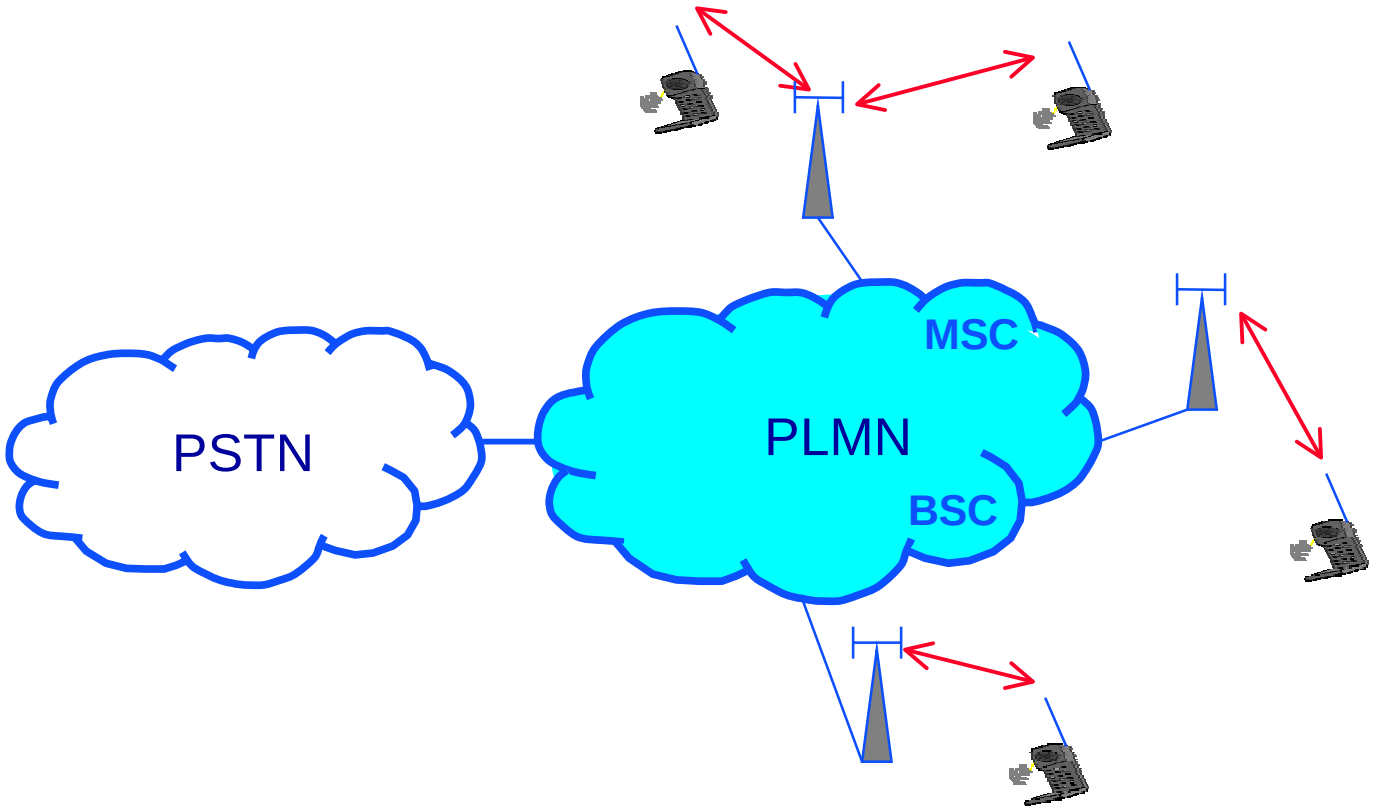
Mobile Radio Communications

Session 8: Mobile networks

Mobile (cellular) networks



Cellular systems around the world

- **US systems (public cellular, cell phone systems)**
  - **AMPS:** Advance Mobile Phone System
    First-generation, analog system
  - **N-AMPS:** Narrowband AMPS (Motorola)
    Temporary improvement to AMPS
  - **IS-136:** Interim Standard 136 (formally IS-54), D-AMPS, USDC
    Second-generation, digital TDMA system
  - **IS-95:** Interim Standard 95
    Second-generation, digital CDMA system

Cellular systems around the world

- **US systems (cont'd)**
  - **PCS1900:** Personal Communications System, 1900 MHz band
    Based on GSM and DCS1800
  - **CDMA2000:**
    Third-generation, digital system
    Evolution of IS-95
  - **General:** Dual-mode terminals AMPS/xxxx
    Network protocol IS-41
    Only AMPS national coverage, rest local

Cellular systems around the world

- **European systems**
  - **NMT:** Nordic Mobile Telephone system
    First-generation, analog system
  - **(E)TACS:** (Extended) Total Access Cellular System
    First-generation, analog system
  - **GSM:** Global System for Mobile communications
    Second-generation, digital TDMA system

Cellular systems around the world

- **European systems (cont'd)**
  - **DCS 1800:** Digital Cellular System, 1800 MHz band
    phase 2 in GSM
  - **UMTS:** Universal Mobile Telephone System
    Third-generation, digital CDMA system
  - **General:** Dual-mode terminals GSM/xxxx
    Network protocol (B)ISDN
    Pan-European coverage

Cellular systems around the world

- **ASIA/Australia**
  - **PDC:** Pacific Digital Cellular
    Second-generation, digital TDMA system
    Japan only
  - **AMPS:** first generation
  - **GSM / IS-95:** second generation
  - **UMTS:** third generation

Mobile system design features

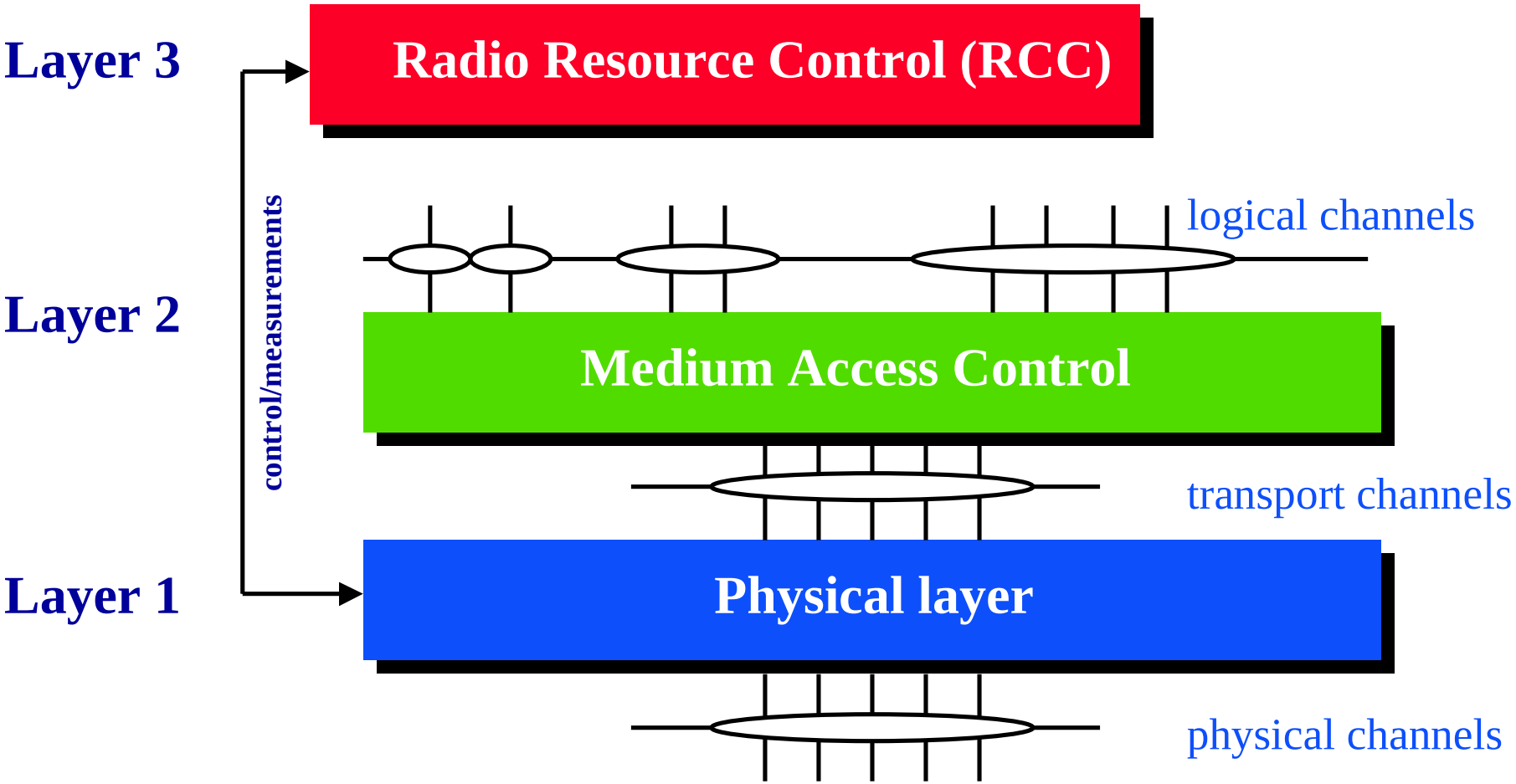
- **System architecture**
  - networking
  - addressing

- **Physical (PHY) layer**
  - radio band
  - modulation
  - error control (FEC/interleaving)
  - frame structure
  - multiple access (multi-user, up/down)

Mobile system design features

- **MAC/DLC layer**
  - channel mapping (control/traffic)
  - medium access techniques
  - call setup
  - standby behavior

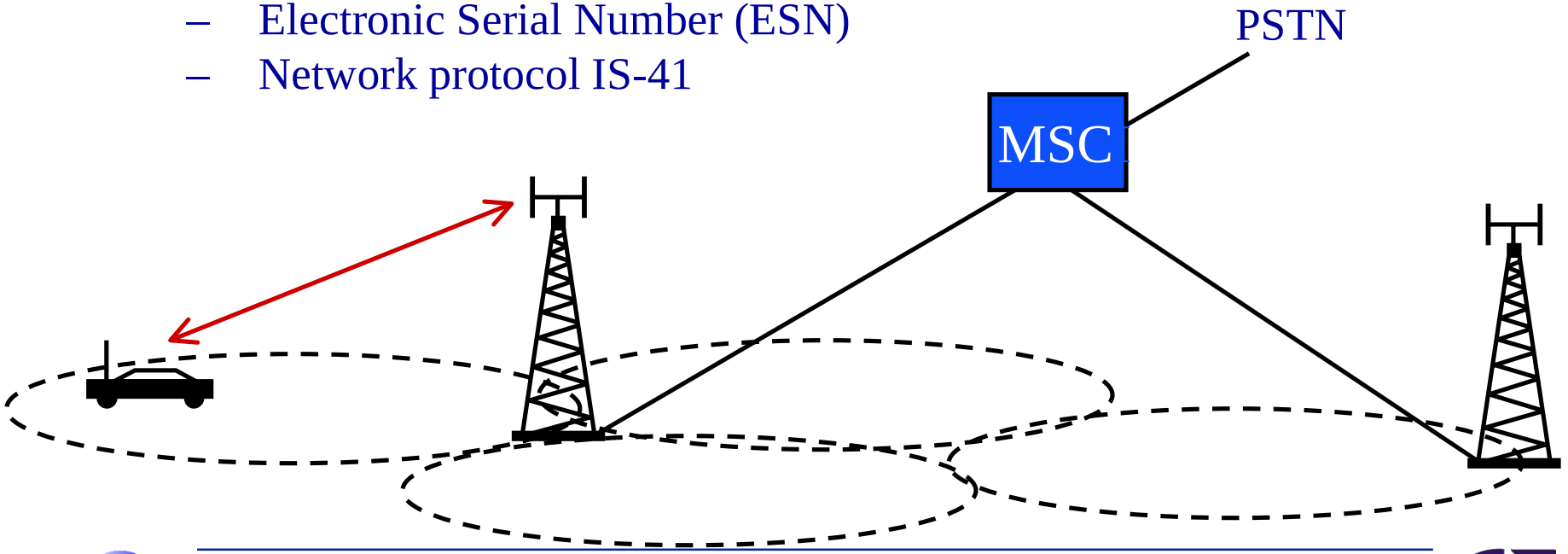
Protocol layering



Advance Mobile Phone System

Architecture

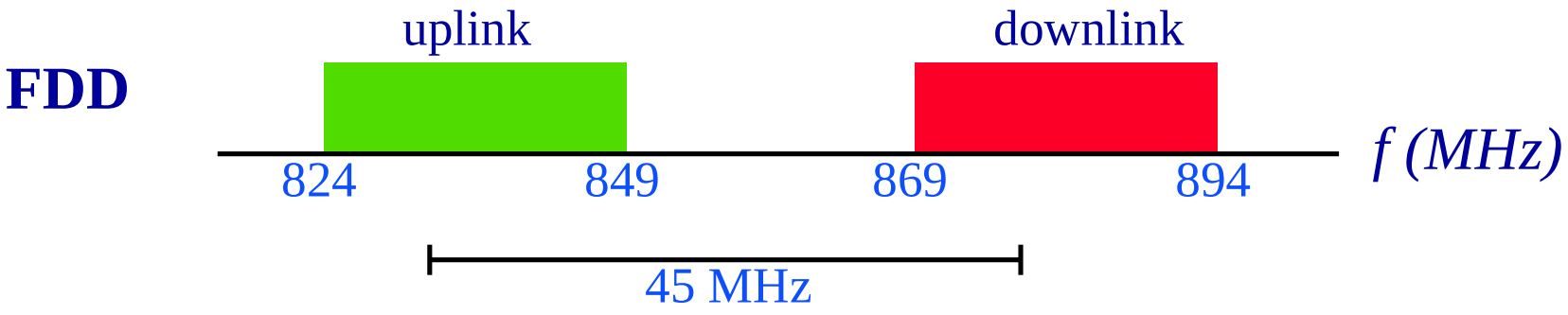
- 7/21 site/sector reuse
- 18 dB C/I
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



