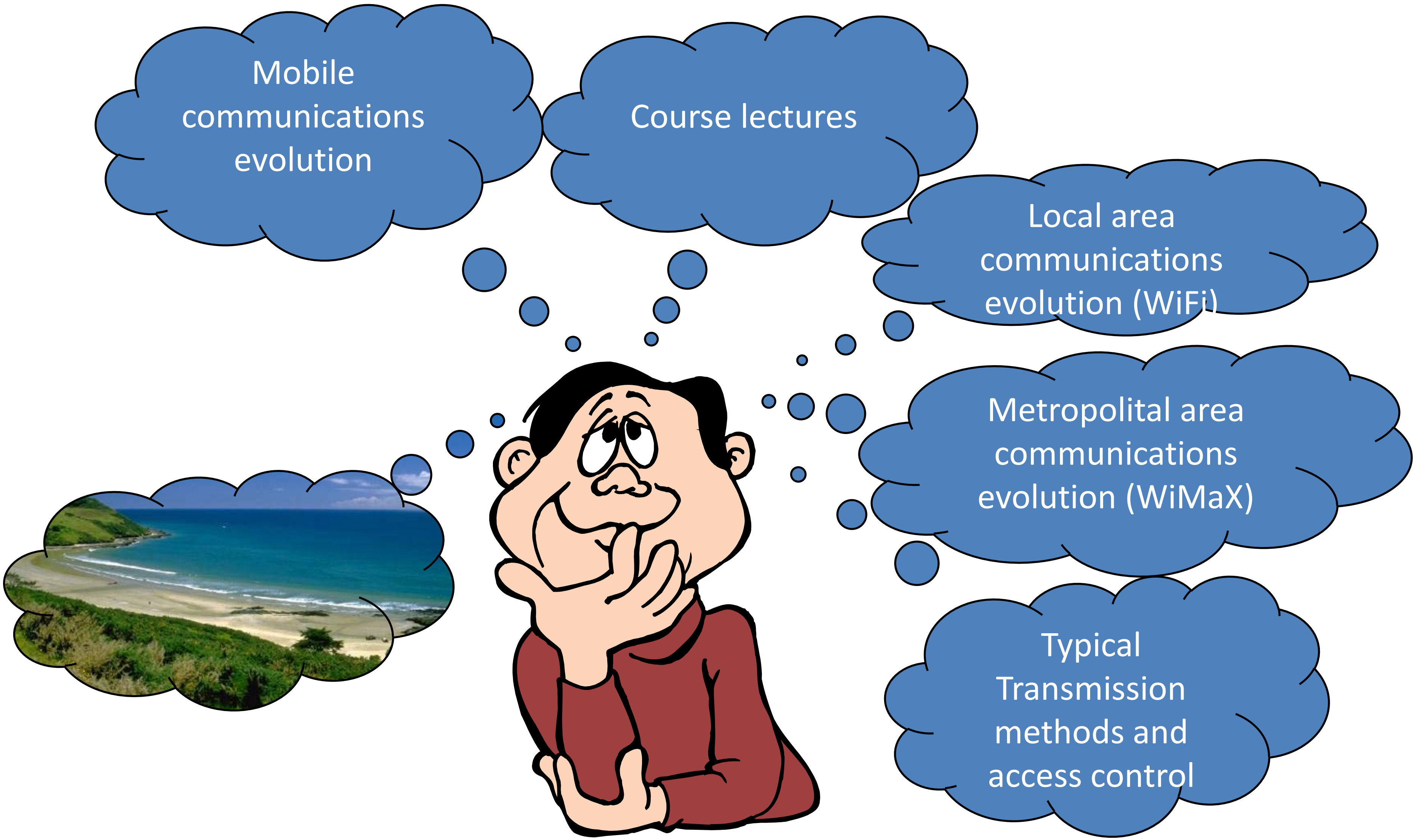
Introduction to Wireless/Mobile Communications

Lecture Contents



The beginning of mobile communications

It all started 100 years ago

Heinrich Hertz, 1857-1894

- Electromagnetic waves 1887

Guglielmo Marconi 1874-1937

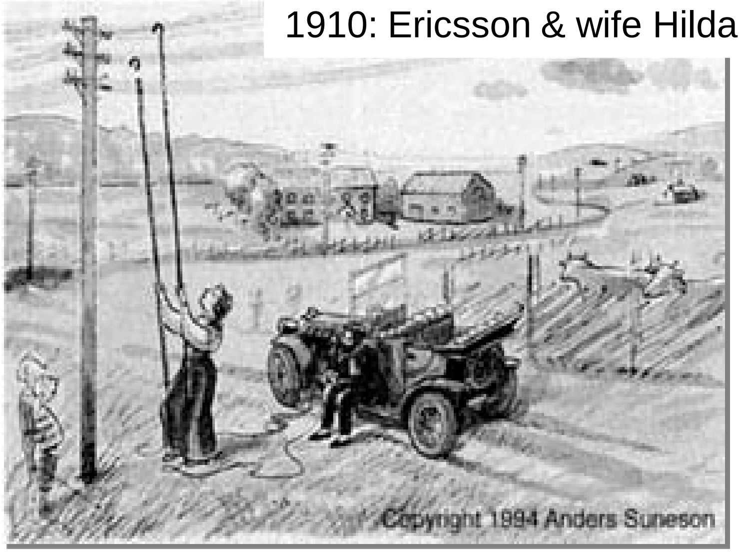
- First radio 1897

Reginald Fessenden 1866-1932

- Voice transmission over radio 1906

Mobile Communications at the beginning of the 21st century

1910: Ericsson & wife Hilda



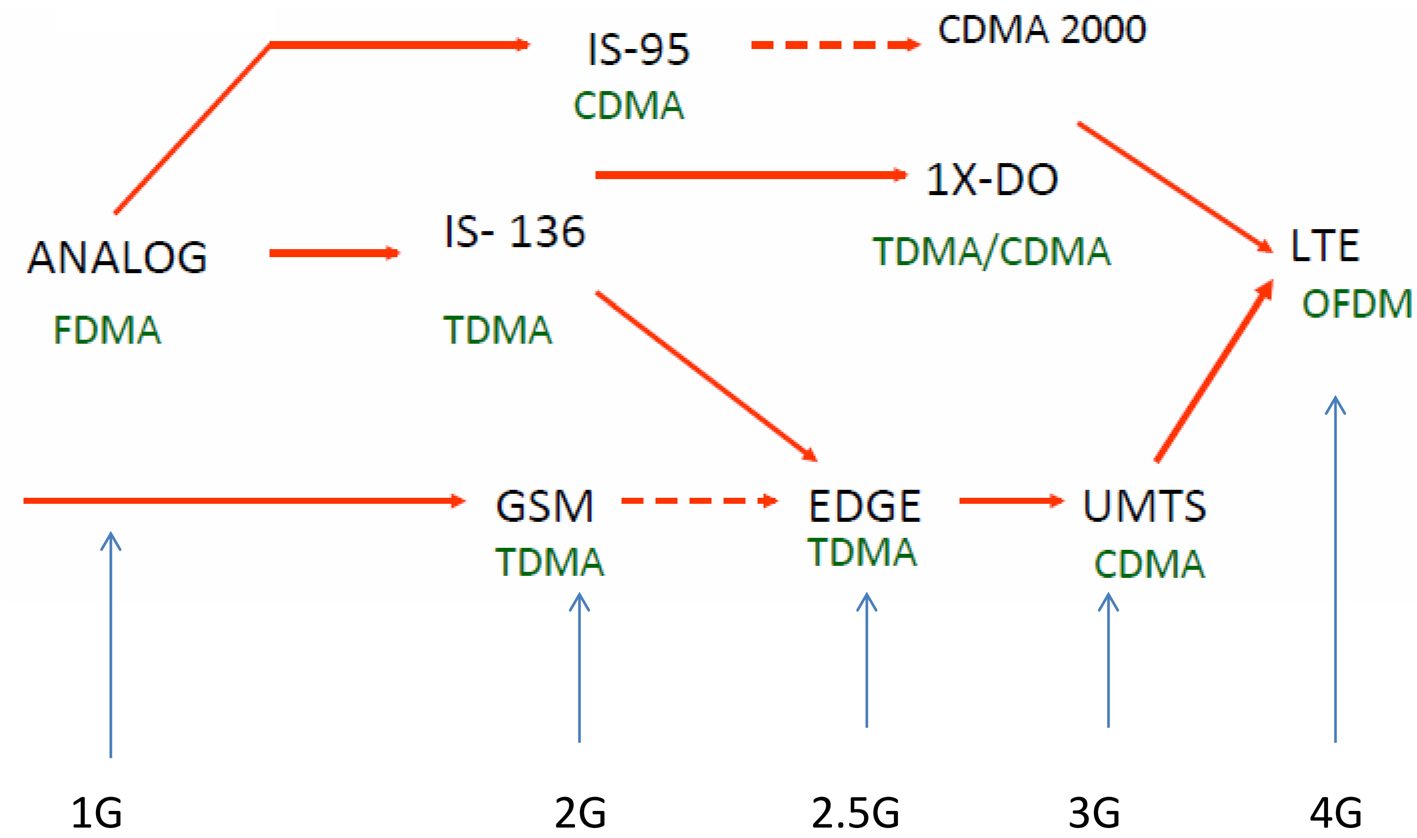
1924: First mobile radio telephone

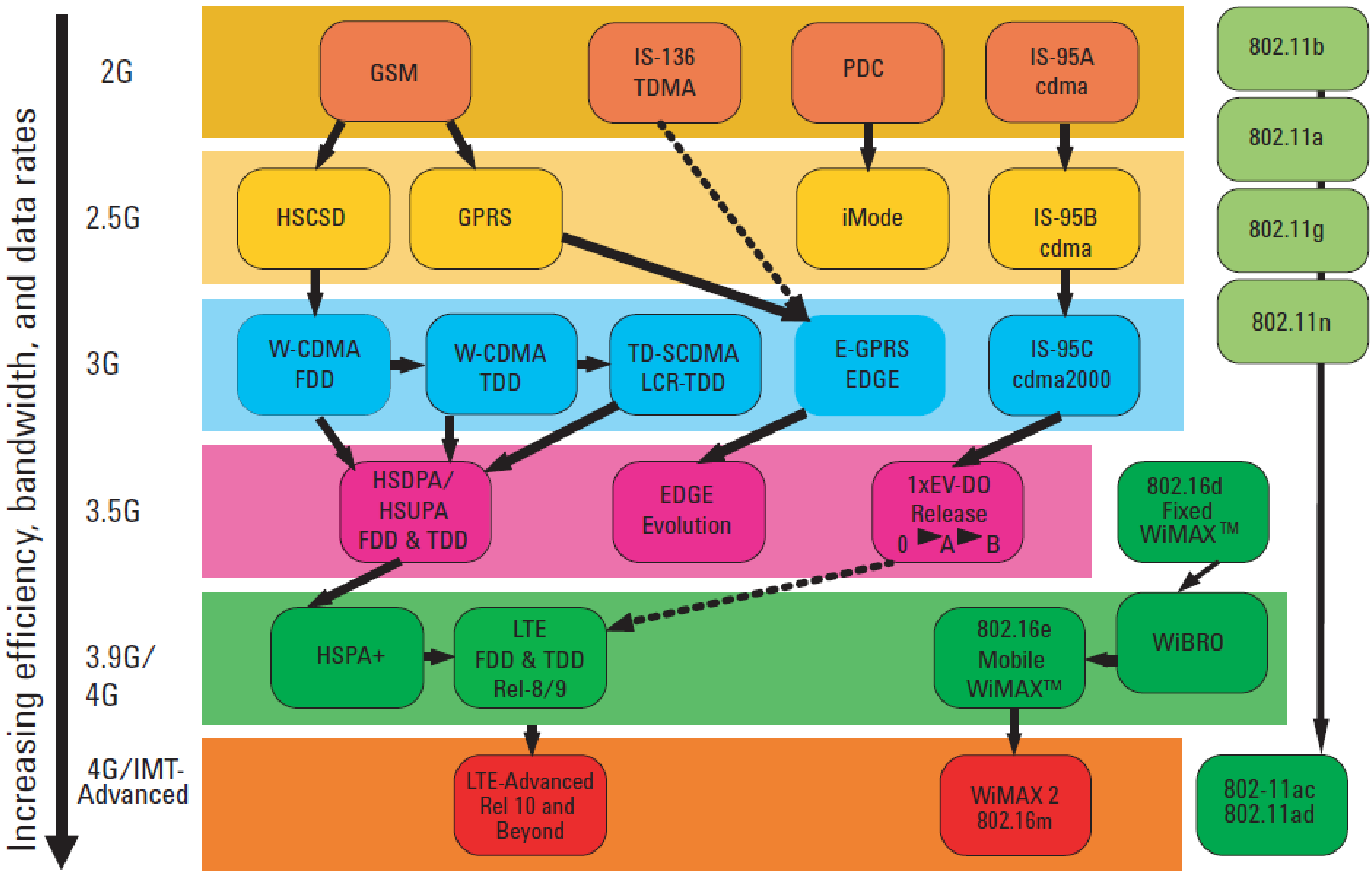
Courtesy of Rich Howard

Cellular Network Generations

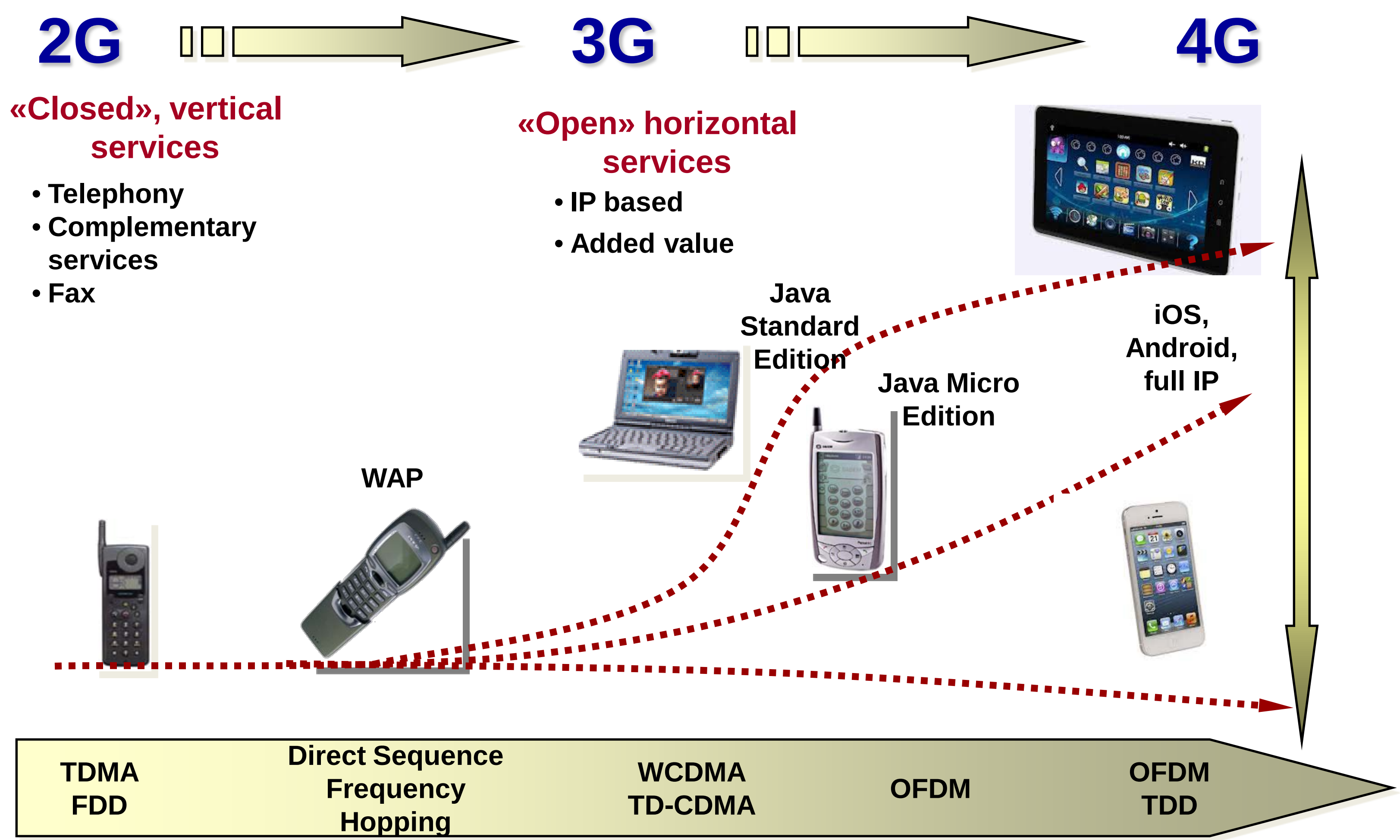
- It is useful to think of cellular Network/telephony in terms of *generations*:
  - 0G: Briefcase-size mobile radio telephones
  - 1G: *Analog* cellular telephony
  - 2G: *Digital* cellular telephony
  - 3G: *High-speed* digital cellular telephony (including *video telephony*)
  - 4G: IP-based “anytime, anywhere” voice, data, and multimedia telephony at *faster* data rates than 3G

Evolution of Cellular Networks

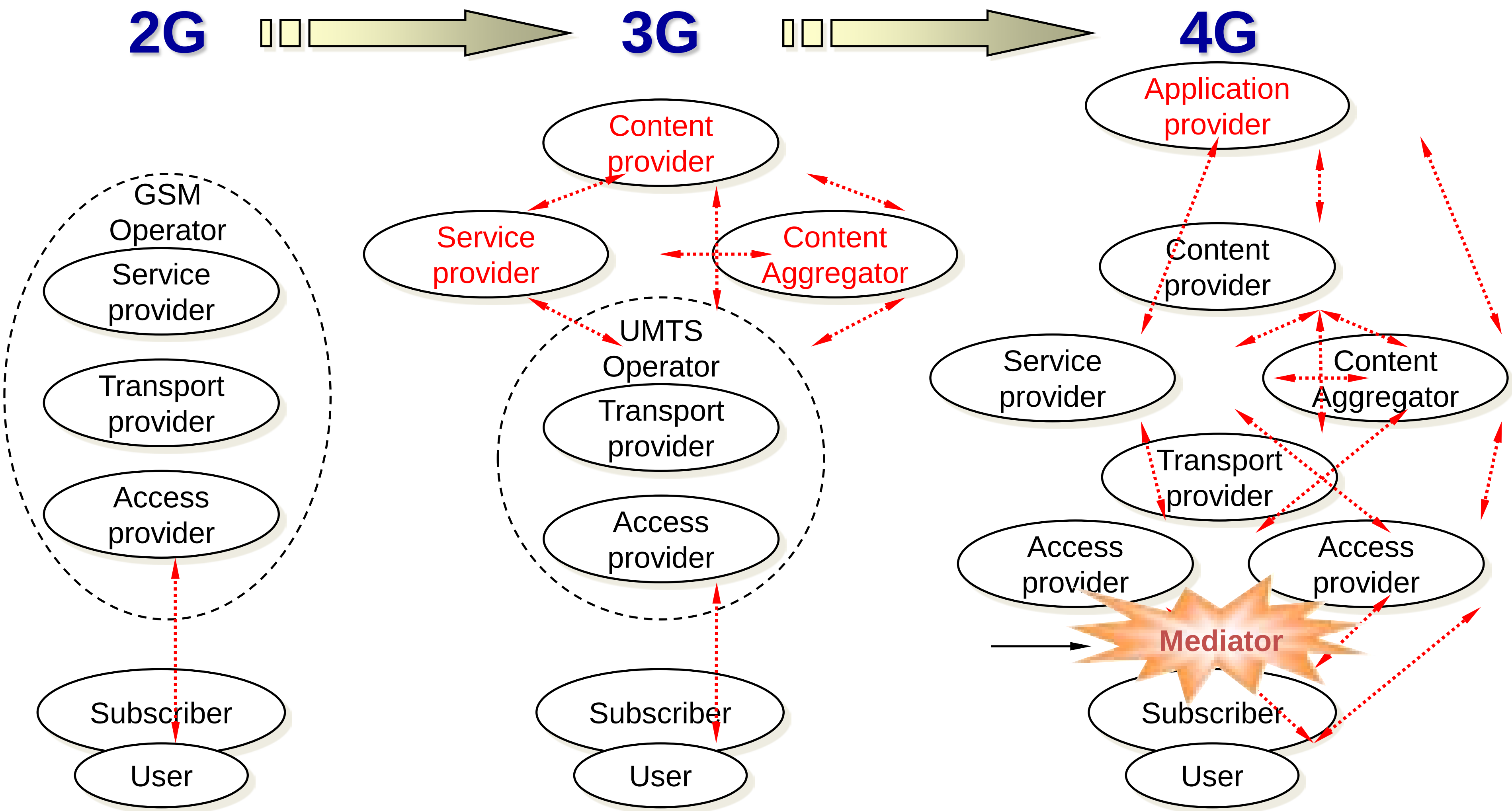



Increasing efficiency, bandwidth, and data rates
2G
2.5G
3G
3.5G
3.9G/
4G
4G/IMT-
Advanced
GSM
IS-136
TDMA
PDC
IS-95A
cdma
HSCSD
GPRS
iMode
IS-95B
cdma
W-CDMA
FDD
W-CDMA
TDD
TD-SCDMA
LCR-TDD
E-GPRS
EDGE
IS-95C
cdma2000
HSDPA/
HSUPA
FDD & TDD
EDGE
Evolution
1xEV-DO
Release
0 A B
HSPA+
LTE
FDD & TDD
Rel-8/9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

