University of Zagreb

Faculty of Electrical Engineering and Computing

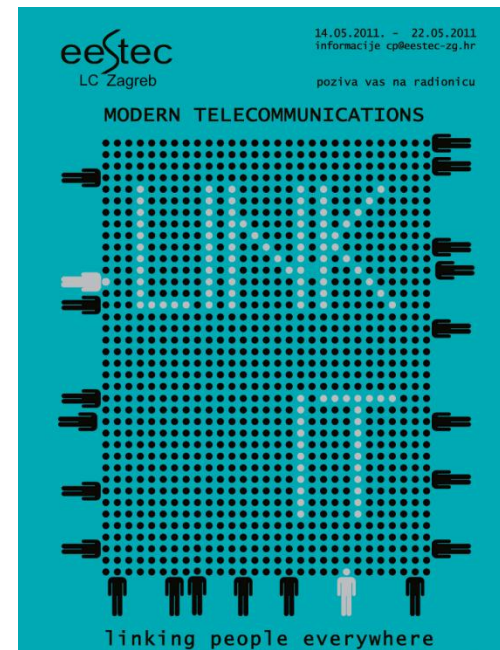**Electrical Engineering STudents European assoCiation**

Local Committee Zagreb

Mobile network fundamentals and evolution

Vedran Podobnik, Ph.D.
Prof. Gordan Jezic, Ph.D.

Modern Telecommunications:
Linking people everywhere!

14-22 May 2011
Zagreb, Croatia

Mobile phones today

♦ it is hard to imagine a world without mobile phones

♦ we use them every day to communicate with the world around us

♦ however, it was not always this easy to get in touch with our friends and family…

Outline

- ## Why?

  - ### The evolution of computing

    - From mainframes to smartphones

  - ### The evolution of the Internet

    - From the four-node network to the ubiquitous network

- ## How?

  - ### The evolution of mobile networks

    - From 1G to beyond 3G

- ## Where are we today?

The evolution of computing
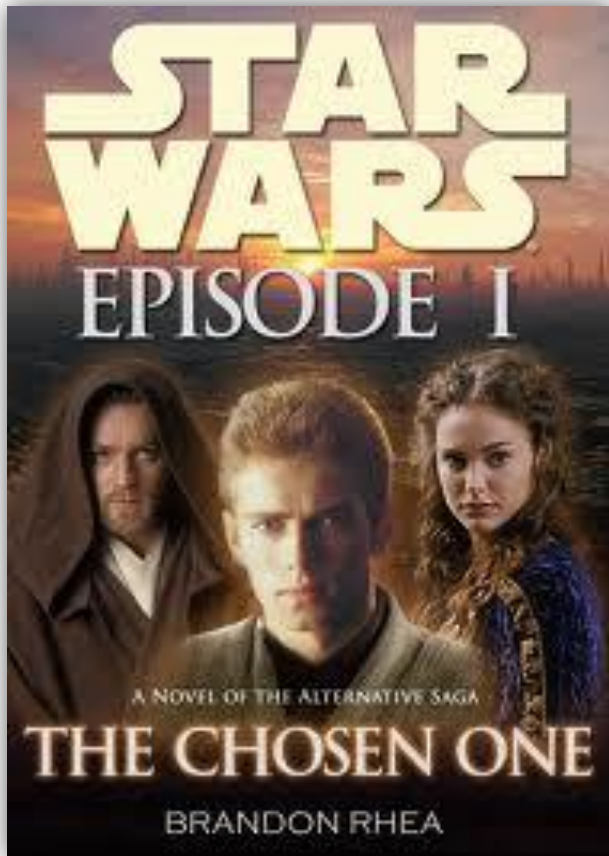
Computing: 1st era (1)
Mainframe computing

- ♦ titanic machines of the early 1950s

- ♦ large and powerful computers

- ♦ utilization of scarce resources shared amongst a number of users
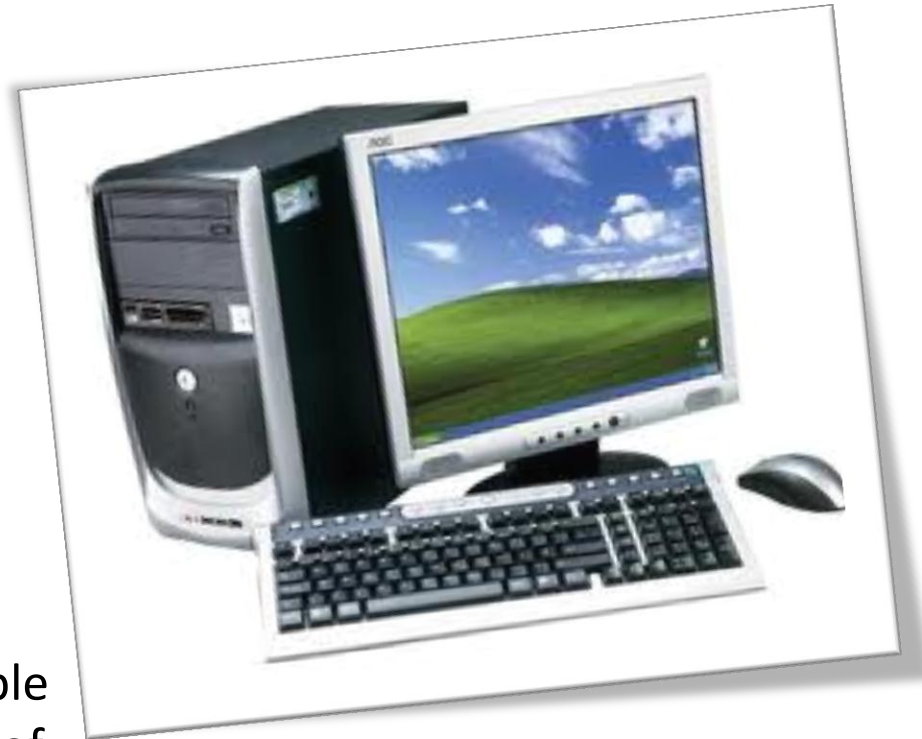
Mainframe computing – problems

- very expensive

- very huge in volume

- available only to the „chosen ones"

Computing: 2nd era (1)
Personal computing (PC)

- ♦ general-purpose computer useful for individuals

    - ■ size

    - ■ capabilities

    - ■ sales price

- ♦ since 1975

    - ■ around 1985 the number of people using PCs surpassed the number of people using shared computers

Computing: 2nd era (2)
Personal computing (PC) – problems

"There is more information available at our fingertips during a walk in the woods than in any computer system, yet people find a walk among trees relaxing and computers frustrating." *

Mark Weiser, John Seely Brown: **The Coming Age of Calm Technology**, 1997

Computing: 3rd era (1)

Ubiquitous/pervasive computing, ambient intelligence, Internet of Things

♦ people interact with a dynamic set of small networked computers, often invisible and embodied in everyday objects in the environment

♦ since 2005

♦ "The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it." *

Mark Weiser

* Mark Weiser: **The Computer for the 21st Century**, 1991

Calm technology

„Our computers should be like our childhood: an invisible foundation that is quickly forgotten but always with us, and effortlessly used throughout our lives." *

* *Mark Weiser:* **The World is not a Desktop**, 1994

Computing: 3rd era (3)
Micro-scale smartphones (1)

- ♦ regularly equipped with a rich set of sensors

- ♦ not used only as a phone anymore, but as well as:
  - ■ gaming device
  - ■ media player, camera, audio recorder
  - ■ social networking tool
  - ■ email client, instant messenger
  - ■ clock, calendar, dictionary
  - ■ GPS device, map, compass
  - ■ remote control, file locker, torch light…

„Your cell phone has more computing power than all of NASA in 1969. NASA launched a man to the moon. We launched a bird into pigs." *

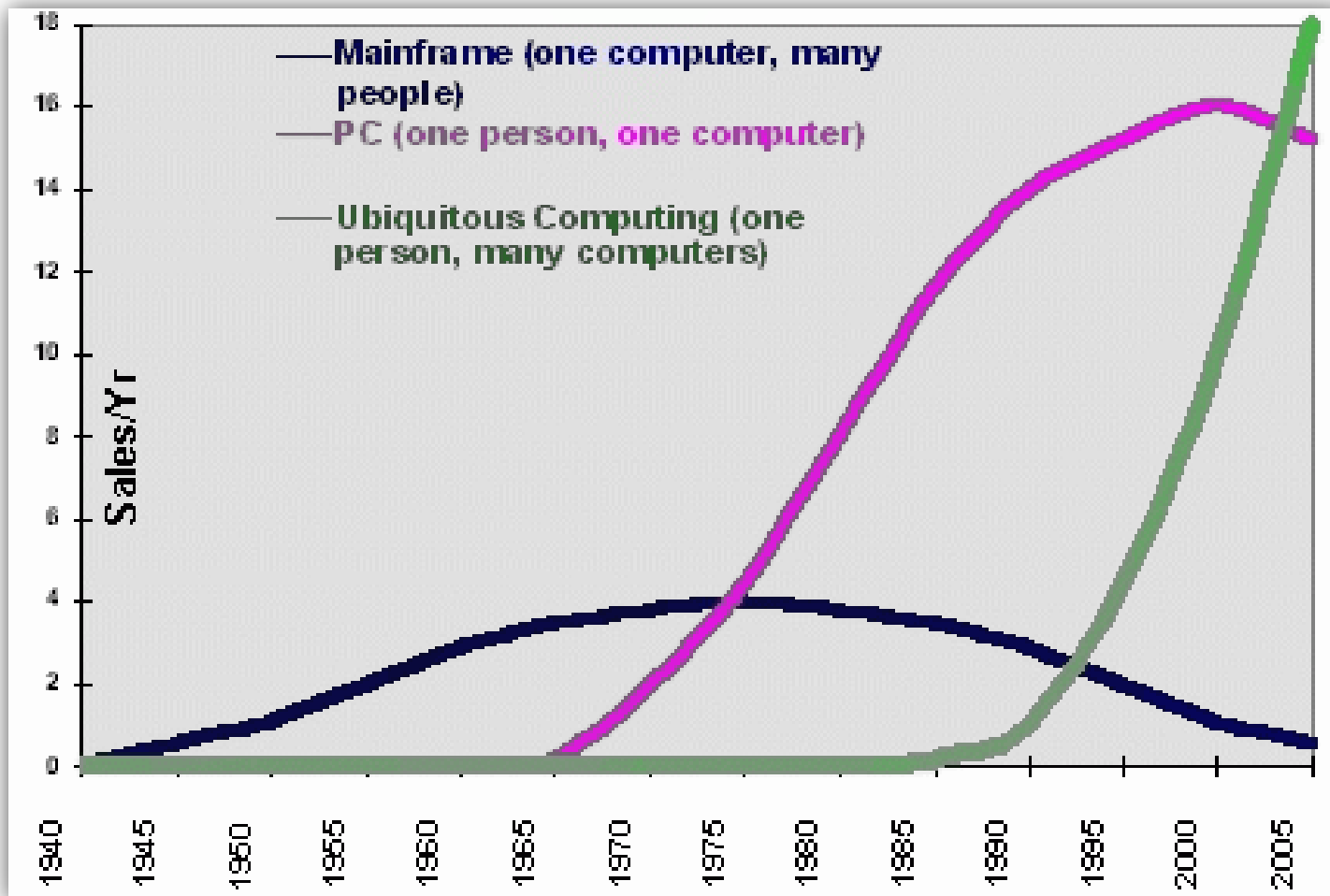** Tweets about Computing (March 23, 2011)*

