# Wireless TCP Performance Issues

# Issues, transport layer protocols

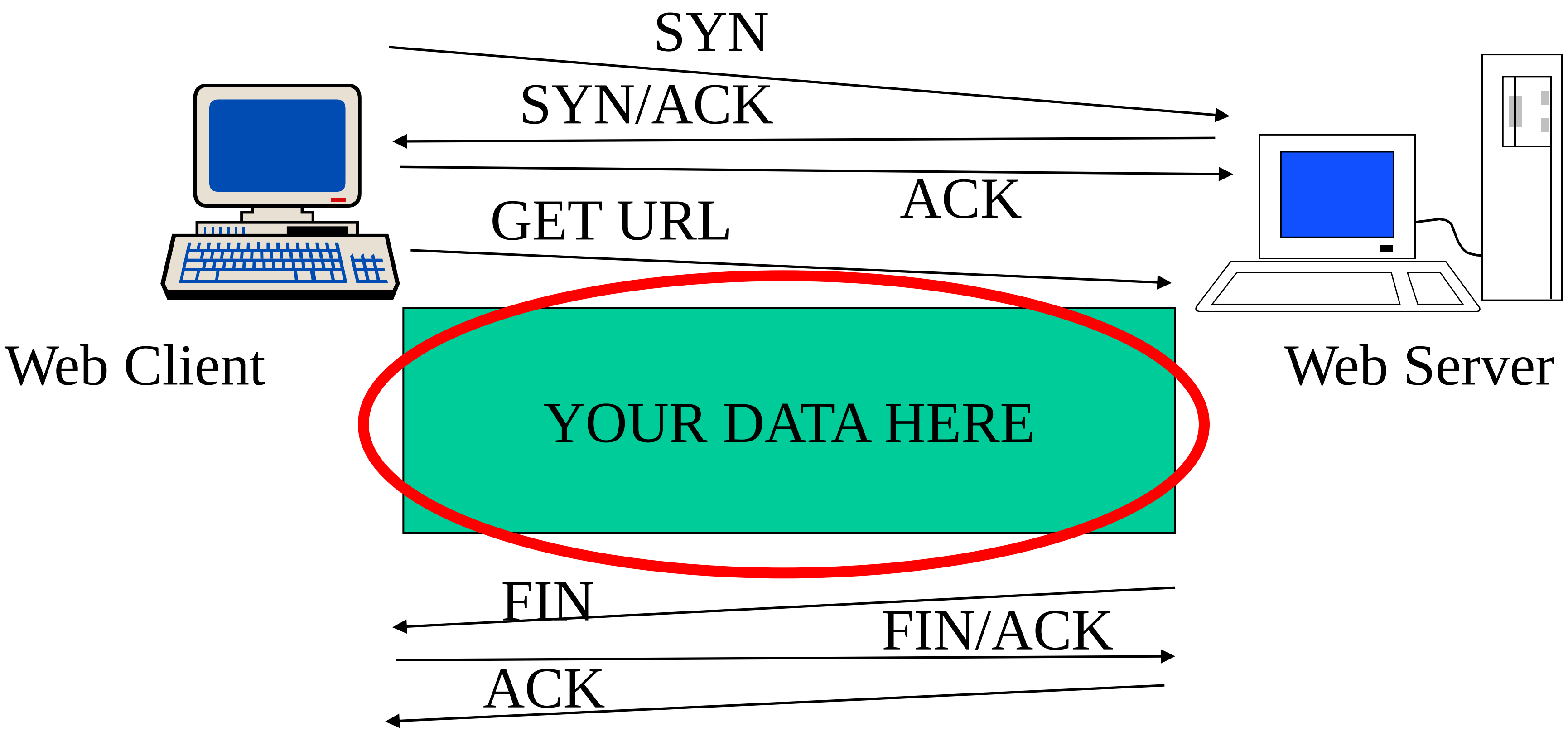
- Set up and maintain end-to-end connections
- Reliable end-to-end delivery of data
- Flow control
- Congestion control

- UDP?

*Assume TCP for the rest of these slides*

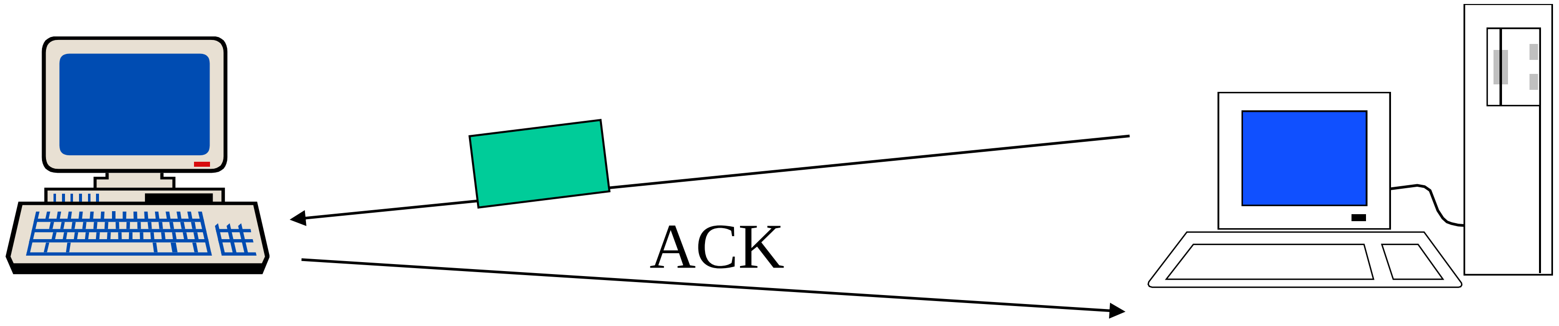
# TCP 101 (Cont'd)

- TCP is a connection-oriented protocol



# TCP 101 (Cont'd)

- TCP slow-start and congestion avoidance



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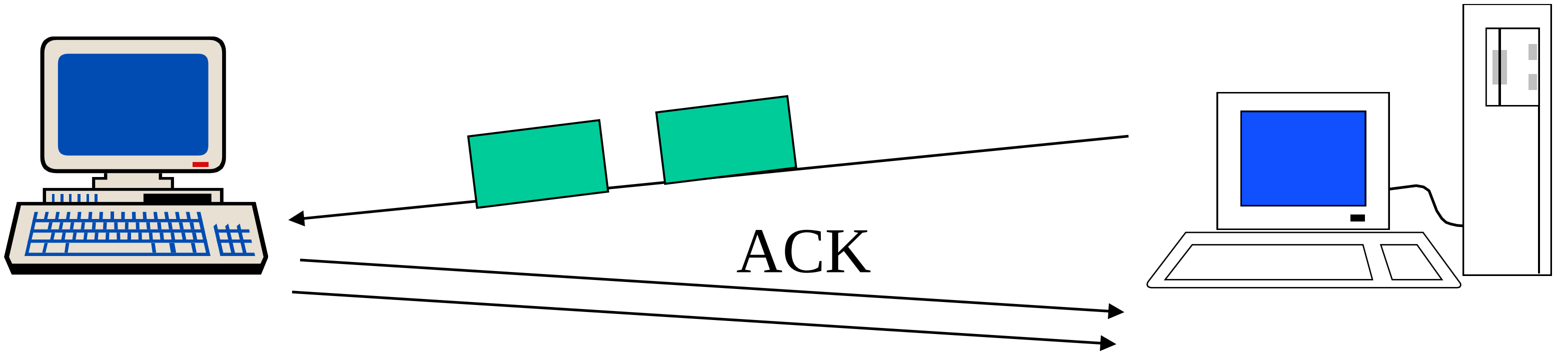
- TCP slow-start and congestion avoidance



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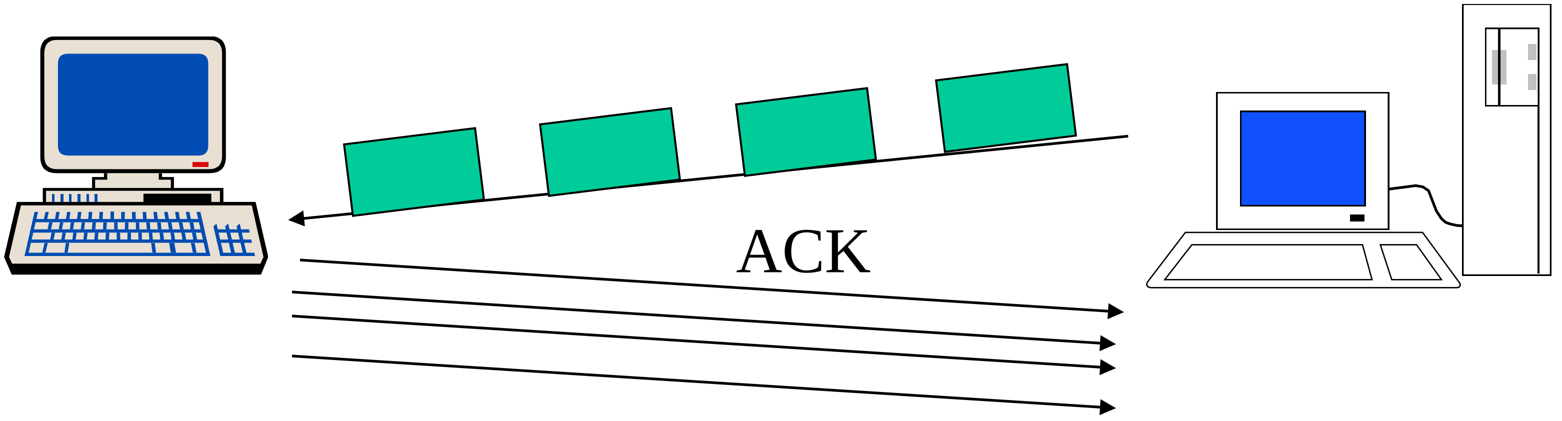
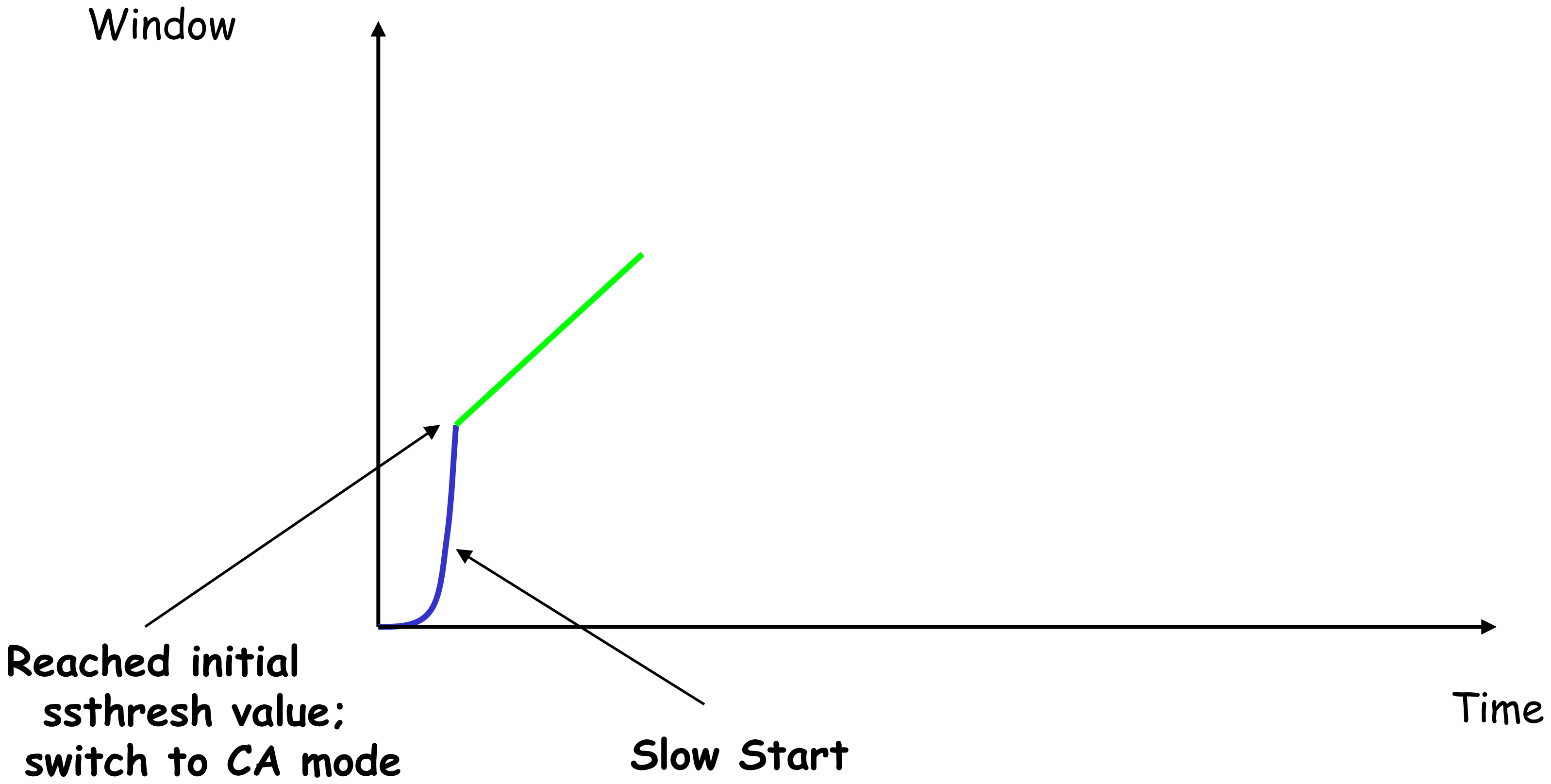
- TCP slow-start and congestion avoidance

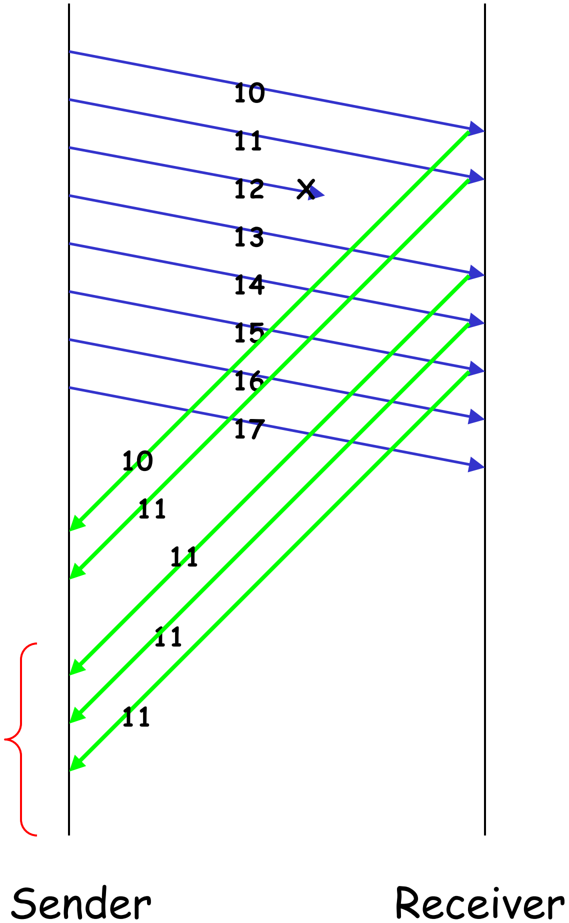


# TCP Reno

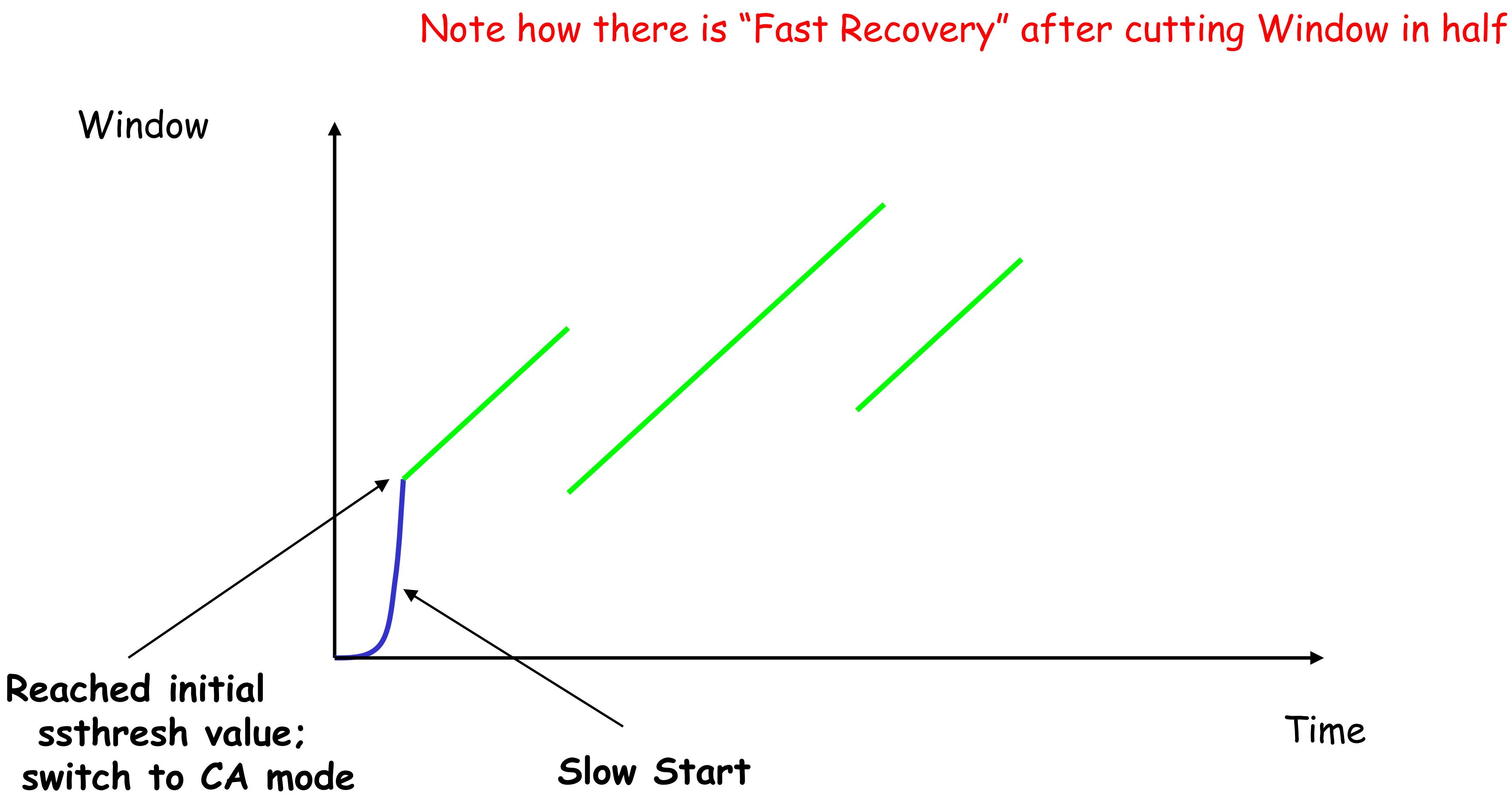

Window
Time
Reached initial ssthresh value; switch to CA mode
Slow Start

# Detecting Packet Loss

- Assumption: loss indicates congestion
- **Option 1: time-out**
  - Waiting for a time-out can be long!
- **Option 2: duplicate ACKs**
  - How many? At least 3.



