

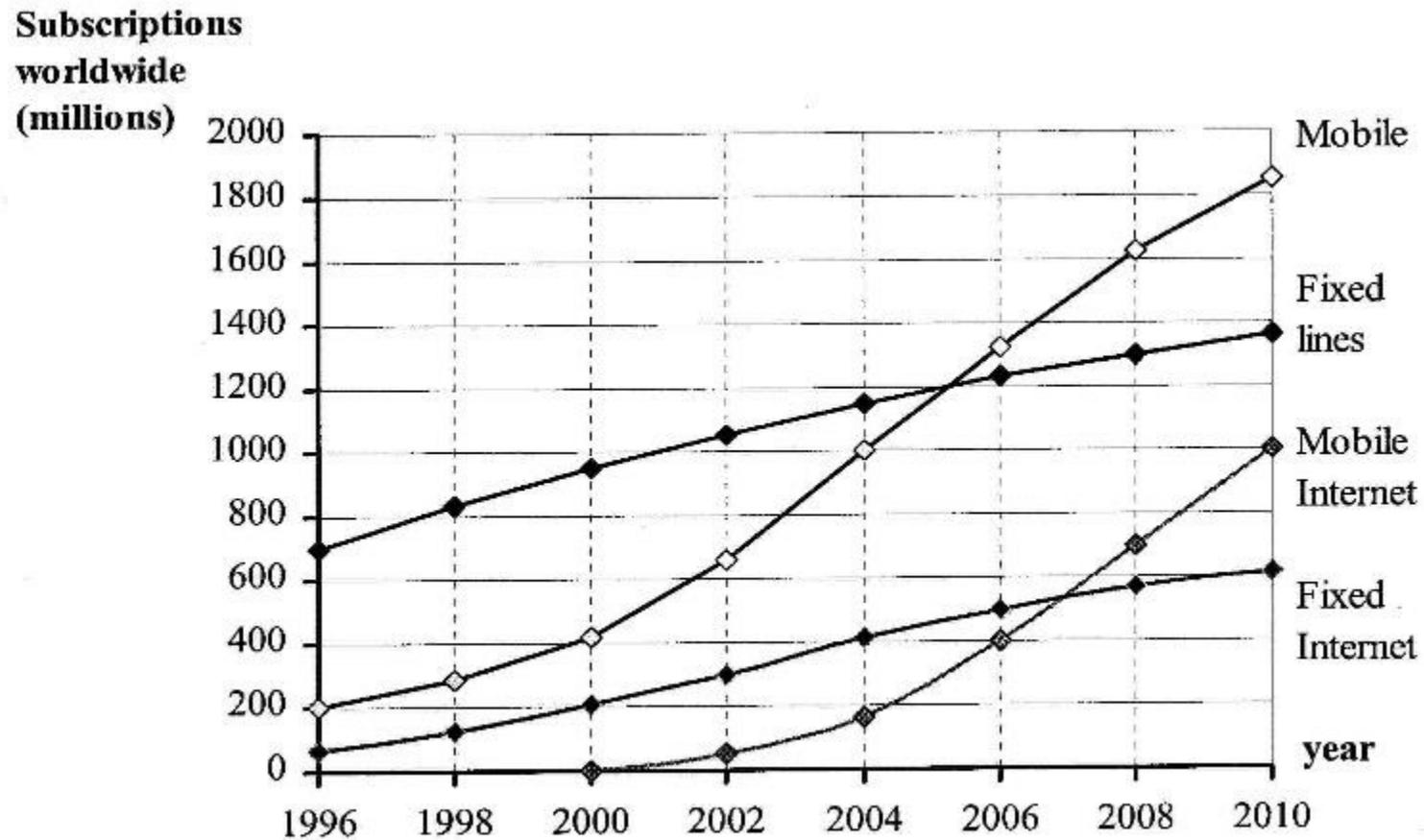


Asean Factori 4.0 Project
School of Information Technology
Mae Fah Luang University
Chiang Rai, November 12, 2022

Cellular Mobile Communications
GSM / GPRS / UMTS / LTE / 5G

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The Telecommunications World



« Instant access to all information whatever you are »

Why Mobile Communications ?



Chiang Rai (city Center)



Doi Tung (mountains)

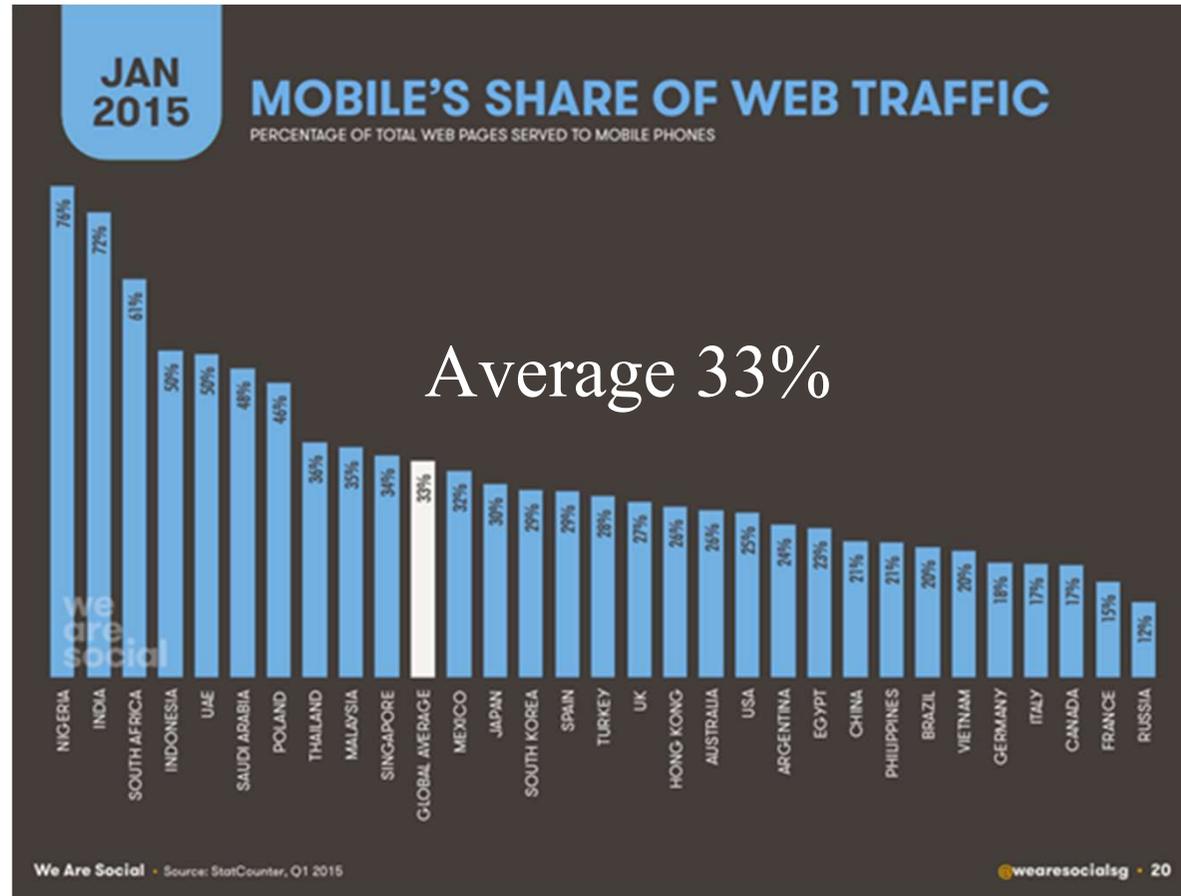
Mobile / Fixed Communications

1. Mature high-speed data radio communications
Technology (OFDM)
2. Cellular networks are much cheaper than fixed
networks (Money)
3. Cellular networks are much faster to install than
fixed networks (Time)

Technology - Money - Time

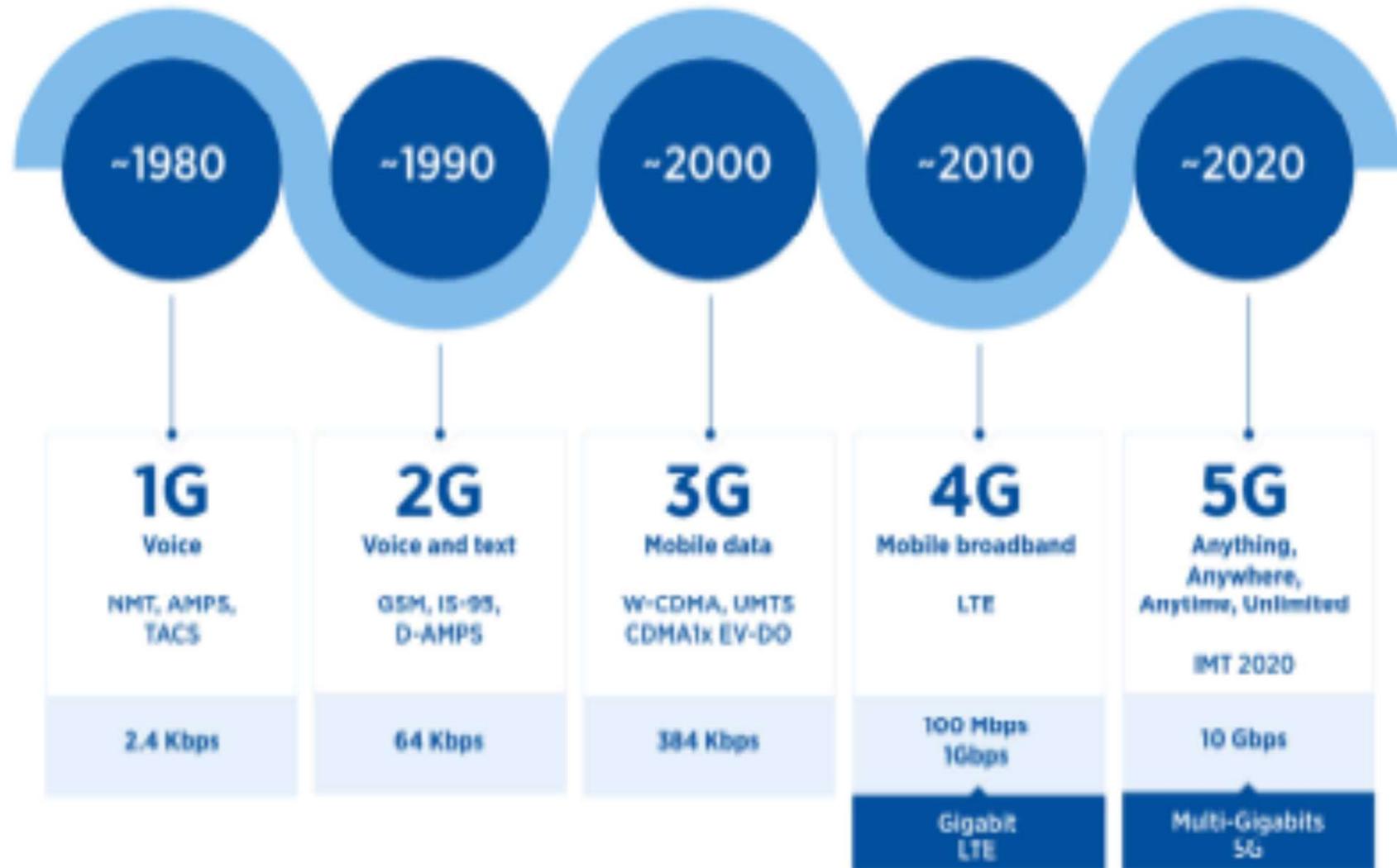
Mobile Internet

Nigeria
75%



Mobile Internet (2015): Thailand 40%, France 15%

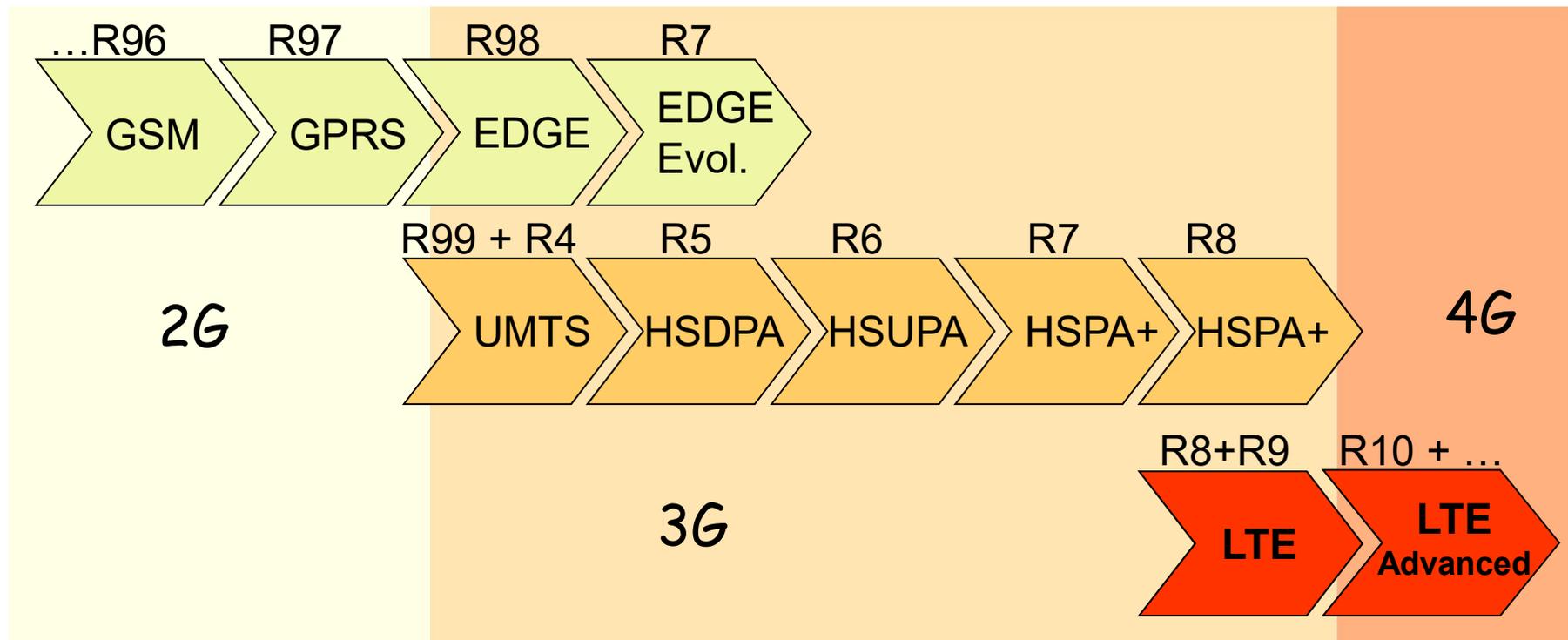
40 Years of Cellular Communications : 5 Generations



From 1G to 4G

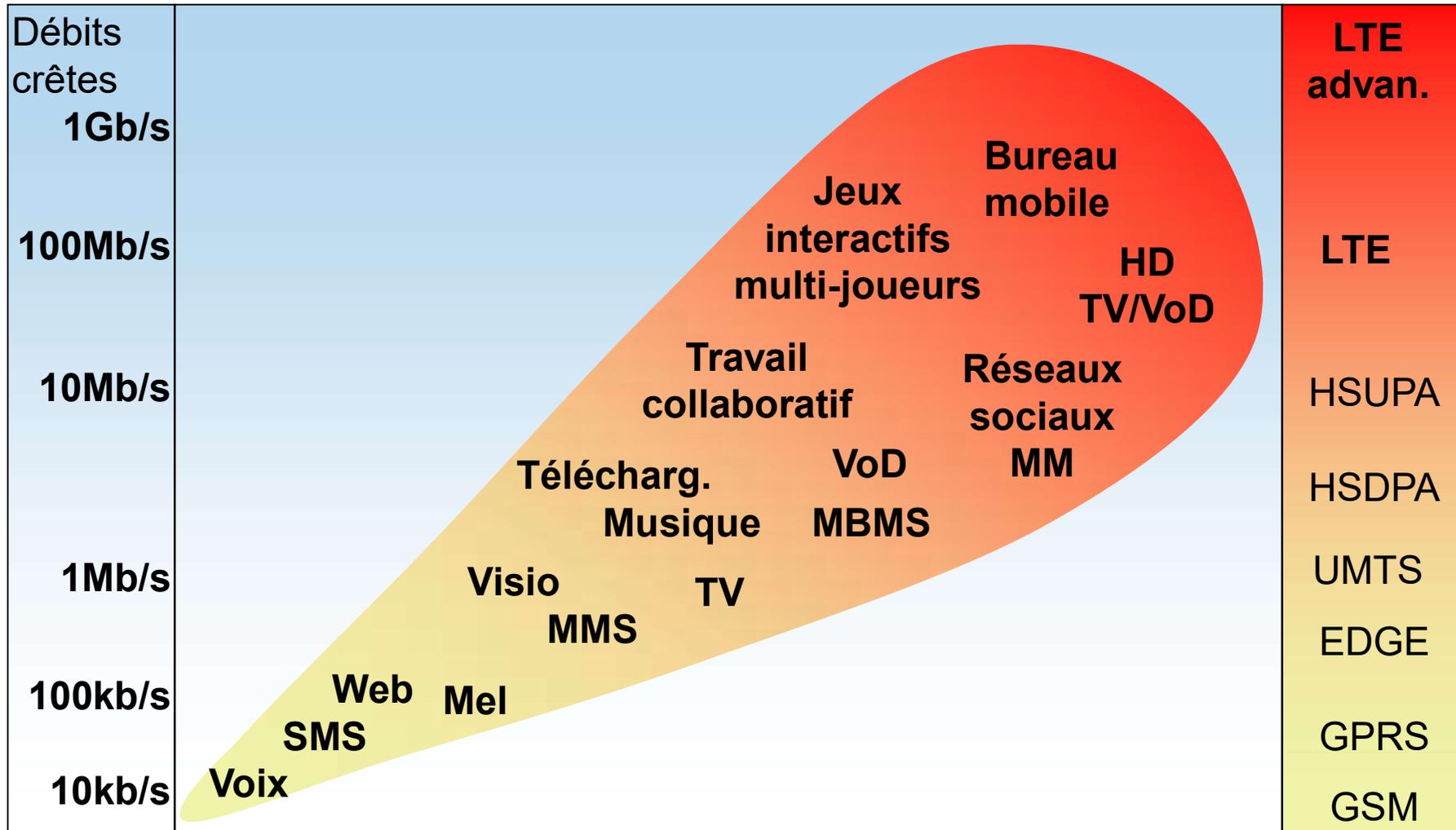
1G

Standardisation ETSI

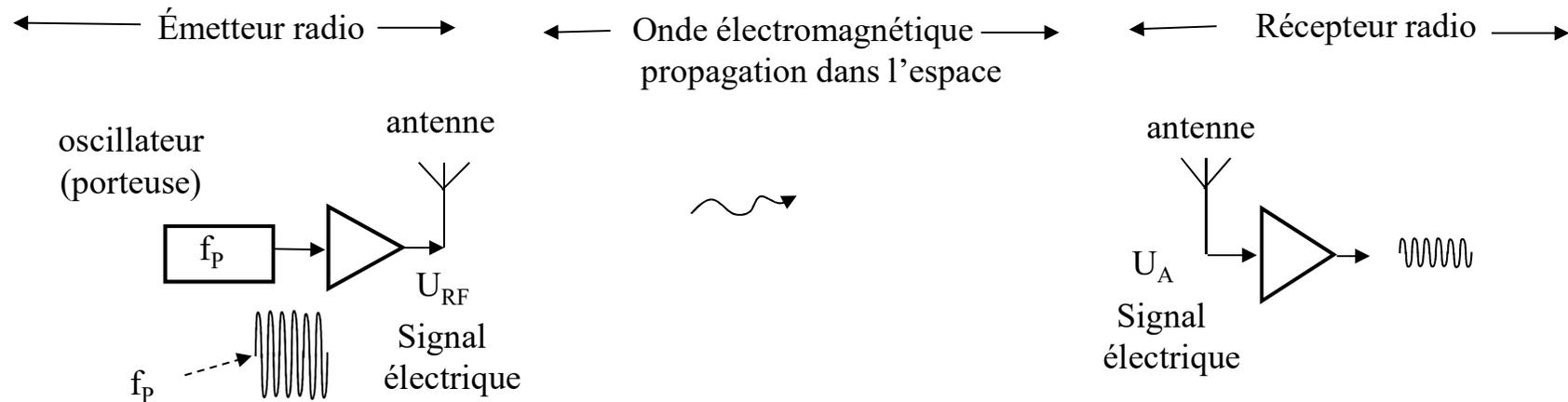


Mobile phone generation = radio communication technology + spectrum + type of access to data & voice networks

