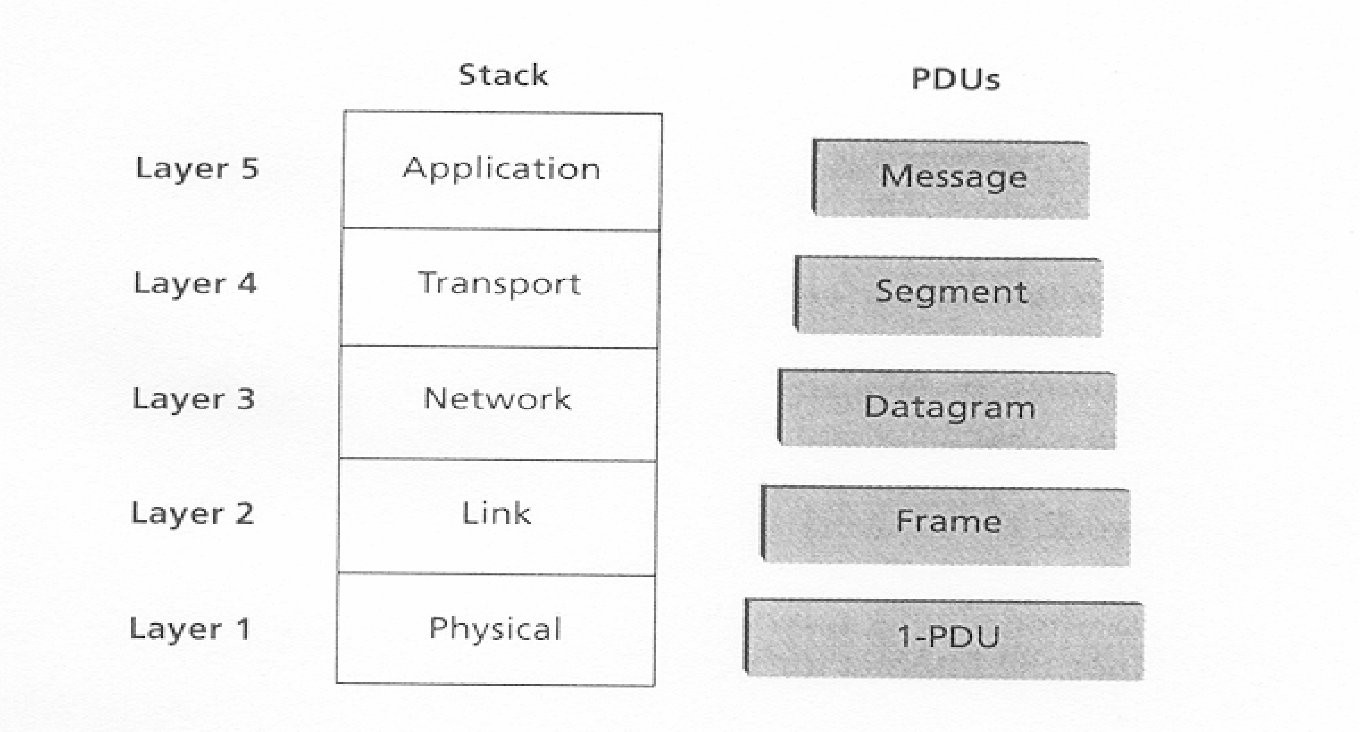
TCP/IP reference model (Internet architecture)

The Internet protocol stack and the respective protocol data units (PDUs):



The **physical layer** is not addressed further. It deals with transmitting raw bits over a physical transmission medium. The delivered service at the interface to the upper layer, however, must **not** guarantee that sending a bit 1 at one side will result in receiving bit 1 at the other side. To do its very best, it must undertake additional measures reflecting the specific properties of the medium.

