Error Detection

Outline

- Parity
- Checksum
- CRC

2-Dimensional Parity

	Data	Parity bits
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; 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);
}
```

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., $C(x) = x^3 + x^2 + 1$

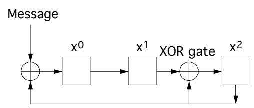
CRC (cont)

- 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 $C(x)$

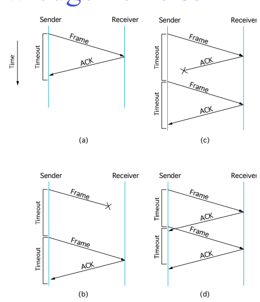
Selecting $C(x)$

- 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 2.5 on page 96 for common $C(x)$

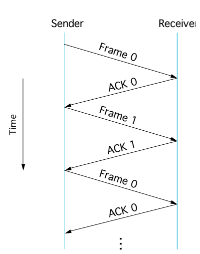
Hardware Implementation



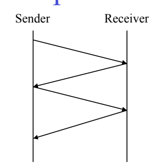
Acknowledgements & Timeouts



Stop-and-Wait



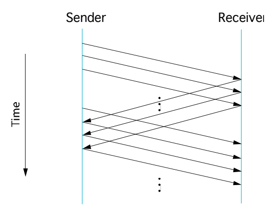
Stop-and-Wait



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

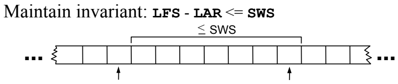
Sliding Window

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



SW: Sender

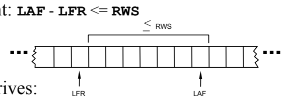
- Assign sequence number to each frame (`SeqNum`)
- Maintain three state variables:
  - send window size (`SWS`)
  - last acknowledgment received (`LAR`)
  - last frame sent (`LFS`)
- Maintain invariant: `LFS` - `LAR` <= `SWS`



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

SW: Receiver

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



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

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Sequence Number Space

- **`SeqNum`** field is finite; sequence numbers wrap around
- Sequence number space must be larger than 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

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