

EFREI M1

Mobile Networks

Réseaux Mobiles: Introduction
(*Fundamentals of Cellular Networks*)

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Tamum Consulting February 2013

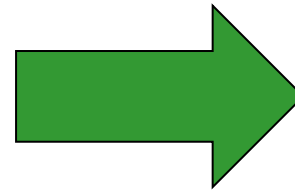
Mobile Networks: Fundamentals

- Introduction
 - Market and technological context
- Spectrum
 - Radio spectrum
 - Radio propagation
 - Regulation
- Standards

The mobile phone revolution



1983



30 years



2013

- **7 billion subscriptions by end 2013**
- **1.6 billion mobile phones sold in 2012**

Mobile networks: a society-changing revolution



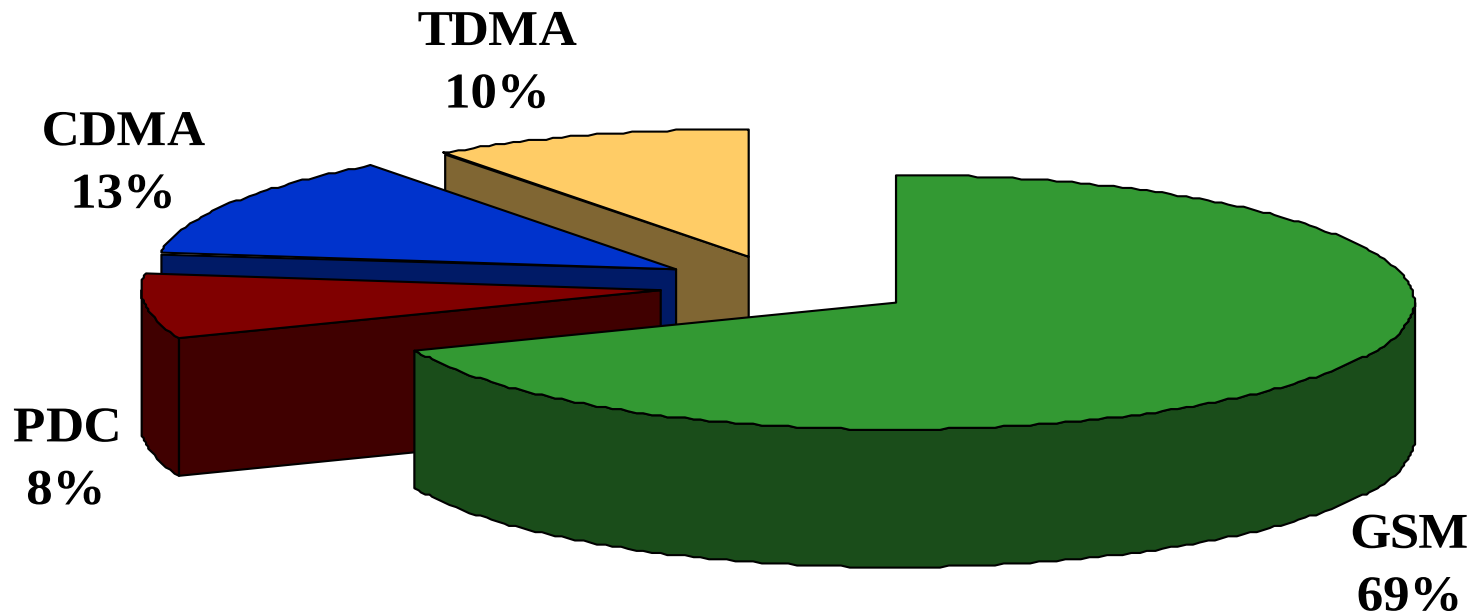
“I'd never handled one before...
It was so small, and there was no
mouthpiece..”

Nobel Prize Winner
Aung San Suu Kyi,
13 November 2010
after speaking on a mobile
phone to her son following her
release from house arrest.
First detained 1989

The Development of Mobile Networks: The Historical Context

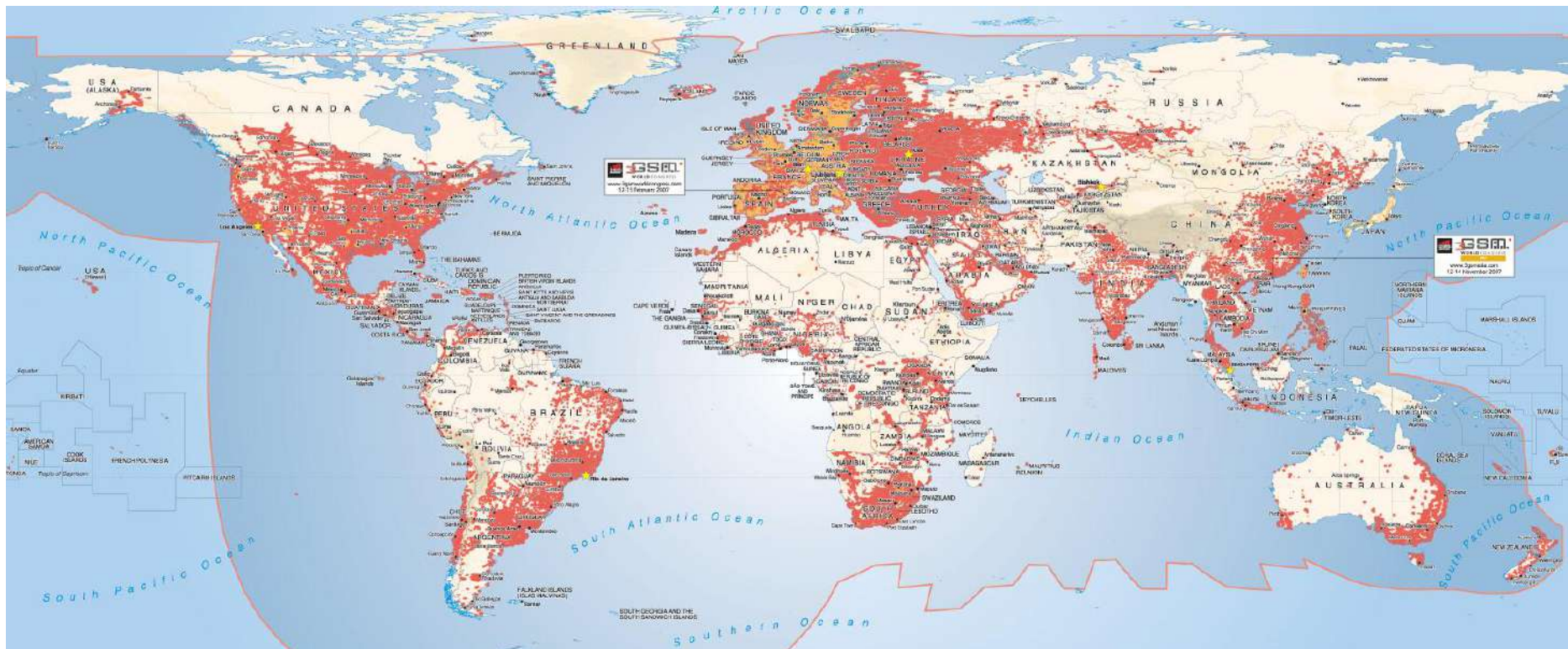
- 1947-1973 Mobile phone service in Cars
- 1960s Star Trek shows handheld phones
- 1973 First handheld mobile telephone
- 1982 GSM project begins
- 1987 GSM MoU signed (13 countries)
- 1990 12 million mobile subscriptions
- 1991 First commercial GSM (digital)
- 2012 >6 billion mobile subscriptions
 - Most people have access to mobile phones

2000: GSM becomes the dominant mobile technology



Source : EMC World Cellular Database end of 2000

GSM Coverage today



- 700 operators in 218 countries/territories
- GSM has 84% of the world market and it is still increasing
- Not bad for an “*outdated French standard*”

Why the enormous success?

- Market Potential
 - 100 years of telephone
 - 100 000 years of speech
 - Fragmented market in Europe; EU political will
- Technology - transistor, digital, batteries...
- System standards agreed internationally
 - CEPT/GSM ->ETSI/SMG->3GPP
 - Interfaces and full system design

Mobiles: value to the poor

❑ The following quotes* from a Kenya study are revealing.

- “I am trying to look for some job. So I can get about say five shillings, so that the children can eat. It is a big tug of war whether to spend money on the phone or food for my family. But when I was not having the phone I had very hard times.”
- “Now I can call the doctor directly and explain how I feel. He can then tell me what to do. Before, I had to travel there, 250 shillings return. The doctor is not always there, so I sit there and wait while my shop is closed. A waste of time and money!”
- “My parents are always conscious of their kids, so when you call them they are very happy because they know nothing is wrong and we know home is safe. They feel they are living in the modern world.”
- “My boyfriend knows I don't have money so he Sambazas me every week (sends account top-up). When I beep my brothers know they must Sambaza me .”

* “Communication for All: Growing the mobile market in Africa” by M Bjärhov, Ericsson. GSA Forum, Jo'burg, 19 July 2006

Telephony is an essential

A possible monthly balance sheet for a poor household *

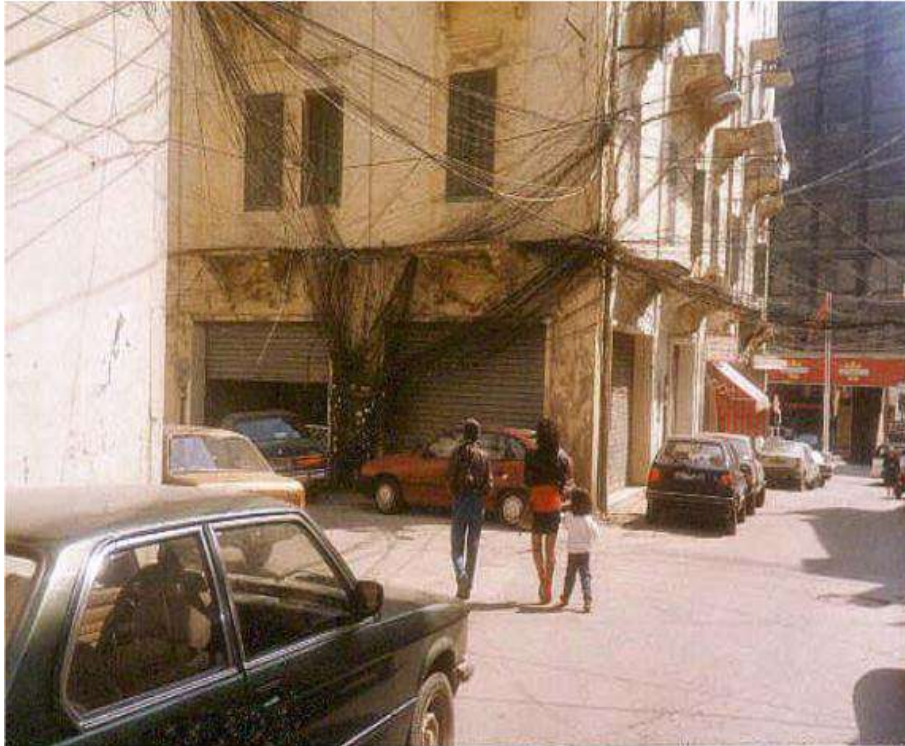
Income		\$108
Old Age Pension		\$108
Expenditure		\$108
Food		\$65
Water & electricity/paraffin (kerosene)		\$10
Funeral insurance ¹		\$9
Informal savings		\$5
Taxi trips		\$10
Sundries, clothes, lotto tickets		\$6
Phone calls ²		\$3

1. A serious allocation (AIDS pandemic)
 2. Bottom end ARPU in segmentation analysis

* "The Challenges of Rural Telecommunications Access" by A Johnson, MTN. GSA Forum, Johannesburg, 19 July 2006.
 Assume a household size of about 4-5, no informal income, only a fixed government pension. Government grants are pension (\$108) and child (\$25).

Telephone line
please...

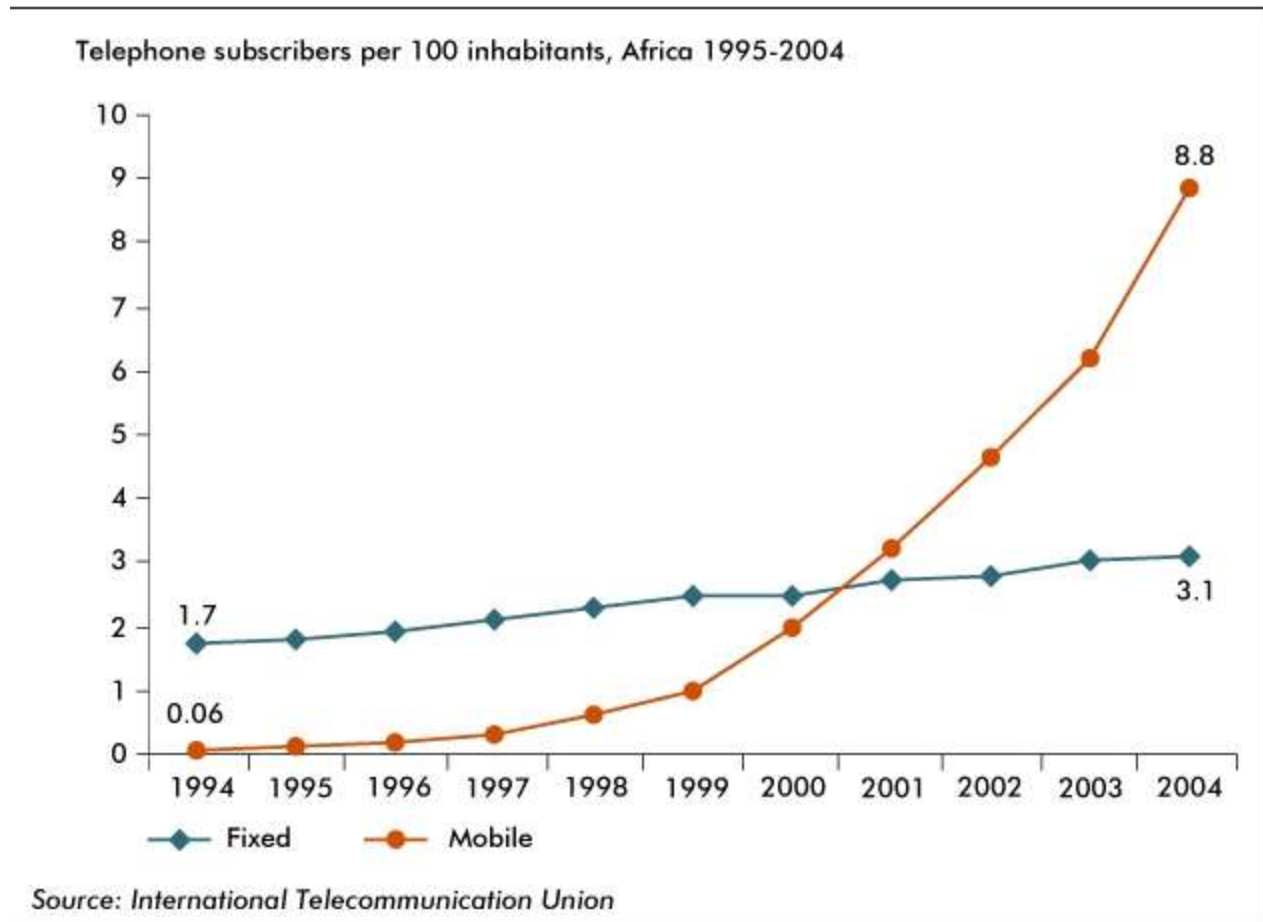
The Fixed Line Network



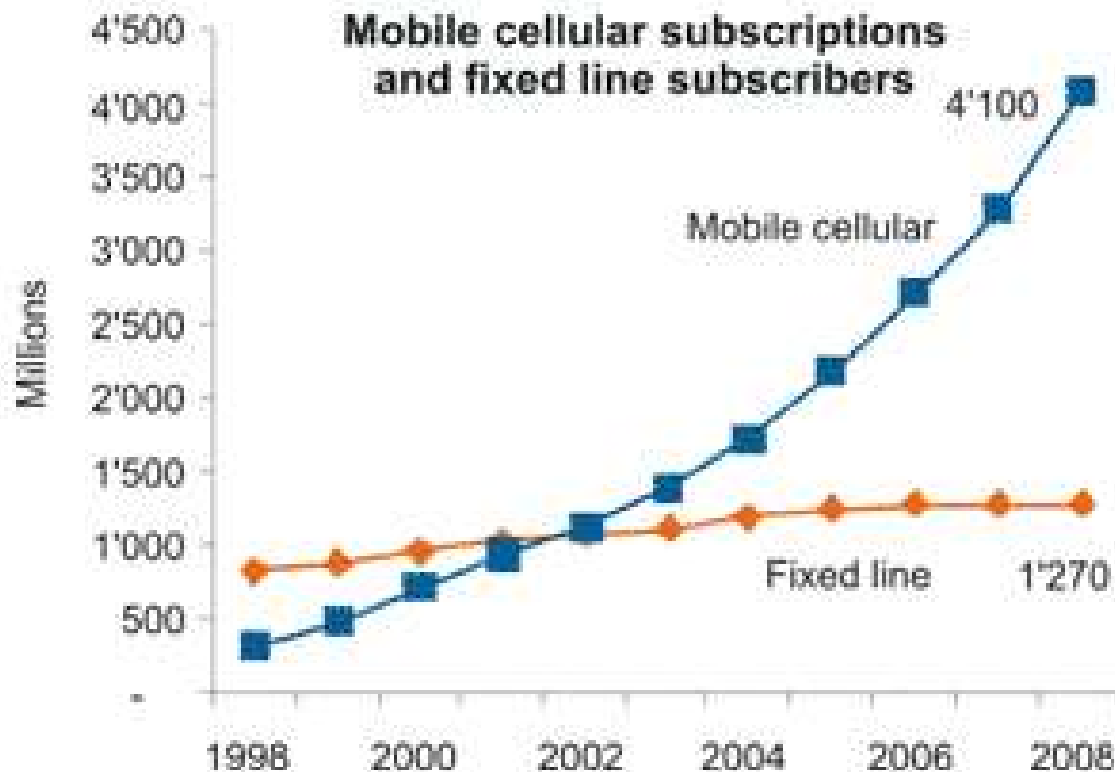
The Mobile Network's Competitor?



