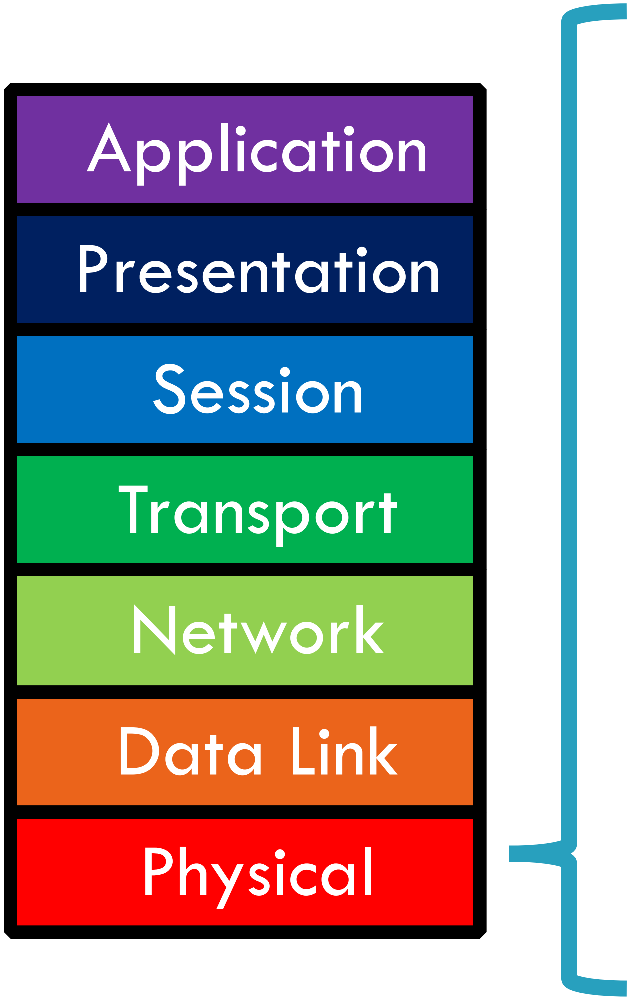
CS 3700

Networks and Distributed Systems

Lecture 3: Physical and Data Link

Revised 1/14/13

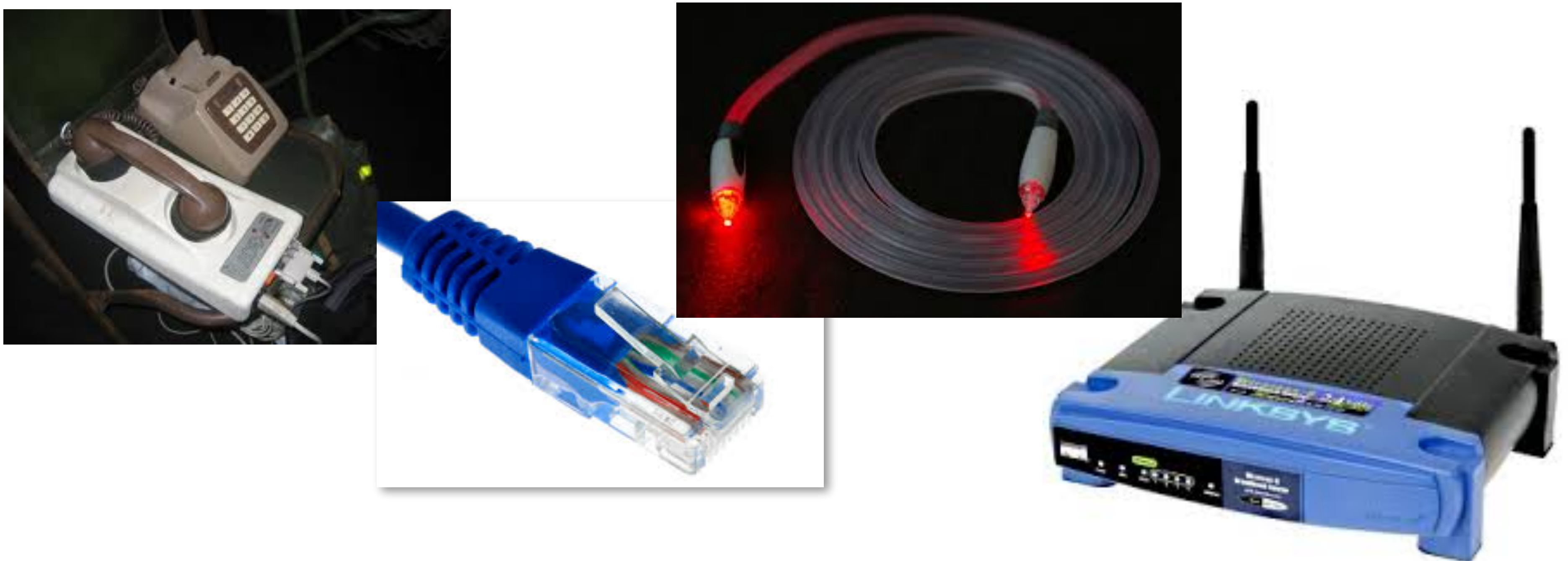
Physical Layer



- Function:
  - Get bits across a physical medium
- Key challenge:
  - How to represent bits in analog
  - Ideally, want high-bit rate
  - But, must avoid desynchronization

Key challenge

- Digital computers
  - 0s and 1s
- Analog world
  - Amplitudes and frequencies



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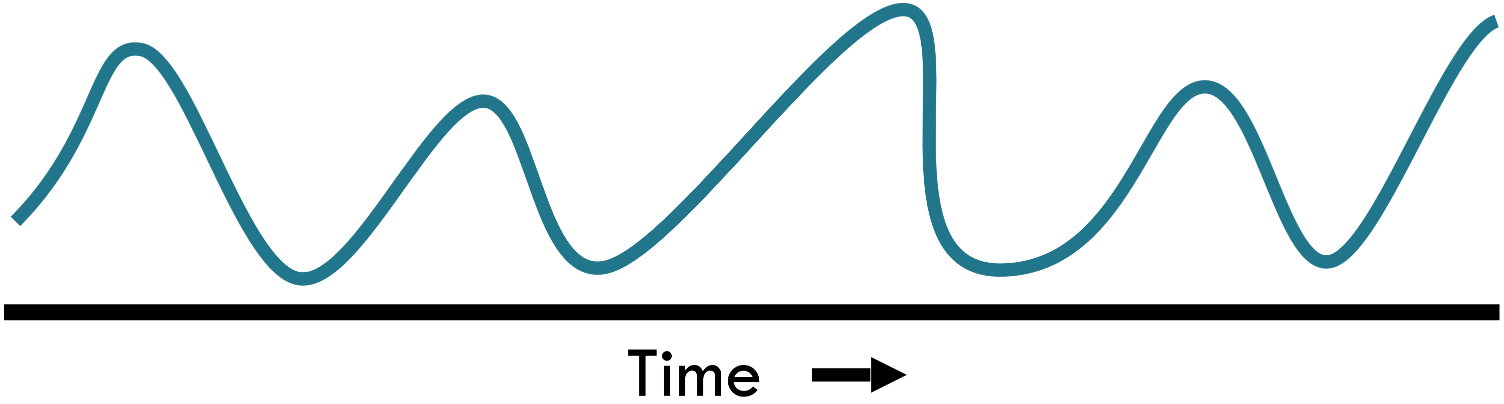

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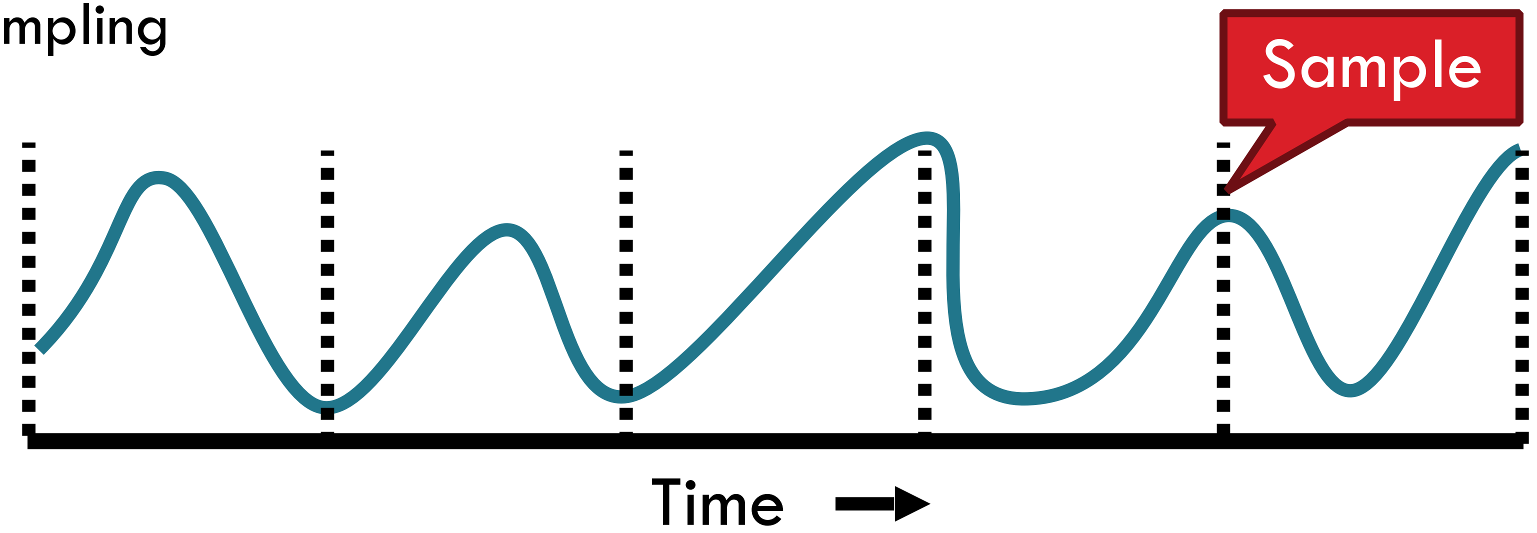