Mobile services



Basic principle of radio communications



Onde (champ) électromagnétique : phénomène physique oscillatoire qui se propage dans l'espace vide et qui transporte de l'énergie

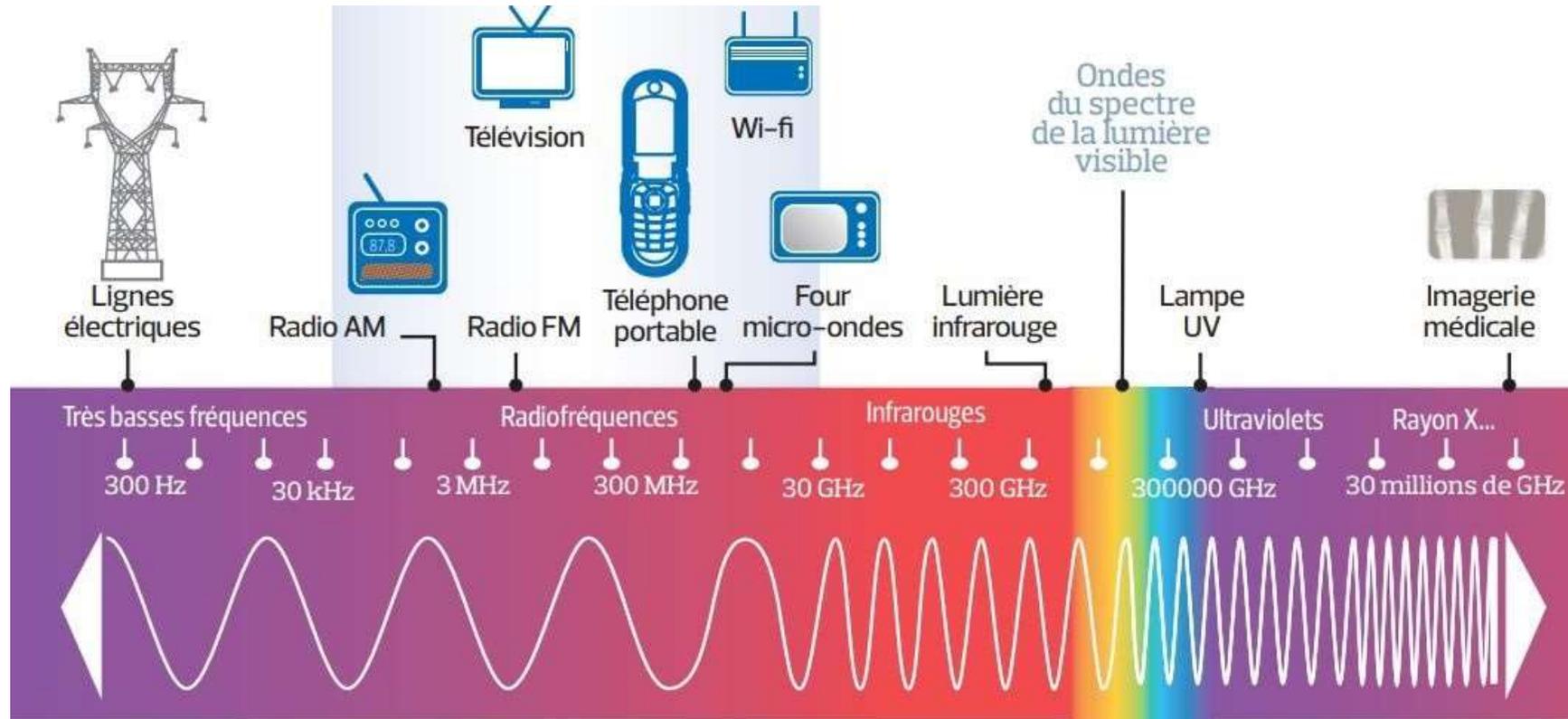
Antenne : transducteur signal électrique \leftrightarrow champ électromagnétique

Communication radio : transfert d'énergie entre l'émetteur et le récepteur par l'intermédiaire d'une onde électromagnétique

Transfer d'énergie – transfert d'information

Rem.: l'énergie minimale correspondante au transfert d'un bit d'information est $E_{\text{MIN}} = kT \ln(2)$

Electromagnetic waves



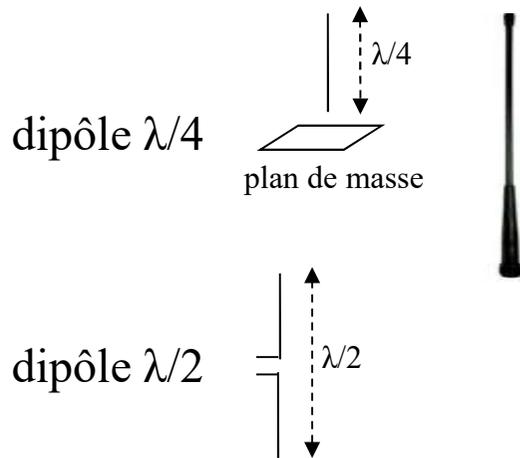
Rem.: the human eye is a "radio receiver"

Antennas

Antenne : transducteur signal électrique RF \leftrightarrow champ électromagnétique

Transducteur réversible : émission et réception

La dimension de l'antenne dépend de la fréquence du signal à émettre



Fréquences et longueurs d'ondes typiques:

$$f_p = 3\text{kHz} \quad \lambda = 100 \text{ km} \quad (\text{voix})$$

$$f_p = 1\text{MHz} \quad \lambda = 300 \text{ m} \quad (\text{radio AM})$$

$$f_p = 100\text{MHz} \quad \lambda = 3 \text{ m} \quad (\text{radio FM})$$

$$f_p = 300\text{MHz} \quad \lambda = 1 \text{ m} \quad (\text{TV - TNT})$$

$$f_p = 900\text{MHz} \quad \lambda = 33 \text{ cm} \quad (\text{GSM - 2G})$$

$$f_p = 2.4\text{GHz} \quad \lambda = 12.5 \text{ cm} \quad (\text{WiFi})$$

$$f_p = 10\text{GHz} \quad \lambda = 3 \text{ cm} \quad (\text{TV satellite})$$



Omnidirectional versus directional antenna



$$G = 1$$



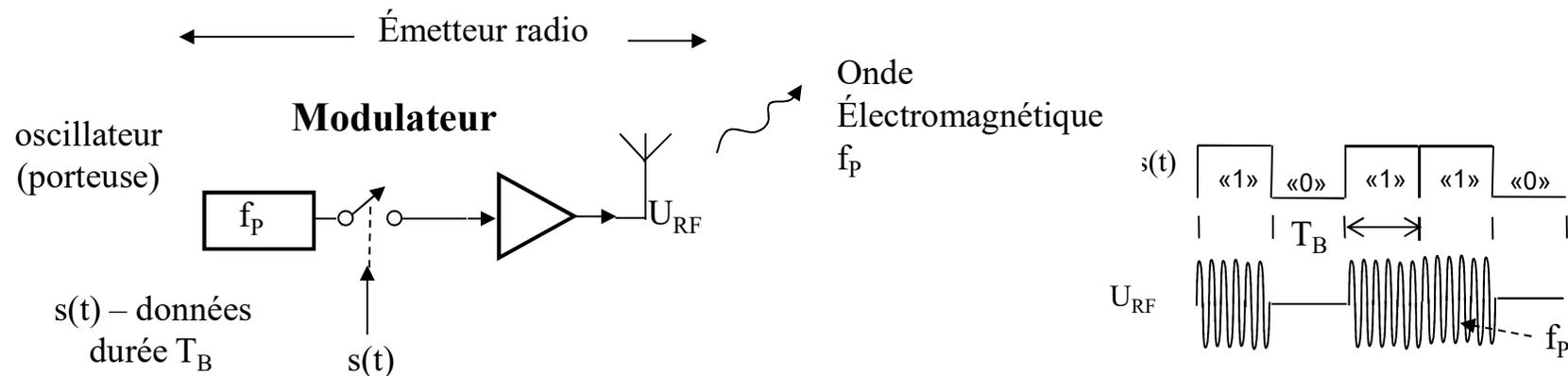
$$G > 1$$

Modulation / Multiplexing

1. Comment transmettre des signaux de basse fréquence (voix, données) par ondes électromagnétiques ?

Ex. $D = 1 \text{ Mbit/s}$, $T_B = 1/D = 1 \mu\text{s}$, $T_{\text{période}} \approx 2 \mu\text{s}$, $f \approx 500 \text{ KHz}$, $\lambda = 600 \text{ m}$

Modulation : Transfer d'un signal $s(t)$ sur une fréquence porteuse f_p



Ex. $f_p = 2.4 \text{ GHz}$, $\lambda = 12.5 \text{ cm}$

2. Comment transmettre plusieurs signaux dans le même milieu ? **Multiplexage**

Frequency bands

1. Radio broadcast :

- 150kHz – 40MHz (Amplitude Modulation- AM)
- 88 – 108MHz (Frequency Modulation - FM)

2. Television (TV broadcast):

- 170 – 960MHz (Image modulation-AM, sound modulation -AM or FM, now →DVB)

3. Radiocommunications :

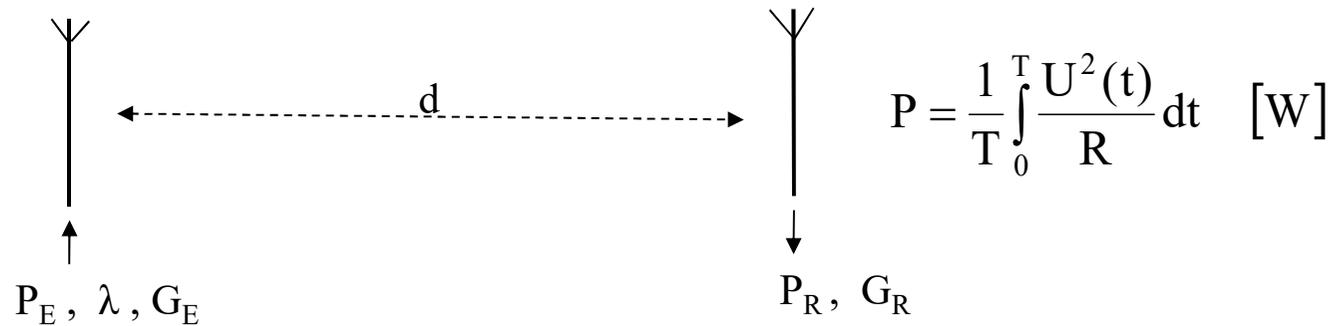
- Bands in 800MHz, 900MHz, 1800MHz et 1900MHz – Cellular mobile networks (GSM/GPRS/EDGE). Communication distance : $L = 100\text{m} - 20\text{km}$
- Bands in 2GHz – 3G Cellular communications (UMTS)
- 7 GHz – 39 GHz : long distance point-to-point communications ($L = 50 - 200 \text{ km}$),
- Bands in 2.4GHz and 5.4GHz (ISM - *Industrials, Scientific and Medical*),
PAN/LAN : Bluetooth, ZigBee, Wi-Fi (Internet). $L = 1 - 100\text{m}$
- satellite communications: 4-6GHz (C band), 11-14GHz (Ku band), 20-30GHz (Ka band)

4. Special applications :

- satellite localization GPS : 1.559GHz – 1.61GHz

Radio propagation

Free space radio propagation (*Friis law*)

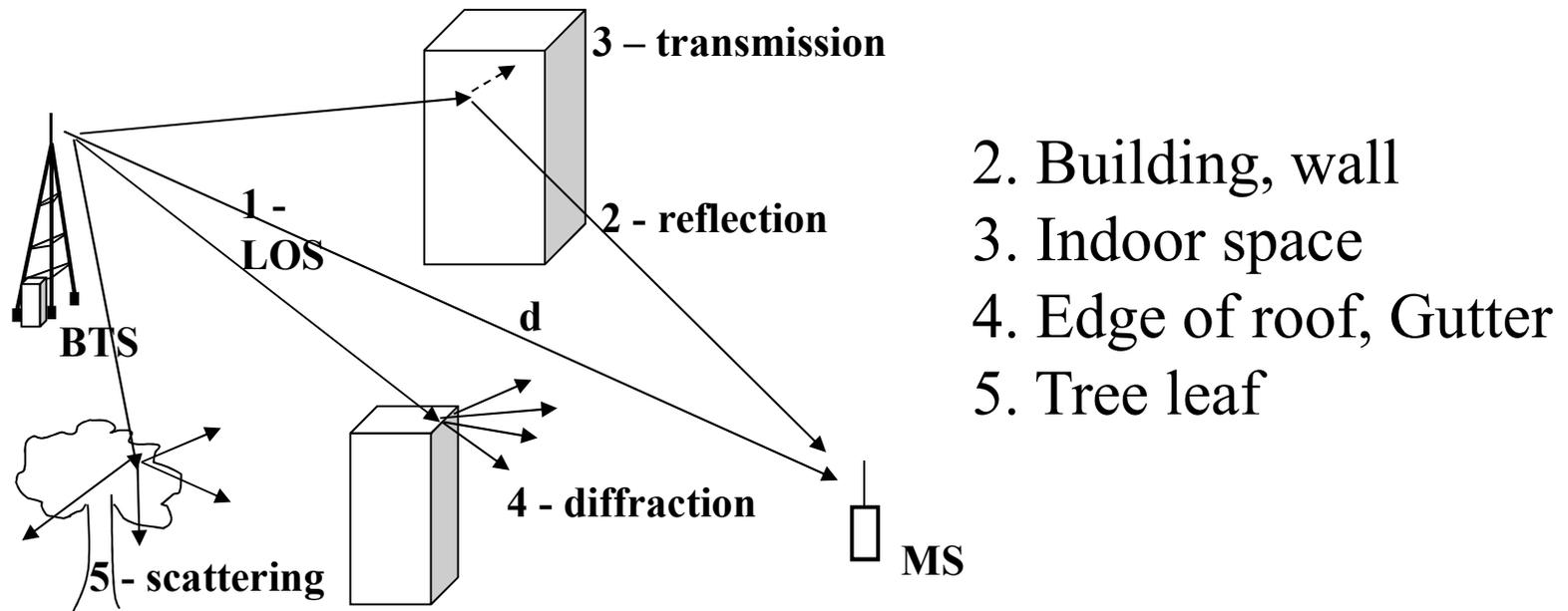


$$\lambda = \frac{c}{f} \quad \lambda[m], \quad f[\text{Hz}], \quad c \approx 3 * 10^8 [m/s] \quad \lambda[m] = \frac{300}{f[\text{MHz}]}$$

$$P_R = \frac{P_E G_E G_R}{[4\pi d / \lambda]^2} = \frac{P_E G_E G_R}{[(4\pi / c) d f]^2} \quad G_{\text{vide}} = \frac{G_E G_R}{[(4\pi / c) d f]^2} \quad A_{\text{vide}} = \frac{1}{G} = k f^2 d^2$$

