Systems cdma

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Generations of mobile systems

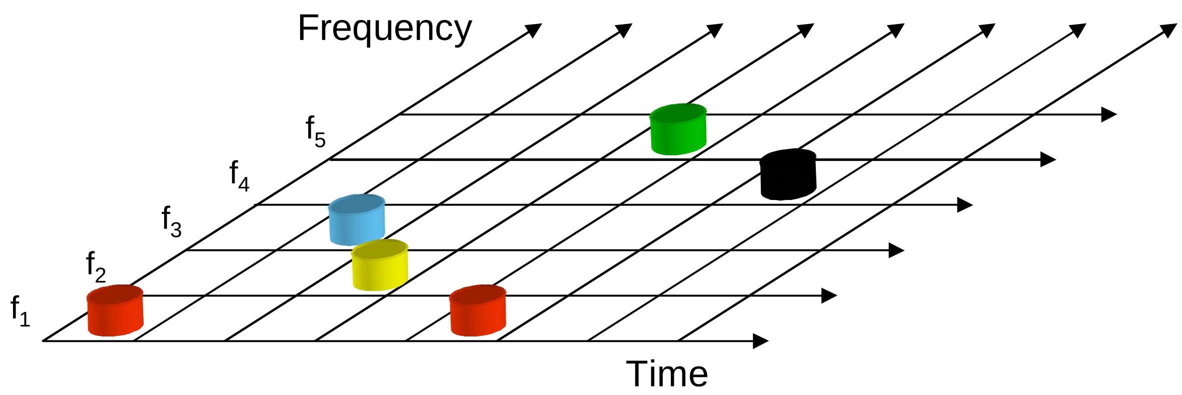
Generation	Names	Features
1 (1980)	NMT (*Nordic Mobile Telephone*), …	Analog systems National systems Voice
2 (1992)	GSM (*Global System for Mobile communications*) - GSM 900, GSM 1800 IS95 (*Interim Standard*) based on CDMA - IS95a,b …cdmaOne	Digital systems Voice + Data
2,5 (1999)	GPRS (*General Packet Radio Service*) EGPRS/EDGE (*Enhanced GPRS/Enhanced Data rates for Global Evolution*)	
3 (2004)	UMTS (*Universal Mobile Telecommunication System*) cdma2000 (*code division multiple access*)	Multimedia
…		

Spread Spectrum Techniques

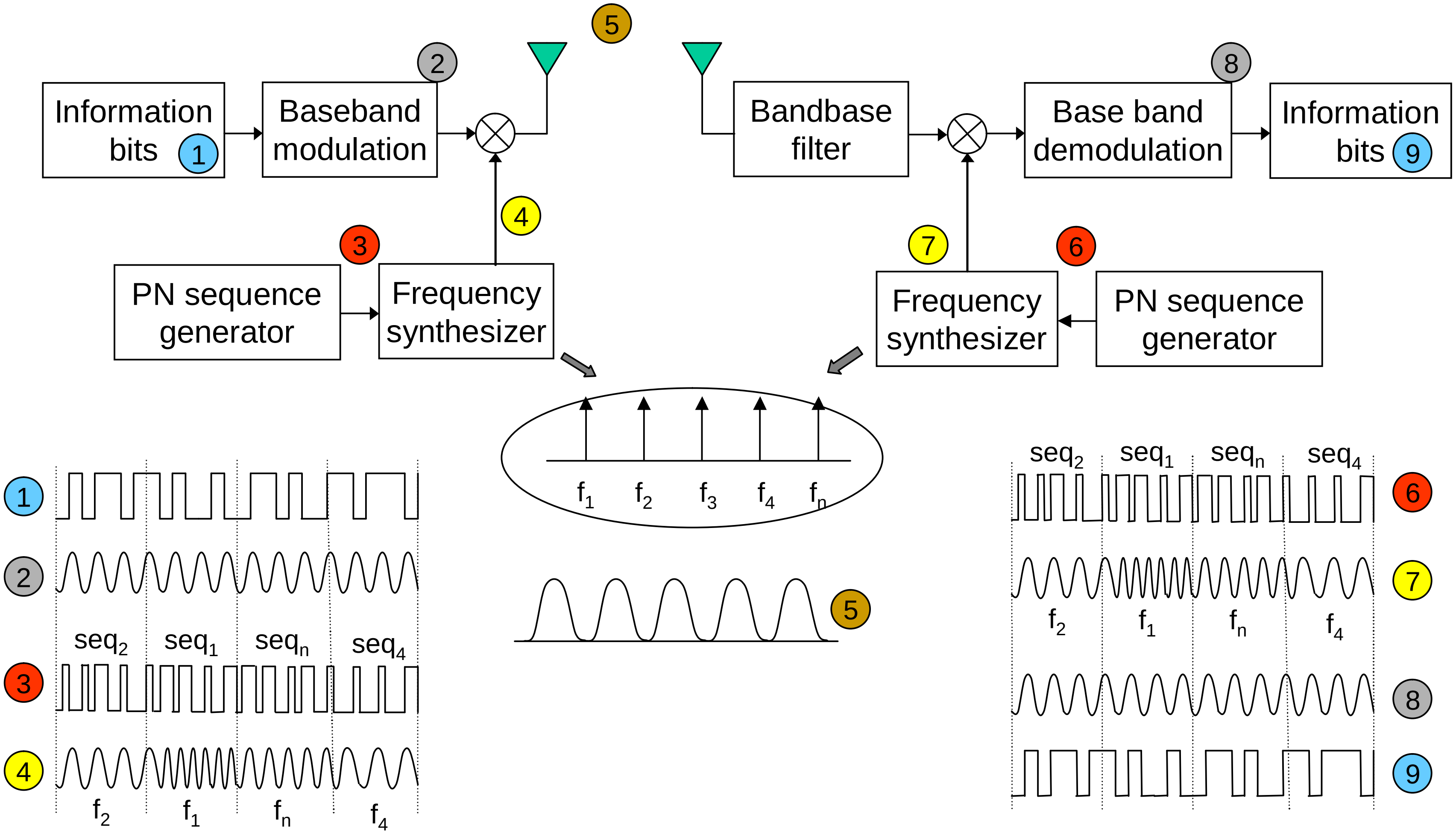
- Frequency Hopping (FH)
- Direct Sequence (DS)
- …

Frequency Hopping (1/3)

- Carriers periodically change
- Frequencies
  - Ø are selected from a pre-determined group within available spectrum
  - Ø change in order defined by pseudo-random sequence
    (… PN, Pseudo-Noise sequence)



Frequency Hopping (2/3)



Frequency Hopping (3/3)

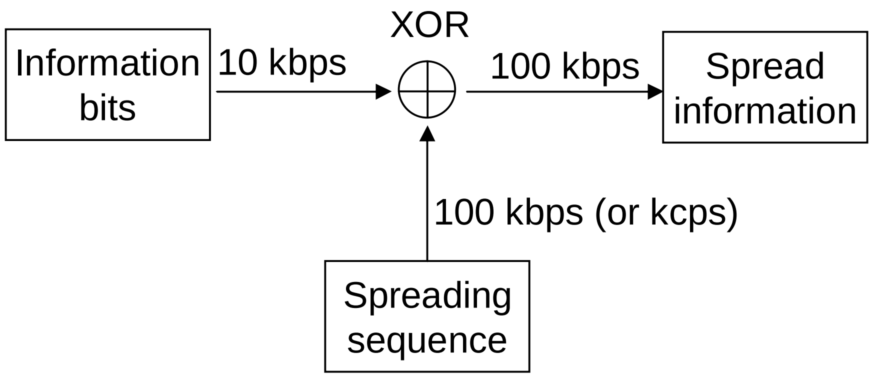
- Tx&Rx PN sequences have to be identical + synchronized
- Hopping
  - Ø Fast Frequency Hopping (FFH)
    - hopping rate ≥ bit rate of the base band signal
  - Ø Slow Frequency Hopping (SFH)
    - hopping rate ≤ bit rate of the base band signal

