Computer Networks

Error Detection and Correction & Media Access Control

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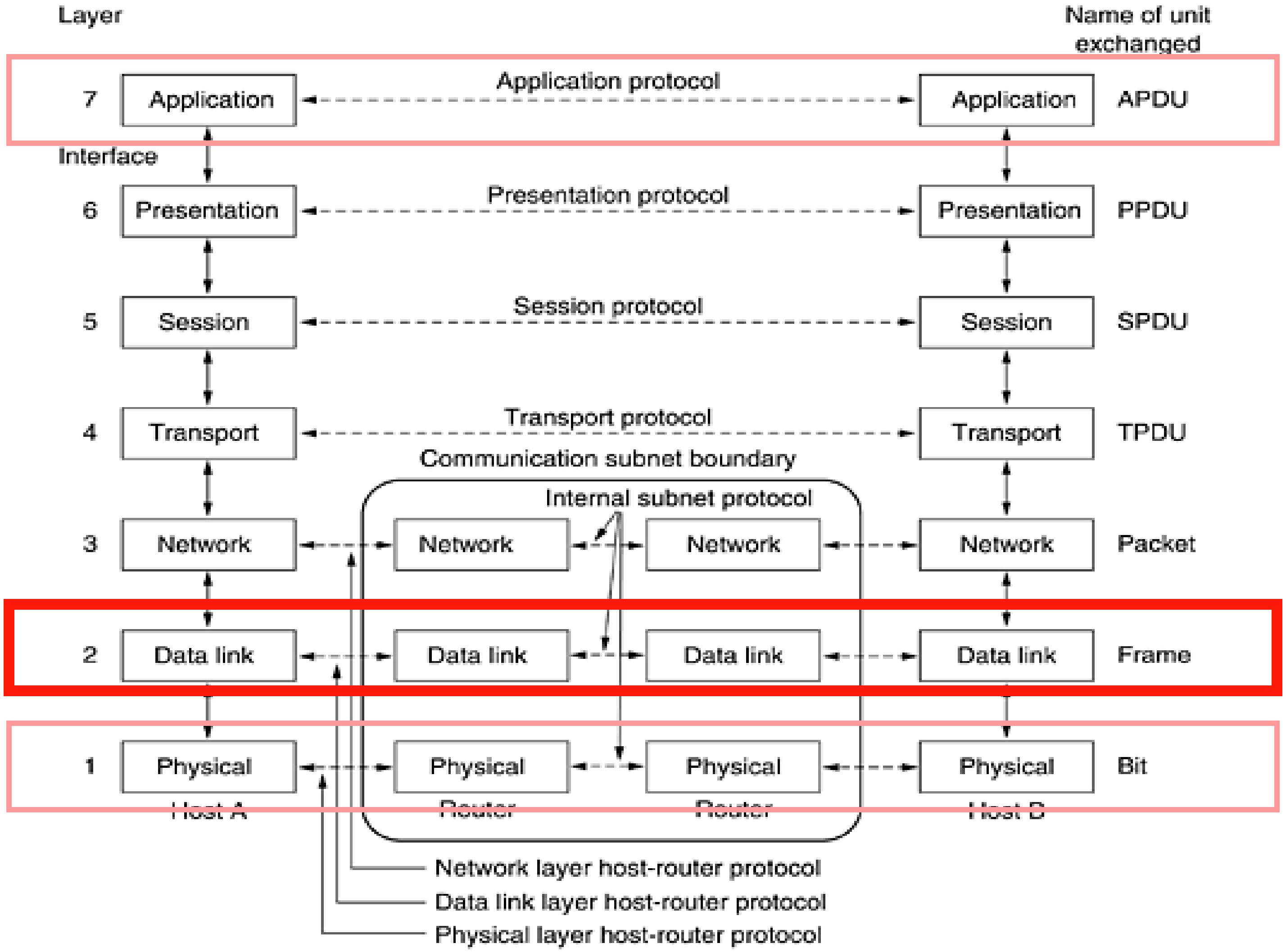
Lecture 6

