Chapter 17
Wireless Networks

17.1 Wireless Networks

- **Cell**: Geographical division unit of wireless networks.
- **Access Point**: Gateway to the network for mobile phones in a cell to contacts.
- Levels of cells in hierarchical cellular network:
  - **picocell**: Each covers up to 100 meters, useful for wireless/cordless applications and devices (e.g. PDAs) in an office or home.
  - **microcell**: Each covers up to 1,000 meters in cities or local areas, e.g. radio access pay-phones on the streets.
  - **cell**: Each has up to 10,000 meters coverage, good for national or continental networks.
  - **macrocell**: World-wide coverage, e.g. satellite phones.

Analog Wireless Networks

- 1G cellular phones used analog technology and FDMA.
  - **AMPS** (Advanced Mobile Phone System) in North America, operating at 800-900 MHz frequency band.
    a) Each of the two-way communication is allocated 25 MHz with *(MS Transmit)* in the band of 824 to 849 MHz and *(BS Transmit)* in the band of 869 to 894 MHz.
    b) Each of the 25 MHz band is then divided up for two Operator bands, A and B, giving each 12.5 MHz.
    c) FDMA further divides each of the 12.5 MHz operator bands into 416 channels – each channel having a bandwidth of 30 KHz.
  - **TACS** (Total Access Communication System) and **NMT** (Nordic Mobile Telephony) were similar standards in Europe and Asia.

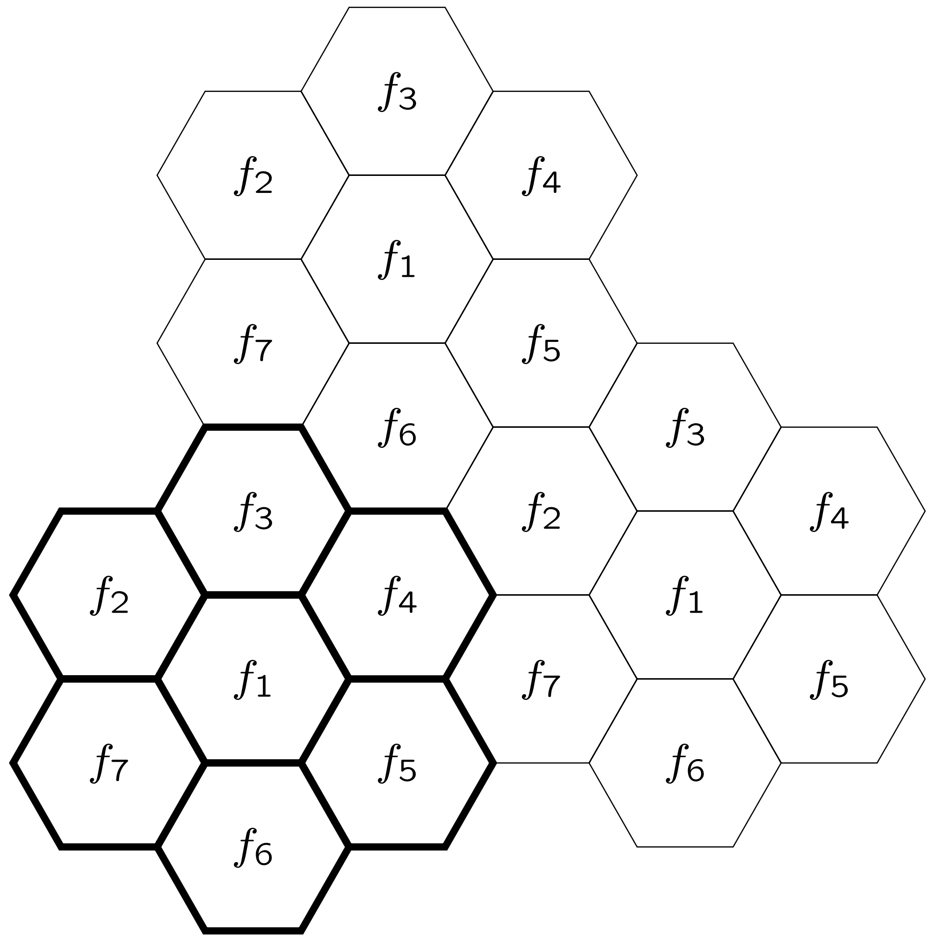

Fig 17.1: A possible geometric layout for an FDMA cellular system

A layout for FDMA cellular system (Fig. 17.1)

- Each cell in the seven-cell cluster is assigned a unique set of frequency channels, the interference from neighboring cells is negligible.
- The same set of frequency channels (denoted as f_1 to f_7) will be reused once in each cluster.

  The so called *reuse factor* is $K = 7$.
- In an AMPS system, for example, the maximum number of channels (including control channels) available in each cell is reduced to $416/7 \approx 59$.

Digital Wireless Networks

- 2G wireless networks use digital technology.
- In North America, the digital cellular networks adopted two competing technologies in 1993:
  - **TDMA** (Time Division Multiple Access).
  - **CDMA** (Code Division Multiple Access).
- In Europe and Asia:
  - **GSM** (Global System for Mobile communications), which used TDMA, was introduced in 1992.

TDMA and GSM

- TDMA creates multiple channels in multiple time slots while allowing them to share the same carrier frequency.

- GSM was established by CEPT, a standard for a mobile communication network throughout Europe:
  - GSM 900: operate in the 900 MHz frequency range.
  - GSM 1800: the original GSM standard modified to operate at the 1.8 GHz frequency range.

- In North America:
  - **GSM 1900**: GSM network uses frequencies at the range of 1.9 GHz.
  - TIA/EIA **IS-54B** and the **IS-136** standards – the most predominant use of TDMA technology.
  - IS-136, superseding IS-54B, operates in the frequencies of 800 MHz and 1.9 GHz (the PCS frequency range).