- ◆ lecture and mini-workshop
  - ■ "Software development for mobile devices"
    - ● Asst. Prof. Mario Kusek
  - ■ Thursday, May 19
    - ● 10:15-12:00
    - ● 13:15-15:00

FER Droid

Computing
An overview of evolution
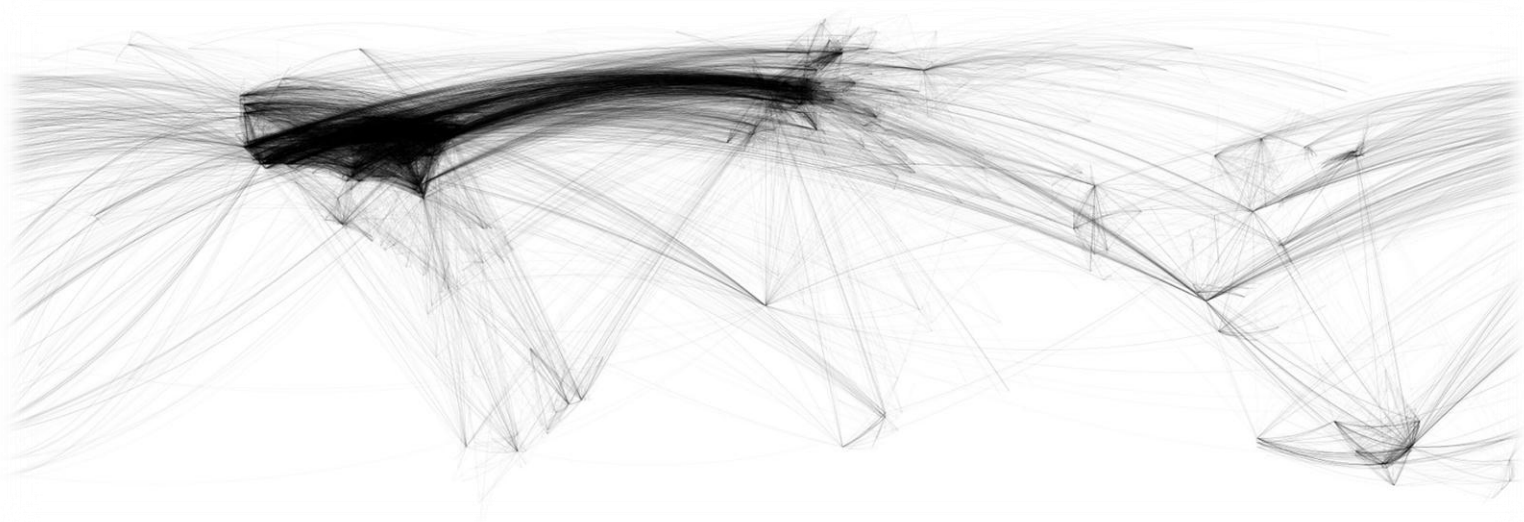

Figure:
Mark Weiser

The evolution of the Internet

Internet: the Weiser's view
A transtion towards ubiquitous computing

„Over the next decade the results of the massive interconnection of personal, business, and government information will create a new field, a new medium, against which the next great relationship will emerge" *

* *Mark Weiser, John Seely Brown:* **The Coming Age of Calm Technology**, 1997
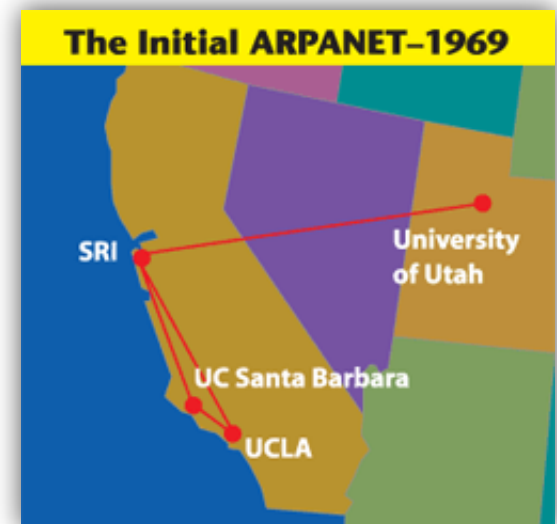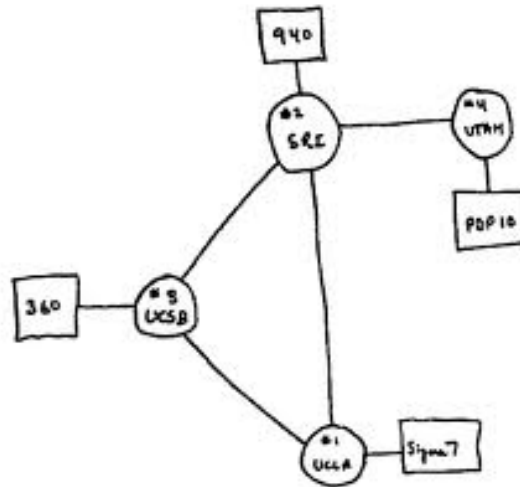
Figure: *http://www.chrisharrison.net/*

Internet: the genesis (ARPANET)
1970-1990

♦ emerged in the early 1970s, as a small network interconnecting just a few computers

♦ as Internet grew through the 1970s and 1980s, many people started to realize its potential

the very first transmission on the ARPANET, on October 29, 1969, was from UCLA to SRI

* SRI International

Internet: the global proliferation

1990-2000 – an advent of the World Wide Web

- WWW or simply Web 1.0

- invented by *Sir Tim Berners-Lee* in 1991

- information medium enabling users to read and write via computers connected to the Internet

- bearer of the digital revolution in the 1990s

- critical global service that touches almost all aspects of modern life

"He wove the World Wide Web and created a mass medium for the 21st century. He designed it. He loosed it on the world. And he more than anyone else has fought to keep it open, nonproprietary and free..." *

* TIME 100 Persons Of The 20th Century

Internet: becoming social

2000-nowadays

- ◆ **Web 2.0 ("the Social Web")**
  - ■ no longer simply about connecting information
  - ■ about connecting people to collaborate in ad-hoc groups
    - ● groups are created and dismantled with minimal overhead
  - ■ social networking phenomenon

  - ■ lecture
    - ● "Social Networking and Social Responsibility"
      - ‣ Vedran Podobnik, Ph.D.
    - ● Friday, May 20
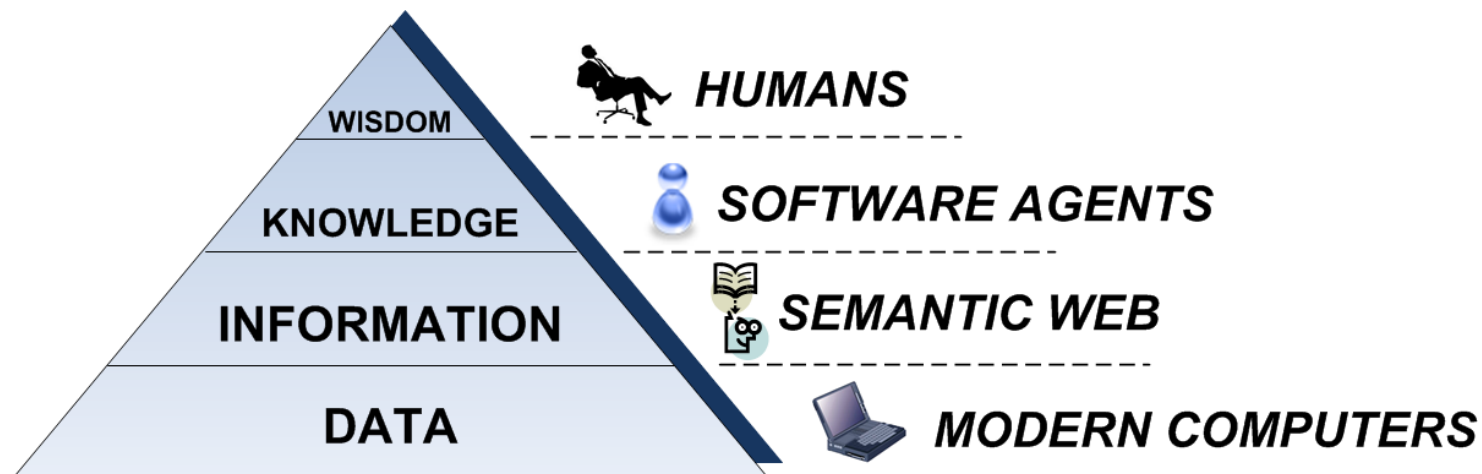   - ‣ 10:15-11:00

