Fundamentals of Computer Networks
ECE 478/578

Lecture #3: Encoding and Framing
Instructor: Loukas Lazos
Dept of Electrical and Computer Engineering
University of Arizona

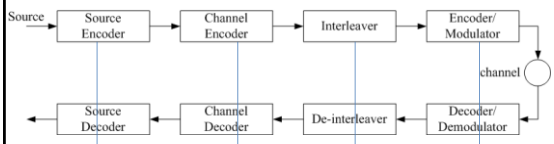
Direct Link (Point-to-Point) Networks

Simplest network possible, consisting of two hosts and one link

Look into different functions at the link level

- Encoding
- Framing
- Error detection/correction
- Reliable delivery
- Media access control

Typical Communication System



Compresses a stream of bits

Adds redundancy to detect/correct errors at the receiver (bits are mapped to codewords)

Scrambles the bits of consecutive codewords to spread burst errors

Converts a stream of bits to analog signals modulated for transmission over a medium

Physical Medium

Signals travel through the medium and represent bits

Nyquist Bandwidth: Given an error-free medium of bandwidth B, the highest signal (symbol) rate (bauds) that can be carried is 2B

Bauds to bits: R = 2B * log2M bits, M: signal levels

Shannon's Capacity Theorem

$$C = B \log_2(1+S/N)$$

Defines the upper bound on the link capacity C in Hz

Can be used to evaluate the "error-free" bandwidth of a line

4

Shannon's Theorem: Example

Voice-grade phone line: B =3,300 -300 Hz = 3 KHz

Typical SNR = 30 dB, where

$$dB = 10 \times \log_{10}(S/N)$$

For 30 db → S/N =1,000

$$C = 3{,}000 \times \log_2(1+1{,}000) \approx 30 \text{ Kbps}$$

Higher bandwidth B (in Hz), higher capacity

Higher S/N, higher capacity

5

Shannon's Theorem: Example 2

Can the signal be weaker than noise?

Assume capacity of 50 Kbps over 1MHz bandwidth

The required SNR would then be

$$C = B \log_2(1+S/N)$$

$$S/N = 2^{C/B} - 1 = 0.035 \text{ or } -14.5\ dB$$

Think of spread spectrum communications

Transmit a weak signal over a large bandwidth

6

Relating Nyquist and Shannon

Assume B = 1 MHz and SNR = 24 dB. How many signal levels are required to achieve the max rate?

24 dB = 10 log10 (S/N)→ S/N = $10^{2.4}$ = 251

Using Shannon's formula

$C = 10^6 \times \log_2(1+251) = 10^6 \times 8 = 8$ Mbps (Theoretical limit)

Using Nyquist's theorem

$C = 2B \log 2M \rightarrow 8 \times 10^6 = 2 \times 10^6 \times \log_2 M \rightarrow M = 16$

7

Encoding

Map binary bits into signals

Example: Low signal represents a 0, high signal represents a 1

NonReturn-to-Zero (NRZ)

Problem: Long periods of silence (zero) or high signals are possible

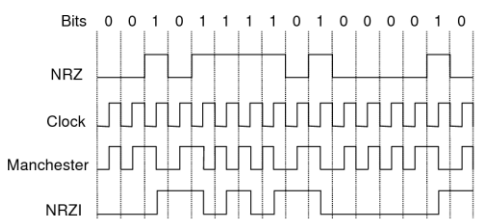
- Baseline wander (receiver loses track of reference sig)
- Clock recovery (receiver loses clock synchronization)

8

Encoding: More Schemes

NRZ Inverted (NRZI): Switch from current state to represent a 1

Manchester: XOR the bit stream with the clock



9

4B/5B Encoding Scheme

Encode 4-bit symbols into 5-bit codes

2^4 symbols must be mapped to 2^4 codewords out of the possible 2^5

Each codeword has no more than one starting zero, and no more than two trailing zeros

No more than 3-consequtive zeros

Then use NRZI to solve the consecutive 1s problem

80% efficiency (1 bit is overhead)

10

Example of 4B/5B Encoding

4-bit data symbol	5-bit code	4-bit data symbol	5-bit code
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

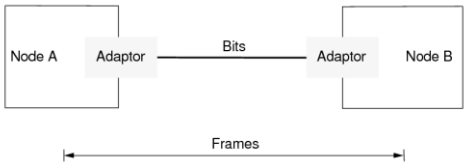
11

Framing

The process of grouping bits into frames (messages or packets)

Typically implemented by the network adaptor

Why frames?