AMPS: physical layer

Radio bands

- 832 duplex (paired) channels
- A/B separation: 416 channels each
- channel spacing 30 kHz



AMPS: physical layer

Modulation

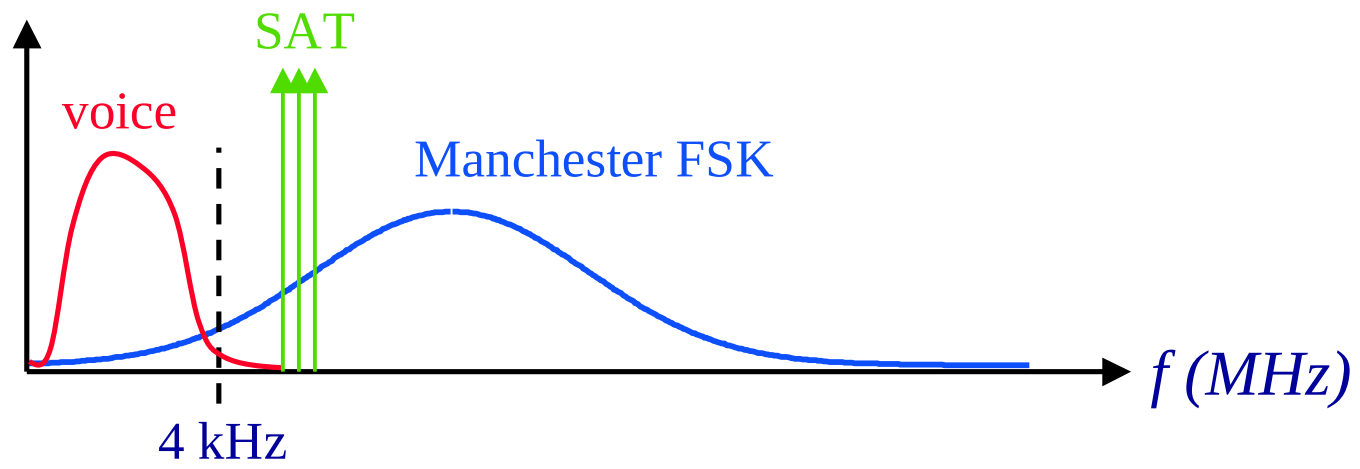
- traffic (voice): analog FM
  peak deviation $\Delta f = \pm 12$ kHz
  companding / expanding
  pre-emphasis / de-emphasis

- control (data): binary FSK ("0" $\rightarrow$ -8 kHz, "1" $\rightarrow$ +8 kHz)
  10 kb/s data rate
  Manchester NRZ coding
  BCH(40,28) downlink, BCH(48,36) uplink
  blank-and-burst

- Supervisory Audio Tone (SAT)
  5970 / 6000 / 6030 tone
  co-channel separation

AMPS: physical layer

Separation: traffic / control / SAT



AMPS: physical layer

Multiple Access

- FDMA: 30 kHz channels
- FDD: 45 MHz separation
- Circuit-switched connections

AMPS: MAC/DLC

Channel mapping

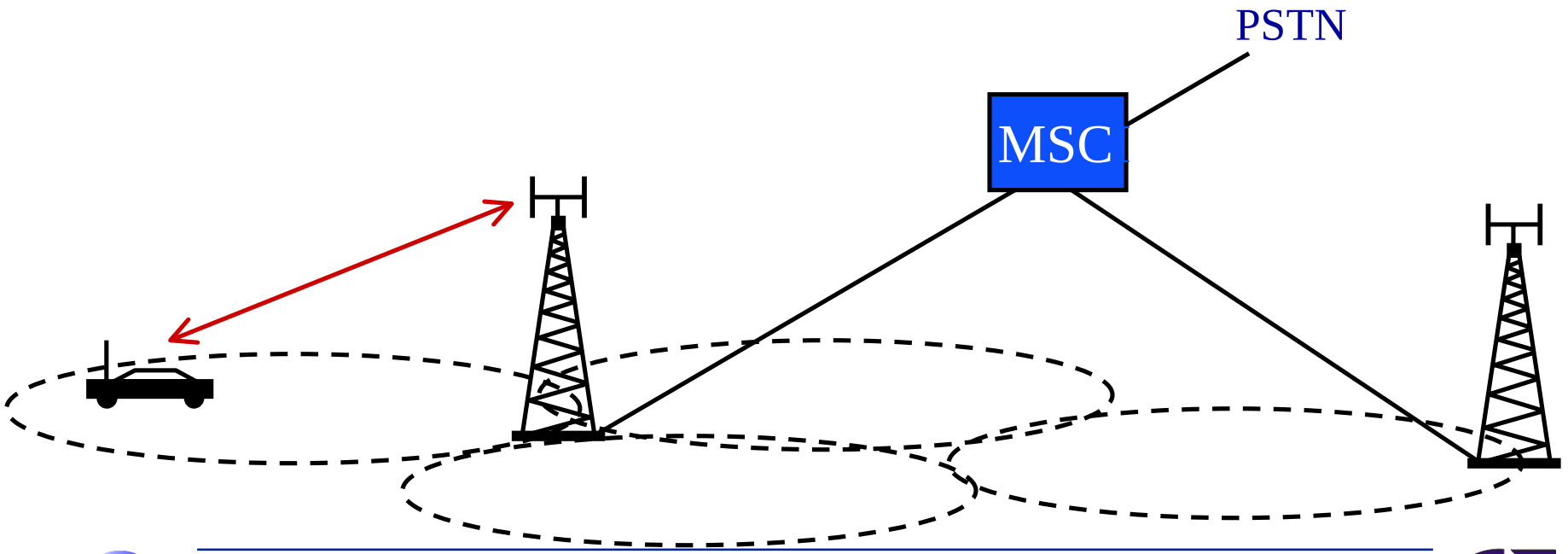
- FCC: Forward Control Channel
  blank-and-burst
  standby / handover
- RCC: Reverse Control Channel
  blank-and-burst
- FVC: Forward Voice Channel
  continuous analog voice
- RVC: Reverse Voice Channel
  continuous analog voice

US Digital Cellular

- **Standard: USDC = D-AMPS = IS-54 = IS-136 (EIA/TIA)**
- **TDMA/AMPS dual-mode terminals**
- **Split each AMPS FDMA channel into six TDMA channels**
- **Reuse of AMPS analog control channels: IS-54**
- **New digital control channels: IS-136**

USDC: architecture

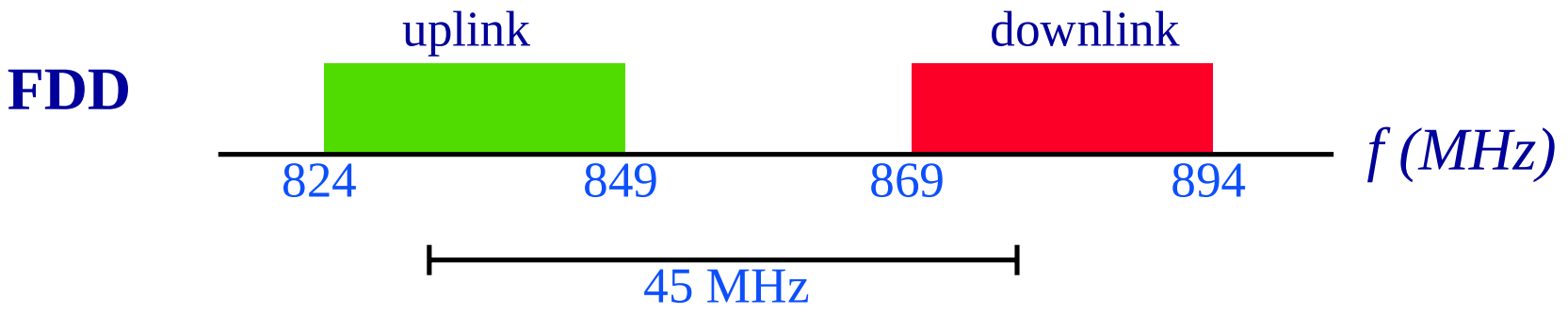
- 7/21 site/sector reuse
- 18 dB C/I
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



USDC: physical layer

Radio bands

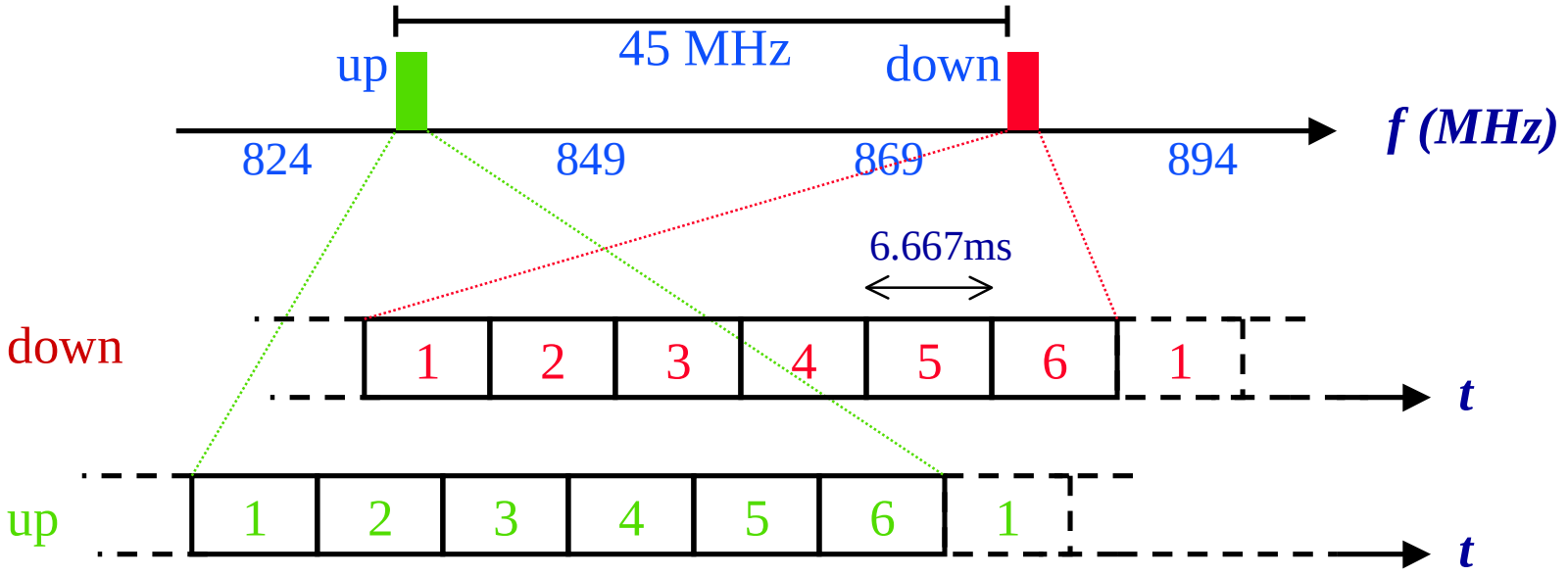
- 832 duplex channels
- channel spacing 30 kHz
- identical as for AMPS
- co-existence with AMPS (replacing AMPS channel by 6 USDC channels)



USDC: physical layer

Radio bands and time slots

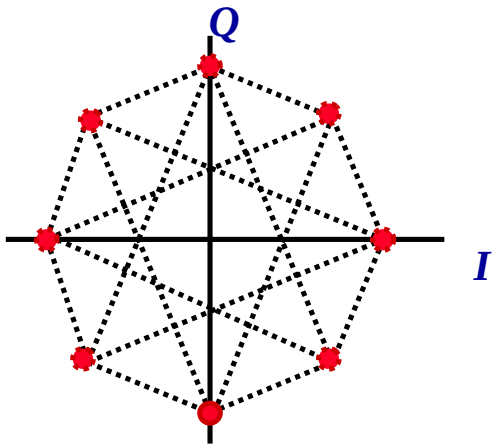
- 6 time slots per 30 kHz channel
- offset-FDD: uplink leads by 1.27 slots



USDC: physical layer

Modulation

- $\pi/4$-DQPSK
- 48.6 kb/s bit rate; 24.3 ks/s symbol rate (T_s = 41.1523 μs)
- Root-Raised Cosine (RRC) shaping
- Roll-off factor $\alpha = 0.35$
- Equalization to satisfy $\sigma_\tau = 15$ μs

