Chapter 2

The Physical Layer

Existing Transmission Systems

- Public Switched Telephone System
- The Mobile Television System
- The Cable Television

The Mobile Telephone System

- First-Generation Mobile Phones: Analog Voice
  - AMPS
- Second-Generation Mobile Phones: Digital Voice
  - D-AMPS, GSM, CDMA
- Third-Generation Mobile Phones: Digital Voice and Data
  - Broadband CDMA

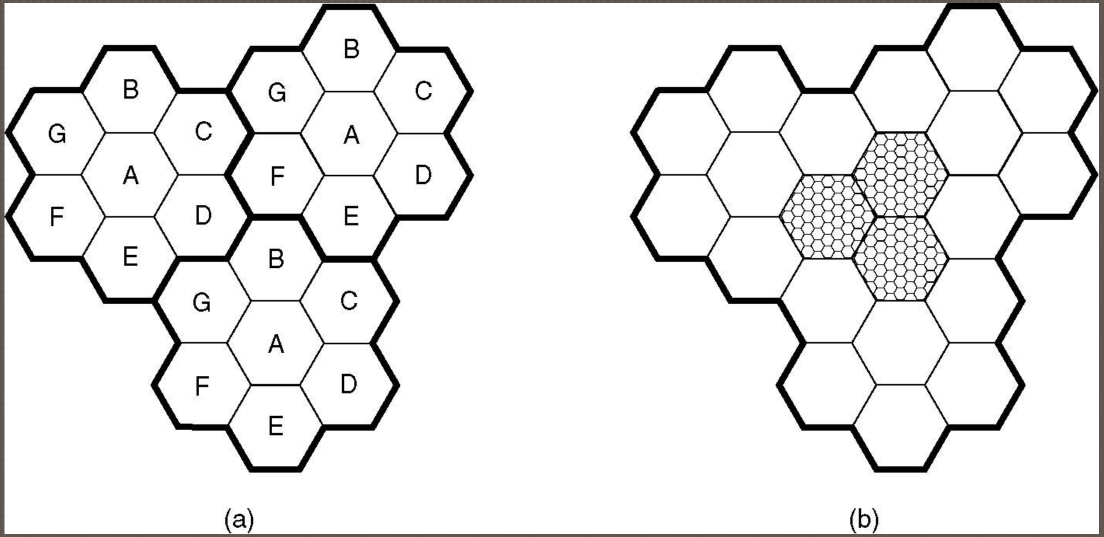
Advanced Mobile Phone System (AMPS)

Handoff: acquire a new base station

soft: tone both frequency at the same time (no loss of continuity)

- 1st and 2nd generation devices CANNOT do this

hard: old base drops the call, new base acquire it (chance of cut)



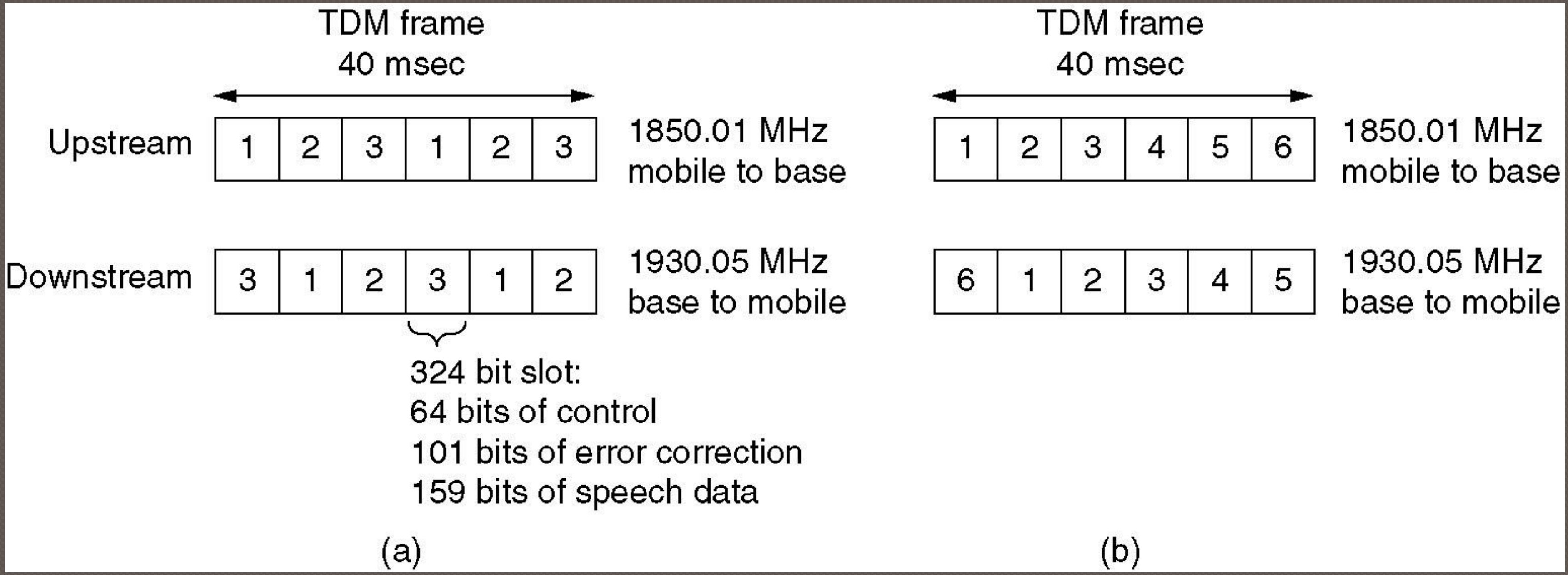
(a) Frequencies are not reused in adjacent cells.

