CS 218 Fall 2003

October 23, 2003

- Cellular Wireless Networks
  - AMPS (Analog)
  - D-AMPS (TDMA)
  - GSM
  - CDMA

Reference: Tanenbaum Chpt 2 (pg 153-169)

Cellular Wireless Network Evolution

- **First Generation**: Analog
  - AMPS: Advance Mobile Phone Systems
  - Residential cordless phones
- **Second Generation**: Digital
  - IS-54: North American Standard - TDMA
  - IS-95: CDMA (Qualcomm)
  - GSM: Pan-European Digital Cellular
  - DECT: Digital European Cordless Telephone

Cellular Evolution (cont)

- **Third Generation: T/CDMA**

– combines the functions of: cellular, cordless, wireless LANs, paging etc.

– supports multimedia services (data, voice, video, image)

– a progression of integrated, high performance systems:

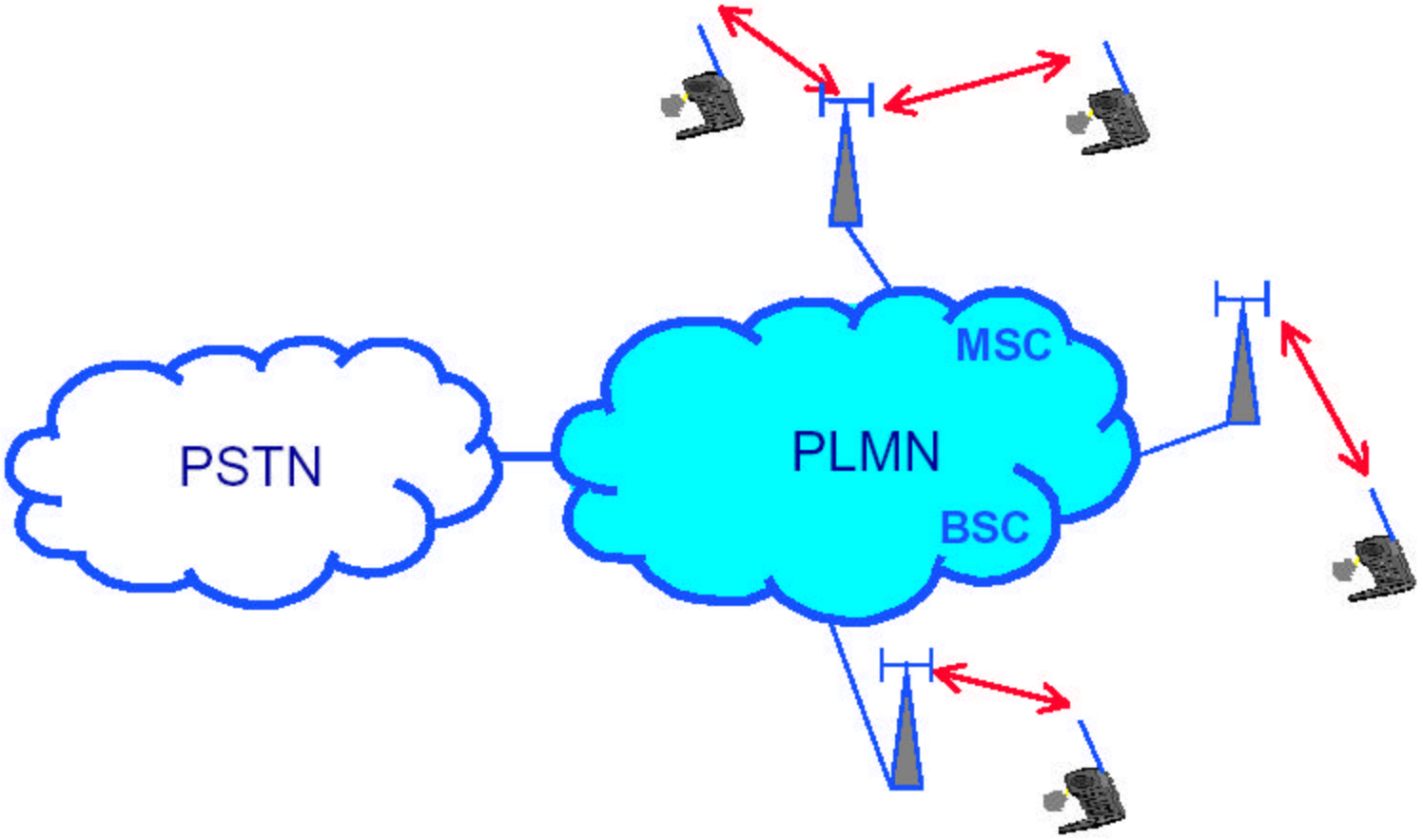
(a) GPRS (for GSM)

(b) EDGE (for GSM)

(c) 1xRTT (for CDMA)

(d) UMTS

Mobile (cellular) networks



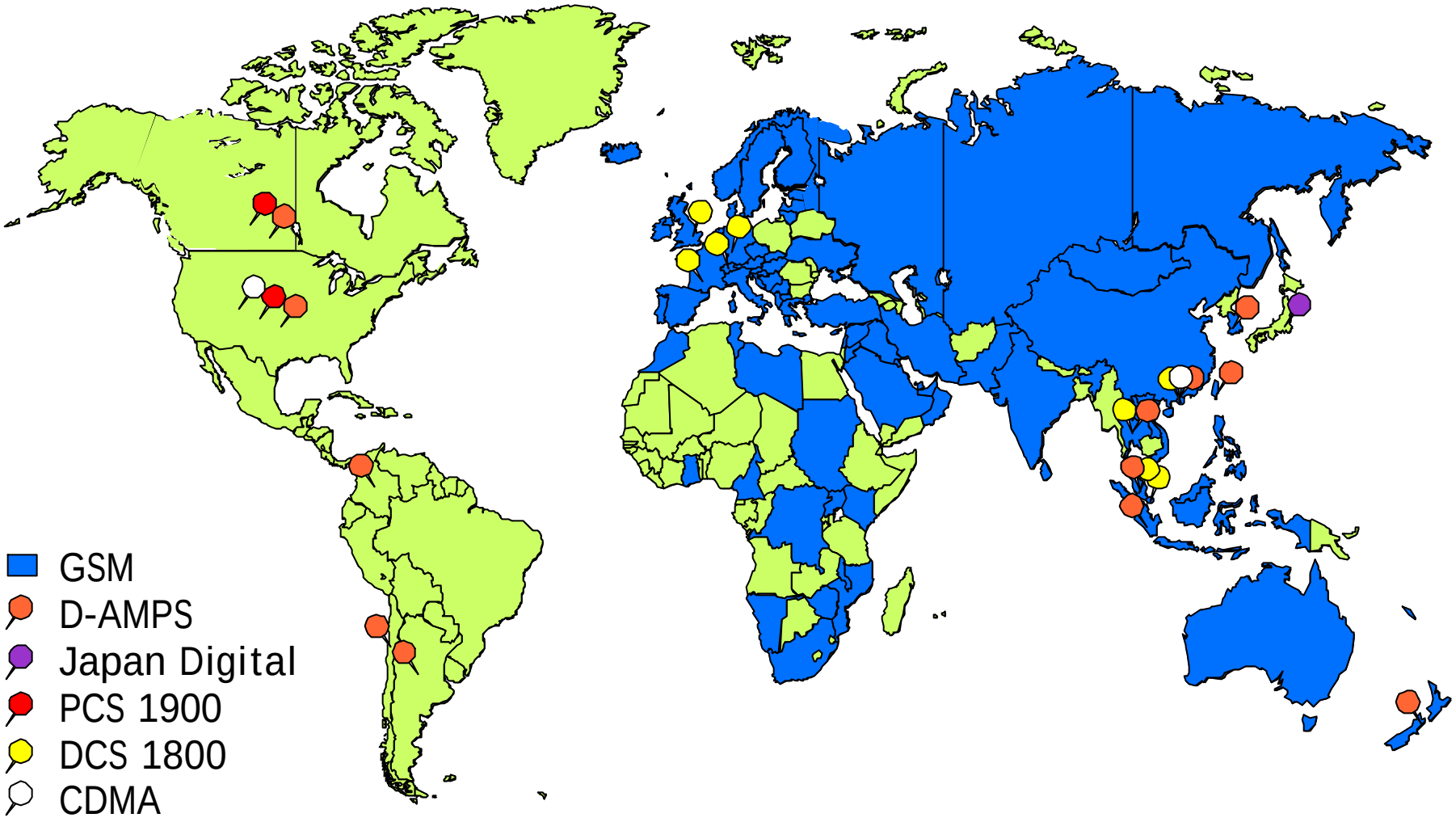
Cellular systems around the world

- **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

Digital Cellular Systems World-wide



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

Mobile system design features

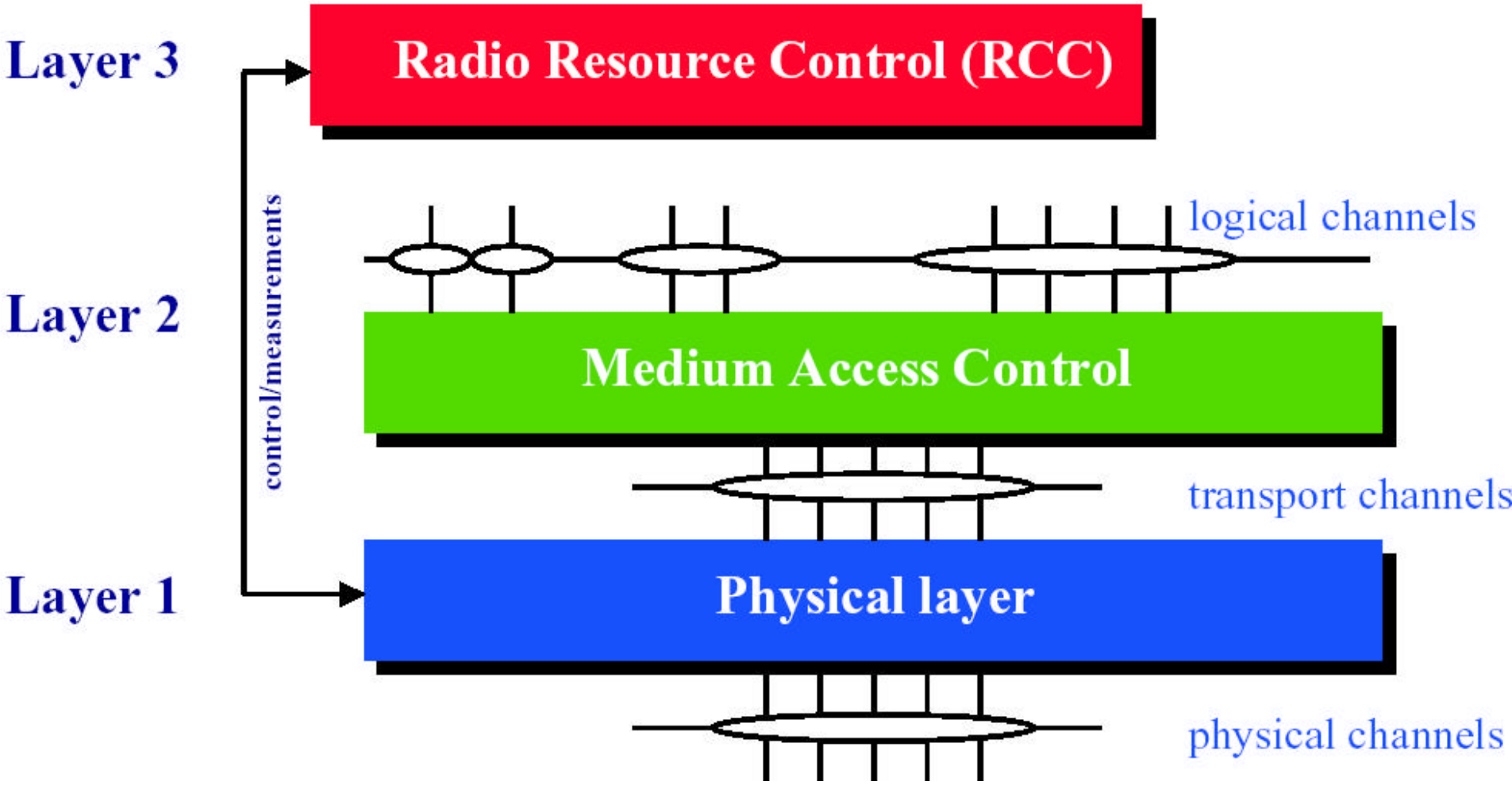
- **System architecture**
  - networking
  - addressing