21st Century: The telephone goes wireless-I



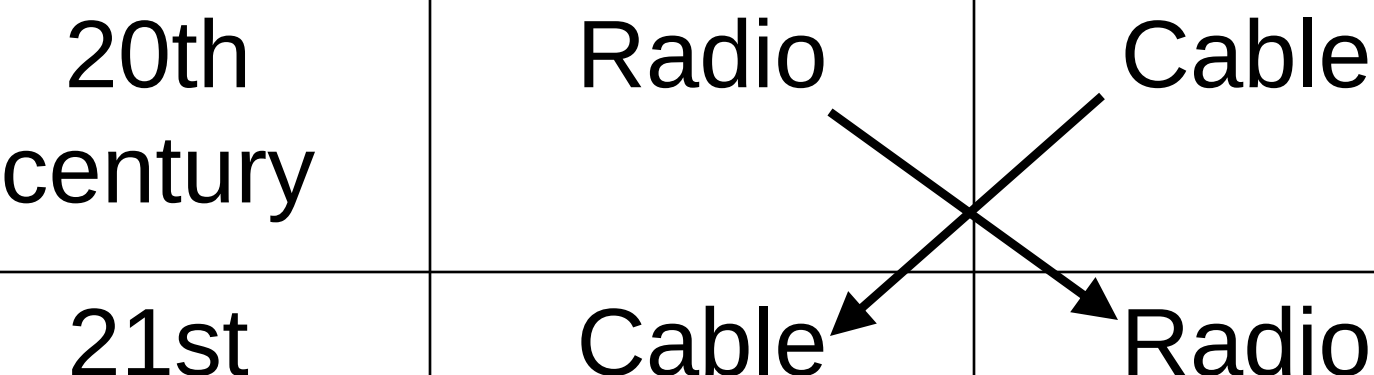
21stC: The telephone goes wireless-II



Source: ITU World Telecommunication/ICT database

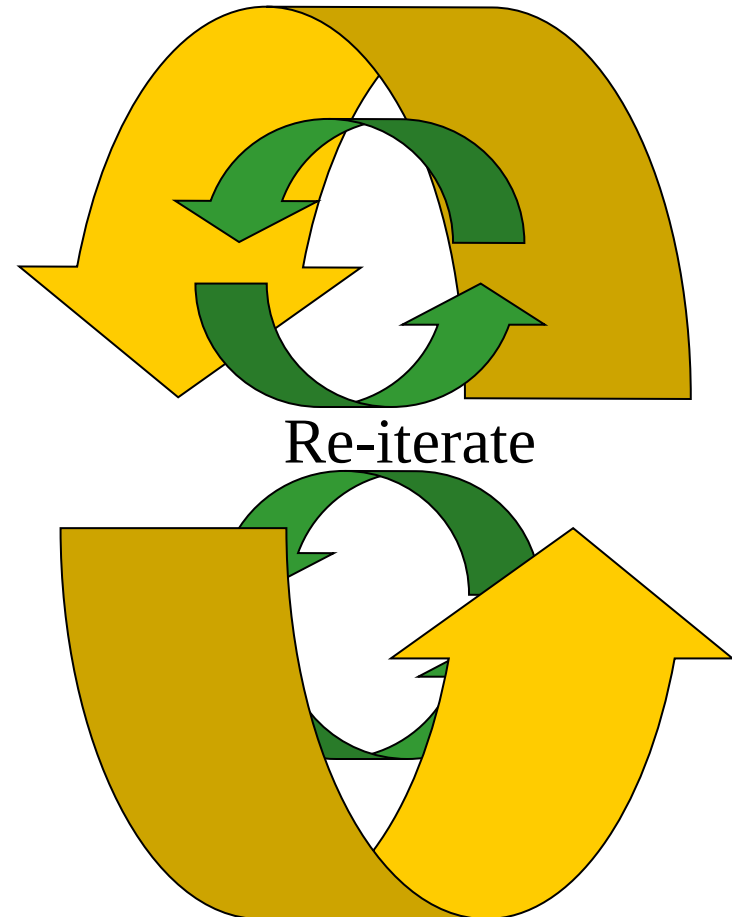
Communications Media

	Broadcast	Point-point
20th century	Radio	Cable
21st century	Cable	Radio



Engineering Problems

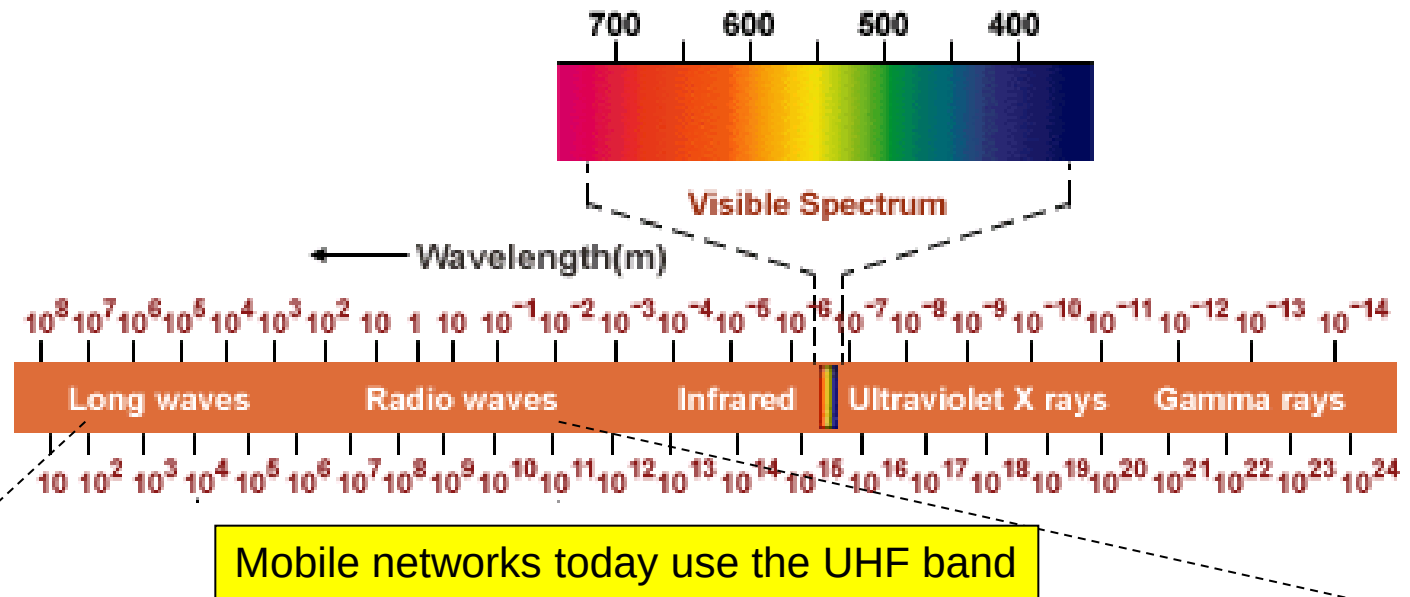
- State problem
- Analyse problem
- List possible solutions
- Compare solutions
- Develop winner(s)
- Implement
- Test
- Market



Engineering Problem No.1 (EP1): Spectrum

- Specific problem: how to enable everyone on earth to use their wireless telephones without restriction due to limited spectrum?
- General Problem: How to divide a scarce shared resource so that users optimally benefit?

Electromagnetic Spectrum



Wavelength Max (m)	10 ⁷	10 ⁶	10 ⁵	10 ⁴	10 ³	10 ²	10	1	10 ⁻¹	10 ⁻²
Wavelength Min (m)	10 ⁶	10 ⁵	10 ⁴	10 ³	10 ²	10	1	10 ⁻¹	10 ⁻²	10 ⁻³
Designation	ELF	VF	VLF	LF	MF	HF	VHF	UHF	SHF	EHF
Frequency Min	30Hz	300 Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz
Frequency Max	300Hz	3 kHz	30 kHz	300 kHz	3 MHz	30 MHz	300 MHz	3 GHz	30 GHz	300 GHz

Radio Bands

- Terminology subdivides spectrum into logarithmic bands with similar characteristics.
 - High Frequency: HF – 3MHz – 30MHz
 - Long range communications
 - Very High Frequency: VHF – 30MHz – 300MHz
 - FM Radio
 - Ultra High Frequency UHF – 300MHz – 3GHz
 - Mobile Communications, fixed links
 - Super High Frequency SHF – 3GHz – 30GHz
 - Satellite TV; Point to Point Systems (Cellular Backhaul)

Radio Spectrum Basics

- Frequency x Wavelength=Constant (c, speed of light
~ $3 \times 10^8 \text{ ms}^{-1}$)
 - $c = f\lambda$
- Power ratio $L(\text{dB}) = 10 \log_{10}(P_1/P_0)$
 - P_1, P_2 measured in Watts(W)
 - dBm: power ratio referenced to 1mW (P_0)
 - 0dBm:1mW;
 - 30dBm: 1W
- Isotropic Radiator
 - Theoretical antenna type which radiates equally well in all directions (has a gain of 0dBi by definition)

Logarithms, Bels, dB: revision

- Logarithmic representation allows:
 - smaller dynamic range of numbers
 - natural to our bodies (eyes, ears..)
 - simpler arithmetic
- $10^L = P_1/P_0$
 - $L(B) = \log_{10} (P_1/P_0)$
 - With common ratios and engineering precisions, the Bel (B) is a bit awkward
 - $1B \text{ (Bel)} = 10dB$
 - $L \text{ (dB)} = 10 \log_{10} (P_1/P_0)$

Channel Capacity

- Channel Capacity is finite and determined by the bandwidth available and the Signal to Noise Ratio.
- $C \text{ (bit/s)} \propto \text{Bandwidth } B \text{ (Hz)}$
 - Shannon-Hartley Theorem:
 - $C = B \log_2 (1 + S/N)$
 - S/N : Signal-to-noise ratio (linear)
- Hence the need for frequency reuse in multiple cells to deliver high capacity

Log base conversion

- $y = b^n$ (1)
- $\Rightarrow \log_a y = n \log_a b$... (2)
- (1) $\Rightarrow \log_b y = n$ (3)
- (2) + (3) $\Rightarrow \log_a y = \log_b y \cdot \log_a b$ (4)
- $\Rightarrow \log_b y = \log_a y / \log_a b$
- $\Rightarrow \log_2 y = \log_{10} y / \log_{10} 2$
- $\Rightarrow \log_2 y \approx \log_{10} y / 0.3$

Radio Propagation

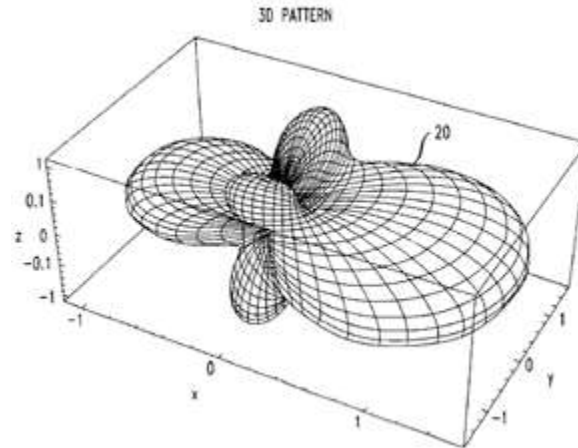
- Power flux density $s(\text{W/m}^2)$ received at a range $r(\text{m})$ from an isotropic radiator transmitting $p_T(\text{W})$ in free space:
 - $s = p_T / (4\pi r^2)$
 - $\text{Log } s = \log p_T - 2\log r - \log 4\pi$
 - $S(\text{dB}) = P_T(\text{dB}) - 20\log r - 11$
 - or if d in km ($d=r/1000$):
 - $S = P_T - 20\log d - 41$

Spectrum Basics

- Frequency x Wavelength=Constant (c, speed of light)
 - $c = f\lambda$
- Channel capacity C (bit/s) ~ Bandwidth B (Hz)
 - Shannon-Hartley Theorem:
 - $C = B \log_2 (1 + S/N)$
 - S/N: Signal-to-noise ratio
- Power ratio L(dB)= $10\log_{10}(P_1/P_0)$
 - P_1, P_2 measured in Watts(W)
 - dBm: power ratio referenced to 1mW (P_0)
 - 0dBm:1mW; 30dBm: 1W

Antenna Radiation and reception

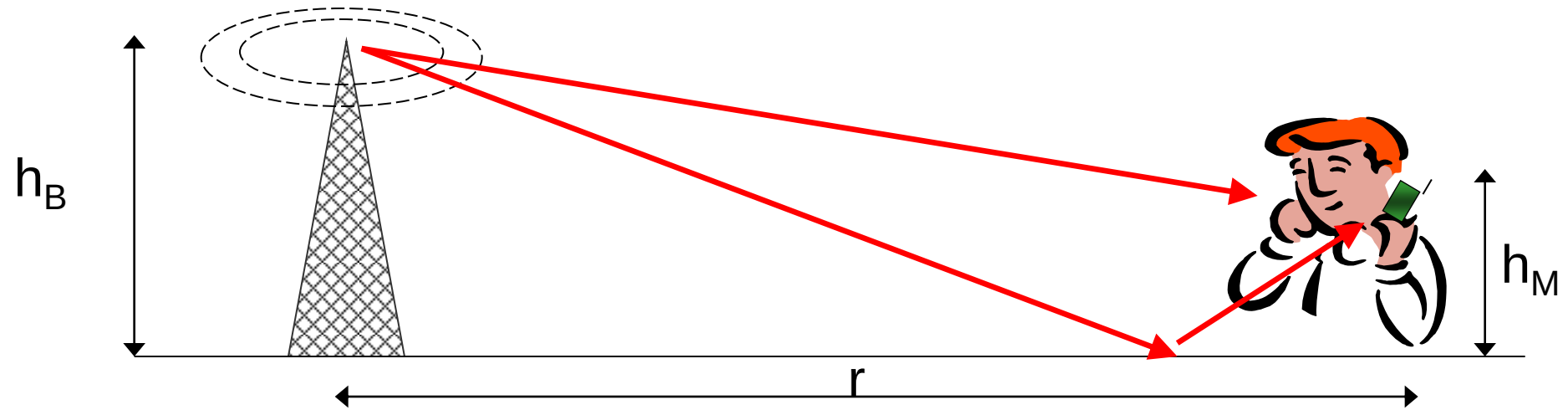
- In practice, antennas have transmit and receive directivity, and depend on wavelength



