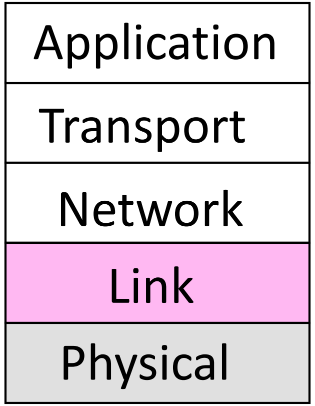
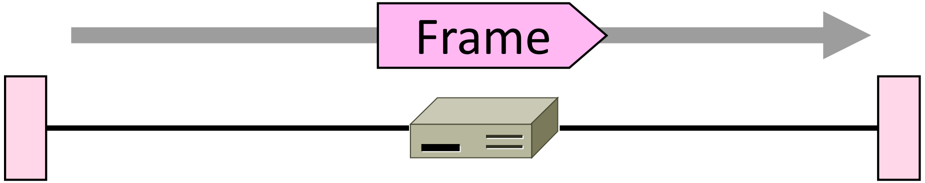
Where we are in the Course

- Moving on to the Link Layer!

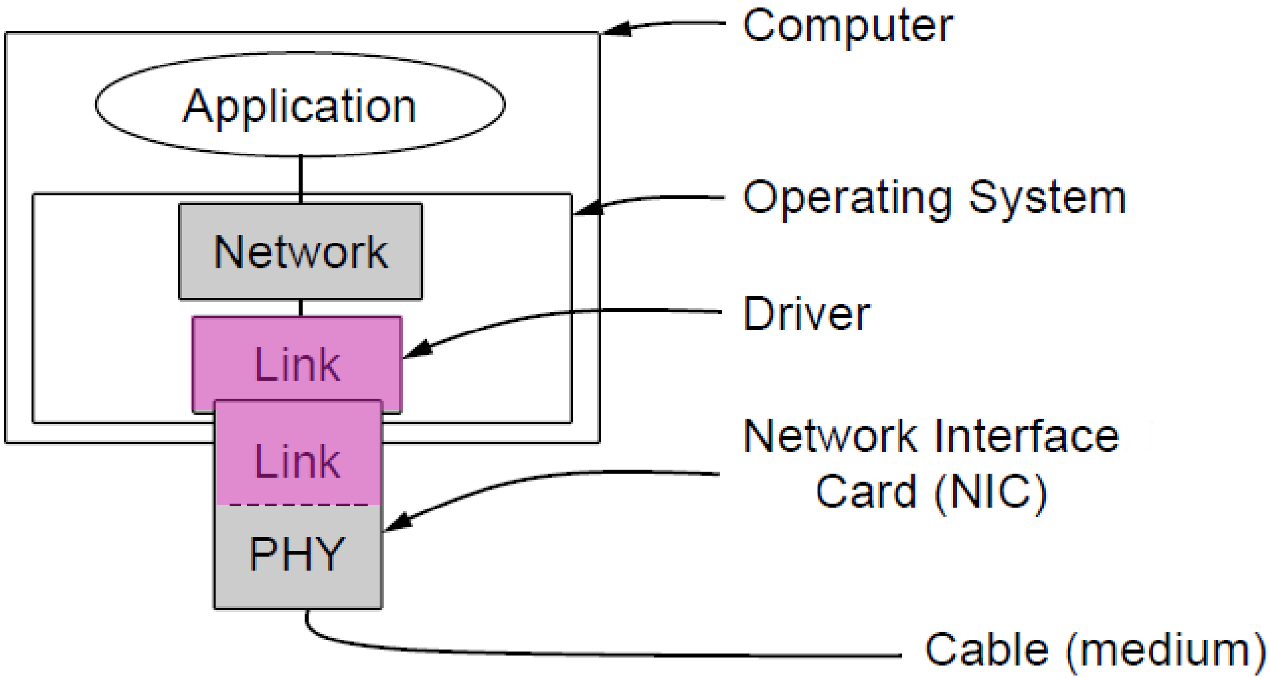


Scope of the Link Layer

- Concerns how to transfer messages over one or more connected links
  - Messages are frames, of limited size
  - Builds on the physical layer



Typical Implementation of Layers (2)