Antenna →
Free space →

Real radio propagation



2. Building, wall
3. Indoor space
4. Edge of roof, Gutter
5. Tree leaf

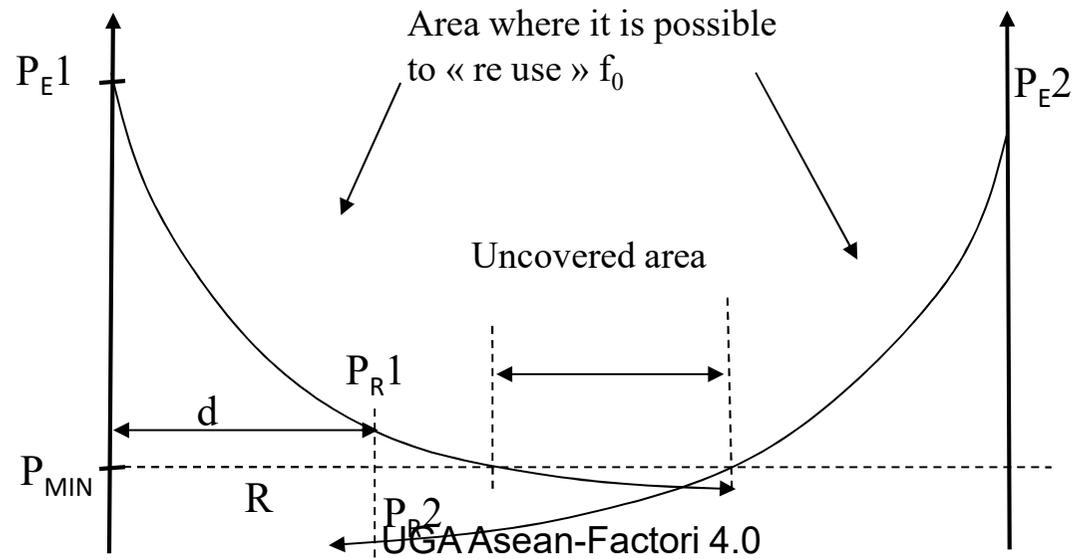
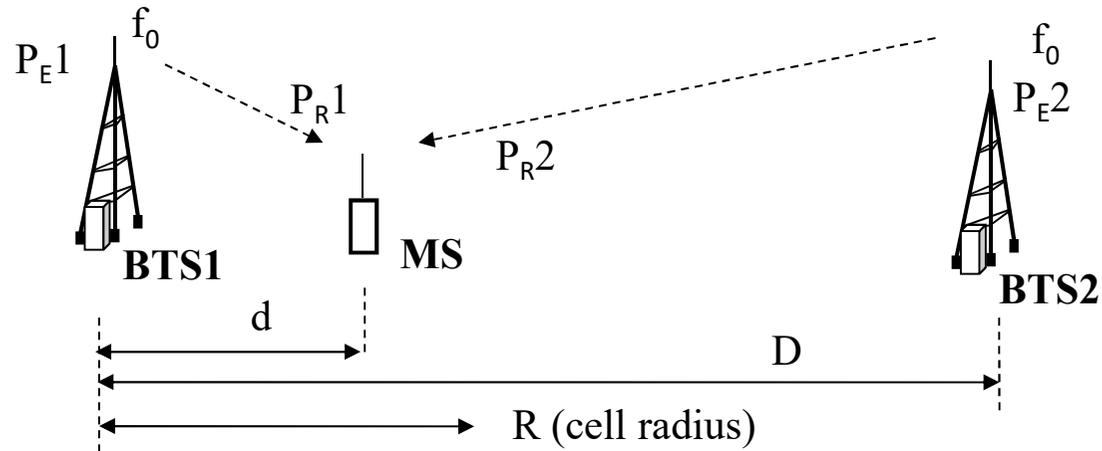
BTS – Base Transceivers Station, *MS* – Mobile Station

LOS Propagation (LOS - *Line Of Sight*) - 1

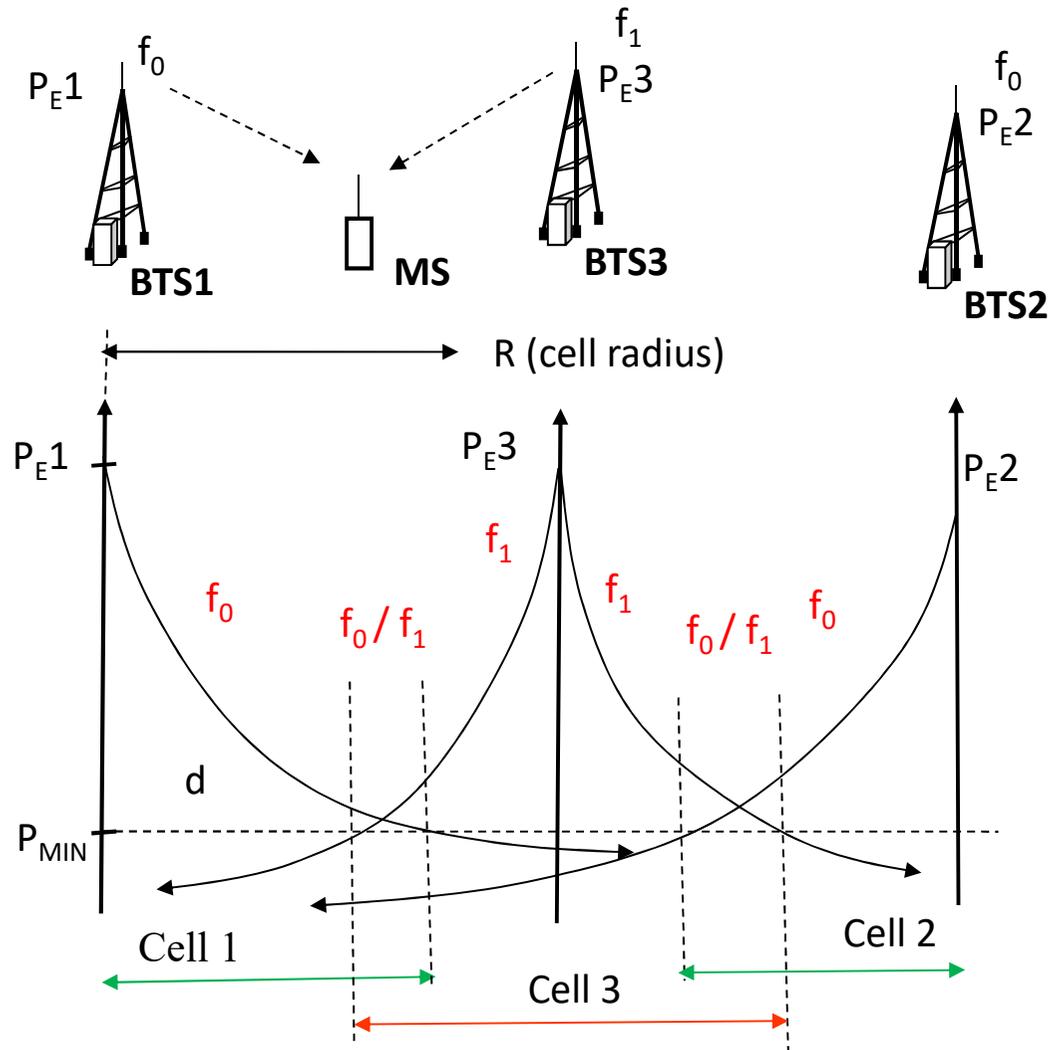
NLOS (*Non Line Of Sight*) propagation - 2, 3, 4, 5

Friis law is not anymore valid ! $A \approx k f^2 d^n$ $n = 2 \div 5$

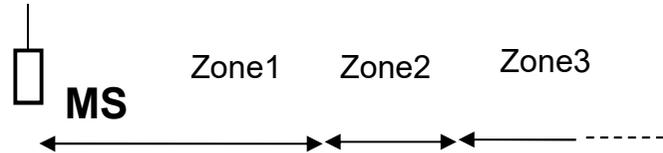
Cellular Principle



Cellular Principle



Frequency re-use



Zone 1: $P_R > P_{MIN}$: zone of normal reception

Zone 2: $P_R < P_{MIN}$: zone where BTS1 can be detected but cannot be received (demodulated). The signal of BTS1 is regarded as interference (I)

Zone 3: $P_R < P_{MIN}$: zone where BTS1 cannot be detected nor demodulated. It is possible to re-use f_0 .

In Zone 1 and Zone 3 we can use the same frequency for two different communications.

Zone1, Zone 3 → **cells**

Advantage of the frequency re-use:

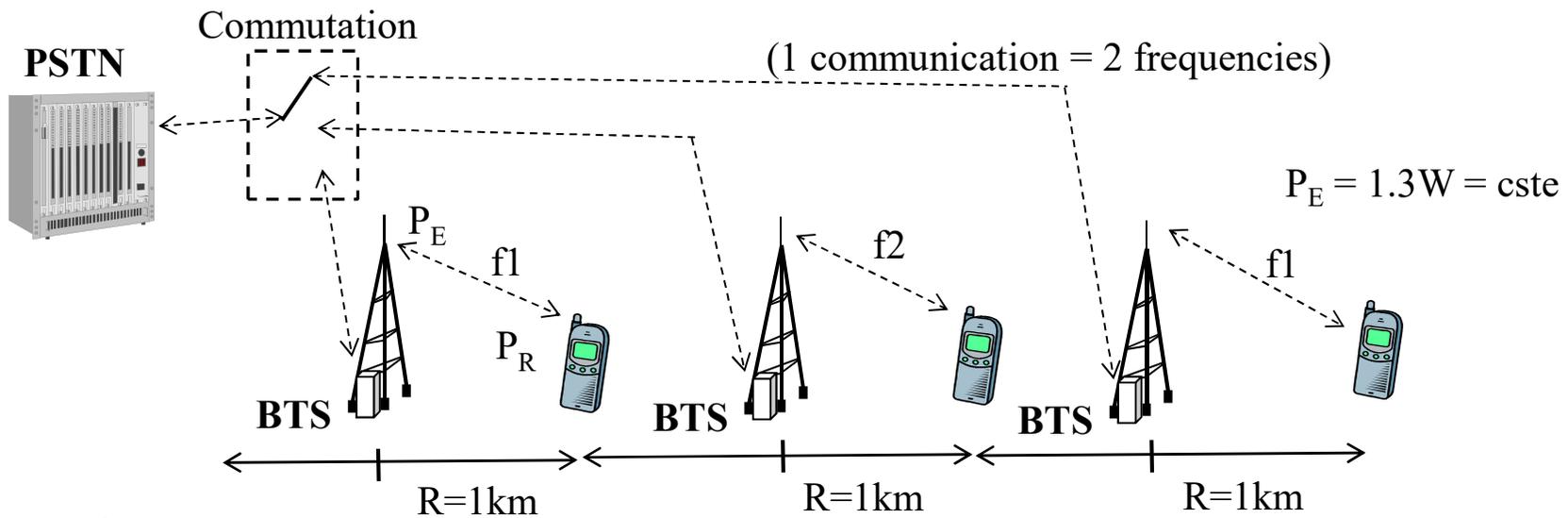
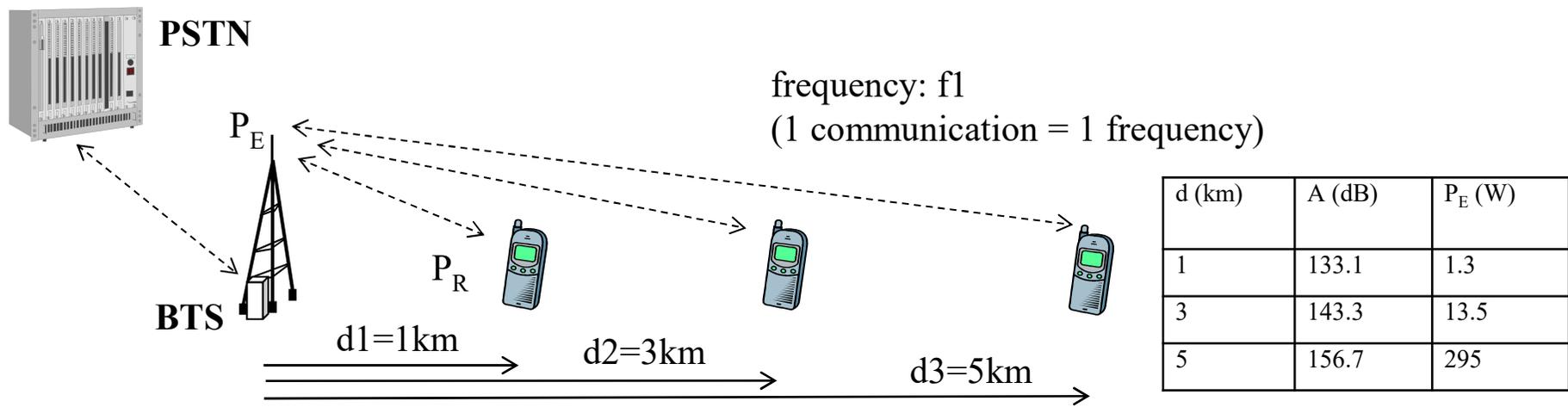
Saving in frequencies

Saving in power

Disadvantages:

if MS moves → Need for cell change

System complexity



Example :

$$f_0 = 1800\text{MHz}, P_{\text{MIN}} = -102\text{dBm},$$

$$A = 133,1 + 33,8 \log(d), d [\text{km}], P_E = A + P_R, P_{\text{EMAX}} = 33\text{dBm} = 2\text{W}$$

Cellular coverage

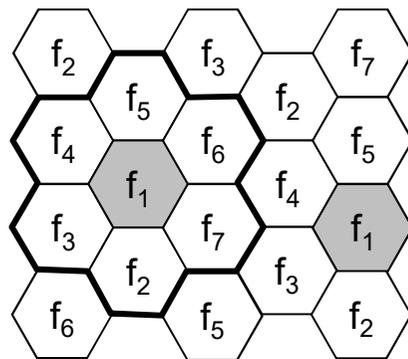
Exemple:

$$P_E = 33\text{dBm (2W)}$$

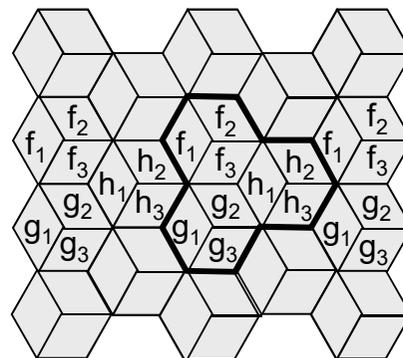
$$P_R = -102\text{dBm}$$

$$A = P_E - P_R = 135\text{dB}$$

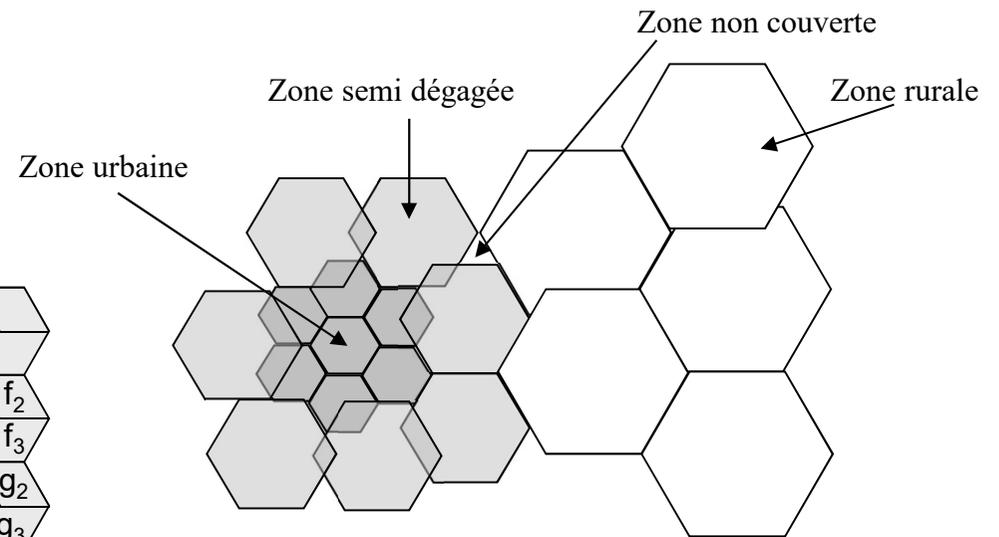
Environment	Rural	Partial visibility	Urban
900MHz	24km	17km	2km
1800MHz	15km	11km	1km



7 cell cluster



Sectorized cell



Real network

Base Station Type

Macro BTS



Mobile BTS



12.11.2022



UGA Asean Factor 4.0

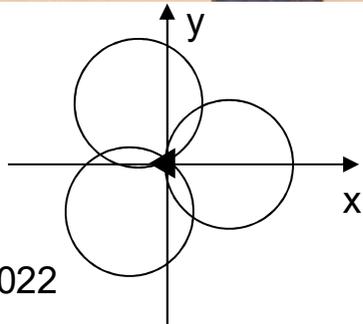
Micro / Femto BTS



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GSM Cellular Network

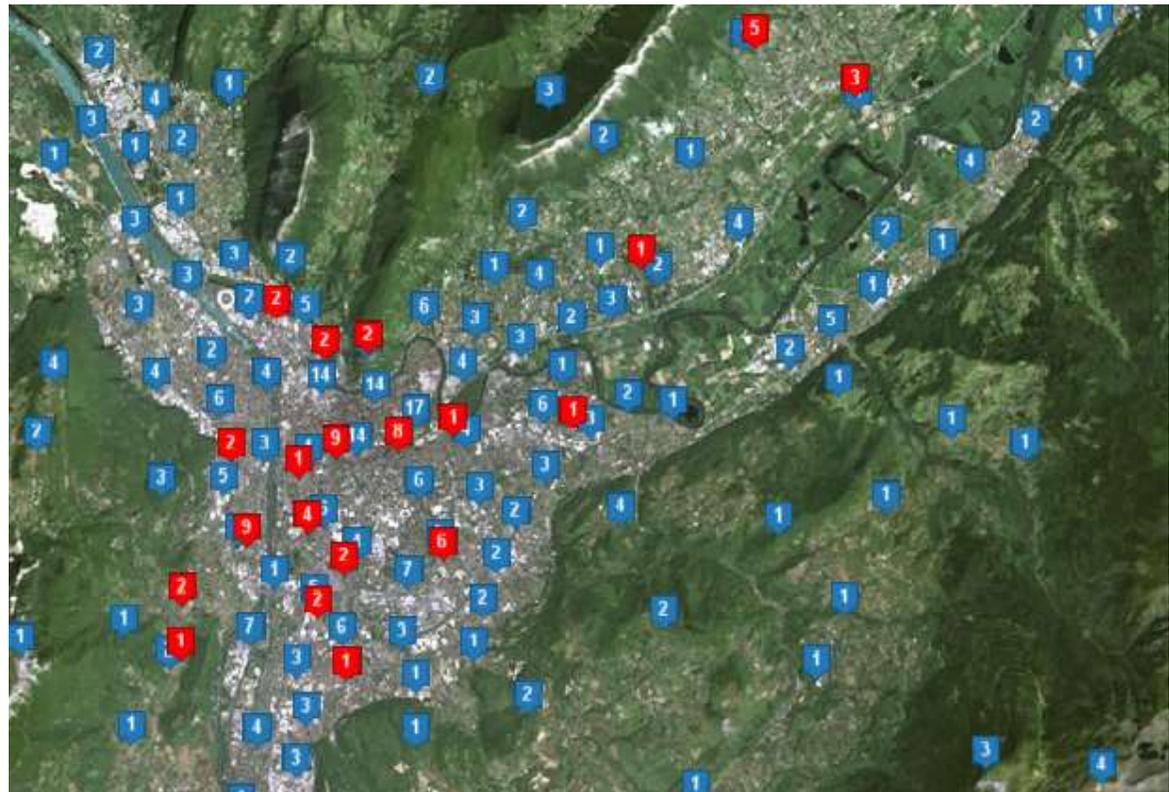
BTS (3 sectors)