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

AMPS Channels

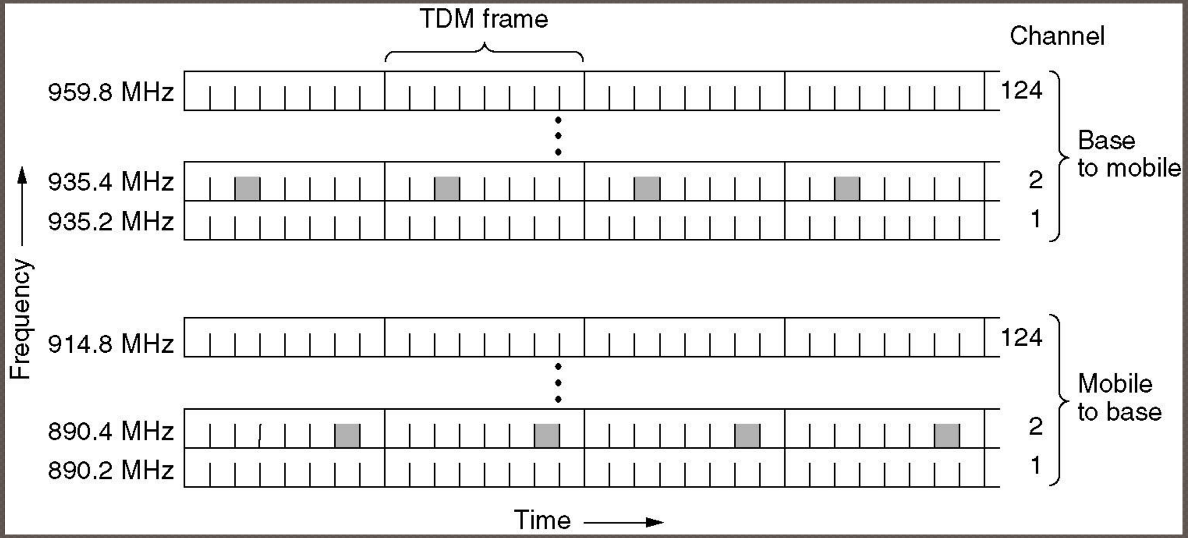
- AMPS uses FDM to separate the channels
- 832 channels full-duplex made of 2 simplex channels
  - 832 transmitting simplex from 824-849 MHz
  - 832 receiving simplex from 869 to 894 MHz
  - 30 kHz per channel
- They are divided into four categories:
  - Control (base to mobile) to manage the system
  - 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

D-AMPS
Digital Advanced Mobile Phone System



(a) A D-AMPS channel with three users.
(b) A D-AMPS channel with six users.

GSM
Global System for MobileCommunications



- Used in Europe
- 124 frequency channels
  - each uses an 8-slots TDM system

CDMA
Code Division Multiple Access

A: 0 0 0 1 1 0 1 1
B: 0 0 1 0 1 1 1 0
C: 0 1 0 1 1 1 0 0
D: 0 1 0 0 0 0 1 0

(a)

A: (−1 −1 −1 +1 +1 −1 +1 +1)
B: (−1 −1 +1 −1 +1 +1 +1 −1)
C: (−1 +1 −1 +1 +1 +1 −1 −1)
D: (−1 +1 −1 −1 −1 −1 +1 −1)

(b)

Six examples:

— — 1 —	**C**	$S_1 = (-1\ +1\ -1\ +1\ +1\ +1\ -1\ -1)$
— 1 1 —	**B + $\overline{C}$**	$S_2 = (-2\ \ 0\ \ 0\ \ 0\ +2\ +2\ \ 0\ -2)$
1 0 — —	**A + $\overline{B}$**	$S_3 = (\ 0\ \ 0\ -2\ +2\ \ 0\ -2\ \ 0\ +2)$
1 0 1 —	**A + $\overline{B}$ + C**	$S_4 = (-1\ +1\ -3\ +3\ +1\ -1\ -1\ +1)$
1 1 1 1	**A + B + C + D**	$S_5 = (-4\ \ 0\ -2\ \ 0\ +2\ \ 0\ +2\ -2)$
1 1 0 1	**A + B + $\overline{C}$ + D**	$S_6 = (-2\ -2\ \ 0\ -2\ \ 0\ -2\ +4\ \ 0)$

(c)

$S_1 \bullet C = (1 +1 +1 +1 +1 +1 +1 +1)/8 = 1$
$S_2 \bullet C = (2 +0 +0 +0 +2 +2 +0 +2)/8 = 1$
$S_3 \bullet C = (0 +0 +2 +2 +0 -2 +0 -2)/8 = 0$
$S_4 \bullet C = (1 +1 +3 +3 +1 -1 +1 -1)/8 = 1$
$S_5 \bullet C = (4 +0 +2 +0 +2 +0 -2 +2)/8 = 1$
$S_6 \bullet C = (2 -2 +0 -2 +0 -2 -4 +0)/8 = -1$

(d)

Binary chips are
pair wise orthogonal
i.e.
for channels X and Y
XY = 0
but
XX = YY = 1

(a) Binary chip sequences for four stations
(b) Bipolar chip sequences
(c) Six examples of transmissions
(d) Recovery of station C's signal – multiply the sequence by the chip sequence of C

