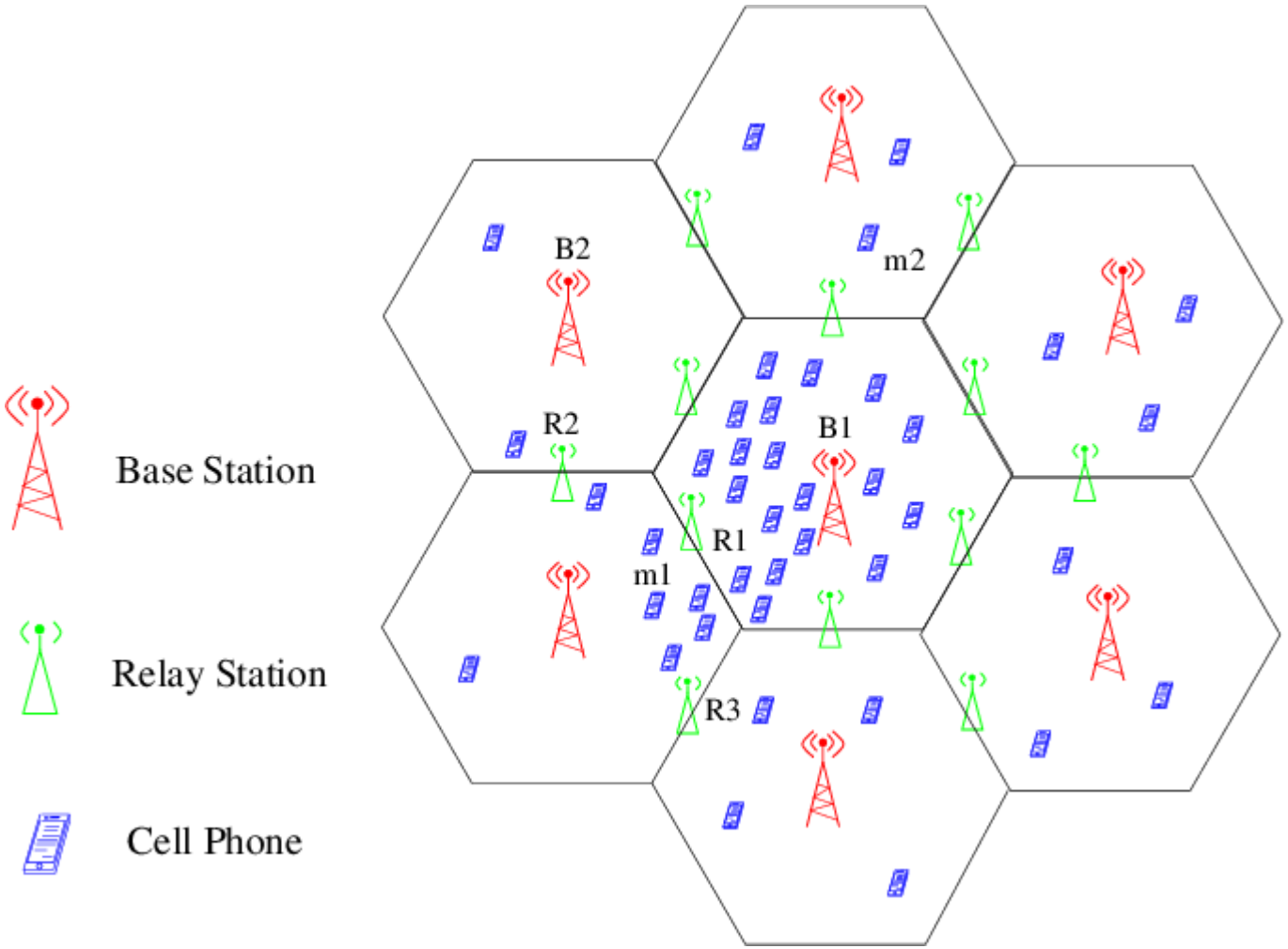
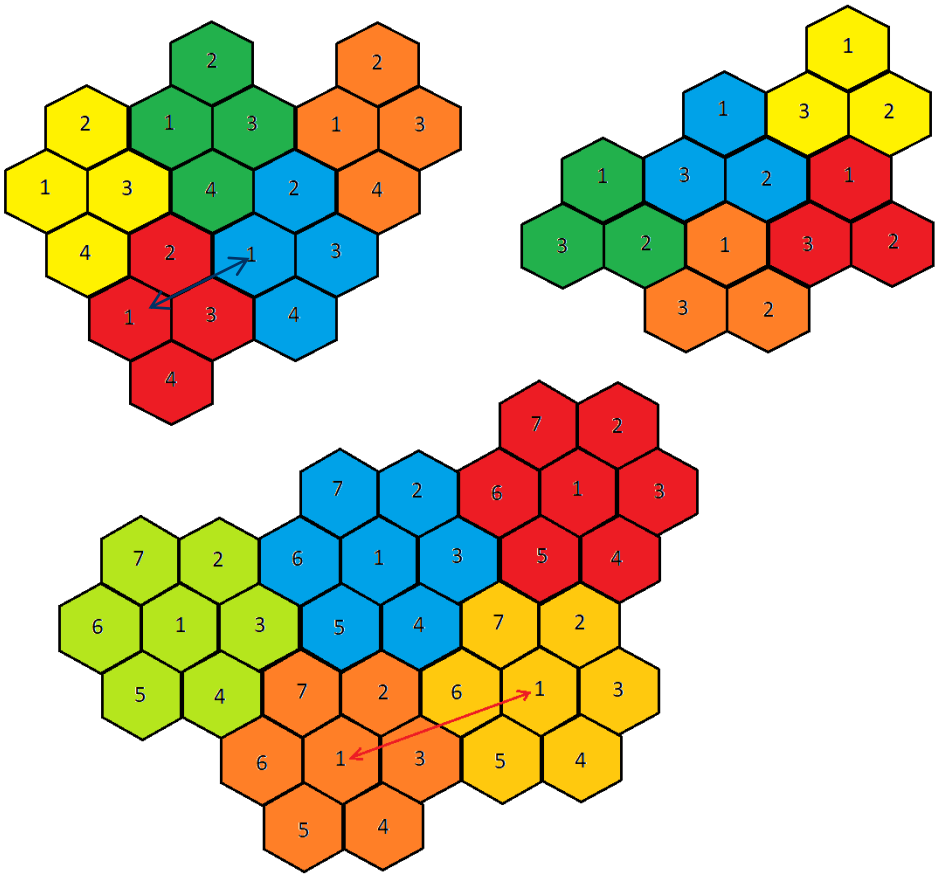
# Mobile and Wireless Networks

## Cellular Structure

# Cellular Network Organization



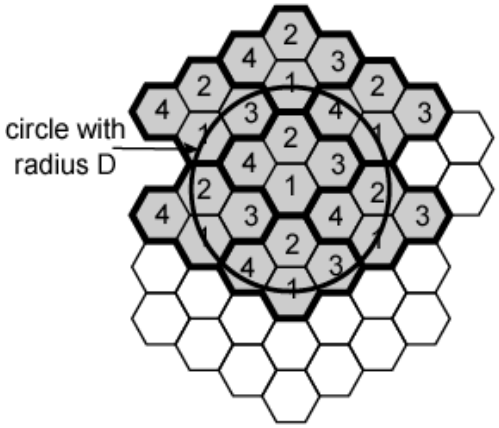
# Frequency Reuse



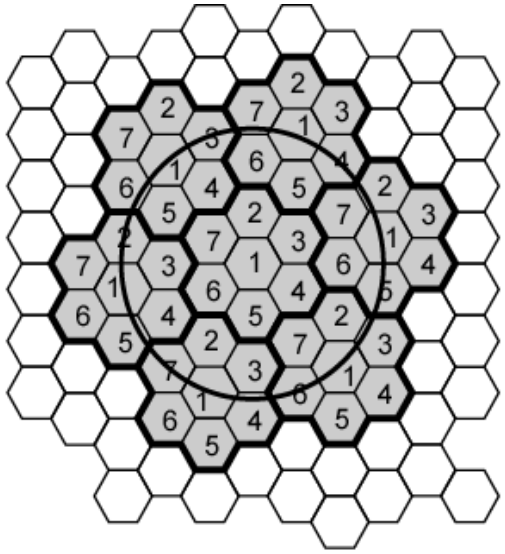
# Frequency Reuse

- Power of base transceiver controlled
  - Allow communications within cell on given frequency
  - Limit escaping power to adjacent cells
  - Allow re-use of frequencies in nearby cells
  - Use same frequency for multiple conversations
- *E.g.*
  - *N* cells all using same number of frequencies
  - *K* total number of frequencies used in systems
  - Each cell has *K/N* frequencies
  - *K*=395, *N*=7 giving 57 frequencies per cell on average