- Directivity represented for Transmit and Receive by antenna gains G_T , G_R
- Received power is, by the Friis Transmission Equation:

$$p_R = p_T G_T G_R \lambda^2 / (4 \pi r)^2$$

Plane Earth Loss

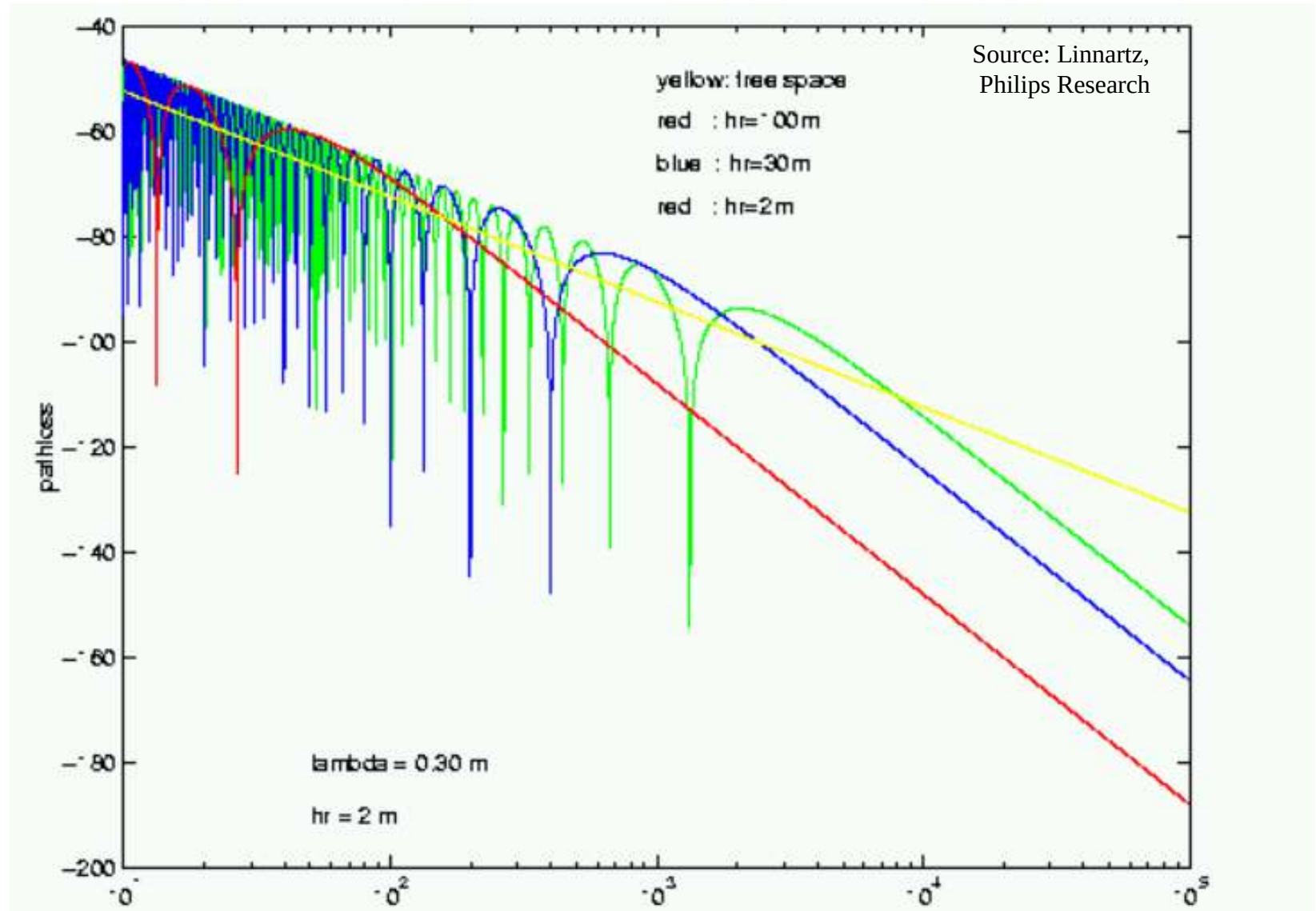


The two rays interfere with each other, due to the phase difference at a given wavelength λ

$$p_R = [2 \sin 2\pi h_B h_M / \lambda r]^2 p_T G_T G_R \lambda^2 / (4 \pi r)^2$$

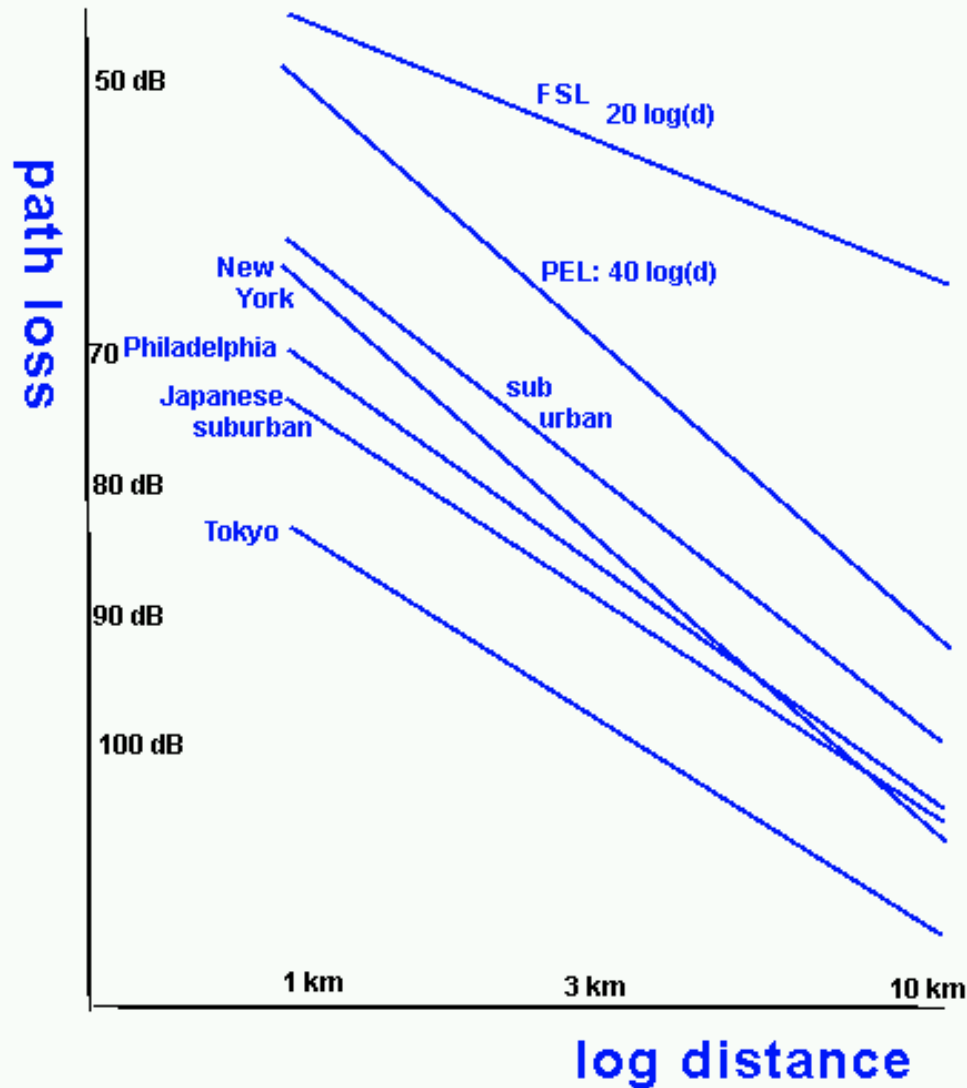
$$\text{Path Loss } L(\text{dB}) = P_T - P_R = \log (p_T / p_R)$$

Plane Earth Loss; 2-ray model

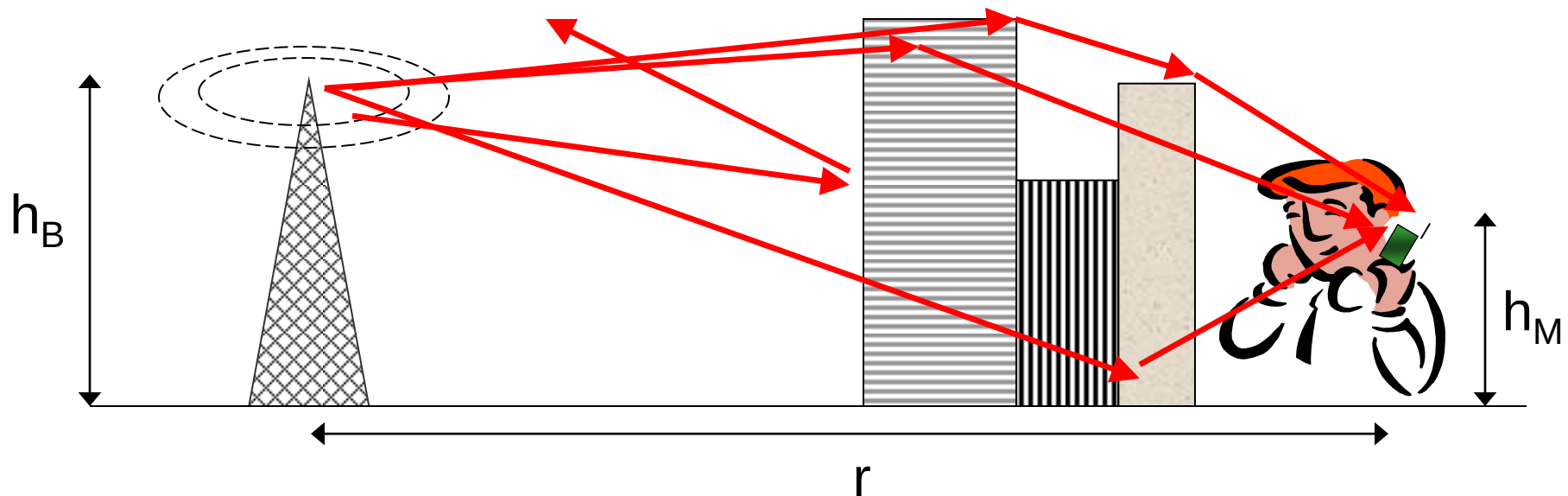


Urban Path Loss

Source: Linnartz,
Philips Research



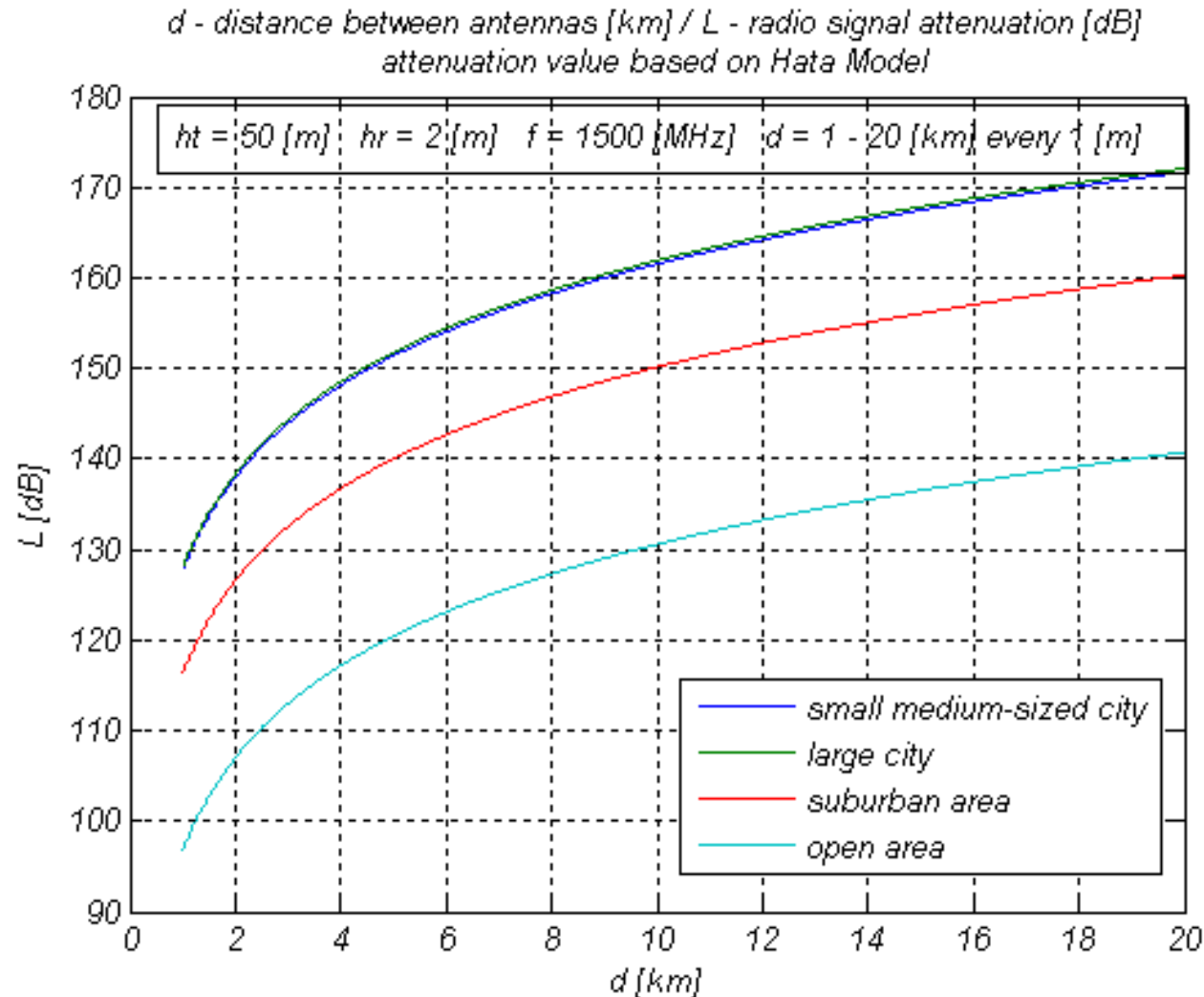
Shadowing, reflection and diffraction by obstacles