The Data Link Layer

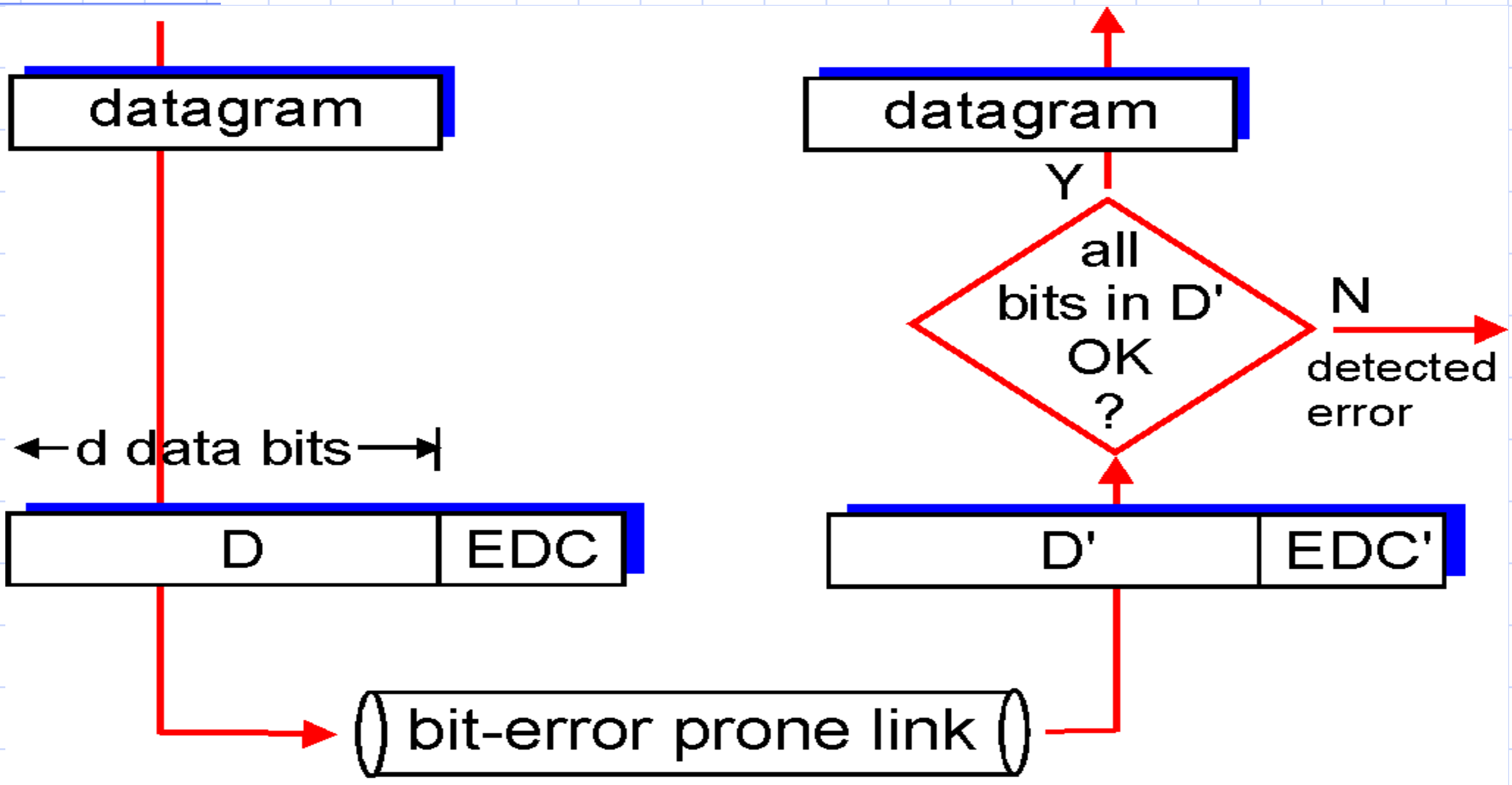


All **P**eople **S**eem **T**o **N**eed **D**ata **P**rocessing

Handling Errors

- Data can be corrupted during transmission
  - Bits lost
  - Bits changed
  - Bits added
- Frame additional data to protect
  - Link-level addressing, seq no., etc
- **Handling ? – add redundant bits (data)**

Error detection/correction scenario



Send **D+EDC**

Receive **D’+EDC’**

Detection vs Correction

- Error Detection Techniques
  - Allow for error detection but no possible correction
  - Require frame re-transmission
  - Used in low error rate transmission medias (fiber optics).
- Error correction techniques (FEC)
  - Involve more redundant data and processing power
  - Used in high error transmission medias (radio)

