Encoding, Framing, Error Detection

Network Links

- Different physical media are used to propagate signals, full duplex links are usually used
- Twisted pair
  - e.g. telephone wire
- Coaxial cable
  - E.g. TV cable
- Optical fiber
  - for long distance, high speed communication
- Space (wireless media)
  - Satellite communication

Features of Cables/Fibers

cable	Bandwidth (Mbps)	distance
category 5 twisted pair	10-100	100 m
thin coax	10-100	200 m
thick coax	10-100	500 m
multimode fiber	100	2 km
single-mode fiber	100-2400	40 km

Leased lines from the Phone Company

Connection	Bandwidth
DS1 (T1)	1.544 Mbps
DS3 (T3)	44.736 Mbps
STS1 (OC1)	51.84 Mbps
STS3 (OC3)	155.52 Mbps
STS12 (OC12)	622.08 Mbps
STS24 (OC24)	1.24416 Gbps
STS48 (OC48)	2.48832 Gbps
STS192 (OC192)	9.95328 Gbps

STS: Synchronous Transport Signal

OC: Optical Carrier

OC = Optical Carrier

Last-Mile Links to Home

- DS and OC links
  - Provide dedicated bandwidth
  - Connect any arbitrary pair of nodes
  - Expensive
- Last Mile Links
  - To connect home to telephone/cable company
  - Inexpensive
  - Cannot connect arbitrary pair of nodes

Last Mile Links : Services

- POTS
  - Plain old telephone service
  - Modem supporting 28.8 – 56 Kbps
- ISDN
  - Integrated Services Digital Network
  - 1 64-kbps data + 1 64-kbps digitized voice channels (OR) 2 64-kbps data channels
- xDSL (Digital Subscriber Line)
  - High speed transmission over Twisted pair copper
  - ADSL (Asymmetric DSL)
    - Upstream: 16 - 640 kbps and higher
    - Downstream: 1.554 – 8.448 Mbps and higher
- Cable MODEM (upto 40 Mbps downstream and higher), asymmetric

Modem Speed

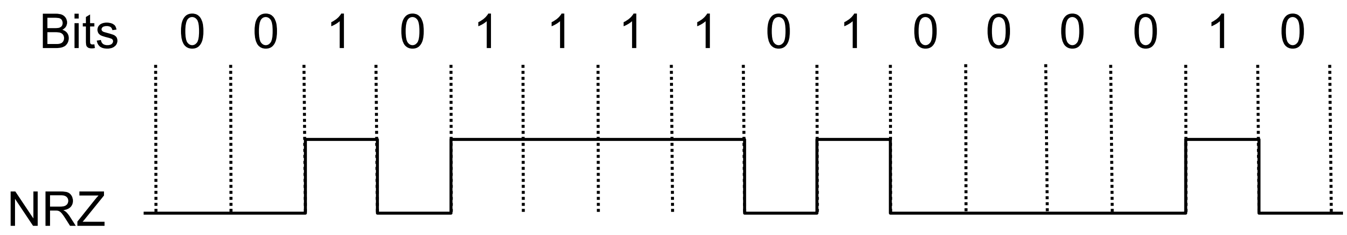
- Shannon's capacity theorem
- B = 3300-300 = 3000 Hz
  - $C = B \log_2(1+S/N)$
  - C: channel capacity, B: bandwidth
  - S/N: Signal-to-Noise ratio
- Typical decibel ratio is 30 dB
  - $dB = 10 \log_{10}(S/N)$
  - $30\ dB \Rightarrow S/N = 1000$
- $C = 3000 \times \log_2(1001) \approx 30$ Kbps

Encoding

- This topic is left as self study.
- It is not examinable.

What is Encoding?

- Signals propagate over a physical medium
  - modulate electromagnetic waves
  - e.g., vary voltage
- Encode binary data onto signals
  - e.g., 0 as low signal and 1 as high signal
  - known as Non-Return to zero (NRZ)



Problem: Consecutive 1s or 0s

- Low signal (0) may be interpreted as no signal
- Baseline wander problem
  - Usually the receiver keeps the average value of the signal to distinguish low and high signals
  - Long sequence of 1s or 0s can change the average
- Unable to recover clock

Why Transitions are necessary?