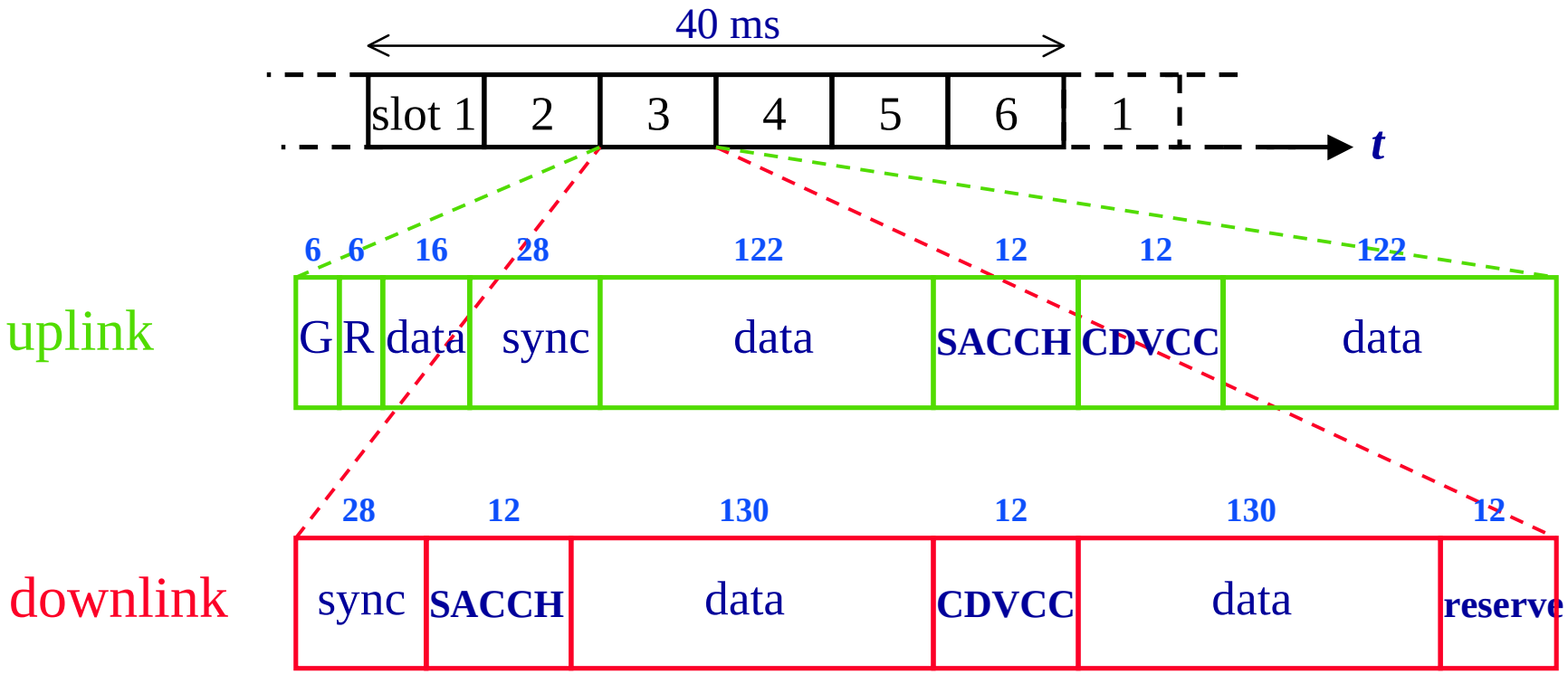


b_k, b_{k-1}	ϕ_k
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

USDC: physical layer

Frame structure and burst format

- 6 slots per TDMA frame; 324 bits/slot
- 40 ms frame duration (1944 bits); 6.666 ms slot duration



USDC: physical layer

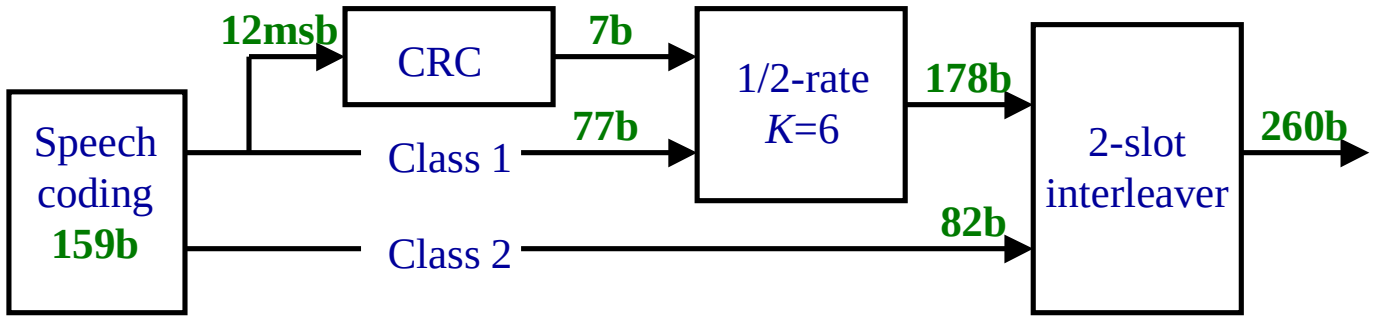
Control fields

- CDVCC: Coded Digital Verification Color Code
  SAT-like purpose (co-channel)
  8-bit value, (12,8) shortened Hamming code
- SACCH: Slow Associated Control CHannel
  handover, power control
- FACCH: Fast Associated Control CHannel
  DTMF, call control

USDC: physical layer

Channel coding

– voice: 159 bits / 20 ms
7b CRC
protection classes
2-slot interleaving



USDC: physical layer

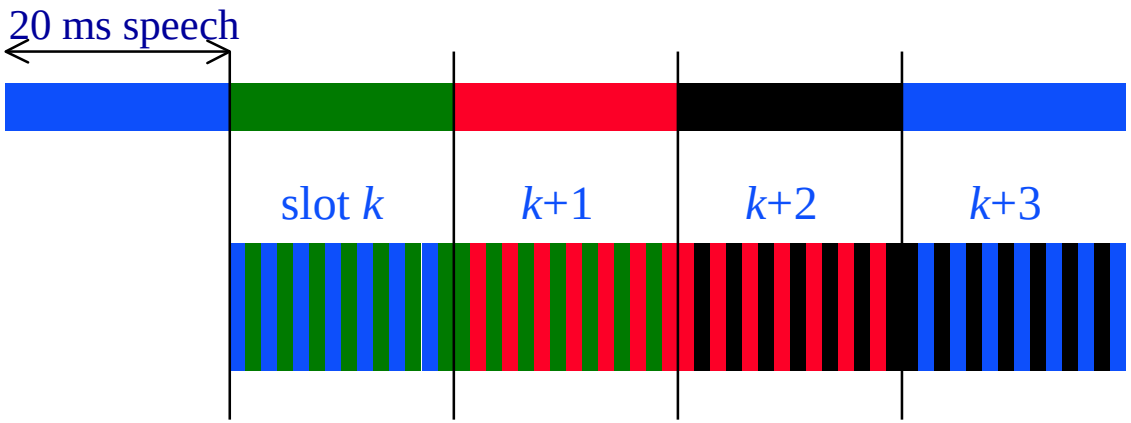
Channel coding

- SACCH: 6 bits / 20 ms
  1/2-rate convolutional coding
  12-slot interleaving

- FACCH: 49 bits / 20 ms
  16b CRC
  1/4-rate convolutional coding
  2-slot interleaving
  (FACCH replaces voice data)

USDC: physical layer

Interleaving: odd-even bits



0	26	52	234	0	26	52	234	0	26	52	234
1	27	53	235	1	27	53	235	1	27	53	235
2	28	54	236	2	28	54	236	2	28	54	236
24	50	76	258	24	50	76	258	24	50	76	258
25	51	77	259	25	51	77	259	25	51	77	259

USDC: MAC/DLC

Channel mapping

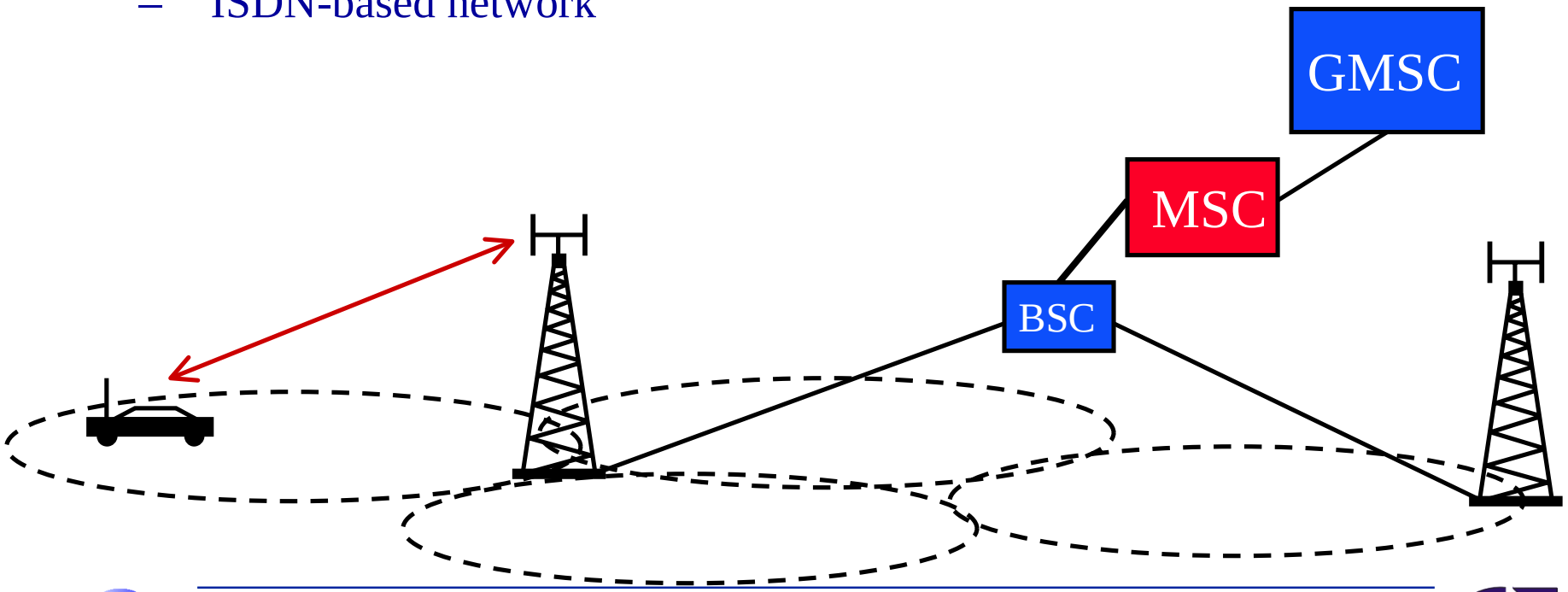
- DTC: Dedicated Traffic Channel
  full-rate: 2 slots/frame; 7.95 kb/s VSELP coder
  half-rate: 1 slot/frame; 3.973 kb/s
- SACCH: Slow Associated Control CHannel
  300 b/s
- FACCH: Fast Associated Control CHannel
  2.45 kb/s
  replaces DTC

GSM

- **Groupe Spéciale Mobile**
- **Standard: GSM - DSC1800 - PCS1900 (ETSI)**
- **Pan-European system**

GSM: architecture

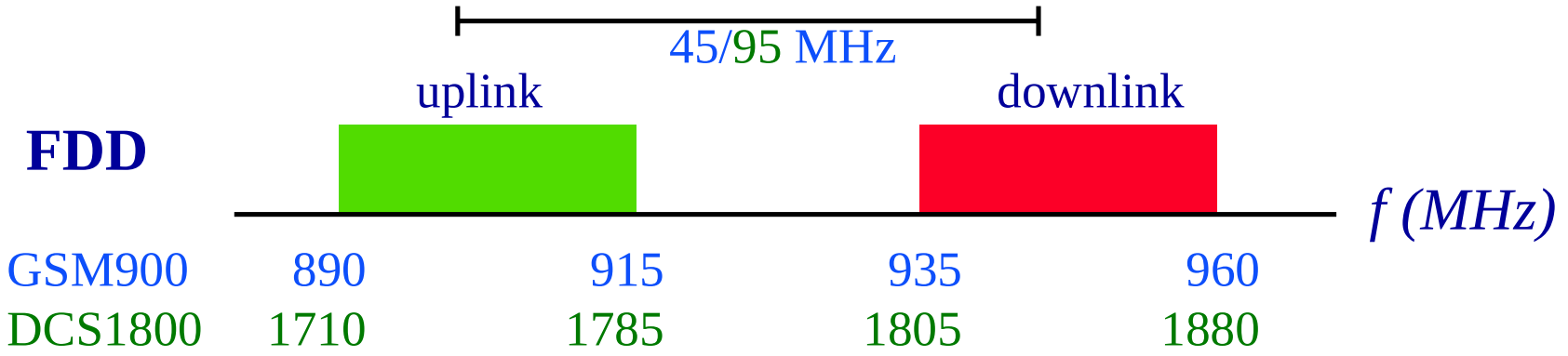
- 3/9 site/sector reuse
- 11 dB C/I
- International Mobile Subscriber Number (IMSI/TMSI)
- International Mobile Equipment Identity (IMEI)
- ISDN-based network