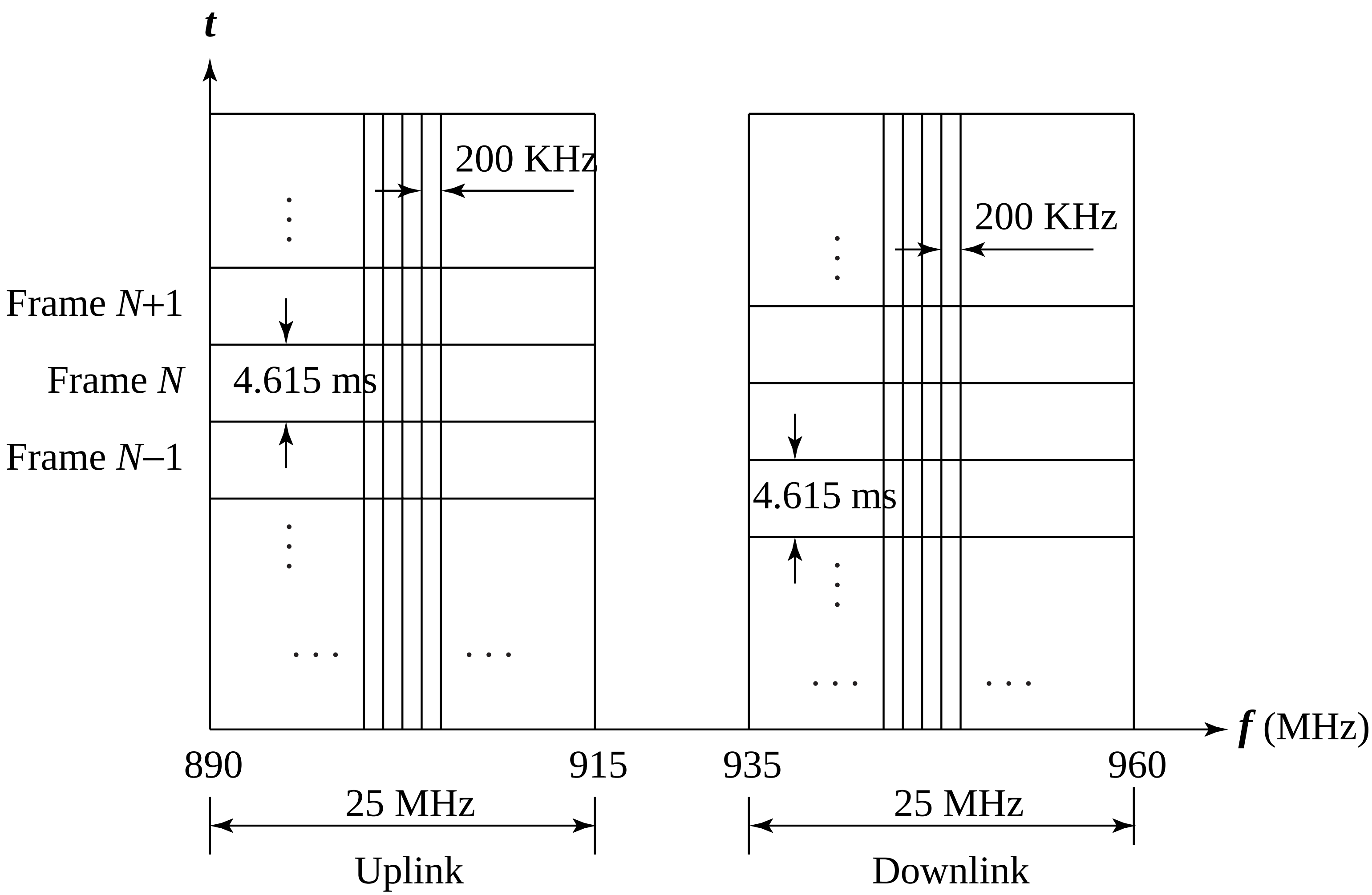

Fig. 17.2: Frequency and Time Divisions in GSM.

Spread Spectrum and CDMA

- **Spread spectrum**: A technology in which the bandwidth of a signal is spread before transmission.
  - Distinct advantages of being secure and robust against intentional interference (jamming).
  - Applicable to digital as well as analog signals because both can be modulated and "spread".
  - It is the digital applications in particular CDMA that made the technology popular in various wireless data networks.
  - Two ways of implementing spread spectrum: *frequency hopping* and *direct sequence*.

Frequency Hopping

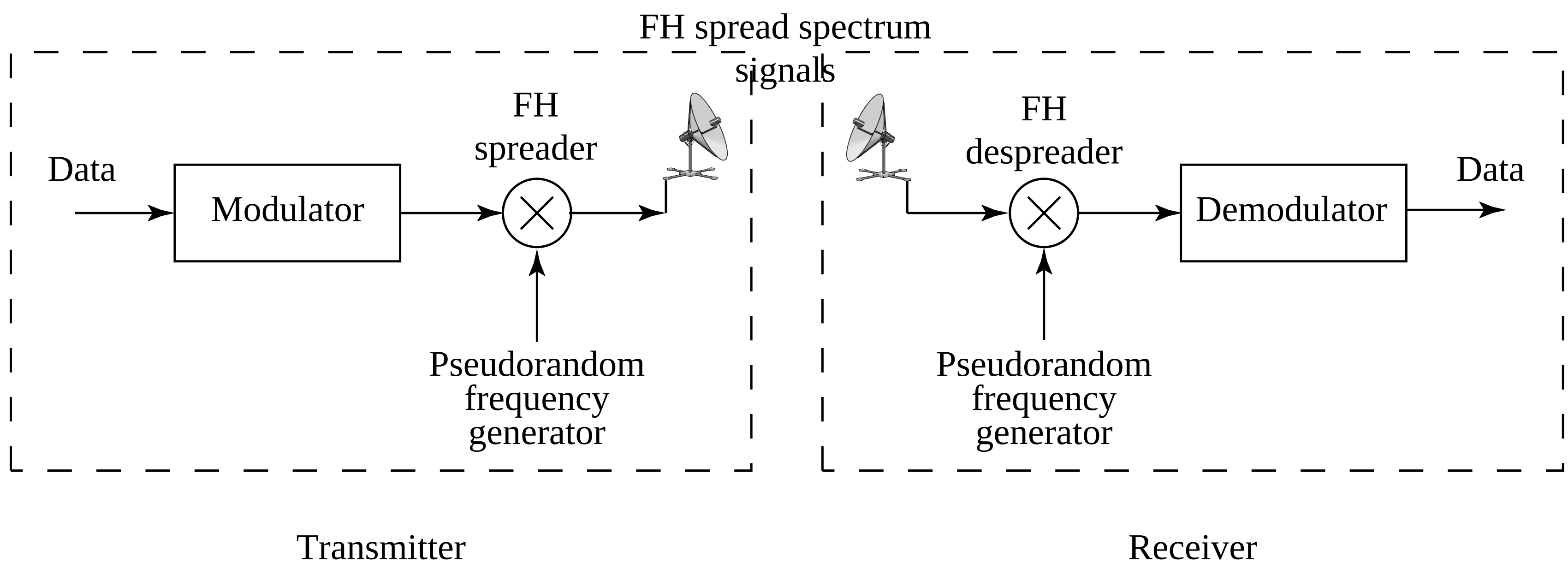

Fig 17.3: Transmitter and Receiver of Frequency Hopping (FH) Spread Spectrum.

Frequency Hopping (Cont'd)

- At the Frequency-Hopping (FH) Spreader, f_r is modulated by the baseband signal to generate the Spread Spectrum Signal:

$$f_c = f_r + f_b \tag{17.1}$$

  Since f_r changes randomly in the wideband, f_c of the resulting signal is "hopping" in the wideband accordingly.

- At the Receiver side, the process is reversed.
  - As long as the same pseudo-random frequency generator is used, the signal is guaranteed to be properly despread and demodulated.

- Although the FH method uses a wideband spread spectrum, at any given moment during the transmission the FH signal only occupies a small portion of the band, i.e. B_b.

Direct Sequence

- A major breakthrough in wireless technology is the development and adoption of **CDMA** — its foundation is *Direct Sequence (DS)*.

- Multiple CDMA Users can make use of the same (and full) bandwidth of the shared wideband channel during the entire period of transmission.

- Reuse factor is $K = 1$ — it has the potential of greatly increasing the maximum number of users as long as the interference from the multiple users is manageable.

