University of Pittsburgh

ECE 1150: Computer Networks

Data Link Layer – Error & Flow Control

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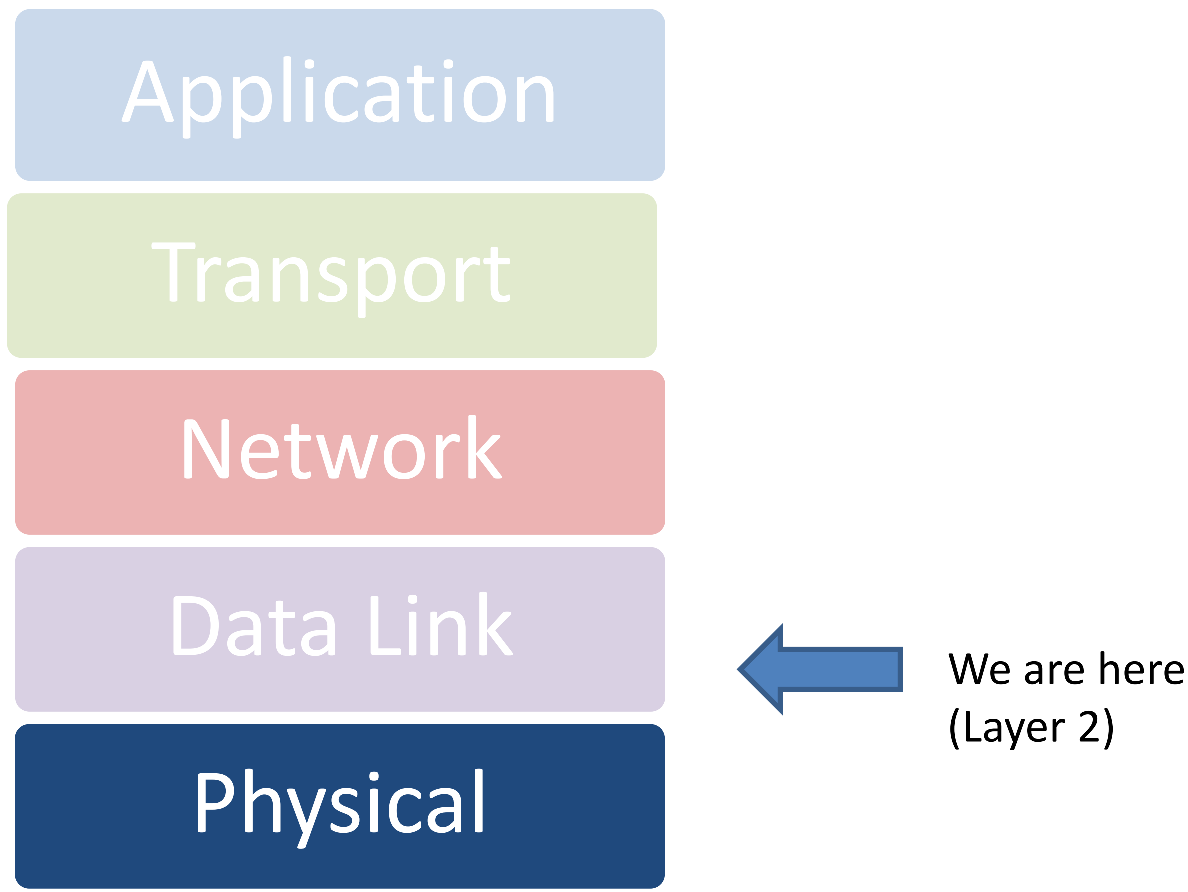
Previous Unit

- Data link layer functions
- Medium access control (MAC) protocols

Context


Application
Transport
Network
Data Link
Physical
We are here
(Layer 2)

Error Control

- Errors occur in transmissions
  - **Imperfections** of the physical **medium**
    - Noise from power spikes, outages etc.
  - **Collisions**

- Networks should be designed with:
  - Error prevention
  - Error detection
  - Error correction

Impact of error on throughput

- Let P be the probability that a frame will be corrupted (e.g. due to collisions)
  - 1–P is the probability of successful transmission

- Throughput = (1-P) x Useful data / (Delay when attempt is successful)

Objectives of the rest of this unit

- Explain the how errors control strategies at the link layer
  - Error detection
  - Error correction
  - Flow control

