Wireless Communications

Introduction

Primary Textbooks:

- Theodore S. Rappaport, “Wireless Communications”, Prentice Hall, 2nd Edition, 2002,
- Andrea Goldsmith, „Wireless Communications“, Cambridge University Press, 2005

Recommended Reading: John Proakis, “Digital Communications 4th Edition”, McGraw Hill, ISBN 0072321113, http://www.mhhe.com/engcs/electrical/proakis/

Wireless Communication History:

The first version of a mobile radio telephone being used in 1924.“

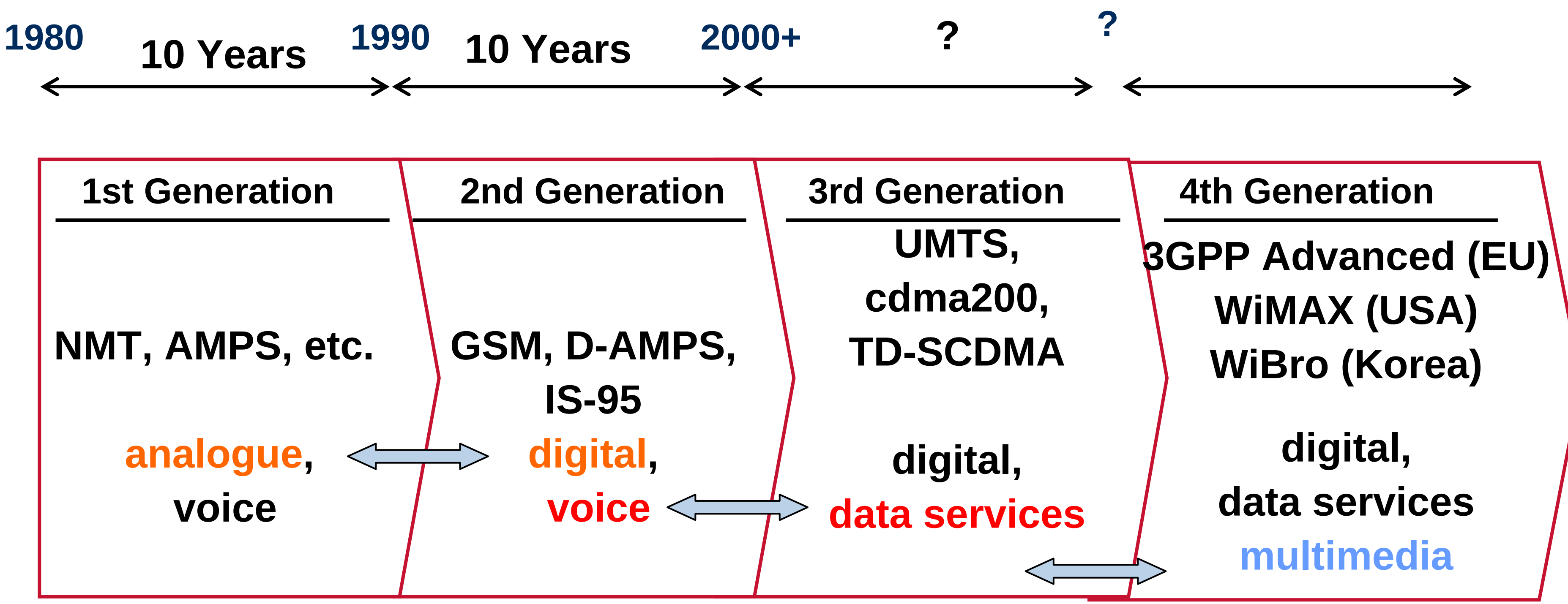
source: www.bell-labs.com/technology/wireless/earlyservice.html

Some historical notes:

- *1946, the first public mobile telephone service in the USA. Single high-powered transmitter on large tower (50 km coverage). Bandwidth 120 kHz for 3 kHz user bandwidth.*
- *Invention of the cellular concept: **1979**, Verne H. MacDonald "The Cellular Concept," Bell System Technical Journal 58, No. 1 (January, 1979), pp 15-42*
- *First cellular system: **1979**, Nippon Telephone and Telegraph company (NTT) in Japan (600 FM duplex channels, 25 kHz channel bandwidth, 800 MHz frequency range)*
- *In Europe: **1981**, The Nordic Mobile Telephone system (NMT 450), (200 FM duplex channels, 25 kHz channel bandwidth, 450 MHz frequency range)*
- *In USA: **1983**, The Advanced Mobile Phone System (AMPS), (666 FM duplex channels, 30 kHz channel bandwidth, 800 MHz frequency range)*

Read more in : T. K. Sarkar, R. J. Mailloux, A. A. Oliner, M. Salazar-Palma, and D. L.Sengupta, *History of Wireless*. John Wiley & Sons, Inc., 2006.

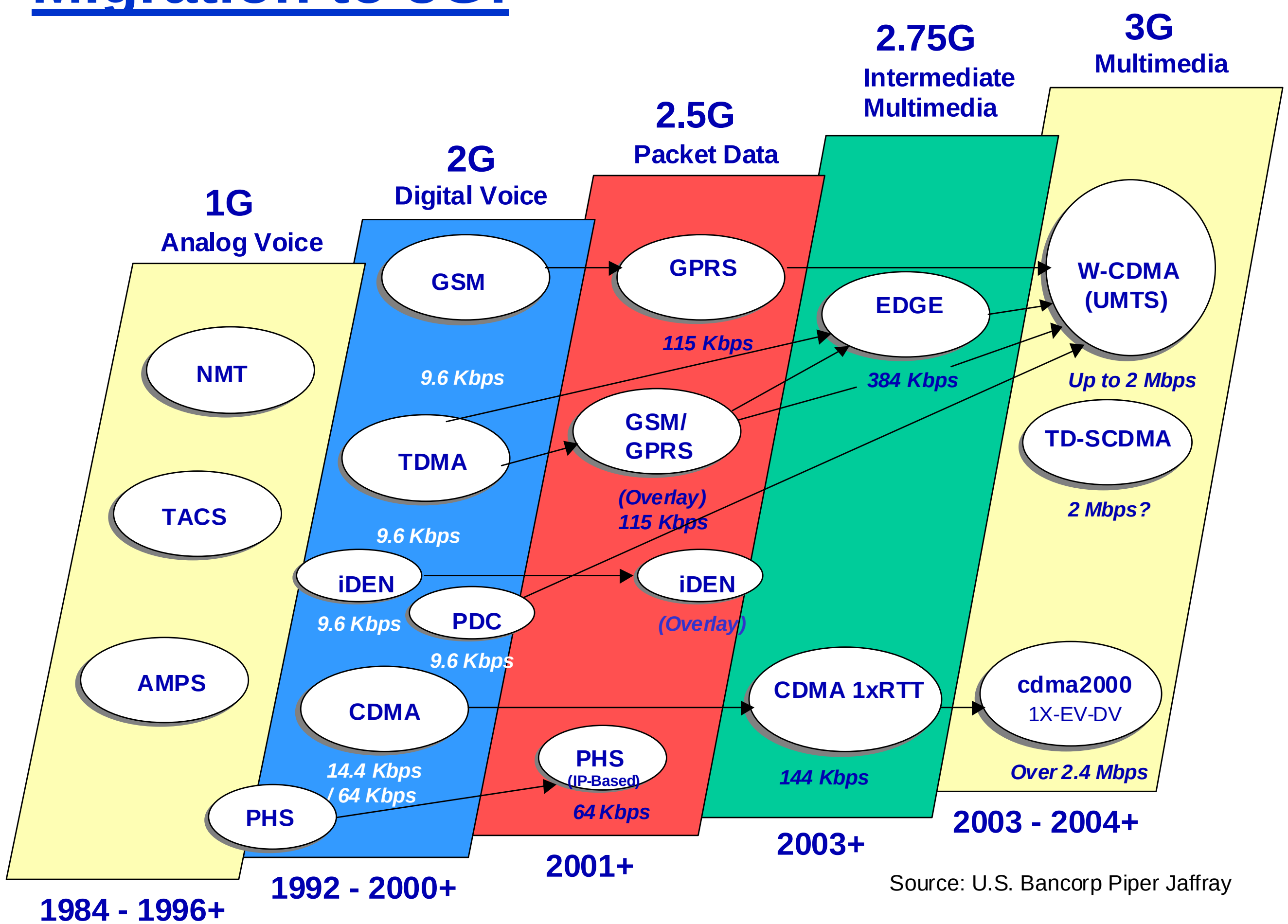
Paradigm shifts ( ):



We are only at the beginning!

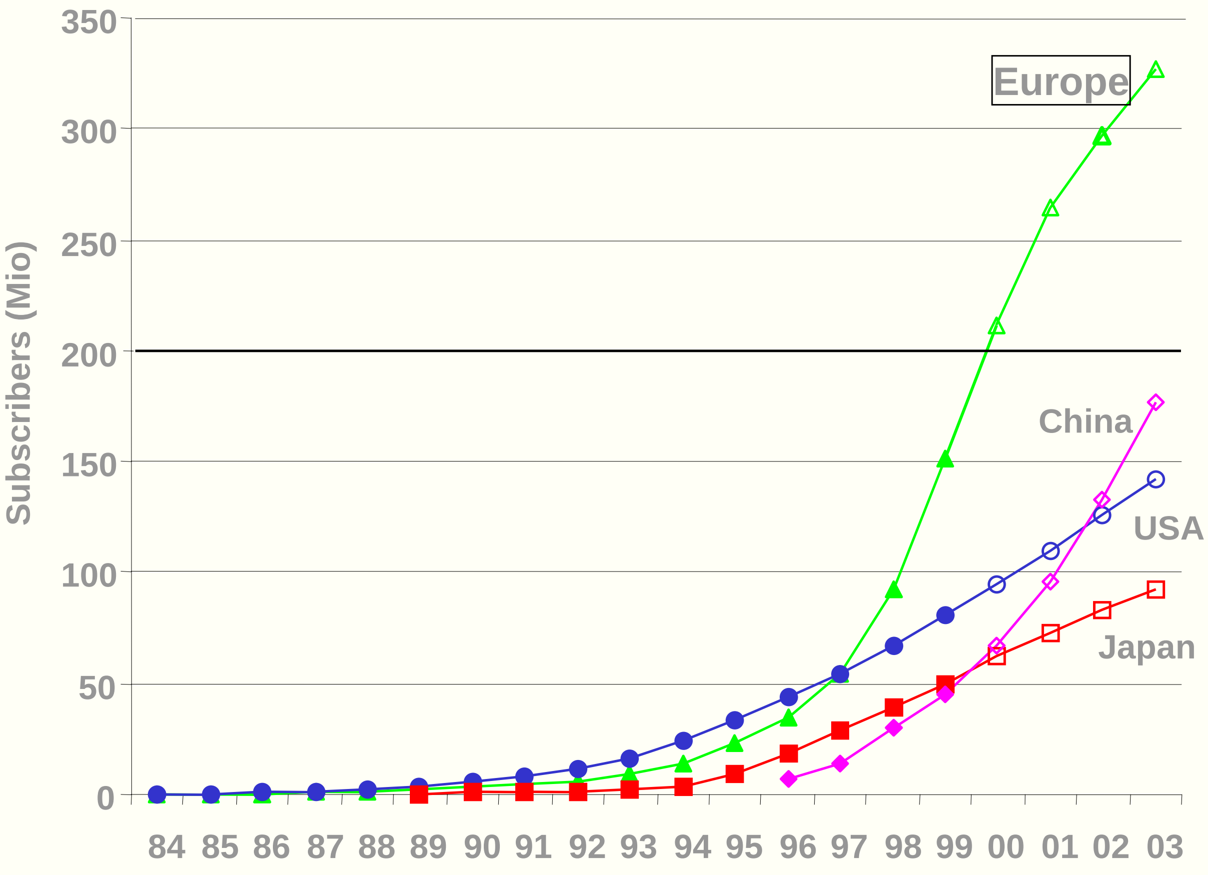
Rapid development poses great challenges to research