12.11.2022

ANFR

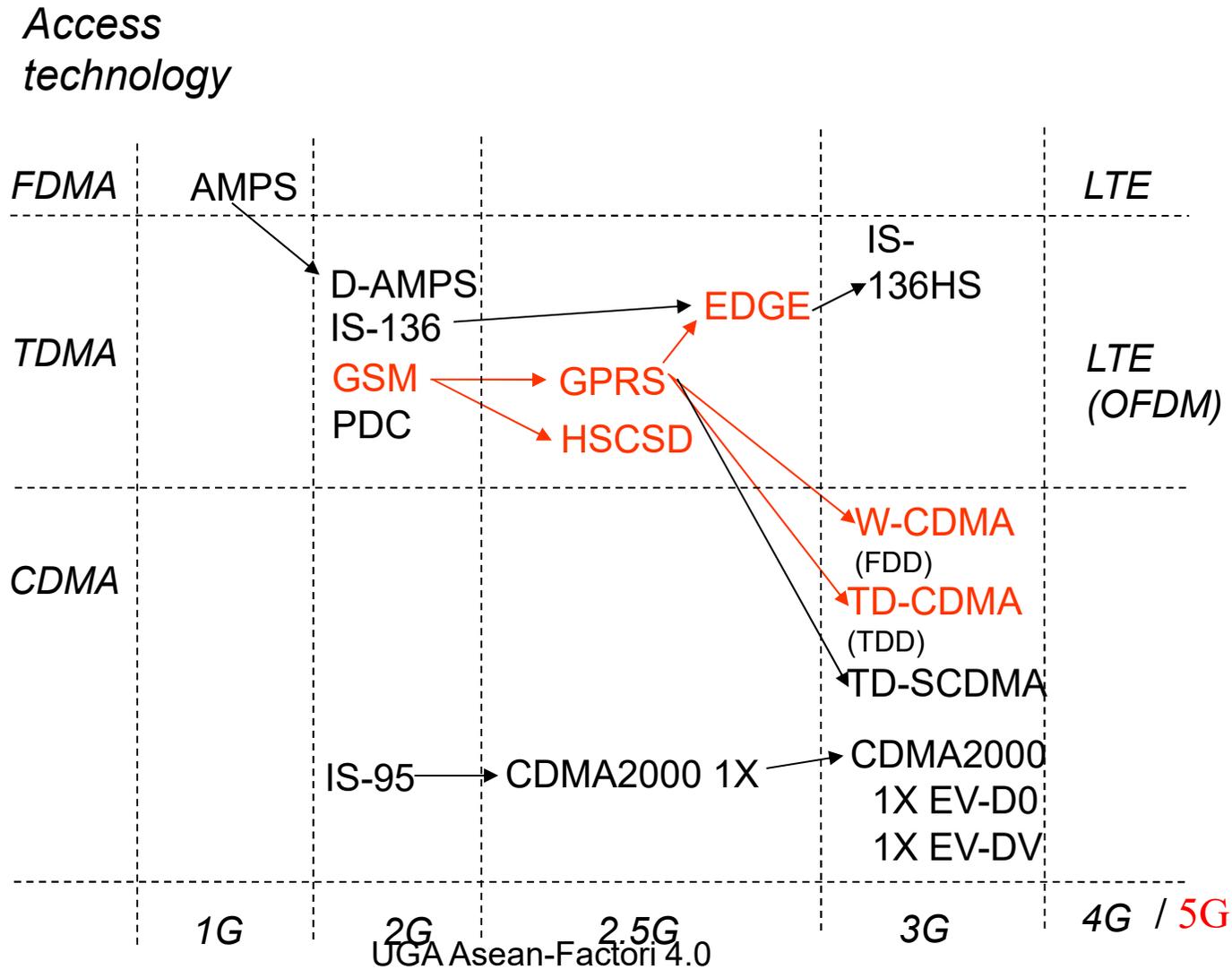
www.cartoradio.fr



UGA Asean-Factori 4.0

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Introduction to the GSM



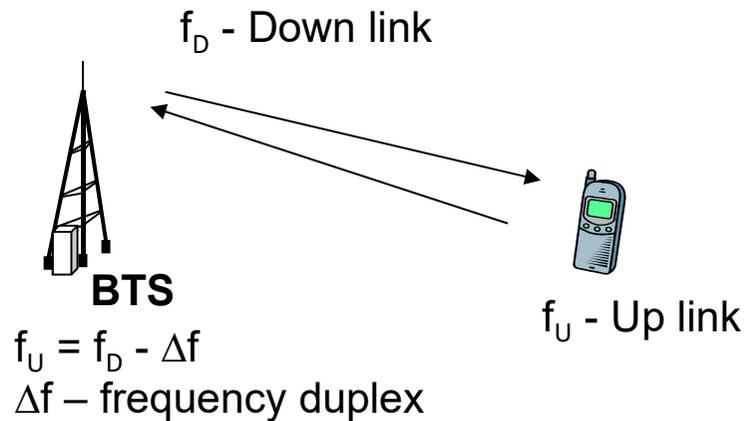
GSM History

- ~70 - Validation of the cellular concept
- AMPS - Advanced Mobile Phone System – USA , Radiocom - France
- GSM - “Groupe Spécial Mobile” (Global System for Mobile Communications)
 - 1982 – Decision of development
 - Digital System
 - Allocation of the frequencies: 890-915 / 935-960MHz
- 1987 - Selection of the radio communication technology :
 - Full digital system (data and signaling)
 - TDMA/FDD
 - Digital voice coder (RPE-LTP)
 - channel coder
 - services (voice, SMS, data 9600bit/s)
 - Communications protocols
 - Structure of the network
- 1991 - 1st experimental system
- 1992 - Beginning of the commercial exploitation
- 2000 - Introduction of the HSCSD/GPRS (~50kbit/s - 170kbit/s)
- 2004 - Introduction of EDGE (~350kbit/s)
- 2005 - Production of 850 000 000 mobile telephones (110 billion dollars business)
- End 2009 - 2 billion mobile phone user (GSM ~ 70%)

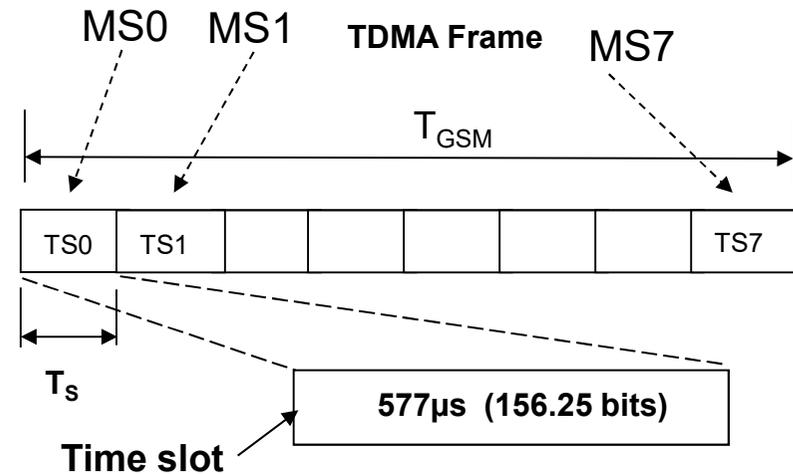
Public system: www.etsi.org www.3gpp.org

Radio transmission technology

Frequency division duplex - FDD

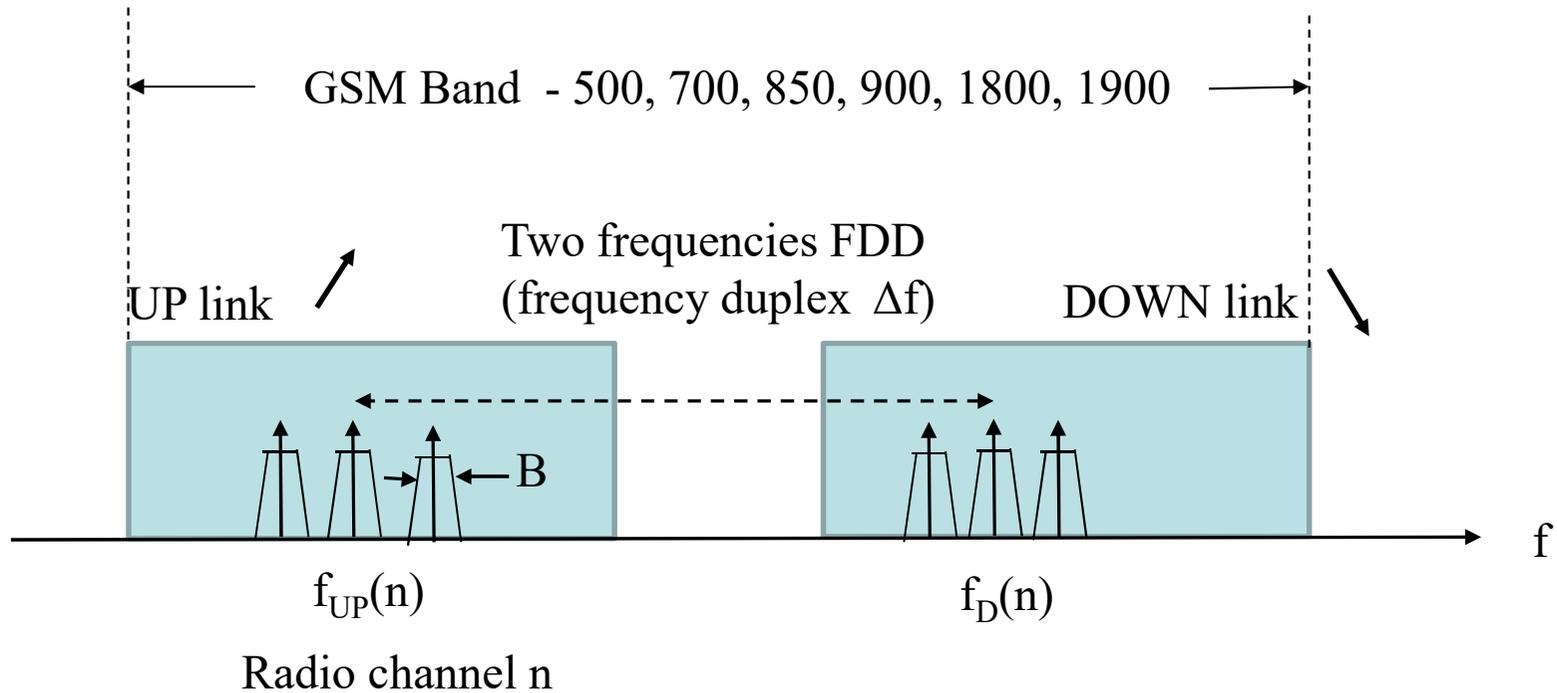


Time division multiplexing - TDMA



GSM Access radio technology – TDMA / FDD

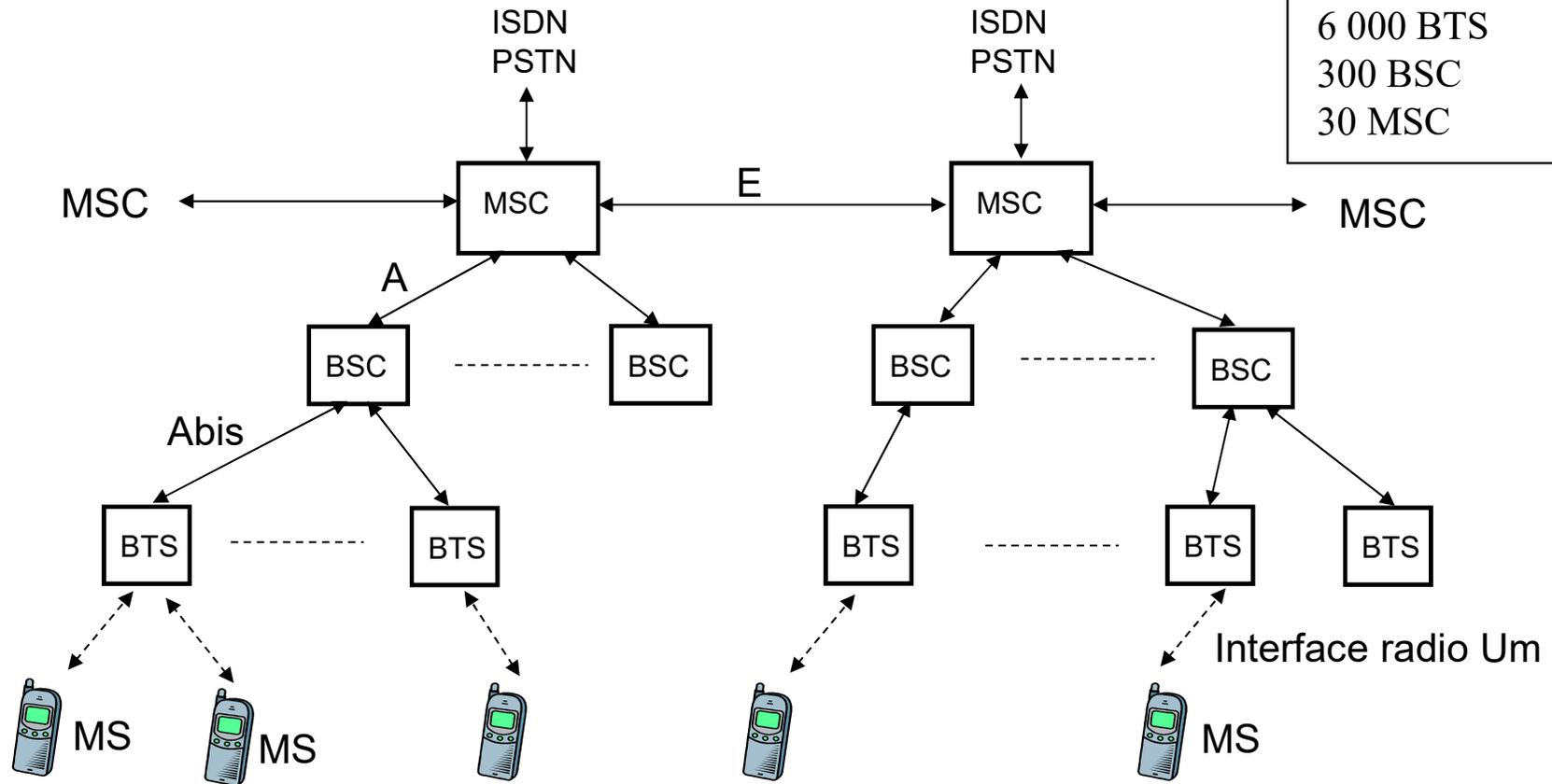
GSM Bands



$n = \text{ARFCN}$

Basic structure of the GSM network (version 1991 – 2G)