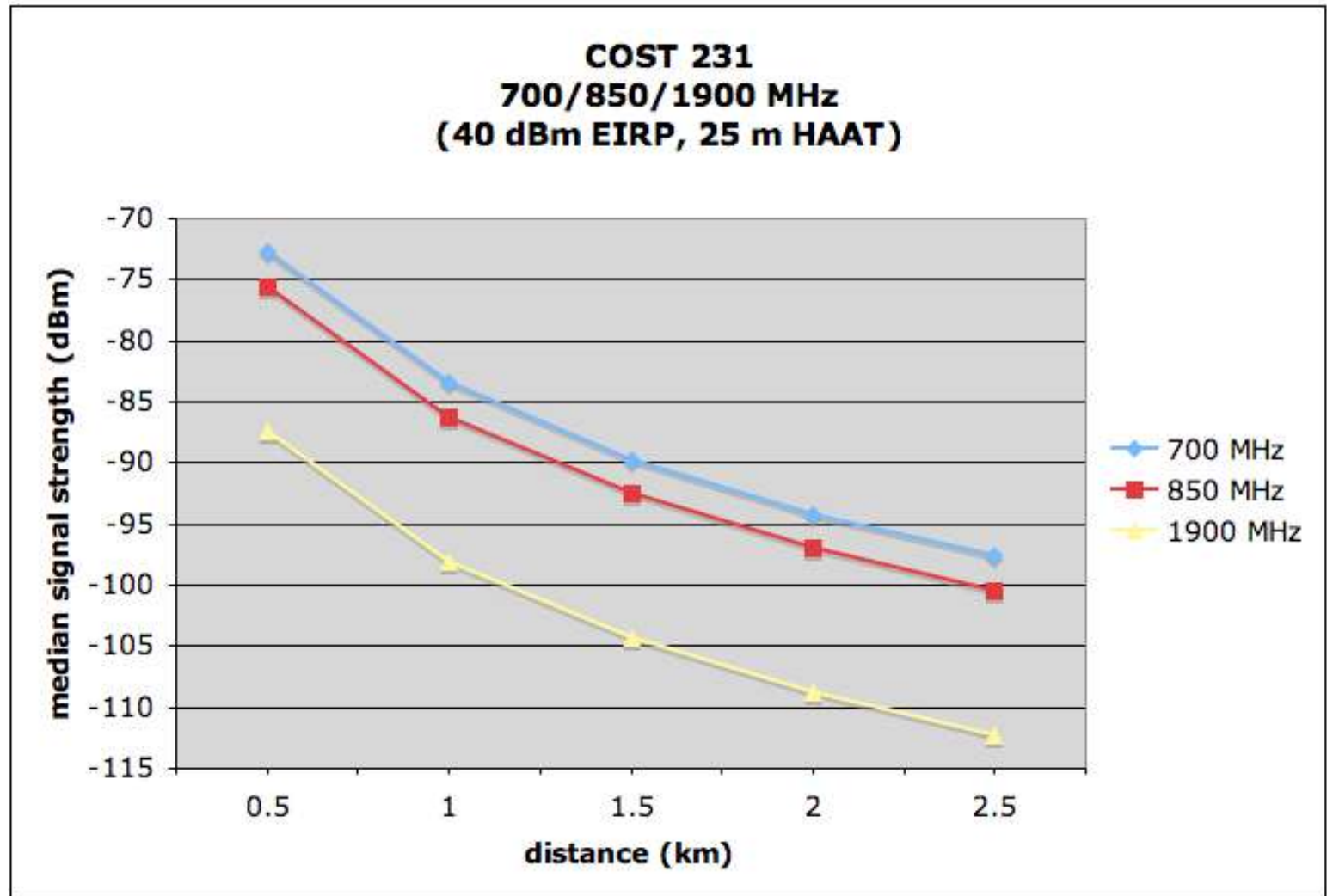
Hata Urban Model: $P_R = P_T + A \log h_B + B \log \lambda - [C - D \log h_B] \log r + E(\lambda, h_M) - F$

A, B, C, D, F are positive constants; E is a correction factor dependent on urban terrain (large urban, suburban..) as well as λ and h_M

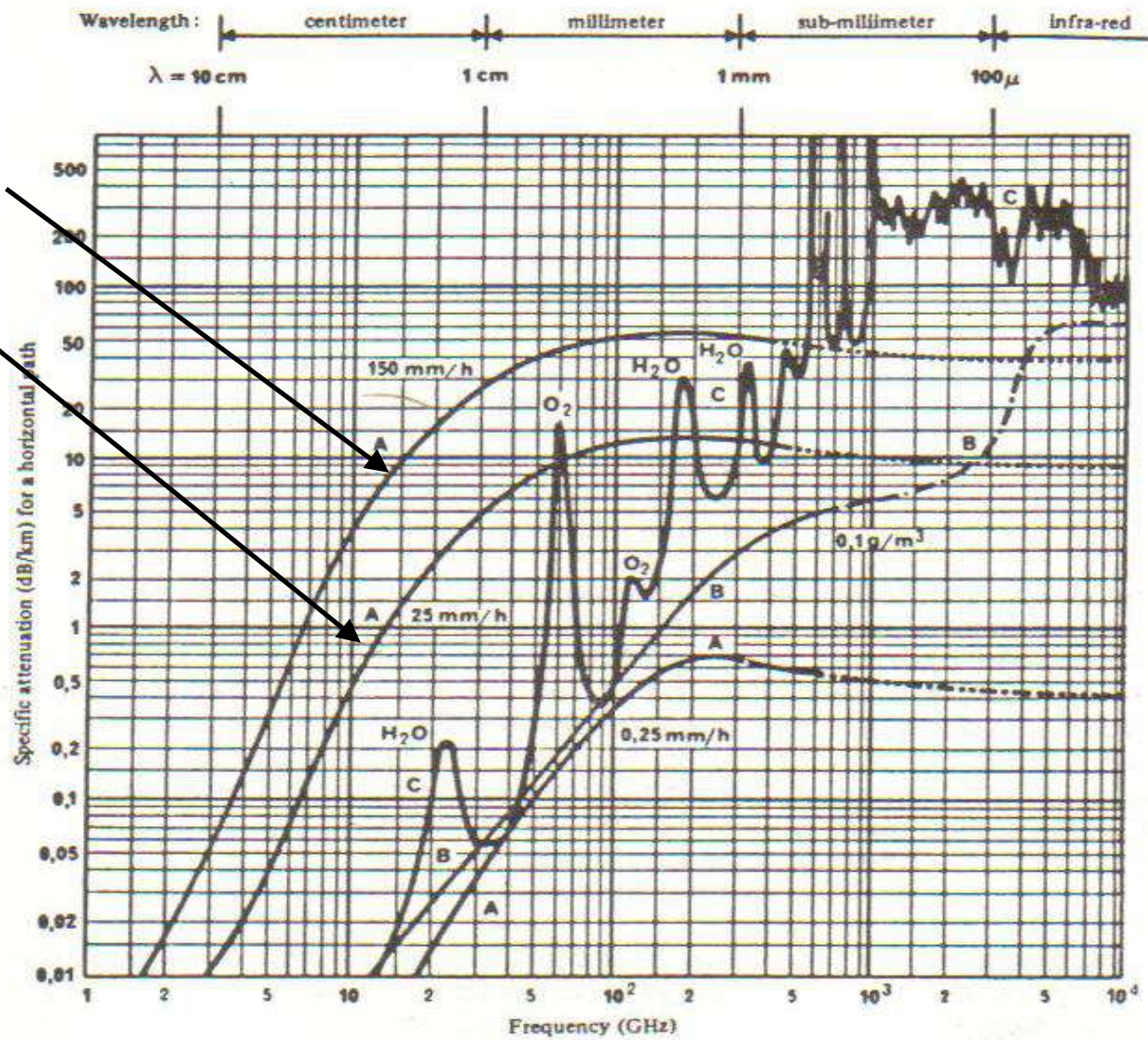
Urban correction (Hata Model)



Frequency Dependence (Hata Model)



The Rain Wall



Source: ITU

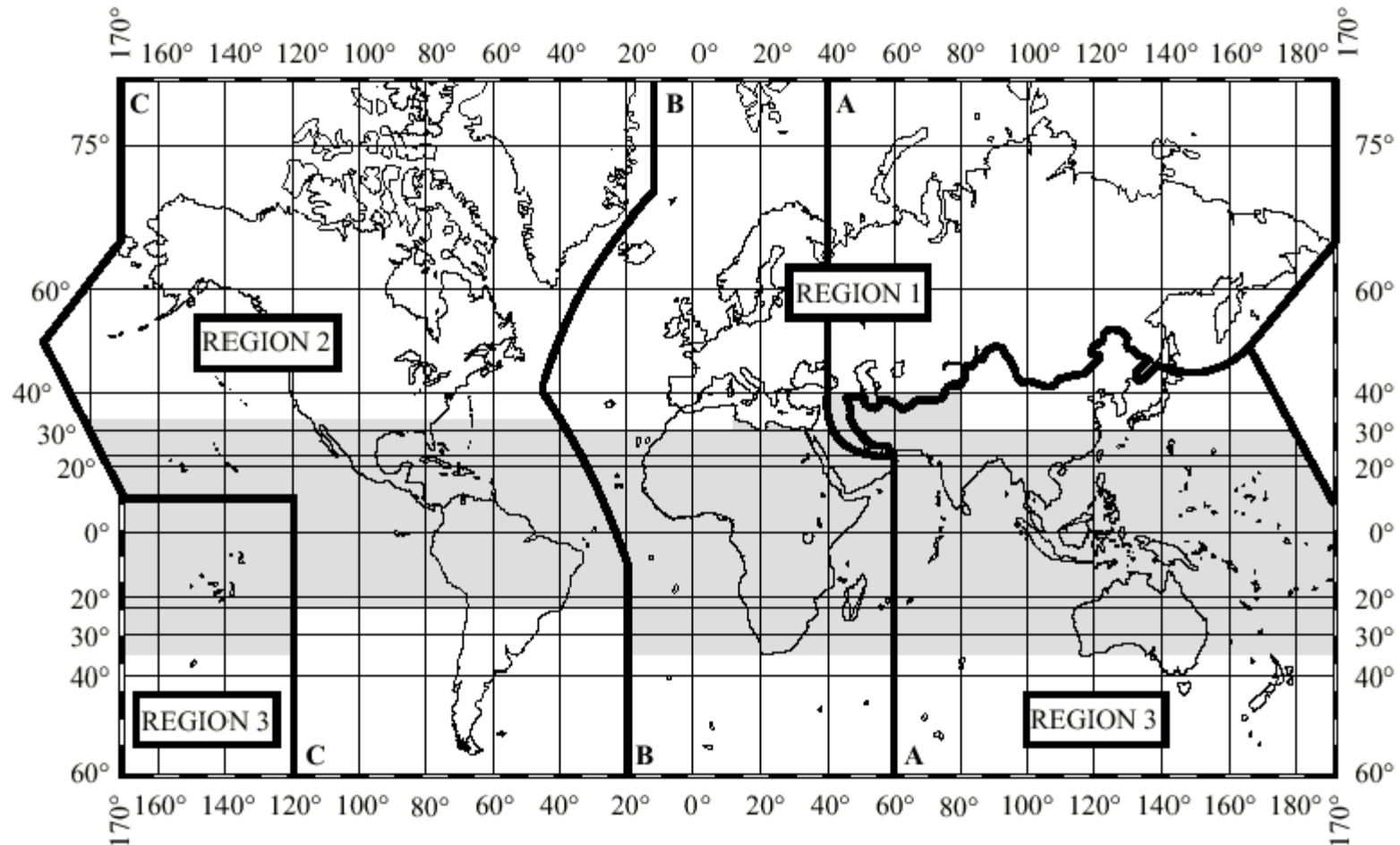
Users of UHF band

- TV
- Aircraft navigation and landing
- Radar
- Fixed network communications
- Satellite communications
- Mobile radio

Mobile spectrum: invisible gold

- 20th century : broadcast on radio; telephone on wires
- Since 1980s Migration of telephone onto radio, broadcast onto fixed
- Radio uses a common resource: co-ordination among users
- Globally co-ordinated by World Radio Conference

WRC/ITU-R regions

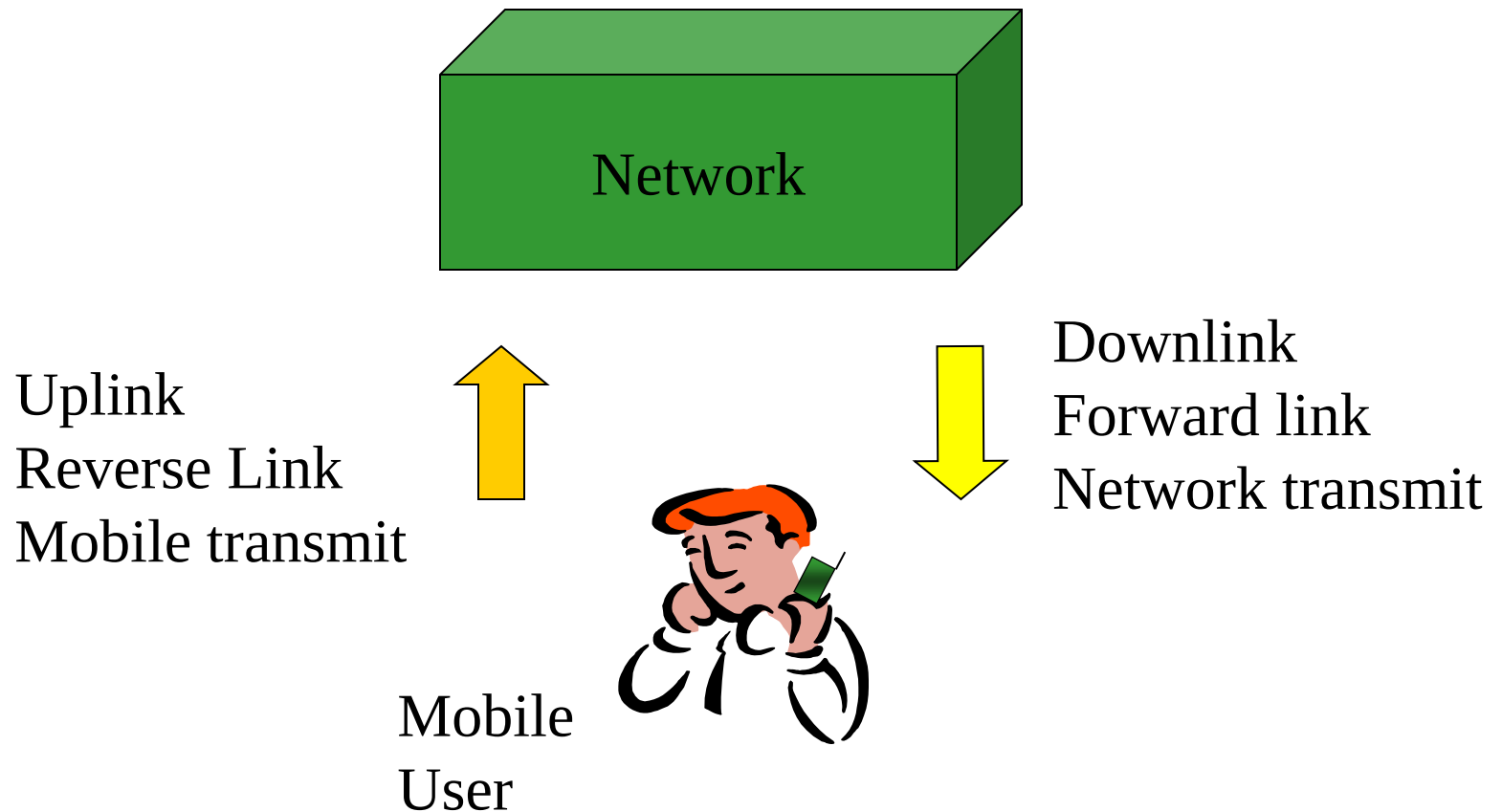


The shaded part represents the Tropical Zones as defined in Nos. S5.16 to S5.20 and S5.21.