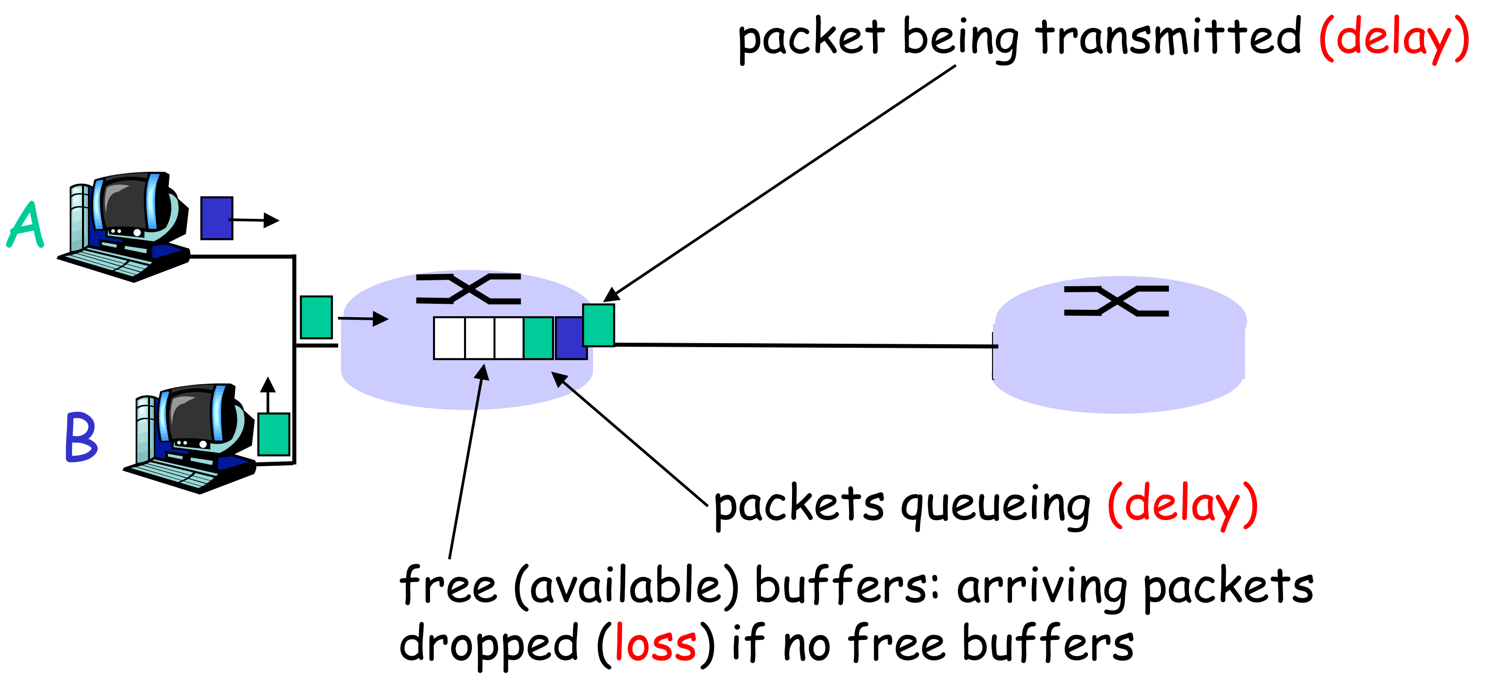
# TCP Reno


Note how there is "Fast Recovery" after cutting Window in half
Window
Time
Reached initial
ssthresh value;
switch to CA mode
Slow Start

# How do losses occur?

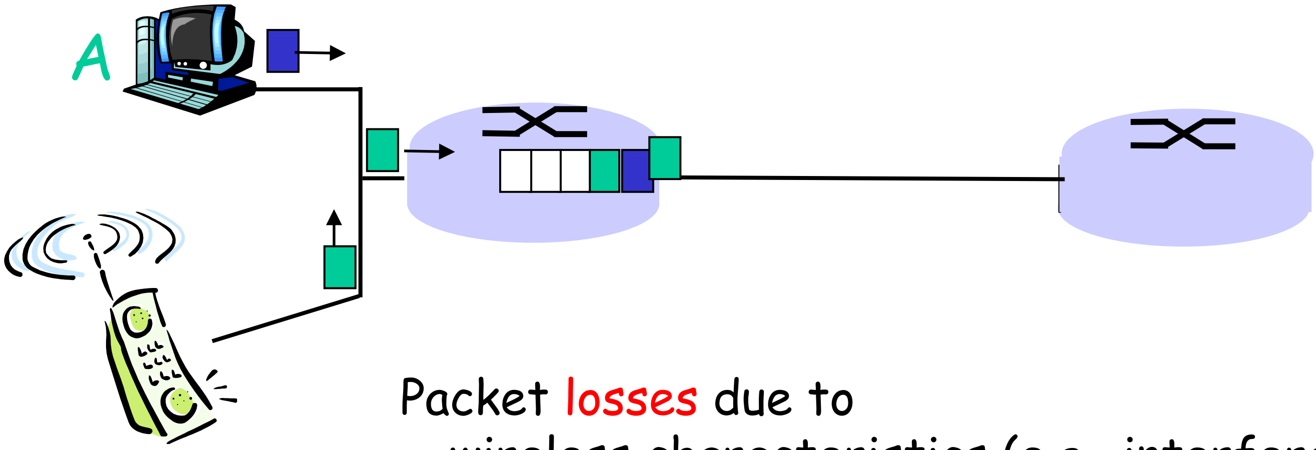
Congestion control assumes loss due to congestion

- packets *queue* in router buffers
- if queue is full, arriving packets dropped (Drop-Tail)



# How do losses occur?

In wireless (and mobile) environment … We find many other reasons …




Packet losses due to
- wireless characteristics (e.g., interference, bit errors, etc.)
- mobility (including handover issues)

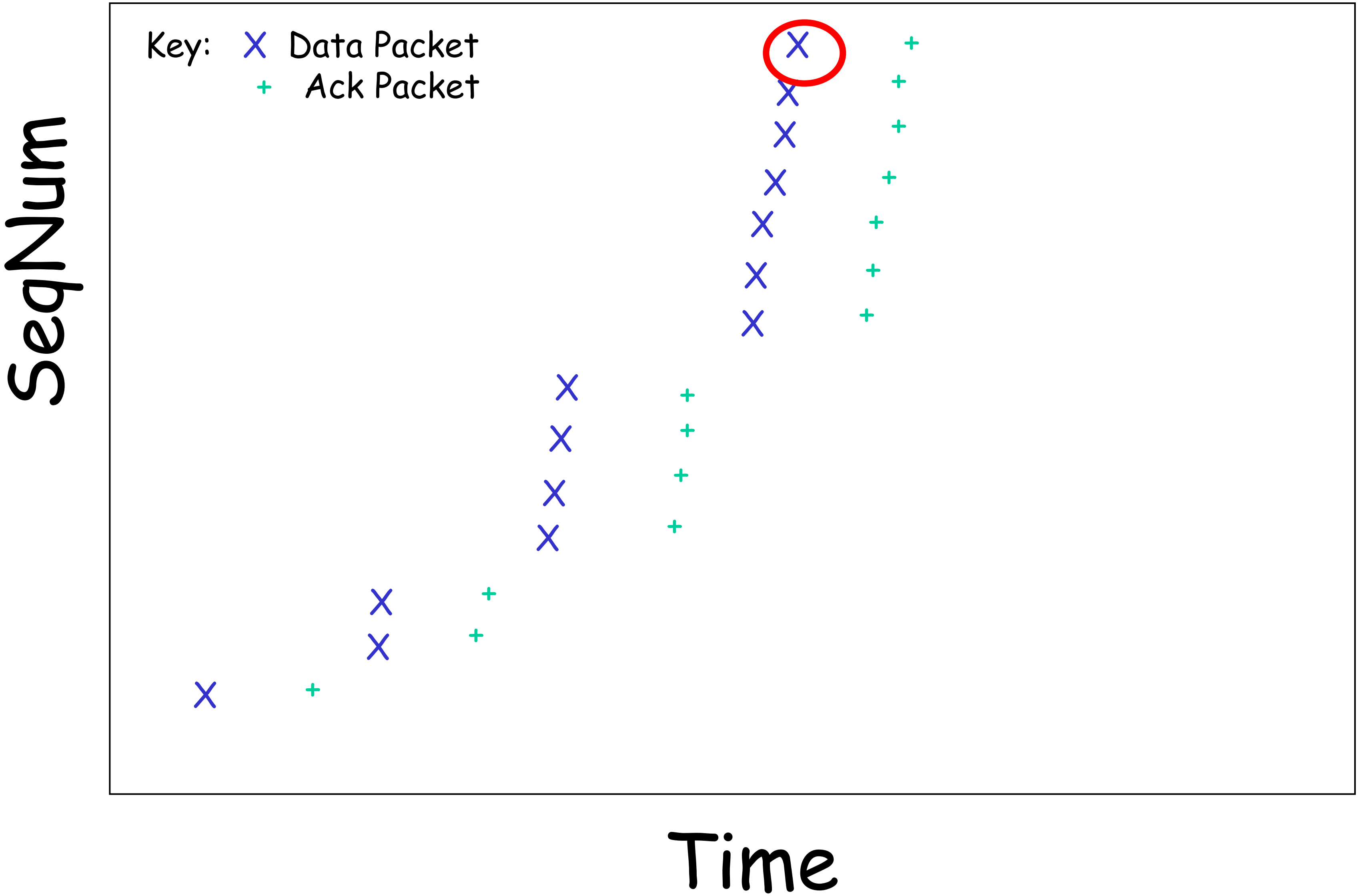
# Wireless, mobility: impact on higher layer protocols

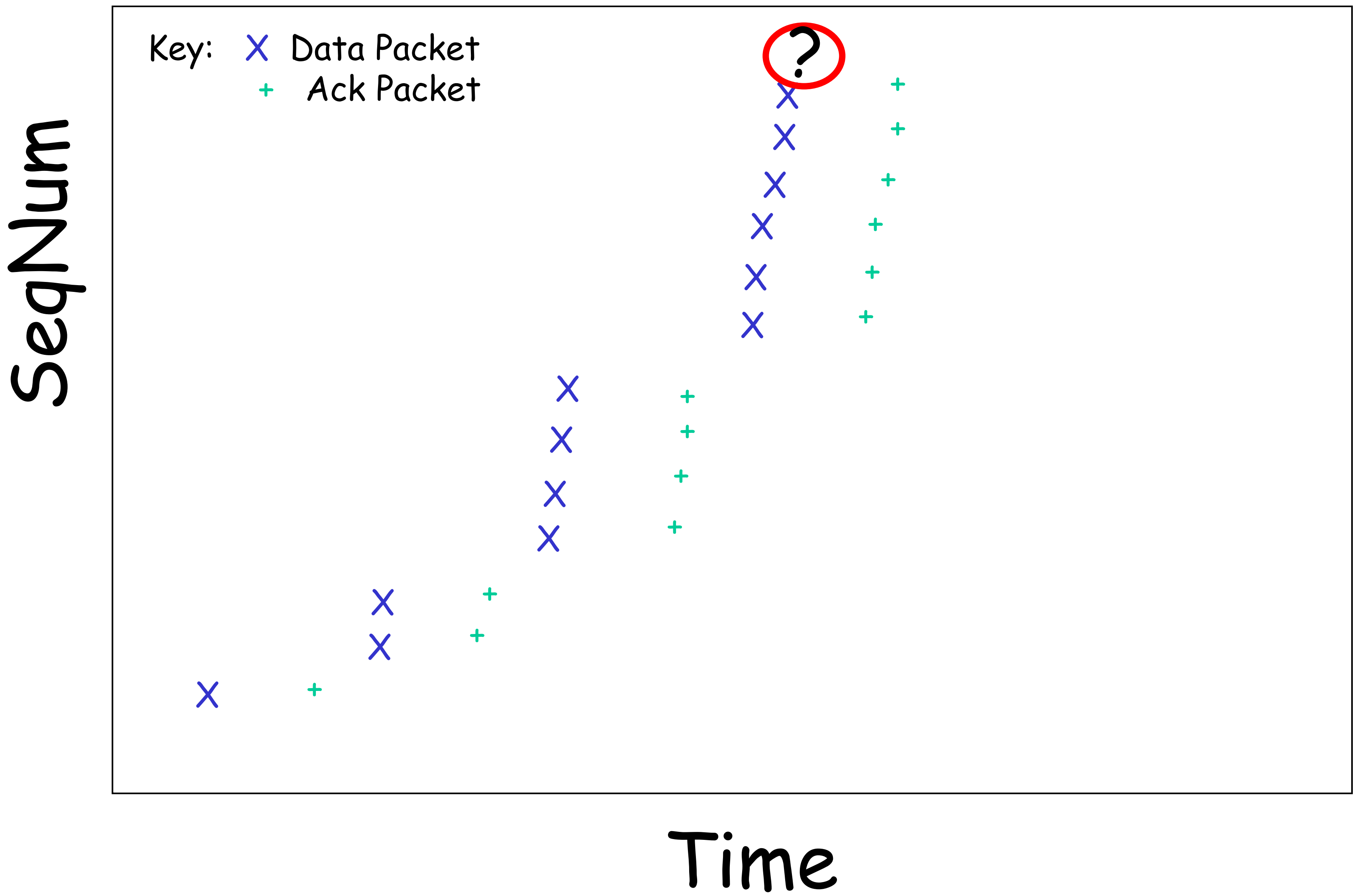
- logically, impact *should* be minimal …
  - best effort service model remains unchanged
  - TCP and UDP can (and do) run over wireless, mobile
- … but performance-wise:
  - packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
  - TCP interprets loss as congestion, will decrease congestion window un-necessarily
  - delay impairments for real-time traffic
  - limited bandwidth of wireless links