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

Mobile system design features

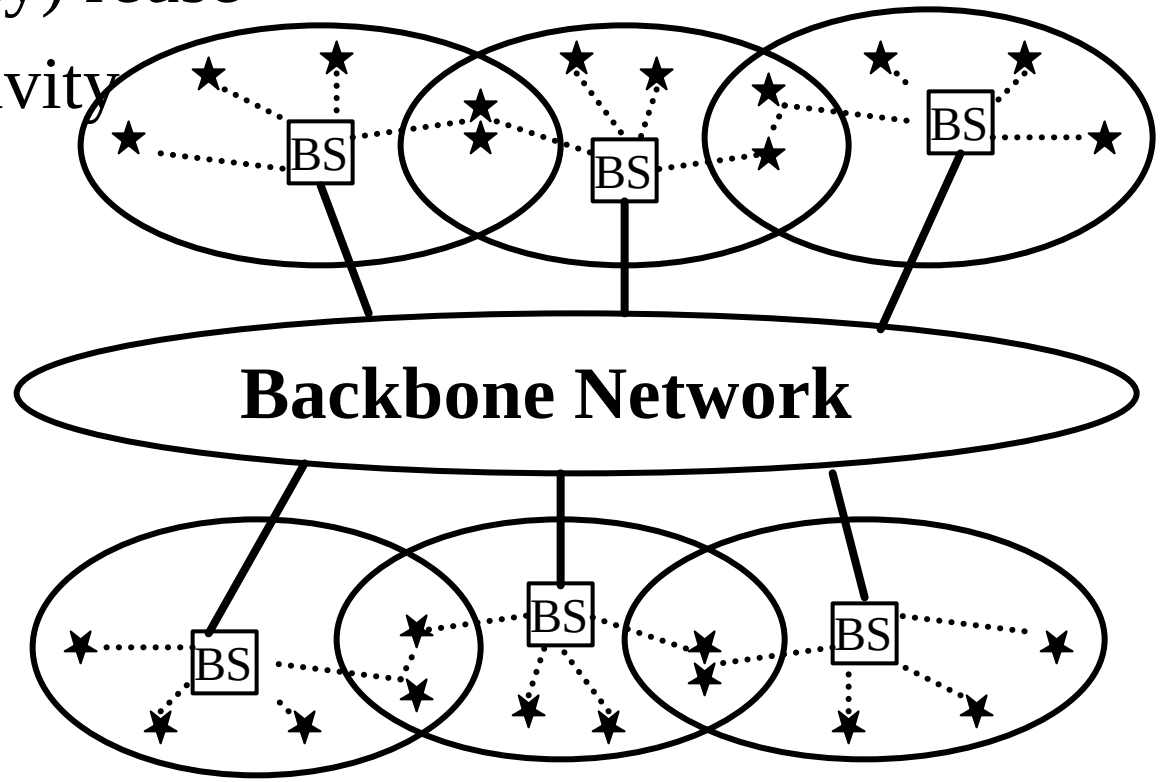
- **MAC/DLC layer**
  - channel mapping (control/traffic)
  - medium access techniques
  - call setup
  - standby behavior

Protocol layering



Cellular Concept

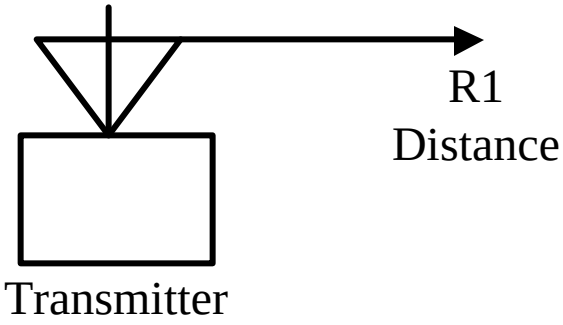
- Geographical separation
- Capacity (frequency) reuse
- Backbone connectivity

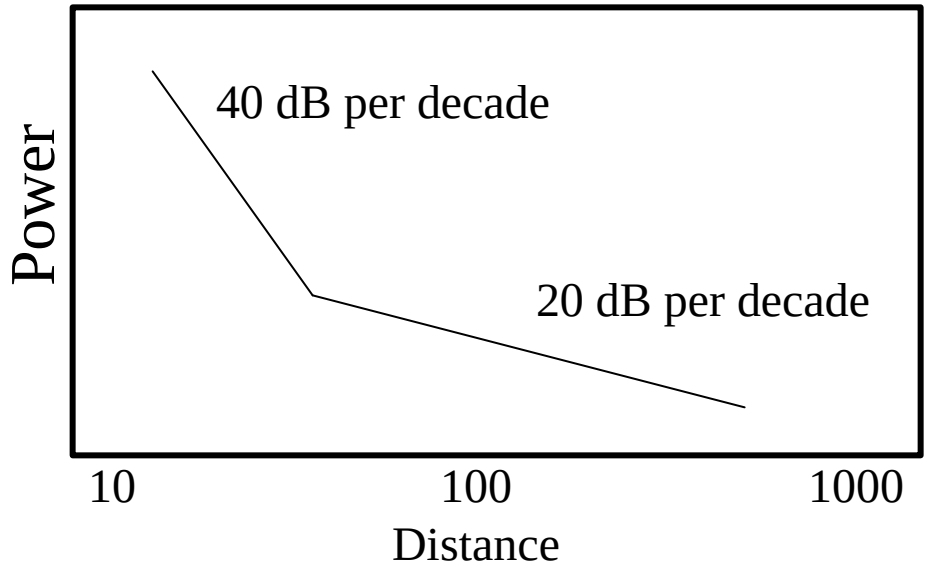


Characteristics of Radio Medium

Path Loss

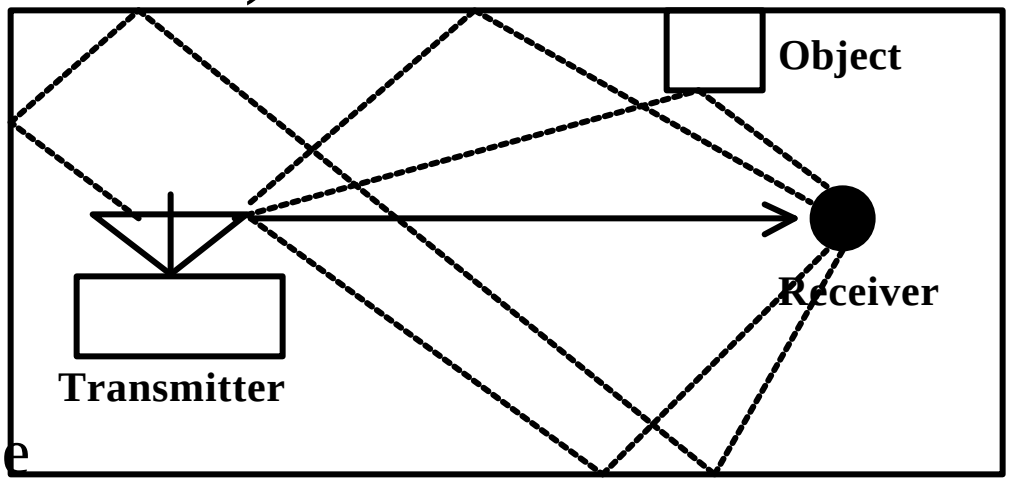
- Attenuation increases with respect to frequency and distance
  - Free space loss = square of distance
  - Indoor mobile radio = fourth power of distance

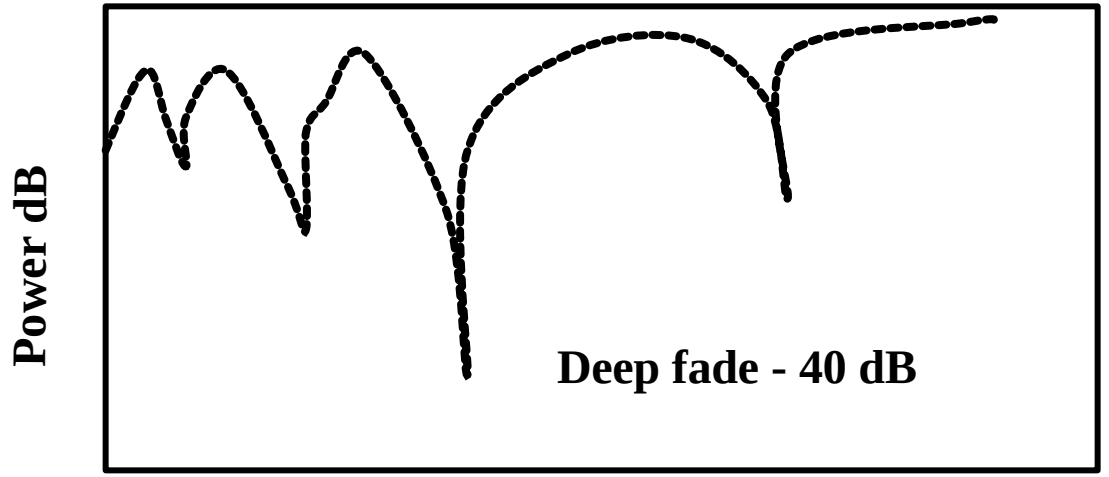




Characteristics of Radio Medium (cont'd)

- Fading
  - Multipath fading
  - Shadowing
- Delay spread
  - Intersymbol interference
- Interference
  - Across channels



