Error Control

- **Automatic Repeat Request (ARQ)**
  - A lost message will be retransmitted by the sender
  - Error detection (redundancy) > handle as loss
  - Needs a return path ("acknowledgement")
  - In the exercise: Ask the sender again if you don’t know the word, or if you feel unsure.

- **Forward error control (FEC)**
  - Redundancy to correct errors
  - Does not need return path
  - In the exercise: The sender spells a word, or point out difficulties. Repeat a word.

ARQ: Loss Detection at Sender

Problems:
- appropriate values for the timers
  - Timeout > RTT
  - RTT not known a priori, not constant
- control messages can get lost

ARQ: Loss Detection at Receiver

Problems:
- exchange of control information must be made reliable (loss detection for control information)
- appropriate values for the timers

Advantage:
- no unnecessary retransmissions

Alternatives:
- checksum based
  - gap based (if messages arrive in order)
  - gap in sequence numbers > NAK
  - problem: last message

ARQ: Acknowledgement Schemes

- **Cumulative ACK**
  - ACK(x) = message i is received ∀ i<x (receiver expects message x)
  + redundancy (ACK(j) can get lost; j<x)
  + simplicity (one number)
  - can not justify message j (i+1 < j < i+k) if message i is lost until message i is received

- **Selective ACK**
  - ACK(x1, x2, ...) = message i is received ∀ i ∈ {x1, x2, ...}
  - loss of redundancy (option: send each ACK sequence number in multiple ACK messages; combined with cumulative ACK)

- **Negative ACK (NAK)**
  + speed-up
  + reduce dependance on good timeout mechanisms
ARQ: Retransmission Schemes 1

- Independent of strategies used for loss detection and acknowledgement generation!
- ARQ Protocols
  - Stop and Wait
  - Go-Back-N
  - Selective Retransmission
- Pipelining: sender allows multiple unacknowledged pkts

ARQ: Retransmission Schemes 2

**Go-Back-N** (w/o window)

- no need for a queue at the receiver
- inefficient use of transmission capacity

Sender
- Resend all sent but not ack:ed PDUs.
  - Timeout:
    - 1 single timer (oldest not ack:ed PDU)
    - ACK > reset timer

Receiver
- PDU in-order: send ACK, deliver to application
- PDU out-of-order: send ACK of last in-order PDU.
  - cumulative ACK natural
  - not buffered

ARQ: Retransmission Schemes 3

**Selective Repeat** (w/o window)

Sender
- Resend only oldest not acked PDU.
  - selective ACK > Timeout: Individual timers
  - cumulative ACK > Timeout: one timer

Receiver
- PDU: individual ACK (in-order or not)
  - Buffer out-of-order PDUs
ARQ: Retransmission Schemes 3

Selective Repeat (w/o window)
- Selective ACK: Retransmission of message i if NAK(i) or TOi
- Cumulative ACK:
  - TOi > send message i; TOi=0 \( i \leq sk 
  - avoid unnecessary retransmissions
  - burst errors > requires several RTT to retransmit all lost messages
- messages in receiver buffer have to be reordered (high buffer storage)

S

\[ \begin{array}{c}
1 \\
2 \\
3 \\
N \\
N+1 \\
N+2 \\
\end{array} \]

R

ARQ: Efficiency

Stop & Wait | Go-Back-N | Selective Repeat
---|---|---
\[ \begin{array}{c}
1 \\
2 \\
3 \\
\end{array} \] | \[ \begin{array}{c}
1 \\
2 \\
3 \\
\end{array} \] | \[ \begin{array}{c}
1 \\
2 \\
3 \\
4 \\
\end{array} \]

efficiency = channel usage for successful transmissions

\[
\frac{(1-p)T}{T+\alpha} = \frac{1-p}{1+2\alpha} \quad \frac{(1-p)T}{T+\alpha 2P} \quad \frac{(1-p)T}{T} = 1-p
\]

T: Transmission time (size/rate) 
P: Propagation time (distance/speed) 
A = P/T: measure about un-ack'd messages
(Satellite: A>>1; LAN: A ~0)

ARQ: Timeout

Forward Error Correction (FEC)

- Transmit redundant information that can be used to reconstruct lost or erroneous packets at the receiver.

- Advantage: avoidance of retransmissions. This is meaningful for long communication delays (satellite link, compact disc).

- Problem: redundant information is not efficient.

- Example 1: Redundancy
  - Messages T1,T2,T3
  - send T1,T2,T3,R1,R2 with R1=T1⊕T2, R2=T2⊕T3

- Example 2: Error correcting codes
  - e.g., Hamming code
Error Control in TCP

- Loss detection: sender based (Timer)
  - adaptive timeout calculation
  - triple duplicate ACK

- Acknowledgement: cumulative ACK
  - sequence number: next octet that the receiver expects to get.
  - variable message length; retransmitted messages can include more than the original.

- Retransmission: (no specification)
  - until 1987: GBN
  - since 1987: Selective Retransmit
  - proposed modification: selective ACK