Migration to 3G:



Source: U.S. Bancorp Piper Jaffray

the 4 larges mobile markets



Wireless services:

- *<u>Past</u>: primarily voice (single service)*
- *<u>Future</u>: multimedia (incl. video, TV, gaming) and wireless computing, sensor networks (plurality of services)*

New powerful terminals: Moore’s law (1965)

- *Processing speed and storage capacity double every 18 month (at same price)*
- *Bottleneck: battery technology*
- *Cognitive radio*

Terms	Meaning
mobile station (MS) **user** **portable** **handset** **subscriber**	**mobile unit**
access point **base station (BS)**	**fixed unit**
uplink **reverse link**	**MS → BS**
downlink **forward link**	**BS → MS**
handover **handoff**	**Process of transferring a mobile from one channel/BS to anther**

Roaming	**The ability to use the same service in different networks, usually in different countries, with the same terminal**
time slot (TS)	**radio resource sub-unit in time domain**
sub-carrier	**radio resource sub-unit (frequency domain)**

IMT 2000 (International Mobile Telecommunications)

ITU-R

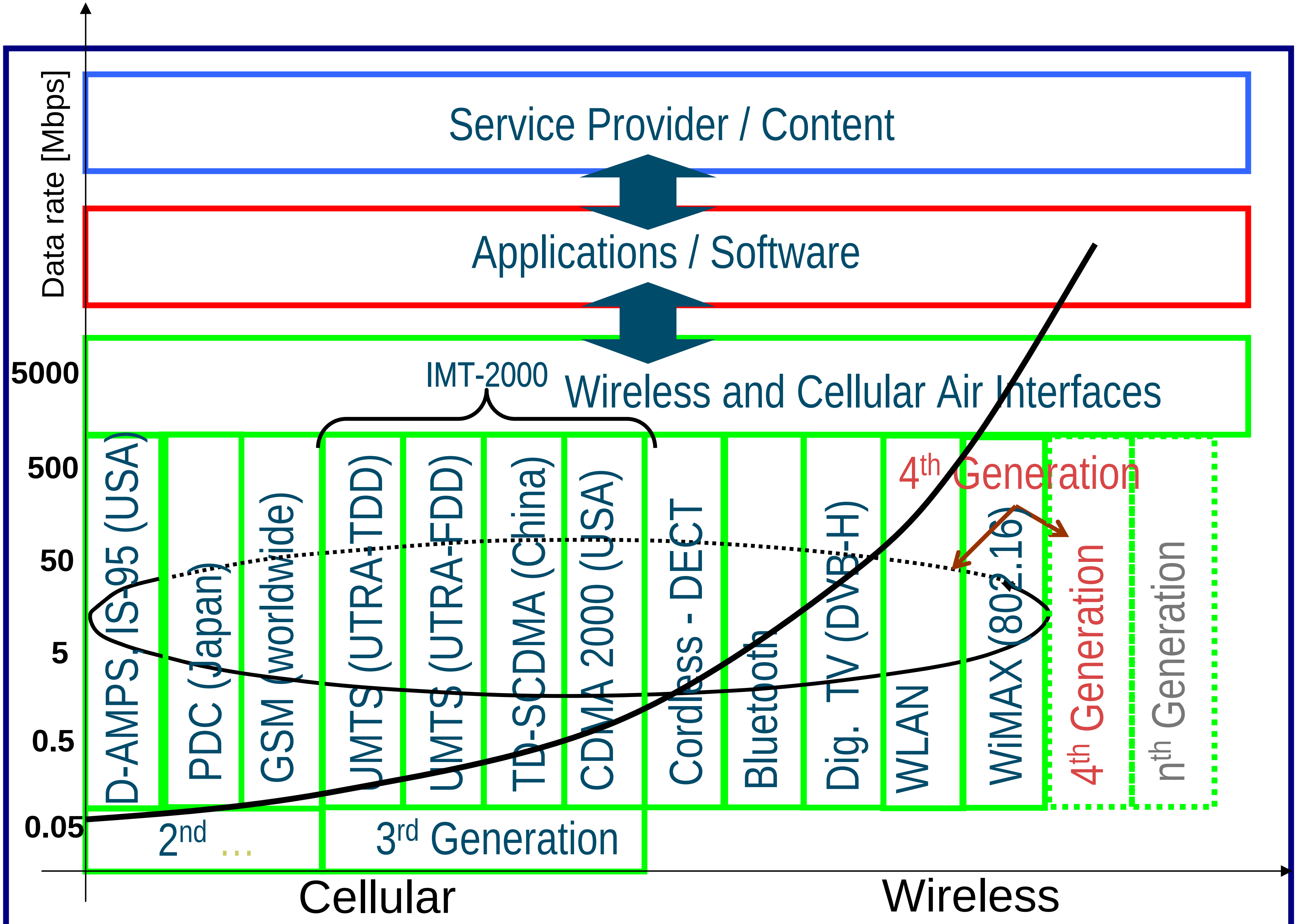
Radio frequency spectrum and radio system aspects

ITU-D

Studies, activities and assistance related to implementation of IMT-2000 in developing countries

ITU-T

Network aspects of IMT-2000 and beyond: Wireless Internet, convergence of mobile and fixed network mobility management


Data rate [Mbps]
5000
500
50
5
0.5
0.05
Service Provider / Content
Applications / Software
IMT-2000
Wireless and Cellular Air Interfaces
D-AMPS, IS-95 (USA)
PDC (Japan)
GSM (worldwide)
UMTS (UTRA-TDD)
UMTS (UTRA-FDD)
TD-SCDMA (China)
CDMA 2000 (USA)
Cordless - DECT
Bluetooth
Dig. TV (DVB-H)
WLAN
WiMAX (802.16)
4th Generation
4th Generation
nth Generation
2nd ...
3rd Generation
Cellular
Wireless

GSM (200 kHz carrier bandwidth)
(see: 3GPP TS 45.001 V7.1.0 (2005-06))

High Speed Circuit Switched Data (HSCSD)
4xTX $\rightarrow$ 57.6kbps (=4x14.4kbsp)

General Packet Radio Service (GPRS)
8xTX $\rightarrow$ 171.2kbps (=8x21.4kbps)

Enhanced data rates for GSM evolution (EDGE)
8xTX, 8PSK, no error protection $\rightarrow$ 547.2kbps (practical: 384 kbps)

CDMA2000 (1.25 MHz carrier bandwidth)

1xRTT

(single carrier radio transmission technology)

**(307 kbps DL,
152 kbps UL)**

1xEV

(evolutionary advancement)

incl. HDR (high data rate technology

(up to 2.4 Mbps) highly depending on mobile speed, propagation conditions, interference

1xEV - DO
- DV

(data only, or data and voice)

3xRTT

(Multicarrier transmission)

Industrial, scientific and medical (ISM) bands <u>unlicensed</u>

- **Currently:**
  - **5150 – 5350 MHz**
  - **5725 – 5825 MHz**

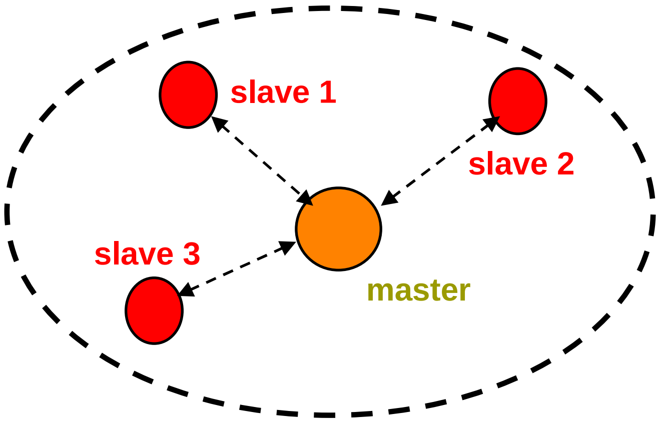
- **In the late 1980's the following frequencies were already specified as ISM bands:**
  - **902 – 928 MHz**
  - **2400 – 2483.5 MHz (Wireless LAN and Bluetooth)**

- **WLAN, 802.11, standardised in 1997**
  - **2 Mbps user data rate**
- **In 1999, 802.11(b) approved (Wi-Fi)**
  - **11 Mbps @ 5 GHz**
- **In 2001, 802.11(a) approved**
  - **54 Mbps**
- **802.11(g) = 802.11(b) @ 2.4 GHz + 802.11(a) @ 5 GHz (roaming)**
- **In 2003, 802.11(e) approved**
  - **QoS features added**

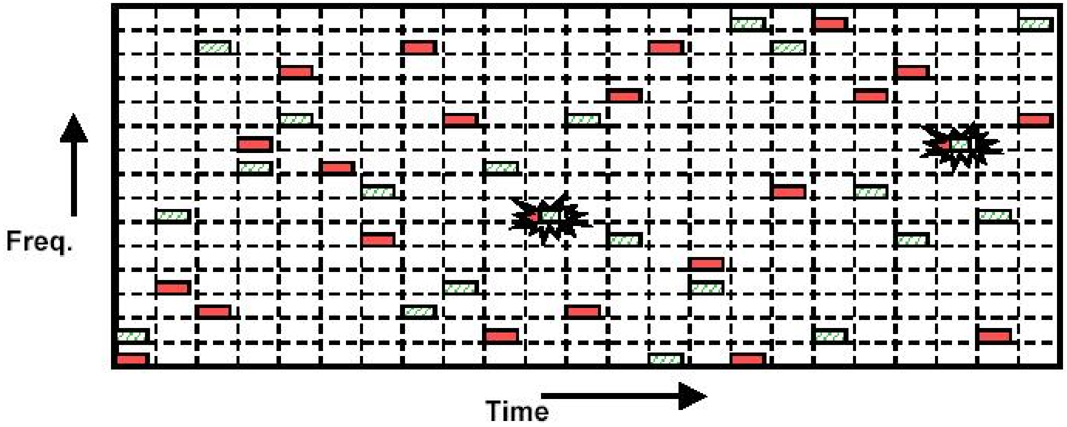
- Bluetooth is a universal radio Interface working in the license free ISM band in the range 2400-2483.5 MHz.
- The frequency range is divided in 79 RF frequencies separated by 1 MHz.