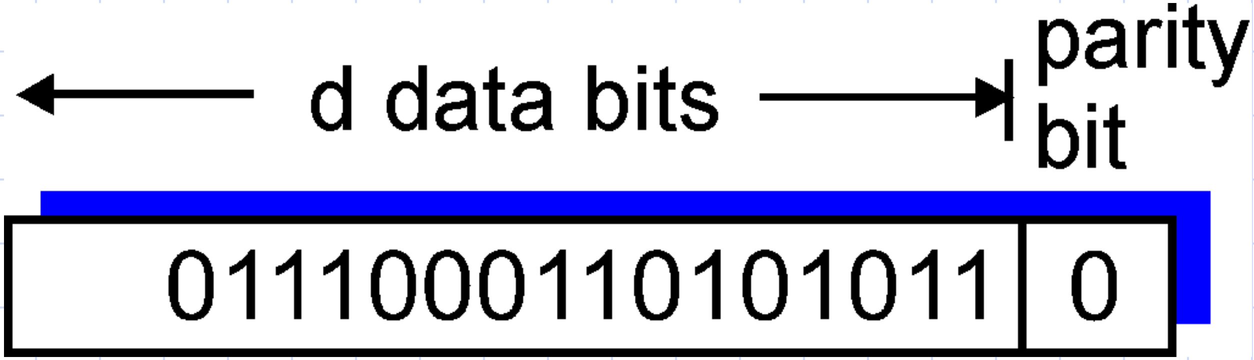
Advantages/disadvantages of Error detection/correction

- Error detection/correction techniques allow the receiver to sometimes *but no always* detect errors.
- *Undetected errors* might still remain => corrupted packets delivered to the network layer.
- **Goal** – have techniques that minimize the number of undetected errors

Detection/Correction Techniques

- Parity Checks
- Checksumming methods
- Cyclic redundancy checks

Parity Checks



- Parity Bit (PB)
  - One additional bit per character
  - *Even parity*
  - *Odd Parity*

How many bit errors can PB detect ?

10001110 ---→ 10101110 => error !

10001110 ---→ 10100110 => **No error detected** !!!

Conclusion – 1 PB can only detect an odd number of errors !

Hamming Distance

- **Hamming distance** = the number of bit positions in which two code-words differ.
- How to calculate ?(Exclusive OR=XOR):

10001001
10110001

00111000

=> The number of 1's give the number of different bits.

Hamming and error detection

- Error detection of *d* single-bit errors needs a *d*+1 distance code.

- Example:
  - BP has a distance of 2 => can detect single bit errors.

Bit Parity – YES or NO ?

Suppose a channel with BER: $p=10^{-4}$ =>

1) $P(\text{sb error})=p$
2) $P(\text{no sb error})=1-p$
3) $P(\text{no error in 8 bits})=(1-p)^8$
4) $P(\text{undetected error in 8 bits})=1-(1-p)^8$

$P(\text{undetected error in 8 bits})=\mathbf{7.9x10^{-4}}$

Bit Parity – YES or NO ? (2)

- After adding a parity bit :

