Lesson 7: Ethernet/LAN

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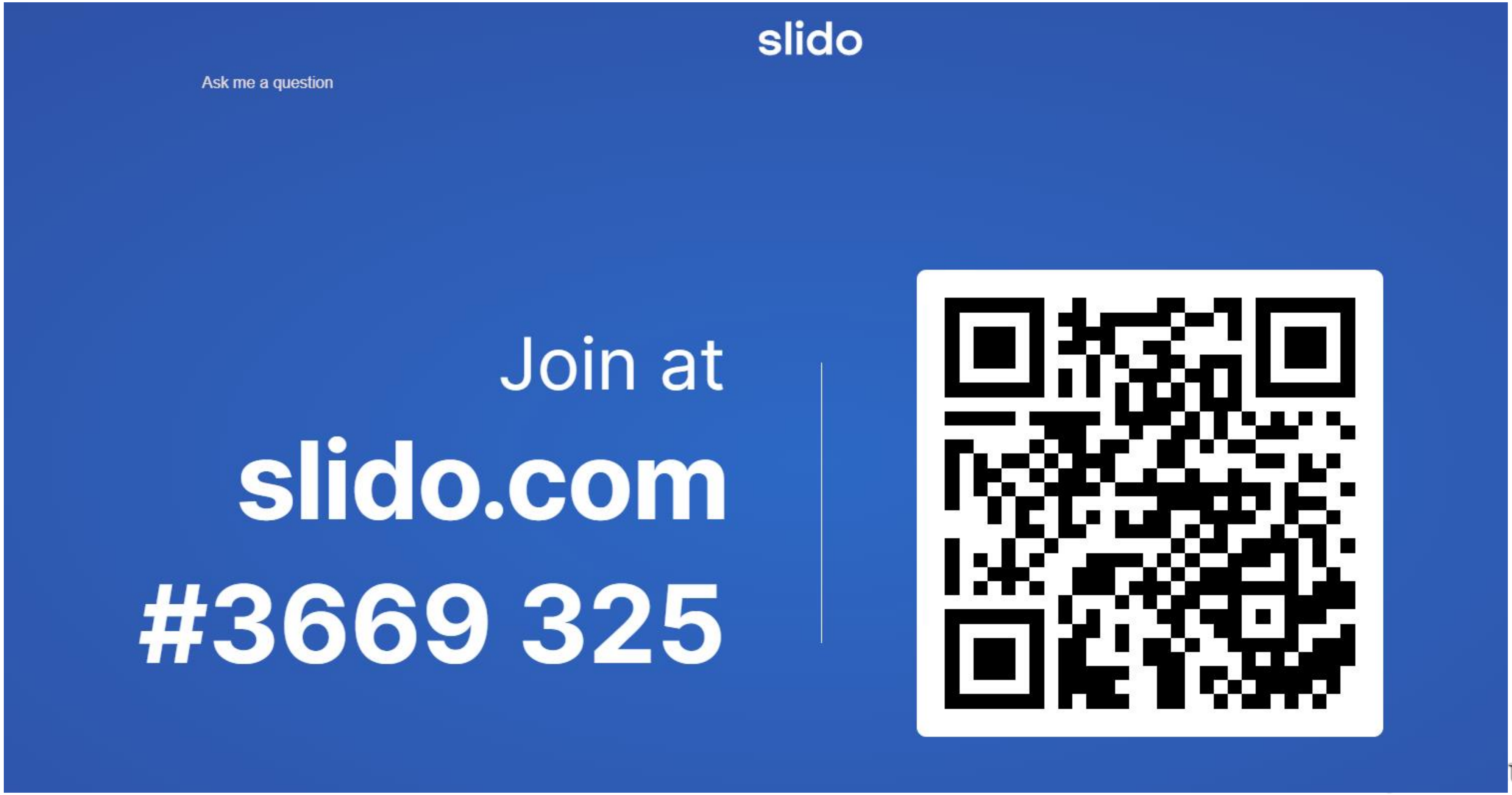
Fall 2024

Ask me a question without revealing your name



Outline

- Ethernet/LAN
  1. Encoding
  2. Framing
  3. Error Detection
  4. Reliable Transmission
  5. Ethernets/LAN

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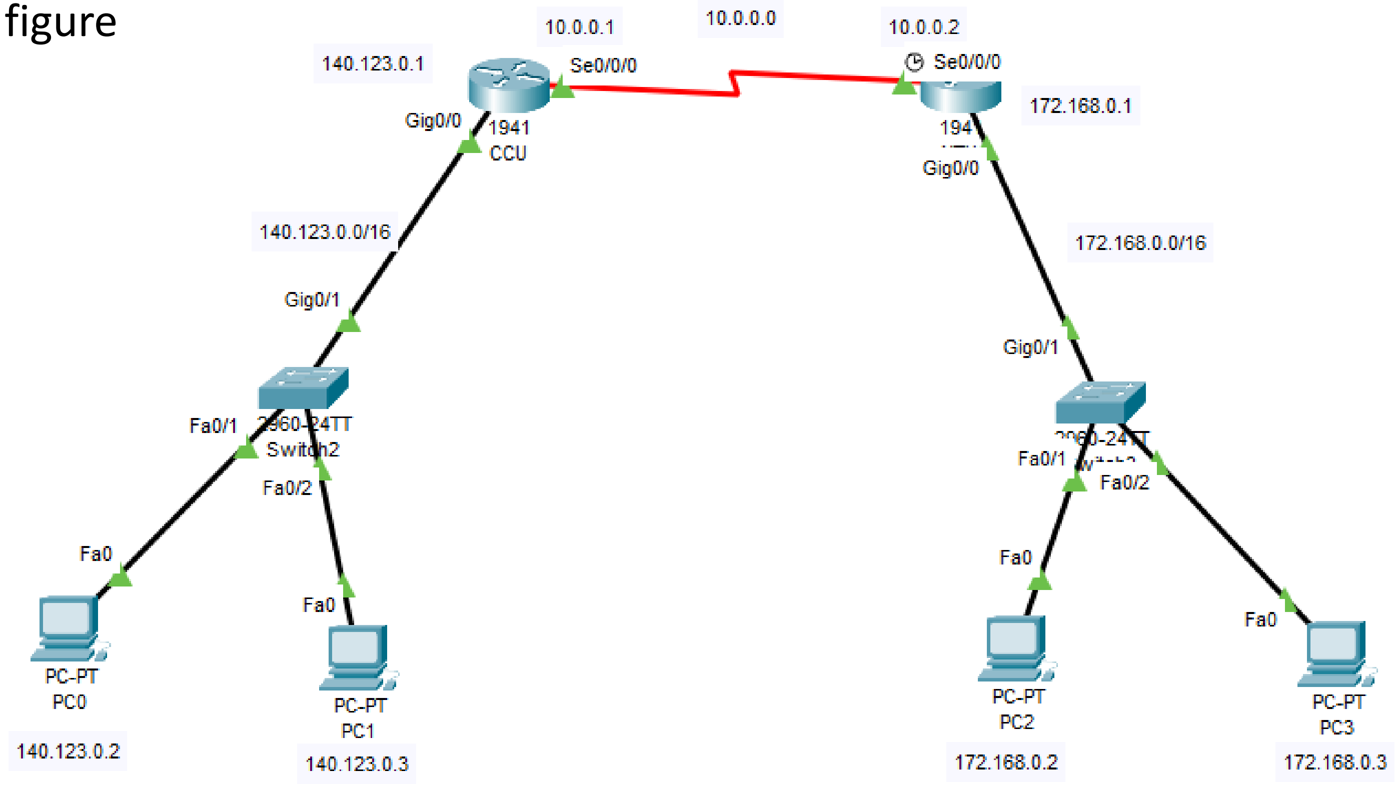
Configure OSPF [small]

Configure routing for a network with topology as the figure



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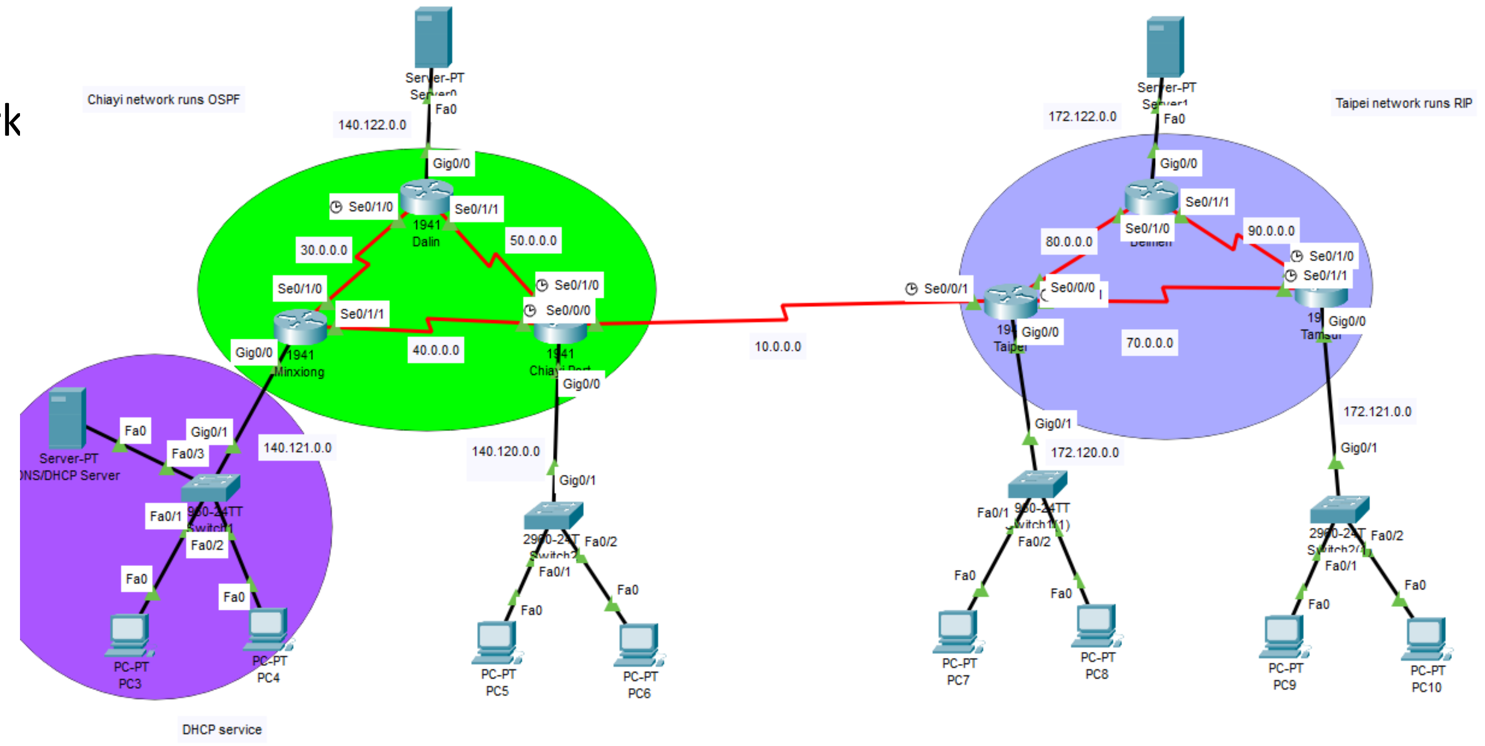
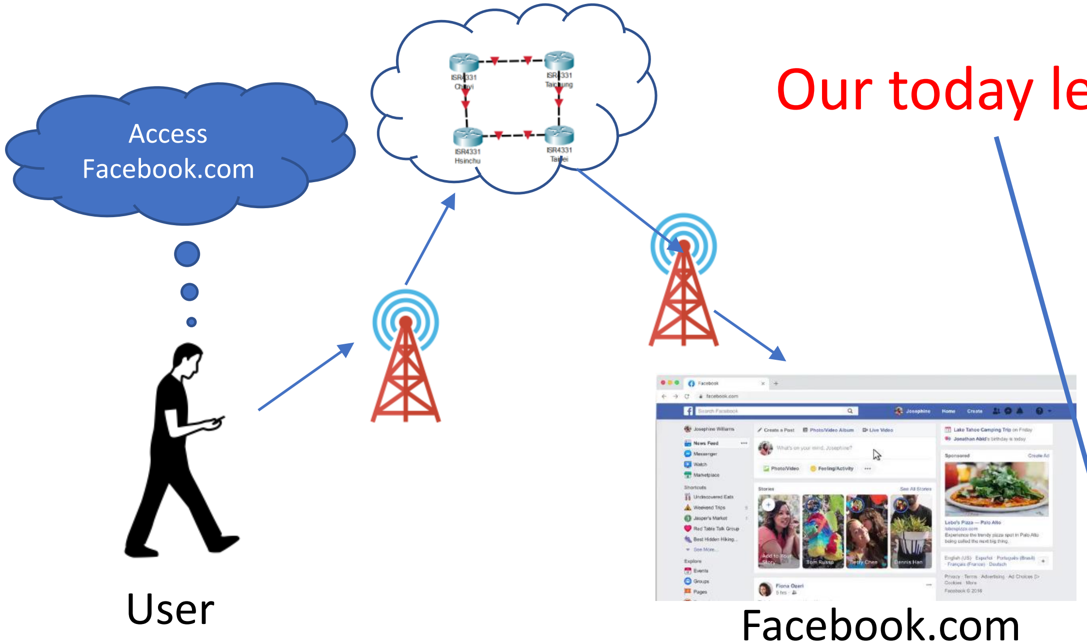
Configure OSPF –RIP – BGP [big]