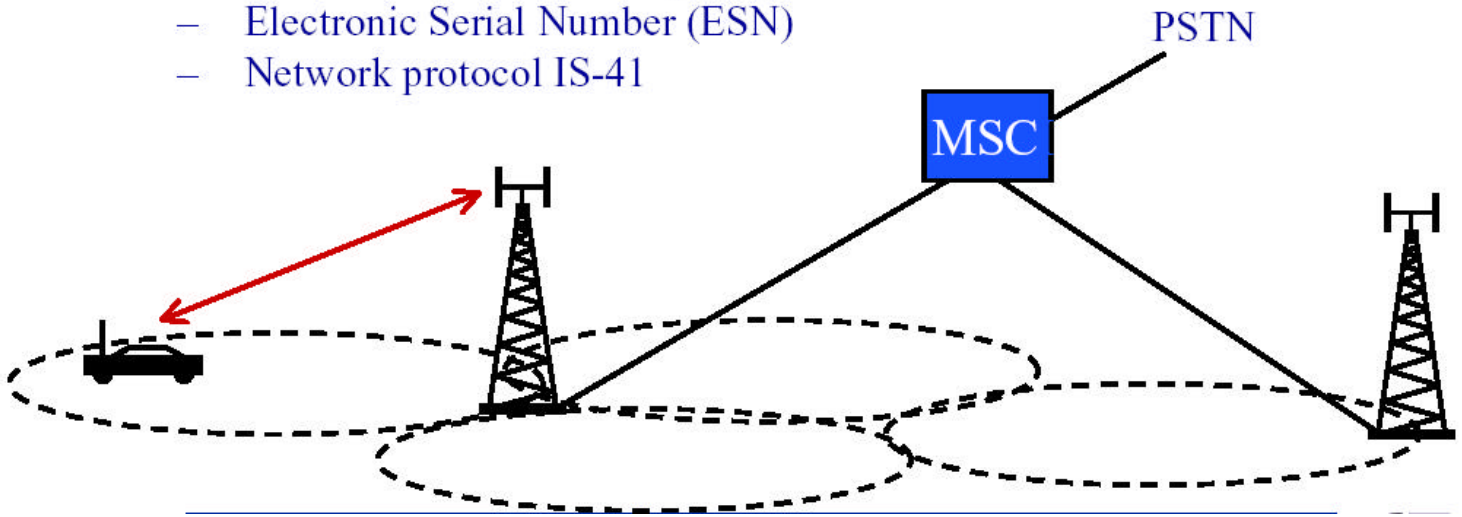


Advance Mobile Phone System

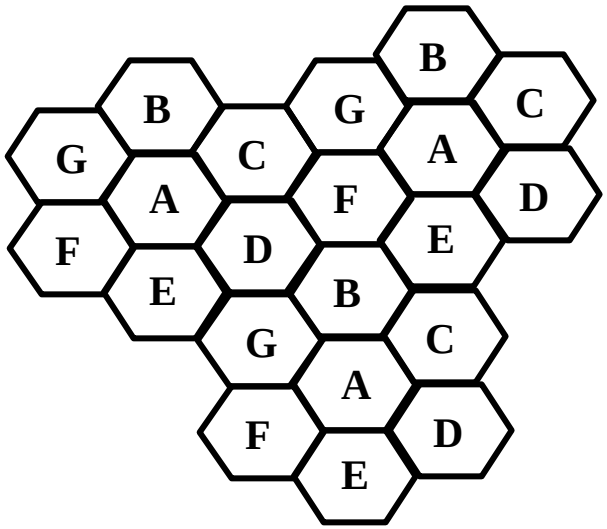
Architecture

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

Invented by Bell Labs; installed In US in 1982; in Europe as TACS



AMPS (Advance Mobile Phone System):

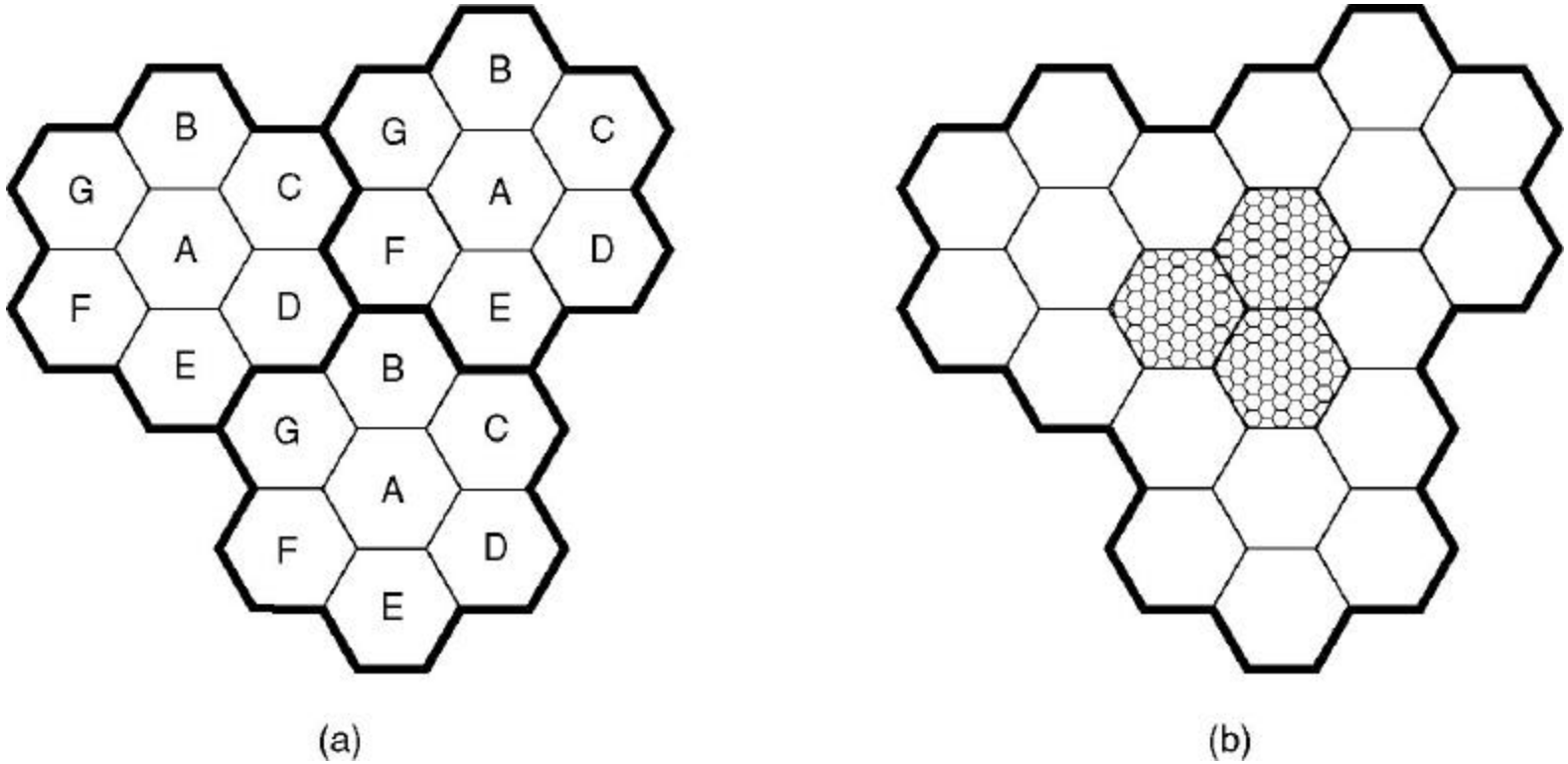


FDMA (Frequency Div Multiple Access): one frequency per user channel

Frequency Reuse:
Frequencies are not reused in a group of 7 adjacent cells

In each cell, 57 channels each for A-side and B -side carrier respectively; about 800 channels total (across the entire AMPS system)

Advanced Mobile Phone System



(a) Frequencies are not reused in adjacent cells.

(b) To add more users, smaller cells can be used.

Channel Categories

The channels are divided into four categories:

- **Control** (base to mobile) to manage the system
- **Paging** (base to mobile) to alert users to calls for them
- **Access** (bidirectional) for call setup and channel assignment
- **Data** (bidirectional) for voice, fax, or data

Handoff

- **Handoff**: Transfer of a mobile from one cell to another
- Each base station constantly monitors the received power from each mobile.
- When power drops below given threshold, base station asks neighbor station (with stronger received power) to pick up the mobile, on a new channel.
- In APMS the handoff process takes about 300 msec.
- **Hard handoff**: user must switch from one frequency to another (noticeable disruption)
- **Soft Handoff** (available only with CDMA): no change in frequency.

To register and make a phone call

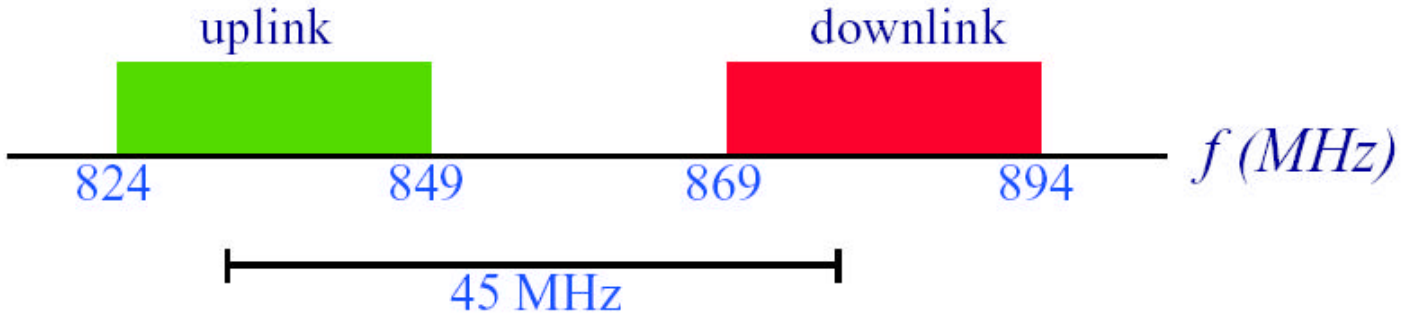
- When phone is switched on , it scans a preprogrammed list of 21 **control** channels, to find the most powerful signal.
- It transmits its ID number on it to the MSC – which informs the home MSC (registration is done every 15 min)
- To make a call, user transmits dest Ph # on random **access** channel; MSC will assign a **data** channel
- At the same time MSC **pages** the destination cell for the other party (idle phone **listens** on all page channels)

AMPS: physical layer

Radio bands

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

FDD



(Freq Division Duplex)

AMPS: physical layer

Modulation

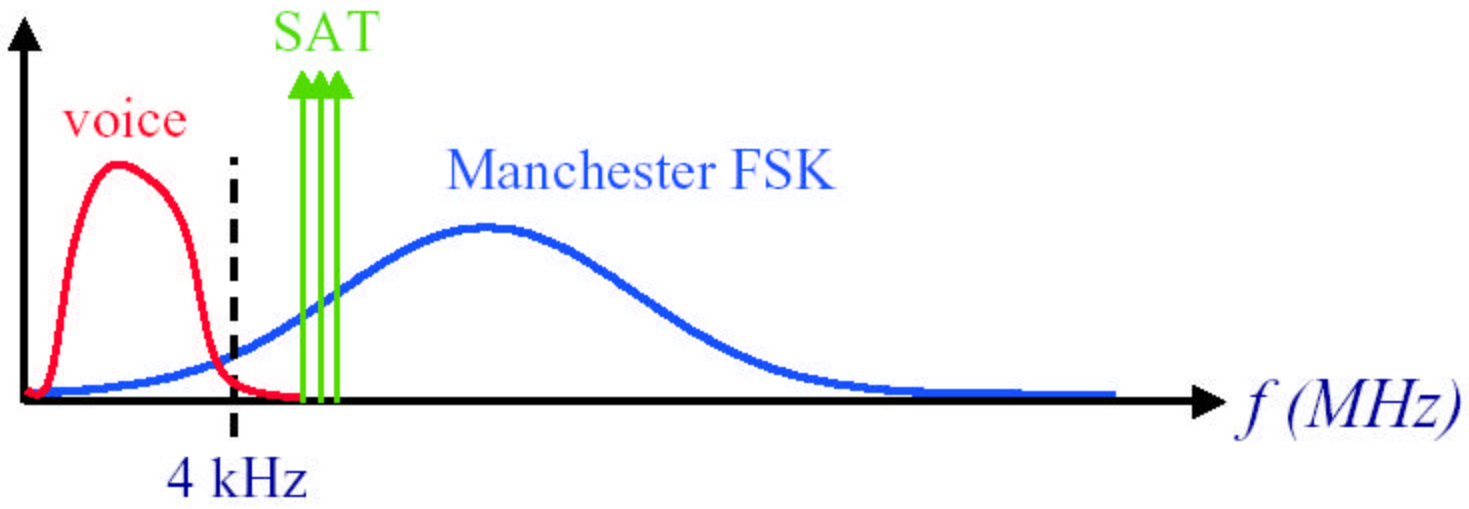
- traffic (voice): analog FM
  peak deviation $\Delta f = \pm 12$ kHz
  companding / expanding
  pre-emphasis / de-emphasis

- control (data): binary FSK ("0" → -8 kHz, "1" → +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

Digital Cellular: IS-54 TDMA System

- Second generation: **digital** (as opposed to analog as in AMPS)
- Same frequency as AMPS
- Each 30 kHz RF channel is used at a rate of 48.6 kbps
  - 6 TDM slots/RF band (2 slots per user)
  - 8 kbps voice coding
  - 16.2 kbps TDM digital channel (3 channels fit in 30kHz)