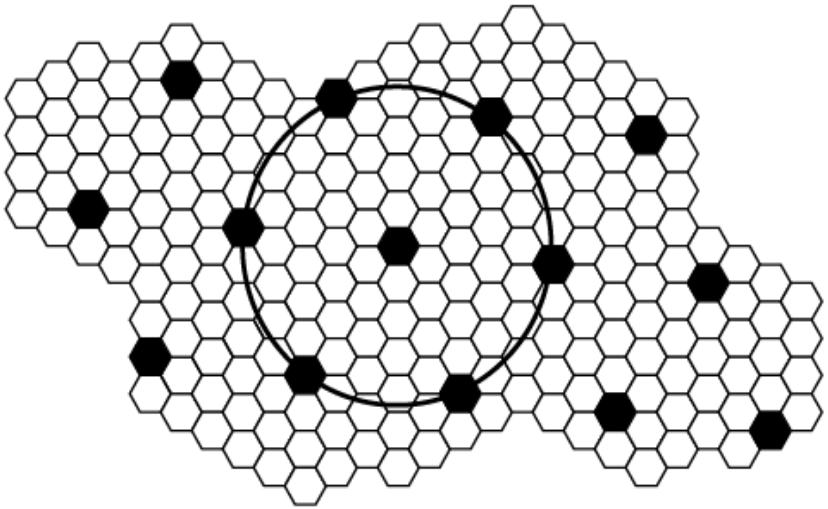
# Frequency Reuse Patterns




(a) Frequency reuse pattern for N = 4

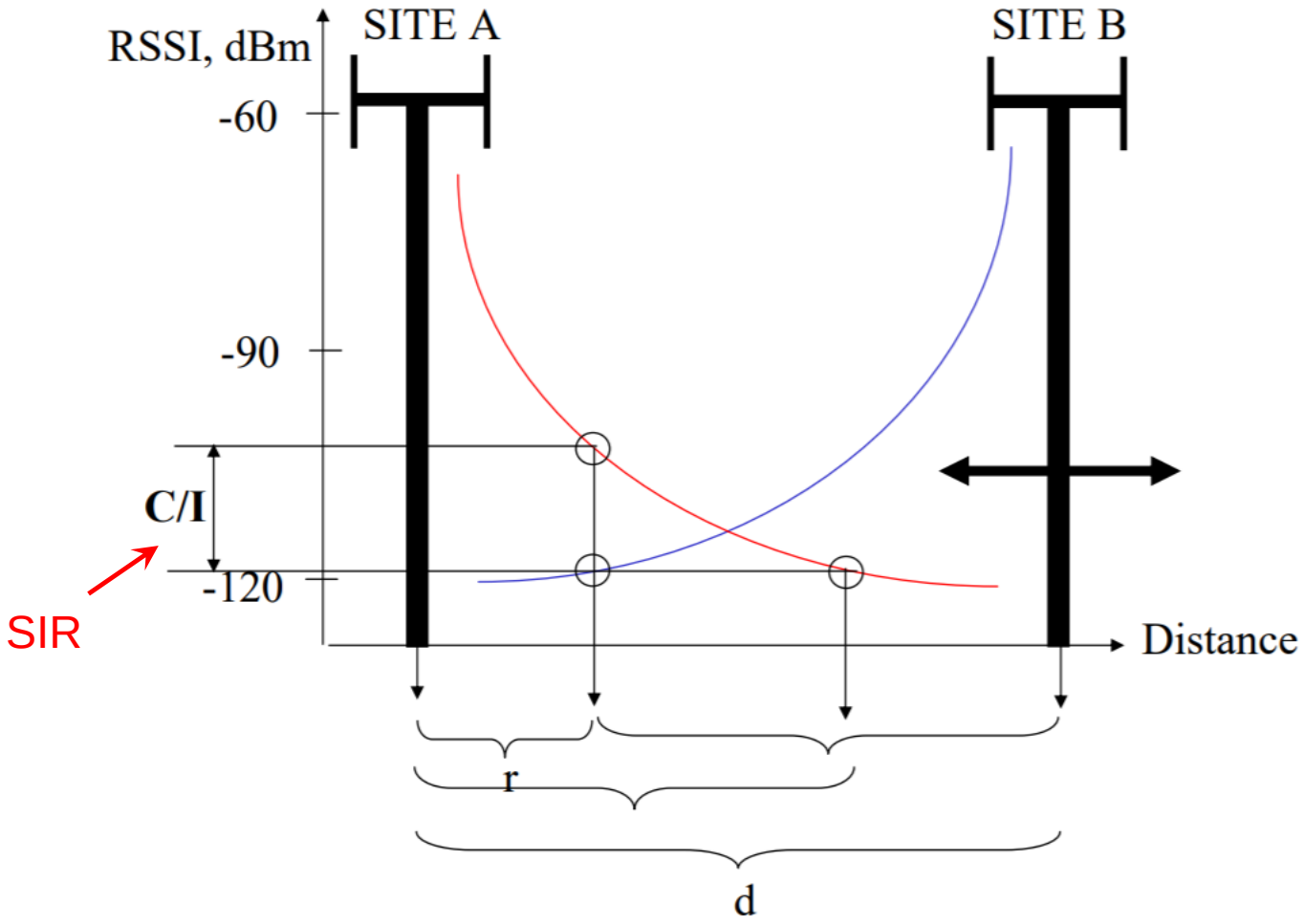


(b) Frequency reuse pattern for N = 7

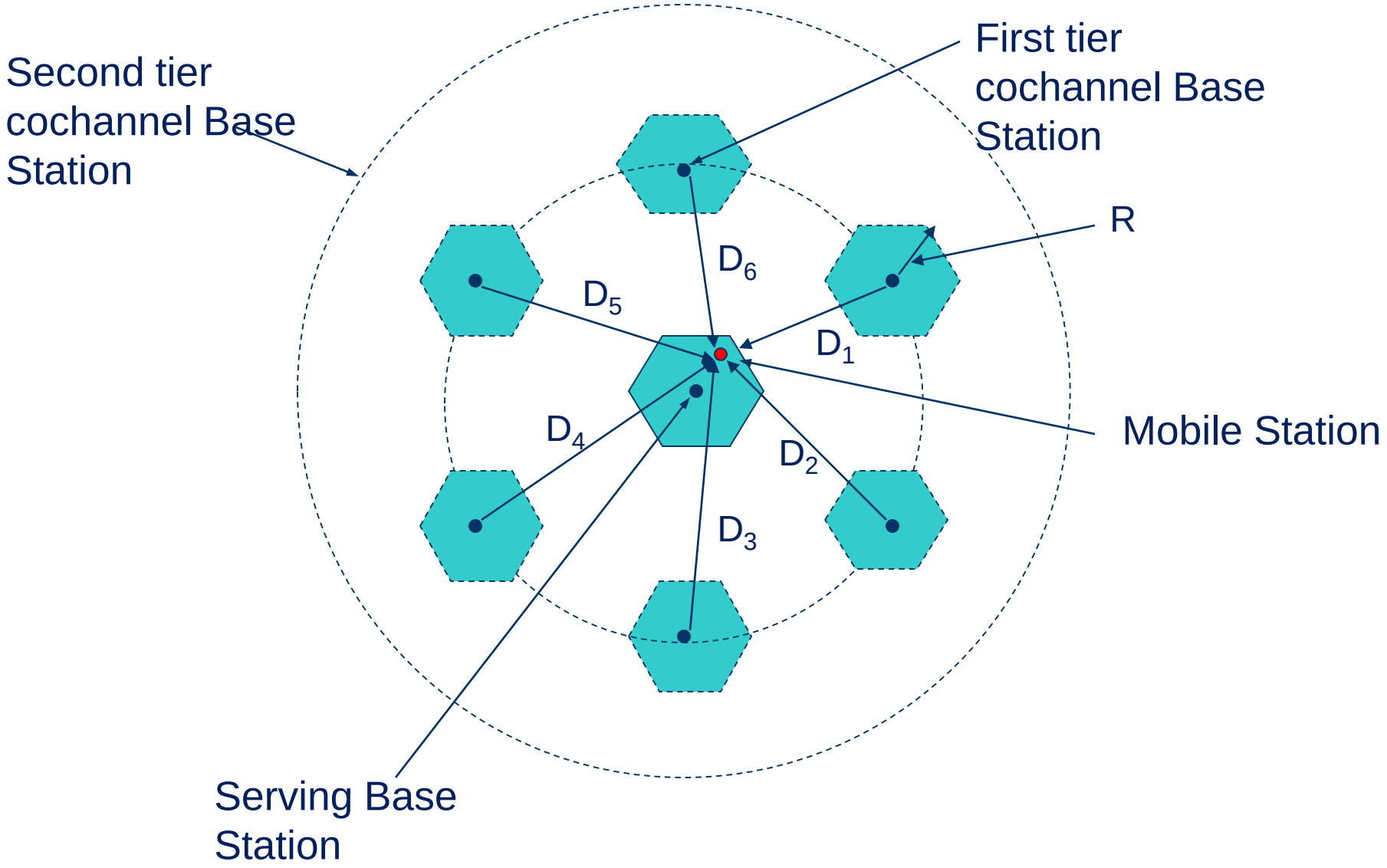


(c) Black cells indicate a frequency reuse for N = 19

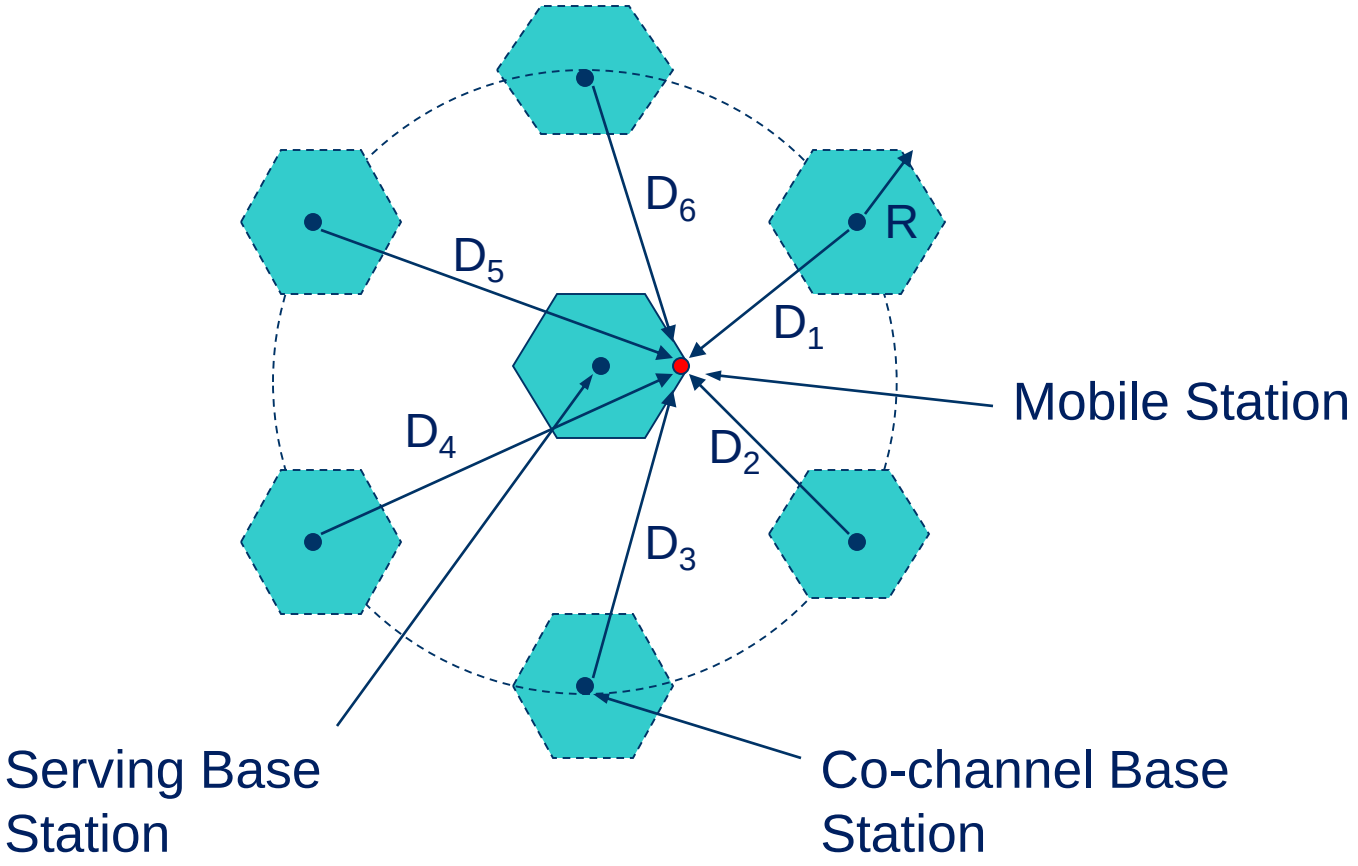
# Frequency Reuse Distance



# Cochannel Interference

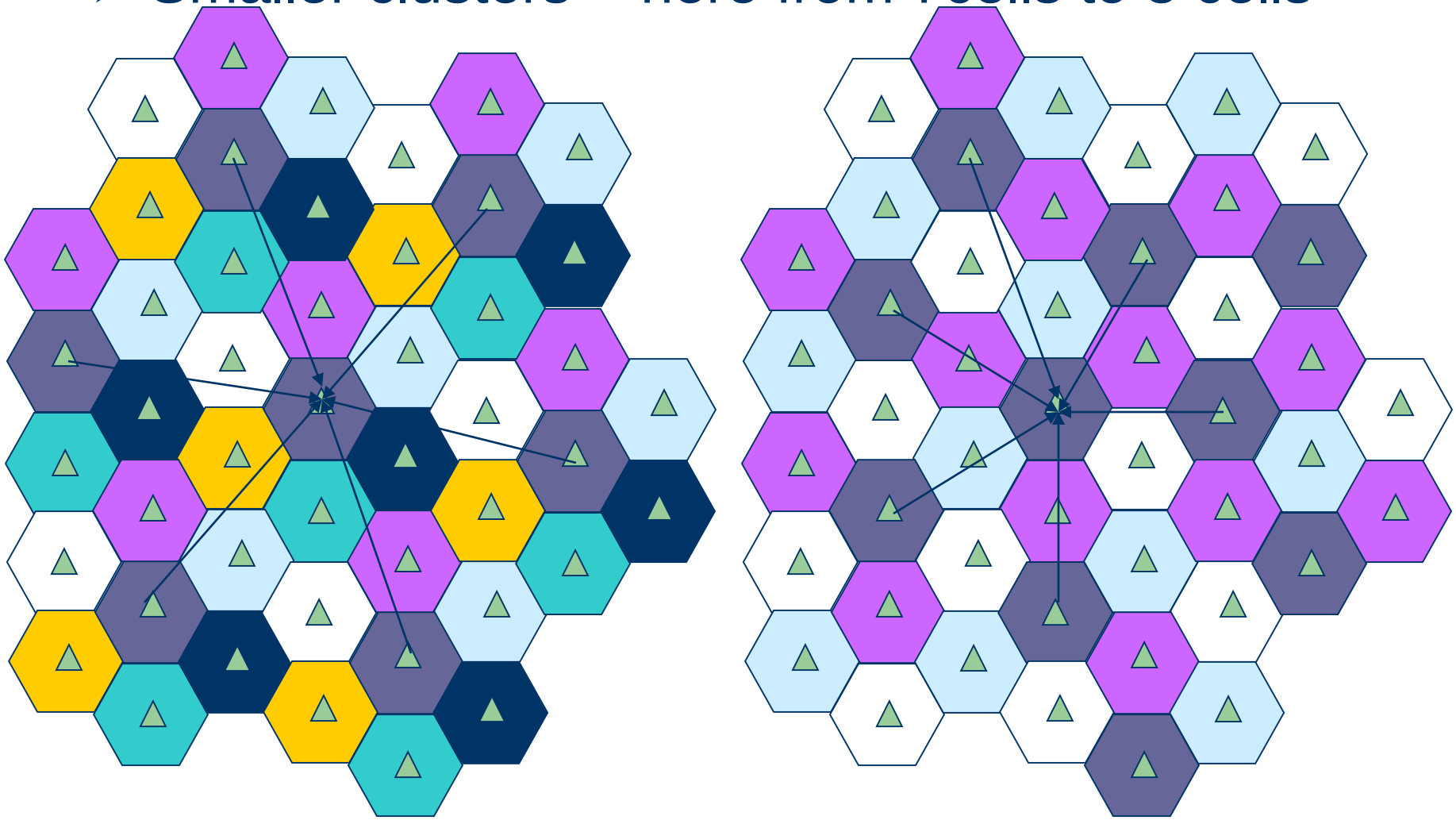


# Worst Case of Cochannel Interference



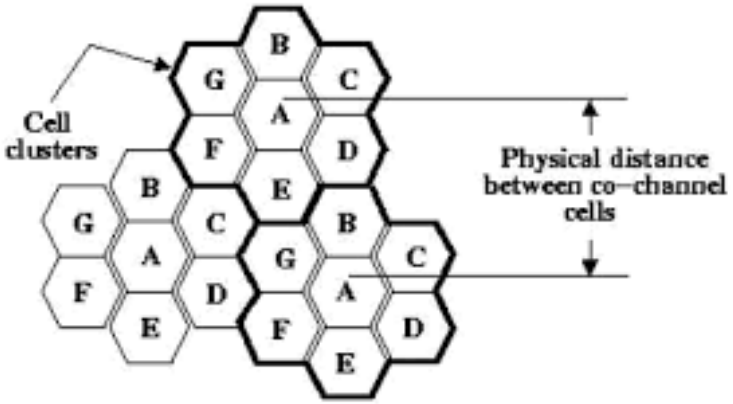
# Increasing Capacity (1)

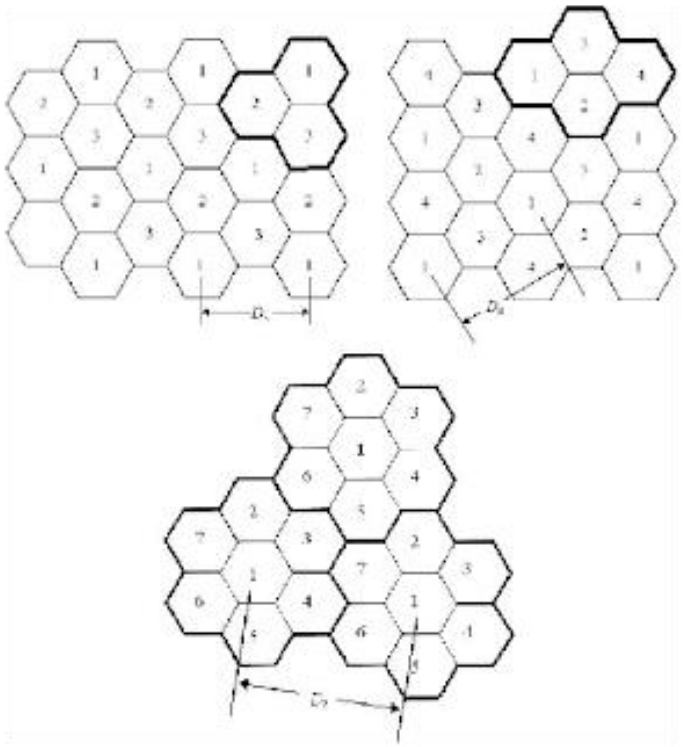
- Smaller clusters - here from 7cells to 3 cells



Interfering cells are closer when cluster size is smaller.

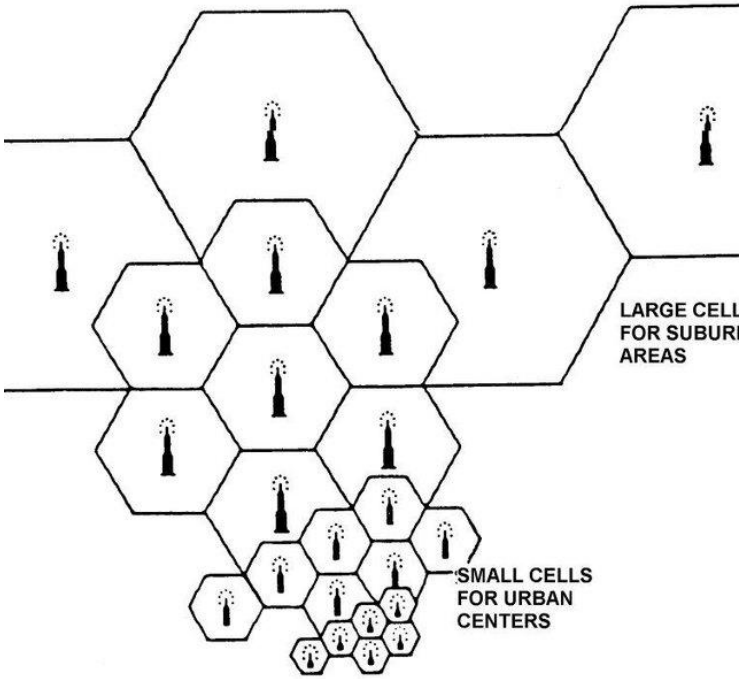
# Increasing Capacity (1)



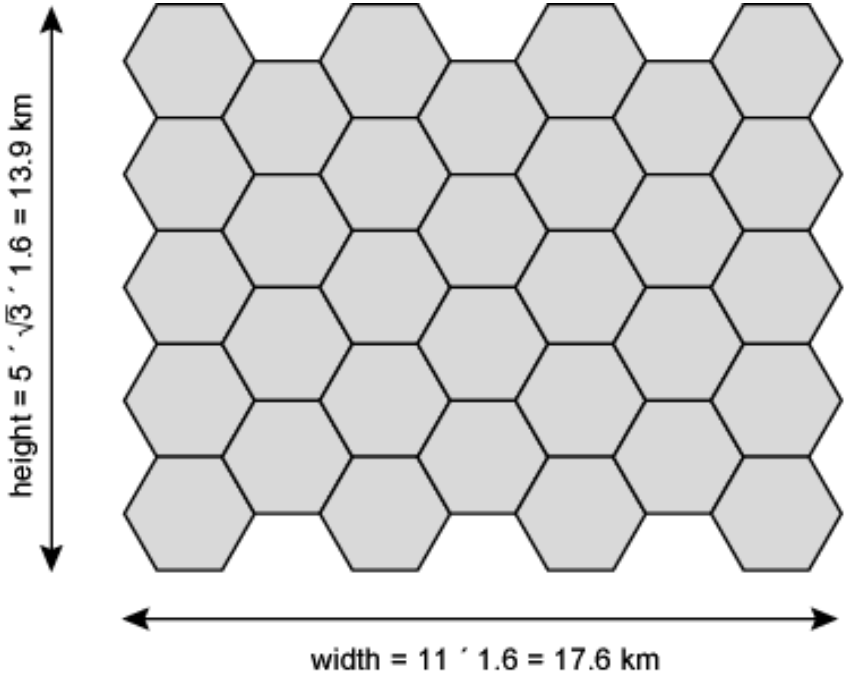
# Increasing Capacity (2)

- Cell Splitting
  - Cells of high usage can be split into smaller cells
  - Leads to increased capacity but more frequent handovers

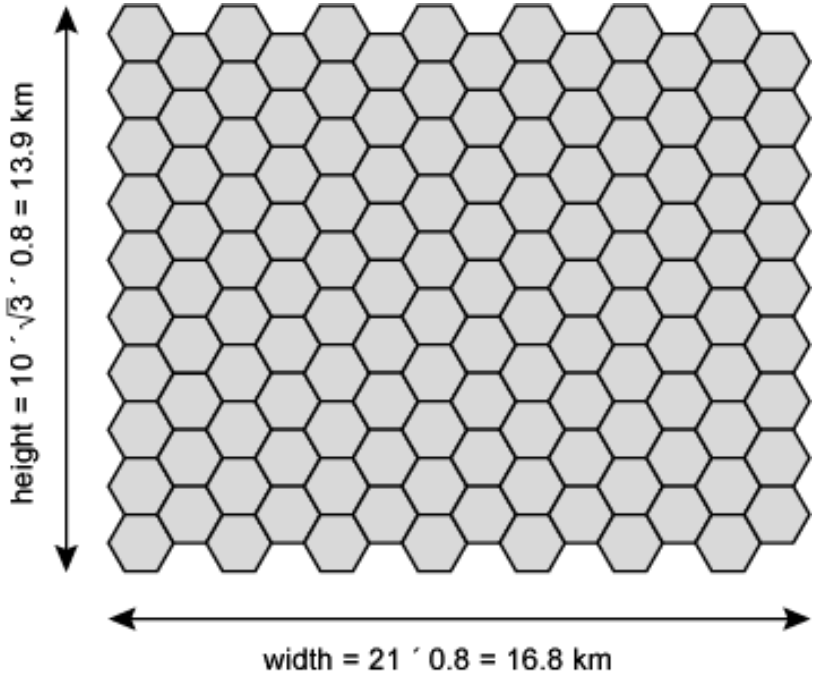


# Increasing Capacity (3)

- Smaller cells




(a) Cell radius = 1.6 km




(b) Cell radius = 0.8 km

# Increasing Capacity (4)

- Cell Sectoring
  - Cell divided into wedge shaped sectors
  - 3 – 6 sectors per cell
  - Each with own channel set
    - Subsets of cell's channels
  - Directional antennas

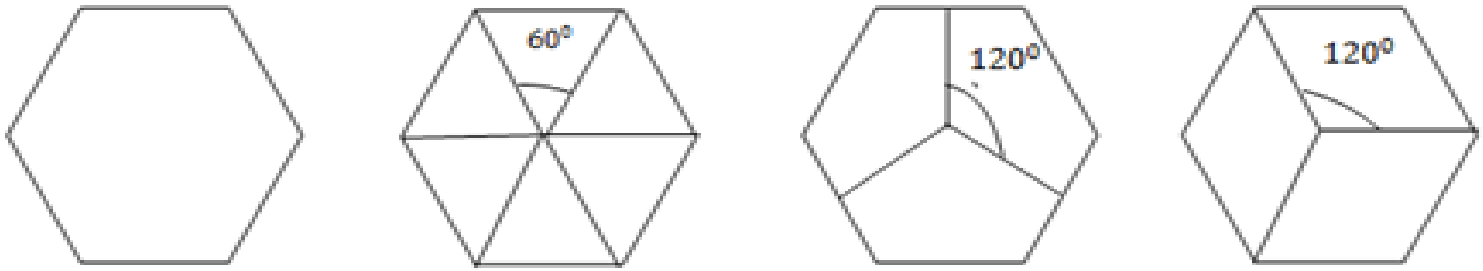
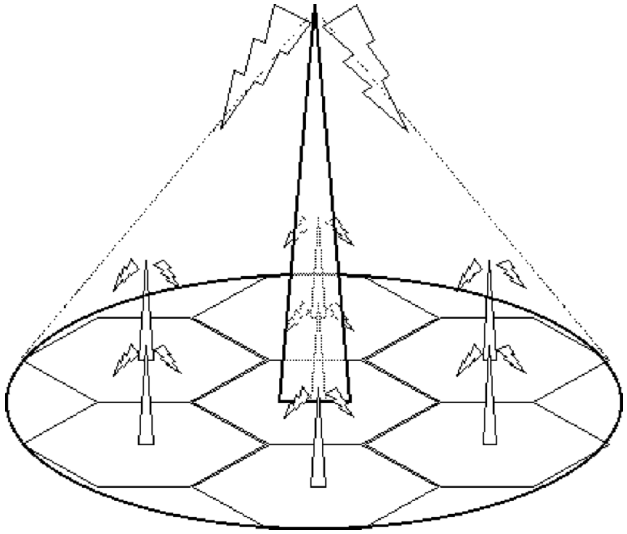



Fig: omni-directional $60^0$ sectoring $120^0$ sectoring

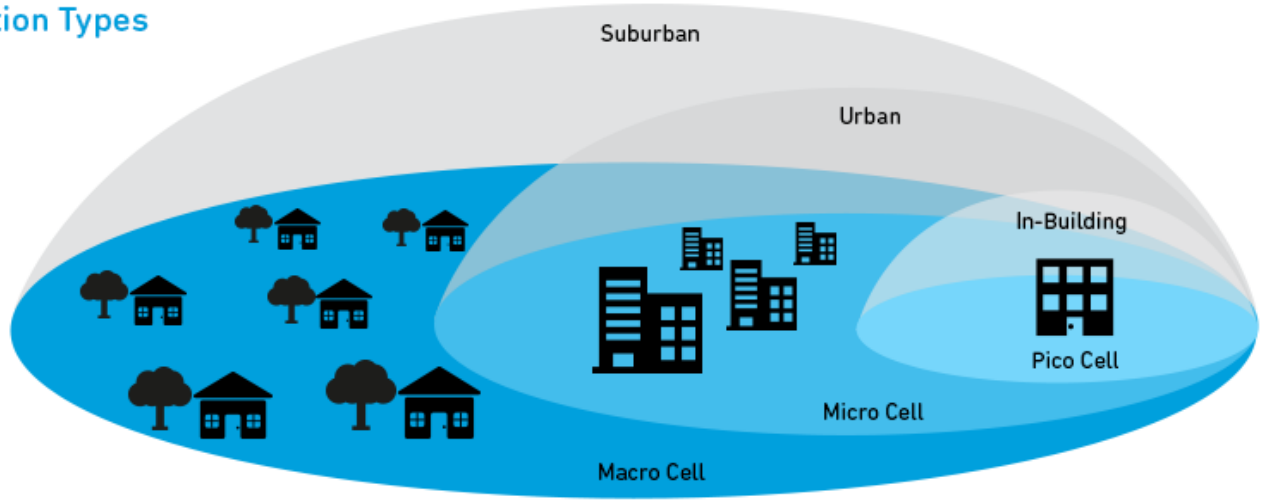
# Increasing Capacity (5)

