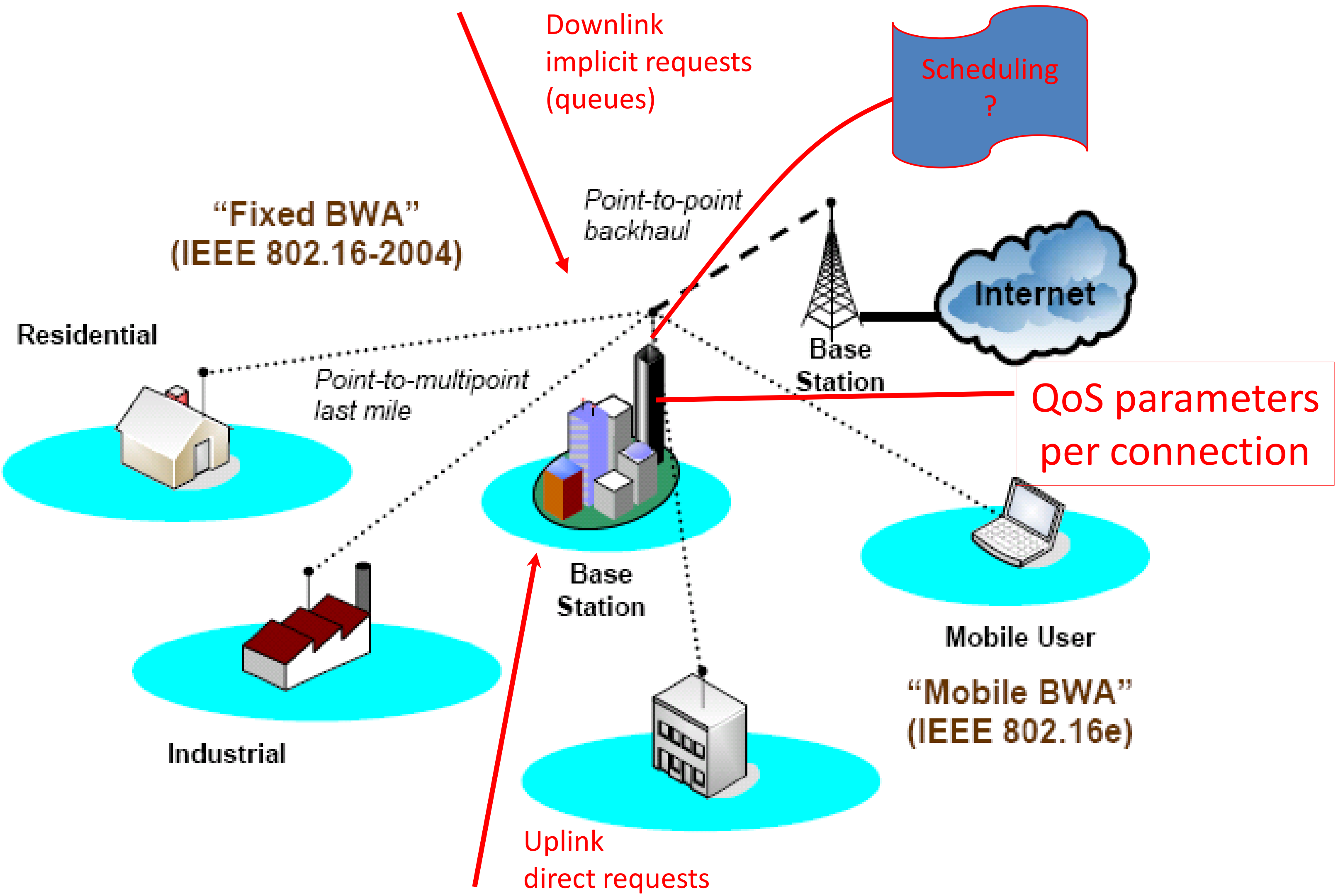
- Channel access:
    - UL-MAP
        - Includes reservation information for the uplink
        - Who transmits (to the Base Station) and when
    - DL-MAP
        - Includes reservation information for the downlink
        - Who receives (from the Base Station) and when
    - UL-MAP and DL-MAP are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





QoS - Priorities
Uplink → problem ?