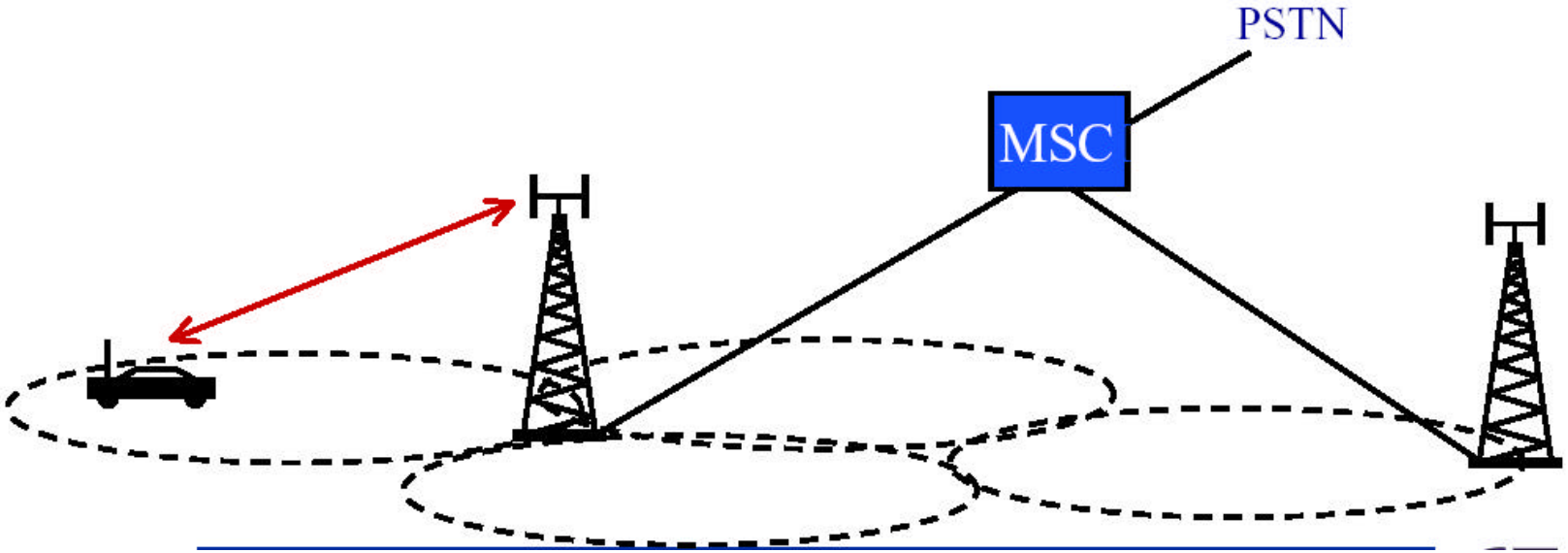
- 4 cell frequency reuse (instead of 7 as in AMPS)
- Capacity increase per cell per carrier
  - 3 x 416 / 4 = 312 (instead of 57 in AMPS)
  - Additional factor of two with speech activity detection.

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

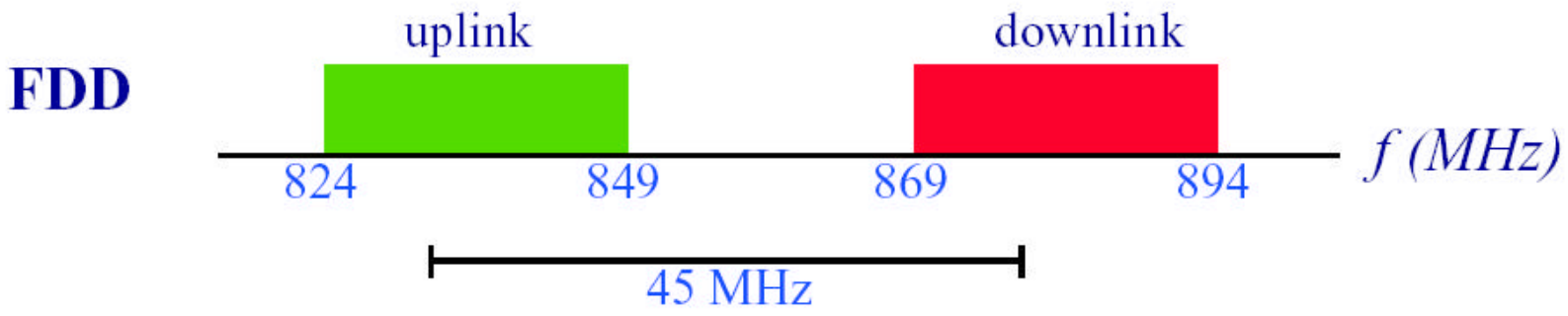
- 7/21 site/sector reuse
- 18 dB C/I
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



USDC: physical layer

Radio bands

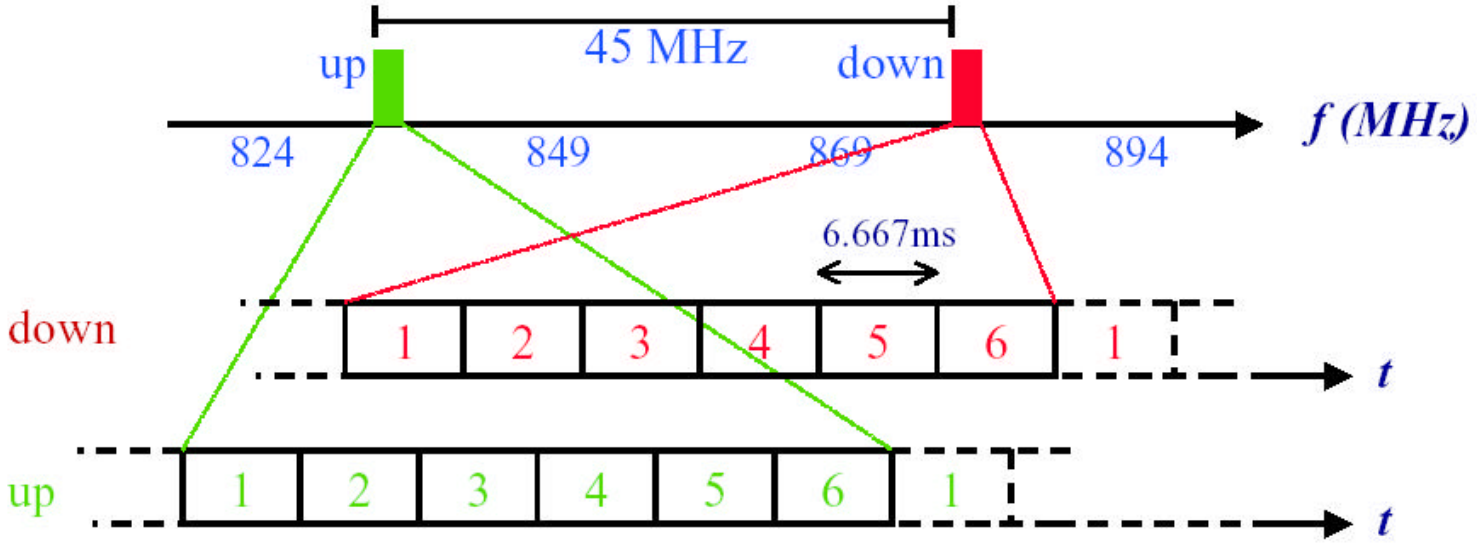
- 832 duplex channels
- channel spacing 30 kHz
- identical as for AMPS
- co-existence with AMPS (replacing AMPS channel by 6 USDC channels)



USDC: physical layer

Radio bands and time slots

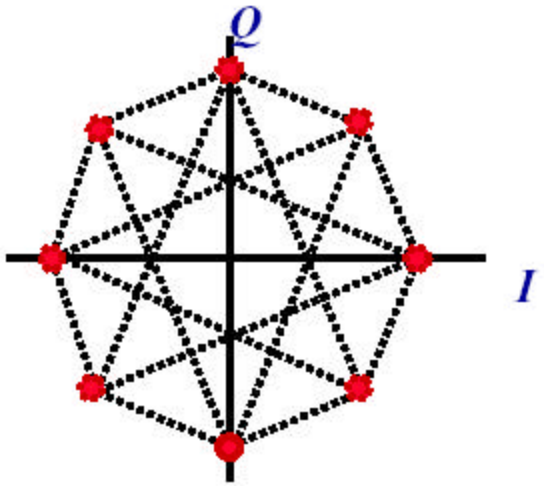
- 6 time slots per 30 kHz channel
- offset-FDD: uplink leads by 1.27 slots