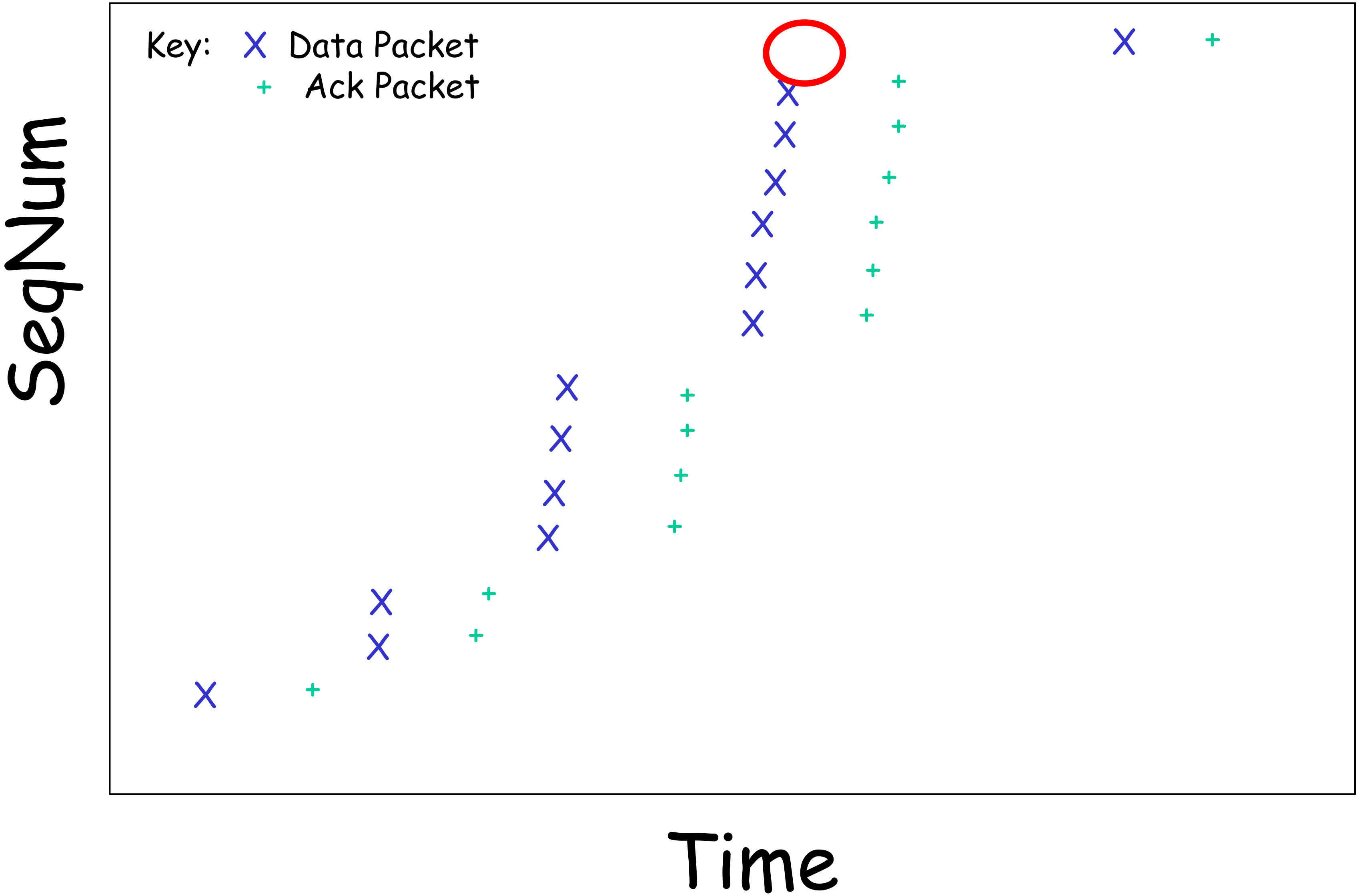
# Also, not all packet losses the same …

- What happens when a packet loss occurs?

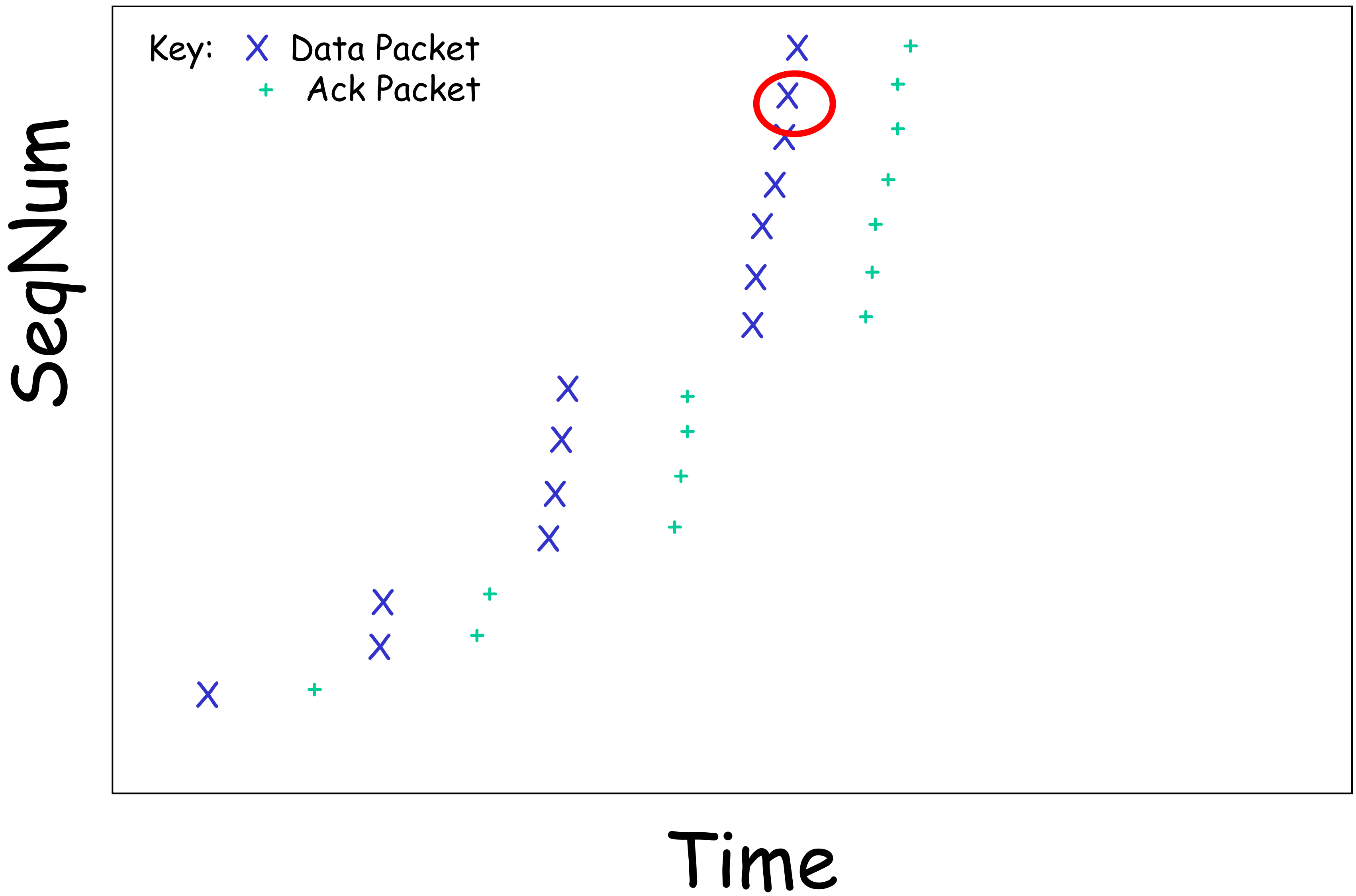
- Quiz Time...
  - Consider a 14-packet Web document
  - For simplicity, consider only a single packet loss


Key:
Data Packet
Ack Packet
SeqNum
Time


Key:
Data Packet
Ack Packet
?
SeqNum
Time



Key: X Data Packet
+ Ack Packet
SeqNum
Time



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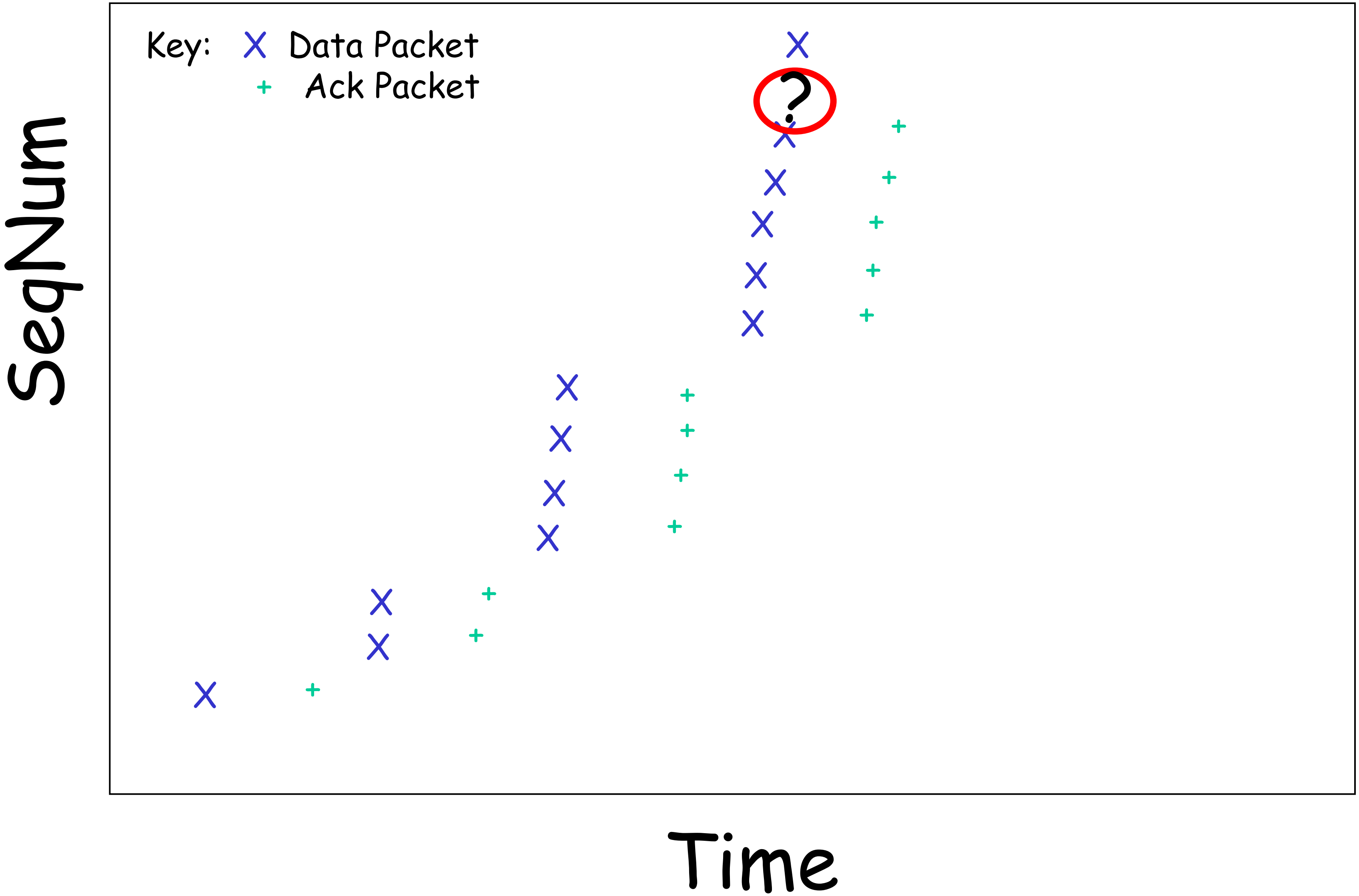
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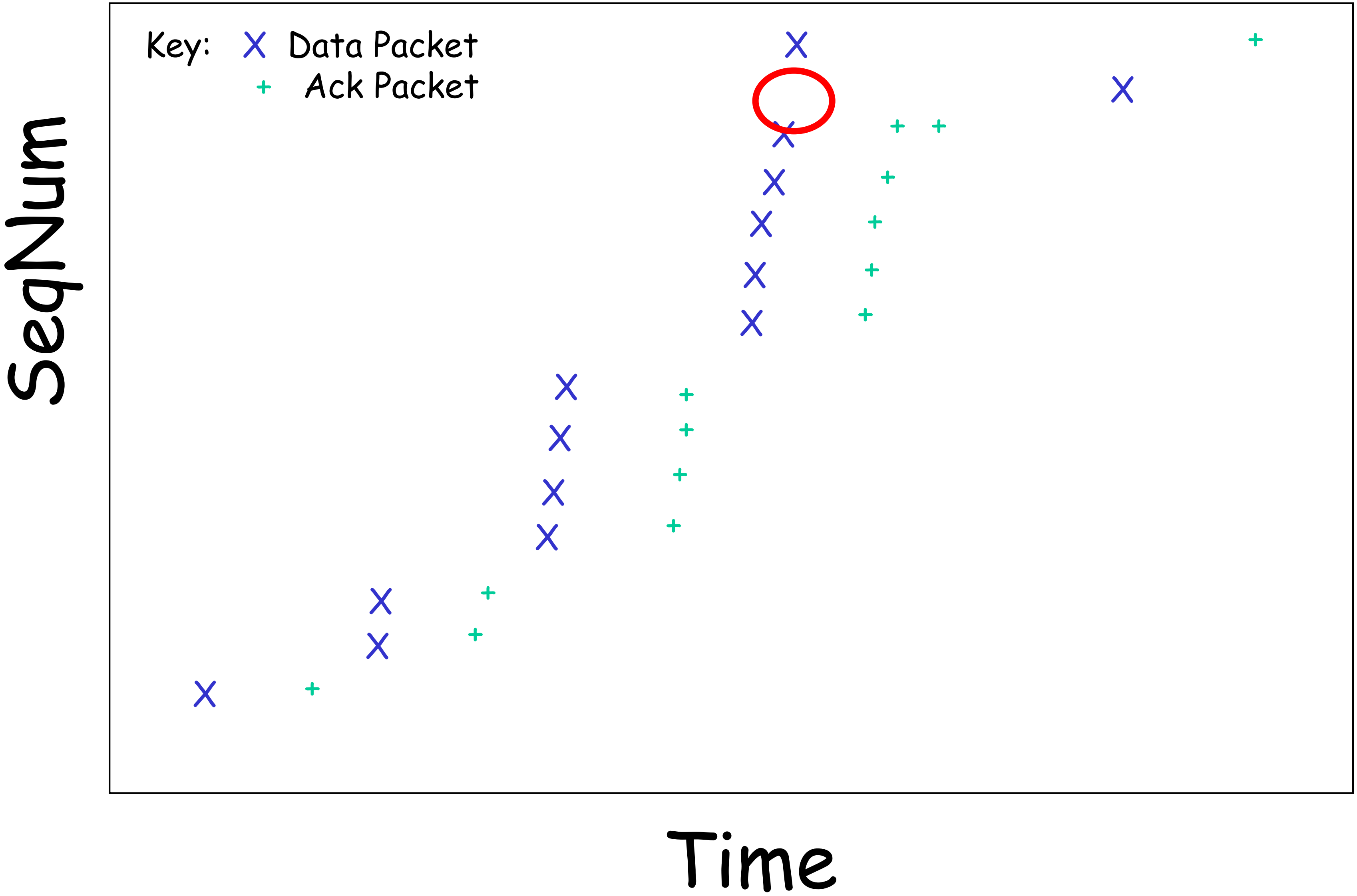
Time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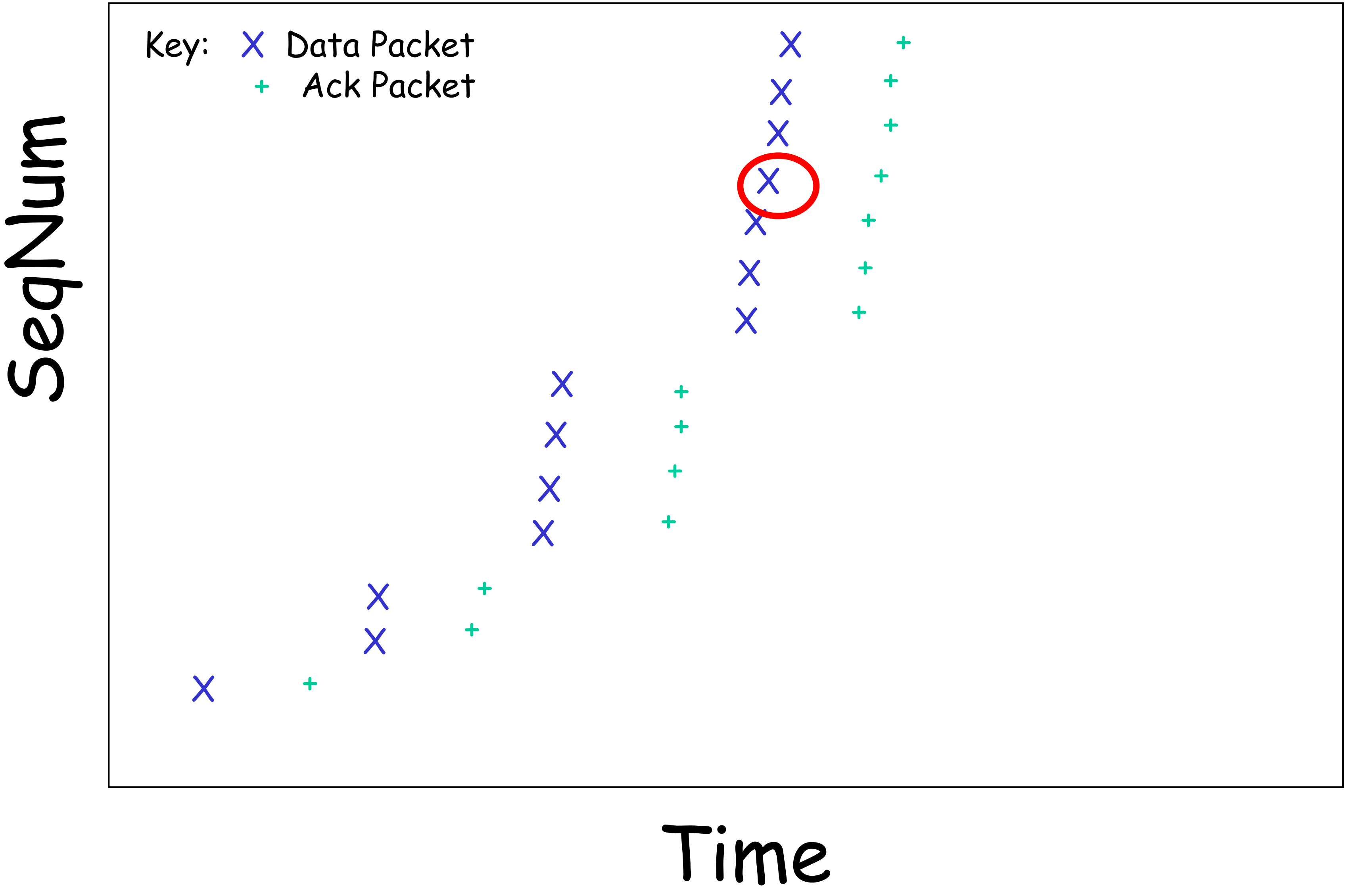
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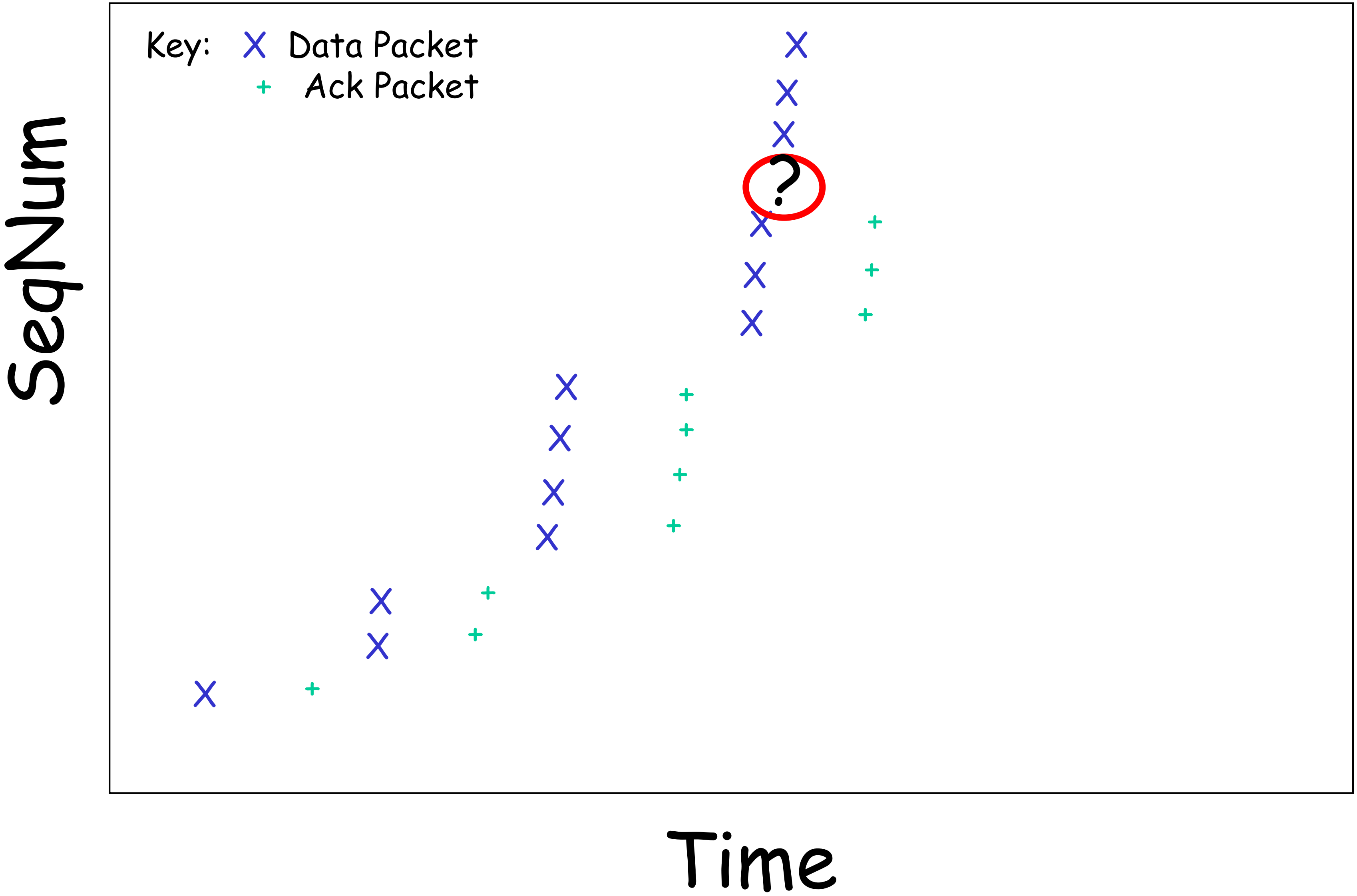
Time