1. Configure routing for a network with topology as the figure
2. Configure DHCP for the local network

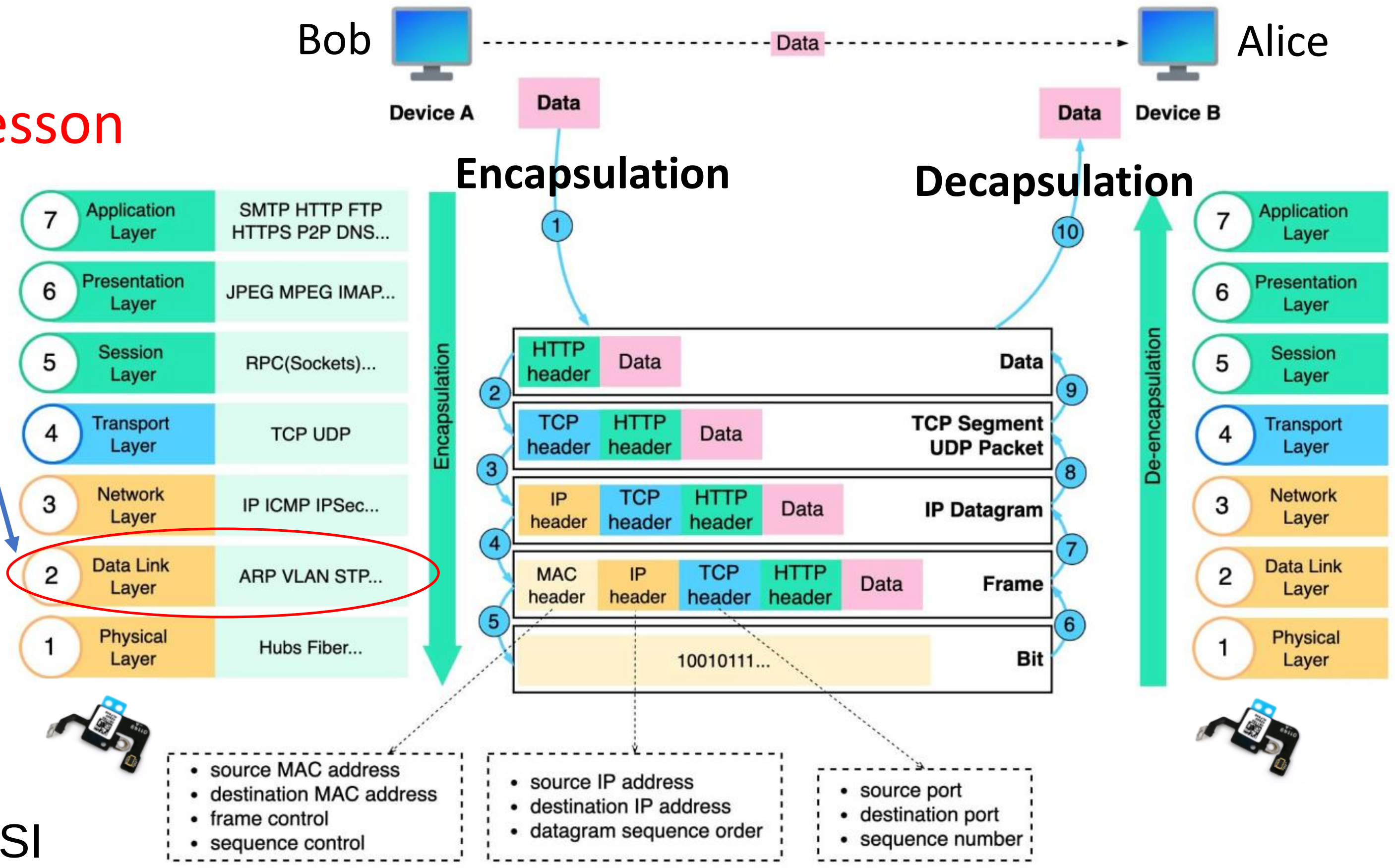


Today lesson

Encapsulation/Decapsulation



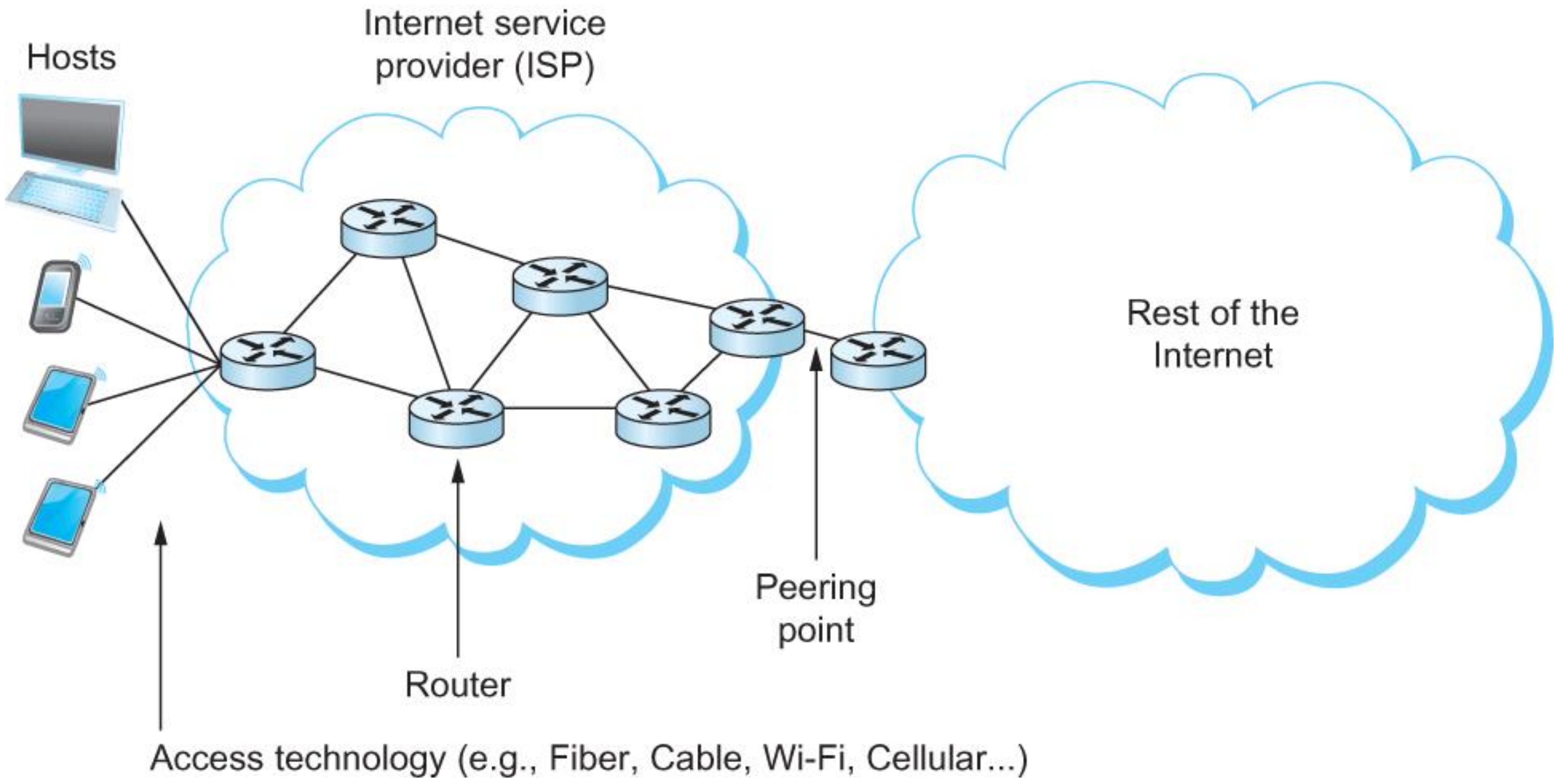
Our today lesson



TCP/IP Model is more popular in industry than OSI
OSI is for academic research

https://blog.bytebytego.com/

Perspectives on Connecting



An end-user's view of the Internet

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Shannon formula – Link capacity

- How much bit per second we get from every Hz?

$$C = W * n * Log_2\left(1 + \frac{S}{N}\right)$$

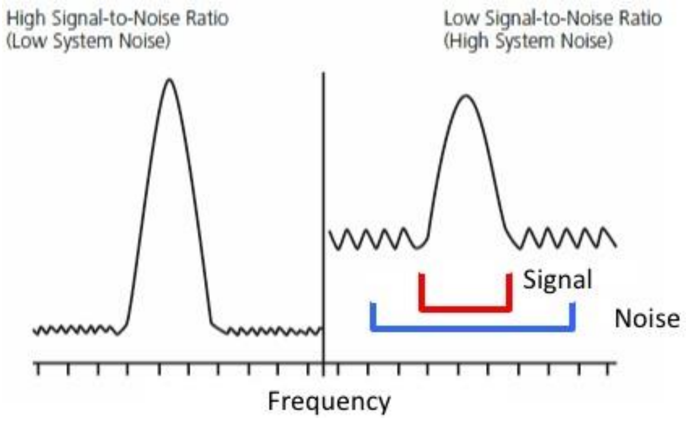
Signal power

Channel Capacity or Data rate (bits/sec)

Channel bandwidth (Hz)

Number of antennas

Signal to noise ratio (SNR) in dB



Distance

Speed of light

* Signal power S is decreased by path loss = $\left(\frac{4\,\pi\,d\,c}{f}\right)^2$

Frequency

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Other Shannon variant

- How much bit per second we get from every Hz?

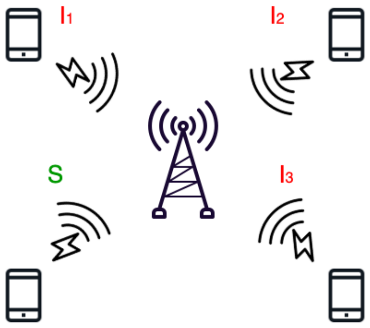
$$C = W * n * Log_2\left(1 + \frac{S}{I + N}\right)$$

Channel Capacity or Data rate (bits/sec)

Channel bandwidth (Hz)

Number Of antennas

Signal-to-interference-plus-noise (SINR)



* Interference is influenced by surrounding signal sources = $\sum_i^N \mathrm{I}_i$

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Link Capacity

- C = W * n* $Log_2\,(1 + \frac{S}{N})$
- W = 3300 – 300 = 3000Hz, S is the signal power, N the average noise.
- The signal to noise ratio (S/N) is measured in decibels is related to dB = 10 x $\log_{10}$(S/N).
- If there is 30dB of noise then S/N = 1000.
- Now C = 3000 x $\log_2$(1001) = 30kbps.
- How can we get 56kbps?

Links

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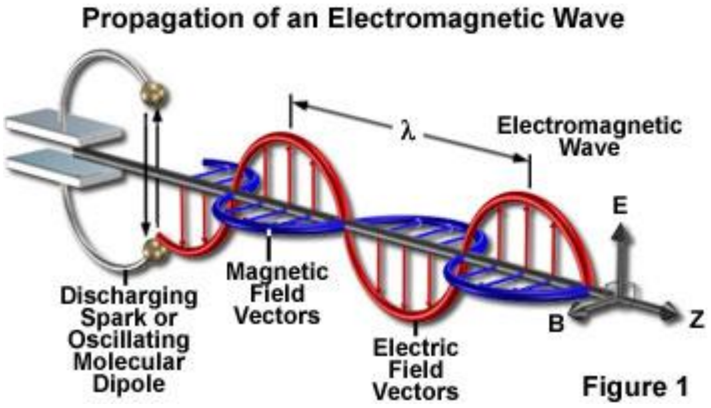
- All practical links rely on some sort of electromagnetic radiation propagating through a medium or, in some cases, through free space



- One way to characterize links, then, is by the medium they use
  - Typically copper wire in some form (as in Digital Subscriber Line (DSL) and coaxial cable),
  - Optical fiber (as in both commercial fiber-to-the home services and many long-distance links in the Internet's backbone)
  - Air/free space (for wireless links)

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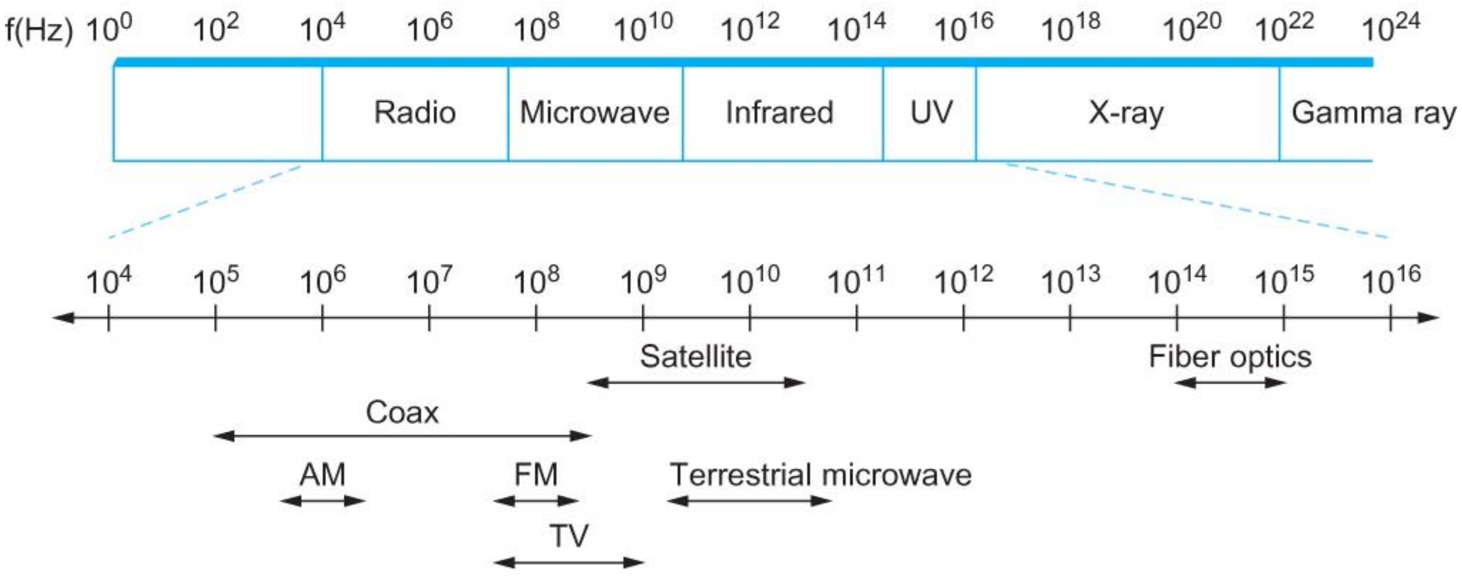
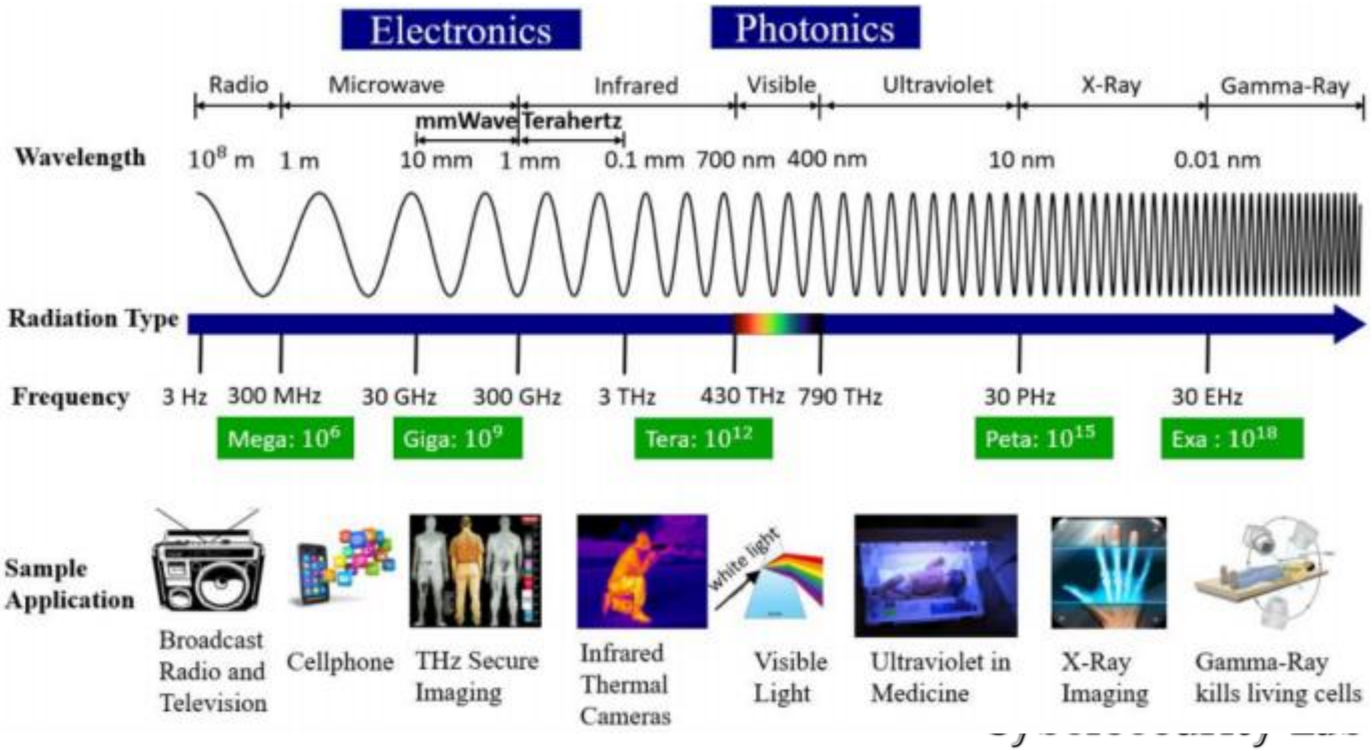
Links

- Another important link characteristic is the *frequency*
  - Measured in hertz, with which the electromagnetic waves oscillate
- Distance between the adjacent pair of maxima or minima of a wave measured in meters is called *wavelength*
  - Speed of light divided by frequency gives the wavelength.
  - Frequency on a copper cable range from 300Hz to 3300Hz; Wavelength for 300Hz wave through copper is speed of light on a copper / frequency
  - $2/3 \times 3 \times 10^8 / 300 = 667 \times 10^3$ meters.
- Placing binary data on a signal is called *encoding*.
- Modulation involves modifying the signals in terms of their frequency, amplitude, and phase.

