Measuring Packet Reordering

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Motivation

- Why is reordering important?
  - **Performance** (TCP fast retransmit)
  - Race conditions (bad protocols)
- What is hard about measuring it?
  - [Bennett et al 99]: active ICMP probing (ping)
    - Round-trip only; ICMP filtering/rate limiting bias
  - [Paxson 99]: pair-wise TCP endpoint analysis
    - Scale issues (need software at each endpoint)
  - [Jaiswal et al 02]: passive TCP analysis in net
    - Significant infrastructure requirement

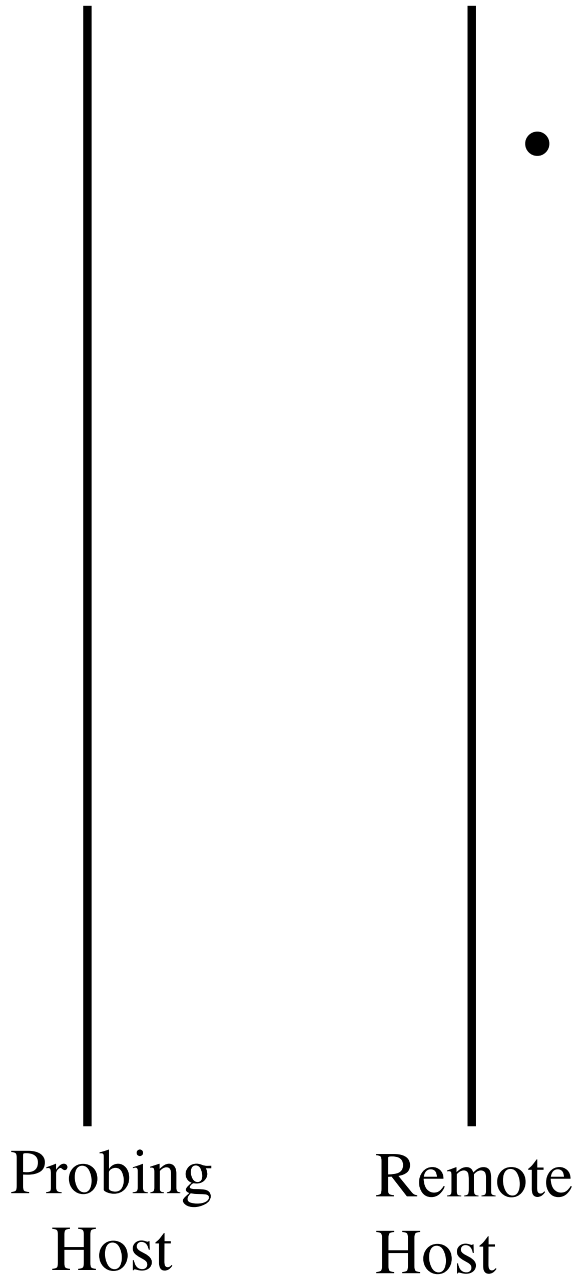
Our contributions

- Unidirectional measurement techniques
  - Active approach
    - Send packet pairs and check for reordering
  - Code runs only at sender
    - Leverage TCP/IP protocol/implementation features
    - Infer if reordering is outbound or on return path
- Implementation of same
- Early experiences

First attempt: Single Connection Test

- Leverage TCP's *error control* mechanisms
  – Every packet is labeled w/sequence number
  – Latest in-order sequence number acknowledged
  – Idea: Craft packets so ACKs reveal reordering
- Assumption
  – *ACK parity*: ACK generated for each packet