Key:
Data Packet
Ack Packet
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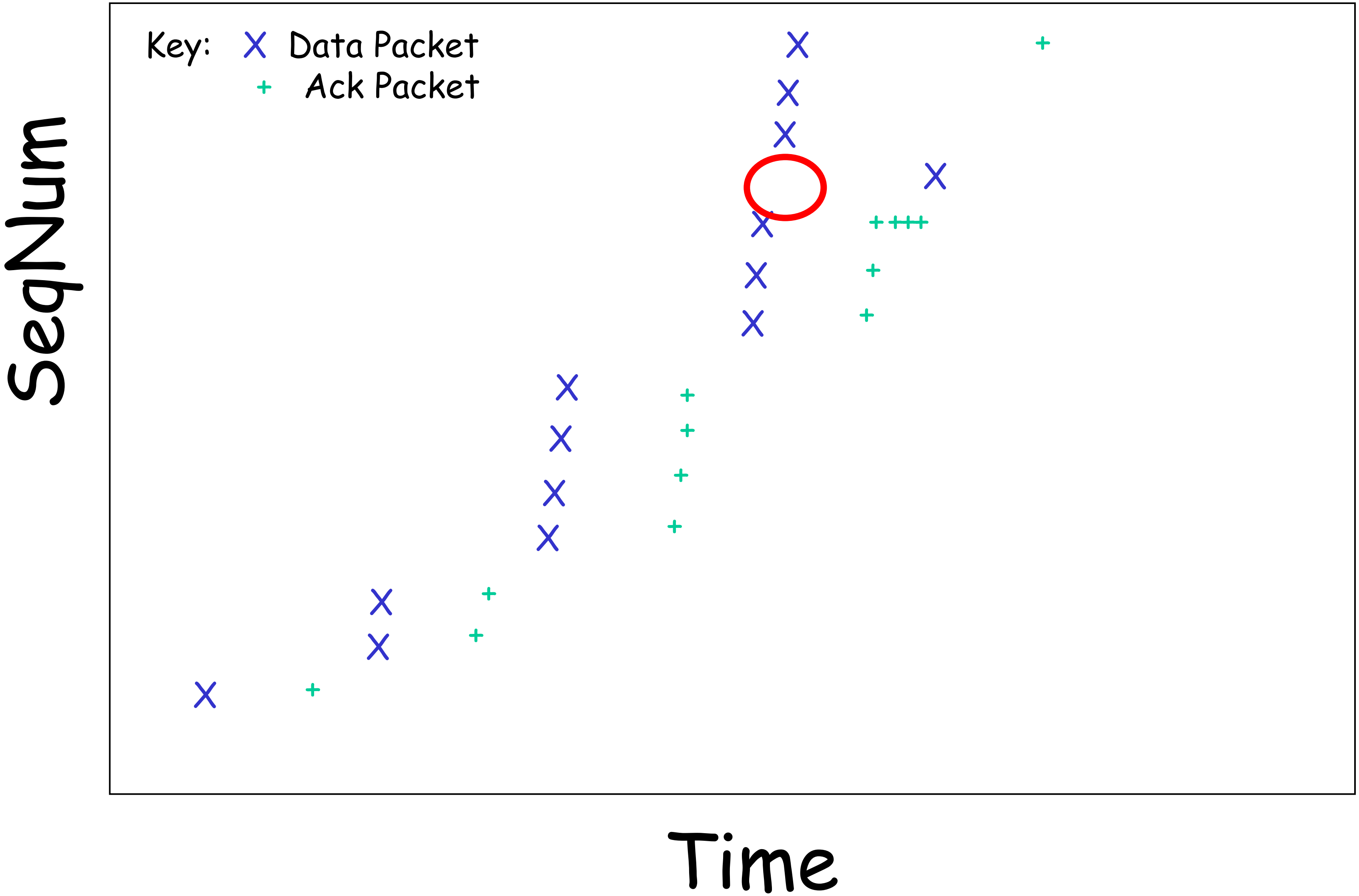
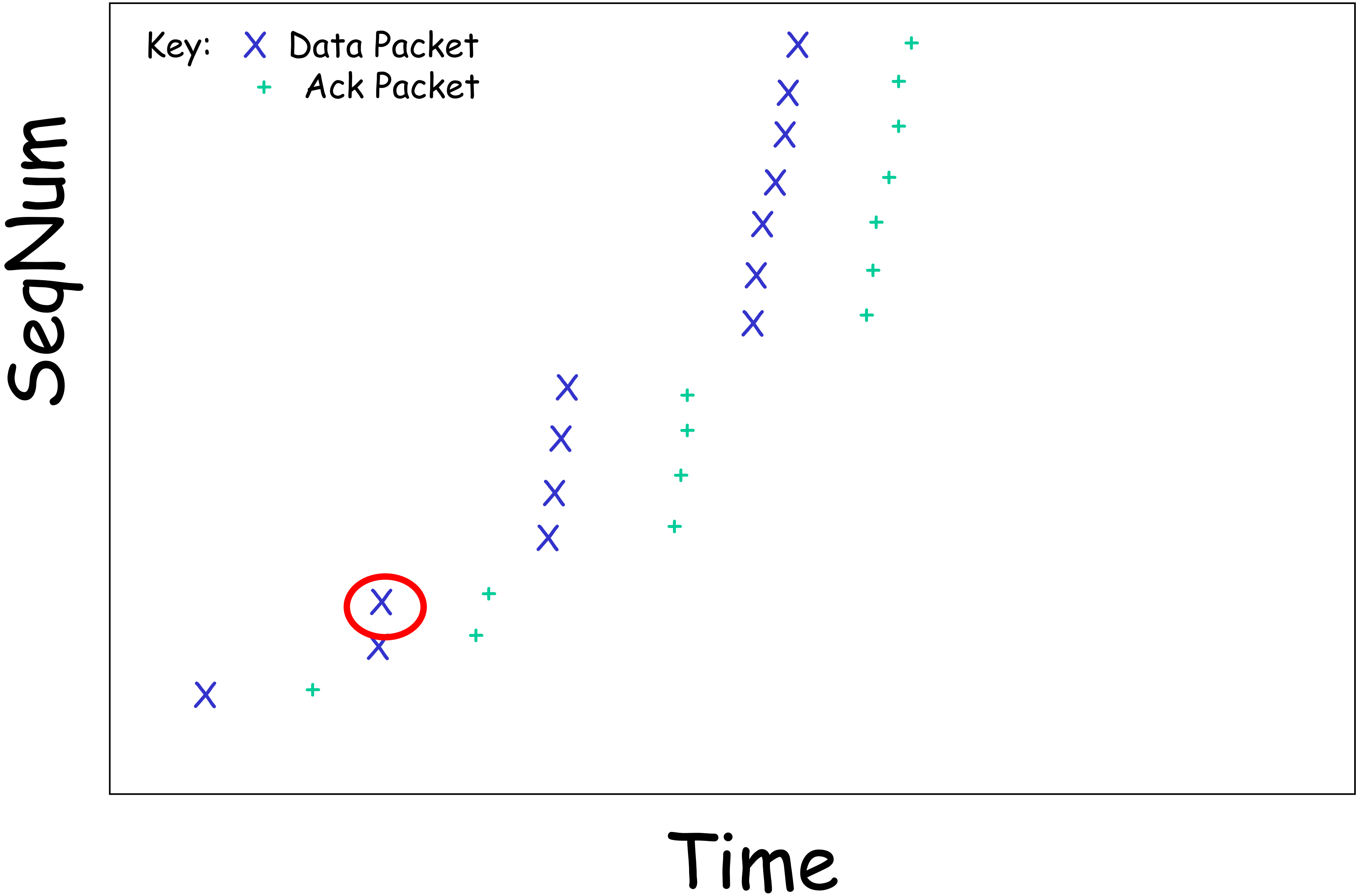
SeqNum
Time


Key: X Data Packet
+ Ack Packet
SeqNum
Time



Key: X Data Packet
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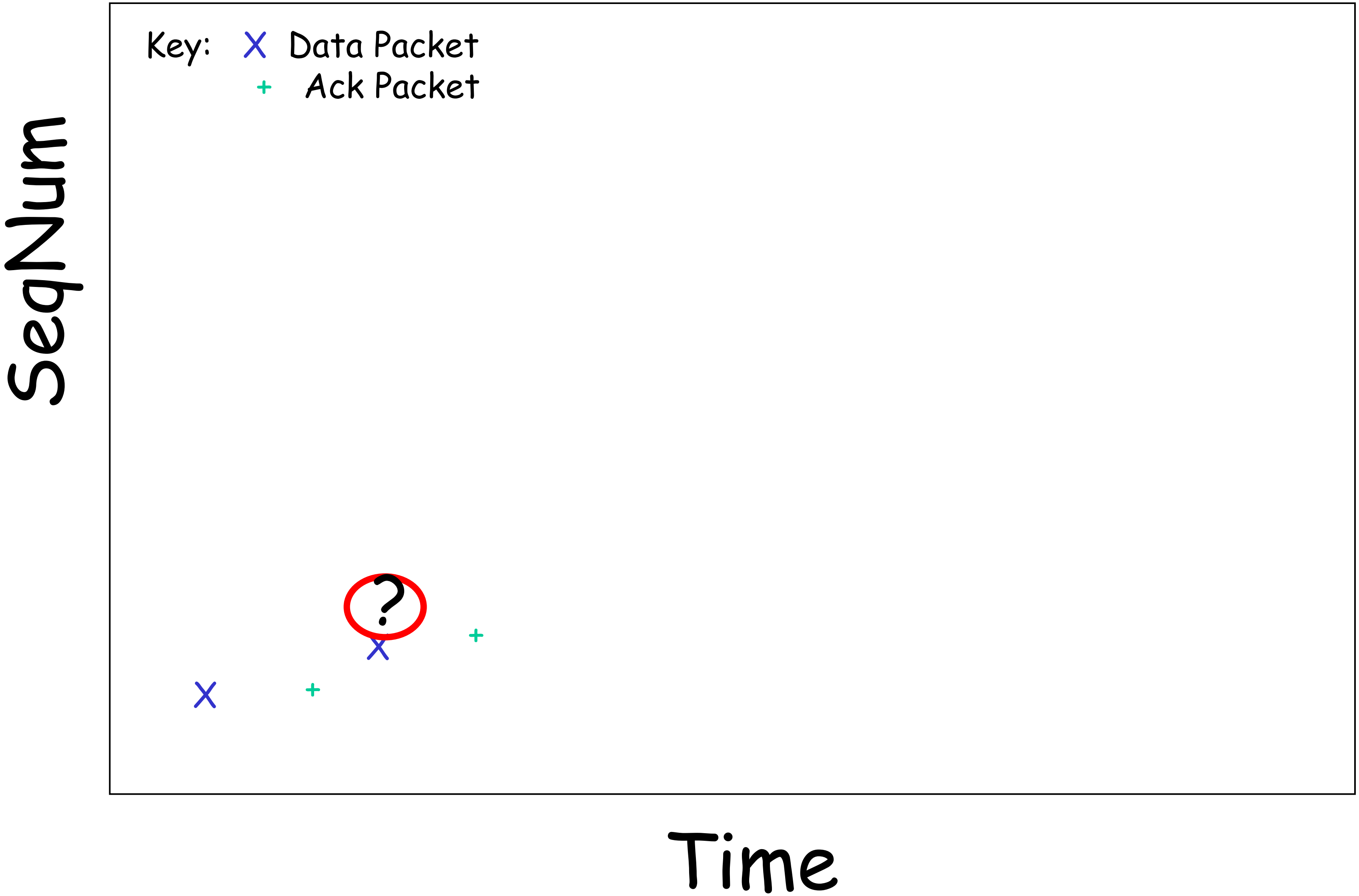
Time