France :
18 000 cell
6 000 BTS
300 BSC
30 MSC

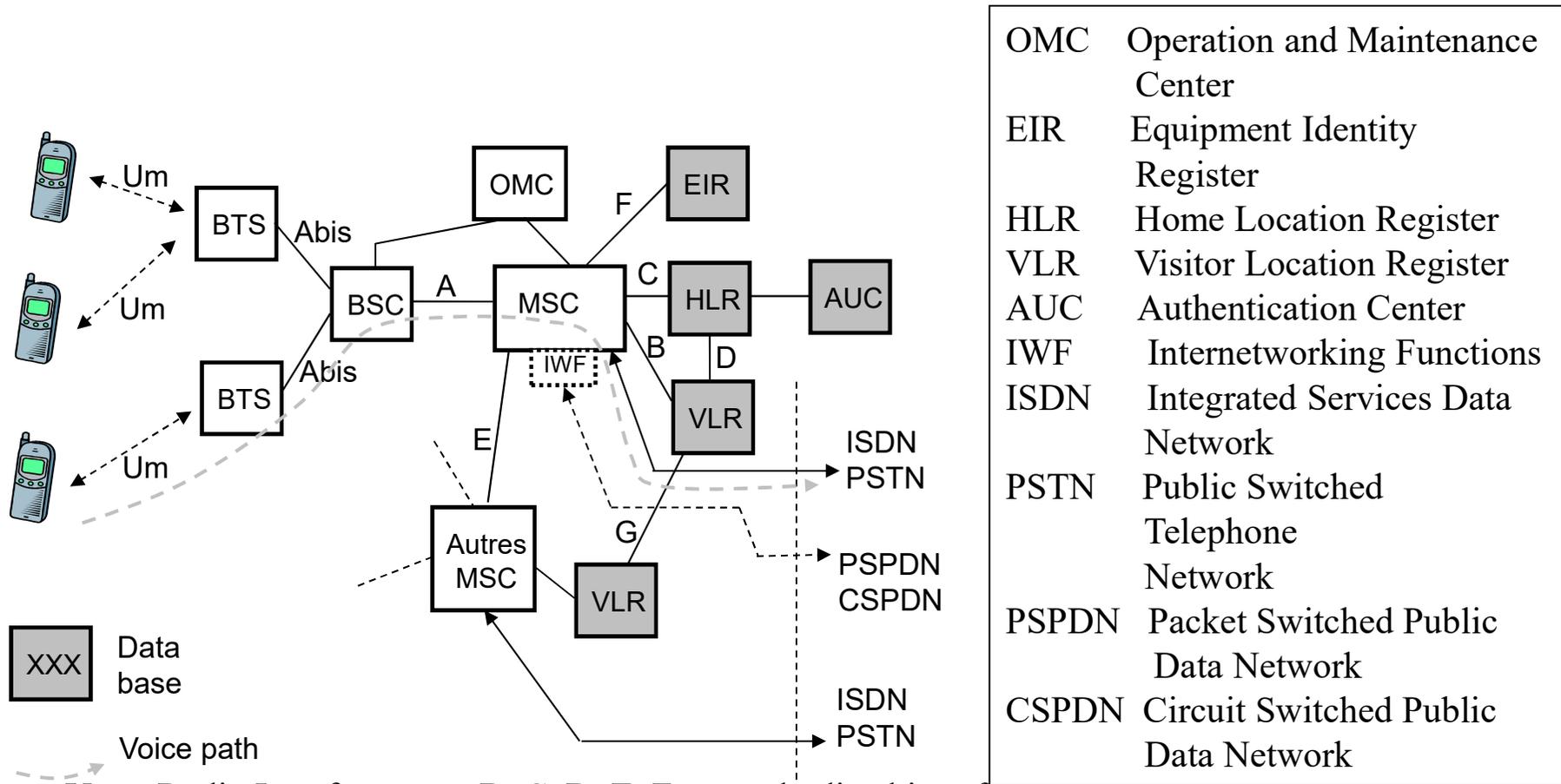


MS – Mobile Station
BSC – Base Stations Controller
MSC – Mobile Switching Center

BTS – Base Transceivers Station
BSS – Base Stations Sub-system

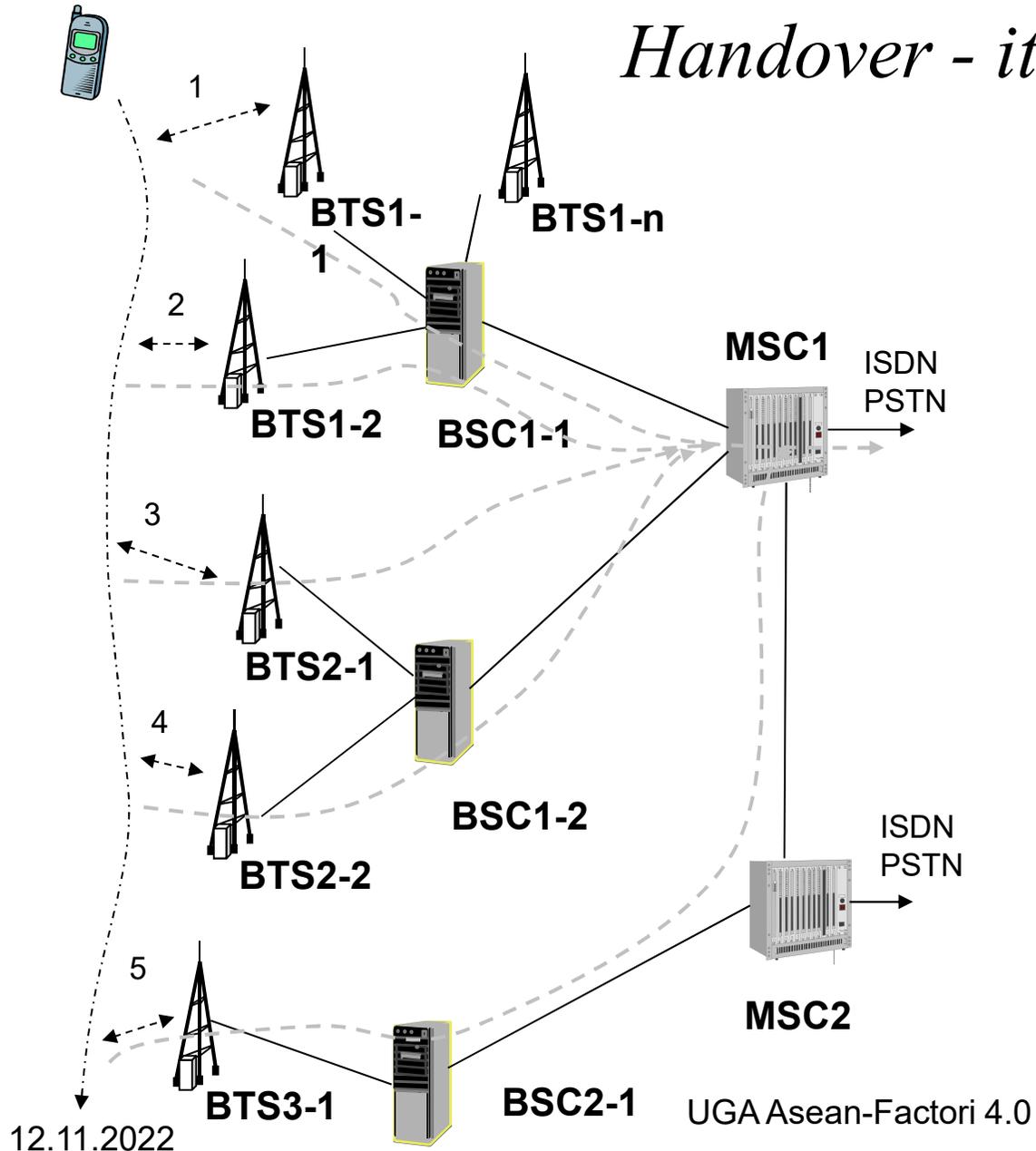
1 BTS : 1- 48 Tx-Rx
1 BSC : 1- 30 BTS

GSM network and interfaces



Um – Radio Interface
 Abis – standardized channel 16 / 64 kbit/s
 A - standardized channel 64 / 2.048 kbit/s
 B, C, D, E, F – standardized interfaces

Handover - itinerancy



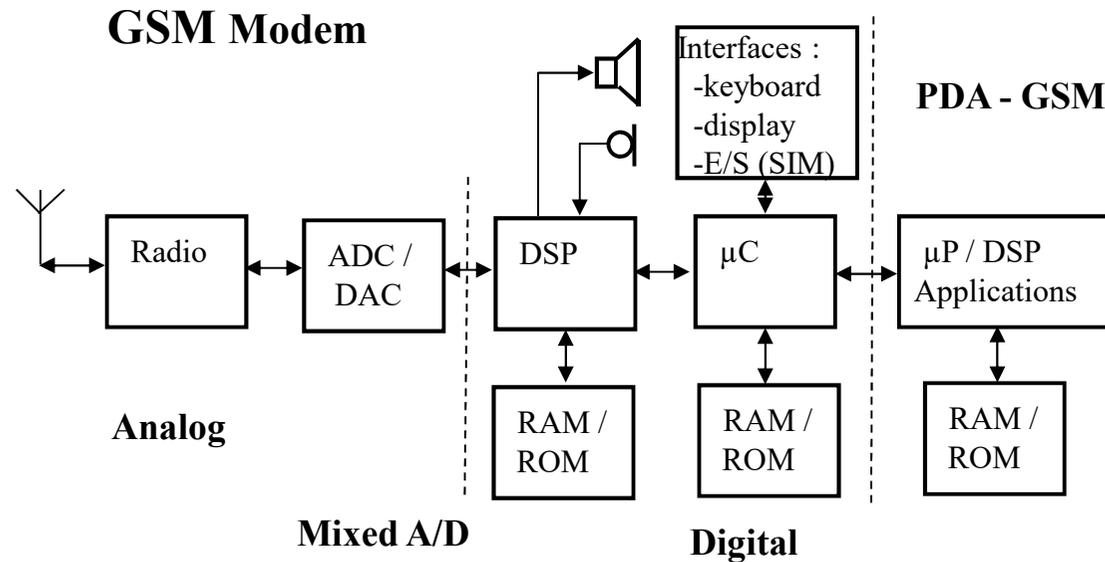
- 1 - 2 Change of cell without change of BSC (*Inter BSC handover*)
- 2 - 3 Change of cells with change of BSC but with the same MSC (*Intra MSC handover*)
- 3- 4 Change of cell without change of BSC
- 4 -5 Change of cells with change of MSC (*Inter MSC handover*)

Rem:

1. If MSC1 and MSC2 belong to different providers: a special subscription is needed to carry out the handover (*Roaming*).

2. The connection with the PSTN is always carried out by the MSC which initiated the communication (*anchor MSC or GMSC – gateway MSC*). 31

GSM Modem



Performances :

DSP : 10 – 40 MIPS, 4-32 k RAM, 16 – 128 k ROM

μC : 5 – 10 MIPS, 256k – 1M RAM, 1 – 32 M ROM

Applications: PDA, MP3, VIDEO, GPS

GSM phones: 1998 - 2008

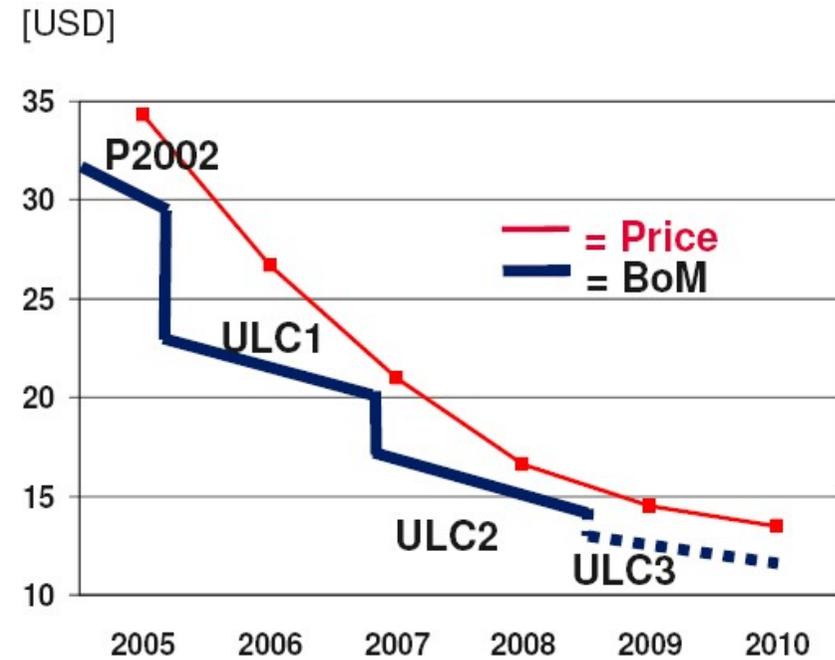


XMM1010
Infineon



2cm
↔

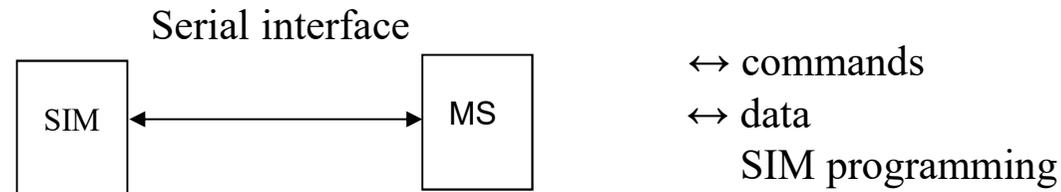
GSM – 3 generations



iPhone 5 / 2013



SIM Card (*Subscriber Identity Module*)



SIM card (Subscriber Identity Module) : User data base / security control.

The data on the card have a file structure:

- Safety data (PINE, PUK, Ki – authentication)
- mandatory data (identifications, IMSI, services, access control, localization, frequencies list of the preferential base stations, list of prohibited BTS, network key Kc, preferential language)
- optional GSM data (directory, SMS, service)
- optional telecom data (last called numbers, annular, additional services)

Protection : PIN (CHV1, CHV2), PUK

GSM Identities

- MSISDN (*Mobile Station ISDN Number*): phone N° of the subscriber (06 xx ... xx)
this number is not used during the GSM communication!
- IMSI (*International Mobile Subscriber Identity*):
permanent identity of the subscriber.
- TMSI (*Temporary Mobile Subscriber Identity*): temporary identity of the user,
this number is allotted by the network.
- MSRN (Mobile Station Roaming Number): temporary code used
during the routing of a call towards a mobile.
- IMEI (*International Mobile Equipment Identity*): serial N° of the mobile.
(read IMEI *#06#)

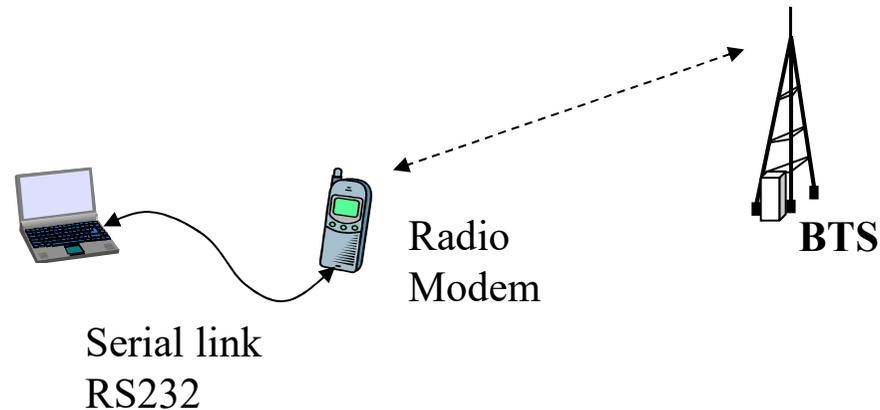
GSM Security

Objectives:

- confidentiality of the subscriber (protect the IMSI)
- authentication of the subscriber
- protection (confidentiality) of the user data
- confidentiality of the signaling (to avoid locating the user)

GSM and Internet

The GSM (Phase1) has a data transfer at the maximum speed of 9600bit/s (14400 bit/s). The commutation mode is by circuit switched data (CS – *Circuit Switched*). The GSM terminal can be used as a radio modem (RLP – *Radio Link Protocol*) . It is possible to make Internet or data transfer (WAP – *Wireless Access Protocol*). However there are three disadvantages in this system:



- the data rate is low
- the communication is in CS mode (the user pay the time he stay on the radio channel independently of the quantity of transmitted information)
- the data flow is symmetrical and cannot be adjustable. In Internet very often one uses a non symmetrical data flow.

Moreover in GSM system Phase 1 the concept of Quality of Service (QoS) does not exist. The GSM infrastructure is not adapted to operate in Internet mode.

GSM-GPRS

In 1998 ETSI decided to introduce the Internet technology into the GSM - Phase 2. To increase the data rate two new technologies were introduced:

- HSCSD (*High Speed Circuit Switched Data*) - technology based on the circuit switching which did not have commercial success and was abandoned
- GPRS (*General Packed Radio Services*) - technology based on the packet switching which was introduced on broad scale in 2002.

Two techniques are used for the increase of the data rate:

a. Multi slot Communication.

In one time slot in GSM it is possible to transfer $D_1 = 2 \times 57 = 114$ bits. On N slots ($N = 1-8$)

it is possible to transmit $N \times 114$ bits. $D_{max} = (8 \times 114 \times 1000) / 4.165 = 197\ 616 \text{ bit/s}$

The 114 bits are not only “user” bits. Among these bits there are data bit and protection bits.

b. Protection control according to the quality of the channel.

If the quality of the transmission is good one can decrease protection against the errors and transmit more “user” bits by slot. This occurs for example when the mobile is close to the BTS. By adapting the type of convolutional coding to the quality of radio channel it is possible to gain in data rate.

This is done by the introduction of different Coding Scheme (CS).

GPRS services

PS - Packet Switched Data communication

In this mode a “virtual” connection is established between MS and the network. The parameters of the communication channel (radio channel) are negotiated and the network books the necessary resources. However the radio channel is not established physically. As soon as there are sufficient data to be transmitted (accumulation of a packet) the channel is established, the data are transferred and the channel is released. Thus the radio resources are used only where there is a need for that.

- Optimization of the use of the radio interface and the network
- Only the quantity of transmitted information is paid (and not the connection time)!

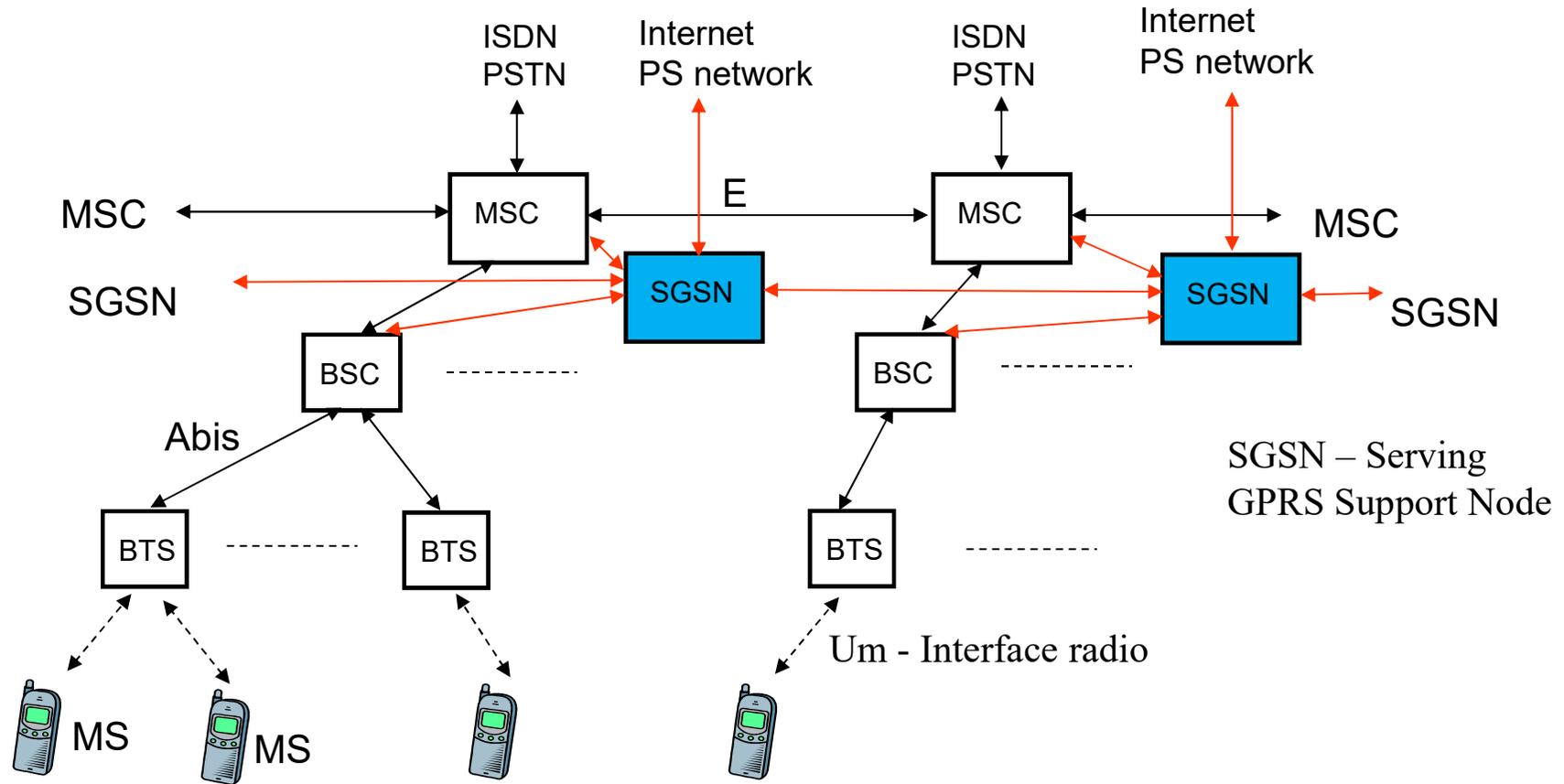
Quality of the service (QoS)

The Quality of Service (QoS) comprises four parameters:

- Data rate (kbit/s)
- Delay Time (maximum delay between transmission and reception of the data)
- Reliability (acceptable maximum errors rate)
- Precedence (the packages are delivered in the order of transmission)

Each portable, according to the application which it will carry out and of the subscription which the user has, can negotiate the QoS during its connection to the GPRS network.