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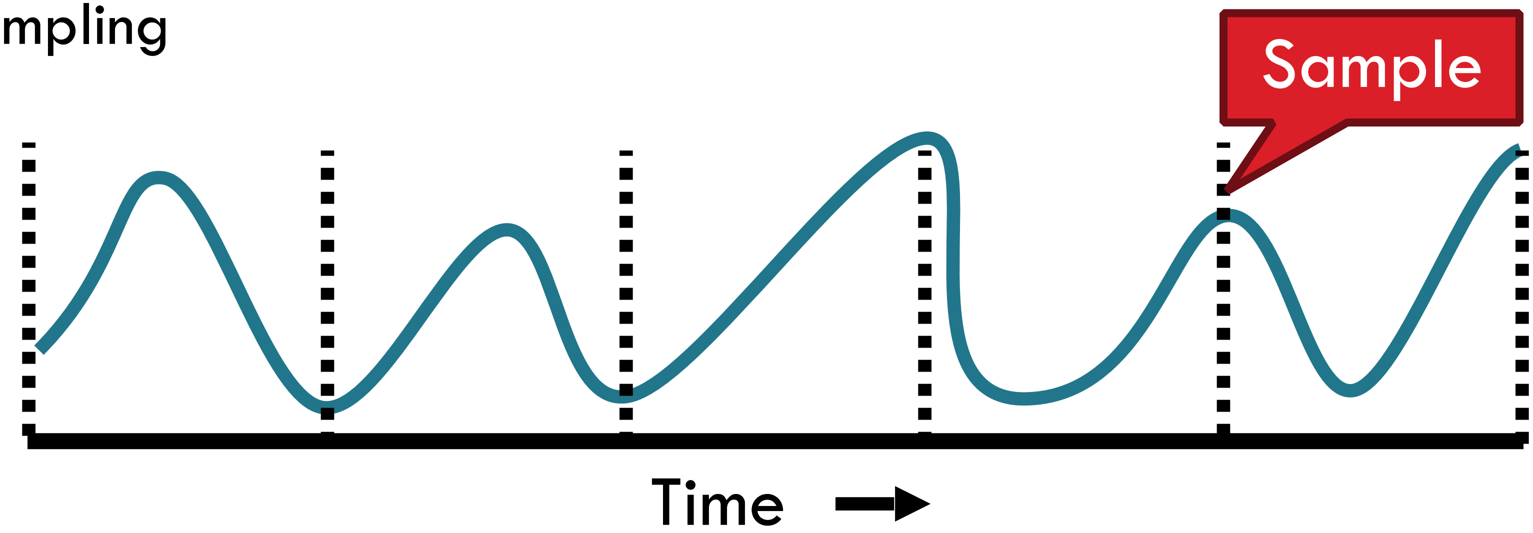
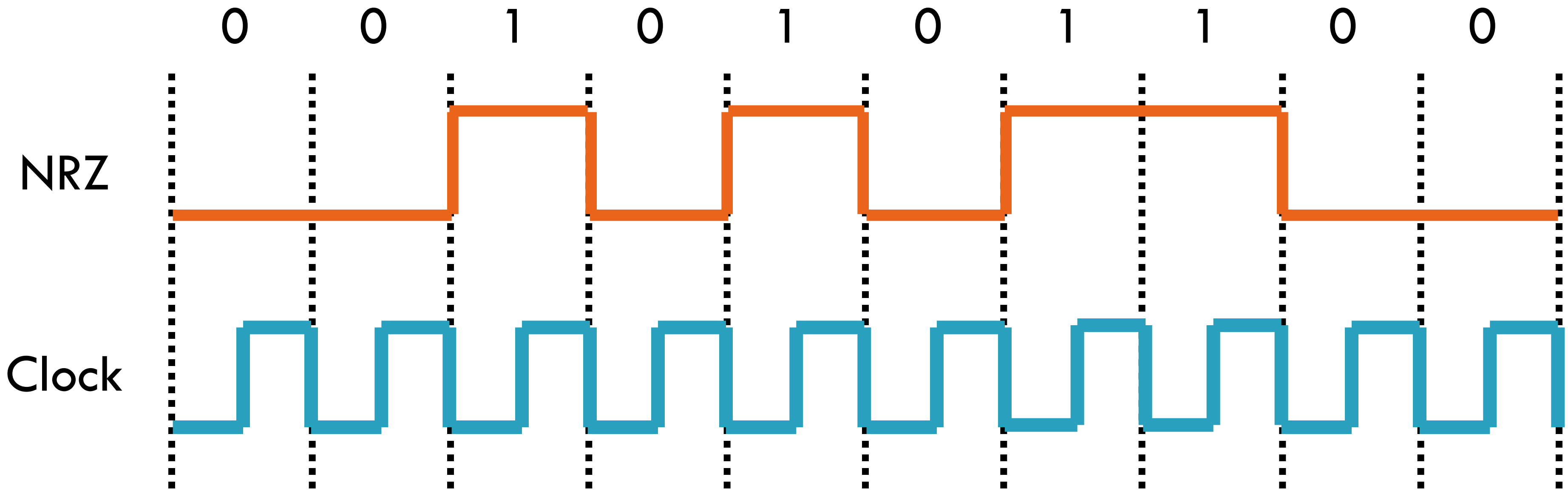


- Amplitude and duration of signal must be significant

Non-Return to Zero (NRZ)

- 1 → high signal, 0 → low signal



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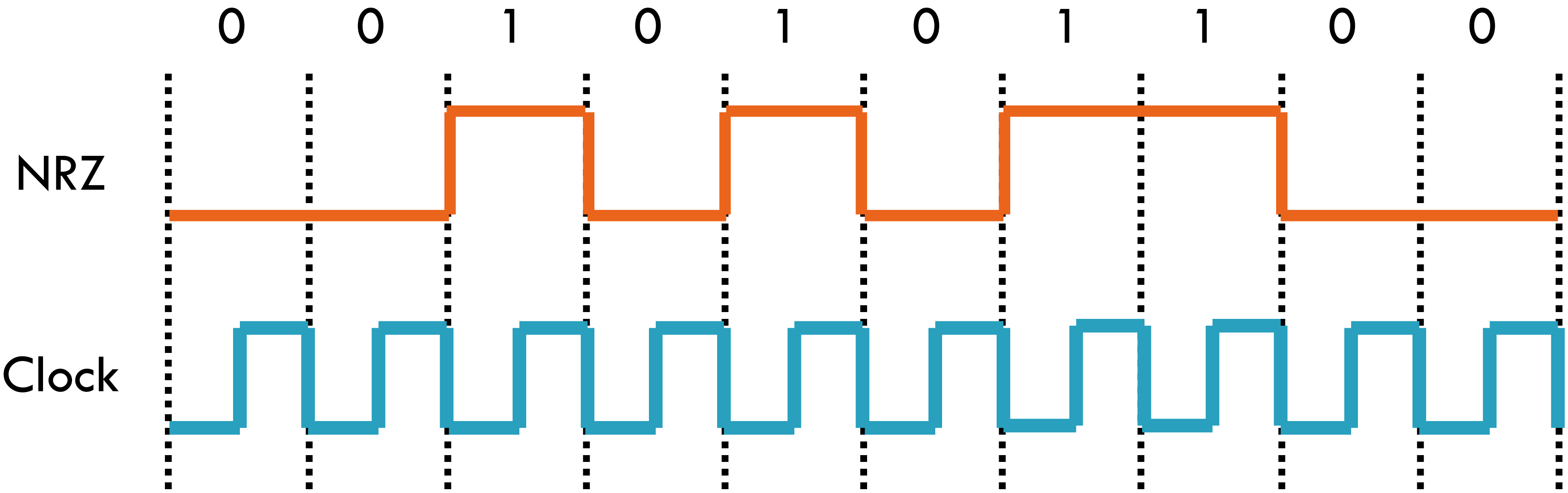
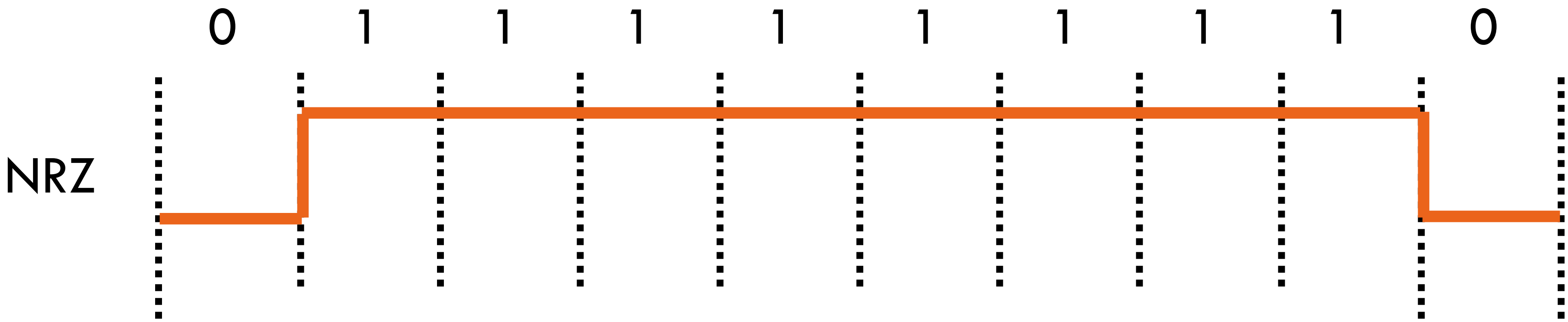


- Problem: long strings of 0 or 1 cause desynchronization
  - How to distinguish lots of 0s from no signal?
  - How to recover the clock during lots of 1s?

Desynchronization

- Problem: how to recover the clock during sequences of 0's or 1's?



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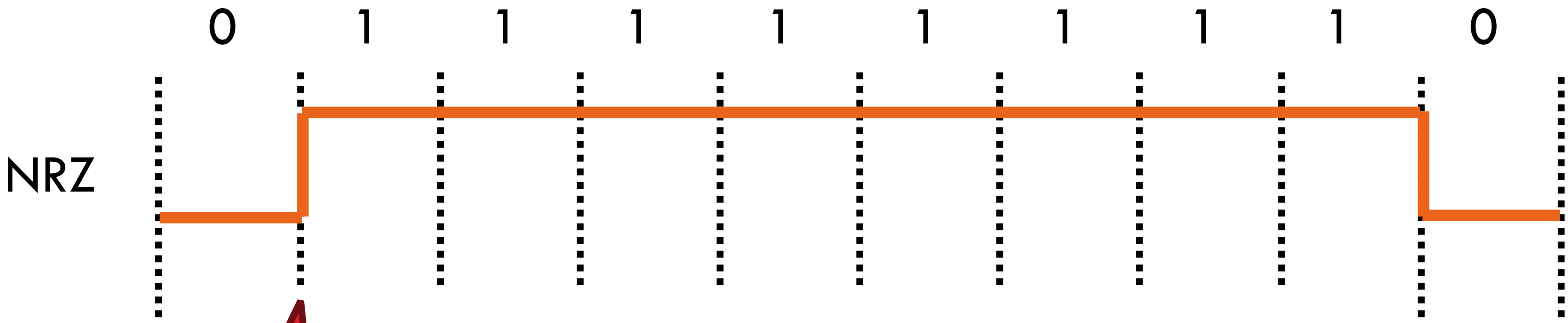

Transitions signify clock ticks

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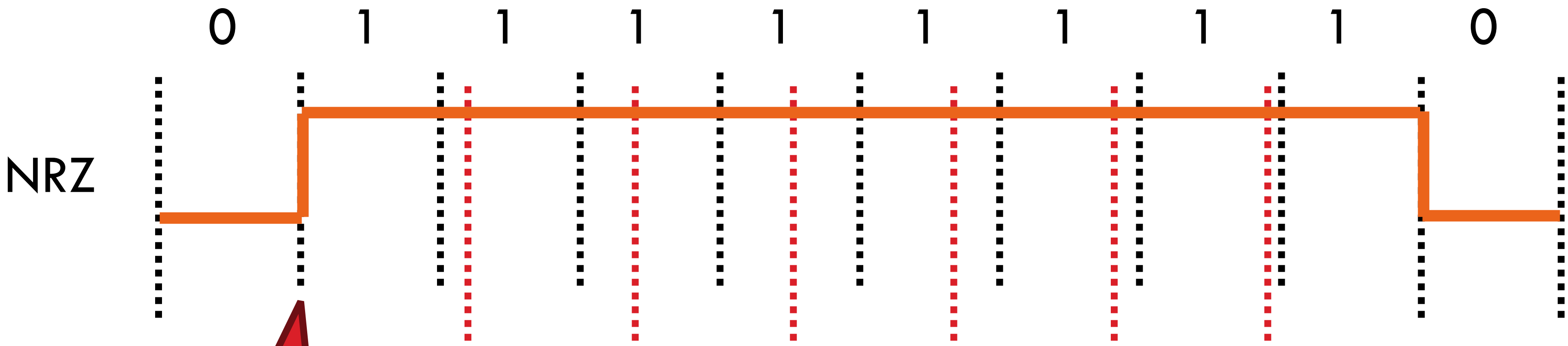

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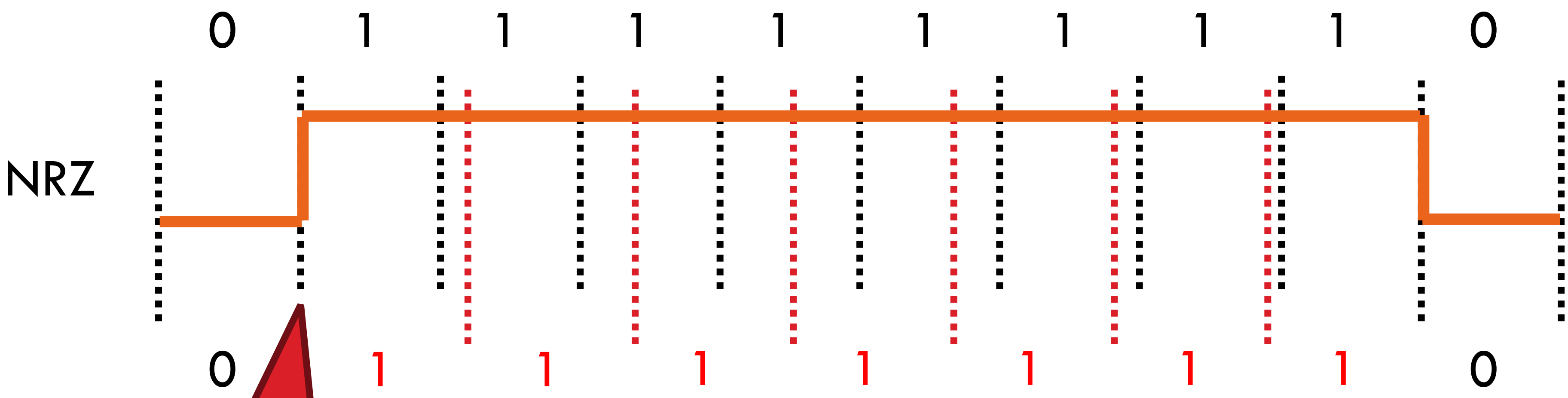