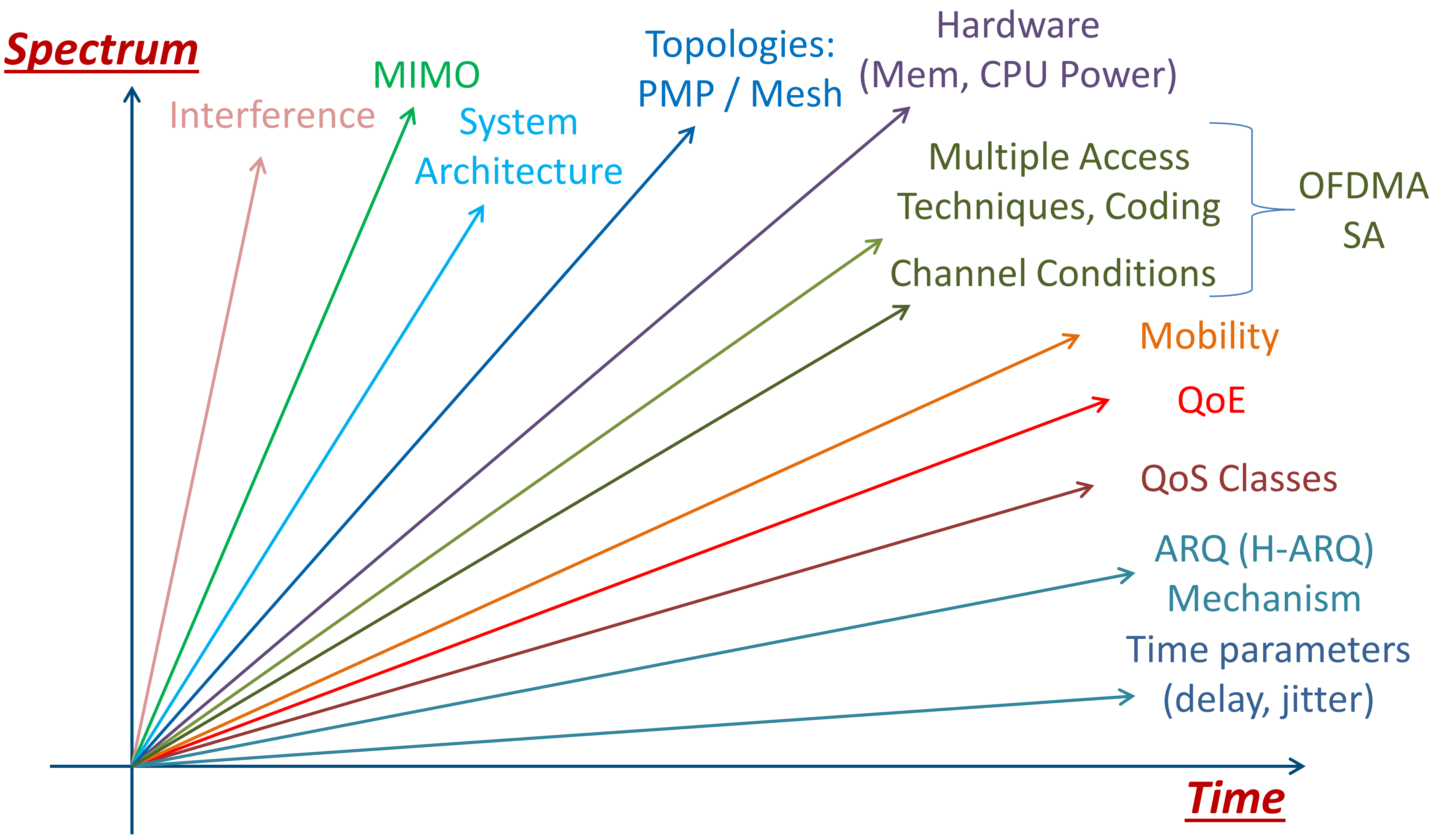
Bandwidth request and allocation



Extensions in 802.16e

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

Dimensionize Resource Management



Scheduler/RA's role

QoS