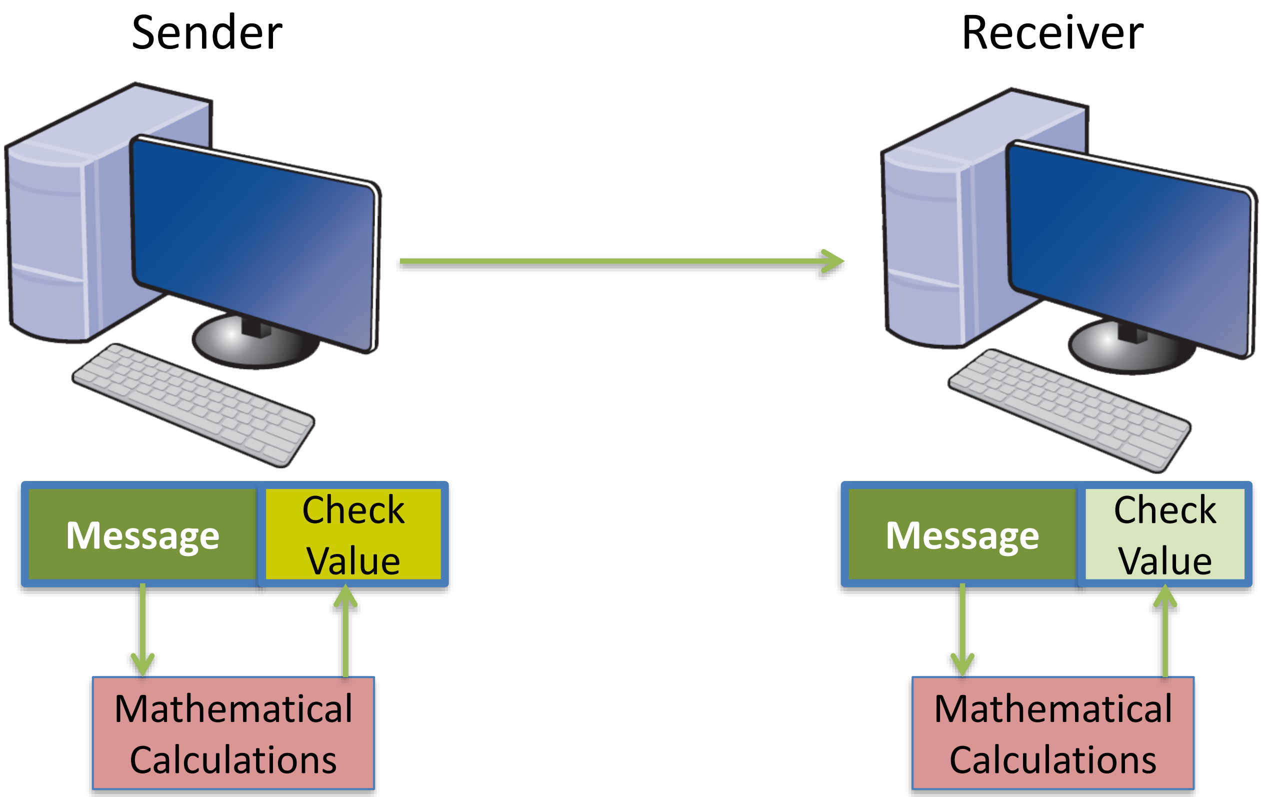
Slide modified from Agrawal

Error correction in computer communication by adding metadata

- The general approach to error detection in data communications is to **add some meta-data to the original data**
  - The meta-data is generated from the data itself
  - The receiver use the meta-data to check if error exists

Error Detection

- Both sender and receiver calculate check value
- Receiver tests whether the check values match



Ref.: Fitzgerald et al.

- Can metadata be of any size?

Error Detection Schemes

- Parity check
- Checksum
- Cyclic redundancy check (CRC)

Error Detection: Parity Check

- Parity check
  - 1-bit check value
  - Based on the number of 1’s in the message
  - Two techniques:
    - Even parity: total number of 1’s with remains even
    - Odd parity: total number of 1’s remains odd
  - Simple, but only detects odd number of errors

<u>Example (Even Parity)</u>

Character: ‘A’
Binary: 01000001

Add Parity Bit: 0
(to make total even)

Character: ‘C’
Binary: 01000011

Parity Bit = 1
‘C’ has odd number of ones (3 ones), if we use <u>even parity</u> we add 1 to make the total even (4 instead of 3)