Internet: becoming autonomous
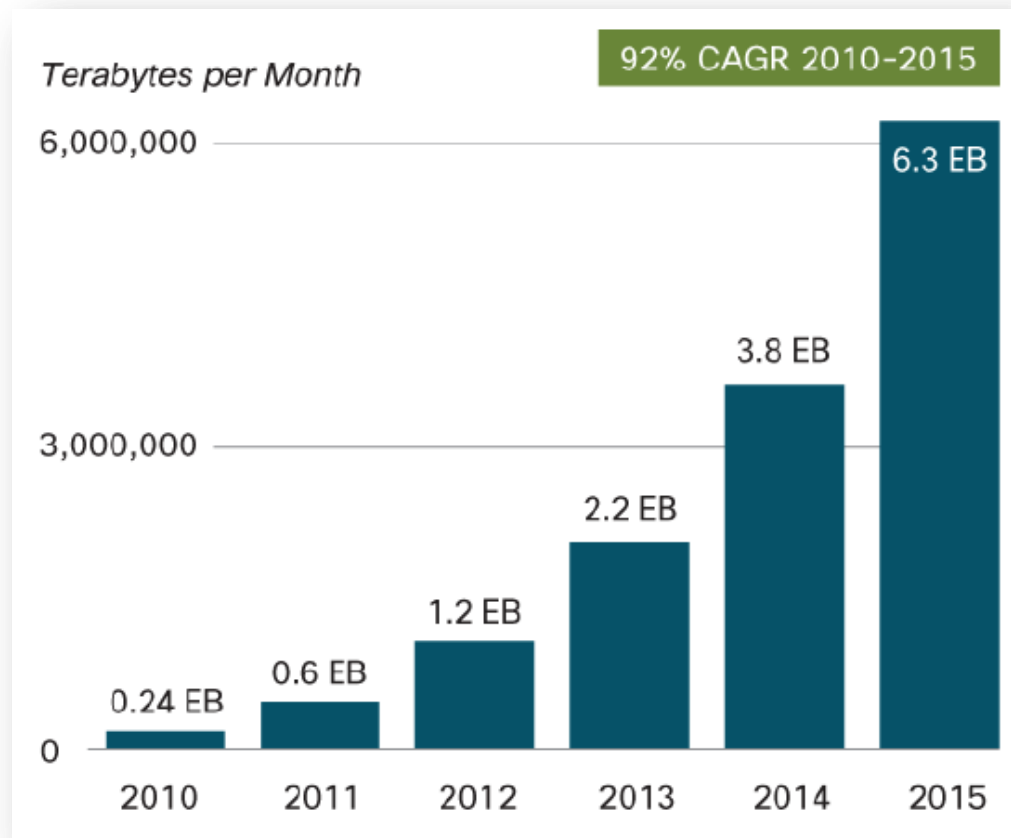## *2005-nowadays*

- ◆ Web 3.0 ("the Semantic Web")
  - ■ Internet as a platform for connecting knowledge
  - ■ enable people and machines to
    - ● connect
    - ● evolve
    - ● share   knowledge on an unprecedented scale
    - ● use

Internet: going mobile (traffic volume)
2010-2015 (Cisco forecast)

Terabytes per Month

92% CAGR 2010-2015

Year	Value
2010	0.24 EB
2011	0.6 EB
2012	1.2 EB
2013	2.2 EB
2014	3.8 EB
2015	6.3 EB

6,000,000
3,000,000
0

- ♦ mobile data traffic doubles every year until 2015
  - ■ 6.3 Exabytes (10^{15}B) per month of mobile data traffic by 2015
    - ● 26-fold increase over 2010

Source: Cisco, 2011

Internet: going mobile (connection speeds)
## *2010-2015 (Cisco forecast)*

- ◆ mobile network connection speeds doubled in 2010
  - ■ the average mobile network downstream speed was 215 kbps
  - ■ the average mobile network connection speed for smartphones was 1040 kbps

- ◆ mobile network connection speeds will increase 10-fold by 2015
  - ■ the average mobile network connection speed will grow at a compound annual growth rate of 60 percent
    - ● 2.2 Mbps in 2015

Internet: going mobile (device profiles)
2010-2015 (Cisco forecast)

♦ devices with high usage profiles are growing in number on the mobile network
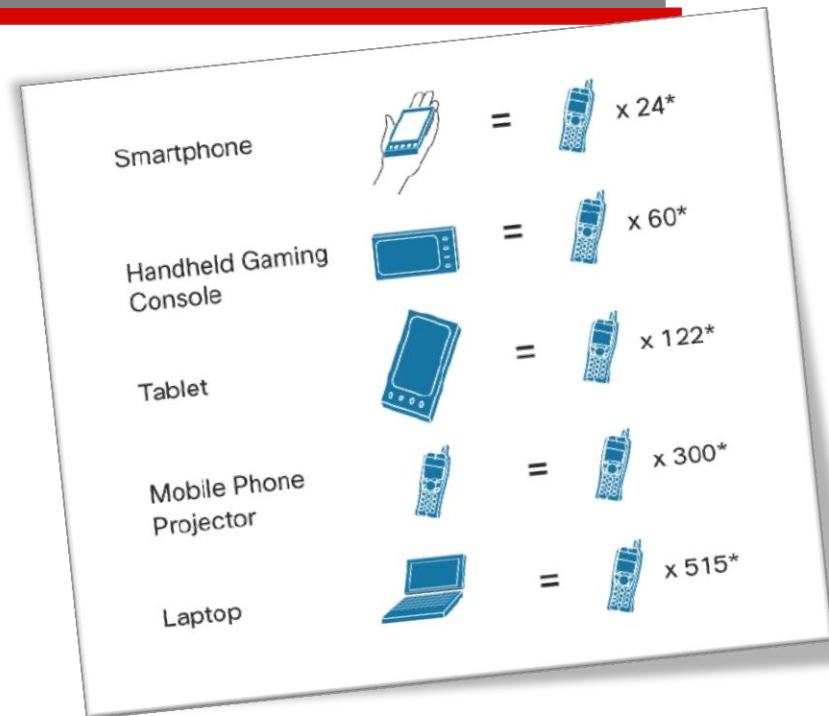
Source: Cisco, 2011

Device	Millions in Use 2009	Millions in Use 2010	Usage Multiplier Relative to Nonsmartphone	Usage Multiplier Relative to Smartphone
Smartphones	399	526	24 Nonsmartphones	1 Smartphone
iOS and Android phones	45	121	96 Nonsmartphones	4 Smartphones
Mobile-connected tablets	0.3	3.0	122 Nonsmartphones	5 Smartphones
Mobile-connected laptops	58	94	515 Nonsmartphones	22 Smartphones

Internet: going mobile (smartphones) (1)
2010-2015 (Cisco forecast)

- ◆ average smartphone usage doubled in 2010
  - ■ the average amount of traffic per smartphone in 2010 was 79 MB per month, up from 35 MB per month in 2009
  - ■ smartphones represent only 13 percent of total global handsets in use today, but they represent over 78 percent of total global handset traffic

- ◆ the average smartphone will generate 1.3 GB of traffic per month in 2015
  - ■ a 16-fold increase over the 2010 average of 79 MB per month

Internet: going mobile (smartphones) (2)
2010-2015 (Cisco forecast)

- ◆ Android approaches iPhone levels of data use
  - ■ the beginning of the 2010
    - iPhone consumption was at least 4 times higher than that of any other smartphone platform
  - ■ the end of the 2010
    - iPhone consumption was only 1.75 times higher than that of the second-highest platform, Android

VS

Internet: going mobile (tablets)
2010-2015 (Cisco forecast)

- 3 million tablets were connected to the mobile network in 2010
  - each tablet generated 5 times more traffic than the average smartphone
    - mobile data traffic per tablet was 405 MB per month

- 110 million mobile-connected tablets will generate as much traffic in 2015 as the entire global mobile network in 2010
  - 248 petabytes per month
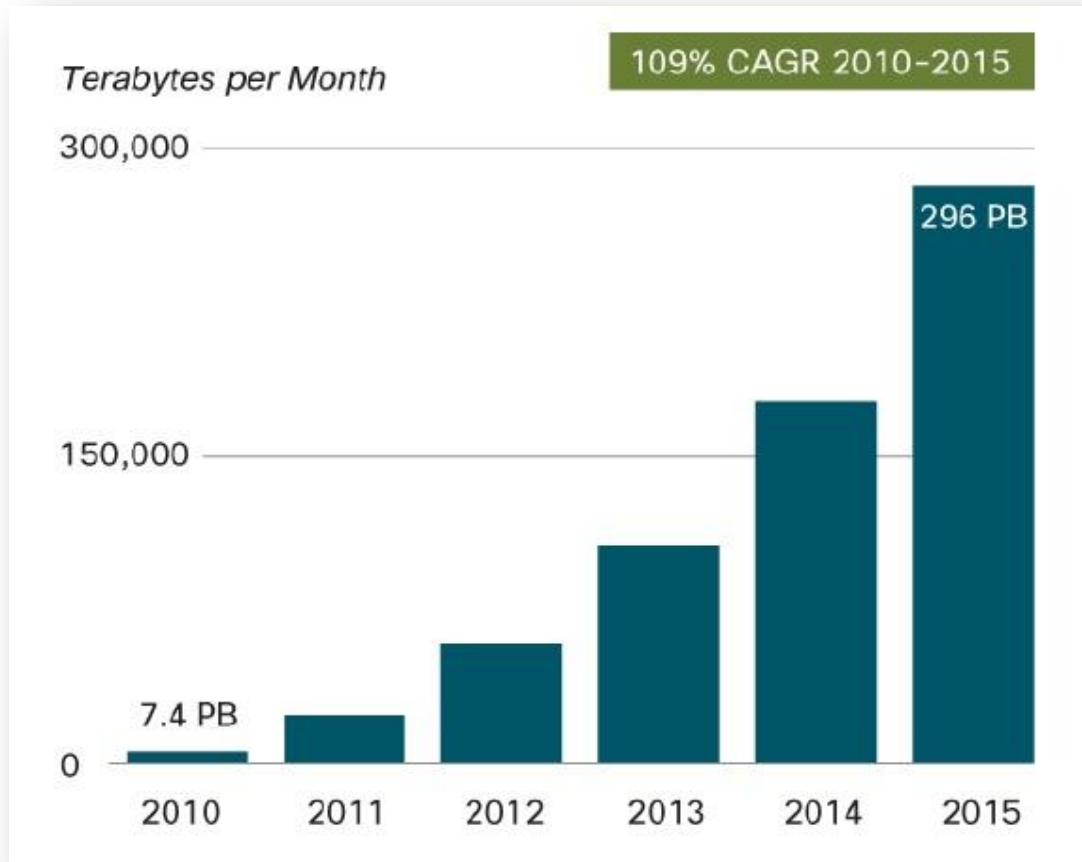
Internet: going mobile (laptops)
2010-2015 (Cisco forecast)

