The Evolution of Mobile Communications

Dr. Hassan Al-Mahdi

Professor of computer networks

Computer Science Department

Faculty of Computer Science & Information

Suez Canal University

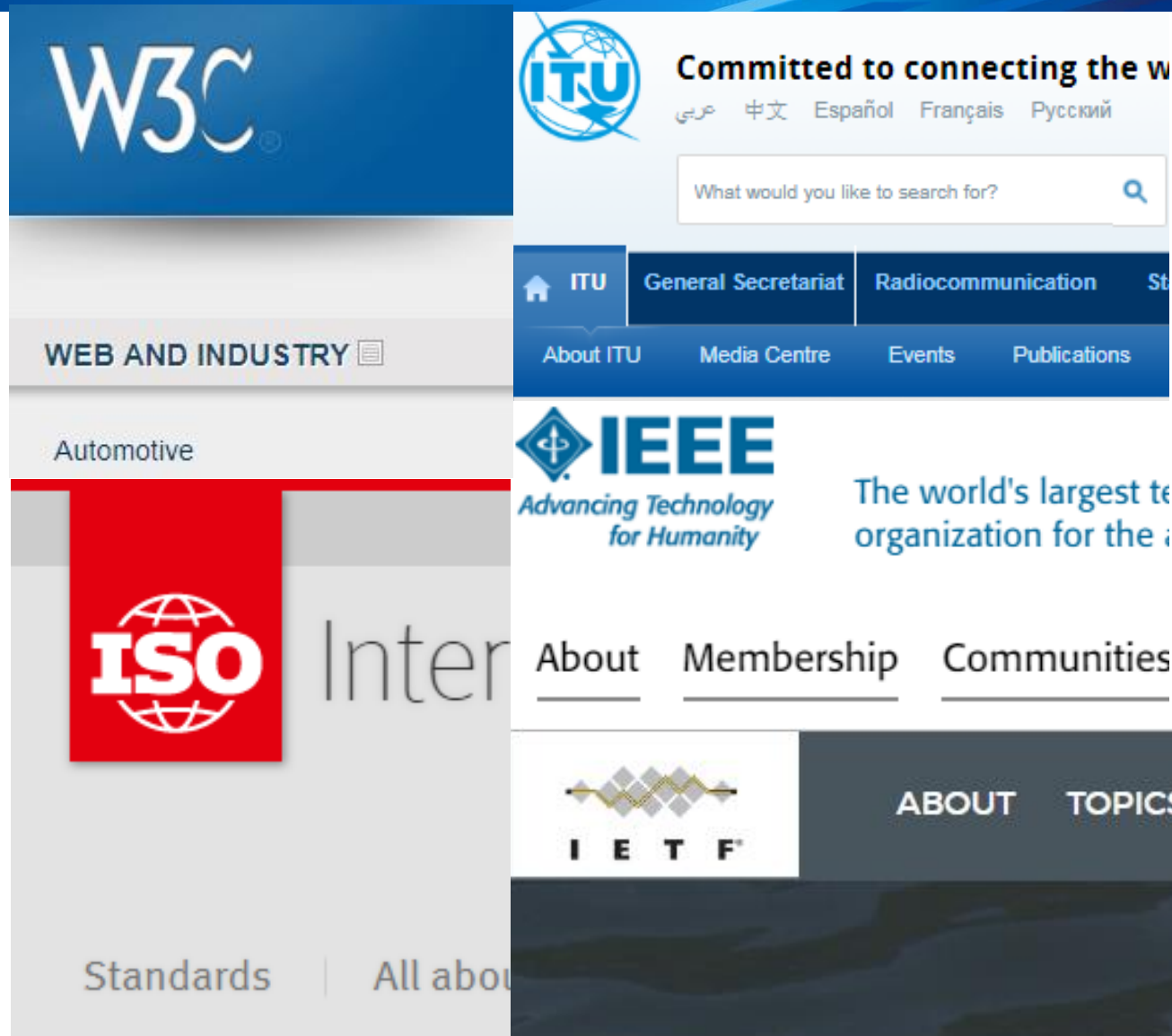
Standardization Bodies

What needs to be Standardization ?

- Basic network architecture.
- Functionality of essential network elements.
- Protocol and protocol stack.
- Interfaces (HW and spectrum).
- Information storage (i.e., USB).
- Everything else related to interworking.

Five major organization for standardization

- ITU for lower layers, multimedia collaboration
- IEEE for LAN standards (802.x).
- IETF for network, transport & some applications
- W3C for web-related technology (XML, SOAP).
- ISO for media content (MPEG)



Standardization Bodies

The International Telecommunication Union (ITU)

Specialized agency of the United Nations (UN) that is responsible for issues of information and communication technologies.

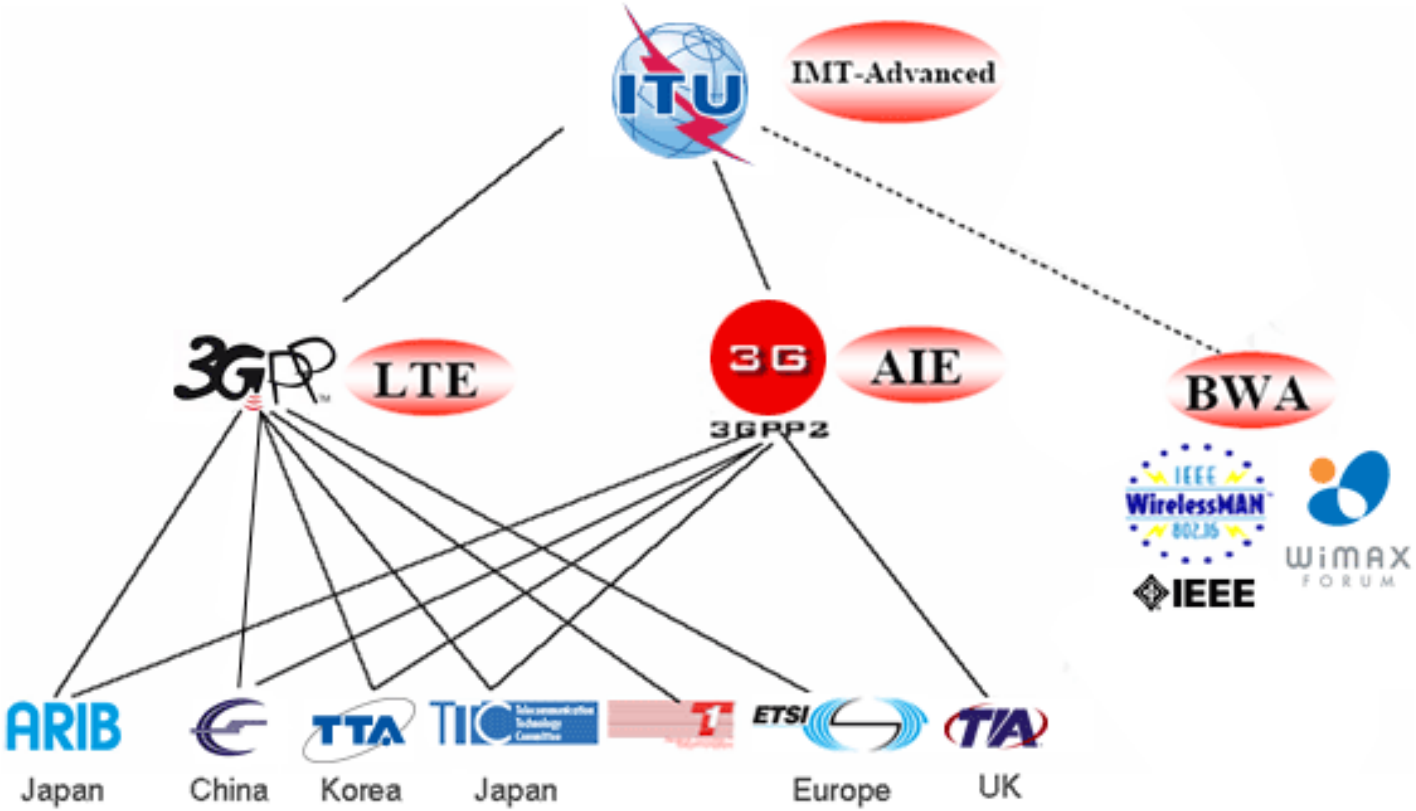
❖ ITU Responsibilities

- Coordinates the shared global use of the radio spectrum.
- Promotes international cooperation in assigning satellite orbits.
- Works to improve telecommunication infrastructure in the developing world
- Assists in the development and coordination of worldwide technical standards.

❖ ITU Sectors

ITU-R	ITU-T	ITU-D
○ Managing RF and ITU radio communications ○ Managing spectrum allocation ○ Managing Satellite orbits	Standards covering all fields of telecommunications (except for radio)	○ Creating policies, regulation and providing training programs ○ Financial strategies. ○ Accessing to information and communication technologies.

Standardization Bodies



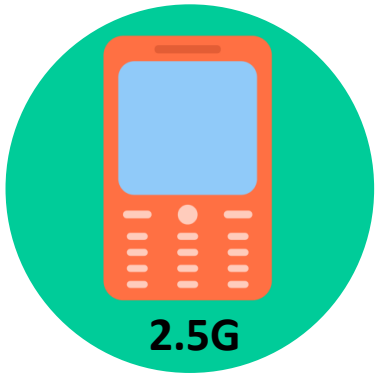
- The **3rd Generation Partnership Project** (**3GPP**) is a collaboration between groups of telecommunications standards associations, known as the Organizational Partners:
  - GSM , 2G and 2.5G standards, including GPRS and EDGE
  - UMTS and related 3G standards, including HSPA.
  - LTE and related 4G standards, including LTE Advanced and LTE Advanced Pro.
  - Next 5G standards.

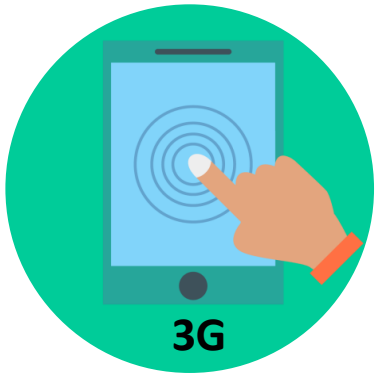
- **3GPP2** is the standard body behind the competing 3G standard CDMA2000 that is the 3G upgrade to cdmaOne networks used mostly in the United States (and to some extent also in Japan, China, Canada, South Korea and India).