GSM: physical layer

Radio bands

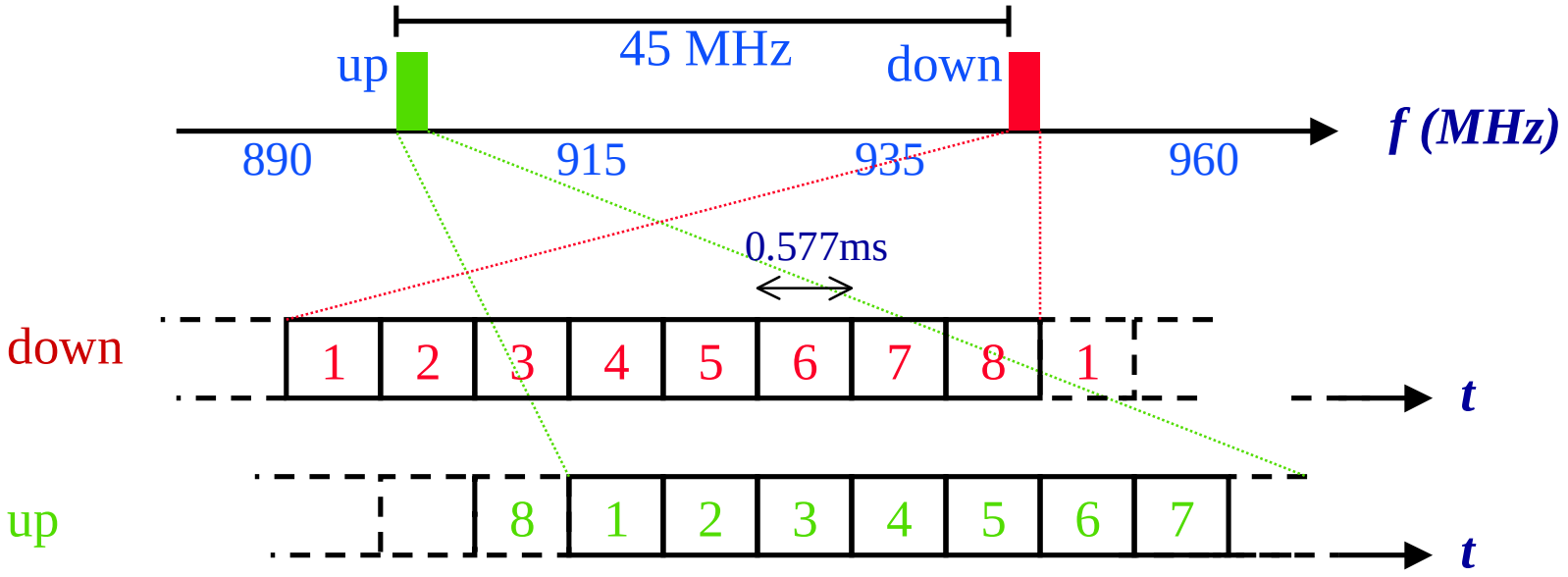
- 125 duplex channels
- channel spacing 200 kHz



GSM: physical layer

Radio bands and time slots

- 8 time slots per 200 kHz channel
- offset-FDD: uplink lags by 3 slots
- time



GSM: physical layer

Modulation

- GMSK; $\Delta f = \pm 67.708$ ($= R_b/4$)
- 270.833 kb/s bit rate ($T_s = 3.692$ μs)
- Gaussian shaping
- $BT = 0.3$
- Constant envelope
- Equalization to satisfy $\sigma_\tau = 15$μs

- (Slow) Frequency Hopping (at frame rate = 217.6 hops/s)

GSM: physical layer

Frame structure and burst format

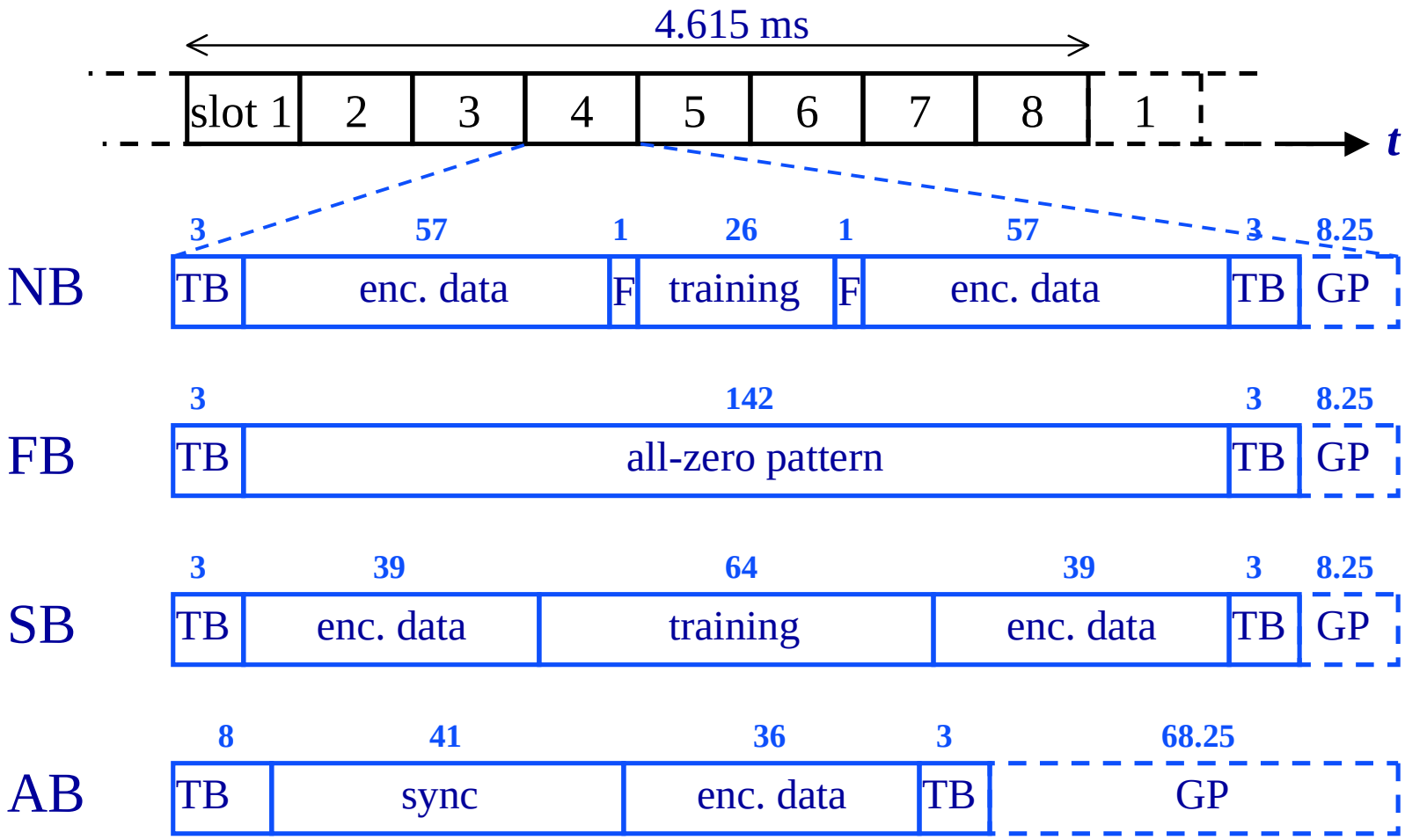
- 8 slots per TDMA frame; 148 bits/slot
- 4.615 ms frame duration (1184 bits); 0.57692 ms slot duration

- four burst types:

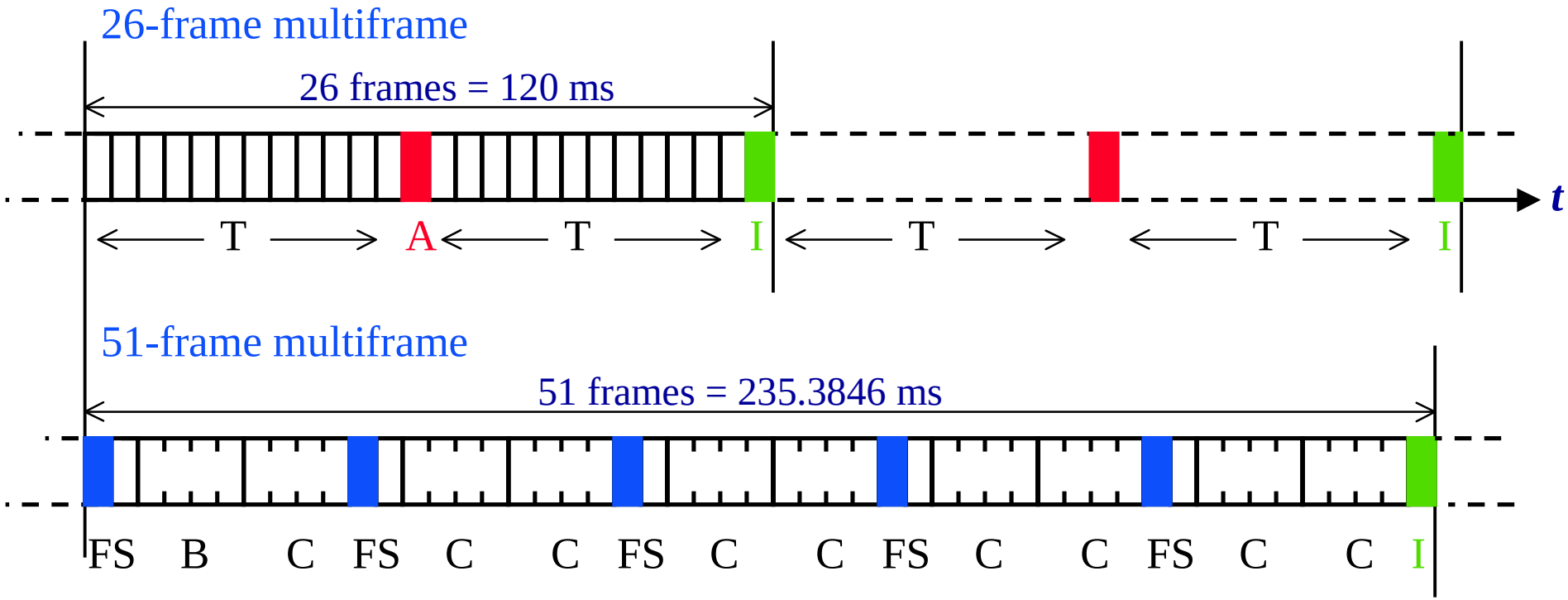
traffic (up- and downlink):	normal burst (NB)
control downlink:	frequency correction burst (FB)
	synchronization burst (SB)
control uplink:	access burst (AB)

GSM: physical layer

Burst formats



GSM: physical layer



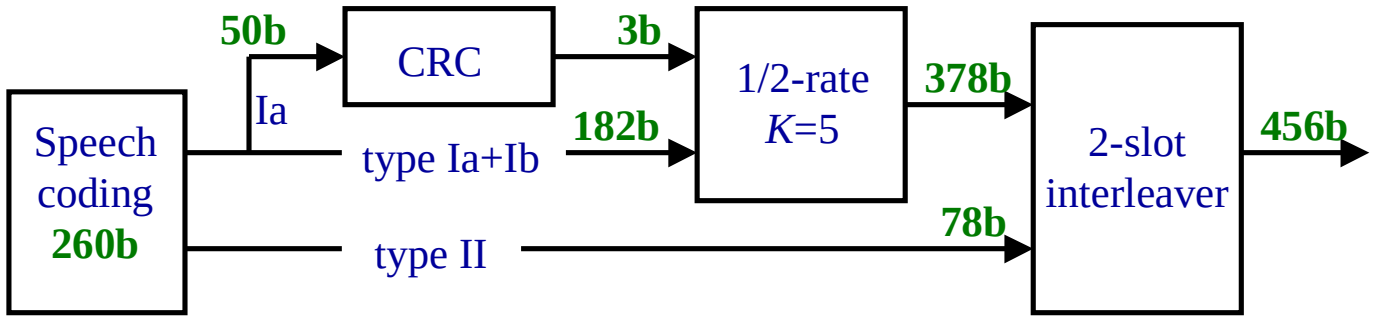
SUPERFRAME: 51×26-frame multiframes = 26×51-frame multiframes = 6.12s

HYPERFRAME: 2048 superframes = 2715648 TDMA frames > 3 hours

GSM: physical layer

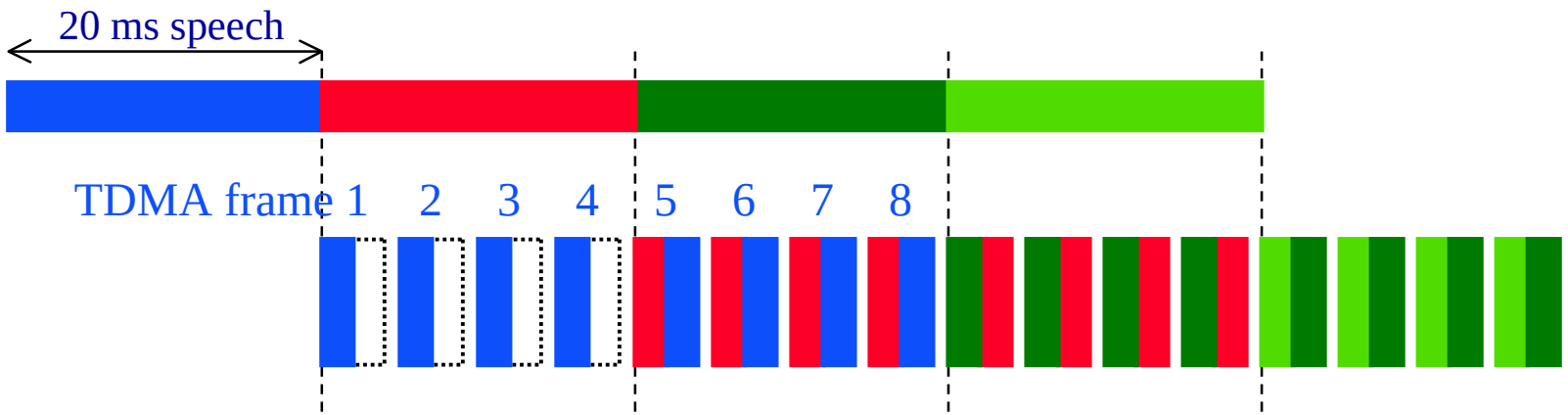
Channel coding

– voice: LPT-RELP coder
260 bits / 20 ms
3b CRC
protection classes
8-slot interleaving



