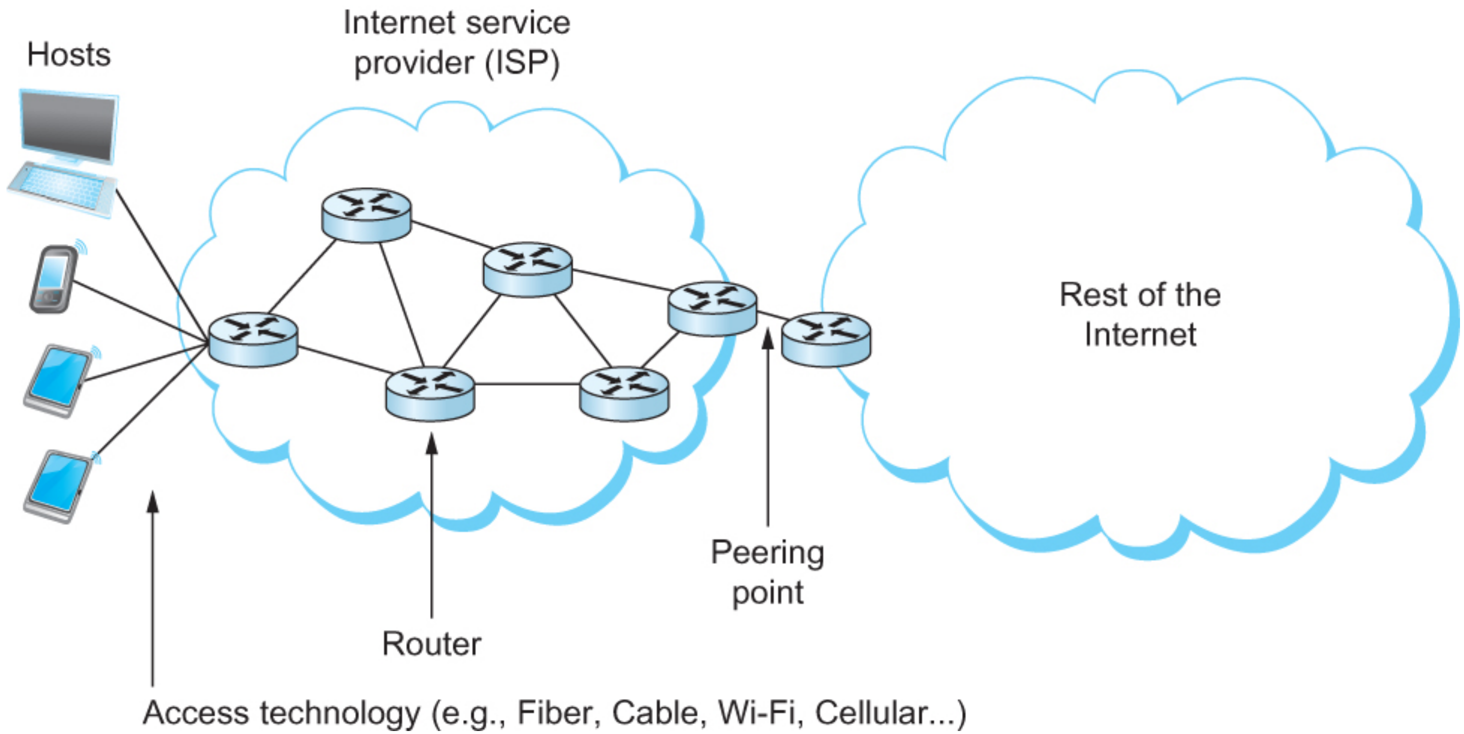
Networks and Distributed Systems

Lecture 3 – Physical layer

Outline

- Perspectives on Connecting nodes
- Encoding
- Framing
- Error Detection
- Reliable Transmission
- Ethernet and Multiple Access Networks
- Wireless Networks

Perspectives on Connecting



An end-user's view of the Internet

Link Capacity and Shannon-Hartley Theorem

- Gives the upper bound to the capacity of a link in terms of bits per second (bps) as a function of signal-to-noise ratio of the link measured in decibels (dB).
- $C = B\log_2(1+S/N)$
  - Where B = 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?