- ♦ **94 million laptops on the mobile network in 2010**
  - each laptop generated 22 times more traffic than the average smartphone
    - mobile data traffic per laptop was 1.7 GB per month

- ♦ **543 million mobile-connected laptops in 2015**
  - mobile data traffic per laptop in 2015 will be 6.5 GB per month

Internet: going mobile (M2M)
2010-2015 (Cisco forecast)

Terabytes per Month

109% CAGR 2010–2015

300,000

296 PB

150,000

7.4 PB

0

2010   2011   2012   2013   2014   2015

- ♦ Machine-to-Machine Traffic to increase 40-fold in period 2010-2015
  - Business and consumer security and surveillance
  - Health care
  - Inventory and fleet management
  - Telematics

Source: Cisco, 2011

♦ **48 million people in the world have mobile phones, even though they do not have electricity at home**

■ **the off-grid, on-net population will reach 138 million by 2015**

Source: Cisco, 2011

♦ nearly one mobile device *per capita* by 2015

- over 7.1 billion mobile-connected devices, including machine-to-machine (M2M) modules
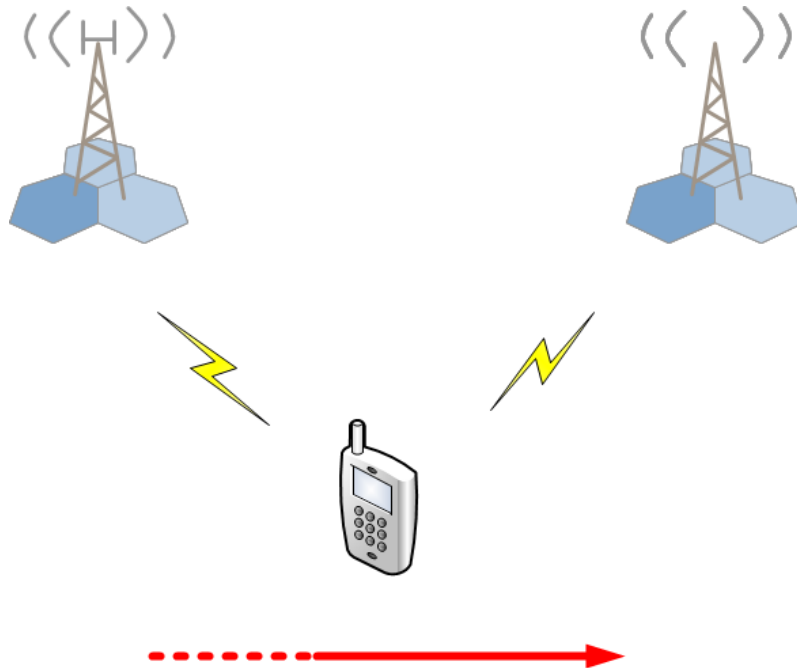
- estimated world's population of 7.2 billion

♦ 788 million mobile-only Internet users by 2015

- the 56-fold grow from 14 million in 2010 to 788 million by the end of 2015

The evolution of mobile networks
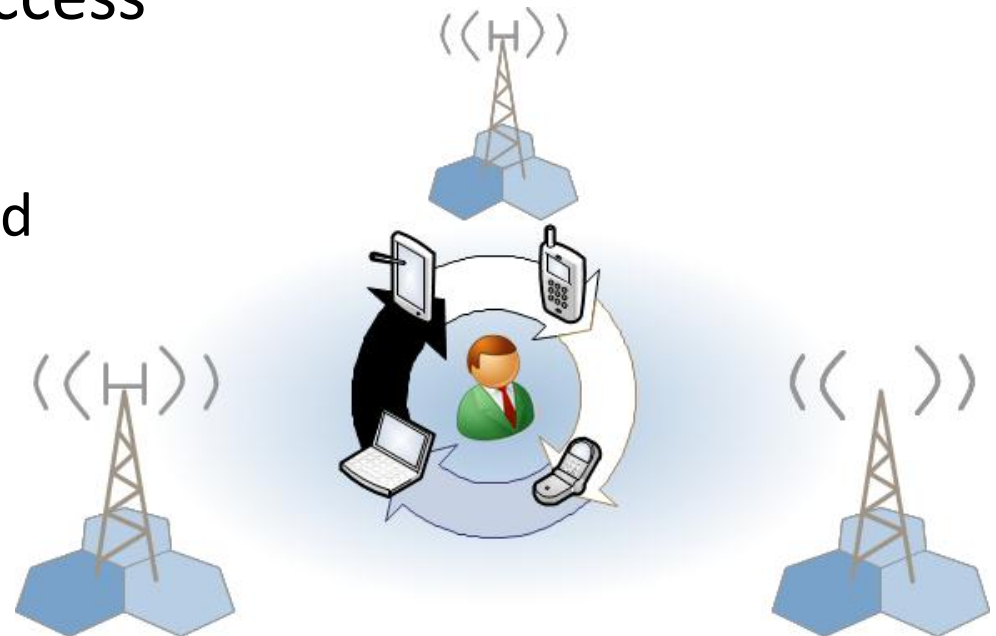
Different aspects of mobility (1)
Terminal mobility

- the ability for the same user device to communicate whilst changing its point of attachment to the network

- wireless access – mobile terminal

- network intelligence
  - determination of user device location
  - user movement tracking

Different aspects of mobility (2)
Personal mobility

- ♦ the ability for the subscriber to communicate using the device or devices of his/her choice

- ♦ wireless and wireline access

- ♦ network intelligence
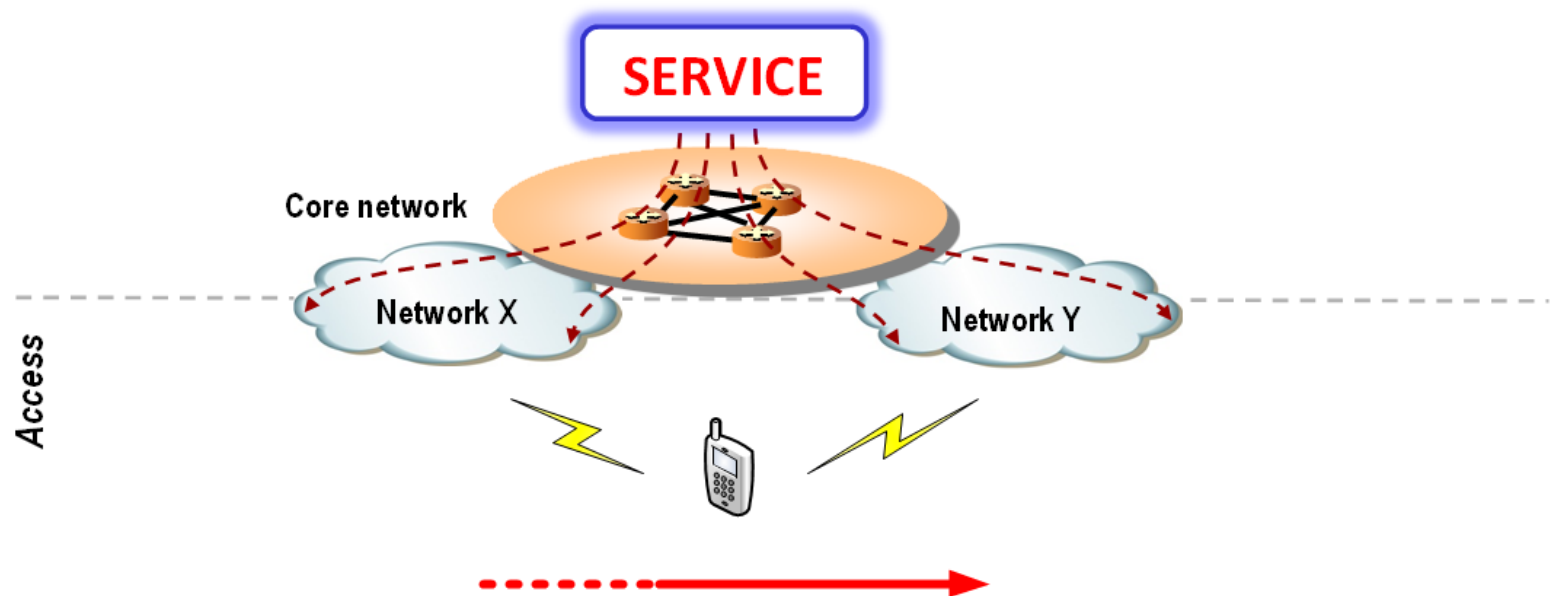 - ■ person identification and accessability

Different aspects of mobility (3)
Service mobility

- ♦ the ability for the service whilst user device is changing its point of attachment to the different network