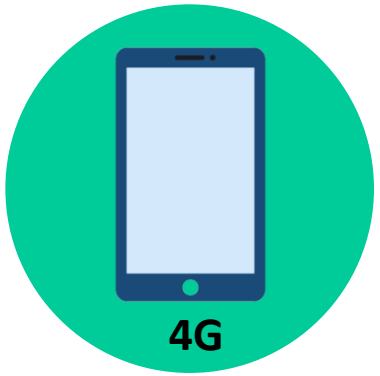
The Evolution of Mobile Communications

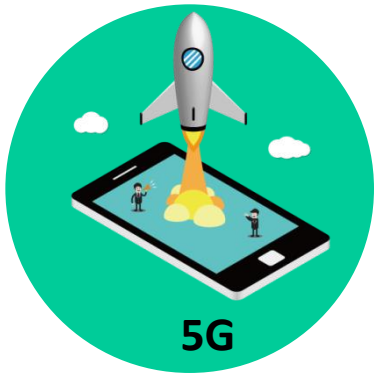

1G


2G


2.5G


3G


4G


5G

Benefits and challenges

Updates and Evolution Paths


Standard Technologies


Specifications


Transitions


Backward Compatibility

The mobile experience is expanding everywhere

~9.9 Billion
Mobile connections, 2018

~25 Billion
Interconnected devices forecast in 2020

~4 Billion
Internet Users in the world, 2018

~1.7 Billion
Total number of Websites, 2018

~280 Billion
App downloads , 2018

GSMA Intelligence

Data | Research | Feed | Feedback

Definitive **data** and **analysis** for the mobile industry

Connectivity is the foundation of a great mobile experience

Connect Reliably

Talk and browse without interruption with more bars in more places

Connect Real-Time

Get instant access to content with less delay for "always-on" experience

Connect On-the-Go

Talk and browse with seamless mobility anywhere you get a signal

Connect Fast

Stream, surf, upload, and download with fast, predictable data rates

Connect Longer

Go longer without plugging in with improved battery efficiency

Delivering rich mobile broadband experiences

Every new Wireless Mobile Generation Delivers

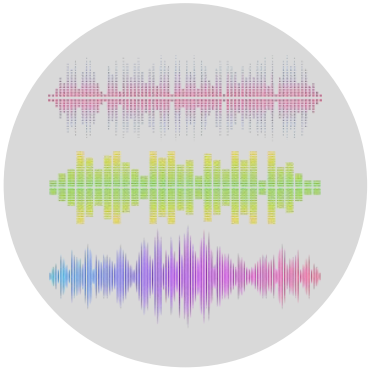
Speed

Maximize the peak data rate

Phone Quality

Size, battery, weight, etc.

More Functions



Transmissions Quality

Security

Pre-Cellular Mobile Communications

- **MTS** Mobile Telephone System
- **IMTS** Improved Mobile Technology
- **AMTS** Advanced Mobile Telephone System
- **PTT** Push to Talk
- **MTD** Mobile telephony system D
- **OLT** Norwegian for Landmobil Telefoni

Features

- Mounted in cars or trucks.
- Briefcase models were also made.
- Lower capacity and weaker mobility.
- A mobile operator was needed to set up calls.
- VHF radio system linked PSTN.
- Single high power transmitters.
- AM modulation techniques.
- Coverage up to about 50 miles .
- Voice services.

Established the Foundation of Mobile Cellular System

1 Licensed Spectrum

Cleared spectrum for exclusive use by mobile technologies

Operator-deployed **base stations** provide access for subscribers

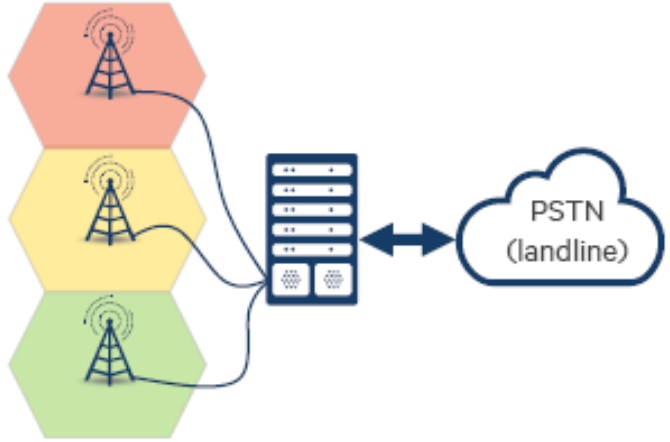
2 Frequency Reuse

Reusing frequencies without interference through geographical separation

Neighboring **cells** operate on different frequencies to avoid interference

3 Mobile Network

Coordinated network for seamless access and seamless mobility



Integrated, transparent **backhaul network** provides seamless access

Handoff provides seamless connection

Base stations serve multiple subscribers

Frequencies are geographically reused in cells.

First-Generation Mobile Cellular Standards

Advanced Mobile Phone Services (AMPS)

- Voice service only
- Used in North America, 1983.
- Developed by Bell Labs.
- Supports N-AMPS with 30 kHz channel bandwidth.

Total Access Communication System (TACS)

- Introduced in the U.K. in 1985.
- Operating in the 890-915 MHz and 935-960 MHz.

Nordic Mobile Telephone (NMT)

- Developed by Ericsson in 1981 -1985
- Switzerland, Netherlands, Eastern, Europe, Russia.
- Supported roaming in European
- Deployed either 25 kHz or 12.5 kHz

Japanese Total Access Communication System (J-TACS)

- A modified version of TACS
- Japan and Hong Kong, 1985

Characteristics

- Frequency Reuse and Handoff/Handover
- FDMA/FDD systems with 30 KHz per channel.
- Analog Modulation Technology
- Analog Voice only using FM
- Digital Control channels for signaling
- Adjustable Mobile Power levels
- Macro Cells : 1-40 km radius.
- Analog Switching.

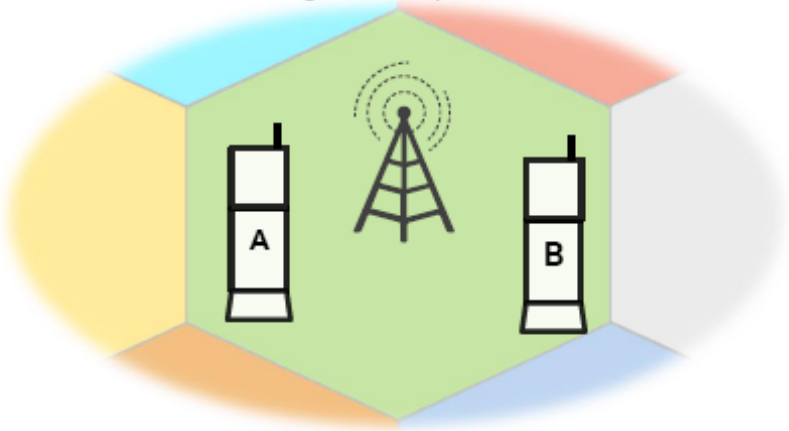
AMPS is The Most Popular Standard

Feature	Value	Feature	Value
Starts	from 1970-85	Multiplexing	FDMA
Frequency	800-900 MHZ	Switching	Circuit
Data capacity	2.4 Kbps	Service	**Voice only**
Technology	Analog wireless	Main network	PSTN
Standard	AMPS	Handoff	Hard

1G analog voice was amazing, but limited

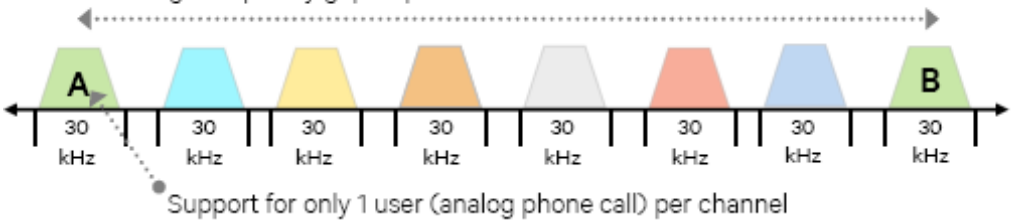
Limited Capacity

Analog transmissions are inefficient at using limited spectrum



Frequency Division Multiple Access (FDMA)

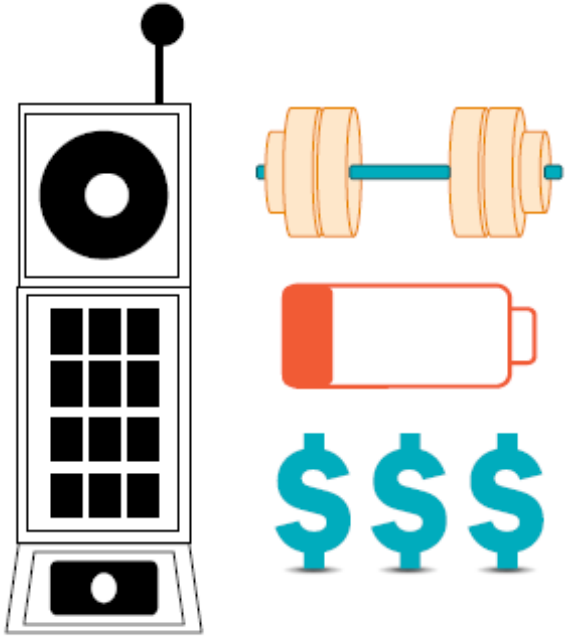
Large frequency gap required between users to avoid interference



Support for only 1 user (analog phone call) per channel

Limited Scalability

Analog devices are large/heavy, power inefficient, and high cost

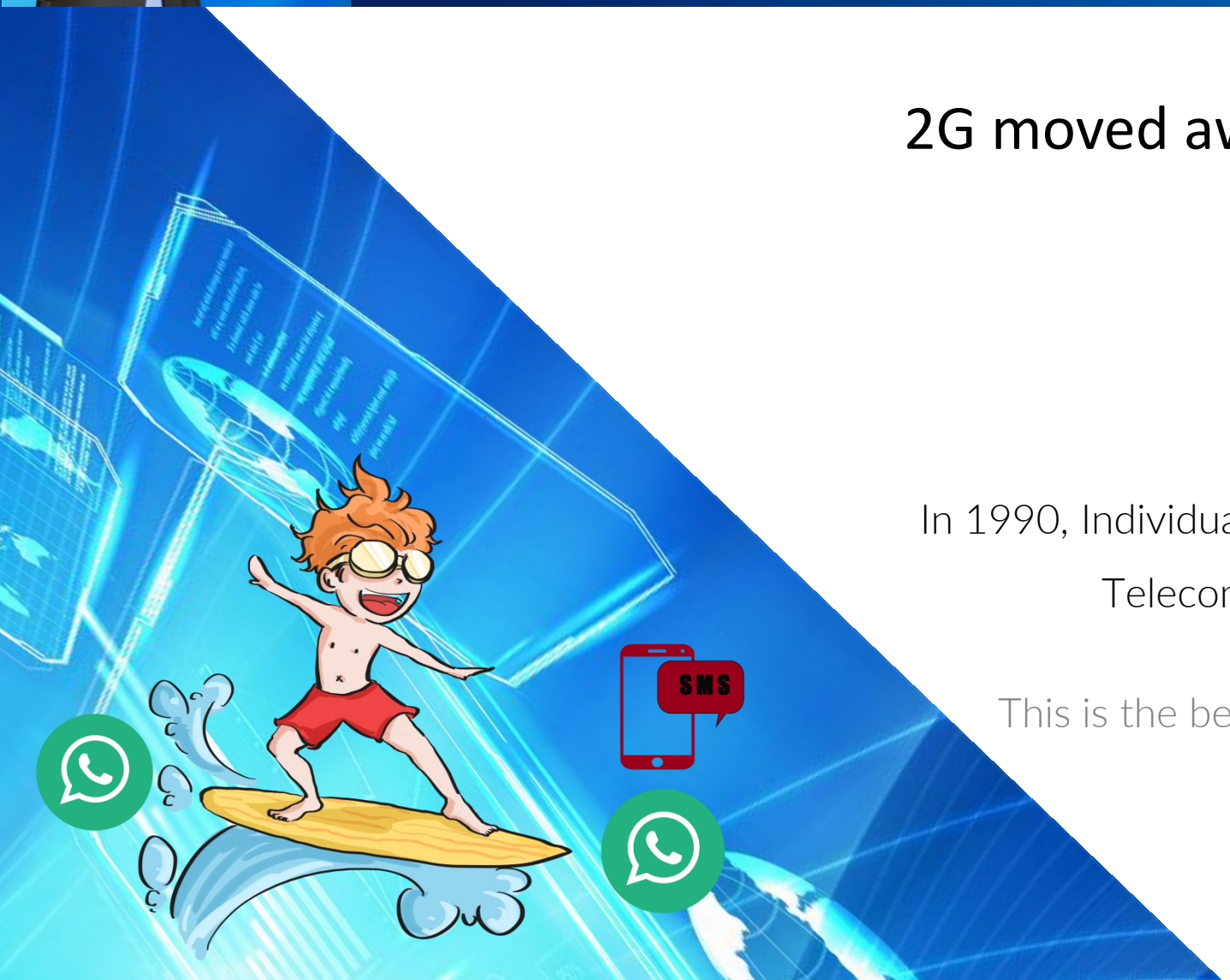


Disadvantages of 1G

- Single standard in Europe
- Poor voice quality due to interference
- Poor battery life
- Large sized mobile phones.
- Less security.
- Limited number of users and cell coverage
- No roaming between similar systems

Moving to the Second-Generation Cellular Mobile System

The Second-Generation Cellular Mobile System



2G moved away from analog and toward digital modulation.