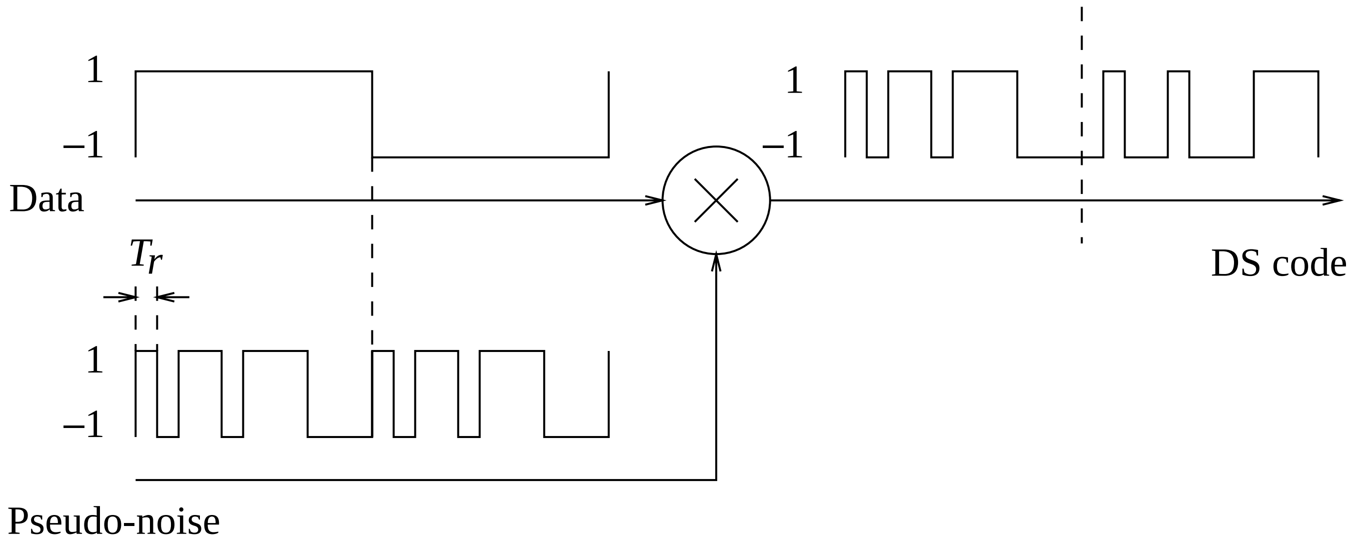

Fig. 17.4: Spreading in Direct Sequence (DS) Spread Spectrum.

- For each CDMA transmitter a unique pseudo-noise sequence is fed to the Direct Sequence (DS) Spreader.
- The pseudo-noise (also called *chip code* or *spreading code*) consists of a stream of narrow pulses called *chips* with a bit width of T_r.

Direct Sequence (Cont'd)

- The spreading code is multiplied with the input data.
- When the data bit is 1 the output DS code is identical to the spreading code, and when the data bit is -1 the output DS code is the inverted spreading code.
- As a result, the spectrum of the original narrowband data is spread, and the bandwidth of the DS signal is:

$$B_{DS} = B_r \tag{17.2}$$

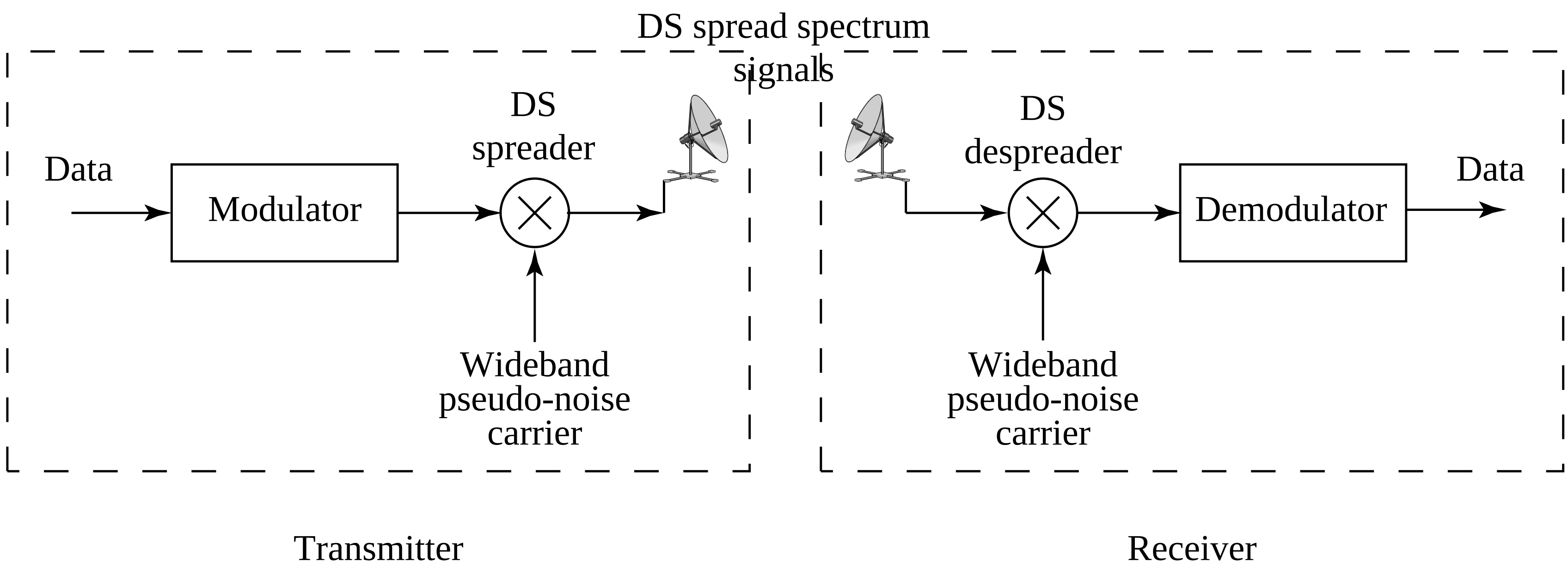

Fig 17.5: Transmitter and Receiver of Direct Sequence (DS) Spread Spectrum.

Direct Sequence (Cont'd)

- The despreading process involves the multiplication of the DS code and the spreading sequence.
- Fig. 17.5 shows the implementation of the transmitter and receiver for the DS spread spectrum.
- Two ways to implement CDMA multiple access:
  - Orthogonal Codes: the spreading codes in a cell are orthogonal to each other.
  - Non-orthogonal codes: Pseudo-random Noise (PN) sequences.