- Receiver can recover clock and synchronize with the detected transition
- Absence of transitions may imply that some error has occurred, thus aiding error detection
- An encoding scheme must ensure that sufficient number of transitions take place and at the same time keeping the signal/modulation rate (baud rate) close to the data rate (bit rate)
- Signal rate: the rate at which signal elements are transmitted

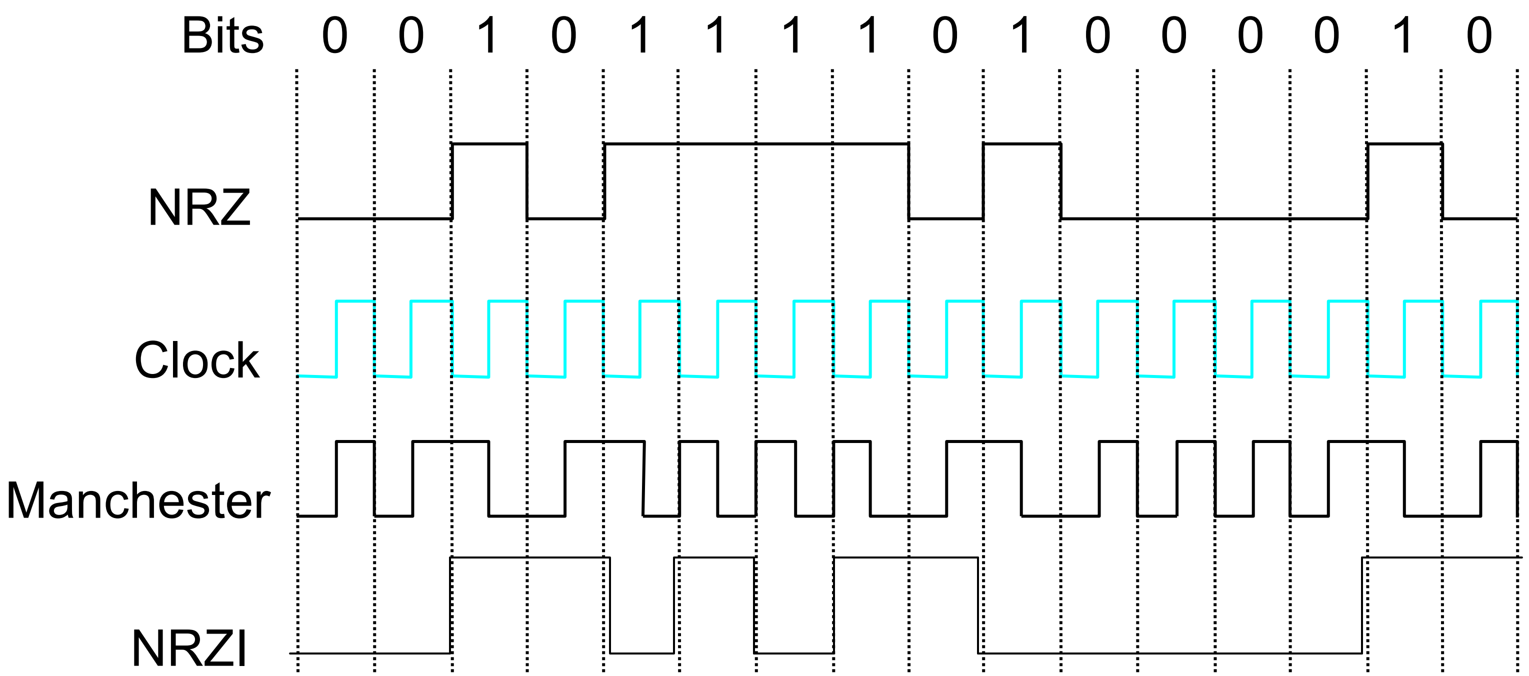
Alternative Encoding Techniques

- Non-return to Zero Inverted (on 1's) (NRZI)
  - make a transition from current signal to encode a one; stay at current signal to encode a zero
  - solves the problem of consecutive ones
  - Used in digital magnetic recording and signal transmission from terminals to computers
- Manchester
  - Low-to-high transition to encode a 0 and high-to-low transition to encode a 1
  - Used in LANs (e.g. Ethernet)
  - only 50% efficient (data rate/signal rate)