Links

Wireless communications





Links

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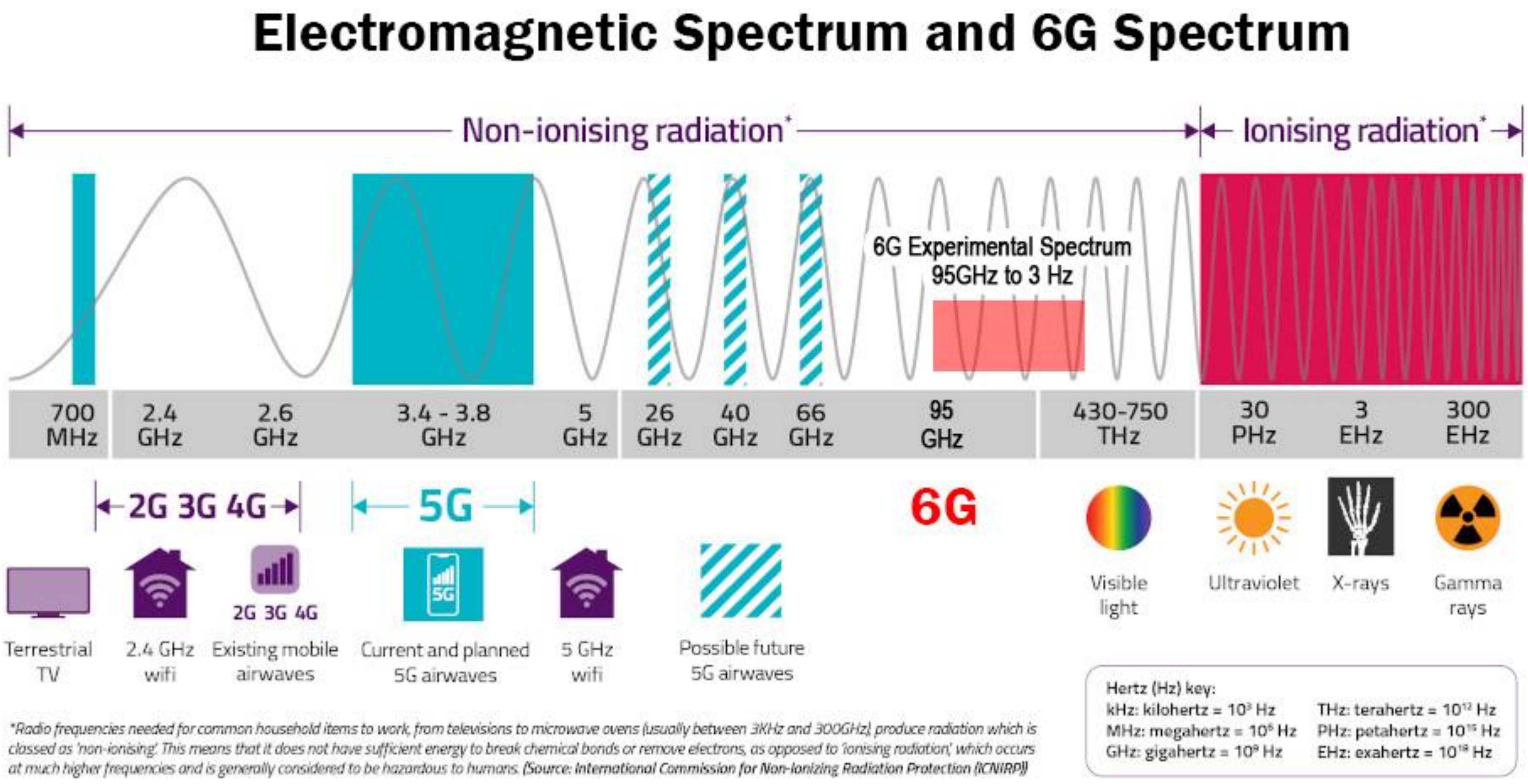

https://precisionmmw.com/what-is-6g/

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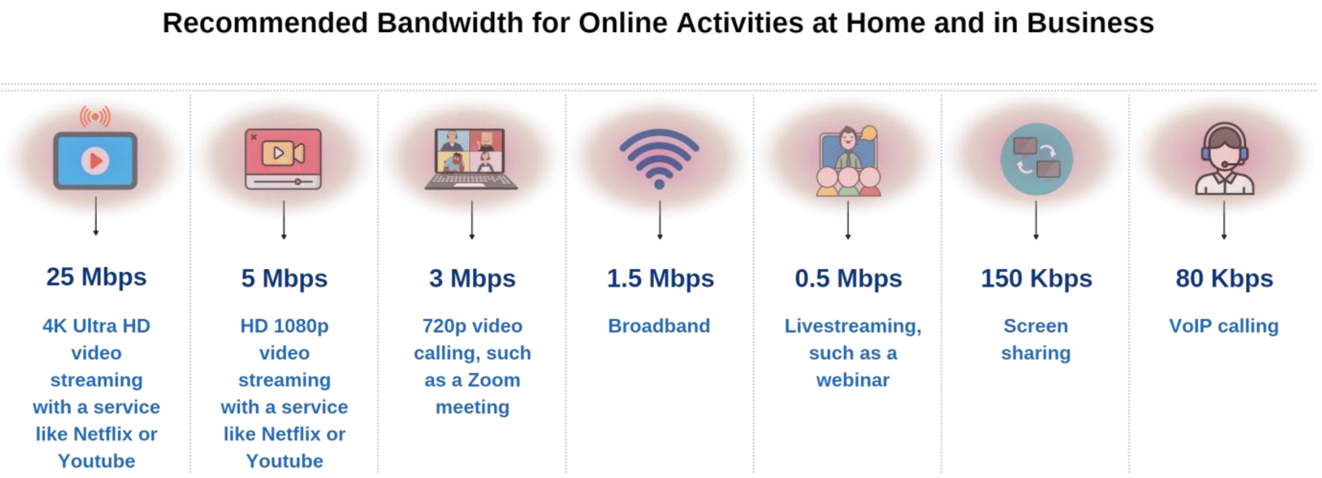
Links

- Some common services and typical bandwidth

Service	Bandwidth (typical)
Dial-up	28–56 kbps
ISDN	64–128 kbps
DSL	128 kbps–100 Mbps
CATV (cable TV)	1–40 Mbps
FTTH (fibre to the home)	50 Mbps–1 Gbps



#broadbandsearch

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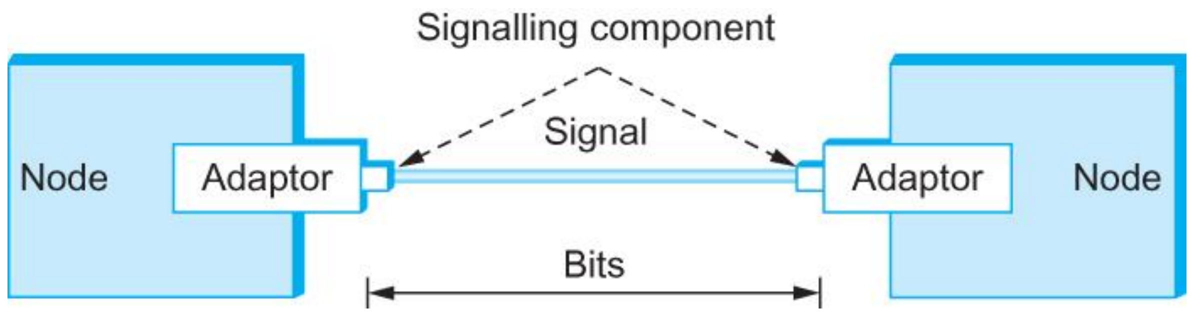
Encoding

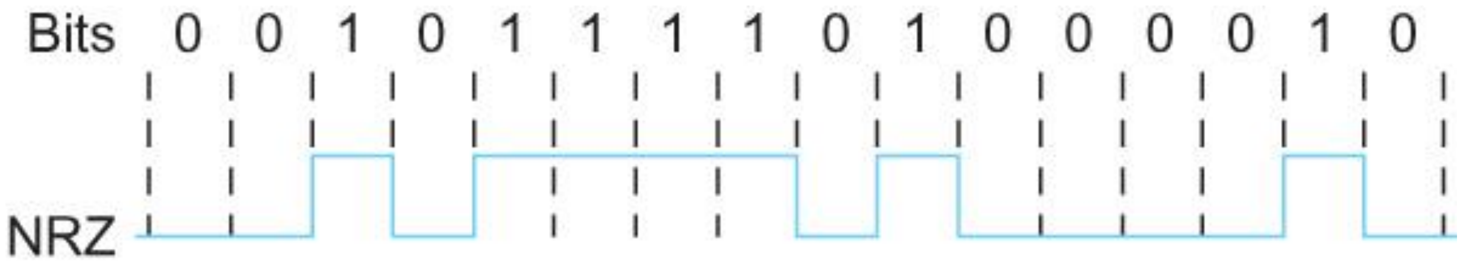
Binary code is represented:

1: a positive voltage

0: the rest conditions



Signals travel between signaling components; bits flow between adaptors



NRZ encoding of a bit stream

Encoding

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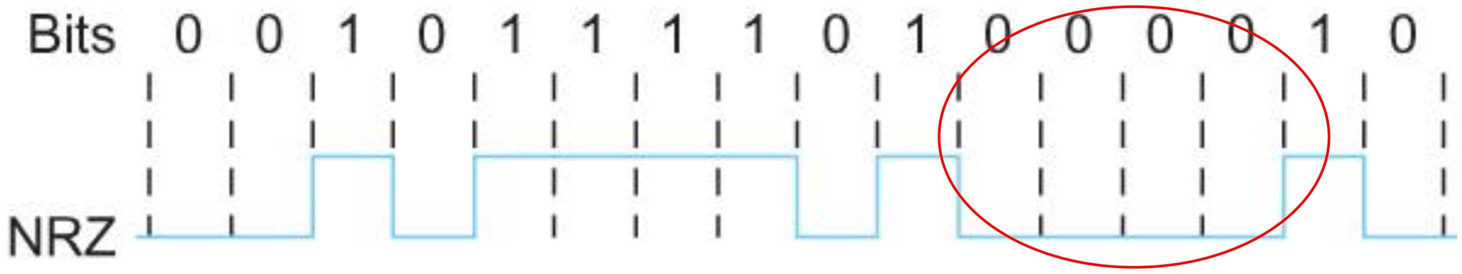
- Problem with Non-return-to-zero (NRZ)
  - Baseline wander
    - The receiver keeps an average of the signals it has seen so far
    - Uses the average to distinguish between low and high signal
    - When a signal is significantly low than the average, it is 0, else it is 1
    - Too many consecutive 0's and 1's cause this average to change, making it difficult to detect



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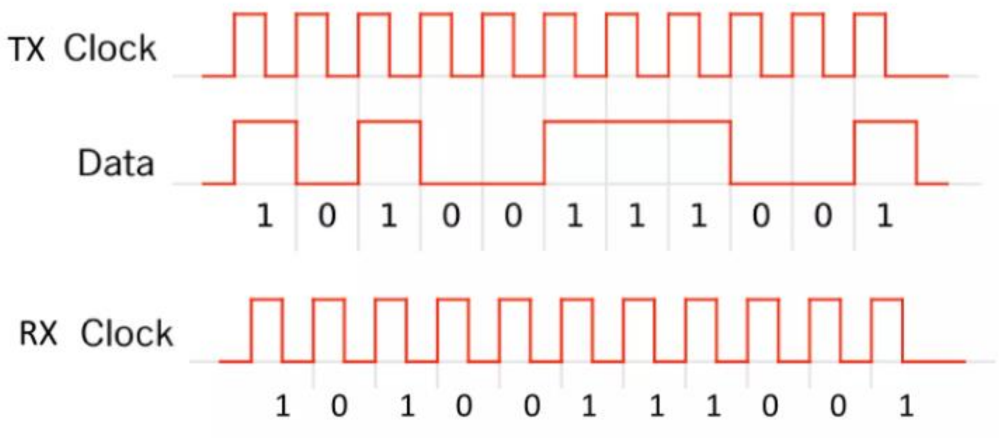
Encoding

- Problem with NRZ
  - Clock recovery
    - Frequent transition from high to low or vice versa are necessary to enable clock recovery
    - Both the sending and decoding process is driven by a clock
    - Every clock cycle, the sender transmits a bit and the receiver recovers a bit
    - The sender and receiver have to be precisely synchronized



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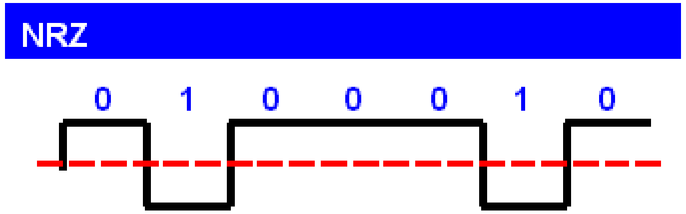
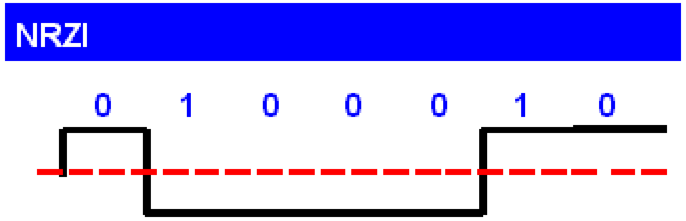
Encoding

- NRZI
  - Non Return to Zero Inverted
  - Sender makes a transition from the current signal to encode 1 and stay at the current signal to encode 0
  - Solves for consecutive 1's





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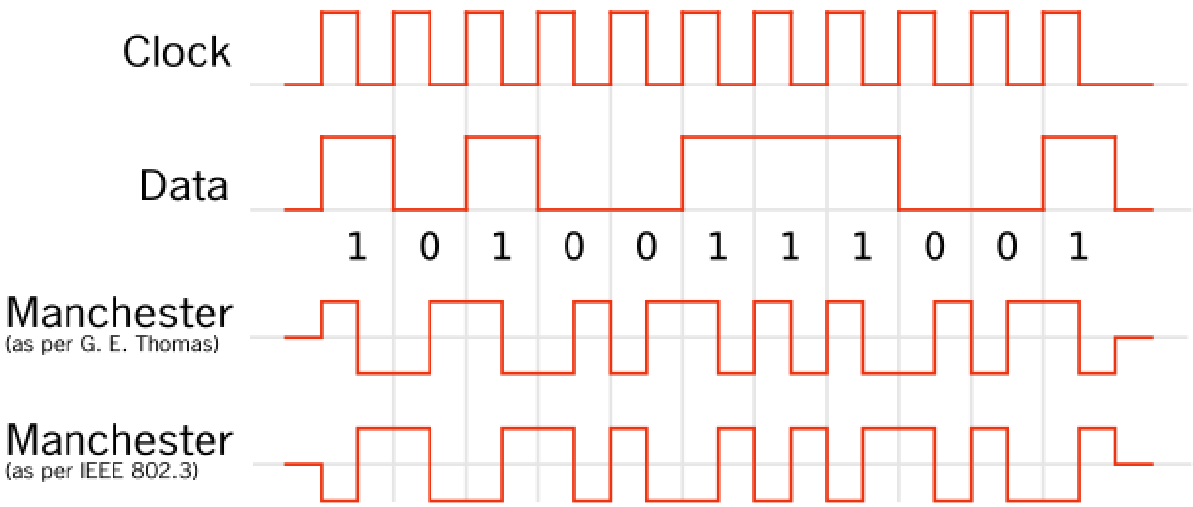
Encoding

- Manchester encoding
  - Merging the clock with signal by transmitting Ex-OR of the NRZ encoded data and the clock
  - Clock is an internal signal that alternates from low to high, a low/high pair is considered as one clock cycle
  - In Manchester encoding
    - 0: low→ high transition
    - 1: high→ low transition



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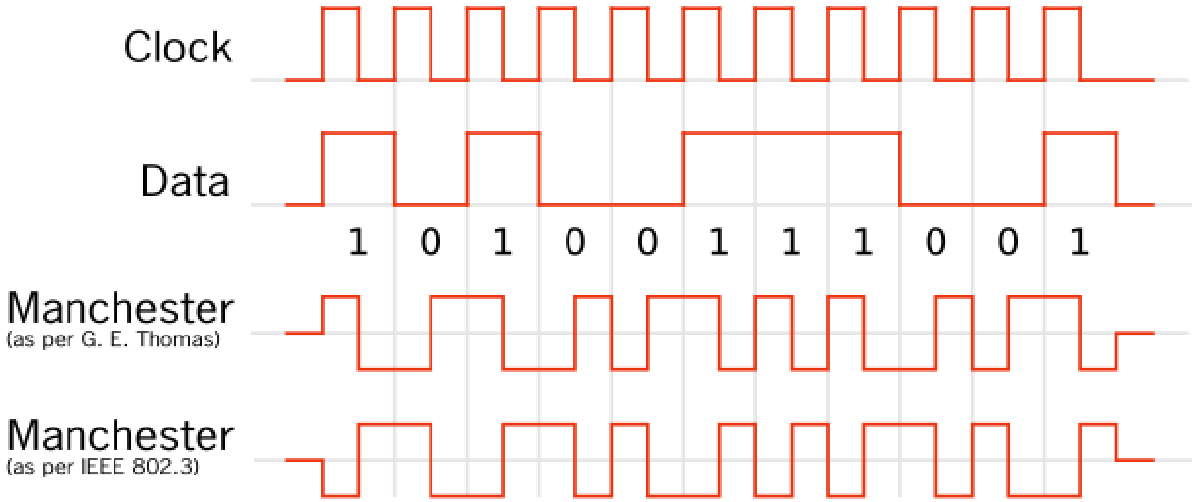
Encoding