- Higher hopping rate & number of frequencies, the greater privacy and interference protection

Direct Sequence

- Easy implementation → mostly used
  - … is not required a high speed frequency synthesizer
- Occupies whole available frequency band continuously
- cdma2000, WCDMA

Spreading of signal

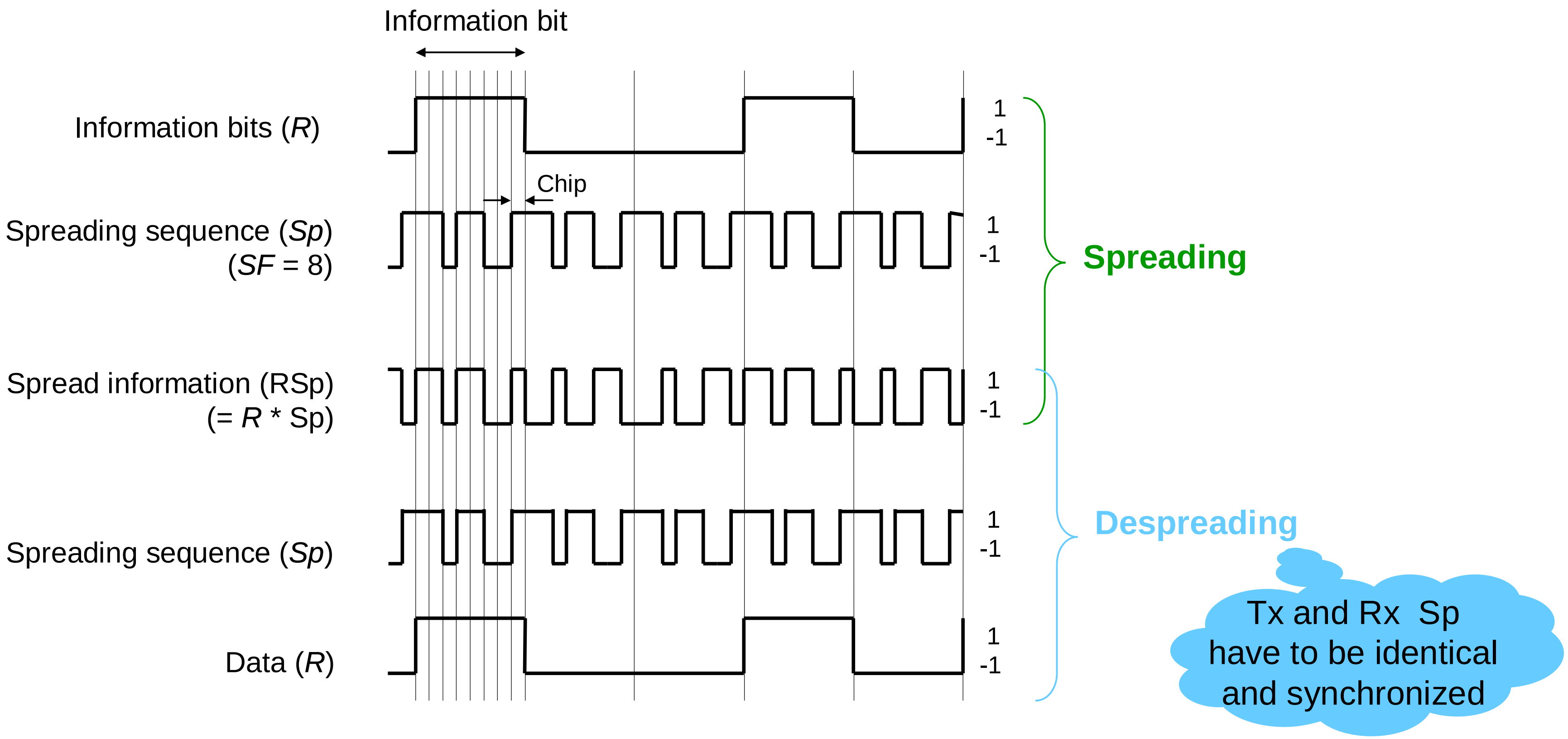


A	B	A⊕B
0	0	0
0	1	1
1	0	1
1	1	0

A	B	A⊗B
+1	+1	+1
+1	-1	-1
-1	+1	-1
-1	-1	+1

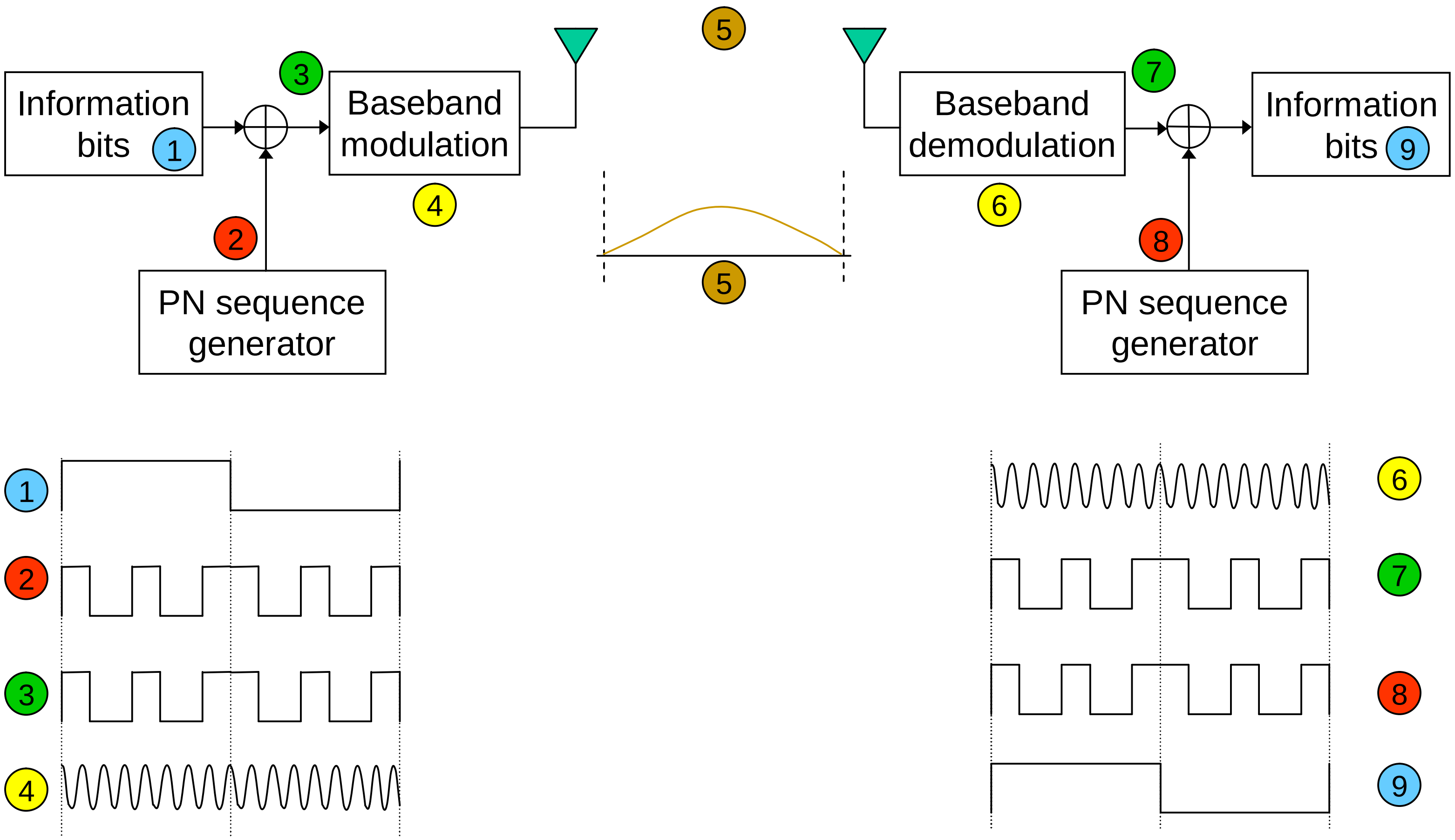
- Spreading - an information bit is processed by *n* consecutive bits of spreading sequence
  - bits of Spreading sequence = chips
  - # of chips/per one information bit = Spreading Factor (e.g., SF= 4, 8, 16, …512)