Radio Spectrum Regulatory Bodies

- International:
 - ITU (part of United Nations)
 - follows WRC
 - From 2000 uses “IMT/IMT-2000” for “3G” mobile spectrum
- Regional:
 - CEPT (Conférence européenne des administrations des postes et télécommunications)
 - ECC Electronic Communications Committee (formerly ERC *European Radiocommunications Committee*)
- National:
 - France: ARCEP (Autorité de régulation des communications électroniques et des postes) formerly ART (Autorité de régulation des télécommunications)
 - USA: FCC (Federal Communications Commission)

Direction of Communication

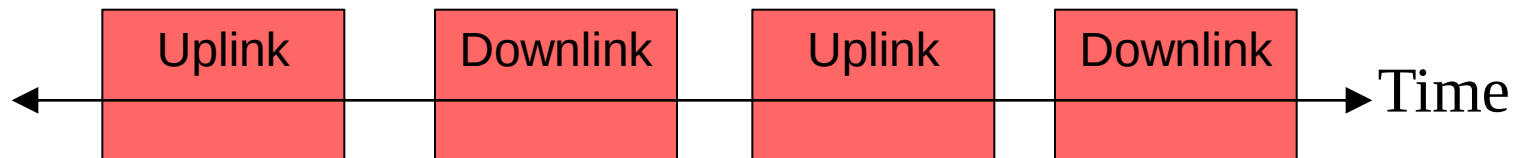


Frequency Division Duplex (FDD) and Time Division Duplex (TDD)

FDD



TDD



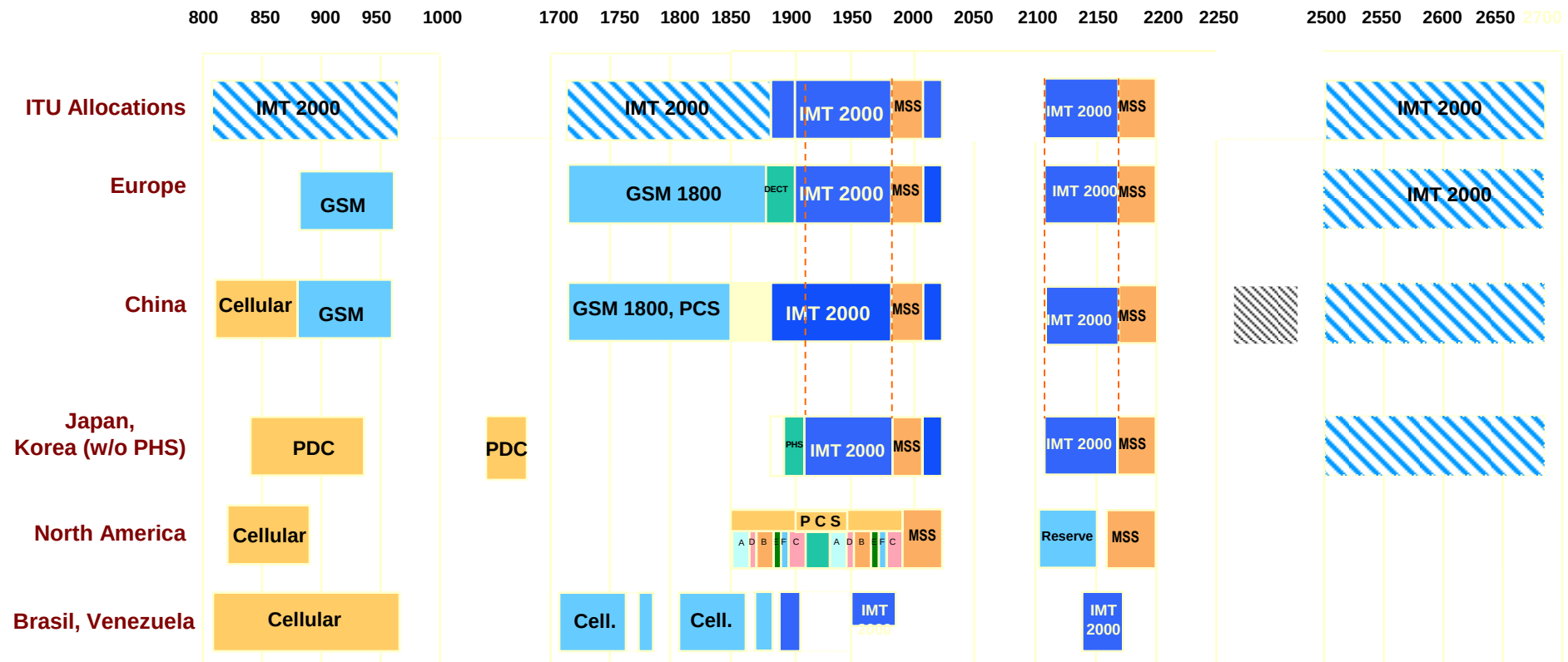
FDD and Paired Spectrum

- Frequency Division Duplex (FDD)
 - requires separate frequency channels in uplink and downlink
 - filtering requirements are stronger between duplex channels than adjacent channels
 - Thus uplink channels and downlink channels are grouped in separate band allocations as paired spectrum with a frequency offset
 - Requires fixed up/downlink bandwidth allocations
 - Generally, but not necessarily, equal bandwidth
 - Up and downlink propagation may differ
 - Generally for mobile networks, lower frequency is mobile transmit (better propagation); some exceptions
 - Full duplex requires a duplexer: half-duplex FDD (as in normal GSM mobiles) does not

TDD and Unpaired Spectrum

- Time Division Duplex (TDD):
 - can operate in a single frequency channel
 - Requires time synchronization with neighbouring cells: generally harder than frequency synchronization
 - Requires time synchronisation within cell
 - loss of channel capacity to system time delays
 - TDD channels can be assigned to unpaired spectrum
 - Flexible up/downlink bandwidth allocation
 - Uplink and downlink path propagation similar
 - Traditionally used for small-scale systems, The current WiMax standard is TDD, and some countries (e.g. China) and companies have been driving it within UMTS and LTE.

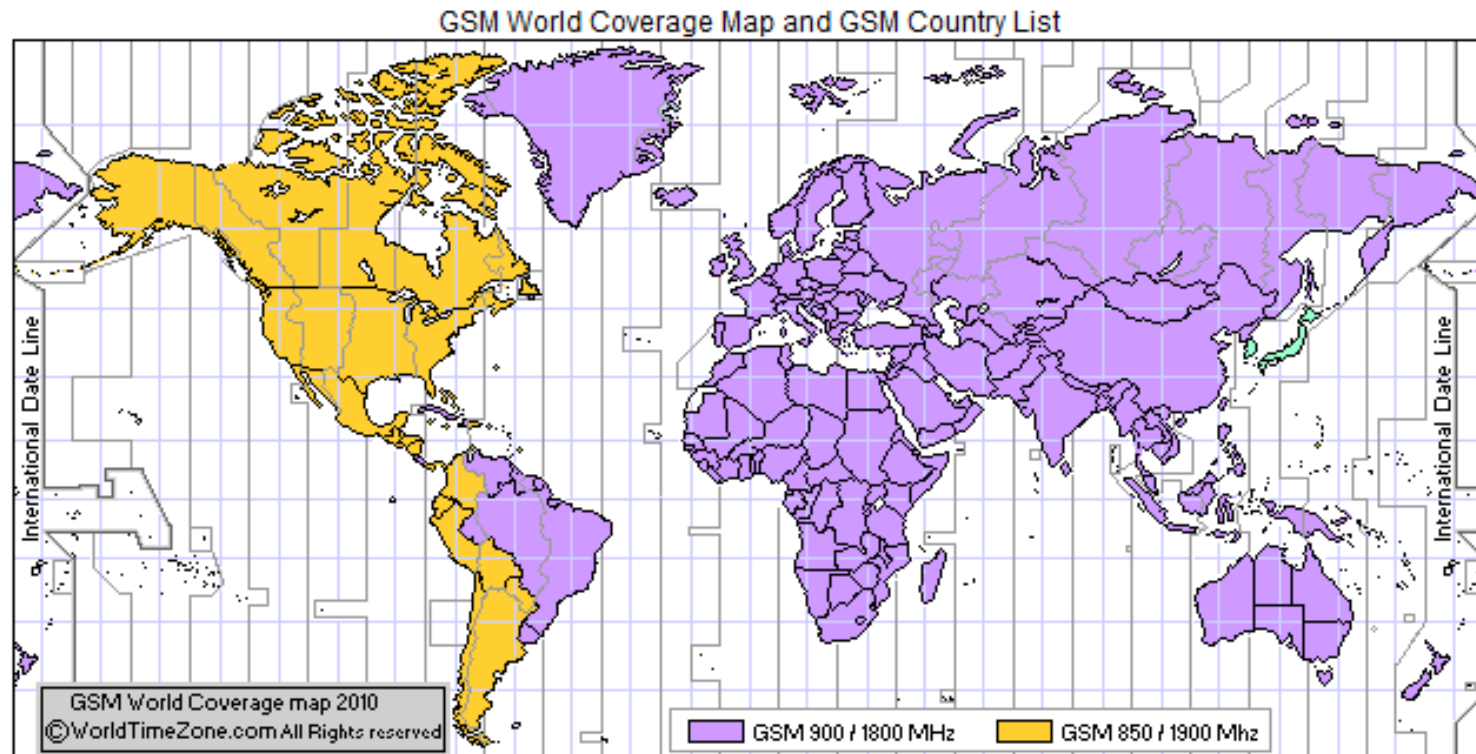
Mobile Spectrum After WRC 2000



IMT-2000 Spectrum for “3rd generation” systems
 PCS: Personal Communication System

MSS: Mobile Satellite System
 PDC: Personal Digital Cellular

Main GSM frequency zones

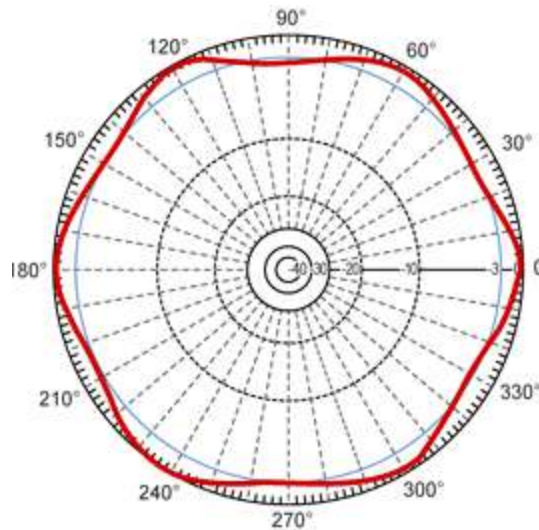


GSM 900 / GSM 1800 MHz are used in most parts of the world: Europe, Asia, Australia, Middle East, Africa.

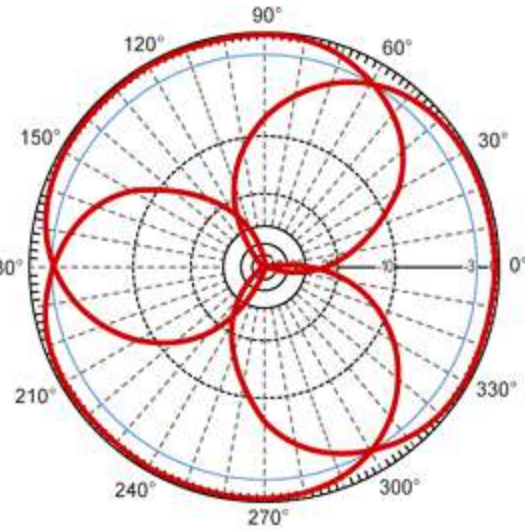
GSM 850 / GSM 1900 MHz are used in the United States, Canada, Mexico and most countries of S. America.

Near Universal Global Coverage (except Japan and Korea)
leads to Economies of Scale / Global Roaming

Antennas, cells and base sites

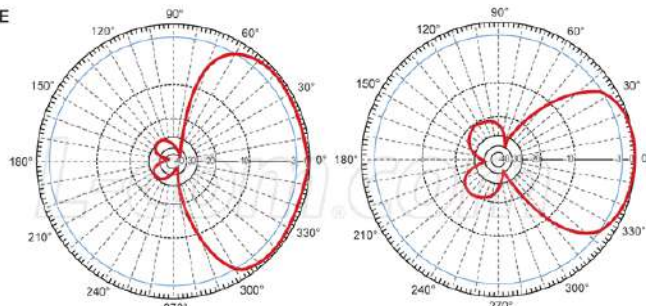


Omnidirectional



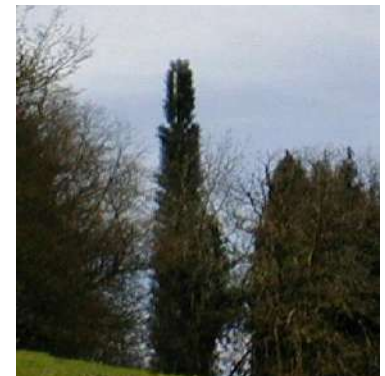
Tri-sectorial

HG903YE

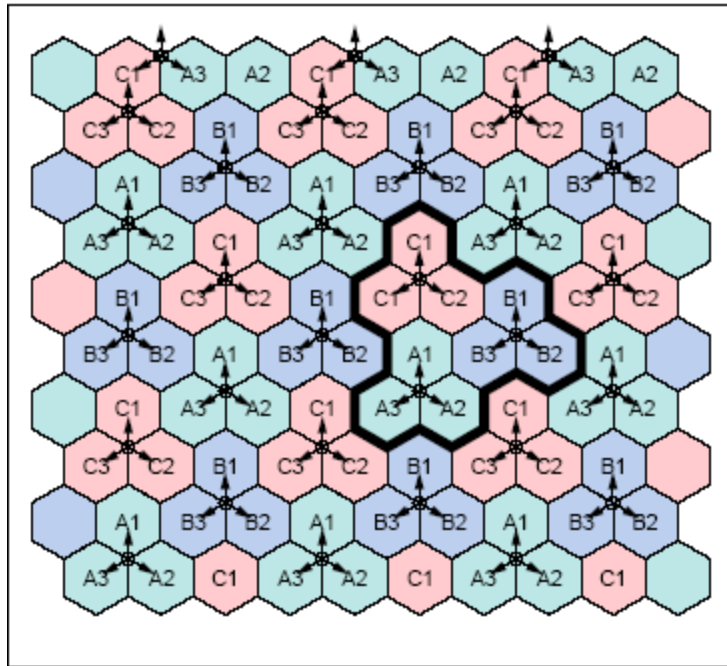


Vertical

Horizontal

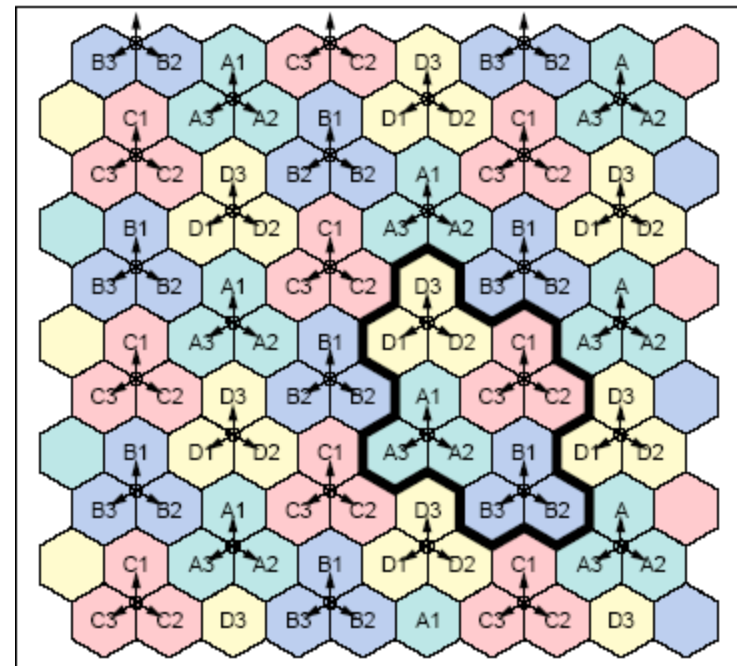


Frequency Planning-2



3/9 Cell Pattern

Freq. groups	A1	B1	C1	A2	B2	C2	A3	B3	C3
Channels	1	2	3	4	5	6	7	8	9
	10	11	12	13	14	15	16	17	18
	19	20	21	22	23	24			



4/12 Cell Pattern

Frequency grouping in 4/12 pattern											
A1	B1	C1	D1	A2	B2	C2	D2	A3	B3	C3	D3
1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	...								