Encoding Techniques (cont)

- 4B/5B
  - every 4 bits of data encoded in a 5-bit code
  - 5-bit codes selected to have no more than one leading 0 and no more than two trailing 0s
  - thus, never get more than three consecutive 0s
  - 1000 mapped to 10010, 11111 signifies that line is idle (special symbol); mapping is predefined
  - resulting 5-bit codes are transmitted using NRZI
  - achieves 80% efficiency
  - Used for long distance communication (eg. FDDI)
  - FDDI: Fiber Distributed Data Interface used in MANs

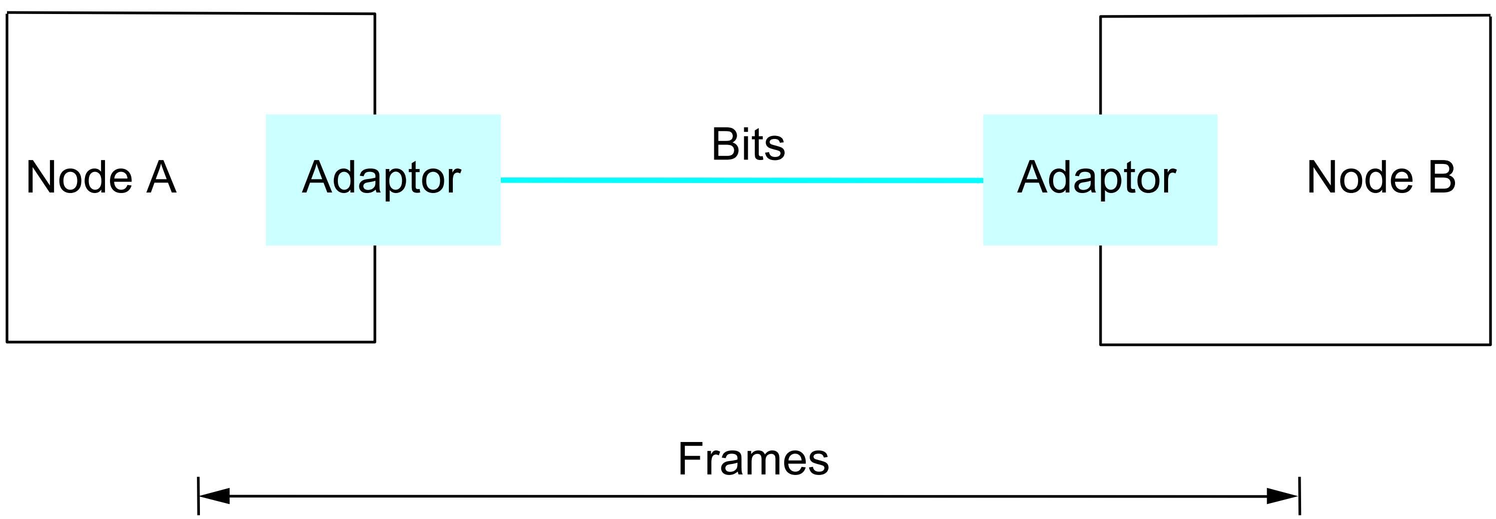
Encoding Techniques (cont.)



Framing

What is Framing?