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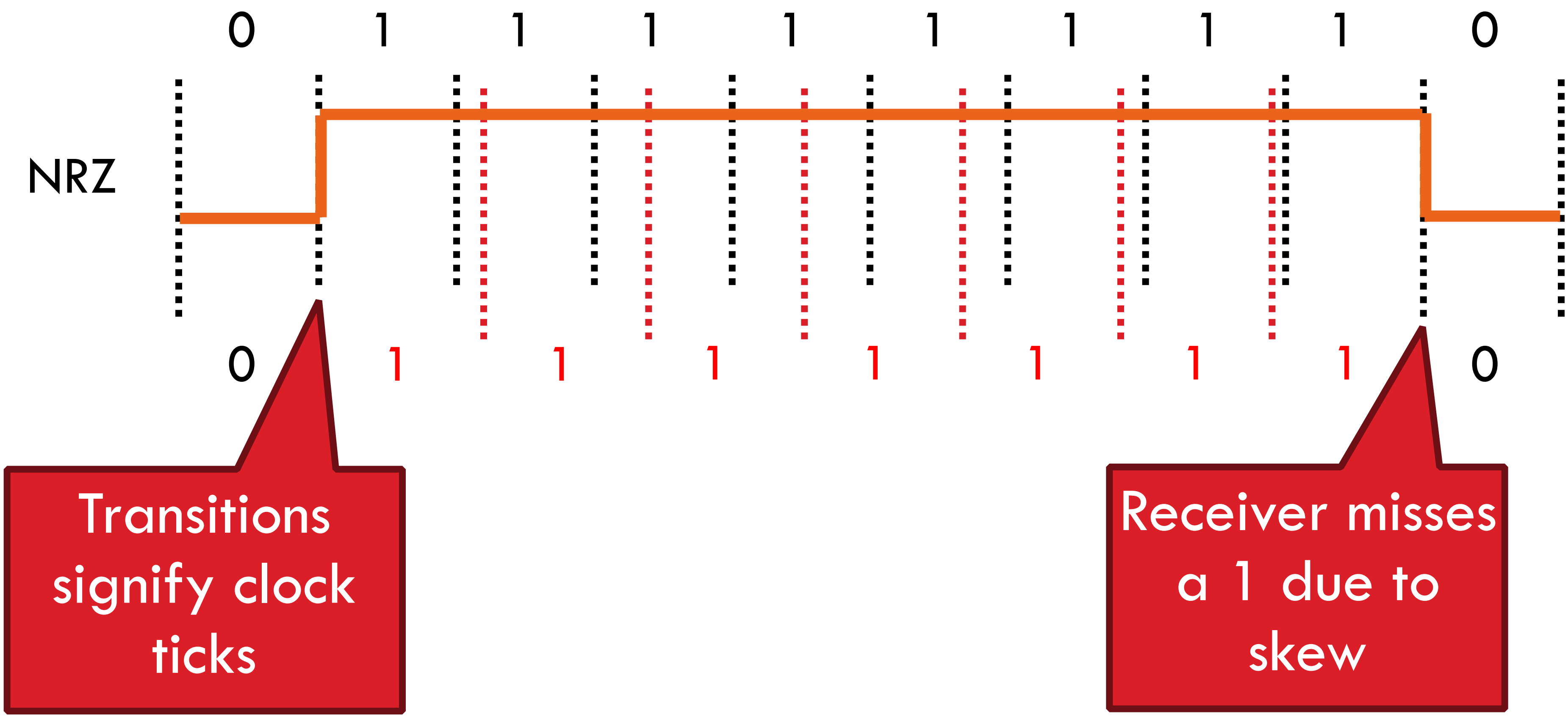
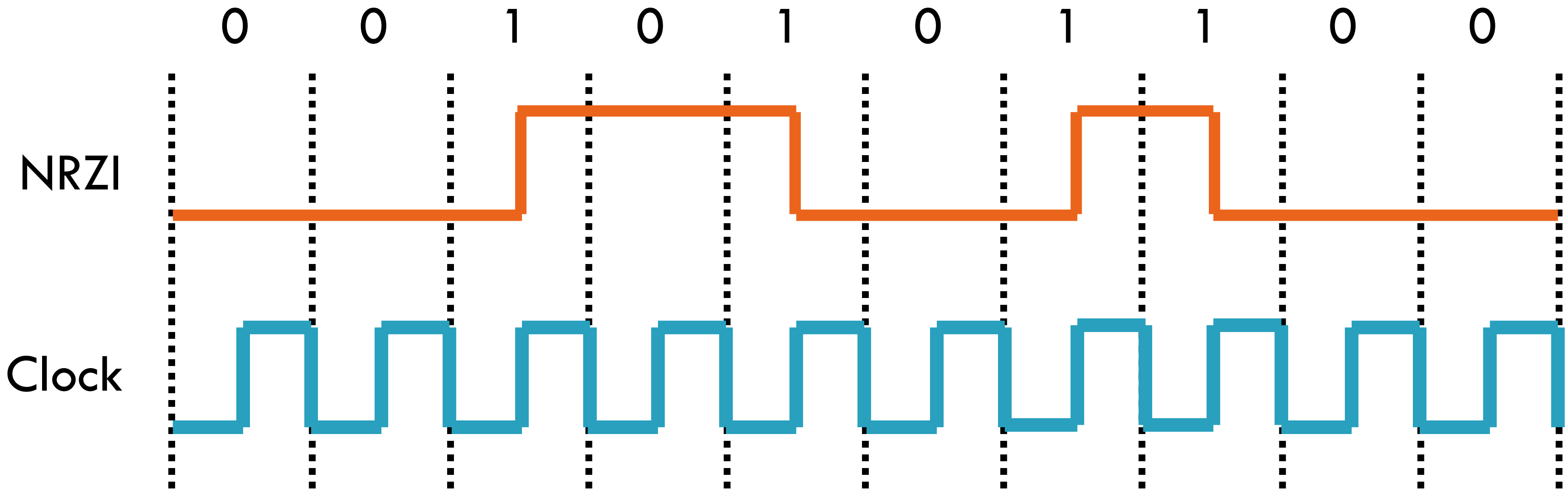


Transitions signify clock ticks

Receiver misses a 1 due to skew

Non-Return to Zero Inverted (NRZI)

- 1 → make transition, 0 → remain the same



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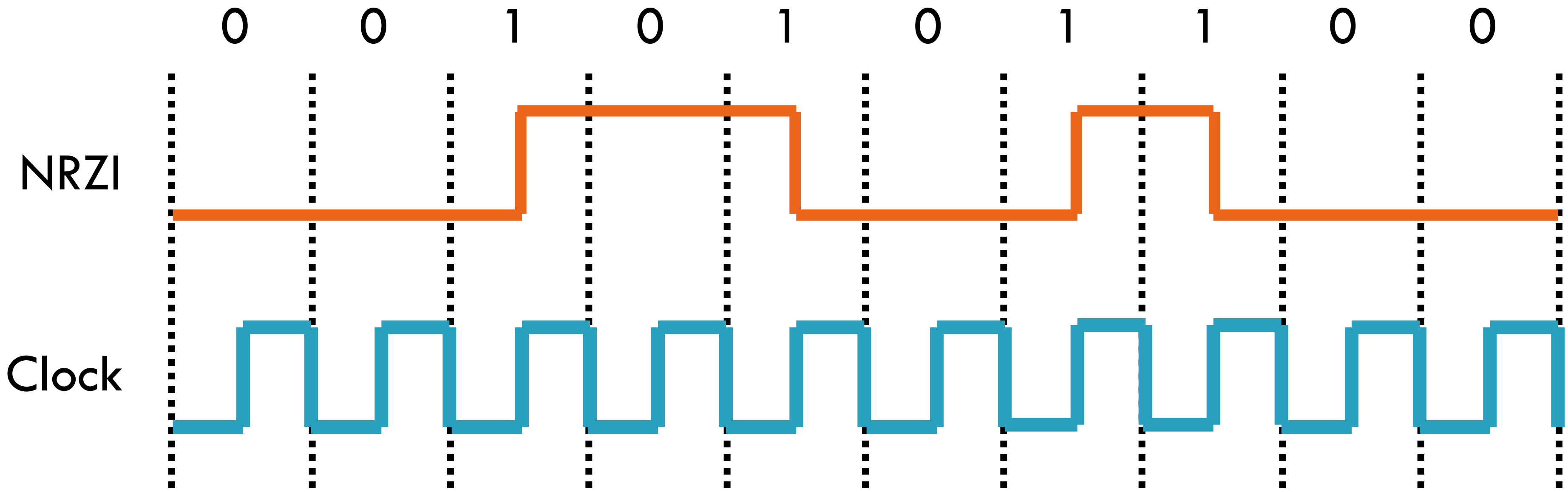

- Solves the problem for sequences of 1s, but not 0s

4-bit/5-bit (100 Mbps Ethernet)

4-bit	5-bit
0000	11110
0001	01001
0010	10100
0011	10101
0100	01010
0101	01011
0110	01110
0111	01111

4-bit	5-bit
1000	10010
1001	10011
1010	10110
1011	10111
1100	11010
1101	11011
1110	11100
1111	11101

4-bit/5-bit (100 Mbps Ethernet)

- Observation: NRZI works as long as no sequences of 0
- Idea: encode all 4-bit sequences as 5-bit sequences with no more than one leading 0 and two trailing 0

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- Tradeoff: efficiency drops to 80%

4-bit/5-bit (100 Mbps Ethernet)

8-bit / 10-bit used in Gigabit Ethernet

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0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
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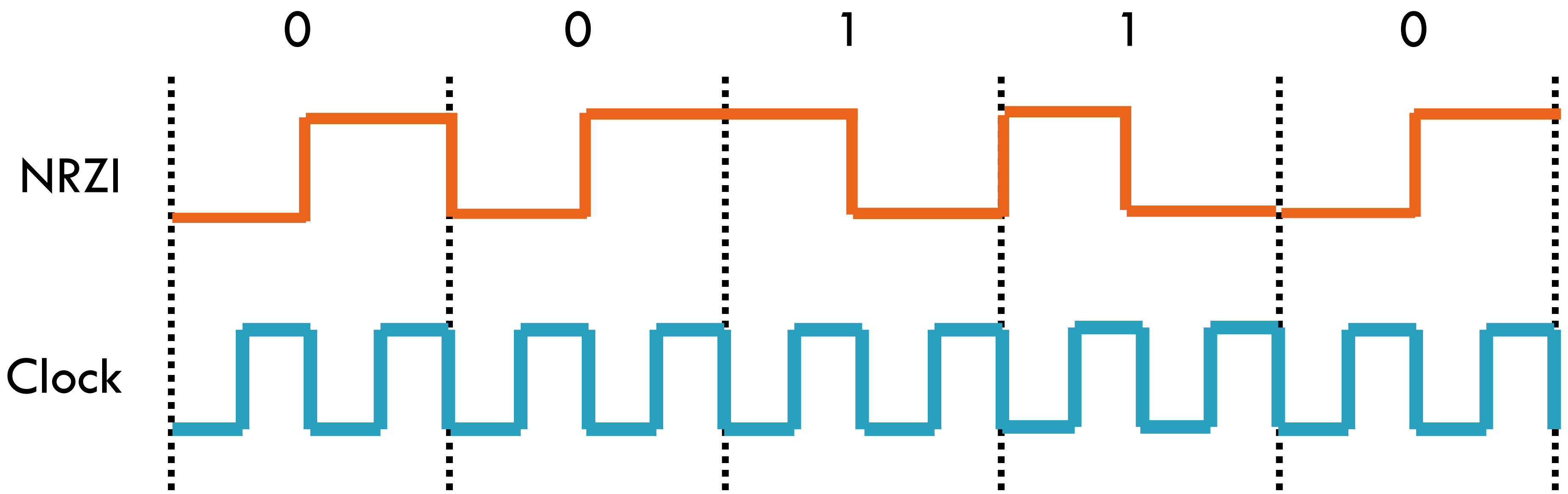
Manchester