Third-Generation Mobile Phones: Digital Voice and Data

Basic services an IMT-2000 network should provide

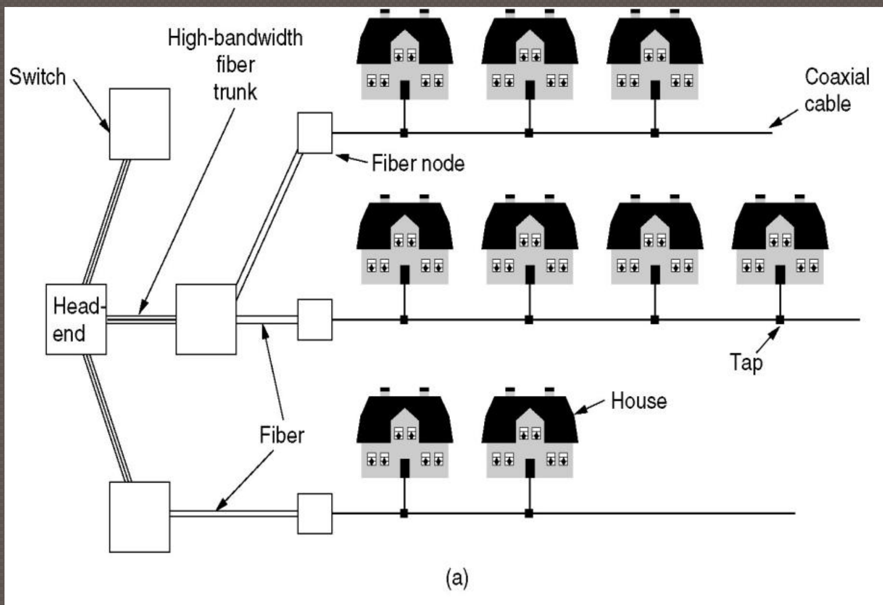
- High-quality voice transmission
- Messaging (replace e-mail, fax, SMS, chat, etc.)
- Multimedia (music, videos, films, TV, etc.)
- Internet access (web surfing, w/multimedia.)

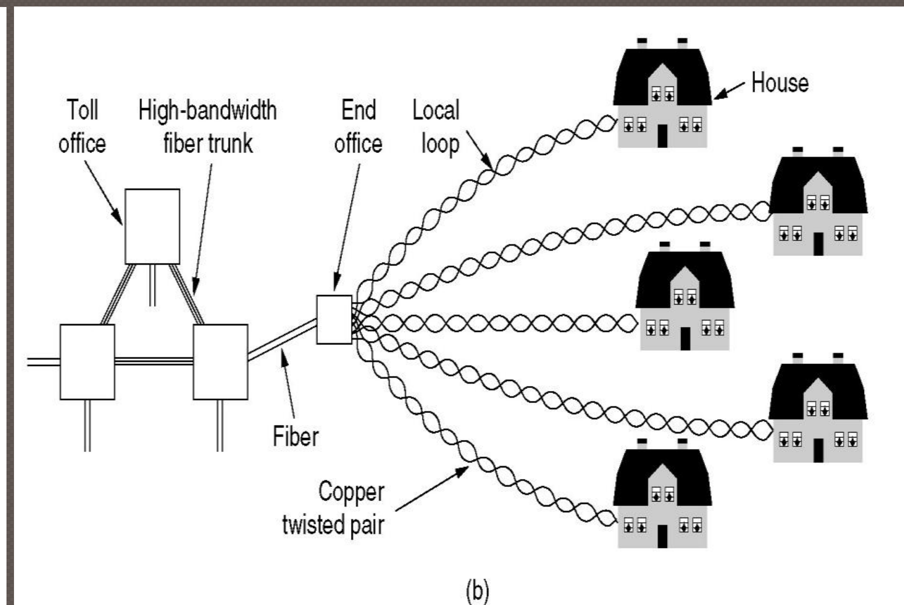
Cable Television

- Community Antenna Television
- Internet over Cable
- Spectrum Allocation
- Cable Modems
- ADSL versus Cable