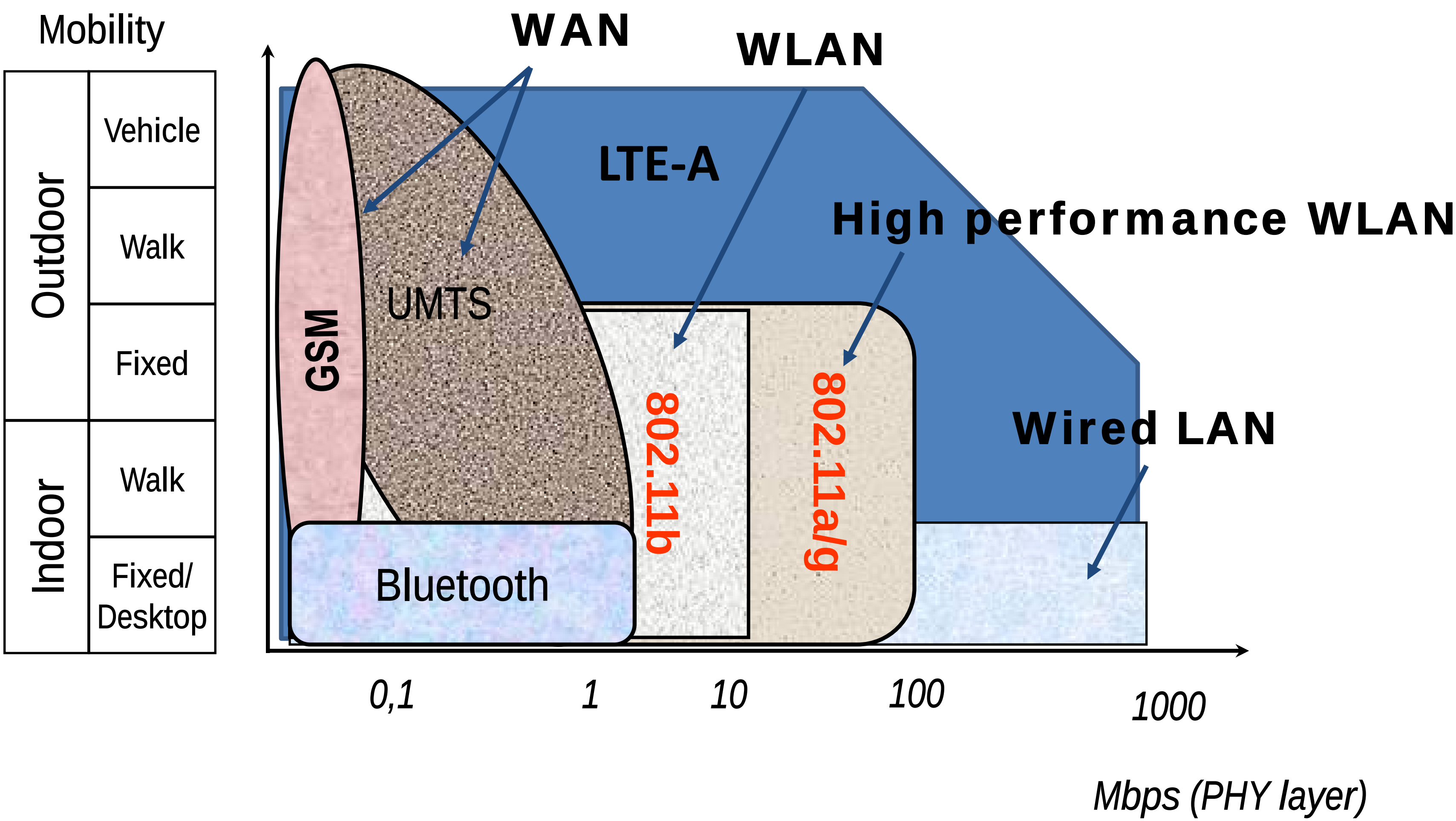
Evolution of terminals and services



Business model evolution



Wireless Standards



Forthcoming lectures

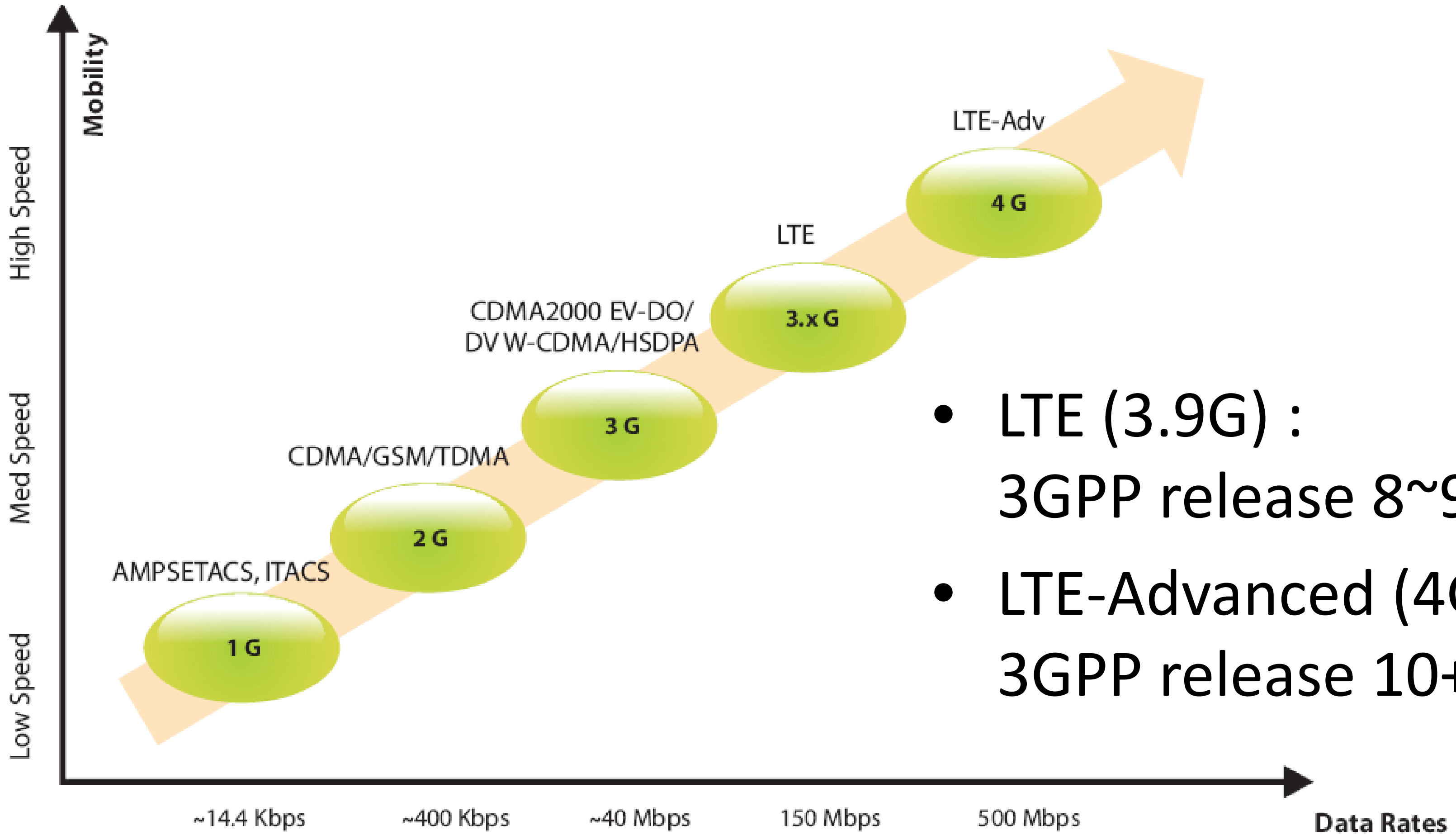
1. LTE Basics
2. Mobility management in LTE-A
3. Energy saving in LTE-A
4. Interference management in LTE-A
5. Quality of service and quality of experience in LTE-A
6. Device-to-device communications in LTE-A
7. Support for new network applications in LTE-A
8. Security mechanisms for 3G/4G mobile networks
9. Radio resource management in wireless/mobile networks
10. Satellite communications and interworking with mobile networks

1. LTE basics

- Mobile standards evolution towards 4G

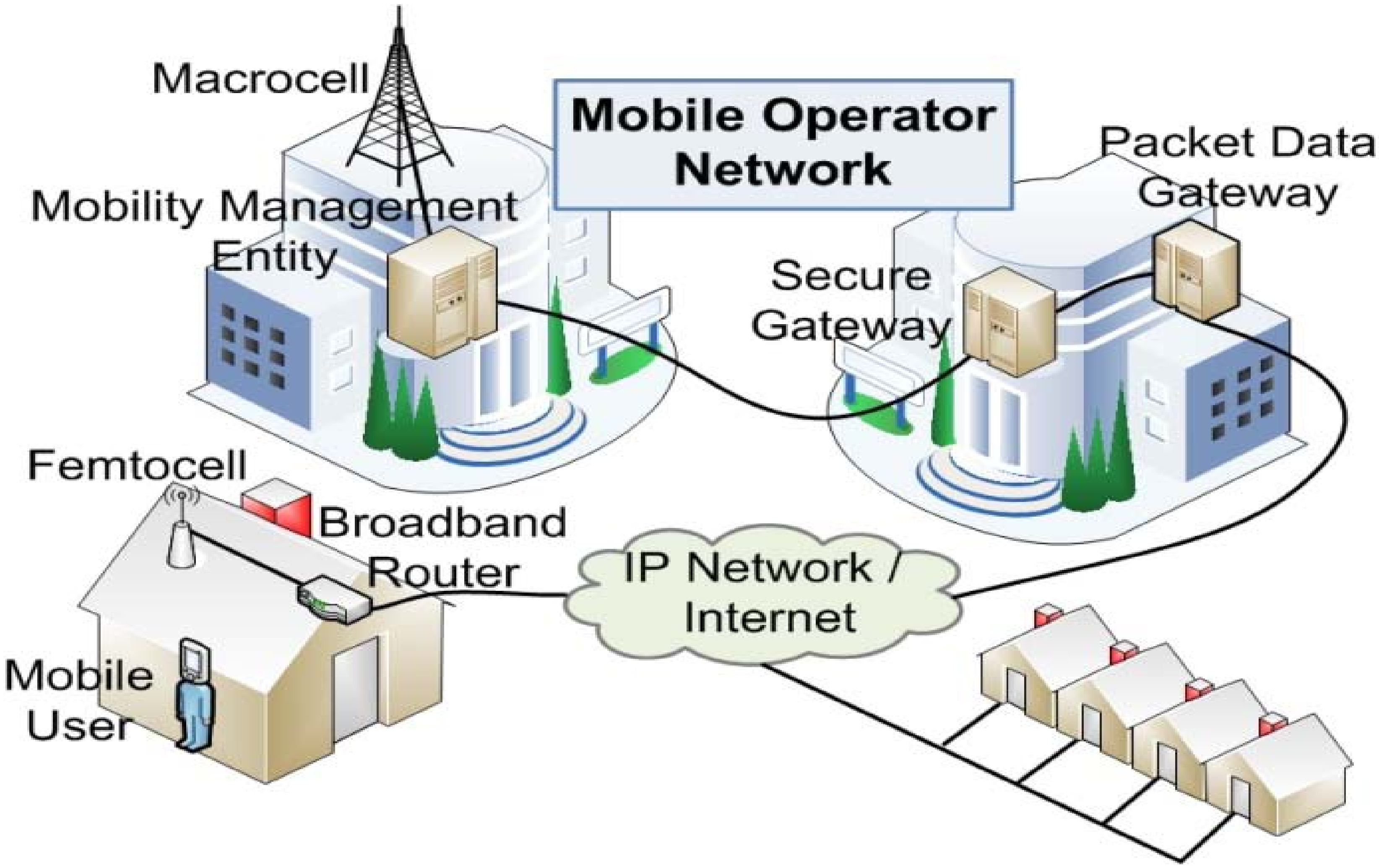
  GSM->GPRS->UMTS->LTE->LTE-A
- Key features of Long Term Evolution (LTE)
- LTE architecture / components / functionality
- LTE transmission techniques
- LTE-Advanced enhancements

Evolution of Radio Access Technologies



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

2. Mobility management in LTE-A



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

3. Energy saving in LTE-A

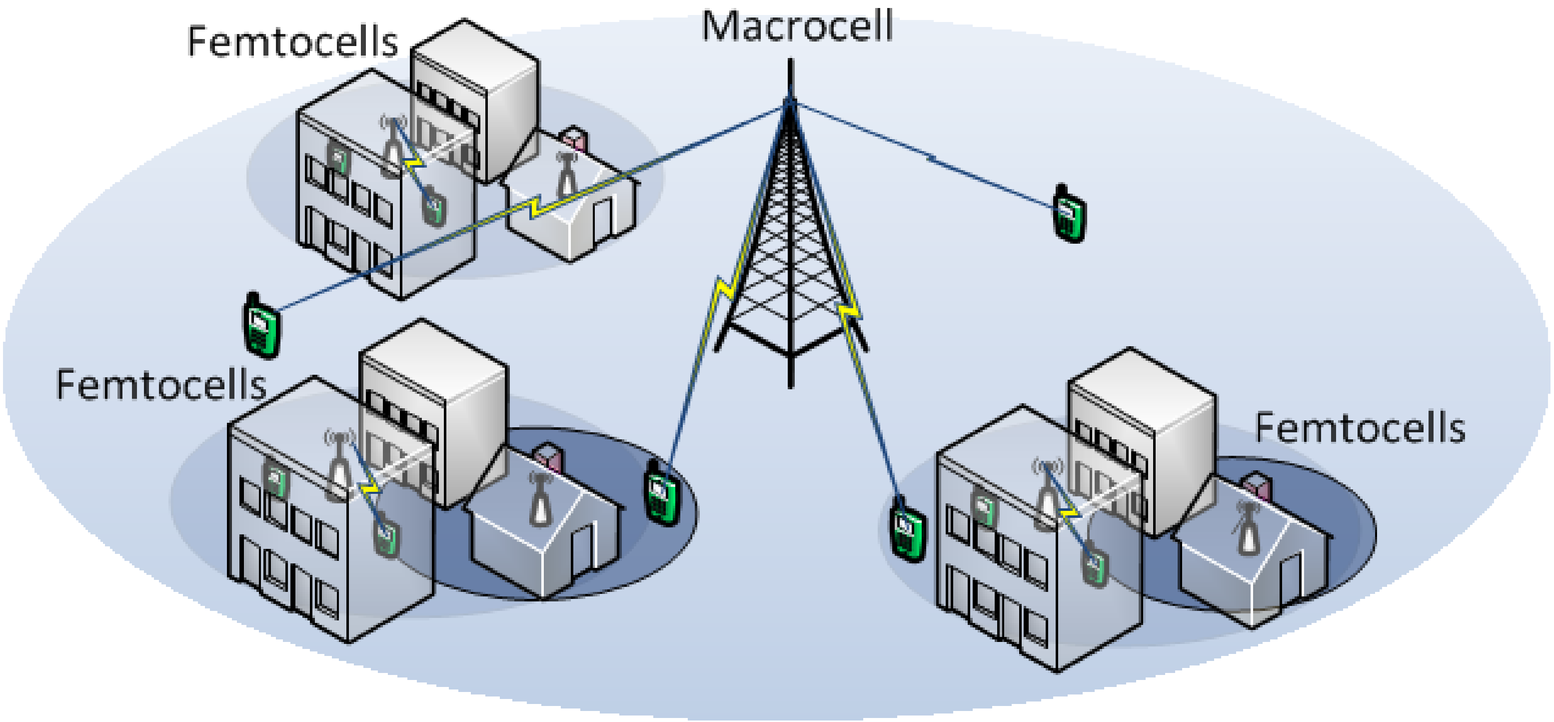
- The use of devices such as smart phones, tablets etc. , is widespread.
- Inevitably user expectations also rise in terms of higher data rates, instant internet connectivity and a much larger variety of applications to play with.
- Higher speed data transmission or reception requires higher power consumption;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

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

4. Interference management in LTE-A

Heterogeneous environment - Different types of interference



The Interference problem in Femtocell-Overlaid LTE-A networks

LTE-A provides a series of tools-technologies that can be used for Interference Management (IM):

- Enhanced inter-cell interference coordination (eICIC)
- Multiple Input Multiple Output (MIMO) antennas
- Coordination Multipoint (CoMP) transmission/reception
- Interference cancelation (IC)

And, of course, we can use

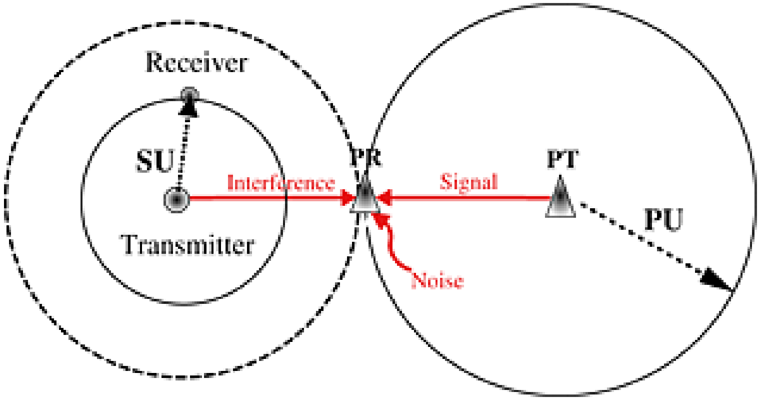
- Interference-aware power control (PC)/resource allocation (RA)

The question that arises is how, when, and under what circumstances we can exploit these tools!

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



5. Quality of service and quality of experience in LTE-A

Why the study of the QoE is important?

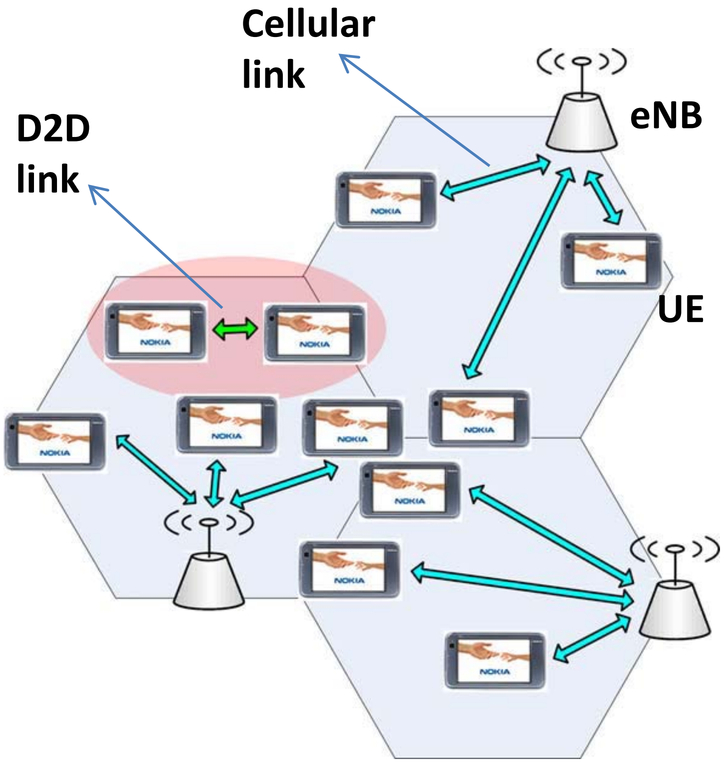
- The QoE encompasses the issue of the user's decision on retaining a service (and keep paying for it) or giving it up
- It is more efficient to focus on guaranteeing QoE than promising high QoS
  - Obviously, high QoS results in high QoE, however the quantification of this relation may be useful from the perspective of saving network resources or providing QoE-centric services
- QoE is the most reliable way to evaluate real time services such as VoIP and video conference which are currently used by more and more people

5. Quality of service and quality of experience in LTE-A

What are the main challenges in studying QoE?

- **QoE estimation**
  - Can be based on subjective or objective methods. How to assure the reliability of subjective methods and how to map objective parameters to QoE?
- **QoE monitoring**
  - Find user-transparent and passive ways to feed QoE measures back to the core network
- **QoE management**
  - How QoE variations can drive the resource, interference and mobility management?

6. Device-to-device communications in LTE-A



Why D2D?

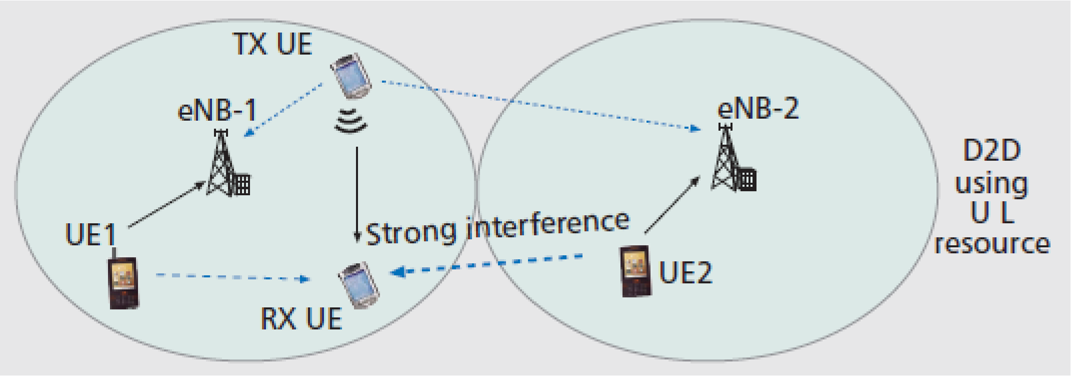
- Higher throughput, lower delays, reduced power consumption
- Increased spectrum utilisation
- eNB offloading and network decongestion
- All benefits of centralised eNB control (higher security etc.)
- New service opportunities
- Can be transparent to the user

➢ D2D is ideal for short range data intensive peer-to-peer communications, e.g. games, video streaming etc.