Single Connection Test



- Fully establish a TCP session
  - Sequence space starts at 1

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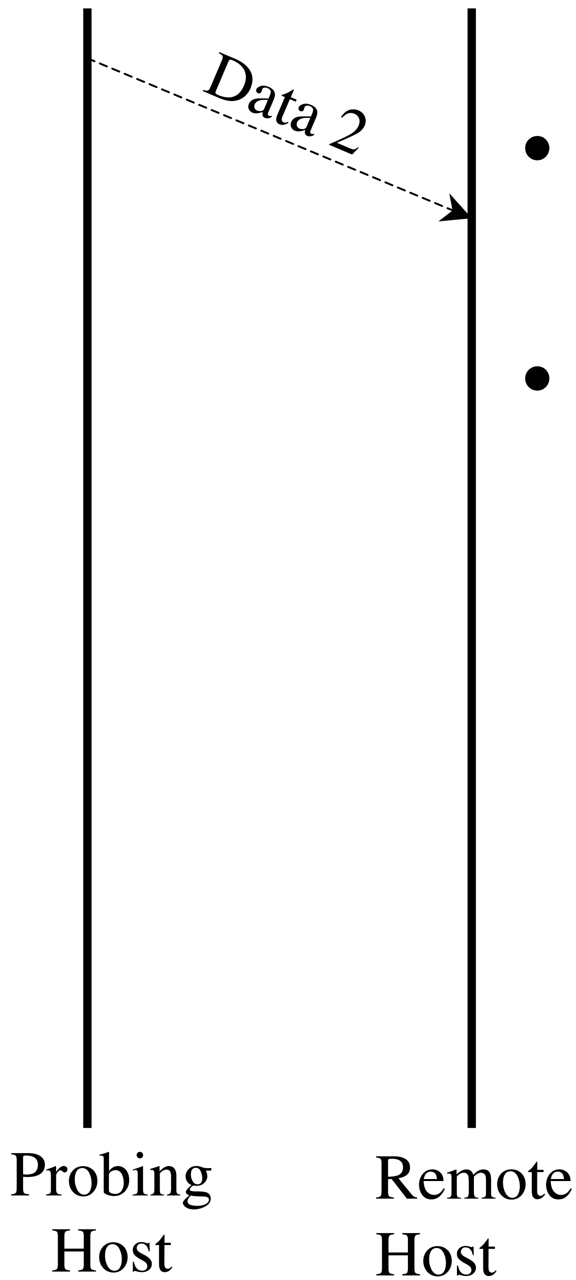

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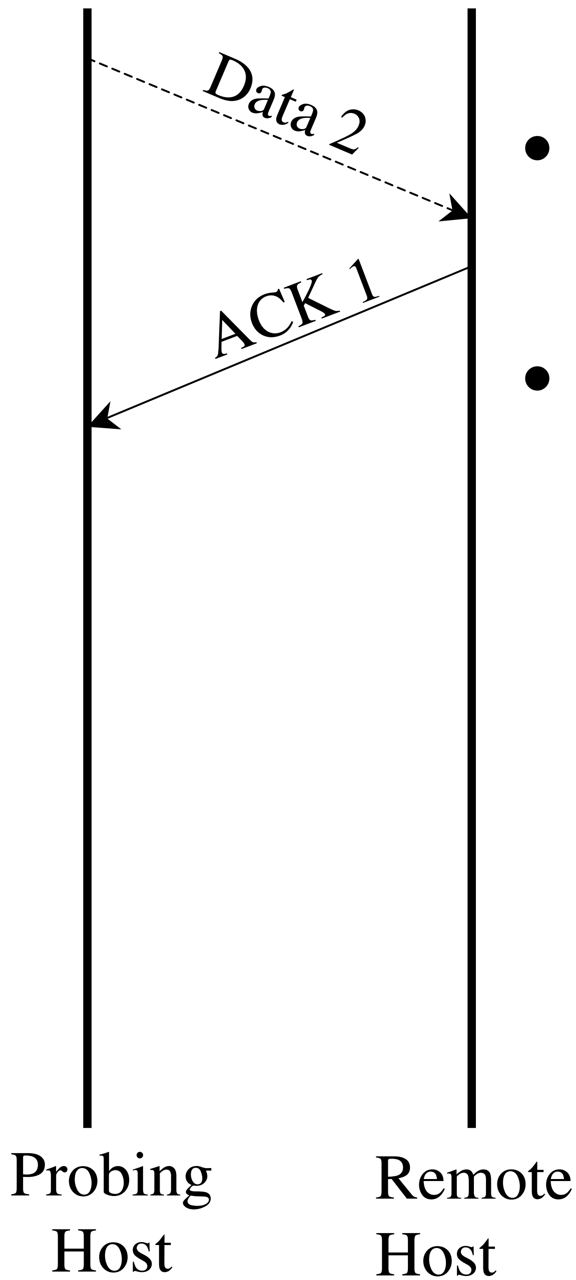