- Microcells
  - Move antennas from tops of hills and large buildings to tops of small buildings and sides of large buildings
    - Even lamp posts
  - Form microcells with reduced power
  - Good for city streets, along roads and inside large buildings



# Multi-tier architectures

## Base Station Types




| Cell Type | Output Power (W) | Cell Radius (km) | Users | Locations |
|---|---|---|---|---|
| Femtocell | 0.001 to 0.25 | 0.010 to 0.1 | 1 to 30 | Indoor |
| Pico Cell | 0.25 to 1 | 0.1 to 0.2 | 30 to 100 | Indoor/Outdoor |
| Micro Cell | 1 to 10 | 0.2 to 2.0 | 100 to 2000 | Indoor/Outdoor |
| Macro Cell | 10 to >50 | 8 to 30 | >2000 | Outdoor |

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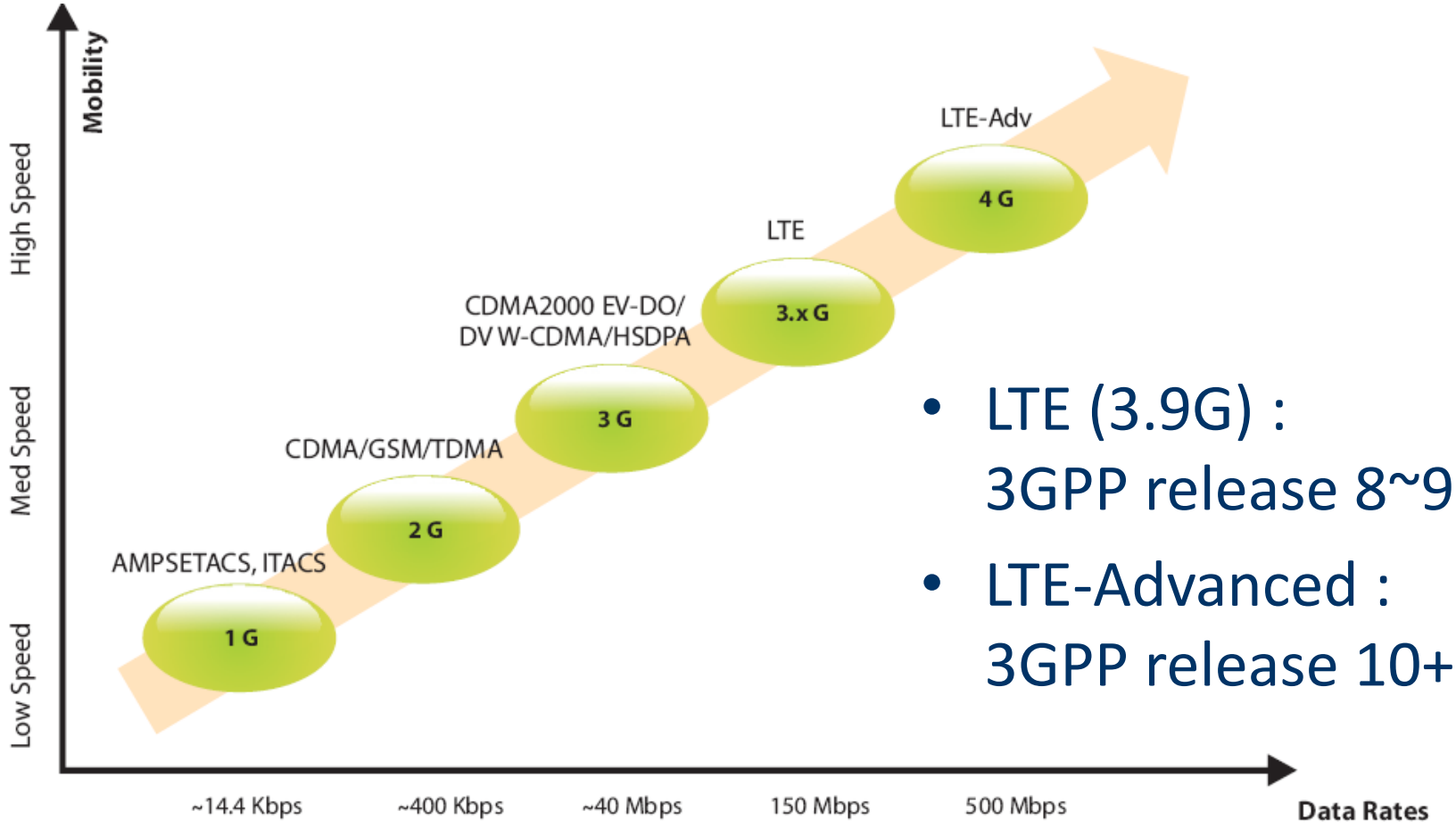
# Cellular Network Generations

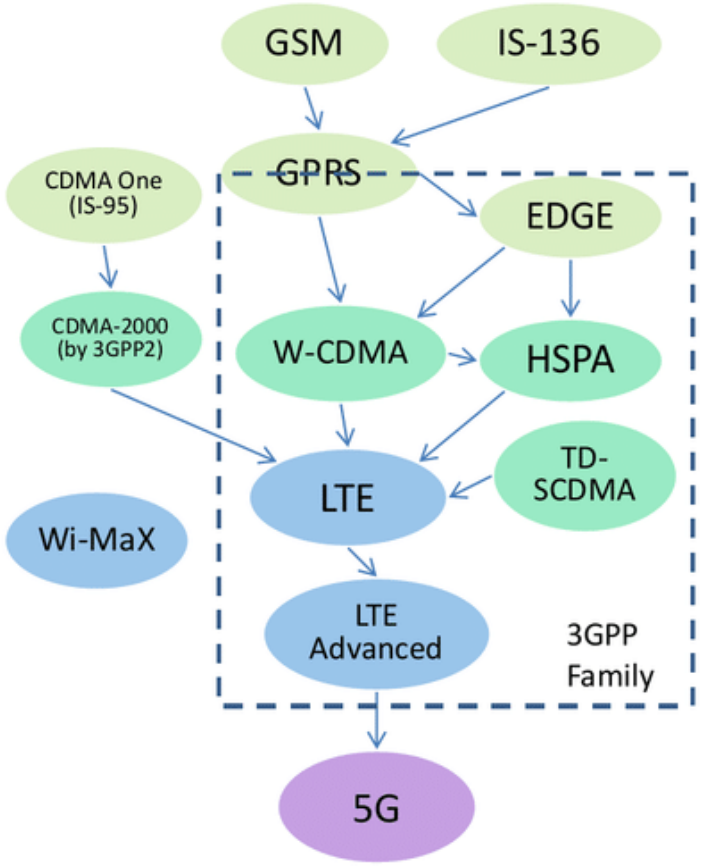
- It is useful to think of cellular Network/telephony in terms of *generations*:
  - 0G: Briefcase-size mobile radio telephones
  - 1G: *Analog* cellular telephony (end ‘70s)
  - 2G: *Digital* cellular telephony (beg ’90’s)
  - 3G: *High-speed* digital cellular telephony (including *video telephony*) (beg ’00)
  - 4G: IP-based “anytime, anywhere” voice, data, and multimedia telephony at *faster* data rates than 3G (beg ’10)
  - 5G: 10-times faster data rates, much more flexible in mobility, Internet of Things (IoT) support (cheap, low energy, massive number of devices) (beg ’20)

# Evolution of Radio Access Technologies




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

# Evolution of Cellular Standards




**2G**

- Mainly circuit switched, with packet-switching introduced since GPRS
- Based on TDMA (and CDMA for CDMA One)

**3G**

- Circuit and Packet-switched
- (Primarily) based on wideband CDMA

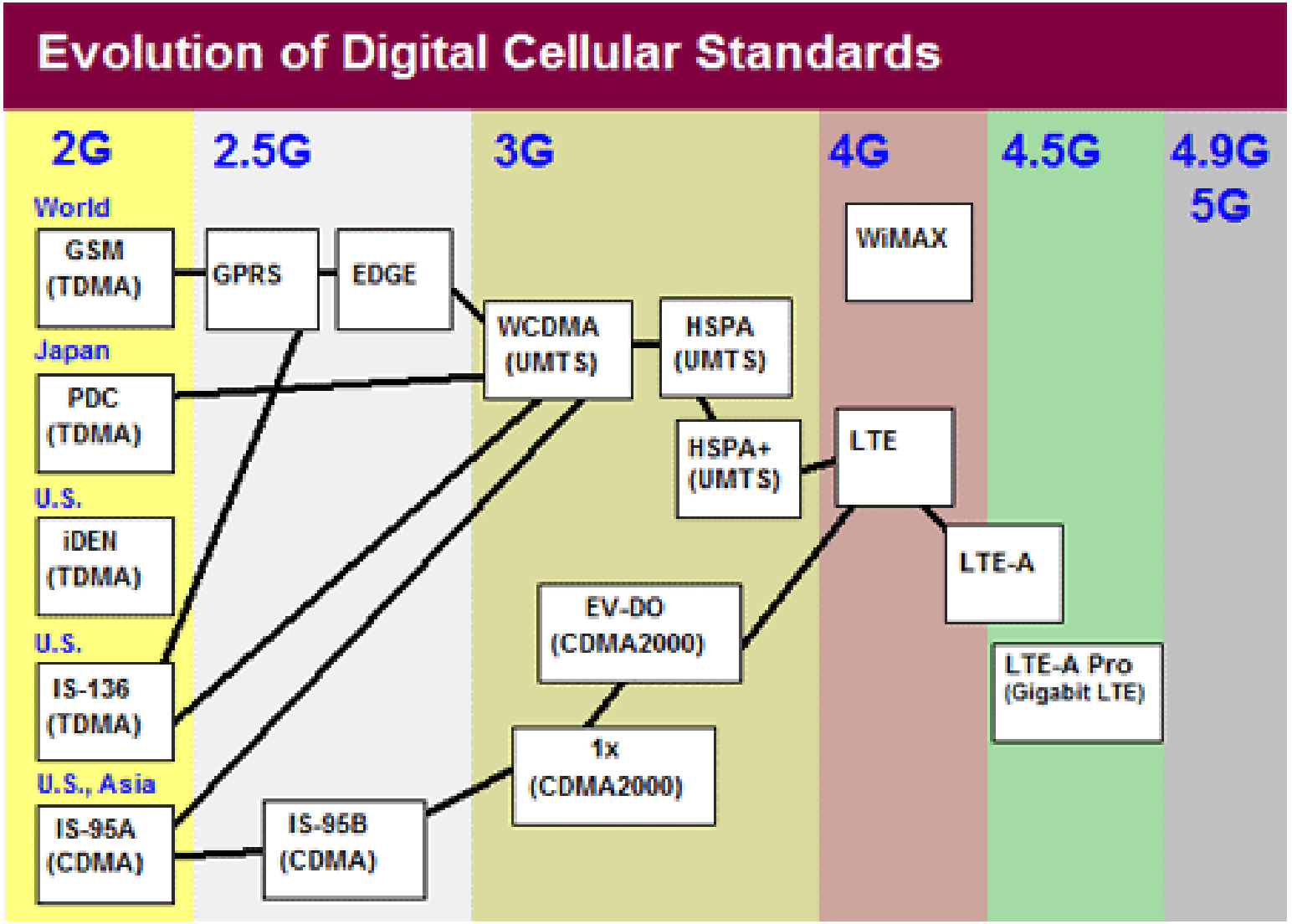
**4G**

- All IP flat architecture with evolved packet core.
- Based on OFDM and MIMO
- Cooperative processing

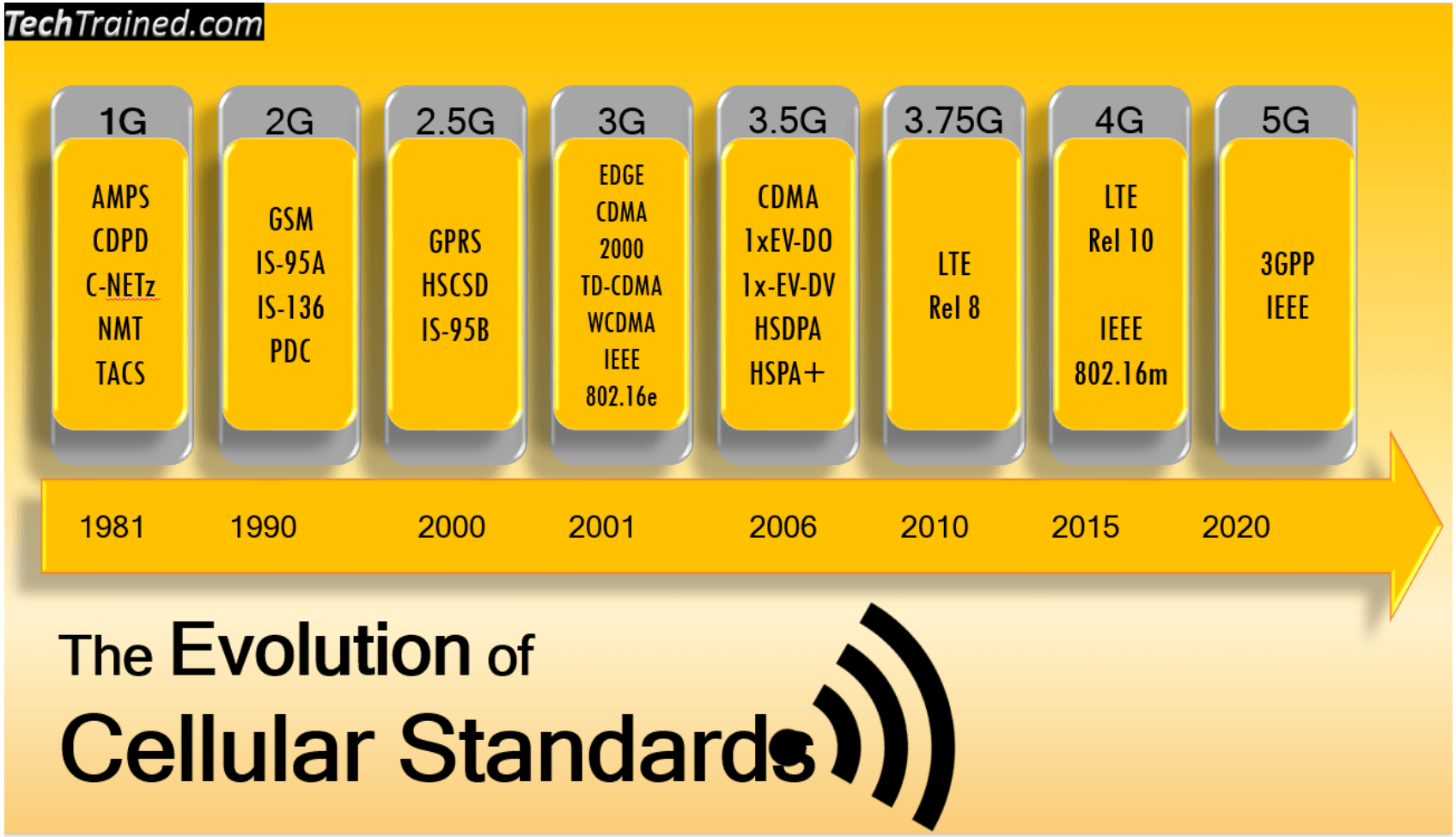
**5G**

- Based on massive MIMO, Small Cell and centralized processing techniques
- Integrated wire and wireless full IP networks