Internet over Television Cable

Internet over Telephone

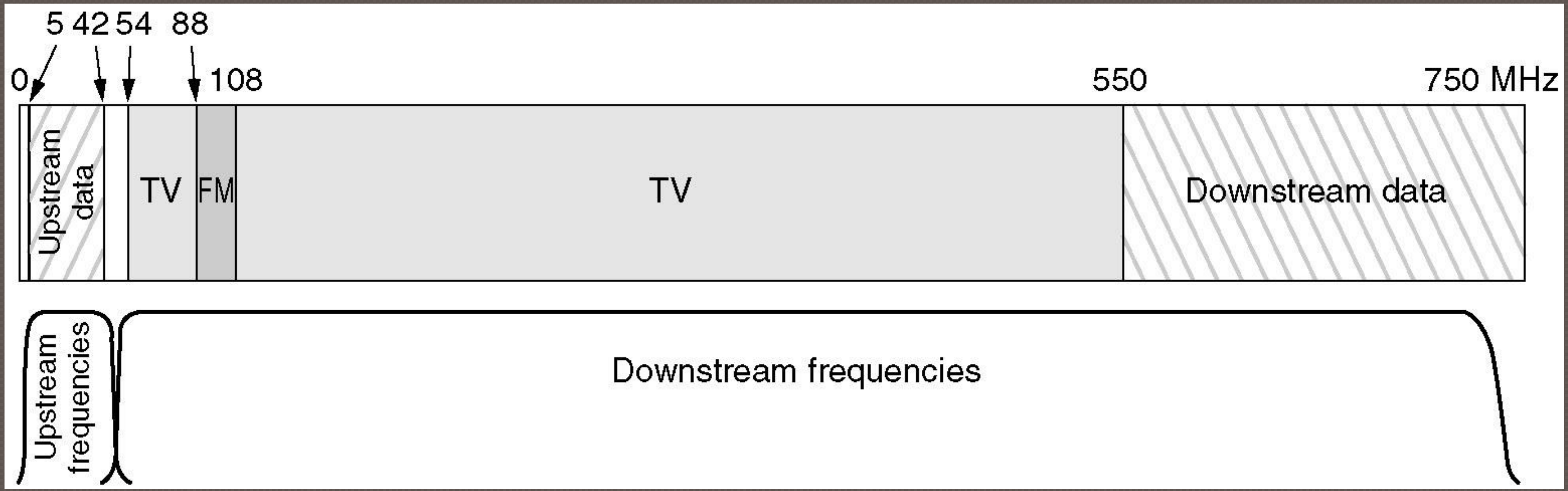




Cable television

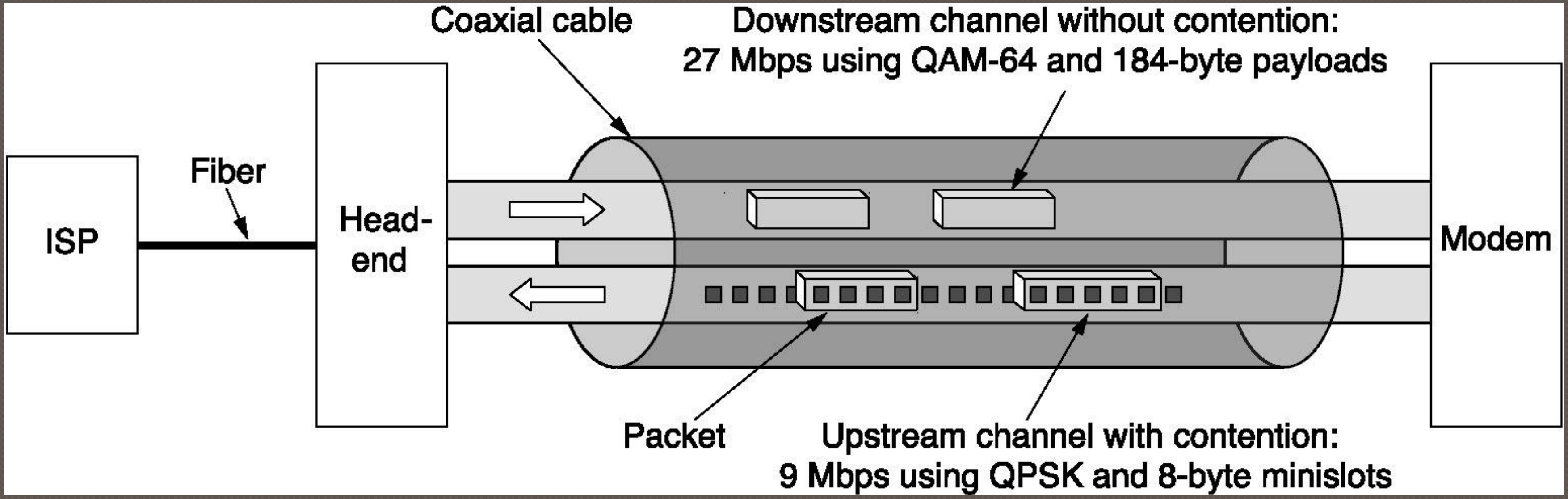
The fixed telephone system

Spectrum Allocation



Frequency allocation in a typical cable TV system used for Internet access

Cable Modems



Typical upstream and downstream channels in US.

- Name of standard modem:
  - DOCSIS (Data Over Cable Service Interface Specification)

ADSL vs. Cable

Item	ADSL	Cable
Media	Twisted pairs	Coax
Media Capacity	Smaller	Larger
Use of Capacity	Small part used for voice	Large part used for television
Bandwidth	1Mbps downstream 256 kbps upstream	Unclaimed
Capacity availability	Full (due to point-to-point connection)	Depends on people active at the moment
Security	More secure	Less secure
Service Availability	No, if user distant from end office	No, if cable not offered – distance not an issue
Choice of ISP offer	Yes	No/Sometimes

Summary

- Physical limitation determine bandwidth
  - Nyquist (noiseless) and Shannon (noisy)
- Transmission media is guided or unguided
  - Guided: twisted pairs, coax, fiber optics
  - Unguided: radio, microwaves, infrareds, laser
- Telephone system components
  - Local loops (analogs), trunks and switches

Summary (2)

- Local loops are analogs
  - ADSL speeds up to 50 Mbps by dividing the local loop into many channels and modulating each one separately
- Trunks are digital
  - Are multiplexed in FDM, TDM and WDM
  - Both Circuit Switching and Packet witching are important
- Mobile Phone
  - 1st generation
    - Analog
    - Dominated by AMPS
  - 2nd generation
    - Digital
    - D-AMP, GMS and CMDA available
  - 3rd generation
    - Digital and broadband CMDA

Summary (3)

- Cable Television
  - Evolved from community antenna to hybrid fiber coax
  - Offers high bandwidth
  - Actual bandwidth depends on currently active users what they are doing