GSM: physical layer

Interleaving: diagonal burst interleaving



GSM: MAC/DLC

Channel mapping

- TCH: Traffic CHannel
  full-rate: 1 slots/frame; 13 kb/s LTP-RELP coder
  half-rate: 1 slot/ two frames; 6.5 kb/s

- SACCH: Slow Associated Control Channel (DCCH)
  one A-burst / 120ms
  power control, handover

- FACCH: Fast Associated Control Channel (DCCH)
  replaces TCH (flag indication)

GSM: MAC/DLC

Channel mapping (cont'd): TS0

- BCCH: Broadcast Control CHannel
  4 slots / 51-frame multiframe

- CCCH: Common Control CHannel
  - PCH: paging channel
  - AGCH: access grant channel
  - RACH: random access channel (slotted ALOHA)

- SDCCH: Stand-alone Dedicated Control CHannel

GSM: MAC/DLC

Full-rate traffic channels:

- TCH/FS 13 kb/s full-rate speech
- TCH/F9.6 9.6 kb/s full-rate data
- TCH/F4.8 4.8 kb/s full-rate data
- TCH/F2.4 2.4 kb/s full-rate data

Half-rate traffic channels:

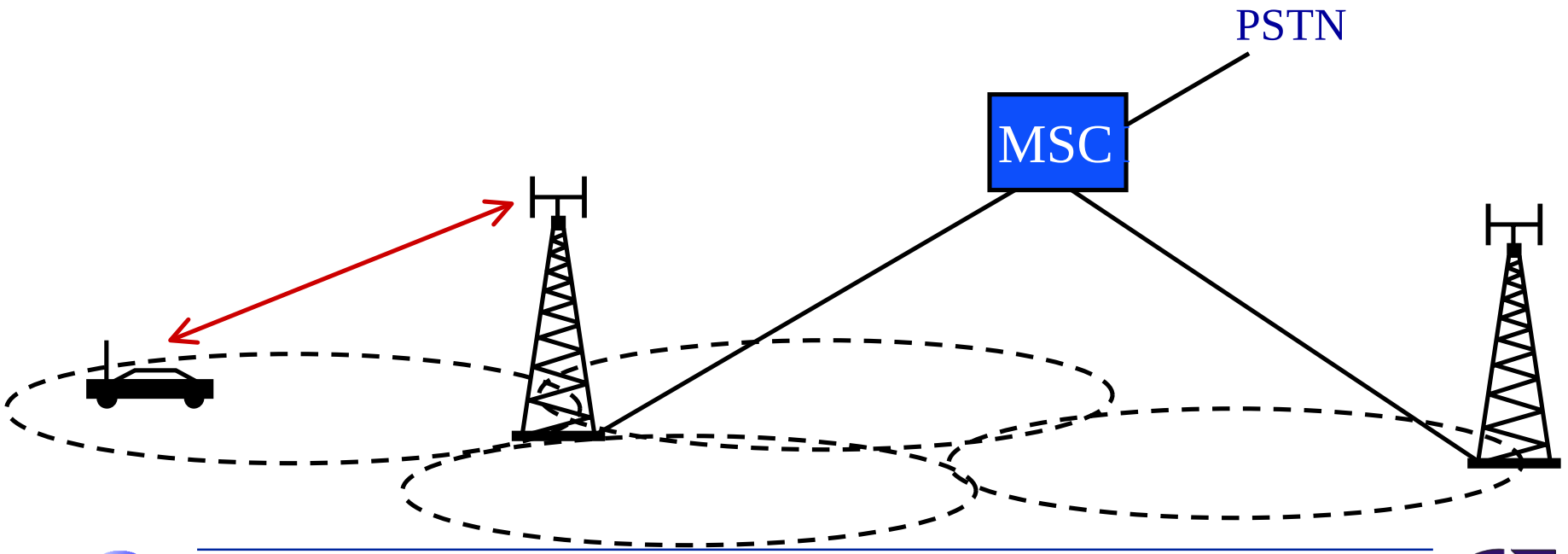
- TCH/HS 6.5 kb/s half-rate speech
- TCH/H4.8 4.8 kb/s half-rate data
- TCH/H2.4 2.4 kb/s half-rate data

IS-95

- **Interim Standard 95; (TIA)**
- **CDMA/AMPS dual-mode terminals**
- **Narrowband CMDA (BW ≈ 1.25 MHz)**
- **Qualcomm (1994)**

IS-95: architecture

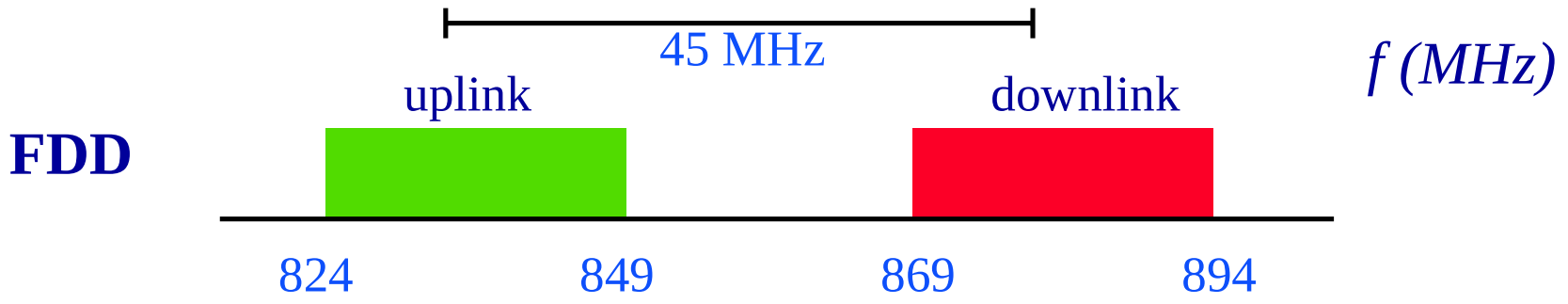
- 1/1 reuse
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



IS-95: physical layer

Radio bands

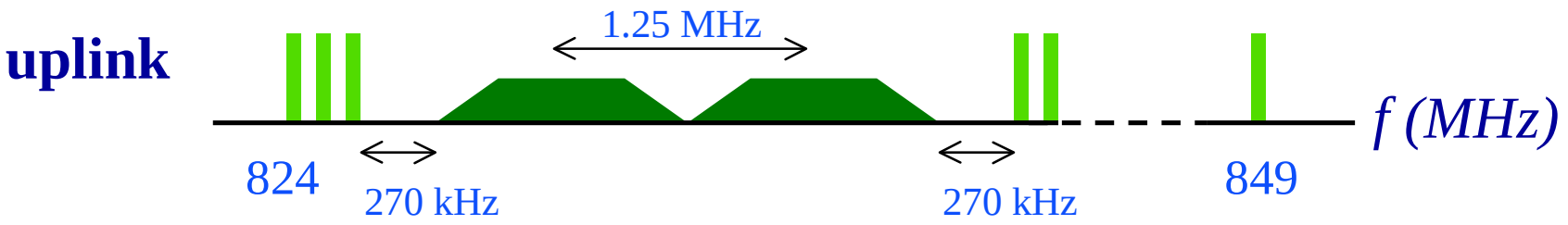
- co-existence with AMPS
- 20 wideband channels
- spreading rate 1.2288 Mc/s
- channel spacing 1.25 MHz



IS-95: physical layer

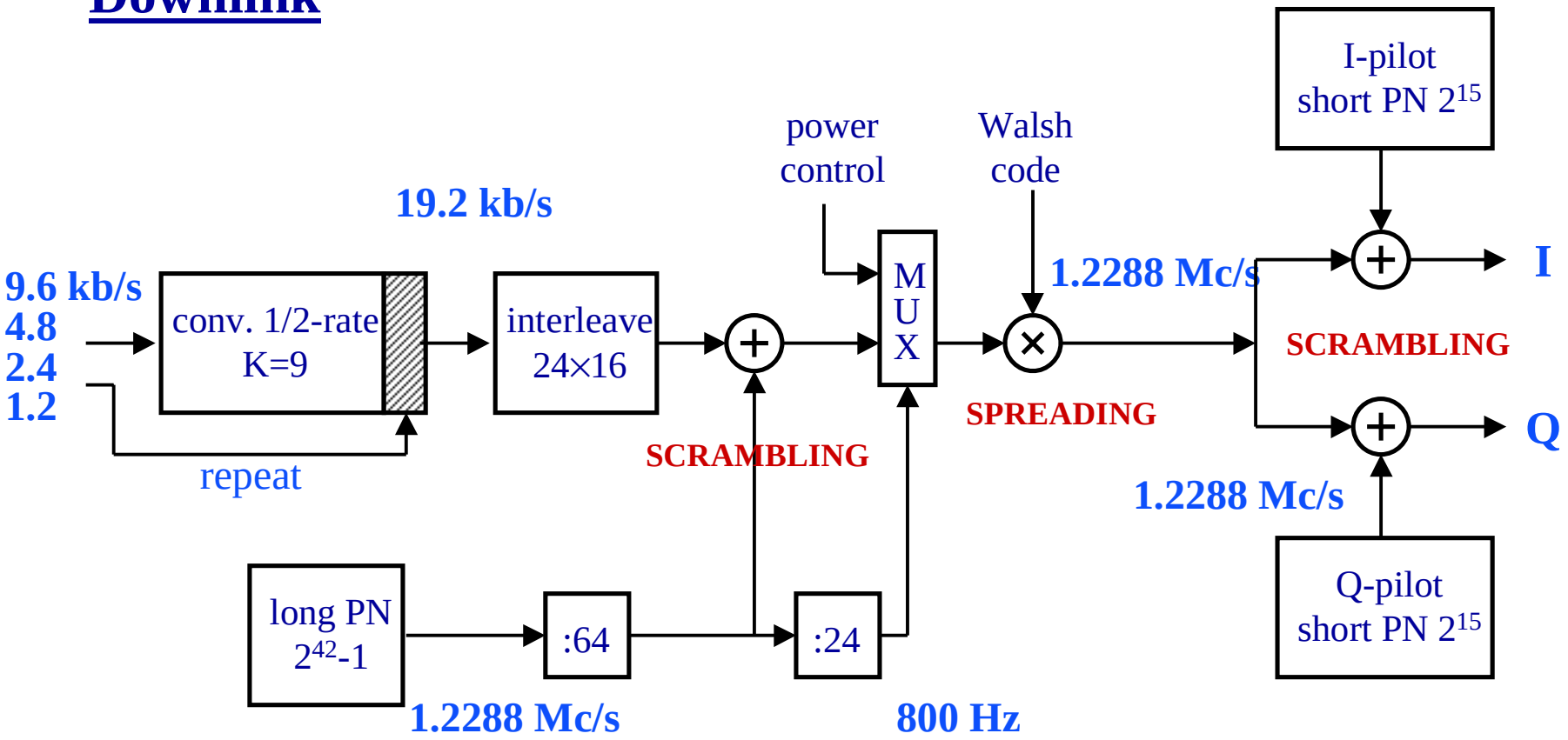
Radio bands

- co-existence with AMPS
- 9 AMPS channels guard space (270 kHz)



IS-95: physical layer

Downlink



IS-95: physical layer

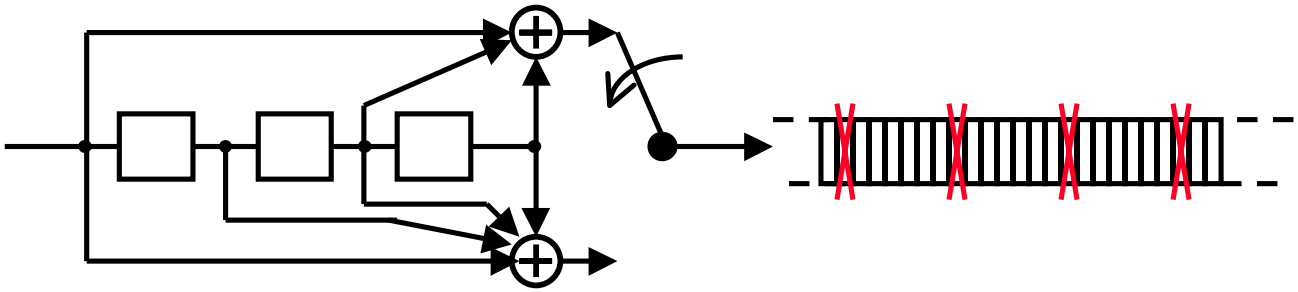
Downlink spreading

- **Channelization** separating channels: 64-chip Walsh codes (orthogonal)
  separating users: 2^{42}-1 length long PN sequences (MIN/ESN)
- **Scrambling** separating cells: 2^{15} length short PN codes
- **Pilot** all-one Walsh code 0 (W0: 111…1)
  phase reference, coherent detection
- **Sync** Walsh code 32 (W32: 111…1000…0)
  good auto-correlation