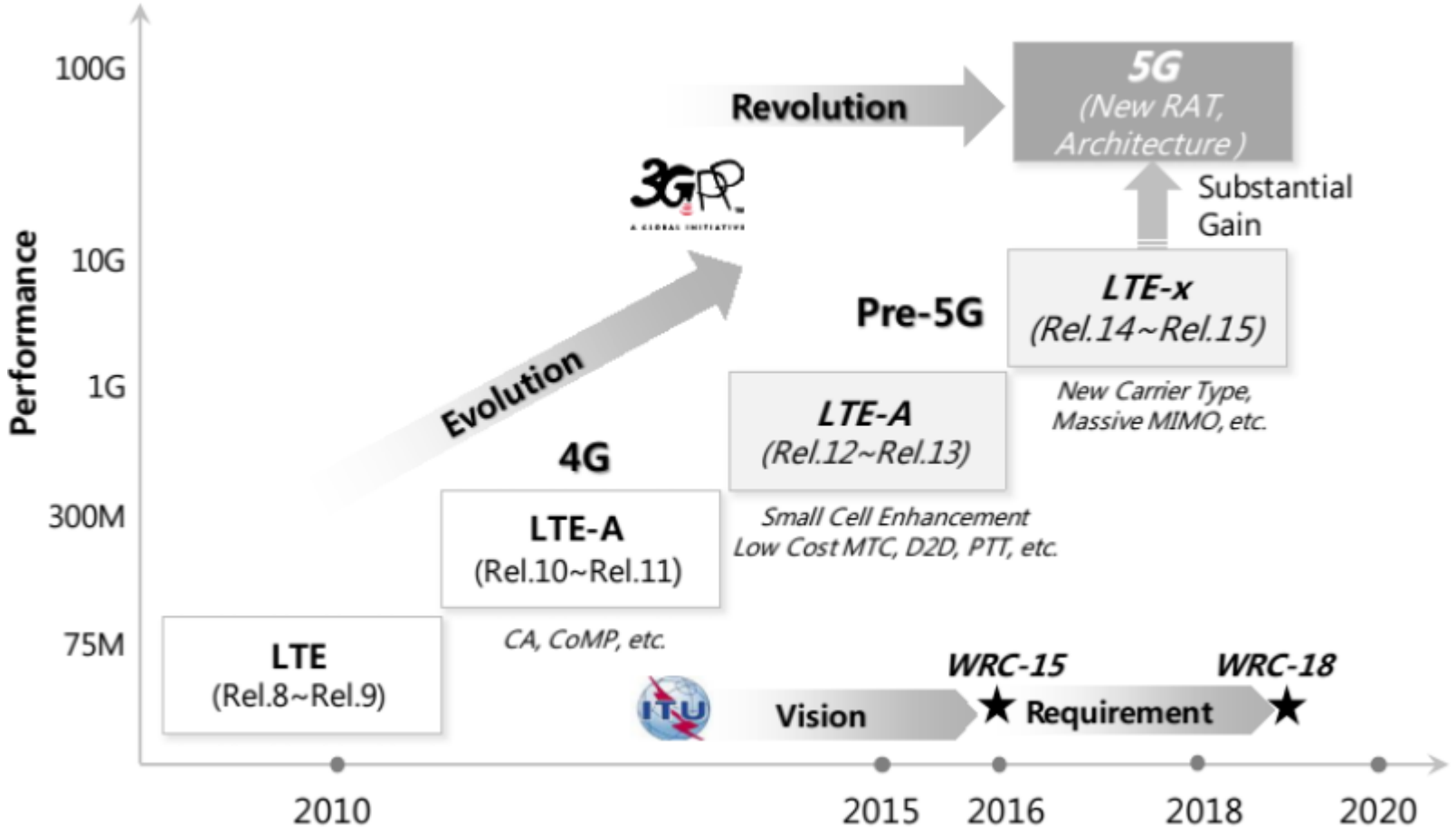
# Evolution of Cellular Standards



# Evolution of Cellular Standards

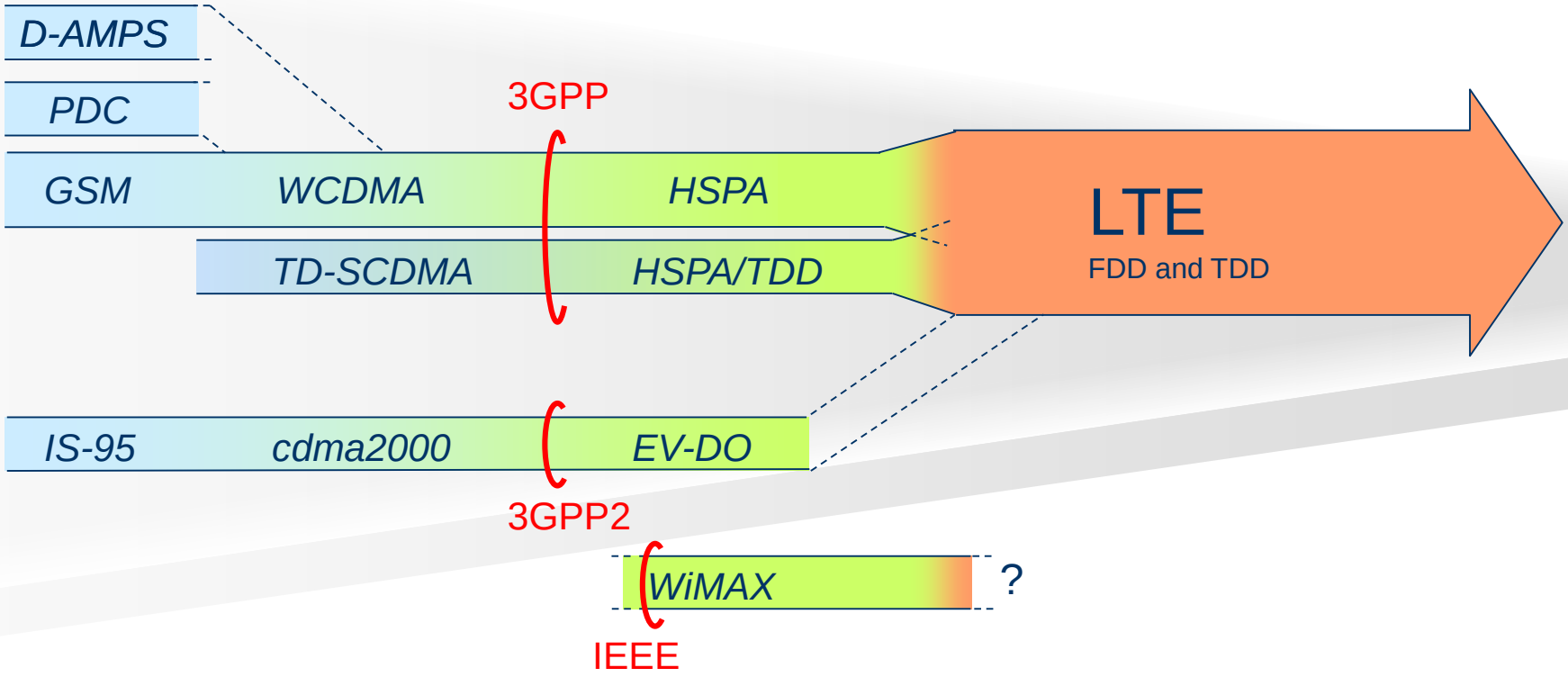


# Evolution of Cellular Standards

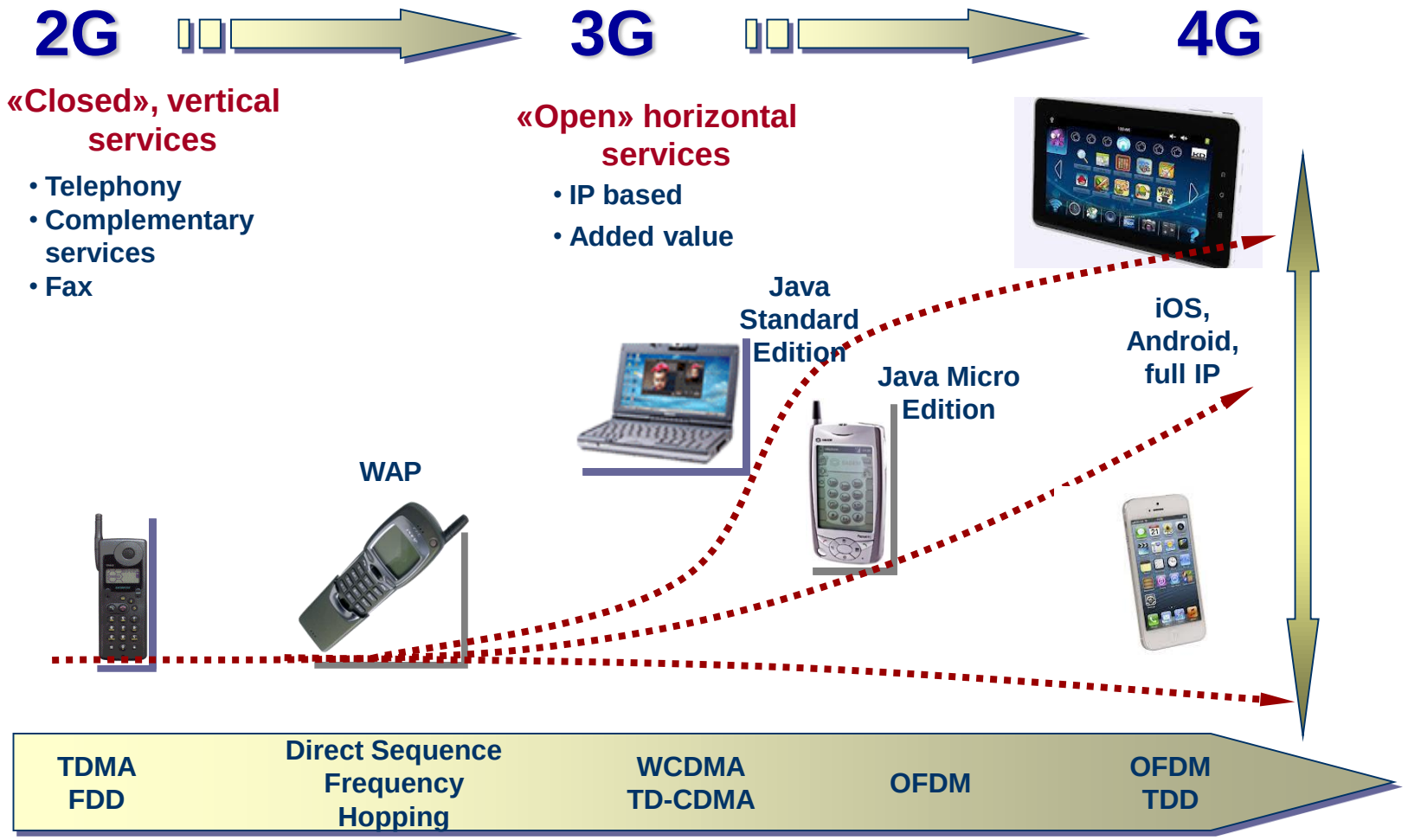


# Global Convergence

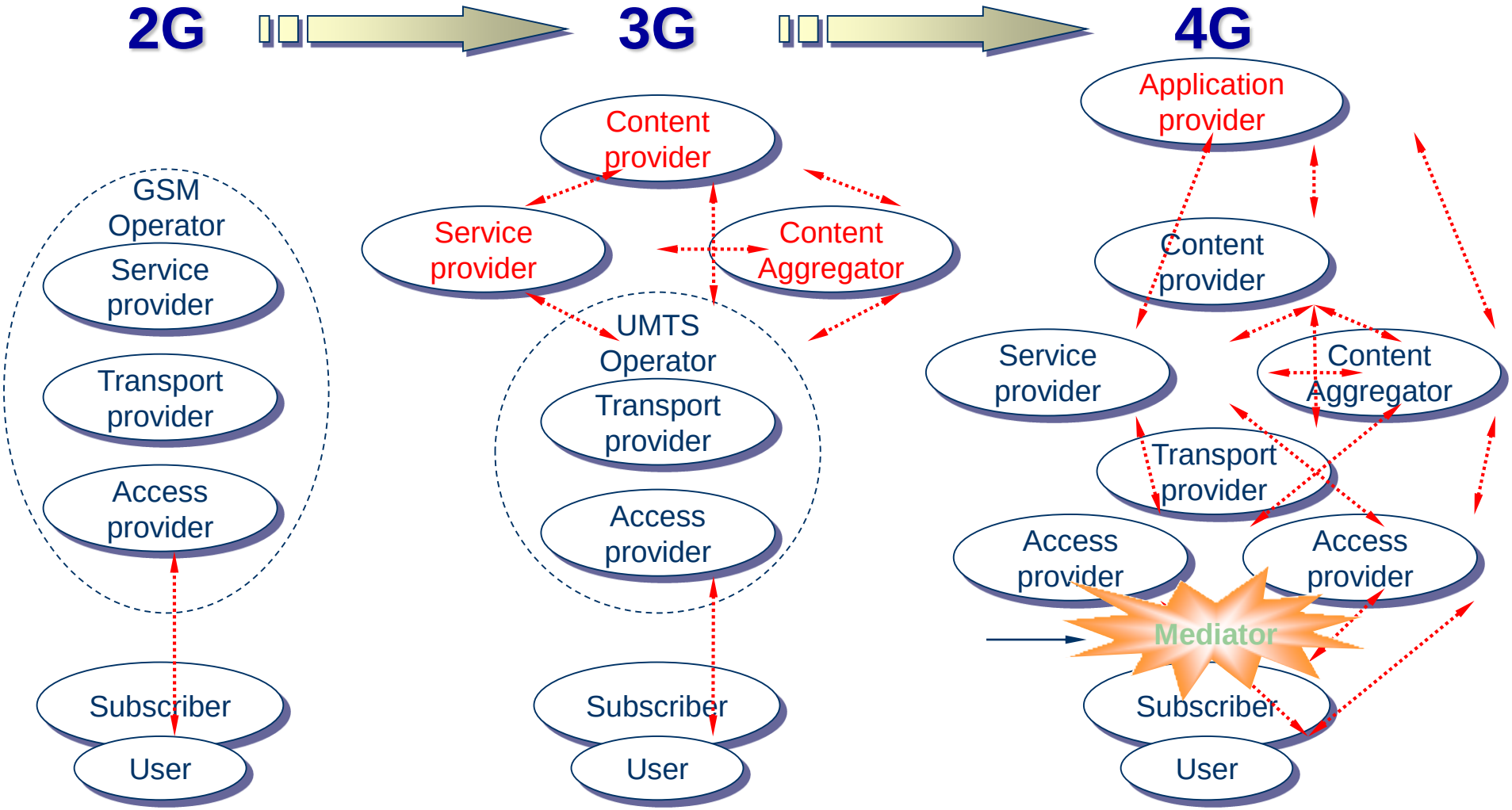
- LTE is the major technology for mobile broadband communications
  - Convergence of 3GPP and 3GPP2 technology tracks
  - Convergence of FDD and TDD into a single technology track



# Evolution of terminals and services



# Business model evolution



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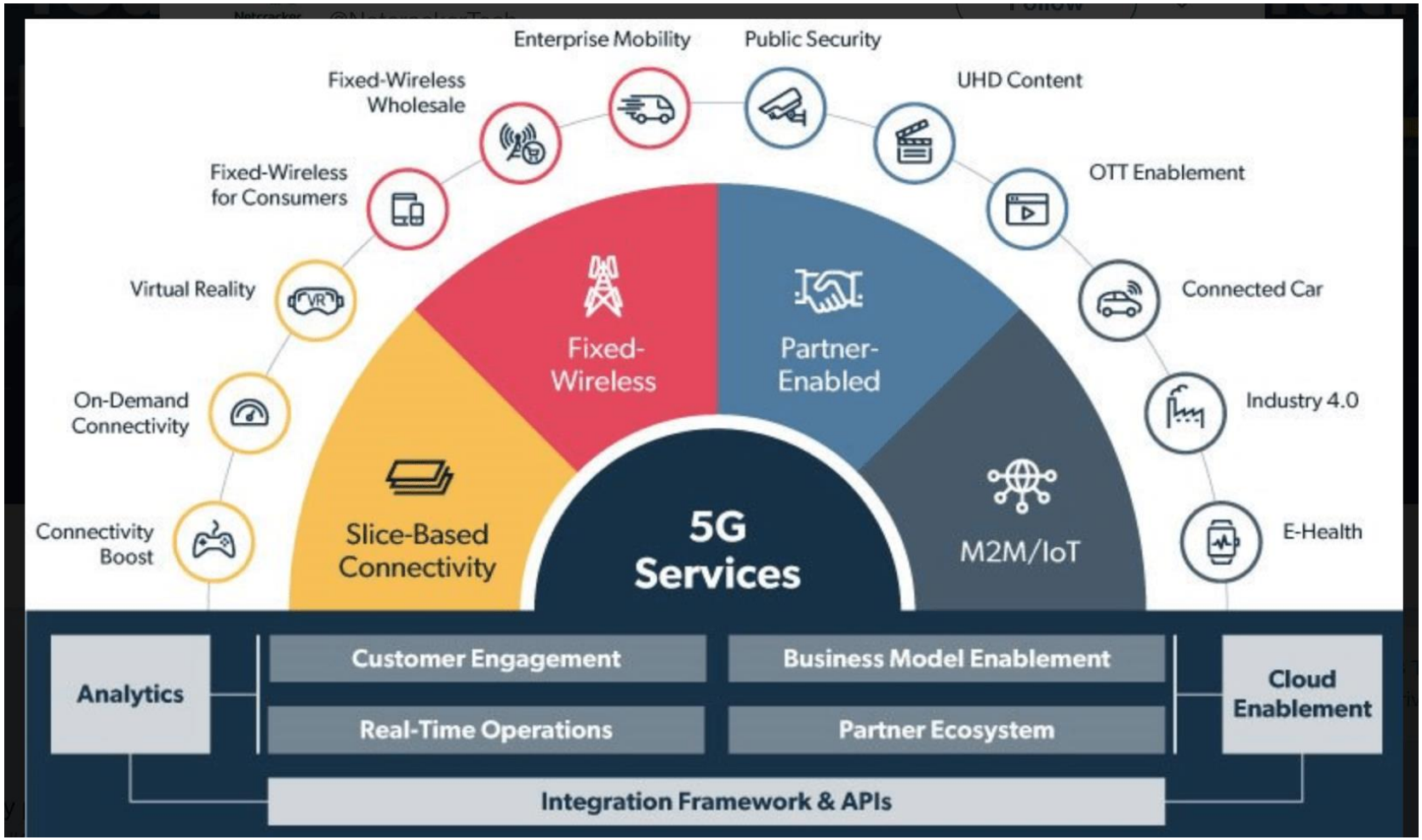
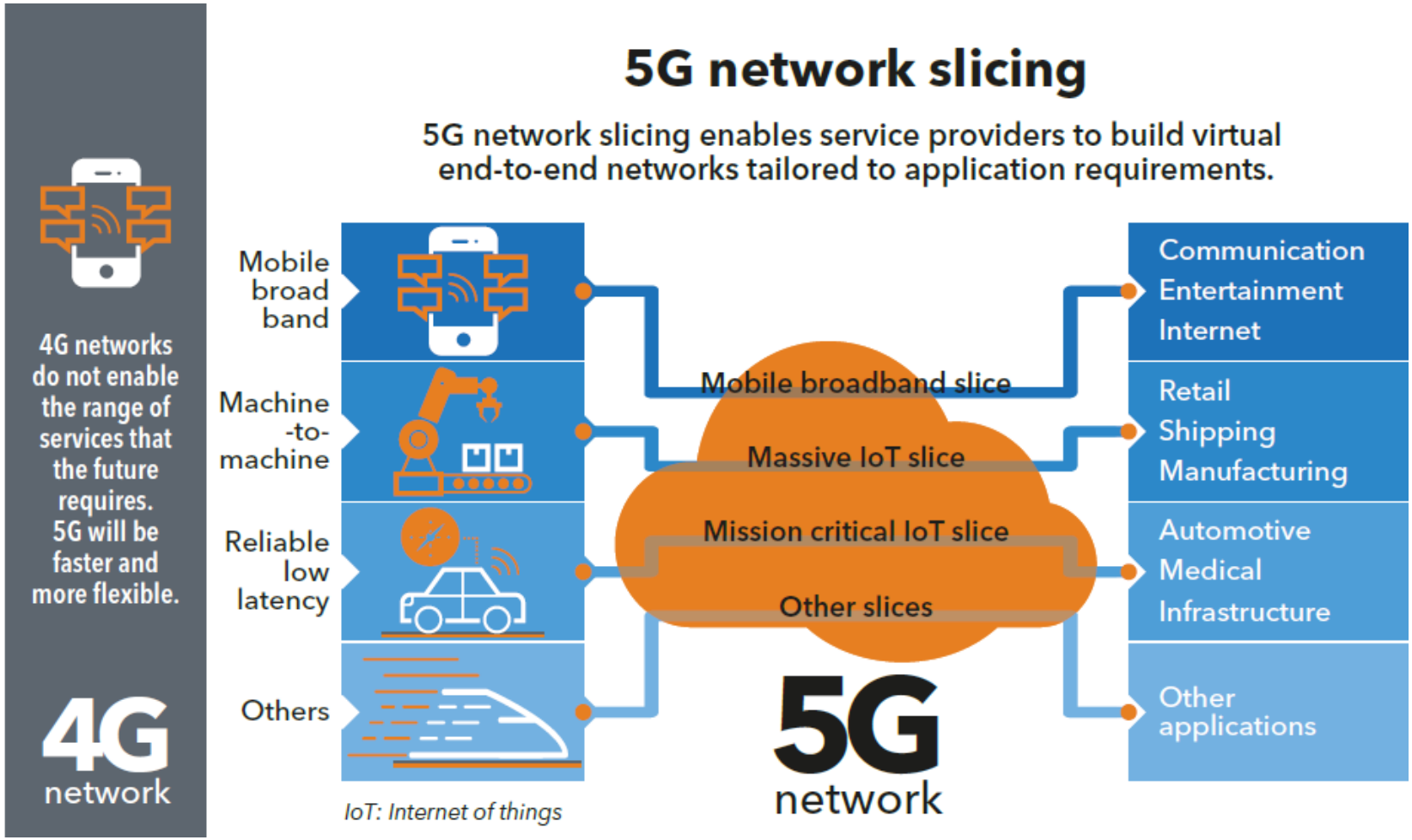
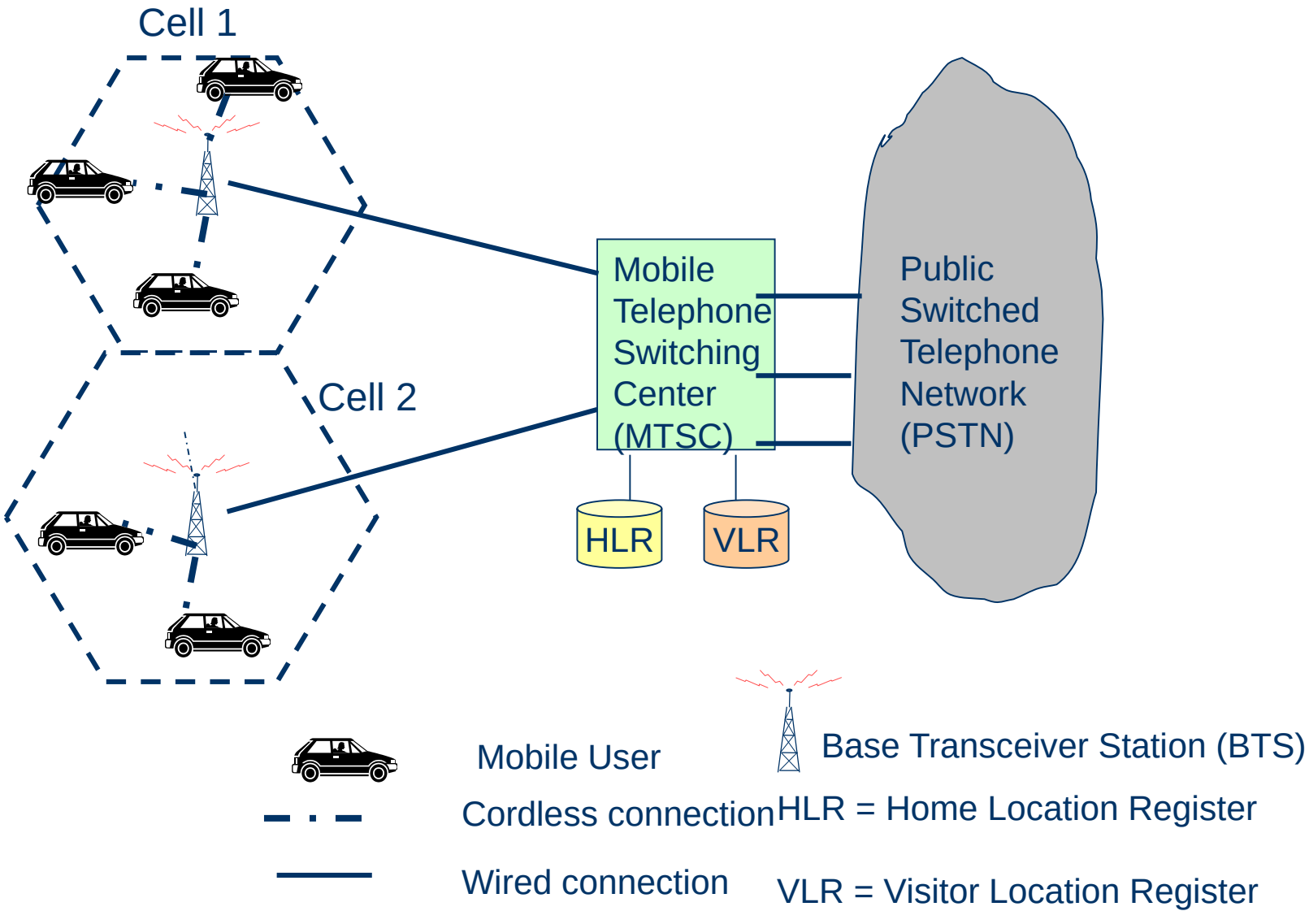