Spreading/despreading



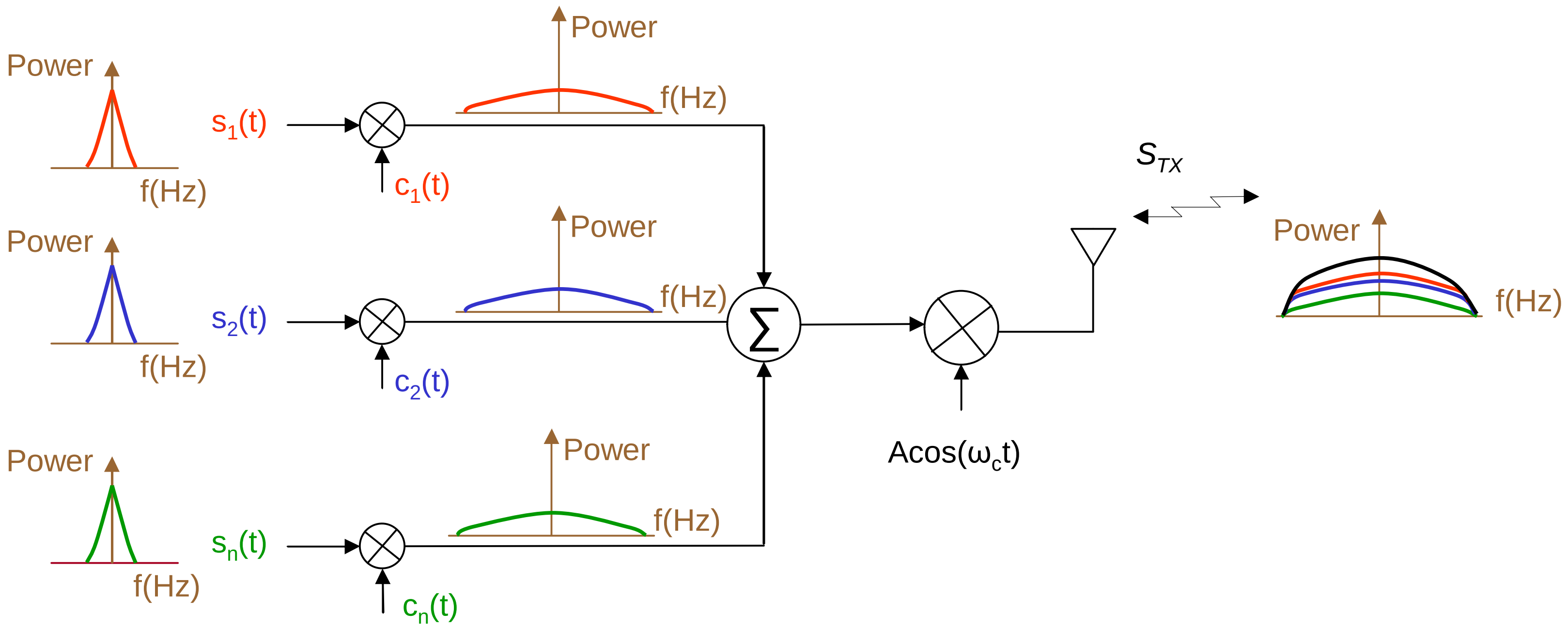
- RSp has the same random (pseudo-noise-like) appearance as Sp
- R * Sp ð widening of the occupied spectrum of the spread signal

Direct Sequence system



Spreading of DS-CDMA signal

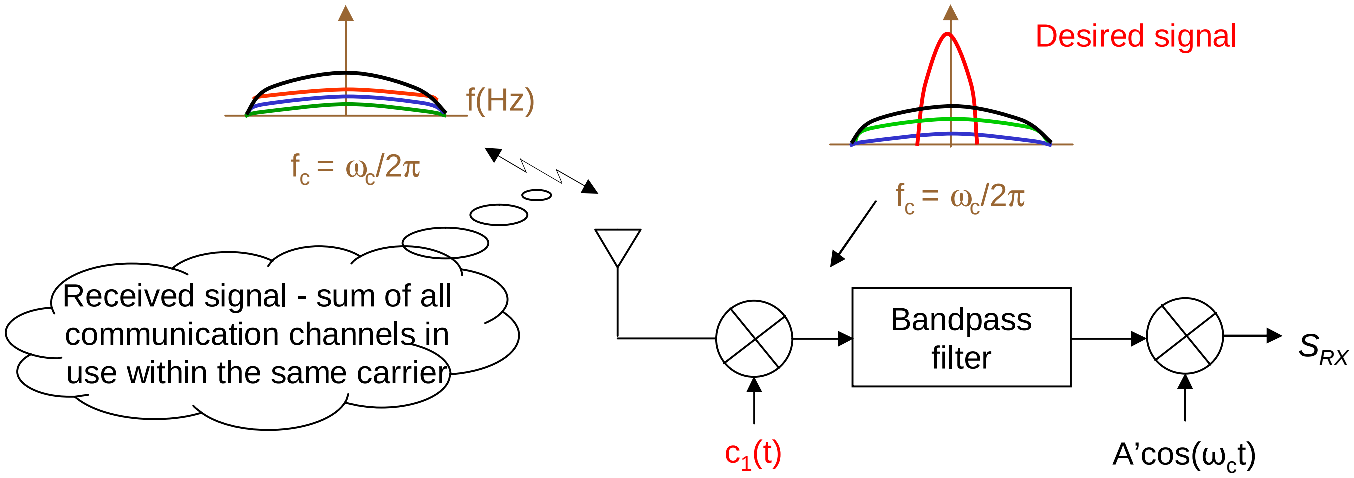
- All users share the same frequency band (they are distinguished via codes)



$$S_{Tx} = [s_1(t)c_1(t) + s_2(t)c_2(t) + \ldots + s_n(t)c_n(t)]\, A\cos(w_c t)$$