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

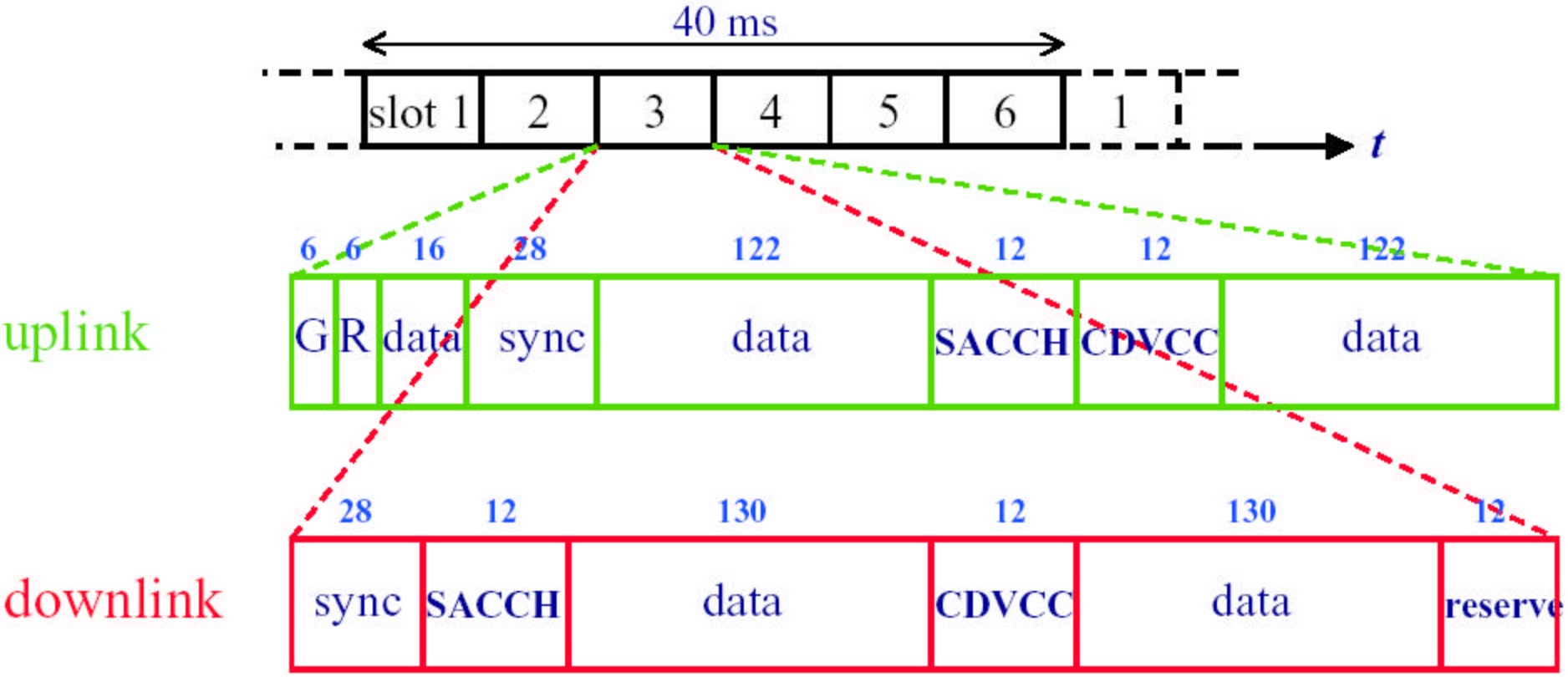


b_k, b_{k-1}	ϕ_k
11	$\pi/4$
01	$3\pi/4$
00	$-3\pi/4$
10	$-\pi/4$

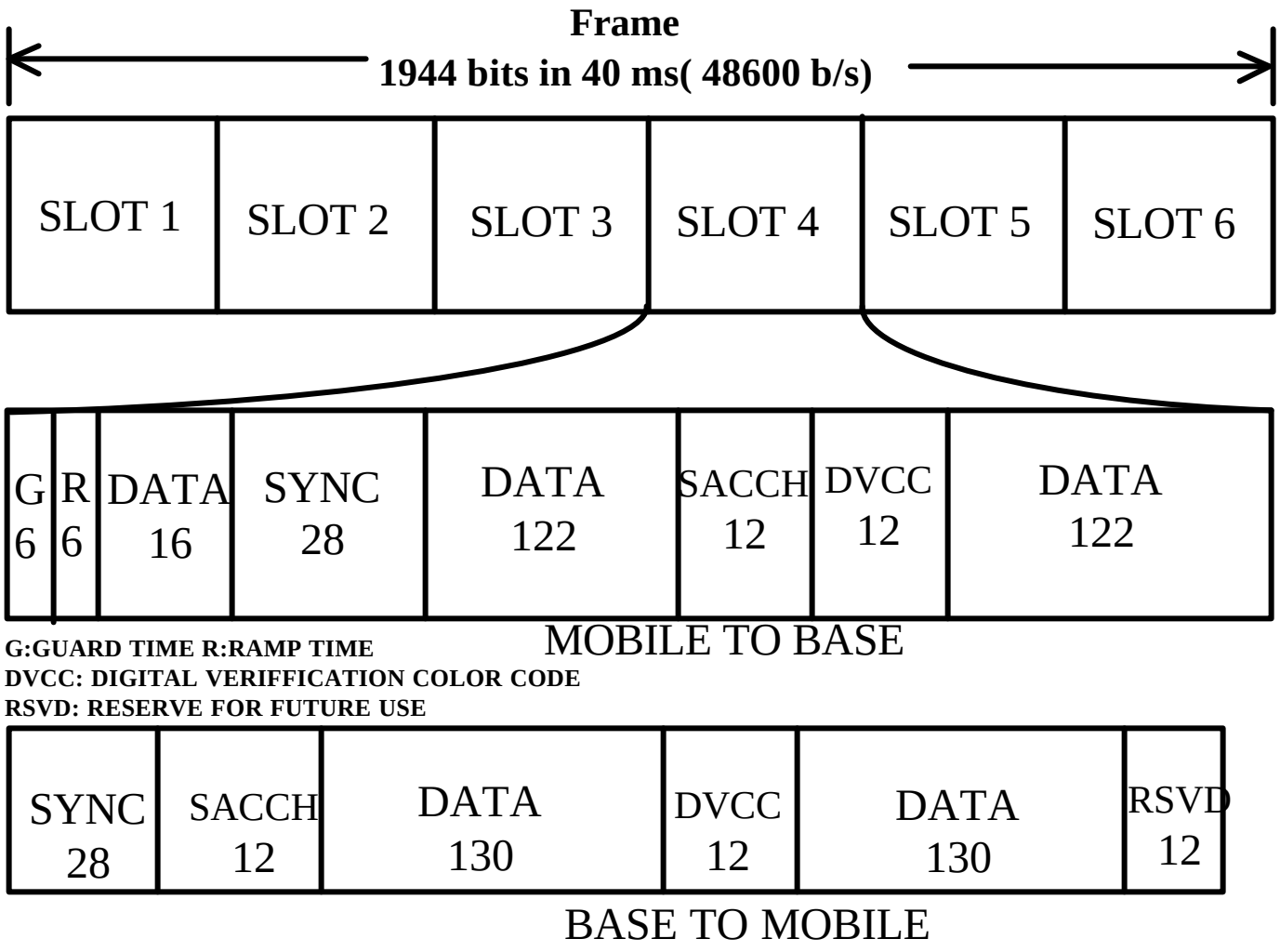
USDC: physical layer

Frame structure and burst format

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



IS-54 slot and frame structure



USDC: physical layer

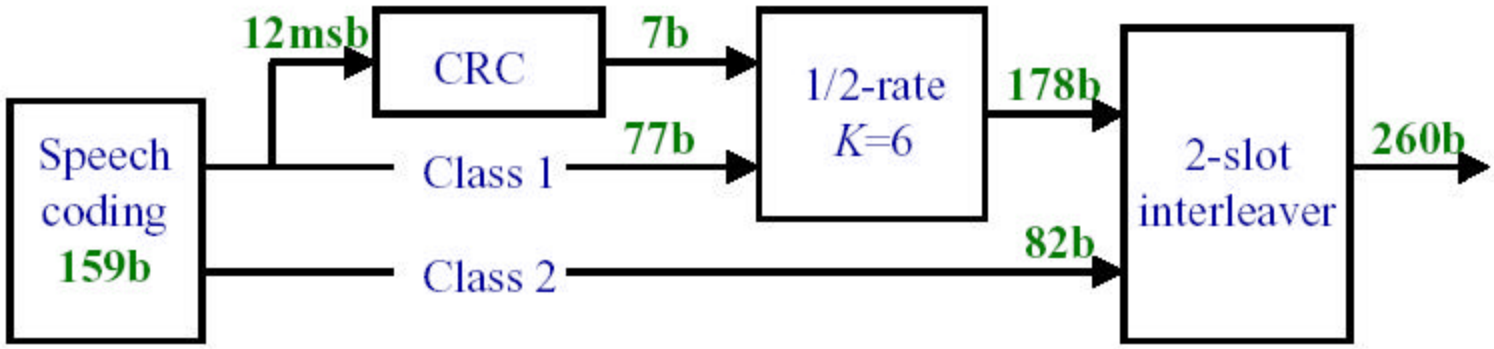
Control fields

- 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

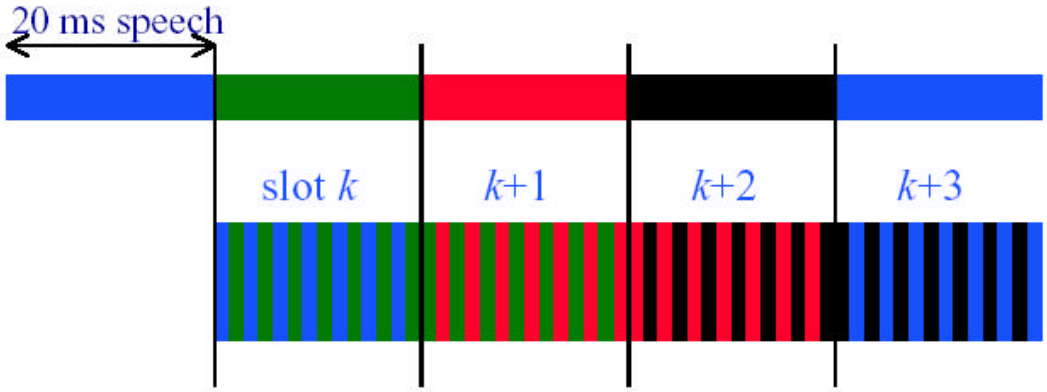
Channel coding

- 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 (Group Speciale Mobile)

Pan European Cellular Standard
Second Generation: **Digital**
Frequency Division Duplex (890-915 MHz Upstream; 935-960 MHz Downstream)
125 frequency carriers

Carrier spacing: 200 Khz
8 channels per carrier (Narrowband Time Division)

Speech coder: linear predictive coding (Source rate = 13 Kbps)

Modulation: phase shift keying (Gaussian minimum shift keying)

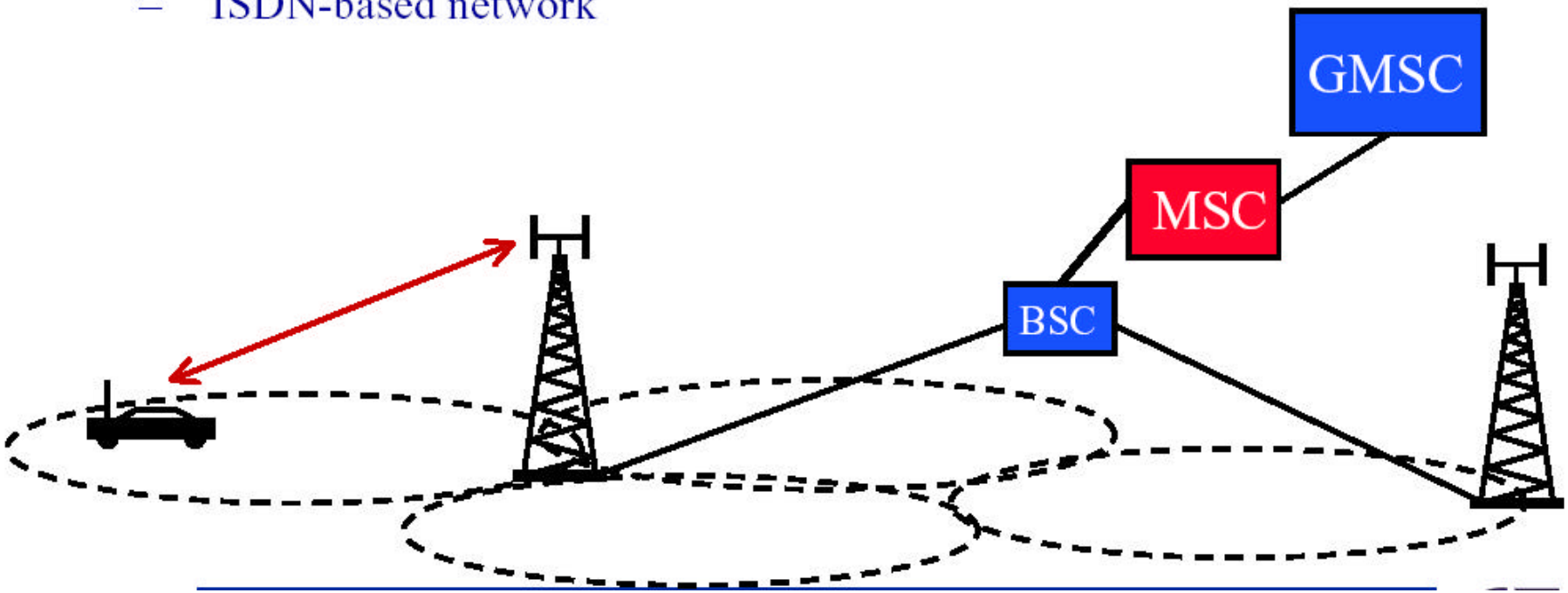
Slow frequency hopping to overcome multipath fading