GPRS – network architecture



UMTS

Objectives of UMTS (*Universal Mobile Telecommunications System*)

- to replace the GSM by ensuring a continuity and improvement of the existing services (voice, SMS, data)
- to propose a broad range of new services (music, video, TV)
- to ensure high data rates under various conditions of radio propagation and particularly in urban and indoor environments
- to ensure the convergence “telephony – data” towards the IP network
- maximal re-use of the GSM infrastructure.

Open system: spécifications : www.3gpp.org, commercial exploitation : 2004

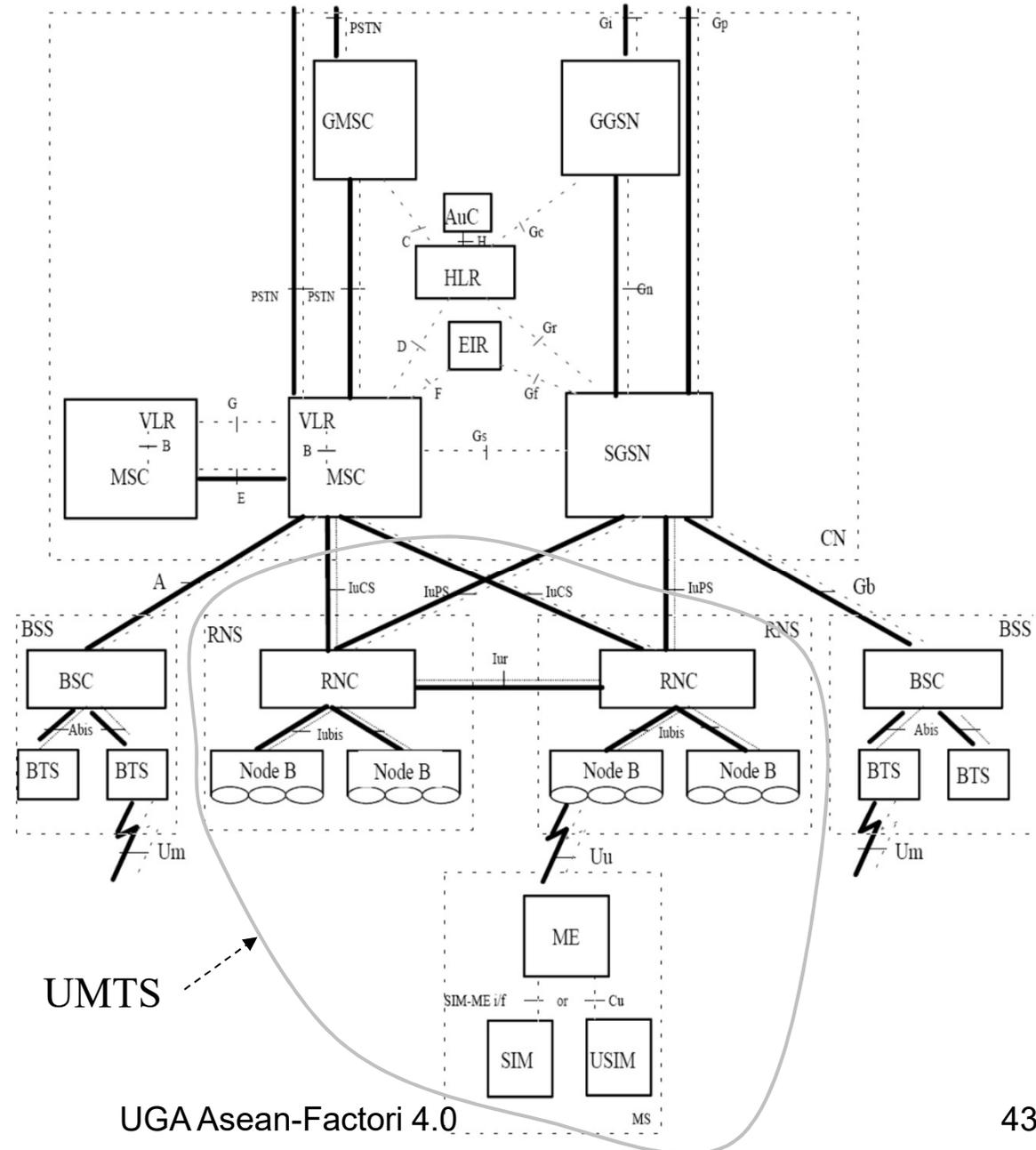
Radio technology: Direct sequence spread spectrum (DS-SS) with Code Division Multiple Access (CDMA).

Data rates :

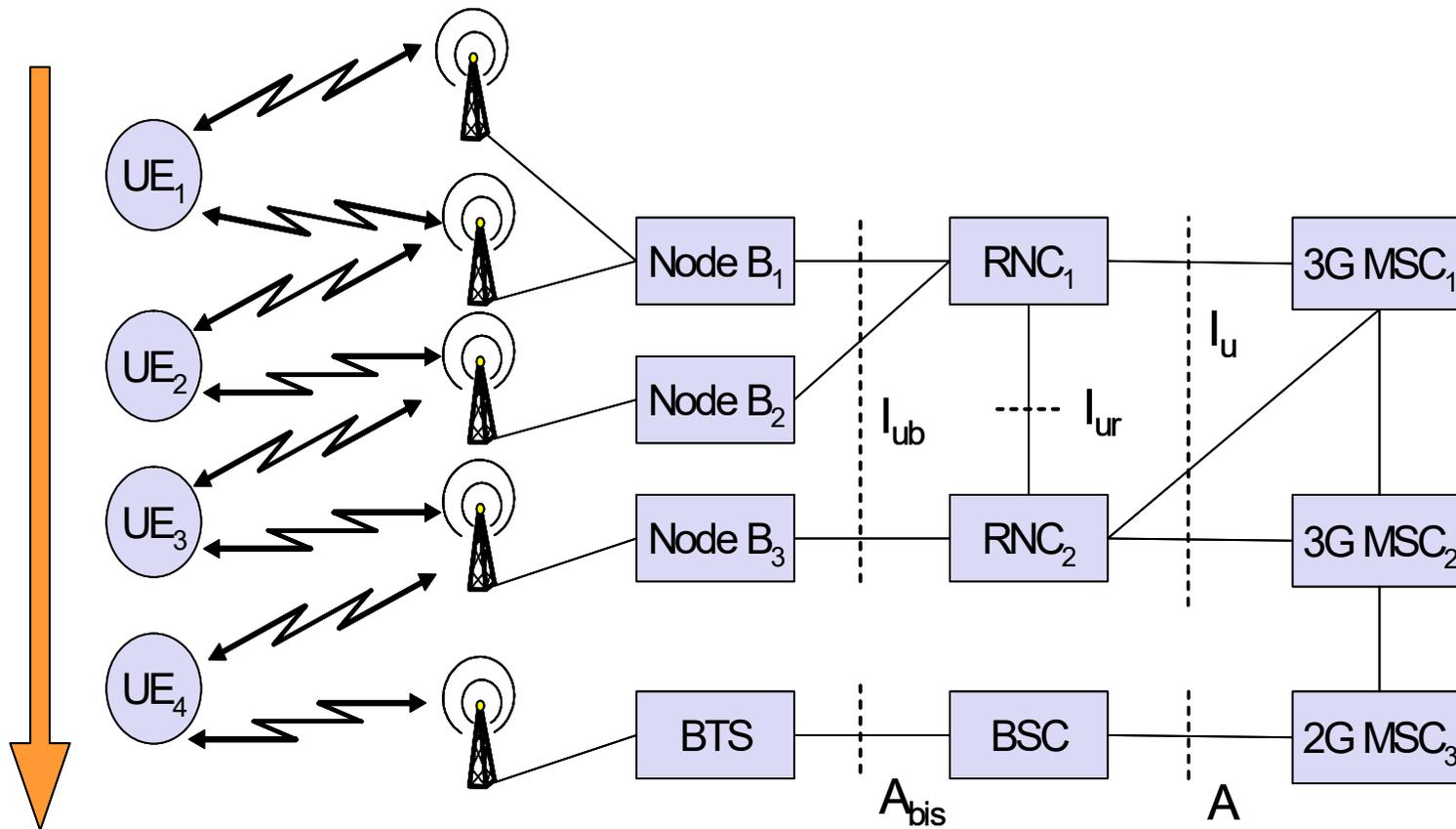
min. 144 kbit/s rural (384 kbit/s)
min. 384 kbit/s semi urbain (512 kbit/s)
up to 2 Mbit/s urbain

Rem. HSDPA (*High Speed Downlink Packet Access*) - 2004:

UMTS / GSM (reuse of the GSM / GPRS core network)



Inter system handover : GSM ↔ UMTS



LTE – 4G

But de LTE (*Long Terme Evolution*)

- satisfaire le besoin de données mobiles (Internet mobile)
- proposer du haut débit et accès direct aux réseaux IP
- PS data
- diminuer le prix de l'infrastructure (Réutilisation des réseaux IP)
- utilisation de petites et très petites cellules (*femto cell*)
- développement du système : 2008 – 2012

(spécifications : www.3gpp.org)

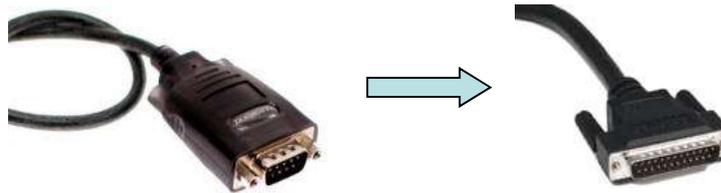
introduction commerciale du service : 2015

Technologie radio : OFDMA (station de base), SC-FDMA (mobile) ,
utilisation d'antennes multiples MIMO, technique de multiplexage : FDD, TDD,
Contrôle flexible de la bande passante radio (1,4 – 20 MHz)

Débit théorique: Up 50 Mbit/s, Down 100 Mbit/s

High Data Rate Radio Communications

- Techniques de diminution (élimination) de l'ISI:
 - égalisation GSM
 - étalement du spectre DS-SS UMTS
 - allongement artificiel de la durée du bit – OFDM LTE
- OFDM (Orthogonal Frequency Division Multiplexing) : Idée de base - transformer **les bits en série rapides en bits (ou symboles) lents en parallèle** de durée plus grande que l'étalement maximal du canal de propagation.



- L'OFDM a été développée dans les années 60. Actuellement la modulation est utilisée en :
 - Radio numérique : DAB
 - Télévision numérique: TNT / DVBT
 - Télévision satellite
 - WiFi (801.11a/g/n), WiMax (802.16d)

Minuaturization

Computers



Mainframe



Mini-computer



Personal - computer

Cellular Base Stations



Macrocell



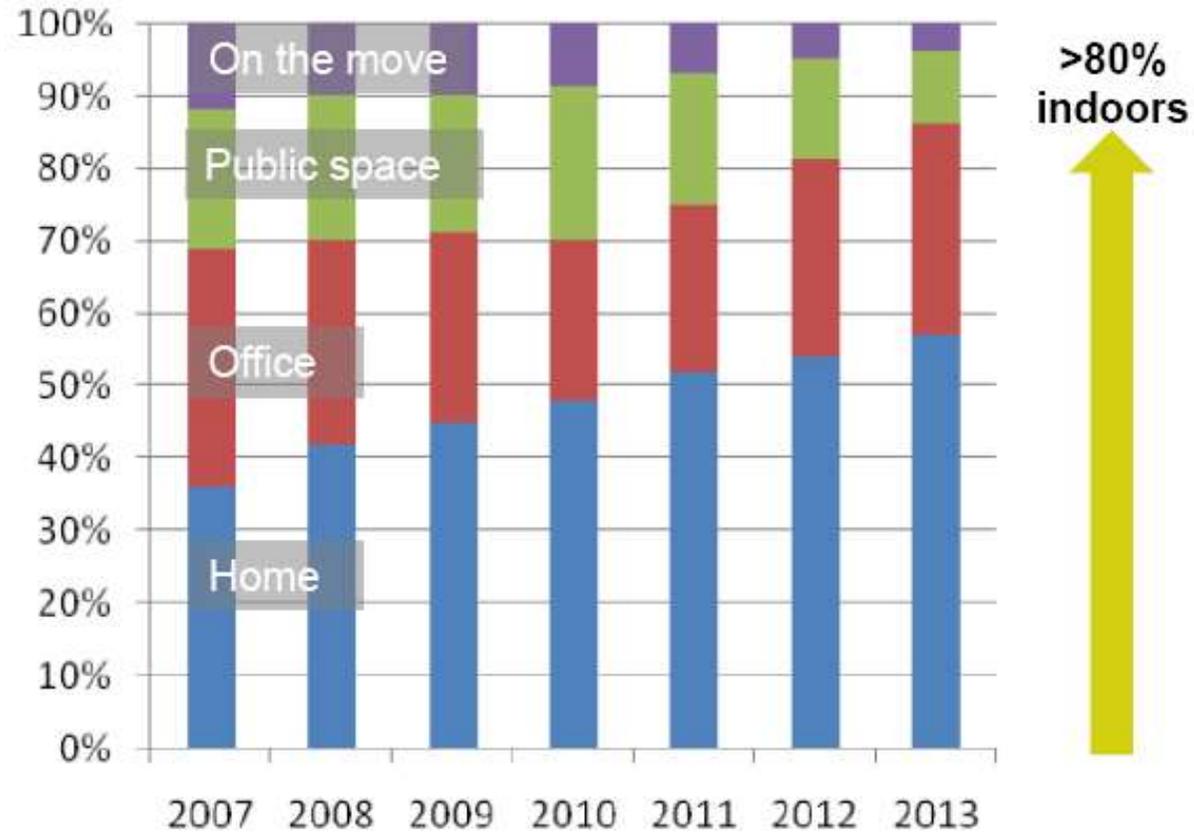
Picocell



Femtocell

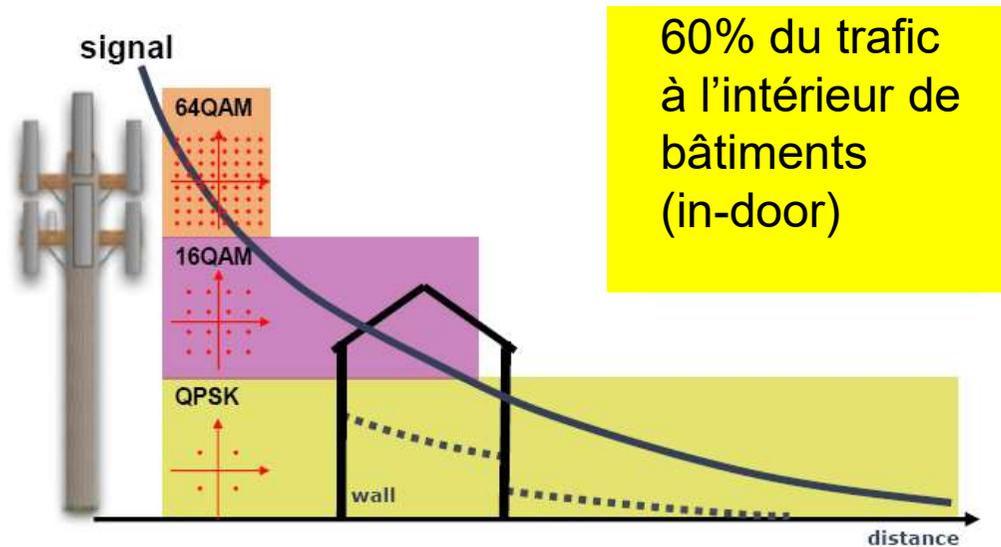
Nano-, pico-, and femto-cell : WCDMA / UMTS et LTE

Traffic Evolution



Source: VisionGain

Why do we need small cells for LTE?