P(no sb error)=1-p

P(no error in 9 bits)=$(1-p)^9$

P(sb error in 9 bits)=9xP(sb error)xP(no error in 8 bits) = $9p(1-p)^8$

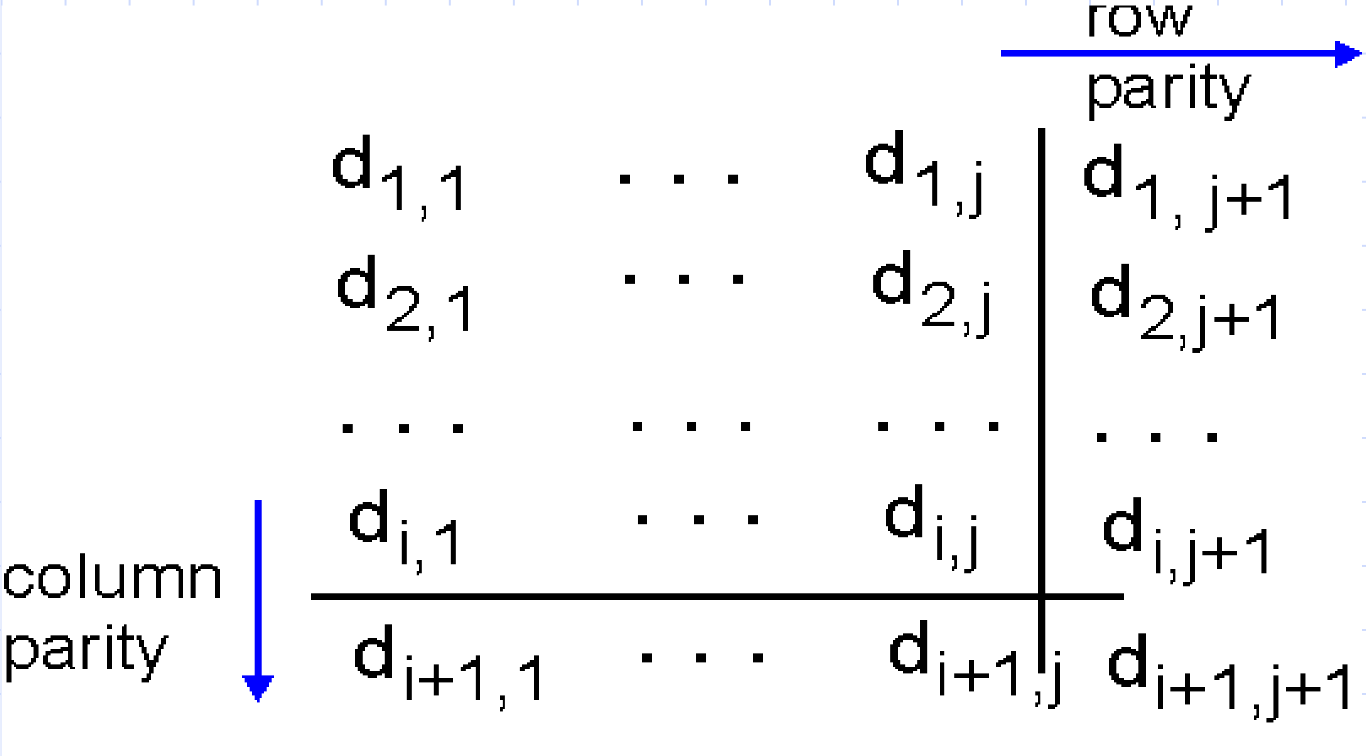
P(undetected error in 9 bits)=1-P(no error in 9 bits)-P(sb error in 9 bits)

= $1-(1-p)^9 - 9p(1-p)^8$

$\Rightarrow$ P(undetected error in 9 bits)=**$3.6x10^{-7}$**

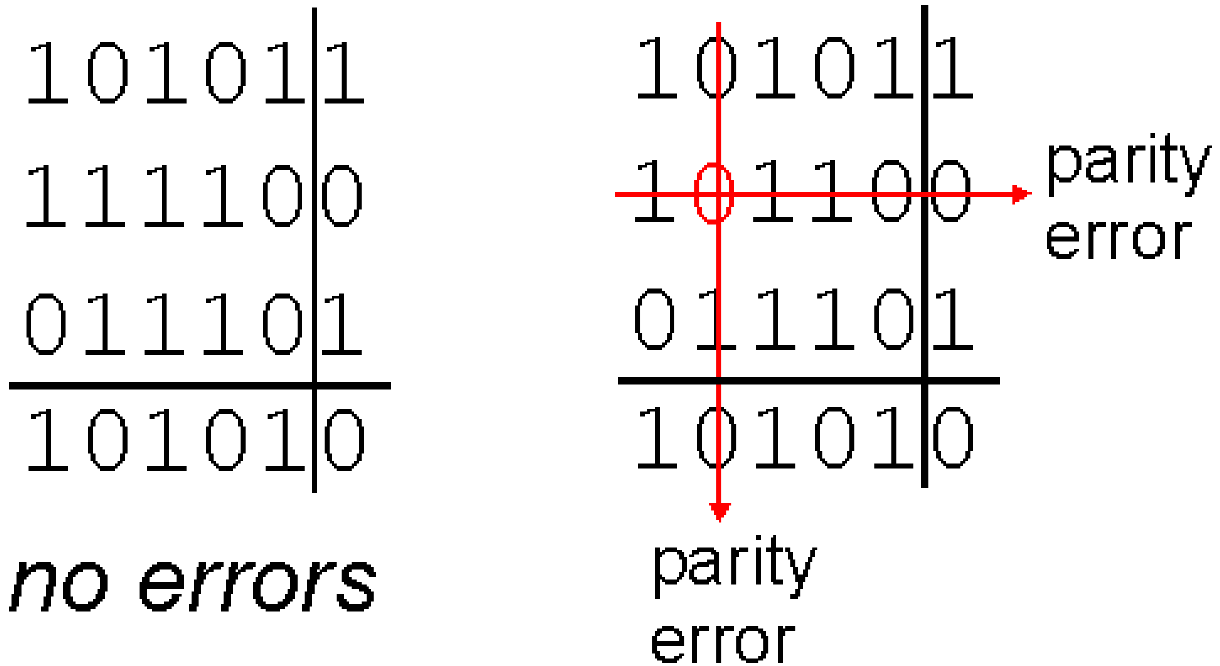
$$\frac{\text{P(undetected error in 8 bits)}}{\text{P(undetected error in 9 bits)}} = \frac{7.9x10^{-4}}{3.6x10^{-7}} \sim= 10^3$$