GSM

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

GSM: architecture

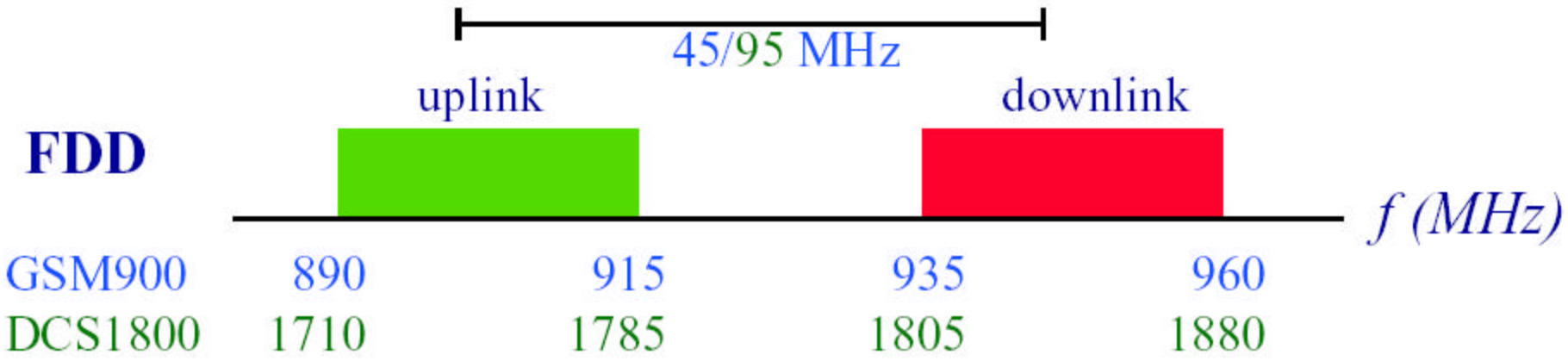
- 3/9 site/sector reuse
- 11 dB C/I
- International Mobile Subscriber Number (IMSI/TMSI)
- International Mobile Equipment Identity (IMEI)
- ISDN-based network



GSM: physical layer

Radio bands

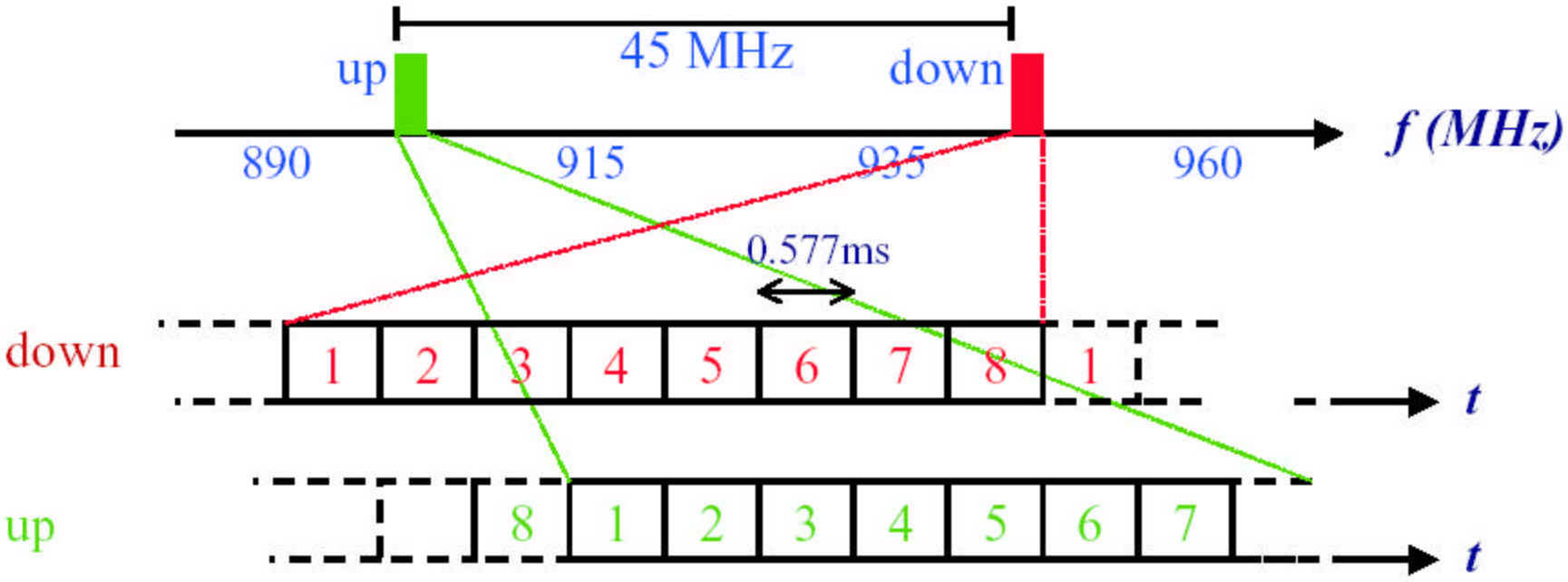
- 125 duplex channels
- channel spacing 200 kHz



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)
  (To combat multipath fading)

GSM: physical layer

Frame structure and burst format

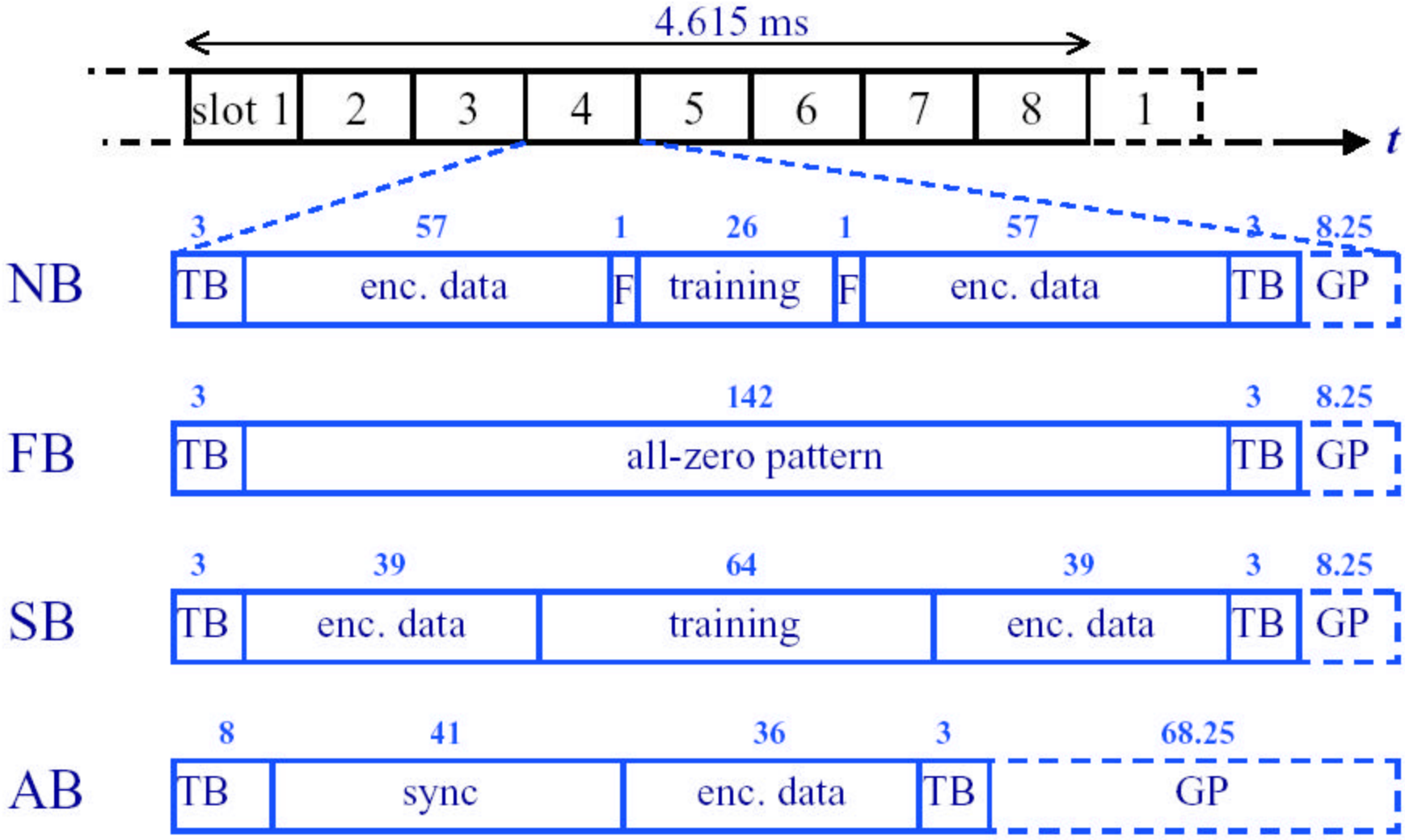
- 8 slots per TDMA frame; 148 bits/slot
- 4.615 ms frame duration (1184 bits); 0.57692 ms slot duration

- four burst types:

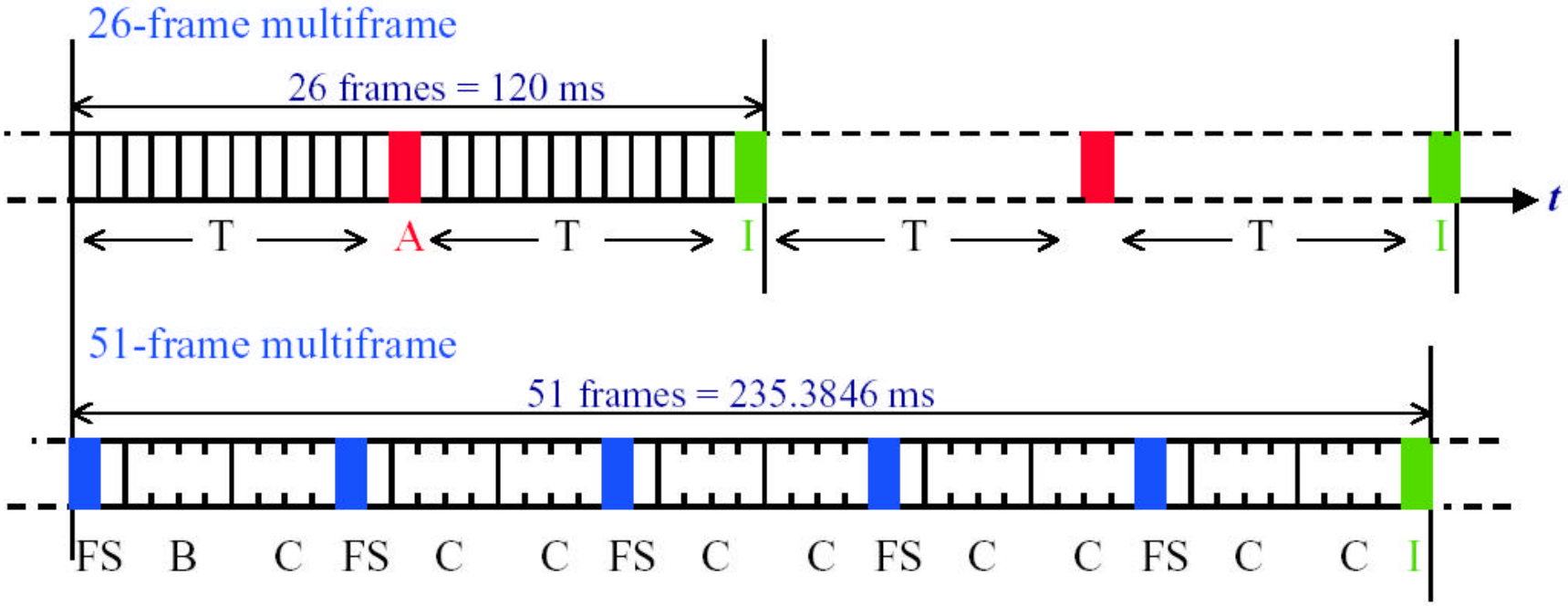
traffic (up- and downlink):	normal burst (NB)
control downlink:	frequency correction burst (FB)
	synchronization burst (SB)
control uplink:	access burst (AB)

