Agenda

• Today: General principles of reliability

• Next time: details of one concrete, very popular protocol: TCP
The Two Generals Problem

- Two army divisions (blue) surround enemy (red)
  - Each division led by a general
  - Both must agree when to simultaneously attack
  - If either side attacks alone, defeat
- Generals can only communicate via messengers
  - Messengers may get captured (unreliable channel)
The Two Generals Problem

- How to coordinate?
  - Send messenger: “Attack at dawn”
  - What if messenger doesn’t make it?
The Two Generals Problem

- How to be sure messenger made it?
  - Send acknowledgment: “I delivered message”
In the “two generals problem”, can the two armies reliably coordinate their attack?

• A. Yes (explain how)

• B. No (explain why not)
The Two Generals Problem

- **Result**
  - Can’t create perfect channel out of faulty one
  - Can only increase probability of success
Give up? No way!

• As humans, we like to face difficult problems.
  – We can’t control oceans, but we can build canals
  – We can’t fly, but we’ve landed on the moon
  – We just need engineering!

(Unsinkable)
Engineering

• Concerns
  – Message corruption
  – Message duplication
  – Message loss
  – Message reordering
  – Performance

• Our toolbox
  – Checksums
  – Timeouts
  – Acks & Nacks
  – Sequence numbering
  – Pipelining
Engineering

• Concerns
  – Message corruption
  – Message duplication
  – Message loss
  – Message reordering
  – Performance

• Our toolbox
  – Checksums
  – Timeouts
  – Acks & Nacks
  – Sequence numbering
  – Pipelining

We use these to build Automatic Repeat Request (ARQ) protocols.

(We’ll briefly talk about alternatives at the end.)
Automatic Repeat Request (ARQ)

- Intuitively, ARQ protocols act like you would when using a cell phone with bad reception.
  - Message garbled? Ask to repeat.
  - Didn’t hear a response? Speak again.
- Refer to book for building state machines.
  - We’ll look at TCP’s states soon
ARQ Broad Classifications

1. Stop-and-wait
Stop and Wait

- Up next: concrete problems and mechanisms to solve them.
- These mechanisms will build upon each other
- Questions?
Corruption?

- Error detection mechanism: checksum
  - Data good – receiver sends back ACK
  - Data corrupt – receiver sends back NACK
Could we do this with just ACKs or just NACKs?

Error detection mechanism: checksum
- Data good – receiver sends back ACK
- Data corrupt – receiver sends back NACK

A. No, we need them both.
B. Yes, we could do without one of them, but we’d need some other mechanism.
C. Yes, we could get by without one of them.
Could we do this with just ACKs or just NACKs?

- With only **ACK**, we could get by with a timeout.
- With only **NACK**, we couldn’t advance (no good).

A. No, we need them both.
B. Yes, we could do without one of them, but we’d need some other mechanism.
C. Yes, we could get by without one of them.
Timeouts and Losses

- Sender starts a clock. If no response, retry.

- Probably not a great idea for handling corruption, but it works.

(Timeout)

(Timeout)

(Timeout)
Timeouts and Losses

• Timeouts help us handle message losses too!
Adding timeouts might create new problems for us to worry about. How many? Examples?

A. No new problems (why not?)
B. One new problem (what is it?)
C. Two new problems (what are they?)
D. More than two new problems (what are they?)
Sequence Numbering

**Sender**
- Add a monotonically increasing label to each msg

**Receiver**
- Ignore messages with numbers we’ve seen before
- When pipelining (a few slides from now)
  - Detect gaps in the sequence (e.g., 1, 2, 4, 5)
Suppose we had a modest 8 Mbps (one megabyte per second) link. Our RTT is 100 ms, and we send 1024-byte (1K) segments. What is our link utilization with a stop and wait protocol?

A. $< 0.1 \%$
B. $\approx 0.1 \%$
C. $\approx 1 \%$
D. 1-10 \%
E. $> 10 \%$

**Big Problem:** Performance is determined by RTT, not channel capacity!
Keep multiple segments “in flight”

– Allows sender to make efficient use of the link
– Sequence numbers ensure receiver can distinguish segments
– We’ll talk about “how many” next time (windowing).
What should the sender do here?

What information does the sender need to make that decision?
What is required by either party to keep track?

A. Start sending all data again from 0.
B. Start sending all data again from 2.
C. Resend just 2, then continue with 4 afterwards.
ARQ Broad Classifications

1. Stop-and-wait

2. Go-back-N
Go-Back-N

Sender

Data-0

Data-1

Data-2

Receiver

Time

...
Go-Back-N

- Retransmit from point of loss
  - Segments between loss event and retransmission are ignored
  - “Go-back-N” if a timeout event occurs
Go-Back-N

Sender

Receiver

Data-0

Data-1

Data-2

Ack-0

Data-3

Time

...
Go-Back-N

Time

Sender

Data-0
Data-1
Data-2
Ack-0

Receiver

Data-2
Ack-1
Data-3

Data-4

...
Go-Back-N

Sender

Receiver

Time

Data-0

Data-1

Data-2

Ack-0

Ack-1

Ack-1

Ack-1

Data-3

Data-4

...
Go-Back-N
Go-Back-N

Sender

Receiver

Data-0
Data-1
Data-2

Ack-0
Ack-1

Data-3
Data-4

Ack-1

Timeout

Time

...
Go-Back-N

Sender

Receiver

Data-0
Data-1
Data-2
Data-3
Data-4

Ack-0
Ack-1
Ack-1
Ack-1

Time
Timeout

Lecture 16 - Slide 32
Go-Back-N

- Retransmit from point of loss
  - Segments between loss event and retransmission are ignored
  - “Go-back-N” if a timeout event occurs
- Fast retransmit
  - Don’t wait for timeout if we get N duplicate ACKs
Go-Back-N

- Retransmit from point of loss
  - Segments between loss event and retransmission are ignored
  - “Go-back-N” if a timeout event occurs

- Fast retransmit
  - Don’t wait for timeout if we get N duplicate ACKs
ARQ Broad Classifications

1. Stop-and-wait

2. Go-back-N

3. Selective repeat
   • a.k.a selective reject, selective acknowledgement
Selective Repeat

Sender

Data-0
Data-1
Data-2

Receiver

Time

...
Selective Repeat

Sender

Receiver

Data-0
Data-1
Data-2

Ack-0
Ack-1

Time
Selective Repeat

Sender

Receiver

Time

Data-0
Data-1
Data-2
Ack-0
Data-3
Ack-1
Data-4

...
Selective Repeat

Sender

Receiver

Data-0
Data-1
Data-2
Ack-0
Ack-1
Data-3
Data-4
Ack-3
Ack-4

Time

...
Selective Repeat

Sender

Receiver

Data-0
Data-1
Data-2
Ack-0
Ack-1
Data-3
Data-4
Ack-3
Ack-4
Data-5
Data-6
...

Time
Selective Repeat

- Receiver ACKs each segment individually (not cumulative)
- Sender only resends those not ACKed
- Requires extra buffering and state on the receiver
ARQ Alternatives

• Can’t afford the RTT’s or timeouts?

• When?
  – Broadcasting, with lots of receivers
  – Very lossy or long-delay channels (e.g., space)

• Use redundancy – send more data
  – Simple form: send the same message N times
  – More efficient: use “erasure coding”
    • For example, encode your data in 10 pieces such that the receiver can piece it together with any subset of size 8.