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CDMA Technology :

- Introduction to Spread Spectrum Technology
- CDMA / DS : Principle of operation
- Generation of PN Spreading Codes
- Advanced Spreading codes
- Principles of CDMA/DS decoding

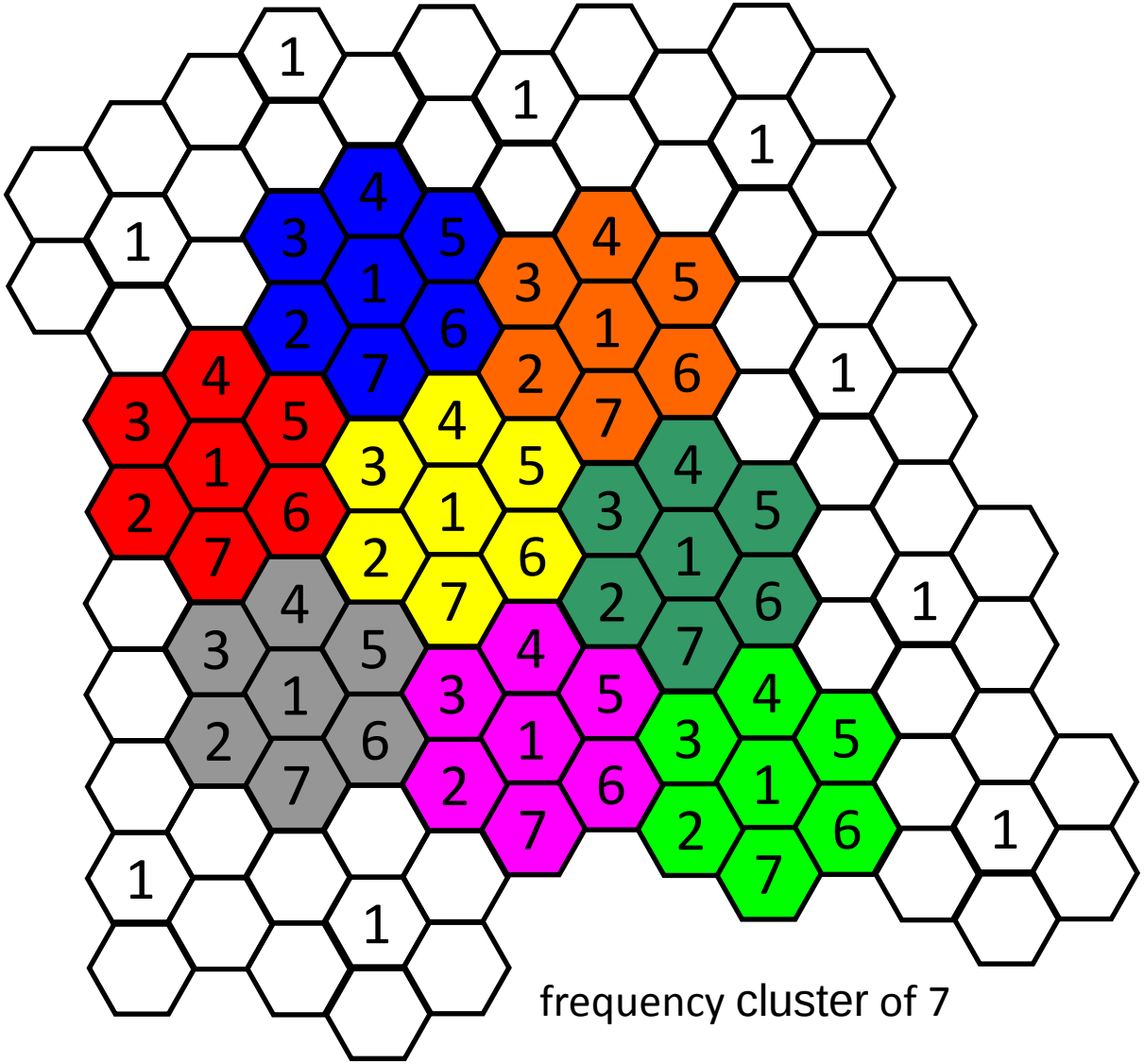
- **Radio Cells & System Capacity**

- Basics of Global Navigation Satellite Systems
- Galileo : European GNSS

CDMA Technology :