12

Byte-Oriented Framing

BISYNC: Binary synchronous communication

- Frame is a collection of bytes
- Need to indicate the beginning and end of a frame
- Sentinel characters are used

SYN: Synchronization character
SOH: Start of header
STX, ETX: Start of text, End of text
CRC: Cyclic redundancy check

13

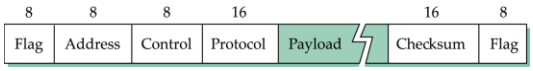
Problem with Byte-oriented Framing

ETX may occur in the payload

Precede it with a DLE (data-link-escape) character

Problem propagates, precede DLE with another DLE (extra overhead)

Point-to-Point (PPP) protocol used by IP



STX: 0111110

Payload: 1,500 bytes

Checksum: 2 or 4 bytes

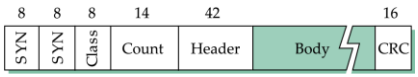
Overhead: 8/1508 =0.5%

14

Byte-counting Framing

Include the # of bytes in the frame as a field in the header

Digital Data Communications Protocol (DDCMP)



Count: Specifies # of bytes in the body

CRC ensures that count field is not corrupted

15

Bit-oriented Framing

High-Level Data Link Control (HDLC)

Beginning/end of frame, flag: 01111110
Instead of inserting bytes do bit stuffing
Sender adds a 0 after five consecutive 1s
Receiver removes zero after five 1s

16

Example of Bit-stuffing

Sender

1 1 1 1 1 1 0 1 1 1 1 1 1 1 1 1 1 1 1 0 1 1 1 1 1 0

0 0 0 0

Receiver

1 1 1 1 1 ~~0~~ 1 0 1 1 1 1 1 ~~0~~ 1 1 1 1 1 ~~0~~ 1 0 1 1 1 1 1 ~~0~~ 0

Length of frame

Variable, depends on the data

We can calculate and optimize the overhead of bit stuffing

17

Maximum Frame Size

Let each frame contain V overhead bits
Let a message of M bits be broken into frames of size K_{max}
# of packets : $\lceil M / K_{max} \rceil$
The total # of bits for all frames: $M + \lceil M / K_{max} \rceil V$
If K_{max} ↓, # of frames ↑, and overhead also ↑
If # of frames ↑, then each frame must be processed then more processing delay at each host

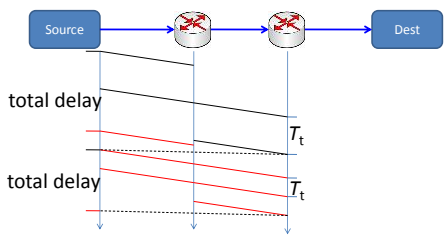
Increase frame length as much as possible

18

Maximum Frame Size - Pipelining

Why not make $K_{max} = M$?

Pipelining delay: frame must be received before forwarding



19

Tradeoff between K_{max} and V

Let message be of length M, frame size K_{max} and overhead V, over a path of j equal capacity links

First packet hop over (j -1) switches + entire message transmission.
Total number of bit transmission times

$$TC = (K_{max} + V)(j-1) + M + \lceil M / K_{max} \rceil V$$

Expected value over message lengths

$$E\{TC\} \approx (K_{max} + V)(j-1) + E\{M\} + (E\{M\}/K_{max} + 1/2)V$$

Minimize $E\{TC\}$ at

$$K_{max} = \sqrt{E\{M\}V/(j-1)}$$

20