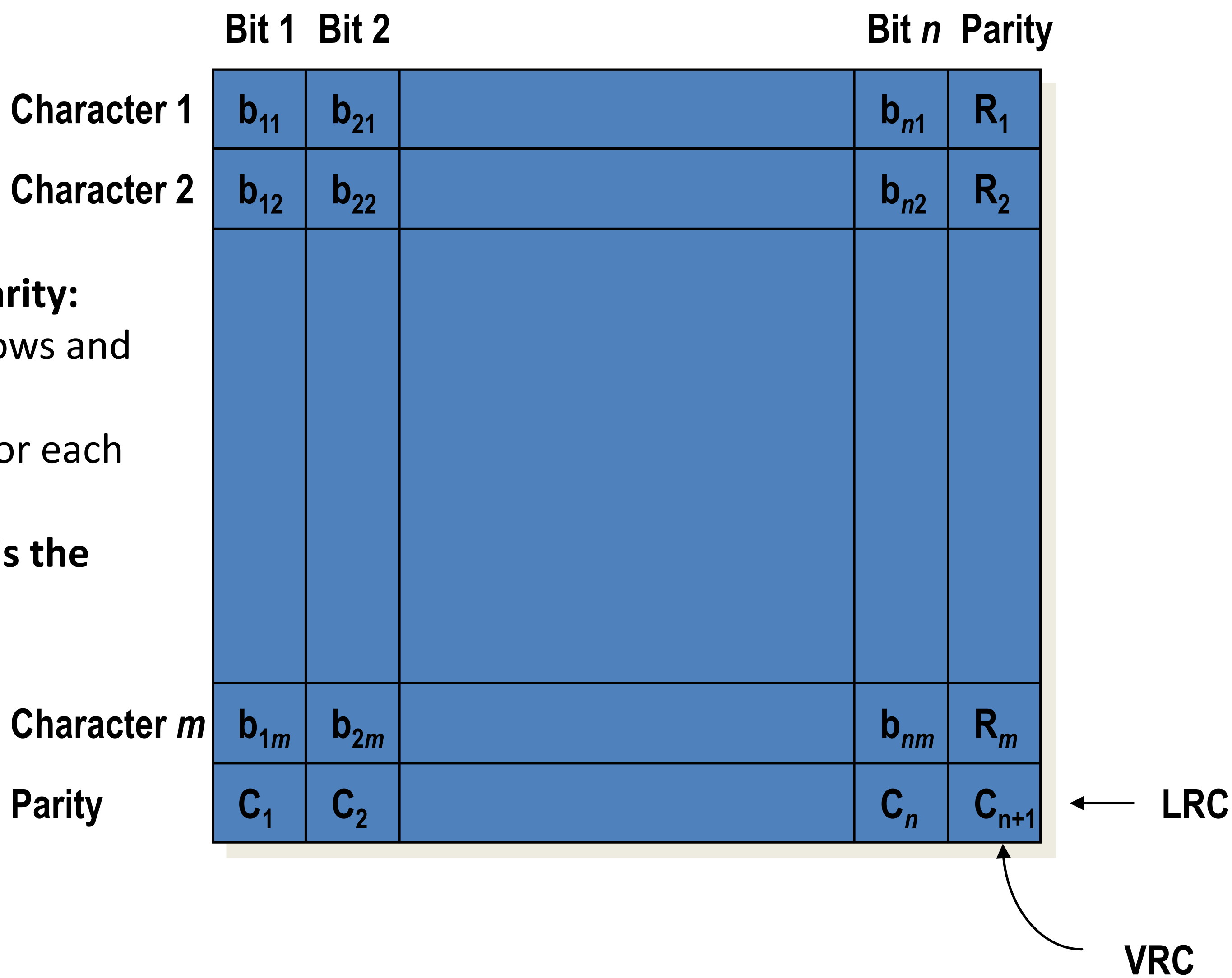
Tophat

Q_Odd parity

If we are using odd parity, then for the sequence 01000011 we append

A	bit '0'
B	bit '1'

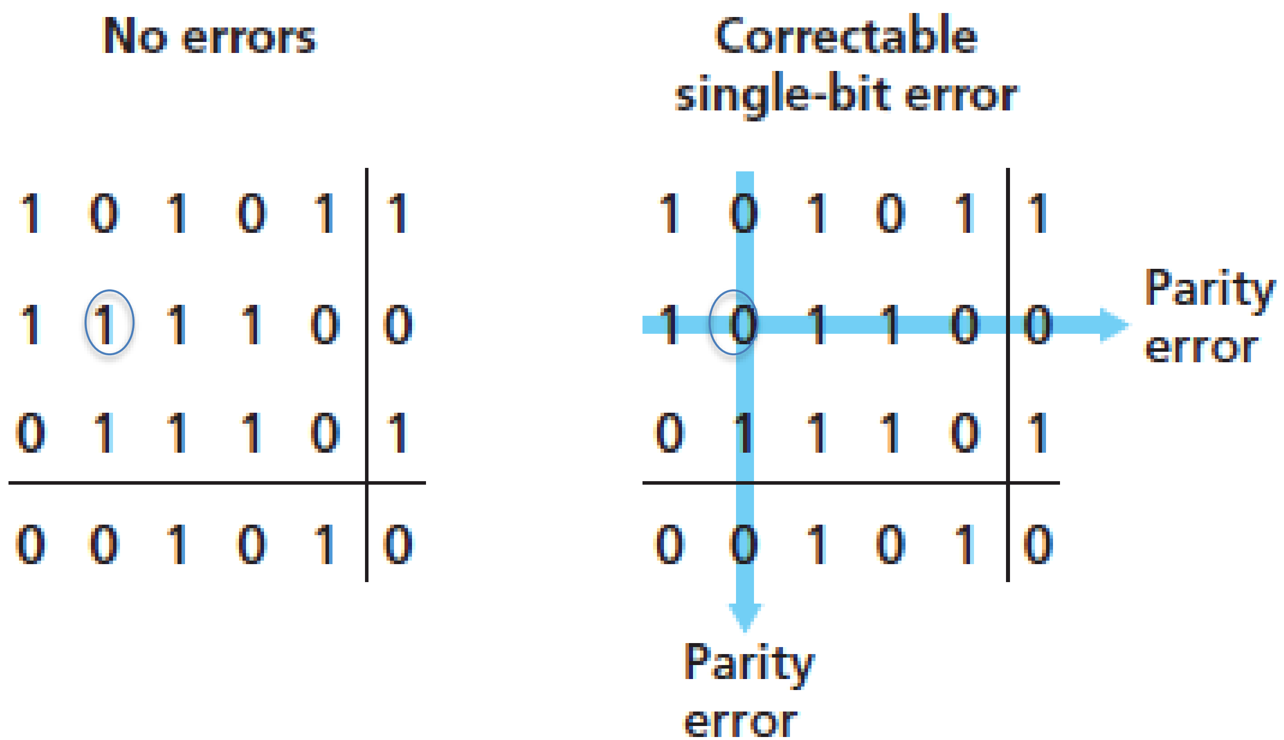
Error Detection: Vertical and Longitudinal Parity Checks