Analysis of CDMA

- **CDMA** — allows users in the same channel to share the entire channel bandwidth:
  - As long as an adequate level of SNR is maintained, the quality of the CDMA reception is guaranteed.
  - The interference to the source signal received at the base station is:

$$N = N_T + \sum_{i=1}^{M-1} P_i$$

N_T − thermal noise of the receiver,

P_i − received signal power of each user,

M − maximum number of users in a cell

  - If we assume that the thermal noise N_T is negligible and the received P_i from each user is the same, then:

$$N = (M-1)P_i \tag{17.3}$$

Analysis of CDMA (Cont'd)

– The received signal energy per bit E_b is the ratio of P_i over the date rate R (bps)

$$E_b = P_i/R \tag{17.4}$$

– The interference N_b is

$$N_b = N/W = (M-1)P_i/W \tag{17.5}$$

W (Hz) – bandwidth of the CDMA wideband signal carrier

– The signal-to-noise ratio (SNR) is thus

$$E_b/N_b = \frac{P_i/R}{(M-1)P_i/W} = \frac{W/R}{M-1} \tag{17.6}$$

Rewriting Eq.(17.6), we have

$$M - 1 = \frac{W/R}{E_b/N_b}$$

Analysis of CDMA (Cont'd)

or approximately,

$$M \approx \frac{W/R}{E_b/N_b} \tag{17.7}$$

- Equation (9) states that the capacity of the CDMA system, i.e., maximum number of users in a cell, is determined by two factors: W/R and E_b/N_b.
  - W/R – ratio between CDMA bandwidth W and user's data rate R:
    - This is the **bandwidth spreading factor** or the **processing gain**.
    - Note this is equivalent to the number of chips in the spreading sequence. Typically, it can be in the range 10^2 to 10^7.
  - E_b/N_b is the bit-level SNR:
    - Depending on the QoS and the implementation, a digital demodulator can usually work well with a bit-level SNR in the range 3 to 9 dB.

3G Digital Wireless Networks

- **Third generation (3G)** wireless services feature various multimedia services such as (low rate) video over the Internet:
  - Applications include wireless web-surfing, video mail, continuous media on demand, mobile multimedia, mobile e-commerce, remote medical service, etc.
  - 3G is mostly for public networks, while the current WLAN (Wireless LAN) is by and large for private networks.
  - An intermediate step that is easier and cheaper to achieve called 2.5G – associated with enhanced data rates and packet data services.
  - Table 17.1 summarizes the 2G, 2.5G and 3G standards that have been (or will be) developed using the IS-41 core networks (in North America) and GSM MAP core networks (in Europe, etc).

Table 17.1: Evolution from 2G to 3G Wireless Networks

	ANSI-41 Core Network	**Peak Data Rate R**	**Carrier Spectrum W**
2G	cdmaOne (IS-95A)	14.4 kbps	1.25 MHz
2.5G	cdmaOne (IS-95B)	115 kbps	1.25 MHz
3G	cdma2000 1X	307 kbps	1.25 MHz
3G	cdma2000 1xEV-DO	2.4 Mbps	1.25 MHz
3G	cdma2000 1xEV-DV	4.8 Mbps	1.25 MHz
3G	cdma2000 3X	$>$ 2 Mbps	5 MHz

	GSM MAP Core Network	**Peak Data Rate R**	**Carrier Spectrum W**
2G	GSM (TDMA)	14.4 kbps	1.25 MHz
2.5G	GPRS (TDMA)	170 kbps	1.25 MHz
3G	EDGE (TDMA)	384 kbps	1.25 MHz
3G	WCDMA	2 Mbps	5 MHz

The IS-95 Evolution

- **IS-95A** and **IS-95B**, now known as *cdmaOne*, are based on the IS-41 core network and use narrowband CDMA air interface:
  - IS-95A (2G) has only circuit switched channels with data rates up to 14.4 kbps.
  - IS-95B (2.5G) supports packet switching and achieves maximum rates of 115 kbps.
- IMT-2000 MC mode, originally called cdma2000 can operate in all bands of the IMT spectrum (450, 700, 800, 900, 1700, 1800, 1900, and 2100 MHz).
- The cdma2000 deployment is divided into four stages, each stage is backwards compatible with previous stages and cdmaOne.

Four Stages of cdma2000 Deployment

- cdma2000 1X (or 1X RTT) specification, delivers enhanced services up to 307 kbps peak rate and 144 kbps on the average – twice to three times the data capacity of IS-95B.

- The cdma2000 1xEV (EV for EVolution) is split into two phases:

  1. 1xEV-DO (Data Only), supporting data transmission only at rates up to 2.4 Mbps.
  2. 1xEV-DV (Data and Voice),promises an even higher data rate up to 4.8 Mbps.

- IMT-2000 – referred to as cdma2000 3X (or 3X RTT) since it uses a carrier spectrum of 5 MHz (3 × 1.25 MHz channels) to deliver a peak rate of at least 2-4 Mbps.

The GSM Evolution

- The **GSM** Radio Access Network (RAN) uses the GSM MAP core network, and the IMT-2000 DS and TDD modes are based on the WCDMA technology that is developed for the GSM MAP network:
  - GSM is TDMA-based and hence is less compatible with the WCDMA technology than IS-95.
  - GSM is a 2G network providing only circuit switched communication. A 2.5G enhancement is **GPRS** (General Packet Radio Service) that supports packet switching and higher date rates.

The GSM Evolution (Cont'd)

- EDGE [(Enhanced Data rates for Global Evolution) or (Enhanced Data GSM Environment)] supports up to triple the data rate of GSM and GPRS.
  - EDGE is still a TDMA-based standard, defined mainly for GSM evolution to WCDMA.
  - EDGE is defined in IMT-2000 as UWC-136 for Single Carrier Mode (IMT-SC) – a 3G solution.
  - EDGE can achieve a data rate up to 384 kbps by new modulation and radio techniques so as to optimize the use of available spectrum.

Differences in WCDMA from a Narrowband CDMA

- To support bit-rates up to 2 Mbps, the WCDMA channel bandwidth is 5 MHz as opposed to 1.25 MHz for IS-95 and other earlier standards.

- To effectively use the 5 MHz bandwidth, the chip rate specified is 3.84 Mcps, as opposed to 1.2288 Mcps for IS-95.

- WCDMA supports variable bit-rates from 8 kbps up to 2 Mbps.

- WCDMA base stations use Asynchronous CDMA with Gold codes, this eliminates the need for a GPS in the base station for global time synchronization as in IS-95 systems.

Wireless LAN (WLAN)

- **IEEE 802.11**: the earlier standard for WLAN developed by the IEEE 802.11 Working Group:
  - It specified MAC (Medium Access Control) and PHY (Physical) layers for wireless connectivity in a local area within a radius of several hundred feet.
  - For PHY, both Frequency Hopping (FH) Spread Spectrum and Direct Sequence (DS) Spread Spectrum were supported.
  - The ISM frequency band used was 2.4 GHz, and (diffused) infrared light was also supported for indoor communications in the range of 10-20 meters.
- The basic access method of 802.11 is *CSMA/CA (Carrier Sense Multiple Access with Collision Avoidance)*. The data rates supported by 802.11 were 1 Mbps and 2 Mbps.

Wireless LAN (WLAN) (Cont'd)

- The 802.11 standards also address the following important issues:
  - Security — since WLAN is even more susceptible to break-ins, *authentication* and *encryption* are enhanced.
  - Power management — so power will be saved during no transmission, and *doze* and *awake* will be handled.
  - Roaming — so the basic message format will be accepted by different access points.

IEEE 802.11b

- **802.11b**: an enhancement of 802.11, still uses DS Spread Spectrum and operates in the 2.4 GHz band.
  - Supports 5.5 and 11 Mbps in addition to the original 1 and 2 Mbps, and its functionality is comparable to Ethernet.
  - In North America, for example, the allocated spectrum for 802.11 and 802.11b is 2.400-2.4835 GHz.
  - Regardless of the data rate (1, 2, 5.5 or 11 Mbps), the bandwidth of a DS Spread Spectrum channel is 20 MHz.
  - Three non-overlapped DS channels can be accommodated simultaneously, thus allowing a maximum of 3 access points in a local area.