- Fully establish a TCP session
  - Sequence space starts at 1
- Create a gap in sequence space
  - Wait for remote host to ACK the gap

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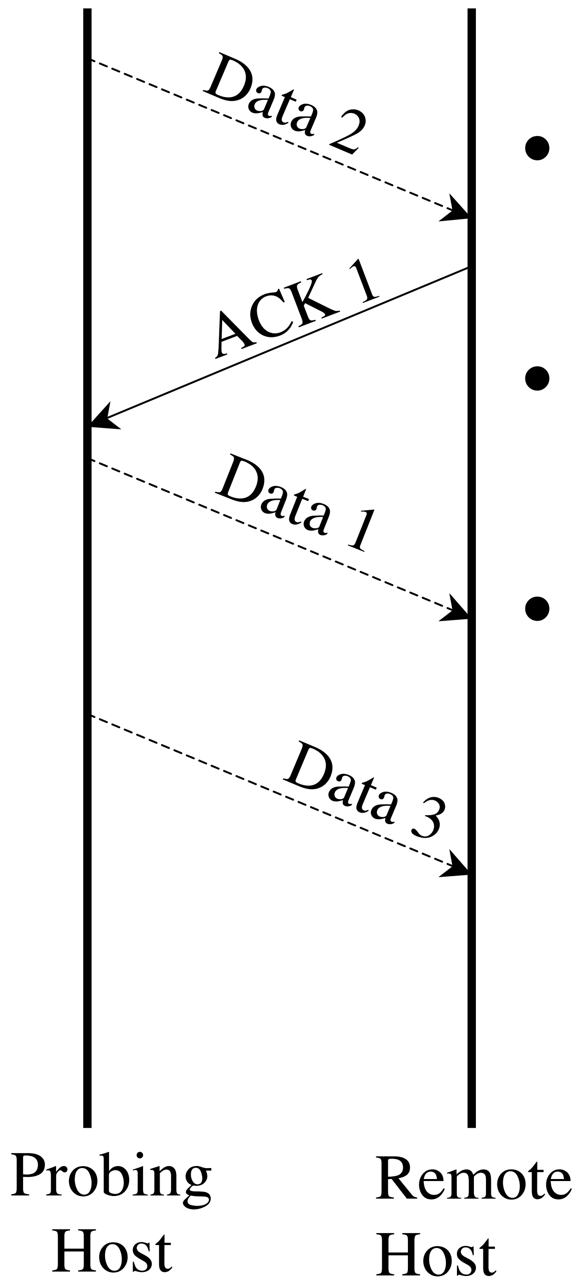

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- Send two sample packets that straddle the previous packet