- 1 → high-to-low, 0 → low-to-high



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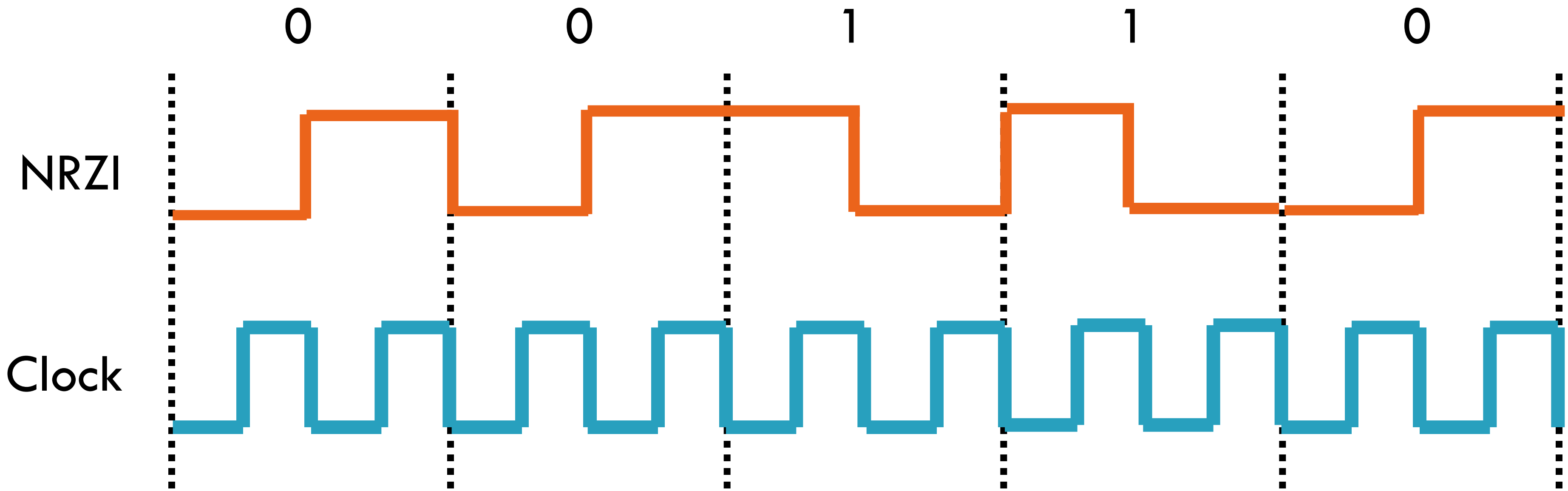


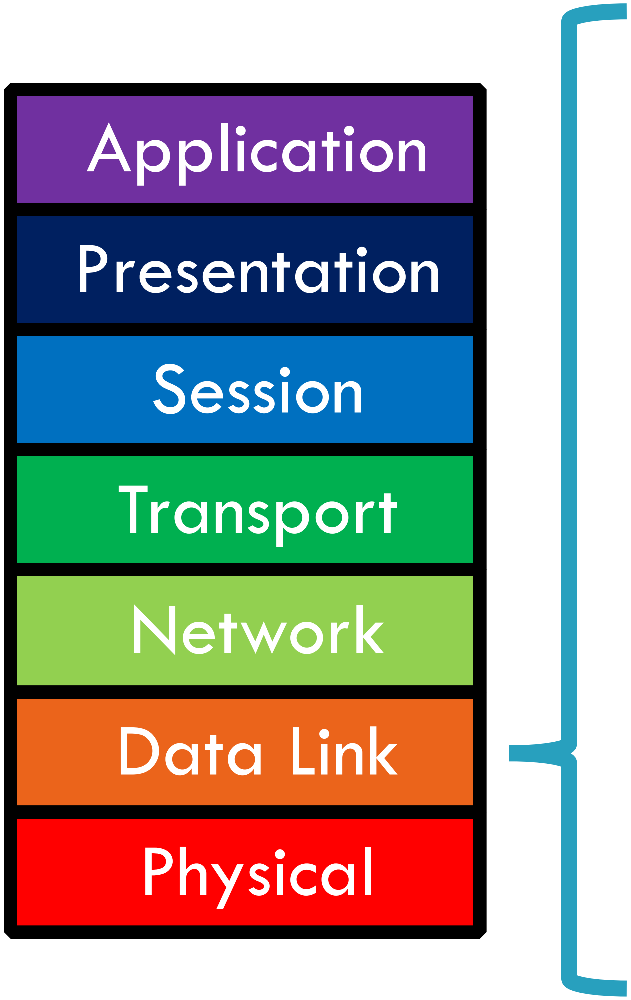
- Good: Solves clock skew (every bit is a transition)
- Bad: Halves throughput (two clock cycles per bit)

General comment

- Physical layer is the lowest, so…
  - We tend not to worry about where to place functionality
  - There aren't other layers that could interfere
  - We tend to care about it only when things go wrong

- Physical layer characteristics are still fundamentally important to building reliable Internet systems
  - Insulated media vs wireless
  - Packet vs. circuit switched media

Data Link Layer



- Function:
  - Send blocks of data (frames) between physical devices
  - Regulate access to the physical media
- Key challenge:
  - How to delineate frames?
  - How to detect errors?
  - How to perform media access control (MAC)?
  - How to recover from and avoid collisions?

Outline

- Framing
- Error Checking and Reliability

Framing

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  - Packet switched networks
  - Each packet includes routing information
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- Types of framing
  - Byte oriented protocols
  - Bit oriented protocols
  - Clock based protocols

Byte Oriented: Sentinel Approach

Data

- Add **START** and **END** sentinels to the data

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START | DLE | DLE | Data | DLE | END | END

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START DLE DLE Data DLE END END

- Add **START** and **END** sentinels to the data
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  - Add a special **DLE** (Data Link Escape) character before **END**
  - What if **DLE** appears in the data? Add **DLE** before it.
  - Similar to escape sequences in C
    - printf(“You must \”escape\” quotes in strings”);
    - printf(“You must \\escape\\ forward slashes as well”);
- Used by Point-to-Point protocol, e.g. modem, DSL, cellular

Byte Oriented: Byte Counting

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Data

Byte Oriented: Byte Counting

- Sender: insert length of the data in bytes at the beginning of each frame
- Receiver: extract the length and read that many bytes

Bit Oriented: Bit Stuffing

Data

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- Add sentinels to the start and end of data
  - Both sentinels are the same
  - Example: 01111110 in High-level Data Link Protocol (HDLC)

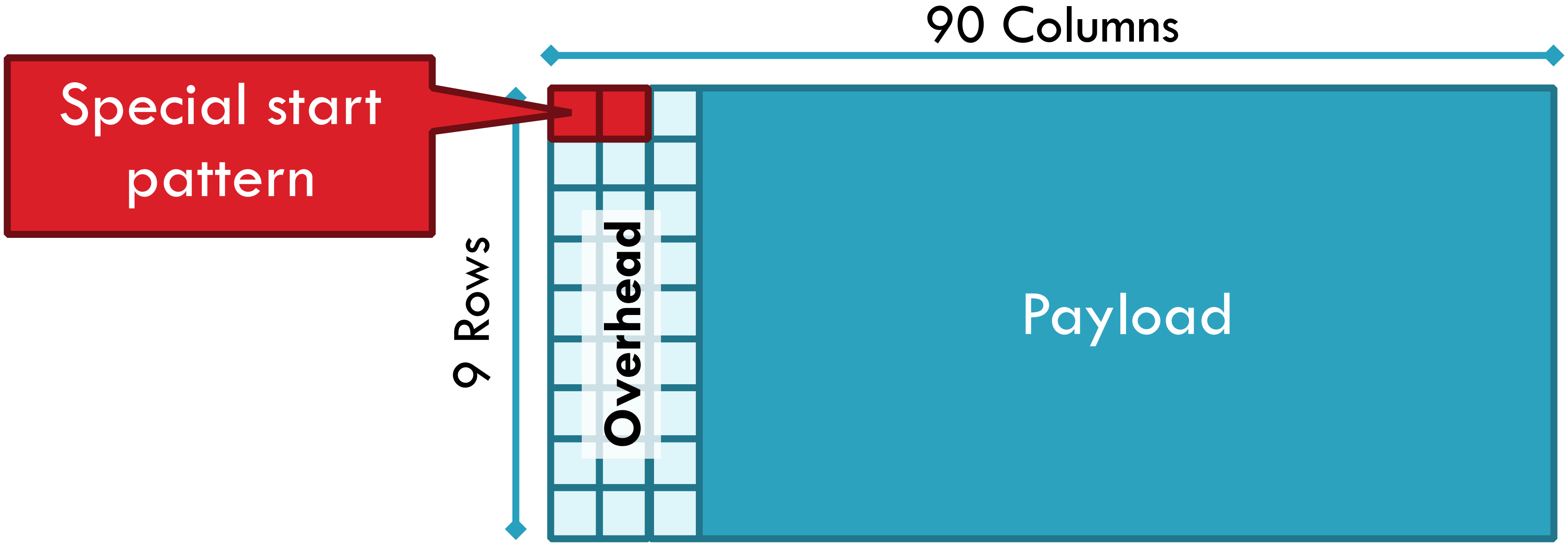
Bit Oriented: Bit Stuffing

01111110 Data 01111110

- Add sentinels to the start and end of data
  - Both sentinels are the same
  - Example: 01111110 in High-level Data Link Protocol (HDLC)
- Sender: insert a 0 after each 11111 in data
  - Known as “bit stuffing”
- Receiver: after seeing 11111 in the data…
  - 11111**0** → remove the 0 (it was stuffed)
  - 11111**1** → look at one more bit
    - 11111**10** → end of frame
    - 11111**11** → error! Discard the frame
- Disadvantage: 20% overhead at worst

Clock-based Framing: SONET

- **S**ynchronous **O**ptical **Net**work
  - Transmission over very fast optical links
  - STS-*n*, e.g. STS-1: 51.84 Mbps, STS-768: 36.7 Gbps
- STS-1 frames based on fixed sized frames
  - 9*90 = 810 bytes



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- STS-1 frames based on fixed sized frames
  - 9*90 = 810 bytes
- Physical layer details
  - Bits are encoded using NRZ
  - Payload is XORed with a special 127-bit pattern to avoid long sequences of 0 and 1

Outline

- Framing
- Error Checking and Reliability

Dealing with Noise

- The physical world is inherently noisy
  - Interference from electrical cables
  - Cross-talk from radio transmissions, microwave ovens
  - Solar storms
- How to detect bit-errors in transmissions?
- How to recover from errors?

Naïve Error Detection

- Idea: send two copies of each frame
  - if (memcmp(frame1, frame2) != 0) { OH NOES, AN ERROR! }
- Why is this a bad idea?