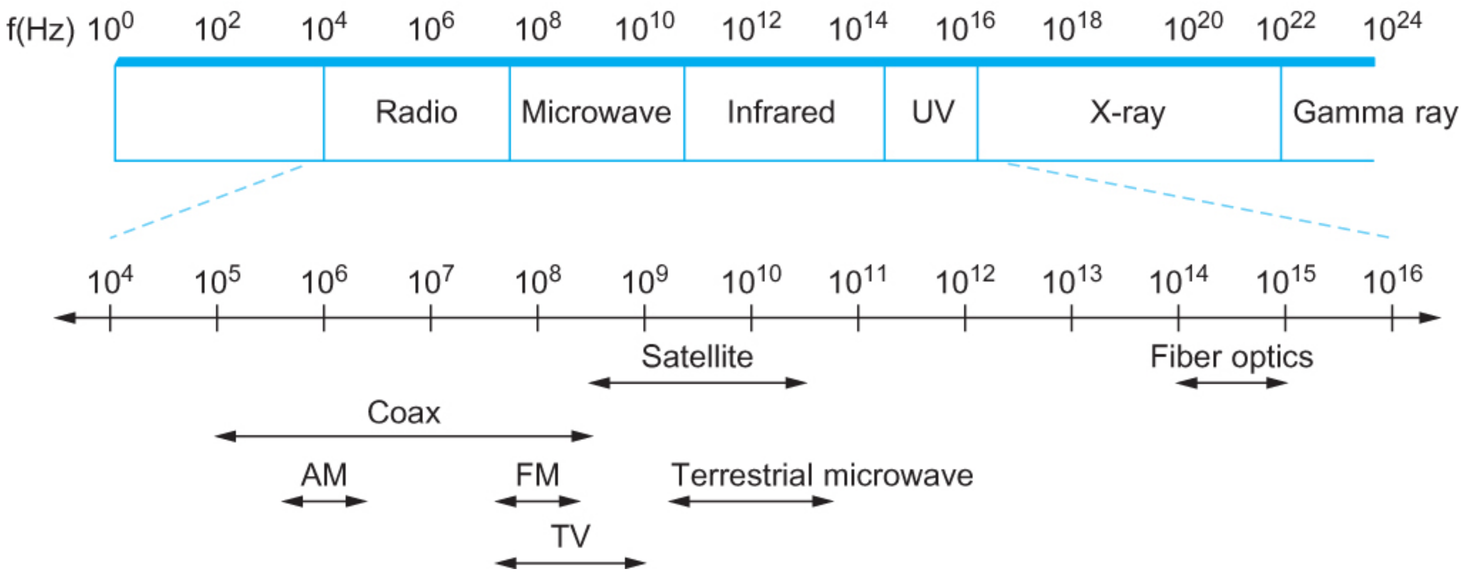
Links

- 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), or
  - Air/free space (for wireless links)