Terrain effects on cells

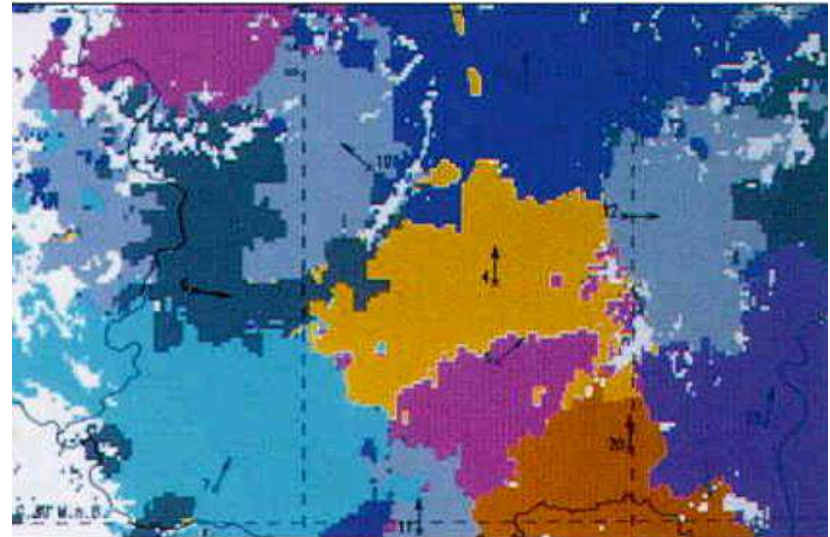
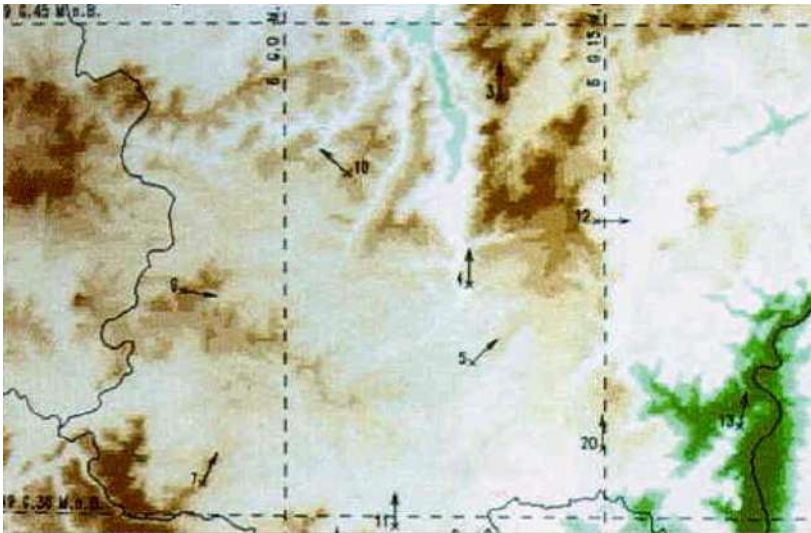
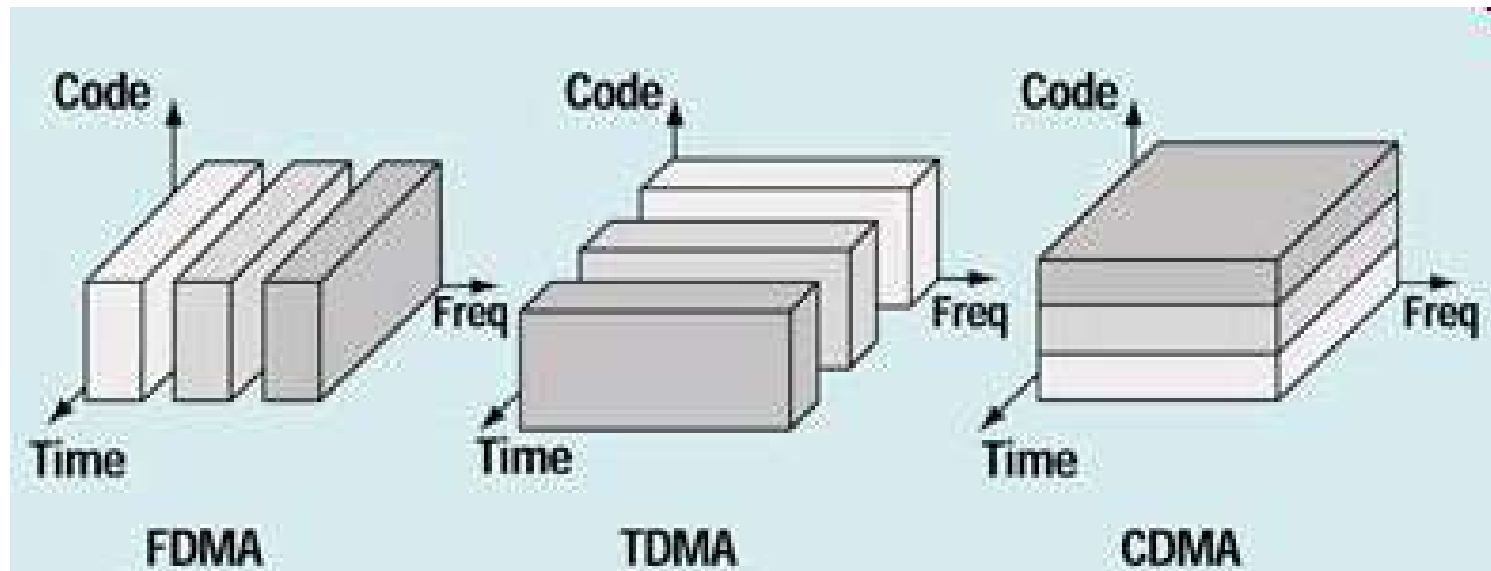


Image Source: Siemens

Terrain will impact the exact shape of cells

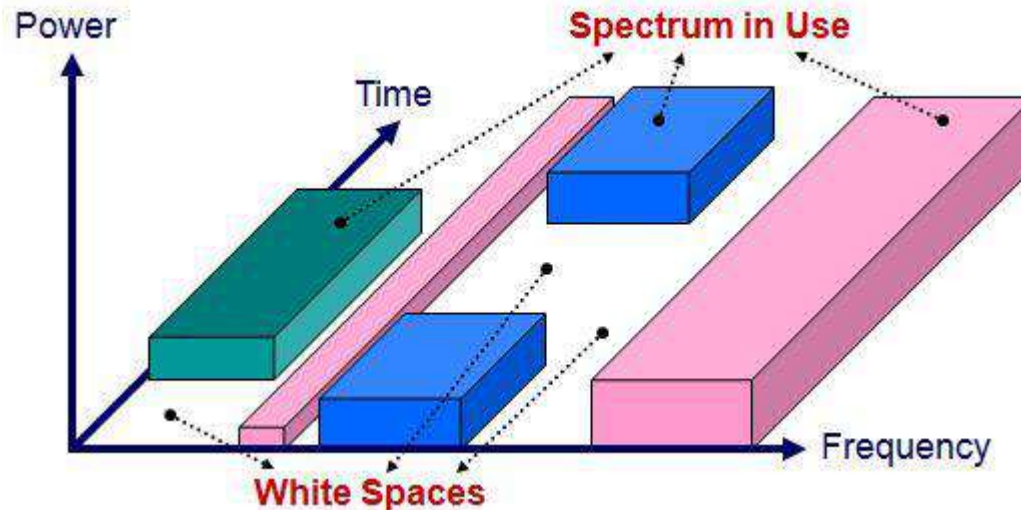
Multiple Access Schemes



3 users multiplexed in each scheme

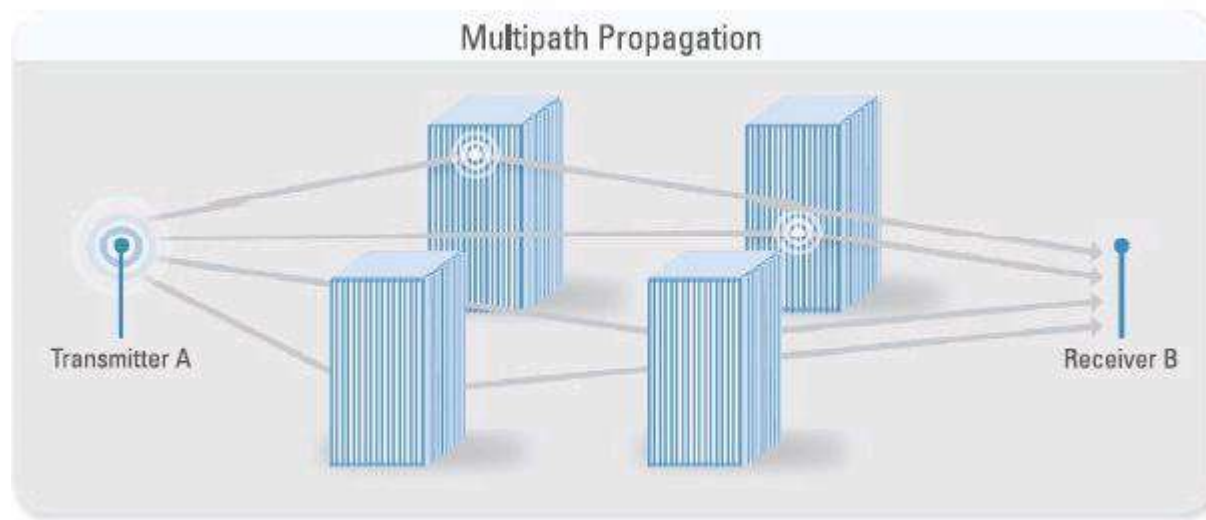
GSM uses all three schemes, but is principally classed TDMA

“White Spaces”



With classic frequency planning, there may be possibilities to use the “white spaces” between users of spectrum. Examples are various UHF “TV White Space” projects.

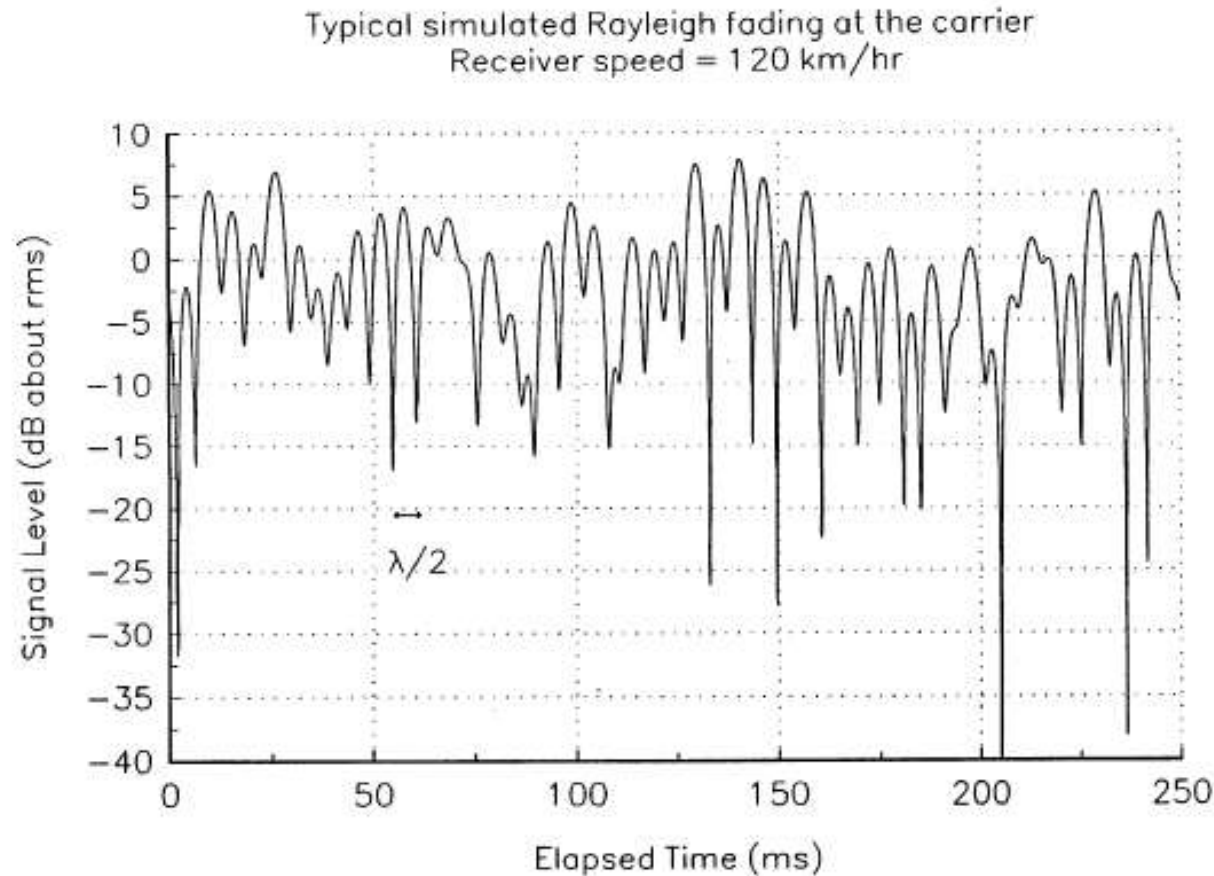
Multipath Effects



Multipath causes:

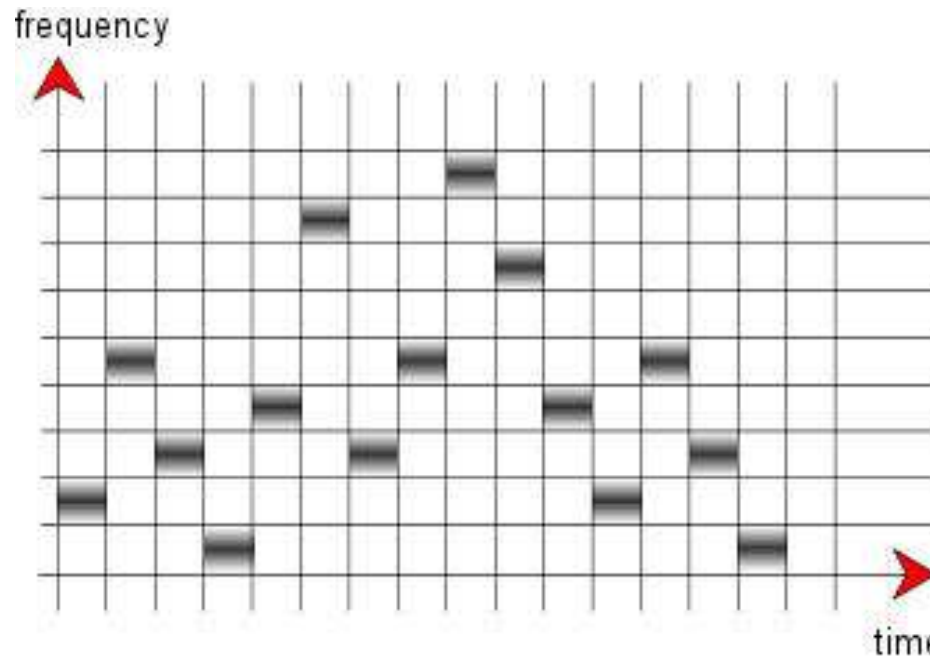
- a) Time dispersion of signal
- b) Interference between radio waves (multipath interference)

Rayleigh fading



Frequency hopping protects slow mobiles from Rayleigh fading

Frequency Hopping



Frequency hopping provides:

Source: Mouly & Pautet

1. **Frequency diversity:** notably protects against Rayleigh fading
2. **Interferer diversity** (cf CDMA). Hopping sequences can be designed on a cell re-use pattern basis to reduce interference/cluster size

