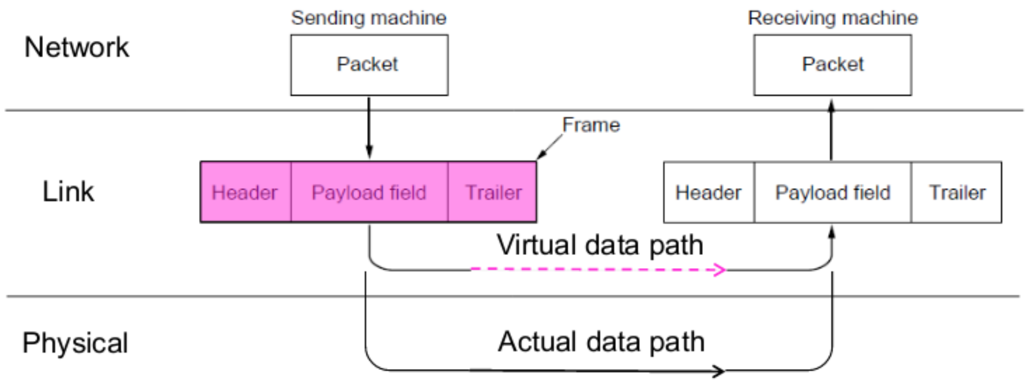
Data Link Layer

1 Frames

- Link layer accepts packets from the network layer, and encapsulates them into frames that it sends using the physical layer; reception is the opposite process
- The physical layer (below) is responsible for the transmission of raw sequences of bits



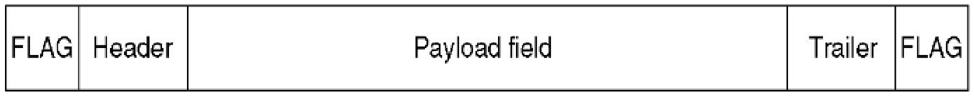
2 Framing methods

2.1 Byte count

Frame begins with a count of the number of bytes in it - simple, but difficult to resynchronize after an error. If any of the counts are incorrect then everything will be shifted wrong and all the frames will be incorrect.

2.2 Headers and trailers

We add a header (e.g. the length of the data, etc.) and a trailer (extra data that can be used e.g. error-detection or error-correction)

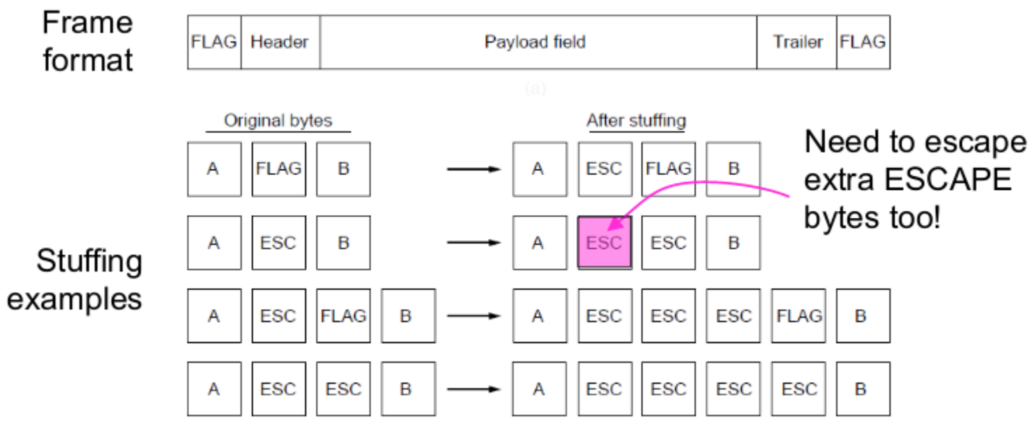


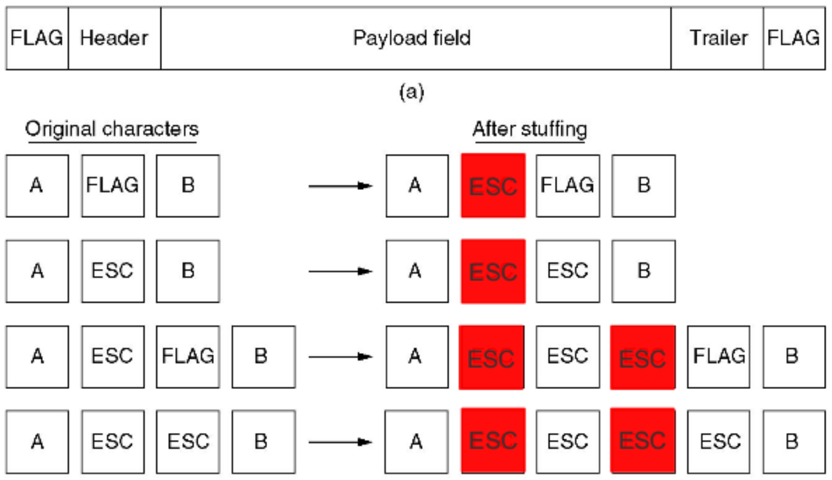
Two adjacent frames are separated by a flag