IEEE 802.11a

- **IEEE 802.11a** operates in the 5 GHz band and it supports data rates in the range of 6 to 54 Mbps:
  - Uses *Orthogonal Frequency Division Multiplexing (OFDM)*.
  - Allows 12 non-overlapping channels, hence a maximum of 12 access points in a local area.
  - Operates in the higher frequency (5 GHz) band, it faces much less Radio Frequency (RF) interference.
  - Coupled with the higher data rate, it has a great potential of supporting various multimedia applications in a LAN environment.
- HIPERLAN/2 (High Performance Radio LAN) is the European sibling of IEEE 802.11a:
  - Also operates in the 5 GHz band and is promised to deliver a data rate of up to 54 Mbps

IEEE 802.11g and Others

- **IEEE 802.11g**: an extension of 802.11b, attempt to achieve data rates up to 54 Mbps in the 2.4 GHz band
  As in 802.11a, OFDM instead of DS Spread Spectrum will be used.

- 802.11g still suffers from higher RF interference than does 802.11a, and as in 802.11b, has the limitation of 3 access points in a local area.

- IEEE 802.11g is designed to be downward compatible with 802.11b, which actually brings a significant overhead for all 802.11b and 802.11g users on the 802.11g network.

- Another half dozen 802.11 standards are being developed that deal with various aspects of WLAN. Notably, 802.11e deals with MAC enhancement for QoS, especially prioritized transmission for voice and video.

Bluetooth

- **Bluetooth**: a new protocol intended for short-range (piconet) wireless communications.
  - Can be used to replace cables connecting mobile and/or fixed computers and devices.
  - Uses FH spread spectrum at the 2.4 GHz ISM band and full-duplex signal which hops among 79 frequencies at 1 MHz intervals and at a rate of 1,600 hops/sec.
  - Supports both circuit switching and packet switching.
  - Supports up to three voice channels (each 64 kbps symmetric) and more than one data channel (each over 400 kbps symmetric).

Bluetooth (Cont'd)

- WAP (Wireless Application Protocol) in the Bluetooth environment:
  - In the "Briefcase trick", for example, the user's mobile phone will communicate with his/her laptop periodically so e-mail can be reviewed from the handheld-phone without opening the briefcase.
  - Some new Sony camcorders already have a built-in Bluetooth interface so moving or still pictures can be sent to a PC or to the web directly (without a PC) through a mobile phone equipped with Bluetooth at a speed of over 700 kbps within a distance of 10 meters.

17.2 Radio Propagation Models

- **Multipath fading models** are available for small-scale fading channels and **path loss models** are available for long-range atmospheric attenuation channels.

- For indoor channels, Multipath fading is the main factor for signal degradation — each path having its own attenuation, phase delay and time delay.

- For outdoors, long-range communication is dominated by atmospheric attenuation:
  - Radio waves can penetrate the ionosphere ($>$ 3 GHz) and establish a Line Of Sight (LOS) communication.
  - For lower frequencies reflect off it and off the ground, or travel along it to the receiver.
  - At frequencies over 3 GHz though (which are necessary for satellite transmissions to penetrate the ionosphere) there are gaseous attenuations, primarily influenced by oxygen and water (vapor and rain).

Multipath Fading

- For narrowband signals, the most popular models are **Rayleigh fading** and **Rician fading**.

- The Rayleigh model assumes an infinite number of signal paths with no Line Of Sight (LOS) to the receiver for modeling the probability density function P_r of received signal amplitude r:

$$P_r(r) = \frac{r}{\sigma^2} \cdot e^{\frac{-r^2}{2\sigma^2}} \tag{17.9}$$

  where σ is the standard deviation of the probability density function

- Rayleigh model does provide a good approximation when the number of paths is over 5

Multipath Fading (Cont'd)

- A more general model that assumes a LOS is the Rician model:
  - K is the factor by which the LOS signal is greater than the other paths, The Rician probability density function P_c is:

$$P_c(r) = \frac{r}{\sigma^2} \cdot e^{\frac{-r^2}{2\sigma^2} - K} \cdot I_o\left(\frac{r}{\sigma}\sqrt{2K}\right), \quad \text{where } K = \frac{s^2}{2\sigma^2} \quad (17.10)$$

  - r and σ are the signal amplitude and standard deviation respectively, and s is the LOS signal power. I_o is a modified Bessel function of the first kind with 0 order

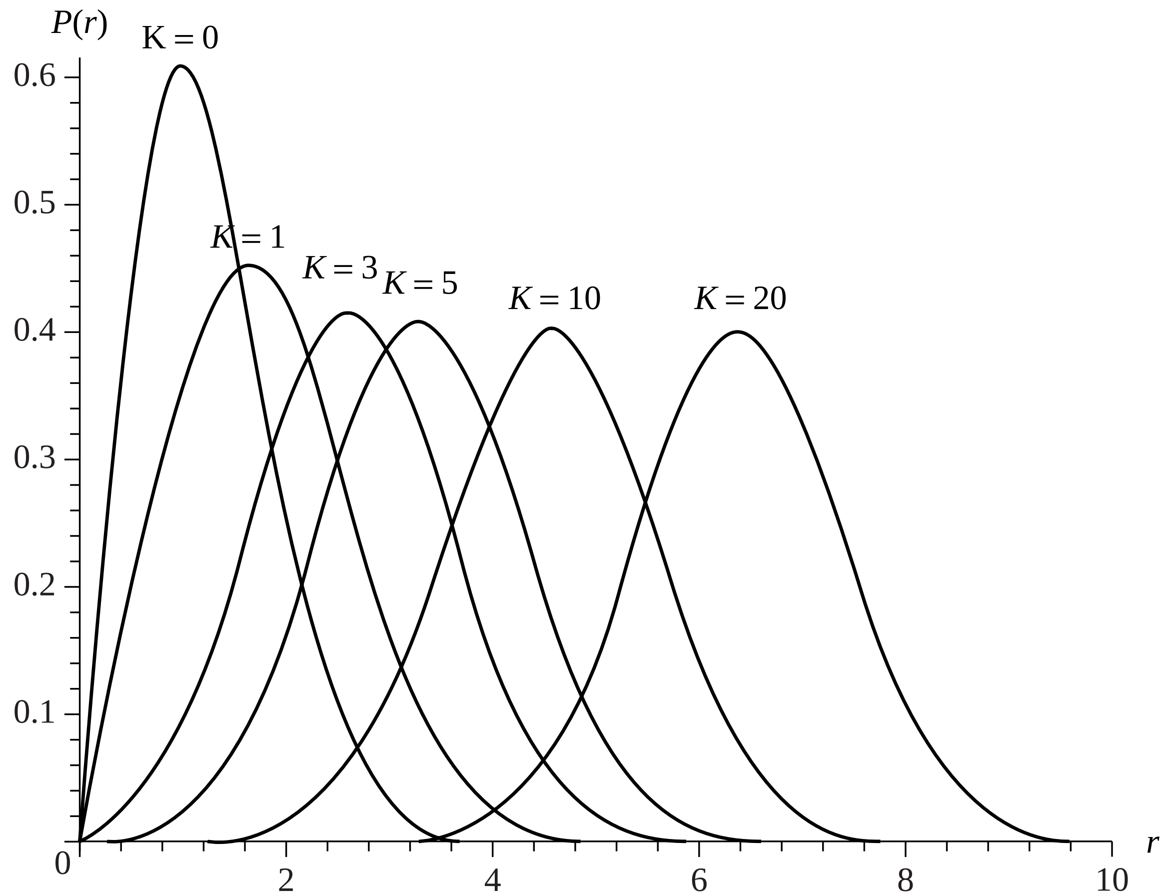

Fig. 17.6: Rician PDF plot with K-factor = 0, 1, 3, 5, 10, 20.