Naïve Error Detection

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  - if (memcmp(frame1, frame2) != 0) { OH NOES, AN ERROR! }
- Why is this a bad idea?
  - Extremely high overhead
  - Poor protection against errors
    - Twice the data means twice the chance for bit errors

Parity Bits

- Idea: add extra bits to keep the number of 1s even
    - Example: 7-bit ASCII characters + 1 parity bit

0101001 1101001 1011110 0001110 0110100

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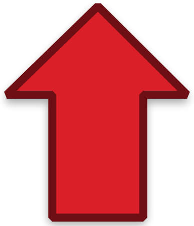

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- Detects 1-bit errors and some 2-bit errors
- Not reliable against bursty errors

Two Dimensional Parity

0101001
1101001
1011110
0001110
0110100
1011111

Two Dimensional Parity

0101001	1
1101001	0
1011110	1
0001110	1
0110100	1
1011111	0

Parity bit for each row

Two Dimensional Parity

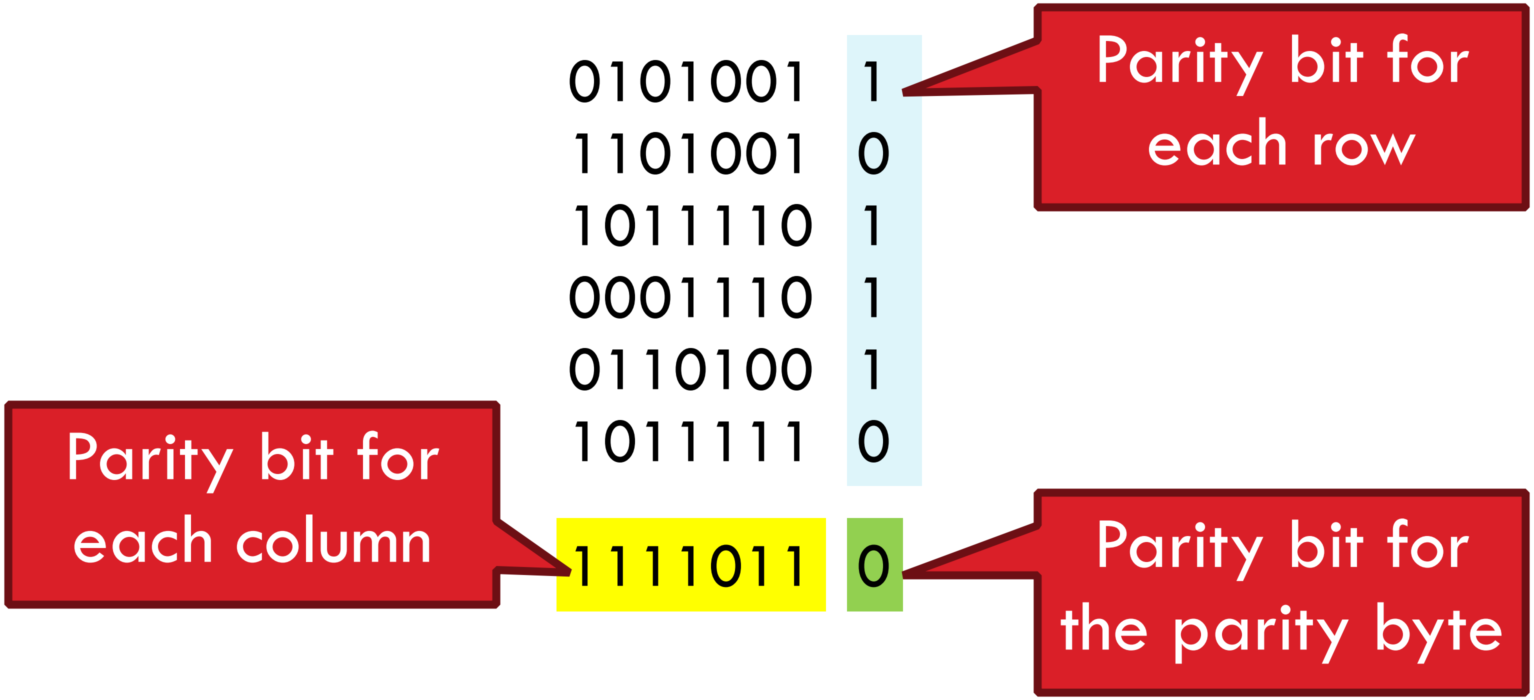
```
0101001  1
1101001  0
1011110  1
0001110  1
0110100  1
1011111  0

1111011
```

Parity bit for each row

Parity bit for each column

Two Dimensional Parity



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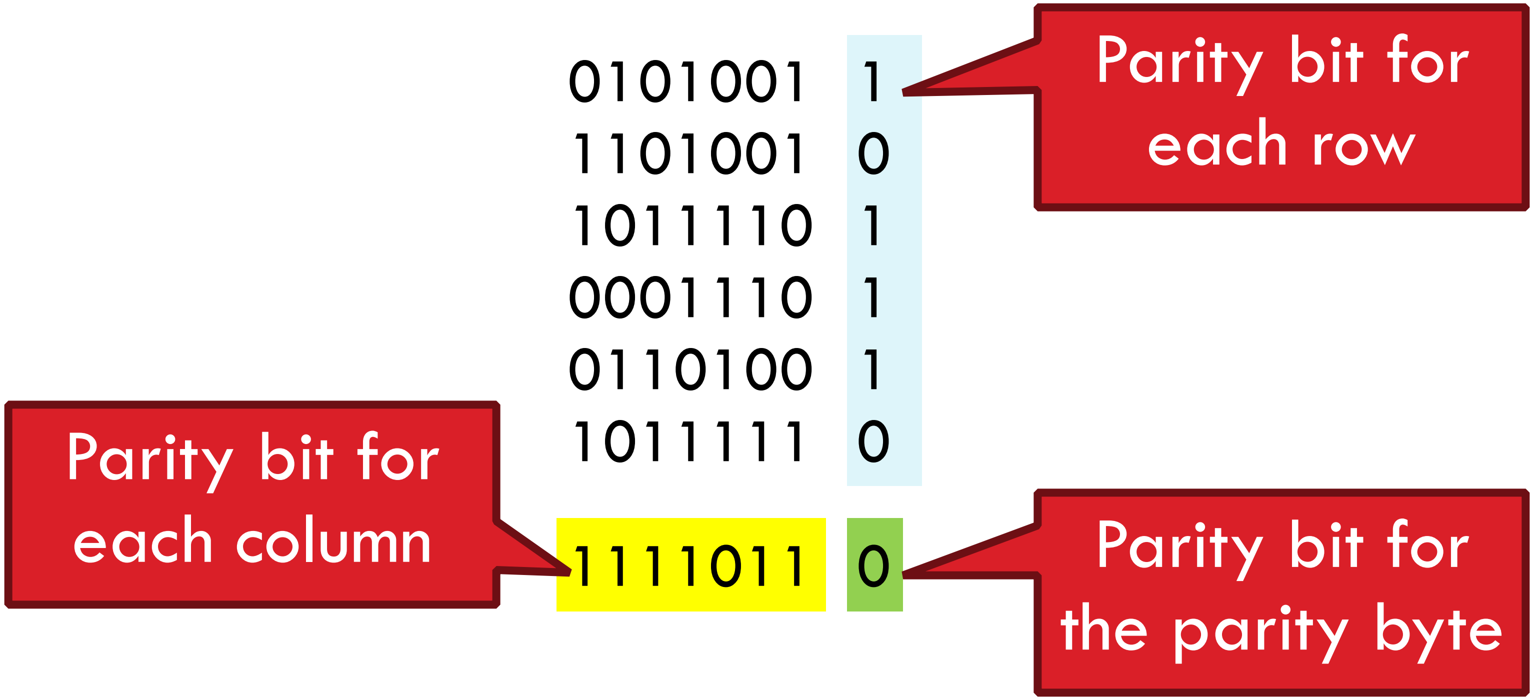

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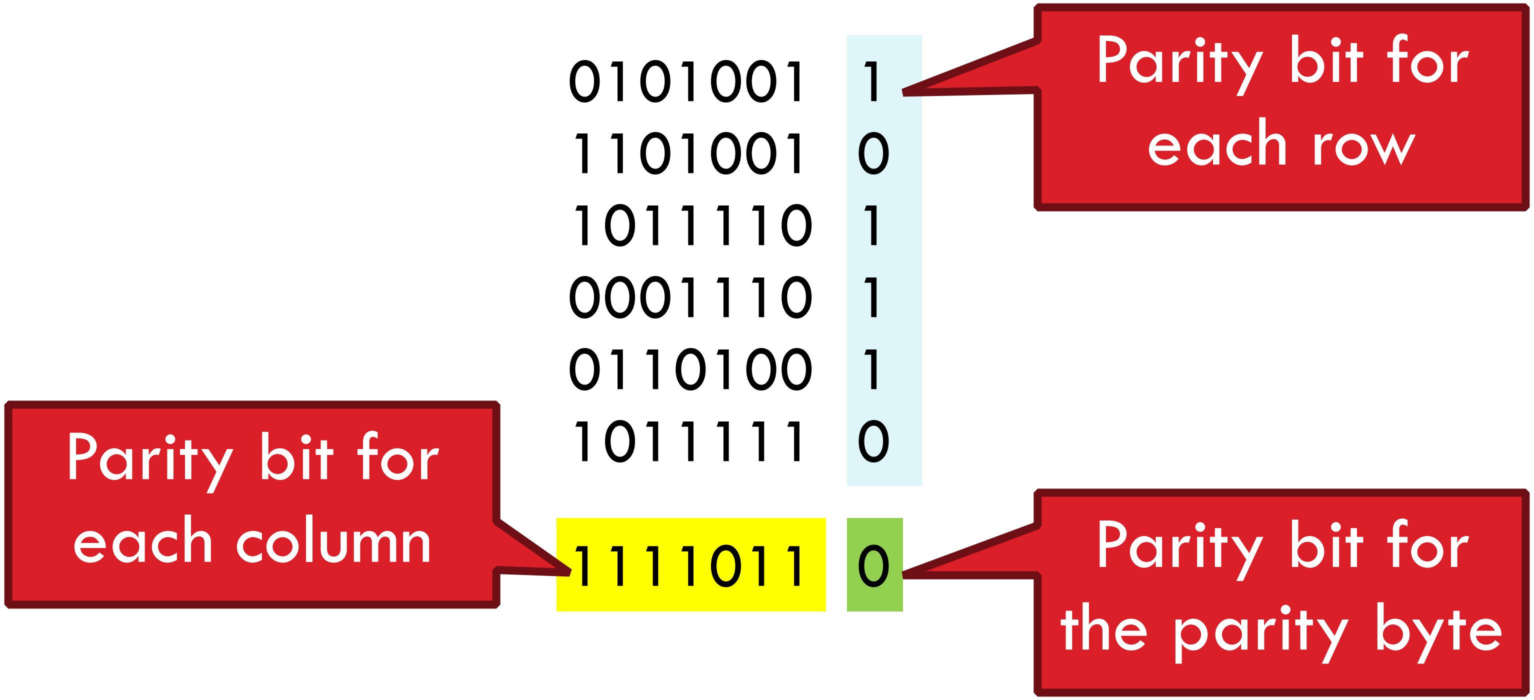

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- 14% overhead

Two Dimensional Parity Examples

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Two Dimensional Parity Examples

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Odd number of 1s

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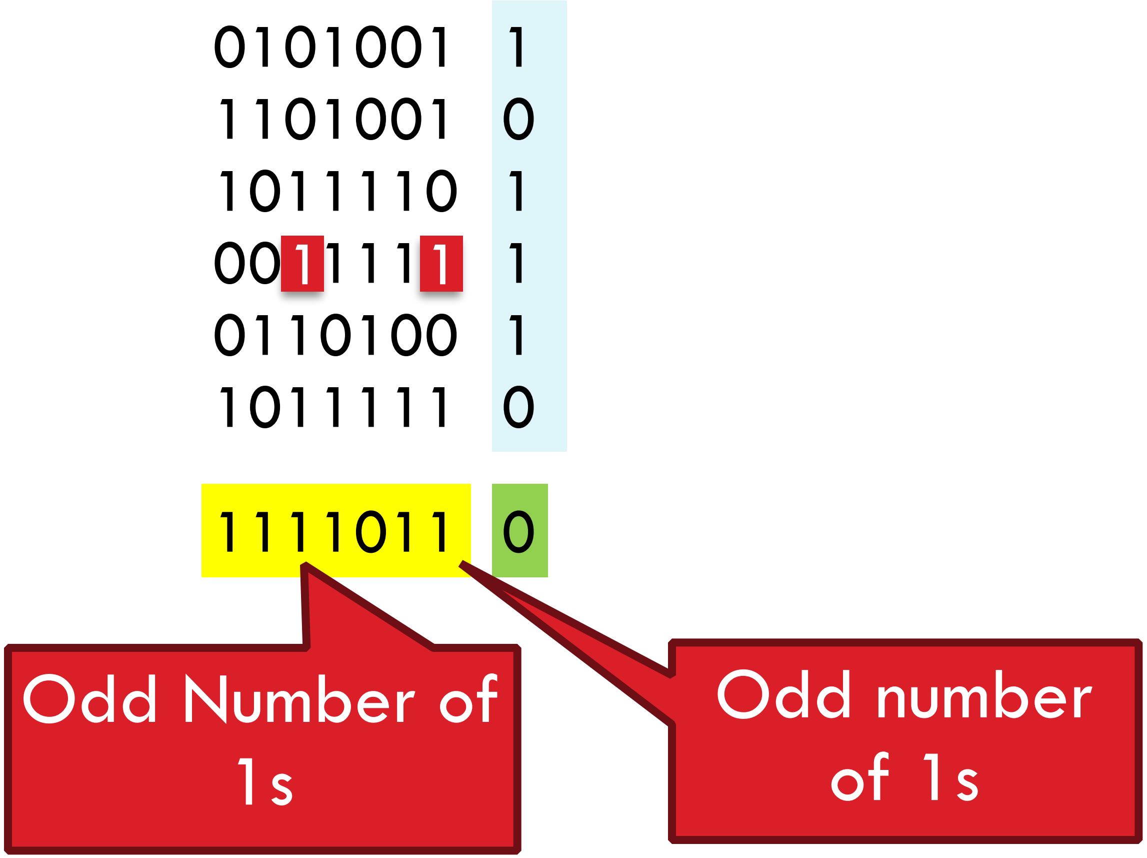