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



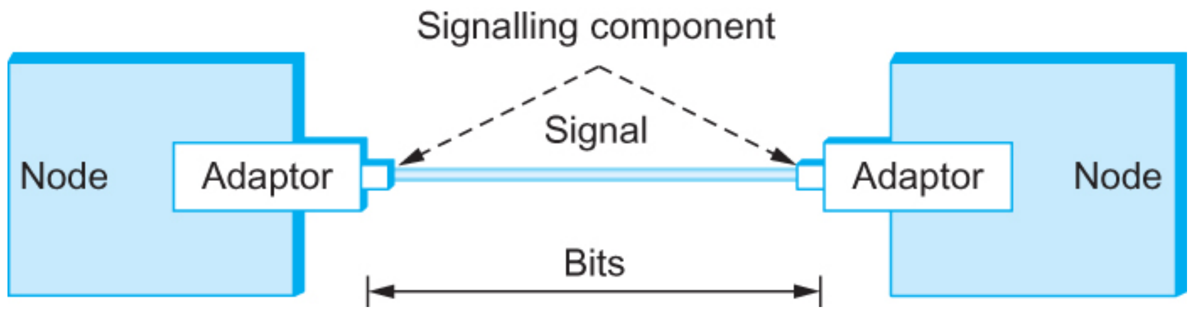
Electromagnetic spectrum

Links

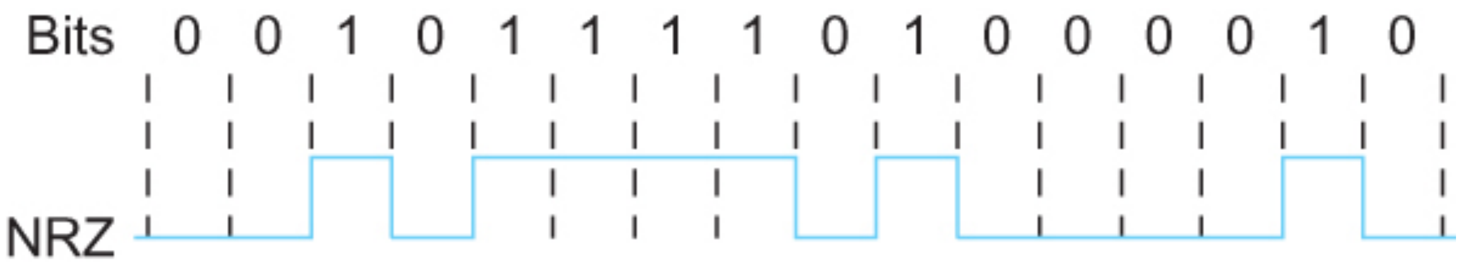
Service	Bandwidth (typical)
Dial-up	28–56 kbps
ISDN	64–128 kbps
DSL	128 kbps–100 Mbps
CATV (cable TV)	1–40 Mbps
FTTH (fibre to the home)	50 Mbps–1 Gbps