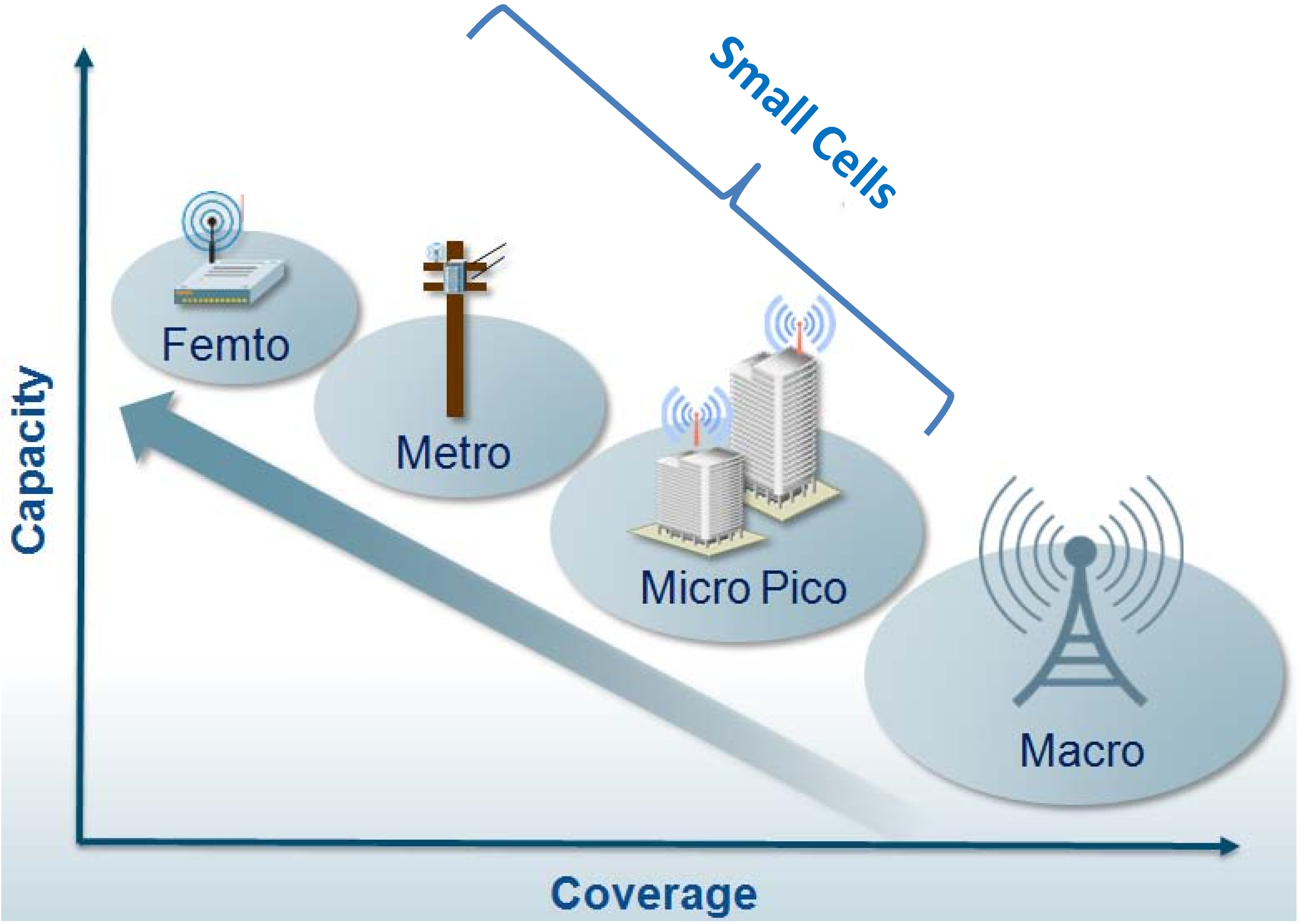
➢ Focus on:
- **Network-assisted** D2D links
- Utilising **licensed** spectrum
- **Direct** pair communication

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

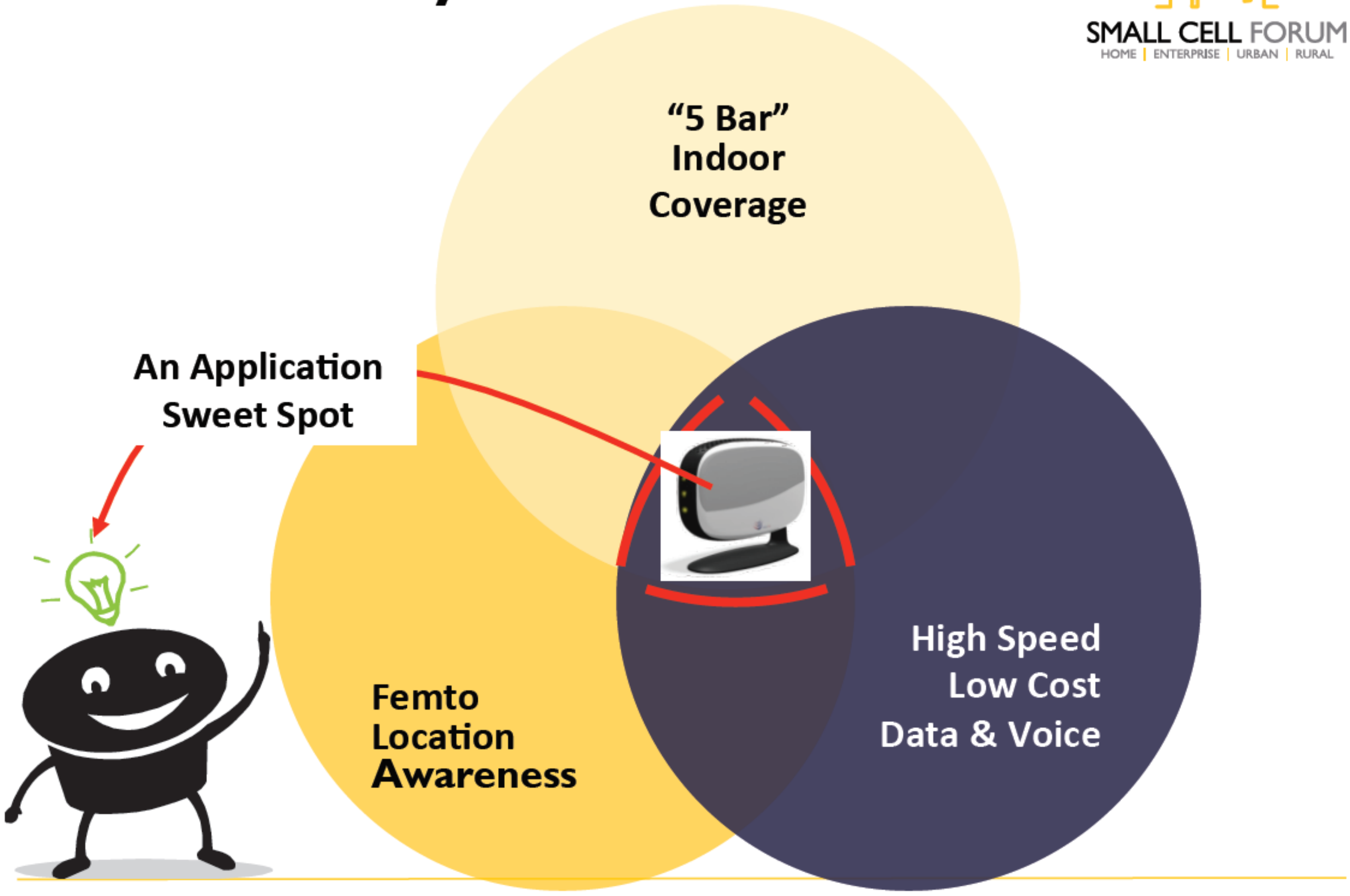


7. Support for new network applications in LTE-A

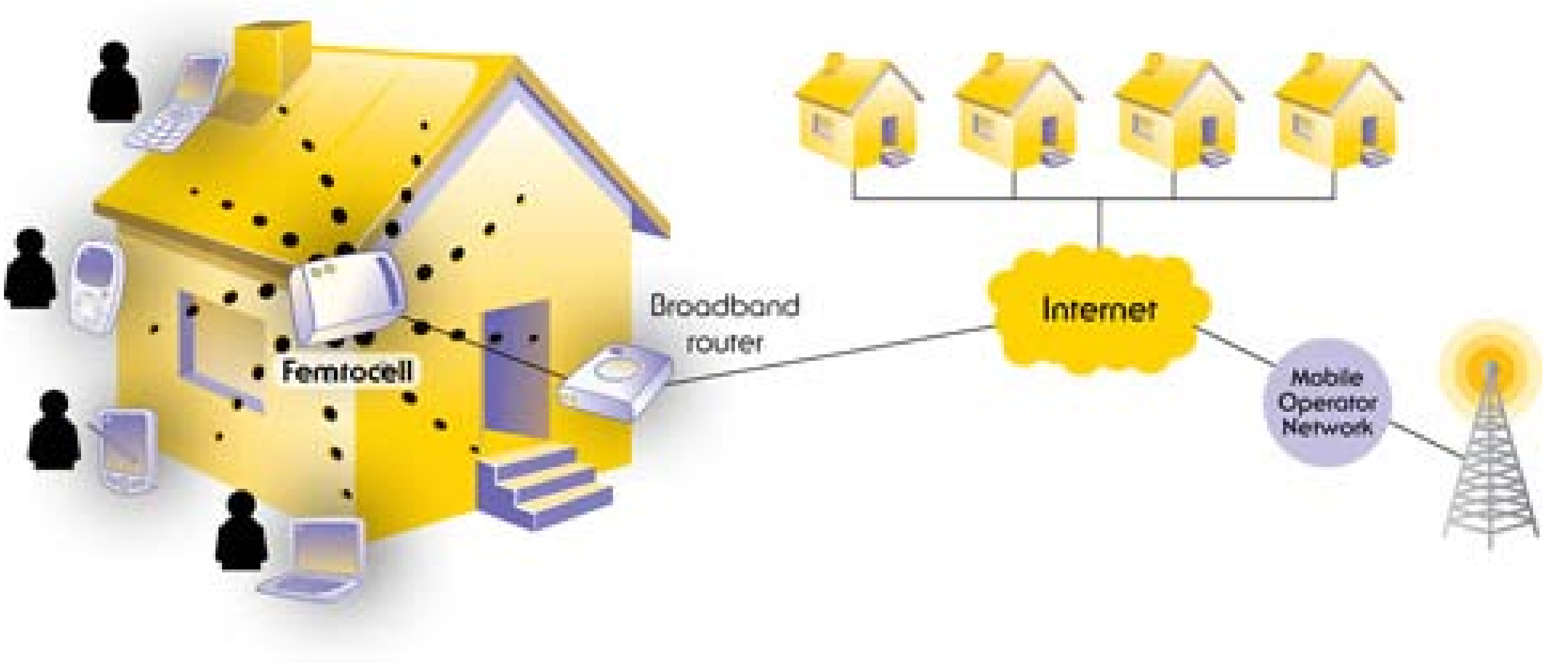


Why Small Cell Services?

SMALL CELL FORUM
HOME | ENTERPRISE | URBAN | RURAL



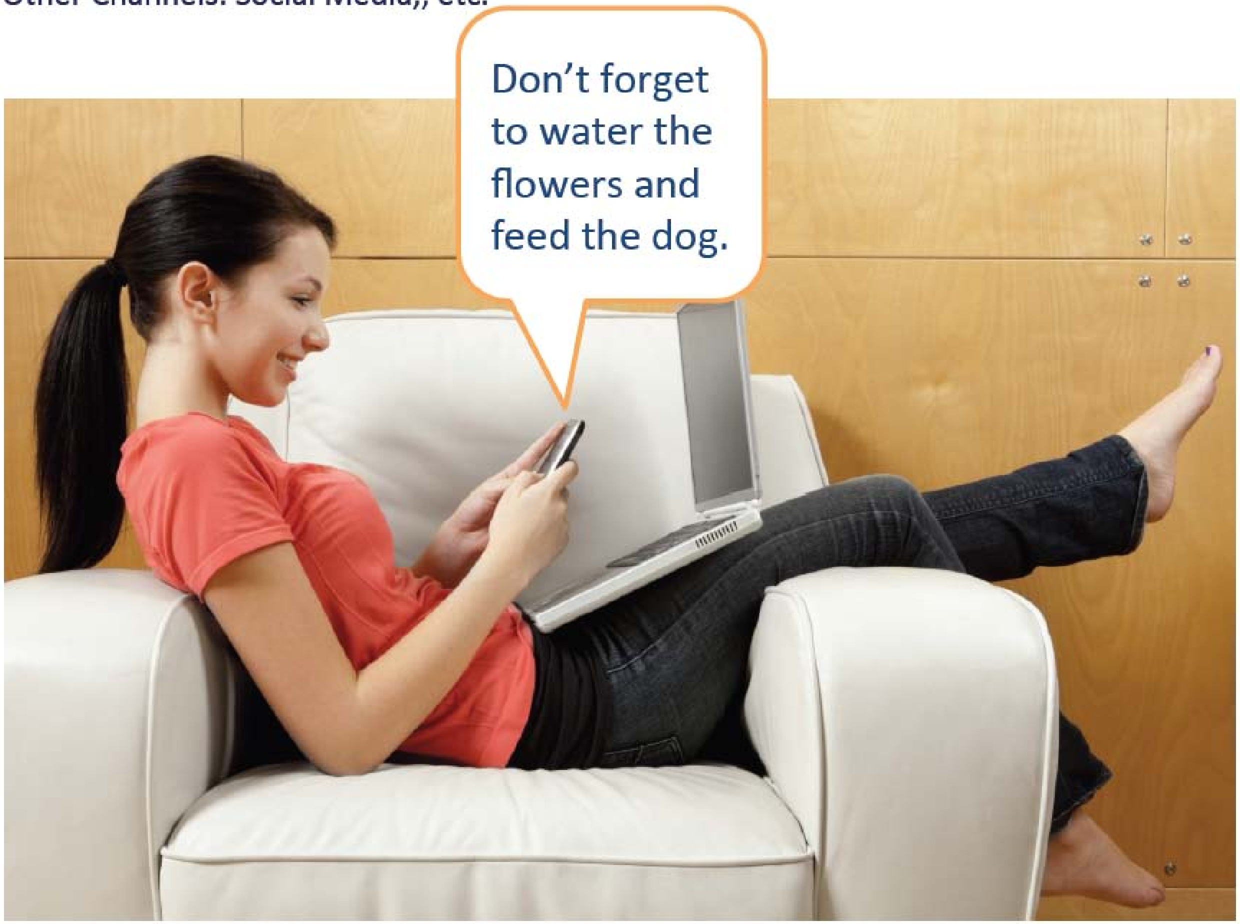
Femtocell is the main focus



Residential services

Mother leaves a note for the first arriving family member.
Jamie gets home and receives an SMS from Mom saying…

Other Channels: Social Media,, etc.



Targeted Advertisements

FREE DRINK with purchase of Large Popcorn

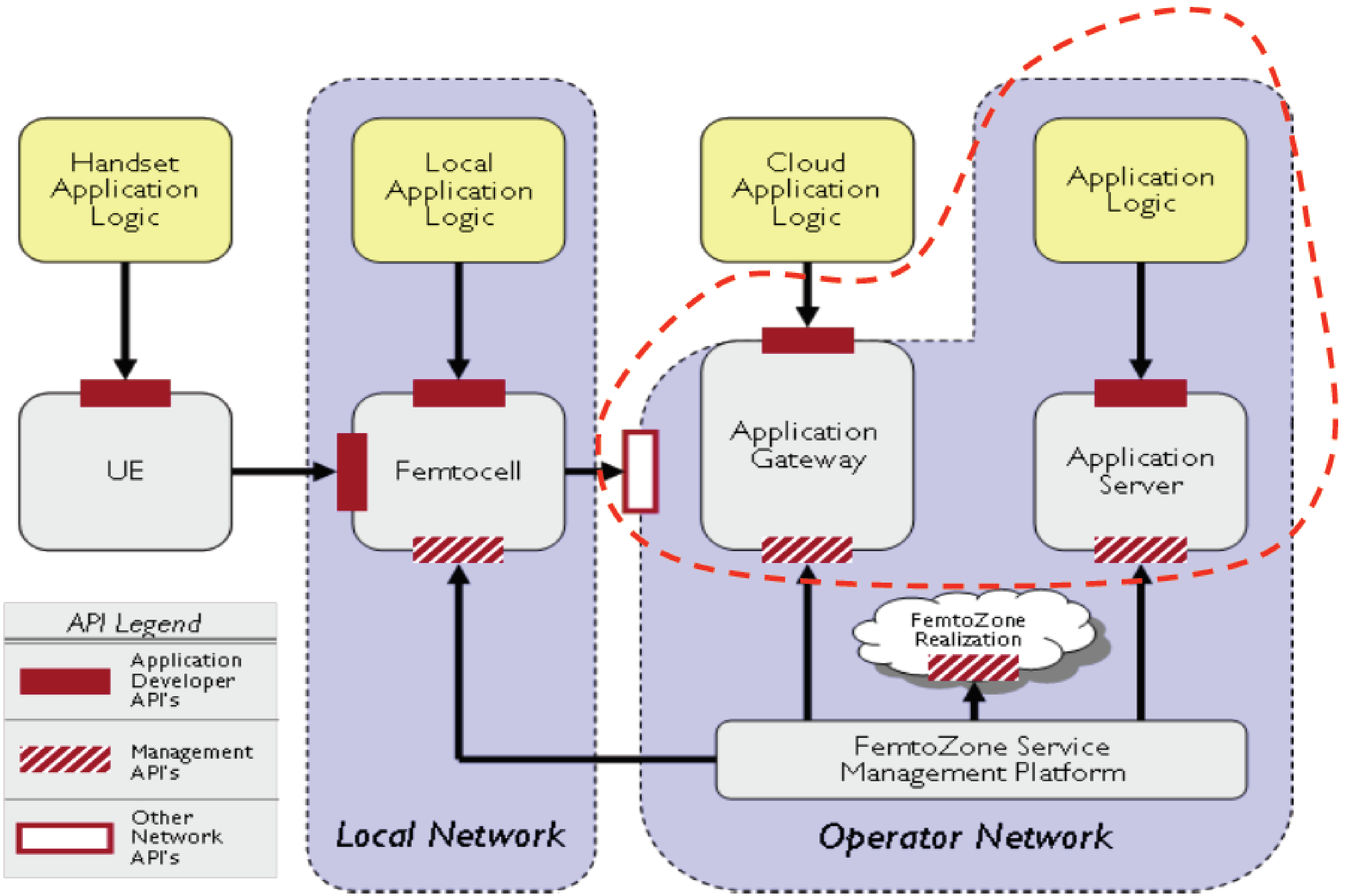
FREE Small Popcorn with purchase of drink.

FREE Small Popcorn with purchase of drink.

Movies – frequent movie goers receive targeted promotional messages.

FREE DRINK with purchase of Large Popcorn

Need for an architecture



Contents of the lecture

- Capabilities to support new applications in LTE networks
- How small cell applications work
- Categories of small cell applications
- Focus on femtocells and LTE
- Femtozone service architectures
- APIs for femtocell applications
- Real working developments

8. Security mechanisms for 3G/4G mobile networks

- 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

9. Radio resource management in wireless/mobile networks

- 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

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
- ISP's point of view
- Customer's (Public/Civil/Military/Industry) point of view
- Case study on WiMaX

10. Satellite communications and interworking with mobile networks

- Challenge to handle long propagation delays (125ms)
- DVB-RCS (Digital Video Broadcasting - Return Channel via Satellite)
- Why interconnect broadband wireless networks and satellite networks?
  - Advantages – Applications
  - Problems