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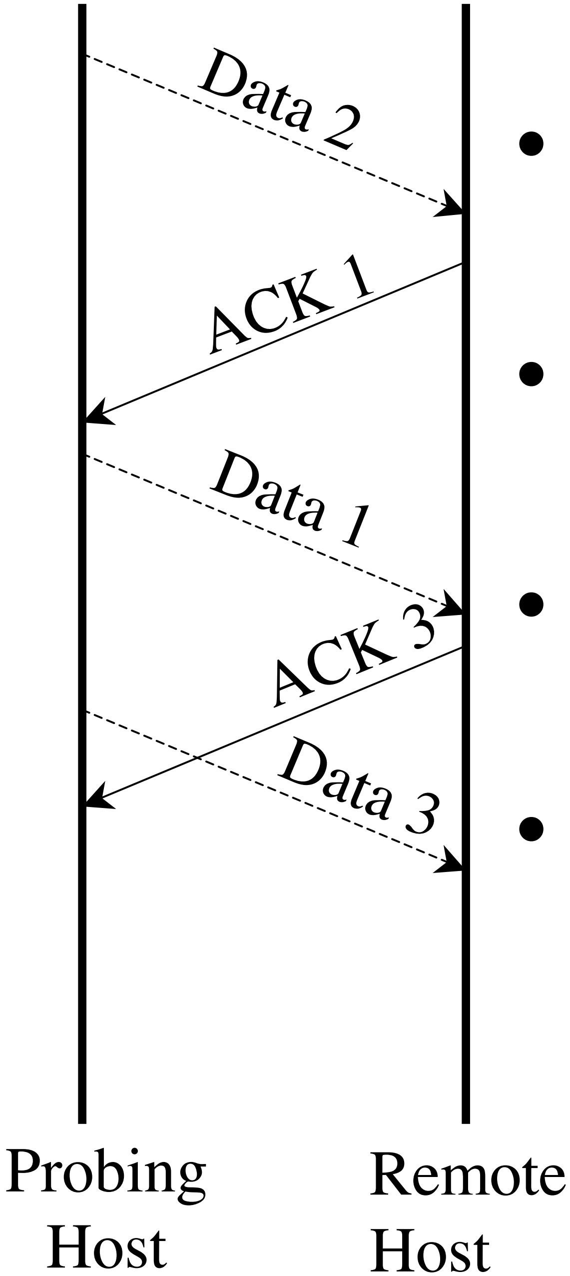

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  - Sequence space starts at 1
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- Send two sample packets that straddle the previous packet
- If there is no reordering
  - First ACK should be for the gap

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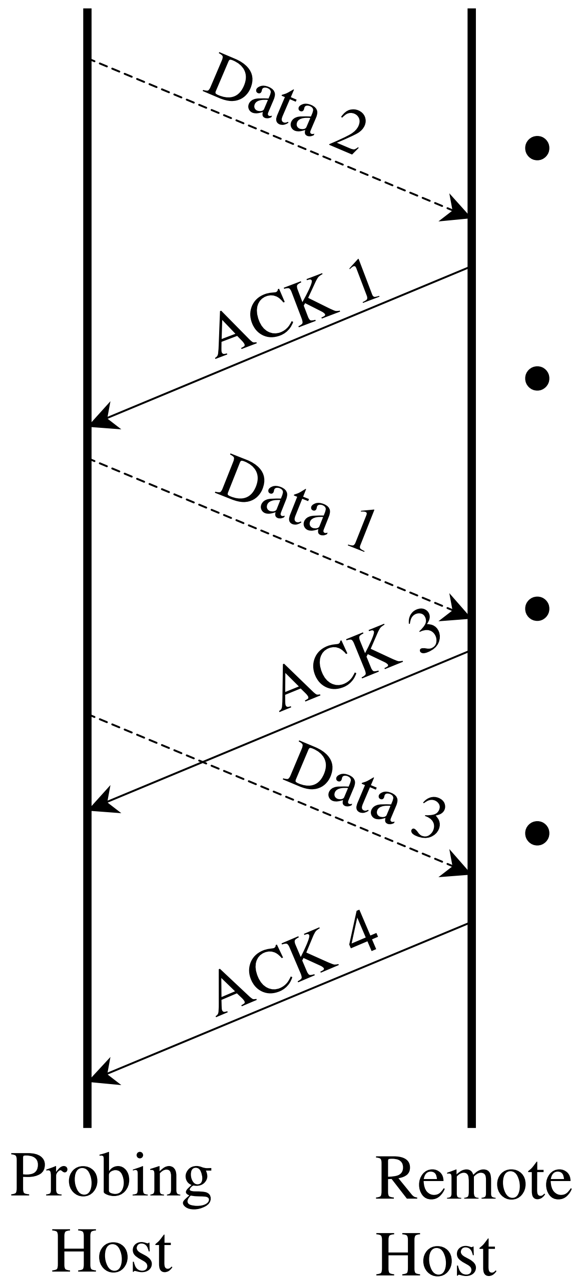