Common services available to connect your home

Encoding



Signals travel between signaling components; bits flow between adaptors



NRZ encoding of a bit stream

Encoding

- Problem with 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

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

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

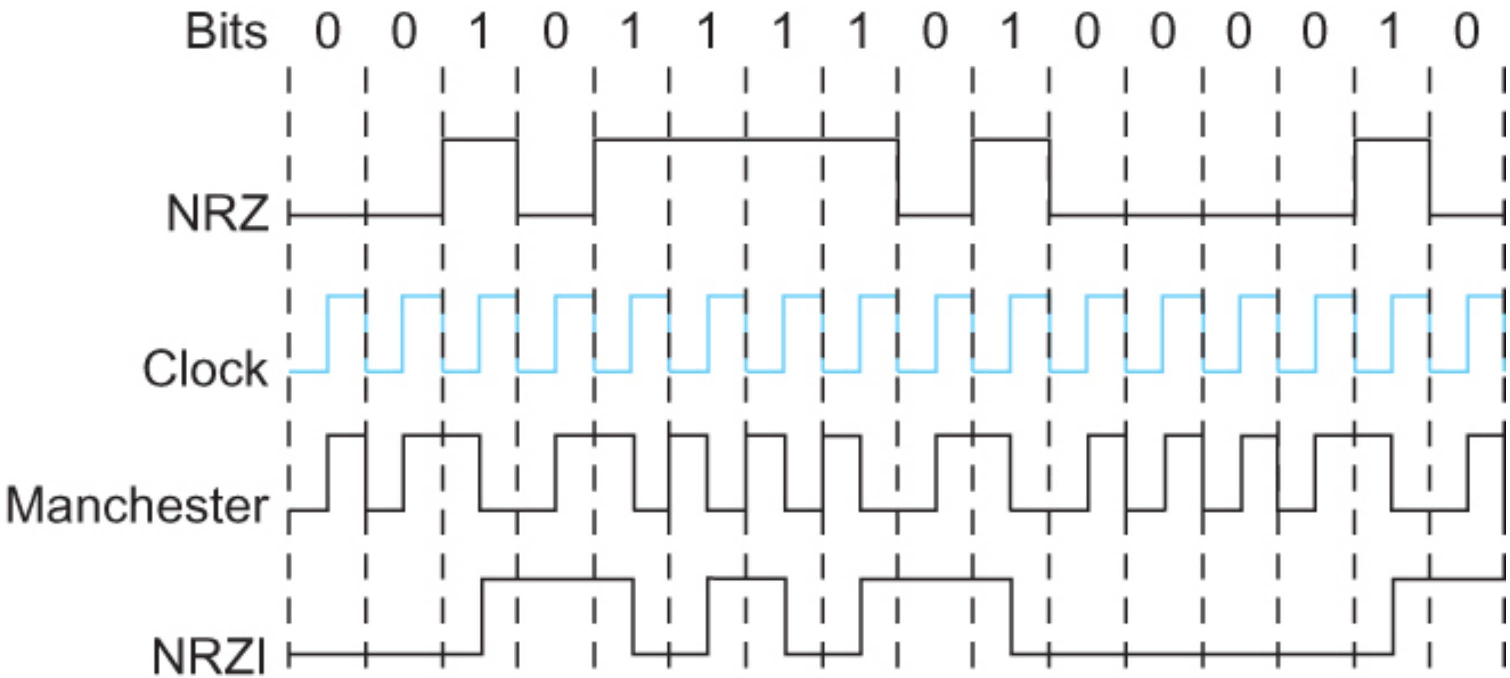
Encoding

- 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

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

Encoding



Different encoding strategies

Encoding

- 4B/5B encoding
  - Insert extra bits into bit stream so as to break up the long sequence of 0's and 1's
  - Every 4-bits of actual data are encoded in a 5- bit code that is transmitted to the receiver
  - 5-bit codes are selected in such a way that each one has no more than one leading 0(zero) and no more than two trailing 0's.
  - No pair of 5-bit codes results in more than three consecutive 0's

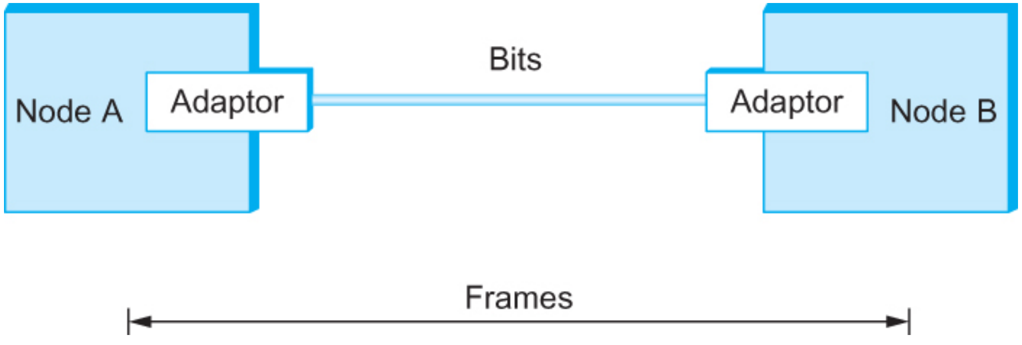
Encoding

- 4B/5B encoding

0000 → 11110	16 left
0001 → 01001	11111 – when the line is idle
0010 → 10100	00000 – when the line is dead
..	00100 – to mean halt
..	
1111 → 11101	13 left : 7 invalid, 6 for various control signals

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

Framing

- 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

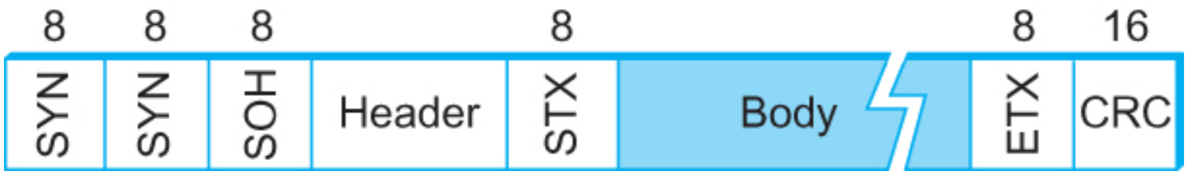
Framing

- 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

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

Framing



BISYNC Frame Format

Framing

- Recent PPP which 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

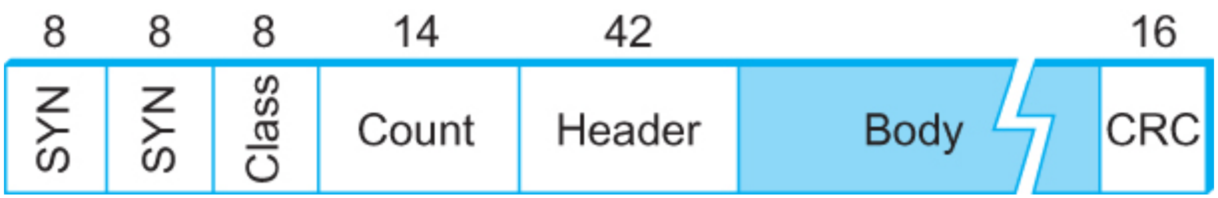
Framing

PPP Frame Format

Framing

- Byte-counting approach
  - DDCMP
  - *count* : how many bytes are contained in the frame body
  - If *count* is corrupted
    - Framing error