Chapter 3

The Data Link Layer

Data Link Layer Design Issues

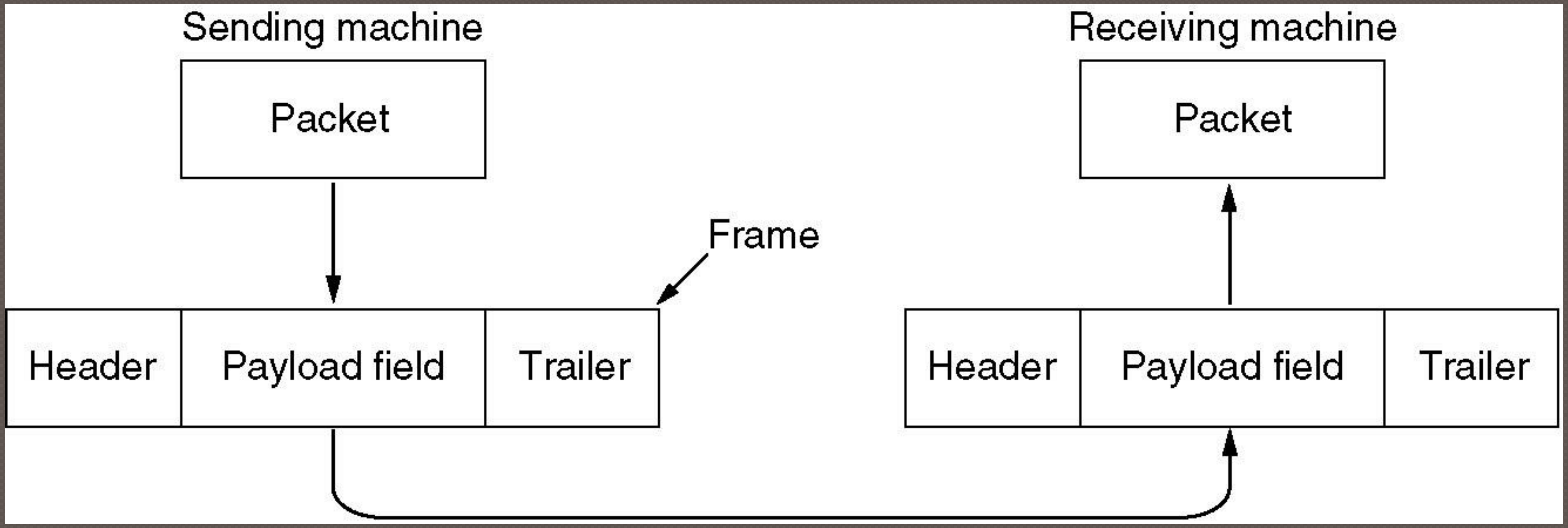
- Services Provided to the Network Layer
- Framing
- Error Control
- Flow Control

Functions of the Data Link Layer

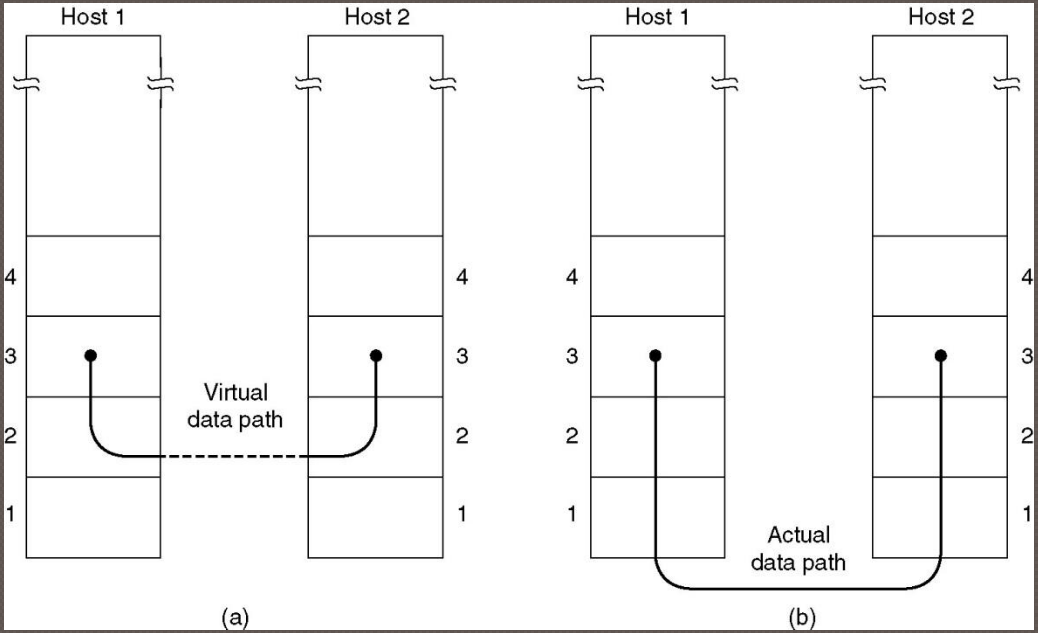
1. Provide service interface to the network layer
2. Dealing with transmission errors
3. Regulating data flow
   - Slow receivers not swamped by fast senders

Packets and Frames

Relationship between packets and frames.



Services Provided to Network Layer



(a) Virtual communication. (b) Actual communication.

- The data link is designed to provide services such as:

1. Unacknowledged connectionless service
2. Acknowledged connectionless service
3. Acknowledged connection-oriented service

Services of the Data Link Layer

1. Unacknowledged connectionless service
   - No logical connection – No ACK – If frame is lost no attempt to detect the loss
   - Appropriate for real-time traffic – e.g. voice or LAN

2. Acknowledged connectionless service
   - No logical connection – sender waits for ACK – If ACK doesn't arrive the entire message is resent
   - Appropriate for wireless since unreliable