Despreading of DS-CDMA signal

- Despreading is done through the multiplication of the received signal by the code associated with the desired channel



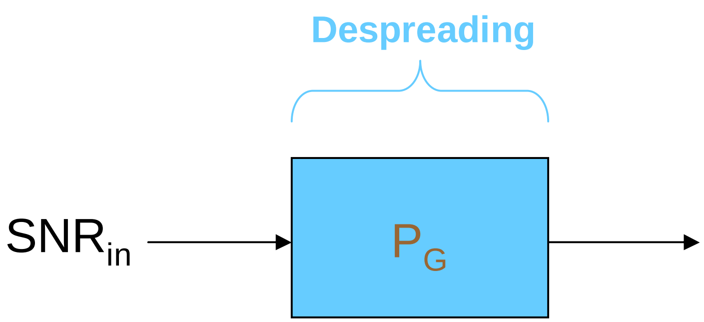
$$S_{Rx}(t)c_1(t) = [s_1(t)c_1(t) + s_2(t)c_2(t) + \ldots + s_n(t)c_n(t)]A^{'}\cos(w_c t)c_1(t)$$

$$S_{Rx}(t)c_1(t) = \underbrace{[\sum_{i=2}^{n} s_i(t)c_i(t)c_1(t)]A^{'}\cos(w_c t)}_{\text{non-desired signals (interference)}} + \underbrace{[s_1(t)c_1(t)c_1(t)]A^{'}\cos(w_c t)}_{\text{desired signal}} \qquad c_i(t)c_1(t) \neq 1, \quad c_1(t)c_1(t) = 1$$

non-desired signals (interference) desired signal

Processing gain (1/4)

- **Despreading** - strengthens the desired signal in relation to other signals ….Processing gain (P_G)



$$SNR_{out}(dB) = SNR_{in}(dB) + P_G(dB)$$

SNR - Signal to Noise Ratio

Processing gain (2/4) …Direct Sequence systems

$$P_G = \frac{R_{PN}}{R_{Info}} \qquad P_G = 10\log_{10}\left(\frac{R_{PN}}{R_{Info}}\right) \ [dB]$$

R_{PN} – chip rate (PN sequence rate)
R_{Info} – information bit rate

- *Example*
  - R_{PN} = 3,84 Mcps
  - R_{Info} = 12,2 kbps
  - $P_G = 10 \cdot \log_{10}(3{,}84 \cdot 10^6 / 12{,}2 \cdot 10^3) = 25$ dB
- After despreading, the signal power needs to be a few dB above the interference and noise power

Processing gain (3/4) …Frequency Hopping systems

- In simple way, P_G is defined as # of frequencies available for hopping

$$P_G = N_{freq} \qquad\qquad P_G = 10\log_{10}\left(N_{freq}\right) \quad [dB]$$

… P_G increases with the number of frequencies

Processing gain (4/4)

- *Example*

R_{PN} = 3,84 Mcps
R_{Info} = <u>12,2 kbps</u>
P_G = 25 dB

R_{PN} = 3,84 Mcps
R_{Info} = <u>2 Mbps</u>
P_G = 2,8 dB

… let's consider (for good communication) SNR_{out} = 7 dB

$SNR_{out} = SNR_{in} + P_G$ ð

$SNR_{IN} = SNR_{OUT} - P_G = -18$ dB
$SNR_{IN} = SNR_{OUT} - P_G = 4,2$ dB

The desired signal level can be 18 dB (4,2 dB) below (above) the interference caused by other users and noise

Systems (w)cdma

- Spreading/dispreading - no signal enhancement for wireless application
  - Ø P_G comes at the price of an increased transmission bandwidth
- Features
  - Ø + Same frequency between cells
  - Ø + To detect the wideband signal the spreading sequence has to be known (…military applications)
  - Ø + Higher accuracy of resolving different propagation paths of wideband signal (than narrow one)
  - Ø - Tight power control and soft handover
  - Ø - ↓ data rates means ↑ processing gain

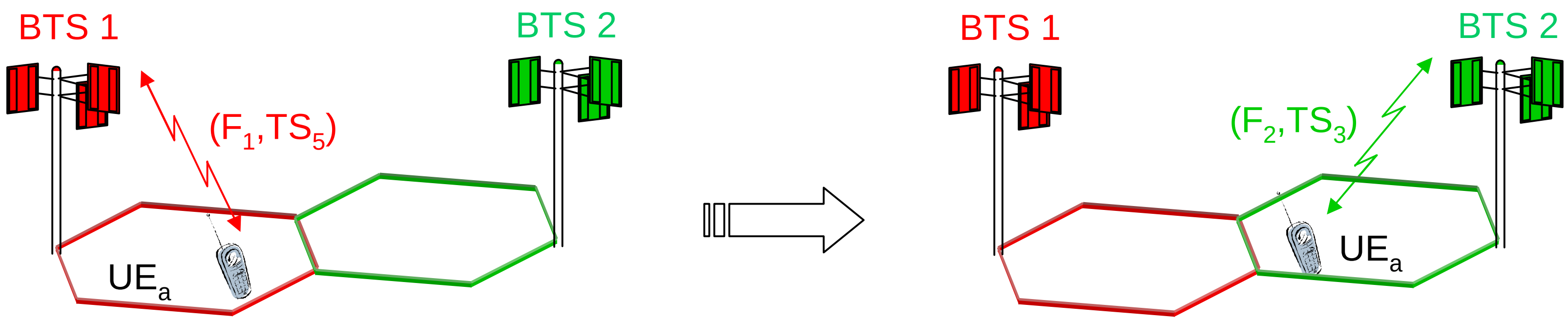
Handover

Handover

- Handover, or Hand-off (Handoff)
- Allow mobility of UEs between cells by changing the communication radio channel
- Types
  - Hard handover
  - Soft handover