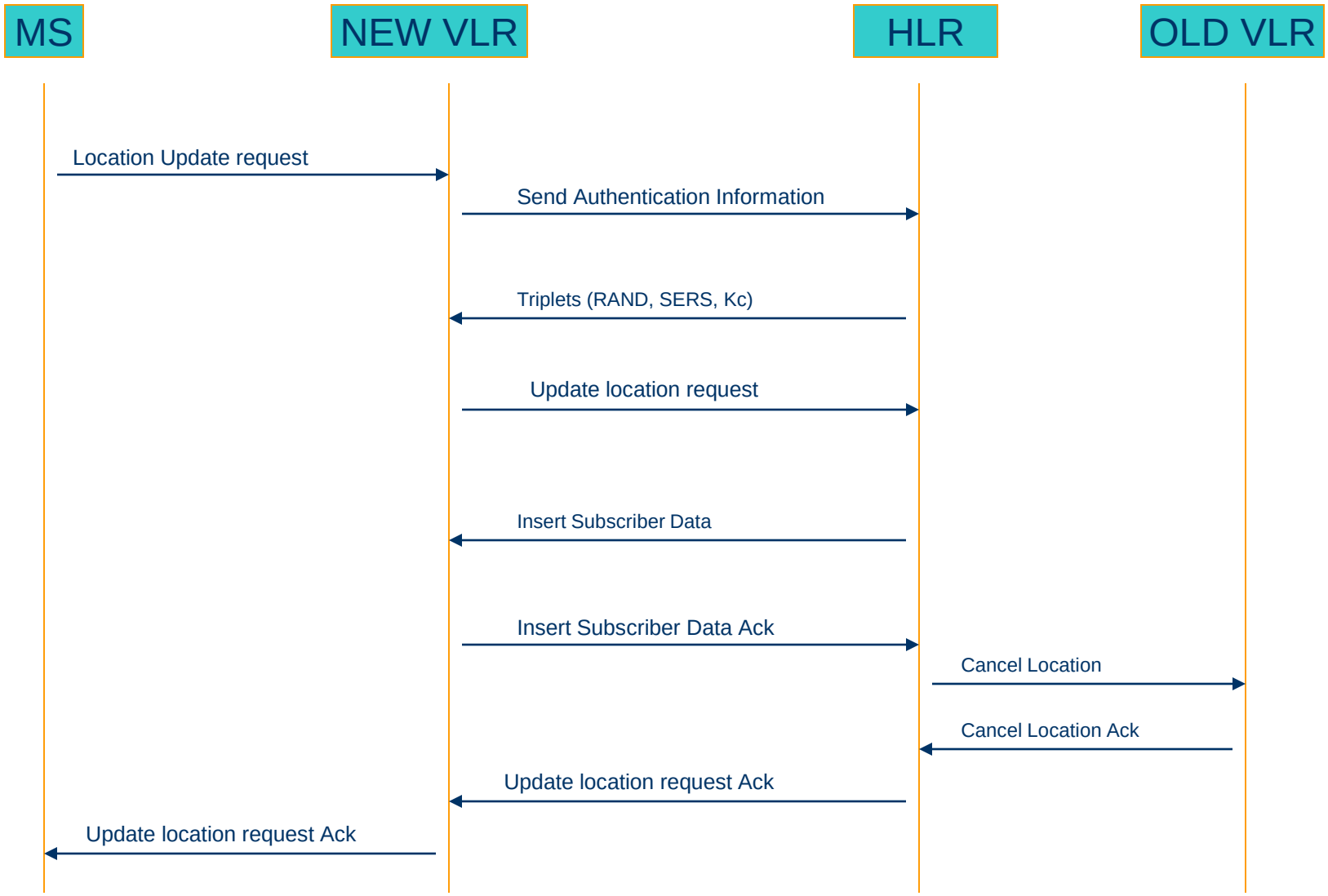
# Business model evolution



# A cellular network



# LOCATION UPDATE



# GSM

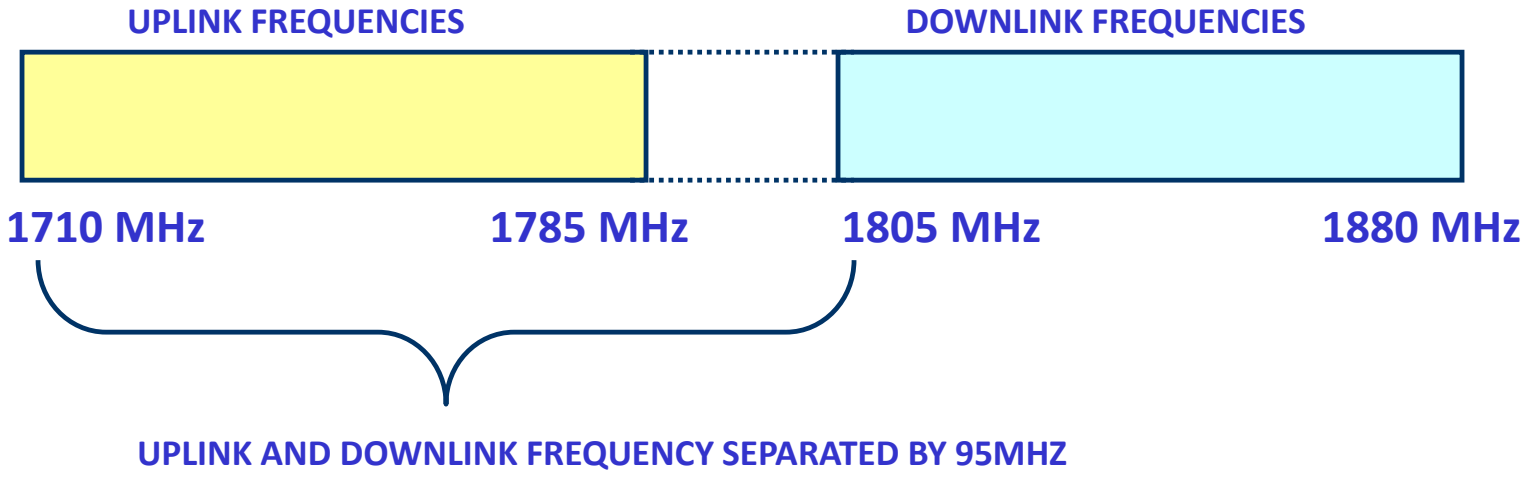
- Abbreviation for Global System for Mobile Communications
- In the mid 1980's, most of Europe didn't have a cellular network
  - They weren't committed to analog
- After many years of research, GSM was proposed around 1990
  - Covered Germany, France, England, and Scandinavia
  - In Greece GSM started in 1993
- Goals:
  - Roaming throughout all of Europe
  - Low power and inexpensive devices
  - All digital to offer 64kbps throughput
    - Never achieved

# GSM Services

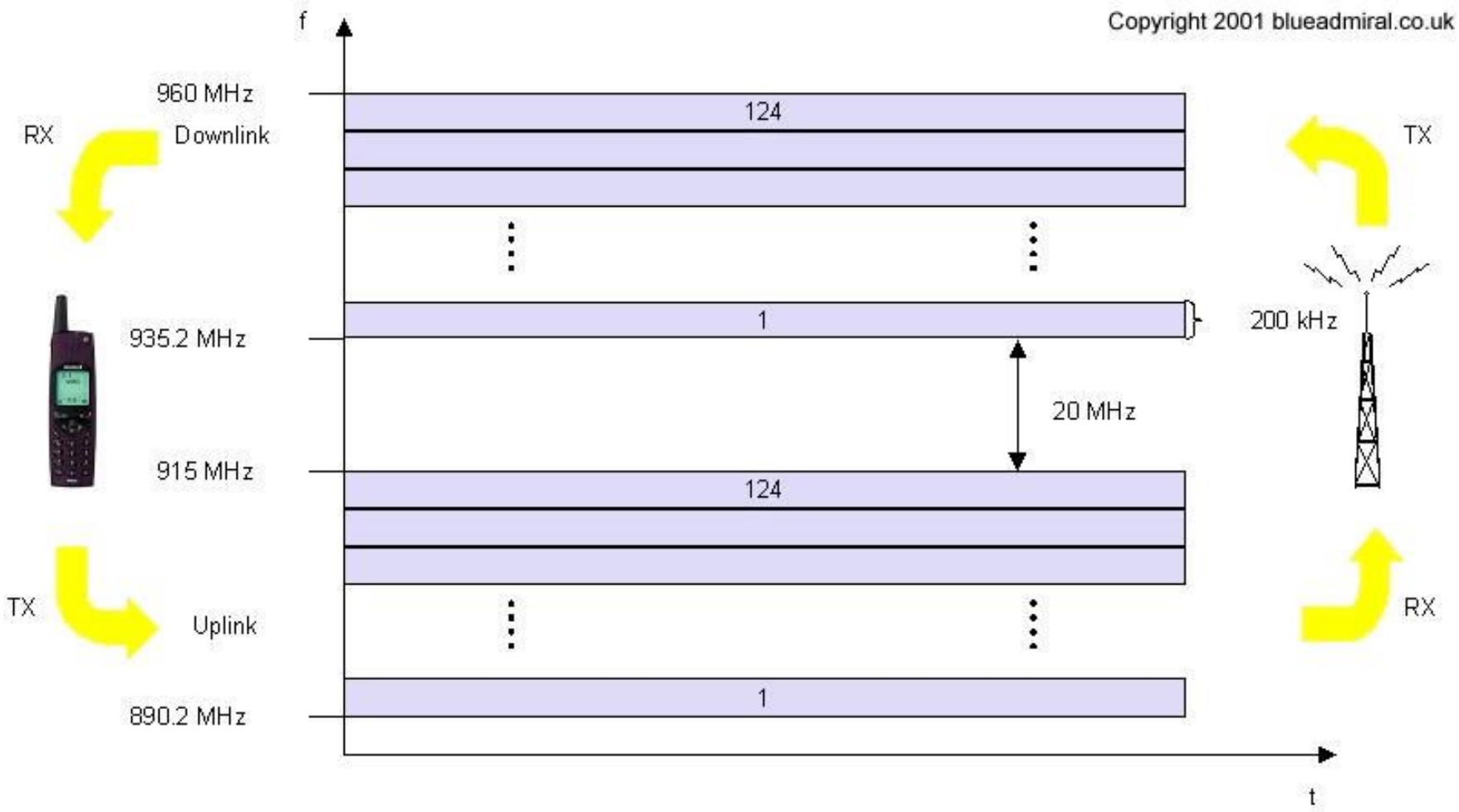
- Voice, 3.1 kHz
- Some data transmission is possible with very low speeds (originally 9.6kbps) – e.g. fax.
- Short Message Service (SMS)
  - 1985 GSM standard that allows messages of at most 160 chars (incl. spaces) to be sent between handsets and other stations
  - SMS was for years the most widely used data application in the world, with 3.6 billion active users, or 78% of all mobile phone subscribers (2011).

# GSM Frequencies

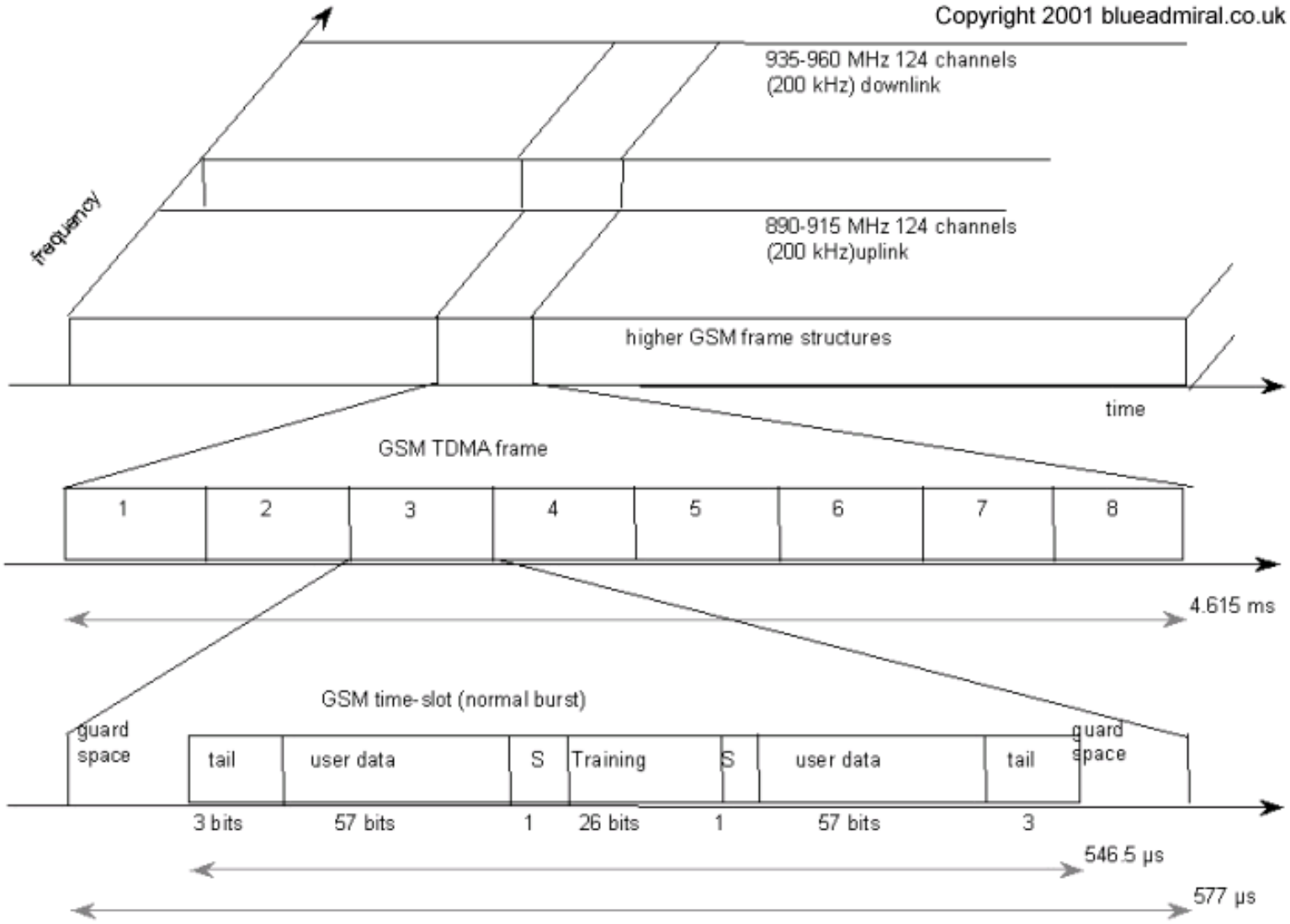
- Originally designed on 900MHz range, later available on 800MHz, 1800MHz and 1900 MHz ranges.
- Separate Uplink and Downlink frequencies
  - One example channel on the 1800 MHz frequency band, where RF carriers are spaced every 200 kHz