In 1990, Individual Organization works under umbrella of European Telecommunications Standards Institute (ETS) .

This is the beginning of 2nd Generation Cellular System

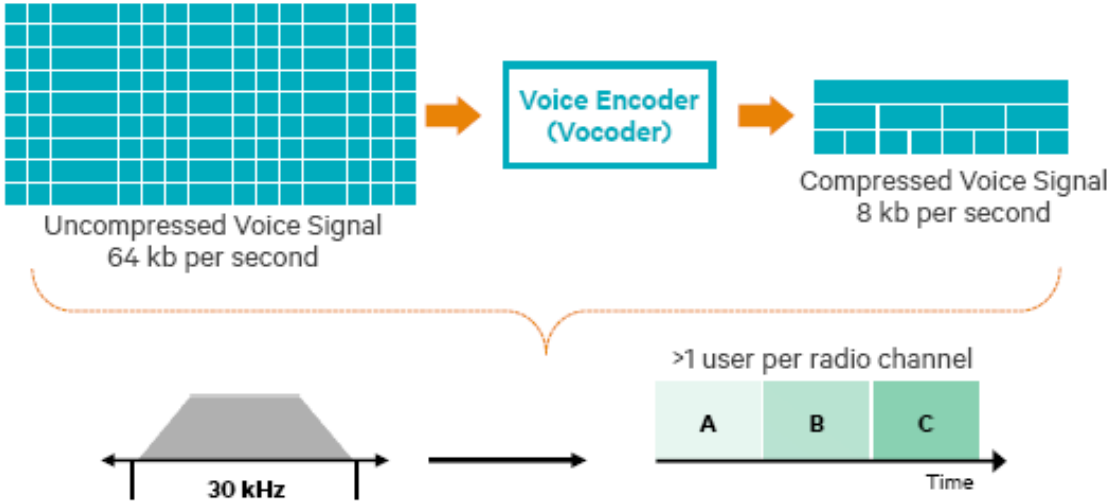
The Second-Generation Cellular System

Initial 2G Characteristics

- TDMA and CDMA
- Support SMS
- Support Encryption
- Increased System Capacity
- Use Multiplexing
- Provides Roaming
- Emits less Mobile Radio Power.
- Speeds up to 14.4 Kbps
- Starts SIM Cards
- Increase Security (CDMA)
- Circuit Switching Technology .

More Voice Capacity

Digital transmissions enable compressed voice and multiplexing multiple users per channel

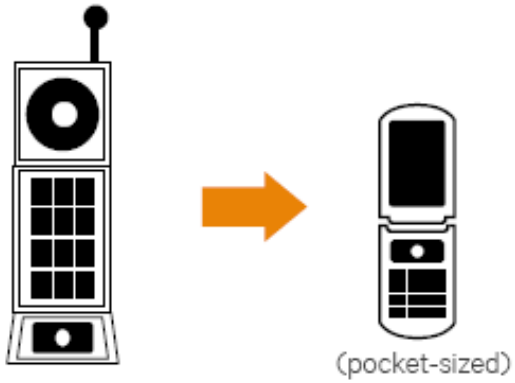


Time Division Multiple Access (TDMA)

Allows multiple users per radio channel with each user talking one at a time

Scalable Technology

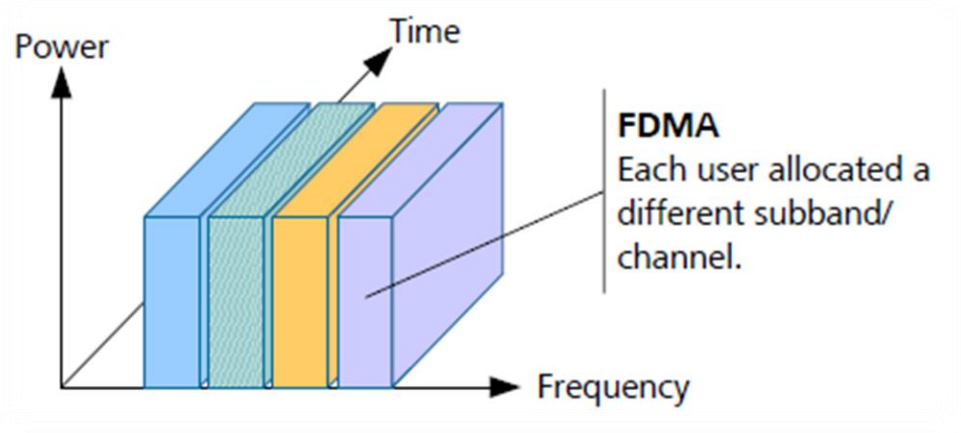
Digital components cost/weight far less plus deliver more secure signal

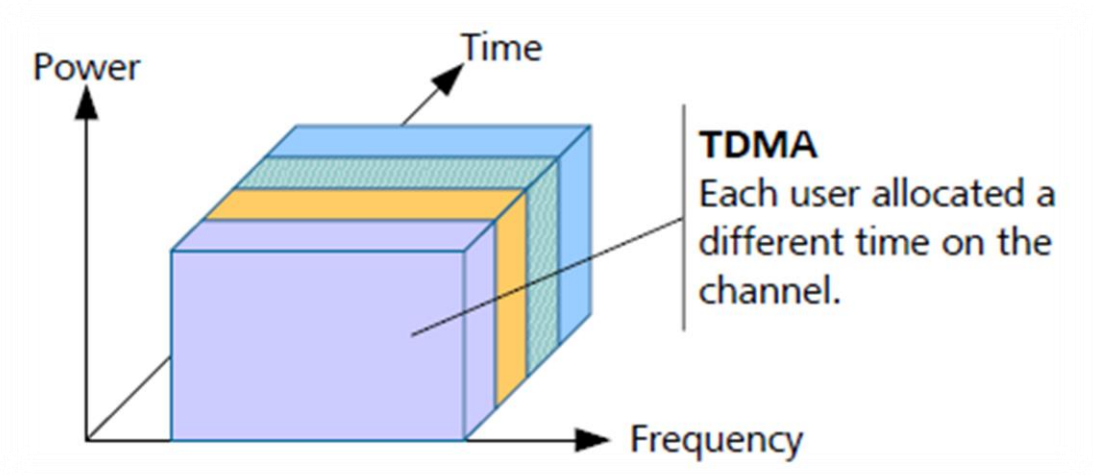


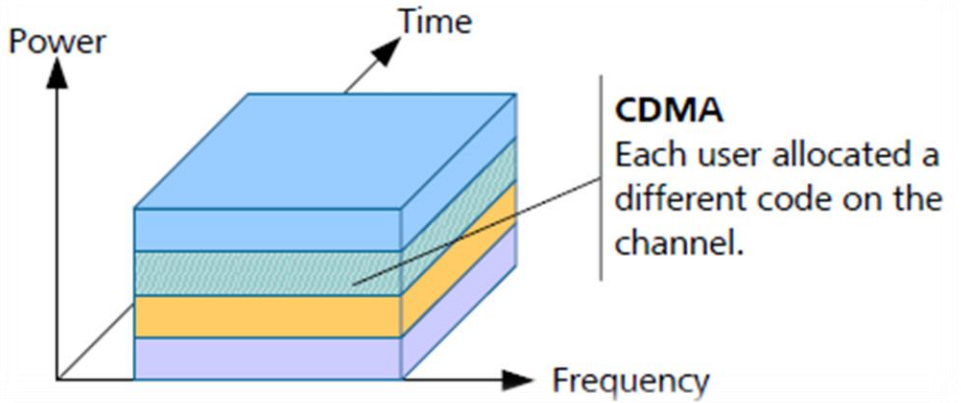
The Second-Generation Cellular System

2nd G Multiple Access Schemes

- The 2G technology based on two standard: CDMA and TDMA on the basis of multiplexing.
- In practice, the TDMA and CDMA schemes are combined with FDMA.







The Second-Generation Cellular System Standards

GSM

Characteristics

- Single standard in Europe based o TDMA
- BW=25MHz, 200KHz/channel, 200KHz guard
- Frame duration = 4.615 ms
- Time slot 0.557 ms (8 slots/frame)
- Digital modulation (π/4-DQPSK), FDD duplex
- Digital modulation (GMSK), FDD duplex
- Data Rate = 270.833 Kbps
- UL: 890-915 MHz , DL : 935–960 MHz
- Frequency Hopping Sequences FHS

D-AMPS Digital AMPS

Characteristics

- Known as US-TDMA, IS-136, or just TDMA)
- Used in the Americas, Israel, and Asia.
- Standard as IS-54 (later renamed IS-135
- Backward compatible with AMPS.
- Frame duration = 40 ms.
- Time slot duration = 6.67 ms (6 slots/frame).
- Digital modulation (π/4-DQPSK), FDD duplex.
- BW=25MHz, UL: 824-849, DL: 869–894 KHz
- Data Rate 48.6 Kbps

PDC Personal Digital Cellular

Characteristics

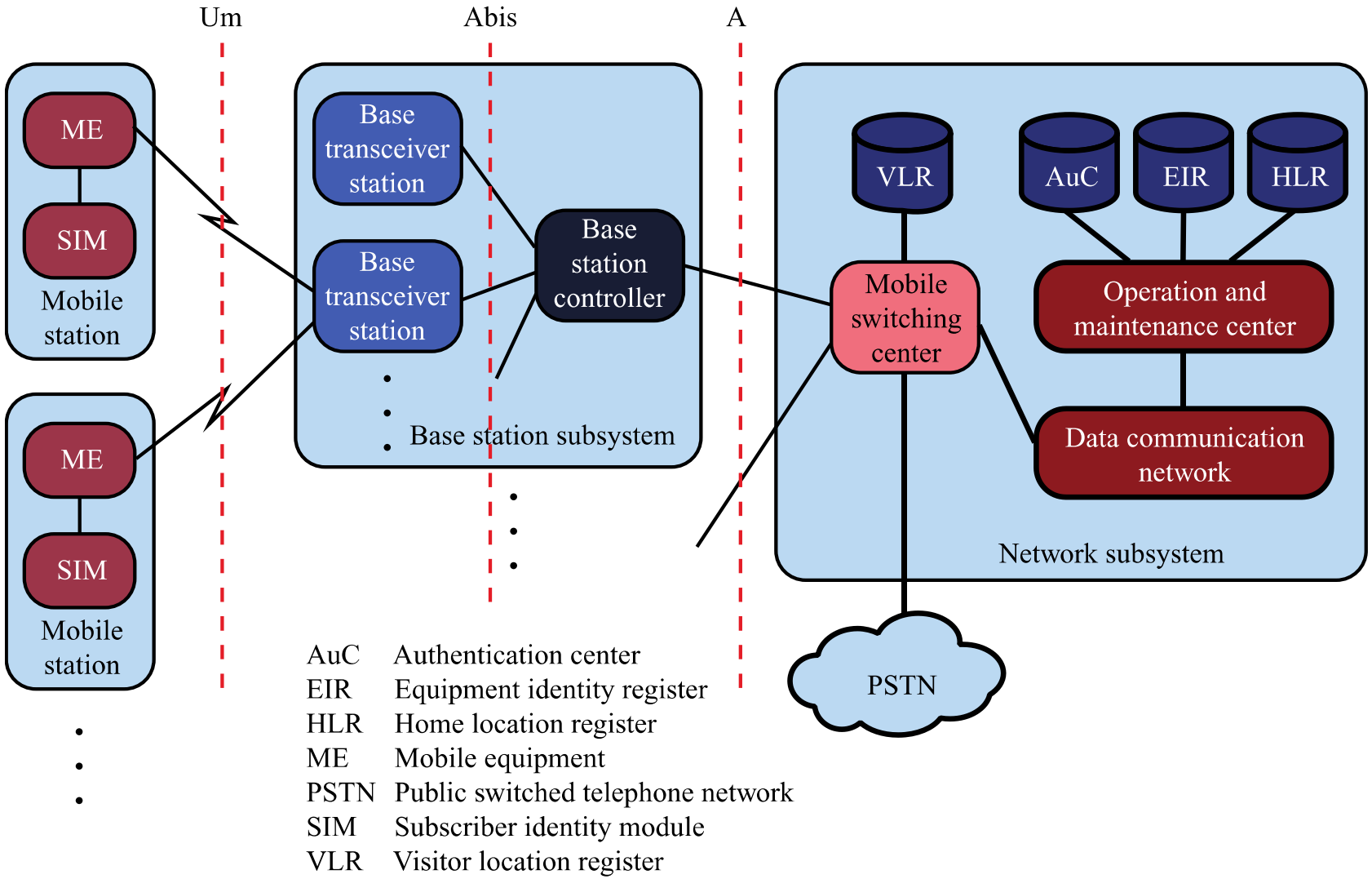
- The popular 2G standard in Japanese.
- Originally it was known as Japanese Digital Cellular (JDC).
- The specification is known as RCR STD-27.
- Uses the two bands: 800 MHz and 1,500 MHz.
- Resembles GSM protocol stack.
- Running out when the Japanese develop the 3G systems.
- The services include voice, call waiting, voice mail,
- Data service (up to 9.6 Kbit/s CSD), and PCD up to 28.8 kbit/s.