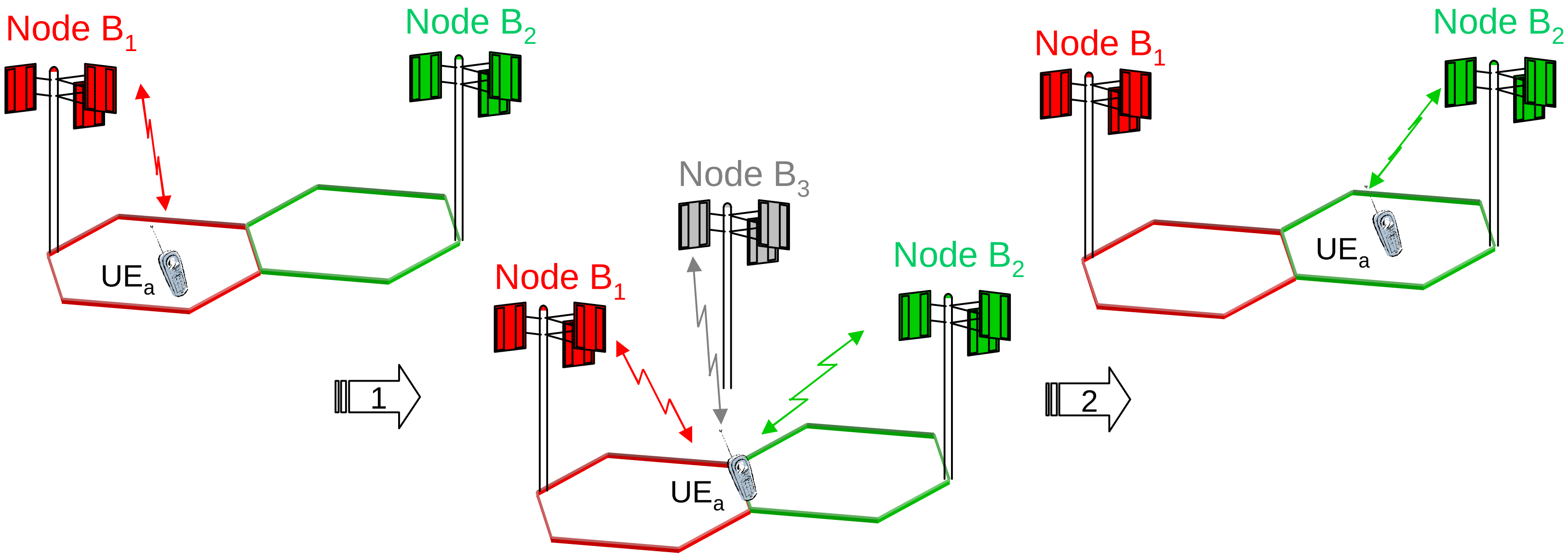
Hard handover

- UE communicates simultaneously with just one BTS
- UE may experience a brief interruption in the connection when switching from the old channel to the new one
  - Ø (e.g., GSM)



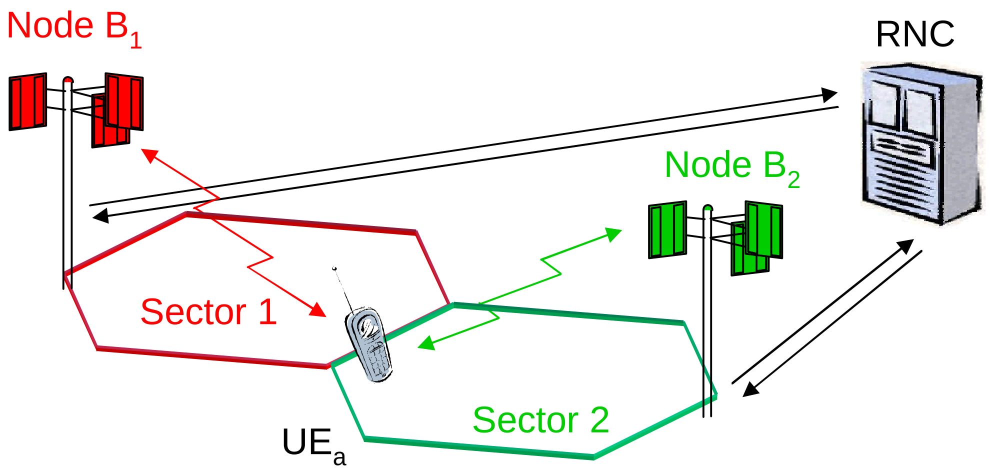
Soft handover … general

- Soft handover
  - UE can communicate with 2 or more Node Bs simultaneously (A UE starts communication with a Node B_2 while still connected to the Node B_1)
  - Seamless transmission between cells
- Several simultaneous connections to different Node Bs → Macro-diversity
- CDMA systems



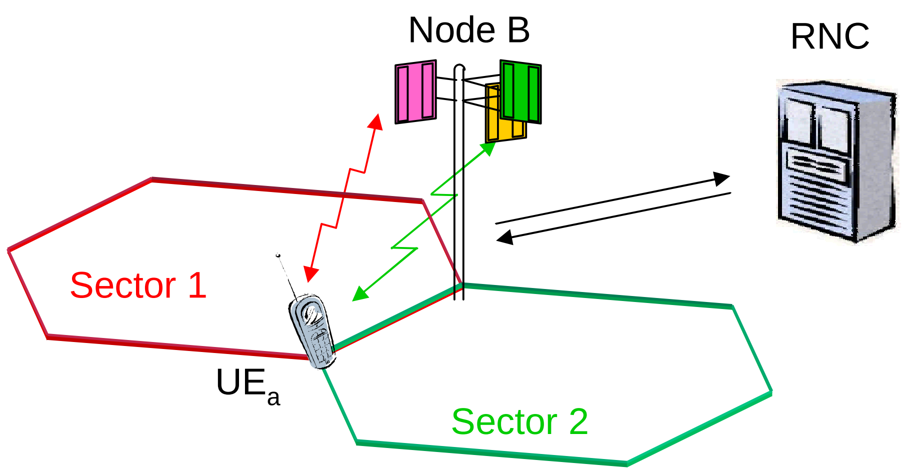
Soft handover

- UE is located in a coverage area of 2 different Node Bs
  - Ø Communication UE/Node B takes place via 2 radio channels
  - Ø Combination of signals (uplink) is realized in the RNC
  - Ø Multipath reception – Rake processing
- 2 power control are active (one for each Node B)
- ~ 20-40% of connections



Softer handover

- UE is located in a coverage area of 2 sectors of the same Node B
  - Communication UE/Node B takes place via 2 radio channels
  - Combination of signals (uplink) is realized in the Node B
  - Multipath reception – Rake processing
- 1 power control is active
- ~ 5-15% of connections ([1])



Other Handovers

- Inter-frequency hard handovers
  - Handovers between WCDMA frequency carriers (a high capacity cell with several carries)
- Inter-system hard handovers
  - Handovers between WCDMA FDD system and another system (e.g., WCDMA TDD, GSM, etc.)

Handover overview

(Hard) Handover	BTS_1 – BTS_1 BTS_1 - BTS_2	- GSM/GPRS - interruption in communication
Soft handover	Node B_1 - Node B_2	- cdma2000, UMTS - no interruption in communication
Softer handover	Node B_1 - Node B_1	- UMTS
Inter-frequency hard handover	Carrier f_1 - Carrier f_2	- UMTS
Inter-system hard handover	System 1 – System 2	- WCDMA FDD / GSM

Power control

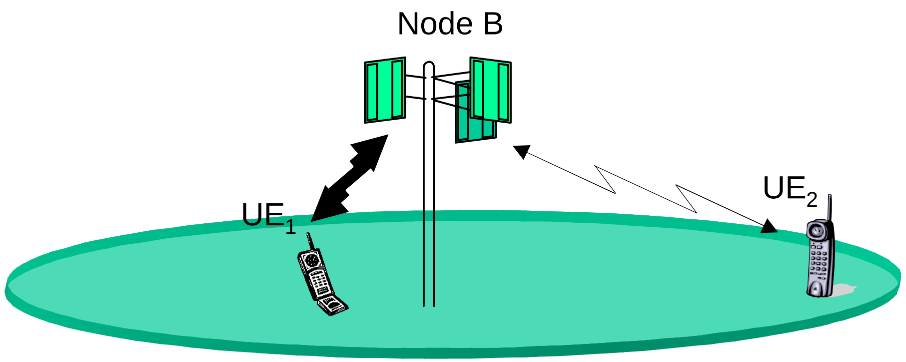
Power control (1/2)

- ↑ number of active UE = ↑ level of interference in the system
  - UE generates interference
    - a) To all other MSs within the same cell
    - b) To all MSs in neighbor cells