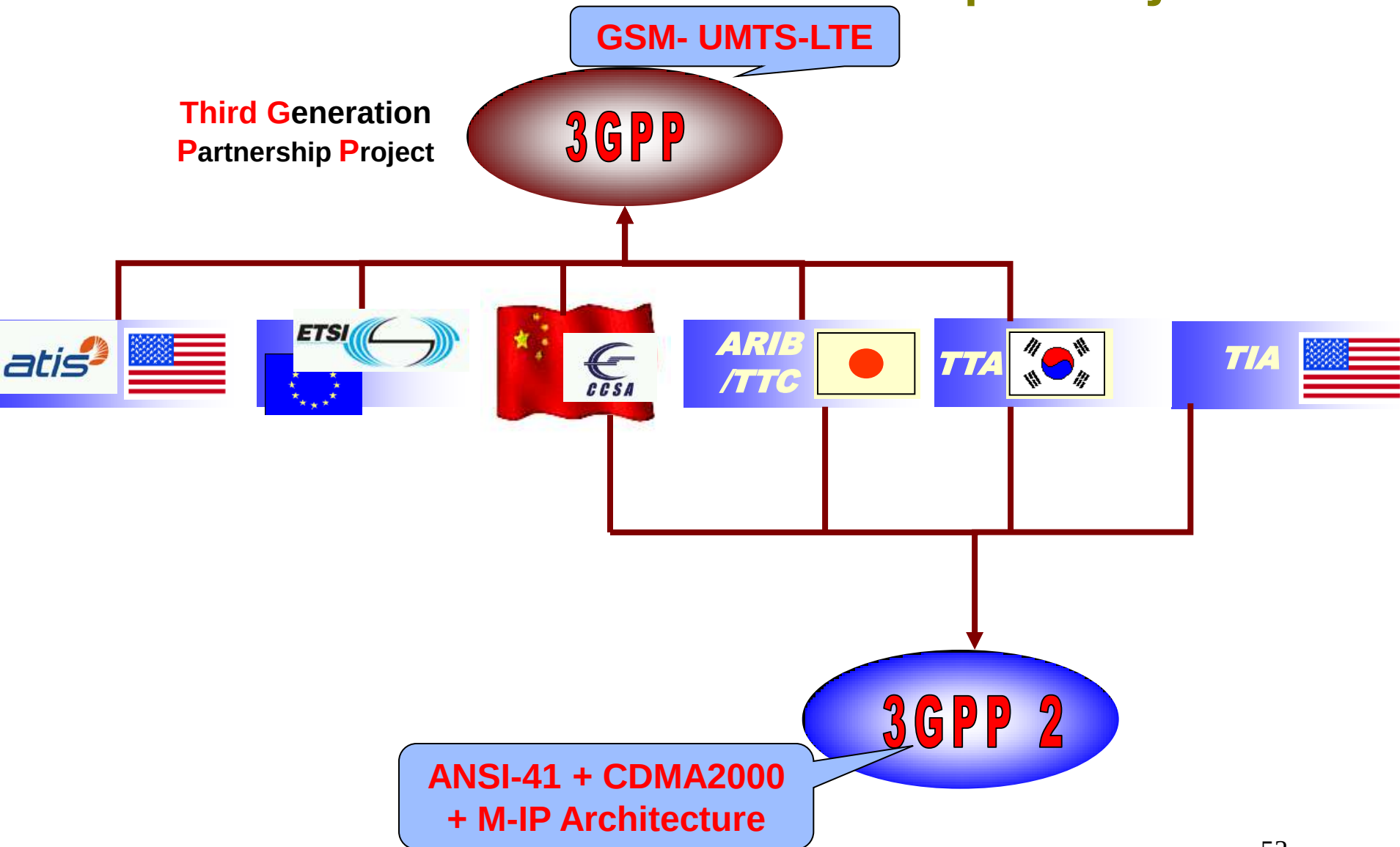
Spectrum: EP1 Solution

- Specific problem:
 - how to enable everyone on earth to use their wireless telephones without restriction due to limited spectrum?
- Solution:
 - International agreements on spectrum bands
 - Frequency re-use on a cell pattern
 - Efficient modulation of data
 - Multiplexing of users by time/frequency/code
 - All taking into account radio characteristics and geographical distribution of users

Engineering Problem 2: Mobile Network Standards

- Problem: How to create a market where equipment from competing suppliers can successfully inter-operate?
- Method:
 - Get all potential suppliers and operators to agree on standard interfaces
 - Test for compliance
 - Operators only purchase equipment meeting standards

3G Standards Partnership Projects

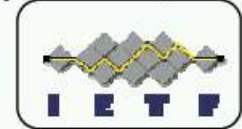


Standardisation Organisations

Communicating with 3GPP



Developing internet protocol specs



Developing Mobile application specs



MRP



Referring to specs

Cross reference of specs

Requirements

Terminal certification based on 3GPP specs

Terminal Certification



Cross reference of specs

Partners of 3GPP
Referring to 3GPP specs for the local specs

Developing Wireless LAN/MAN specs



Developing Recommendations



Input specs

Referring to 3GPP specs
(contributed by individual members)

Organisational Partners

EU



Japan



Korea



China



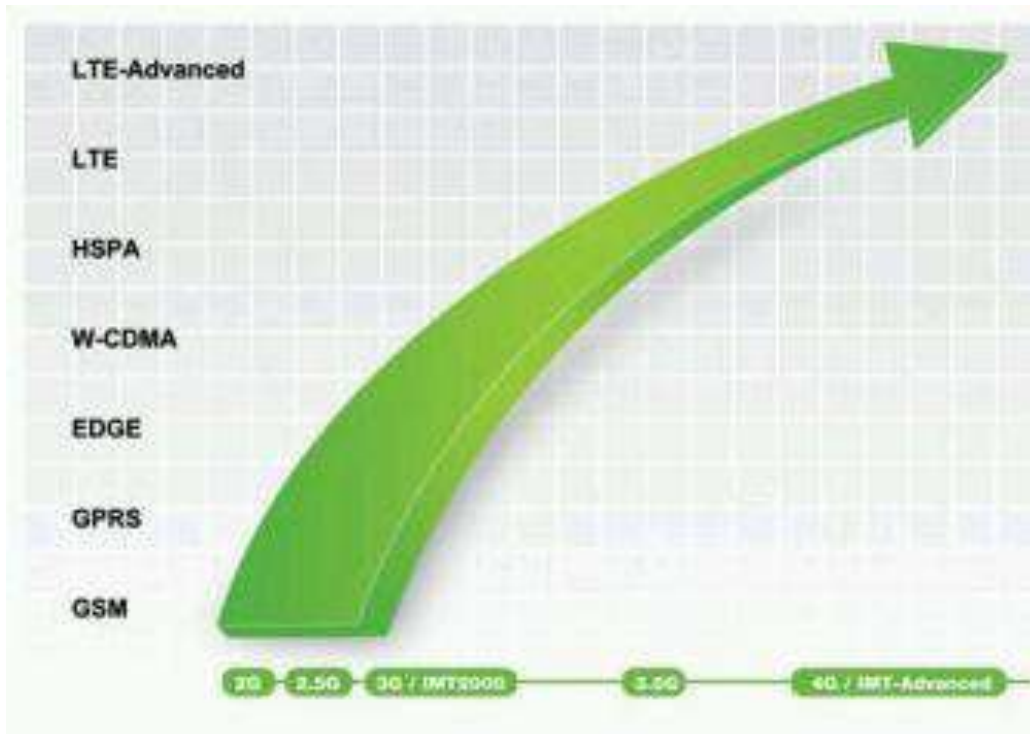
North America



Main Standards Bodies affecting GSM/UMTS/LTE Mobile networks

- 3GPP (formerly GSM, SMG): Main standardisation group
- GCF (Global Certification Forum): *Influence on terminal availability, roll-out*
- NVIOT: Network Vendors Interoperability Testing *Terminal and network compatibility, roll-out*
- OMA: Open Mobile Alliance: *Application Interfaces, market roll-out*
- CEPT (ECC/PT1): *Regulatory, spectrum*
- DIGITALEUROPE (formerly EICTA): *regulatory from vendor side*
- ETSI subgroups (TFES, MSG) *Europe-specific adaptation*
- GSMA (GSM association): *Operator co-ordination*
- UMTS forum: *Mainly UMTS*
- IETF: *IP standards development*
- ITU: *International (UN) framework*

3GPP Scope



Source: 3GPP

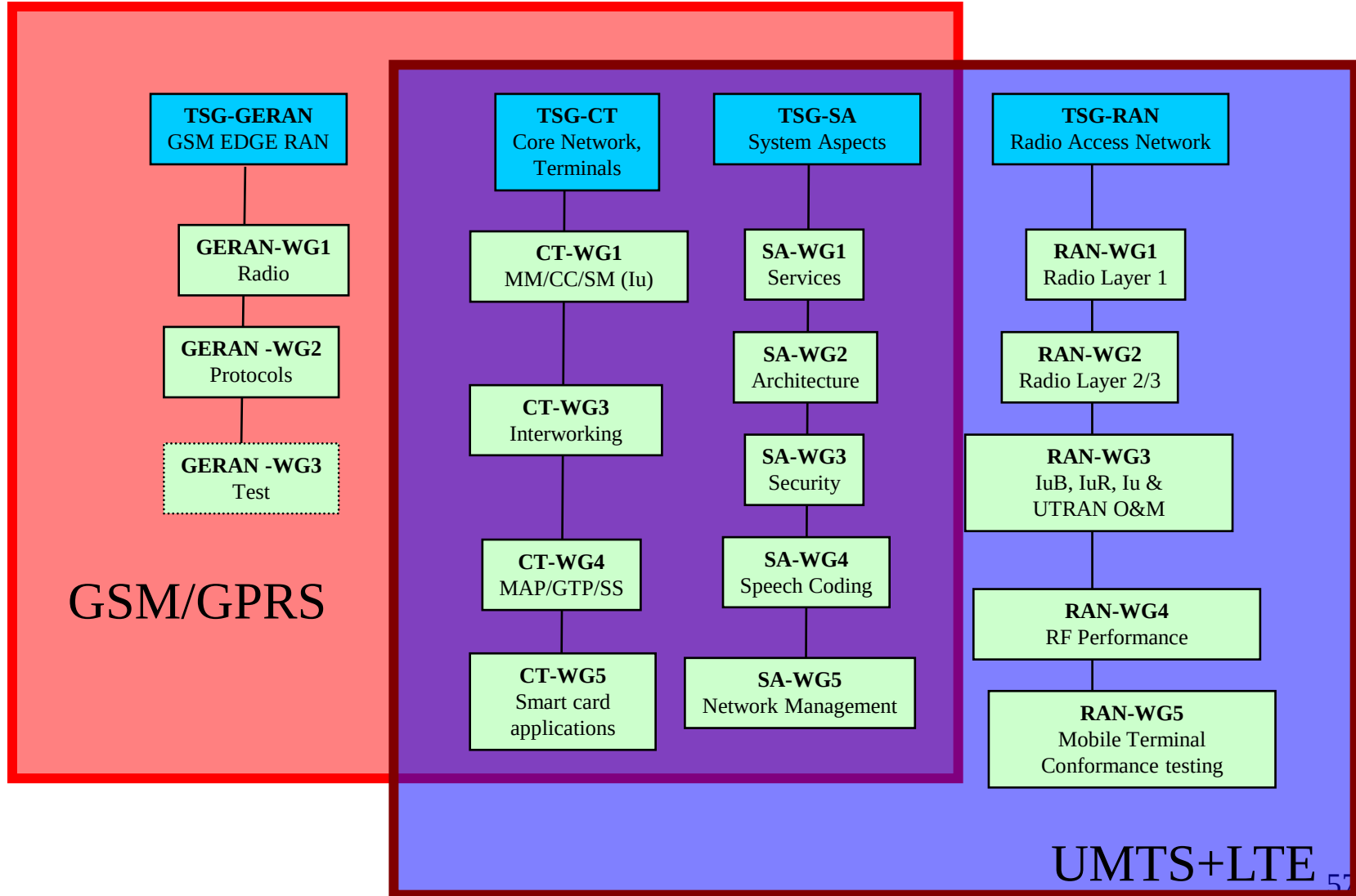


A set of mobile radio
and network standards.

CM, MM, MAP,
GTP, CAMEL,
GUP, IMS...

Structure & Domains of 3GPP

(2010)



Technical Specifications, Standards, Releases, and change control

- 3GPP Technical Specifications (TS) in “Releases”
- Releases:
 - are self consistent sets of TS describing operational network features
 - provide developers with a stable platform for implementation
 - are produced roughly on a 15-month cycle
- Correction and completion of TS by change requests (CRs) approved by 3GPP
- Regional/national bodies approve TS -> Standards

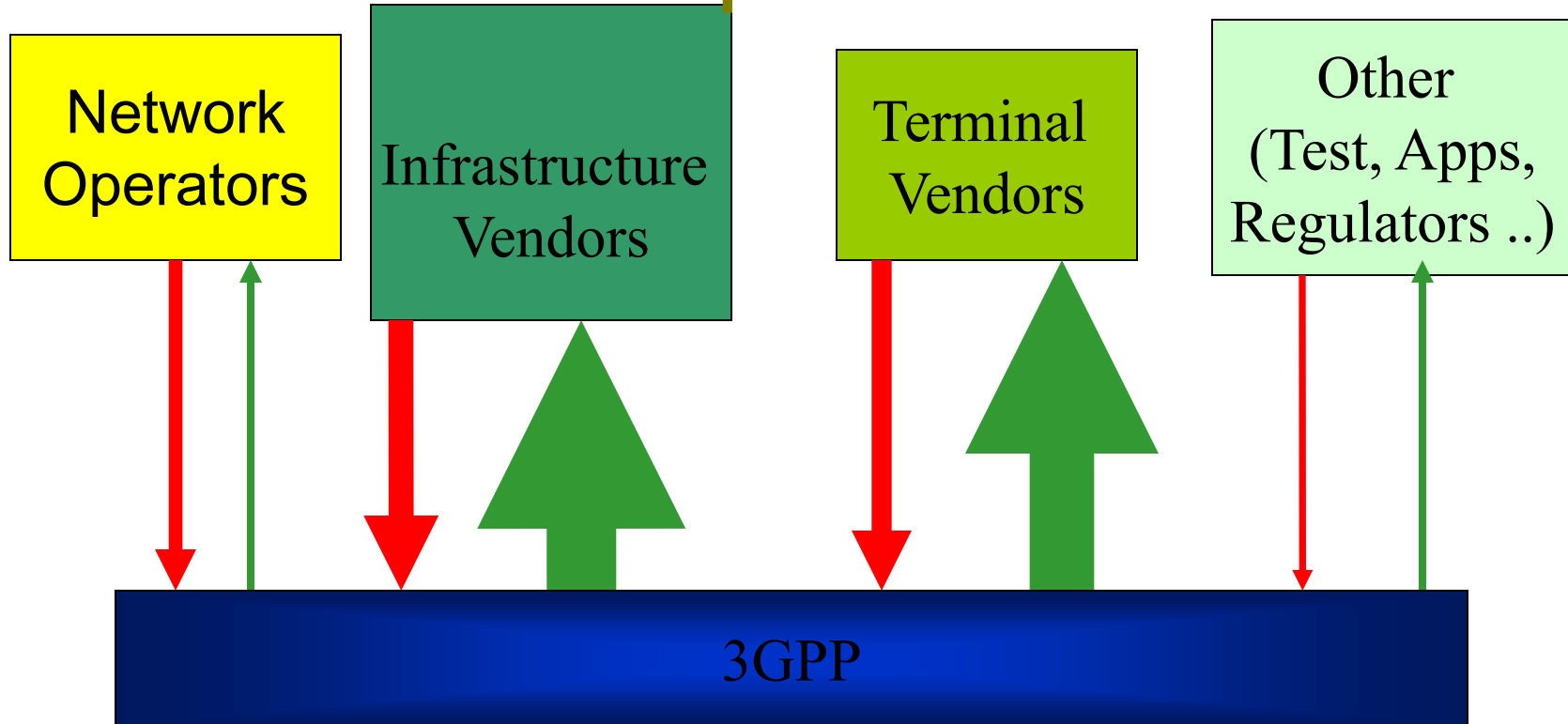
Specification Releases 2011

RELEASE	NUMBER OF SPECS *
GSM Phase 1 #	123
GSM Phase 2 #	184
GSM Phase 2+ Release 96 #	201
GSM Phase 2+ Release 97	220
GSM Phase 2+ Release 98	282
GERAN / UTRAN Release 99	447 [447]
GERAN / UTRAN Release 4	517 [517]
GERAN / UTRAN Release 5	582 [582]
GERAN / UTRAN Release 6	761 [761]
GERAN / UTRAN Release 7	873 [873]
GERAN / (E-)UTRAN Release 8	1052 [1052]
GERAN / (E-)UTRAN Release 9	1095 [1095]
GERAN / (E-)UTRAN Release 10	1061 [391]
GERAN / (E-)UTRAN Release 11	64 [40]
TOTAL	7462 [6770]

Greyed Releases are closed.. * Figures in brackets are values reported last quarter.