- Problem with Manchester encoding
  - Doubles the rate at which the signal transitions are made on the link
    - Which means the receiver has half of the time to detect each pulse of the signal
  - The rate at which the signal changes is called the link's baud rate
  - In Manchester the bit rate is half the baud rate



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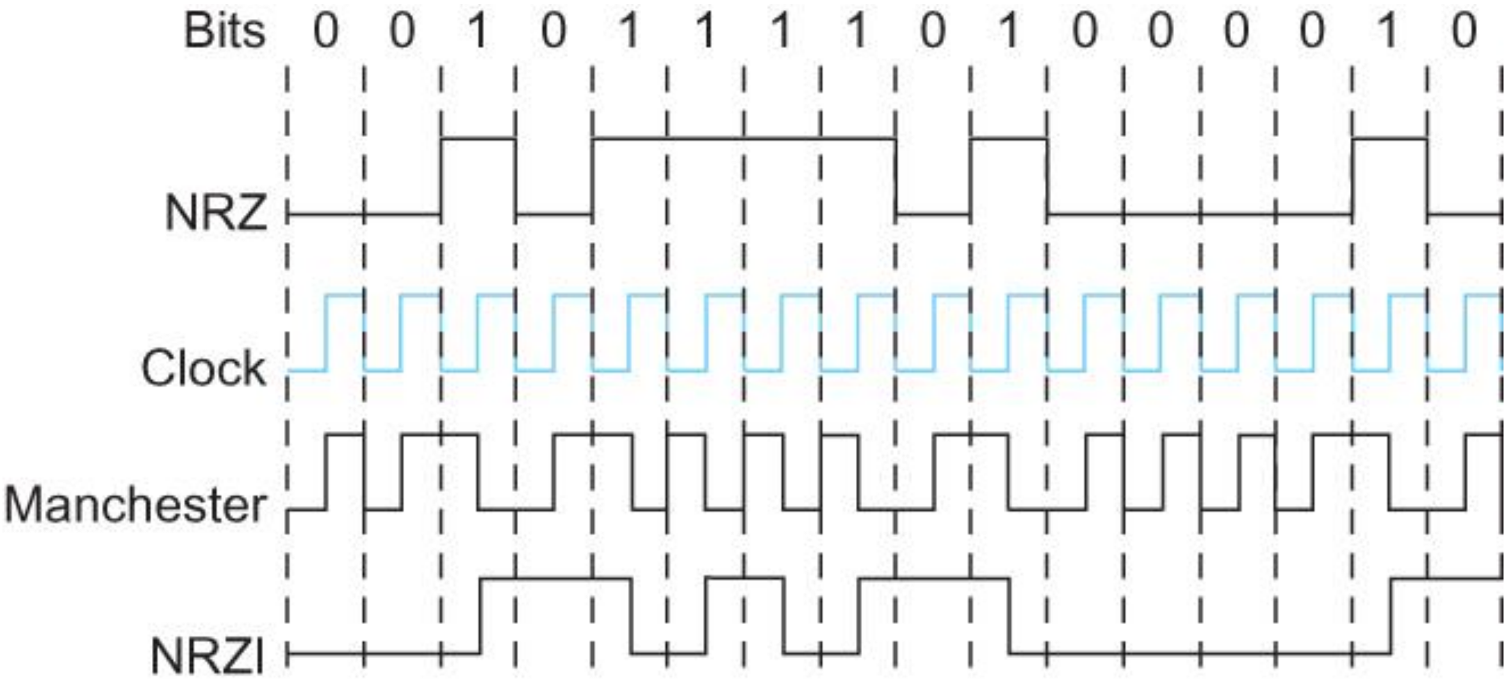
Encoding summary



Different encoding strategies

Funny game!

- Draw NRZ, NRZI, Manchester Code for the following bit string

100011101

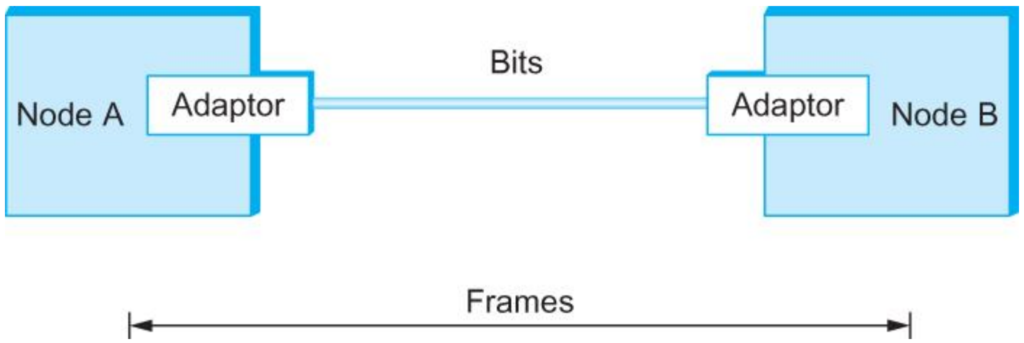
Funny game!

- Draw NRZ, NRZI, Manchester Code for the following bit string

100111001

Framing

- We are focusing on packet-switched networks, which means that blocks of data (called *frames* at this level), not bit streams, are exchanged between nodes.
- It is the network adaptor that enables the nodes to exchange frames.



Bits flow between adaptors, frames between hosts

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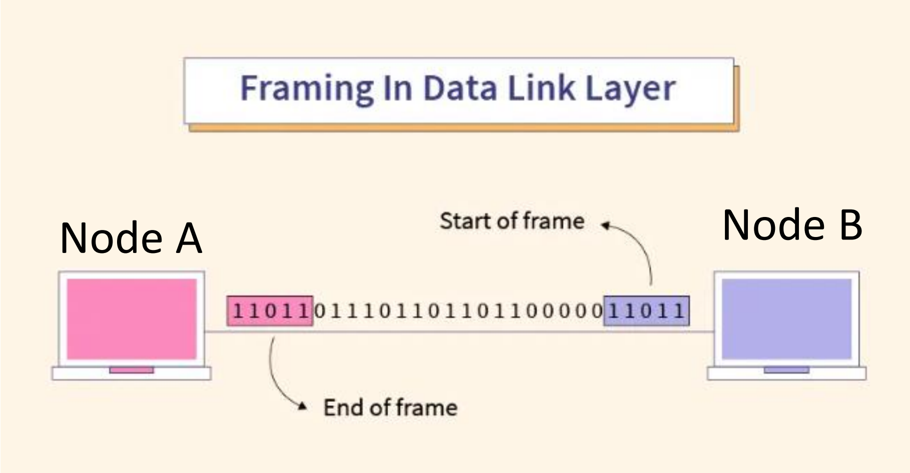
Framing [key]

- When node A wishes to transmit a frame to node B, it tells its adaptor to transmit a frame from the node's memory. This results in a sequence of bits being sent over the link.
- The adaptor on node B then collects together the sequence of bits arriving on the link and deposits the corresponding frame in B's memory.
- Recognizing exactly what set of bits constitute a frame—that is, determining where the frame begins and ends—is the central challenge faced by the adaptor



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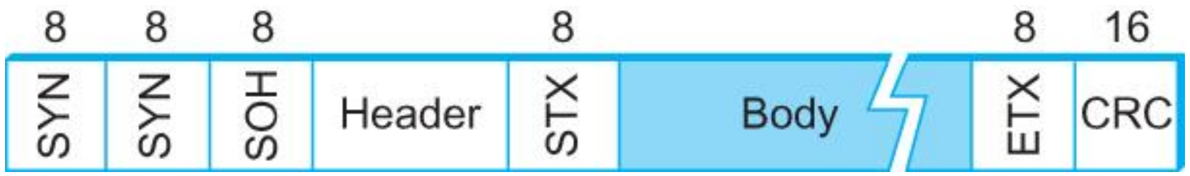
Framing

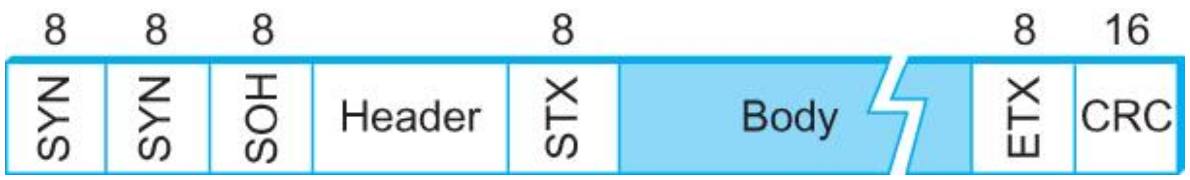
- Byte-oriented Protocols
  - To view each frame as a collection of bytes (characters) rather than bits
  - BISYNC (Binary Synchronous Communication) Protocol
    - Developed by IBM (late 1960)
  - DDCMP (Digital Data Communication Protocol)
    - Used in DECNet



BISYNC Frame Format

Framing

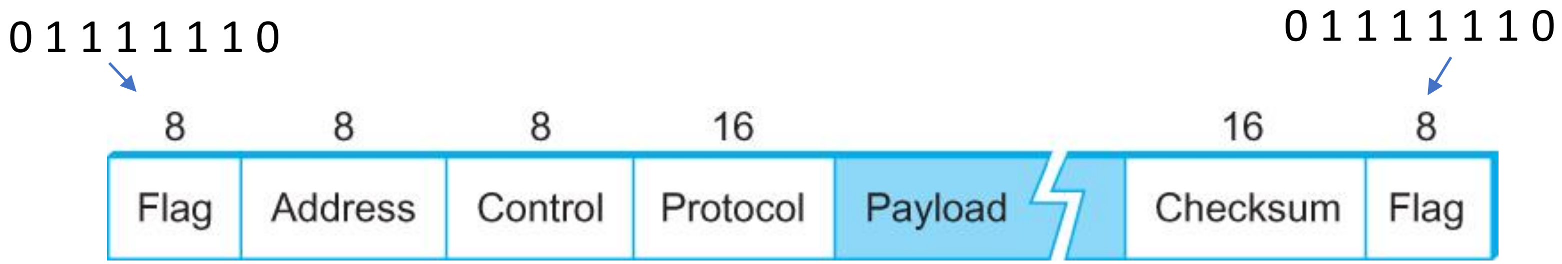
- BISYNC – sentinel approach
  - Frames transmitted beginning with leftmost field
  - Beginning of a frame is denoted by sending a special SYN (synchronize) character
  - Data portion of the frame is contained between special sentinel character STX (start of text) and ETX (end of text)
  - SOH : Start of Header
  - DLE : Data Link Escape
  - CRC: Cyclic Redundancy Check



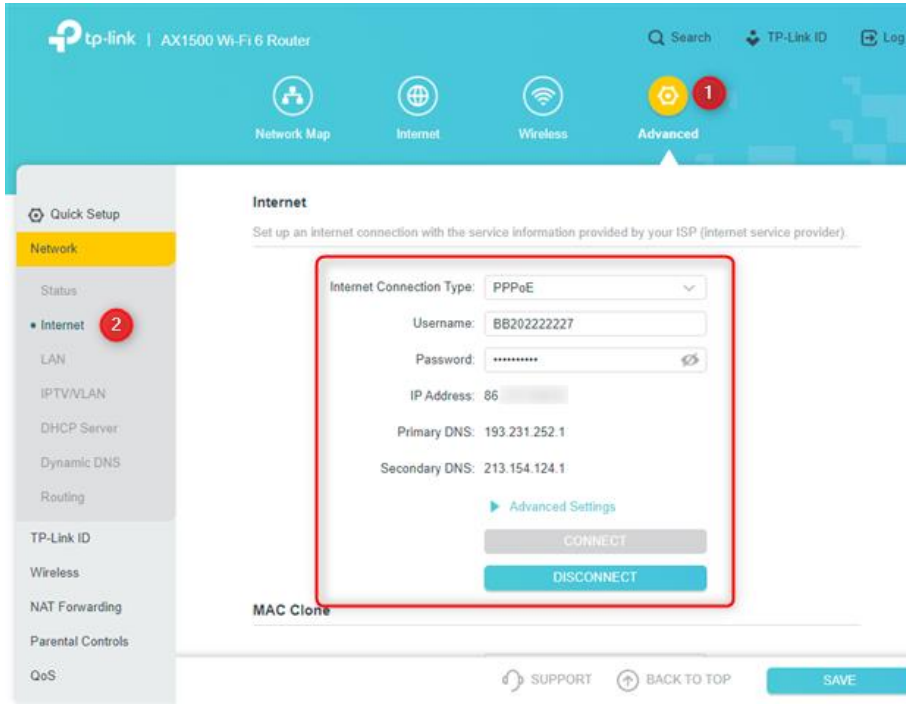
BISYNC Frame Format

Framing [key]

- PPP is commonly run over Internet links uses sentinel approach
  - Special start of text character denoted as Flag
    - 0 1 1 1 1 1 1 0
  - Address, control : default numbers
  - Protocol for demux : IP / IPX
  - Payload : negotiated (1500 bytes)
  - Checksum : for error detection



PPP Frame Format



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Framing [key]

- Bit-oriented Protocol
  - HDLC : High Level Data Link Control
    - Beginning and Ending Sequences

      0 1 1 1 1 1 1 0

HDLC Frame Format

- HDLC Protocol
  - On the sending side, any time five consecutive 1’s have been transmitted from the body of the message (i.e. excluding when the sender is trying to send the distinguished 01111110 sequence)
    - The sender inserts 0 before transmitting the next bit

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Framing

- HDLC Protocol
  - On the receiving side
    - 5 consecutive 1's
      - Next bit 0 : Stuffed, so discard it

        1 : Either End of the frame marker

        Or Error has been introduced in the bitstream

        Look at the next bit

        If 0 (01111110) → End of the frame marker

        If 1 (01111111) → Error, discard the whole frame

        The receiver needs to wait for next 01111110 before it can start receiving again

Error Detection

- Bit errors are introduced into frames
  - Because of electrical interference and thermal noises
- Detecting Error
- Correction Error
- Two approaches when the recipient detects an error
  - Notify the sender that the message was corrupted, so the sender can send again.
    - If the error is rare, then the retransmitted message will be error-free
  - Using some error correct detection and correction algorithm, the receiver reconstructs the message

Error Detection

- Common technique for detecting transmission error
  - **CRC** (Cyclic Redundancy Check)
    - Used in HDLC, DDCMP, CSMA/CD, Token Ring
  - Other approaches
    - **Two Dimensional Parity** (BISYNC)
    - **Checksum** (used in IP packet)

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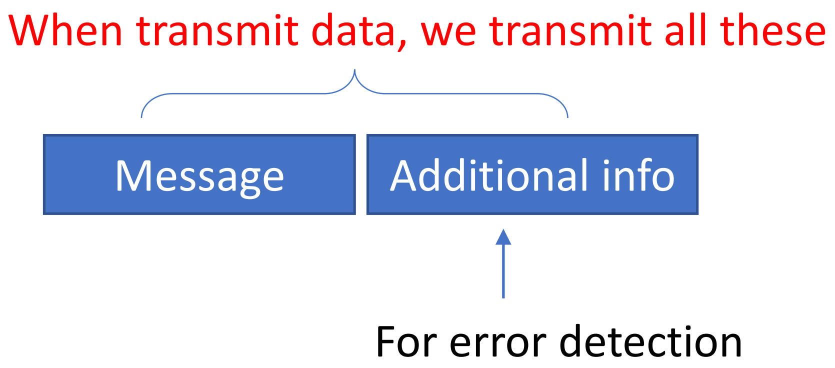
Error Detection

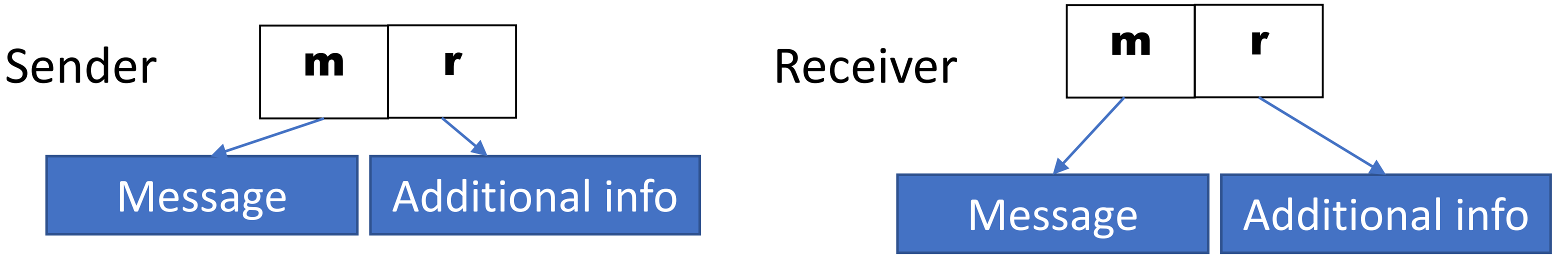
- Basic Idea of Error Detection
  - To add redundant information to a frame that can be used to determine if errors have been introduced
  - Imagine (Extreme Case)
    - Transmitting two complete copies of data
      - Identical → No error
      - Differ → Error
      - Poor Scheme ???
        - n bit message, n bit redundant information
        - Error can go undetected