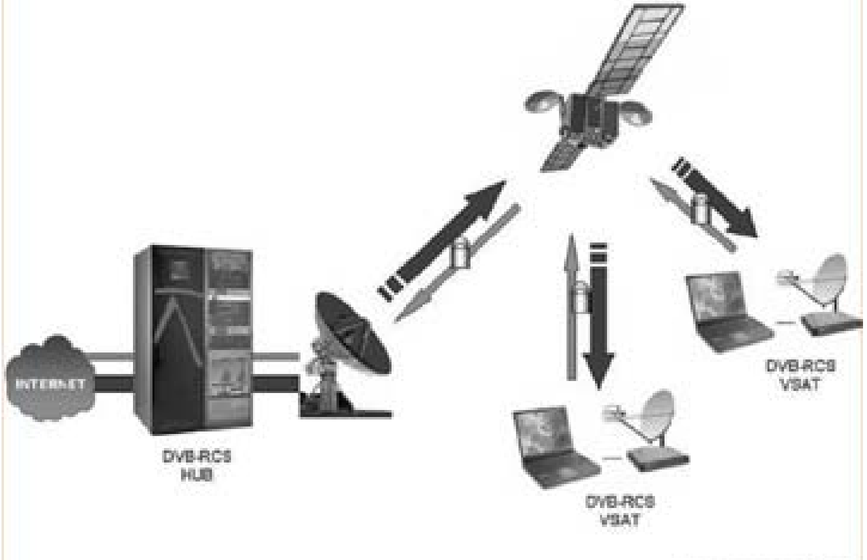
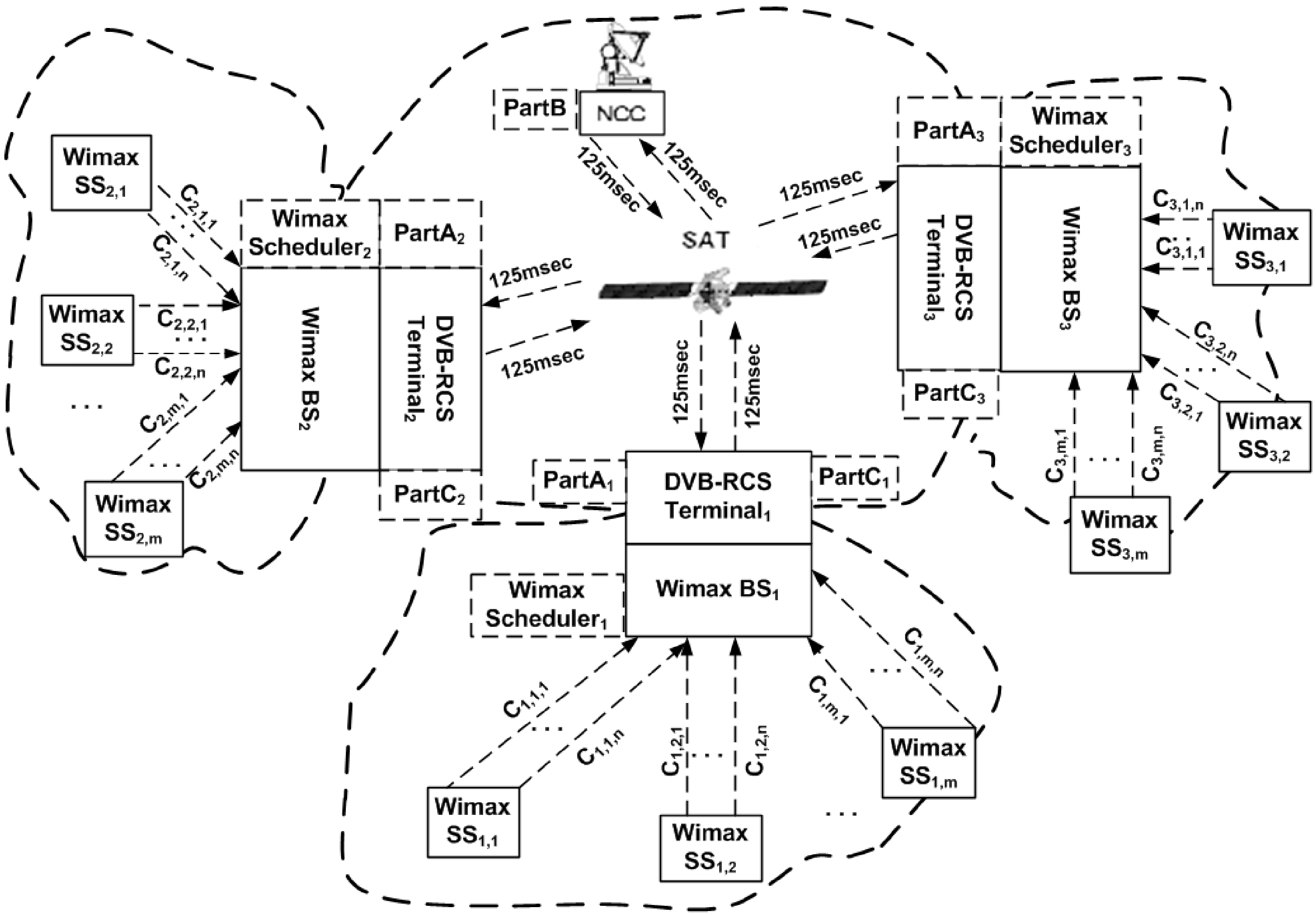
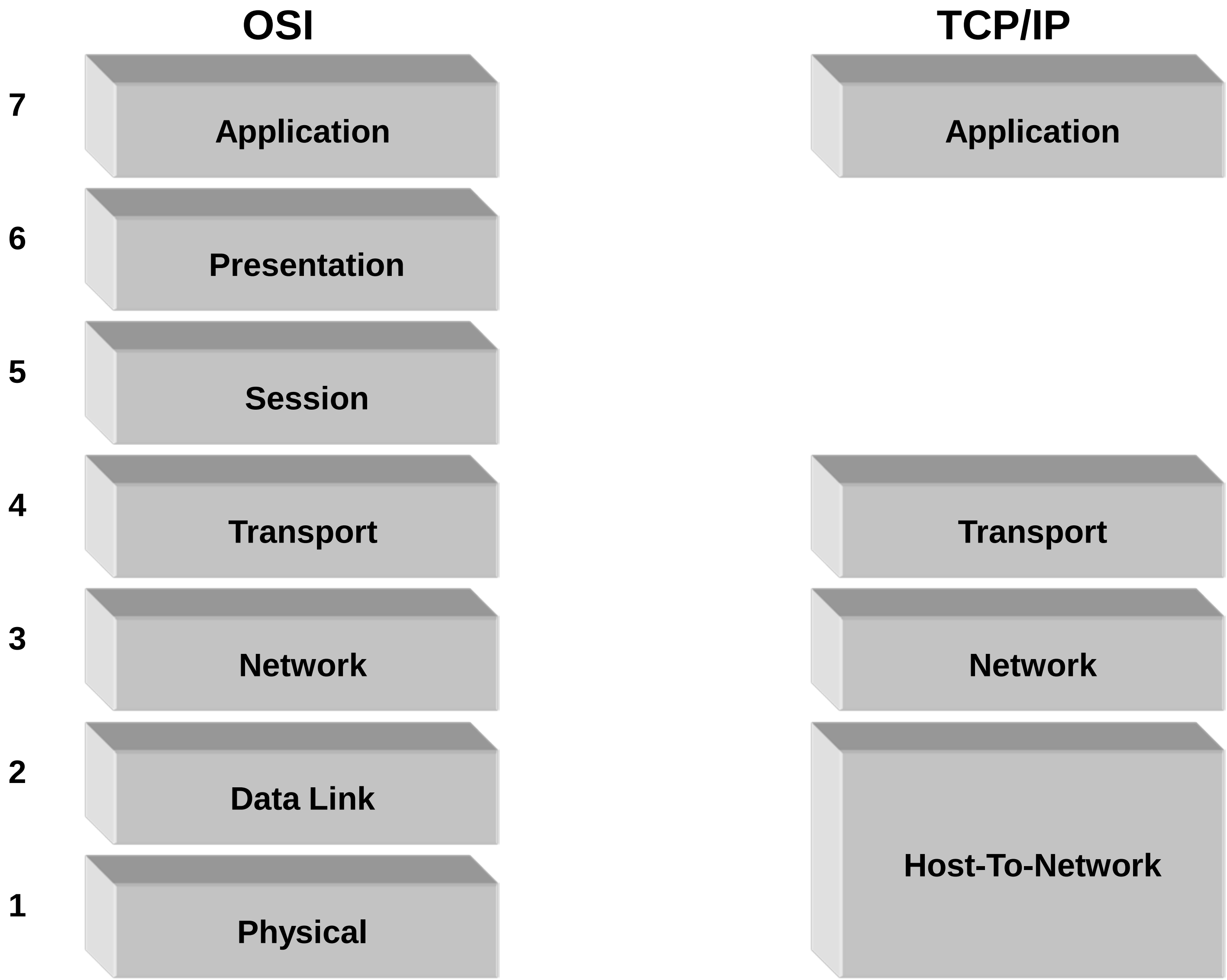


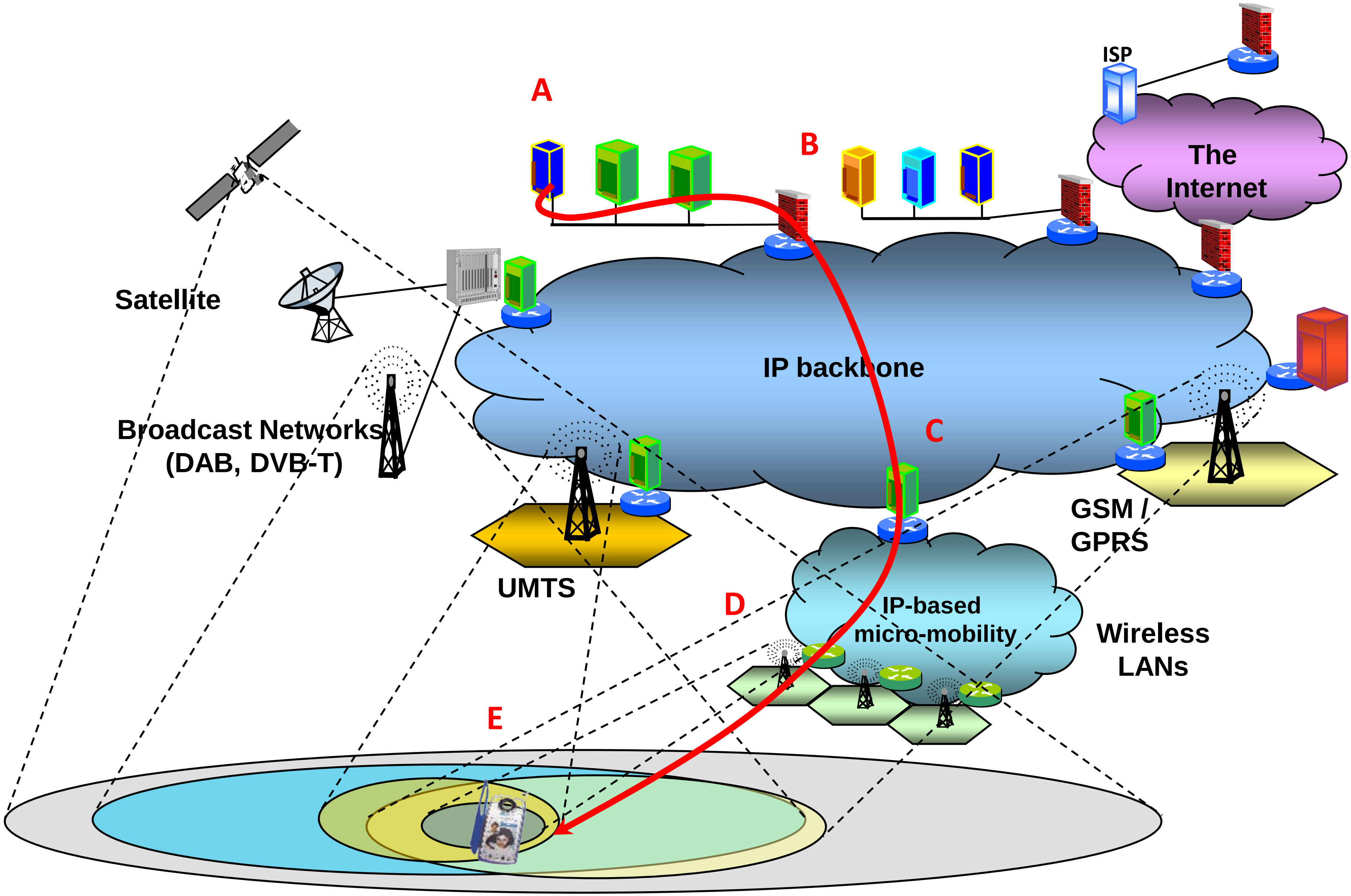
Figure 1. DVB-RCS network block diagram

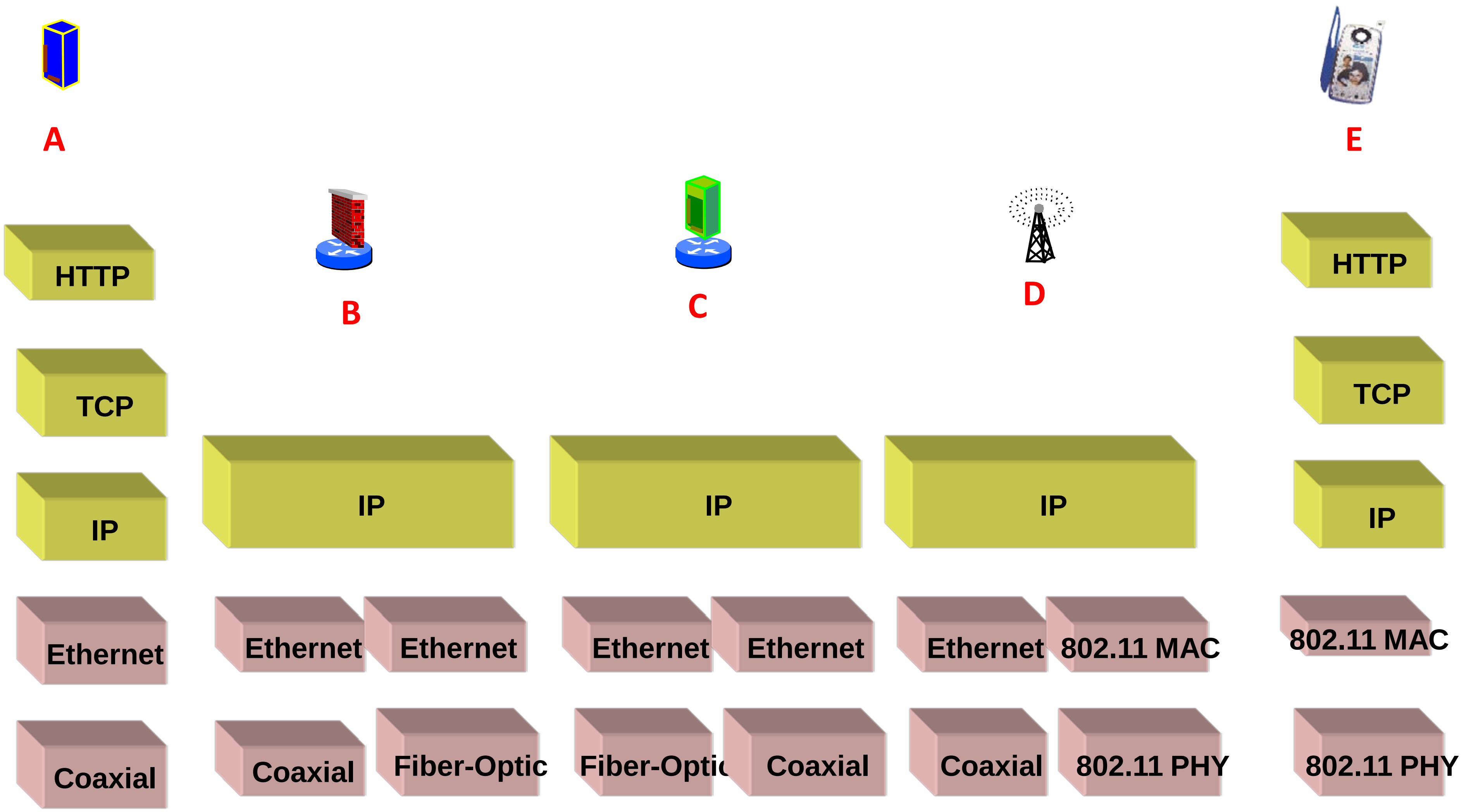
Case Study : Interconnection of WiMAX with satellite networks



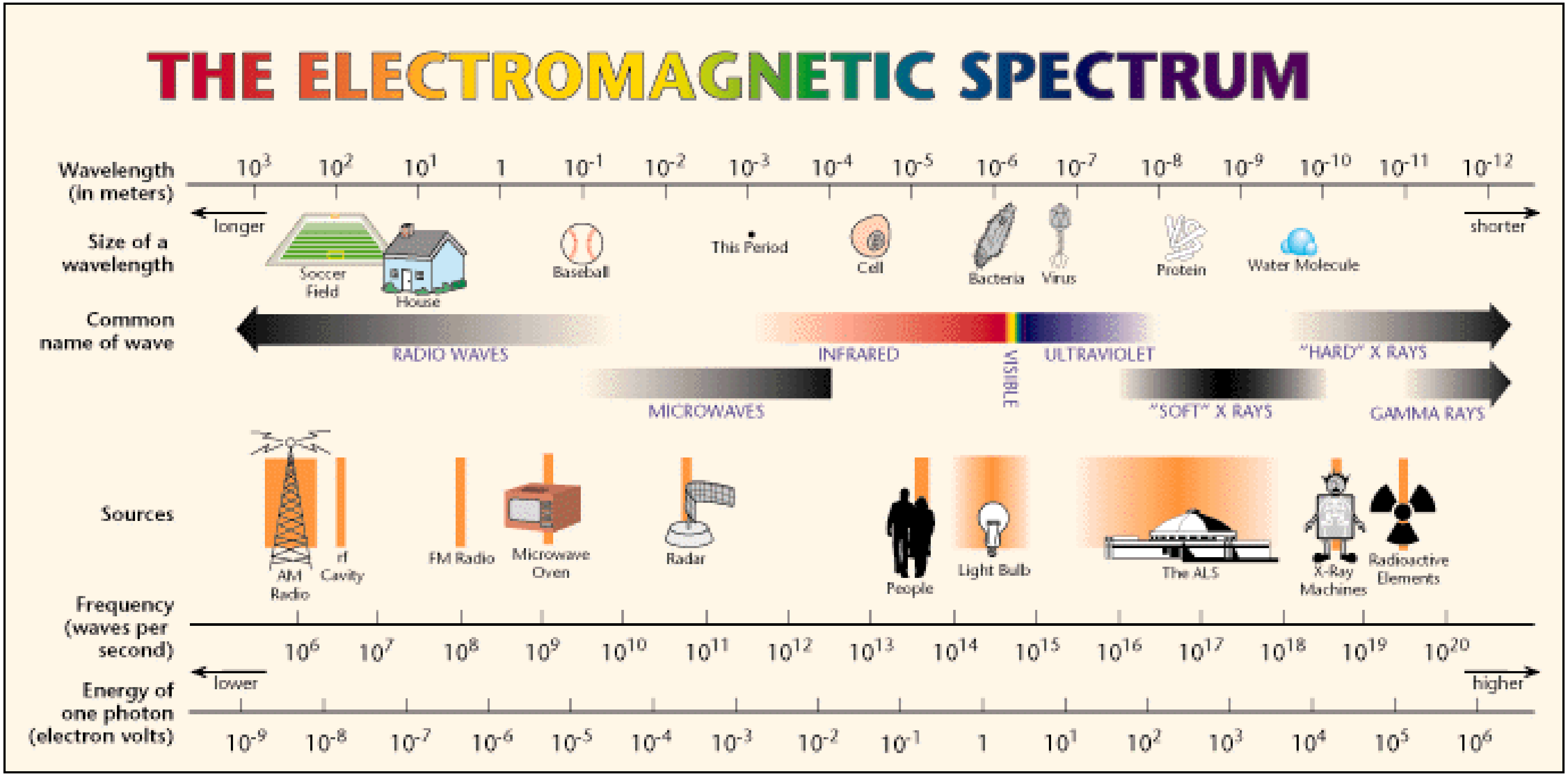
TCP/IP Reference Model



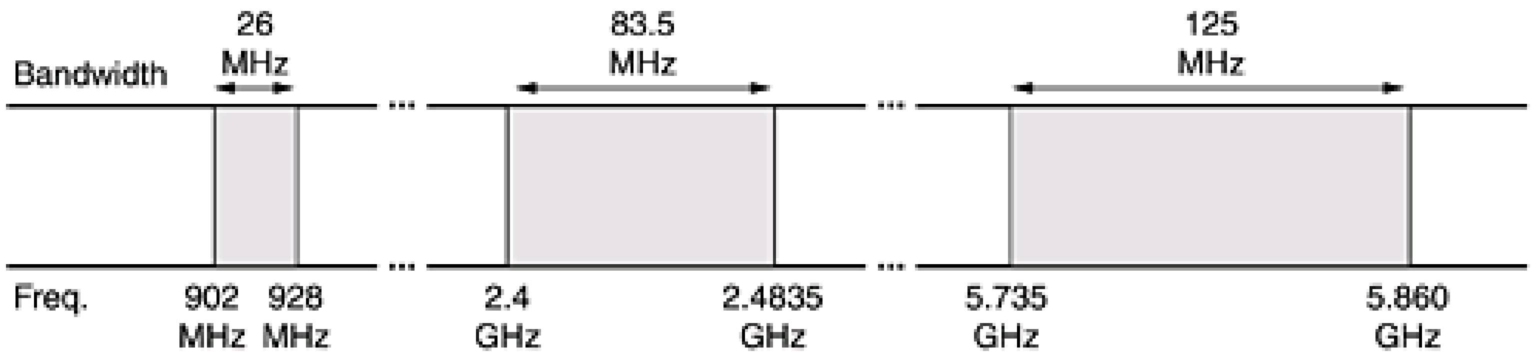

ISP
A
B
The Internet
Satellite
IP backbone
Broadcast Networks (DAB, DVB-T)
C
GSM / GPRS
UMTS
D
IP-based micro-mobility
Wireless LANs
E


A
E
B
C
D
HTTP
TCP
IP
Ethernet
Coaxial
IP
Ethernet
Ethernet
Coaxial
Fiber-Optic
IP
Ethernet
Ethernet
Fiber-Optic
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)