- **Two-dimensional parity:** data is divided into rows and columns
- Parity is computed for each row and column
- **Can identify where is the error**

Error Detection: Vertical and Longitudinal Parity Checks - Example

- Identify errors and correct them
  - Example: Even parity is used for each row and each column



Error Detection: Checksum

- 1-byte (typically) is used as check value
- Checksum algorithms vary in the creation of check values
- Common approach: adds the decimal representation of each character (8 bits), then divide by 256
  - Append the remainder to data

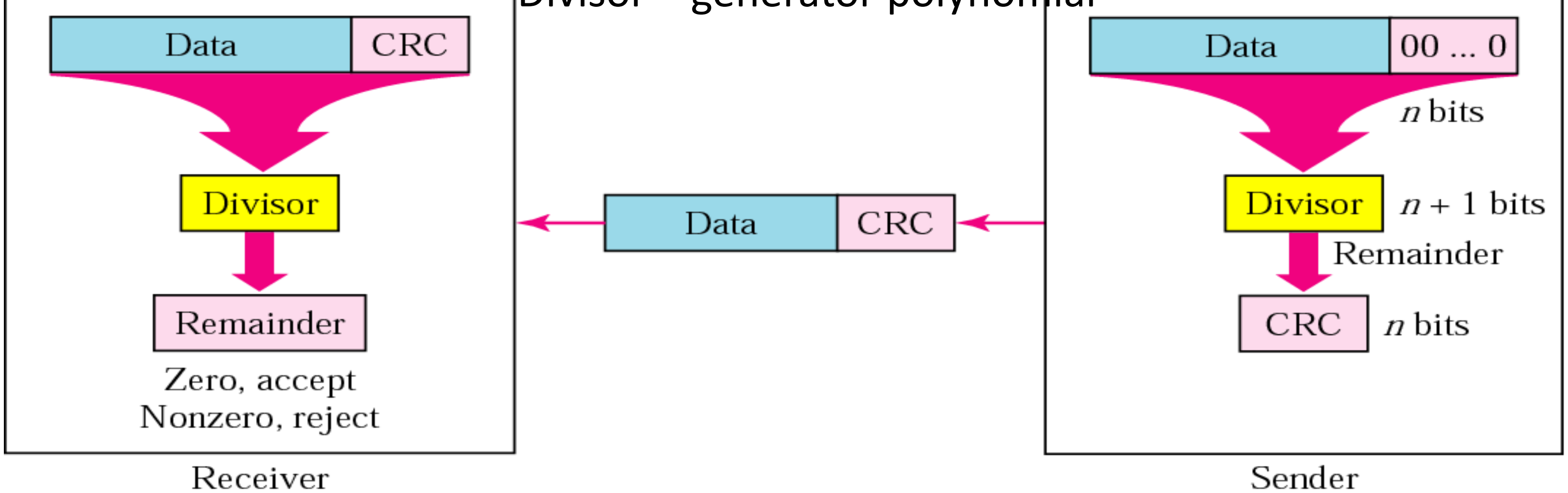
Polynomials

- Each bit sequence can be represented as a polynomial
  - $[b_{n-1} \ldots b_2\, b_1 b_0]$=> $m(x) = b_{n-1}\, x^{n-1} + \ldots + b_1\, x^1 + b_0\, x^0$
  - Note that $x^0 = 1$
  - Example: represent 11000101 in a polynomial
    - 11000101 => $x^7 + x^6 + x^2 + 1$
    - *8 bits* ➔ *<u>Degree</u> of polynomial (largest power of x) is = 7*
- When the generator polynomial g = [1 1 0 1] =>
  - $g(x)=x^3+x^2+1$,
  - Generator polynomial is $g(x)$ of <u>degree</u> $n = 3$

