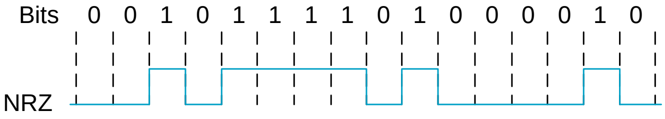
Point-to-Point Links

Outline

- Encoding (bits)
- Framing (frames)
- 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

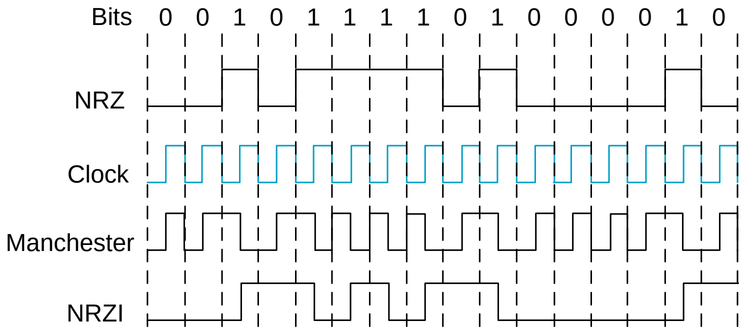
- Low signal (0) may be interpreted as no signal
- High signal (1) leads to baseline wander
  - Attenuation: the receiver uses the average to distinguish between low and high signals.
- Unable to recover clock
  - The clocks of the sender and the receiver must be synchronized
  - The receiver derives the signal from the signal transitions

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)
    - Or requires higher bandwidth for higher baud rate

Encodings (cont)

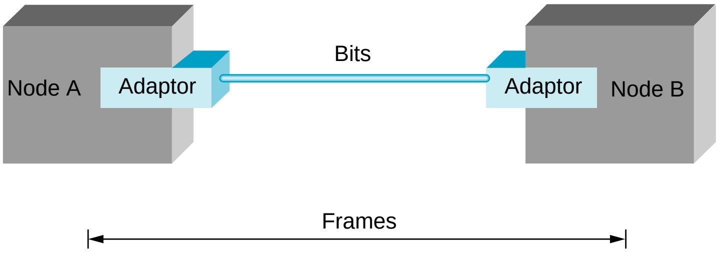


Encodings (cont)

- 4B/5B
  - every 4 bits of data encoded in a 5-bit code (p.79)
  - 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 (for consecutive 1s)
  - achieves 80% efficiency

Framing

- Break sequence of bits into a frame
  - The beginning and the end of a frame?
- Typically implemented by network adaptor

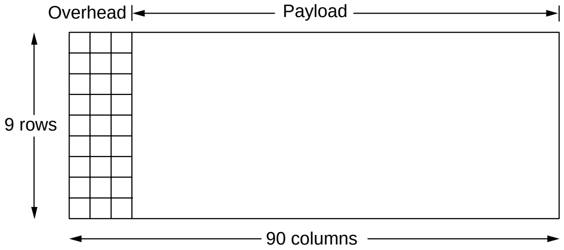


Approaches

- Santinel-based
- Bit-Oriented
  - e.g., HDLC
  - delineate frame with special pattern: 01111110
  - 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
- Byte-Oriented
  - e.g. PPP
  - Escape 01111110 by adding another 01111110

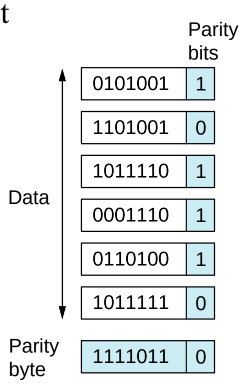
Approaches (cont)

- Clock-based
  - SONET (Synchronous Optical Network) STS-1frame: 90 bytes * 9
  - The first byte of each frame contain a special bit pattern
  - The receiver looks for the bit patterns that occurs every 810 bytes.



Error Detection

- Sending two copies of data is inefficient
- Detect more errors with less overhead
- Two-Dimensional Parity
  - Even number of 1s
- Catches all 1- 2- 3- bit errors
  - and most 4 bit errors



Data	0101001	1
	1101001	0
	1011110	1
	0001110	1
	0110100	1
	1011111	0
Parity byte	1111011	0

Internet Checksum Algorithm

- View message as a sequence of 16-bit integers; sum using 16-bit ones-complement arithmetic
- Simple to implement in software; Relies on complicated in layer CRC
  - E.g. word *A* LSB 1 to 0; Word *B* LSB 0 to 1

```
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);
}
```

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., $C(x) = x^3 + x^2 + 1$ (with degree k)
- Easy to implement in hardware

CRC (cont)

- Transmit polynomial $P(x)$ that is evenly divisible by $C(x)$
  - shift left k bits, i.e., $M(x)x^k$
  - Remainder $E(x)$: $M(x)x^k = C(x) \cdot ? + E(X)$
  - Transmit $P(x) = M(x)x^k + E(x)$
- Receiver receives $P'(x)$
  - $P'(x) = P(x) + \Delta(x) = C(x) \cdot ? + \Delta(x) = C(x) \cdot ?? + e(x)$
  - $e(x) = 0$ implies no errors, or $\Delta(x)$ happens to be divisible by $C(x)$
  - If no errors, $(P(x) - E(x))/x^k$ is the original message