GSM derivatives

DCS 1800	PCS 1900	GSM 800	GSM 400
Europe	North America	Europe	North America

The Second-Generation Cellular System Standards

GSM



The Second-Generation Cellular System Standards

IS-95A CDMA

Characteristics

- CDMA-based developed by Qualcomm.
- IS-95 air interface standardized by TIA .
- May 1995, IS-95A Ref. A (cdmaOne) ..
- Digital modulation (QPSK, O-QPSK), FDD duplex
- Soft handoffs and uses circuit-switched voice.
- Frame duration = 20 ms, Chip Rate 1.2288 Mcps
- Used in the United States, South Korea, Hong Kong, Japan, Singapore, and many other east Asian countries.
- Data rate = 115 Kbps.

CDMA Benefits

- Increased voice capacity by several times
- Provided more efficient use of spectrum resources
- Increased battery life in mobile devices
- Better security with CDMA encoding

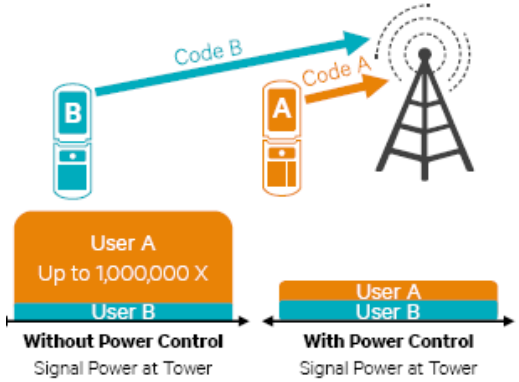
Qualcomm solved complex challenges to commercialize CDMA

Near-Far Power Challenge

Users close to the tower overpower the uplink signal minimizing capacity on the shared channel

Solution:

Continuous control of transmit power based on signal strength

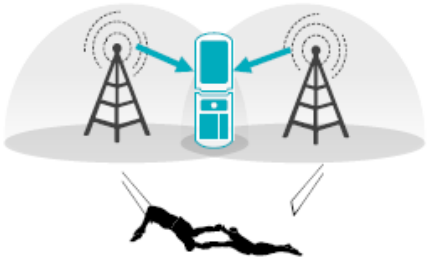


Cell-Edge Challenge

Interference caused by users in close proximity, on the same frequency, and communicating with different towers

Solution:

Users simultaneously communicate with multiple towers at cell edge



+ Soft (vs. Hard) Handoffs

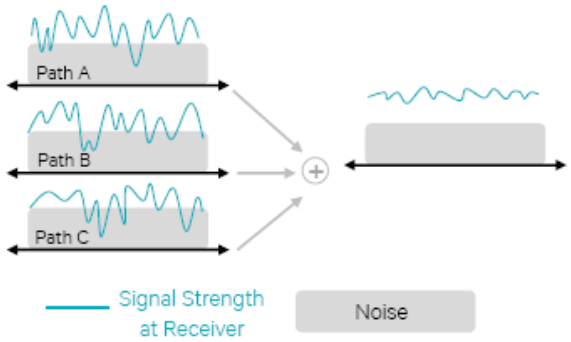
Additional benefit of simultaneous connections – more reliable handoffs

Multipath Fading Challenge

Interference caused by the reception of the same signal over multiple paths resulting in poor signal-to-noise ratio

Solution:

Advanced ("rake") receivers combine energy of multiple signal paths



The Second-Generation Cellular System Standards

Moving to 2.5nd generation (Speeds Data)

- "Generation 2.5" is broadly includes all advanced upgrades for the 2G networks.

- High-speed circuit-switched data (HSCSD).
- General Packet Radio Services (GPRS).
- Enhanced Data Rates for Global Evolution (EDGE).
- IS-95B.

The Second-Generation Cellular System Standards

increase data rates

Packet Switching

More Services

Foundation for 3G

Enhance Mobile Quality

GSM Evolution

High-speed circuit-switched data (HSCSD).

- GMSK (Gaussian Minimum-Shift Keying).
- MS can use 4 time slots per frame.
- Data rate 38.4-Kbps or 57.6-Kbps.
- Allocates slots constantly (drawback).
- Good choice for real-time applications.
- Services include data files, email, Internet and other file transfers three times faster
- Moved directly to GPRS handsets.

General Packet Radio Services (GPRS)

- Overcome the GSM data rate limitation.
- GMSK (Gaussian Minimum-Shift Keying).
- Packet switching technology.
- Uses 8 time slots continuously.
- The data rate varies from 64-171 Kbps.
- Not suited for real-time applications.
- GMSK (Gaussian Minimum-Shift Keying).
- GPRS was implemented in IS-136 networks.

Enhanced Data Rates for Global Evolution (EDGE)

- Roaming data services of up to 400 Kbps.
- threefold. Of GSM data rate.
- Uses FDMA and TDMA in combined
- Uses GMSK in wide range.
- Uses 8PSK in short distance.
- Uses 8 slots per channel.
- Max. data rate 473.6 kbps
- IS-136 (TDMA) is also upgraded using EDGE.