Error Detection: CRC

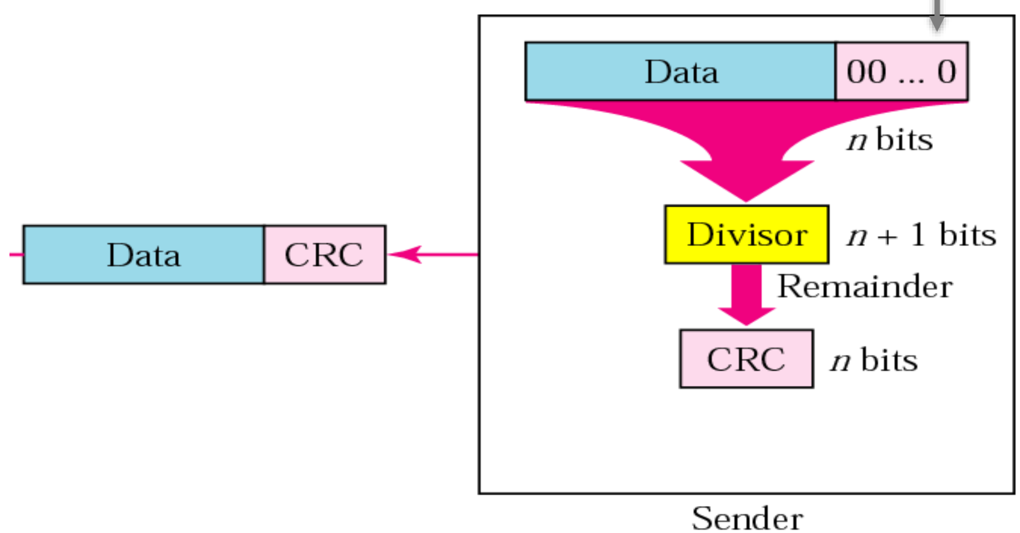
- Treats message as a single binary number
- Sender and receiver must **agree** on a **pattern** of n+1 bits, known as **generator polynomial or divisor**
  - n is degree of the polynomial
- **CRC** is the **remainder** with data is divided by divisor
- International standards define: **8, 12, 16** and **32 bits** CRC
  - degree of polynomial= number of bits appended

Divisor = generator polynomial



CRC Sender Procedure

- **Step 1:** User data is dividend, technology specifies a **divisor**
- **Step 2:** At sender, **add n zeros** to the **end** of the data (divisor has n+1 bits)
- **Step 3:** At sender, **perform modulo-2 division** of appended data with divisor
- **Step 4:** At sender, **append remainder** to data as CRC and send to receiver



CRC Receiver Procedure

- Step 5: At receiver, perform modulo-2 division of entire frame (data & CRC) with same divisor
  - Divisor is known because it is specified by technology
- Step 6: At receiver, if remainder = 0, accept data (no errors).
  - Else remainder $\neq$ 0, error detected => reject data

Error Detection: CRC

- Divisions in the CRC operations are modulo-2:
  - Like regular long division, however addition and subtraction and equivalent to bitwise XOR (Exclusive OR)
    - 0 – 0 = 0
    - 0 – 1 = 1
    - 1 – 0 = 1
    - 1 – 1 = 0

Example

- Example: Message: [101010],
  divisor =g = [1101],
  get CRC bits.

CRC – Sender Operation

Message: [101010], divisor = [1101] ➔ n+1=4, n=3

User data (Message)

n=3, 0's appended

							1	**1**	**0**	**1**	**1**	**1**
1	1	0	1	1	0	1	0	1	0	0	0	0
				1	1	0	1	⋮	⋮	⋮	⋮	⋮
					1	1	1	1	⋮	⋮	⋮	⋮
					1	1	0	1	⋮	⋮	⋮	⋮
							1	0	0	0	⋮	⋮
							1	1	0	1	⋮	⋮
								1	0	1	0	⋮
								1	1	0	1	⋮
									1	1	1	0
									1	1	0	1
										0	1	1

Divisor
$g(x)=x^3+x^2+1$

Send: 101010 011

CRC remainder

CRC – Receiver Operation

Data from sender

CRC from sender

							1	**1**	**0**	**1**	**1**	**1**
1	1	0	1	1	0	1	0	1	0	0	1	1
				1	1	0	1	⋮	⋮	⋮	⋮	⋮
					1	1	1	1	⋮	⋮	⋮	⋮
					1	1	0	1	⋮	⋮	⋮	⋮
							1	0	0	0	⋮	⋮
							1	1	0	1	⋮	⋮
								1	0	1	1	⋮
								1	1	0	1	⋮
									1	1	0	1
									1	1	0	1
										0	0	0

Divisor

NO ERRORS ← **Remainder is 0**

Another Method: Get CRC using Polynomials

- Generator polynomial: g = [1 1 0 1] => $g(x)=x^3+x^2+1$
  - Degree: n =3
- Append n zeros to the message then get polynomial representation
  - Message|000: [1 0 1 0 1 0 0 0 0] => m(x) = ?