2.3 Byte stuffing

Special flag bytes delimit frames; occurrences of flags in the data must (escapes) - longer, but easy to resynchronize after error

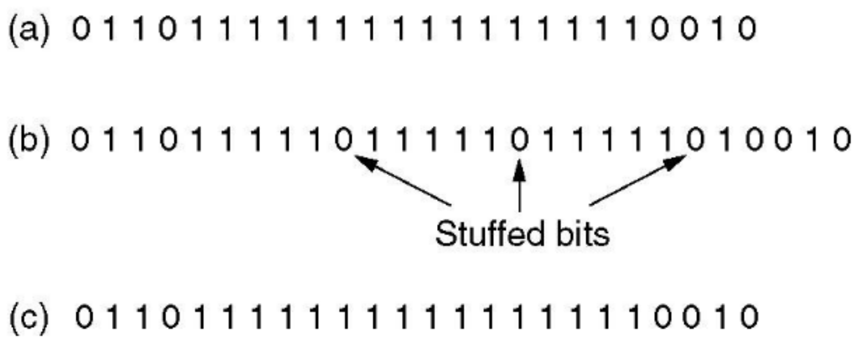
If the flag value is found in the data you get lost again. The solution to this is byte or bit stuffing





This is the same idea as doing \delta in latex

2.4 Bit stuffing


(a) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0
(b) 0 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 1 1 1 1 0 1 0 0 1 0
Stuffed bits
(c) 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

This is useful where you aren't working in bytes, as frames can be any size now

The flag is six consecutive ones. Within the data, a zero is stuffed after each five consecutive ones to void instances of the flag in the data
Bit stuffing

(a) The original data

(b) The data as they appear on the line

(c) The data as they are stored in receiver's memory after de-stuffing

Sender:

- Encloses packet (bit stream): 0 1 1 1 1 1 1 0
- Appends a 0 after each 1 1 1 1 1 in body (bit stuffing)

Receiver, upon receiving 0 1 1 1 1 1:

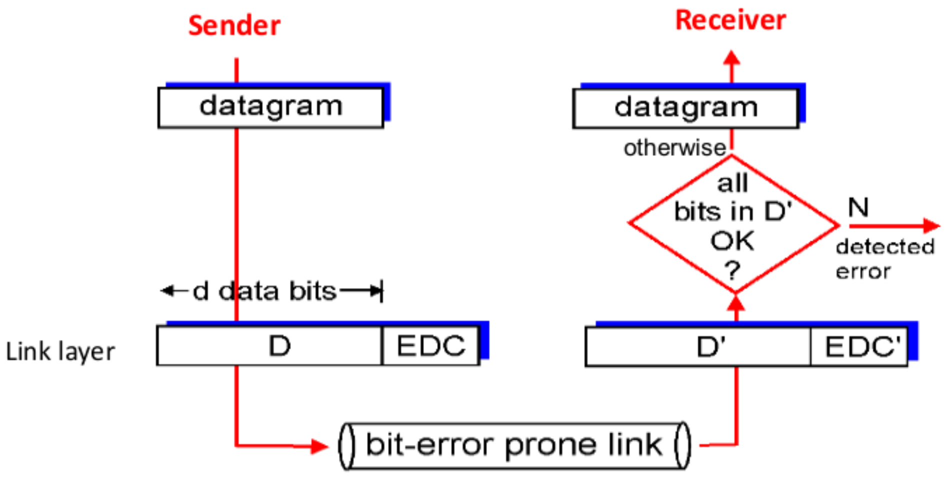
- next bit 0: stuffed bit is removed
- next bit 1
  - if next bit 0: end of frame marker
  - if next bit 1: error

3 Error detection and correction

- Errors occur during frame transmission
- Two strategies to deal with error
  - Include enough redundant information to help receivers deduce original data (**error correcting**)
  - Include enough information to deduce an error occurred (**error detecting**)
  - Neither error-correcting codes nor error-detecting codes can handle all possible errors

EDC = Error detection and correction bits (redundancy)
D = Data protected by error checking, may include header fields