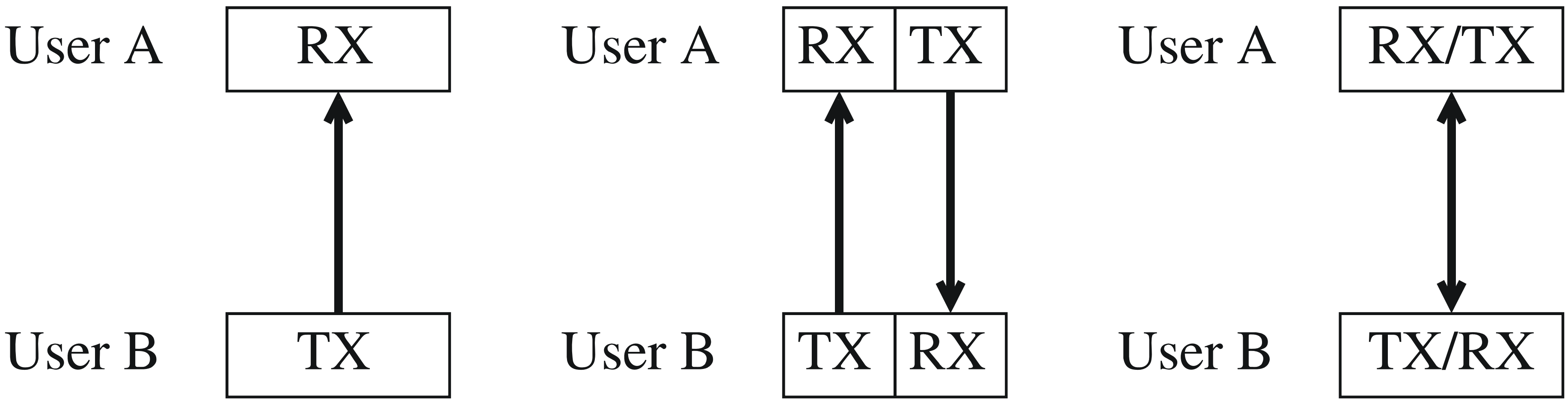
  $f = 2402\ GHz + k\ MHz,\ k = 0, \ldots, 78$

- The channels are hopping between the 79 frequencies at 1600 hops/s (TS: 625μs)
- The frequency selection follows the Kernel algorithm defined in the specifications.



- The basic Bluetooth network is called a Piconet. It is formed by a Master and up to 7 slaves.
- Each piconet is defined by a different hopping pattern to which users synchronize to.