- ♦ network intelligence
  - ■ selection of the best access

Different aspects of mobility (4)
Session mobility

- the ability for a communication session to be moved from one device to another under the control of the user
- network intelligence
  - customization of the session based on user profile
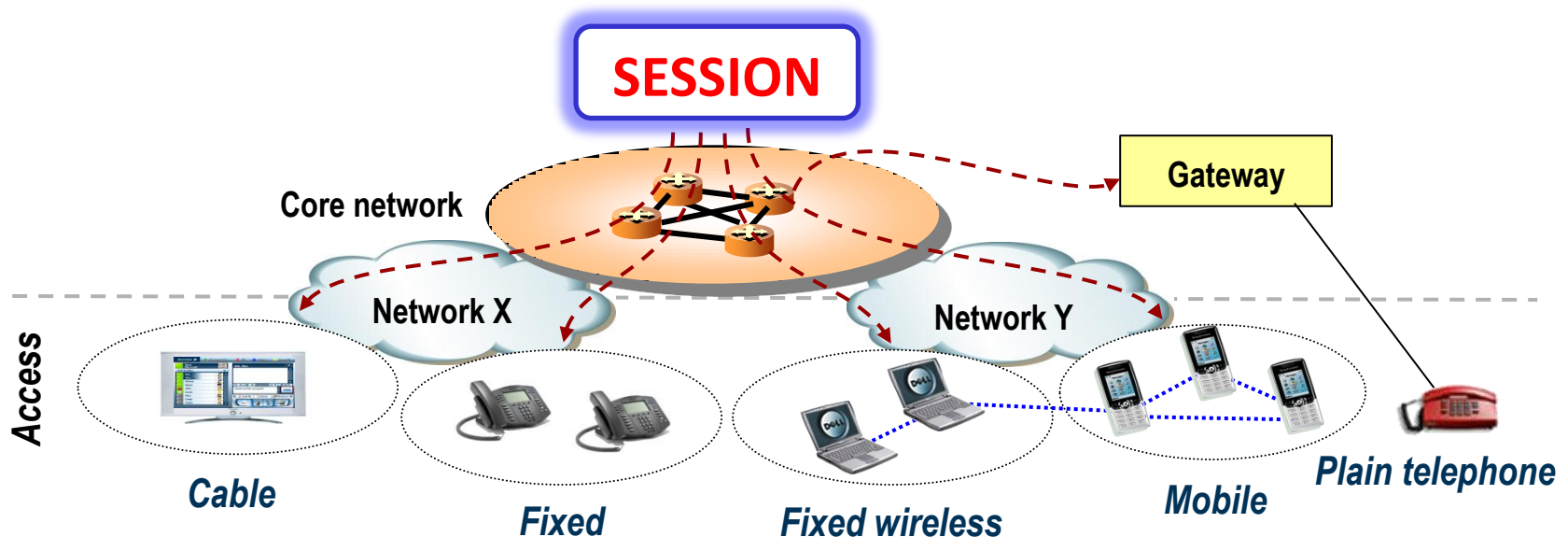
Mobile network

A public network in which an access is based on radio communications

Cellular System

Mobile Network

Other Networks
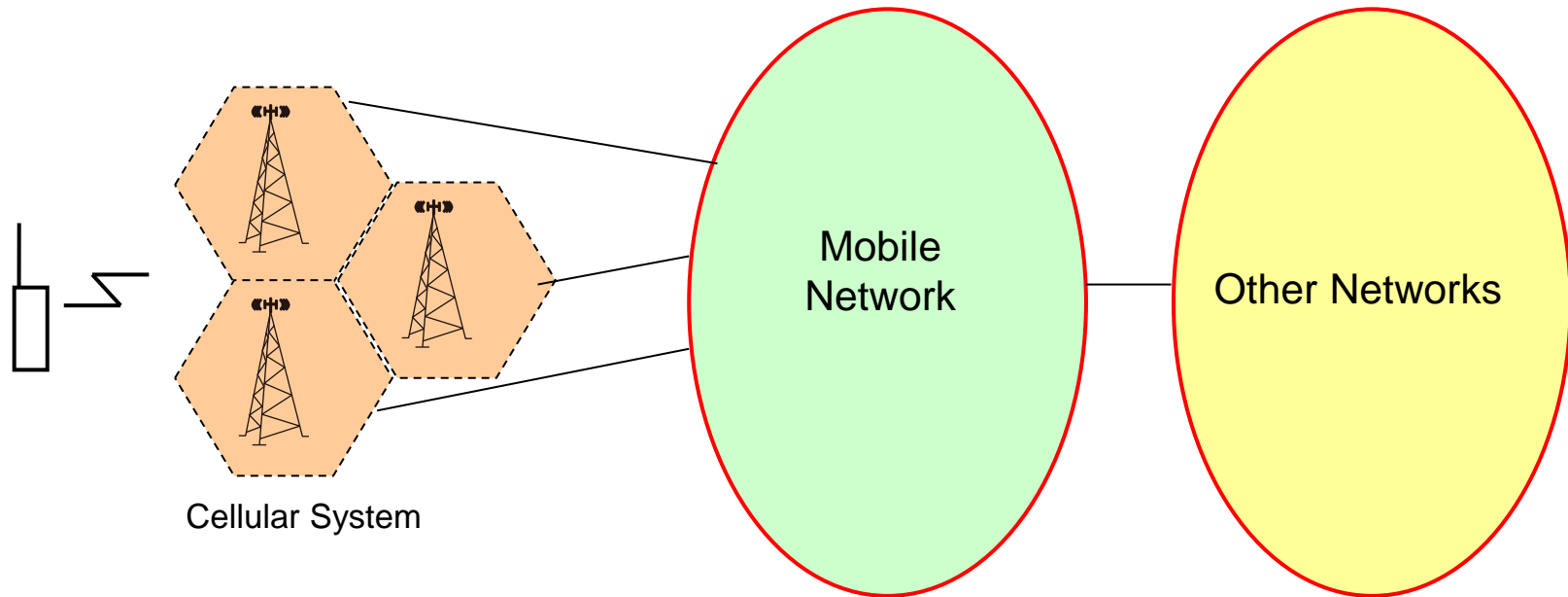
- ◆ *core network*
  - ■ *fixed Network*
- ◆ *access network*
  - ■ *radio access network based on cellular system*

Evolution of Mobile Telecommunications
Generations

Functionality

Data rates

LTE

HSPA

UMTS   HSPA+

MMS

EDGE

GPRS

HSCSD

57.6 kbit/s

Packets

GSM - Data

9.6 kbit/s

SMS

GSM - Voice

NMT

Time

| 1980. | 1990. | 2000. | 2011. | 2012. |

1G   *2G*   *2.5G*   *3G*   *4G*
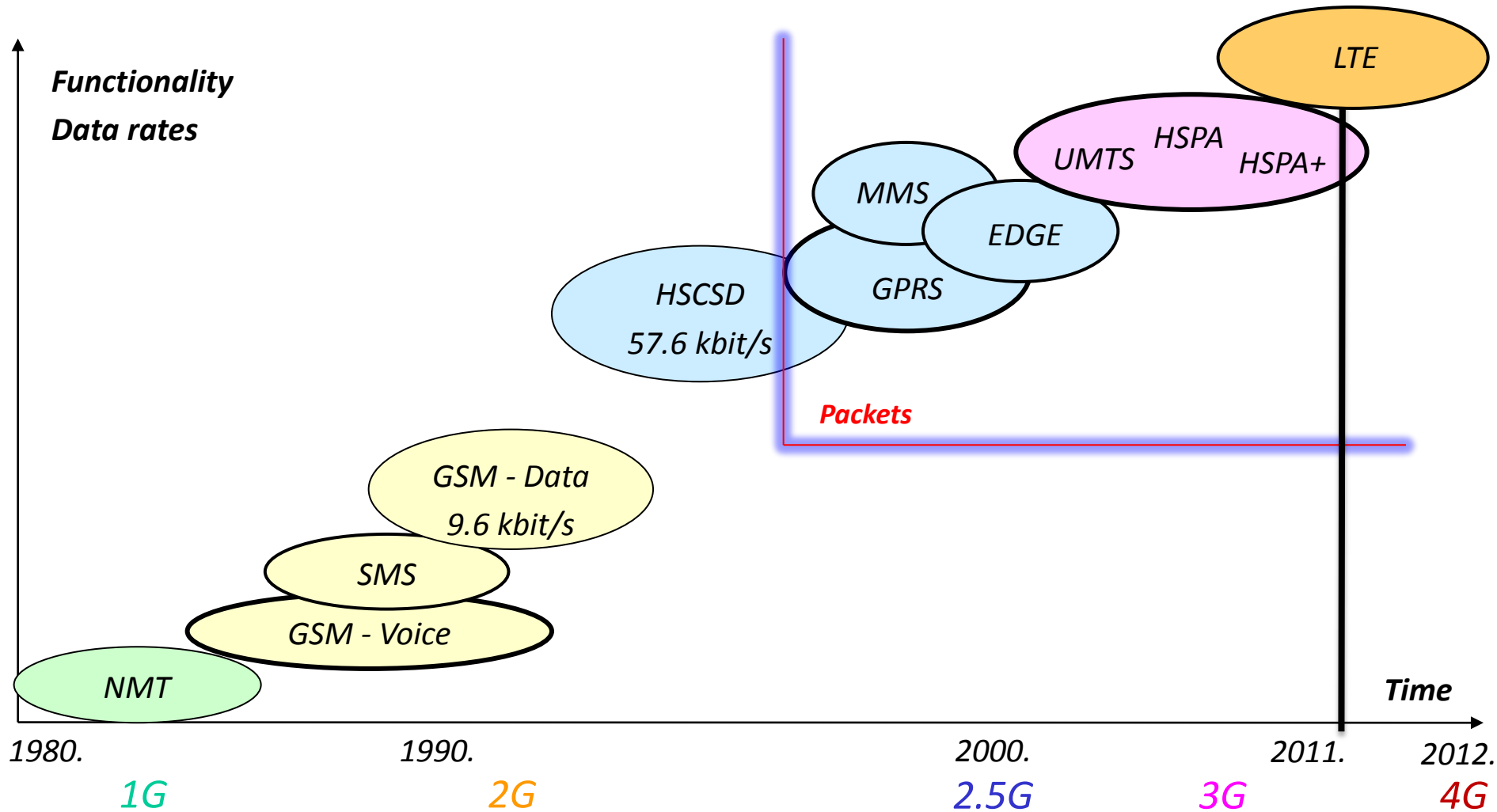
First Generation (1G) (1)
Analog system – Frequency Division Multiple Access, FDMA

- ♦ invented in AT&T's Bell Labs in the early 1970s
- ♦ deployed in early 1980s
  - ■ NMT (*Nordic Mobile Telepohony*) (1981)
    - • Scandinavian countries
  - ■ AMPS (*Advanced Mobile Phone System*) (1983)
    - • US, South America, China, Australia
  - ■ TACS (Total Access Communication System) (1983)
    - • UK, Ireland, Japan

- ♦ frequency band = channel
  - ■ different frequencies for *downlink* and *uplink*
- ♦ large cells with omni-directional base station antennas