GSM: physical layer

Burst formats



GSM: physical layer



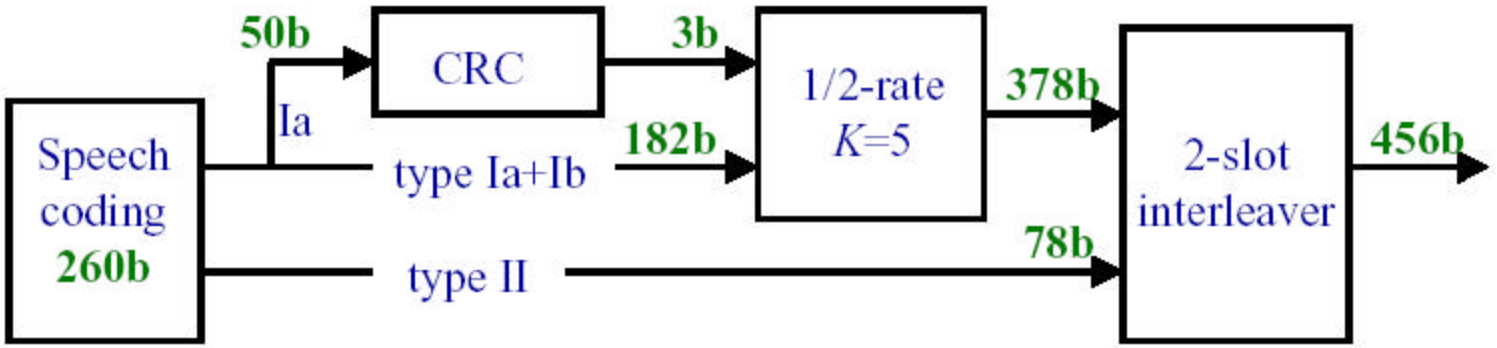
SUPERFRAME: 51×26-frame multiframes = 26×51-frame multiframes = 6.12s

HYPERFRAME: 2048 superframes = 2715648 TDMA frames > 3 hours

GSM: physical layer

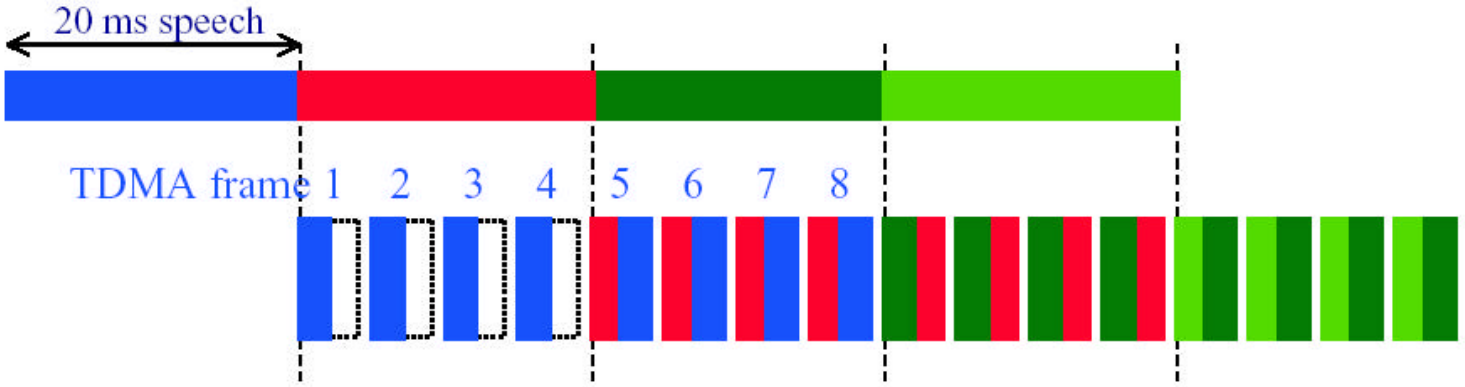
Channel coding

– 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

GSM Signalling channels

BCCH: Broadcast Control Channel

- point-to-multipoint unidirectional control channel broadcasting system information to MS

CCCH: Common Control Channel

up-link:	RACH (Random Access CHannel)
down-link:	PCH (Paging Channel)
	AGCH (Access Grant CHannel)

DCCH: Dedicated Control CHannel

- point-to-point bidirectional control channel
- SACCH (Slow Associated Control CHannel)
- FACCH (Fast Associated Control CHannel)
- SDCCH (Stand Alone Dedicated Control CHannel)

CDMA (Code Division Multiple Access): IS-95 QUALCOMM, San Diego

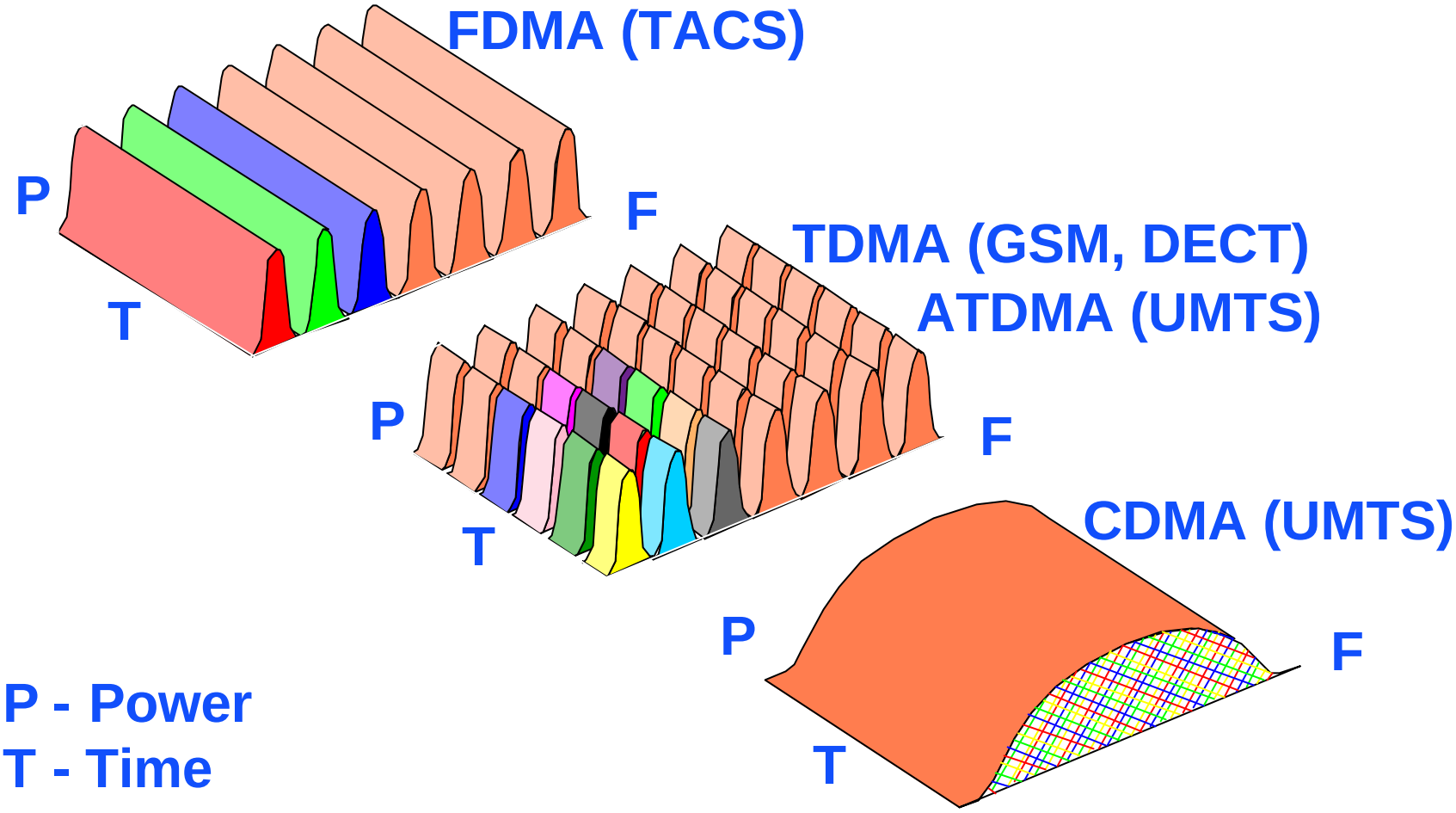
• Based on DS spread spectrum

• Two frequency bands (1.23 Mhz), one for forward channel (cell-site to subscriber) and one for reverse channel (sub to cell-site)

• CDMA allows reuse of same spectrum over all cells. Net capacity improvement:

- 4 to 6 over digital TDMA (eg. GSM)
- 20 over analog FM/FDMA (AMPS)