# Uplink/Downlink frequency channels

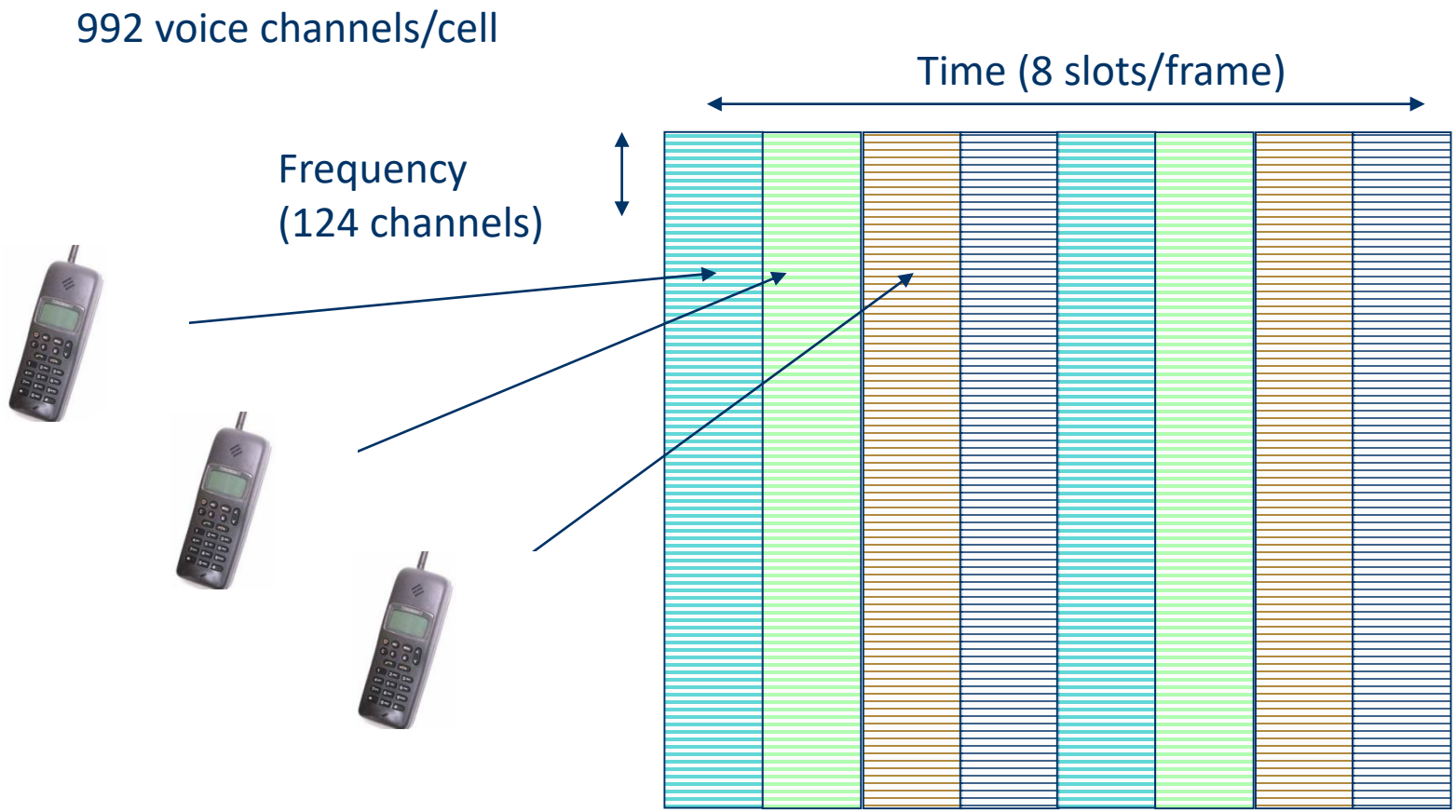


# GSM resource allocation

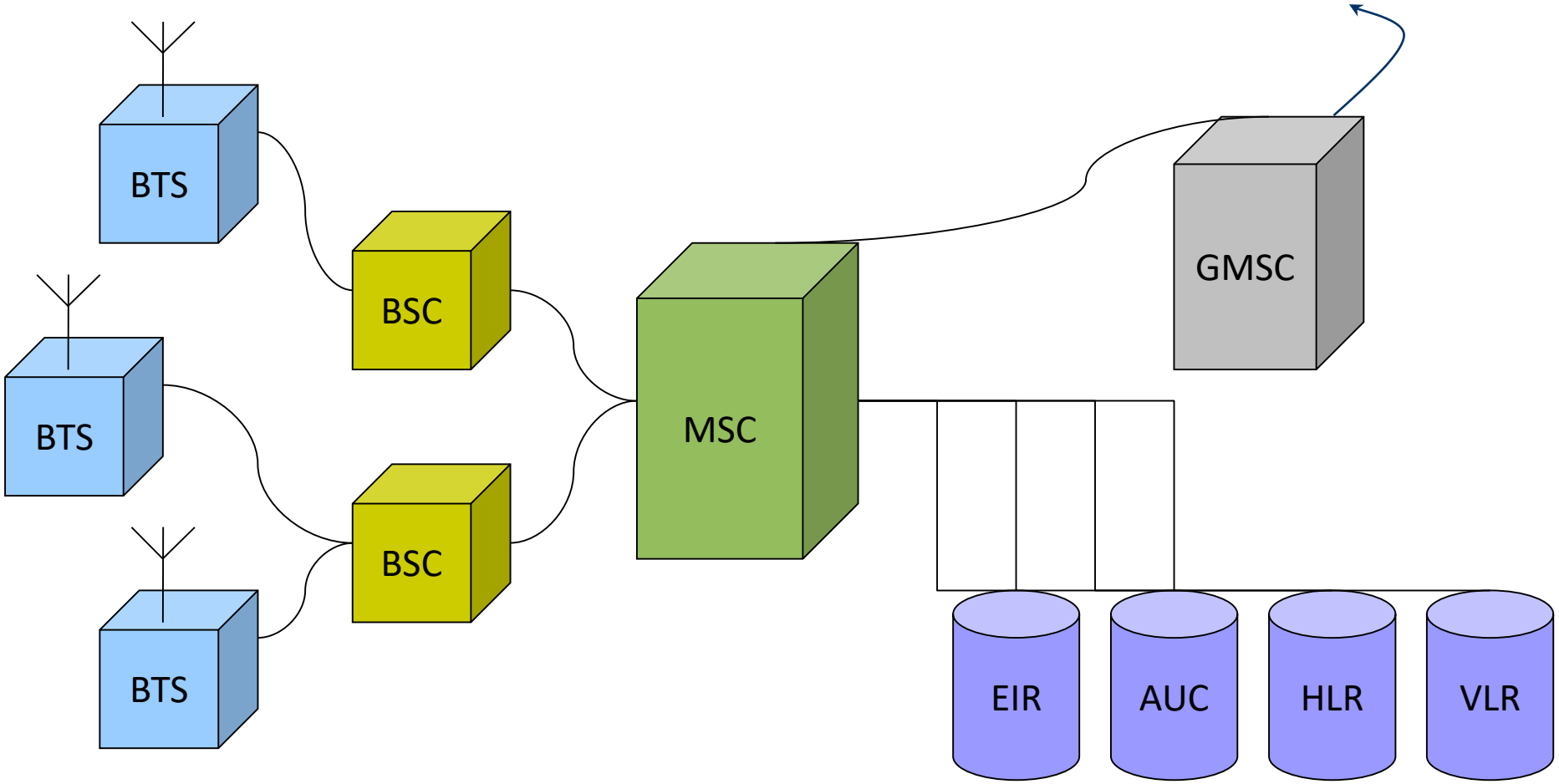


# GSM System – Multiple Access

## Time Division Multiple Access (TDMA)



# GSM architecture



# GSM main components

**Base Transceiver Station (BTS):** Encodes, encrypts, multiplexes, modulates and feeds the RF signals to the antenna.

**Base Station Controller (BSC):** Manages Radio resources for BTSs, assigns frequency and time slots for all mobile terminals in its area.

**Mobile Switching Center (MSC):** Heart of the network, call setup function and basic switching, call routing , billing information and collection, mobility management.

**Home/Visiting Location Registers (HLR/VLR):** permanent/temporary database about mobile subscribers in a large service area.

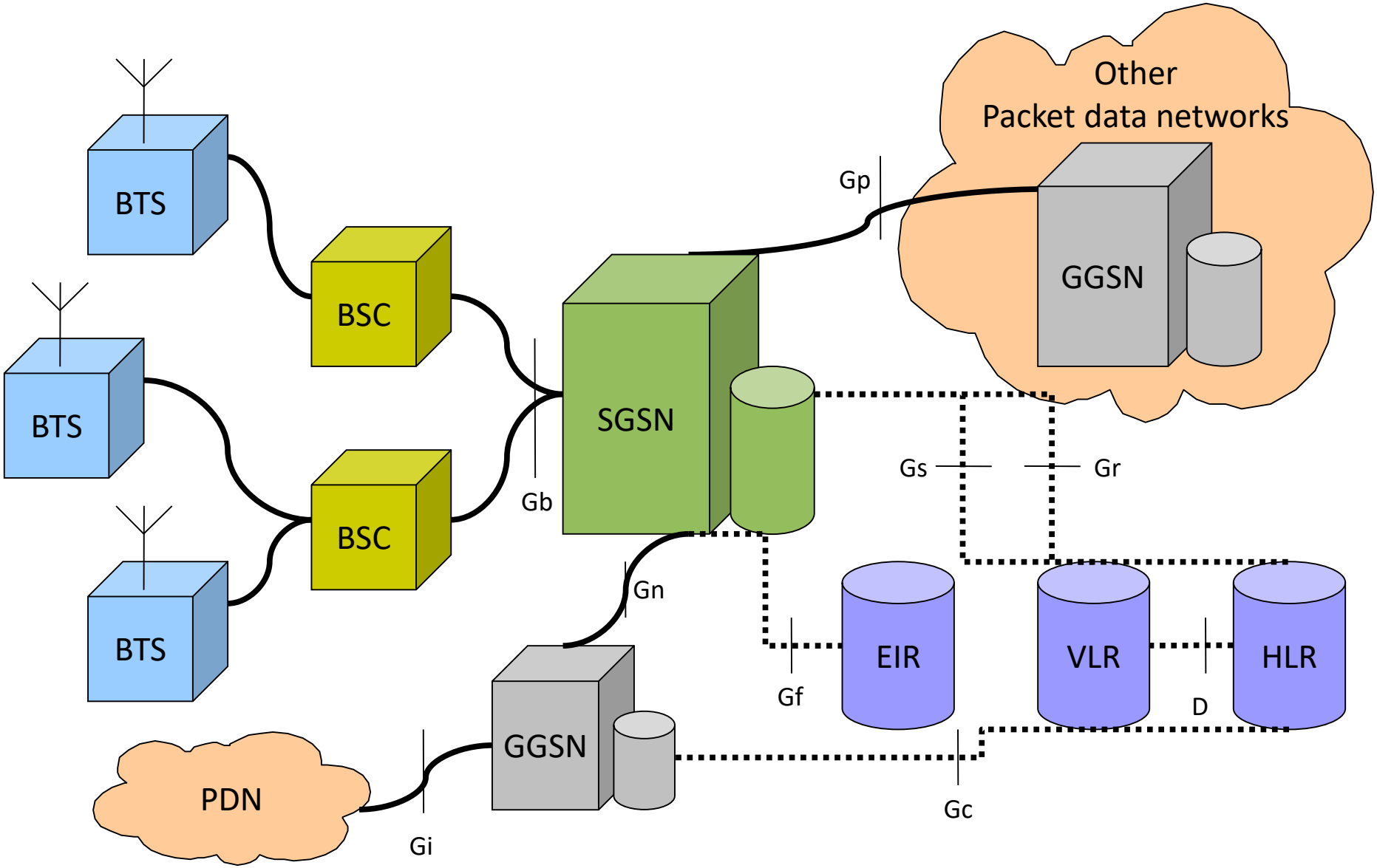
**Authentication Center (AUC):** Protects against intruders in air interface, maintains authentication keys and algorithms.

**Equipment Identity Register (EIR):** Database that is used to track handsets using the IMEI (International Mobile Equipment Identity).

# GPRS (General Packet Radio Service)

- GSM upgrade that provides IP-based packet data transmission up to 171 kbps (never allowed)
- Users can “simultaneously” make calls and send data
- GPRS provides “always on” Internet access and the Multimedia Messaging Service (MMS)
- Performance degrades as number of users increase
- GPRS is an example of 2.5G telephony

# GPRS Architecture

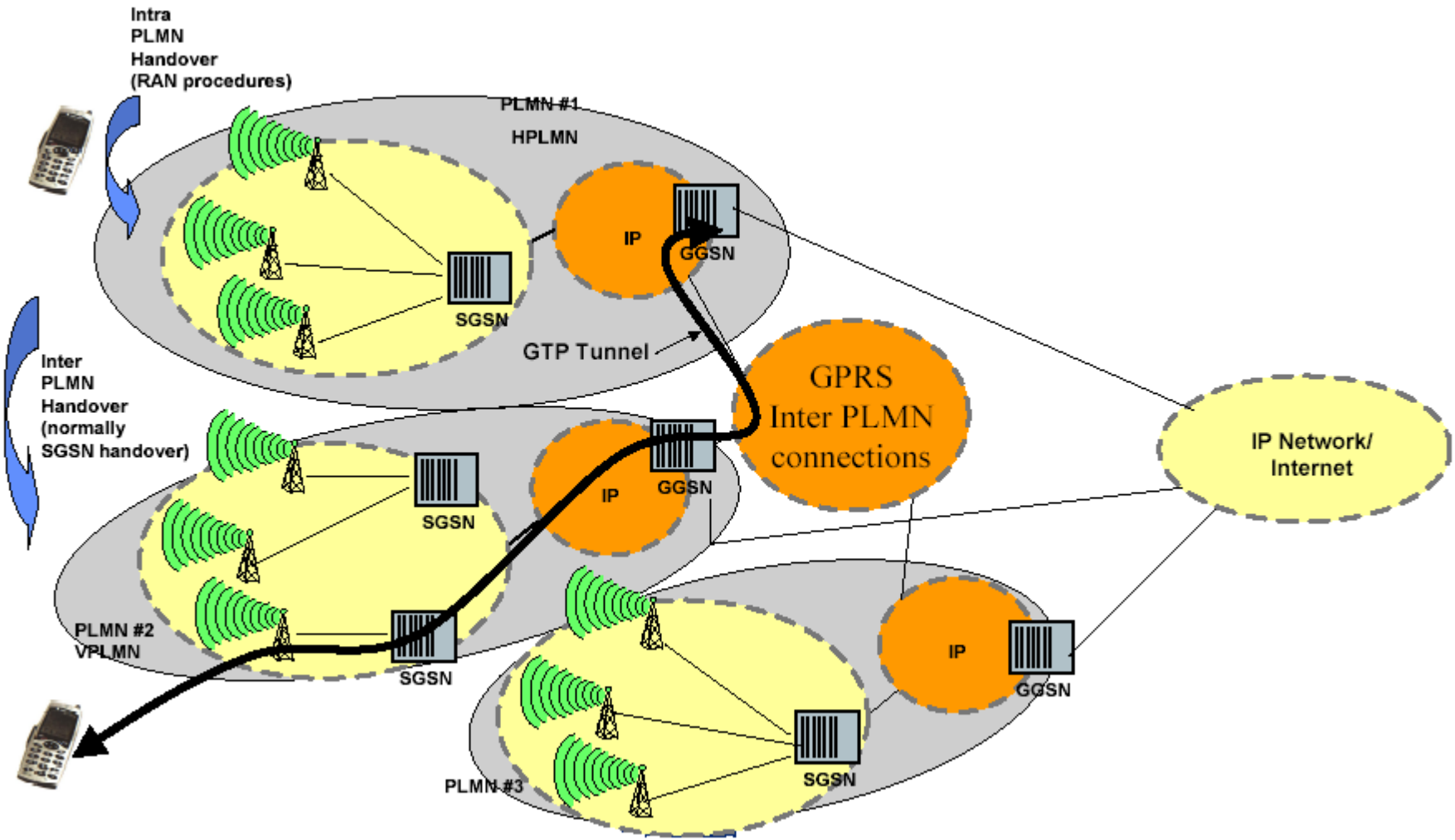


# Main difference with GSM

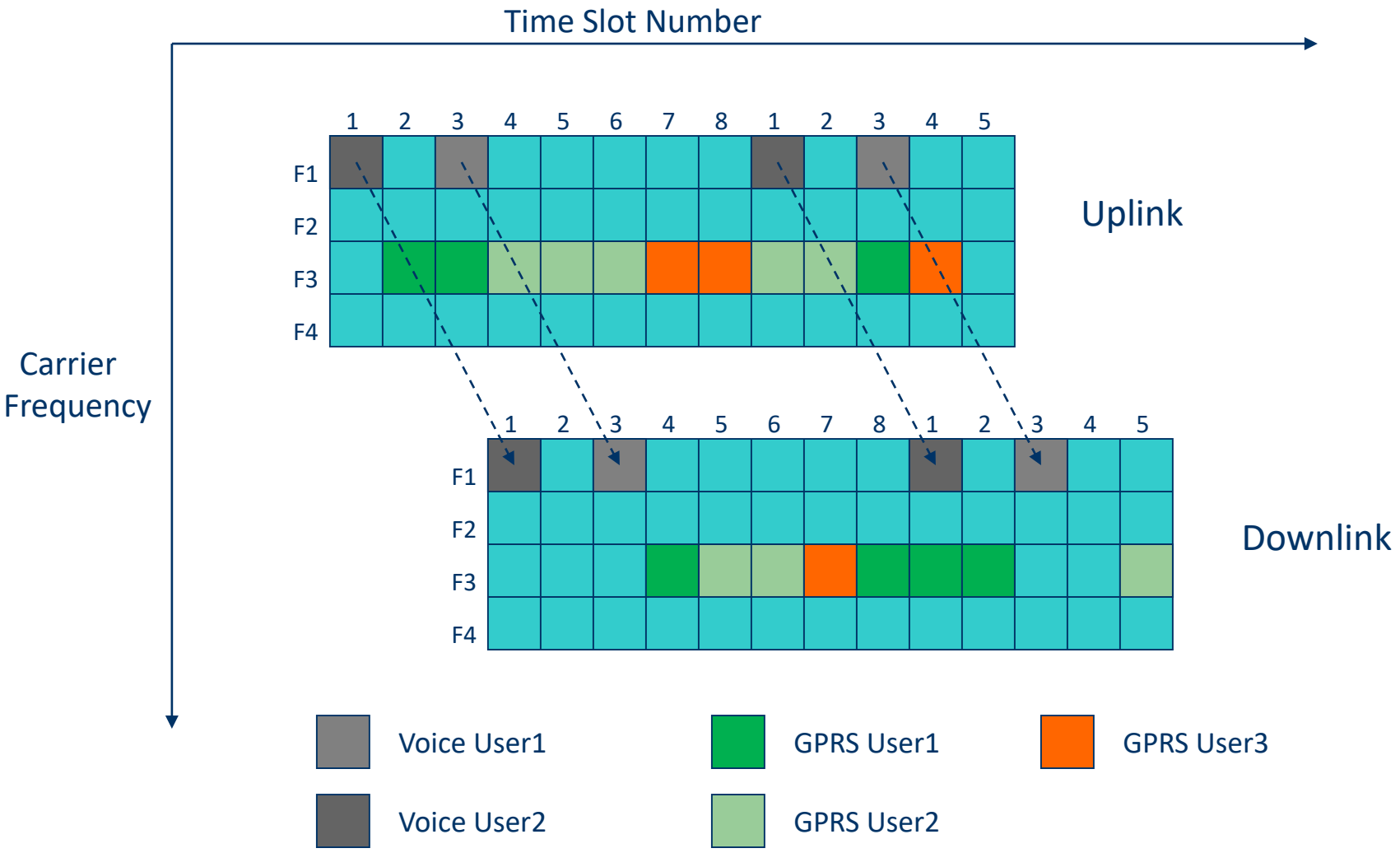
SGSN (Serving GPRS Support Node): Packet switching with mobility management capabilities. Responsible for the delivery of data packets from and to the mobile stations within its geographical service area.