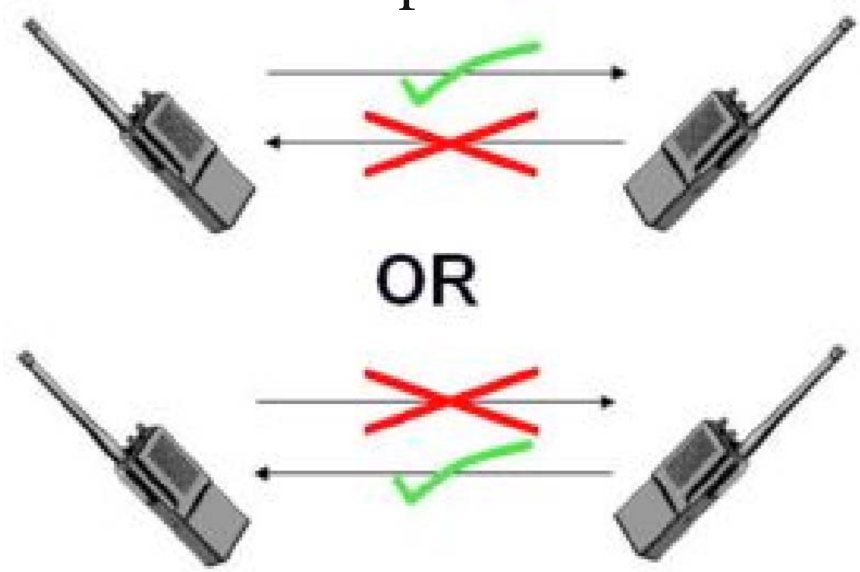


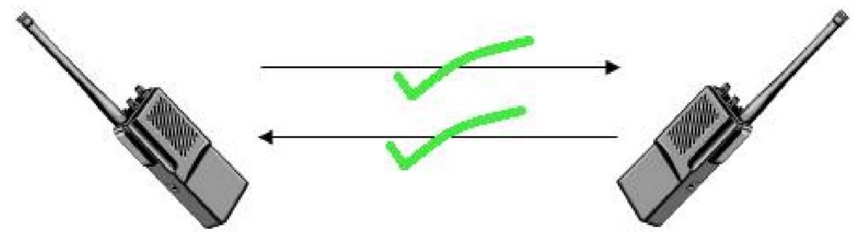


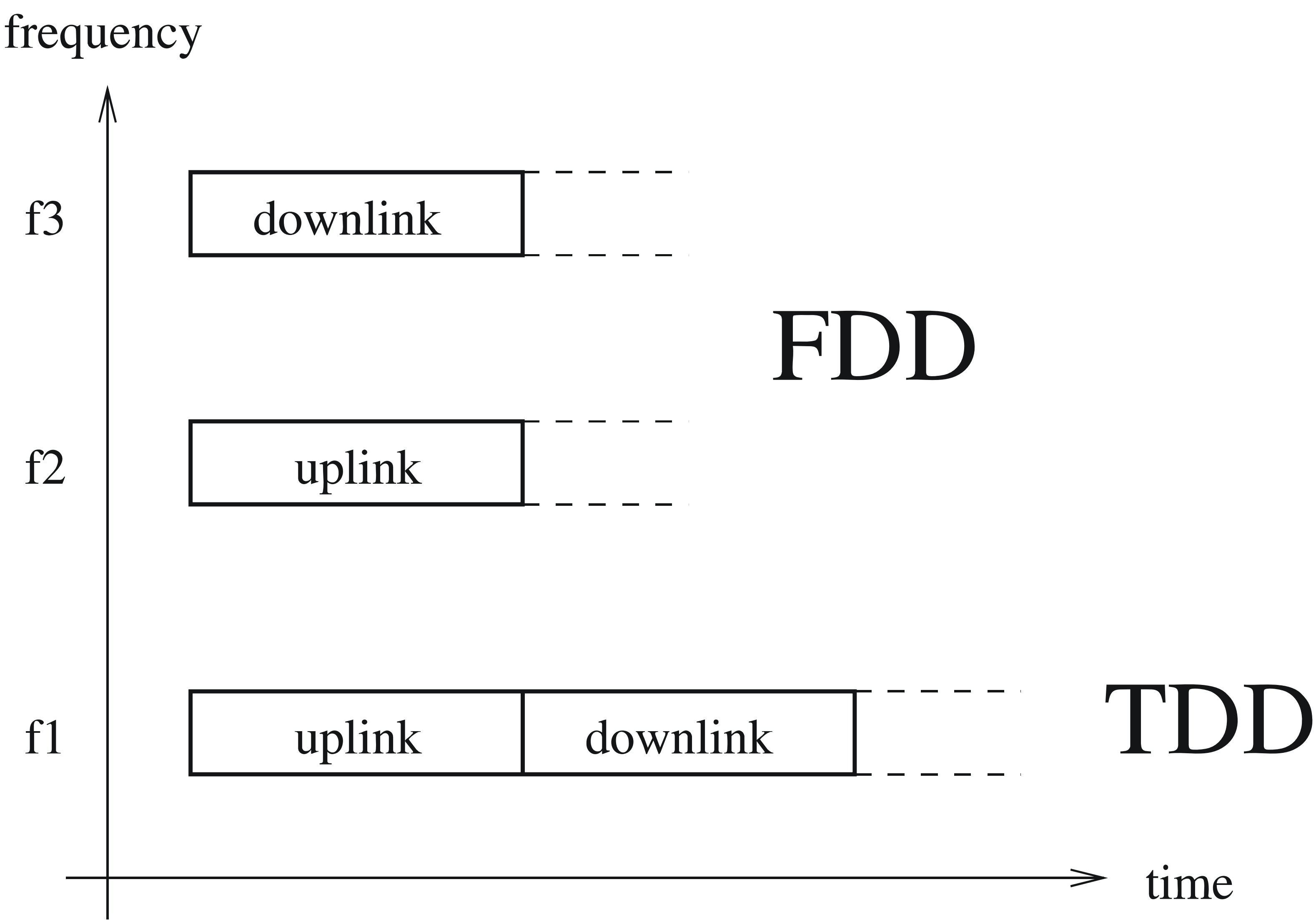
Simplex

Half duplex

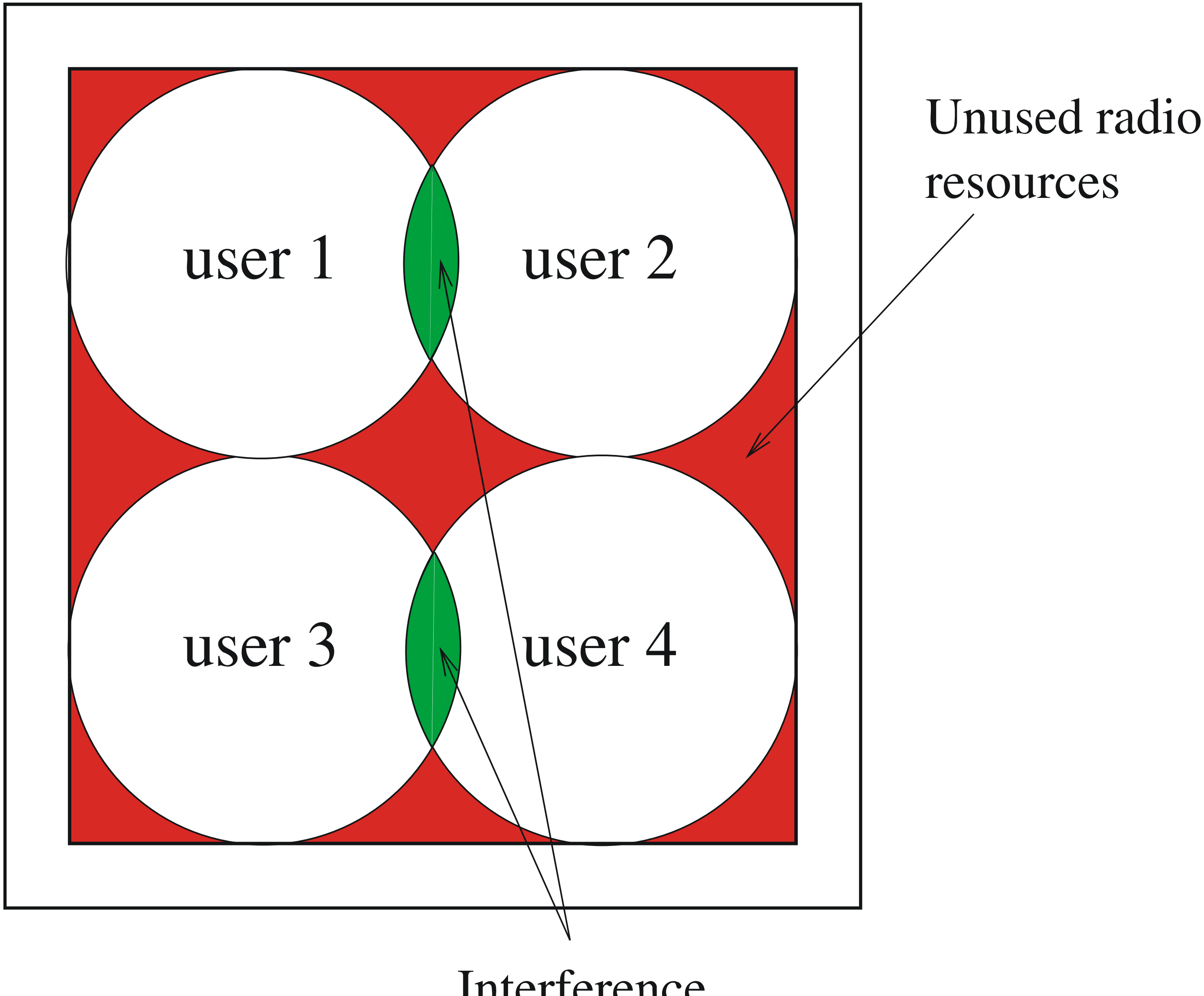
Full duplex

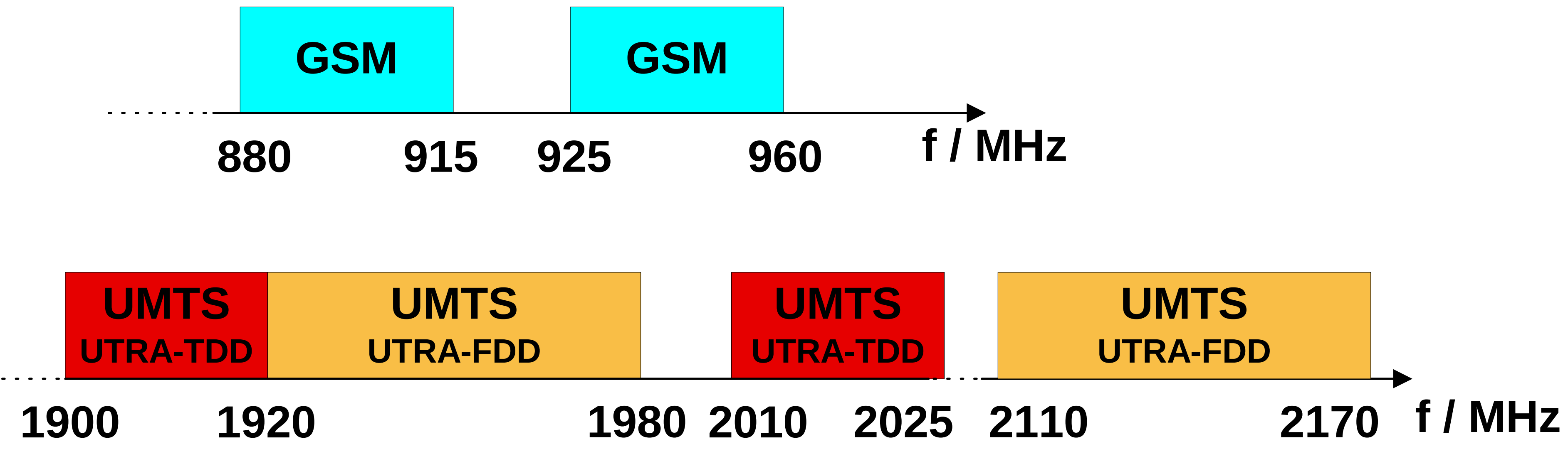




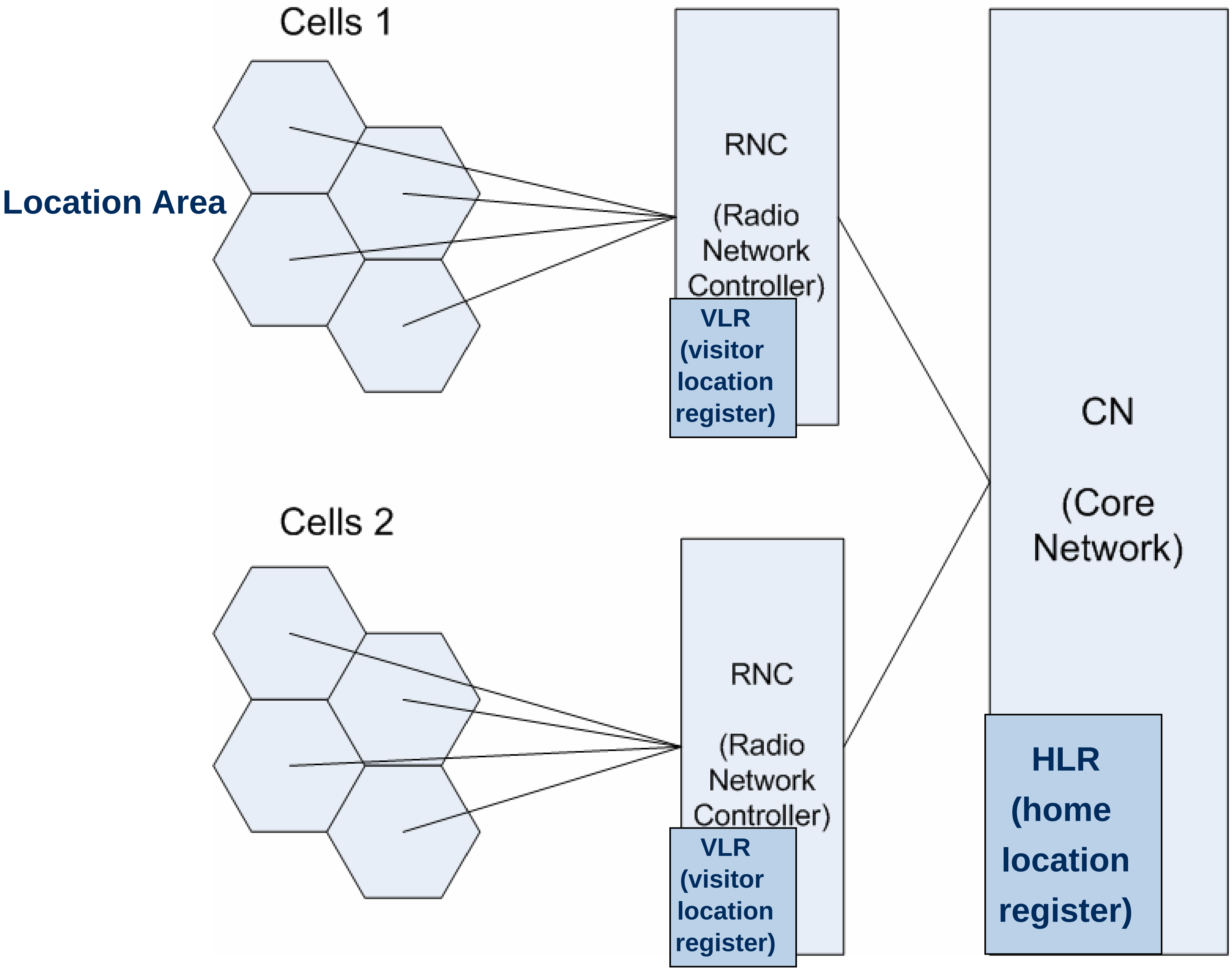

frequency
f3
downlink
FDD
f2
uplink
f1
uplink
downlink
TDD
time

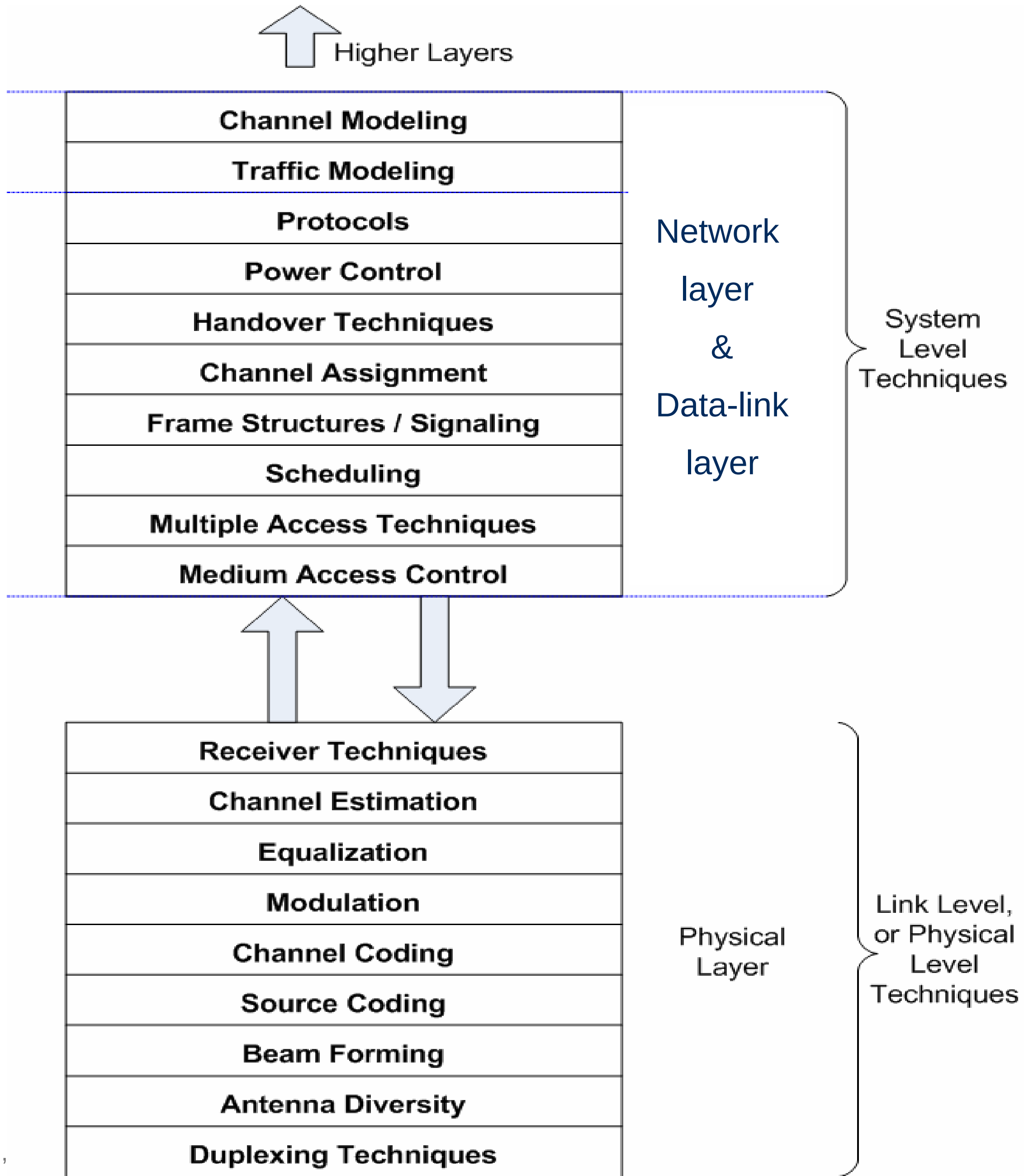
Wireless Channel

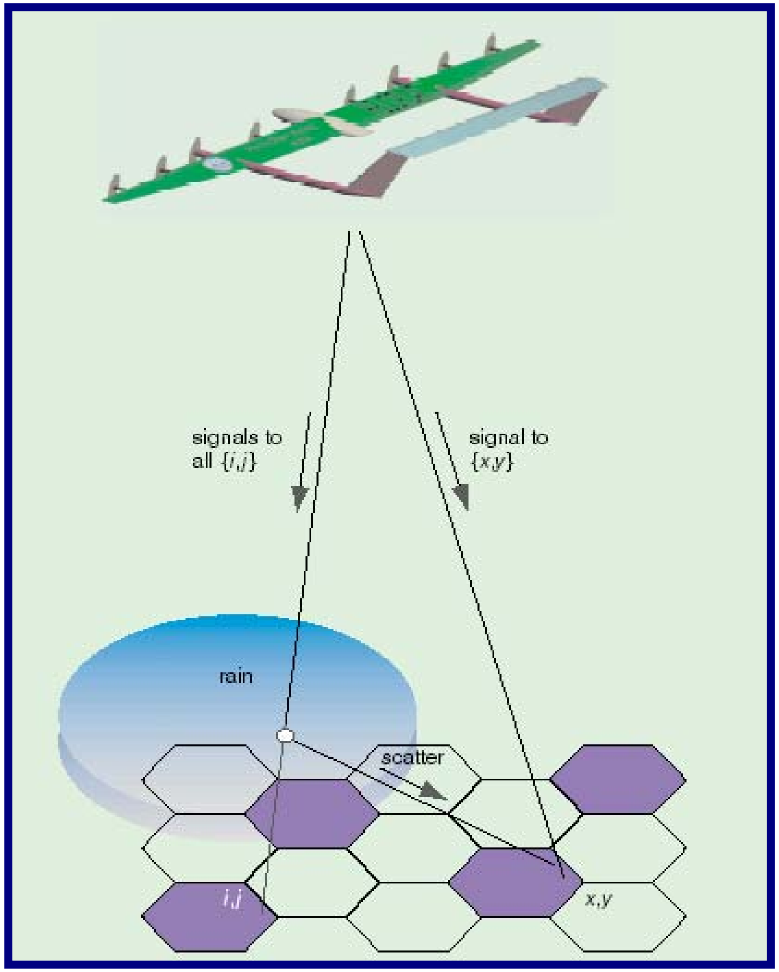




- **Challenge: Scarce, limited, expensive radio resources**
- **Goals:**
  1) Full coverage with limited resources
  2) Many subscribers (high revenue)
  3) High Quality of Service


Location Area
Cells 1
RNC
(Radio Network Controller)
VLR (visitor location register)
Cells 2
RNC
(Radio Network Controller)
VLR (visitor location register)
CN
(Core Network)
HLR (home location register)

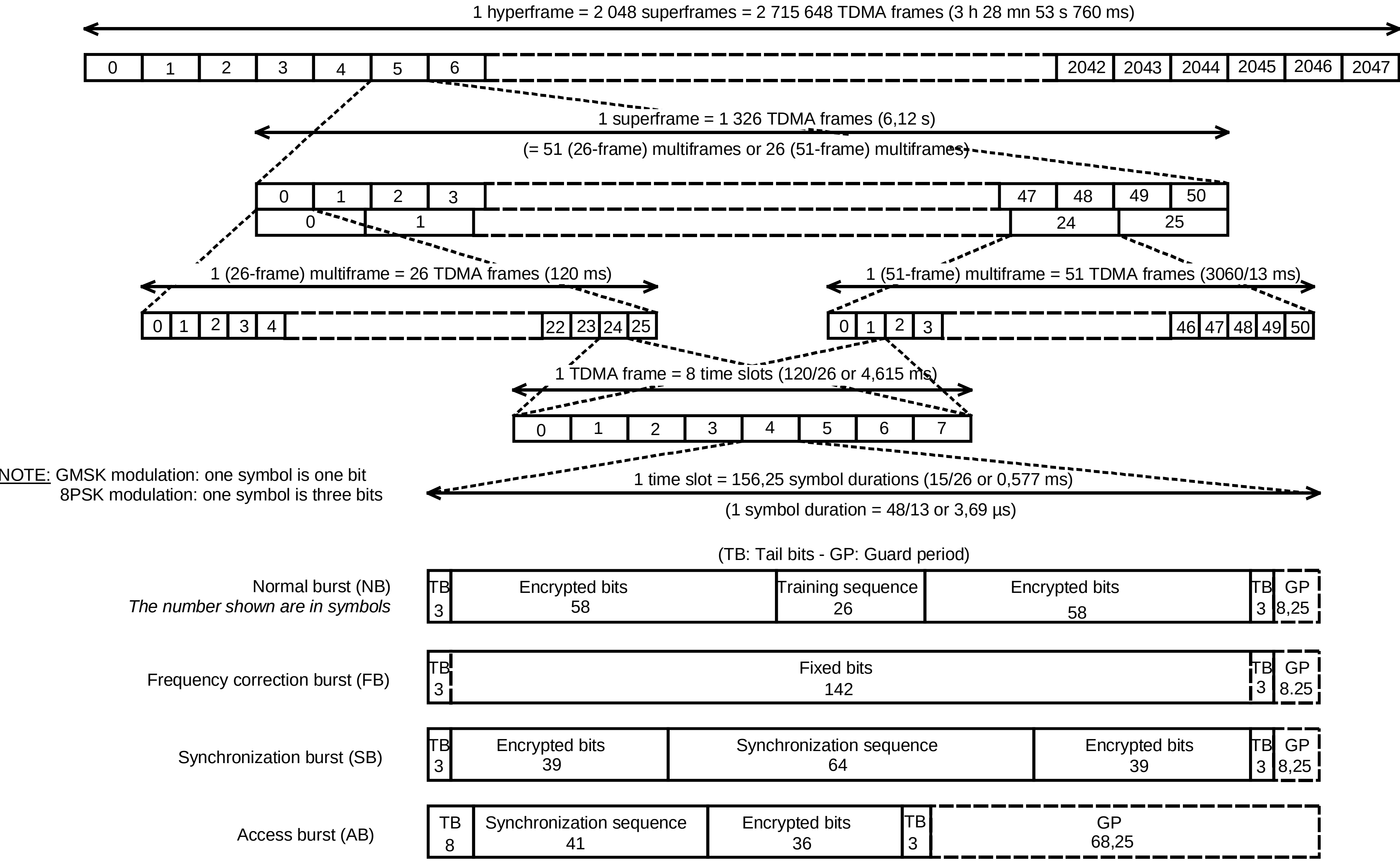

Higher Layers
Channel Modeling
Traffic Modeling