♦ DynaTAC8000X (Motorola)

- ■ it was created by Martin Cooper in 1984

- ■ it took over a decade to develop and $100 million

- ■ there were only about 2,000 of these mobile phones available to the public

Martin Cooper

First Generation (1G) (3)
DynaTAC8000X

- retail price $9000 (in present-day terms)

- weighted 1 kg

- could store only 30 phone numbers

- battery needed to be charged for 10 hours

- talk time only 1 hour

- the phone is well known for being used by *Gordon Gekko* in *Wall Street* movie

- too heavy, too impractical, and too expensive for most people to buy

- GSM (*Global System for Mobile communications*)
  - deployed in early 1990s
- digital voice coding and digital modulation
- phone conversations were digitally encrypted
- provides advanced call capabilities and a better system capacity than 1G
  - more users per unit bandwidth
  - allows for far greater mobile phone penetration levels

Second Generation (2G) (2)
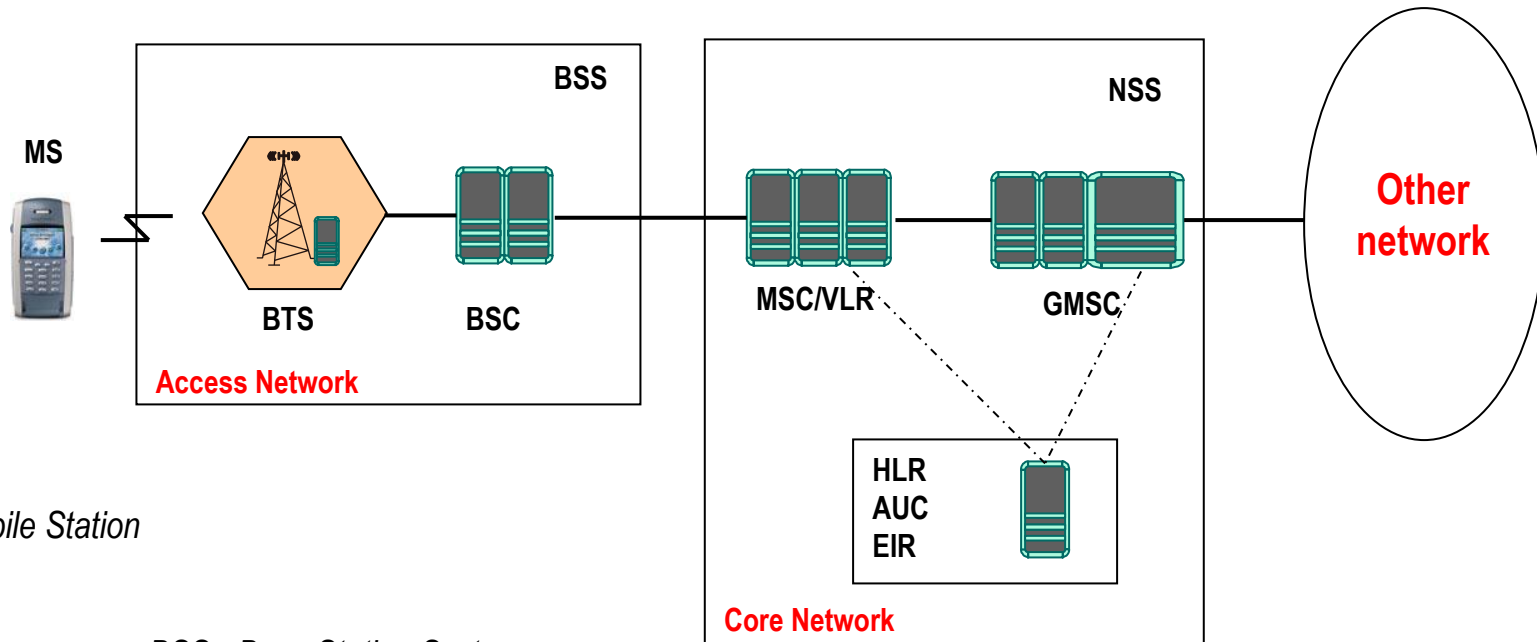## *Time Division Multiple Access, TDMA*

- ◆ 124 frequencies x 8 channels = 992 channels

- ◆ designed before the widespread of the Internet
  - ■ voice traffic is dominant
    - ● circuit switched network
  - ■ limited data services
    - ● data rate: on the order 10 kbps
  - ■ SMS (*Short Message Service*)
    - ● the „killer service"

Second Generation (2G) (3)

The GSM network architecture

MS

BSS

NSS

Other network

BTS

BSC

MSC/VLR

GMSC

Access Network

HLR AUC EIR

Core Network

MS - Mobile Station

BSS - Base Station System
BSC - Base Station Controller
BTS - Base Transciever Station

NSS - Network SubSystem
GMSC - Gateway Mobile Switching Centre
MSC - Mobile Switching Centre
HLR - Home Location Register
VLR - Visitor Location Register
AUC - Authentication Centre
EIR - Equipment Identification Register

Second Generation (2G) (4)

GSM antennas
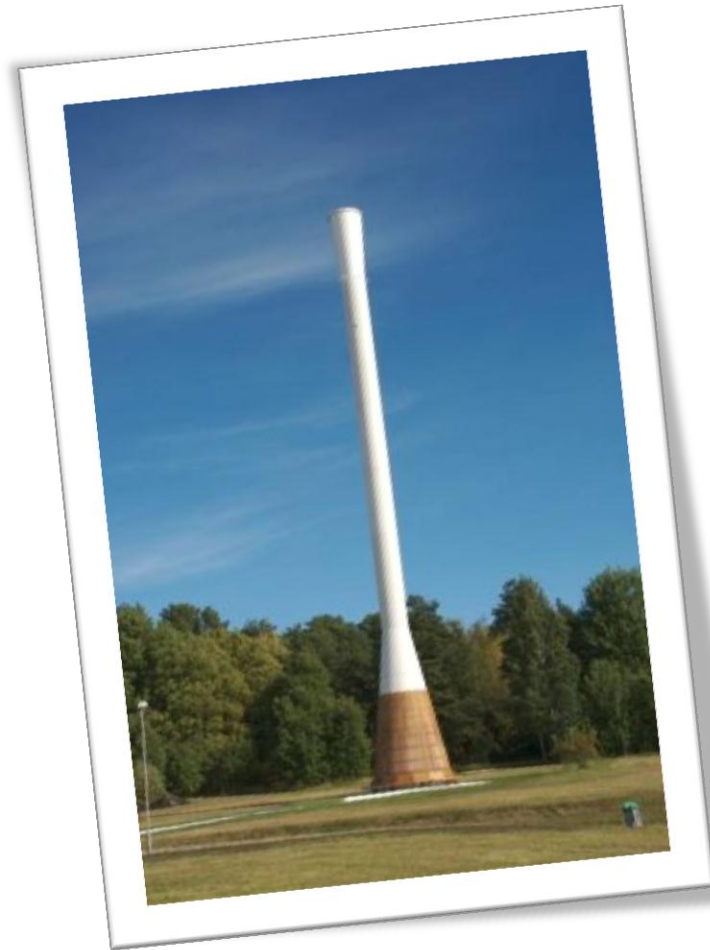
GSM devices

♦ trend away from the large 1G "brick" phones toward tiny 2G devices

- 100–200g hand-held devices

- more advanced batteries

  - more energy-efficient electronics

- practical

- affordable for most people to buy

- additional functionalities

  - camera, mp3 player, …

Advanced Second Generation (2.5G) (1)
High-Speed Circuit-Switched Data (HSCSD)

♦ an enhancement to the original data transmission mechanism of the GSM

- different error correction methods to be used for data transfer
  - from 9.6 kbit/s to 14.4 kbit/s
- ability to use multiple time slots at the same time
  - from 1 time slot to maximum of 4 time slots
- data rates up to 57.6 kbit/s

Advanced Second Generation (2.5G) (2)
GPRS (General Packet Radio Service)
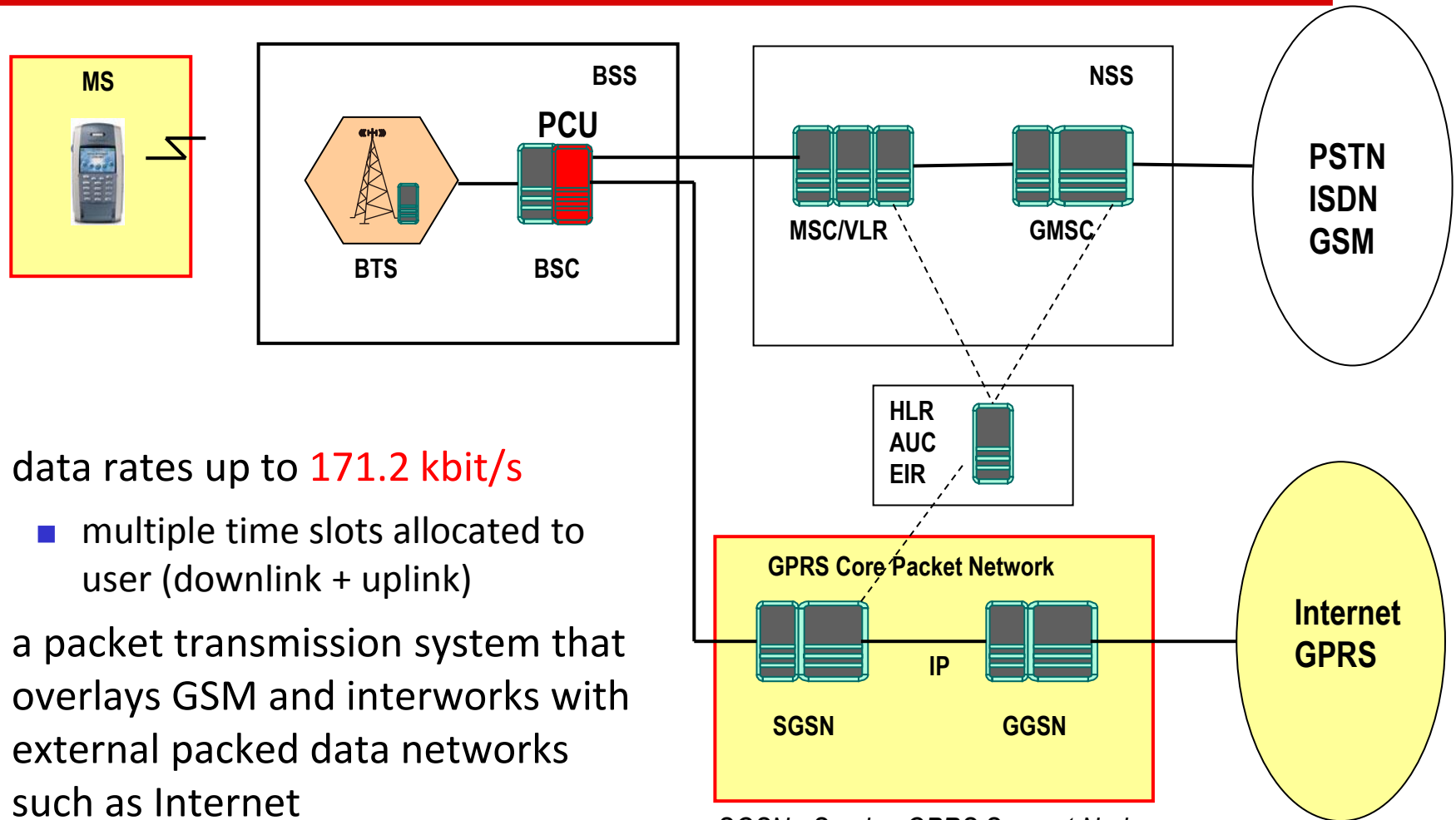
- data rates up to 171.2 kbit/s
  - multiple time slots allocated to user (downlink + uplink)
- a packet transmission system that overlays GSM and interworks with external packed data networks such as Internet