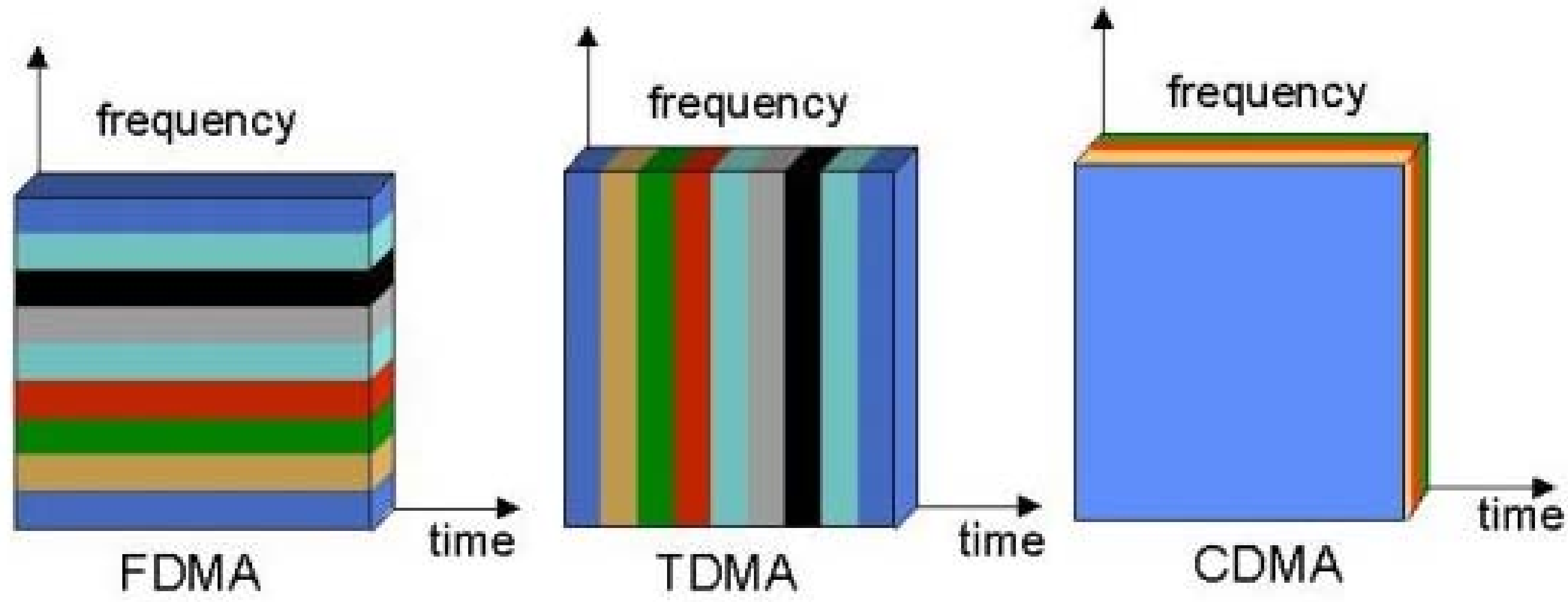


- Unlicensed, free to use
- Mainly used for WLANs

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

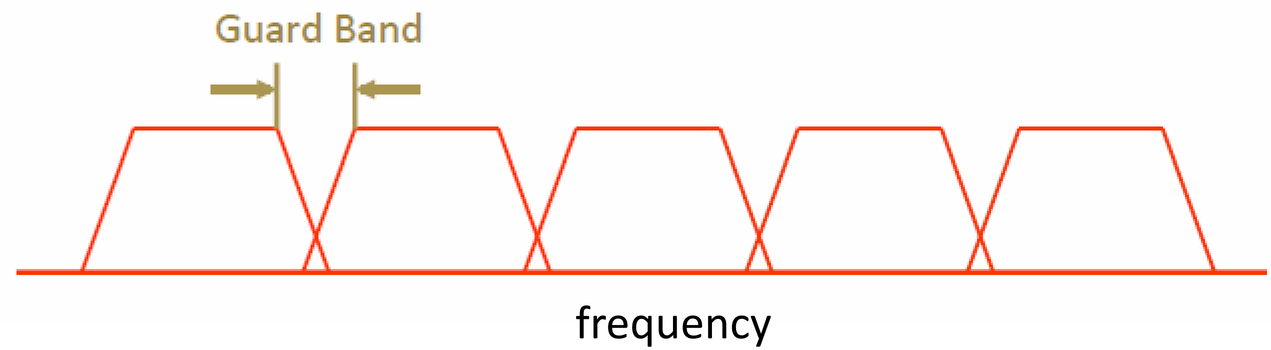
Multiple Access Schemes



3 orthogonal Schemes:

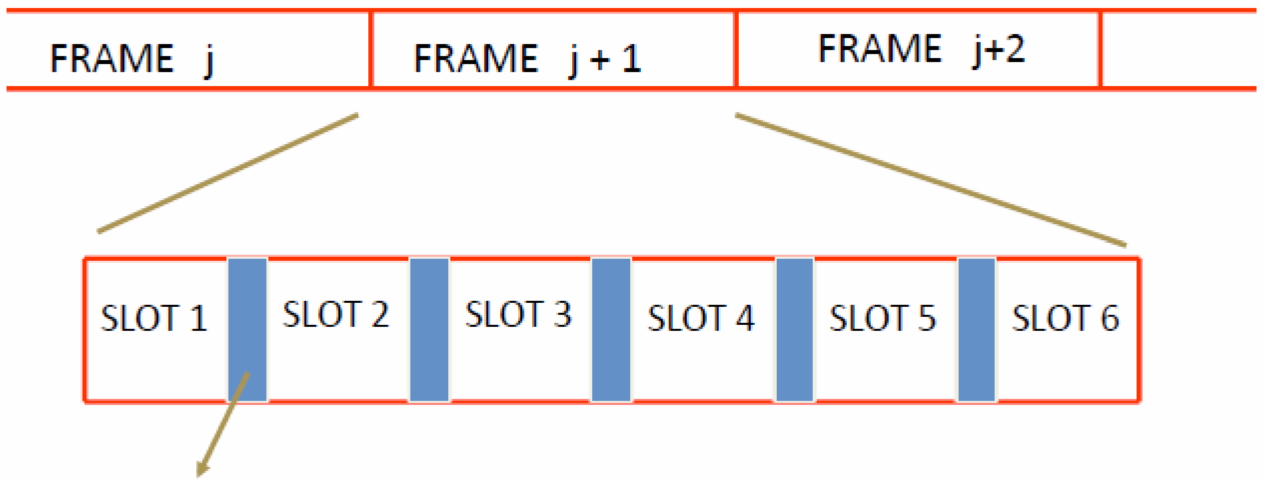
- Frequency Division Multiple Access (FDMA)
- Time Division Multiple Access (TDMA)
- Code Division Multiple Access (CDMA)

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

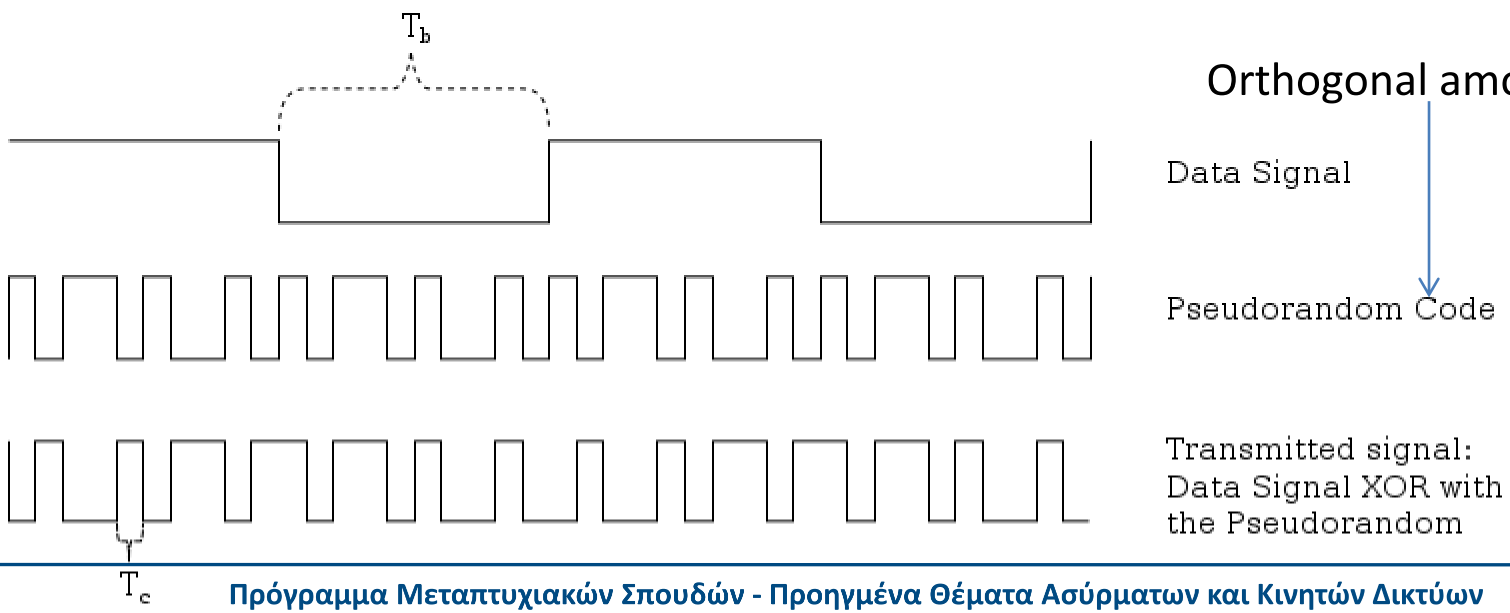


Guard time – signal transmitted by mobile terminals at different locations do no arrive at the base station at the same time

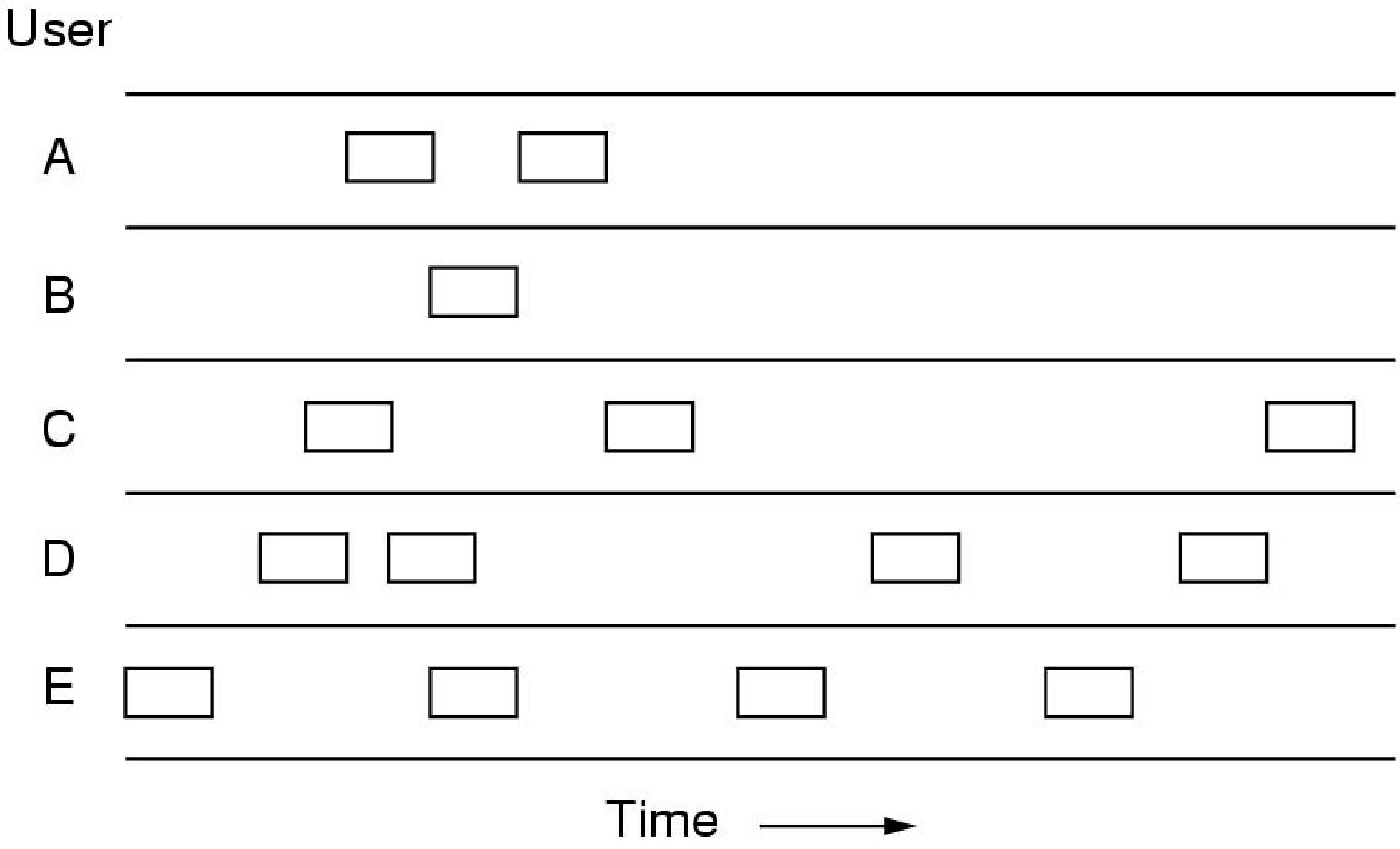
- Time is divided into slots and only one mobile terminal transmits during each slot
  - Like during the lecture, only one can talk, but others may take the floor in turn
- Each user is given a specific slot. No competition in cellular network
  - Unlike Carrier Sensing Multiple Access (CSMA) in WiFi

Code Division Multiple Access

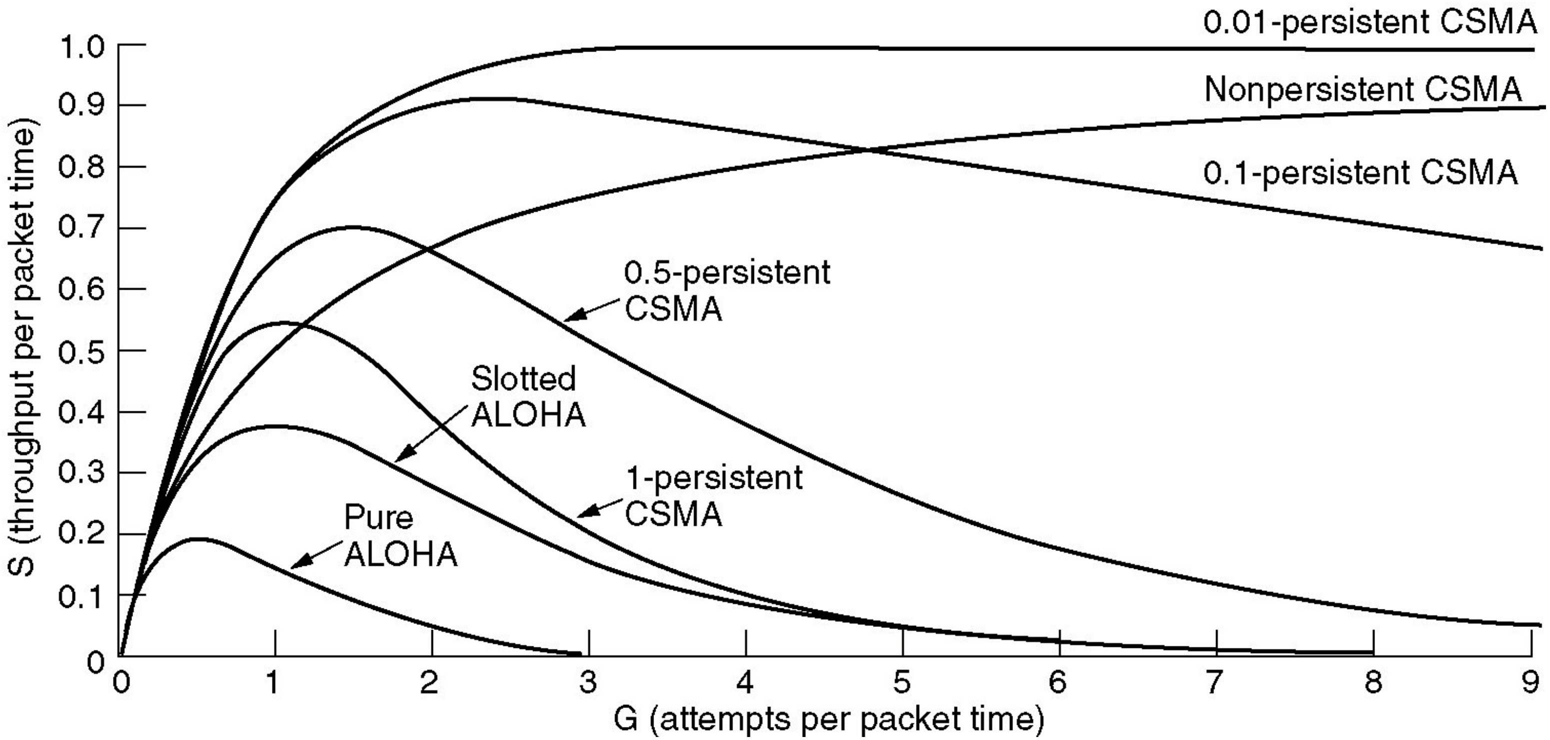
- Use of orthogonal codes to separate different transmissions
- Each symbol of bit is transmitted as a larger number of bits using the user specific code – Spreading
  - Bandwidth occupied by the signal is much larger than the information transmission rate
  - But all users use the same frequency band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



ALOHA

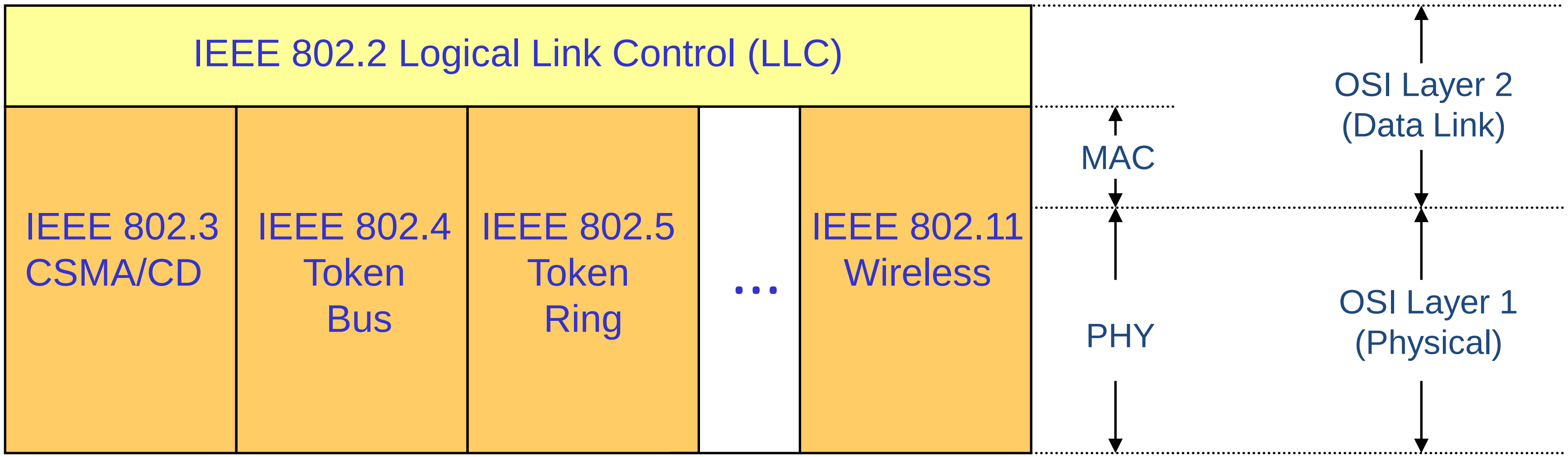


A comparison of simple protocols

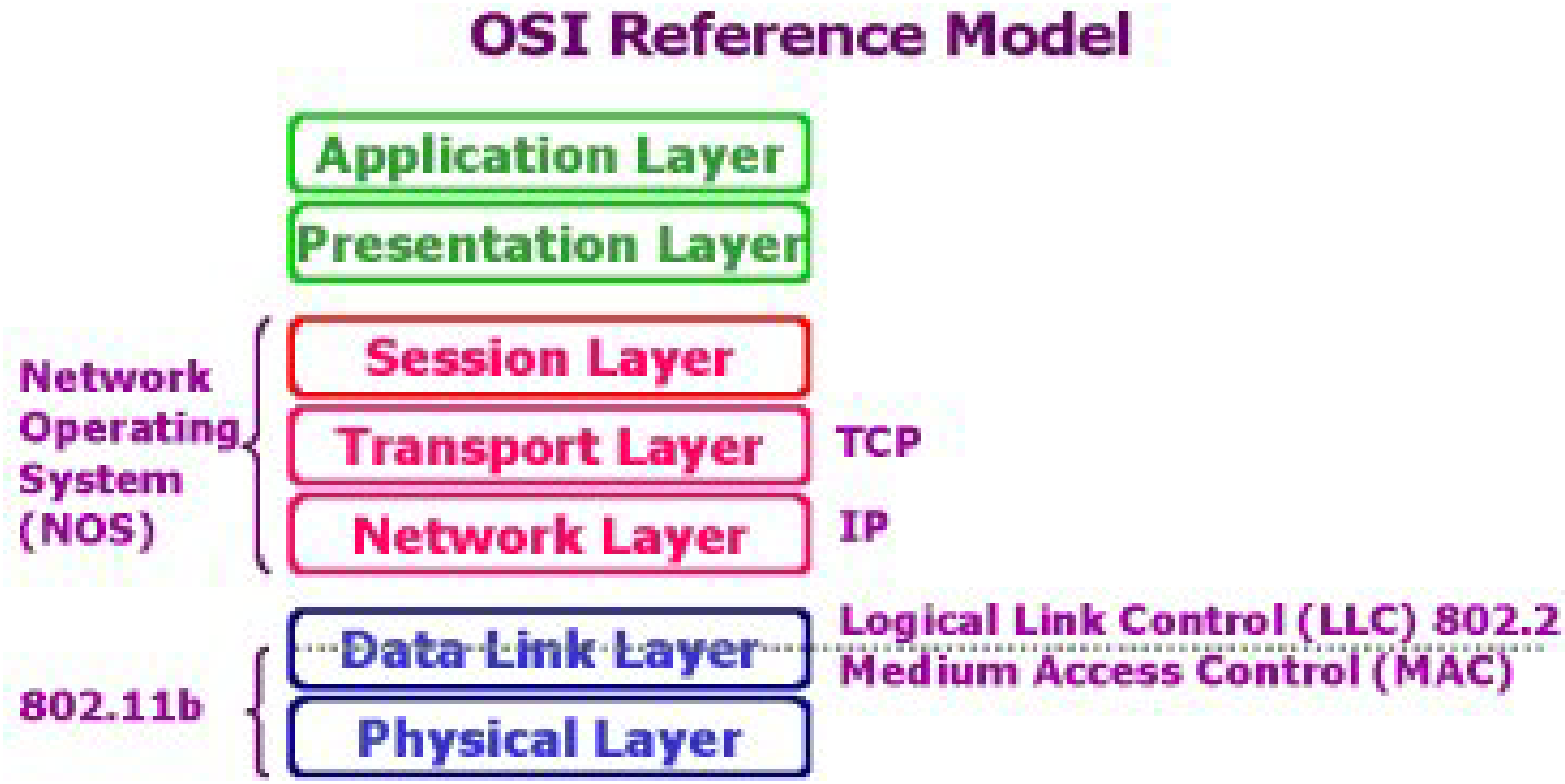


- Based on IEEE 802.11 standard and its amendments (a,b,g,n,…)
- Simple but efficient especially for light/medium traffic
- Cheap to implement and operate
- Constantly upgraded to be up to date
- Follows the evolution in wireless communications