Radio Cells & System Capacity

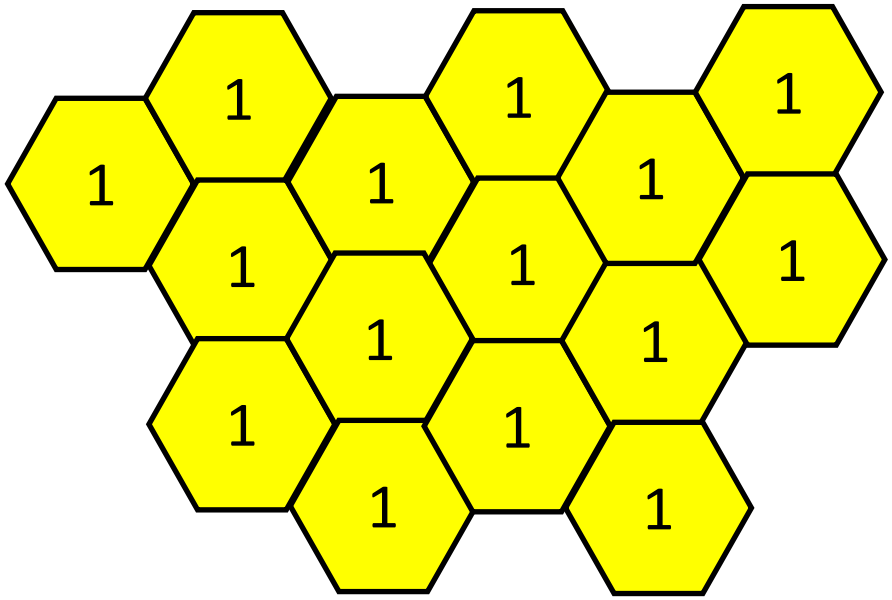
- Part 1 : Cellular Radio
- Part 2 : Frequency Re-use with CDMA/DS
- Part 3 : CDMA/DS Capacity Considerations
- Part 4 : Power Control and System Capacity for CDMA/DS
- Part 5 : Motivation for CDMA/DS in mobile COM
- Part 6 : Dynamic Cell Coverage
- Part 7 : Roaming



In traditional cellular radio systems (GSM) each radio cell (here: hexagon) uses a dedicated frequency.

Re-use of the same frequency is allowed only in a minimum distance to avoid interference and/or low signal-to-interference ratio.

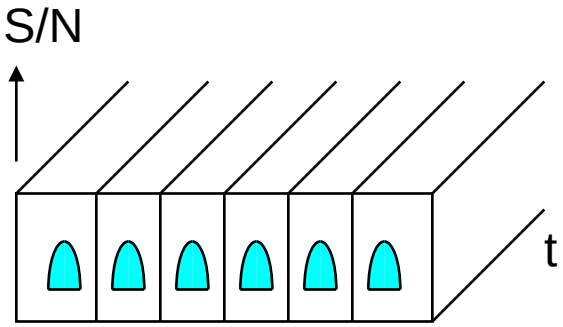
Frequency clusters are built to achieve homo-genious spatial frequency distribution



CDMA/DS allows for low S/I operation. So common frequency operation in adjacent cells is possible. However, logical separation between different radio cells is achieved by different codes ("scrambling codes").

In CDMA/DS cellular radio networks frequencies can be re-used in the adjacent cell. No frequency clusters have to be built. Hand-over between radio cells ("roaming") is simplified. Rake receivers allow for "soft handover").