Framing

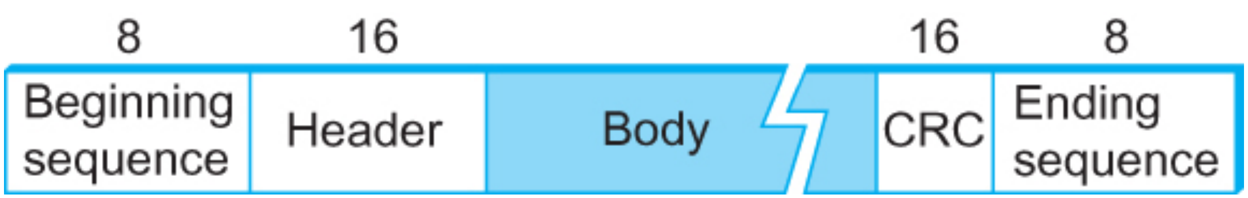


DDCMP Frame Format

Framing

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

      0 1 1 1 1 1 1 0



HDLC Frame Format

Framing

- 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

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 (IP)

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

Sender

m	**r**

Receiver

m	**r**

Receiver computes *r* using *m*

If they match, no error

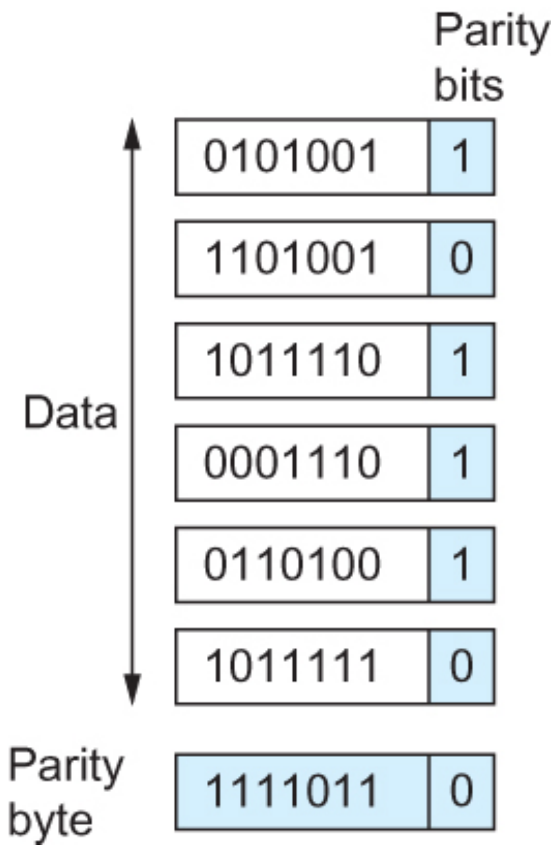
Two-dimensional parity

- 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 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



Two Dimensional Parity

Internet Checksum Algorithm

- Not used at the link level
- Add up all the words that are transmitted and then transmit the result of that sum
  - The result is called the 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

Internet Checksum Algorithm

- Consider the data being checksummed as a sequence of 16-bit integers.
- Add them together using 16-bit ones complement arithmetic (explained next slide) and then take the ones complement of the result.
- That 16-bit number is the checksum

Internet Checksum Algorithm

- In ones complement arithmetic, a negative integer −x is represented as the complement of x;
  - Each bit of x is inverted.
- When adding numbers in ones complement arithmetic, a carryout from the most significant bit needs to be added to the result.

Internet Checksum Algorithm

- Consider, for example, the addition of −5 and −3 in ones complement arithmetic on 4-bit integers
  - +5 is 0101, so −5 is 1010; +3 is 0011, so −3 is 1100
- If we add 1010 and 1100 ignoring the carry, we get 0110
- In ones complement arithmetic, the fact that this operation caused a carry from the most significant bit causes us to increment the result, giving 0111, which is the ones complement representation of −8 (obtained by inverting the bits in 1000), as we would expect