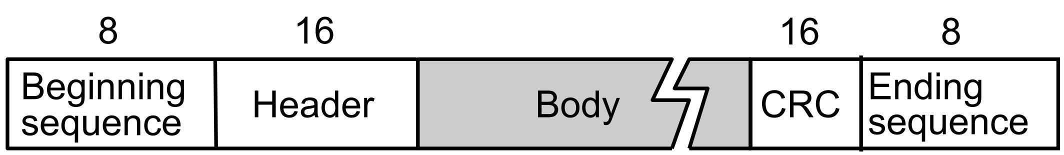
- Break sequence of bits into a frame
- Typically implemented by network adaptor
- Data link layer function



Framing Approaches

- How is a frame recognized?
- Sentinel-based

  delineate frame with special pattern: 01111110 (flag)
  - e.g., HDLC (high-level data link control protocol), PPP (point-to-point protocol)



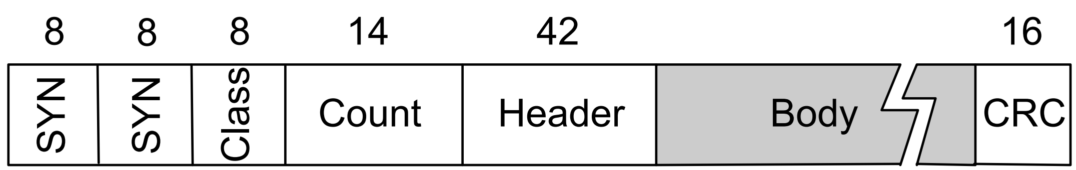
  - HDLC is an important, widely-used ISO-OSI standard data link protocol
    - Basis for other data link control protocols such as LLC (logical link control), frame relay, and ATM
  - problem: special pattern appears in the payload
  - solution: *bit stuffing* (HDLC)
    - sender: insert 0 after five consecutive 1s
    - receiver: delete 0 that follows five consecutive 1s

Byte Stuffing in PPP

- Widely used as a data link control to connect a PC to ISP using dialup modem and a telephone line
- Can also be used as a data link control to connect two routers
- Can operate over ADSL, SONET links etc.
- As in HDLC, a frame is delineated with the special pattern: 01111110 (7E hex) (referred to as flag)
- An integer number of bytes are carried. Byte stuffing is used.
- Byte 7D (hex) is used as escape character
- Sender
  - Replace flag (7E) or escape byte (7D) by two bytes. The first byte is the escape byte (7D) and the second byte is the one obtained by exclusive-or-ing the original byte and 20 (hex). i.e. 7D is replaced by 7D 5D, 7E is replaced by 7D 5E
- Receiver
  - When 7D is received, remove it, and exclusive-or the next byte with 20 (hex)
- Example
  - Original data: 57 8A 7E 0F 7D 17
  - Data sent after byte stuffing and framing: 7E 57 8A 7D 5E 0F 7D 5D 17 7E

Approaches (contd.)

- Counter-based
  - include payload length in header
  - e.g., DDCMP (Digital Data Communication Message Protocol)



  - problem: count field corrupted
  - solution: catch when CRC fails, wait for SYN
  - The above frame error can cause back-to-back frames to be incorrectly received

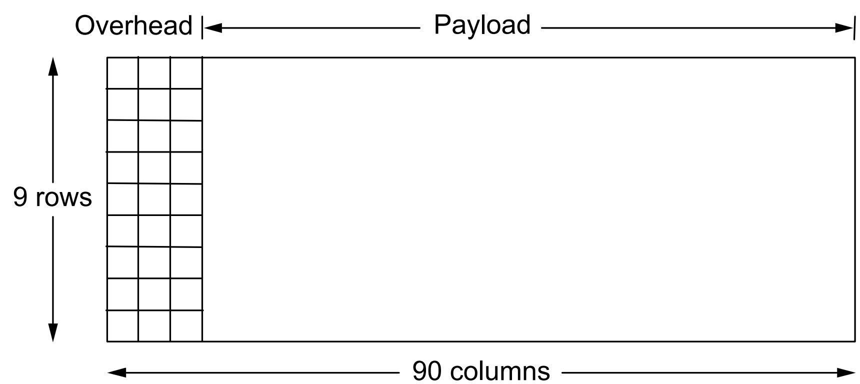
Approaches (contd.)