GGSN (Gateway GPRS Support Node): Packet switch interworking with other data networks (Internet). Converts the GPRS packets coming from the SGSN into the appropriate packet data protocol format (e.g., IP)

# Routing in GPRS



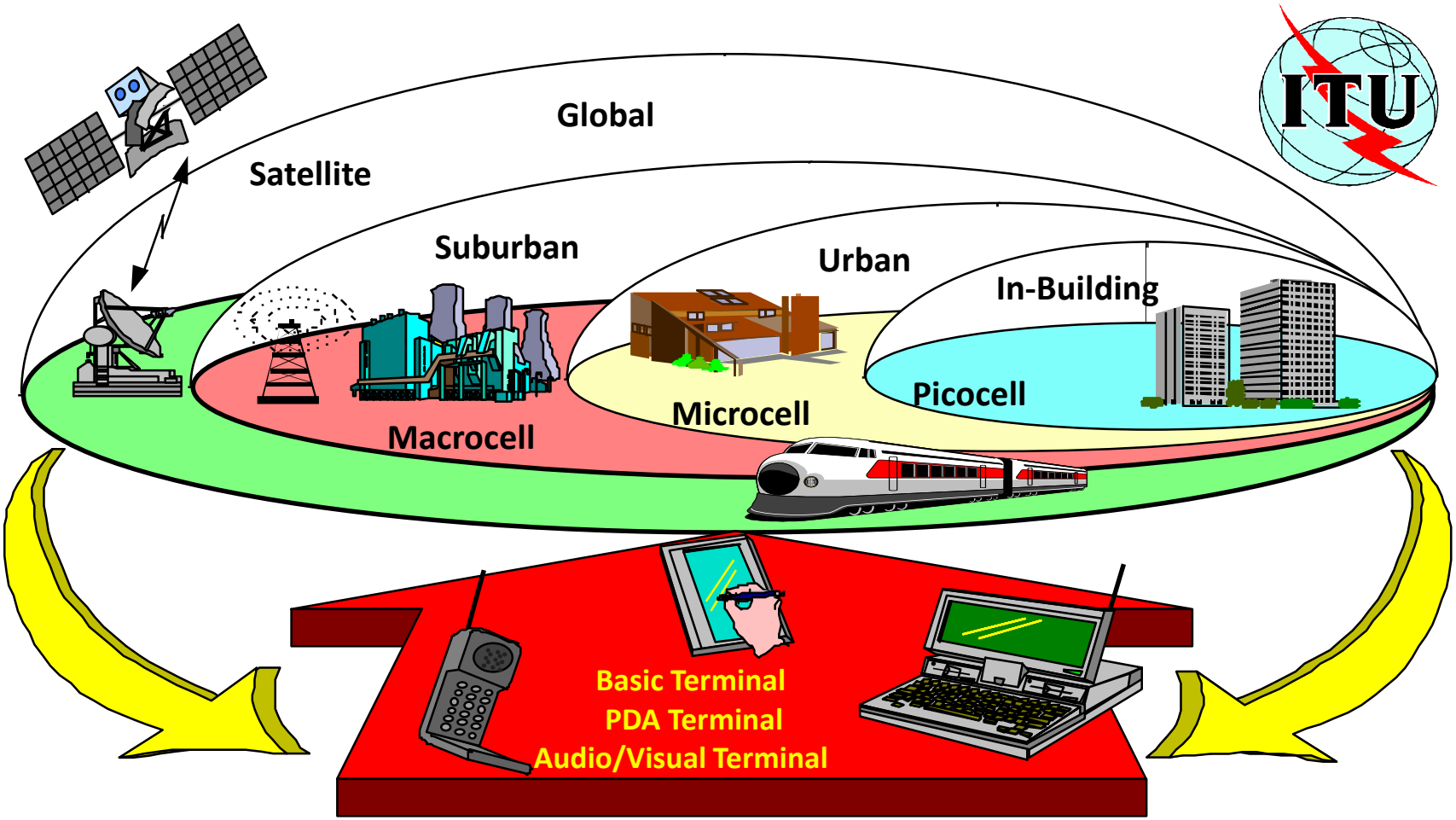
# GPRS System – Multiple Access



# 3G

- 3G refers to a set of standards that comply to IMT-2000 specifications by ITU
- The following standards are typically branded 3G:
  - the UMTS system, first offered in 2001, standardized by 3GPP, used primarily in Europe
  - the CDMA2000 system, first offered in 2002, standardized by 3GPP2, used especially in North America

# IMT-2000 Vision Includes LAN, WAN and Satellite Services

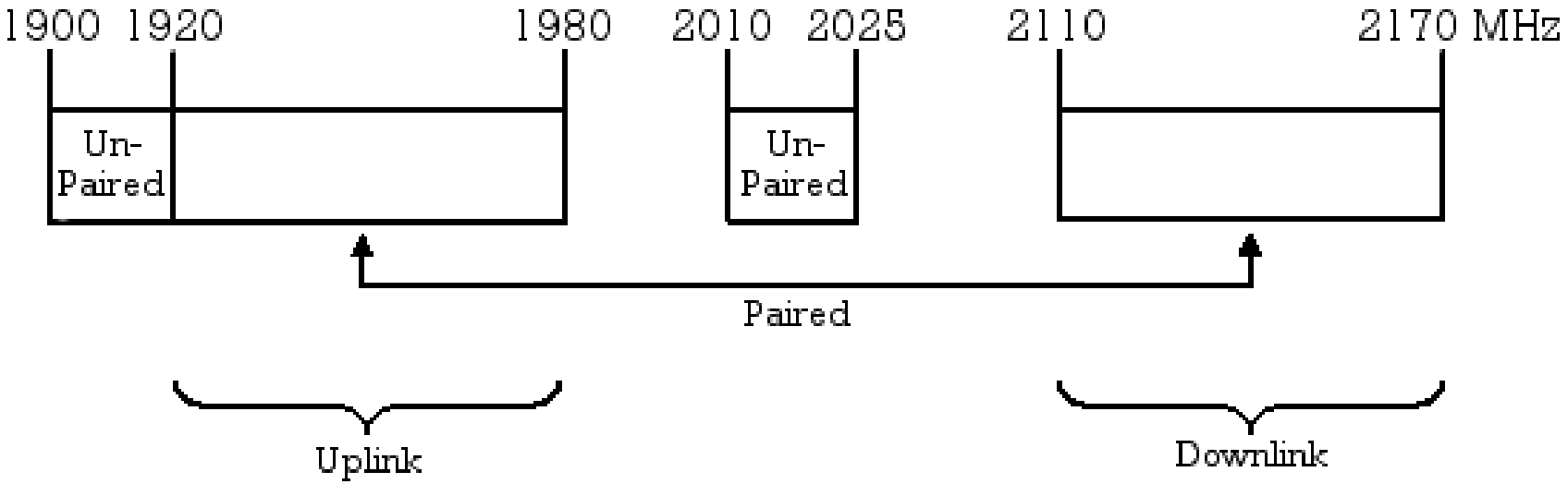


# UMTS (Universal Mobile Telecommunications System)

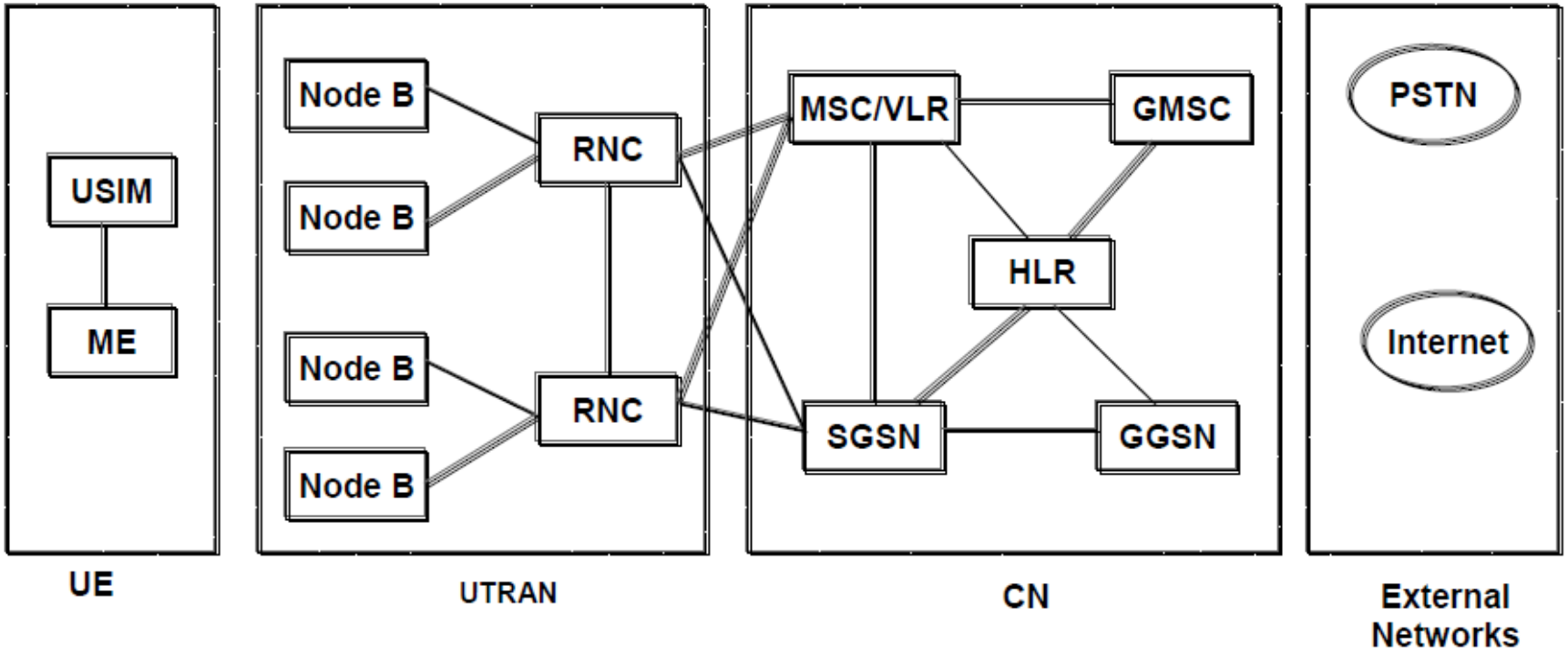
- Voice quality comparable to the public switched telephone network
- 144 Kbps/user in high-speed motor vehicles
- 384 Kbps/pedestrian standing or moving slowly over small areas
- Up to 2 Mbps for fixed applications like office use
- Symmetrical/asymmetrical data transmission rates
- Support for both packet switched and circuit switched data services like Internet Protocol (IP) traffic and real time video

# UMTS Frequency Spectrum

- UMTS Band
  - 1900-2025 MHz and 2110-2200 MHz for 3G transmission
  - In the US, 1710–1755 MHz and 2110–2155 Mhz is used instead, as the 1900 MHz band was already used.



# UMTS Architecture




- UE (User Equipment) that interfaces with the user
- UTRAN (UMTS Terrestrial Radio Access Network) handles all radio related functionality – WCDMA is radio interface standard here.
- CN (Core Network) is responsible for transport functions such as switching and routing calls and data, tracking users

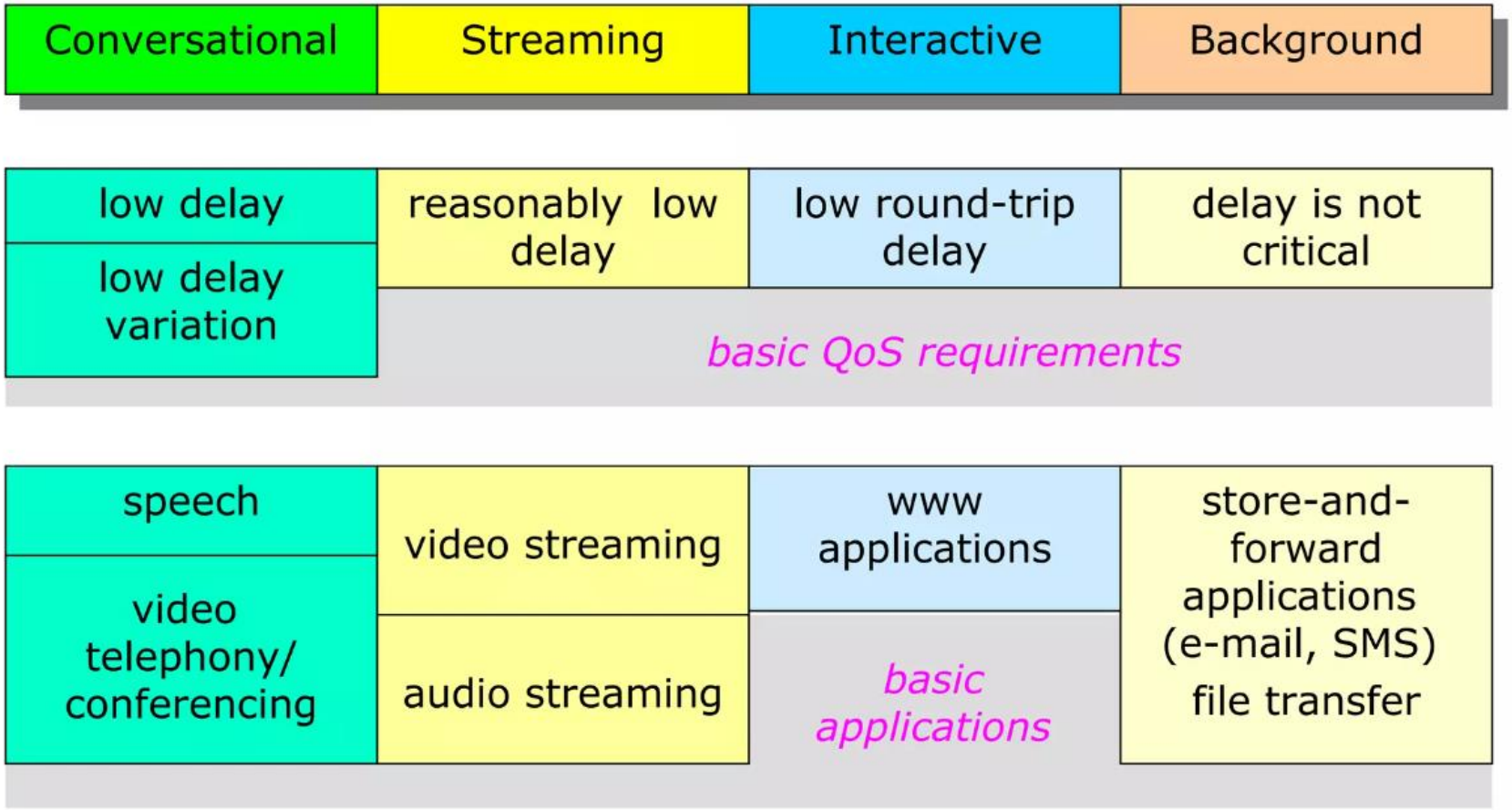
# UMTS Network Architecture

- UMTS network architecture consists of three domains
  - **Core Network (CN):** Provide switching, routing and transit for user traffic
  - **UMTS Terrestrial Radio Access Network (UTRAN):** Provides the air interface access method for user equipment.
  - **User Equipment (UE):** Terminals work as air interface counterpart for base stations.

# UMTS QoS Classes

| Traffic class | Conversational class | Streaming class | Interactive class | Background |
|---|---|---|---|---|
| **Fundamental characteristics** | Preserve time relation between information entities of the stream<br><br>Conversational pattern (stringent and low delay) | Preserve time relation between information entities of the stream | Request response pattern<br><br>Preserve data integrity | Destination is not expecting the data within a certain time<br><br>Preserve data integrity |
| **Example of the application** | Voice, videotelephony, video games | Streaming multimedia | Web browsing, network games | Background download of emails |

# UMTS QoS Classes



# UMTS QoS Classes

| Conversational | Streaming | Interactive | Background |
|---|---|---|---|

- low delay (< 400 ms) and low delay variation
- BER requirements not so stringent
- in the radio network => real-time (RT) connections

- speech (using AMR = Adaptive Multi-Rate speech coding)
- video telephony / conferencing:

  ITU-T Rec. H.324 (over circuit switched connections)

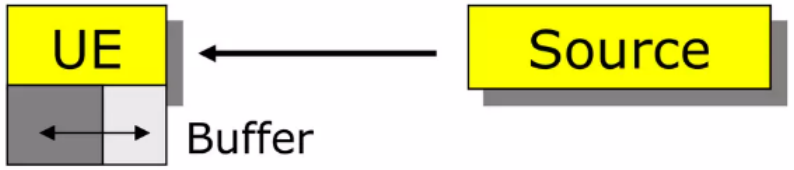
  ITU-T Rec. H.323 or IETF SIP (over packet switched connections)

# UMTS QoS Classes

| Conversational | Streaming | Interactive | Background |
|---|---|---|---|

- reasonably low delay and delay variation
- BER requirements quite stringent
- traffic management important (variable bit rate)
- in the radio network => real-time (RT) connections

- video streaming
- audio streaming




video or audio information is buffered in the UE,
large delay => buffer is running out of content!