Single Bit Error Correction



Parity for each character(byte=line) + parity for each column (set of data bytes sent)

Example - Single Bit Error Correction



Hamming - Correctable single bit error

Correction vs Detection - Practice

- Detection techniques
  - For detecting *d* errors we need *d*+1 distance code.
- Correction Techniques
  - For correcting *d* errors we need *2d*+1 distance code.

Error Correction

Valid codewords: 0000000000, 0000011111, 1111100000, and 1111111111

The Hamming distance of the code=5 => we can correct 2d+1=5 => d=2 bit errors.

a) 0000000000---→0000000011 => the closest code is still 0000000000 !

b) 0000000000---→0000000111 => the closest code is not correctly determined anymore !!

Hamming correcting code

- Bits numbered from lsb to msb 1…n
- Positions power of 2 = check bits => bits 1,2,4,8… etc check bits
- Bit *k* from the sequence is checked by the positions from its binary decomposition k=11=1+2+8 => bits 1,2,8 are check bits

Hamming correcting code

In order to send 7 data bits we need 4 check bits.

Data: 1001101

Check bits 4 : 1,2,4,8

11	10	9	8	7	6	5	4	3	2	1	
1	0	0	x	1	1	0	x	1	x	x	sent as
1	0	0	1	1	1	0	0	1	0	1	

Hamming correcting code

10011100101 is sent as 00011100101

=>the error bit is given by the indices that are in error

8=[11]+[10]+[9] – error =>k=8

4=[7]+[6]+[5] – ok =>k=8

2=[11]+[10]+[7]+[6]+[3]–error=>k=10

1=[11]+[9]+[7]+[5]+[3]-error =**k=11**

Checksum Codes

H	e	l	l	o		w	o	r	l	d	.
48	65	6C	6C	6F	20	77	6F	72	6C	64	2E

4865 + 6C6C + 6F20 + 776F + 726C + 642E + carry = 71FC

soh	data	eot	Checksum

- Byte stream interpreted as series of numbers (16 bit integers)
- Integers are added =>checksum appended to the frame.
- Receiver calculates again the checksum and discovers the errors.

Errors Checksum fails to detect

Data Item Binary	Checksum Value
0001	1
0010	2
0011	3
0001	1
Total	**7**

Data Item Binary	Checksum Value
0011	3
0000	0
0001	1
0011	3
Total	**7**

- Second bit inverted for each value
- Checksum is the same

Cyclic Redundancy Check (CRC)

- Bit strings represented as polynomials with coef. 0 and 1.
- K bit frame =>x^{k-1}+...+1 (first and last coef must be 1)
- Example
  - 110001 => x^5+x^4+1
- Polynomial arithmetic is done module 2 i.e. ⇔ addition/subtraction = XOR operation

CRC (2)

- Sender (S) and Receiver (R) agree on a *generator polynomial* G(x)
- Frame – m bits => M(X) – the checksum of m is the remaining of R(x)=M(x)/G(x)
- Checksum added to frame.
- (R) Gets the frame M'(x)=[M(x)-R(x)]
  - If M'(x)/G(x) has remainder => **error**