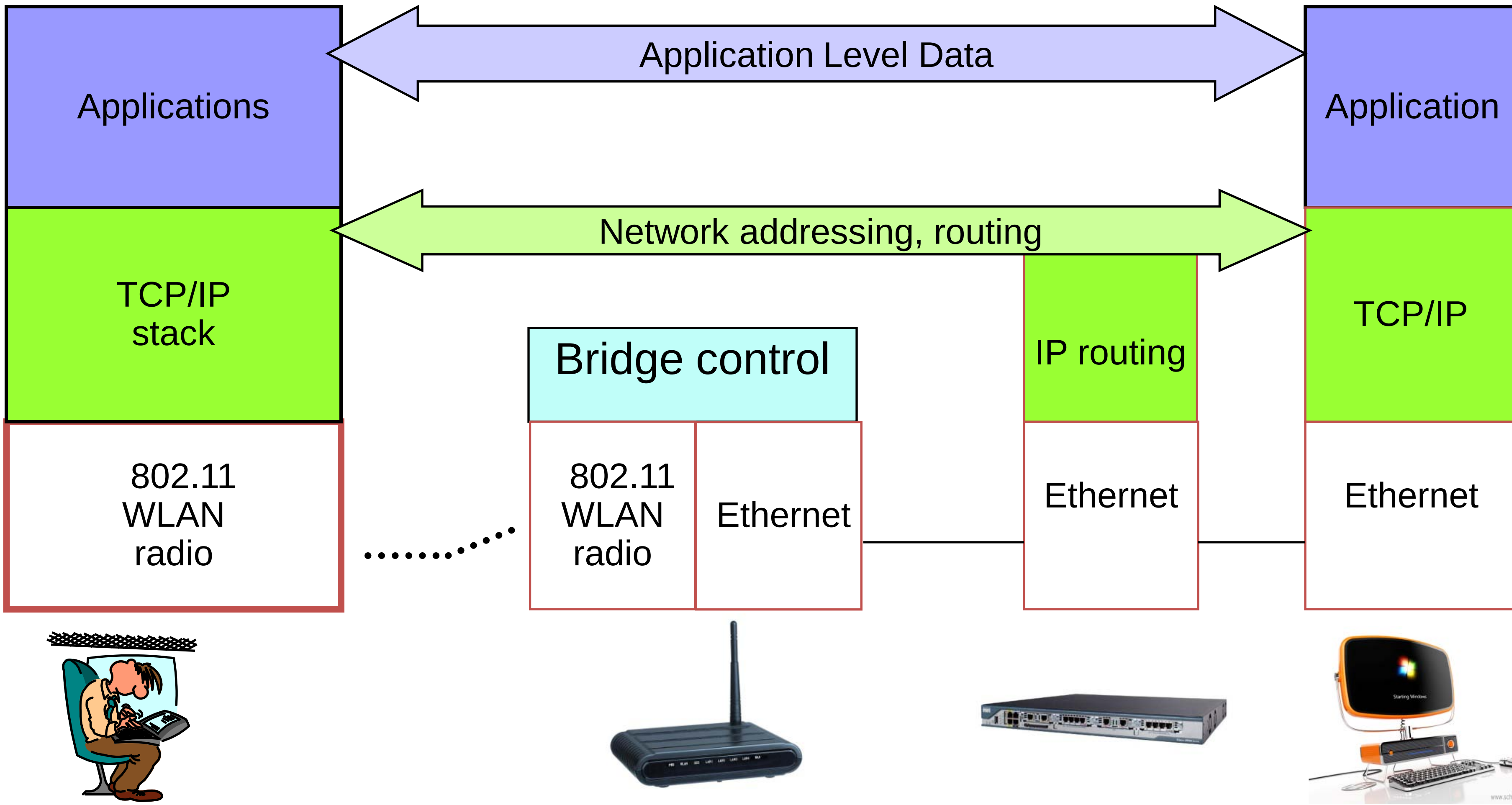
802.X Family of Standards



802.11 OSI Protocol Stack



802.11 – Ethernet Wireless Extension



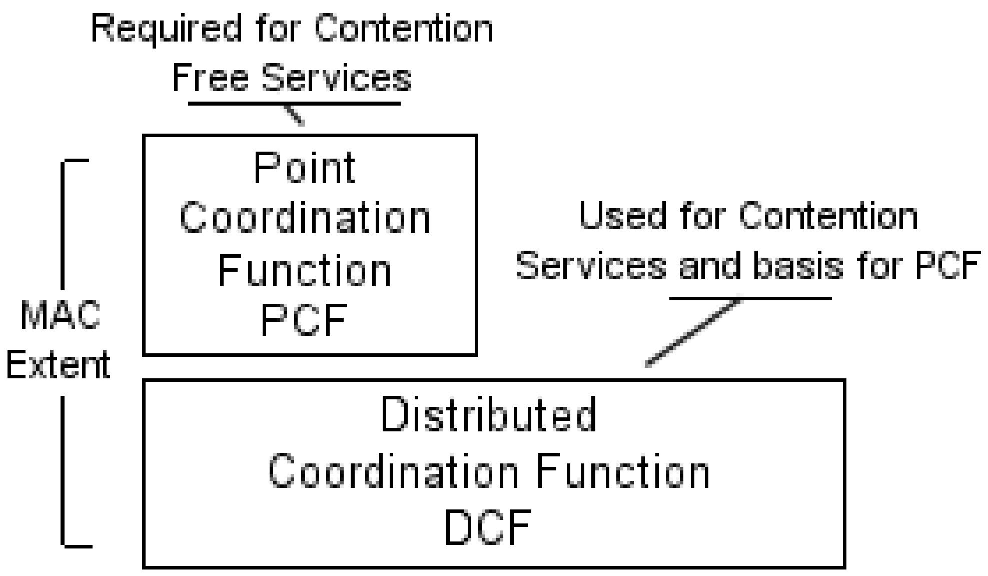
Access Modes

Distributed Coordination Function (DCF)

- Mandatory
- Basic access mode
- Contention-based

Point Coordination Function (PCF)

- Optional
- Contention-free
- Lower delay variance

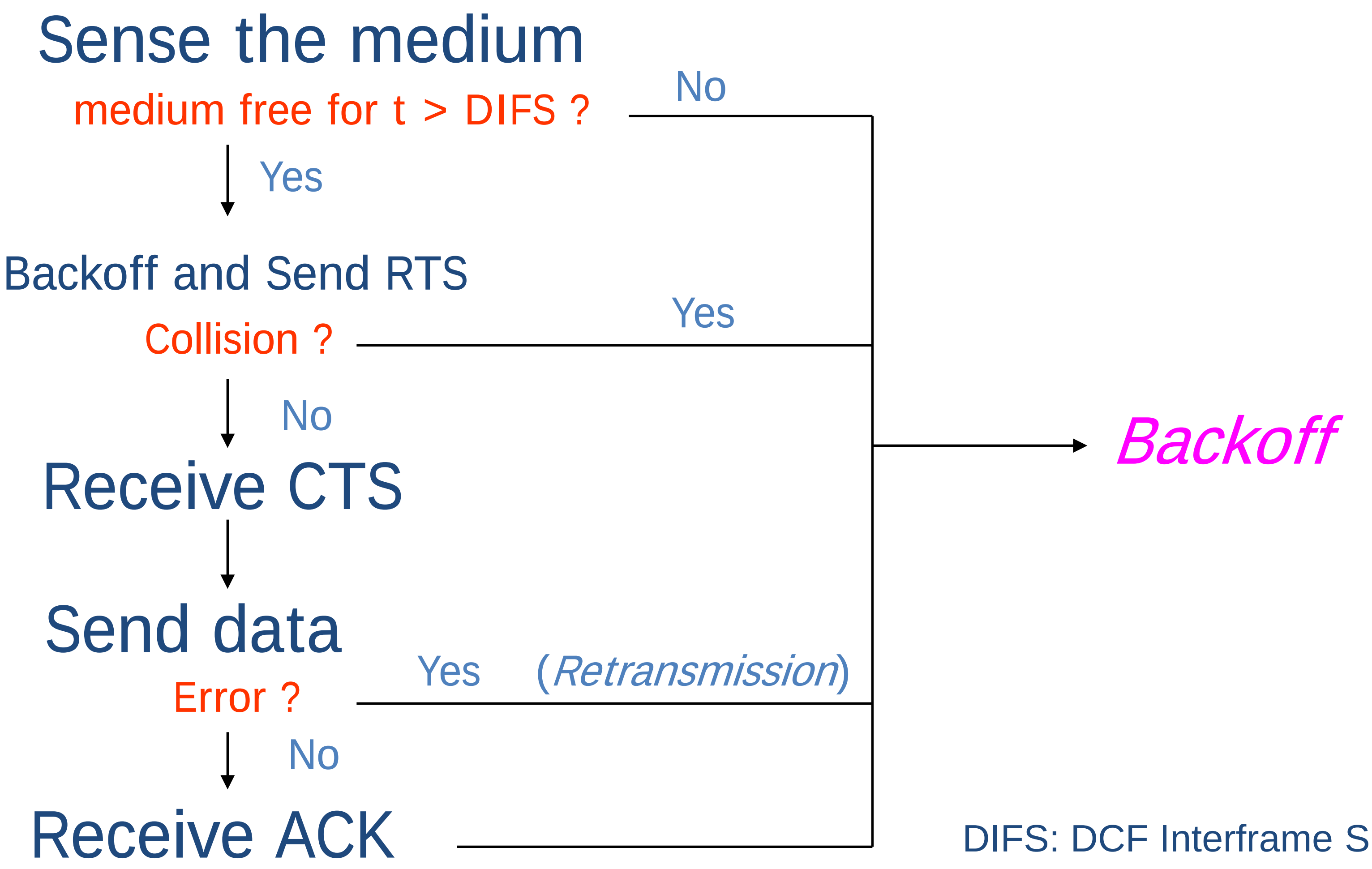


Distributed Coordination Function

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

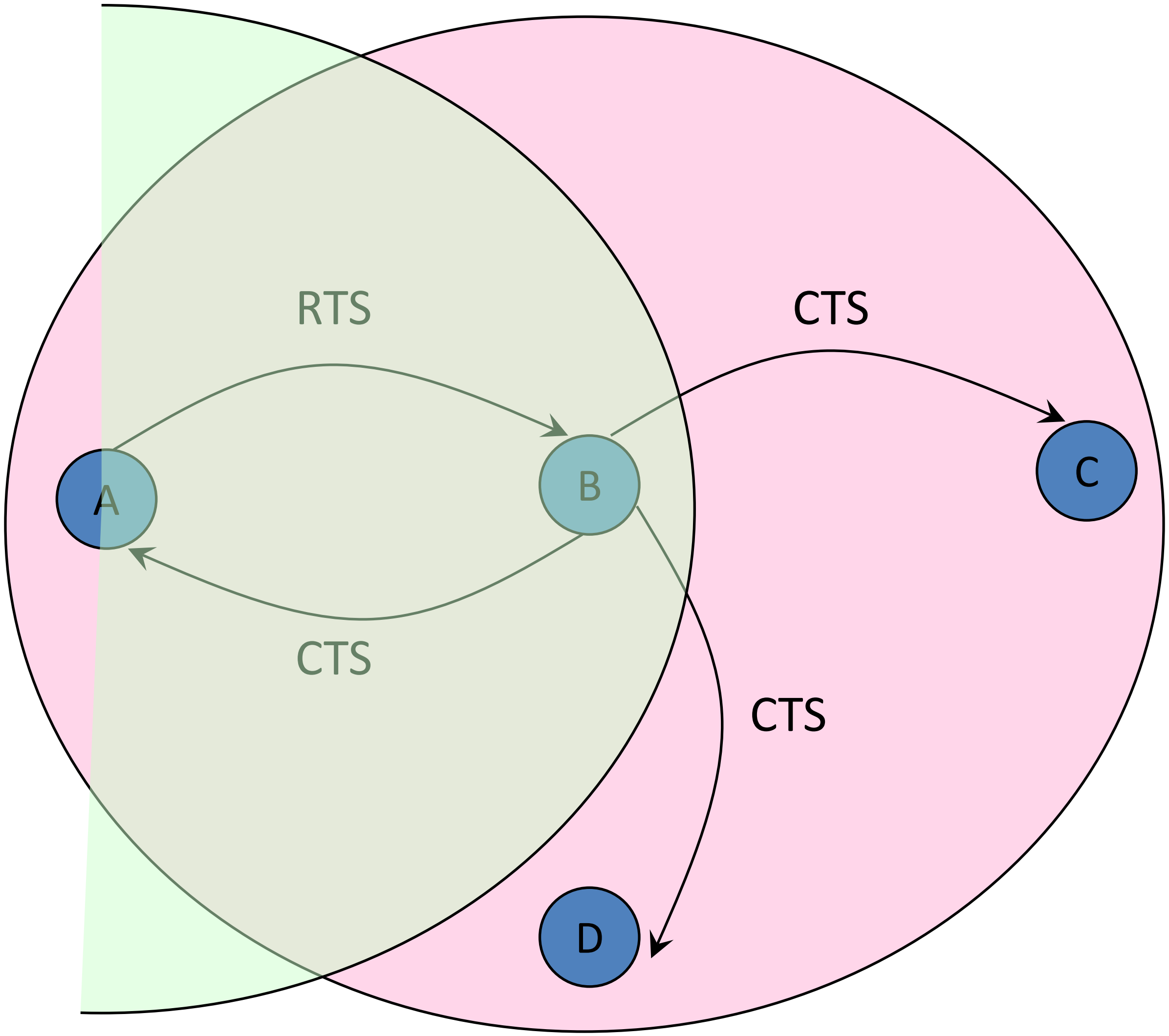
- Uses acknowledgment for all transmission
- Data correction through retransmissions
- 4-way handshake (RTS/CTS/Data/Ack) for «Virtual Carrier Sensing»
- Handles hidden terminal problem