    - In general, we can provide strong error detection technique
      - k redundant bits, n bits message, k << n
      - In Ethernet, a frame carrying up to 12,000 bits of data requires only 32-bit CRC

Error Detection

- Extra bits are redundant
    - They add no new information to the message
    - Derived from the original message using some algorithm
    - Both the sender and receiver know the algorithm



Receiver computes *r* using *m*

If they match, no error

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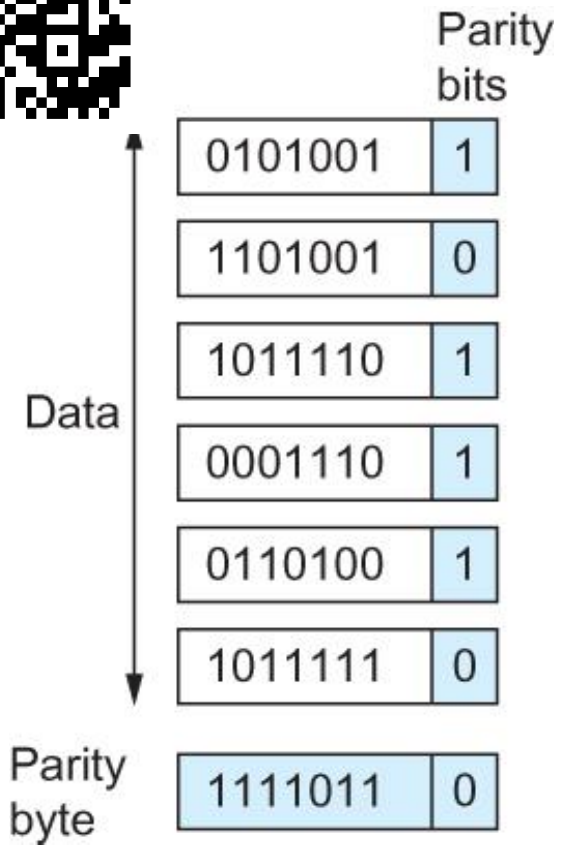
Two-dimensional parity

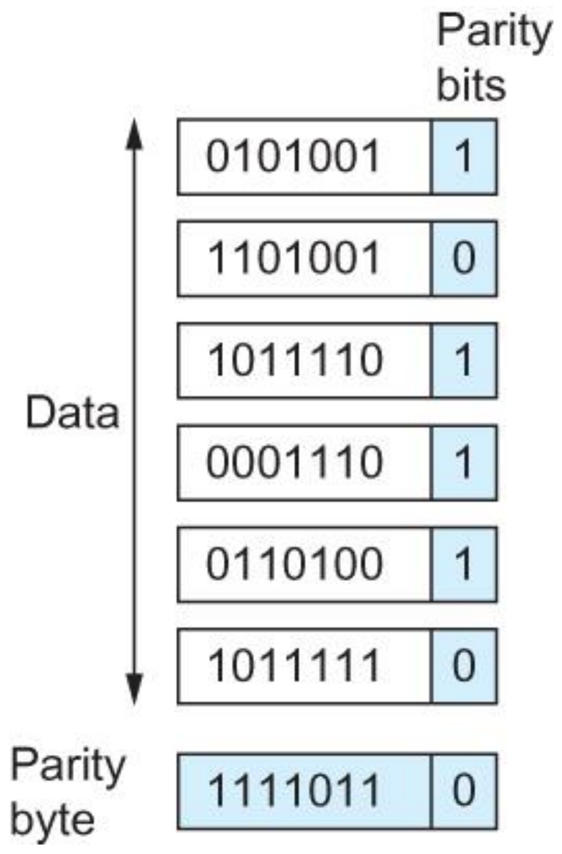
- Two-dimensional parity is exactly what the name suggests
- It is based on “simple” (one-dimensional) parity, which usually involves adding one extra bit to a 7-bit code to balance the number of 1s in the byte. For example,
  - Odd parity sets the eighth bit to 1 if needed to give an odd number of 1s in the byte, and
  - Even parity sets the eighth bit to 1 if needed to give an even number of 1s in the byte



Two Dimensional Parity

Two-dimensional parity

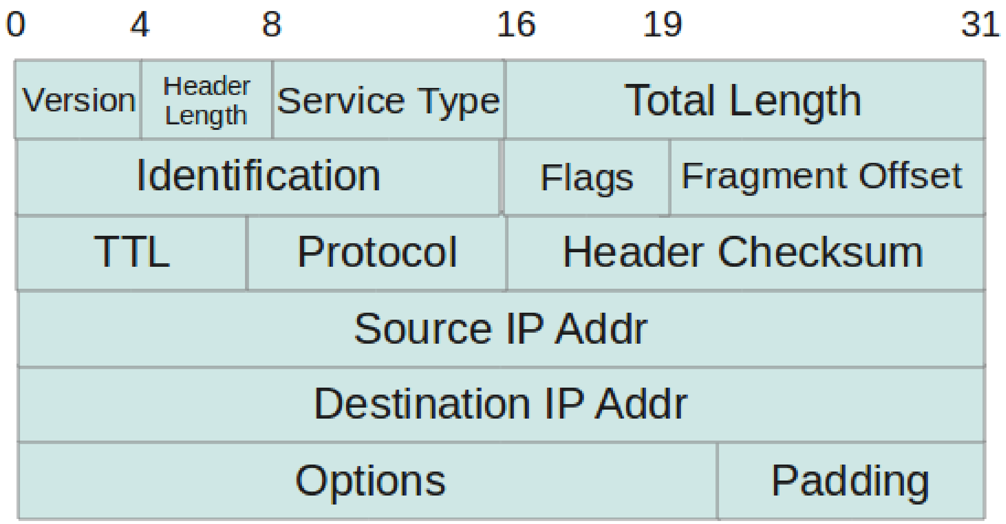
- Two-dimensional parity does a similar calculation for each bit position across each of the bytes contained in the frame
- This results in an extra parity byte for the entire frame, in addition to a parity bit for each byte
- Two-dimensional parity catches all 1-, 2-, and 3-bit errors and most 4-bit errors



Two Dimensional Parity

Internet Checksum Algorithm

- The sender sends data + its sum (checksum)
- The receiver performs the same calculation on the received data and compares the result with the received checksum
- If any transmitted data, including the checksum itself, is corrupted, then the results will not match, so the receiver knows that an error occurred



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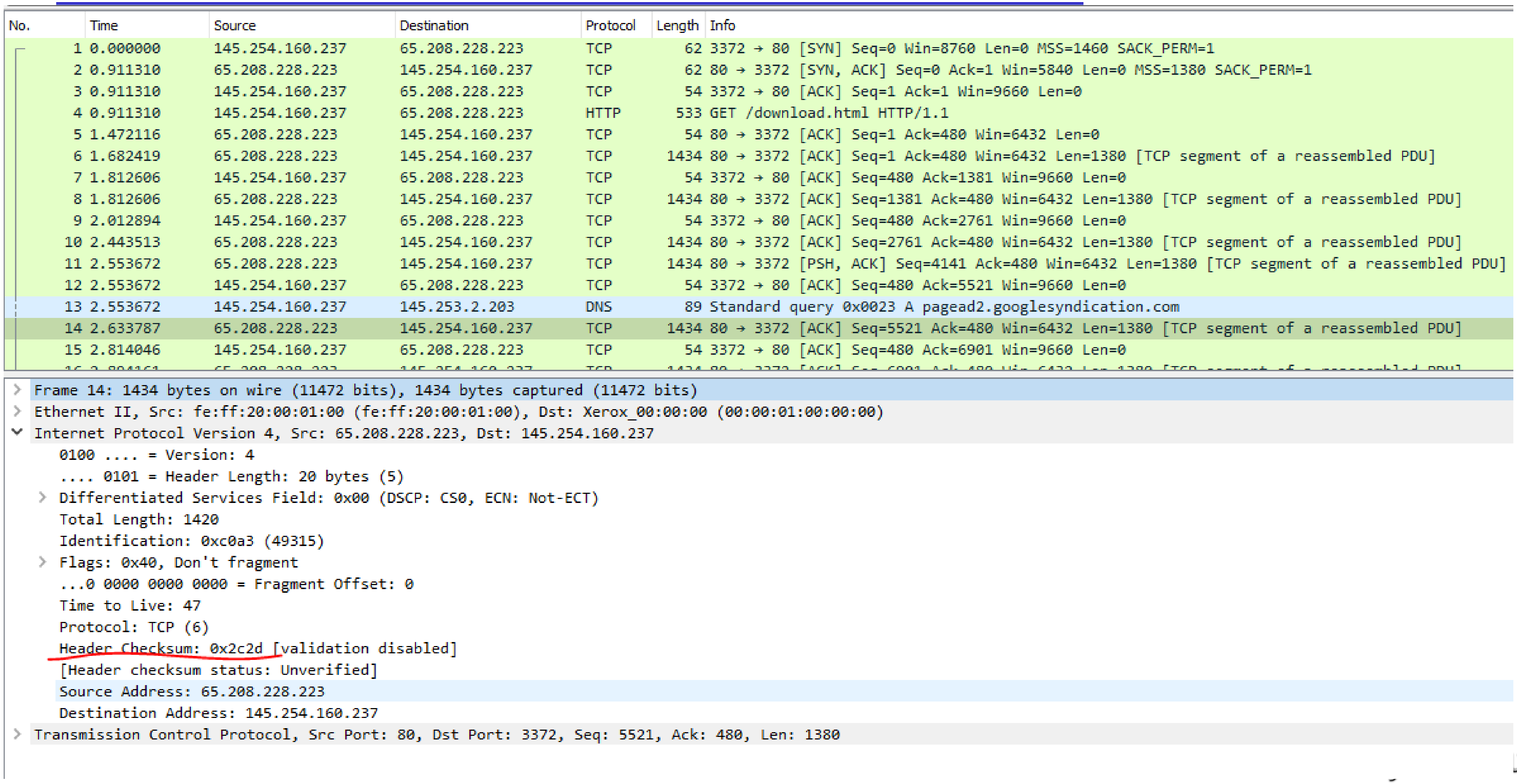
IP Checksum in Wireshark



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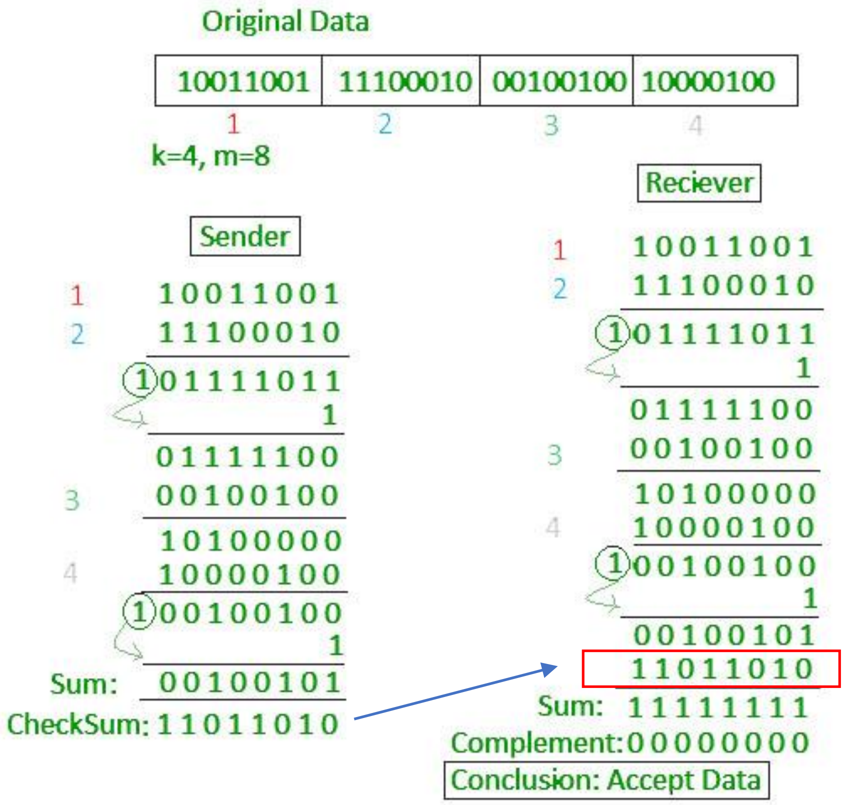
Internet Checksum Algorithm

- **Step 1:** Convert the data segment into a series of 16-bit integers;
- **Step 2:** Calculate the sum of all 16-bit integers, allowing for the carry bit wrap-around;
- **Step 3:** Add the checksum to the final sum total;
- **Step 4:** If the final total is all 1's the data is validated;
- **Step 5:** If any 0's are detected the data has been corrupted.



Cyclic Redundancy Check (CRC)

- A common method of detecting accidental changes/errors in the communication channel.
- CRC uses **Generator Polynomial** which is available on both sender and receiver side
- An example generator polynomial is of the form like $x^3 + x + 1$. This generator polynomial represents key 1011.

```
n : Number of bits in data to be sent from sender side.

k : Number of bits in the key obtained from generator
polynomial.
```

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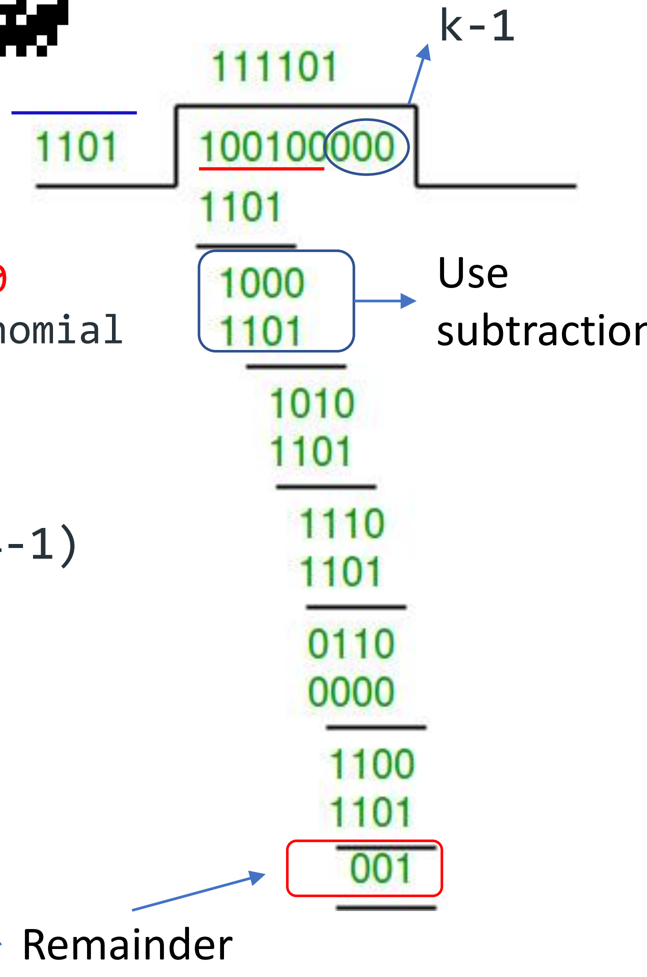
Step to calculate CRC

- **Step 1:** The binary data is first augmented by adding k-1 zeros in the end of the data
- **Step 2:** Use ***modulo-2 binary division*** to divide binary data by the key and store remainder of division.
- **Step 3:** Append the remainder at the end of the data to form the encoded data and send the same

Data word to be sent - 100100
Key - 1101 Or generator polynomial
$x^3 + x^2 + 1$]
Sender Side:

n : 6
k : 3 (=4-1)



n : Number of bits in data to be sent from sender side.
k : Number of bits in the key obtained from generator polynomial.

the remainder is 001 and hence the encoded data sent is 100100001.