Protocols
Power Control
Handover Techniques
Channel Assignment
Frame Structures / Signaling
Scheduling
Multiple Access Techniques
Medium Access Control
Network layer & Data-link layer
System Level Techniques
Receiver Techniques
Channel Estimation
Equalization
Modulation
Channel Coding
Source Coding
Beam Forming
Antenna Diversity
Duplexing Techniques
Physical Layer
Link Level, or Physical Level Techniques



Source: J. Thornton, et al., "Broadband communications from a high altitude platform," IEE Electronics & Communications Engineering Journal, June 2001

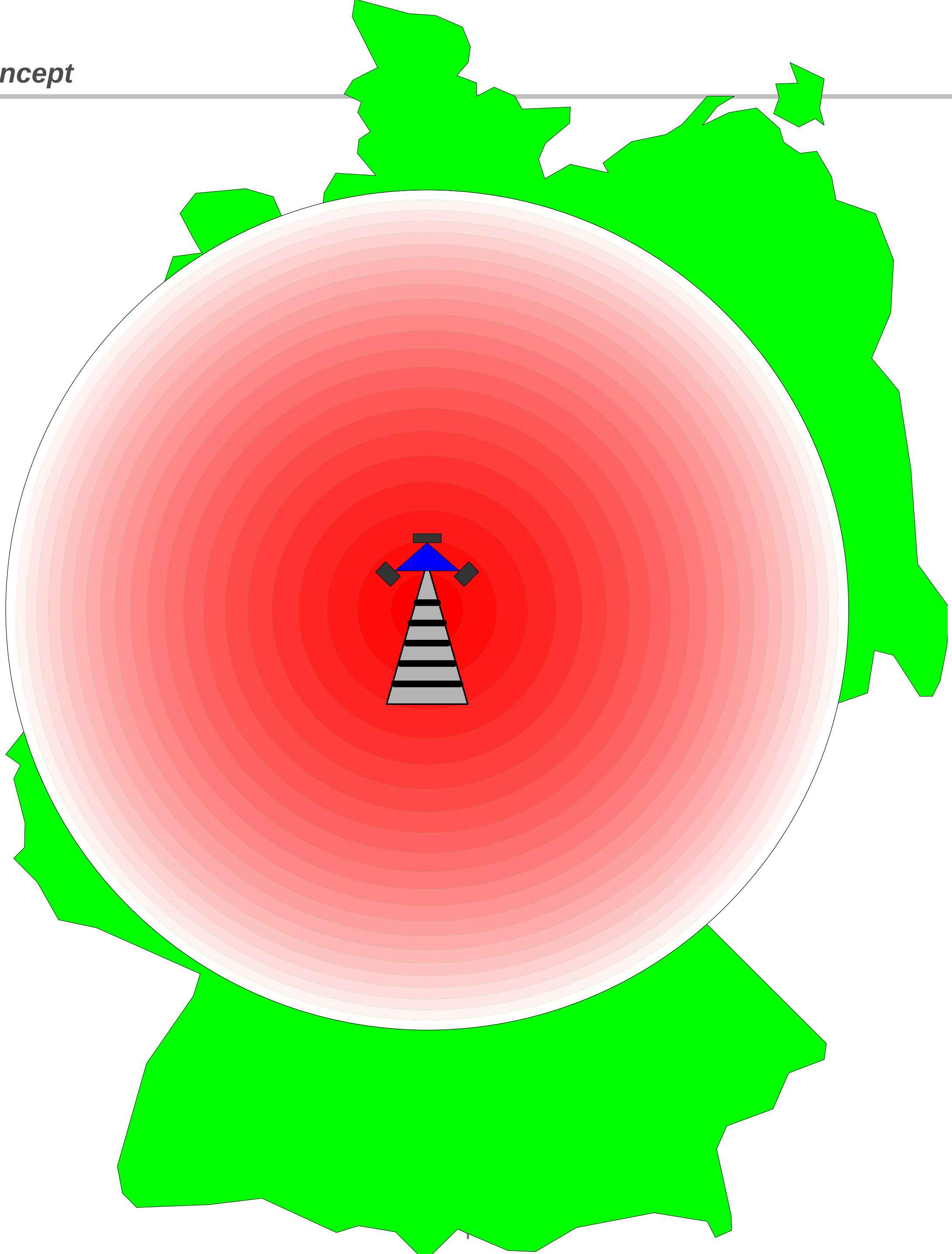
- European HeliNet Project
- Heights 17 – 20 km
- Advantages:
  - *High speed communication in 20 – 50 GHz frequency band*
  - *Low multi-path and line-of-sight conditions*
  - *Large coverage*
  - *Low Doppler*
- Disadvantages:
  - *Antennas with high gain required due to high attenuation*
  - *Scattering causes interference*