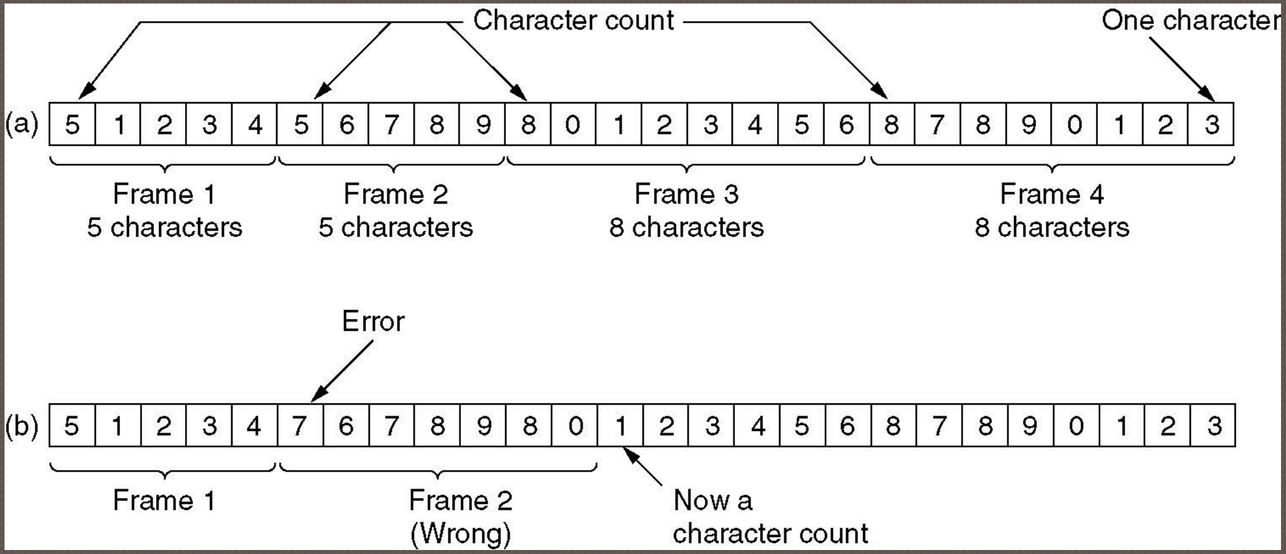
3. Acknowledged connection-oriented service Placement of the data link protocol.
   - Connection established – Sender transmits frames - Transmission is reliable (ie. Frame are received exactly once) – Connection is released.
   - Most reliable service

Framing

Service: Accept a raw bit stream and deliver it to destination

1. Break the stream…how?

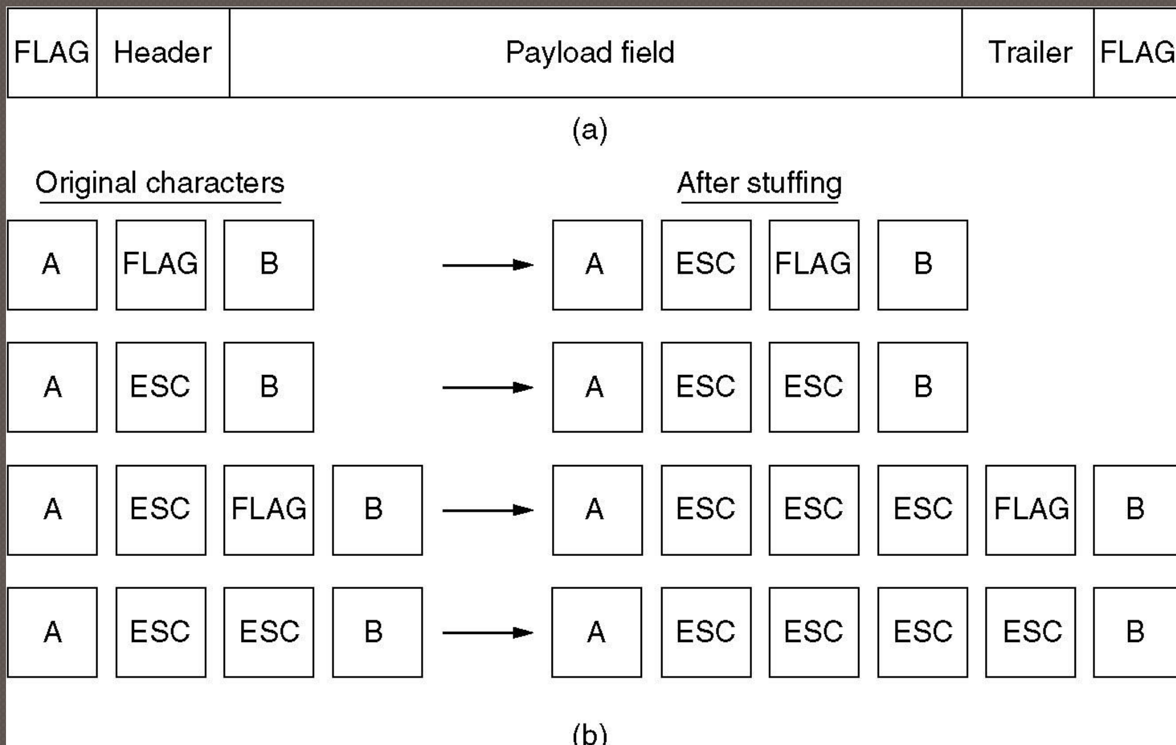
- Character Count.



(a) Without errors. (b) With one error.