    – OR we can get the polynomial of message then multiply by x^n

– Divide by g(x)

– The remainder is the CRC = x+1 => [0 1 1]
  - It should be n bits, so we add zero at the most significant bit

– Similarly, the received sequence with no errors is: [101010 011] => r(x)=?
  - When you divide by g(x) the remainder will be zero. Try it.

Slide modified from Agrawal

Cyclic redundancy check (CRC)

- Most commercial data communication technologies use CRC
- CRC-32 is used in Ethernet
  - CRC-32: generator polynomial of degree 32. This also means that 32 CRC bits will be appended to data
- The generator polynomial is

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

See also: http://www.xilinx.com/support/documentation/application_notes/xapp209.pdf

Slide modified from Agrawal

CRC-32 capabilities

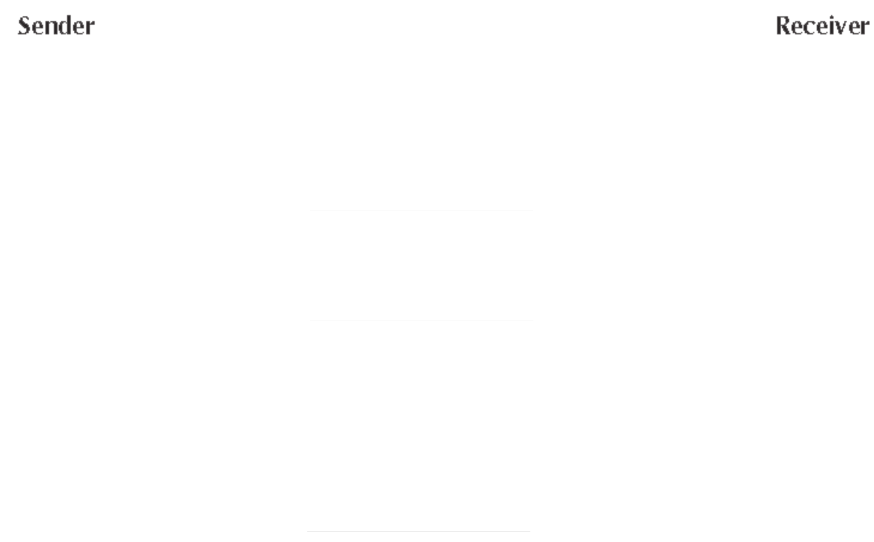
- CRC-32 can detect <u>all</u> errors affecting <u>less</u> than 33 [which is n + 1] bits
- CRC-32 can reasonably detect errors affecting more than 33 bits

Error Correction

- Once detected, errors must be corrected
- Error correction techniques
  - **Retransmission** (or backward error correction)
    - Retransmission is simple and most common
    - **Automatic Repeat reQuest (ARQ)**
      - **Stop-and-wait ARQ**
      - **Continuous ARQ**
  - Forward error correction
    - Receiving device can correct messages without retransmission.. Instead use channel coding techniques(think of repetition code)

Error Correction: Stop-and-Wait ARQ

- Stop-and-wait ARQ
  1. Receiver receives frame and sends:
     - Acknowledgement (ACK) <u>if no error</u>
     - Negative acknowledgement (NAK) <u>if error</u>
  2. If NAK, sender re-sends data