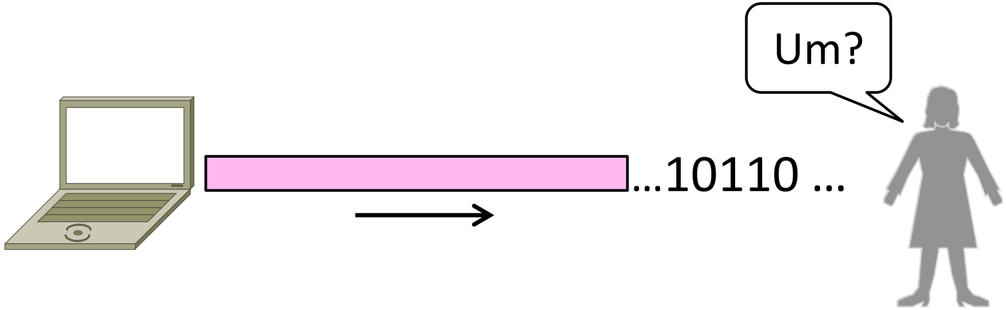
Functions of the Link Layer

1. Framing
   - Delimiting start/end of frames
2. Error detection and correction
   - Handling errors

3. Retransmissions
   - Handling loss
4. Multiple Access
   - 802.11, classic Ethernet
5. Switching
   - Modern Ethernet

Topic

- The Physical layer gives us a stream of bits. How do we interpret it as a sequence of frames?



Framing Methods

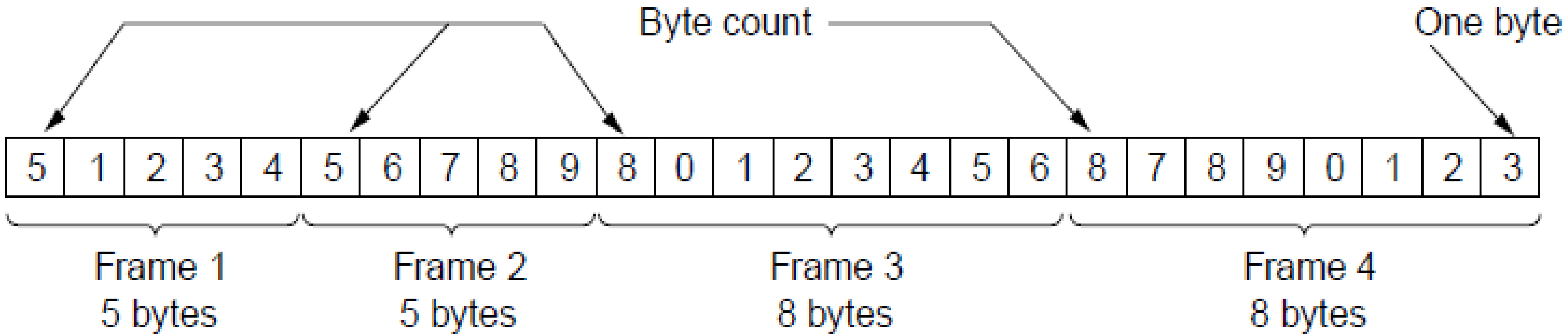
- We'll look at:
  - Byte count (motivation)»
  - Byte stuffing »
  - Bit stuffing »

- In practice, the physical layer often helps to identify frame boundaries
  - E.g., Ethernet, 802.11

Byte Count

- First try:
  - Let’s start each frame with a length field!
  - It’s simple, and hopefully good enough …

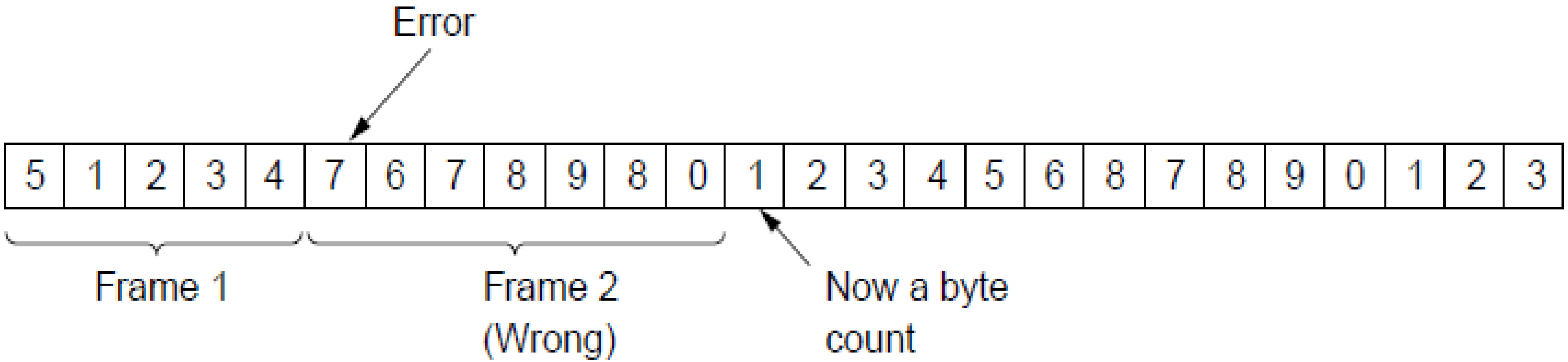
Byte Count (2)