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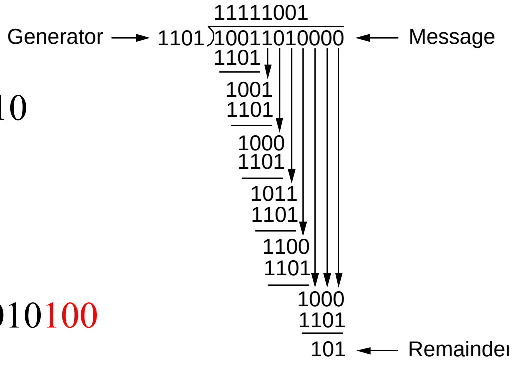
CRC (cont)

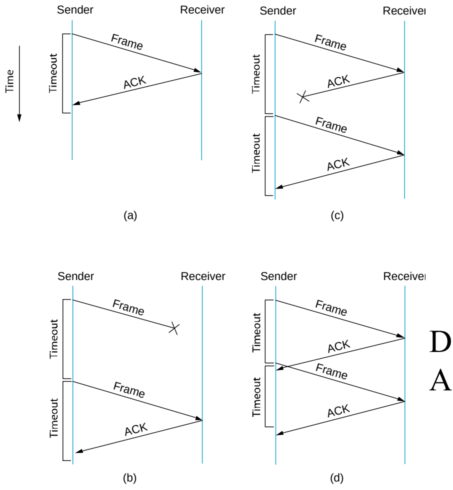
- XOR division!
- Message 10011010
  - ⇒ 10011010000
- Divisor:1101
- Reminder: 100
- Transmit: 10011010100



Selecting $C(x)$

- To detect all single-bit errors ($\Delta(x)=x^i$)
  - the x^k and x^0 terms have non-zero coefficients.
- To detect all double-bit errors
  - $C(x)$ contains a factor with at least three terms
- To detect any odd number of errors
  - $C(x)$ contains the factor $(x + 1)$
- To detect any ‘burst’ error (i.e., sequence of consecutive error bits) with a length 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 $C(x)$

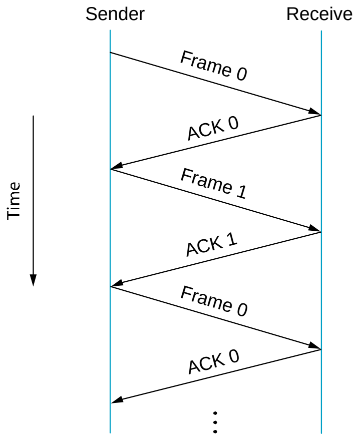
Acknowledgements & Timeouts



Detect duplicate ACKs!

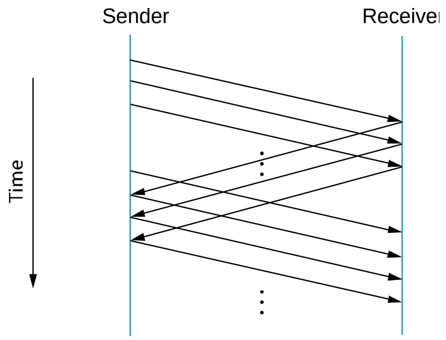
Stop-and-Wait

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



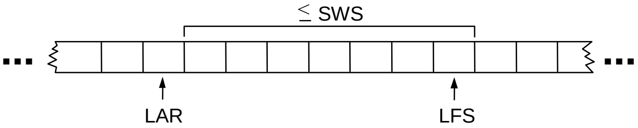
Sliding Window

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



SW: Sender

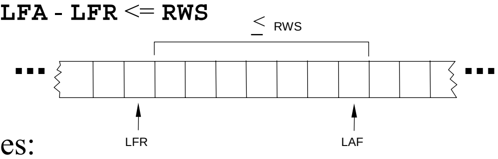
- Assign sequence number to each frame (**SeqNum**)
- Maintain three state variables:
  - send window size (**SWS**)
  - last acknowledgment received (**LAR**)
  - last frame sent (**LFS**)
- Maintain invariant: **LFS** - **LAR** <= **SWS**



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

SW: Receiver

- Maintain three state variables
  - receive window size (**RWS**)
  - largest frame acceptable (**LFA**)
  - last frame received i.e. received in order ! (**LFR**)
- Maintain invariant: **LFA** - **LFR** <= **RWS**



- Frame **SeqNum** arrives:
  - if **LFR** < **SeqNum** < = **LFA** accept
  - if **SeqNum** < = **LFR** or **SeqNum** > **LFA** discarded
- Send cumulative ACKs
- Advance **LFR** and deliver data to the application when **LFR + 1** arrives

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`** ! (similar to Stop&Wait)
- Intuitively, **`SeqNum`** “slides” between two halves of sequence number space