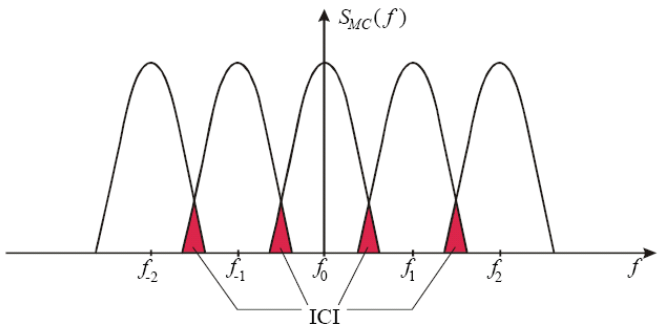
Resources

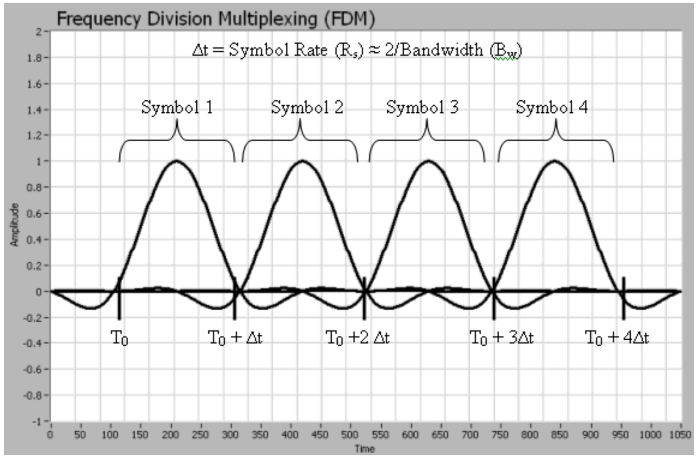
Wireless
System
Architecture

Transmission / Access
Techniques

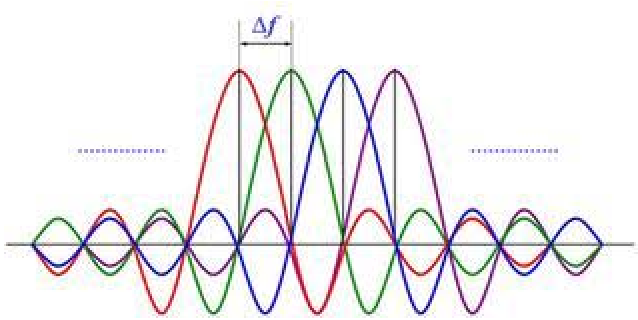
OFDM: Orthogonal Frequency Division Multiplexing