- How well do you think it works?

Byte Count (3)

- Difficult to re-synchronize after framing error
  - Want a way to scan for a start of frame



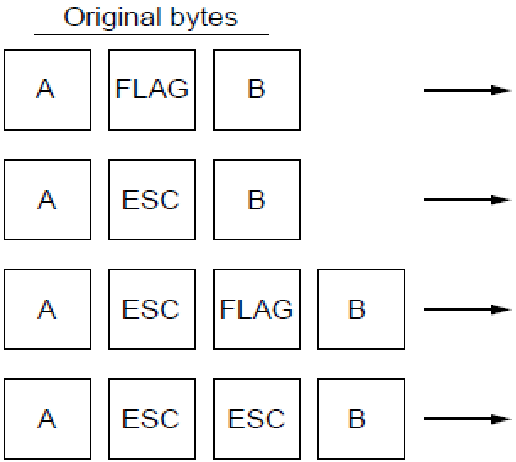
Byte Stuffing

- Better idea:
  - Have a special flag byte value that means start/end of frame
  - Replace ("stuff") the flag inside the frame with an escape code
  - Complication: have to escape the escape code too!

FLAG	Header	Payload field	Trailer	FLAG

Byte Stuffing (2)

- Rules:
  - Replace each FLAG in data with ESC FLAG
  - Replace each ESC in data with ESC ESC



Original bytes

A FLAG B →

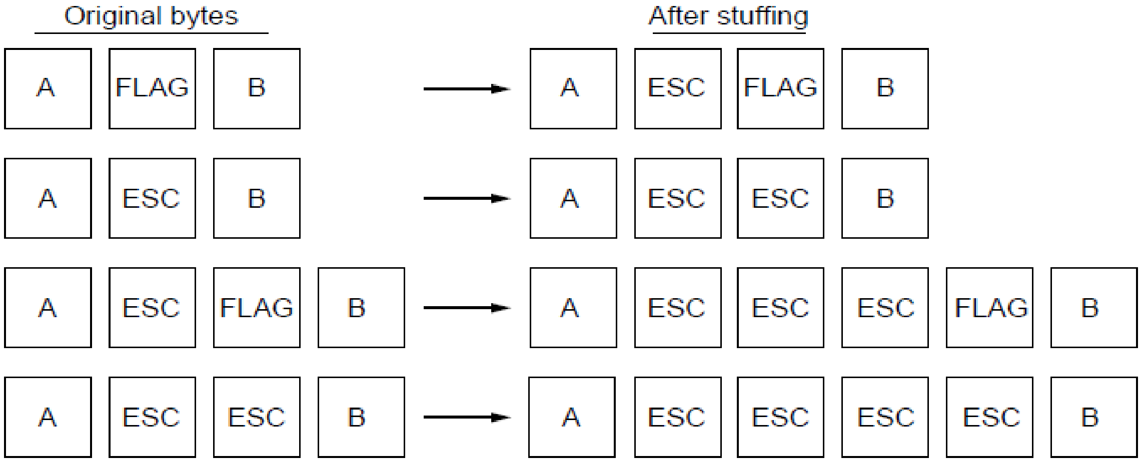
A ESC B →

A ESC FLAG B →

A ESC ESC B →

Byte Stuffing (3)