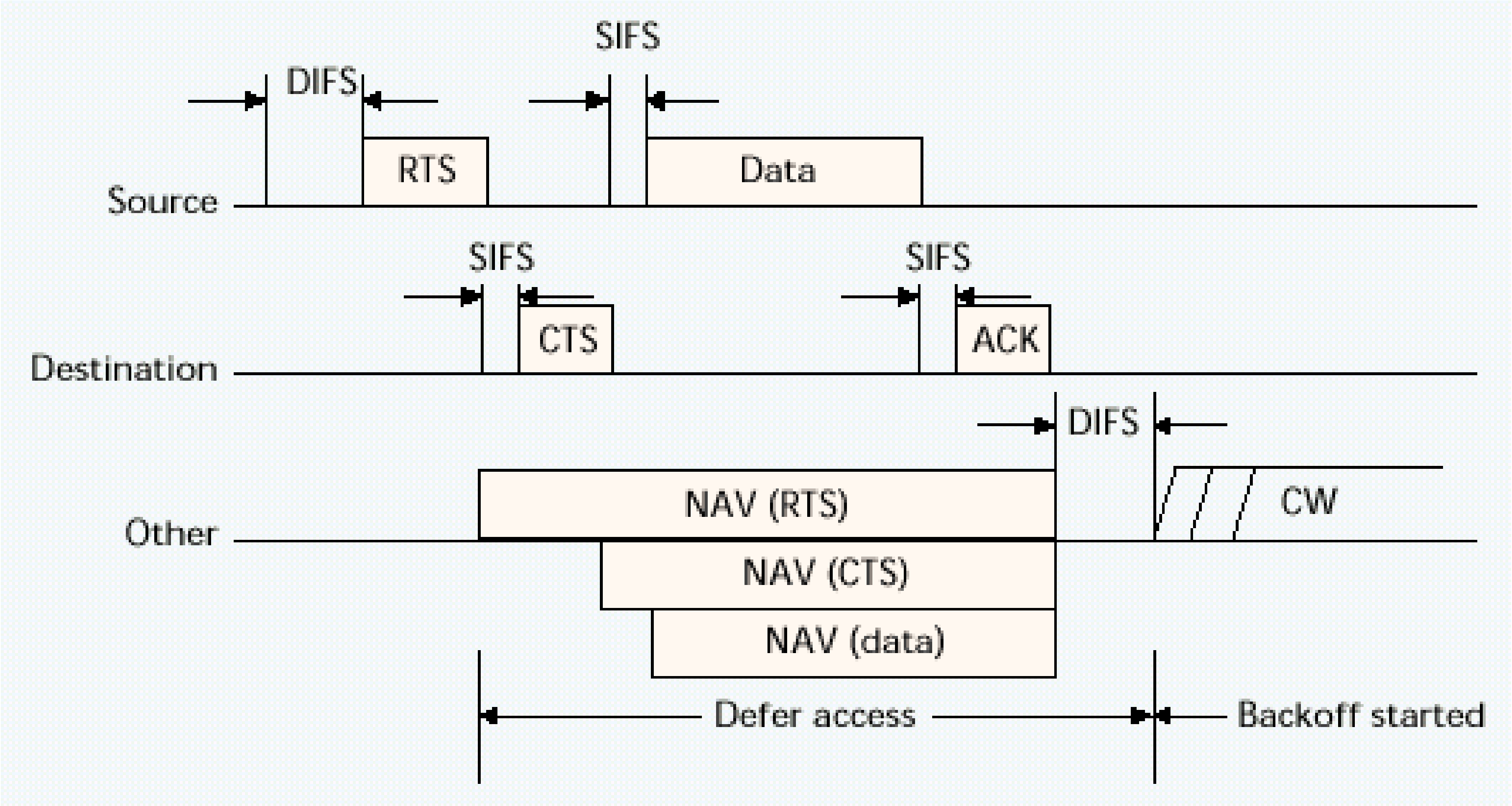
Distributed Coordination Function



DIFS: DCF Interframe Space

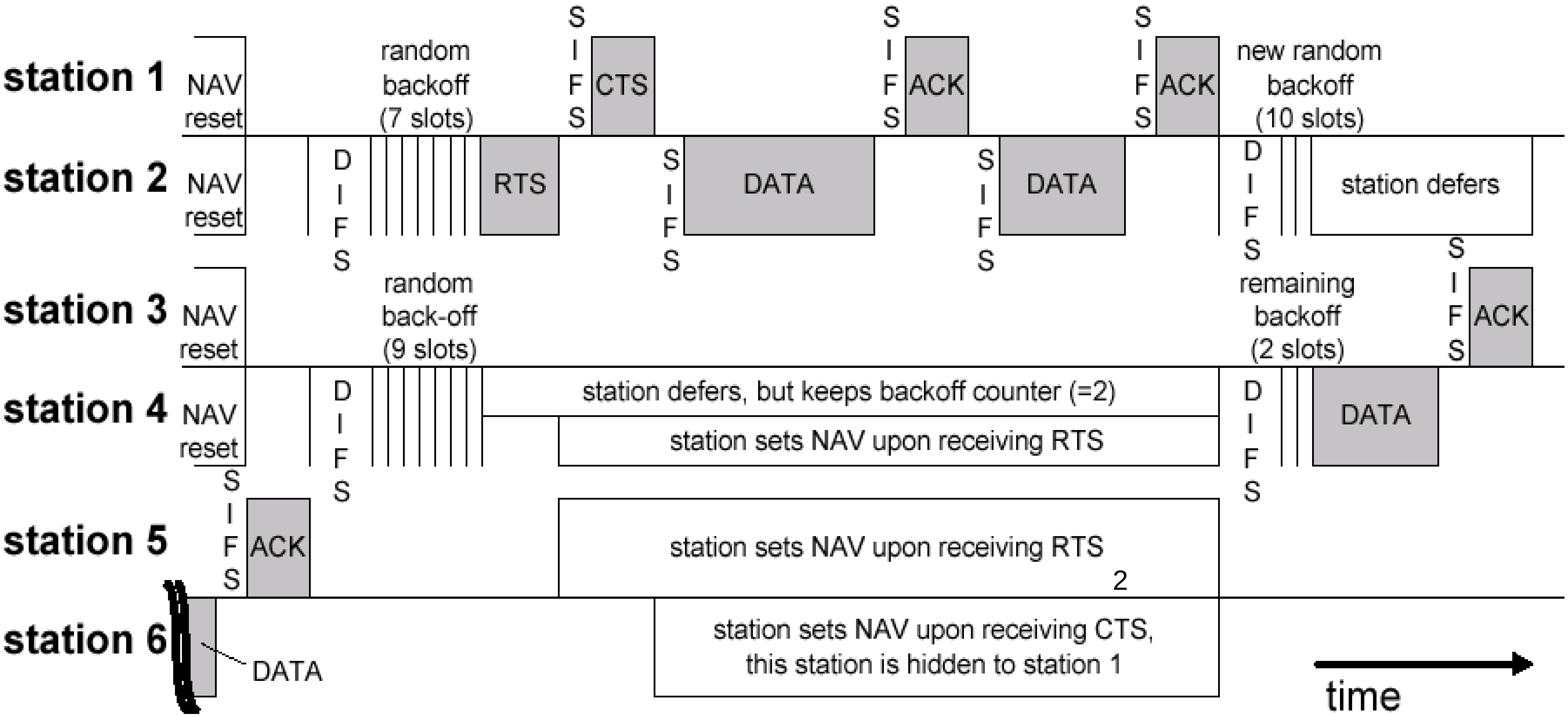
Collision avoidance in node B





- Always SIFS<DIFS
- Power saving through the NAVs

Example of DCF Transmission



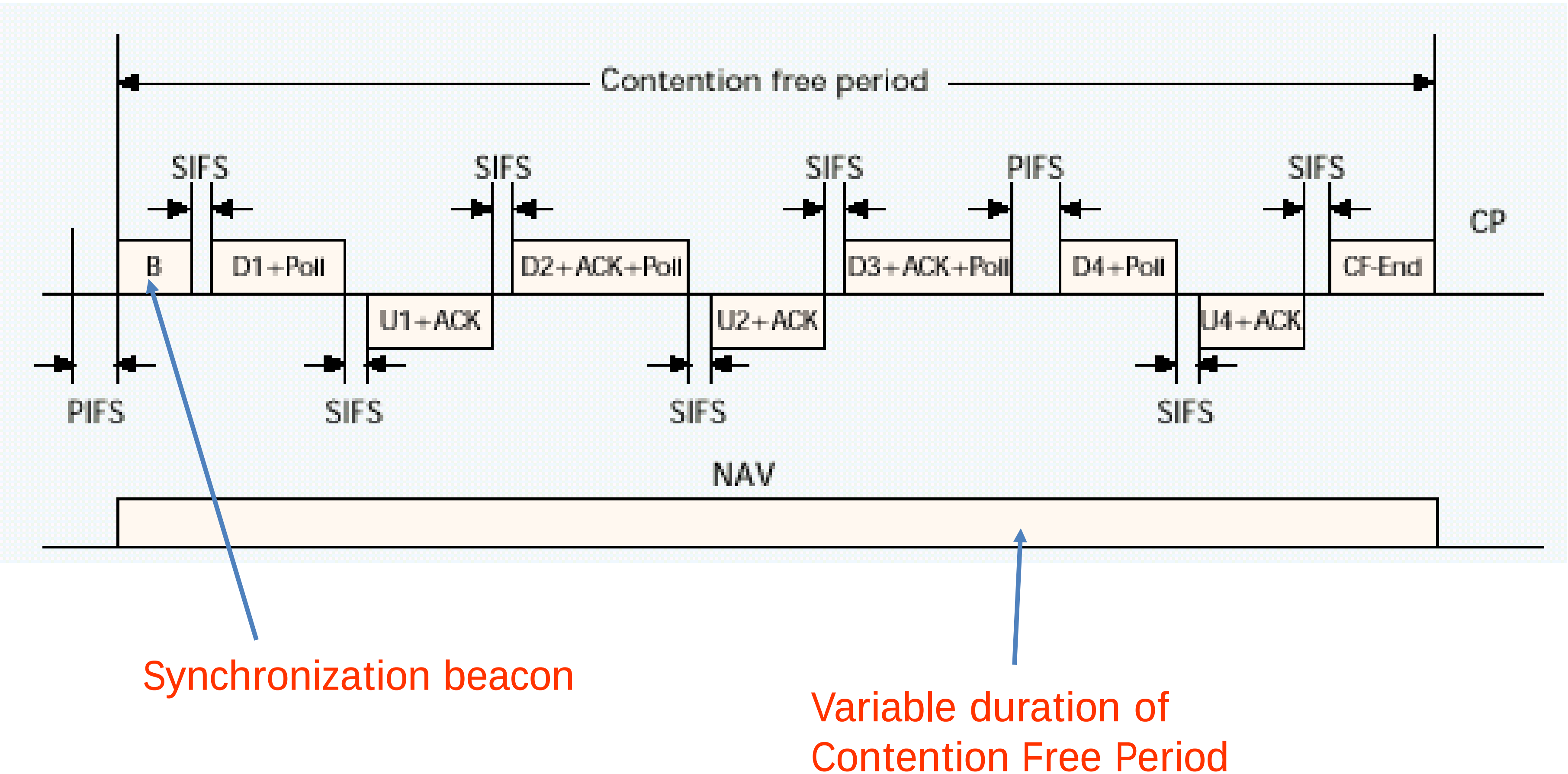
Disadvantages of DCF

- 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

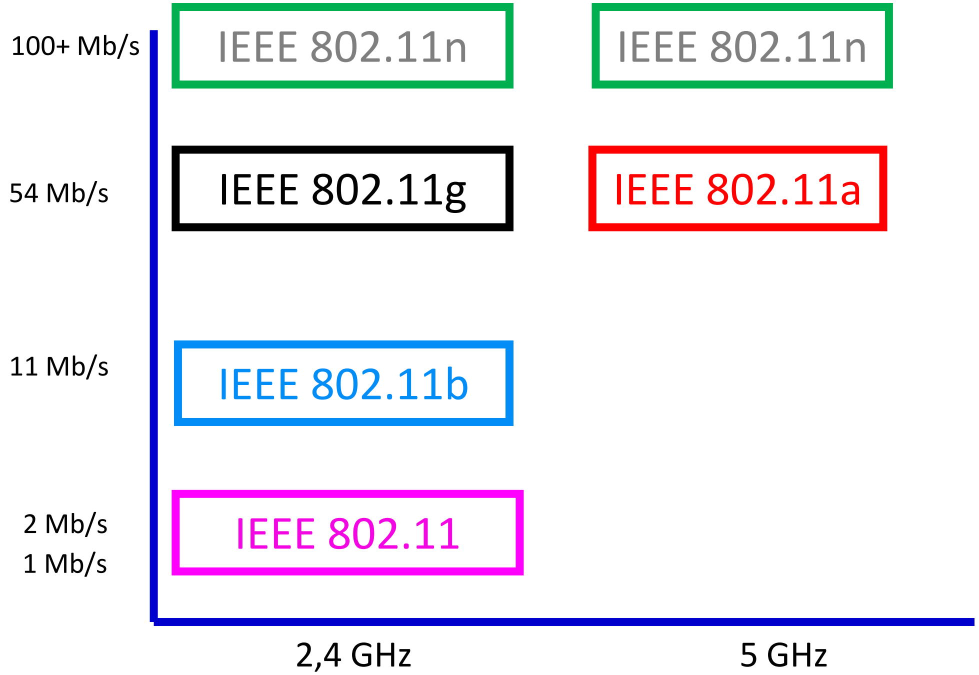
Point Coordination Function



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 *

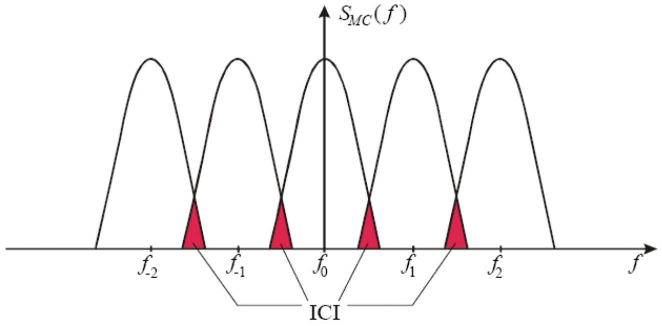
* Maximum packet (MPDU) allowed 4095 bytes = 32760 bits = 32,76 msec (για κανάλι 1Mbps)

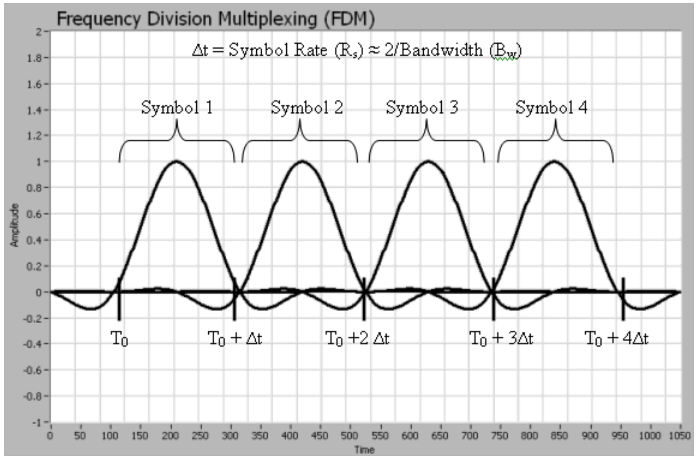


	802.11a	802.11b	802.11g	802.11n
Maximum Data Rate	54 Mbps	11 Mbps	54 Mbps	600 Mbps
Modulation	OFDM	DSSS	OFDM	OFDM
RF Band	5 GHz	2.4 GHz	2.4 GHz	2.4 GHz or 5 GHz
Number of spatial streams (MIMO)	1	1	1	1 to 4
Channel Width	20 MHz	20 MHz	20 MHz	20 MHz or 40 MHz

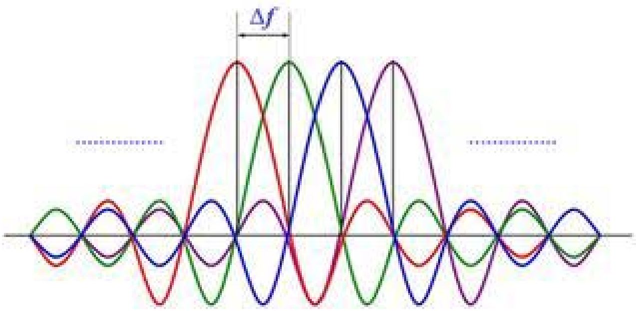
OFDM: Orthogonal Frequency Division Multiplexing

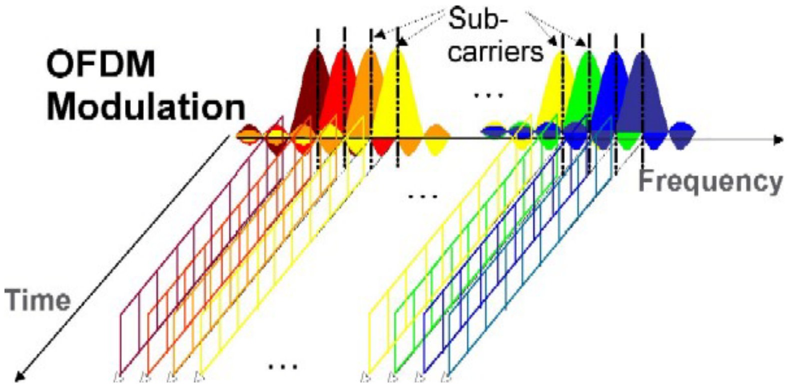
Traditional FDM





OFDM

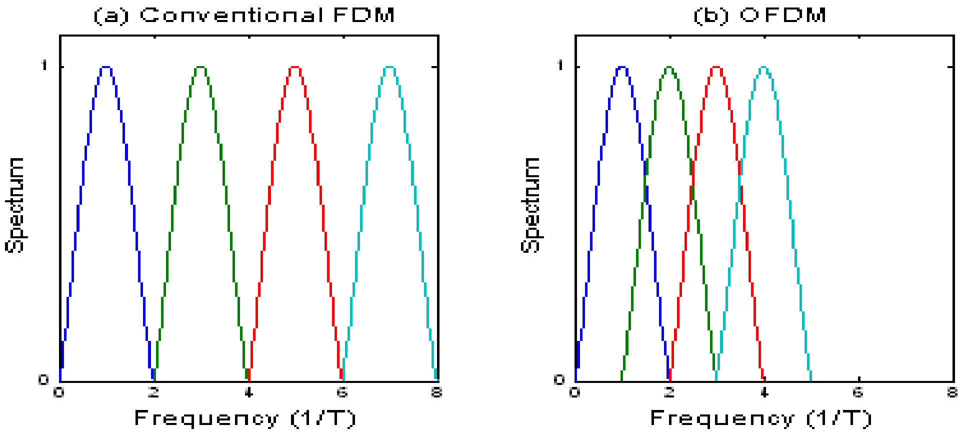




OFDM pros and cons

Pros

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



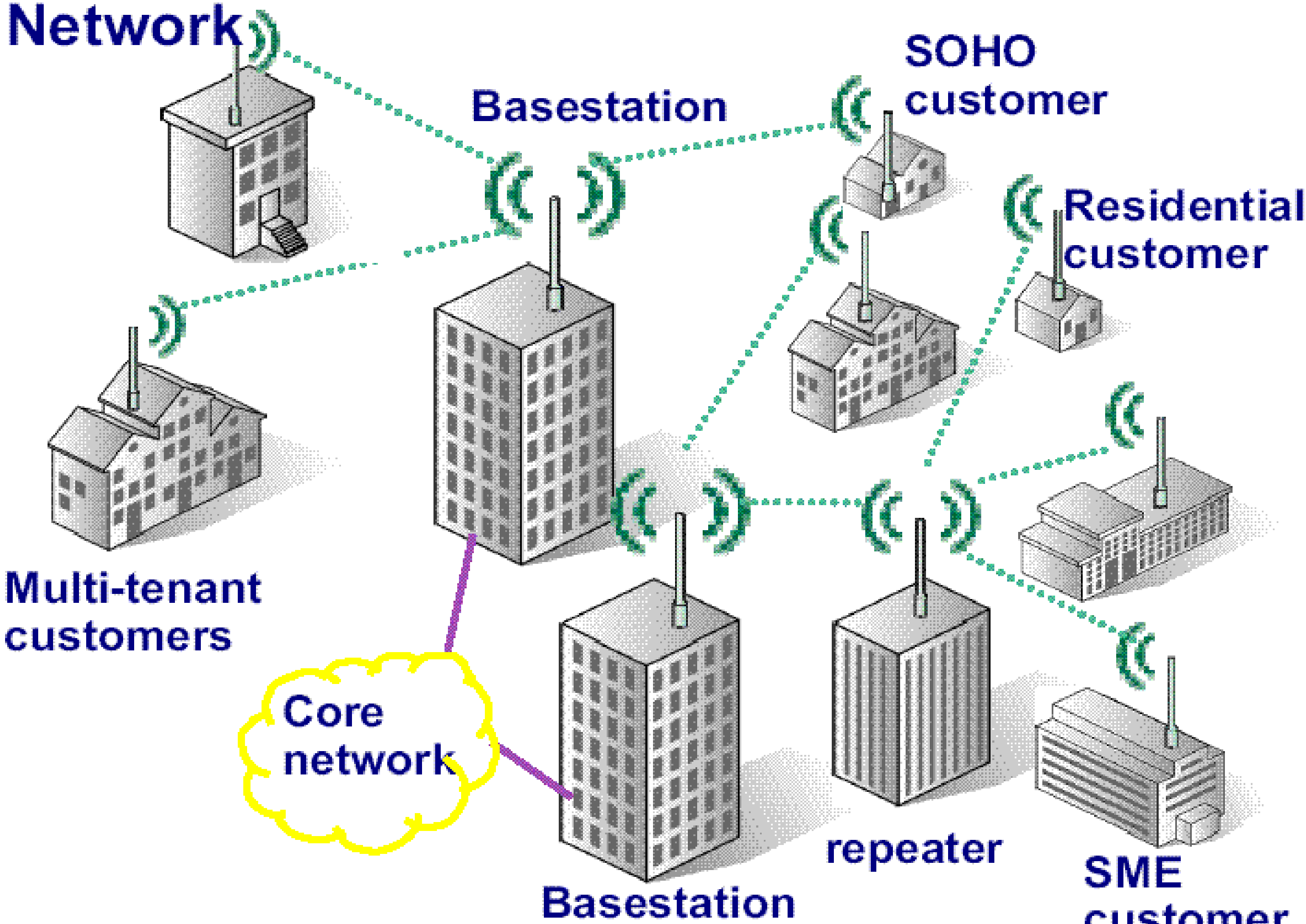
Cons

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

IEEE 802.16
WiMaX

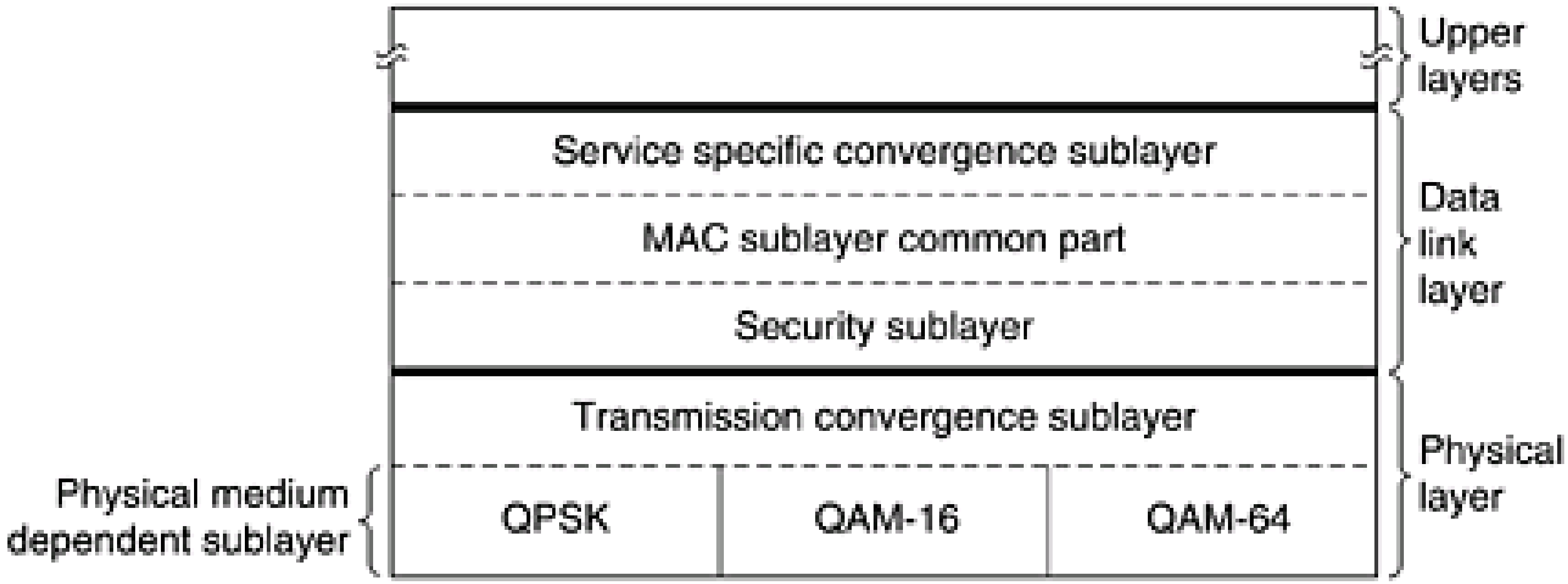
"Air Interface for Fixed Broadband Wireless Access Systems"