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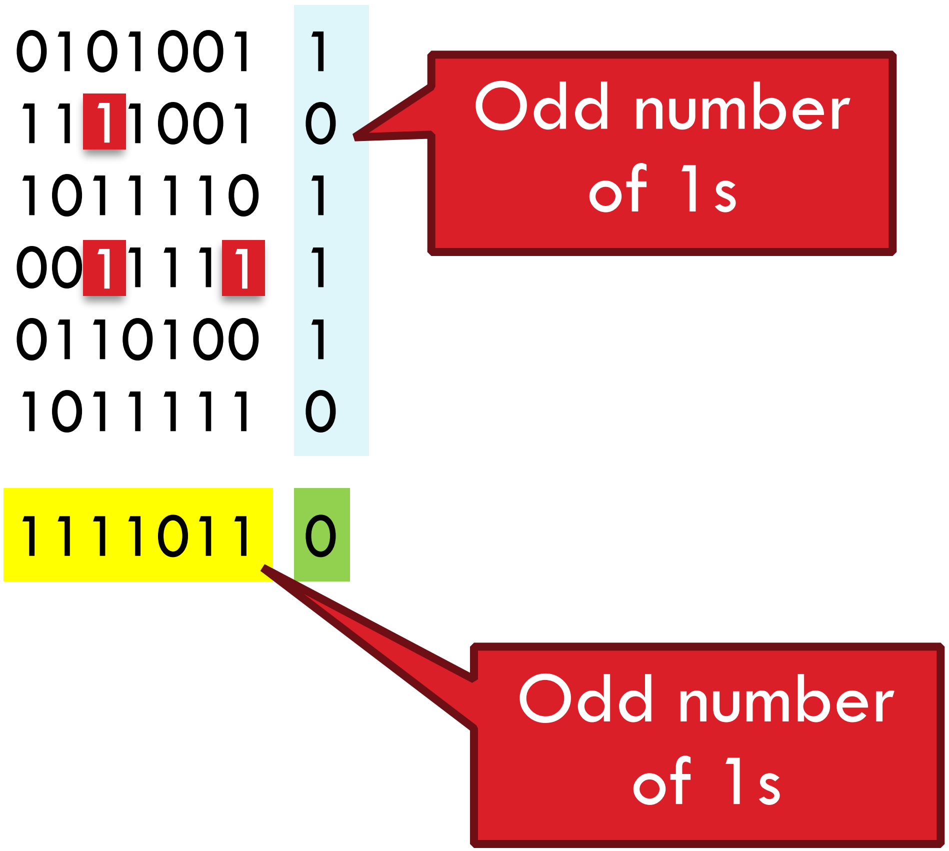

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Two Dimensional Parity Examples

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Checksums

- Idea:
  - Add up the bytes in the data
  - Include the sum in the frame

- Use ones-complement arithmetic
- Lower overhead than parity: 16 bits per frame
- But, not resilient to errors
  - Why?
- Used in UDP, TCP, and IP

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START | Data | Checksum | END

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Cyclic Redundancy Check (CRC)

- Uses field theory to compute a semi-unique value for a given message

- Much better performance than previous approaches
  - Fixed size overhead per frame (usually 32-bits)
  - Quick to implement in hardware
  - Only 1 in 2^{32} chance of missing an error with 32-bit CRC

- Details are in the book/on Wikipedia

What About Reliability?

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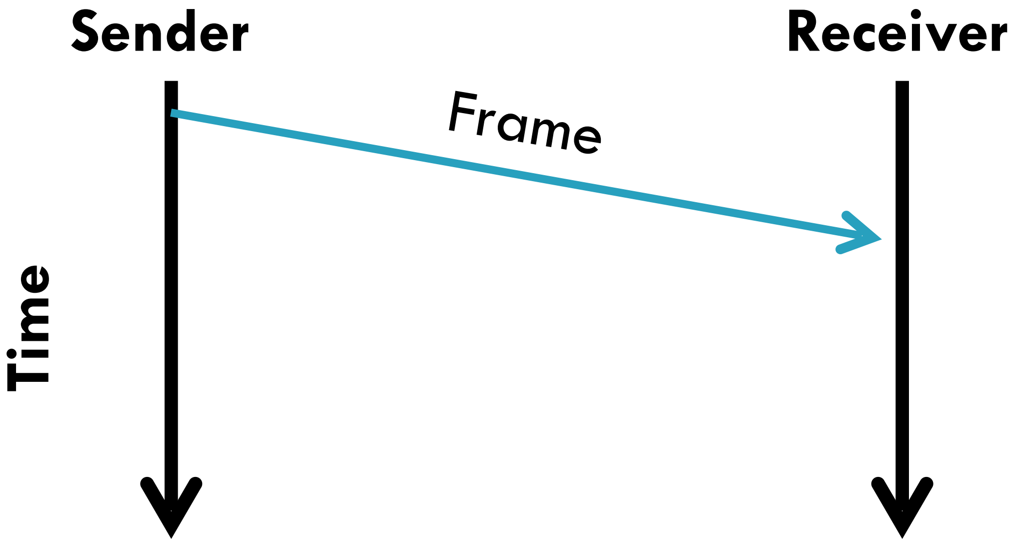

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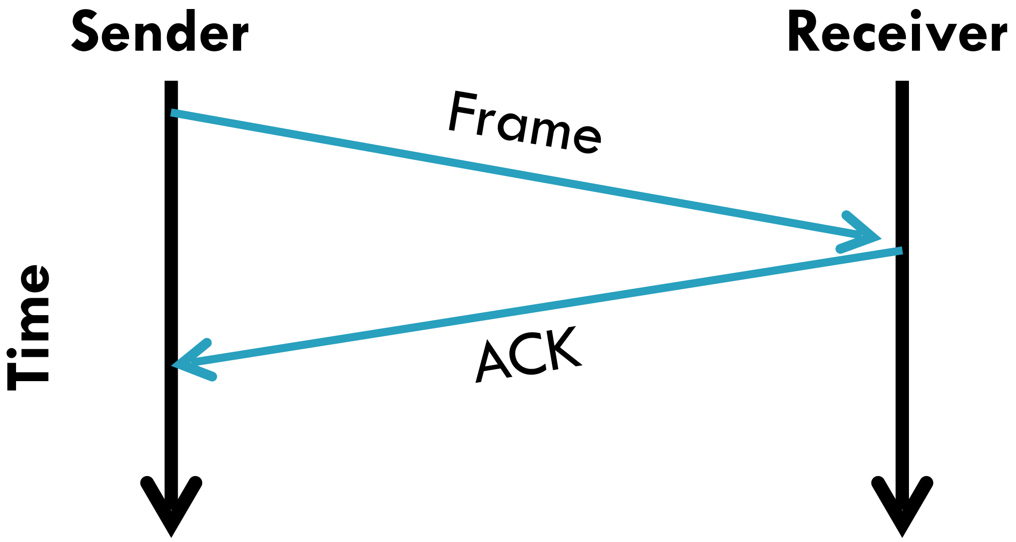

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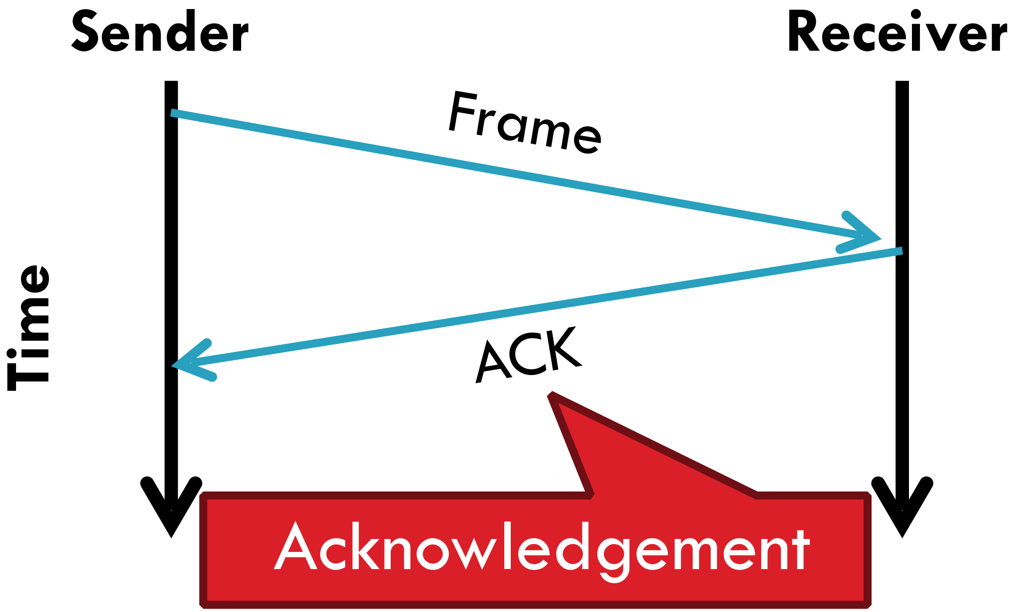
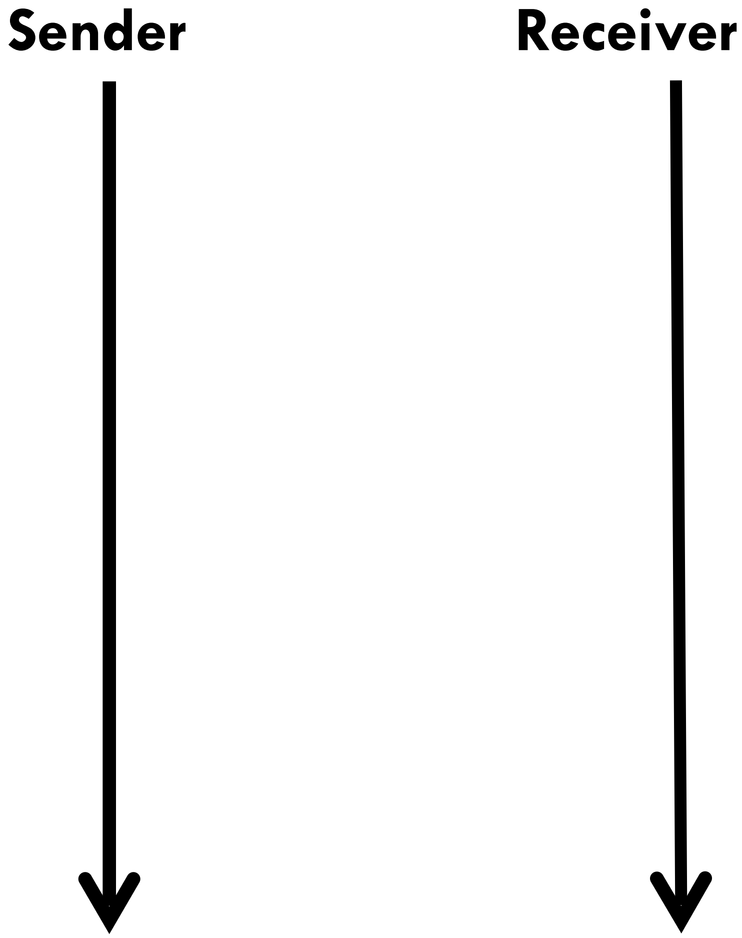