- Now any unescaped FLAG is the start/end of a frame



Original bytes → After stuffing

A FLAG B → A ESC FLAG B

A ESC B → A ESC ESC B

A ESC FLAG B → A ESC ESC ESC FLAG B

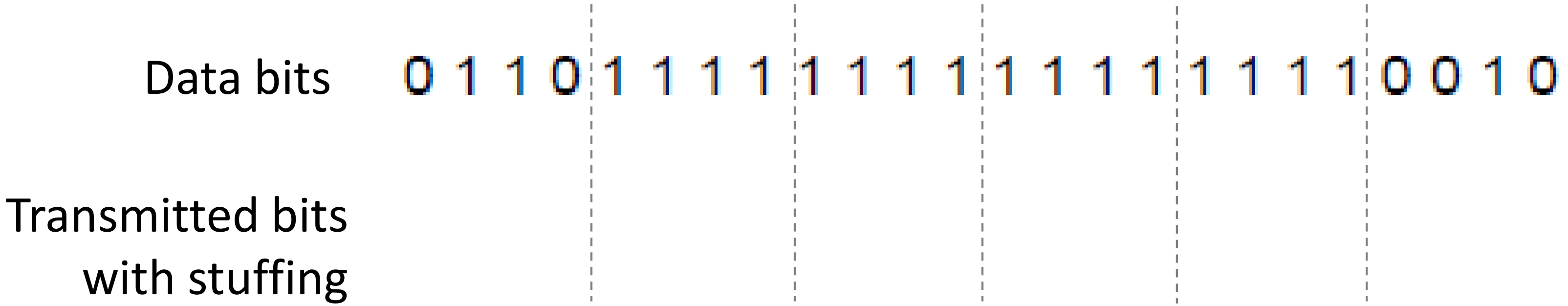
A ESC ESC B → A ESC ESC ESC ESC B

Bit Stuffing

- Can stuff at the bit level too
  - Call a flag six consecutive 1s
  - On transmit, after five 1s in the data, insert a 0
  - On receive, a 0 after five 1s is deleted

Bit Stuffing (2)

- Example:

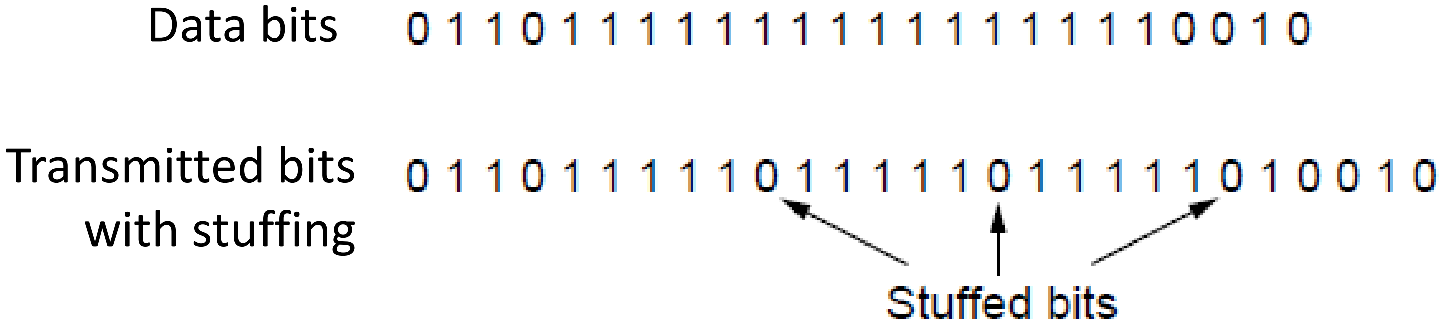


Data bits 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

Transmitted bits with stuffing

Bit Stuffing (3)

- So how does it compare with byte stuffing?



Data bits 0 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 0 0 1 0

Transmitted bits with stuffing 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

Error Correction and Detections

- Some bits will be received in error due to noise. What can we do?
  - Detect errors with codes »
  - Correct errors with codes »
  - Retransmit lost frames ← Later

- Reliability is a concern that cuts across the layers – we'll see it again

Approach – Add Redundancy

- Error detection codes
  - Add check bits to the message bits to let some errors be detected
- Error correction codes
  - Add more check bits to let some errors be corrected

- Key issue is now to structure the code to detect many errors with few check bits and modest computation

Motivating Example

- A simple code to handle errors:
  - Send two copies! Error if different.