Clock-based

- e.g., SONET: Synchronous Optical Network; SDH: Synchronous Digital Hierarchy
- each frame is 125μs long
- STS-1: 810 bytes (6480 bits) per 125μs = 51.84 Mbps
- STS-n: synchronous transport signal level n
- STS-1 frame has 3 bytes overhead per row
- 2 bytes of overhead is a special pattern to indicate the start of a frame
- No bit stuffing used, looks for special bit pattern for every 810 bytes
- STS-*n, n STS-1 frames* ()
- OC-n (optical carrier level n): STS-n in optical domain
- Multiplexing is by byte interleaving
- At STS-1 rate a frame is 810 bytes long, at STS-3 rate a frame is 2430 bytes long

SONET STS-1 Frame

STS-1 Frame



SONET/SDH Line Rates

SONET		Optical Carrier	Line rate (Mbps)
STS-1		OC-1	51.84
STS-3		OC-3	155.52
STS-12		OC-12	622.08
STS-48		OC-48	2488.32
STS-192		OC-192	9953.28

Error Detection

`

Cyclic Redundancy Check

- Add k bits of redundant data to an n-bit message
  - want $k << n$
  - e.g., $k = 32$ and $n = 12{,}000$ (1500 bytes)
- Represent n-bit message as n-1 degree polynomial
  - e.g., MSG=10011010 as $M(x) = x^7 + x^4 + x^3 + x^1$
- Let k be the degree of some divisor polynomial
  - e.g., $C(x) = x^3 + x^2 + 1$

CRC (contd.)

- Transmit polynomial $P(x)$ that is evenly divisible by $C(x)$ (divisor or generator polynomial)
  - shift left k bits, i.e., $M(x)x^k = T(x)$
  - subtract remainder $R(x)$ of $[T(x) / C(x)]$ from $T(x)$ to get $P(x)$
  - Receiver polynomial $P(x) + E(x)$
  - $E(x) = 0$ implies no errors
  - Modulo-2 arithmetic, i.e., binary addition with no carry is used

- **Divide ($P(x) + E(x)$) by $C(x)$; remainder zero only if:**
  - $E(x)$ was zero (no error), or
  - $E(x)$ is exactly divisible by $C(x)$

- Receiver divides whatever it has received (including the k remainder bits) by the divisor polynomial. If the remainder is not zero, the error is detected. If the remainder is zero, wither there is no error or the error is undetected.

Selecting $C(x)$

- All single-bit errors can be detected as long as x^k and x^0 terms have non-zero coefficients.
- Any odd number of errors can be detected as long as $C(x)$ contains the factor $(x + 1)$
- Any 'burst' error (i.e., sequence of consecutive error bits) for which the length of the burst is less than or equal to k bits can be detected
- Most burst errors of larger than k bits can also be detected
- CRC-8, CRC-10, CRC-12, CRC-16, CRC-32
  - CRC-N: a polynomial with degree N. i.e. Divisor C has N+1 bits; remainder R has N bits
  - These CRC- polynomials can be seen in books
  - Ethernet uses CRC-32

CRC Calculation – An Example

```
              1 1 0 1 0 1 1 1
         ________________________
1 1 0 1 |     1 0 1 0 0 1 1 0 0 0 0
              1 1 0 1
              -------
                1 1 1 0
                1 1 0 1
                -------
                    1 1 1 1
                    1 1 0 1
                    -------
                        1 0 0 0
                        1 1 0 1
                        -------
                          1 0 1 0
                          1 1 0 1
                          -------
                            1 1 1 0
                            1 1 0 1
                            -------
                              0 1 1
```

M = 1 0 1 0 0 1 1 0

C = 1 1 0 1

T = 1 0 1 0 0 1 1 0 0 0 0

R = 0 1 1

P = 1 0 1 0 0 1 1 0 0 1 1