The Second-Generation Cellular System Standards

increase data rates

Packet Switching

More Services

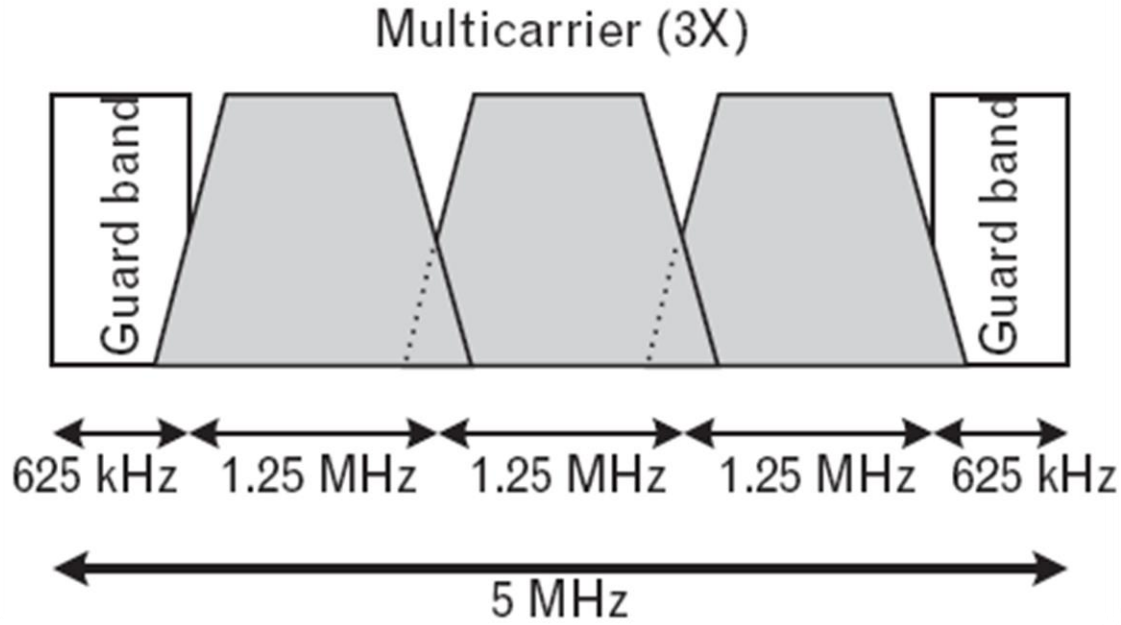
Foundation for 3G

Enhance Mobile Quality

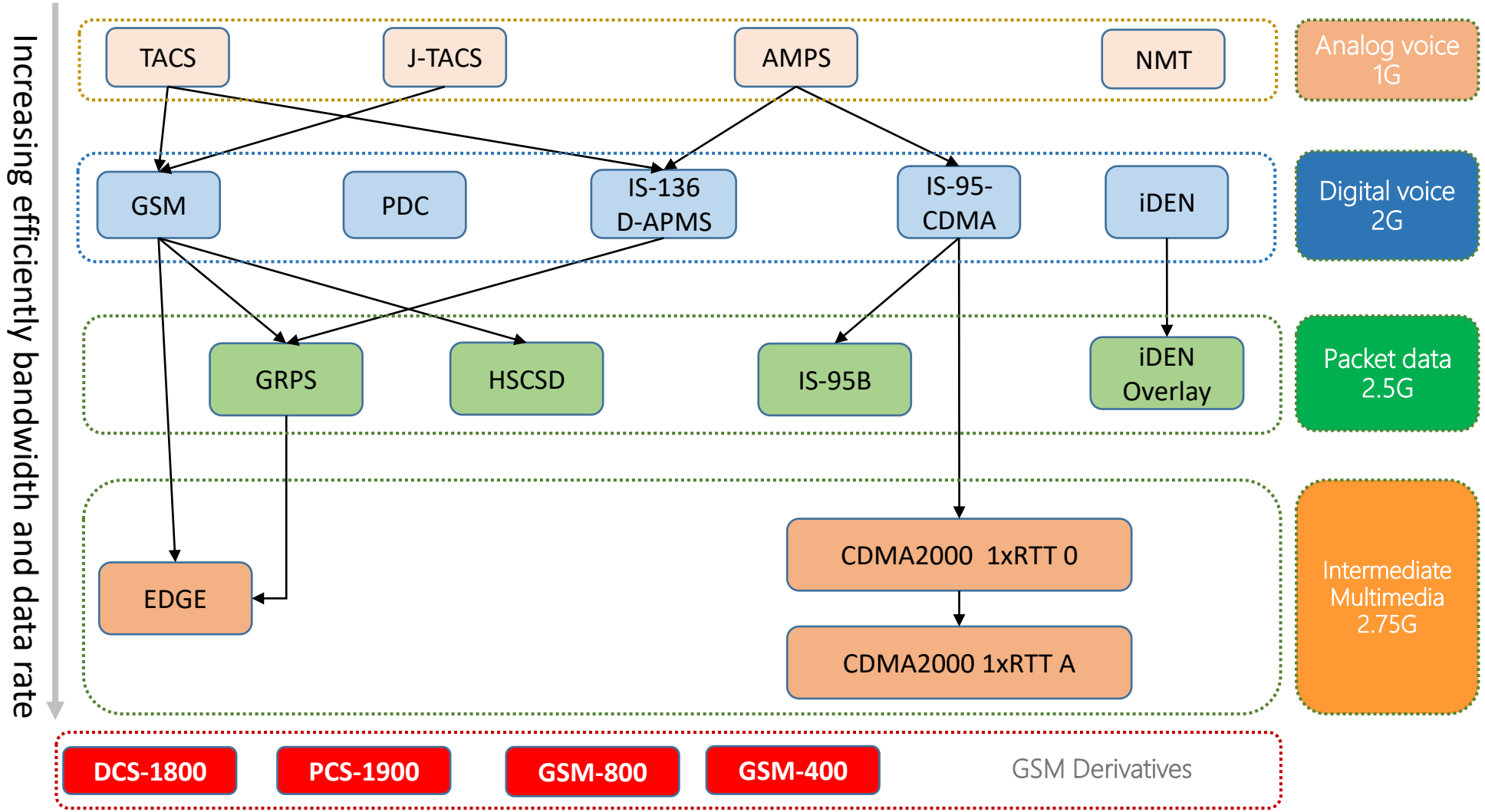
GSM Evolution

IS-95-B

- IS-95B is the upgrades IS-95A technology.
- IS-95B provides mush higher data rates for packet- and circuit-switched CDMA data,
- Data rates up to 115 kbps.
- The 3PP2 has specified the CDMA2000 is backward compatible with IS-95B systems.
- 1xRTT (Single-Carrier Radio Transmission Technology) release 0 an A were was the first version of CDMA2000 base on IS-95B.
- 1X denotes that the standard carrier on the air interface is 1.25 MHz, which is similar to IS-95A and IS-95B.



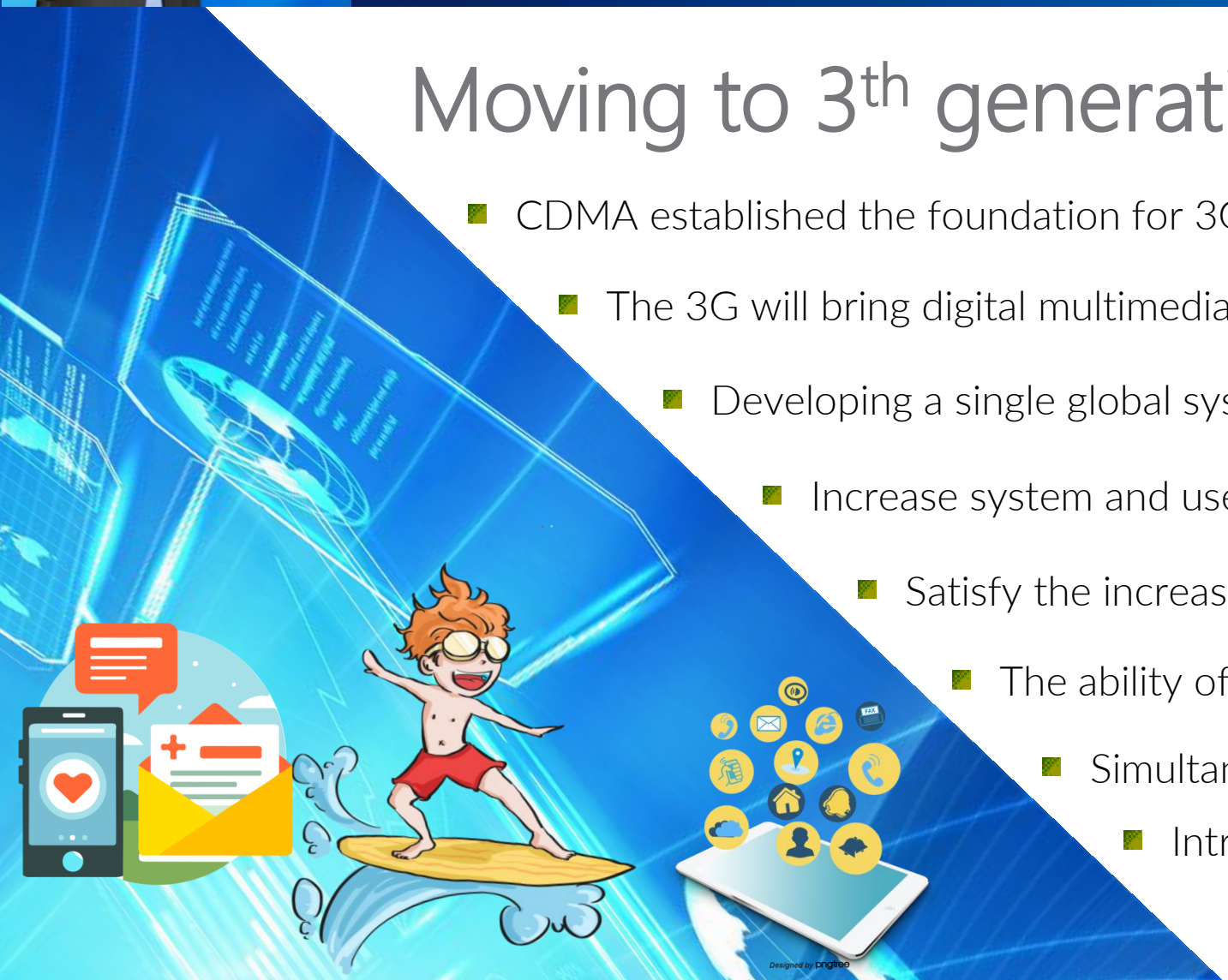
The Second-Generation Evolution Paths



The Third-Generation of Cellular Mobile System

Moving to 3th generation (High Speed Data)

- CDMA established the foundation for 3G technologies.
- The 3G will bring digital multimedia handsets with high data transmission rates.
- Developing a single global system of terrestrial and satellite components.
- Increase system and user capacity.
- Satisfy the increasing data rate appetite
- The ability of the Internet browsing.
- Simultaneous voice and data services.
- Introducing video applications.



The Third-Generation of Cellular Mobile System

❖ International Mobile Telecommunications - 2000 (IMT-2000)

- IMT-2000 is a worldwide set of requirements for a family of standards for 3G of mobile communications.
- The IMT-2000 was developed by ITU).
- Originally it was the intention to have only one truly global standard but that turned out to be impossible.
- Initially known as Future Public Land Telecom System (FPLMTS)
- 1997 FPLMTS changed to IMT-2000.
- IMT-2000 should provide worldwide mobile broadband multimedia services via a single global frequency band.
- The frequency range should be around 2000 MHz.

The most important IMT–2000 proposals

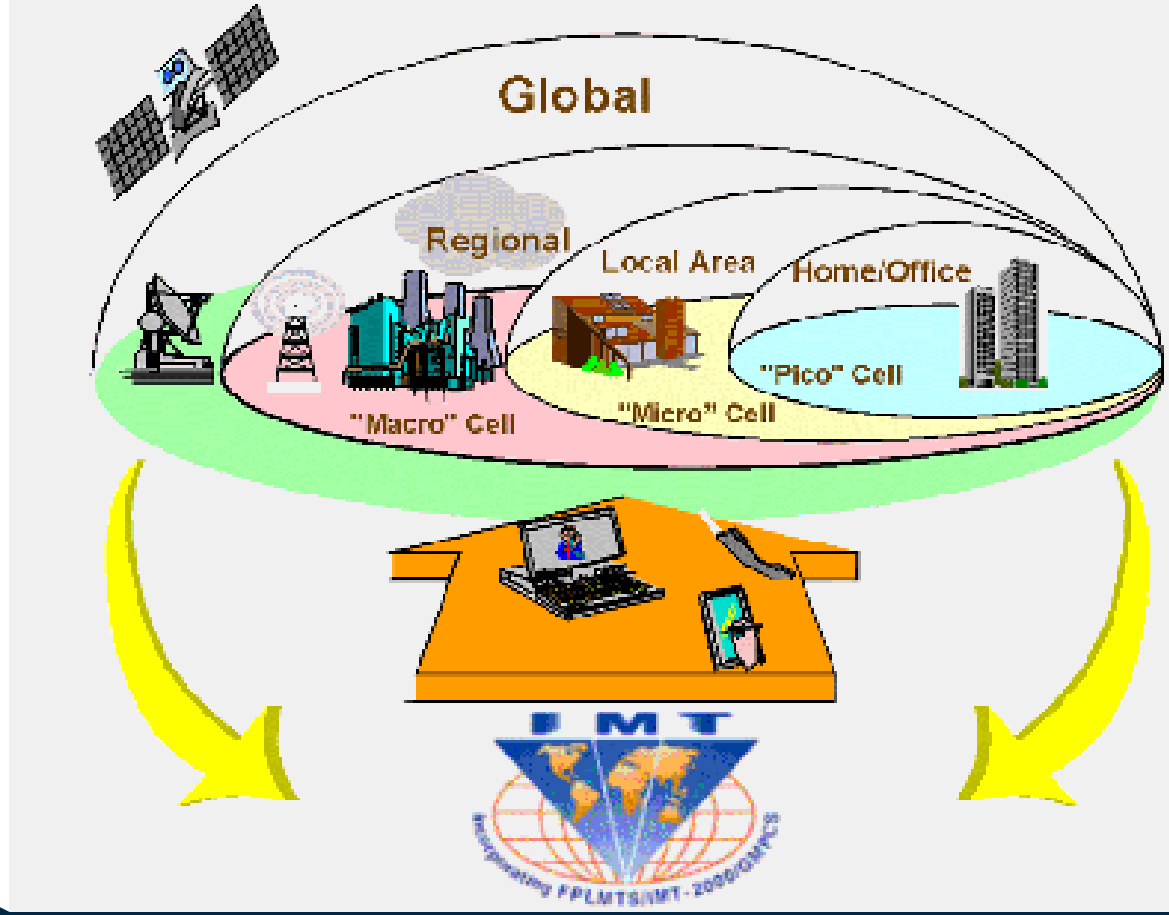
WCDMA GSM successor	**TD–CDMA** **TD-SCDMA** **D–AMPS /GSM successor**	**CDMA2000** **IS95 successor**

UMTS

The Third-Generation of Cellular Mobile System

❖ IMT-2000 Vision of 3G

- 1 global standard in 1 global band.
- Integration of satellite and terrestrial systems to provide global coverage;
- Used for all radio environments, (LAN, cordless, cellular, satellite);
- Wide range of telecommunications services (voice, data, multimedia, internet).
- Support both packet-switched (PS) and circuit-switched (CS)
- Global seamless roaming (changing between various types of networks and communication media)
- Offer high peak data rates up to 2 Mbps.
- **Offer high spectrum efficiency.**