Examples for transmission media:

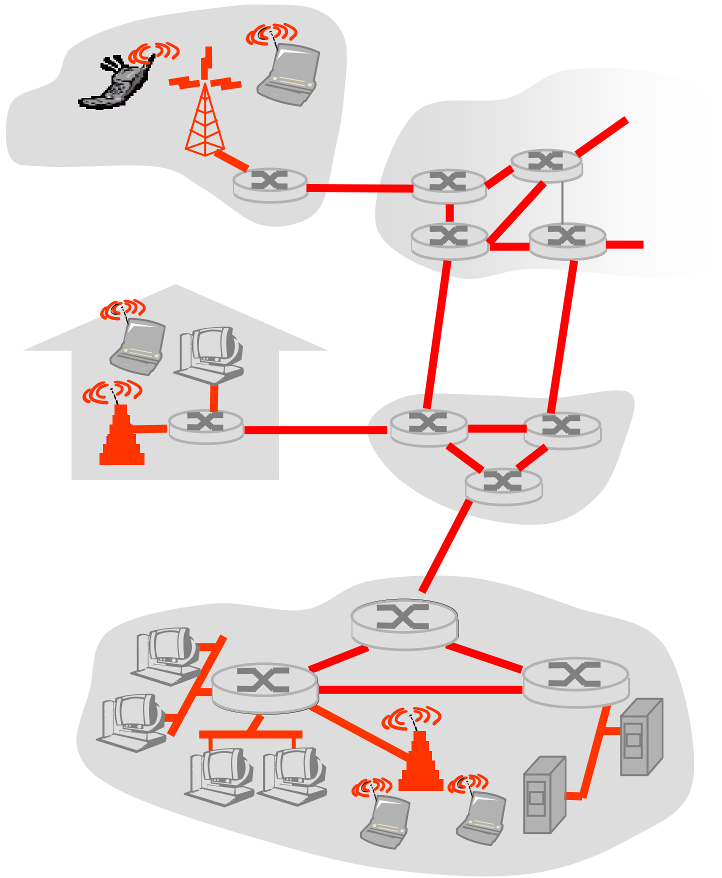
wired: magnetic media, twisted pair, coaxial cable, fiber optics

wireless: electromagnetic spectrum, radio- micro-, infrared waves

Data Link Layer(1a)

Some terminology:

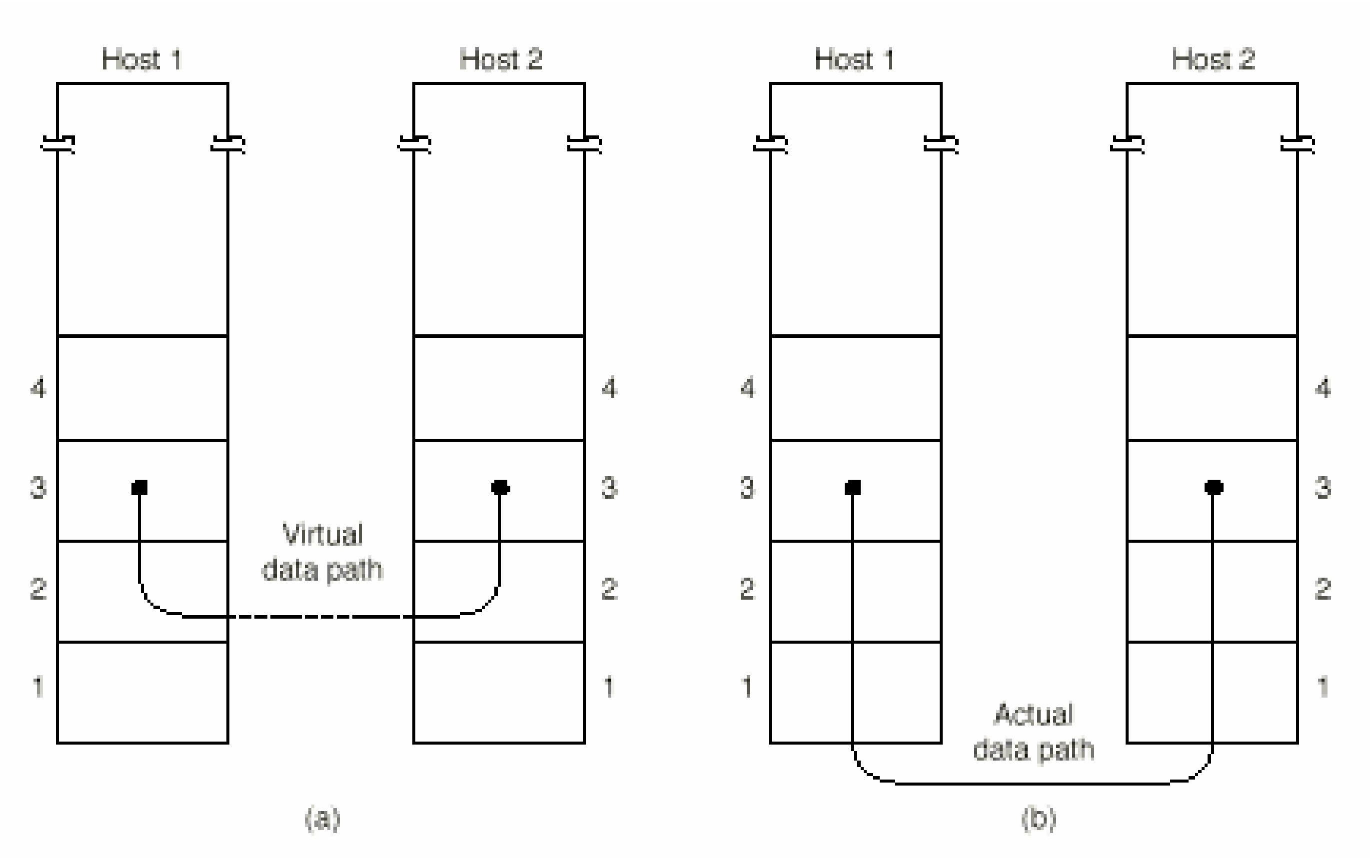
- hosts and routers are **nodes**
- communication channels that connect adjacent nodes along communication path are **links**
  - wired links
  - wireless links
  - LANs
- layer-2 packet is a **frame,** encapsulates datagram from the network layer