Stop and Wait

- Simplest form of reliability
- Example: Bluetooth



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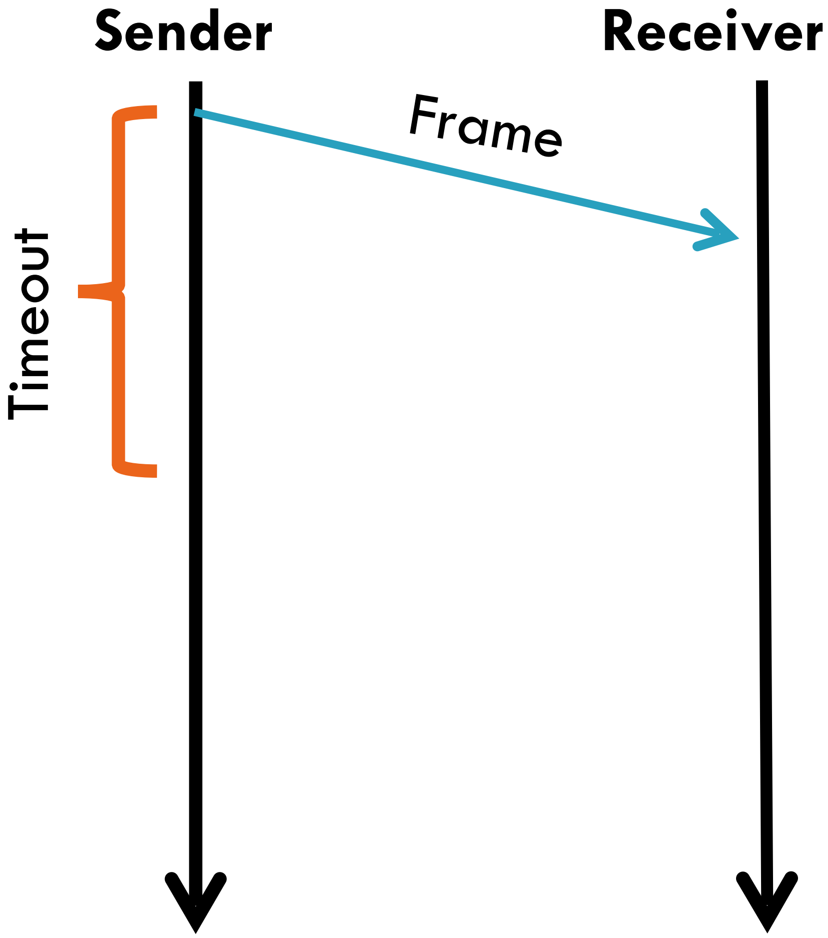

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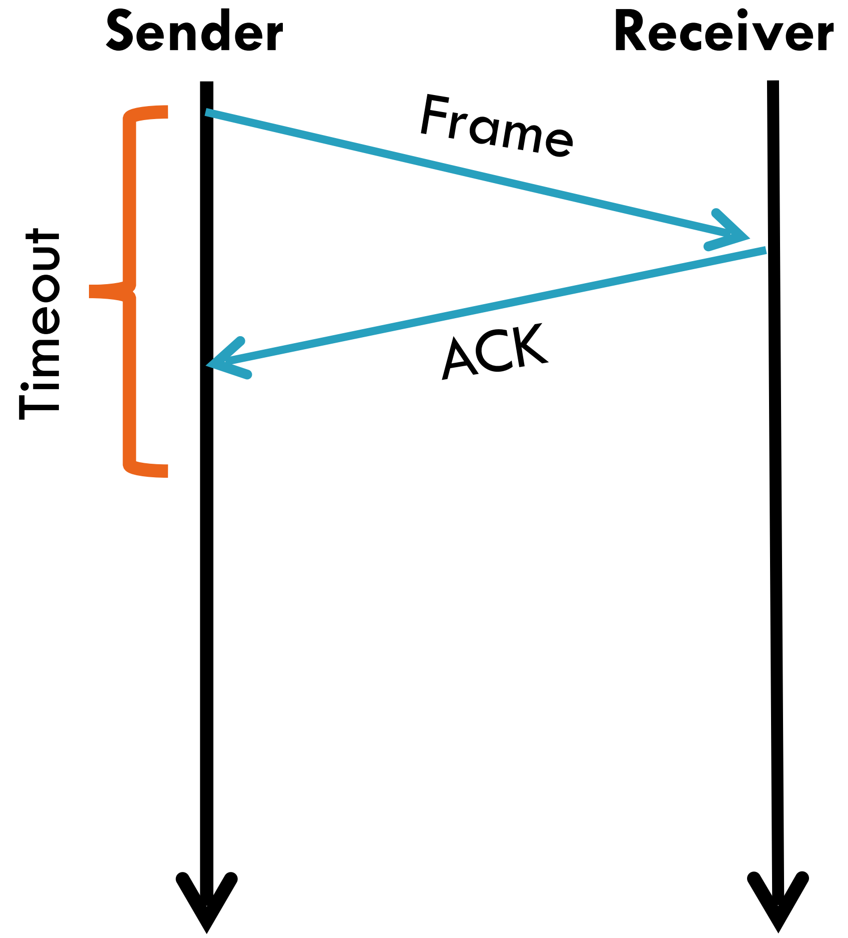

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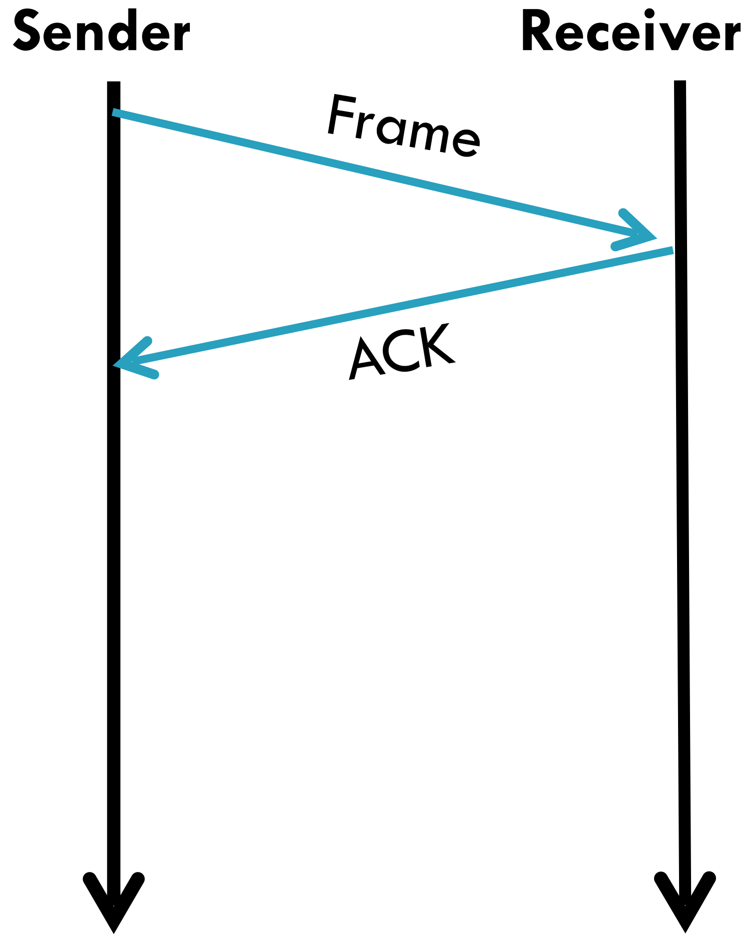

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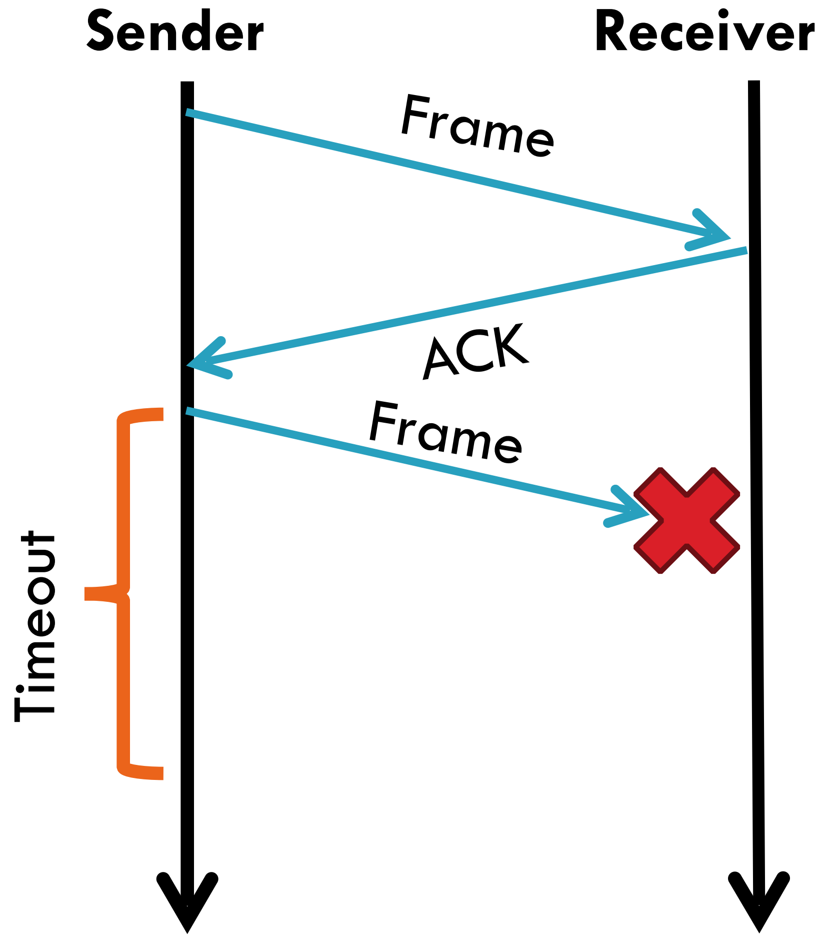

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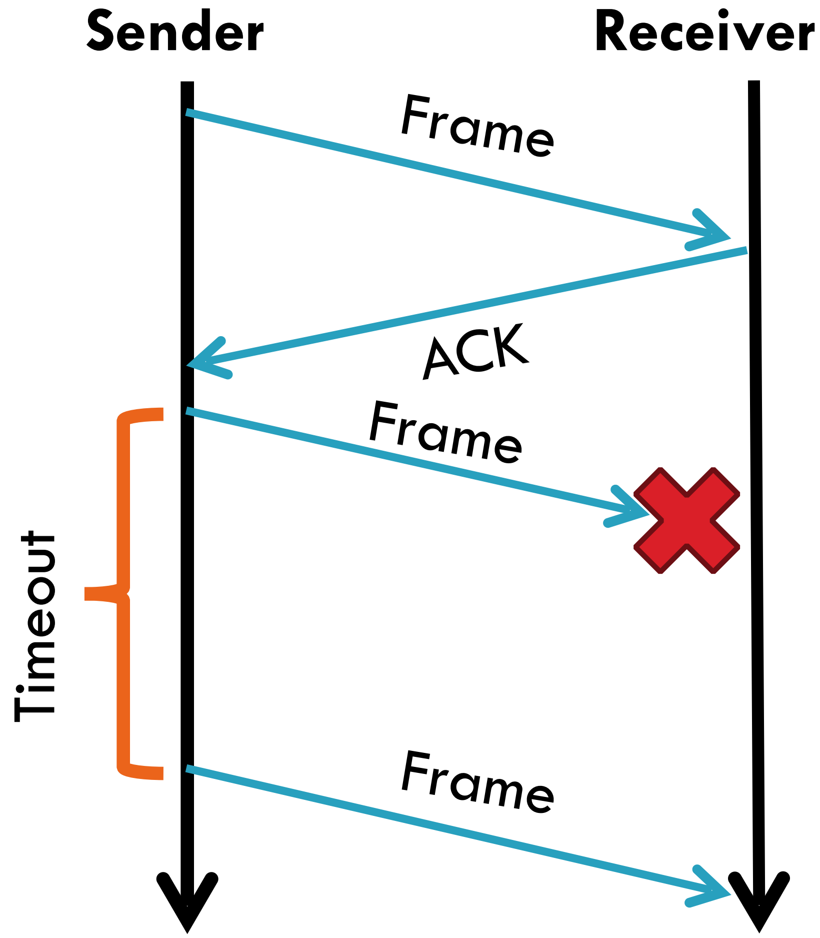