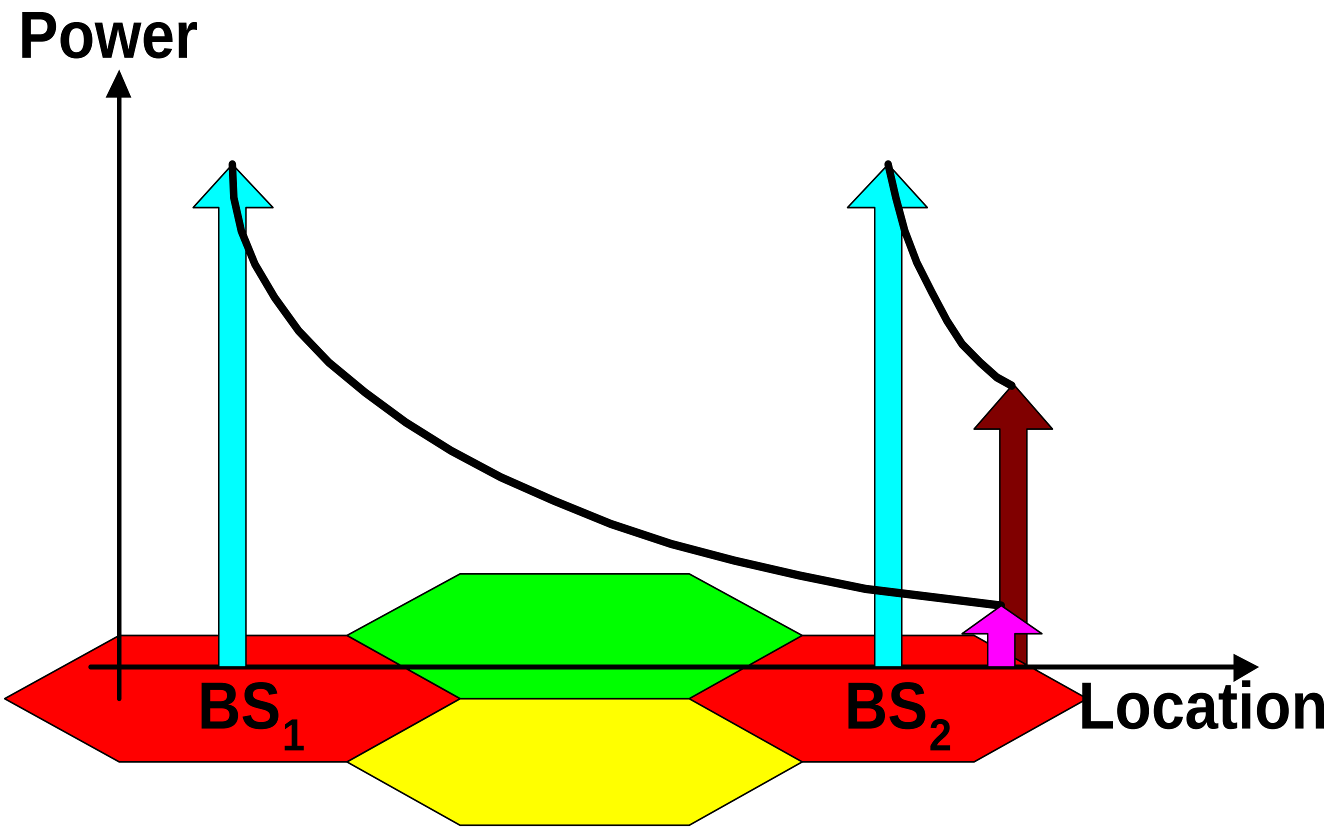
Example: GSM Overview



3GPP TS 45.001 V7.1.0 (2005-06))

The Cellular Concept





- **Concept:** **Frequency Re-Use**
  - **more users can be served**
- **Drawback:** **Generation of interference**
  - **reduction of users which can be served!**

S	Number of duplex channels in the cellular system
K	Number of channels per cell
N	Number of cells (4, 7 or 12)
M	Number of times a cluster is repeatedly used

Available Channels are grouped in blocks and assigned to cells

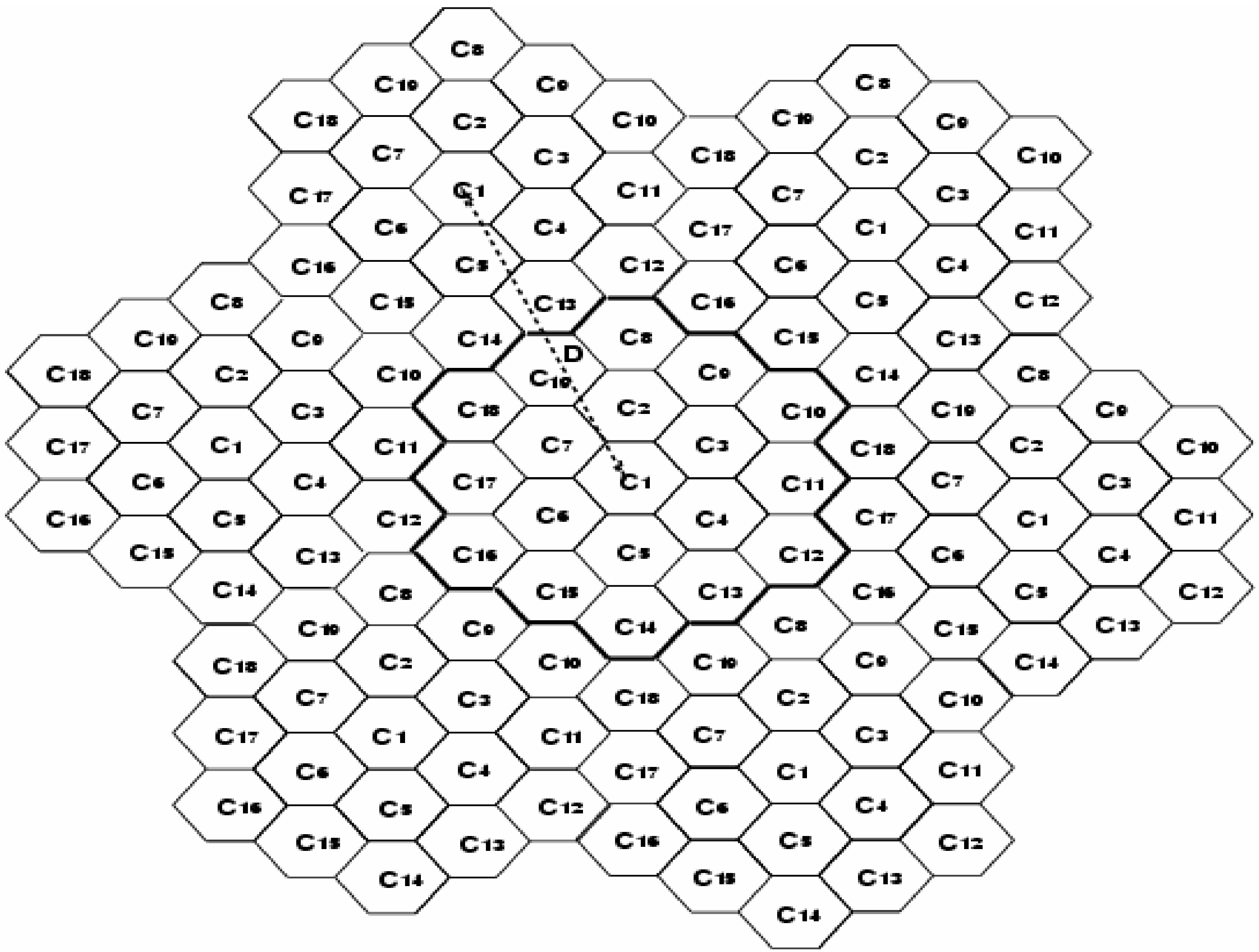
$$K = \frac{S}{N}$$

The system capacity (total number of channels) in the system is:

$$C = M\,S = M\,N\,K$$

If the cluster size, *N*, is reduced while the cell size is constant, more clusters, M, are required and thus the greater the capacity. But, the smaller, N, the smaller the frequency re-use distance and the higher the interference.

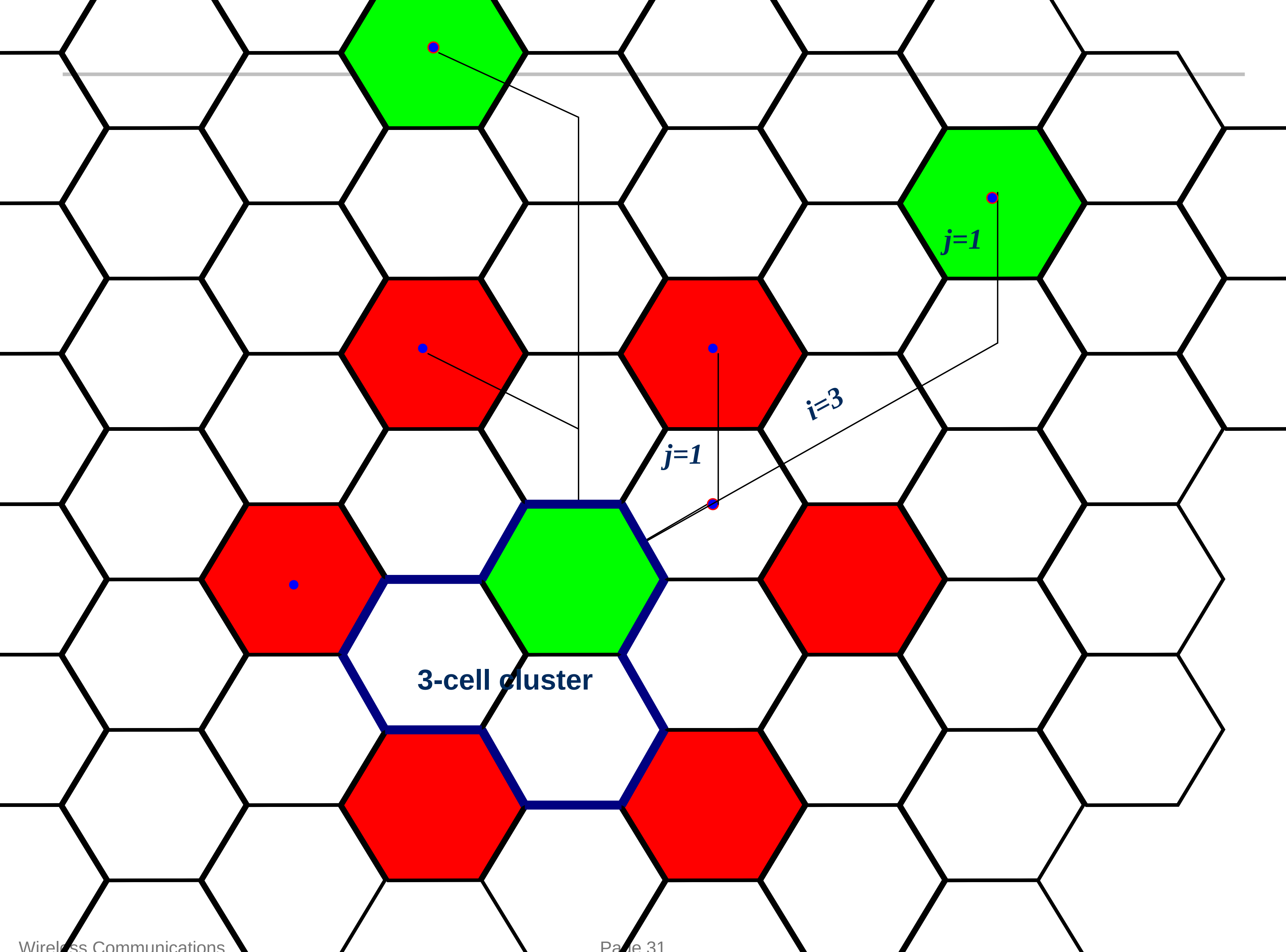
Cell clustering



The frequency reuse factor of a cellular system is given by:

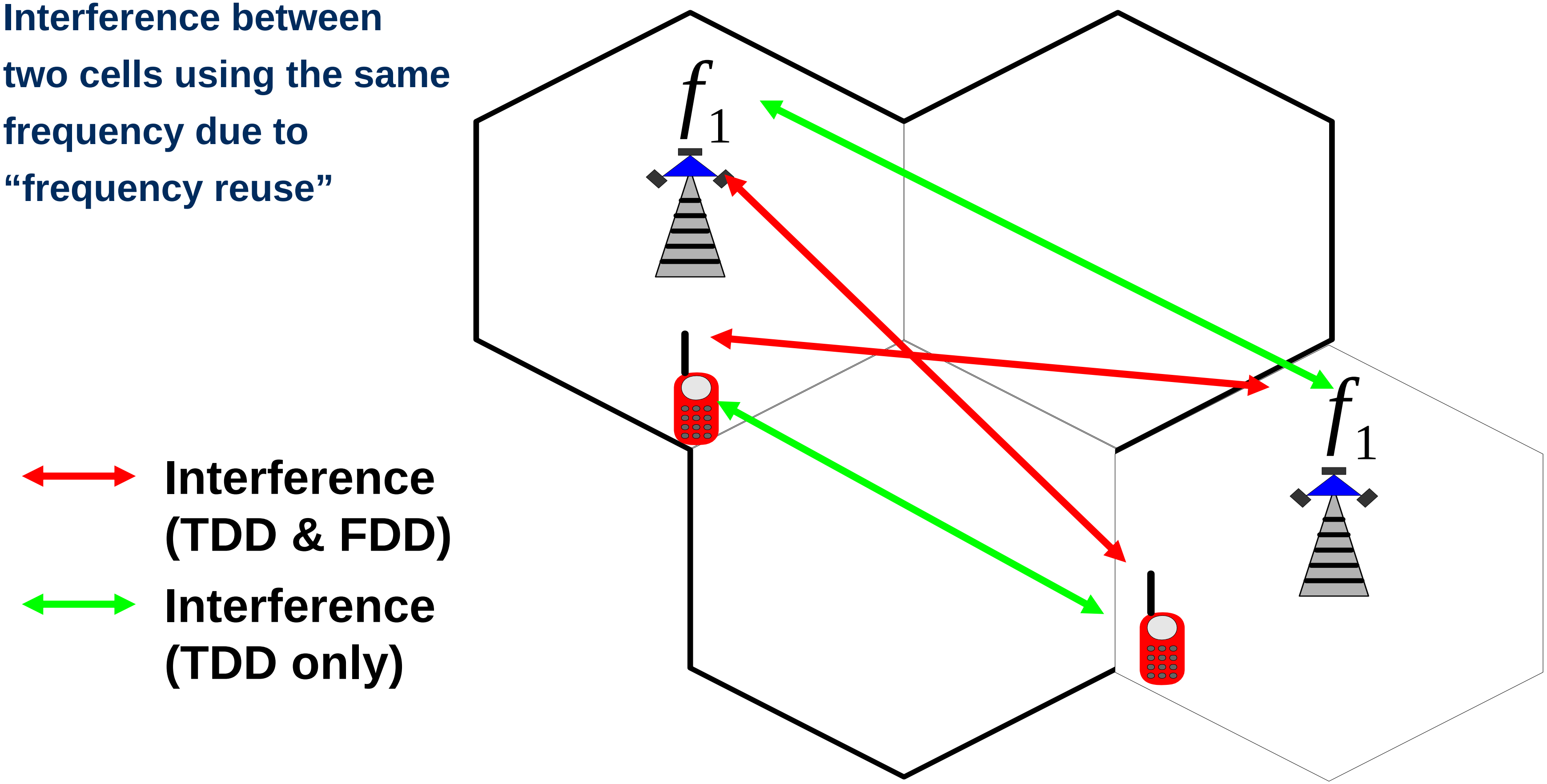
$$\frac{1}{N}$$

Each cell within a cluster is only assigned $\frac{1}{N}$ of the total available channels in the system.


j=1
i=3
j=1
3-cell cluster

Co-Channel Interference

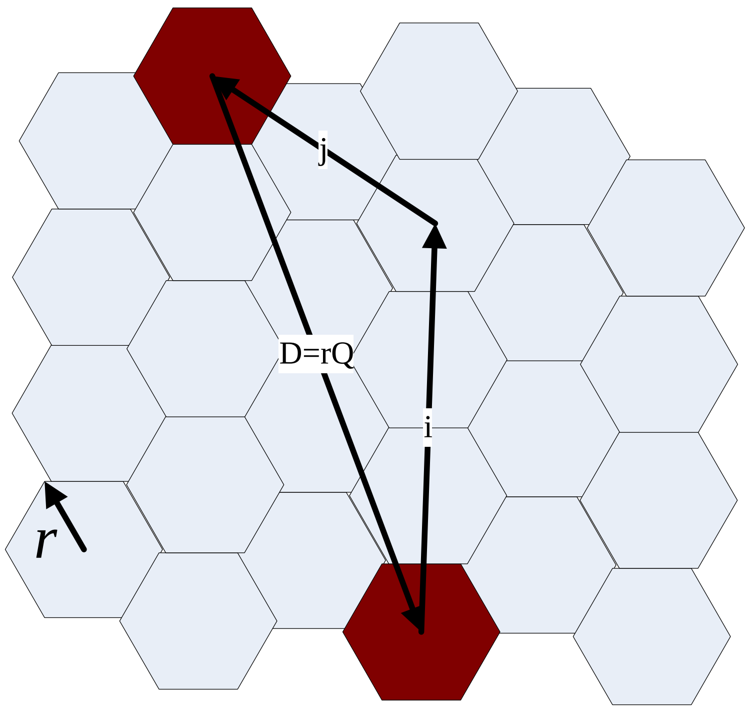
Interference between two cells using the same frequency due to "frequency reuse"



The number of cells per cluster, N, can only have values which satisfy:

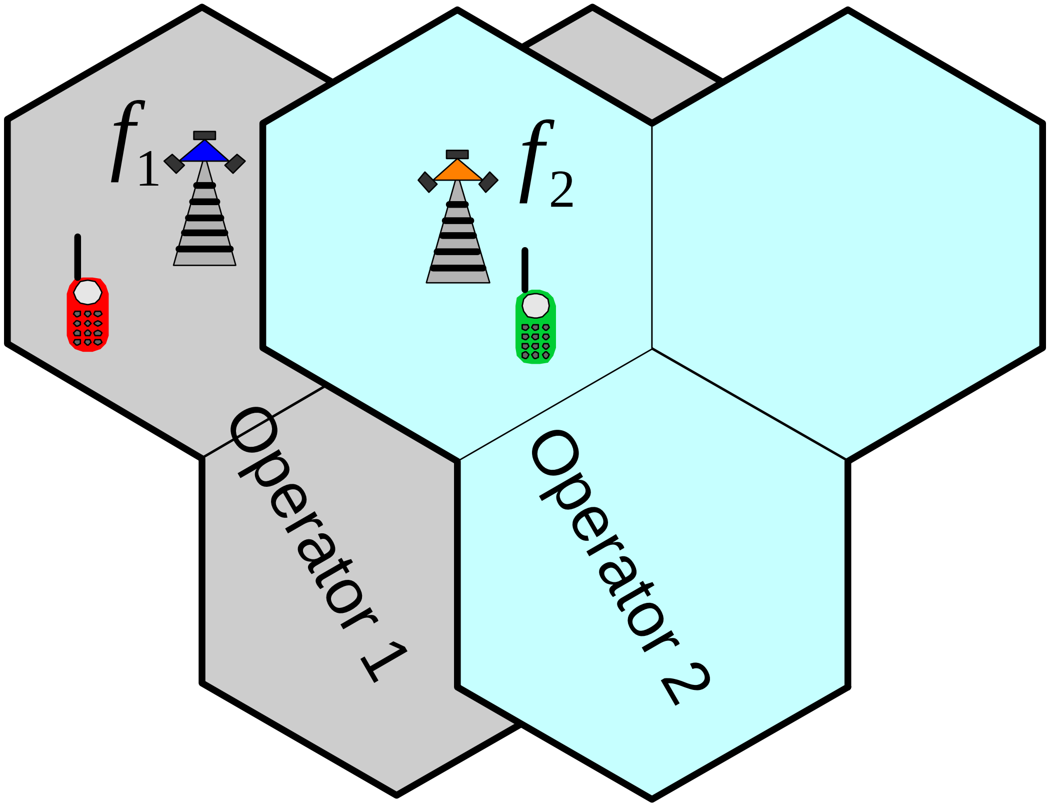
$$N = i^2 + j^2 + i\,j \qquad i, j \in \square$$

HW2: Prove that for a hexagonal geometry, the co-channel reuse ratio is given by $Q = \sqrt{3N}$. (Hint: use the cosine law and the hexagonal cell geometry).



Adjacent-Channel Interference

- **Interference resulting from signals which are adjacent in frequency to the desired signal**
- **This is due to imperfect receiver filters which allow nearby frequencies to leak into the passband.**



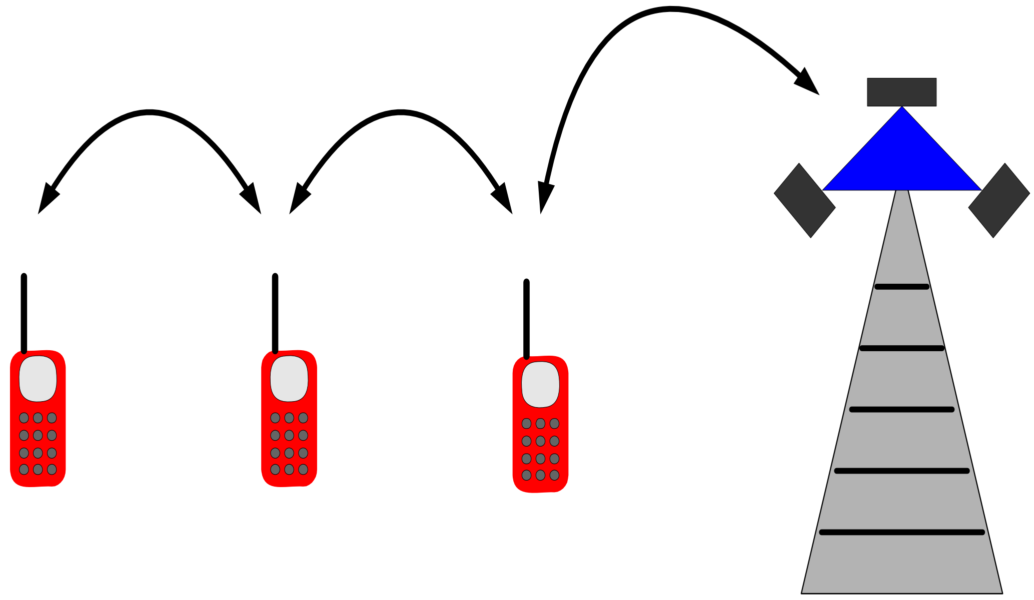
Solutions:

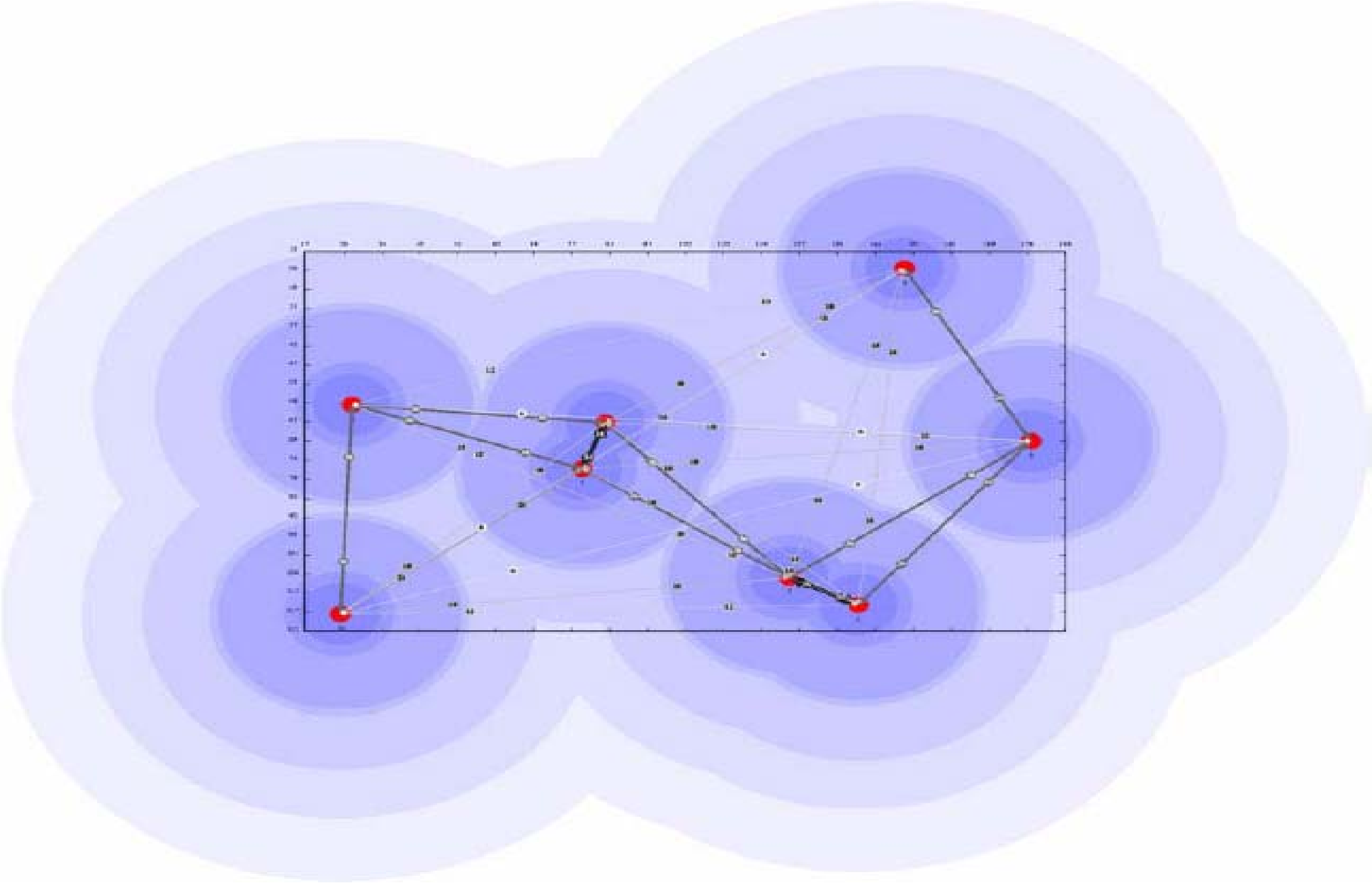
- **Careful filtering**
- **Proper channel assignments**

- **FUTURE: Investigation of techniques which allow low power transmission while maintaining high transmission rates**

- **Possible solution:**

  - **Ad-hoc routing (protocols)**

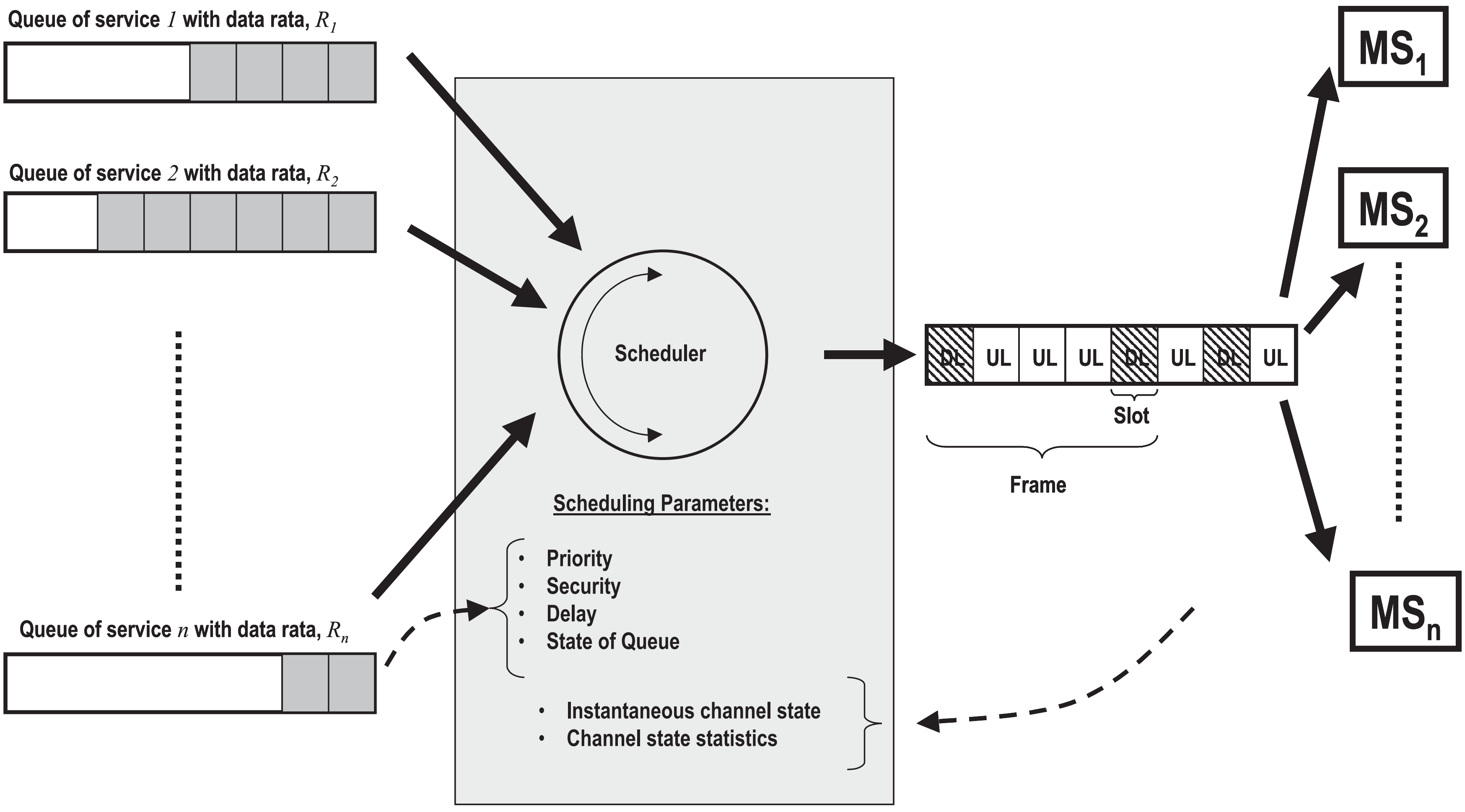




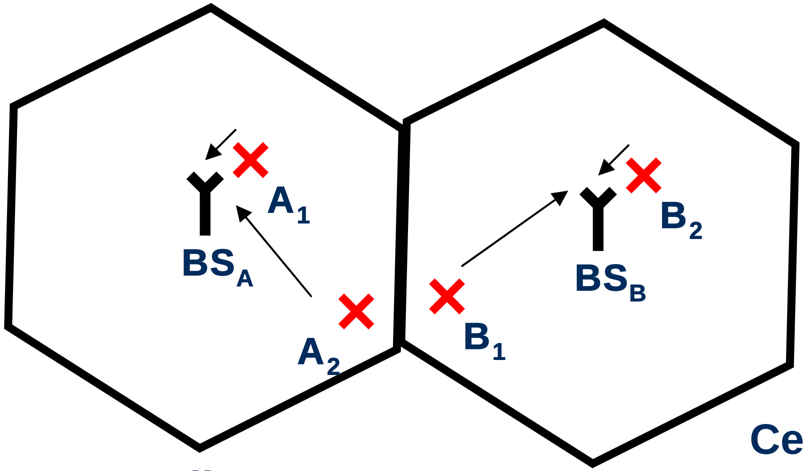
- **Scheduling – QoS support**
  - **HDR (High data rate)**
  - **Round robin**
  - **Proportional fair scheduling**
  - **Greedy rate packing**

- **Channel assignment strategies:**
  - **Intra-cell vs inter-cell**
  - **Fixed channel assignment (FCA)**
  - **Dynamic channel assignment (DCA)**
    - **Combinatorial optimisation problem**
    - **NP-hard**
- **Advantages/disadvantages of DCA:**

  - Radio signal strength measurements required
  - Knowledge of traffic distribution required
  - Control overhead
  + Reduced likelihood of blocking
  + Increased trunking capacity


Queue of service 1 with data rata, R_1
Queue of service 2 with data rata, R_2
Queue of service n with data rata, R_n
Scheduler
Scheduling Parameters:
Priority
Security
Delay
State of Queue
Instantaneous channel state
Channel state statistics
DL
UL
UL
UL
DL
UL
DL
UL
Slot
Frame
MS_1
MS_2
MS_n

- **Constant SINR**
- **Near-far effect**
- **Impact on inter- and intracell interference**
- **Uplink vs downlink power control**
  - **DL: point-to-multipoint**
  - **UL: Multipoint-to-point**



Suppose B_1 and B_2 transmit at the same power

- **Dwell time:**
  - *The time a mobile is served by a particular BS*

- **Dwell time is a random variable and an important parameter for HO algorithms**

- **The smaller the cell, the small the dwell time**

  → *Loss of spectral efficiency*

  → *Umbrella cells*

Requirements for successful MAHO

- *One carrier with constant Tx power in every cell*
- *Free channel in target cell*
  - Reservation of channels for handover
    - + Minimising the risk of HO failure
    - – Decreasing available traffic channels
  - Alternative: queuing of HO requests
    - – Delay
    - – Increased risk for signal falling below minimum threshold
- *In CDMA systems: Soft-handover*
  - Exploitation of macro-diversity
  - Instantaneous link to several BSs
  - Combine receive signals