Frequency Division Multiple Access ≡ FDMA

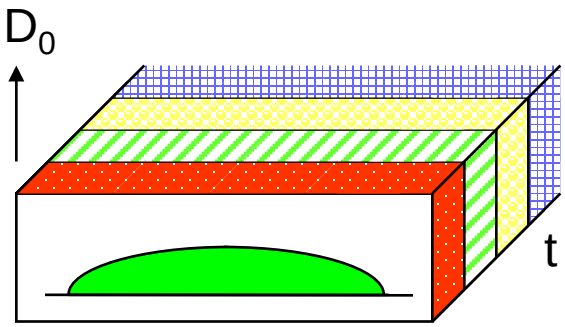


$B_{total} = n \cdot B_{channel}$

S/N: Signal-to-Noise Ratio [dB]

channel is multiplexed into parallel frequency channels

Time Division Multiple Access ≡ TDMA

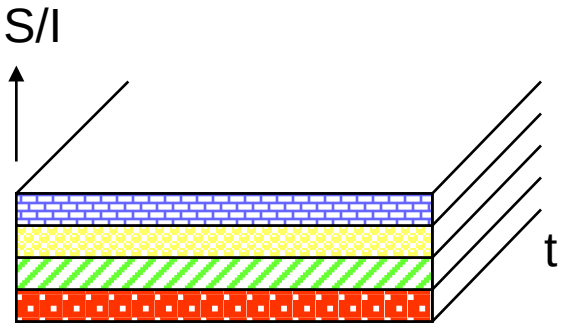


$B_{total} = B_{channel}$

D_0: Signal Dynamic [bit/sample]

channel is multiplexed into time slots / frames / packets

Code Division Multiple Access ≡ CDMA



$B_{total} = B_{channel}$

S/I: Signal-to-Interference Ratio [dB]

channel is multiplexed into differently coded signals

- pure FDMA and TDMA systems have a fixed system capacity
  - → no. of frequency channels is fixed / limited
  - → no. of time slots is fixed / limited
- in CDMA/DS systems the capacity is only limited by the required minimum margin of the signal-to-interference ratio (S/I or SIR) for sufficient quality of service (bit error rate)
- if a new communication link (signal) is added in a CDMA/DS system the SIR is (slightly) reduced and the quality of all other communication links (channels) is (slightly) degraded
- if a new communication signal is added and the total interference power exceeds the defined maximum then all channels will be slightly degraded, but not interrupted!
  - ⇒ CDMA/DS systems show "soft degradation" in the case of overloading
- for optimum system capacity the total power sum of all interfering signals should be kept to a minimum, that still maintains the minimum required quality of service in each link

- if a communication link (channel) does not meet the required quality of service (bit error rate) then there are basically 2 alternatives to overcome this situation:
  a. the transmitter power has to be increased
  b. the total interference power has to be minimized by reducing the transmission power in those links where the minimum quality of service can be still maintained
- a transmitting station located near to the target receiver will usually contribute stronger to the total interference power than a more distant station
  $\Rightarrow$ so called "near-far-effect"
- in an optimum scenario all transmitted signals are received by the rx with equal power $\rightarrow$ to achieve this an individual power control has to be supplied for in each link (channel)
- to keep the total interference power to a minimum and to offer optimum system capacity in a CDMA/DS system the transmission power has to be controlled in each communication link (channel)
  $\rightarrow$ a power control loop is required in CDMA/DS communication systems

The system capacity in the up-link of a CDMA/DS radio cell can be estimated as follows:

Assumptions:

- there is 1 radio cell with N (mobile) users
- all mobile users contribute with equal individual power P_S to the total interference power P_I
- for the required quality-of-service (bit error rate) a minimum SIR or (linear) E_{bit}/I_0 has to be maintained

with: $E_{bit} = P_S / f_D$ (E_{bit}: energy per bit ; f_D: data bit rate)

$I_0 = P_I / f_C$ (I_0: interference power density ; f_C: chip rate)