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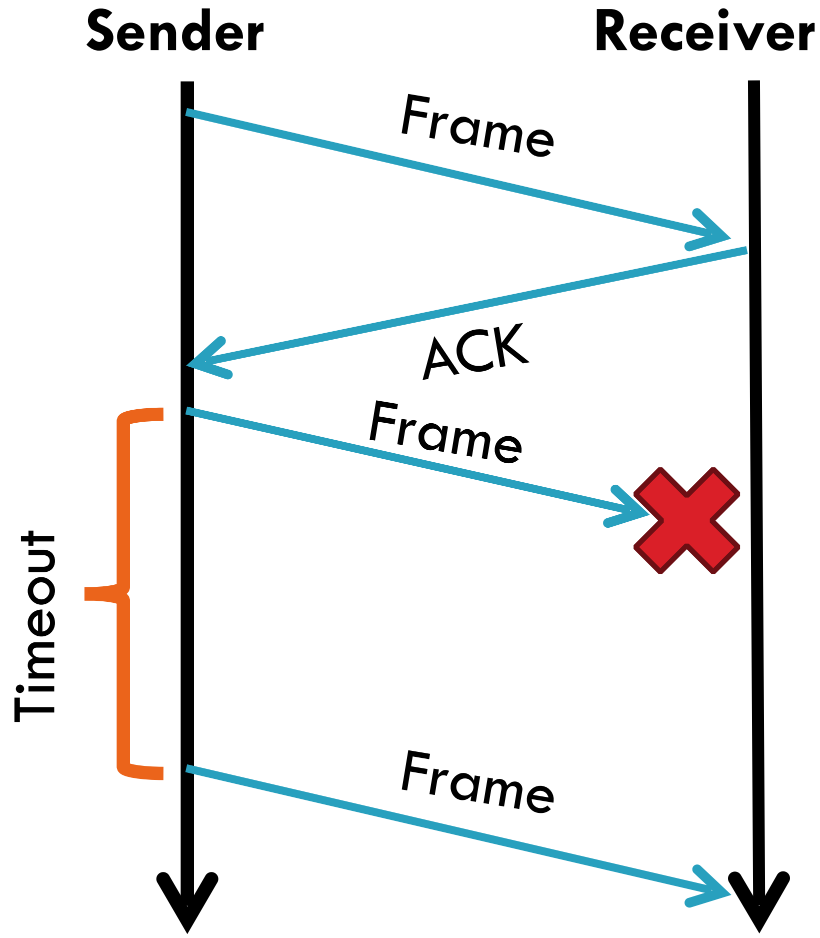
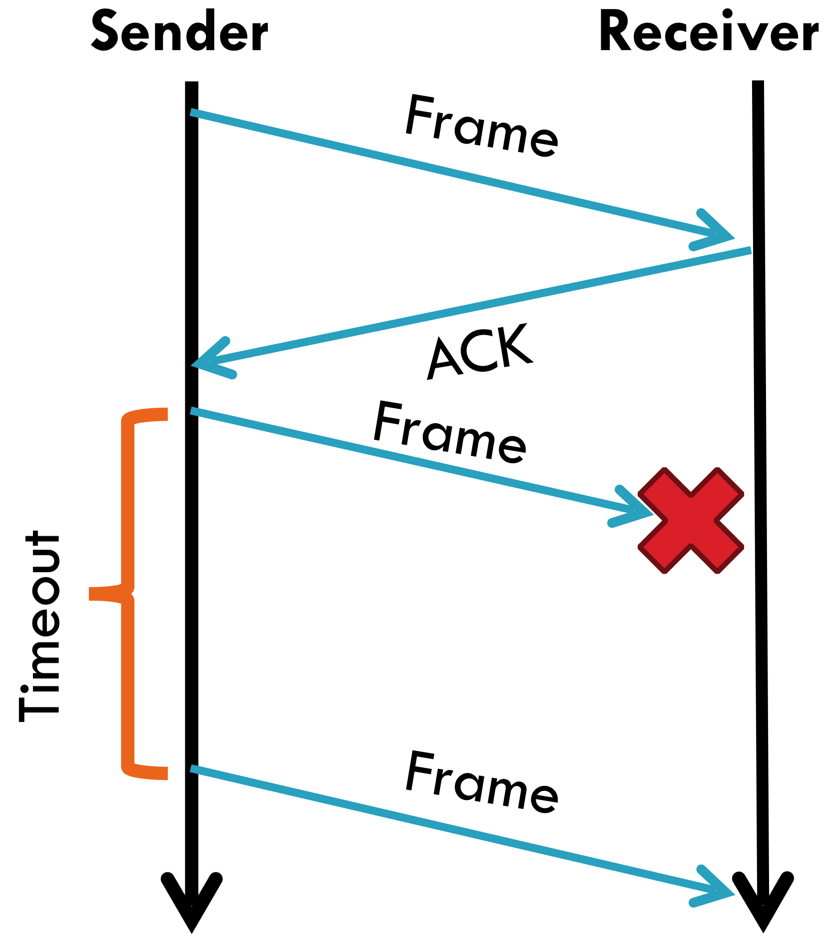
- Example: Bluetooth
- Problems?



Stop and Wait

- Simplest form of reliability
- Example: Bluetooth
- Problems?
  - Utilization
  - Can only have one frame in flight at any time

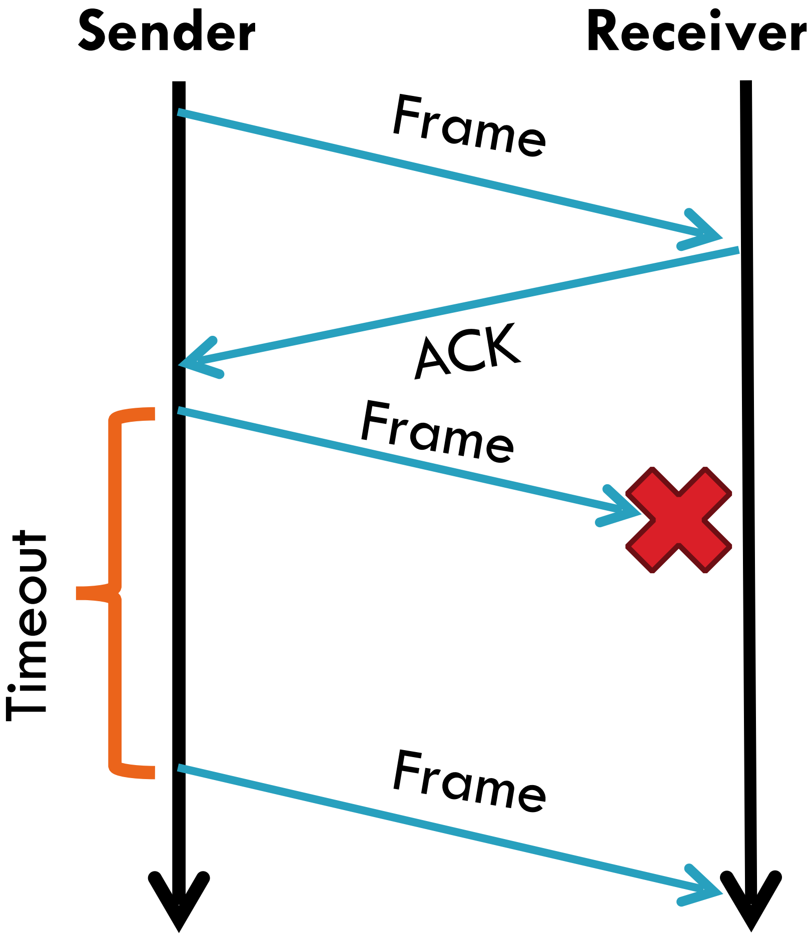


Stop and Wait

- Simplest form of reliability
- Example: Bluetooth
- Problems?
  - Utilization
  - Can only have one frame in flight at any time
- 10Gbps link and 10ms delay
  - Need 100 Mbit to fill the pipe
  - Assume packets are 1500B

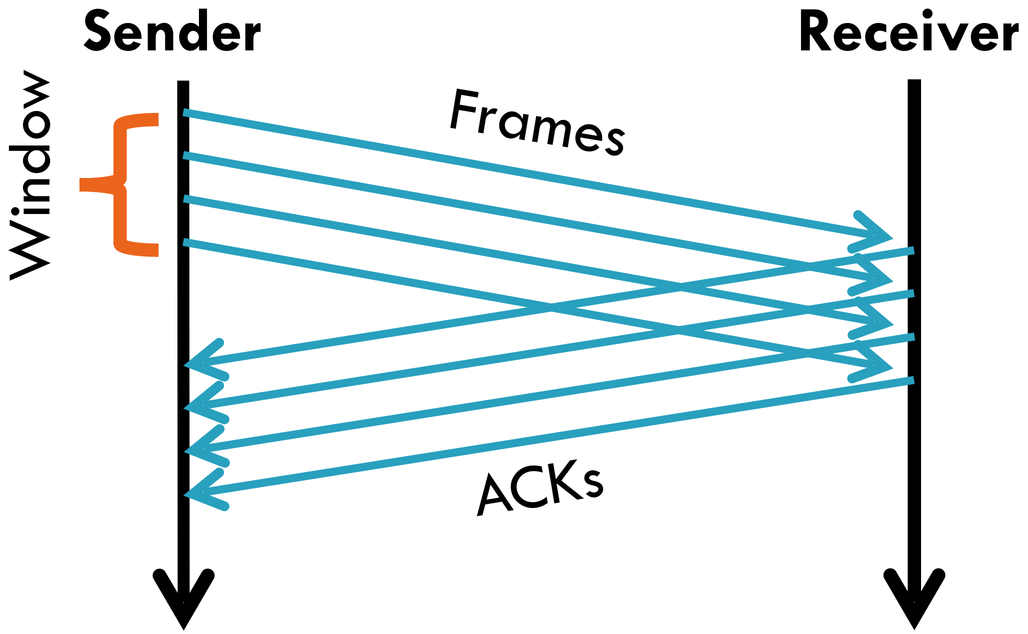
1500B*8bit/(2*10ms) = 600Kbps

Utilization is 0.006%



Sliding Window

- Allow multiple outstanding, un-ACKed frames
- Number of un-ACKed frames is called the window



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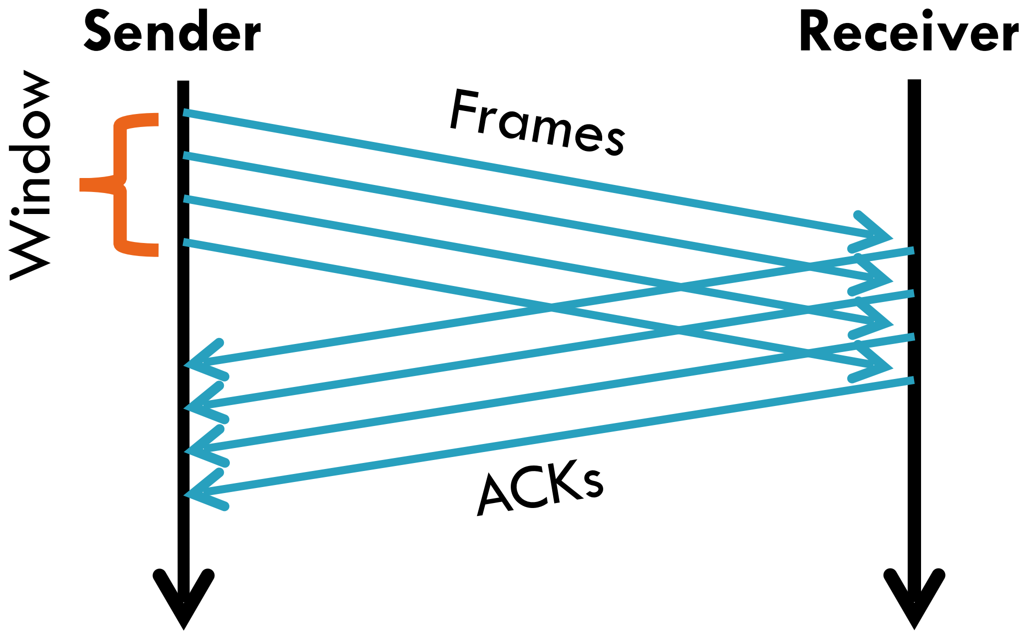

- Made famous by TCP
  - We'll look at this in more detail later

Should We Error Check in the Data Link?

- Recall the End-to-End Argument
- Cons:
  - Error free transmission cannot be guaranteed
  - Not all applications want this functionality
  - Error checking adds CPU and packet size overhead
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- Pros:
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- Data link error checking in practice
  - Most useful over lossy links
  - Wifi, cellular, satellite