IS-95: physical layer

Puncturing

- remove 1 out of every *k* coded bits
- rate increase of *k*/(*k*-1)
- add zero to metric in Viterbi decoder



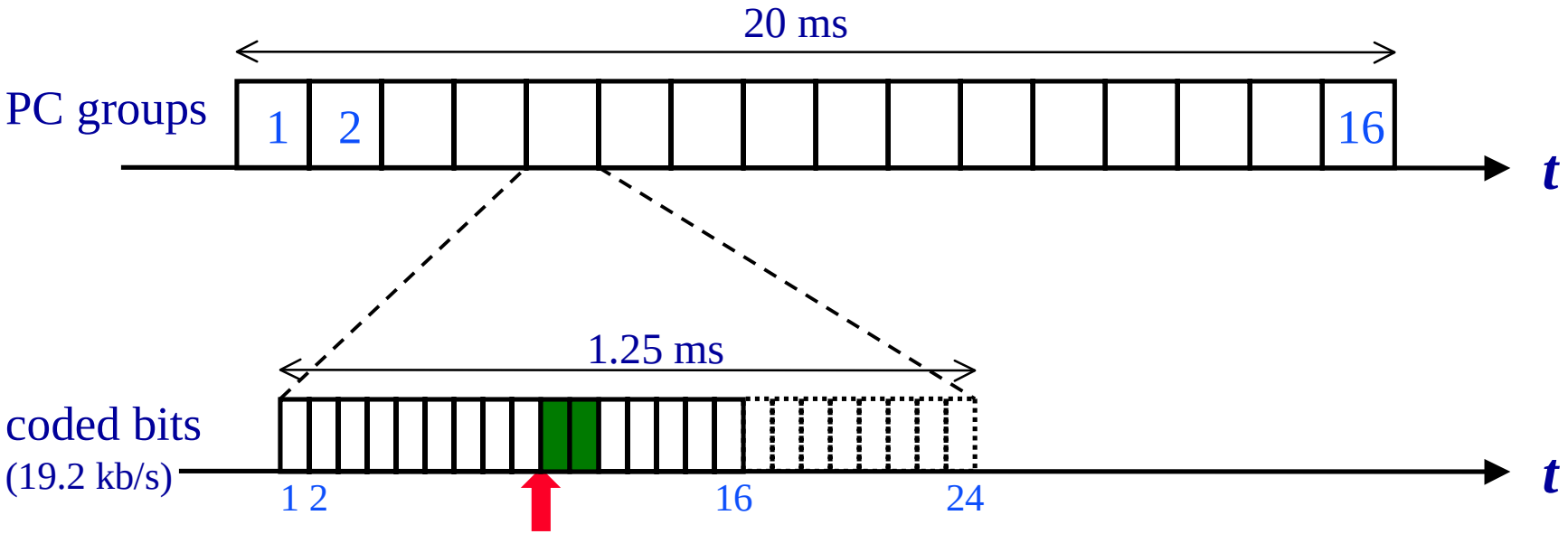
Example: 1/2-rate 7/6-rate

7/12-rate punctured convolutional code

IS-95: physical layer

Power control bits

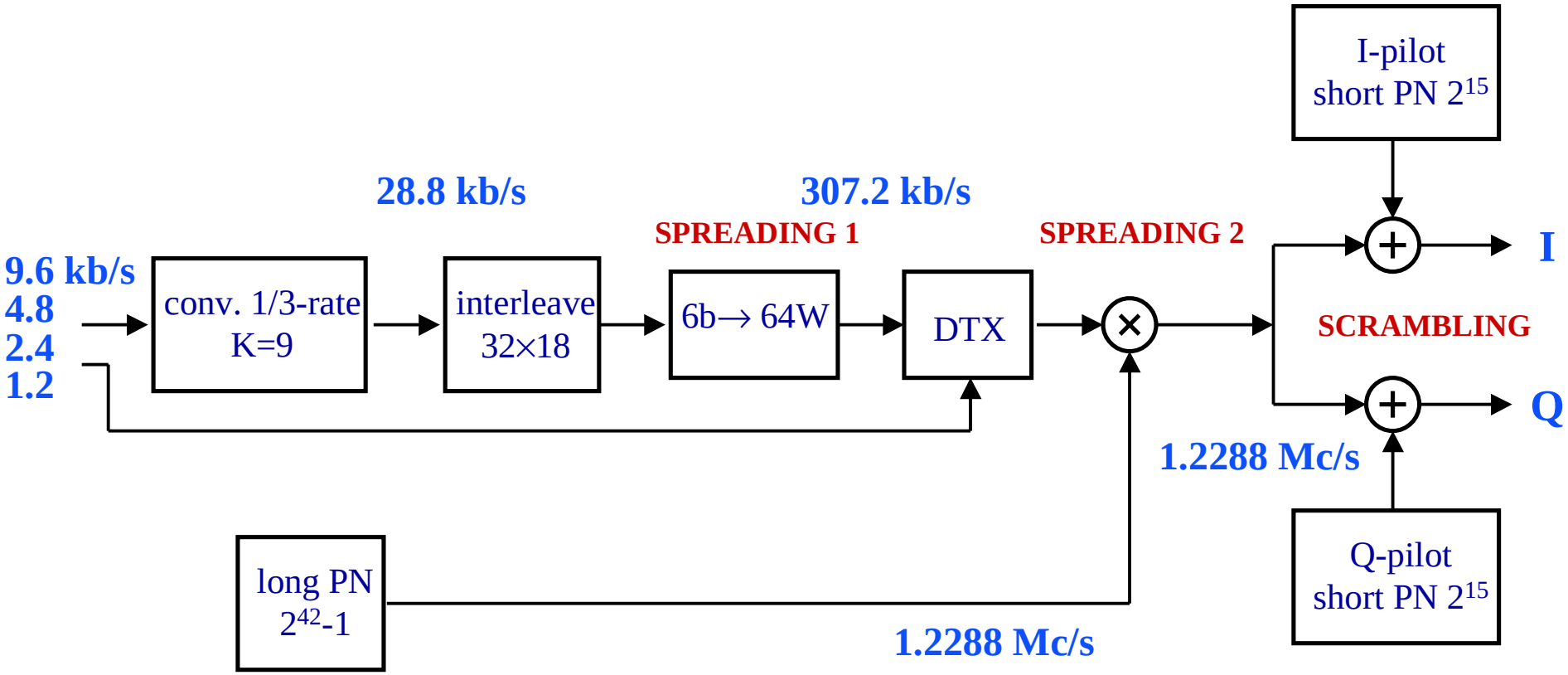
- near-far issues
- 800 b/s, stealing (puncturing) from coded bits from FTC
- 16 PC groups per 20 ms; 1b PC per PC group
- last 4b of 24b part of long PN sequence determines puncture position



start position determined by last 4b of long PN sequence

IS-95: physical layer

Uplink



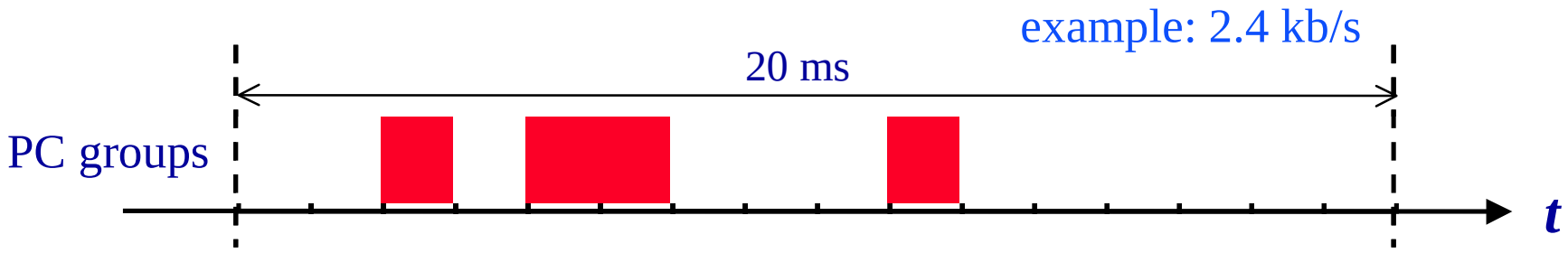
IS-95: physical layer

Uplink variable data rate

- 12 uplink bits per PC group (12b/1.25ms = 9.6 kb/s)

- 9.6 kb/s: use all 16 PC groups
- 4.8 kb/s: use *m*=8 of 16 PC groups
- 2.4 kb/s: use *m*=4 of 16 PC groups
- 1.2 kb/s: use *m*=2 of 16 PC groups

- positions of *m* used groups randomized
- 14b part of long PN sequence determines positions



IS-95: physical layer

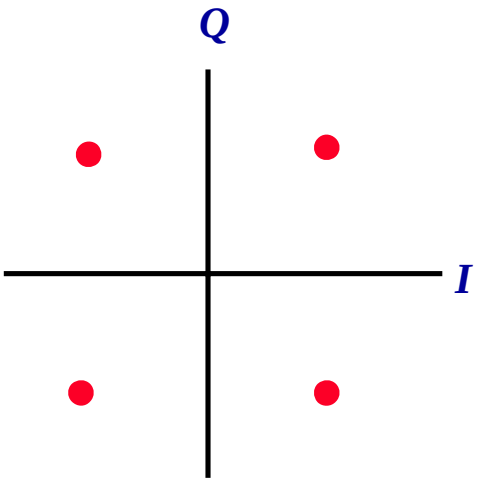
Variable data rates

- Pauses, voice/unvoiced
- Downlink by repetition
  - TX power decrease
  - spreading factors 128, 256, 512, 1024
- Uplink by blanking PC groups

IS-95: physical layer

Modulation

- downlink: QPSK
- uplink: offset QPSK (1/2 chip delay = 406.901 ns)



b_k, b_{k-1}	ϕ_k
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

IS-95: MAC/DLC

Downlink channels:

- Pilot
- SCH synch; 1.2 kb/s
- PCH page; up to 7 (2.4, 4.8, 9.6 kb/s)
- FTC traffic; up to 63 (1.2, 2.4, 4.8, 9.6 kb/s)

Uplink channels:

- ACH random access; 32 per PCH; 4.8 kb/s
- RTC traffic; up to 63 (1.2, 2.4, 4.8, 9.6 kb/s)

IS-95: speech

QCELP:

- variable rate: 1.2, 2.4, 4.8, 9.6 kb/s
- silence periods: 1.2 b/s

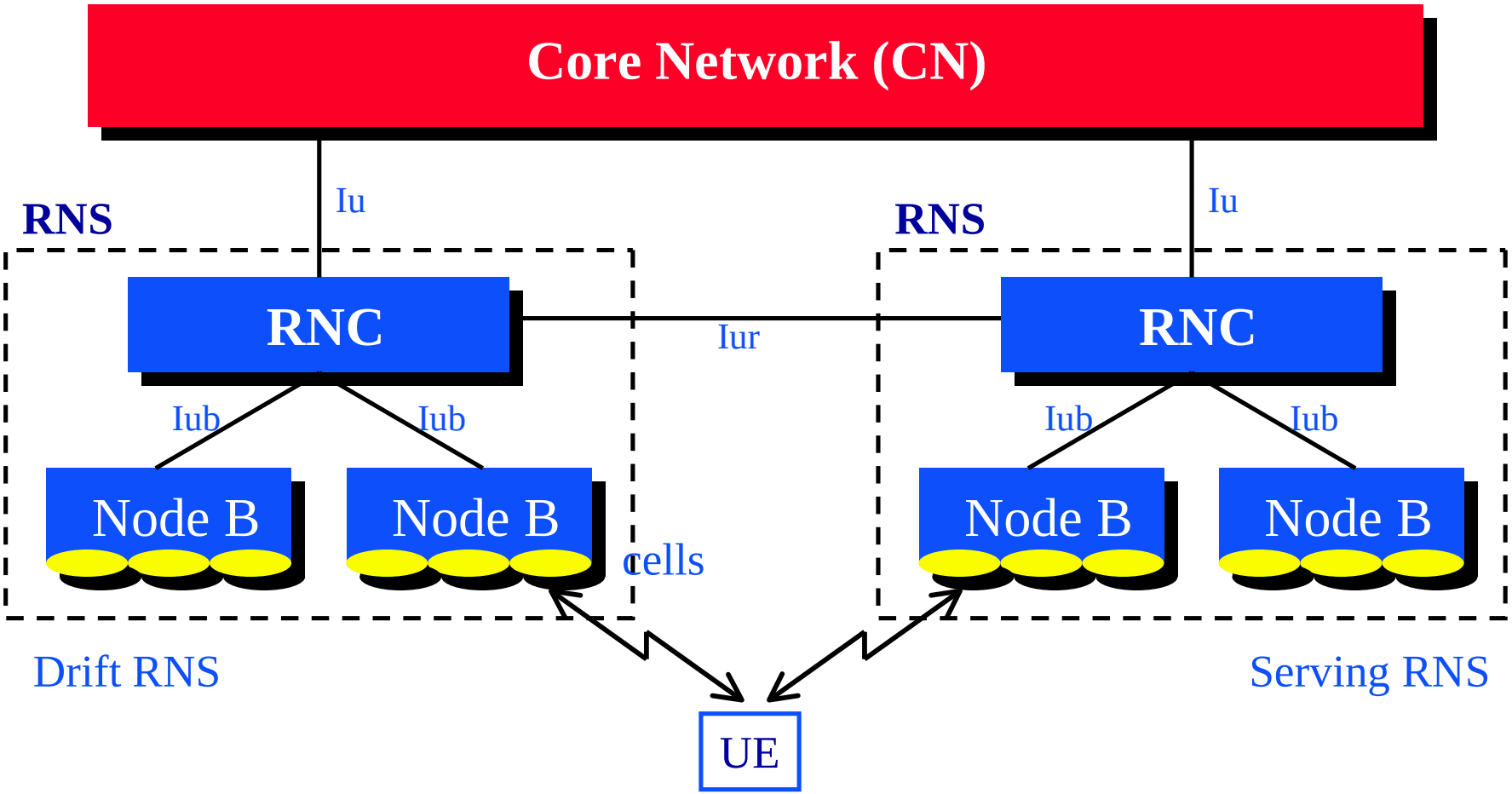
QCELP13:

- improved voice quality
- variable rate 1.8, 3.6, 7.2, 14.4 kb/s
- forward link: 1/2-rate to 3/4-rate punctured
- reverse link: 1/3-rate to 1/2 rate

UMTS

- **Universal Mobile Telephone System**
- **UTRAN: UMTS Terrestrial Radio Access Network**
- **Standardization: ETSI / ARIB / 3GPP**
- **Wideband CMDA (BW ≈ 5 MHz)**

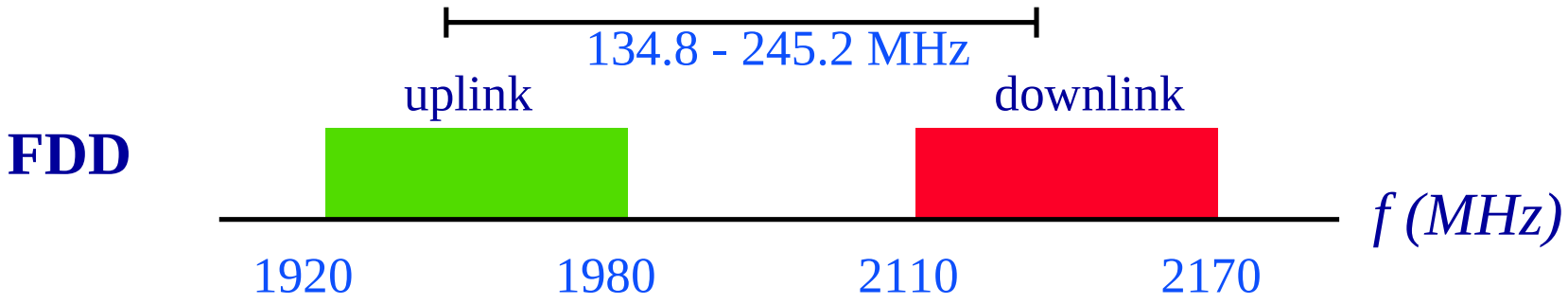
UMTS: architecture



UMTS: physical layer

Radio bands

- FDD and TDD mode (here only FDD is discussed)
- spreading rate 3.84 Mc/s
- channel spacing 5 MHz (raster 200 kHz)
- offset TDD (uplink lags by 1024 chips)



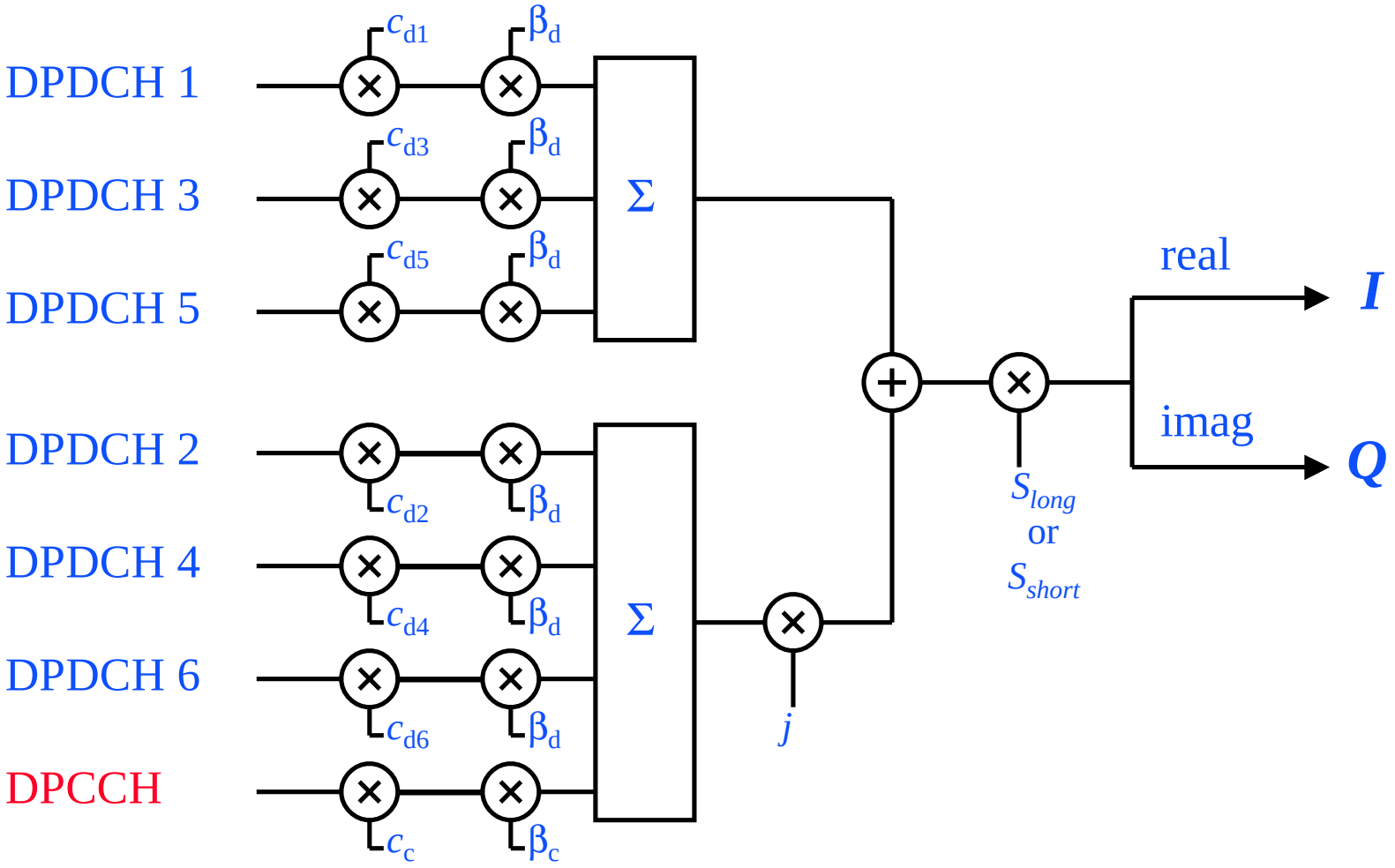
UMTS: spreading

Spreading

- Chiprate R_c=3.84 Mc/s
- **Channelization**: 1) BW expansion, 2) defining logical channels
- **Scrambling**: separating cells, separating mobiles; fixed 3.84 Mc/s

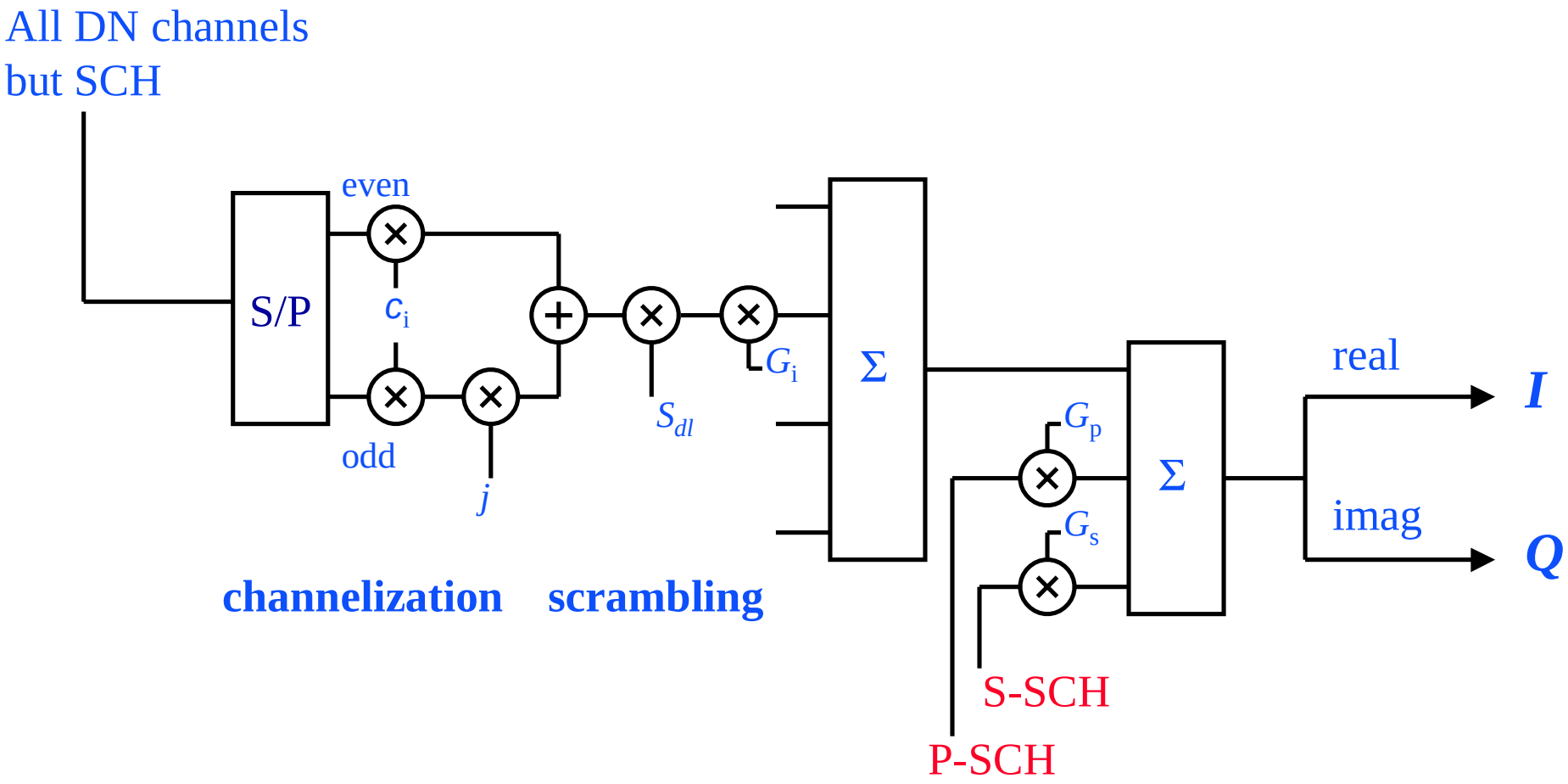
	uplink	**downlink**
channelization	Walsh (SF=4-256) R_b = 15-960 kb/s	Walsh (SF=4-512) R_b = 15-1920 kb/s
scrambling	short PN (255 length) long Gold (2^{25}-1 length)	long Gold (2^{18}-1 length) repeats every 10ms