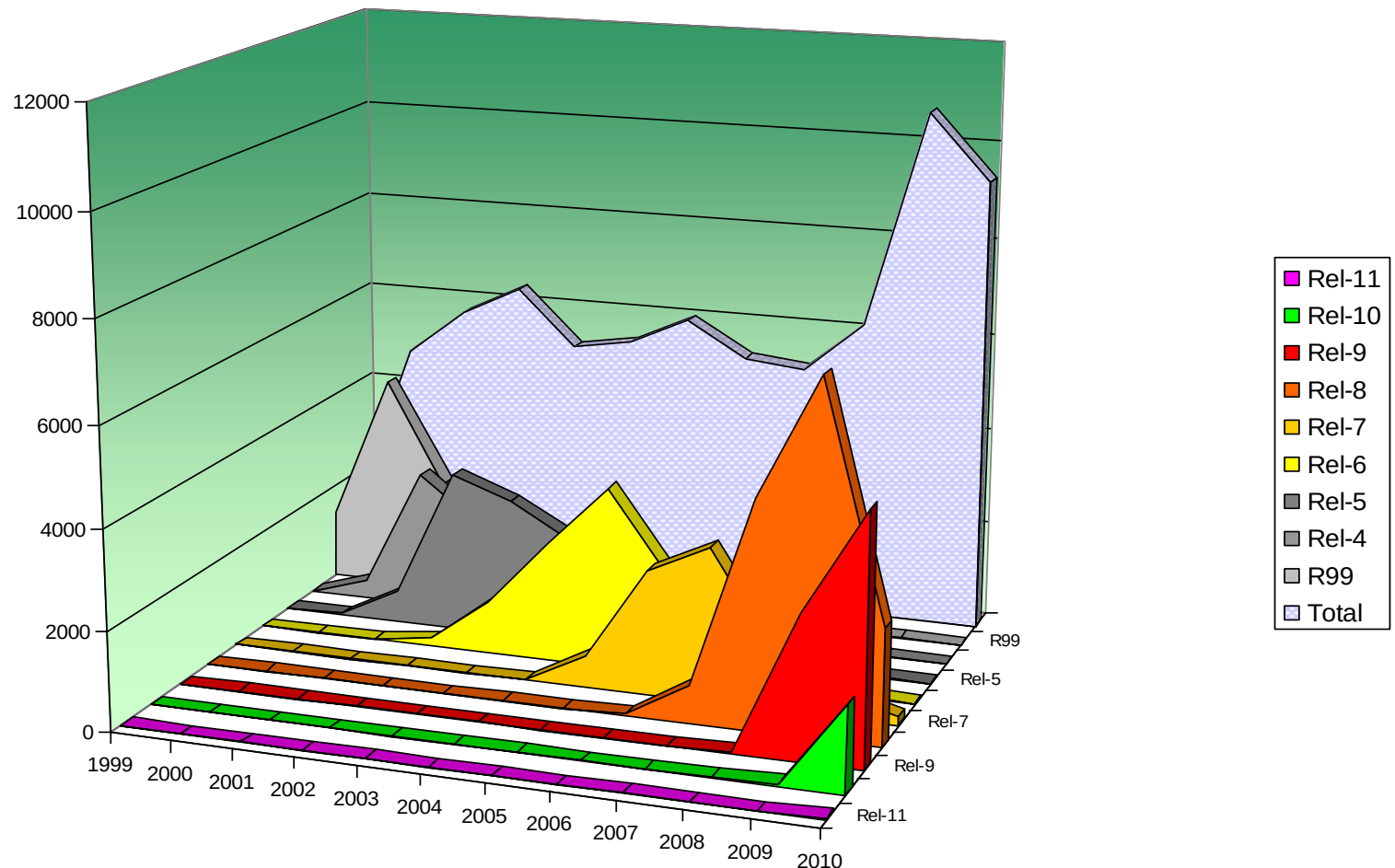
Standards Influence and impact

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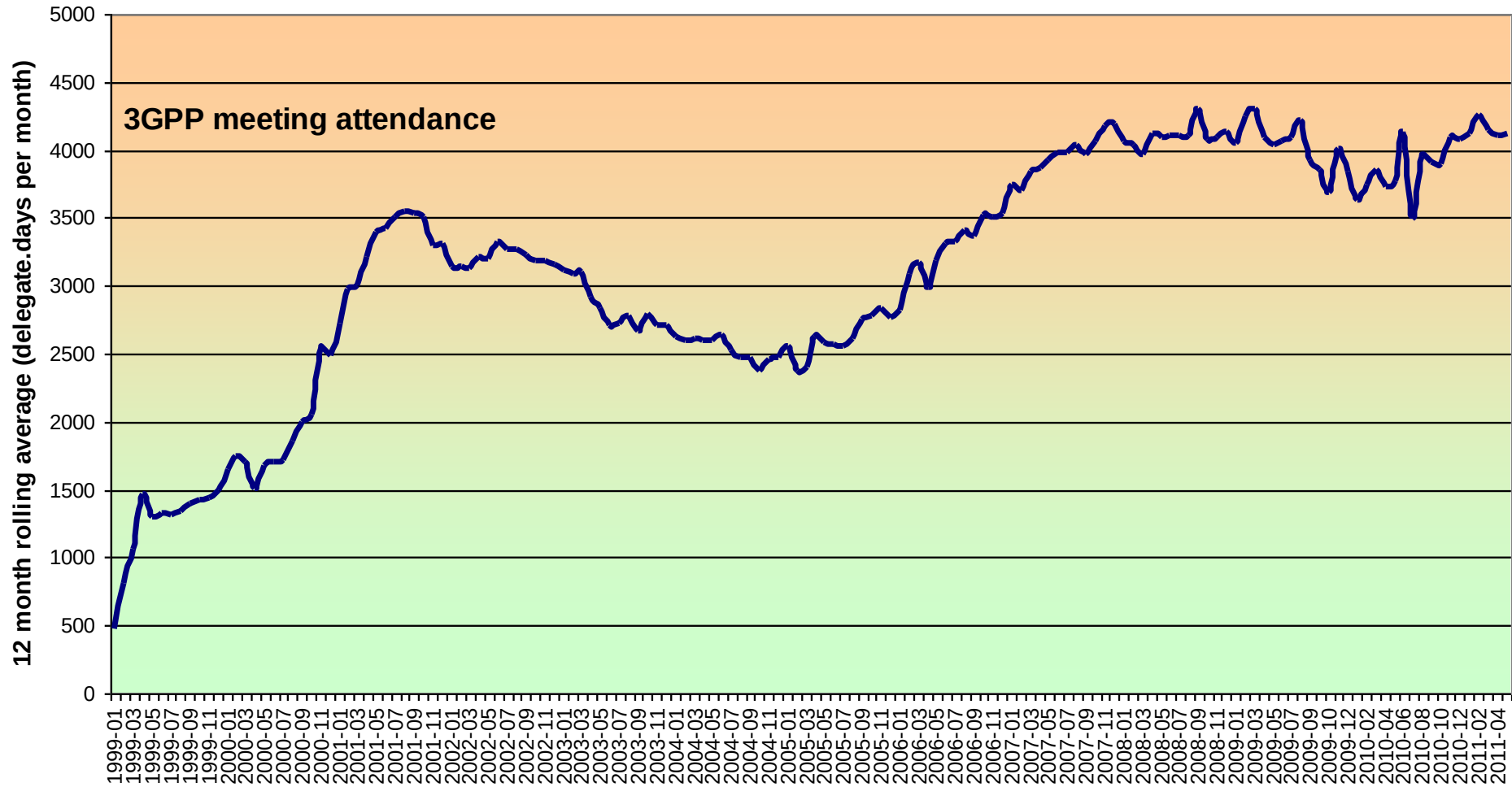


Individual vendor influence on the standard is small;
but each vendor has to comply with the whole applicable standard

Approved CRs per Release per year

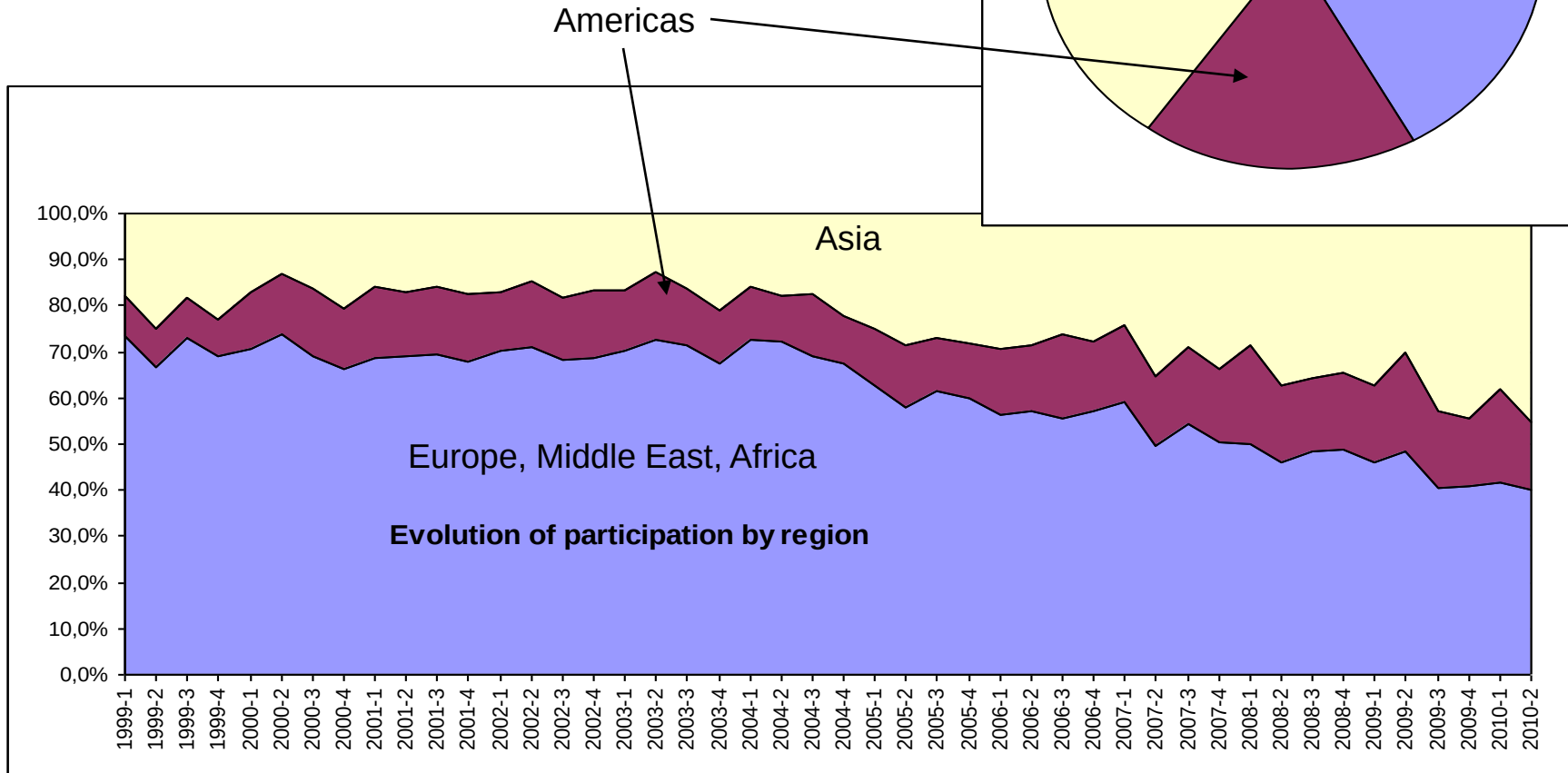
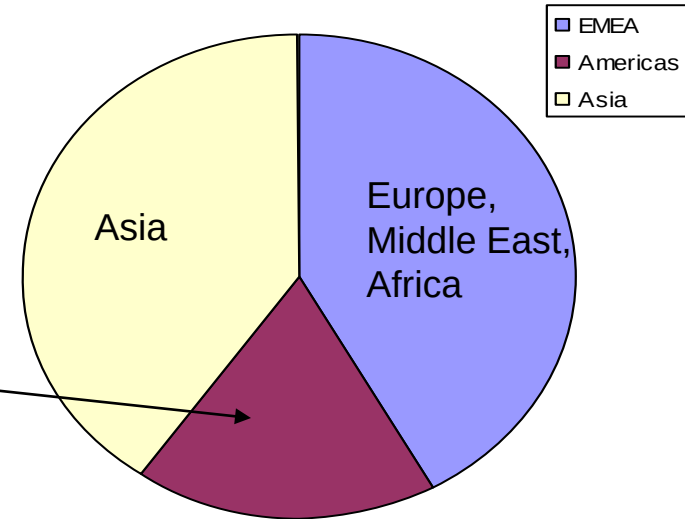


3GPP meeting participation (delegate-days per month)



3GPP participation by region

3GPP meeting participation by ITU region



Network Standards Specification Stages (3GPP, ITU..)

- Stage 1: Service description
 - from a service-user's point of view
- Stage 2: Functional design
 - information flows
- Stage 3: Precise description of the protocols
 - between functional network entities
 - Multi-vendor implementable
 - Bit-level (testable)
- (Stage 4): Test Specification

Inter-release compatibility

- Both backward and forward compatibility are supported by 3GPP releases
- On the radio interface in particular, forward compatibility means that stringent behaviour is specified for the mobile station, e.g. upon receiving unrecognized signalling.

GSM Specification organization

Subject of series	GSM <Rel-4	GSM ≥Rel-4	GSM, UMTS.. (R99+)
Requirements	01 series	41 series	21 series
Service aspects (stage 1)	02 series	42 series	22 series
Technical realization (stage 2)	03 series	43 series	23 series
Signalling protocols (stage 3) MS - network	04 series	44 series	24 series
Radio aspects	05 series	45 series	25 series
CODECs	06 series	46 series	26 series
Data	07 series	47 series	27 series
Signalling protocols (stage 3) (BSS-NSS)	08 series	48 series	28 series
Signalling protocols (stage 3) intra-NSS	09 series	49 series	29 series
Programme management	10 series	50 series	30 series
Subscriber Identity Module (SIM / USIM), Test specs	11 series	51 series	31 series
OAM&P and Charging	12 series	52 series	32 series
Access requirements and test specifications	13 series	13 series	
Security aspects			33 series
UE and (U)SIM test specifications	11 series		34 series
Security algorithms	55 series	55 series	35 series
LTE			36 series
Multiple radio access technology			37 series

03 series means 03.01, 03.02 etc; 43 series means 43.001, etc.⁶⁶

All 3GPP Technical
Specifications and Reports
are publicly available at:

<http://www.3gpp.org/>

Mobile Network Standards: EP2 Solution

- Problem: How to create a market where equipment from competing suppliers can successfully inter-operate?
- Solution: Standardize interfaces
 - International: (GSM Originally Europe, later Global): creates international market
 - Competitive supply reduces cost and risk
 - Bonus: International expertise pooled
- Downside: need to agree on everyone's needs
 - Time to market
 - Sometimes compromise

GSM Bibliography

- The GSM system for mobile communications; *Michel Mouly and Marie-Bernadette Pautet*, [Telecom Publishing 1992]
- GSM Architecture, Protocols and Services. Jörg Eberspächer et al. [Wiley 3rd edition 2009]
- GSM Networks: Protocols, Terminology, and Implementation. *Gunnar Heine* [Artech House, 1999]
– <http://www.scribd.com/doc/34043300/Gsm>
- GPRS in practice, a companion to the specifications *Peter McGuiggan* [John Wiley & Sons Ltd 2004]
- <http://www.3gpp.org/-specifications->

EFREI M1

Mobile Networks

Réseaux Mobiles: Introduction
(*Fundamentals of Cellular Networks*)

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Tamum Consulting February 2012