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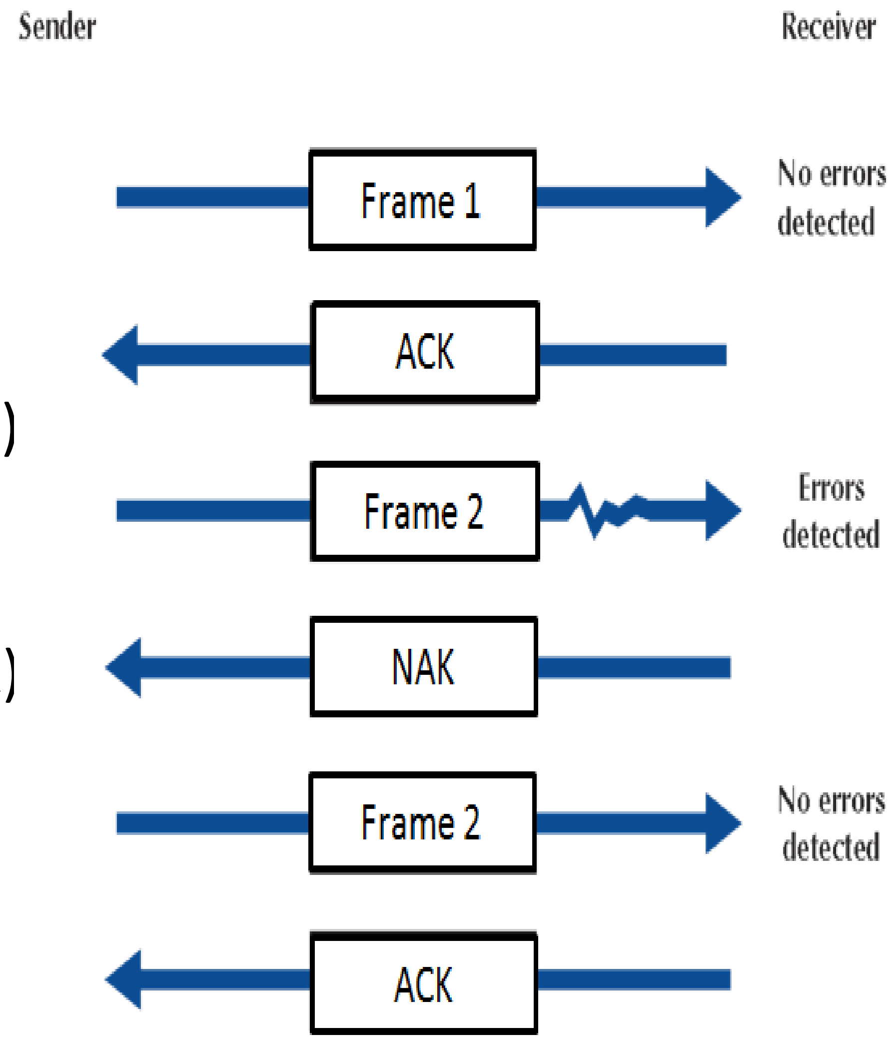

Error Correction: Stop-and-Wait ARQ

- Stop-and-wait ARQ
  3. If no ACK or NAK, Sender retransmits frame after "timeout"
  4. If no ACK, sender re-sends data, receiver sends ACK and deletes duplicate frame

Sender

Receiver

Error Correction: Stop-and-Wait ARQ

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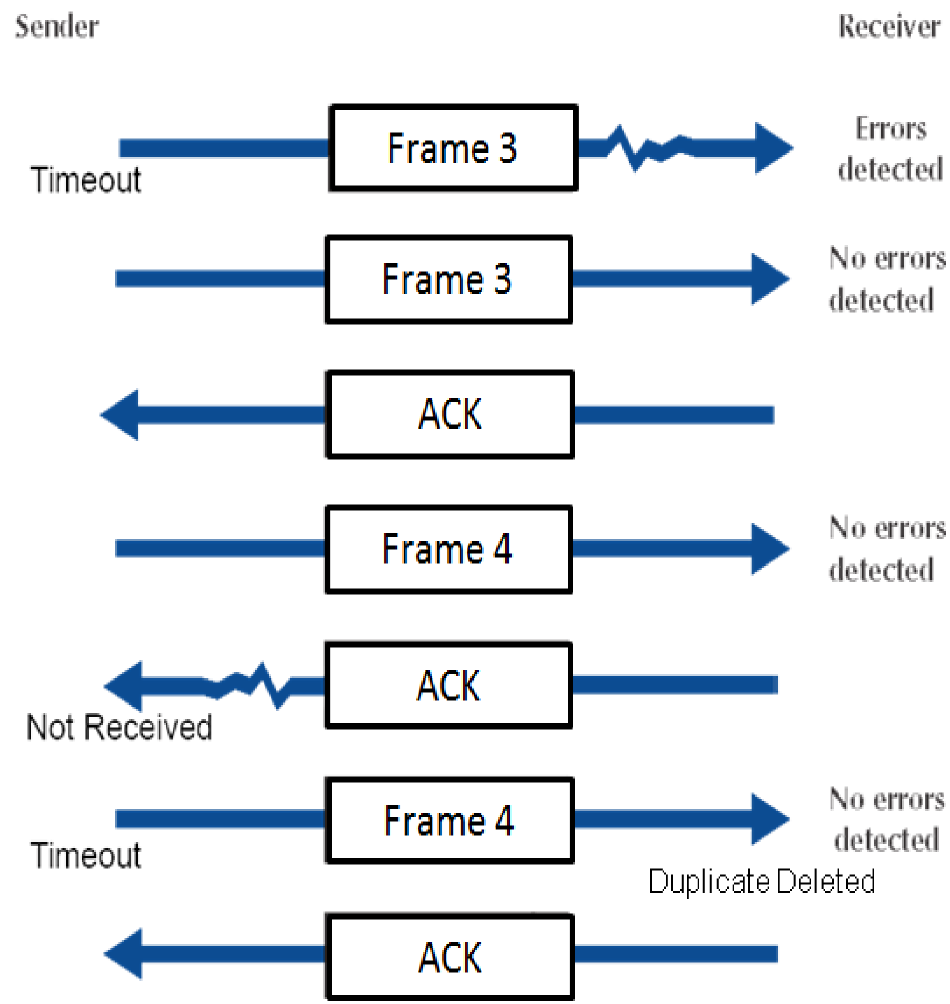