Key:
Data Packet
Ack Packet
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SeqNum
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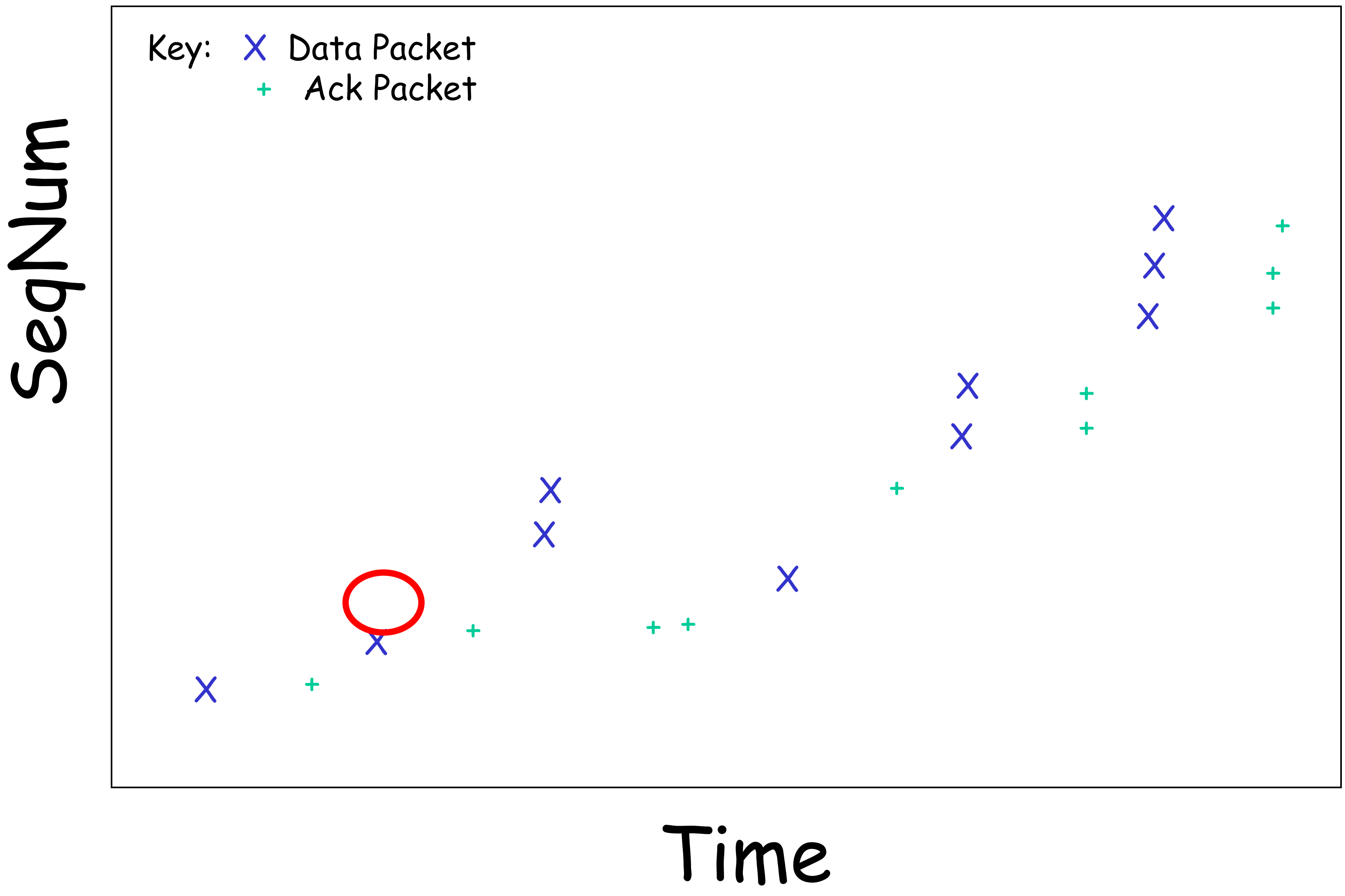


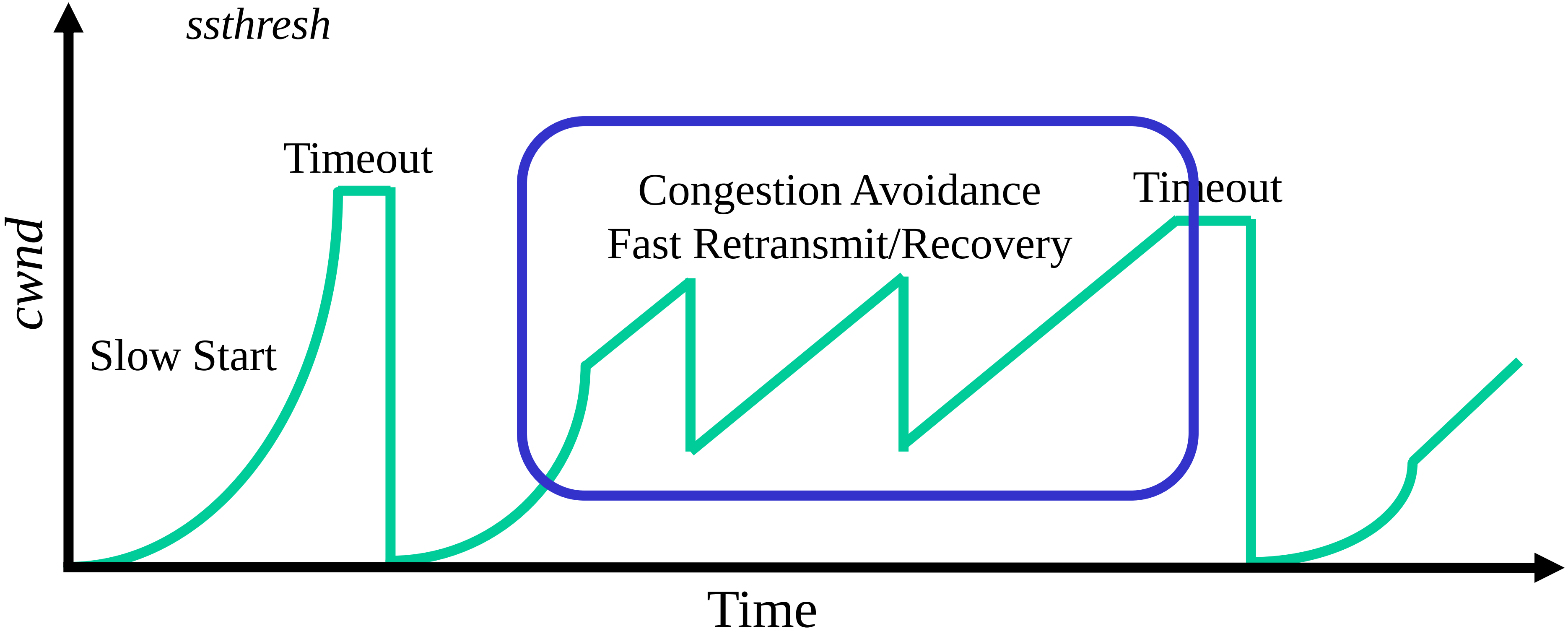
Key: X Data Packet
+ Ack Packet
SeqNum
Time

# TCP 301 (Cont'd)

- Main observation:
  - "Not all packet losses are created equal"

- Losses early in the transfer have a huge adverse impact on the transfer latency
- Losses near the end of the transfer always cost at least a retransmit timeout
- Losses in the middle may or may not hurt, depending on congestion window size at the time of the loss

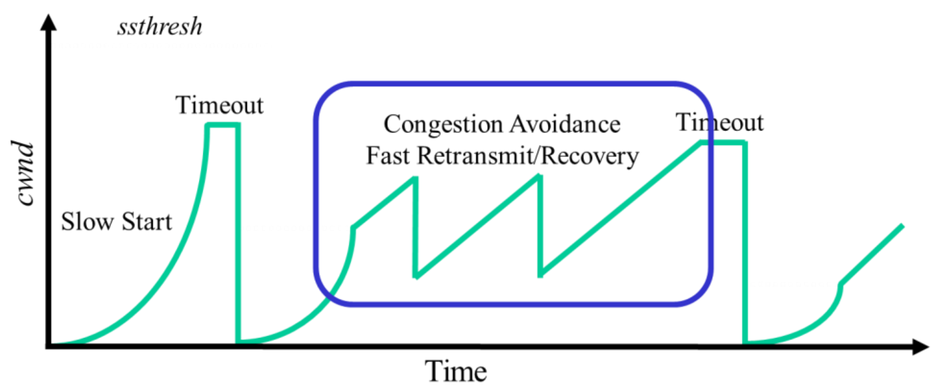
# Fast Retransmit and Fast Recovery




- At steady state, *cwnd* oscillates around the optimal window size
- TCP always forces packet drops

# Let's reason about TCP throughput

- Wired: What's the average throughout of TCP as a function of window size and RTT?
  - Ignore slow start
  - Let W be the window size when loss occurs.
- When window is W, throughput is W/RTT
- Just after loss, window drops to W/2, throughput to W/2RTT.
- Average throughout: .75 W/RTT
- Loss rate proportional to $1/W^2$



# TCP under lots of losses

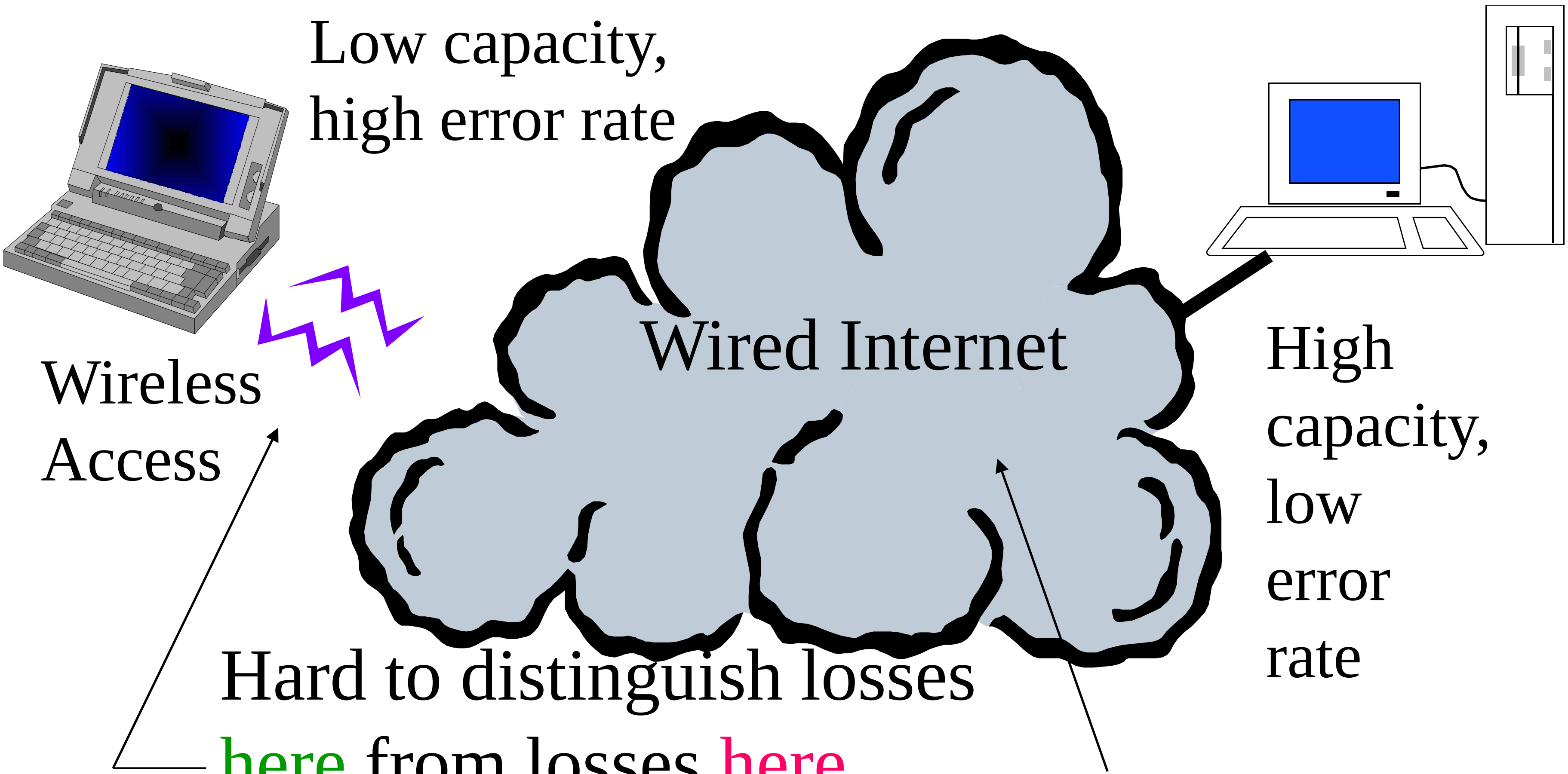
- Throughput in terms of loss rate:

$$\frac{1.22 \cdot MSS}{RTT\sqrt{L}}$$

- Wireless TCP versions or handling losses where they occur …

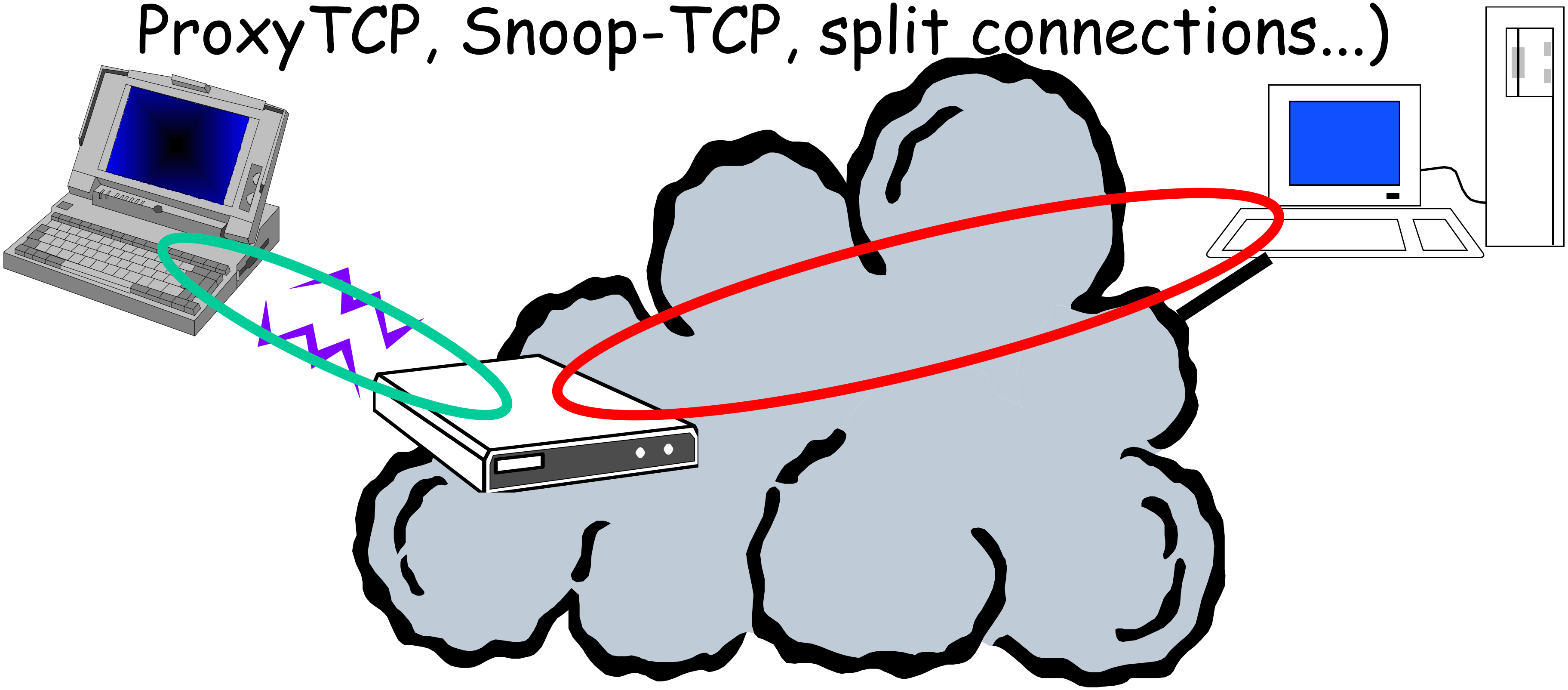
# Example #1

- Wireless TCP Performance Problems



# Example #1 (Cont'd)

- Solution: "wireless-aware TCP" (I-TCP, ProxyTCP, Snoop-TCP, split connections...)