$f_C / f_D = P_G$ (P_G: linear process gain or "spreading factor")

Signal power to total interference power:

- signal power (of selected user): P_S
- total interference power: $P_I = (N-1)\, P_S$

$$P_S / P_I = 1 / (N-1)$$

and

$$E_{bit}/I_0 = (P_S / P_I) \cdot (f_C / f_D) = P_G / (N-1)$$

and with $N \approx (N-1)$ follows:

System Capacity:

$$N \approx P_G / (E_{bit}/I_0)$$

The system capacity of a CDMA/DS system can be enhanced by the following measures:

- Increasing the spreading factor ≡ chips / data bit
  ⇒ increase of process gain → off-channel signals will be suppressed more efficiently
- Decreasing the required minimum signal-to-interference ratio SIR
  ⇒ introduction of more robust modulation schemes and/or more effective error correction channel coding
- Use of directional antennas
  ⇒ sector antennas or beam steering antennas (smart antennas) for power reduction of received unwanted signals (interference)

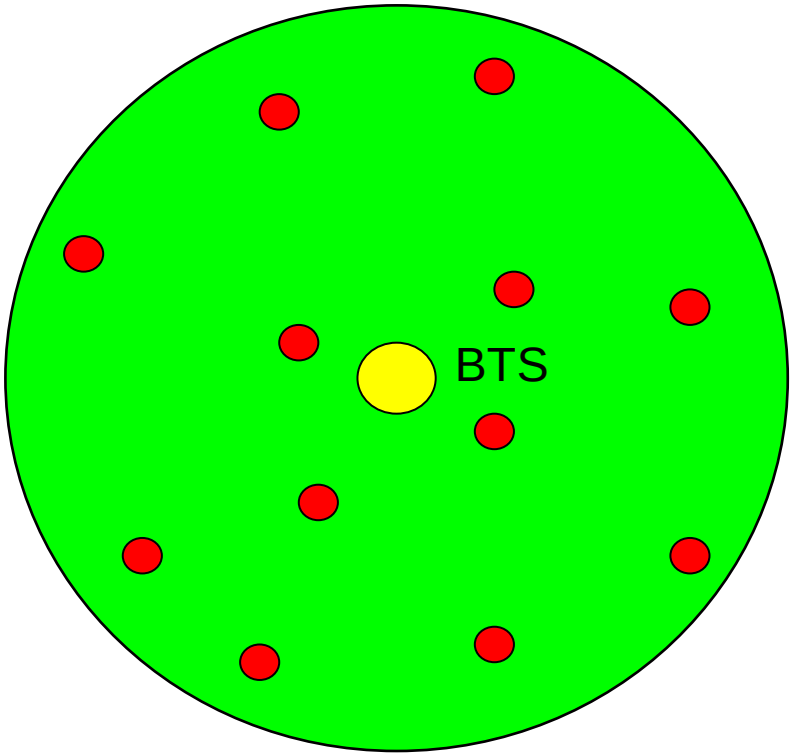
- multipath propagation is the dominant interference mechanism in mobile radio communication systems
  ⇒ CDMA/DS offers high multipath resistance (delayed echoes undergo process gain!)

- control of transmitted power to minimum margin for stable communication link reduces total off channel power
  → higher number of communication channels can be installed
  ⇒ better system efficiency ("frequency economy") compared to FDMA/TDMA

- CDMA signals can be recovered successfully only when correlated with the dedicated code
  ⇒ enhanced privacy / reduced threat of "eavesdropping"

- spread spectrum technique lowers maxima of power density spectrum and distributes the rf power over a greater bandwidth
  ⇒ less problems with emc and environmental protection ("electric smog")

Low Traffic Loading ≡ Low Interference Power (high S/I at BTS)