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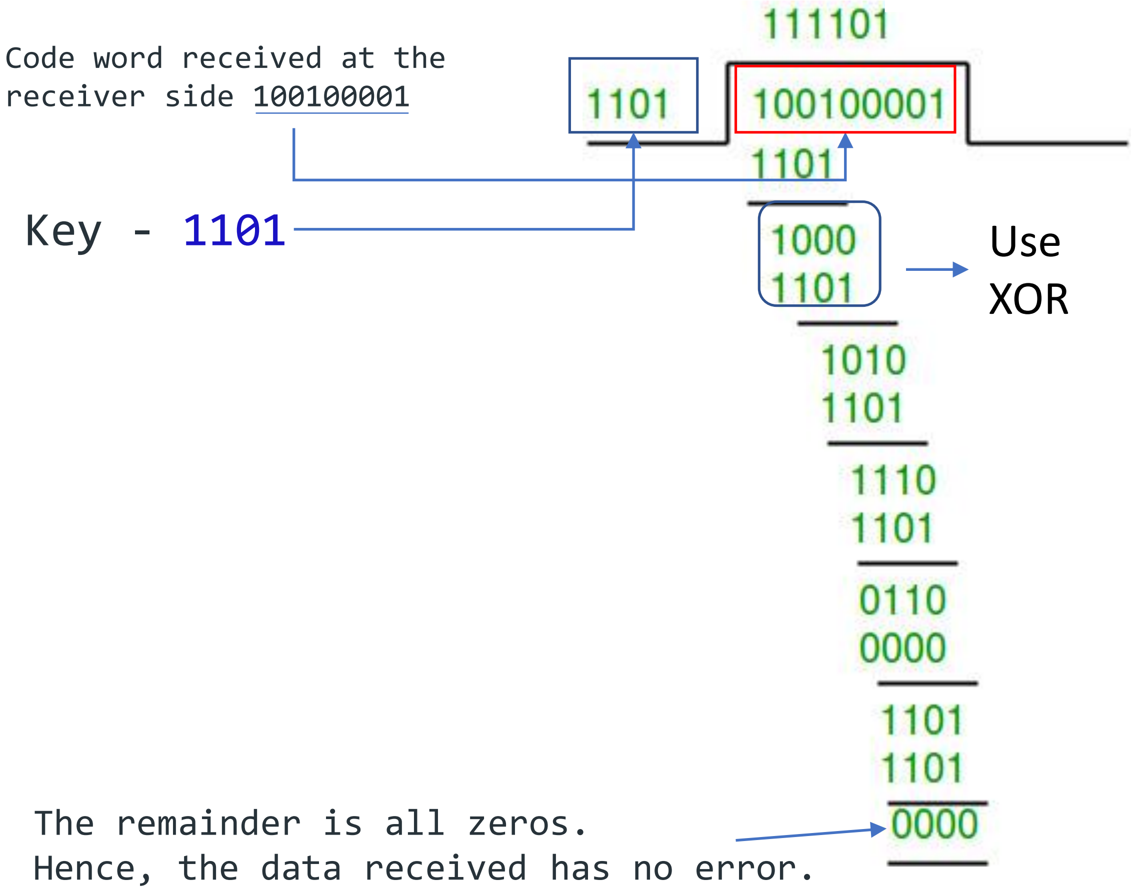
At the receiver side

[no error]

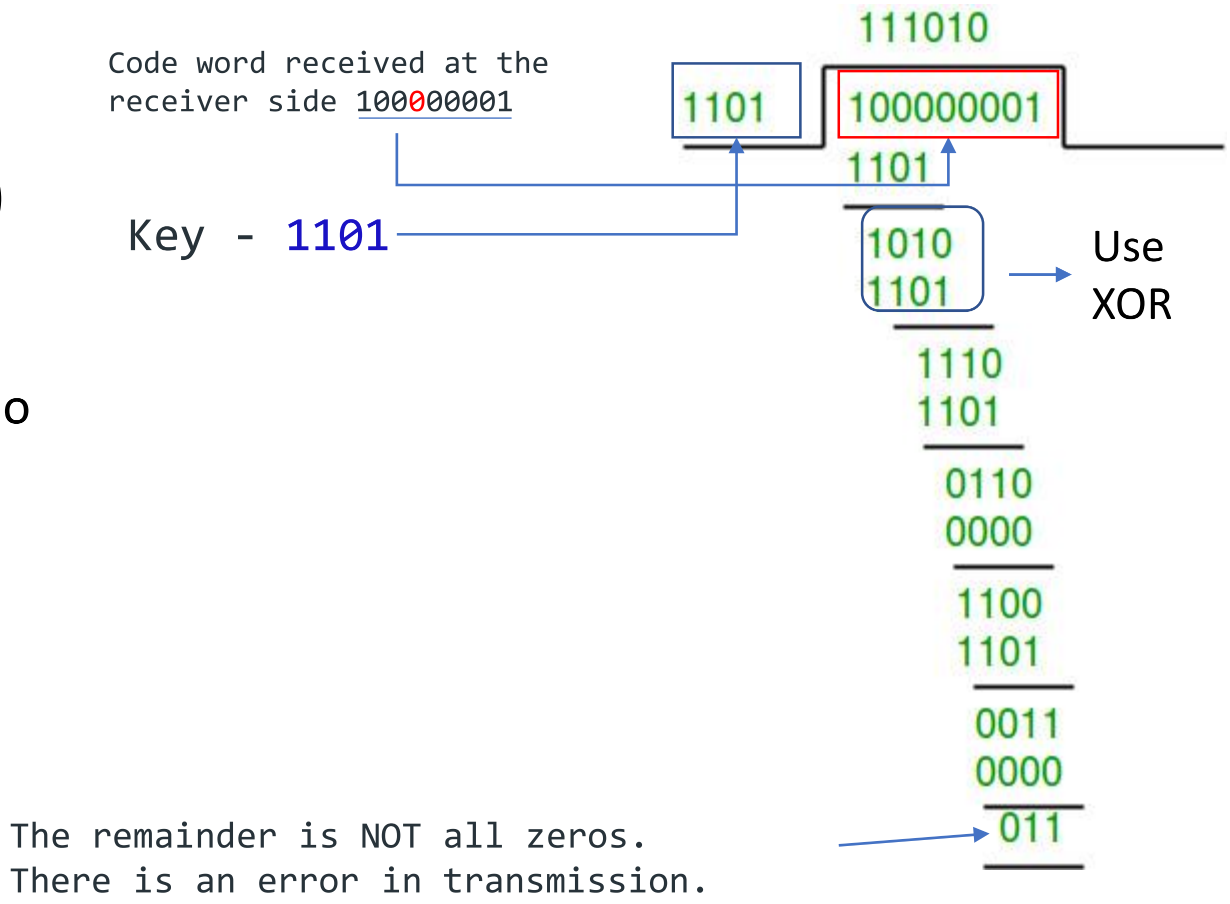
- **Step 1:** The binary data is first augmented by adding k-1 zeros in the end of the data
- **Step 2:** Use ***modulo-2 binary division*** (XOR, instead of subtraction) to divide binary data by the key and store remainder of division.
- **Step 3:** If the remainder is all zeros, there is no error. Otherwise, there is an



At the receiver side

[With error]

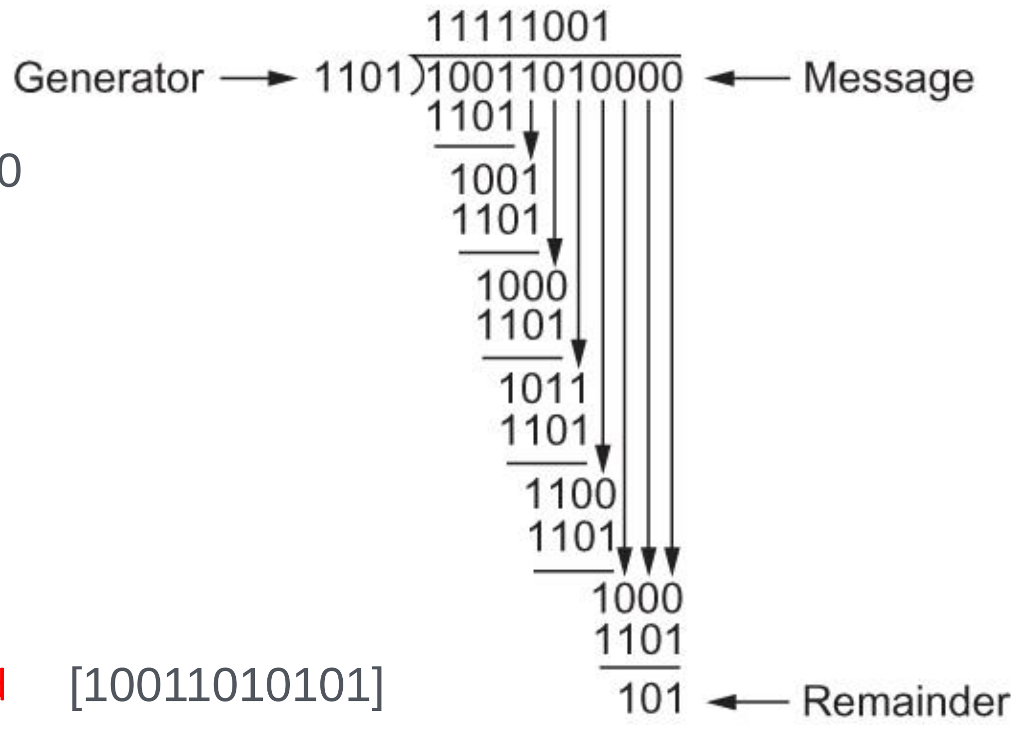
- **Step 1:** The binary data is first augmented by adding k-1 zeros in the end of the data
- **Step 2:** Use ***modulo-2 binary division*** (XOR) to divide binary data by the key and store remainder of division.
- **Step 3:** If the remainder is all zeros, there is no error. Otherwise, there is an error



Another example

The sender side

Original data bit to send 10011010



New data bit to send [10011010101]

CRC Calculation using Polynomial Long Division

Cyclic Redundancy Check (CRC)

- Six generator polynomials that have become international standards are:
  - CRC-8 = x^8+x^2+x+1
  - CRC-10 = $x^{10}+x^9+x^5+x^4+x+1$
  - CRC-12 = $x^{12}+x^{11}+x^3+x^2+x+1$
  - CRC-16 = $x^{16}+x^{15}+x^2+1$
  - CRC-CCITT = $x^{16}+x^{12}+x^5+1$
  - CRC-32 = $x^{32}+x^{26}+x^{23}+x^{22}+x^{16}+x^{12}+x^{11}+x^{10}+x^8+x^7+x^5+x^4+x^2+x+1$

QR Code For Q&A

Reliable Transmission

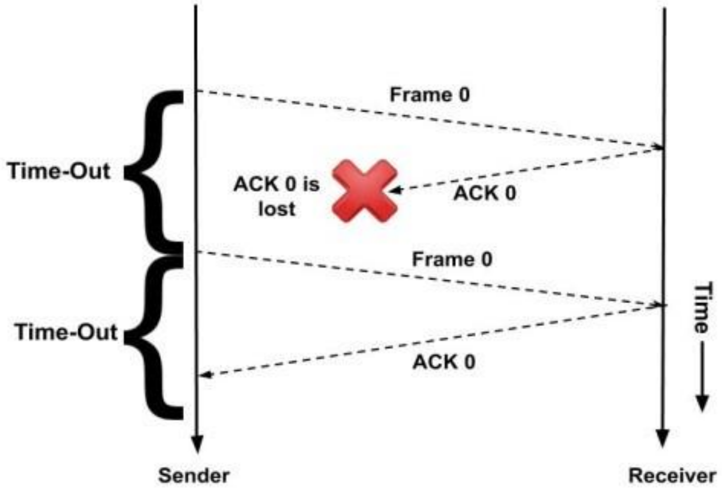
- CRC is used to detect errors.
- Some error codes are strong enough to correct errors.
- The overhead is typically too high.
- Corrupt frames must be discarded.
- A link-level protocol that wants to deliver frames reliably must recover from these discarded frames.
- This is accomplished using a combination of two fundamental mechanisms
  - Acknowledgements and Timeouts

Reliable Transmission

- An *acknowledgement* (ACK for short) is a small control frame that a protocol sends back to its peer saying that it has received the earlier frame.
  - A control frame is a frame with header only (no data).

- The receipt of an *acknowledgement* indicates to the sender of the original frame that its frame was successfully delivered.

- If the sender does not receive an *acknowledgment* after a reasonable amount of time, then it retransmits the original frame.
- The action of waiting a reasonable amount of time is called a *timeout*.
- The general strategy of using *acknowledgements* and *timeouts* to implement reliable delivery is sometimes called Automatic Repeat reQuest (ARQ).



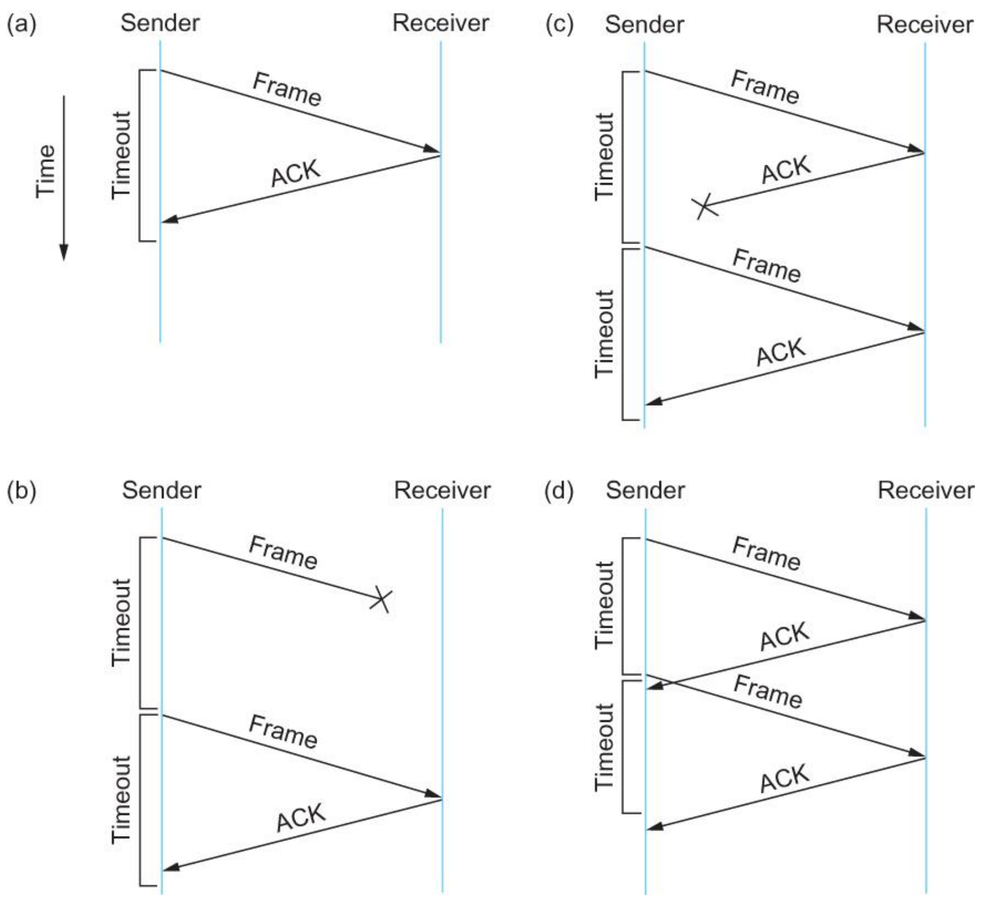
Stop and Wait Protocol

- Is a method to for error and flows control
- Idea of stop-and-wait protocol is straightforward
  - After transmitting one frame, the sender waits for an acknowledgement before transmitting the next frame.
  - If the acknowledgement does not arrive after a certain period of time, the sender times out and retransmits the original frame

Stop and Wait Protocol

Wait for how long?