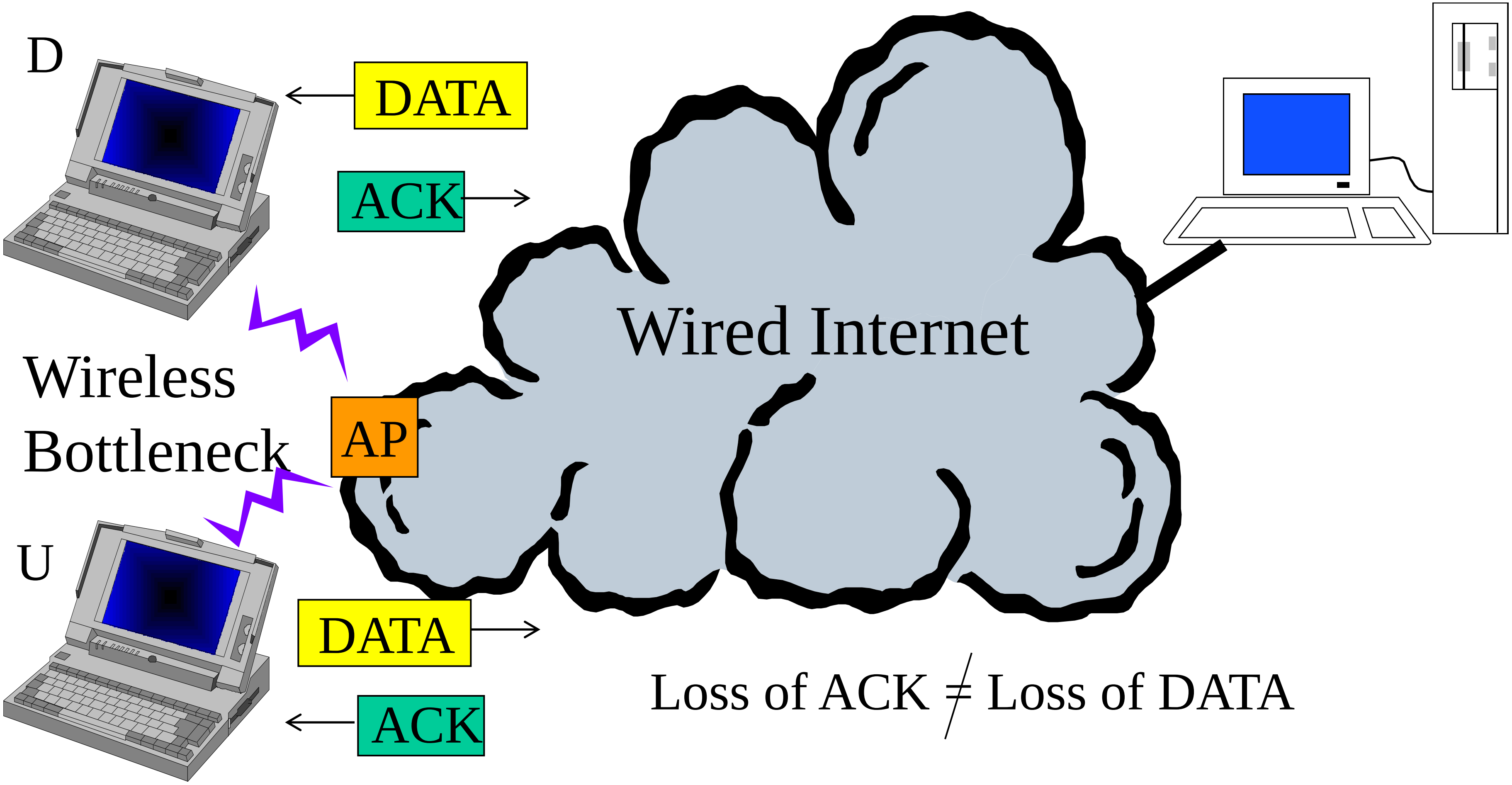


# Example trends and issues ...

- Middle boxes [e2e arguments, equation]
- Customized wireless TCP solutions
- Multi-path TCP

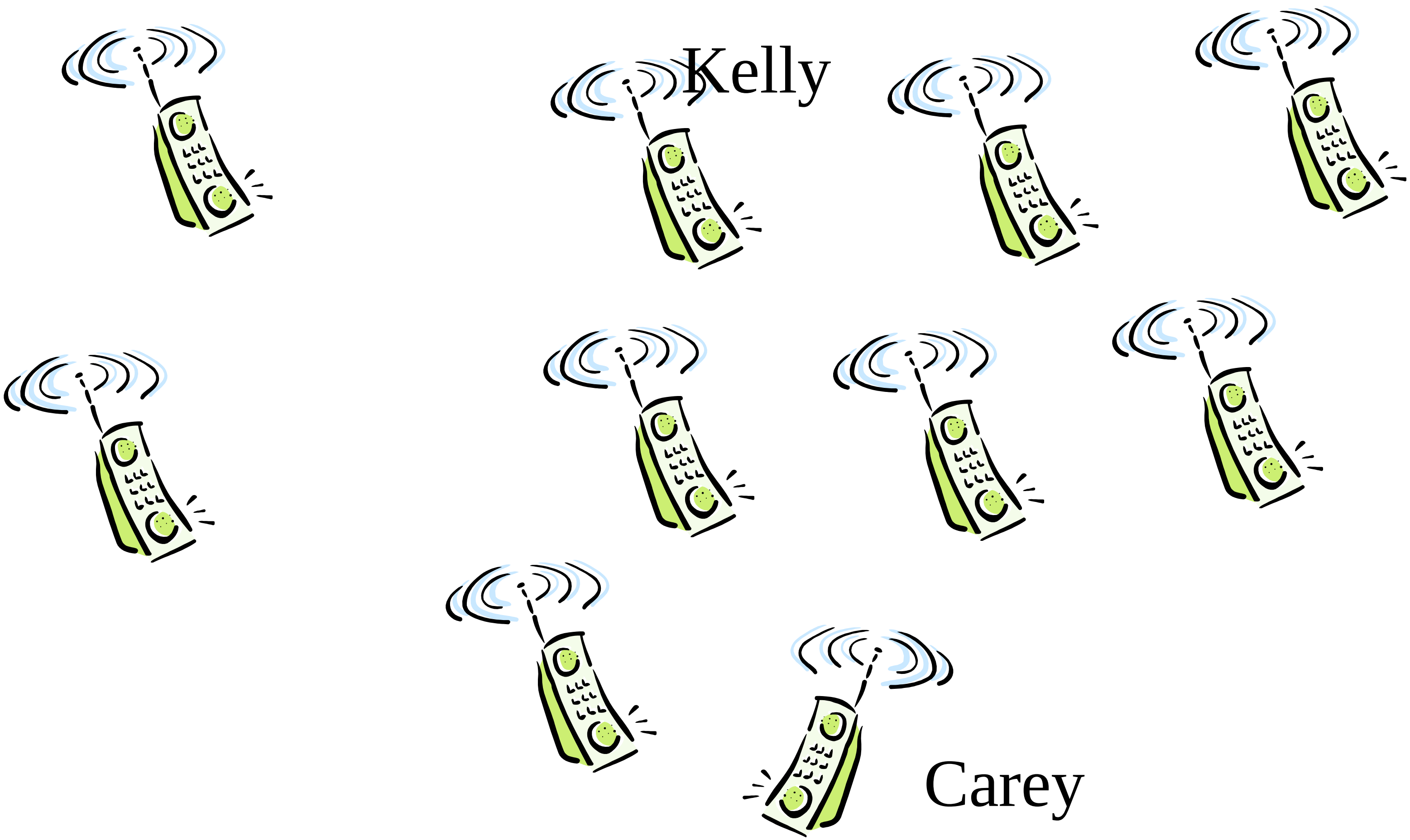
# Example #2

- Wireless TCP Fairness Problems



# Example #3

- Multi-hop “ad hoc” networking



# Example #3 (Cont'd)

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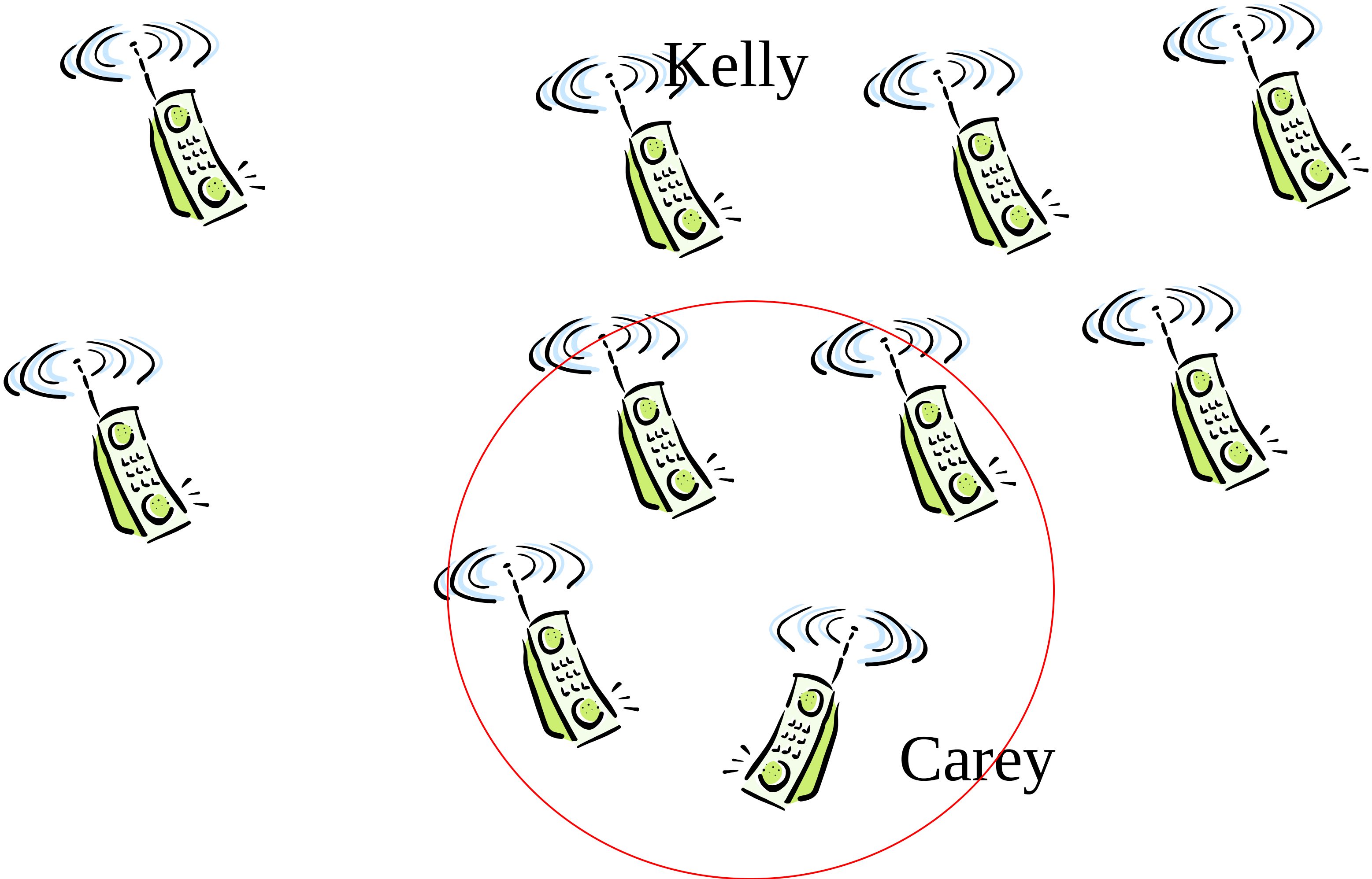

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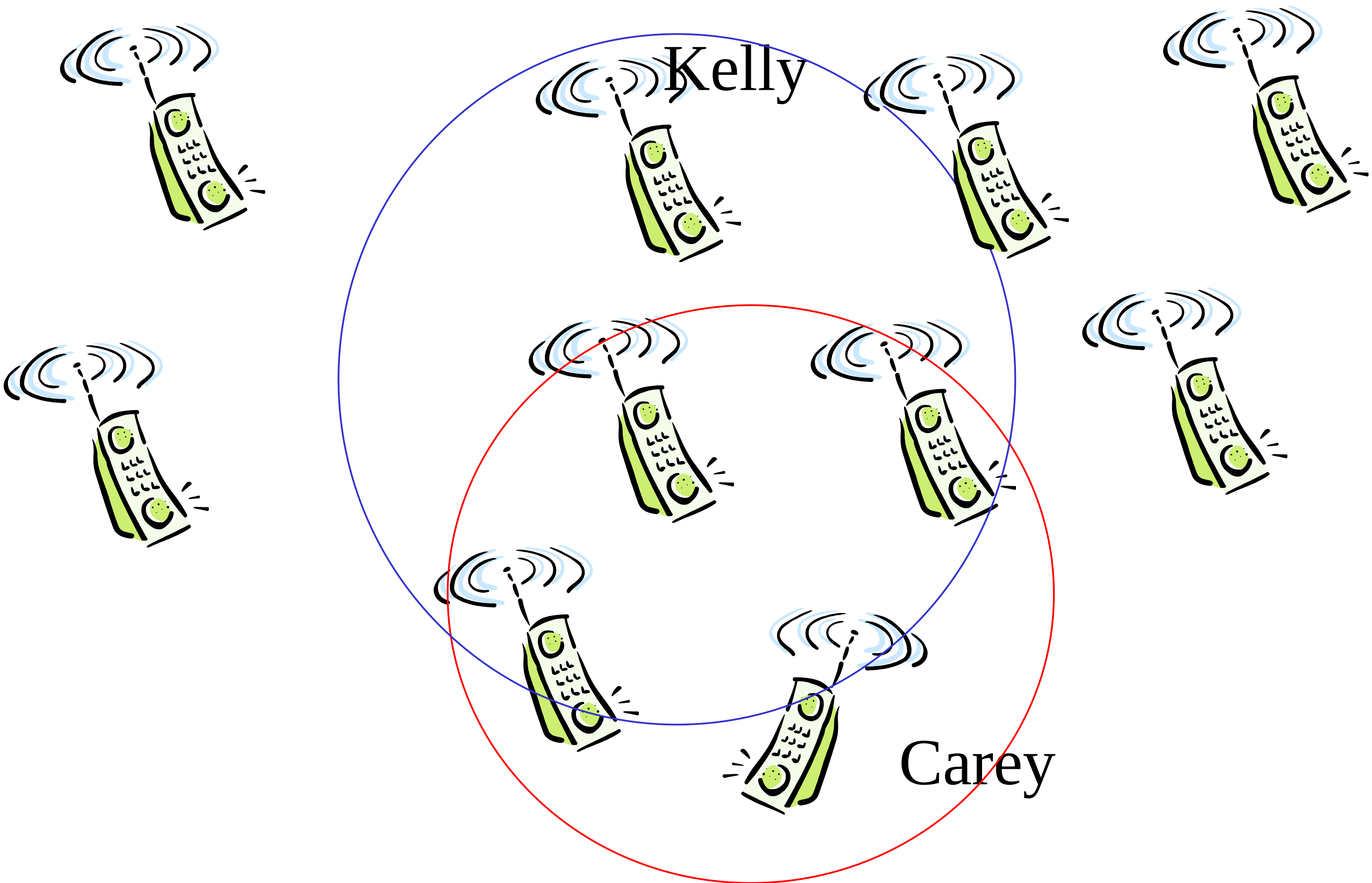