Higher Bit Rates

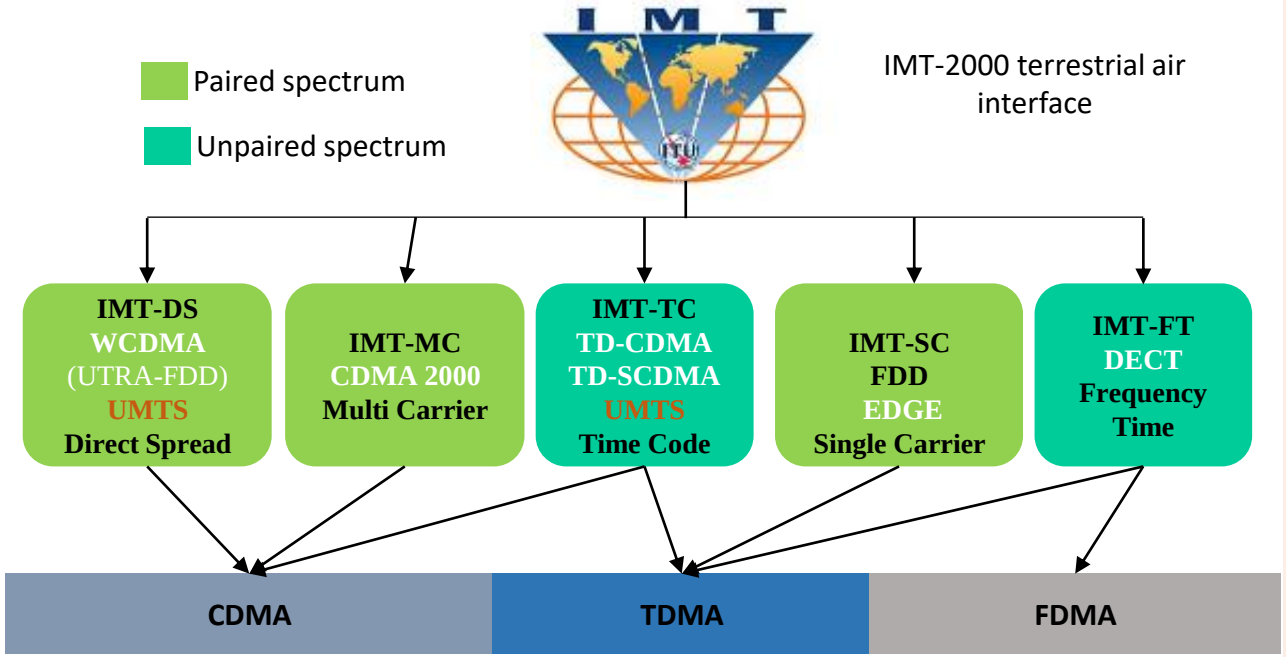
Multi-code CDMA

Multicarrier CDMA

Increase the Chip Rate

The Third-Generation of Cellular Mobile System

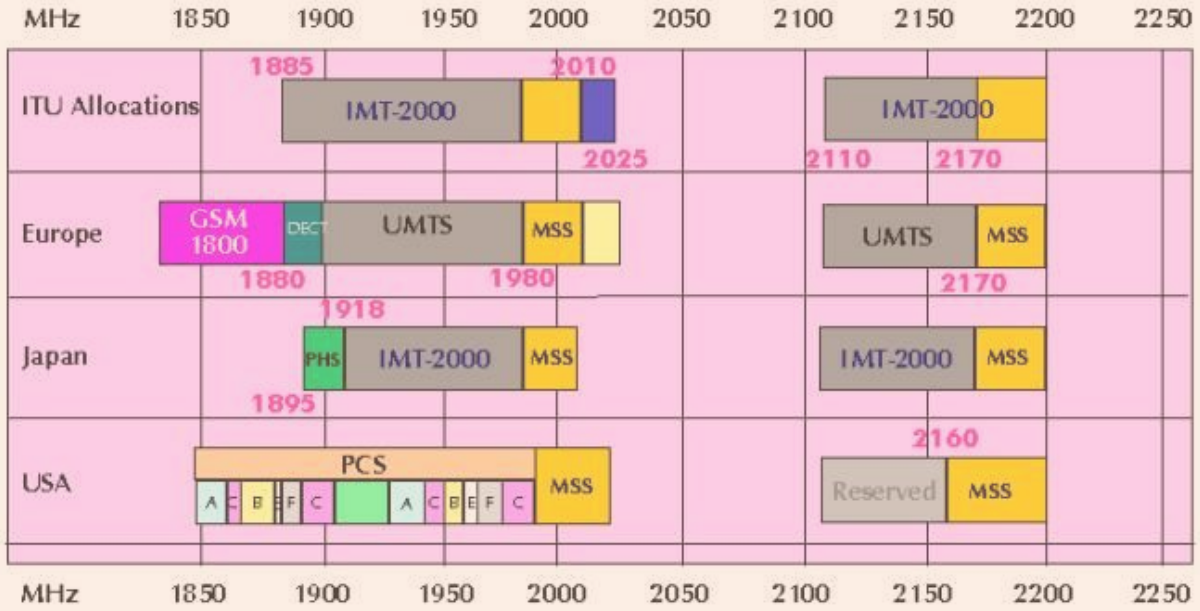
❖ IMT-2000 proposals



❖ UMTS (Universal Mobile Telecommunication System)

- UMTS is a Europe 3G mobile standards.
- Universal Terrestrial Radio Access (UTRA) supports UMTS with terrestrial air interfaces (URRA-FDD and UTRA-TDD).
- UMTS has two standard: WCDMA and TD-CDMA.

IMT-2000 - Frequency Allocations



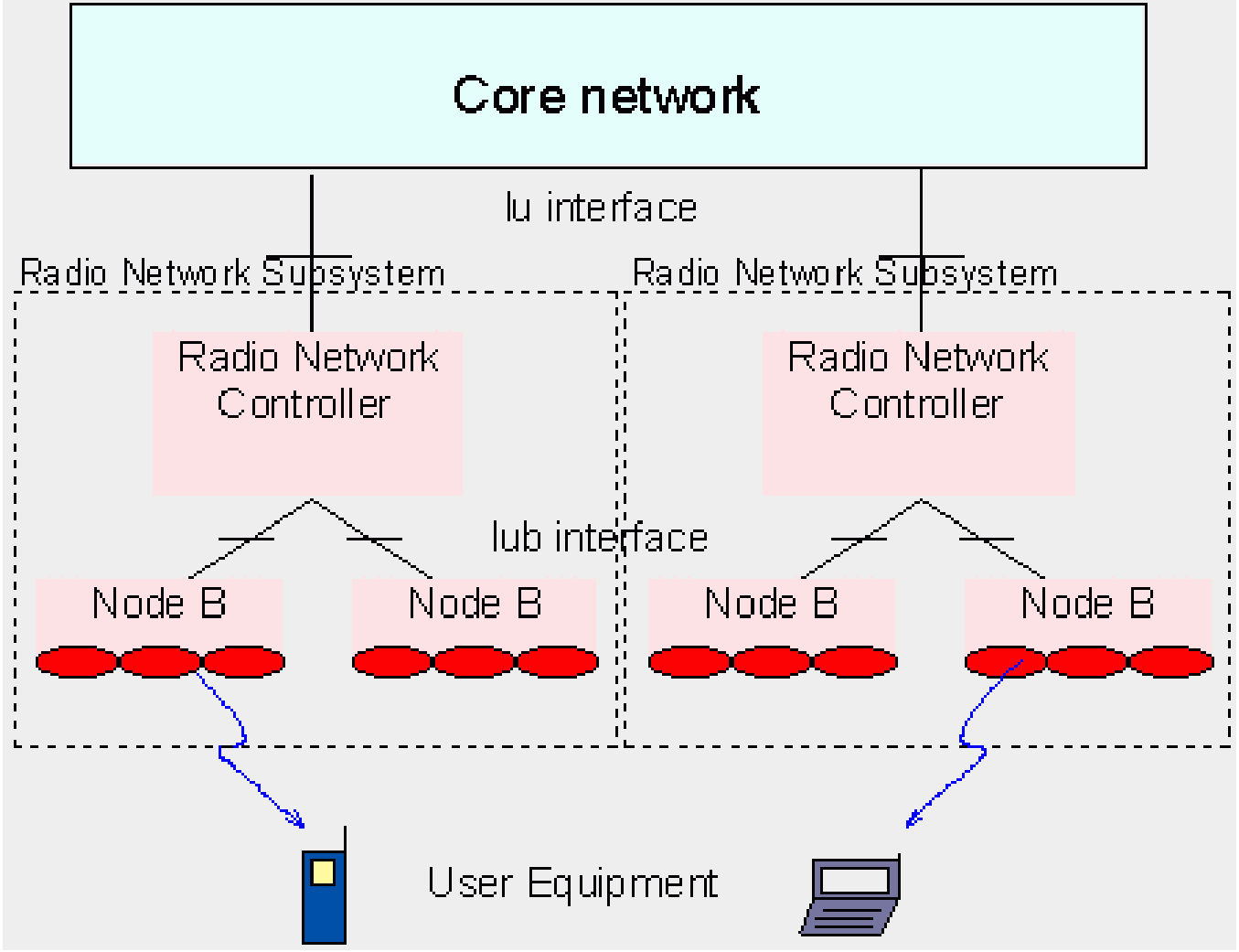
3GPP™ A GLOBAL INITIATIVE

3G 3RD GENERATION PARTNERSHIP PROJECT 2 "3GPP2"

The Third-Generation of Cellular Mobile System

❖ Radio Access Network (UTRAN)

- Admission control
- Congestion control
- Radio channel encryption
- Handover
- Radio network configuration
- Channel quality measurements
- Radio resource control
- Data transmission over the radio interface
- Outer loop power control (FDD and TDD)
- Channel coding



The Third-Generation of Cellular Mobile System - Standards

WCDMA / UMTS-FDD Release 99

- Officially known as CDMA Direct Spread (CDMA DS).
- WCDMA is part of a group of standards from IMT-2000, UMTS and 3GPP industry organization
- Backward compatible with GSM/IS-136.
- Based on UTRA-FDD and support soft handoff.
- Seamless mobility for voice and data applications
- Modulation: DL : QPSK, 16-QAM, 64-QAM. UL: PSK
- Chip rate: 3.84 Mcps, can be extended to 8.192 or 16.384 Mcps.
- BW 4.4 to 5 MHz.
- Data rate 384 Kbps in wide area, 2Mbps in local area
- Simultaneous data and voice..
- Originally it had the backing of Ericsson, Nokia and many big companies in Japan like the NTT DoCoMo.
- QoS differentiation for real-time services. (voice and video, and streaming multimedia traffic)

TD-CDMA

- TD-CDMA is also referred to as UMTS UTRA TDD.
- TD-CDMA uses unpaired spectrum and High Chip Rate.
- The uplink and the downlink are both accommodated on the same frequency.
- Suited for high data rates and low mobility .
- Developed in North American.