# UMTS QoS Classes

| Conversational | Streaming | Interactive | Background |
|---|---|---|---|

- low round-trip delay (< seconds)
- delay variation is not important
- BER requirements stringent
- in the radio network => non-real-time (NRT) connections

- web browsing
- interactive games
- location-based services (LCS)

# UMTS QoS Classes

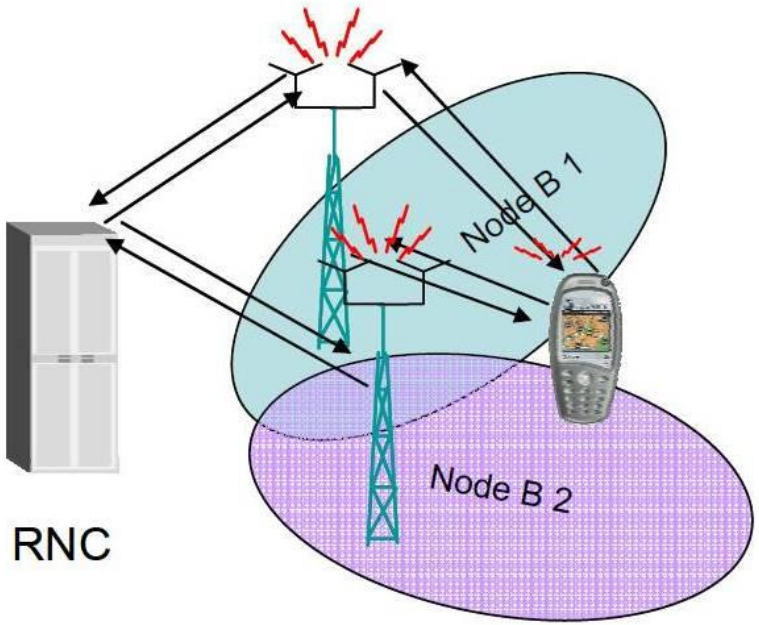
| Conversational | Streaming | Interactive | Background |
|---|---|---|---|

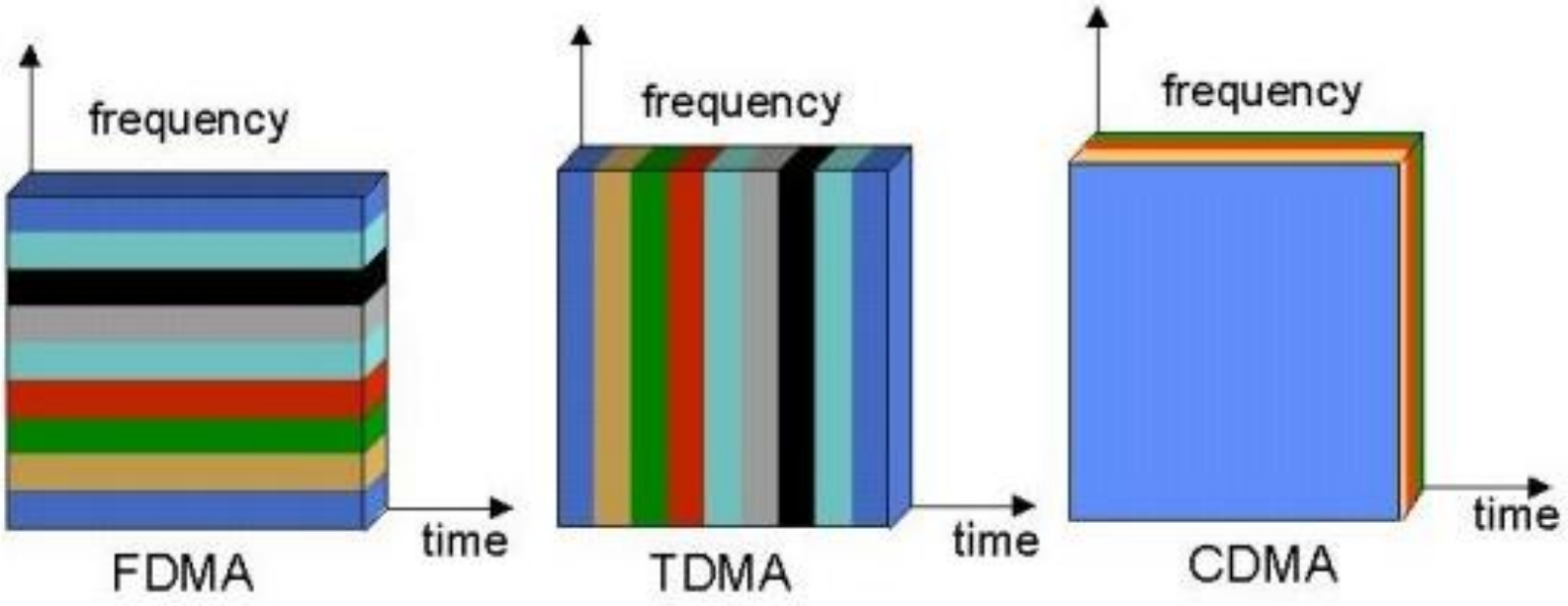
- delay / delay variation is not an important issue
- BER requirements stringent
- in the radio network => non-real-time (NRT) connections

- SMS (Short Message Service) and other more advanced messaging services (EMS, MMS)
- e-mail notification, e-mail download
- file transfer

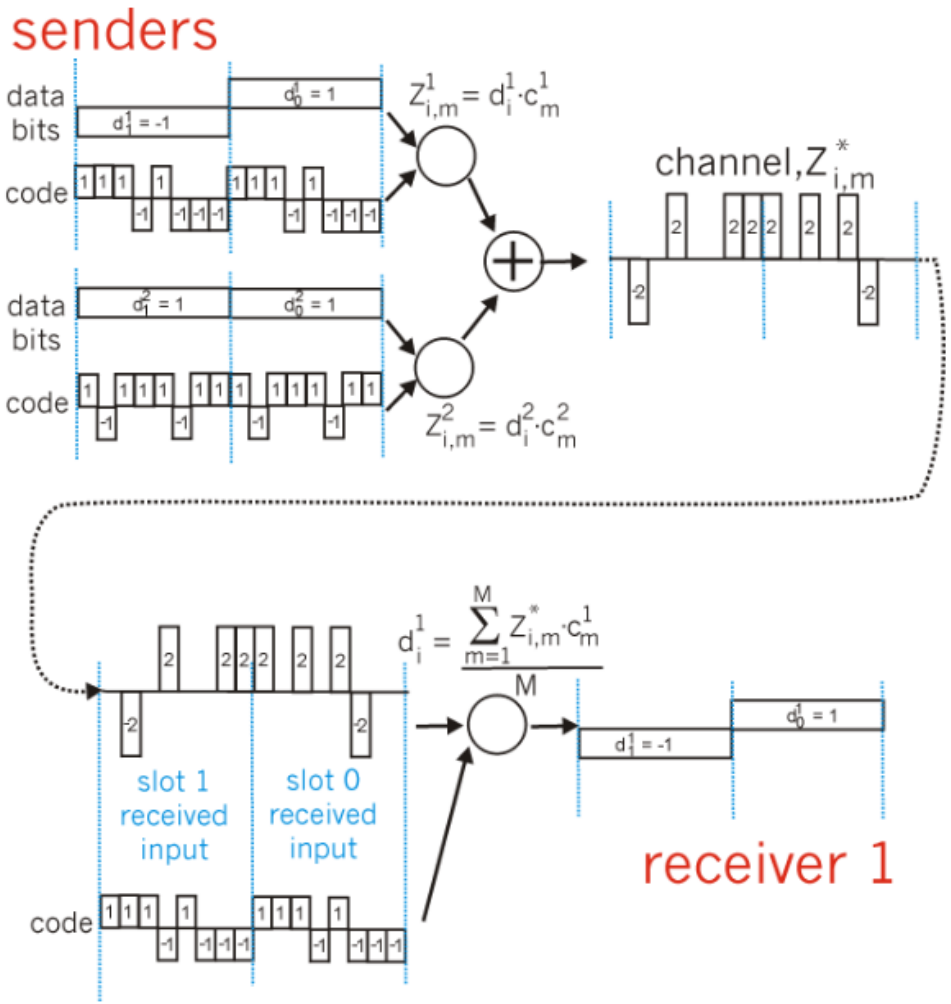
# UTRAN

- Wide band CDMA technology is selected for UTRAN air interface (instead of FDMA/TDMA in GSM and GPRS)
- Advanced mobility support (e.g., **soft handover**)



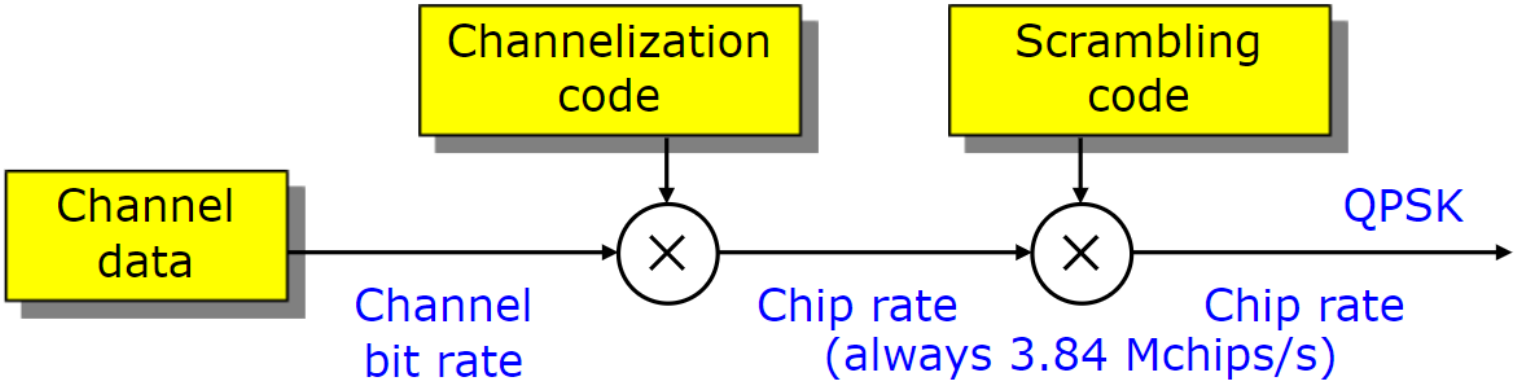

frequency
time
FDMA
frequency
time
TDMA
frequency
time
CDMA

# Code Division Multiple Access (CDMA)



# WCDMA

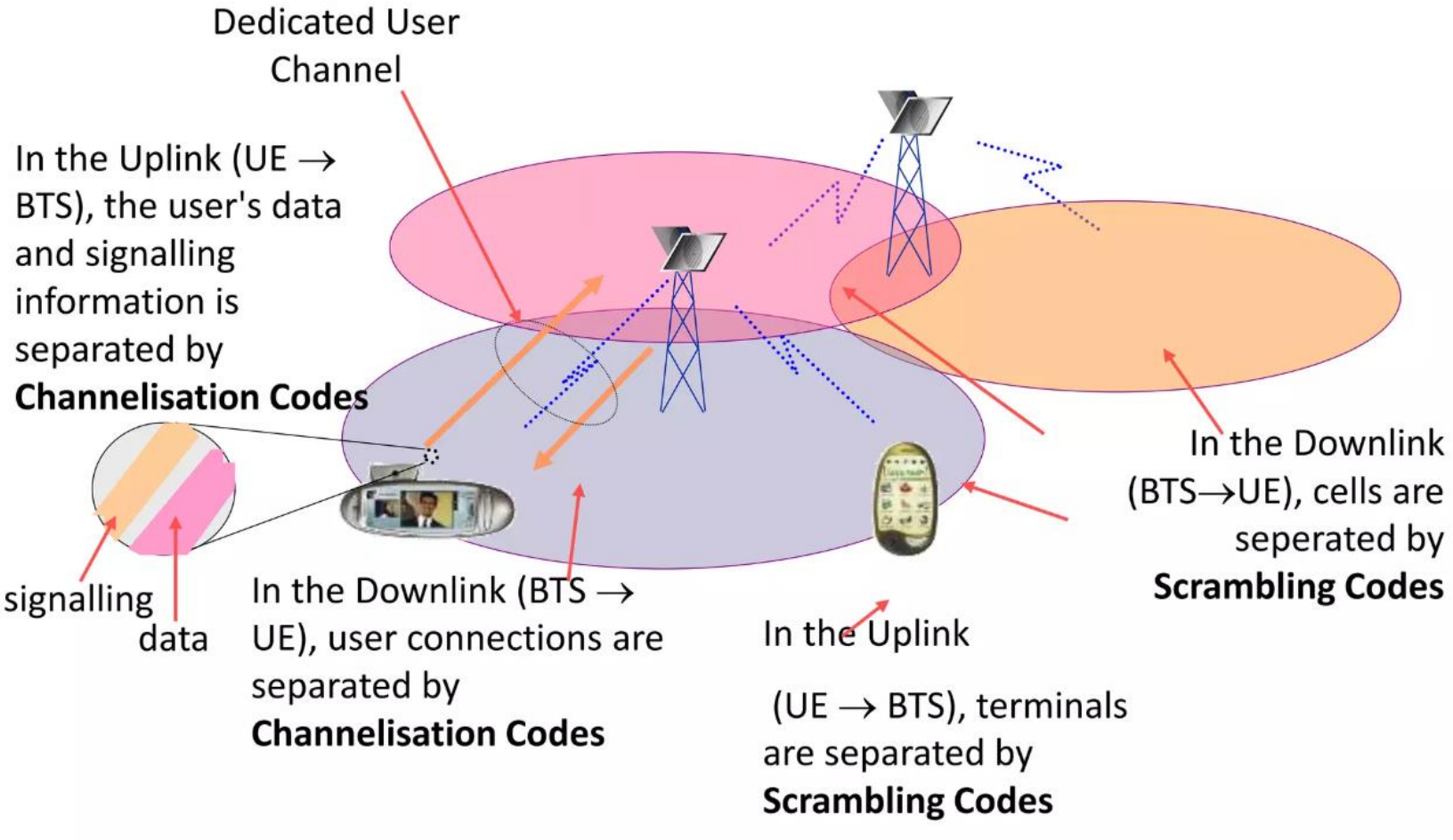
## Spreading in WCDMA




| Usage of code | Uplink | Downlink |
|---|---|---|
| Channelization code | | User separation |
| Scrambling code | User separation | Cell separation |

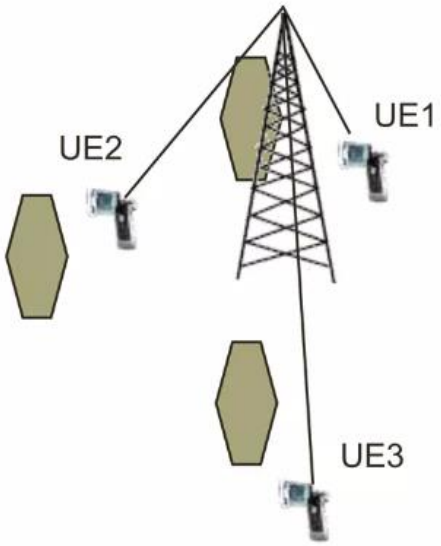
# WCDMA

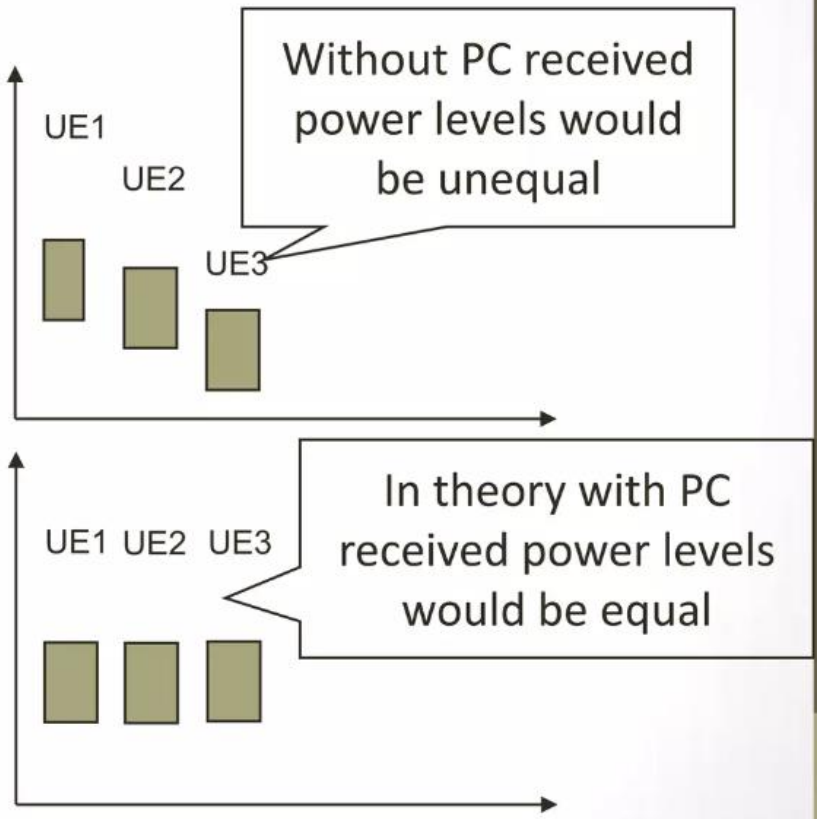
## Code Usage



# Power control in WCDMA

- The purpose of power control (PC) is to ensure that each user receives and transmits just enough energy to prevent:
  - Blocking of distant users (near-far-effect)
  - Exceeding reasonable interference levels



# 3.5G (HSPA)

High Speed Packet Access (HSPA) is an amalgamation of two mobile telephony protocols, High Speed Downlink Packet Access (HSDPA) and High Speed Uplink Packet Access (HSUPA), that extends and improves the performance of existing WCDMA protocols

3.5G introduces many new features that enhance the UMTS technology. These include:

- Adaptive Modulation and Coding
- Fast Scheduling
- Backward compatibility with 3G
- Enhanced Air Interface

# Service Roadmap