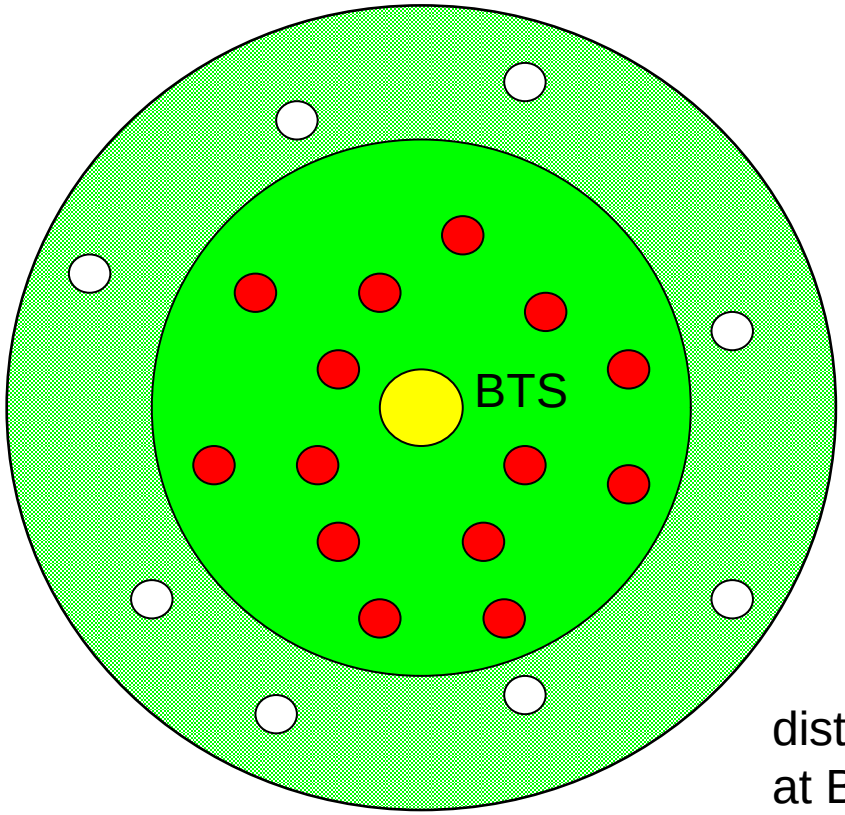


Base Transceiver Station (BTS)

active Mobile Station (MS)

distant MS can exceed required S/I margin at BTS → radio cell has full extension

High Traffic Loading ≡ High Interference Power (low S/I at BTS)



Base Transceiver Station (BTS)

active Mobile Station (MS)

removed Mobile Station (MS)

distant MS can not exceed required S/I margin
at BTS → radio cell extension is reduced

Radio cell coverage depends on traffic loading! Distant MS may be removed!

- mobile users will often travel through multiple radio cells $\Rightarrow$ users will have to be handed over between different radio cells (roaming)
- in traditional cellular radio systems a hard handover has to be used (on-off-switching between adjacent cells)
- fingers of a rake receiver can not only be matched to different multipath signals from one single station, but may be matched to similar signals from different (adjacent) base stations
- rake receivers allow for a soft-handover between different radio cells by combining the signals from different base stations
- smooth transition from one radio cell to the adjacent cell enables more convenient roaming without signal outages or fluttering

- **Spread spectrum communications suited for Cellular Mobile Radio Networks**
  - **CDMA/DS is robust against Multipath**
  - **Power Control enhances total System Capacity**
  - **CDMA/DS enables Soft-Handover between Radio Cells**

- **Key points :**
  - **System Capacity adjustment by Power Control**
  - **« breathing » Radio Cells depending on Traffic Loading**
  - **Roaming with « Soft-Handover » between Radio Cells**

- **If needed, a few related readings in CDMA/DS System Capacity :**
  - **Geerdes, Hans-Florian: UMTS Radio Network Planning – Mastering Cell Coupling for Capacity Optimization Springer Vieweg, Wiesbaden 2008**
  - **http://nwww.ursi.org/Proceedings/.../PDF/F04.2(0531).pdf**