TD-SCDMA/ UMTS - Release 4

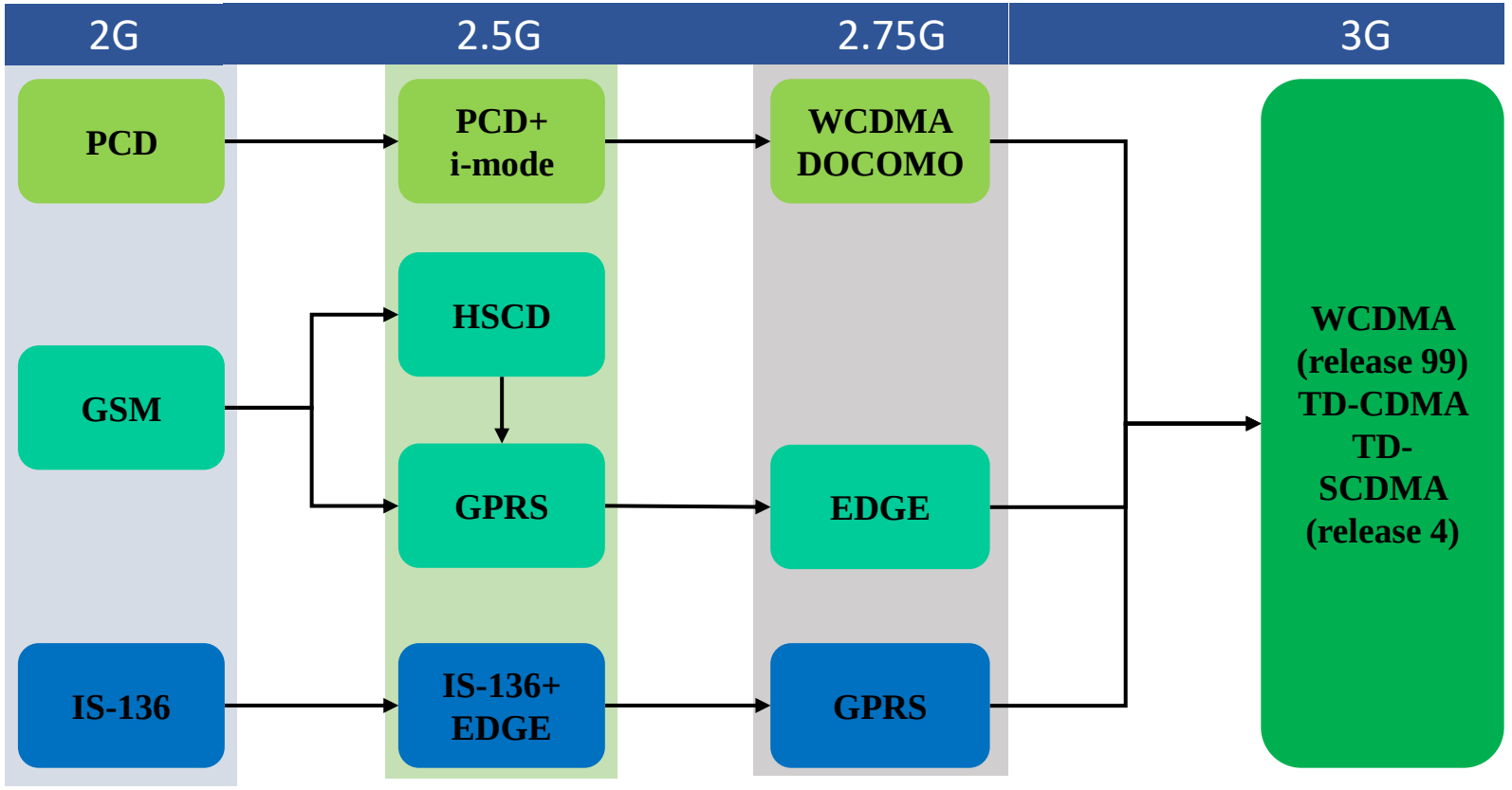
- Developed by Siemens.
- And China Academy of Telecommunications Technology (CATT).
- Data rates from 1.2 kbps up to 2 Mbps;
- Large coverage area, up to 40 km;
- High mobility, at least 120 km/h.
- TD-SCDMA is based on radio channels with a carrier bandwidth of 1.6 MHz.
- The uplink and the downlink use the same radio channel.

3GPP A GLOBAL INITIATIVE

UMTS 2000 ITU

The Third-Generation of Cellular Mobile System - Standards

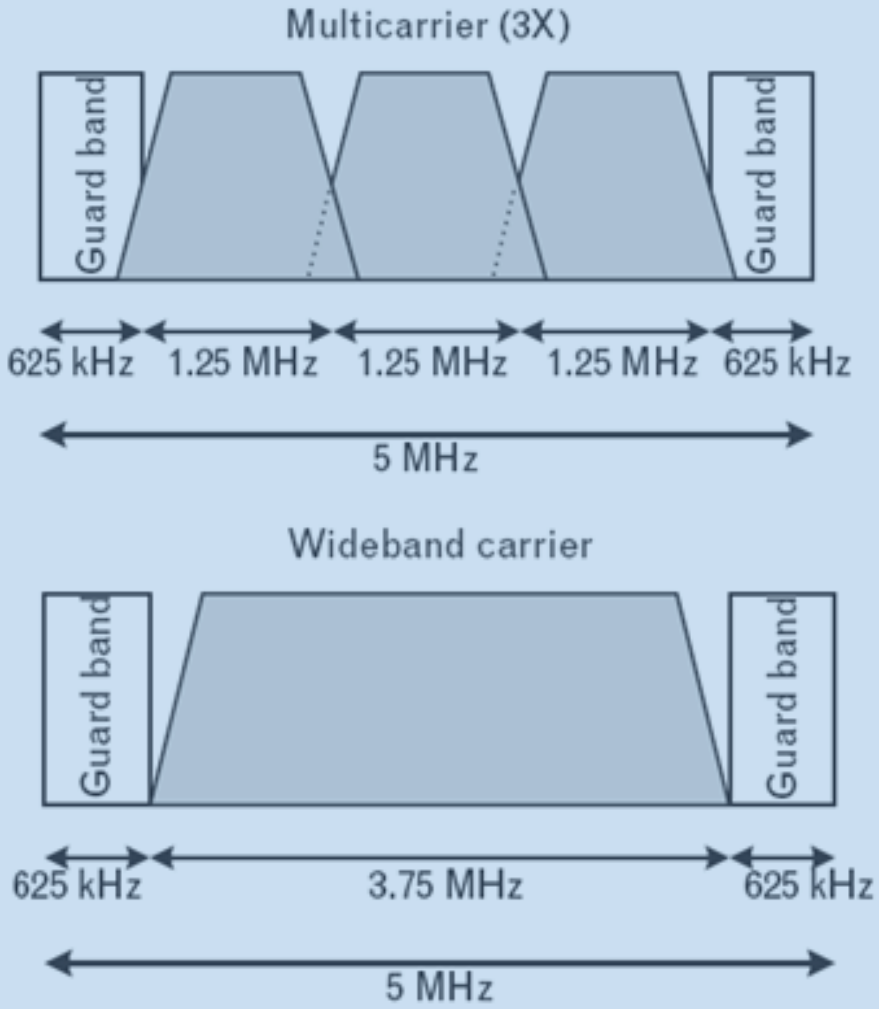
❖ UMTS 3G Evolution Path



The Third-Generation of Cellular Mobile System – Standards CDMA2000)

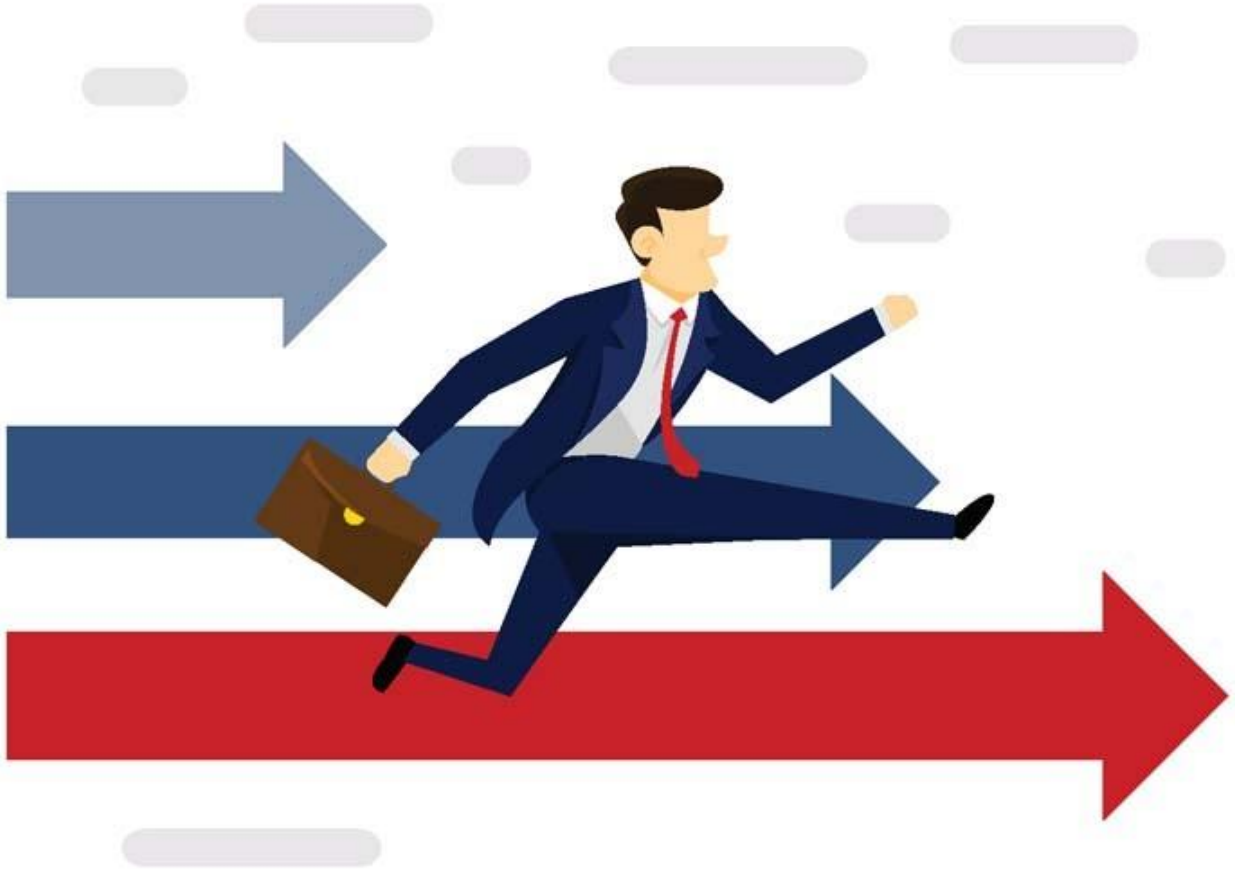
❖ Code Division Multiple Access 2000 (CDMA2000)

- Member of the IMT-2000 with name IMT-CDMA Multi-Carrier.
- commercially developed by Qualcomm based on IS95A.
- Standard by 3GPP2.
- Use 1 up to 3 carriers of 1.25 MHz.
- Chip rate 14.7456 Mcps and is not fixed like UTRAN.
- Uses multicarrier in DL and Direct spread in UL.
- A carrier of 1.25 MHz width is chosen to make a smooth evolution from cdmaOne possible.



