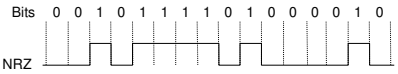
Point-to-Point Links

Outline
- Encoding
- Framing
- Error Detection
- Sliding Window Algorithm

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
- High signal (1) leads to baseline wander
- Unable to recover clock

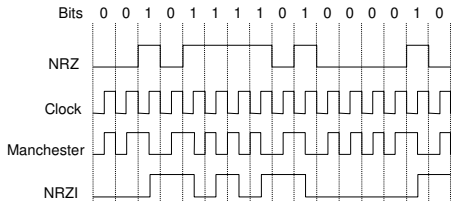
Alternative Encodings

- Non-return to Zero Inverted (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
- Manchester
  - transmit XOR of the NRZ encoded data and the clock
  - only 50% efficient (bit rate = 1/2 baud rate)

Encodings (cont)

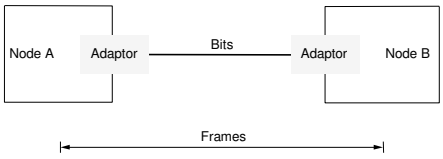
- 4B/5B
  - every 4 bits of data encoded in a 5-bit code
  - 5-bit codes selected to have no more than one leading 0 and no more than two trailing 0s
  - thus, never get more than three consecutive 0s
  - resulting 5-bit codes are transmitted using NRZI
  - achieves 80% efficiency

Encodings (cont)



Framing

- Break sequence of bits into a frame
- Typically implemented by network adaptor



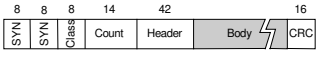
Approaches

- Sentinel-based
  - delineate frame with special pattern: 01111110
  - e.g., HDLC, SDLC, PPP

  - problem: special pattern appears in the payload
  - solution: *bit stuffing*
    - sender: insert 0 after five consecutive 1s
    - receiver: delete 0 that follows five consecutive 1s

Approaches (cont)

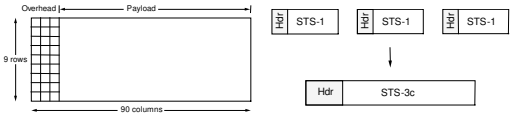
- Couter-based
  - include payload length in header
  - e.g., DDCMP



  - problem: count field corrupted
  - solution: catch when CRC fails

Approaches (cont)

- Clock-based
  - each frame is 125us long
  - e.g., SONET: Synchronous Optical Network
  - STS-*n* (STS-1 = 51.84 Mbps)



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 (cont)

- Transmit polynomial $P(x)$ that is evenly divisible by $C(x)$
  - shift left k bits, i.e., $M(x)x^k$
  - subtract remainder of $M(x)x^k$ / $C(x)$ from $M(x)x^k$
- Receiver polynomial $P(x) + E(x)$
  - $E(x) = 0$ implies no errors
- Divide $(P(x) + E(x))$ by $C(x)$; remainder zero if:
  - $E(x)$ was zero (no error), or
  - $E(x)$ is exactly divisible by $C(x)$

Selecting $C(x)$

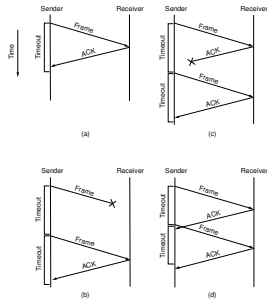
- All single-bit errors, as long as the x^k and x^0 terms have non-zero coefficients.
- All double-bit errors, as long as $C(x)$ contains a factor with at least three terms
- Any odd number of errors, as long as $C(x)$ contains the factor $(x + 1)$
- Any 'burst' error (i.e., sequence of consecutive error bits) for which the length of the burst is less than k bits.
- Most burst errors of larger than k bits can also be detected
- See Table 2.6 on page 102 for common *C(x)*

Internet Checksum Algorithm

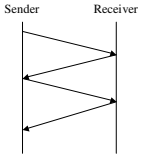
- View message as a sequence of 16-bit integers; sum using 16-bit ones-complement arithmetic; take ones-complement of the result.

```
u_short
cksum(u_short *buf, int count)
{
   register u_long sum = 0;
   while (count--)
   {
      sum += *buf++;
      if (sum & 0xFFFF0000)
      {
         /* carry occurred, so wrap around */
         sum &= 0xFFFF;
         sum++;
      }
   }
   return ~(sum & 0xFFFF);
}
```


Acknowledgements & Timeouts



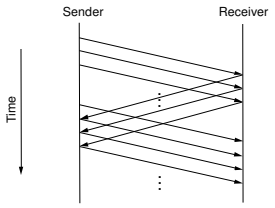
Stop-and-Wait



- Problem: keeping the pipe full
- Example
  - 1.5Mbps link x 45ms RTT = 67.5Kb (8KB)
  - 1KB frames implies 1/8th link utilization

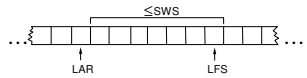
Sliding Window

- Allow multiple outstanding (un-ACKed) frames
- Upper bound on un-ACKed frames, called *window*



SW: Sender

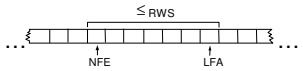
- Assign sequence number to each frame (**`SeqNum`**)
- Maintain three state variables:
  - send window size (**`SWS`**)
  - last acknowledgment received (**`LAR`**)
  - last frame sent (**`LFS`**)
- Maintain invariant: **`LFS`** - **`LAR`** <= **`SWS`**



- Advance **`LAR`** when ACK arrives
- Buffer up to **`SWS`** frames

SW: Receiver

- Maintain three state variables
  - receive window size (**RWS**)
  - largest frame acceptable (**LFA**)
  - last frame received (**NFE**)
- Maintain invariant: **LFA** - **LFR** <= **RWS**



- Frame **SeqNum** arrives:
  - if **LFR** < **SeqNum** < = **LFA** ⟶ accept
  - if **SeqNum** < = **LFR** or **SeqNum** > **LFA** ⟶ discarded
- Send cumulative ACKs

Sequence Number Space

- **SeqNum** field is finite; sequence numbers wrap around
- Sequence number space must be larger then number of outstanding frames
- **SWS <= MaxSeqNum−1** is not sufficient
  - suppose 3-bit **SeqNum** field (0..7)
  - **SWS=RWS=7**
  - sender transmit frames 0..6
  - arrive successfully, but ACKs lost
  - sender retransmits 0..6
  - receiver expecting 7, 0..5, but receives second incarnation of 0..5
- **SWS < (MaxSeqNum+1)/2** is correct rule
- Intuitively, **SeqNum** "slides" between two halves of sequence number space

Concurrent Logical Channels

- Multiplex 8 logical channels over a single link
- Run stop-and-wait on each logical channel
- Maintain three state bits per channel
  - channel busy
  - current sequence number out
  - next sequence number in
- Header: 3-bit channel num, 1-bit sequence num
  - 4-bits total
  - same as sliding window protocol
- Separates *reliability* from *order*