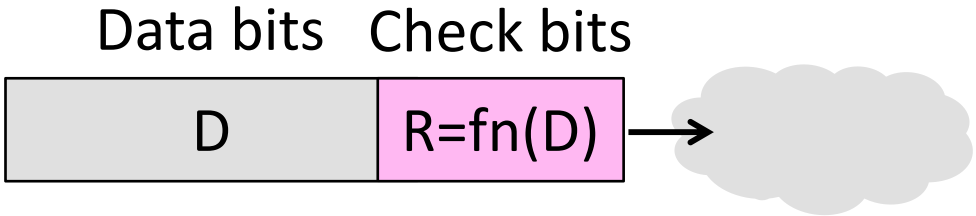
- How good is this code?
  - How many errors can it detect/correct?
  - How many errors will make it fail?

Motivating Example (2)

- We want to handle more errors with less overhead
  - Will look at better codes; they are applied mathematics
  - But, they can’t handle all errors
  - And they focus on accidental errors (will look at secure hashes later)

Using Error Codes

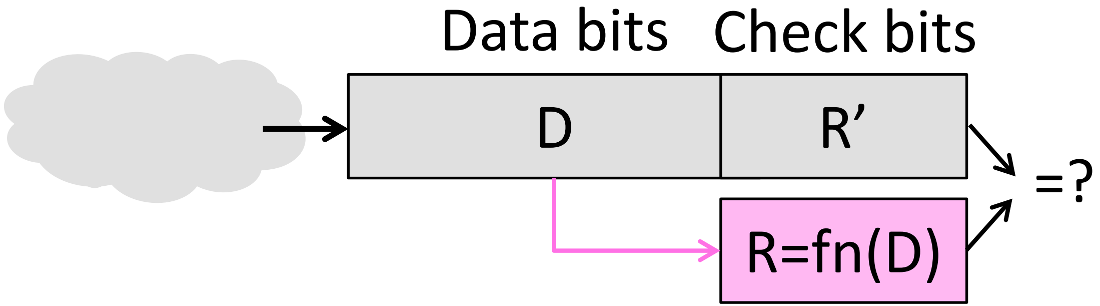
- Codeword consists of D data plus R check bits (=systematic block code)



- Sender:
  - Compute R check bits based on the D data bits; send the codeword of D+R bits

Using Error Codes (2)

- Receiver:
  - Receive D+R bits with unknown errors
  - Recompute R check bits based on the D data bits; error if R doesn't match R'



Data bits Check bits

D

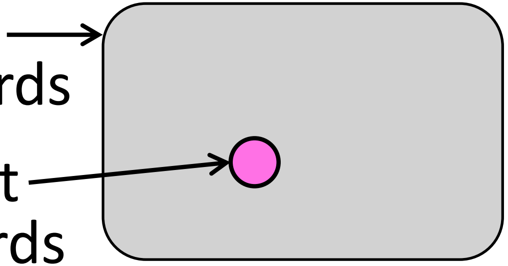
R'

R=fn(D)

=?

Intuition for Error Codes

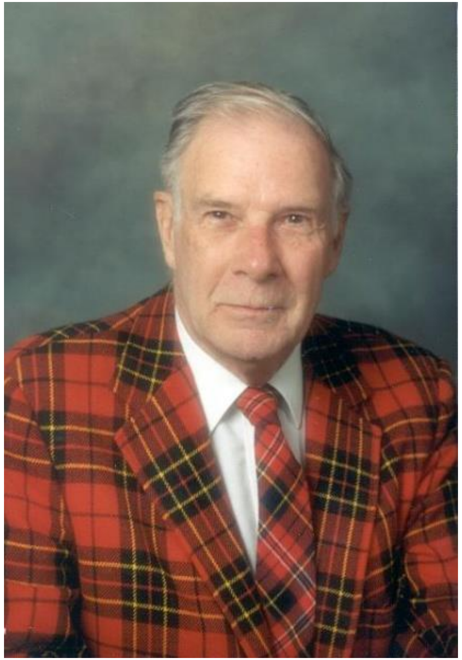
- For D data bits, R check bits:



- Randomly chosen codeword is unlikely to be correct; overhead is low

R.W. Hamming (1915-1998)

- Much early work on codes:
  - “Error Detecting and Error Correcting Codes”, BSTJ, 1950
- See also:
  - “You and Your Research”, 1986



Source: IEEE GHN, © 2009 IEEE

Hamming Distance

- Distance is the number of bit flips needed to change D_1 to D_2
- Hamming distance of a code is the minimum distance between any pair of codewords

Hamming Distance (2)

- Error detection:
  - For a code of distance d+1, up to d errors will always be detected

Hamming Distance (3)

- Error correction:
  - For a code of distance 2d+1, up to d errors can always be corrected by mapping to the closest codeword