- ↓ MS transmission power = ↓ interference (↑system capacity)

Power control (2/2)

...near-far problem in cdma



Near-far problem

- Tight & fast power control is one of the most important aspect in cdma
- A single overpowered UE could block a large part of the cell

Power control

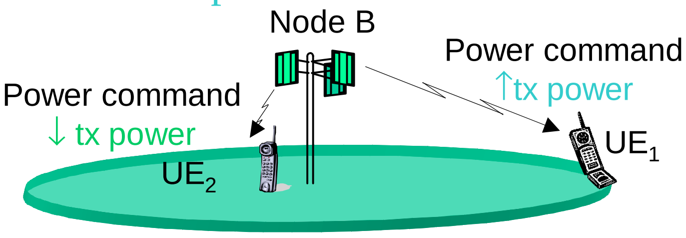
→ minimize interference and thus increase the system capacity

Types of power control

- CDMA employs 3 types of power control
  - Fast closed-loop power control
    (Inner loop power control)
  - Open-loop power control
  - Outer loop power control

Fast closed-loop power control

- Uplink
  - Node B measures the received SIR (Signal to Interference Ratio)
  - *IF* $SIR_{measured} > SIR_{target}$ *then* Node B command the UE to ↓ power
    IF $SIR_{measured} < SIR_{target}$ *then* Node B command the UE to ↑ power
  - Rate 1 commands/slots, i.e. 1500/s (1500Hz)
    - In GSM - slow power control, 2 Hz
    - Mechanism operates faster than any significant path loss change could occur



  - Basic step ±1dB/slot
    - …eventually ± 2dB/slot (30dB correction within 10 ms frame)
    - Smaller step sizes are emulated (0,5dB = 1dB/2 slots …)
  - … UE in a deep fade causes increased inference to other cell (high tx power)

- Downlink
  - No near-far problem (…scenario one Node B to many UEs)
  - Node B increases the power of signal belonging to UEs at the cell edge

Open loop power control

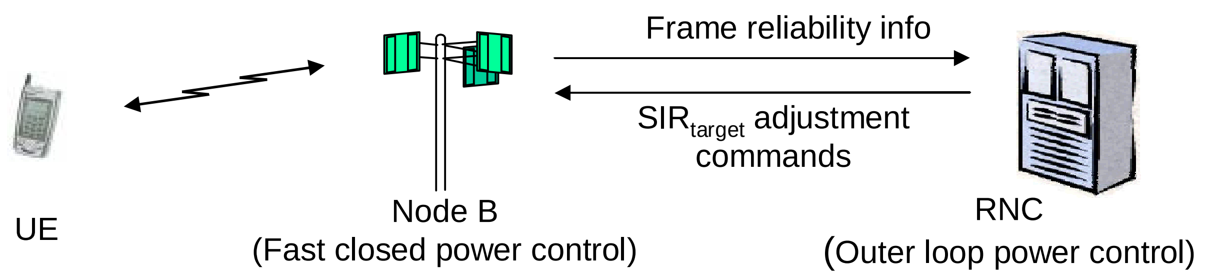
- Rough initial power setting of the UE
  - Ø Downlink beacon signal is used for the setting
  - Ø Setting is very inaccurate
    - Fast fading is uncorrelated between uplink & downlink
    - Large frequency separation of uplink and downlink band

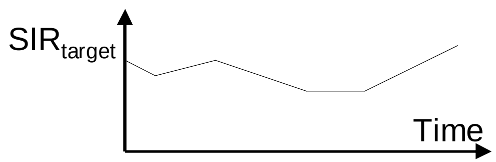
Outer loop power control

- SIR_{target} is set according to required BER or BlER (e.g.,BlER = 1%)
- SIR_{target} = f (speed of UE) … the UE speed change ≈ change of BER

  ⇒ SIR_{target} has to be changed according to the UE speed

- Outer loop power control
  - Ø SIR_{target} (in Node B) is adjusted to keep a constant quality, i.e. BER





Spreading codes

Spreading codes

- Features
  - Influence interference among users
  - Have to have random behavior
- Choice according to
  - Auto-correlation features
  - Cross-correlation features
- Types of codes
  - PN sequence (Pseudo random Noise sequence)
  - Gold code
  - Walsh code

Auto-Correlation Function (1/2)

ð Similarity between a function *F(t)* and itself at different time (phase offset)

$$ACF = \int_{-\infty}^{\infty} F(t)F(t-t)dt$$

- *ACF* of bit sequence
  → bit-by-bit comparison of sequence (length L) with the shift version of itself (offset from 1 to L)

$$ACF = CC - NCC$$

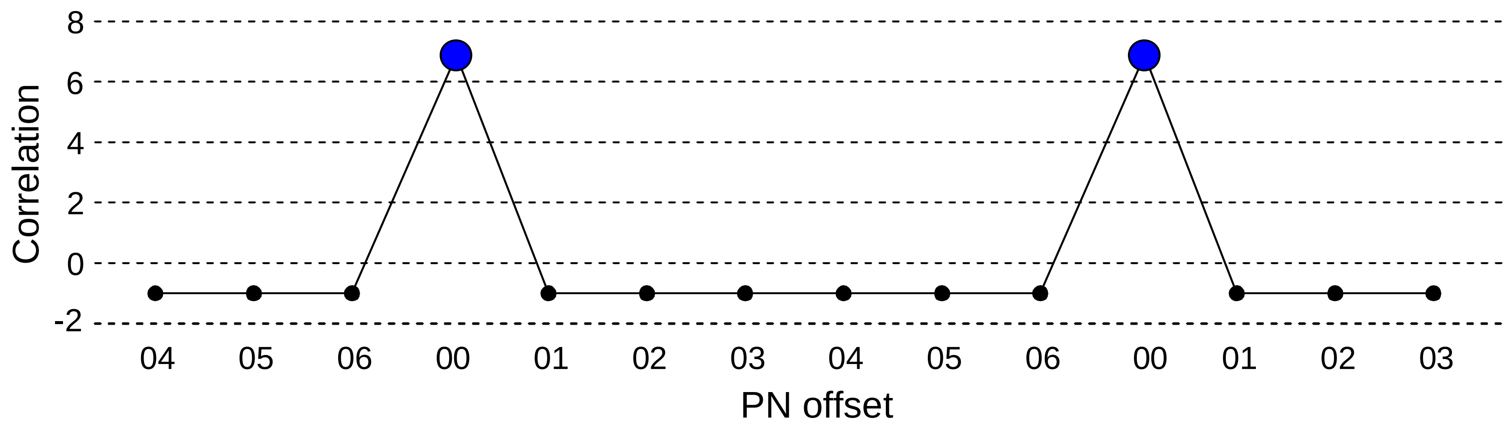
Coinciding bits between sequences

Non-Coinciding bits between sequences

Auto-Correlation Function (2/2)

Phase offset (bits)	Sequence phase	CC	NCC	ACF
0	1011100	7	0	**7**
1	01**11**0**0**1	3	4	-1
2	**11**1001**0**	3	4	-1
3	**1**100**10**1	3	4	-1
4	**10**0**1**011	3	4	-1
5	0**010**1**1**1	3	4	-1
6	010**1110**	3	4	-1
7	**1011100**	7	0	**7**

- The max. of ACF is every time, when both compared sequences have the same phase offset.