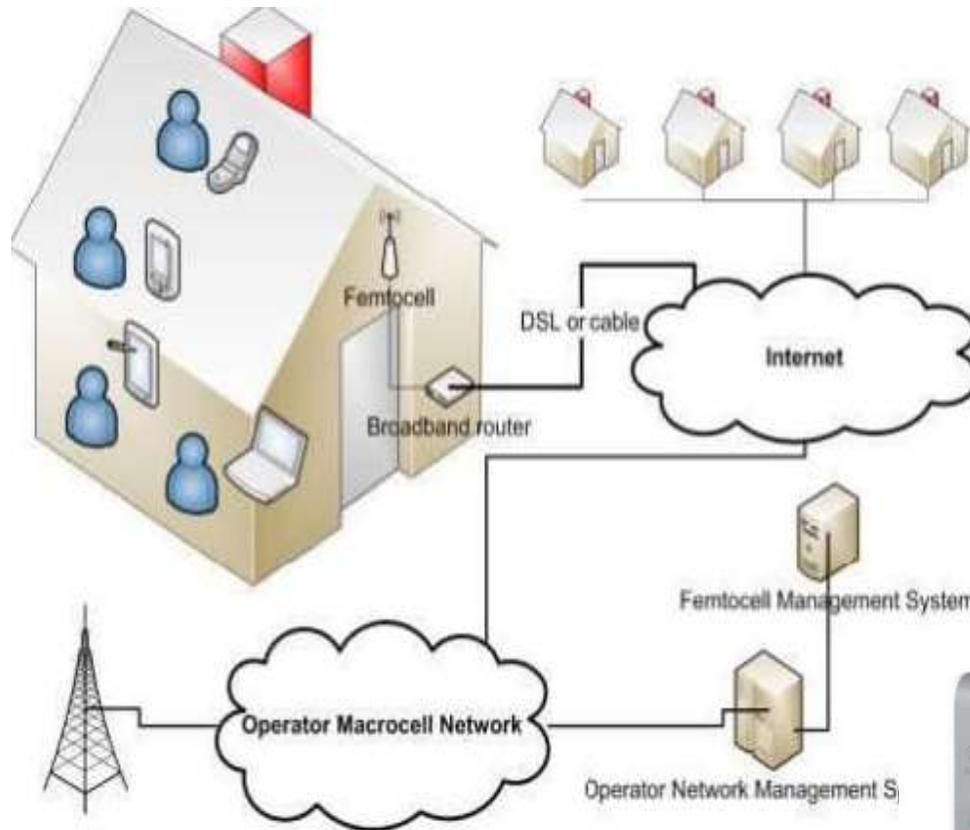


- Modulation nQAM ($n = 2 - 6$) du LTE – très sensible au bruit
Augmenter le rapport Signal/Bruit :
 - augmenter la puissance (impossible)
 - diminuer la distance (petites cellules)

HeNB (Home evolved NodeB)

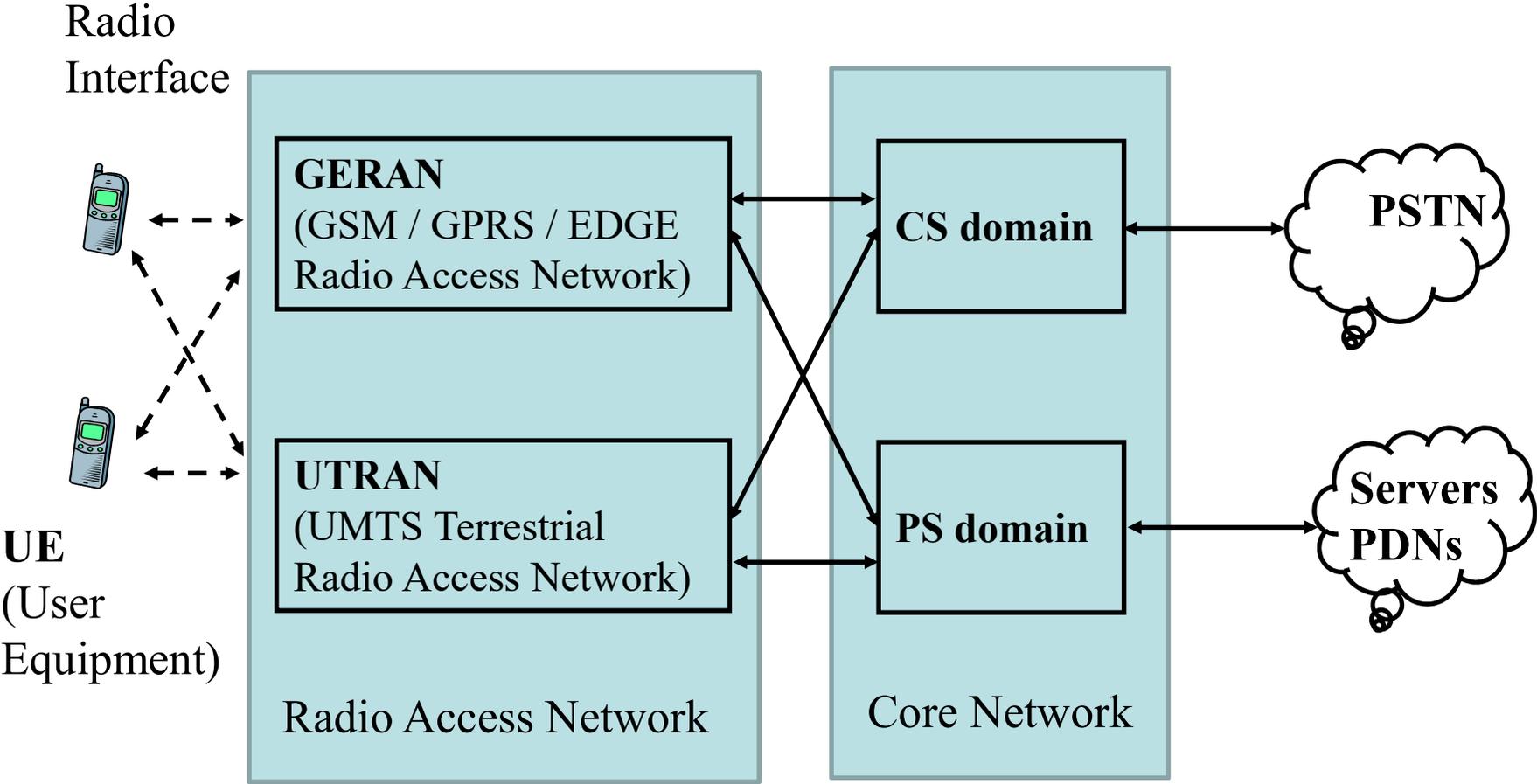
Femtocell

- Point d'accès domestique
- Faible puissance
- Utilise un spectre licencié (géré par l'opérateur)
- Couverture: quelques dizaines de mètres
- Haute capacité de données
- Connexion à l'infrastructure opérateur par Internet
- Faible prix (~20 euros)

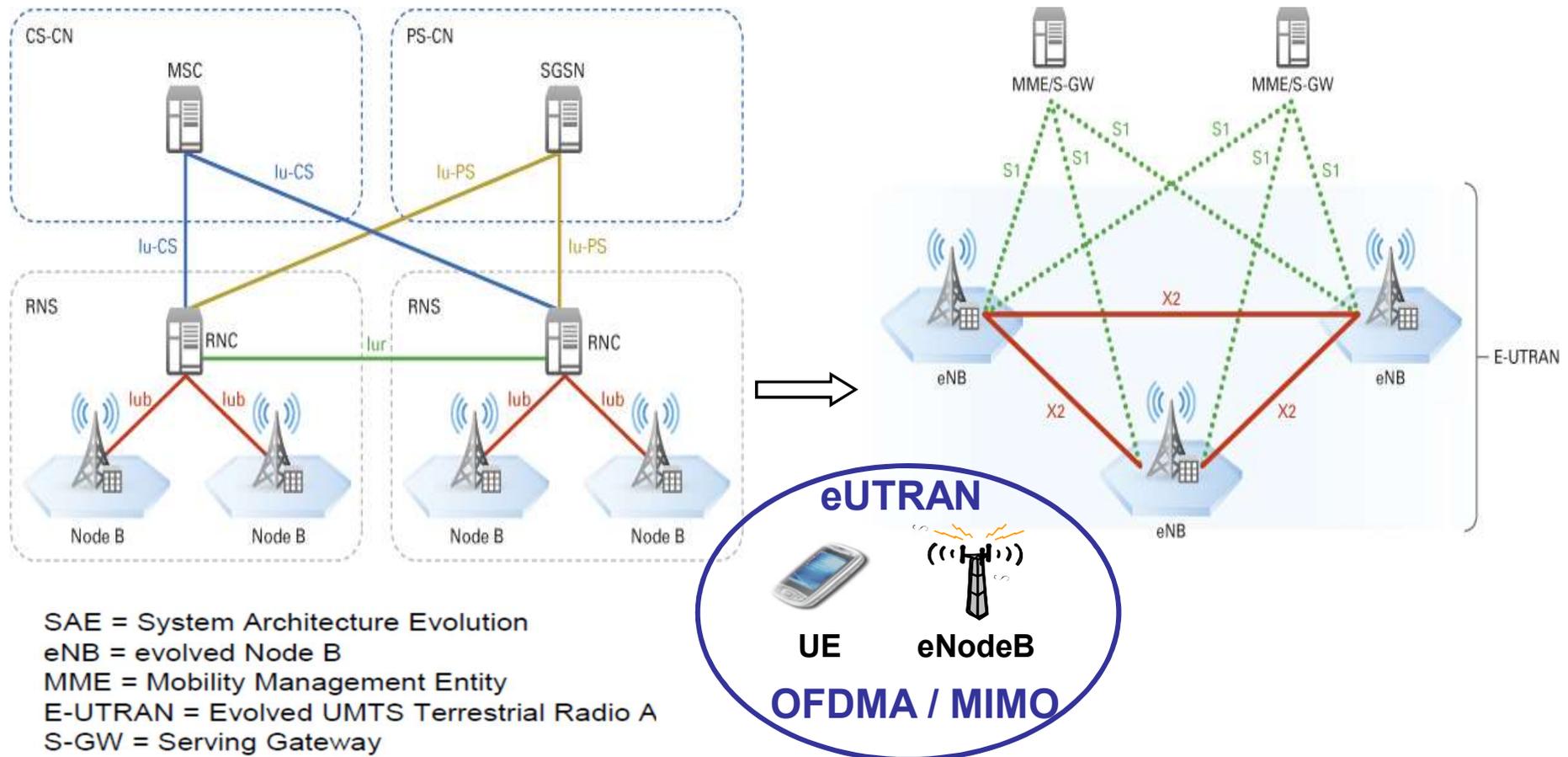


WCDMA femto BTS
8 UE
HSDPA – 15Mbit/s
HSUPA – 5.7Mbit/s
Couverture radio 20m

2G – 3G Architecture



LTE Network Architecture (all IP network)

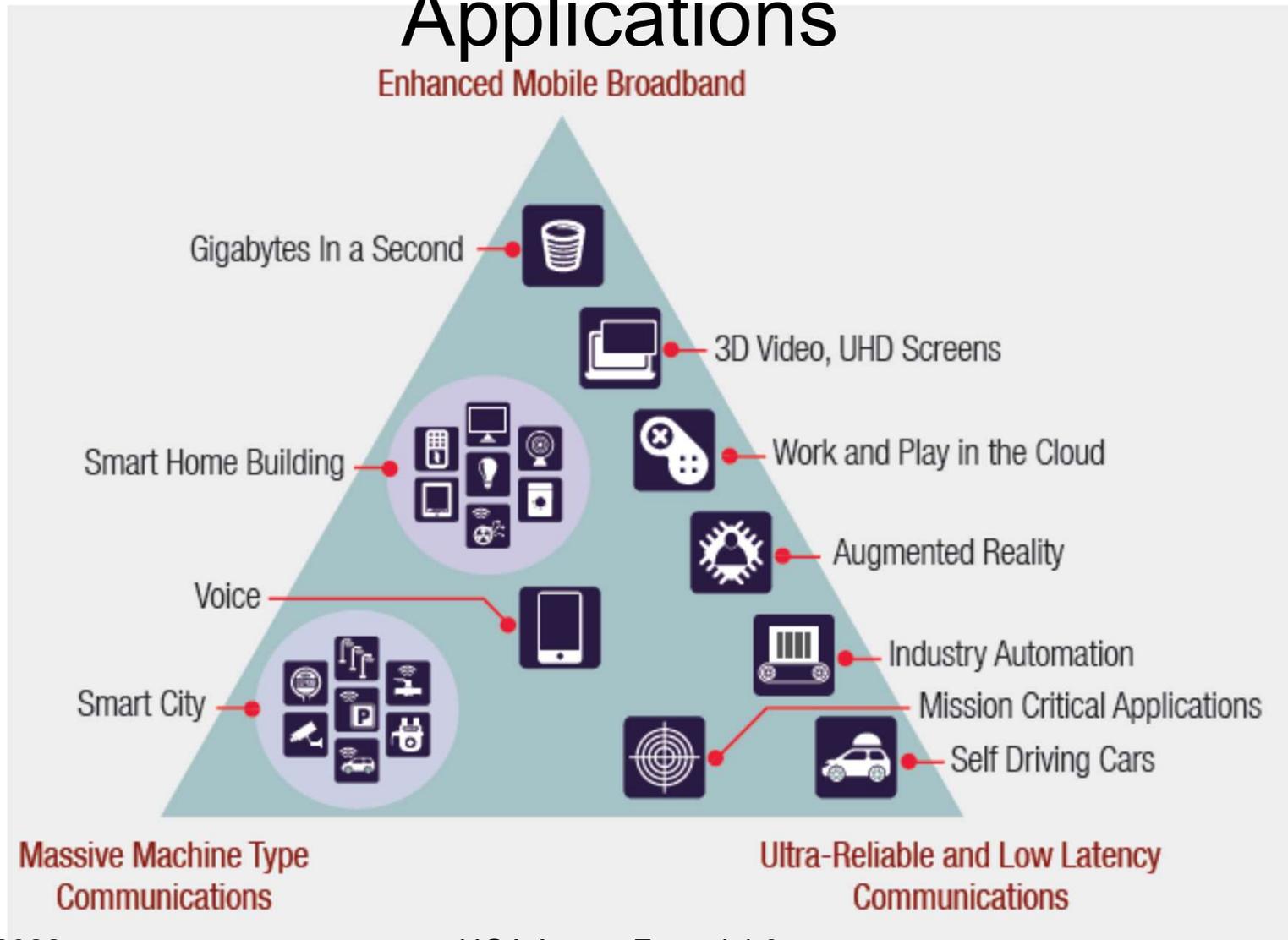


- Les composants de l'infrastructure communiquent entre eux à tous les niveaux
- Les interfaces de communications utilisent le protocole Internet (IP)

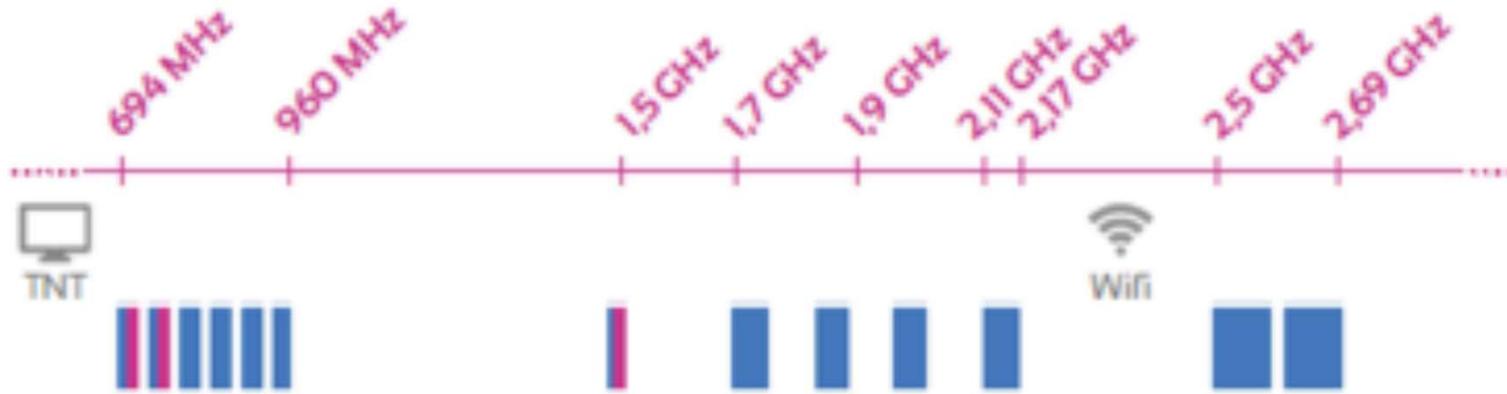
2G – 3G – 4G

	2G - GSM	3G - UMTS	4G - LTE
Bandes de Fréquences [MHz]	880 – 960 1710 - 1880	1885 – 2015 2110 – 2200 + GSM 900	2500 – 2600 + UMTS 700 – 800 (TV)
Puissance d'émission max. du terminal [W]	2	0.25	0.125
Duplex	FDD	FDD et TDD	FDD et TDD
Accès multiple	FDMA/TDMA	CDMA	↓ OFDMA, ↑ SC-FDMA
Modulation	GMSK	PSK, QPSK, n-QAM	PSK, n-QAM
Services	Voix, SMS, données (14.4 kbit/s)	Voix / données (2 Mbit/s)	Données, VoIP ↓ 100 Mbit/s ↑ 50 Mbit/s
Type de commutation	CS (par circuits)	CS / CP (par paquets)	CP
Evolutions	<ul style="list-style-type: none"> • GPRS : CP, 171,2 kbit/s • EDGE : 8-QPSK, 384,4 kbit/s 	<ul style="list-style-type: none"> • HSPA : ↑ 5,76 Mbit/s, ↓ 14,4 Mbit/s • HSPA+ : ↑↓ 21 Mbit/s • MIMO 	<ul style="list-style-type: none"> MIMO ↓ 300 Mbit/s ↑ 75 Mbit/s
Internet of Things IoT			
New 4G standards : NB-IoT, LTE-M (M2M) 2G: EC-GSM 3G : non!			