SGSN - Serving GPRS Support Node
GGSN - Gateway GPRS Support Node

Advanced Second Generation (2.5G) (3)

EDGE (Enhanced data rates for GSM evolution)
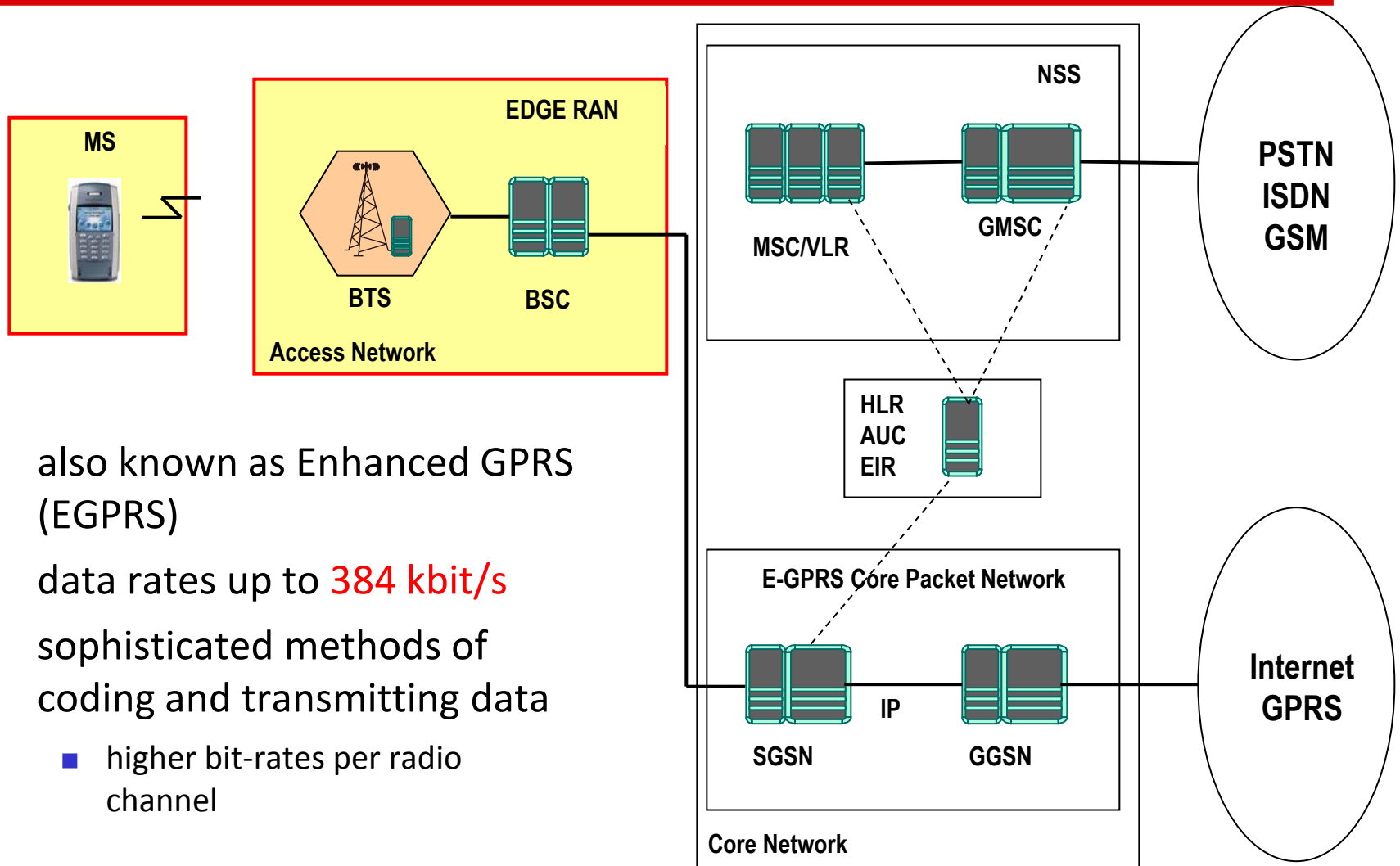
- also known as Enhanced GPRS (EGPRS)

- data rates up to 384 kbit/s

- sophisticated methods of coding and transmitting data

  - higher bit-rates per radio channel

Third Generation (3G) (1)

Digital System – Wideband Code Division Multiple Access (WCDMA)

- voice quality comparable to the PSTN
- data rates
  - symmetrical / asymmetrical data transmission rates
  - support for both packet switched (PS) and circuit switched (CS) data services
- non-orthogonal codes create interference between users
  - frequency reuse of 1
    - no frequency planning needed
- soft handoff – smooth handoff from one cell to the next
  - more complex than hard handoff

Third Generation (3G) (2)

Problems 2G → 3G

- ◆ high prices of UMTS licences in the most of EU countries

- ◆ higher investments in new access networks
    - ■ new nodes
    - ■ new locations for access points for new cells
        - ● required number of cells is increasing

- ◆ new terminals for 2G, 2.5G and 3G

- ◆ content, services, …

Third Generation (3G) (3)

Universal Mobile Telecommunications System (UMTS)

- requires new Radio Access Network (RAN)
- changes in Core Network (CN)
  - CS – 2G and 3G users
  - PS – new functionalities of SGSN and GGSN nodes
- terminal, personal and service mobility
- transfer of voice, data and multimedia
  - up to 144 kbit/s in all conditions, up to 384 kbit/s in outdoor space, up to 2 Mbit/s in indoor space
- more services simultaneously
- integration with fixed network
- coexistence with 2G (GSM)
  - call handover between GSM and UMTS

Third Generation (3G) (4)
The UMTS network architecture
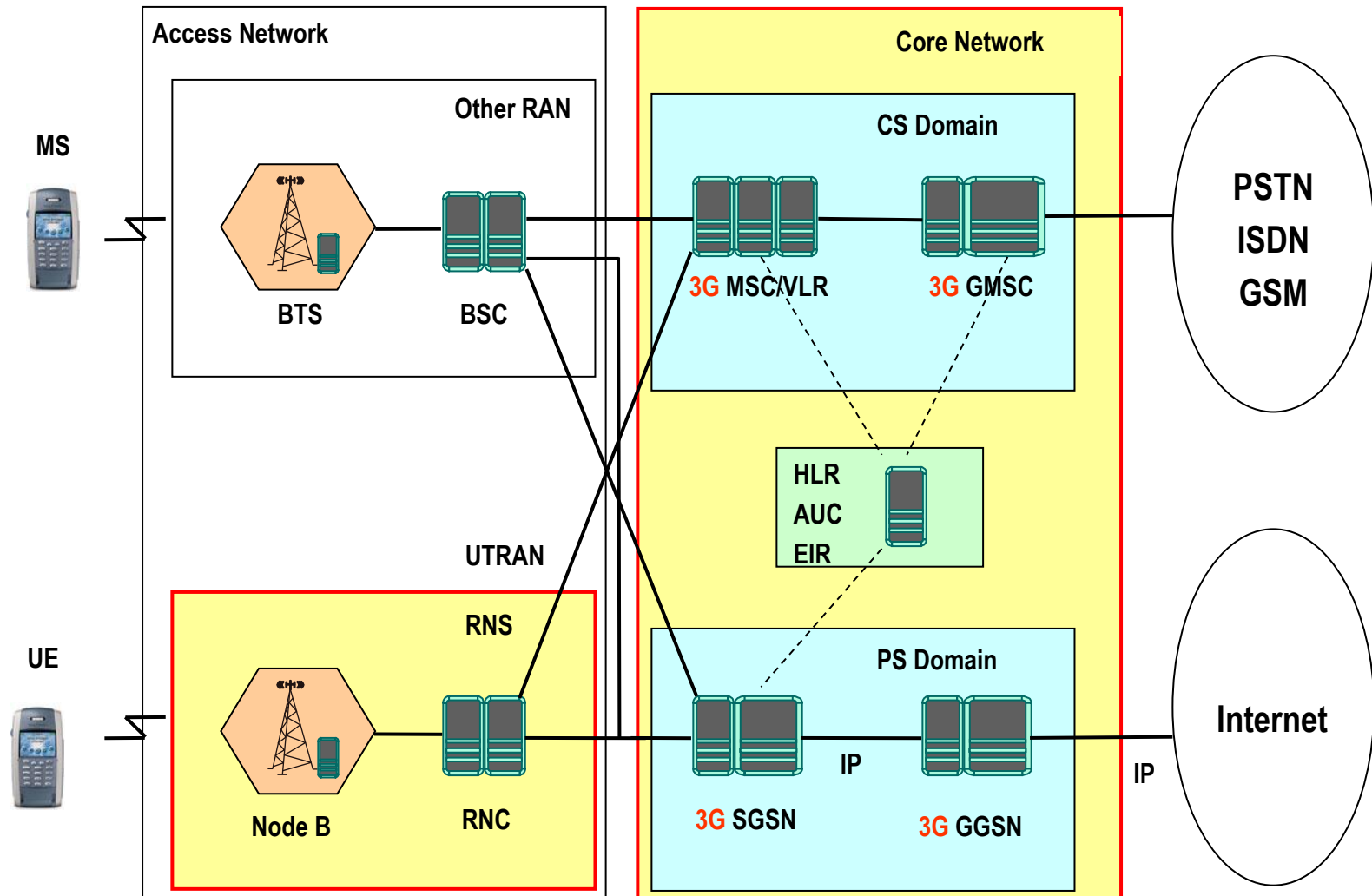
Third Generation (3G) (5)