Auto-Correlation features of codes

- Important role in the synchronization process
- 2 steps in synchronization
  - Ø Acquisition
    - Tries to achieve code alignment of locally generated and received sequences by shifting the locally generated sequence
  - Ø Tracking
    - Maintains the correct alignment

Cross-Correlation Function

ð Similarity between functions *F(t)* and *G(t)* taken with a time difference τ between them

$$CCF = \int_{-\infty}^{\infty} F(t)G(t-t)dt$$

- *CCF* of bit sequence
  → bit-by-bit comparison of sequences *F(t)* and *G(t),* with the same length L

$$CCF = CC - NCC$$

Coinciding bits between sequences

Non-Coinciding bits between sequences

- Orthogonal codes: CCF = 0

PN sequence

- PN sequences – binary sequence with noise like random characteristic
  - Ø … PNs are neither completely deterministic nor truly random
- PNs generator ð Linear Feedback Shift Register
  - Ø A polynomial expression can be associated with each shift register

$$P(x) = a_n x_n + a_{n-1} x_{n-1} + \ldots + a_1 x_1 + 1$$

a_i – if there is a feedback path from x_i output, $a_i = 1$ else $a_i = 0$

x_i – shift register output

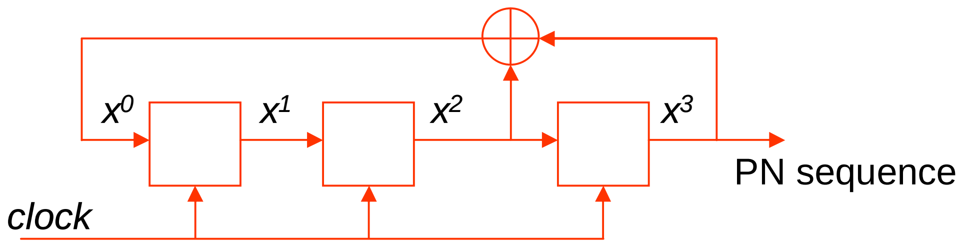
  - Ø The length of PNs

$L = 2^N - 1$ *[chips]* … N – number of shift register in the generator

Example: 3 stage shift register PNs

$$P(x) = x^3 + x^2 + 1$$

$$L = 2^3 - 1 = 7$$



Features of PN sequence

- Thermal noise-like behavior, though deterministic
  - Deterministic … allows reproduction of the sequences in the RX and thus recovering transmitted data
- #“1” = #“0” + 1
- Sequences have bad cross-correlation features
- Type of PN sequences
  - Short (cdma2000 …15-stage long shift register)
  - Long (cdma2000 …42-stage long shift register)

Gold codes

- Gold codes – mod 2 of two *preferred* PN sequences (primitive expression)
  - By shifting one of the two PN sequence, a different Gold sequence is obtained

- Features of codes
  - Single auto-correlation peak at zero (just like ordinary PN sequences)
  - Offer a large number of codes with good correlation properties

Walsh codes

- Walsh, or Walsh-Hadamard codes
- Walsh matrix
  - Square matrix
  - Code matrix of orders 2^x
  - Description of matrix W_i^m (m = matrix length, i = row number)

$$M_1 = 0 \qquad M_2 = \begin{bmatrix} 0 & 0 \\ 0 & 1 \end{bmatrix} \qquad M_4 = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix}$$

$$M_8 = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 & 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 1 & 1 & 0 & 1 & 0 & 0 & 1 \end{bmatrix}$$

W_1^8

$$M_{2N} = \begin{bmatrix} M_N & M_N \\ M_N & \overline{M}_N \end{bmatrix}$$

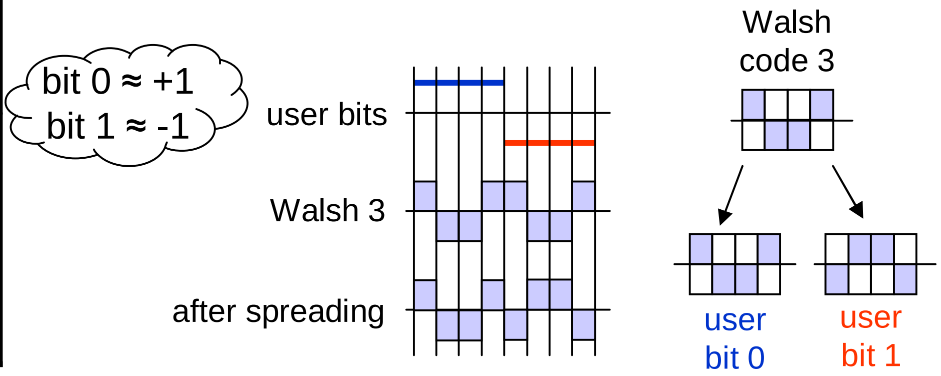
$$[0\,1\,0\,1\,0\,1\,0\,1] = [+\,-\,+\,-\,+\,-\,+\,-]$$

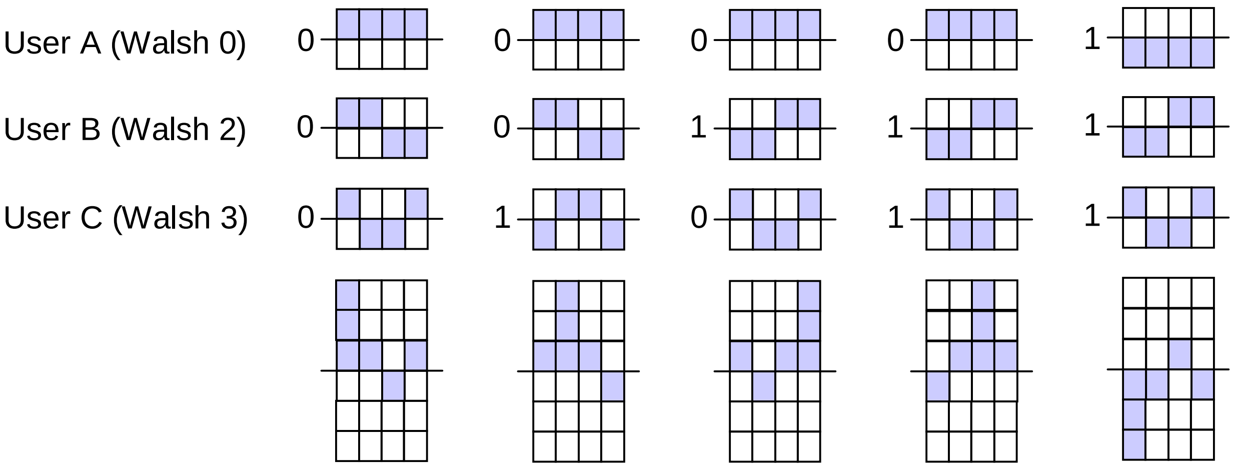
Features of Walsh code

- Codes are orthogonal to each other within the same matrix (CCF = 0)
- Codes have bad auto-correlation features
  - Ø Auto-correlation between a code and its shift copy is not zero

Walsh codes – spreading (1/2) ...example

Code	Chips	Symbol representation
Walsh 0	0000	
Walsh 1	0101	
Walsh 2	0011	
Walsh 3	0110	