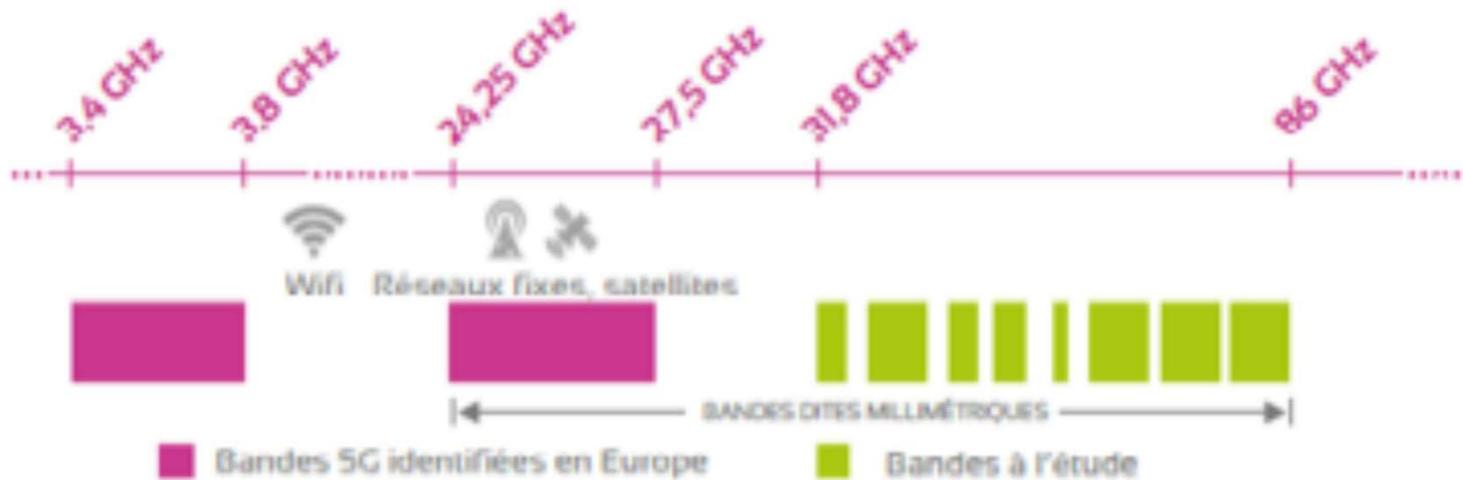
5G – Professional Quality Link & Applications



New Frequency Bands



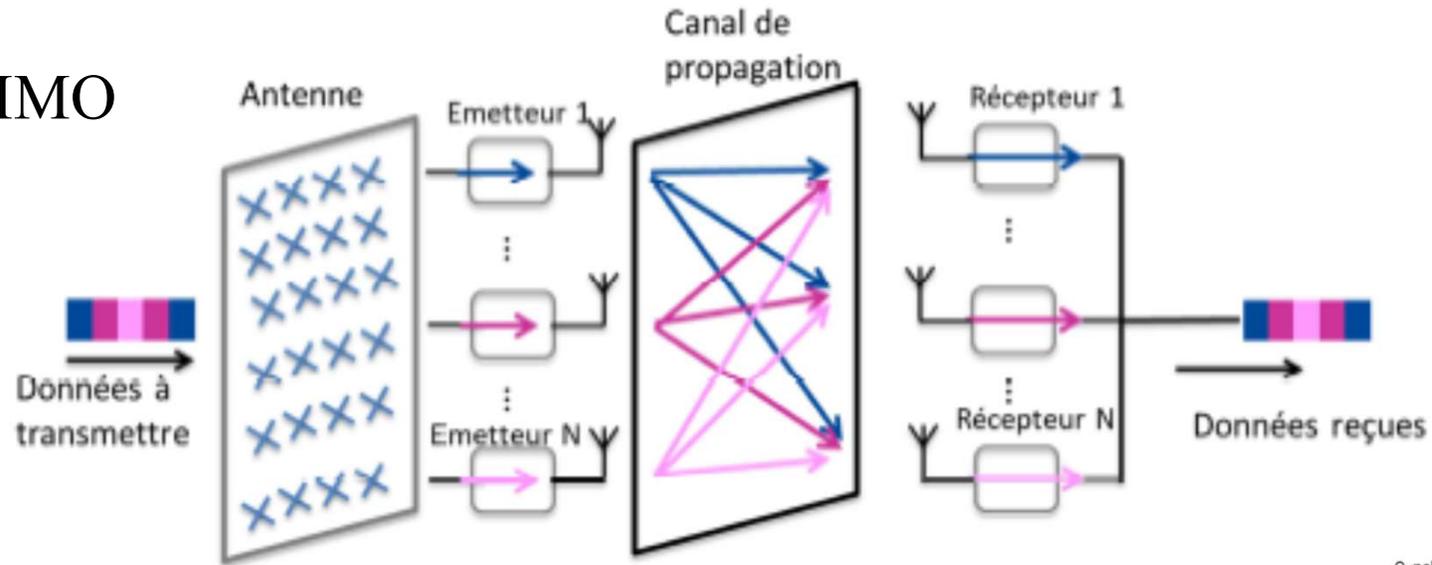
Low" bands: good indoor propagation



High bands: high data capacity, limited indoor propagation

High Data Rate Radio Technologies

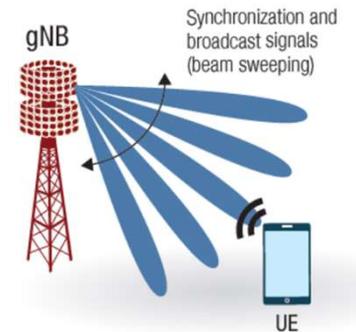
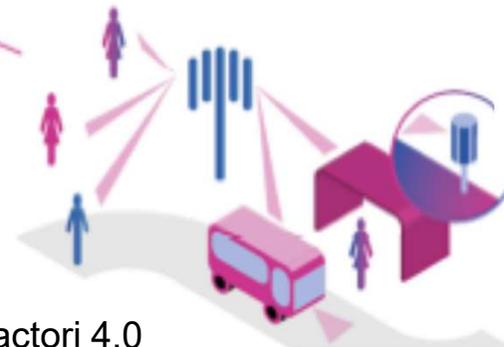
1. MIMO



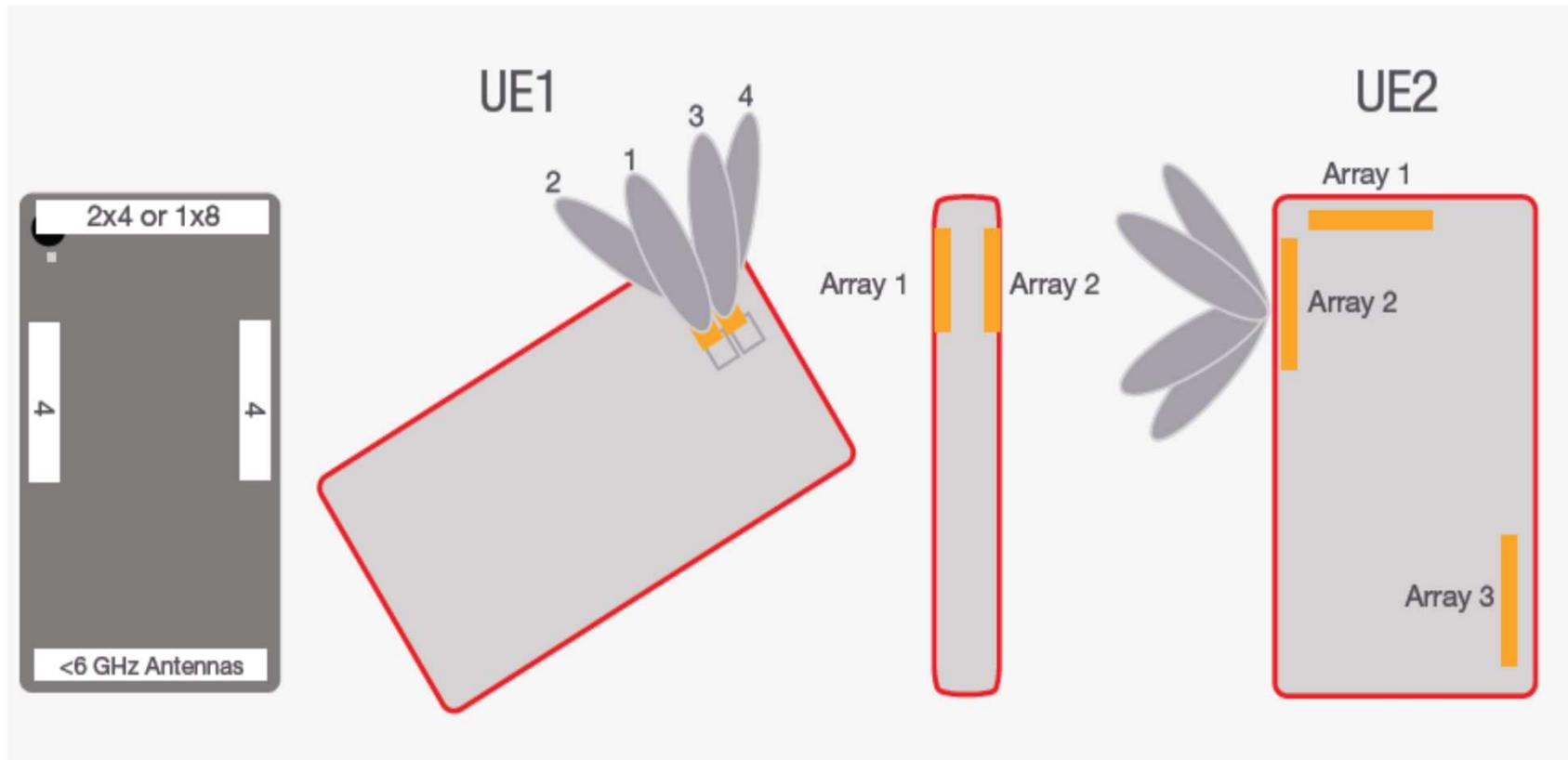
2. RF Beam Steering



ANTENNES 5G
Gain typique 24 dBi



Multiple Antenna (Phased Array) UE

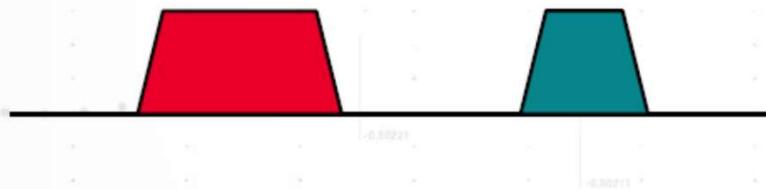


Spectrum management (Band and Carrier frequency aggregation)

- Component Carriers may be in the same band and adjacent



- Or they could be in the same band, non-contiguous



- Or in different bands

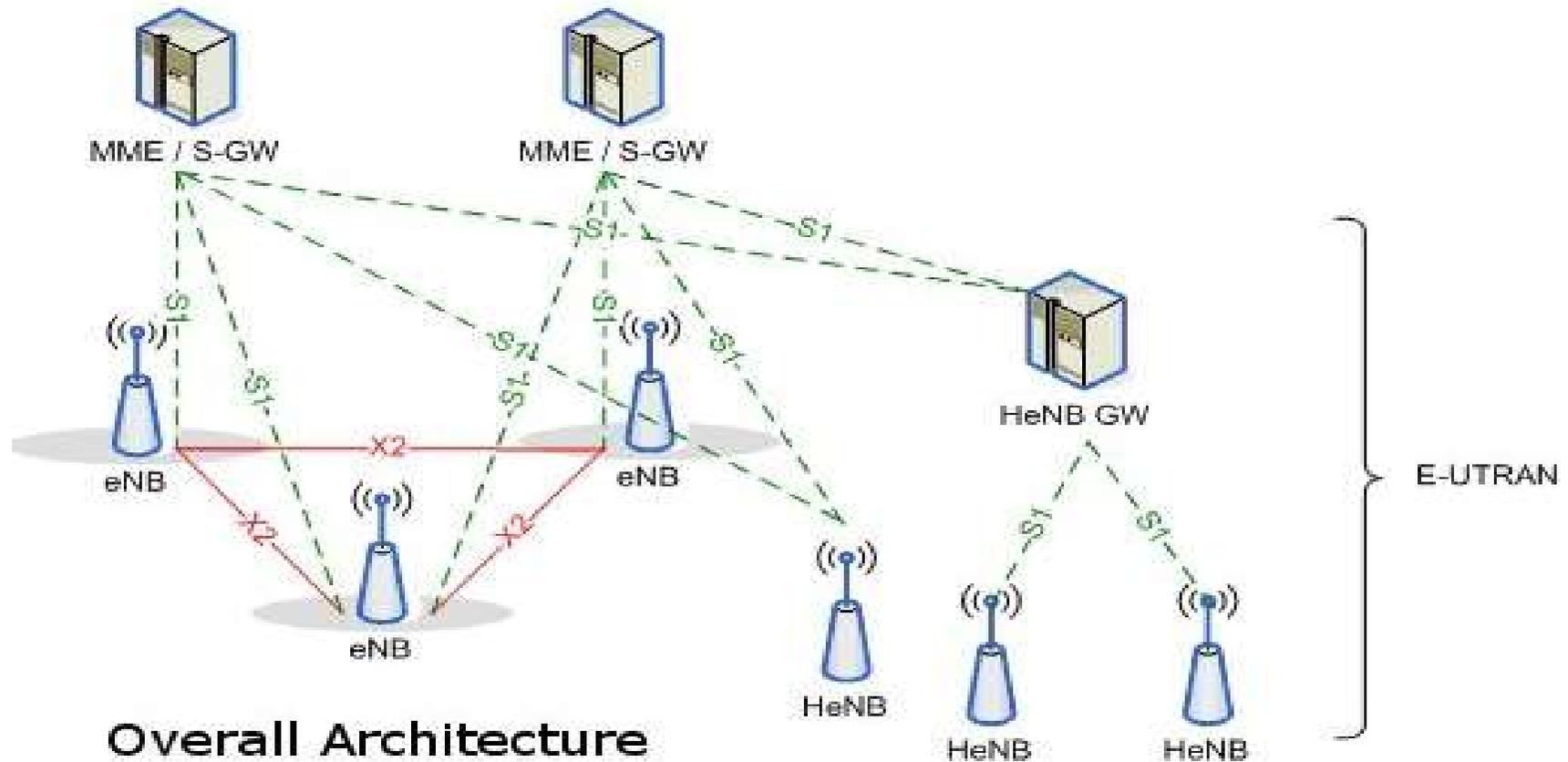


Band A – sub-6 GHz

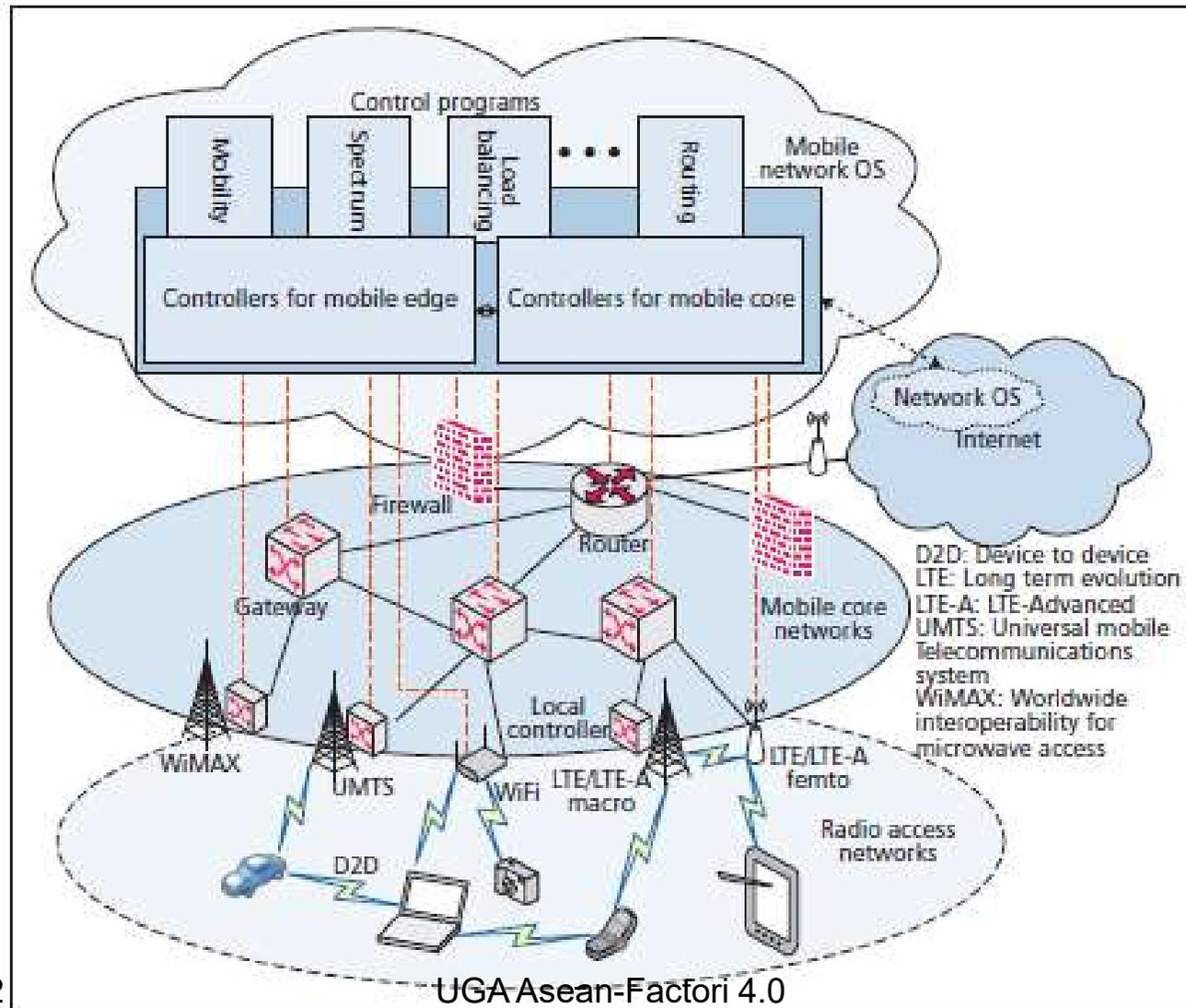


Band B – mm-wave (28GHz)

NG RAN Architecture



SDN – Software Defined Networks (Virtualization)

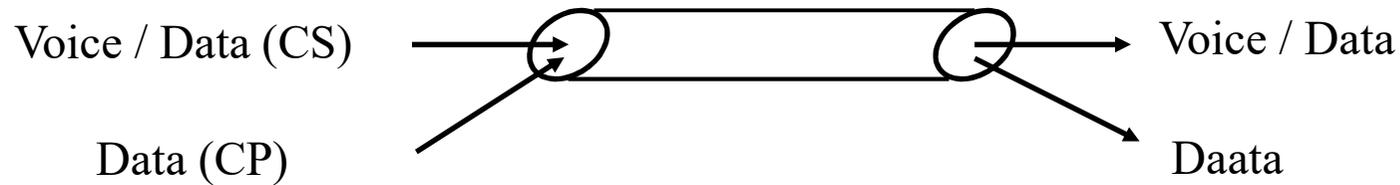


2G – 3G – 4G – 5G

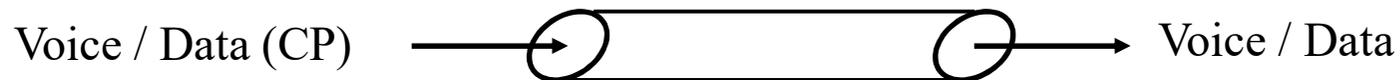
2G GSM



3G UMTS



4G LTE



5G Evolution of 4G