Error detection is not 100% reliable, protocol may miss some errors, but rarely



4 Codeword

Definition: Codeword

The message with check bits added

- A frame consists of m data (message) bits and r redundant (check) bits
- n-bit codewords with n=m+r

5 Error codes

Error codes add structured redundancy to data so errors can be either detected, or corrected

5.1 Hamming codes

Definition: Hamming distance

The number of bit positions in which two codewords differ

We will see a specific hamming code that corrects a single error:

- **Encoding**: we number the data bits starting from one and skipping the powers of two. The powers of two are reserved for parity bits, the rest are message bits.
- **Decoding**: calculate all parities. If they are all OK, there was no error. If not, add up the positions of the incorrect ones - this gives us the position of the error

Hamming code gives a simple way to add check bits and correct up to a single bit error

- Check bits are parity over subsets of the codeword
- Recomputing the parity sums (syndrome) gives the position of the error to flip, or 0 if there is no error

6 Error detection

6.1 Parity

Parity bit is added as the modulo 2 sum of data bits

Single bit parity - detect single bit errors - this has one parity bit for whatever the length of the message

Two dimensional bit parity - detect and correct single bit errors

- Write the message in rows
- Calculate the parity bit for both the row and column
- These can then be used to correct a bit error as there will be a parity error on the corresponding row and column of the bit

6.2 Checksum

The sender:

1. Data is divided into k segment each of m bits (normally 16 bit integers) and summed
2. The 1s complement of the sum forms the checksum.
3. The checksum segment is sent along with the data segments

The receiver

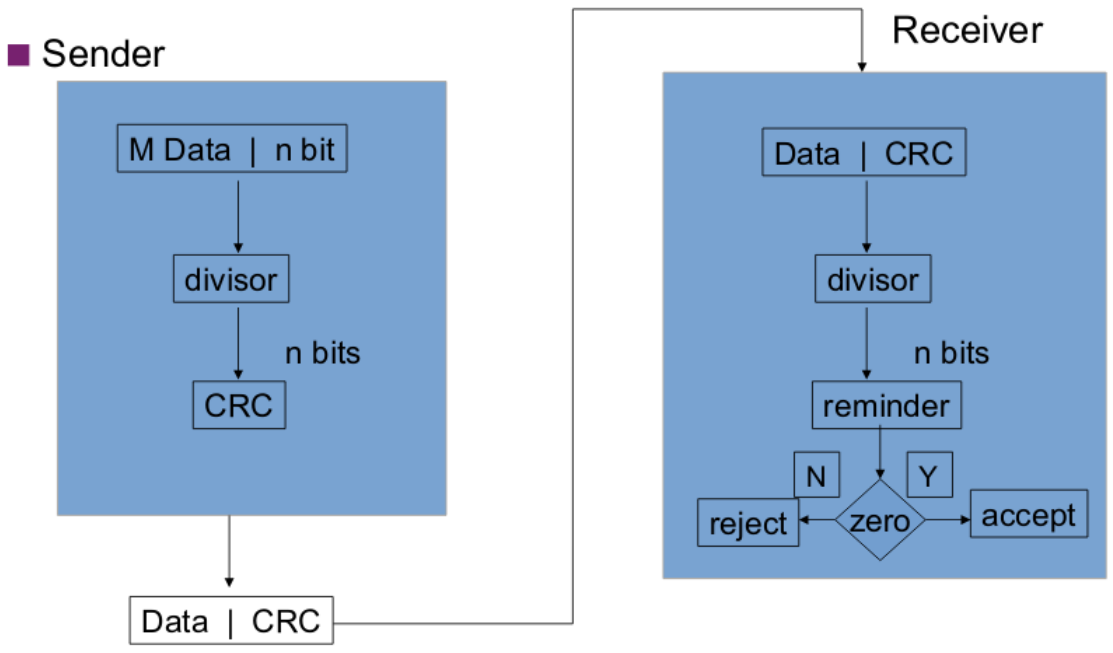
1. All received segments are added
2. The sum is complemented
3. If the result is zero, the received data is OK; otherwise wrong

6.3 Cyclic Redundancy Check

This is a more advanced technique, which uses manipulations with polynomials. This is one of the most commonly used error detection codes

Basic approach:

- Let M1 be the message of n-bits
- M1 is padded with CRC code and send it
- CRC is generated using a given polynomial P1 (or divisor)
- P1 is agreed between sender and receiver
- Receiver gets M1 + CRC and extracts the M1 using P1


Sender
M Data | n bit
divisor
n bits
CRC
Data | CRC
Receiver
Data | CRC
divisor
n bits
reminder
N
Y
reject
zero
accept