data-link layer has responsibility of transferring datagram from one node to adjacent node over a link encapsulated in a frame

Data Link Layer(1b)

Virtual communication versus actual communication:



Data Link Layer(1c)

- frames transferred by different link protocols over different links:
  - e.g., Ethernet on first link, PPP on the intermediate links, 802.11 (WLAN) on the last link
- each link protocol provides different services
  - e.g., may or may not provide rdt (reliable data transfer) over link

transportation analogy

- trip from Princeton to Lausanne
  - limo: Princeton to JFK
  - plane: JFK to Geneva
  - train: Geneva to Lausanne
- tourist = frame
- transport segment = communication link
- transportation mode = link layer protocol
- travel agent = routing algorithm

Data Link Layer (1d)

Specific services to carry out:

- *framing*
  - determining how the bits of the physical layer are grouped into frames
  - addresses used in frame headers to identify destination are different from IP addresses!
- *dealing with transmission errors:*
  - *error detection*:
    - receiver detects presence of errors:
    - signals sender for retransmission and drops frame
  - *error correction:*
    - receiver identifies *and corrects* bit error(s) without resorting to retransmission
- *flow control:*
  - pacing between adjacent sending and receiving nodes
- *separate MAC sublayer*
  - controlling channel access if the link is a shared medium

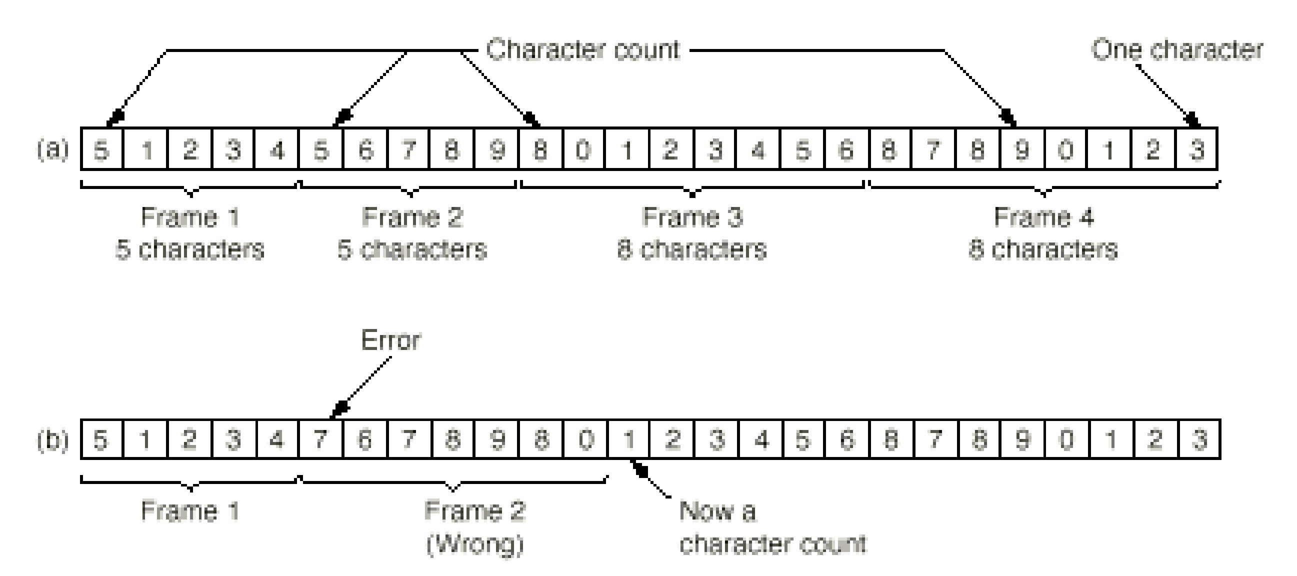
Data Link Layer(2)