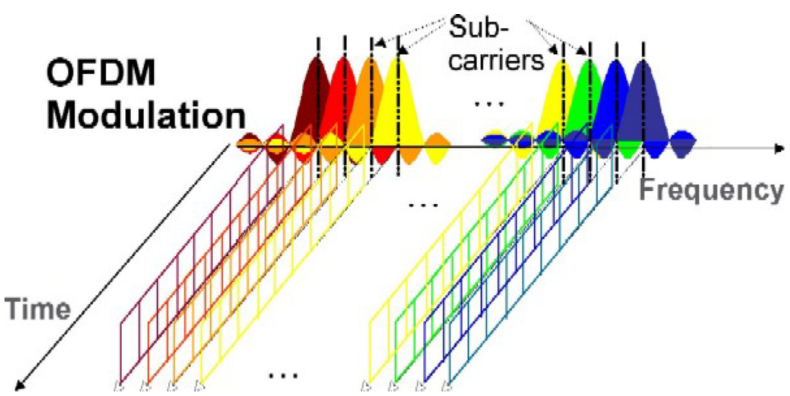
Traditional FDM





OFDM

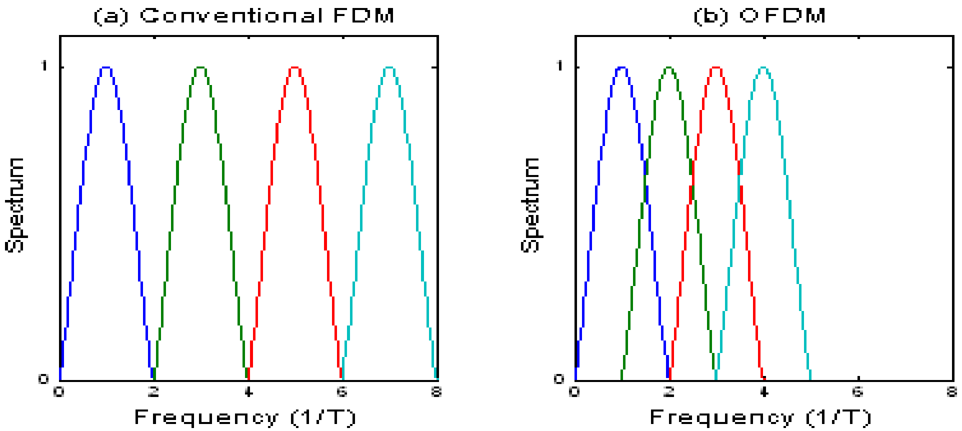




OFDM pros and cons

Pros

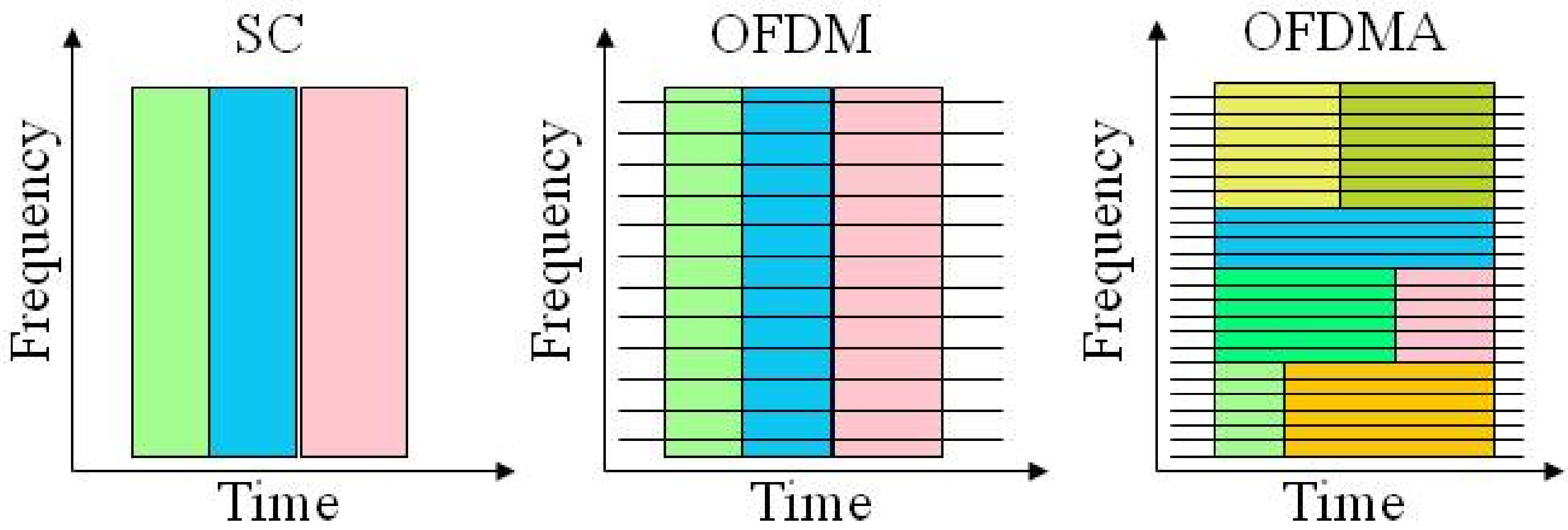
- Spectral efficiency
- Robust against narrow-band co-channel interference
- Higher throughput in the same frequency band (more subcarriers)