WirelessMAN: Wireless Metropolitan Area Network

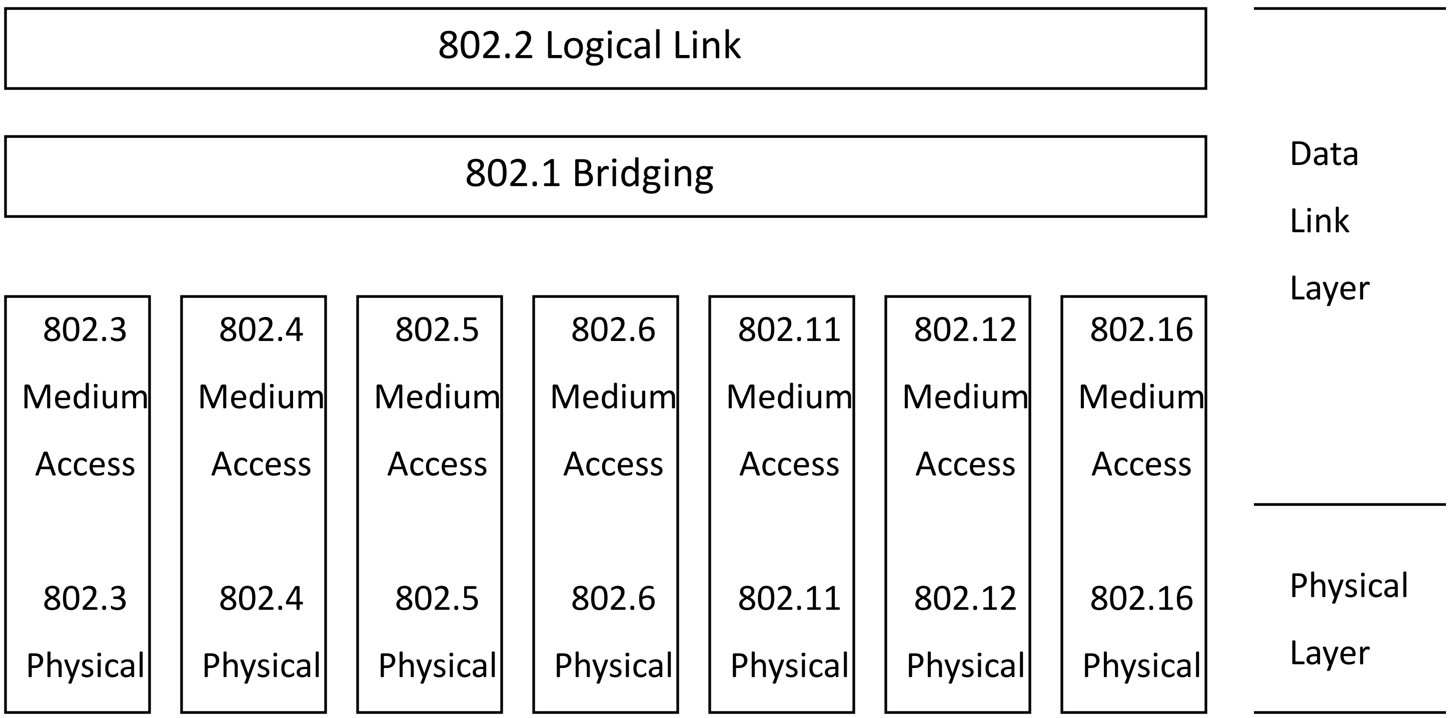


Source: Nokia Networks

WiMaX Layers

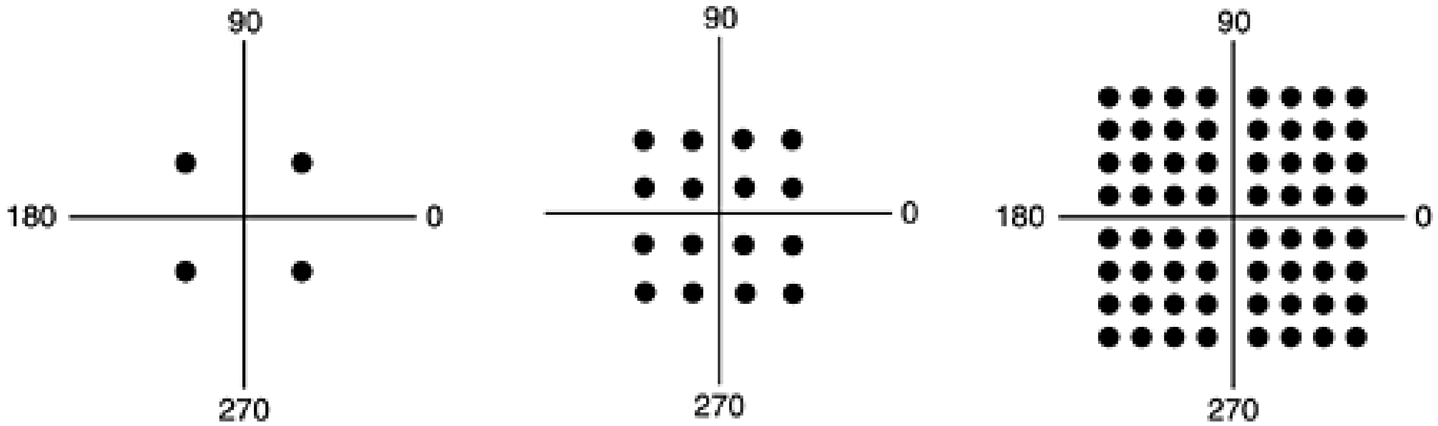


The 802 Family



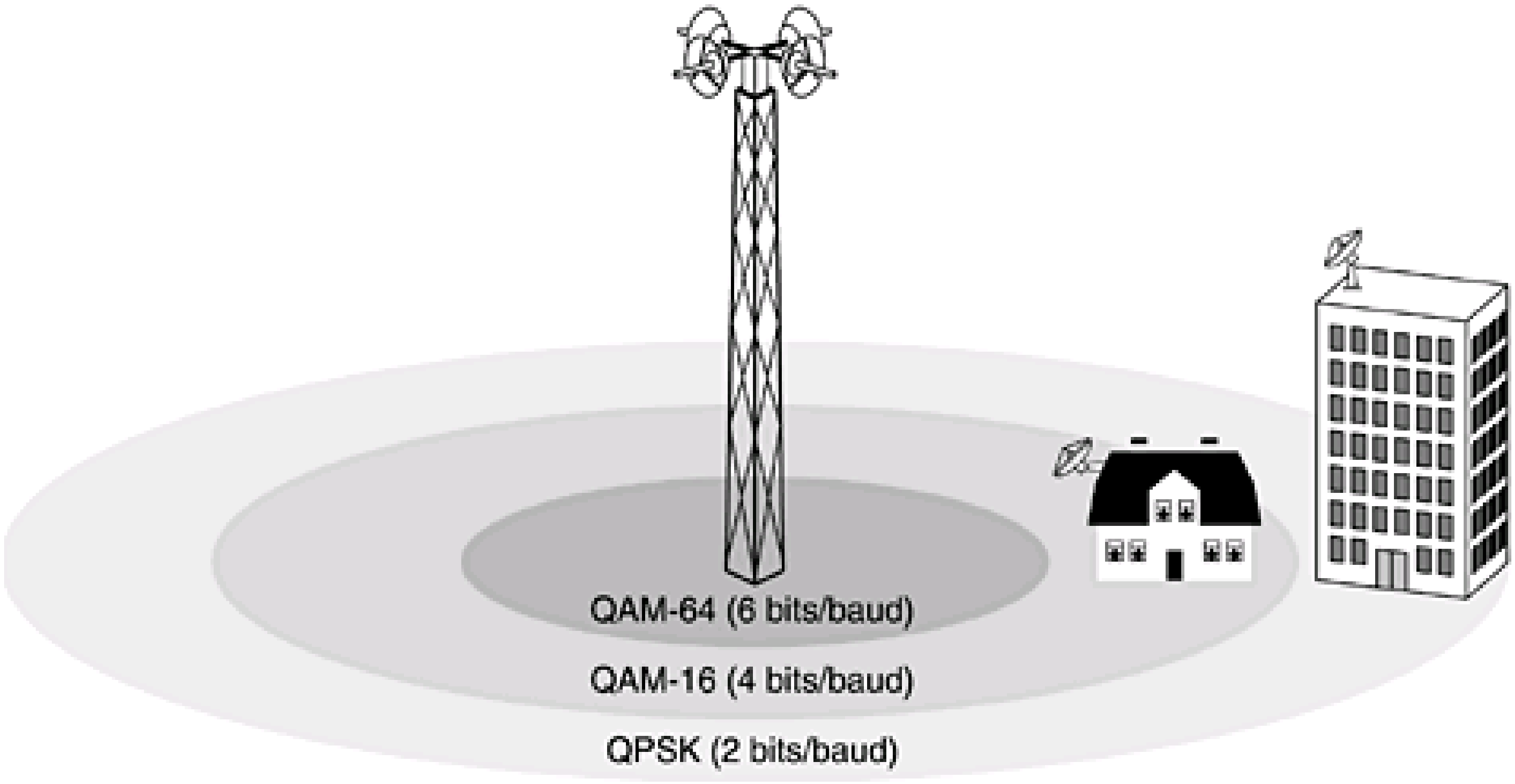
Multiple modulations

- 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

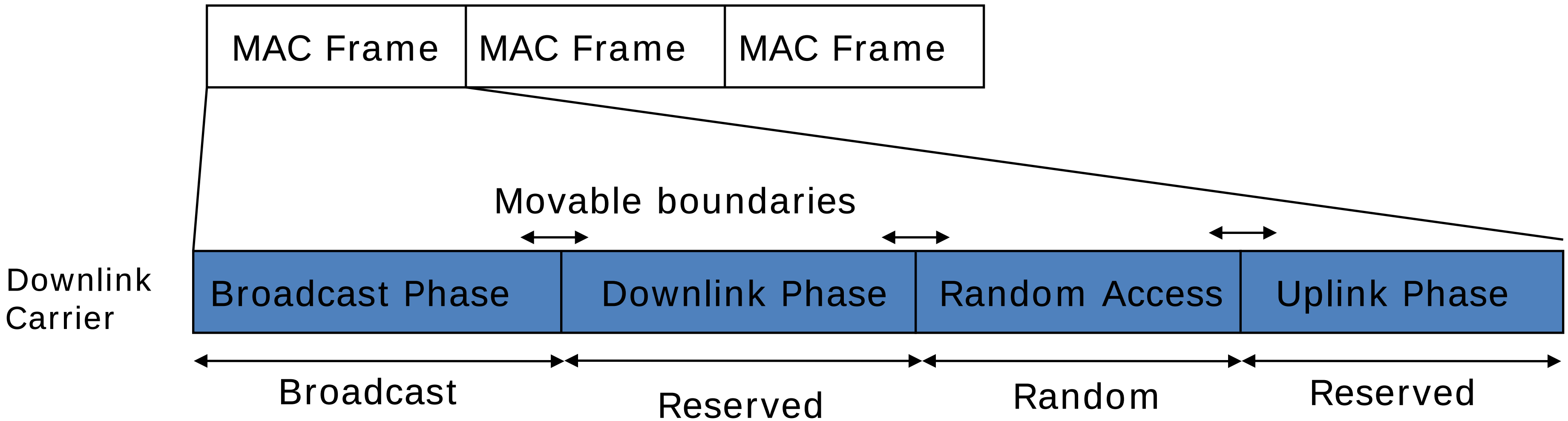
Adaptive modulation



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

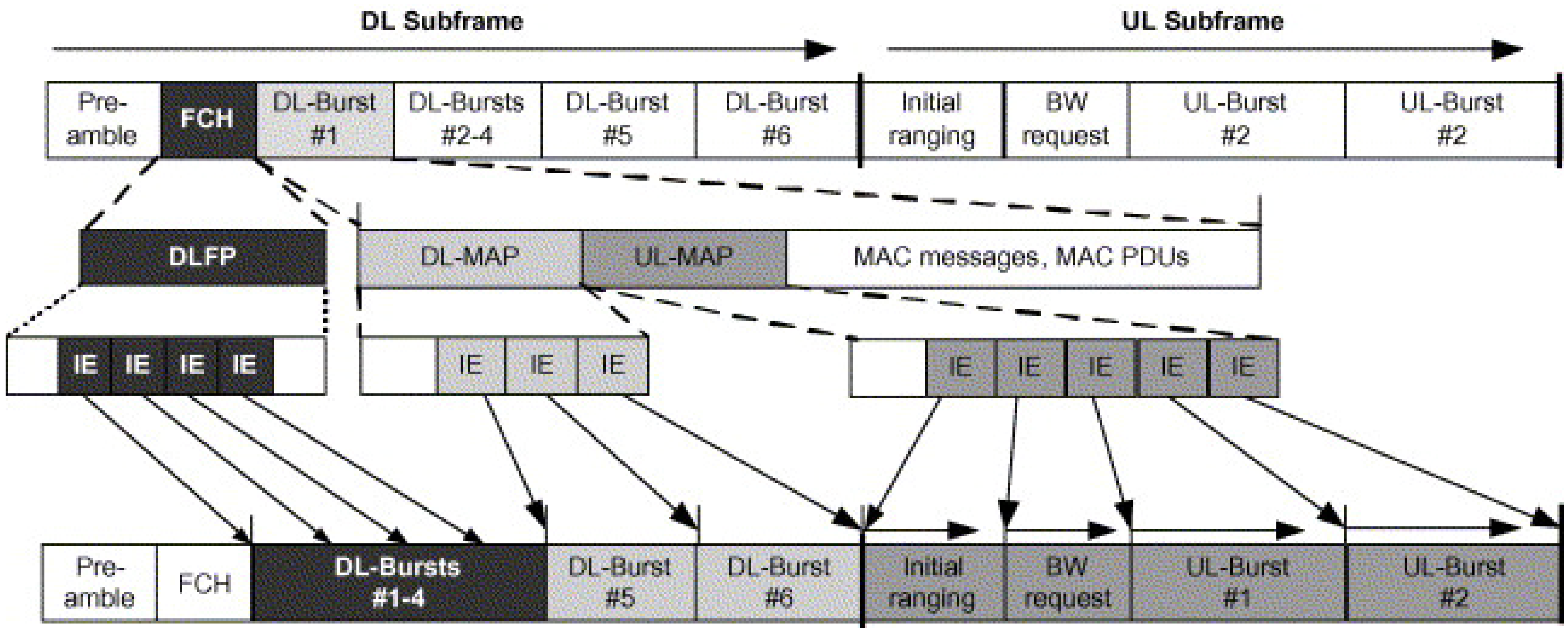
Time Division Duplexing (TDD)

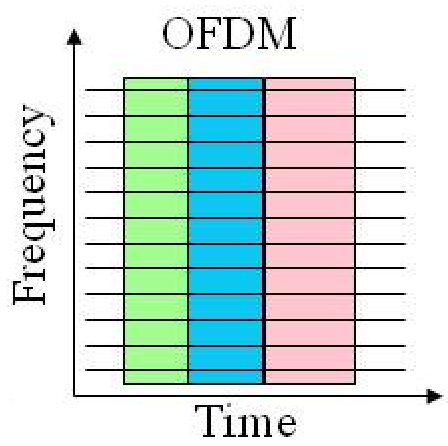


Media Access Control (MAC)

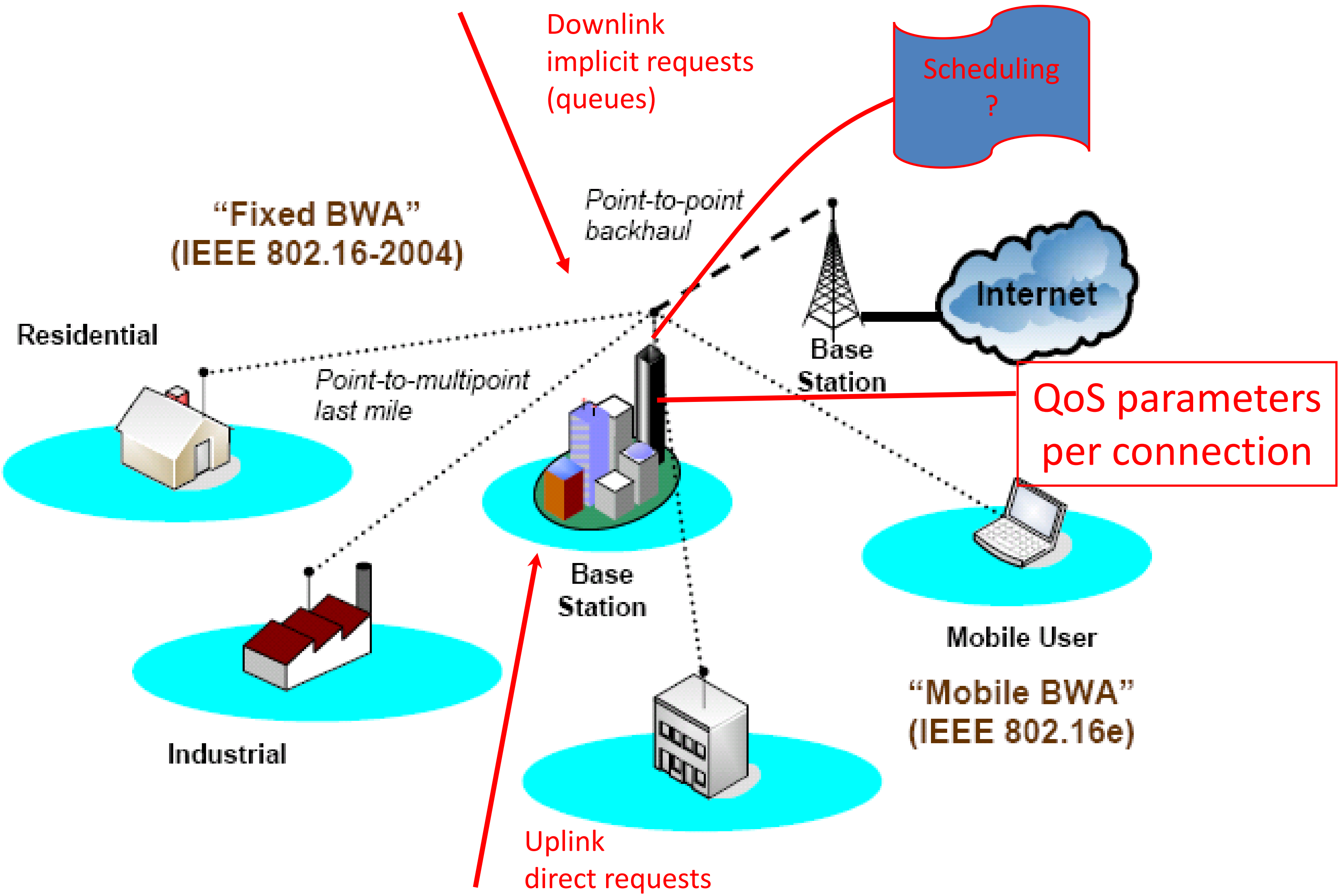
- Connection oriented μετάδοση
  - Connection ID (CID)
  - Uni-directional

- 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).


DL Subframe
UL Subframe
Pre-amble
FCH
DL-Burst #1
DL-Bursts #2-4
DL-Burst #5
DL-Burst #6
Initial ranging
BW request
UL-Burst #2
UL-Burst #2
DLFP
DL-MAP
UL-MAP
MAC messages, MAC PDUs
IE IE IE IE
IE IE IE
IE IE IE IE IE
Pre-amble
FCH
DL-Bursts #1-4
DL-Burst #5
DL-Burst #6
Initial ranging
BW request
UL-Burst #1
UL-Burst #2


OFDM
Frequency
Time

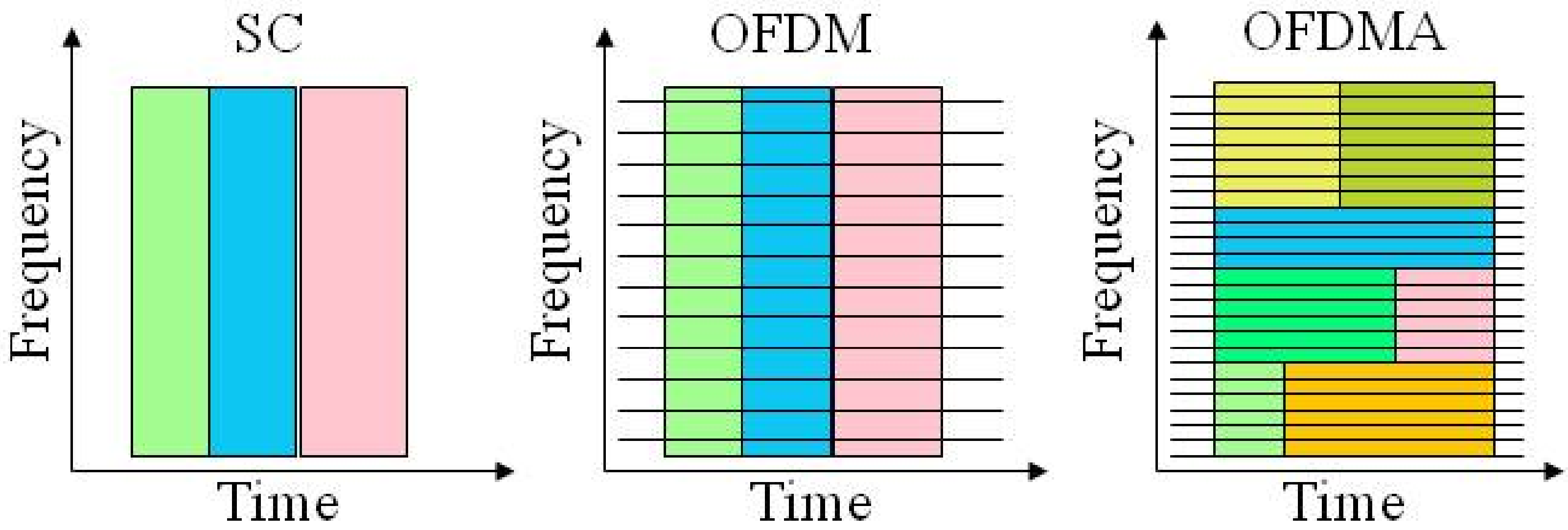
Bandwidth request and allocation



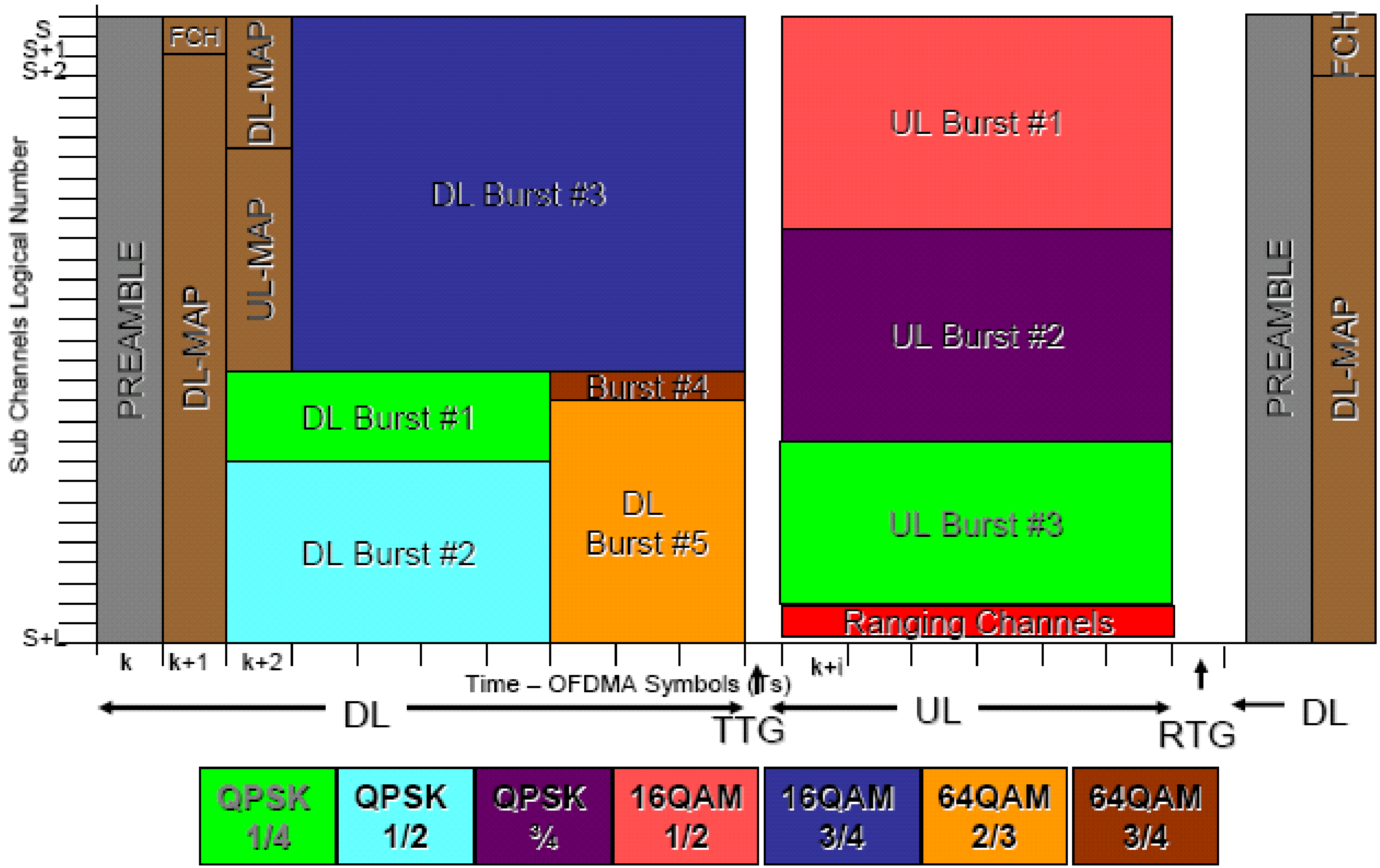
Extensions in 802.16e

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

SC/OFDM/OFDMA



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