Error Correction

Here, window size is 2

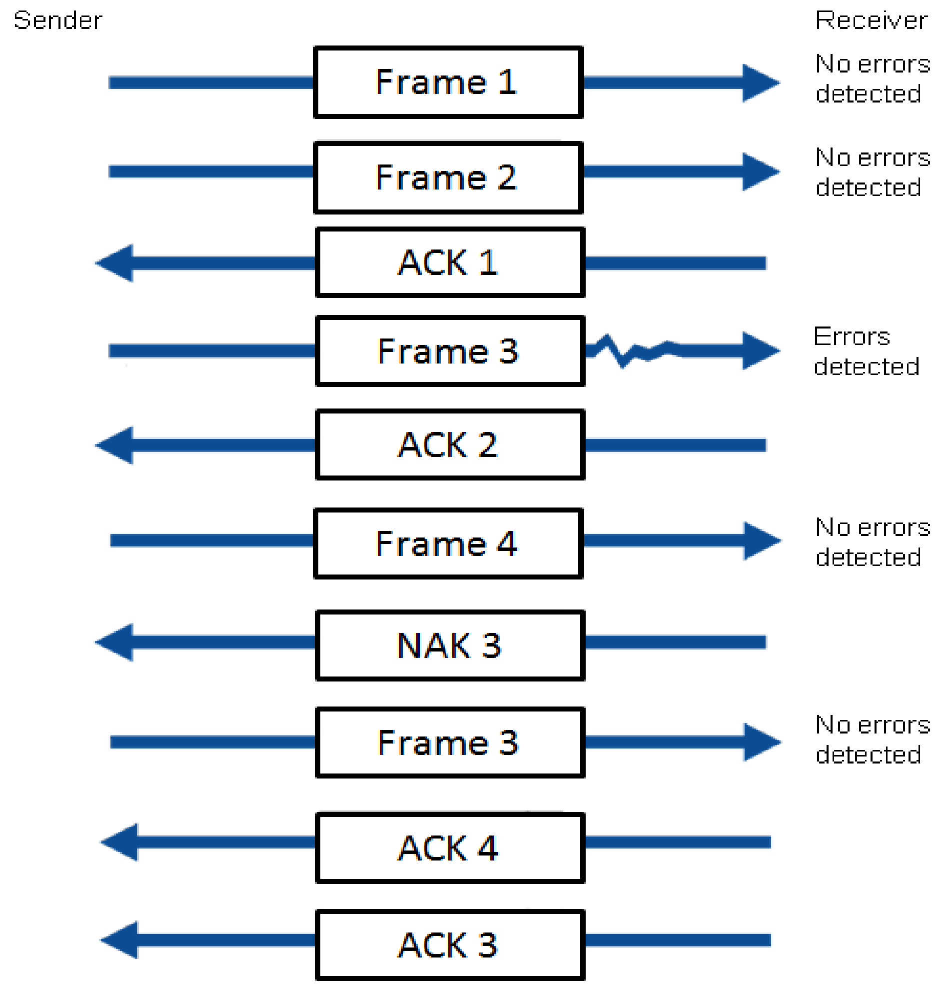
Sender

Receiver

- Continuous ARQ
  - Sender does not wait for ACKs before sending more data
  - "**Sliding window**" is number of frames allowed to be unacknowledged by receiver
    - That is you can send more than one packet before receiving an ACK
  - Number of packets that can be sent depends on window size
    - Window size is **agreed upon by sender and receiver at the beginning**

Error Correction: Continuous ARQ

- Continuous ARQ
  - Sender does not wait for ACKs before sending more data
  - "Sliding window" is number of frames allowed to be unacknowledged by receiver
  - Agreed upon by sender and receiver at the beginning



Here, window size is 2

Tophat

Q_Throughput of ARQ

We expect that throughput using stop-and-wait ARQ

A	is higher than that can be obtained from continuous ARQ
B	is lower than that can be obtained from continuous ARQ

- ARQ is useful in flow control by limiting the number of packets received

Sliding Window

- If an error occurs
  - Transmitter resends everything since the error (Go-Back-N)
  - Only the packet that has errors (Selective Retransmission)

Sliding Window (Go-Back-N)

Key Takeaways

- Important function at Data Link layer is error control
- Error detection
  - Append extra bits for error detection
  - Parity, checksum, CRC
  - CRC is commonly used and is more robust
- Error Correction through retransmission
  - Stop and wait ARQ
  - Continuous ARQ
    - Define sliding window, which is maximum number of frames that can be transmitted before an ACK is received
    - Implement flow control by defining limit on the window size