Grouping into frames

Methods for framing:

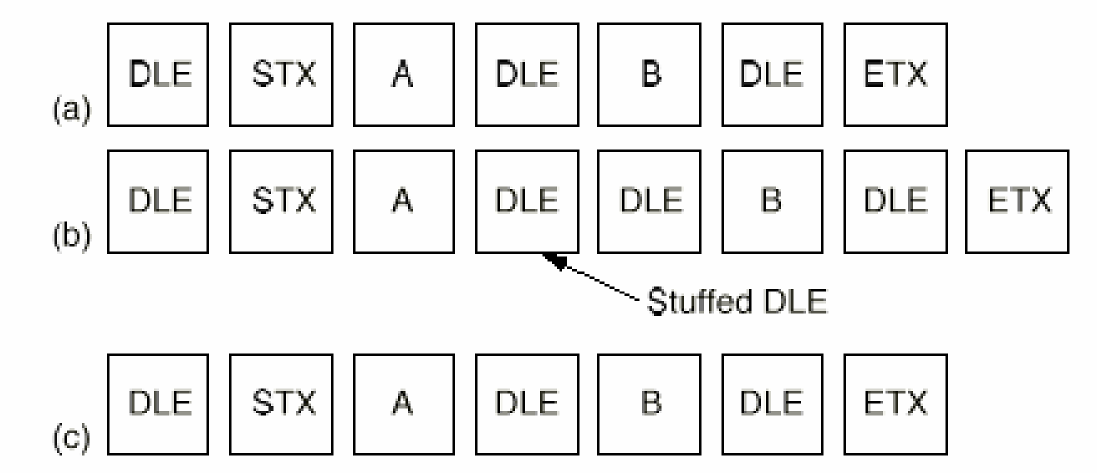
- character count
- character stuffing
- bit stuffing
- exploiting redundancy in the physical layer (Manchester encoding)

Example for character count:

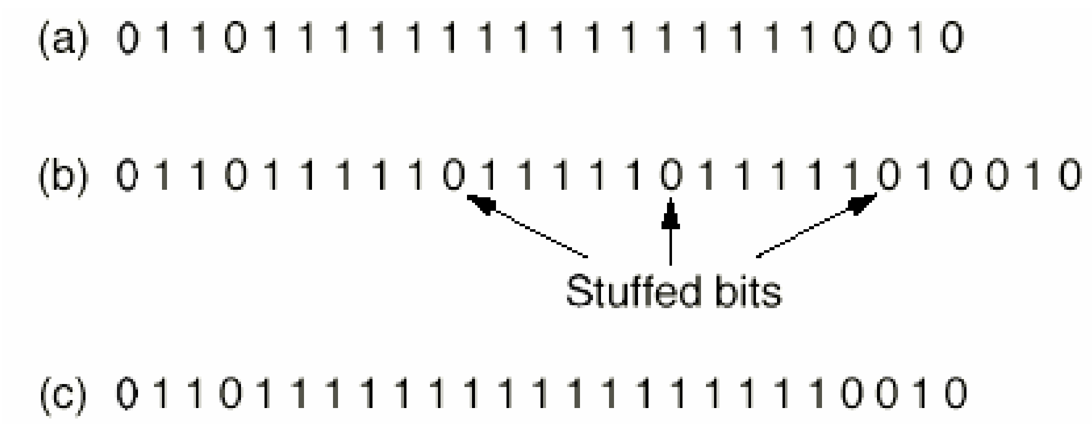


Data Link Layer(3)