Framing (2)

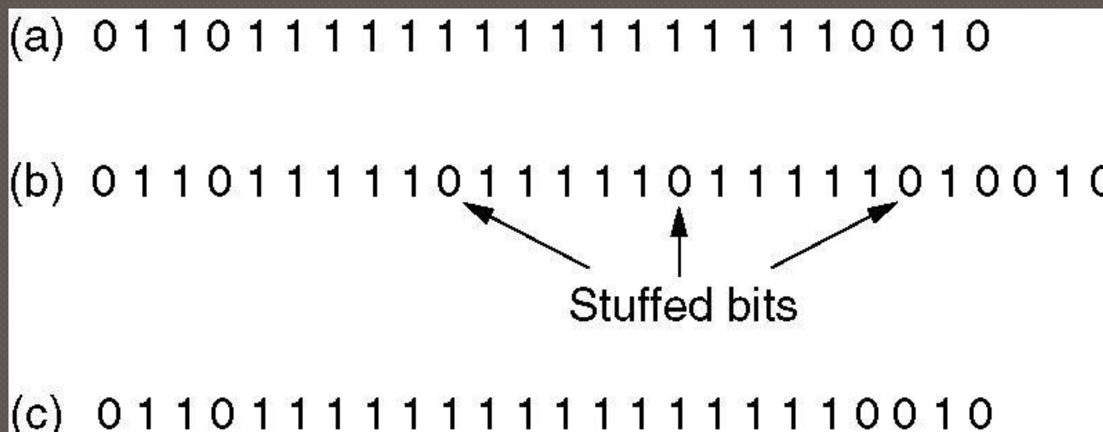
- Flag bytes with byte Stuffing



(a) A frame delimited by flag bytes.
(b) 4 examples of byte sequences before and after stuffing.

Framing (3)

- Bit stuffing



(a) The original data.
(b) Every 5 consecutive 1 bits, a 0 bit is stuffed.
(c) The data as they are stored in receiver's memory after destuffing.

Error Detection and Correction

- Error-Correcting Codes
- Error-Detecting Codes

Error-Correcting Codes

- Occasional errors may occur in computer memories due to voltage spikes or other causes.

- Errors can be handled by adding extra check bits to words of memory. Suppose a word of memory has m data bits and r check bits. Let the total length be $n = m + r$. This n bit unit is often referred to as a **codeword**.

- The number of bits in which two codewords differ is called the **Hamming distance**.

Error-Correcting Codes (2)

- To **detect** d single-bit errors requires a $d + 1$ code.
- To correct d single-bit errors requires a $2d + 1$ code.

- Consider a adding a single **parity bit** to the data. The bit is chosen so that the number of 1 bits in the codeword is even (or odd). Now a single error results in an invalid codeword. It takes two errors to go from one valid codeword to another.

Error-Correcting Codes

- Imagine we want to design a code with m data bits and r check bits that will allow all single-bit errors to be corrected. Each of the 2^m legal memory words has n illegal codewords at a distance 1 from it.
  - Form these by inverting each of the n bits in the n-bit codeword.
  - Each of the 2^m legal memory words requires n + 1 bit patterns dedicated to it.
  - $(n + 1)\ 2^m <= 2^n$ since $n = m + r$, $(m + r + 1) <= 2^r$
  - r is the lowest number of check bits we need to add!!!!

Error-Correcting Codes

Word size	Check bits	Total size	Percent overhead
8	4	12	50
16	5	21	31
32	6	38	19
64	7	71	11
128	8	136	6
256	9	265	4
512	10	522	2

Figure 2-13. Number of check bits for a code that can correct a single error.

Error-Correcting Codes

- The following figure illustrates an error-correcting code for 4-bit words. The three circles form 7 regions. Encode the 4-bit word 1100 in four of those regions then add a parity bit to each of the three empty regions so that the sum of the bits in each circle is an even number.

- Now suppose that the bit in the *AC* region goes bad, changing from a 0 to a 1. Circles *A* and *C* have the wrong parity. The only single-bit change that corrects them is to restore *AC* back to 0, thus correcting the error.

Error-Correcting Codes

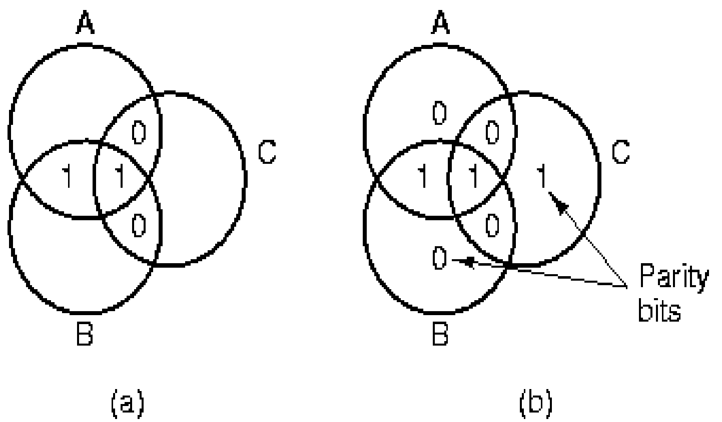


Figure 2-14. (a) Encoding of 1100. (b) Even parity added. (c) Error in *AC*.

Hamming's Algorithm

- **Hamming's algorithm** can be used to construct single error-correcting codes for any size memory word. In a Hamming code, r parity bits are added to an m-bit word, forming a new word of length $m + r$ bits.
- The bits are numbered starting at 1, not 0, with bit 1 the leftmost (high-order) bit. All bits whose bit number is a power of 2 are parity bits; the rest are used for data.
  - In a 16-bit word, 5 parity bits are added. Bits 1, 2, 4, 8, and 16 are parity bits. The word has 21 total bits.

Hamming's Algorithm

- Each parity bit checks specific bit positions; the parity bit is set so that the total number of 1s in the checked positions is even. The positions checked are:

Bit 1 checks bits 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21.

Bit 2 checks bits 2, 3, 6, 7, 10, 11, 14, 15, 18, 19.

Bit 4 checks bits 4, 5, 6, 7, 12, 13, 14, 15, 20, 21.

Bit 8 checks bits 8, 9, 10, 11, 12, 13, 14, 15.

Bit 16 checks bits 16, 17, 18, 19, 20, 21.

  - In general each bit b is checked by those bits $b_1, b_2, \ldots, b_j$ such that $b_1 + b_2 + \ldots + b_j = b$.