Wideband Signal Fading Paths

- Wideband signal fading paths are more empirically driven:
  - One way is to model the amplitude as a summation over all the paths, each having randomized fading.
  - The number of paths can be 7 for a closed room environment (6 walls and LOS), or a larger number for other environments.
  - An alternative technique of modeling the channel fading is by measuring the channel impulse response.
- A similar technique is utilized in CDMA systems and added to WCDMA:
  - A CDMA station (both mobile and base station) has *Rake Receivers* which are multiple CDMA radio receivers tuned to signals with different phase and amplitude.
  - The signal at each Rake receiver is added up to achieve better SNR.
  - CDMA systems have a special *Pilot channel* that sends a well-known Pilot signal, and the Rake receivers are adjusted to recognize that symbol on each fading path.

Path Loss

- For long range communication the signal loss is dominated by attenuation
- The free space attenuation model for LOS transmission is given by the Friis radiation equation

$$S_r = \frac{S_t G_t G_r \lambda^2}{(4\pi^2) d^2 L} \tag{17.11}$$

S_r and S_t – received and transmitted signal power
G_r and G_t – antenna gain factors
λ – signal wavelength
L – receiver loss

Path Loss (Cont'd)

- It can be shown, however, that if we assume ground reflection, the attenuation increases to be inversely proportional to d^4

- Hata model: the basic form of the path loss equation in dB is given by:

$$L = A + B \cdot log_{10}(d) + C \tag{17.12}$$

A – a function of the frequency and antenna heights
B – an environment function
C – a function depending on the carrier frequency
d – the distance from the transmitter to the receiver

17.3 Multimedia over Wireless Networks

- Mainly concerned with sending video robustly over wireless channels, e.g., for a video conferencing.

- Since wireless data transmissions incur the most data loss and distortion, error resilience and error correction become primary concerns.

- Characteristics of wireless handheld devices worth keeping in mind when designing multimedia transmission:

  1. Both the handheld size and battery life limit the processing power and memory of the device – low complexity in encoding and decoding.
  2. Due to memory constraints and other reasons, real-time communication will likely be required.
  3. Wireless channels have much more interference than wired channels – error resilient coding is very important.

3GPP QoS Requirements for Multimedia Transmission

- **Synchronization** — video and audio should be synchronized to within 20 msec.
- **Throughput** — the minimum video bit-rate to be supported is 32 kbps. Video rates of 128 kbps, 384 kbps and above should be supported as well.
- **Delay** — the maximum end-to-end transmission delay is defined to be 400 msec.
- **Jitter** — the maximum delay jitter (maximum difference between the average delay and the 95^{th} percentile of the delay distribution) is 200 msec.
- **Error Rate** — the video conferencing system should be able to tolerate a frame error rate of 10^{-2} or bit error rate of 10^{-3} for circuit switched transmission.

Synchronization Loss

- **Loss of decoder synchronization**: For digital video coding, when there is damage to a packet containing variable bit-length data, that error, if unconstrained, will propagate all the way throughout the stream.

- Other than synchronization loss, errors in prediction reference frames cause much more damage to the signal quality than errors in frames not used for prediction.

  – Similarly, if the video is scalable, an error at the base layer will deteriorate the quality of a video stream more than in enhancement layers.

Synchronization Loss (Cont'd)

- MPEG-4 defines additional error-resilient tools that are useful for coding under noisy and wireless channel conditions:
  - A data partitioning scheme will group and separate header information, motion vectors, and DCT coefficients into different packets, and put synchronization markers between them.
  - An adaptive Intra frame refresh mode is allowed where each MB can be coded independently of the frame as an Inter or Intra block according to its motion, to assist with error concealment.

Synchronization Loss (Cont'd)

- *Sender-Receiver Feedback* techniques can be used if a back channel is available to the encoder:
  - According to the bandwidth available at any moment, the receiver can ask the sender to lower or increase the video bit-rate (transmission rate control), which combats packet loss due to congestion.
  - If the stream is scalable, it can also ask for enhancement layers.
  - Receiver can notice damage in a reference frame, and request that the encoder use a different reference frame for prediction – a reference frame that the decoder has reconstructed correctly.

Error Resilient Entropy Coding (EREC)

- **EREC** can achieve synchronization after every *single* Macroblock (MB), without any of the overhead of the slice headers or GOB headers:
  - EREC takes a coded bitstream of a few blocks and rearranges them so that the beginning of all the blocks are a fixed distance apart.
  - The algorithm proceeds as in Figure 17.7.