Example for character stuffing:



Example for bit stuffing:



Data Link Layer(4)

Dealing with transmission errors

Error Detecting Codes (EDC) and Error Correcting Codes (ECC)

Definitions:

Codeword:= source (payload (packet from layer above) word + header)) + (redundant) check (control) bits

m:= length of the source word (number of bits)

r:= number of check bits

n:= m + r := length of the codeword --->

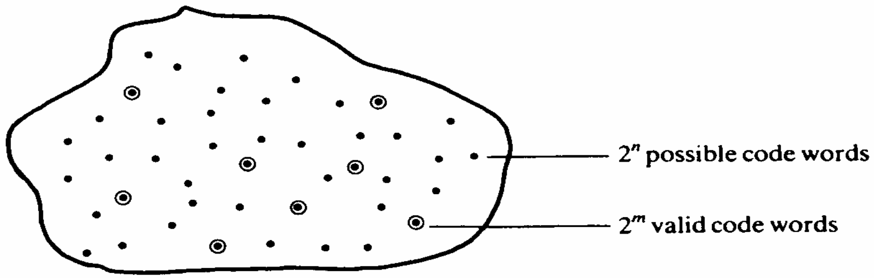
A binary code is a subset of $R^2{}_n$. Its elements (words) also can be considered as code vectors (correct codewords)

Hamming distance:

Let x and y be codewords in $R^2{}_n$. The function
$d(x,y) := \sum x_i$ eor y_i with i= 1,.....,n is called Hamming distance of x and y.
The Hamming distance of the entire code (set of all correct codewords) is defined as the minimal Hamming distance between any 2 codewords of this code.

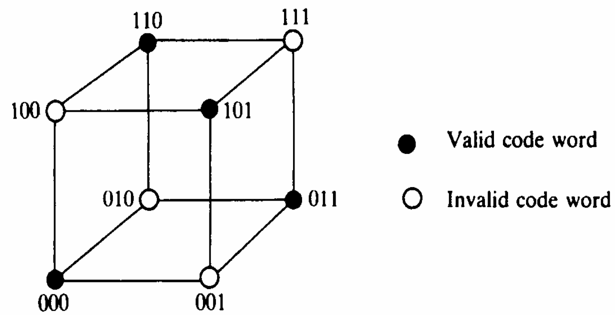
Data Link Layer(4a)

Illustration of the principle of Error-Correcting Codes (ECC´s) and Error-Detecting Codes (EDC´s):

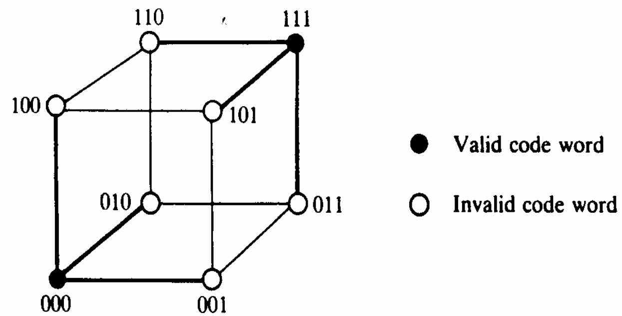


(a)

3-dimensional representation of codes:



(b)



(c)

Data Link Layer(5)

Lower limits on the number of check bits needed to correct single errors depending on the word size:

Each of the 2^m legal codewords has n illegal codewords at a distance 1 dedicated to it --->

$(n+1)\ 2^m <= 2^n$. Using $n = m + r$ --->

$(m + r + 1) <= 2^r$

Some numbers for r depending on m:

Word size	Check bits	Total size	Percent overhead
8	4	12	50
16	5	21	31
32	6	38	19
64	7	71	11
128	8	136	6
256	9	265	4
512	10	522	2