1. RoundTripTime (**RTT**) = Amount of time taken by a packet to reach the receiver + Time taken by the Acknowledgement to reach the sender
2. TimeOut (**TO**) = 2* RTT
3. Time To Live (**TTL**) = 2* TimeOut. (Maximum TTL is 255 seconds)



Timeline showing four different scenarios for the stop-and-wait algorithm.
(a) The ACK is received before the timer expires; (b) the original frame is lost; (c) the ACK is lost; (d) the timeout fires too soon

Stop and Wait Protocol

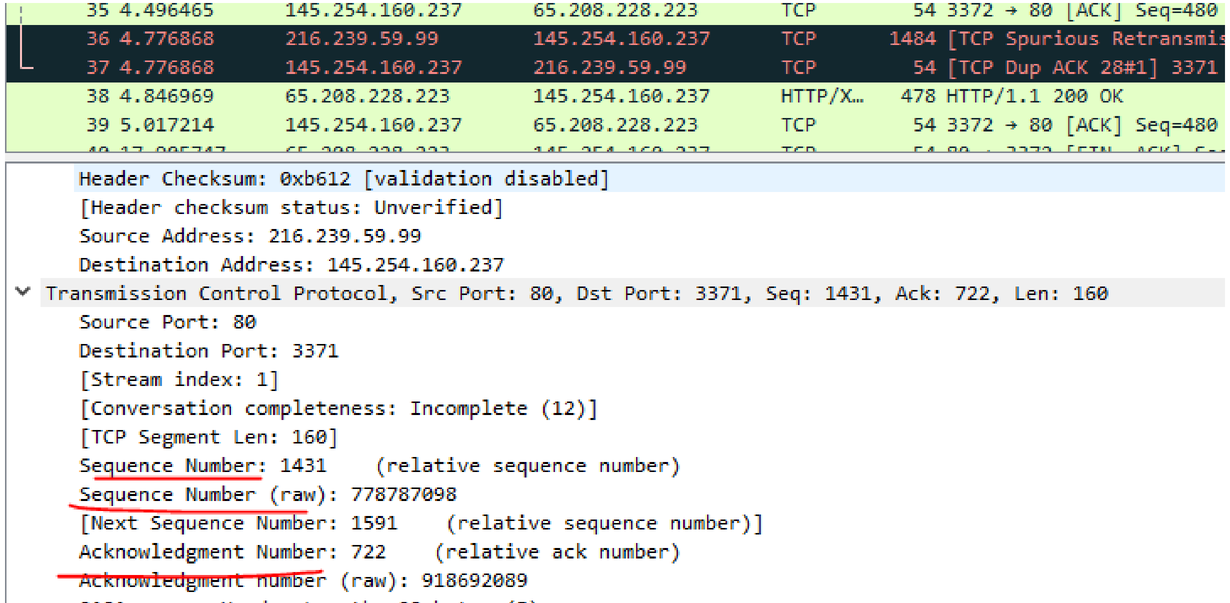
- If the acknowledgment is lost or delayed in arriving
  - The sender times out and retransmits the original frame, but the receiver will think that it is the next frame since it has correctly received and acknowledged the first frame
  - As a result, duplicate copies of frames will be delivered
- How to solve this
  - Use 1 bit sequence number (0 or 1)
  - When the sender retransmits frame 0, the receiver can determine that it is seeing a second copy of frame 0 rather than the first copy of frame 1 and therefore can ignore it (the receiver still acknowledges it, in case the first acknowledgement was lost)

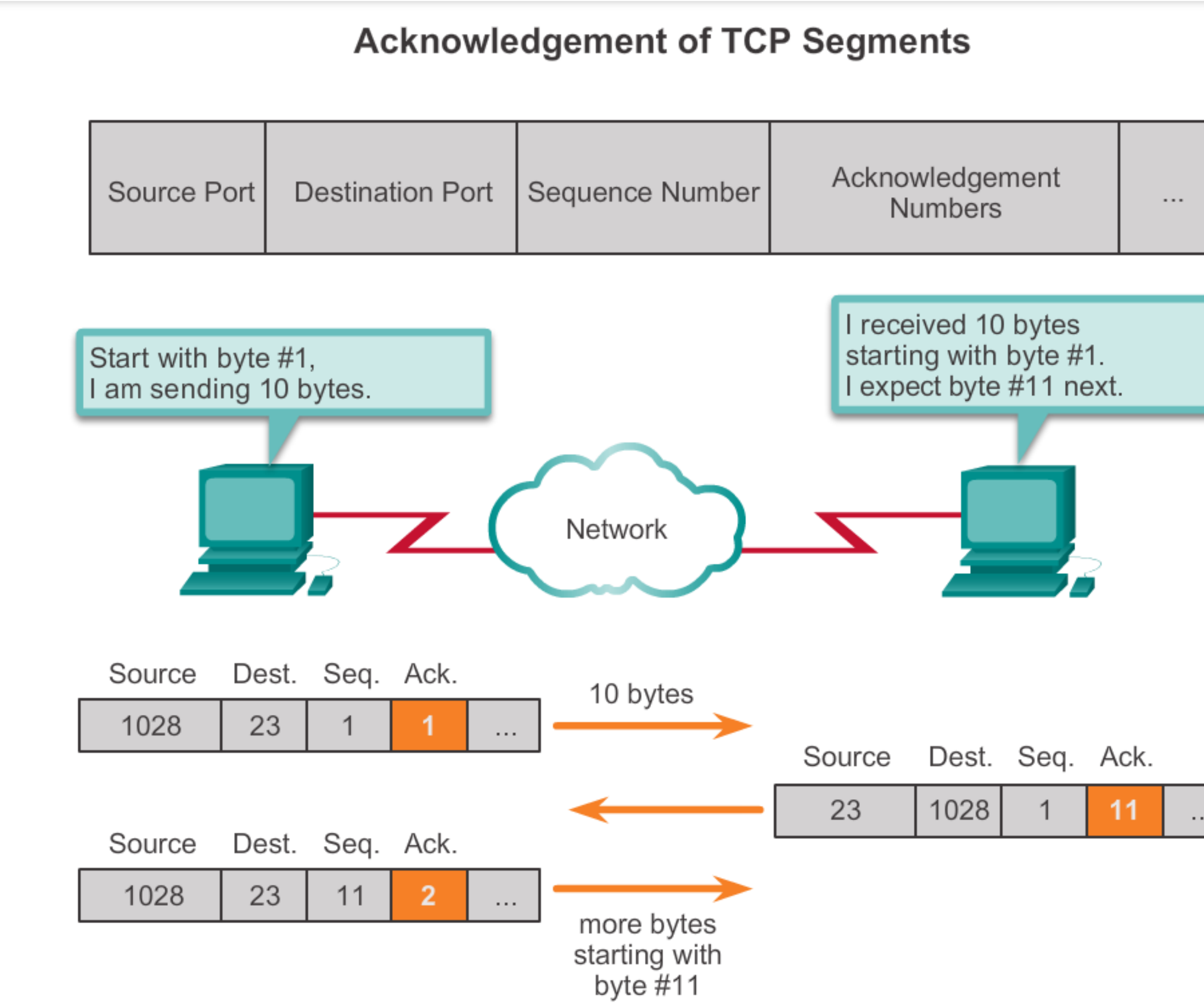
Sequence number

- ACK and Sequence Number

- To determine the data

order and retransmission data





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Stop and Wait Protocol

- The sender has only one outstanding frame on the link at a time
  - This may be far below the link's capacity
- Consider a 1.5 Mbps link with a 45 ms RTT
  - The link has a delay × bandwidth product of 67.5 Kb or approximately 8 KB
  - Since the sender can send only one frame per RTT and assuming a frame size of 1 KB
  - Maximum Sending rate
    - Bits per frame ÷ Time per frame = 1024 × 8 ÷ 0.045 = 182 Kbps

      Or about one-eighth of the link's capacity
  - To use the link fully, then sender should transmit up to eight frames before having to wait for an acknowledgement

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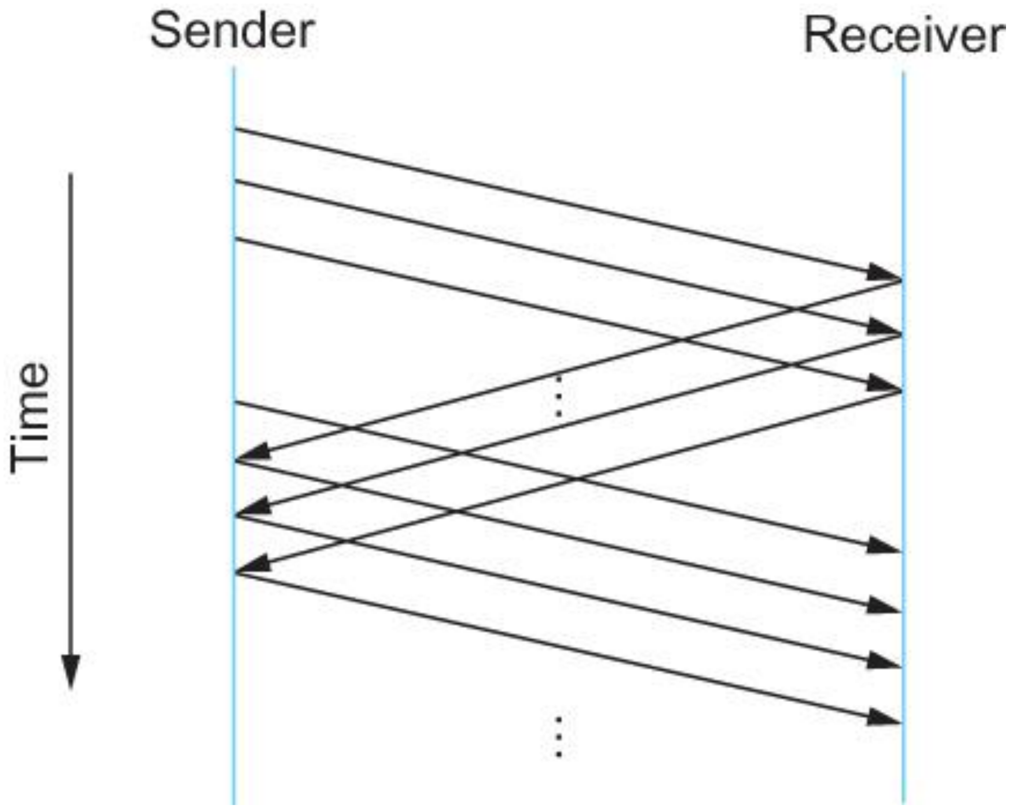
Sliding Window Protocol

1. RoundTripTime (**RTT**) = Amount of time taken by a packet to reach the receiver + Time taken by the Acknowledgement to reach the sender
2. TimeOut (**TO**) = 2* RTT
3. Time To Live (**TTL**) = 2* TimeOut. (Maximum TTL is 255 seconds)



Timeline for Sliding Window Protocol

Sliding window size in Wireshark

```
27 3.955688   216.239.59.99     145.254.160.237   HTTP      214 HTTP/1.1 200 OK  (text/html)
28 3.955688   145.254.160.237   216.239.59.99     TCP        54 3371 → 80 [ACK] Seq=722 Ack=1591 Win=8760 Len=0
29 4.105904   65.208.228.223    145.254.160.237   TCP      1434 80 → 3372 [PSH, ACK] Seq=12421 Ack=480 Win=6432 Len=1380 [TCP segment of
30 4.216062   145.254.160.237   65.208.228.223    TCP        54 3372 → 80 [ACK] Seq=480 Ack=13801 Win=9660 Len=0
31 4.226076   65.208.228.223    145.254.160.237   TCP      1434 80 → 3372 [ACK] Seq=13801 Ack=480 Win=6432 Len=1380 [TCP segment of a re
32 4.356264   65.208.228.223    145.254.160.237   TCP      1434 80 → 3372 [ACK] Seq=15181 Ack=480 Win=6432 Len=1380 [TCP segment of a re
33 4.356264   145.254.160.237   65.208.228.223    TCP        54 3372 → 80 [ACK] Seq=480 Ack=16561 Win=9660 Len=0
34 4.496465   65.208.228.223    145.254.160.237   TCP      1434 80 → 3372 [ACK] Seq=16561 Ack=480 Win=6432 Len=1380 [TCP segment of a re
35 4.496465   145.254.160.237   65.208.228.223    TCP        54 3372 → 80 [ACK] Seq=480 Ack=17941 Win=9660 Len=0
36 4.776868   216.239.59.99     145.254.160.237   TCP      1484 [TCP Spurious Retransmission] 80 → 3371 [PSH, ACK] Seq=1 Ack=722 Win=314
37 4.776868   145.254.160.237   216.239.59.99     TCP        54 [TCP Dup ACK 28#1] 3371 → 80 [ACK] Seq=722 Ack=1591 Win=8760 Len=0
38 4.846969   65.208.228.223    145.254.160.237   HTTP/X…   478 HTTP/1.1 200 OK
39 5.017214   145.254.160.237   65.208.228.223    TCP        54 3372 → 80 [ACK] Seq=480 Ack=18365 Win=9236 Len=0
```

```
    Header Checksum: 0xb612 [validation disabled]
    [Header checksum status: Unverified]
    Source Address: 216.239.59.99
    Destination Address: 145.254.160.237
v Transmission Control Protocol, Src Port: 80, Dst Port: 3371, Seq: 1431, Ack: 722, Len: 160
    Source Port: 80
    Destination Port: 3371
    [Stream index: 1]
    [Conversation completeness: Incomplete (12)]
    [TCP Segment Len: 160]
    Sequence Number: 1431    (relative sequence number)
    Sequence Number (raw): 778787098
    [Next Sequence Number: 1591    (relative sequence number)]
    Acknowledgment Number: 722    (relative ack number)
    Acknowledgment number (raw): 918692089
    0101 .... = Header Length: 20 bytes (5)
  > Flags: 0x018 (PSH, ACK)
    Window: 31460
    [Calculated window size: 31460]
    [Window size scaling factor: -1 (unknown)]
    Checksum: 0xde29 [unverified]
    [Checksum Status: Unverified]
    Urgent Pointer: 0
```

Sliding Window Protocol

- Sender assigns a sequence number denoted as SeqNum to each frame.
  - Assume it can grow infinitely large

- Sender maintains three variables
  - Sending Window Size (SWS)
    - Upper bound on the number of outstanding (unacknowledged) frames that the sender can transmit
  - Last Acknowledgement Received (LAR)
    - Sequence number of the last acknowledgement received
  - Last Frame Sent (LFS)
    - Sequence number of the last frame sent

Sliding Window Protocol

- Receiver maintains three variables
  - Receiving Window Size (RWS)
    - Upper bound on the number of out-of-order frames that the receiver is willing to accept
  - Largest Acceptable Frame (LAF)
    - Sequence number of the largest acceptable frame
  - Last Frame Received (LFR)
    - Sequence number of the last frame received

Issues with Sliding Window Protocol

- When timeout occurs, the amount of data in transit decreases
  - Since the sender is unable to advance its window

- When the packet loss occurs, this scheme is no longer keeping the pipe full
  - The longer it takes to notice that a packet loss has occurred, the more severe the problem becomes

- How to improve this
  - Negative Acknowledgement (NAK)
  - Additional Acknowledgement
  - Selective Acknowledgement

Issues with Sliding Window Protocol

- Negative Acknowledgement (NAK)
  - Receiver sends NAK for frame 6 when frame 7 arrive (in the previous example)
    - However this is unnecessary since sender's timeout mechanism will be sufficient to catch the situation

- Additional Acknowledgement
  - Receiver sends additional ACK for frame 5 when frame 7 arrives
    - Sender uses duplicate ACK as a clue for frame loss

- Selective Acknowledgement
  - Receiver will acknowledge exactly those frames it has received, rather than the highest number frames
    - Receiver will acknowledge frames 7 and 8
    - Sender knows frame 6 is lost
    - Sender can keep the pipe full (additional complexity)

Issues with Sliding Window Protocol

How to select the window size

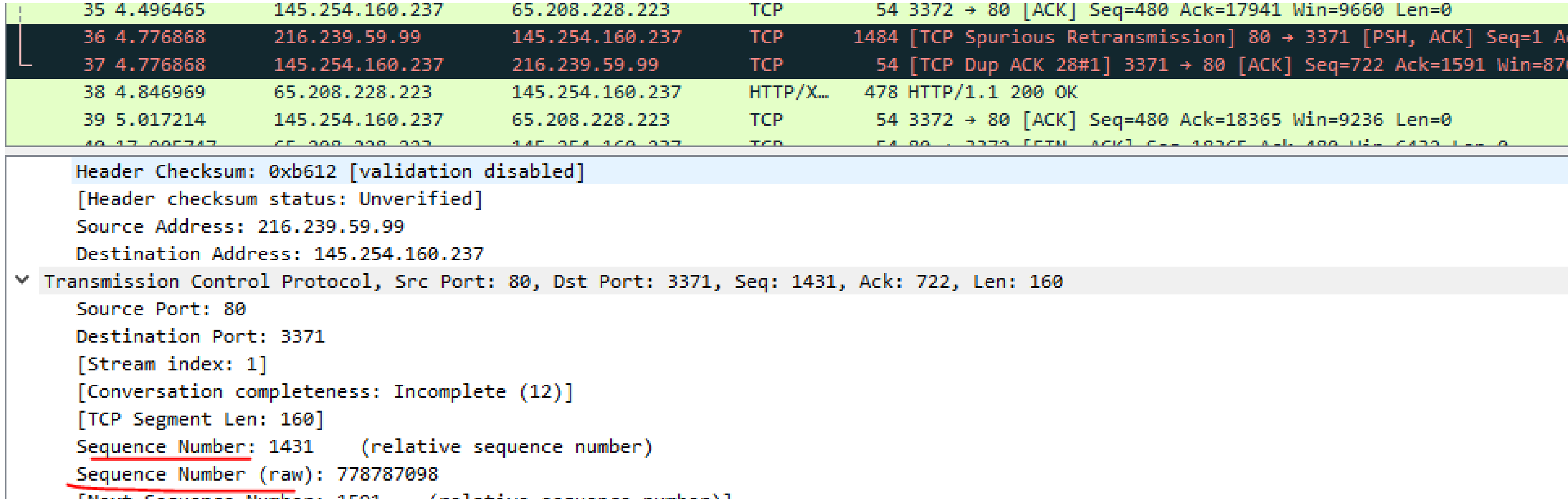
- SWS is easy to compute
  - Delay × Bandwidth
- RWS can be anything
  - Two common setting
    - RWS = 1