Access techniques for mobile communications

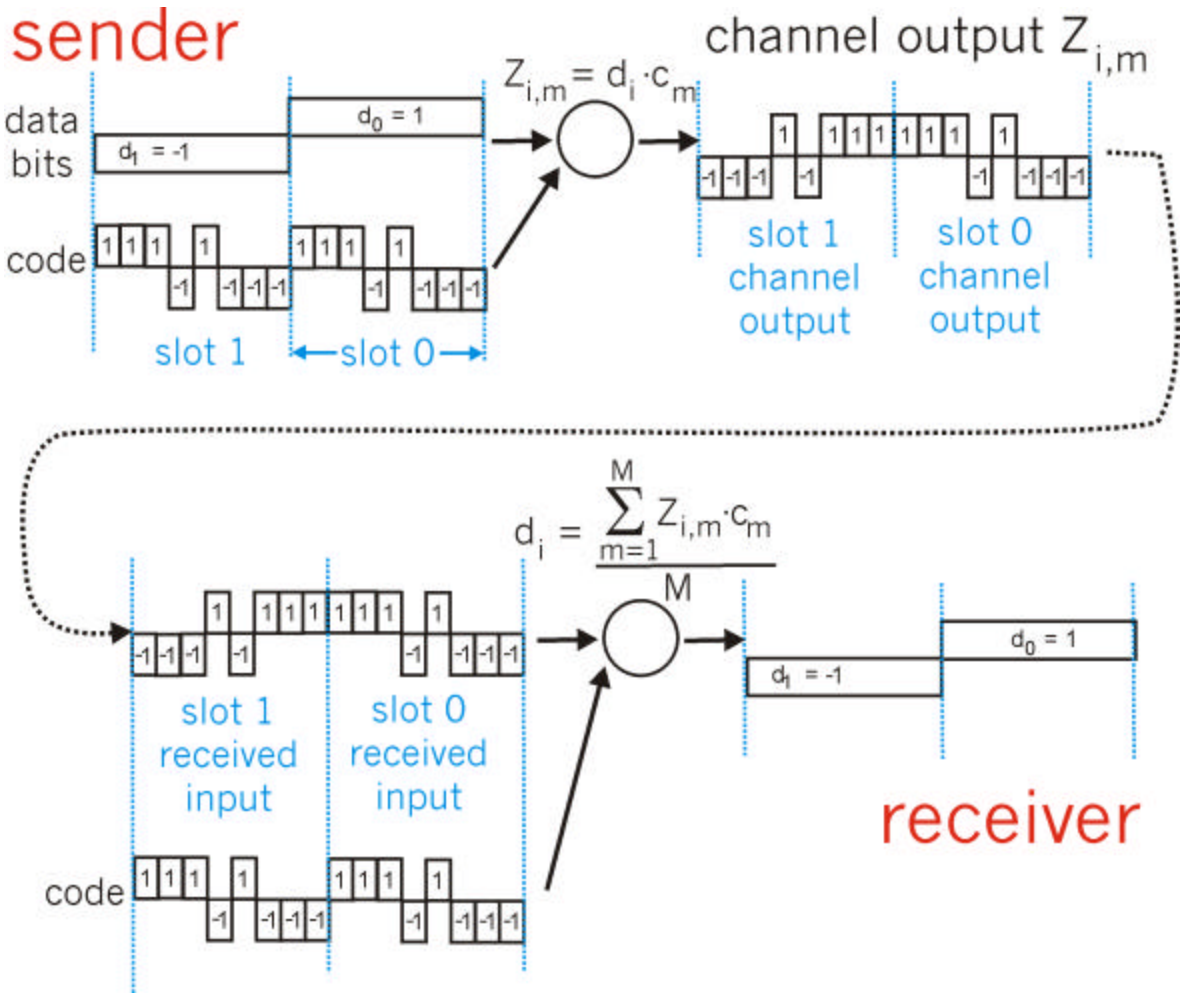


P - Power
T - Time
F - Frequency

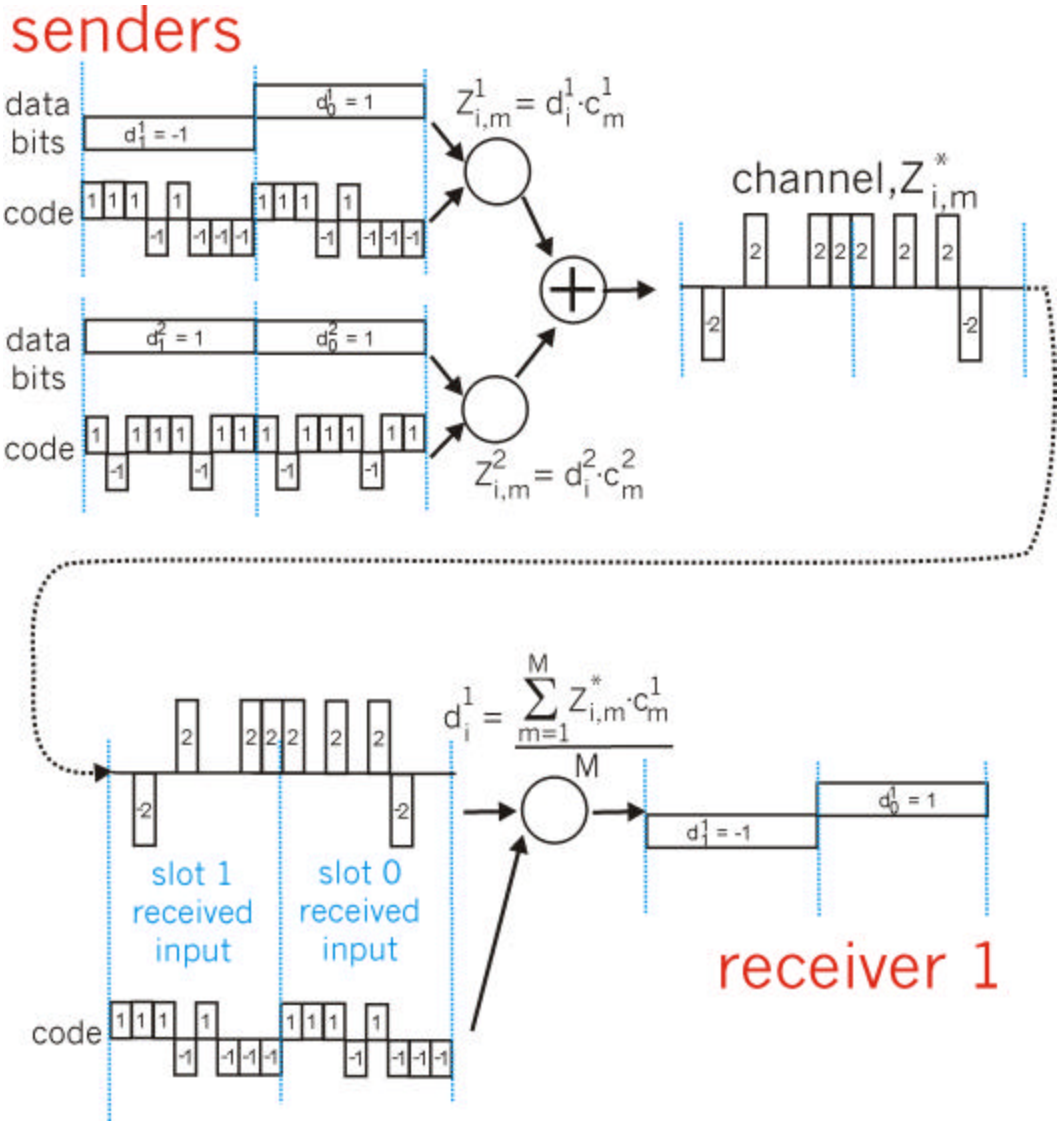
CDMA (Code Division Multiple Access)

- unique “code” assigned to each user; i.e., code set partitioning
- all users share same frequency, but each user has own “chipping” sequence (i.e., code) to encode data
- Note: chipping rate >> data rate (eg, 64 chips per data bit)
- ***encoded signal*** = (original data bit) X (chipping sequence)
- ***decoding:*** inner-product of encoded signal and chipping sequence
- allows multiple users to “coexist” and transmit simultaneously with minimal interference (if codes are “orthogonal”)

CDMA Encode/Decode



CDMA: two-sender interference



CDMA (cont'd)

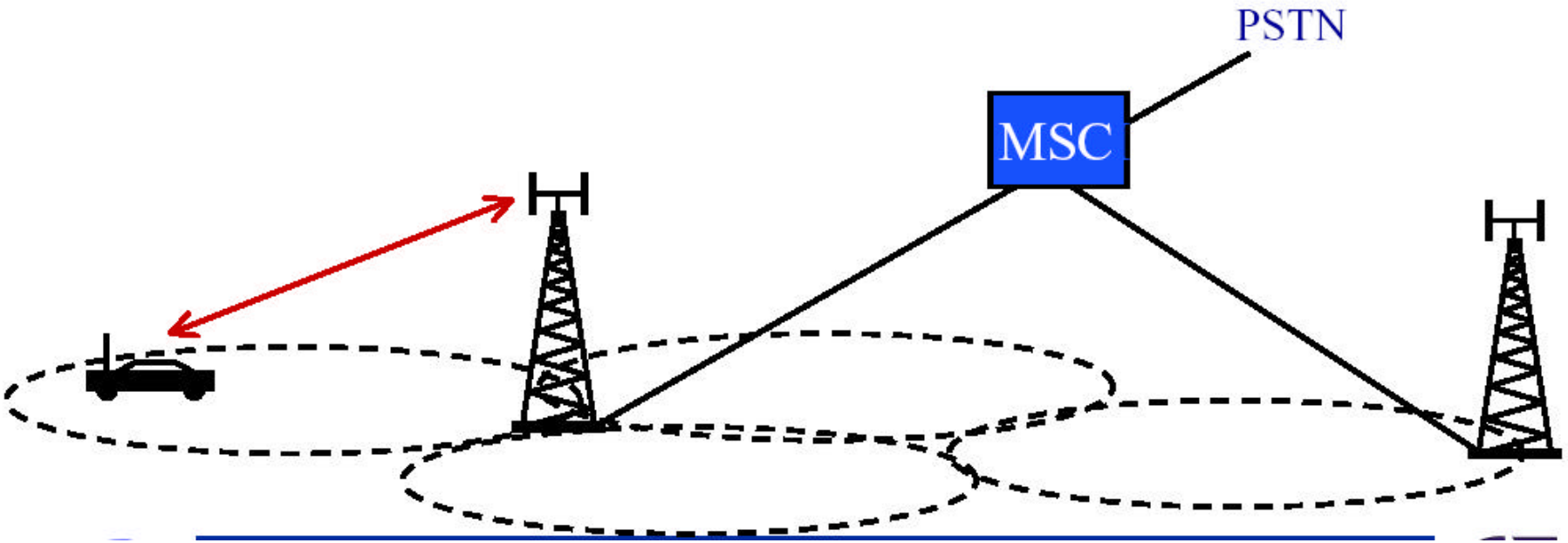
- One of 64 PS (Pseudo Random) codes assigned to subscriber at call set up time
- RAKE receiver (to overcome multi path-fading)
- Pilot tone inserted in forward link for:
  - power control
  - coherent reference
- Speech activity detection
- Voice compression to 8 kbps (16 kbps with FEC)

IS-95

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

IS-95: architecture

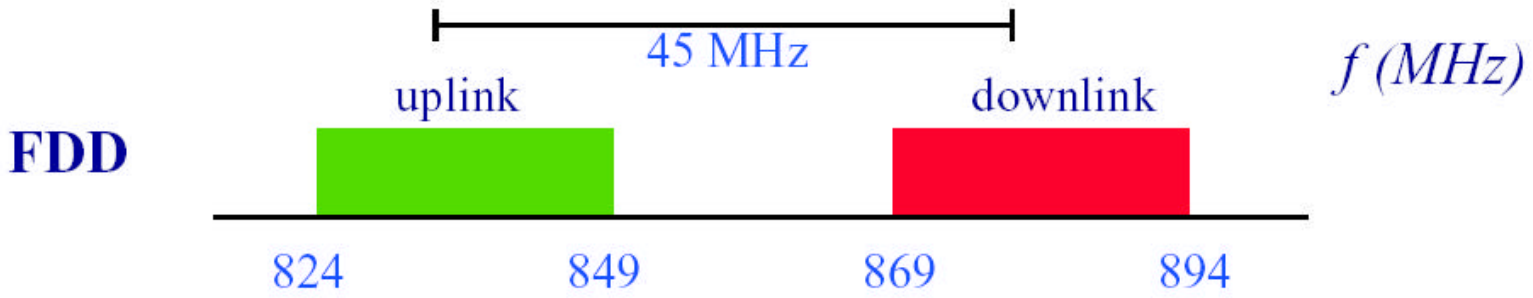
- 1/1 reuse
- Mobile Identity Number (MIN)
- Electronic Serial Number (ESN)
- Network protocol IS-41



IS-95: physical layer

Radio bands

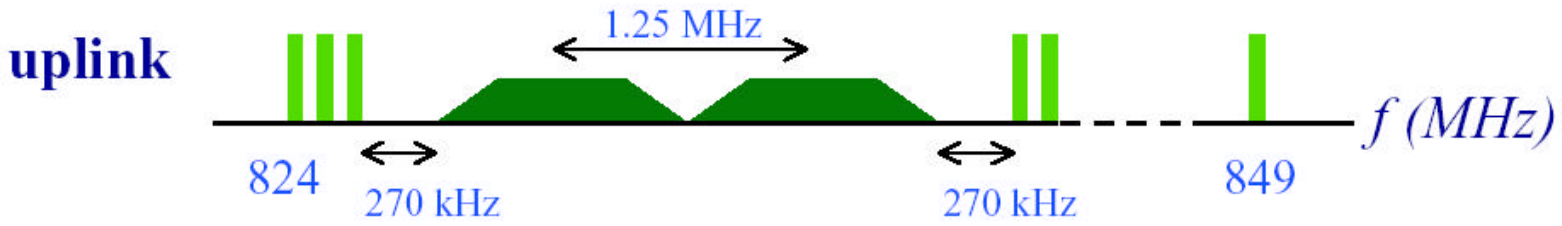
- co-existence with AMPS
- 20 wideband channels
- spreading rate 1.2288 Mc/s
- channel spacing 1.25 MHz



IS-95: physical layer

Radio bands

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



IS-95: physical layer

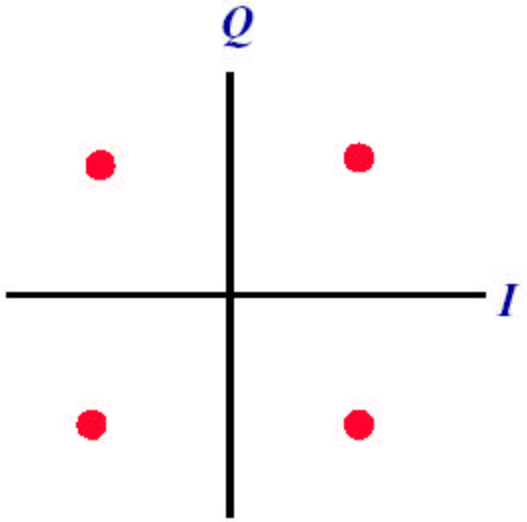
Downlink spreading

- **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

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