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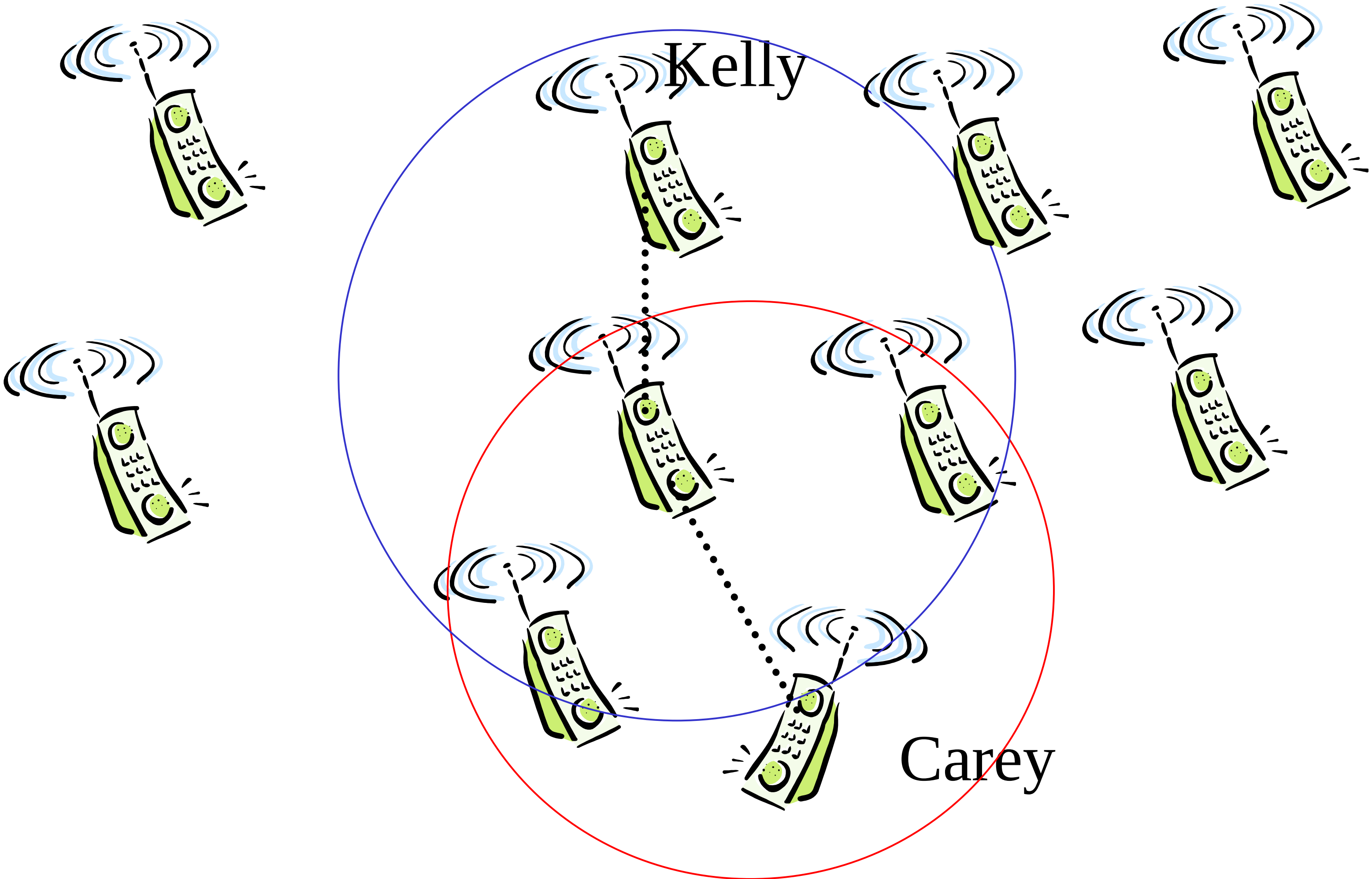

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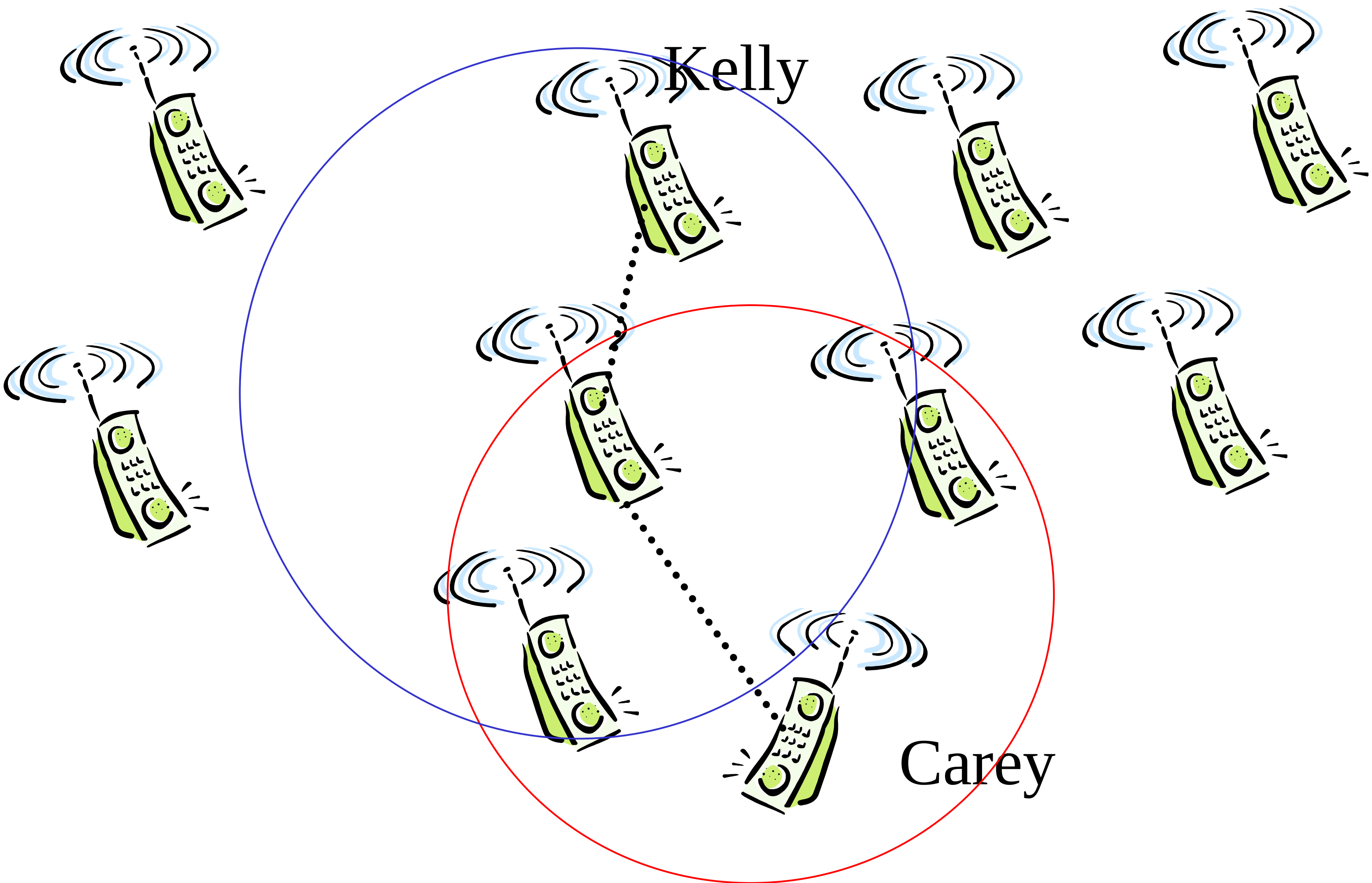

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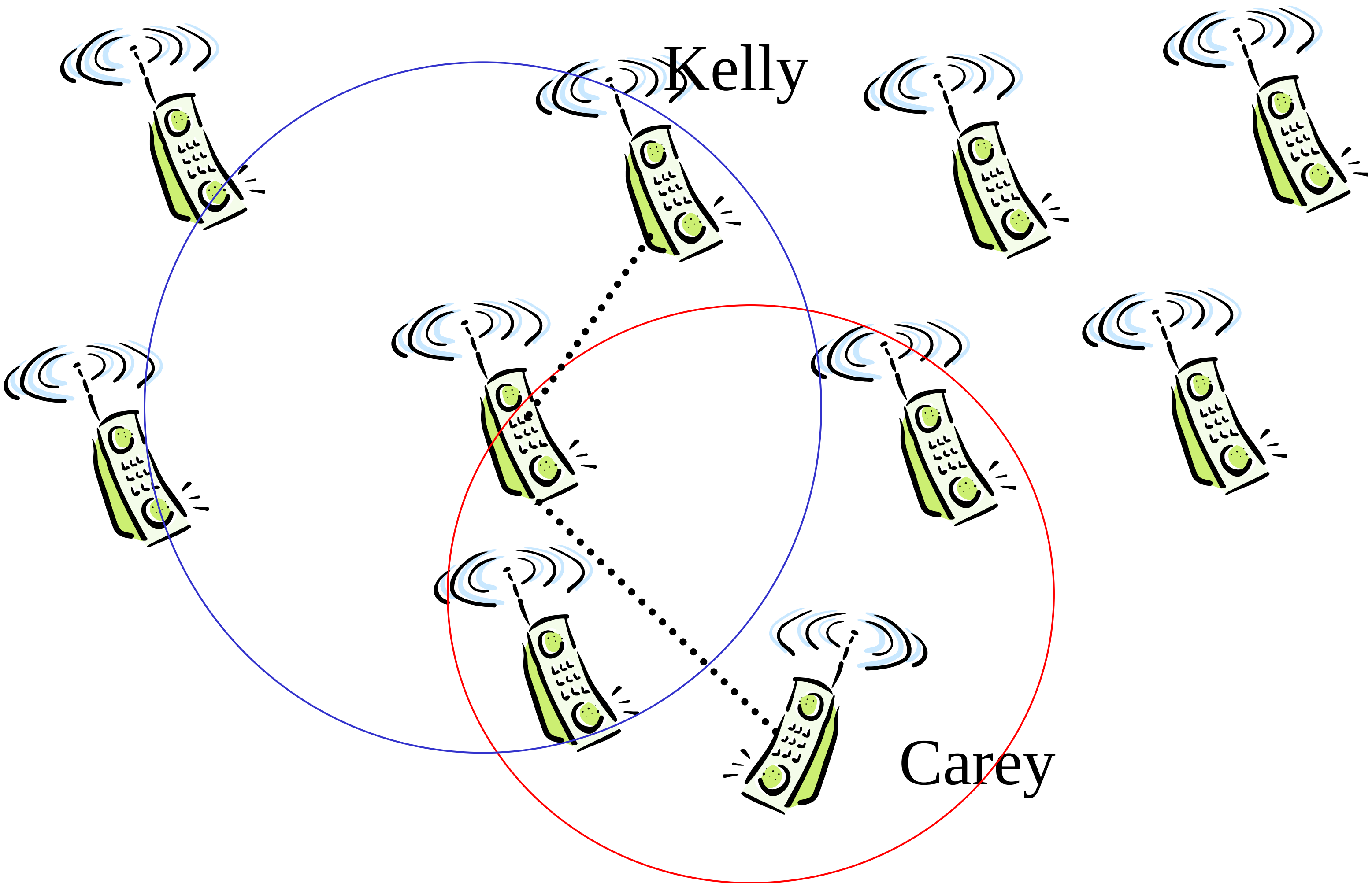

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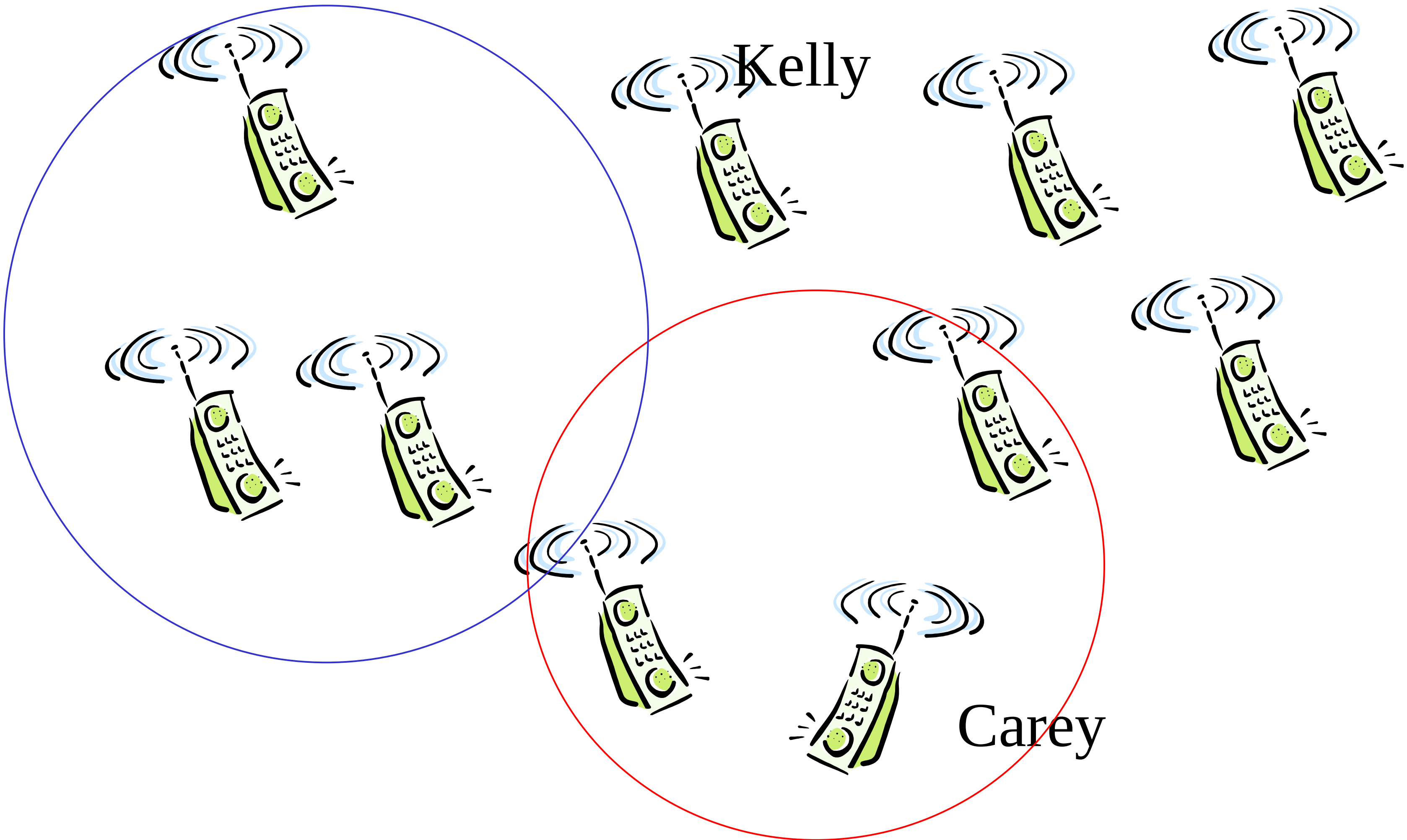
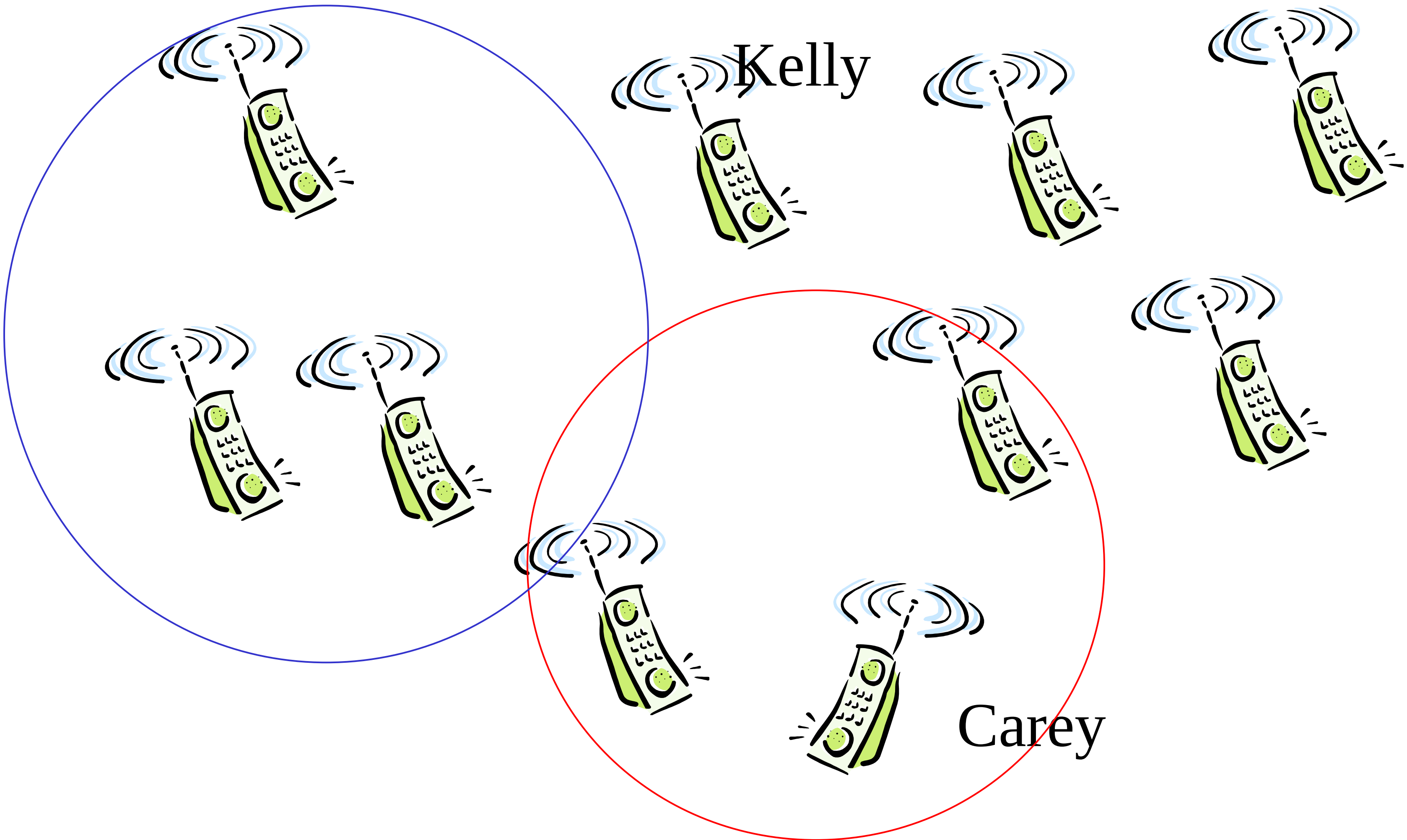


# Example #3 (Cont'd)

- Multi-hop "ad hoc" networking (e.g., TCP-F, TCP-ELFN, etc.)