Error-Correcting Codes

1 checks 1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21.
2 checks 2, 3, 6, 7, 10, 11, 14, 15, 18, 19.
4 checks 4, 5, 6, 7, 12, 13, 14, 15, 20, 21.
8 checks 8, 9, 10, 11, 12, 13, 14, 15.
16 checks 16, 17, 18, 19, 20, 21.

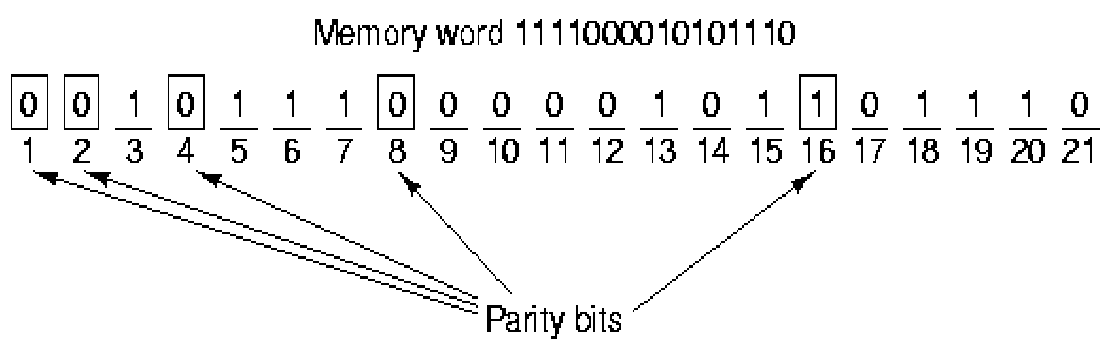


Figure 2-15. Construction of the Hamming code for the memory word 1111000010101110 by adding 5 check bits to the 16 data bits.

Hamming's Algorithm

- Consider what would happen if bit 5 in the word on the previous slide were inverted by a surge on the power line. Bit 5 would then be a 0. The 5 parity bits would be checked with the following results:

Parity bit 1 incorrect (positions checked contain 5 1s)
Parity bit 2 correct (positions checked contain 6 1s)
Parity bit 4 incorrect (positions checked contain 5 1s)
Parity bit 8 correct (positions checked contain two 1s)
Parity bit 16 correct (positions checked contain four 1s)

1+4 = 5 ➔ The error occurred in bit 5!

Hamming's Algorithm

- If all parity bits are correct, there were no errors (or more than one). Otherwise, add up all the incorrect parity bits. The sum gives the position of the incorrect bit.

Error-Correcting Codes

Hamming code.

Char.	ASCII	Check bits
H	1001000	00110010000
a	1100001	10111001001
m	1101101	11101010101
m	1101101	11101010101
i	1101001	01101011001
n	1101110	01101010110
g	1100111	01111001111
	0100000	10011000000
c	1100011	11111000011
o	1101111	10101011111
d	1100100	11111001100
e	1100101	00111000101

Order of bit transmission

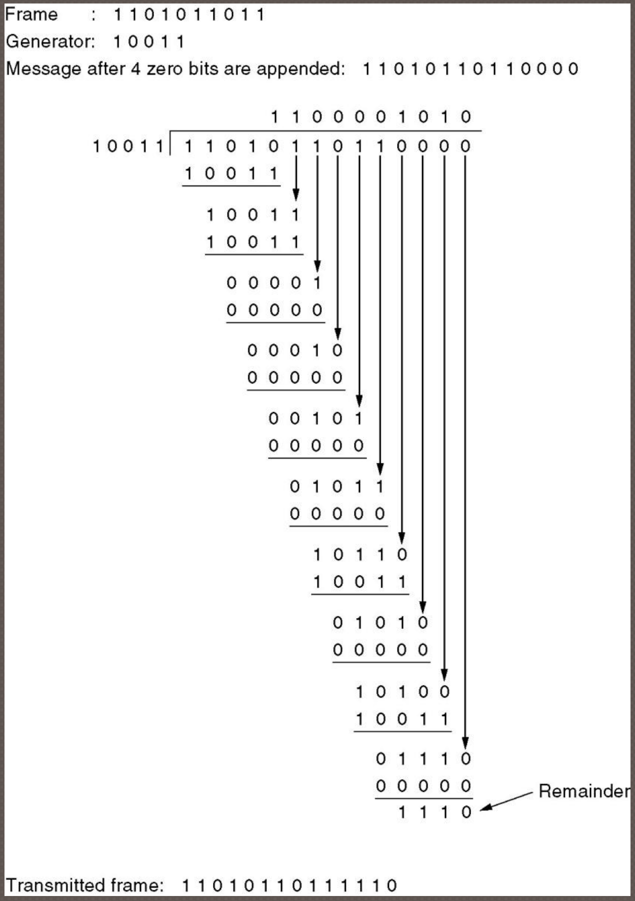
It can be used to correct burst errors if transmitted one codeword per column (instead of raw)

Error-Detecting Codes

Calculation of the polynomial code checksum.

1. Sender and receiver agree on a generator polynomial , degree *r*
   - Ex. G(x) $=x^4+x+x^0$ i.e.10011
   1. Generator polynomial must start and end with 1
2. Append *r* zero bits to the frame M(x) and divide it by G(x)
3. Subtract the remainder from the dividend. This is T(x) the transmitted bits
4. If T(x)+E(x) is received, error occurred

- Complex calculation but a simple shift register circuit is used in hardware.



Next Time

- Review for Exam
  - Each student is invited to bring questions to be answered by other students.
  - We will play a Review Game.
- After the exam we will cover Data Link Protocols