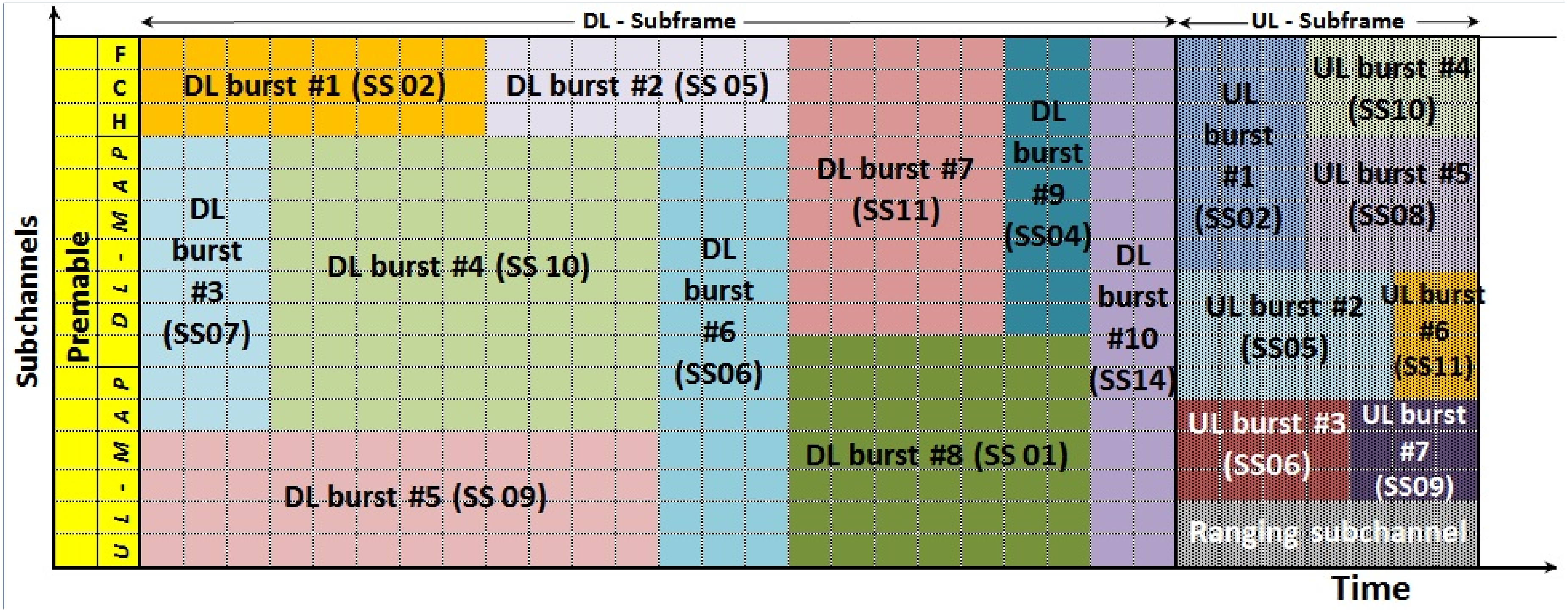
Cons

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