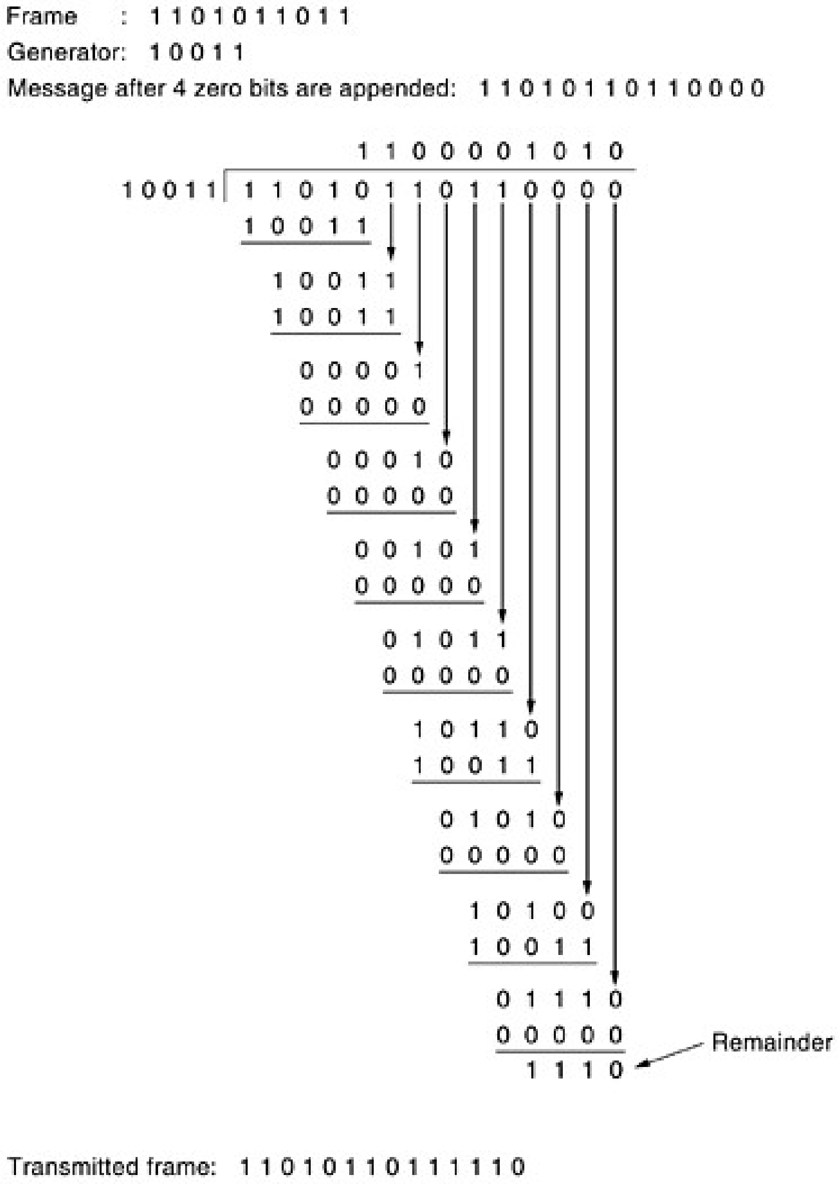
CRC (3)

- Frame *m* bits.   Generator *r* bits.
- Calculate: $x^r M(x)$ – m+r bits
- $x^r M(x) / G(x)$ – take remainder $R(x)$
- Send: $T(x) = x^r M(x) – R(x)$

soh	data	eot	CRC

- Receiver: T(x) should be divisible with G(x). If not we have transmission errors.

CRC - Example



Frame – 1101011011

$G(x)=x^4+x+1$

<u>Transmitted frame:</u>

11010110110000 –

00000000001110

11010110111110

CRC (4)

- (S) – sends $T(x)=M(x)-R(x)$
- (R) – receives $T(x)+E(x)$. $T(x)/G(x)=0$ and **$E(x)/G(x)$** – gives the error.

1. <u>If $E(x)=P(x)G(x)$ => undetected error</u> !!!!
2. $E(x)=x^i$, **Generally** $G(x)$ is multiple term => $E(x)/G(x)\neq 0$ <u>All Single-Bit errors detected</u> !
3. $E(x)=x^i+x^j=x^j(x^{i-j}+1)$ – detected. See (2)
4. $E(x)$ – has odd number of terms. If $G(x)=(x+1)G'(x)$ => any odd number of errors are detected.