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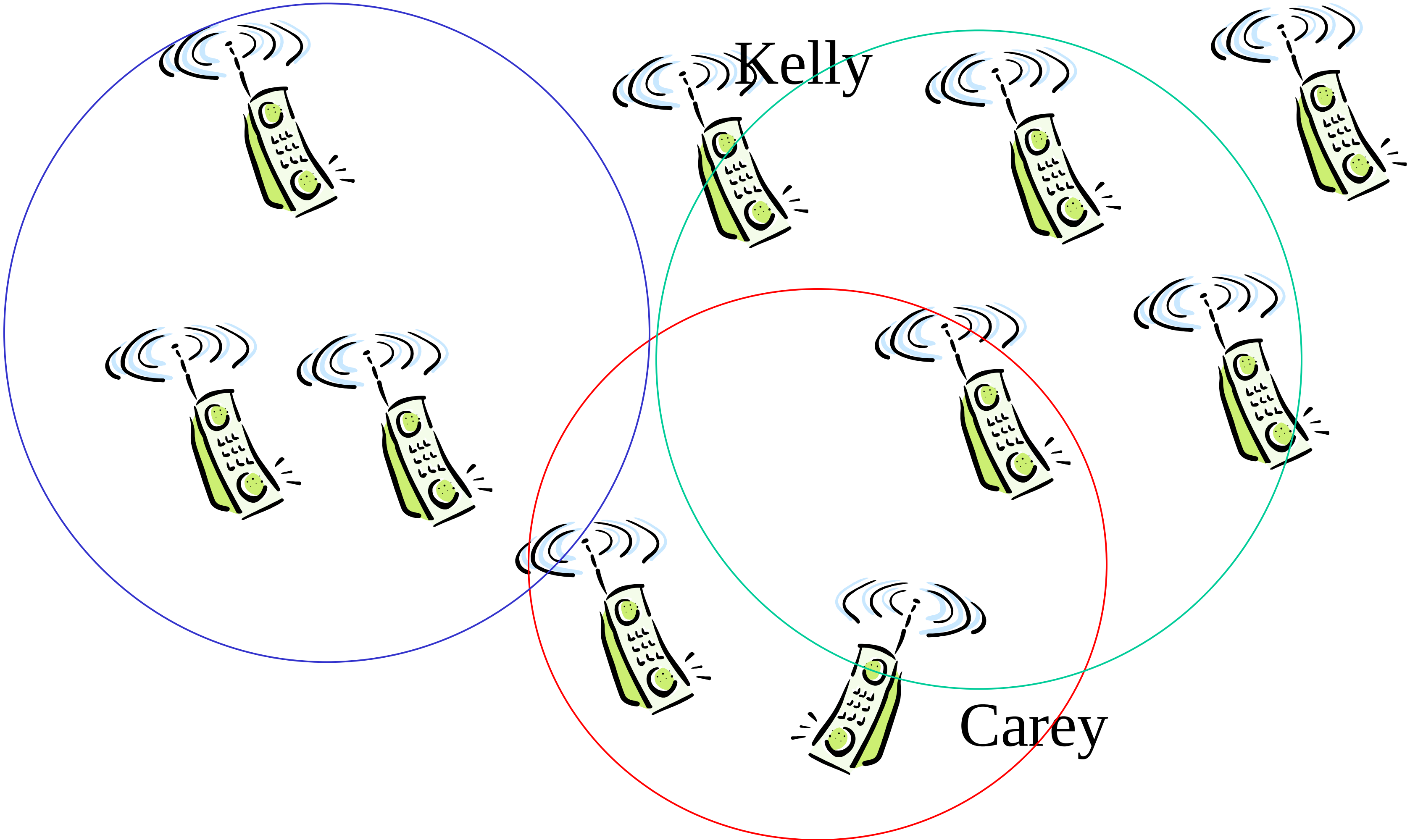

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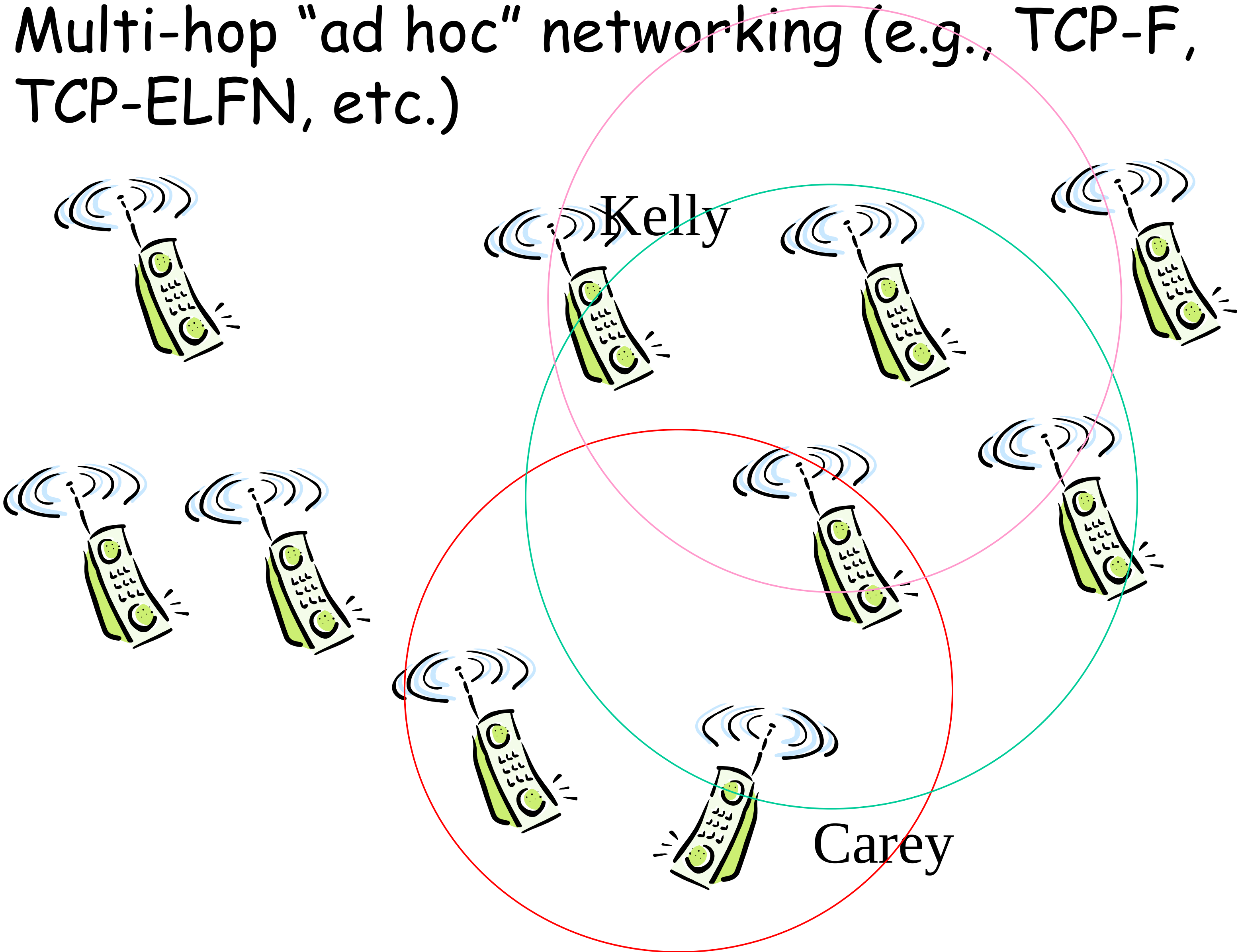

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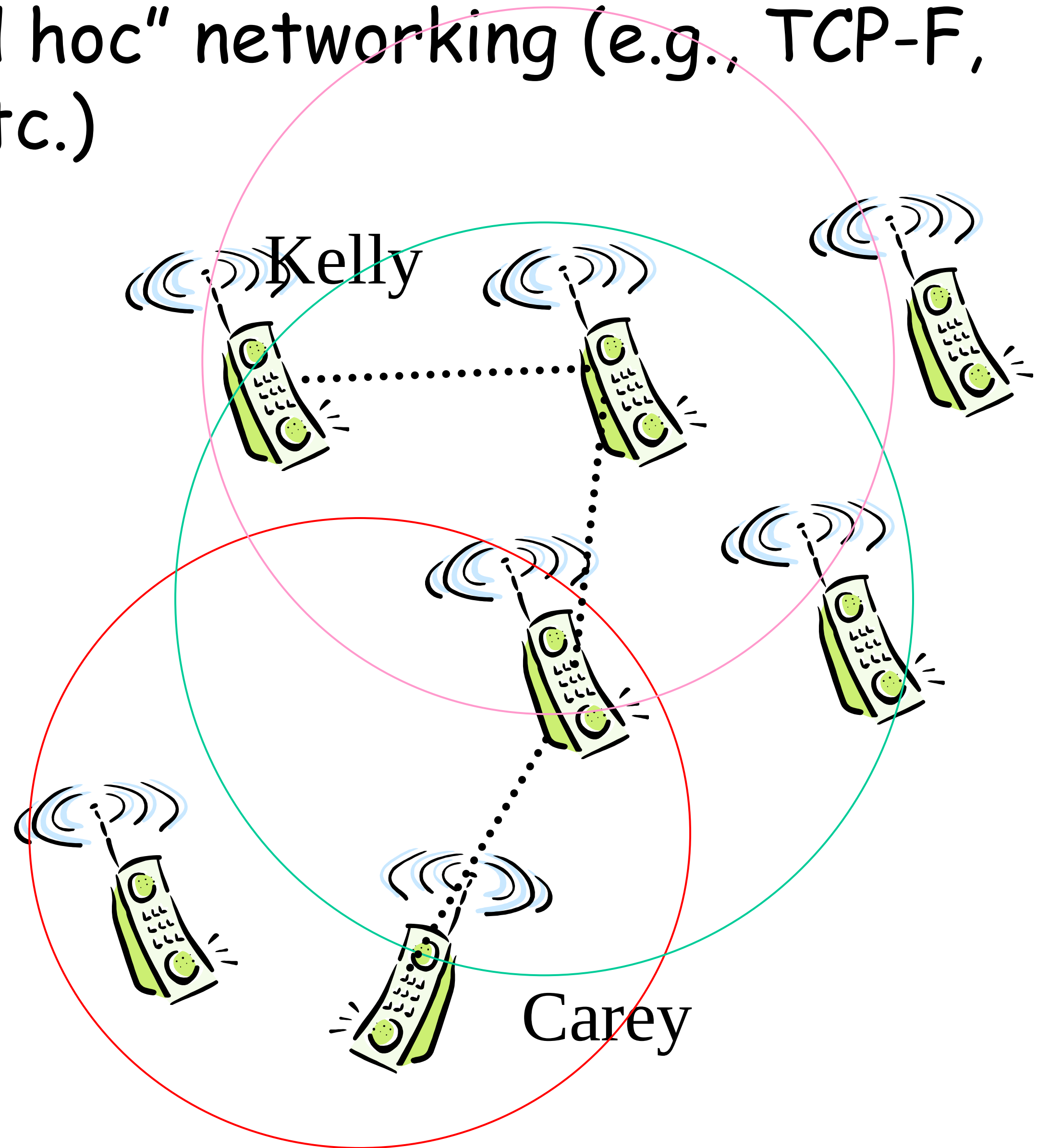

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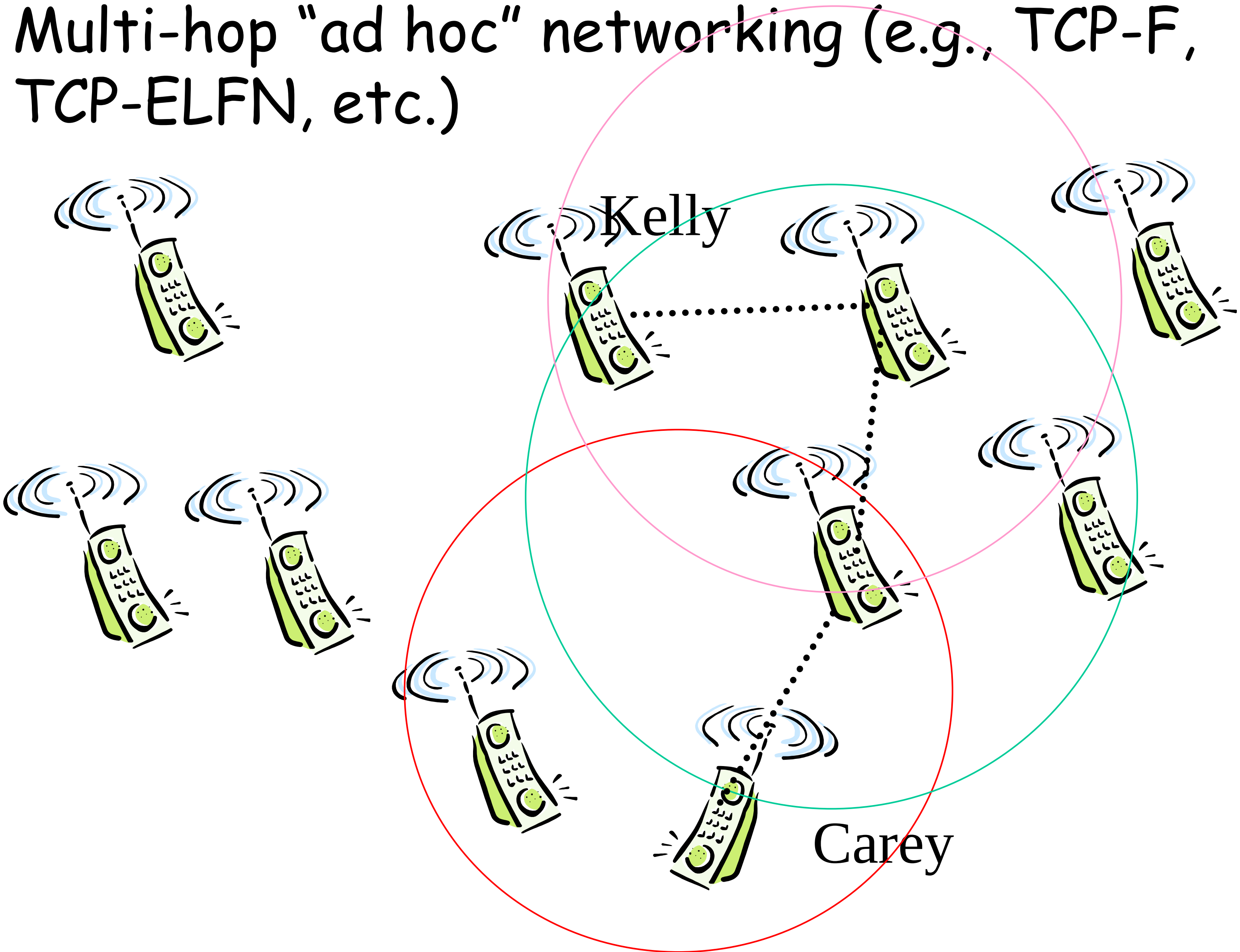

# Summary of Wireless TCP

- TCP is the “four-wheel drive” of TP
- “TCP” and “Wireless” don’t fit together all that well
- Making TCP smarter about wireless helps!

# More slides

# TCP performance issues in Ad-hoc networks

- Misinterpretation of packet loss
  - E.g., packet loss/delay due to bit-errors (discarded packets, delays for link-layer retransmissions), and handoff
- Frequent path breaks
- Network partitioning and remerging
- Path length effects
- Misinterpretation of congestion window
- Asymmetric link behavior
- Uni-directional paths
- Multi-path routing
- The use of sliding window

# More interesting problems …

- Two interesting subproblems:
  - Dynamic ad hoc routing: node movement can disrupt the IP routing path at any time, disrupting TCP connection; yet another way to lose packets!!!; possible solution: Explicit Loss Notification (ELN)? Handoff? Route prediction?
  - TCP flow control: the bursty nature of TCP packet transmissions can create contention for the shared wireless channel among forwarding nodes; collisions between DATA and ACKs possible solution: rate-based flow control? Burst mode? Spatial reuse of channels?