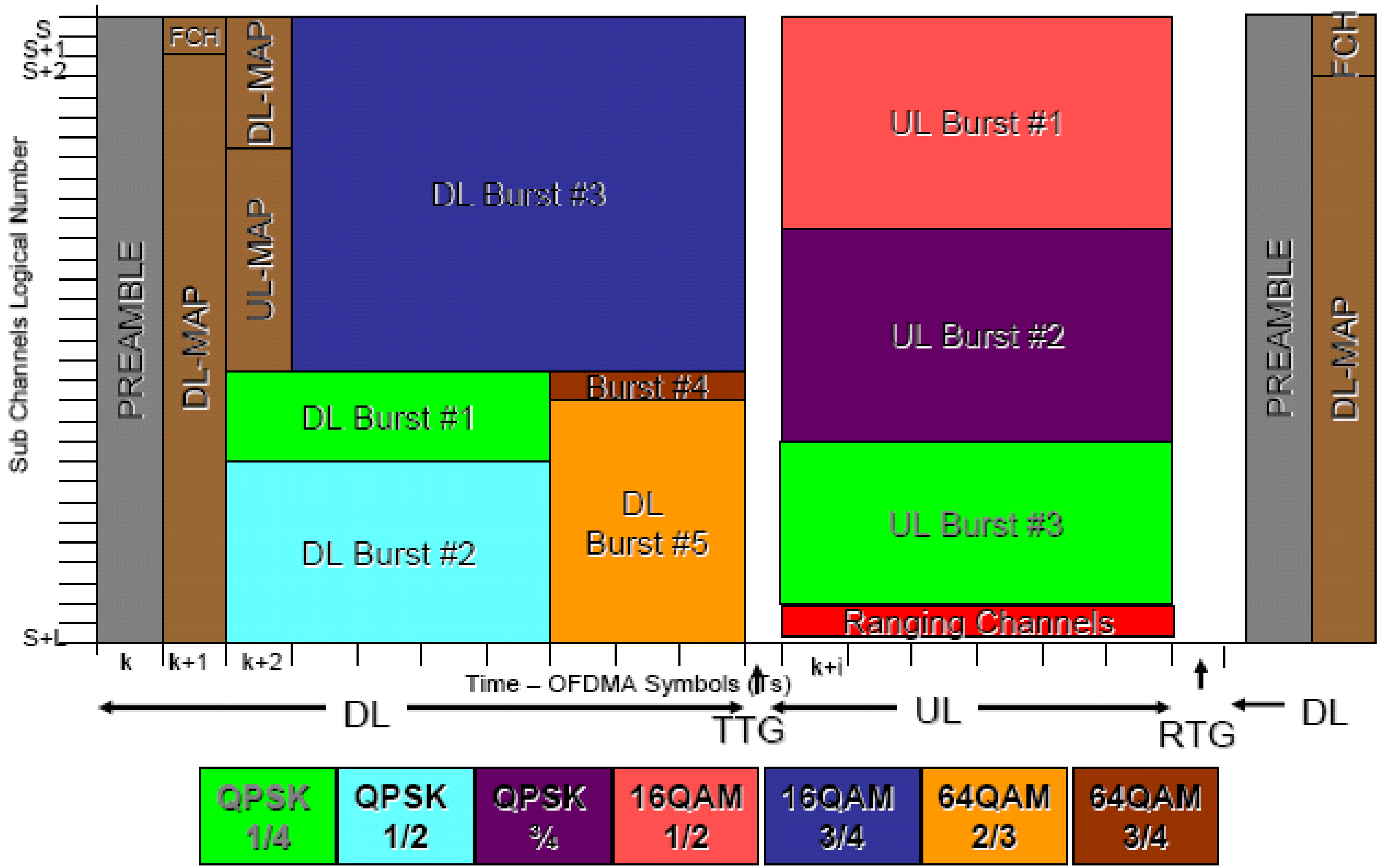
SC/OFDM/OFDMA



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