CRC (5)

- IEEE 802 uses:

$x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+ x^{8}+ x^{7}+ x^{5}+ x^{4}+ x^{2}+ x^{1}+1$

Catches all ≤ 32 bit error bursts and all odd length error bursts.

Medium Access Control

Requirements for a broadcast channel:

- *Give everyone a chance to speaks*
- *Don't speak until you are spoken to*
- *Don't monopolize the conversation*
- *Raise your hand if you have question*
- *Don't interrupt when someone is speaking*
- *Don't fall asleep when someone else is talking*

Channel Allocation Problem Model

- **Station Model** – N stations generating frames within Δt with probab. $\lambda\Delta t$.
- **Single Channel**
- **Collision Assumption**
- **Time**
  - Continuous Time
  - Slotted Time
- **Carrier**
  - Carrier Sense
  - No Carrier Sense

Solution – Multiple Access Protocol

Access protocol requirements for a *R* bps channel:

- When only one node has data to send, that node has a throughput of *R* bps.
- When *M* nodes have data to send, each of these nodes has an avg. throughput of *R/M* bps
- The protocol is decentralized, i.e., there are no master nodes that can fail and bring down the entire system
- The protocol is simple, so that it is inexpensive to implement

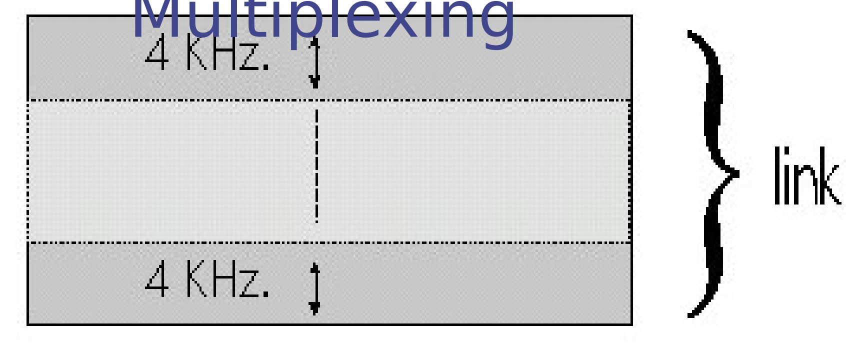
Multiple Access Protocols

- Channel Partitioning
- Random Access Protocols

Channel Partitioning

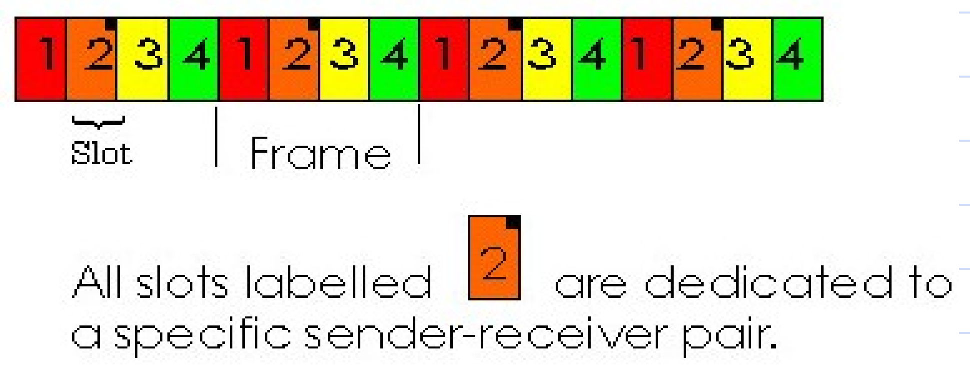
FDM

Frequency Division Multiplexing



TDM

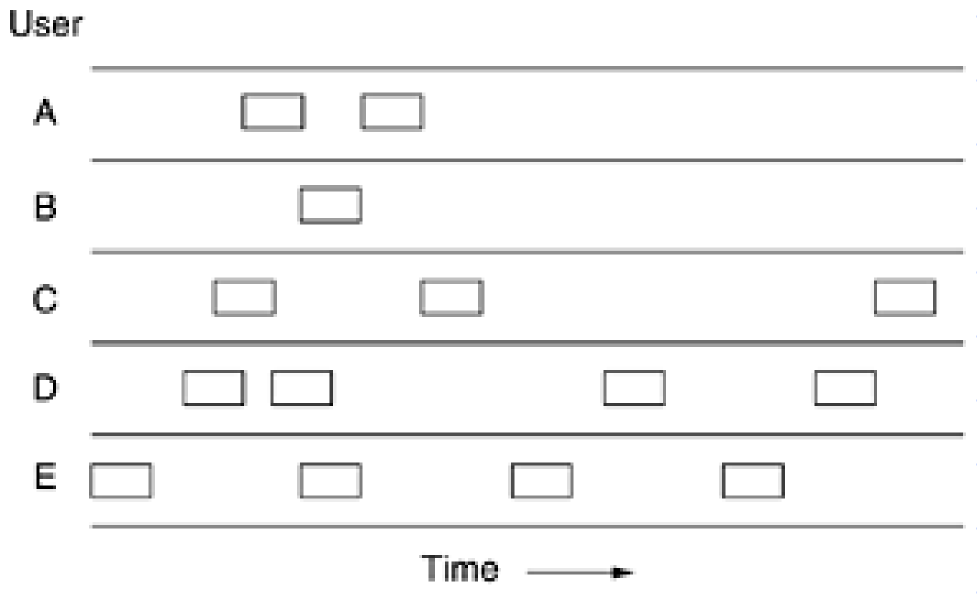
Time Division Multiplexing



Random Access Protocols

- ALOHA
  - Pure Aloha
  - Slotted Aloha
- CSMA (Carrier Sense Multiple Access)
  - CSMA
  - CSMA/CD – with **collision detection**

ALOHA



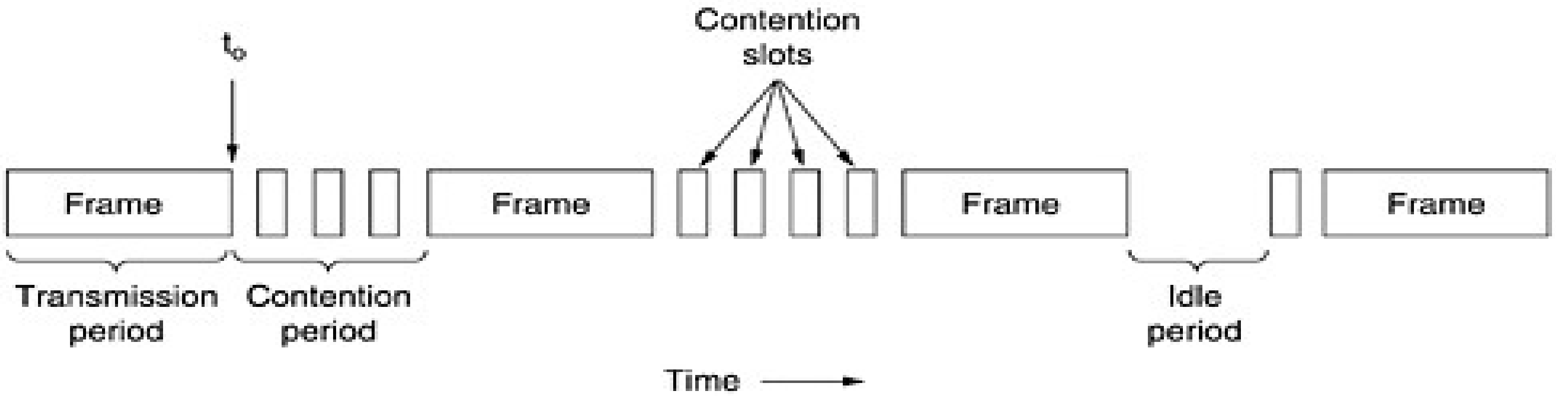
Users send data whenever they want

Two frames on the same channel – collision=> both frames are destroyed

CSMA

- 1-Persistent CSMA
- Non-Persistent CSMA
- P-persistent CSMA

CSMA/CD



- Sense the channel
- Stop sending when detecting collision
- After collision wait a random amount of time and try again.

Readings

- *Computer Networks* (A, Tannenbaum) – Chapters 3,4
- *Computer Networks: A top Down Approach Featuring the Internet* – Chapter 5