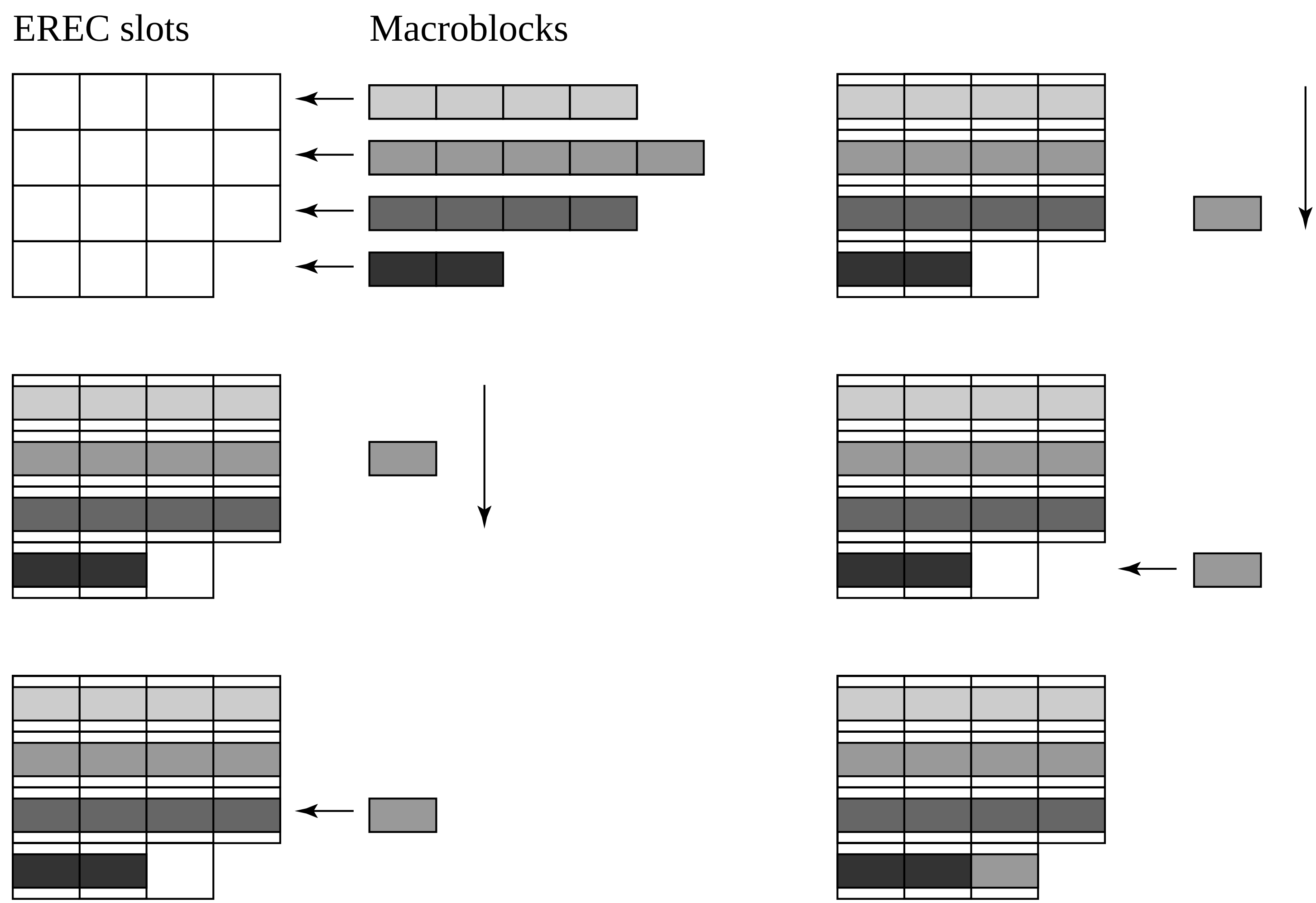

Fig. 17.7: Example of macroblock encoding using EREC

PROCEDURE EREC_Encode

- Let k be the number of macroblocks = the number of slots, l be the total bit-length of all the MBs, $mbs[\,]$ be the MBs, $slots[\,]$ be the EREC slots, then:

PROCEDURE 17.1 EREC_Encode

```
begin
j = 0;
Repeat until l = 0
{
   for i = 0 to k − 1
   {
     m = (i + j) mod k;
     Shift as many bits as possible (without overflow) from mbs[i] into slots[m];
     sb = number of bits successfully shifted into slots[m] (without overflow);
     l = l − sb;
   }
   j = j + 1;        // shift the MBs downwards
}
end
```

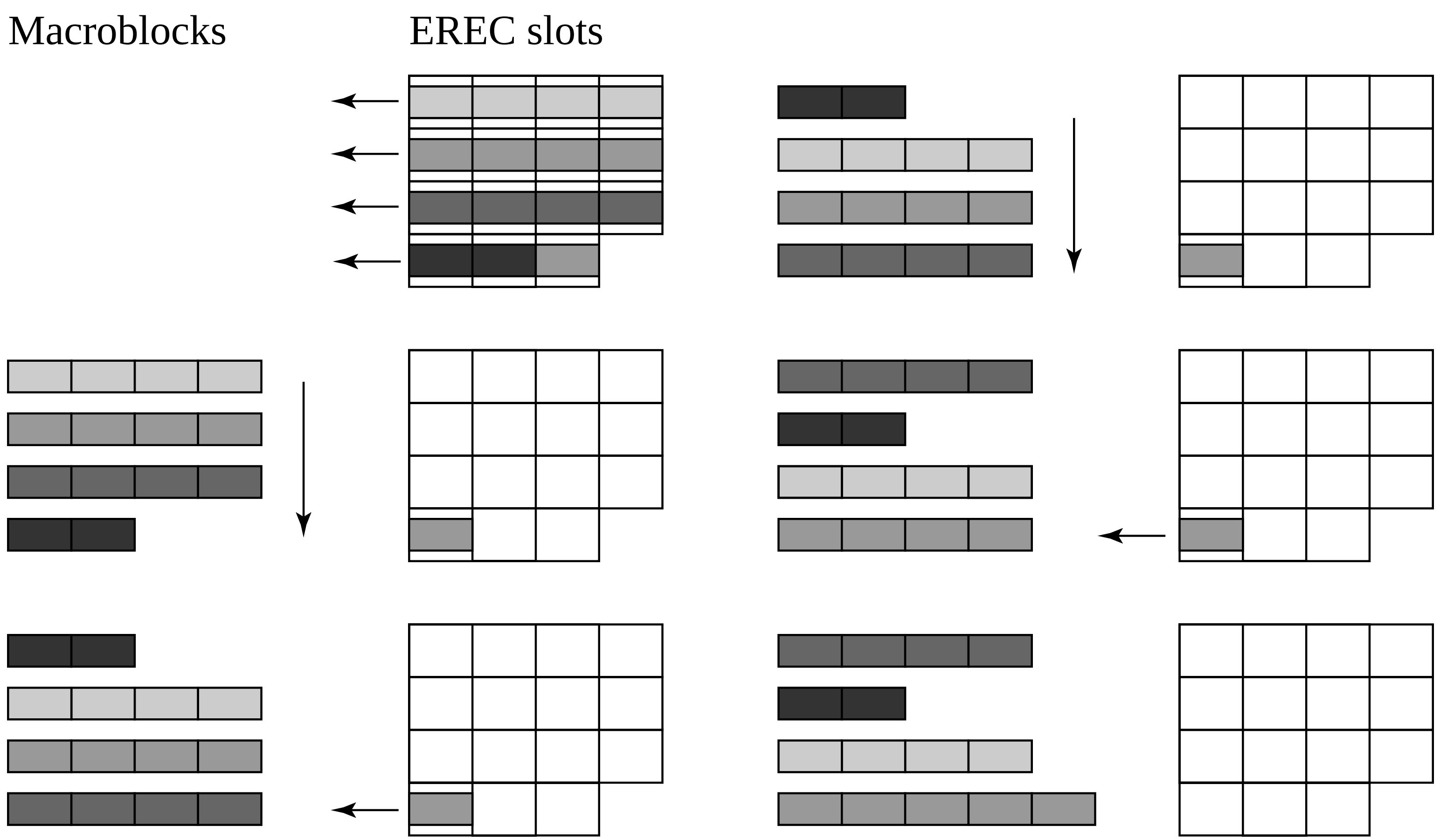

Fig. 17.8: Example of Macroblock decoding using EREC.

Error Concealment

- **Error concealment**: techniques used to approximate the lost data on the decoder side.
  - There are many error concealment techniques that apply either in the spatial, temporal or frequency domain, or a combination of them.
  - All the techniques utilize neighboring frames temporally or neighboring MBs spatially.
  - Error concealment is necessary for wireless video communication since the error rates are higher than for wired channels and might even be higher than can be transmitted with appropriate bit protection.

Summary of Techniques for Error Concealment

- **Dealing with lost macroblock(s)** – A simple and very popular technique for concealment can be used when DCT blocks are damaged but the motion vectors are received correctly.