      No buffer at the receiver for frames that arrive out of order
    - RWS = SWS

      The receiver can buffer frames that the sender transmits

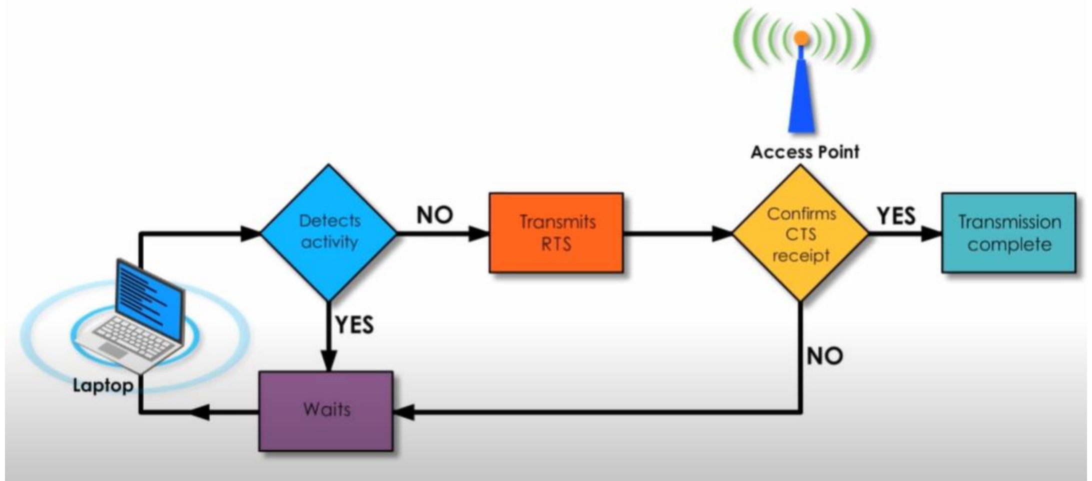
Issues with Sliding Window Protocol

- How to distinguish between different incarnations of the same sequence number?
  - Number of possible sequence number must be larger than the number of outstanding frames allowed
    - Stop and Wait: One outstanding frame
      - 2 distinct sequence number (0 and 1)
    - Let MaxSeqNum be the number of available sequence numbers
    - SWS + 1 ≤ MaxSeqNum
      - Is this sufficient?



Ethernet

- Most successful local area networking technology of last 20 years.
- Developed in the mid-1970s by researchers at the Xerox Palo Alto Research Centers (PARC).
- Uses CSMA/CD technology
  - Carrier Sense Multiple Access with Collision Detection.
  - A set of nodes send and receive frames over a shared link.
  - Carrier sense means that all nodes can distinguish between an idle and a busy link.
  - Collision detection means that a node listens as it transmits and can therefore detect when a frame it is transmitti has collided with a frame transmitted by another node.



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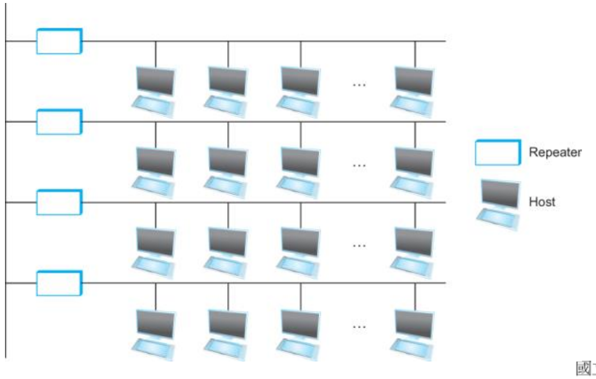
Ethernet

- This standard formed the basis for IEEE standard 802.3
- More recently 802.3 has been extended to include a 100-Mbps version called Fast Ethernet and a 1000-Mbps version called Gigabit Ethernet.
- Multiple Ethernet segments can be joined together by *repeaters.*
- A *repeater* is a device that forwards digital signals.
- No more than four repeaters may be positioned between any pair of hosts.
  - An Ethernet has a total reach of only 2500 m.



Ethernet

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- Any signal placed on the Ethernet by a host is broadcast over the entire network
  - Signal is propagated in both directions.
  - Repeaters forward the signal on all outgoing segments.
  - Terminators attached to the end of each segment absorb the signal.
- Ethernet uses Manchester/Other encoding schemes.

Ethernet LAN Standard	Symbol Encoding	Symbol Rate (Mbaud)	Data Encoding	Data Bits/Symbol	Pairs/Transmit Channel	Number of Pairs Used	Minimum Cable Category Required
10BaseT	Manchester	10	None	1	1	2	3
100BaseT4	Multi-level, 2T/Hz	25	8B6T	8/6	3	4	3
100BaseTX	MLT-3	125	4B5B	4/5	1	2	5
100BaseT2	PAM5x5 (2D-PAM5)	25	None	2	2	2	3
1000BaseT	4D-PAM5	125	None	2	4	4	5 (5e)
10GBase-T	DSQ128 (2D-PAM16)	800	LDPC(1723,2048), 64B/65B, CRC8	3.125	4	4	5e (6a)

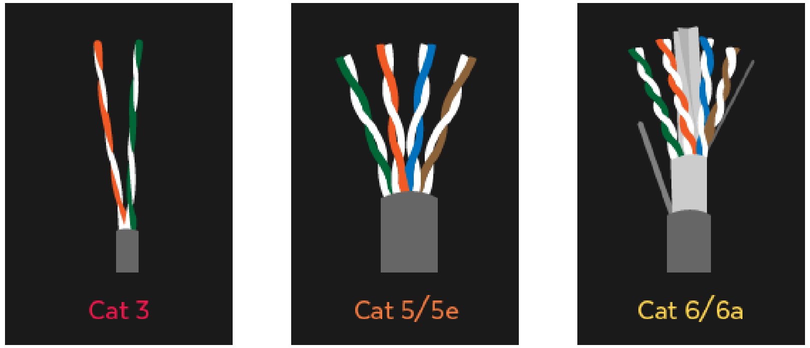
Ethernet

- New Technologies in Ethernet
  - Instead of using coax cable, an Ethernet can be constructed from a thinner cable, e.g., as 10Base2, 100BaseT
    - Base means the cable is used in a baseband system
    - 2 means that a given segment can be no longer than 200 m

Different Ethernet Categories

	Category 3	Category 5	Category 5e	Category 6	Category 6a	Category 7
Cable Type	UTP	UTP	UTP	UTP or STP	STP	S/FTP
Max. Data Transmission Speed	10 Mbps	10/100/1000 Mbps	10/100/1000 Mbps	10/100/1000 Mbps	10,000 Mbps	10,000 Mbps
Max. Bandwidth	16 MHz	100 MHz	100 MHz	250 MHz	500 MHz	600 MHz

Category Cable Wiring



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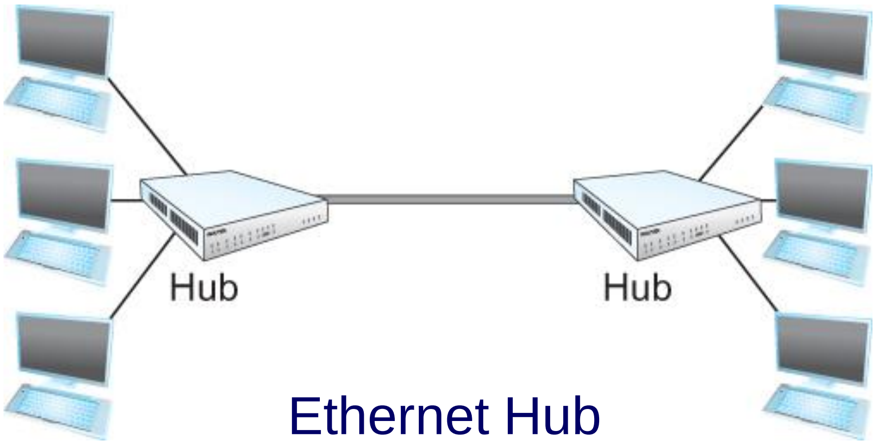
Ethernet

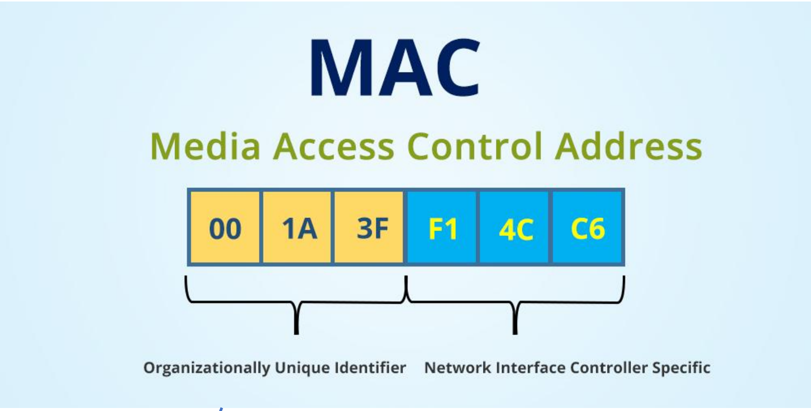
- New Technologies in Ethernet
  - Another cable technology is 10BaseT
    - T stands for twisted pair
    - Limited to 100 m in length
  - With 10BaseT, the common configuration is to have several point to point segments coming out of a multiway repeater, called *Hub*



Ethernet Hub

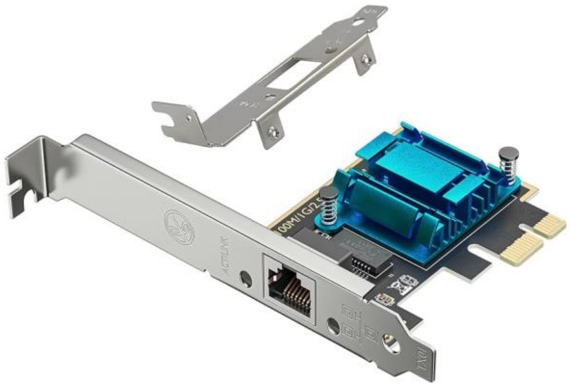
Hub is an old technology

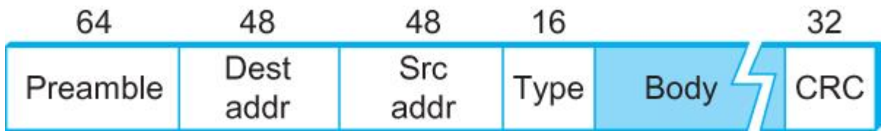
Access Protocol for Ethernet



- The algorithm is commonly called Ethernet's Media Access Control (MAC
  - It is implemented in Hardware on the network adaptor.
- Frame format
  - Preamble (64bit): allows the receiver to synchronize with the signal (sequence of alternating 0s and 1s).
  - Host and Destination Address (48bit each).
  - Packet type (16bit): acts as demux key to identify the higher level protocol.
  - Data (up to 1500 bytes)
    - Minimally a frame must contain at least 46 bytes of data.
    - Frame must be long enough to detect collision.
  - CRC (32bit)

Asus/Tp-Link





Ethernet Frame Format

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Ethernet Addresses

- Each host on an Ethernet (in fact, every Ethernet host in the world) has a unique Ethernet Address.
- The address belongs to the adaptor, not the host.
  - It is usually burnt into ROM.
- Ethernet addresses are typically printed in a human readable format
  - As a sequence of six numbers separated by colons.
  - Each number corresponds to 1 byte of the 6 byte address and is given by a pair of hexadecimal digits, one for each of the 4-bit nibbles in the byte
  - Leading 0s are dropped.
  - For example, 8:0:2b:e4:b1:2 is
    - 00001000 00000000 00101011 11100100 10110001 00000010

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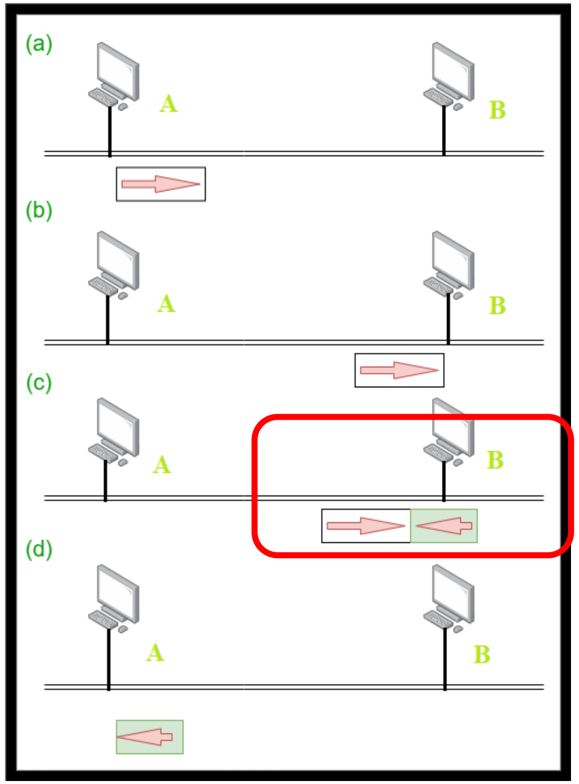
Ethernet Transmitter Algorithm

- Wired/Wireless Channel state:
  - ✓ Idle: The adaptor transmits frames.
    - The upper bound of 1500 bytes in the message means that the adaptor can occupy the line for a fixed length of time.
  - ✓ Busy: The adaptor waits for the line to go idle
  - ✓ Collision: Stop transmitting. After a random amount of time, it will sense the channel (if idle) before transmitting
    - It first makes sure to transmit (64-bit preamble + 32-bit jamming sequence = 96 bits) and then stops transmission
    - Each time the adaptor tries to transmit but fails, it doubles the amount of time it waits before trying again.
    - The strategy of doubling the delay interval between each retransmission attempt is known as *Exponential Backoff*

Ethernet Transmitter Algorithm

- The worst case scenario happens when the two hosts are at opposite ends of the Ethernet.
- To know for sure that the frame its just sent did not collide with another frame, the transmitter may need to send as many as 512 bits.
  - Every Ethernet frame must be at least 512 bits (64 bytes) long = 14 bytes of header + 46 bytes of data + 4 bytes of CRC
- Why 512 bits?
  - Why is its length limited to 2500 m?
- The farther apart two nodes are, the longer it takes for a frame sent by one to reach the other, and the network is vulnerable to collision during this time

The worst case



Worst-case scenario: (a) A sends a frame at time *t; (b) A's frame arrives* at B at time *t + d; (c) B begins transmitting at time t + d and collides with A's frame;* (d) B's runt (32-bit) frame arrives at A at time *t + 2d.*

Experience with Ethernet

- Ethernets work best under lightly loaded conditions.
  - Under heavy loads, too much of the network's capacity is wasted by collisions.
- Most Ethernets are used in a conservative way.
  - Have fewer than 200 hosts connected to them which is far fewer than the maximum of 1024.
- Most Ethernets are far shorter than 2500m with a round-trip delay of closer to 5 μs than 51.2 μs.
- Ethernets are easy to administer and maintain.
  - There are no switches that can fail and no routing and configuration tables that have to be kept up-to-date.
  - It is easy to add a new host to the network.
  - It is inexpensive.
    - Cable is cheap, and only other cost is the network adaptor on each host.

Summary

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- Links
- Encoding
- CRC
- Slide window
- Ethernet and Ethernet Address