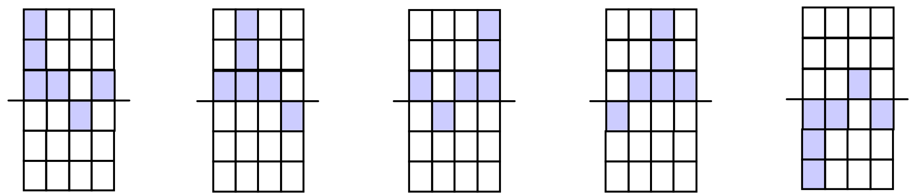


Walsh codes – despreading (2/2) ...example

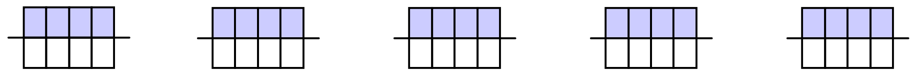
User A (Walsh 0) 0 0 0 0 1

User B (Walsh 2) 0 0 1 1 1

User C (Walsh 3) 0 1 0 1 1



User A (Walsh 0)



Wash code * spreading data / # of chips in the Walsh code	$\frac{4}{4}=1$	$\frac{4}{4}=1$	$\frac{4}{4}=1$	$\frac{4}{4}=1$	$\frac{-4}{4}=-1$
Information bits (user A)	0	0	0	0	1

CCF=1*3+1*1+1*(-1)+1*1

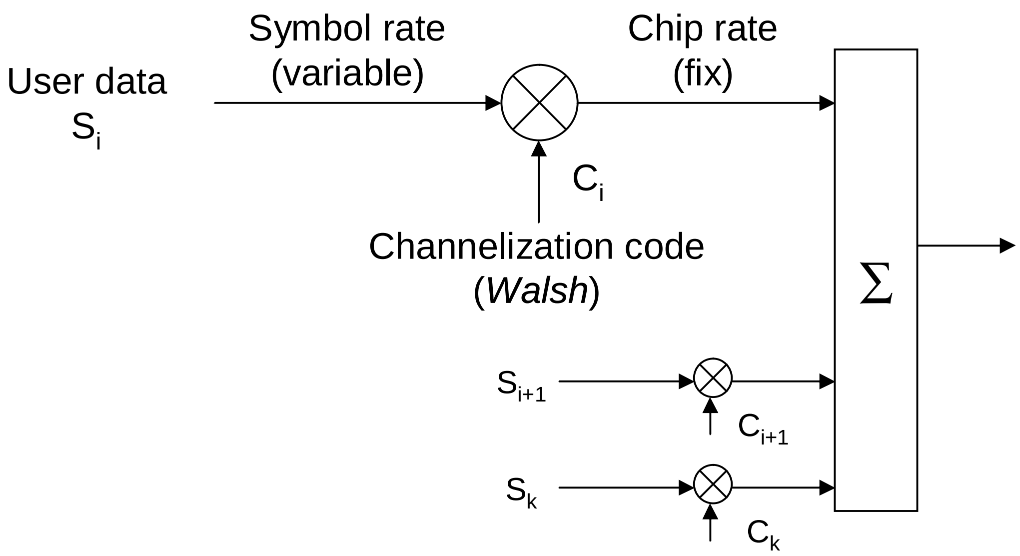
Codes - overview

- Correlation features of codes strongly influence the level of interference in a cellule
  - Ø CDMA capacity depends on the interferences

Code	Employed	Advantages	Disadvantages
Walsh	UMTS, cdmaOne, cdma2000	• Codes are orthogonal	• Bad auto-correlation features • Bad cross-correlation features
PN sequences	cdmaOne, cdma2000	• Good auto-correlation features	• Codes are not orthogonal • Bad cross-correlation features • Small number of generated codes
Gold	UMTS	• Good cross-correlation features • Large number of generated codes • Auto-correlation features Walsh < Gold < PN sequences	• Codes are not orthogonal

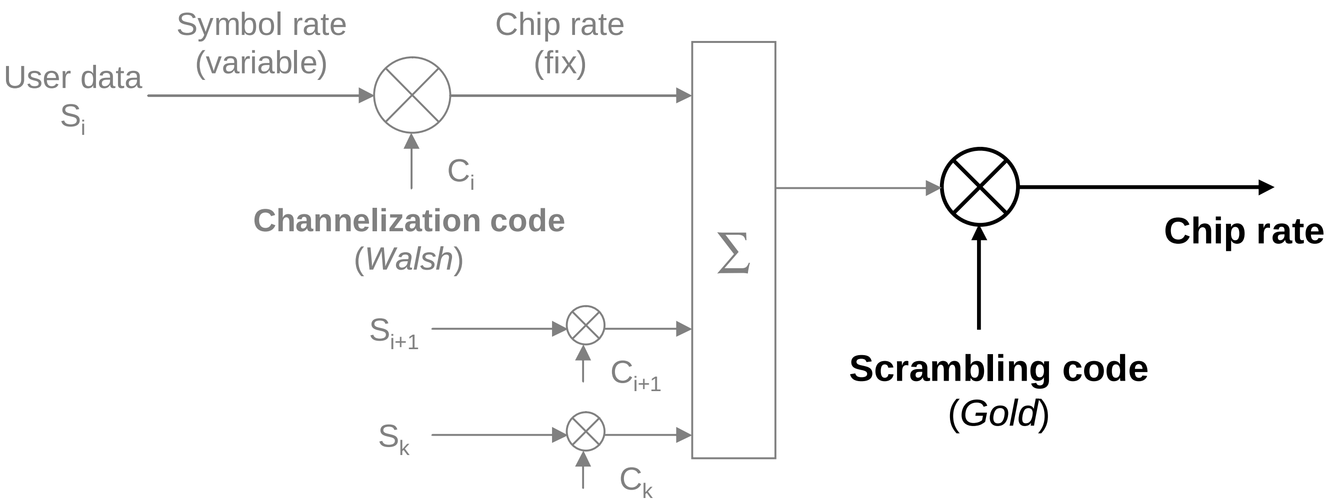
Codes in UMTS (1/4) ...downlink

- Spreading codes = Walsh codes
  - Each code represents one channel → channelisation codes
  - Identify users in the cell
  - Code length is variable and depends on services



Codes in UMTS (2/4) ...downlink

- Scrambling: multiplication of spread sequence by a second sequence
  - Ø Used on the top of spreading
  - Ø No change of the signal bandwidth (… no change of the rate)
- Scrambling codes = Gold codes
  - Ø Improves auto-correlation features of Channelization codes
  - Ø Identifies Node Bs (… to each Node B is assigned different code)



Codes in UMTS (3/4) ...uplink

- Channelisation code
  - Walsh
  - Separation of physical data and control channels
- Scrambling code
  - Short (Gold) or Long (PN sequences)
  - Separation of users
- User's signals are not orthogonal
  - Transmitted signals from UEs are asynchronous

Codes in UMTS (4/4)

	Channelisation code	Scrambling code
Use	Downlink: separation of UE within one cell Uplink: separation of physical/control ch. from same UE	Downlink: separation of cells Uplink: separation of UE
Chip length	Downlink: 4-512 chips Uplink: 4-256 chips	Downlink: 10 ms = 38400 chips Uplink: 10 ms = 38400 chips or 66,7 µs = 256 chips
Number of codes	# of codes under one scrambling code = SF	Downlink: 512 Uplink: several millions
Bandwidth	Increase transmission bandwidth	Does not affect transmission bandwidth