- **Combining temporal, spatial and frequency coherences** – By having rules for estimating missing block coefficients using the received coefficients and neighboring blocks in the same frame, can conceal errors for intra-frames and for frames with damaged motion vector information.

- **Frequency smoothing for high frequency coefficients** – Smoothing can be defined much more simply to save on computational cost.

- **Estimation of lost MVs** – The loss of motion vectors prevents the decoding of an entire predicted block, so it is important to estimate them well.

Forward Error Correction (FEC)

- **FEC**: a technique that adds redundant data to a bitstream in order to recover some random bit errors in it.
- Videos have to be transmitted over a channel with limited bandwidth:
  - Important to minimize redundancy since it comes at the expense of bit-rate available for video source coding.
  - Enough redundancy is needed so that the video can maintain required QoS under the current channel error conditions.
  - There is an optimal amount of redundancy that minimizes video distortion given certain channel conditions.
- FEC codes in general fall into two categories:
  1. Block codes: apply to a group of bits at once to generate redundancy.
  2. Convolutional codes: apply to a string of bits one at a time, and have memory that can store previous bits as well.

Block codes

- Block codes take as input k bits and append $r = n - k$ bits of FEC data, resulting in an n bit long string — referred to as (n, k) codes.
- Two types of block codes are **linear** and **cyclic** codes.
- Linear codes are simple to compute but have higher coding overhead than cyclic codes: in order to correct r errors the Hamming distance must be at least $2r$.
- Cyclic codes are stated in terms of generator polynomials of maximum degree equal to the number of source bits. The source bits are the coefficients of the polynomial, and redundancy is generated by multiplying with another polynomial.

- One of the most used classes of cyclic codes is the Bose-Chaudhuri-Hocquenghem (BCH) codes, since they apply to any binary string.

  – The generator polynomial for BCH is given over GF(2) (the binary Galois field) and is the lowest degree polynomial with roots of α^i where α is a primitive element of the field (i.e., 2) and i goes over the range of 1 to twice the number of bits we wish to correct.

- An important subclass of BCH codes that applies to multiple packets is the Reed-Solomon (RS) codes. The RS codes have a generator polynomial over GF(2^m) with m being the packet size in bits.

  – RS codes take a group of k source packets and output n packets with $r = n - k$ redundancy packets. Up to r lost packets can be recovered from n coded packets if we know the erasure points.

  – It is also possible to use packet-interleaving in order to increase resilience to burst packet loss. As shown in Figure 17.9 the RS code is generated for each of the h rows of k source video packets.

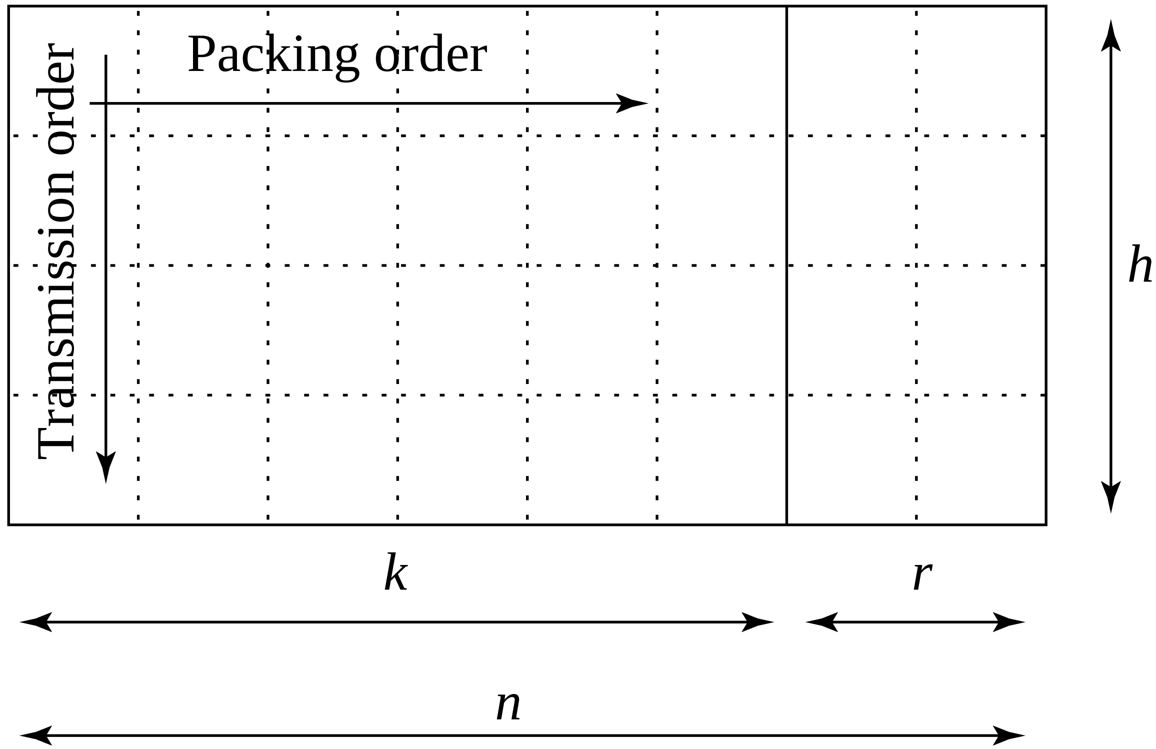

Fig. 17.9: Interleaving scheme for redundancy codes. Packets or bits are stored in rows, and redundancy is generated in the last r columns. The sending order is by columns, top to bottom, and then left to right

Trends in Wireless Interactive Multimedia

- The UMTS forum foresees that by the year 2010 the number of subscribers of wireless multimedia communication will exceed a billion users worldwide, and such traffic will be worth over several hundred billion dollars to operators.

- 3G will also speed the convergence of telecommunications, computers, multimedia content and content providers to support enhanced services.

Trends in Wireless Interactive Multimedia (Cont'd)

- Some of the present and future 3G applications are:
  - Multimedia Messaging Service (MMS).
  - Mobile videophone, VoIP, and voice-activated network access.
  - Mobile Internet access with streaming audio and video services.
  - Mobile intranet/extranet access with secure access to corporate LANs, Virtual Private Networks (VPNs), and the Internet.
  - Customized infotainment service that provides access to personalized content anytime, anywhere based on mobile portals.
  - Mobile online multiuser gaming.
  - Ubiquitous and pervasive computing.

17.4 Further Exploration

- **Text books:**
  - *Computer Networks* by A.S. Tanenbaum
  - *Wireless Multimedia Communications: Networking Video, Voice, and Data* by E.K. Wesel
  - *CDMA: Principles of Spread Spectrum Communication* by A.J. Viterbi
  - *Video Processing and Communications* by Y. Wang et al.

- **Web sites:** ⟶ Link to Further Exploration for Chapter 17.. including:
  - Survey on wireless networks and cellular phone technologies.
  - Report on GSM.
  - Introduction to GPRS.
  - Link to NTIA for information on Spectrum Management.
  - Links to home pages of CDMA Development Group, IMT-2000, UMTS, cdma2000 RTT, 3GPP, etc.
  - Links to Wireless LAN standards.