Overview of UMTS 3GPP realese specifications

UMTS Release	Features
Release 99 (1999):	First Release of UMTS standard, based on W-CDMA technology. Support for GSM/EDGE/GPRS/WCDMA RANs.
R4 (2001)	Separating of CS and PS domains in core network. MSC Server – MGW split core network architecture for the CS domain, MMS support.
R5 (2003)	First Relase that includes IMS, with goal to support an introduction of multimedia services, and IP access network UTRAN. SIP is used as main signaling protocol. Quality of Service control and advanced control of services and charginig possibilities. Introduction of HSDPA.
R6 (2004-2005):	Integration with WLANs. QoS support, PoC and MMS. Introduction of MBMS, HSUPA i advanced charging possibilities.
R7 (2006-2007)	Adding of broadband fixed access through IMS. Seamless hadover of voice call between CS and PS (IMS-WLAN) domains with defined QoS.
R8 (2007-2008)	All-IP Network (AIPN). Long Term Evolution (LTE). Multimedia conferencing in IMS.

- HSDPA – *High Speed Downlink Packet Access* (Rel 5)
  - based on downlink shared channel, data only
  - up to 10 Mbit/s (peak data rates up to 14 Mbit/s)
    - high rates in the downlink and lower rates uplink
  - started in 2006

- HSUPA – *High Speed Uplink Packet Access* (Rel 6)
  - peak data rete up to 5.8 Mbit/s
  - started in 2007

- ◆ beyond present GSM-UMTS-HSPA systems
- ◆ higher levels of capacity and performance
- ◆ data rate may be up to 100 Mbit/s (downlink peak)
- ◆ high level requirements
  - ■ full IP-based
  - ■ increased service provisioning, more services at lower cost
  - ■ flexibility of use of existing and new frequency bands
  - ■ simplified architecture, open interfaces
  - ■ 2009 to 2012 and beyond
- ◆ technology:
  - ■ OFDM (*Orthogonal Frequency Division Multiplexing*)
  - ■ MIMO (*Multiple-Input Multiple-Output*) – multiple antennas, parallel streams to a single user
  - ■ HSOPA (*High Speed OFDM Packet Access*)

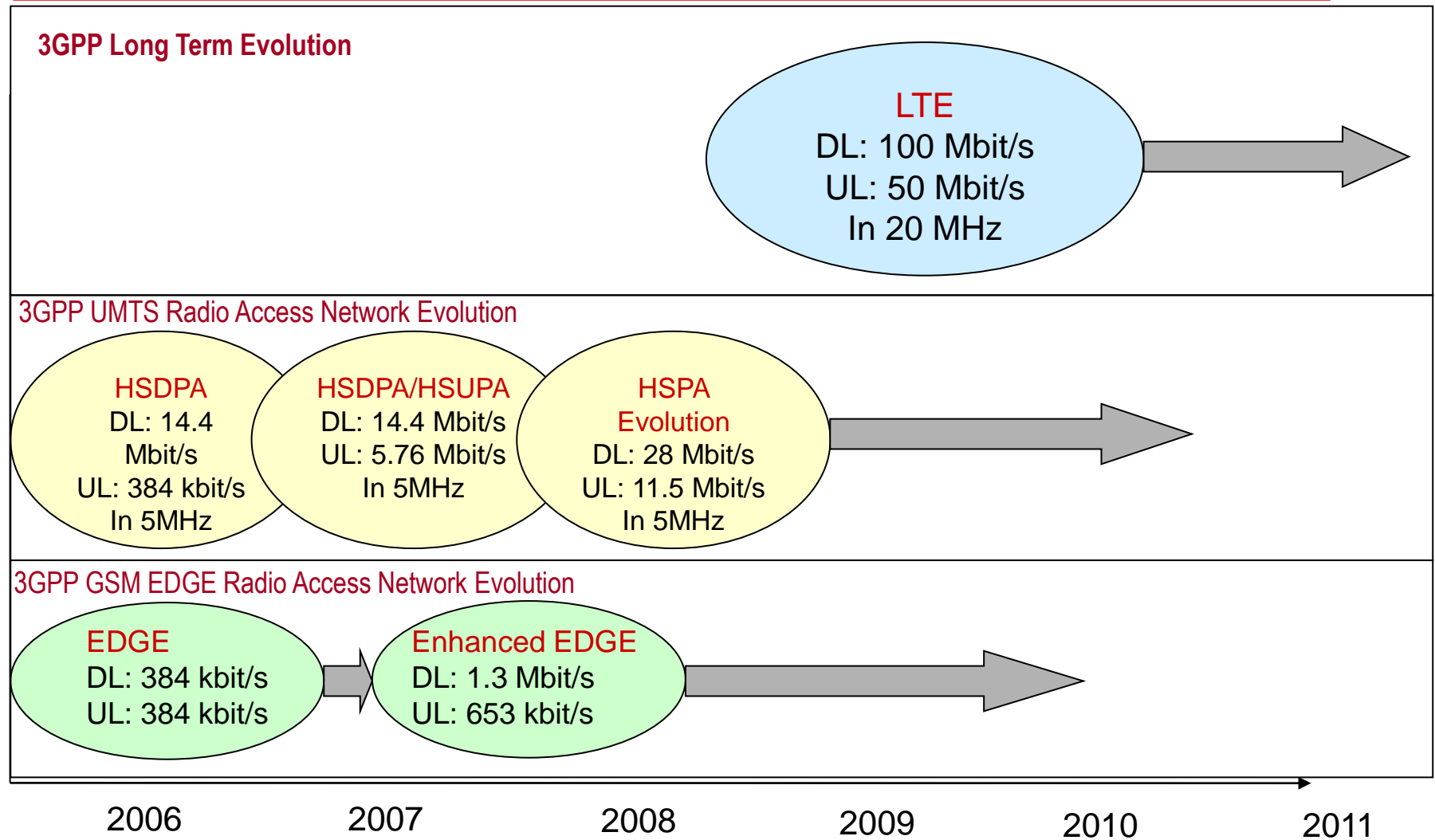- ◆ convergence towards all-IP architecture
  - ■ fixed and mobile
  - ■ circuit-swithed (CS) and packet-switched (PS)
- ◆ support for terminal, personal, service and session mobility including network roaming
- ◆ lecture
  - ■ "Internet and convergence with mobile networks"
    - ● Prof. Maja Matijasevic
  - ■ Tuesday, May 17
    - ● 11:15-12:00
    - ● 13:15-15:00

3G → LTE

3GPP Long Term Evolution

LTE
DL: 100 Mbit/s
UL: 50 Mbit/s
In 20 MHz

3GPP UMTS Radio Access Network Evolution

HSDPA
DL: 14.4
Mbit/s
UL: 384 kbit/s
In 5MHz

HSDPA/HSUPA
DL: 14.4 Mbit/s
UL: 5.76 Mbit/s
In 5MHz

HSPA
Evolution
DL: 28 Mbit/s
UL: 11.5 Mbit/s
In 5MHz

3GPP GSM EDGE Radio Access Network Evolution

EDGE
DL: 384 kbit/s
UL: 384 kbit/s

Enhanced EDGE
DL: 1.3 Mbit/s
UL: 653 kbit/s

2006   2007   2008   2009   2010   2011

Different access to Core Network

Mobility/Range — (vertical axis)

Vehicle
- High speed
- Vehicular Rural
- Vehicular Urban

Walk
- Pedestrian
- Nomadic

Fixed
- Fixed urban Indoor
- Personal area

GSM GPRS, EDGE, 3G/WCDMA, FLASH-OFDM, HSDPA, IEEE 802.16e

Enhanced 3G Evolution >2010

DECT, Bluetooth

WLAN (IEEE 802.11e), IEEE 802.16a,d

WiMAX

0.1   1   10   100 Mbit/s

User data rate

Further reading (1)
The evolution of computing

◆ Weiser, M. The Computer for the 21st Century. *Scientific American*, 265, 3 (1991), 94-104.

◆ Weiser, M. The World is not a Desktop. *ACM Interactions*, 1, 1 (1994), 7-8.

◆ Weiser, M.; and Brown, J.S. The Coming Age of Calm Technology. In *Beyond Calculation: The Next Fifty Years of Computing*. Dening, P.J.; Metcalfe, R.M.; and Burke, J. (Eds.), 75-86. New York: Springer-Verlag, 1997.

Further reading (2)
The standardization of mobile networks

- ITU (*International Telecommunication Union*)
  - http://www.itu.int
- ETSI (*European Telecommunications Standard Institute*)
  - http://www.etsi.org
- UMTS Forum
  - http://www.umts-forum.org
- 3GPP (*3rd Generation Partnership Project*)
  - http://www.3gpp.org
- GSM Association
  - http://www.gsmworld.com

Vedran Podobnik, Ph.D.
Contact info

- University of Zagreb
  - Faculty of Electrical Engineering and Computing
    - Department of Telecommunications

- *E-mail:* **vedran.podobnik@fer.hr**

- *Homepage:* **http://agents.tel.fer.hr/vedran.podobnik**