UMTS: uplink spreading

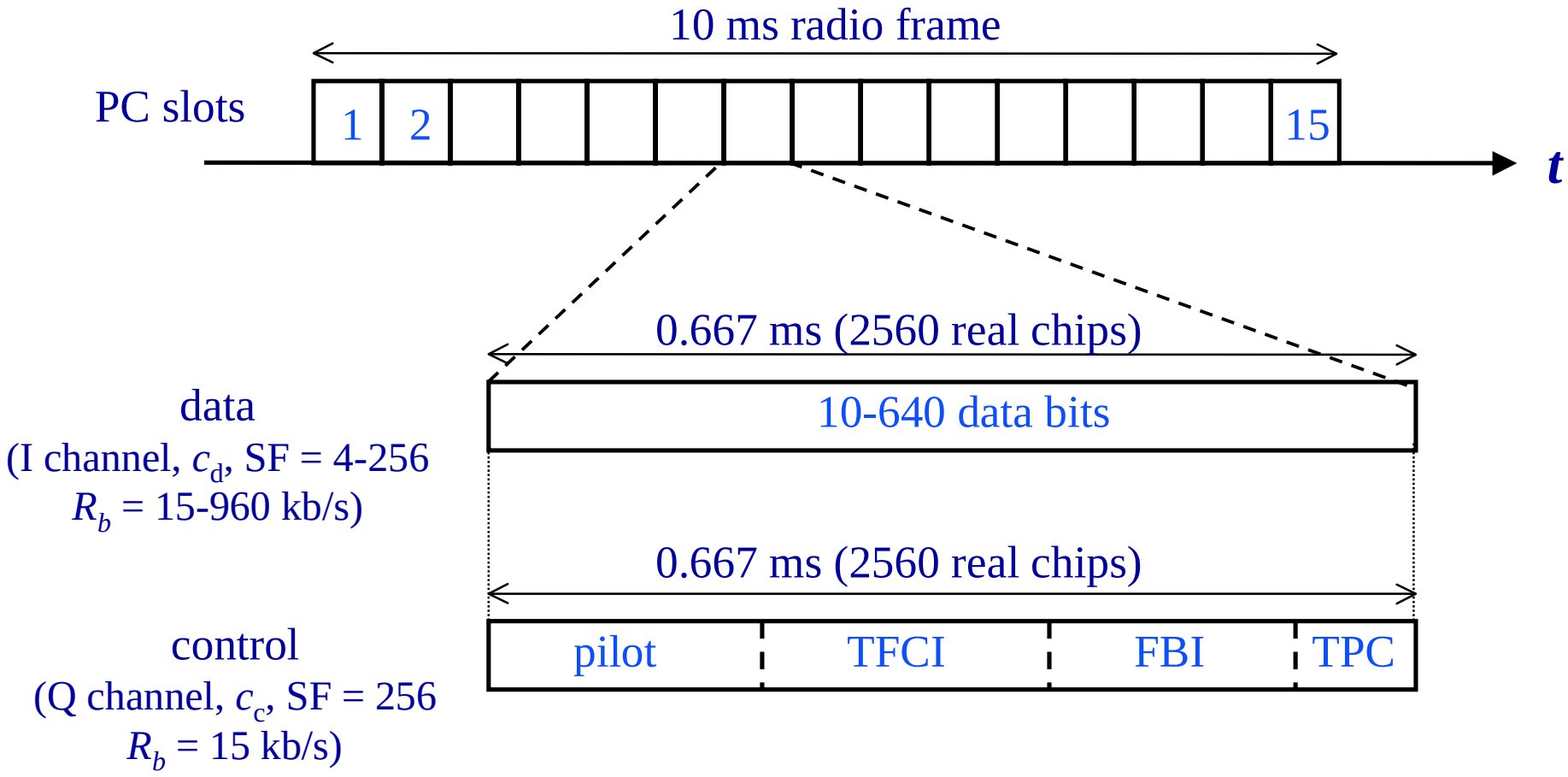


channelization (OVSF; c_c:SF=256) **scrambling**

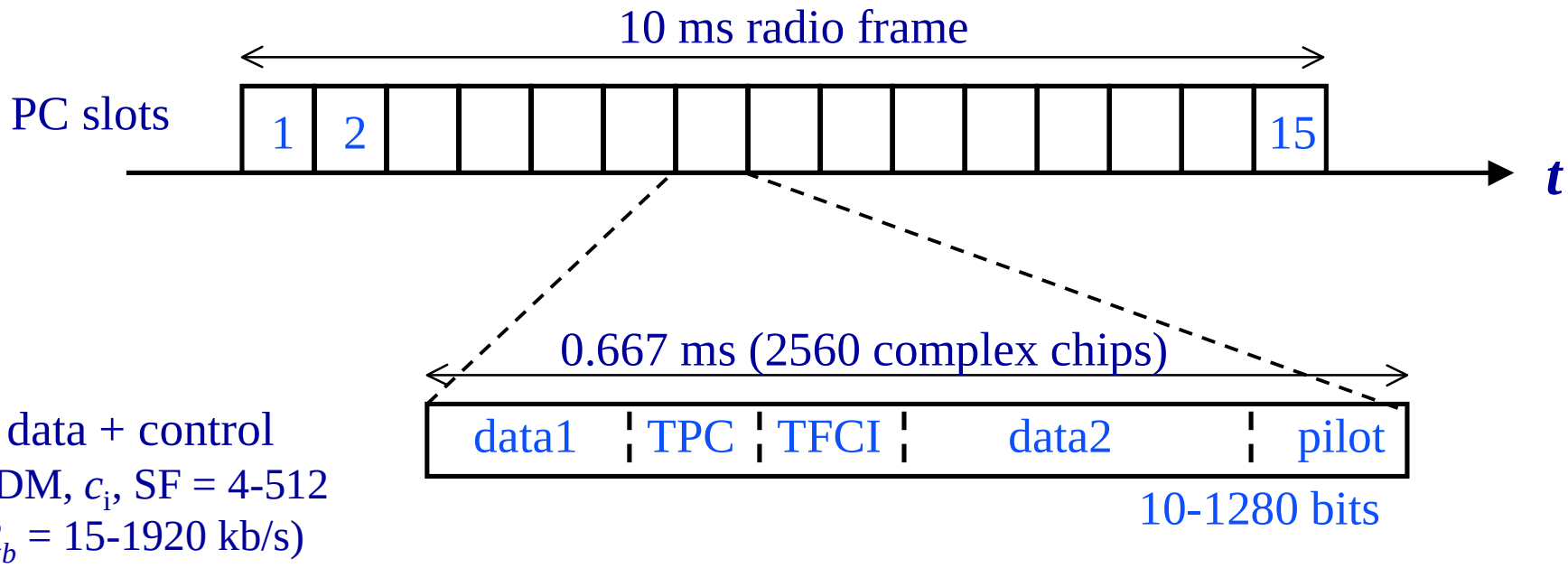
UMTS: downlink spreading



UMTS: uplink framing



UMTS: downlink framing



UMTS: pilot and synchronization

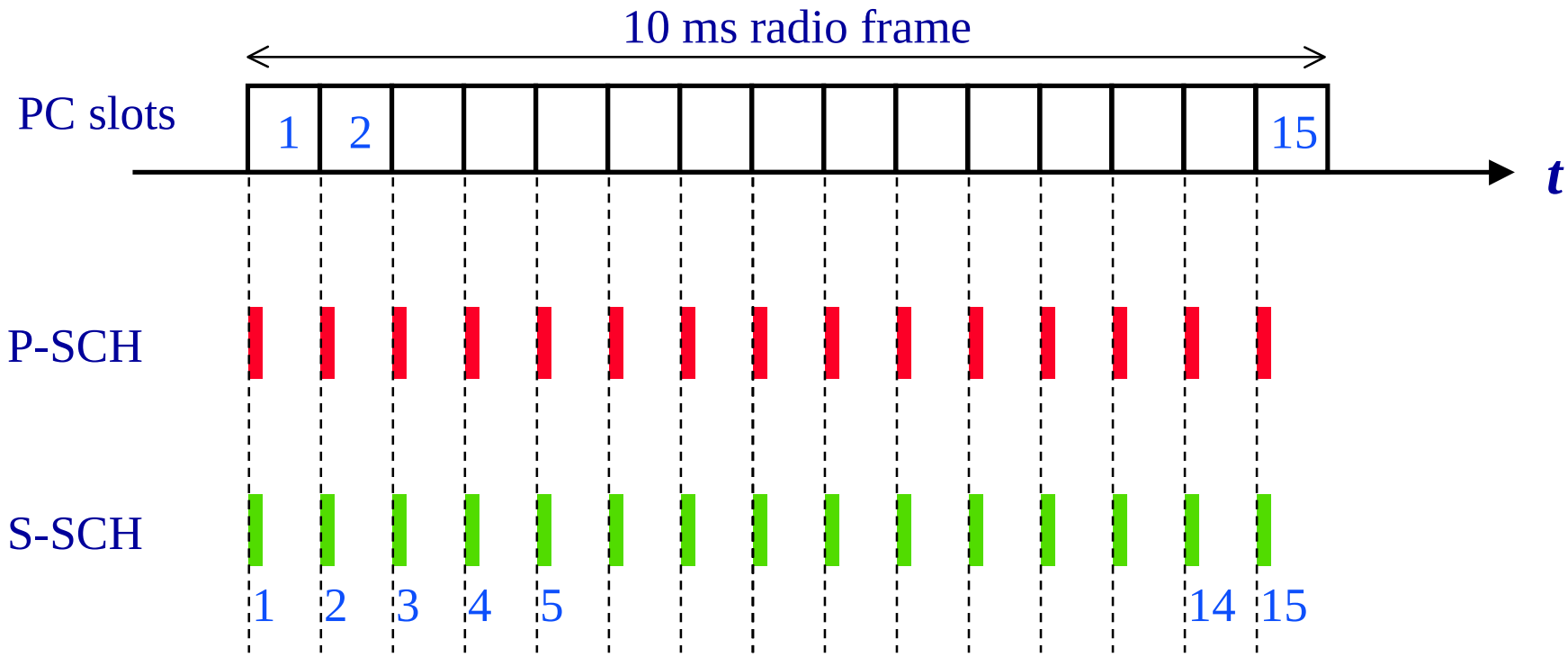
Pilot channel

- Common PIlot CHannel (CPICH)
- Pre-defined symbol sequence @ 30kb/s, SF=256
- broadcast, one per cell

Synch channel

- Cell seach
- Primary SCH:
  - unique 256-chip sync sequence PCS
  - good a-periodic auto-correlation
  - repeated at beginning of every PC slot
- Secondary SCH:
  - 64 codes, indicating primary scrambling code
  - 15 parts of 256 chips transmitted at beginning of every PC slot

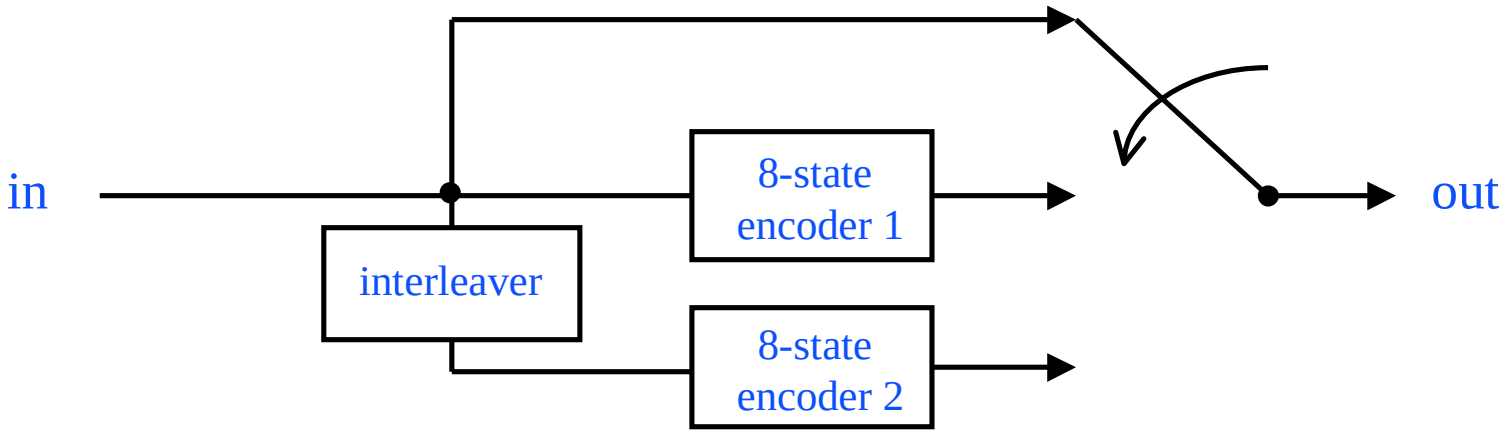
UMTS: downlink synchronization



UMTS: coding

FEC coding

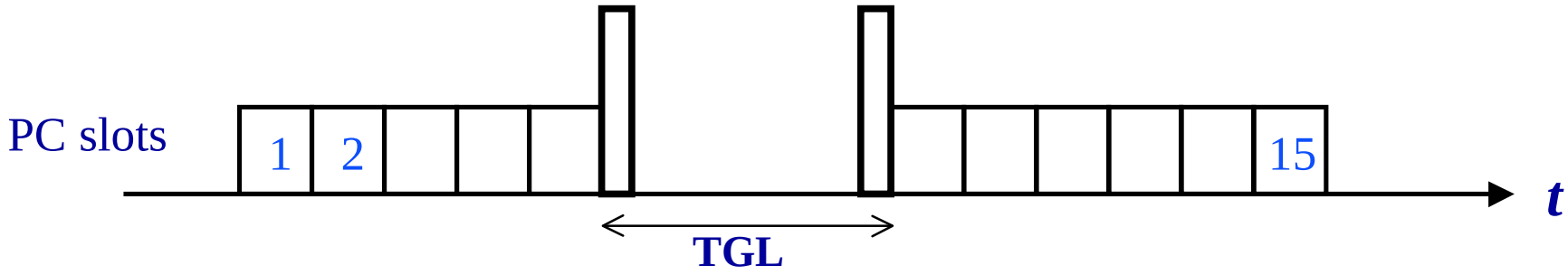
- Control channels
  - 1/2-rate convolutional coding, *K*=9
- Traffic channels
  - no coding
  - 1/2-rate and 1/3 rate convolutional coding, *K*=9
  - 1/3-rate Turbo coding (Parallel Concatenated Conv. Coding)



UMTS: compressed mode

Inter-frequency measurements

- DTX
- SF reduction
- Puncturing (downlink only)
- Transmission Gap Length, TGL≤ 7



FOR NEXT TIME

- **Read:**

  Articles on Bluetooth

- **Solve problems:**

  Chapter 10: 10.1, 10.5, 10.11, 10.19, 10.21, 10.31