3G 3rd Generation Partnership Project 2 "3GPP2"

The Third-Generation of Cellular Mobile System - Standards



The evolution of CDMA2000

The 3G of Cellular Mobile System – cdmaOne to CDMA2000

cdmaOne

IS-95A → **IS-95B** → **IS-2000**

CDMA2000 1xRTT

- DL and UL data rate 144 kbps.
- Backward compatible with cdmaOne
- circuit snitching technology

CDMA2000 1xRTT Enhancements

- 1.5X increase in voice capacity
- DL and UL data rate 153 kbps.
- Backward compatible with cdmaOne
- circuit snitching technology

CDMA2000 1xRTT Advanced -3x

- 4X increase in voice capacity
- DL and UL data rate 307 kbps.
- Backward compatible with cdmaOne
- circuit snitching technology

1xEV-DO Release 0	1xEV-DO Rev. A	1xEV-DO Rev. B Multi carrier only	1xEV-D-DO Rev. B (MC/HW upgrade)	1xEV-DO Advanced
DL: 2.4 Mbps UL: 153 kbps. 1.25 MHz/CH FDD	DL: 3.1 Mbps UL: 1.8 Mbps. 1.25 MHz/ CH FDD	- DL: 9.3 Mbps, UL: 5.4 Mbps, BW= 5 MHz, FDD - Reduce latency using Multiplexing → improved QoS - Longer talk and Standby time. - Reduced interference at cell edge → improved QoS - More efficient asymmetric data rate UL≠ DL (web browning, email, file transferee, Multimedia delivery)	DL: 14.7 Mbps,. UL: 5.4 Mbps. 1.25 MHz per channel FDD	DL: 32 Mbps,. UL: 12.4 Mbps. 4x1 125 MHz/CH DD

1xEV-DV

- DL: 3.1 Mbps, UL: 2.1 Mbps, - Offers complete backward compatibility with CDMA 2000 - Integrate voice and data on a single channel

1xEV-DO (Data Only)

First phase of evolution of CDMA2000

Outs voice and data on separate channels in order to provide data delivery at 2.4Mbps

1xEV-DV (Data and Voice)

Second phase of evolution of CDMA2000

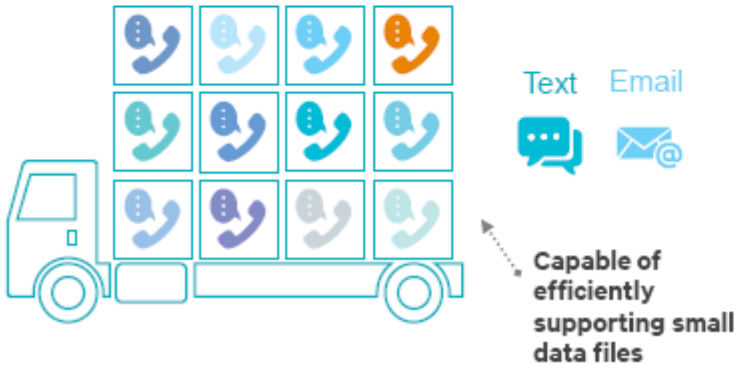
Carry both data and voice services on the same channel.

The Third-Generation of Cellular Mobile System - Standards

EV-DO optimized 3G for data enabling mobile broadband

Data Enabled
Simple Data Services

Mobile 2G
<0.5 Mbps[1]



Data Optimized
Mobile Broadband

CDMA2000/EV-DO
14.7 Mbps[2]

CDMA2000
Voice Services

EV-DO
Data optimized channel with support for larger package sizes

The Third-Generation of Cellular Mobile System - Standards

EV-DO inventions are the foundation to mobile broadband

1 Data Optimized Channel

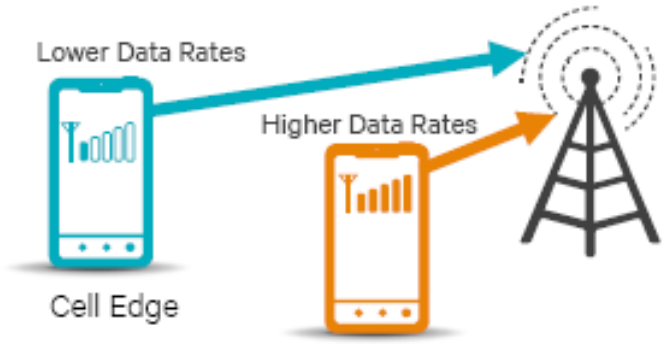
Splits channel into time intervals enabling a single user to get all the resources at once

Enables richer content

2 Adaptive Modulation

Uses higher order modulation to get more bps per Hz for users with good signal quality

Increases peak data rates



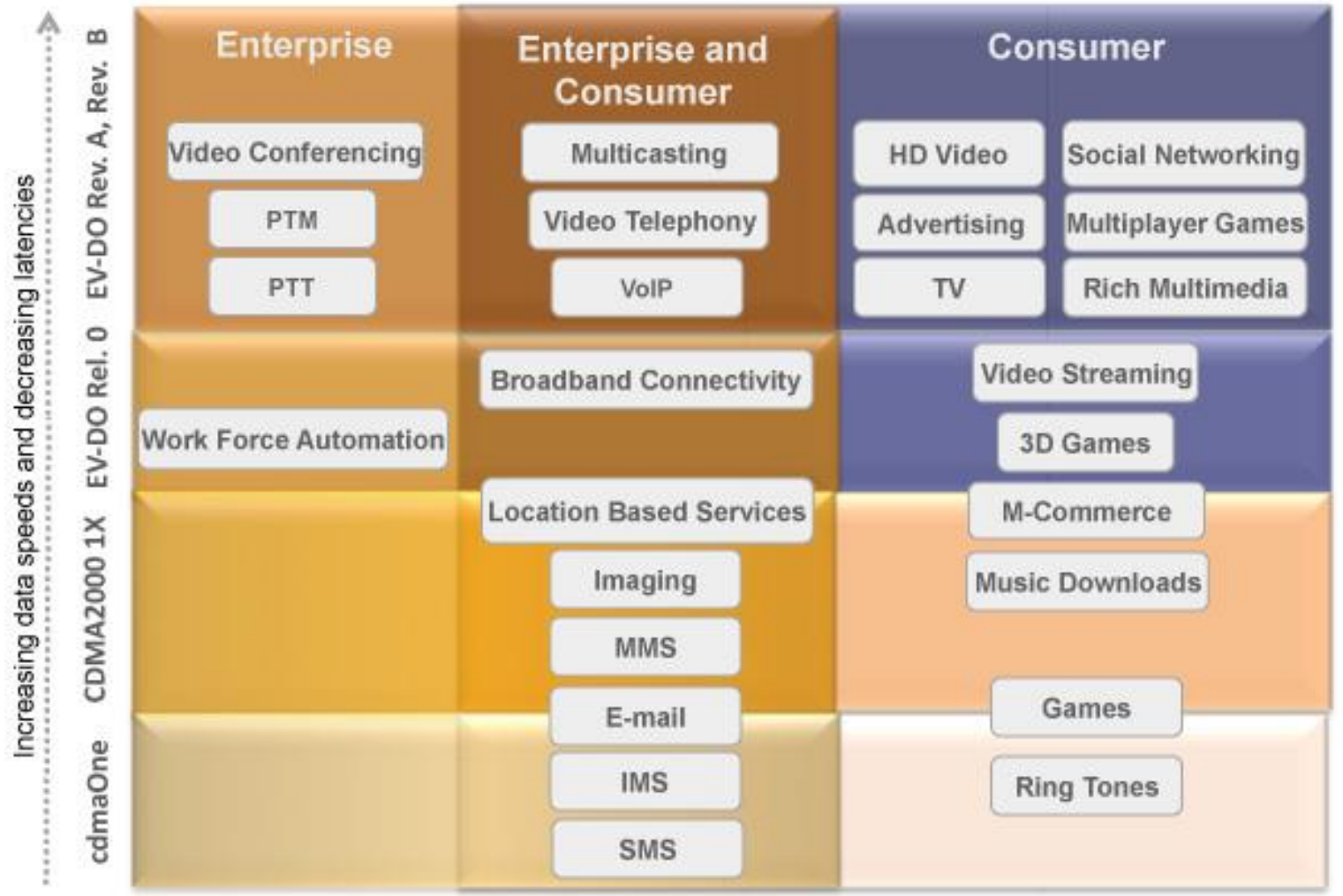
3 Opportunistic Scheduling

Optimizes channel by scheduling users at the time instances when users have good radio signal conditions (with fairness)

Increases overall capacity

3G

The 3G of Cellular Mobile System – CDMA 2000 Applications



The 3.5G of Cellular Mobile System – UMTS enhancements

❖ High Speed Packet Access (HSPA): Enhancement of the UMTS

Standard by 3GPP2.

- ❑ A set of radio resources dynamically shared among multiple users, primarily in the time domain.
- ❑ Fixed set of codes shared between users
- ❑ Adaptive Modulation (QPSK and 16 QAM).
- ❑ A new measure of Radio quality - CQI : Channel Quality Indicator,
- ❑ Fast adaptation/Scheduling based on CQI.
- ❑ New MAC-hs for faster scheduling in Node B
- ❑ 2 ms TTI (Transmission Time Interval) for lesser delay.
- ❑ Best effort service.

HSDPA

- Enhances the DL channel.
- Available in 2005, release 5
- HS DL shared channel (HS-DSCH).
- Theoretical up to 14 Mbps
- Initial capability 1.8 – 3.6 Mbps
- Speeds of 550-1100 kbps /user.
- Lower latency.
- Requires Node B HW modification.
- Requires RNC software upgrade.
- Adaptive modulation (QPSK or 16QAM) and codeing.
- Fast packet scheduling at Node B

HSUPA

- Enhances the UL channel.
- In UMTS, release 6.
- Theoretical up to 5.76 Mbps
- Initial capability 1.46 Mbps
- Improves the coverage
- Improves throughput.
- Reduces delay.

HSPA+

- HSPA+ all IP networks.
- Launched in Hong Kong in 2009.
- HSPA+ is a HSPA evolution.
- Downlink : 21 to 336 Mbps.
- Uplink: 22 Mbps.
- Adding 64 QAM modulation.
- Adding 2x2 and 4x4 MIMO.
- Release 7 and improved in release 11.

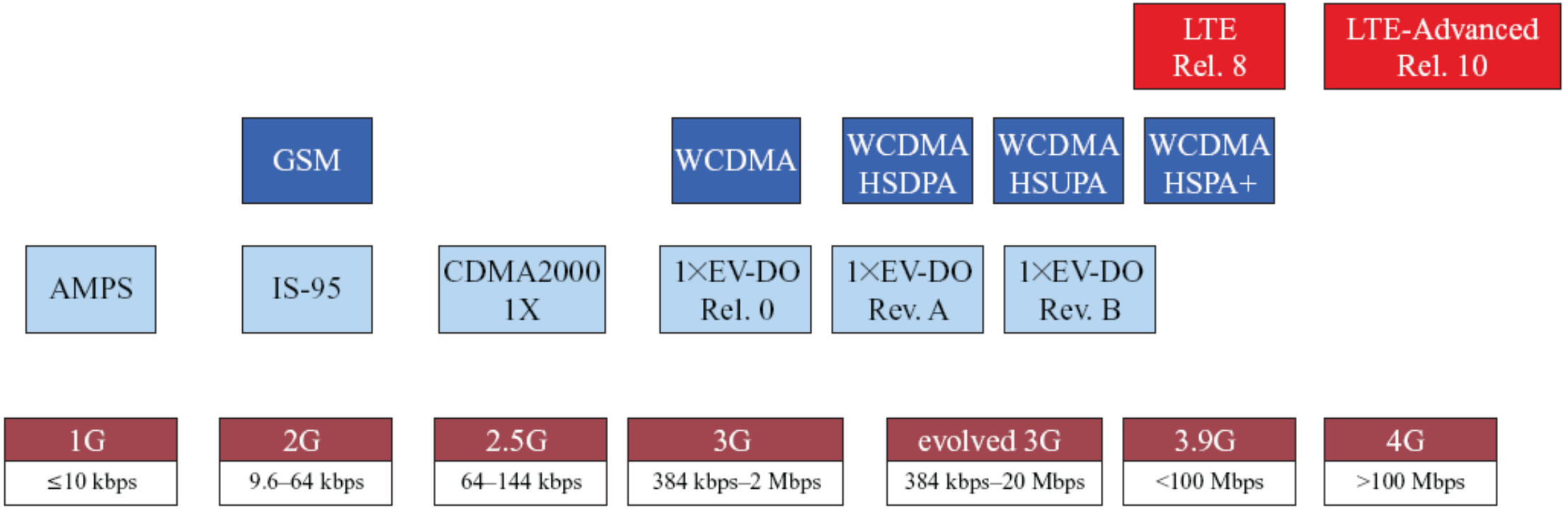
GSM → WCDMA → WCDMA HSDPA → WCDMA HSUPA → WCDMA HSPA+

MAC-hs Function

Resource Estimations
Queue Validation
Queue Selection

The 3.5G of Cellular Mobile System

❖ Evolution summary from 1G to 3G



Thank you