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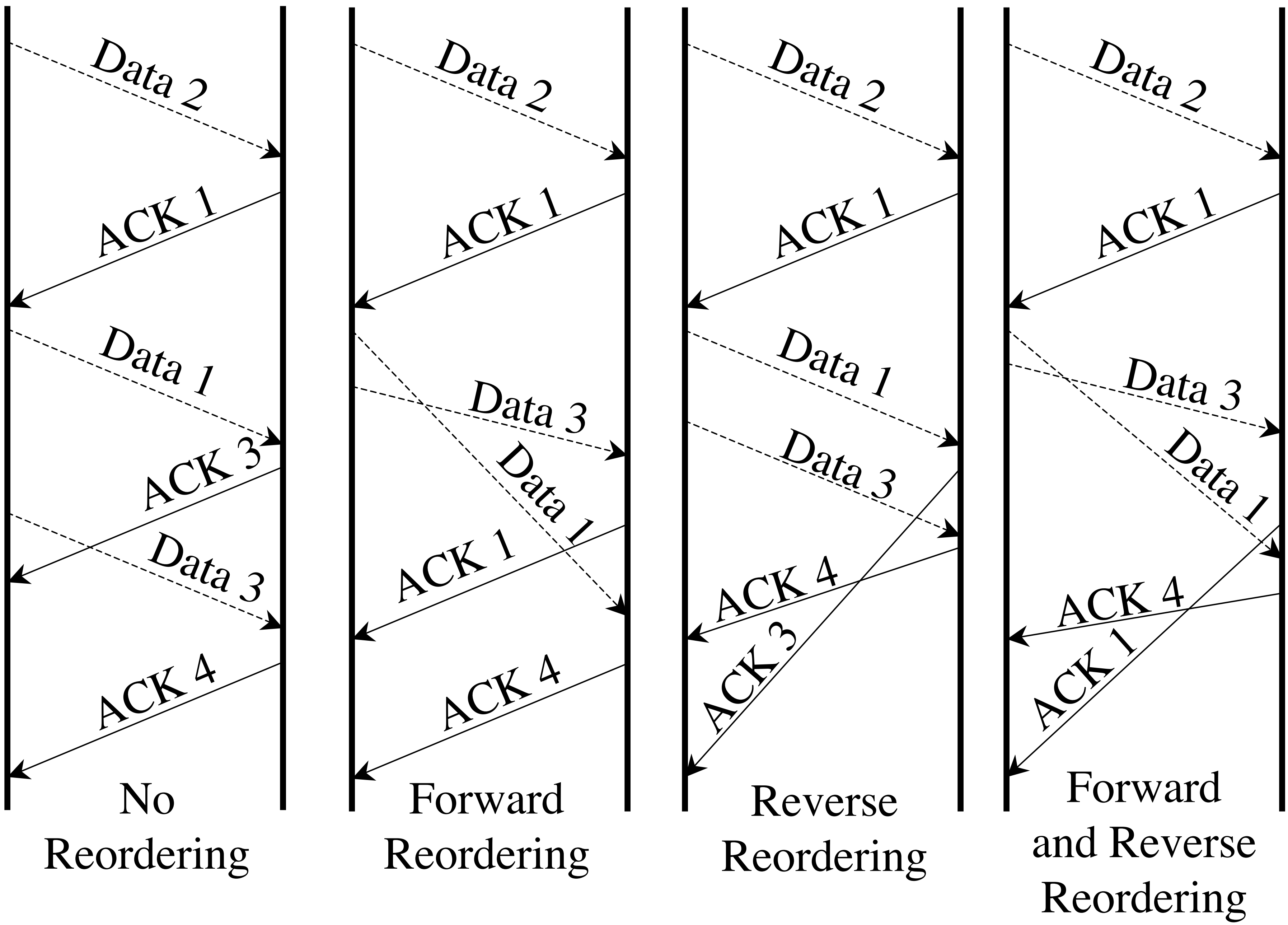
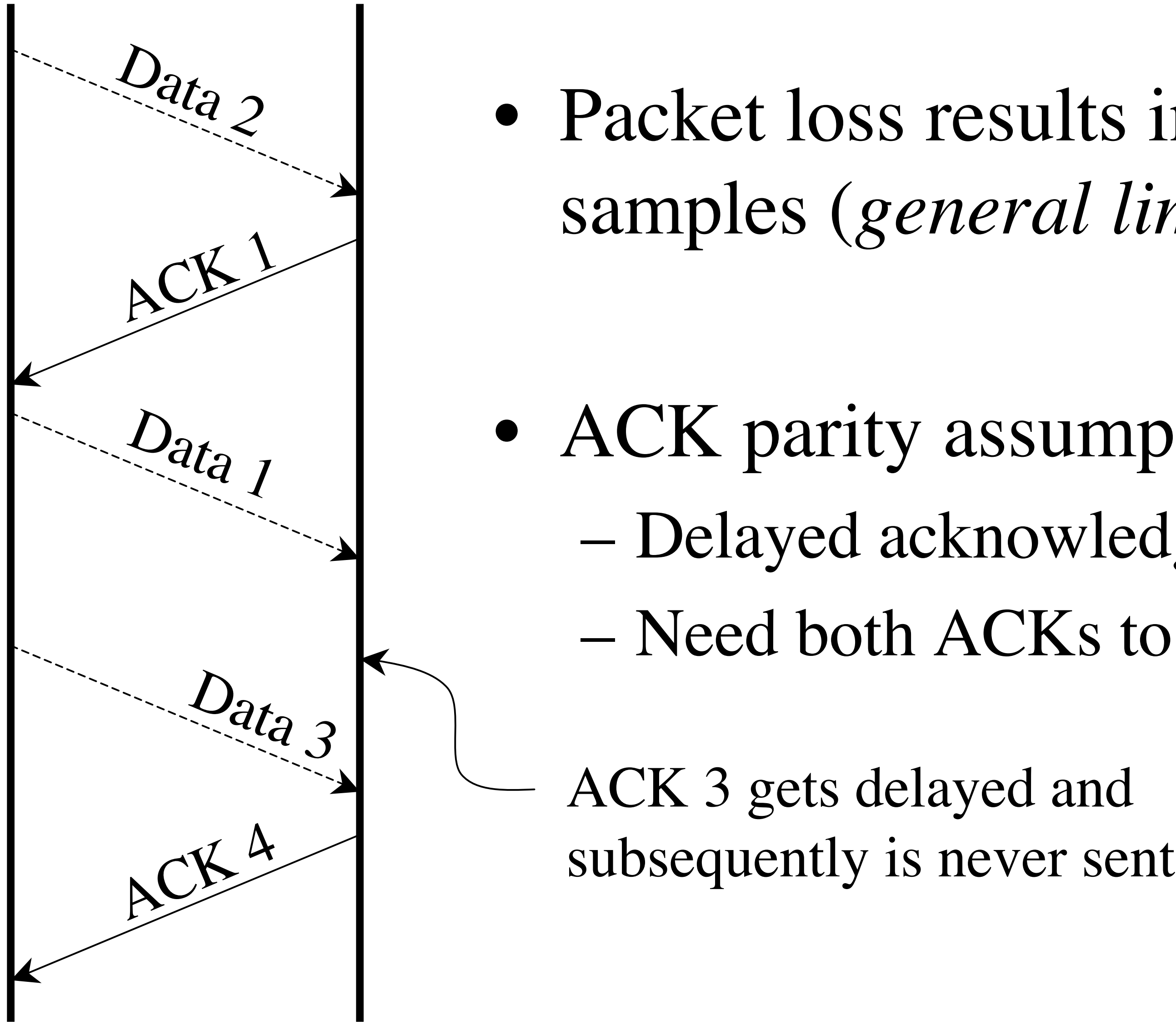
  - Sequence space starts at 1
- Create a gap in sequence space
  - Wait for remote host to ACK the gap
- Send two sample packets that straddle the previous packet
- If there is no reordering
  - First ACK should be for the gap
  - Second ACK is for the whole sequence

Single Connection Test



Single Connection Test Pitfalls

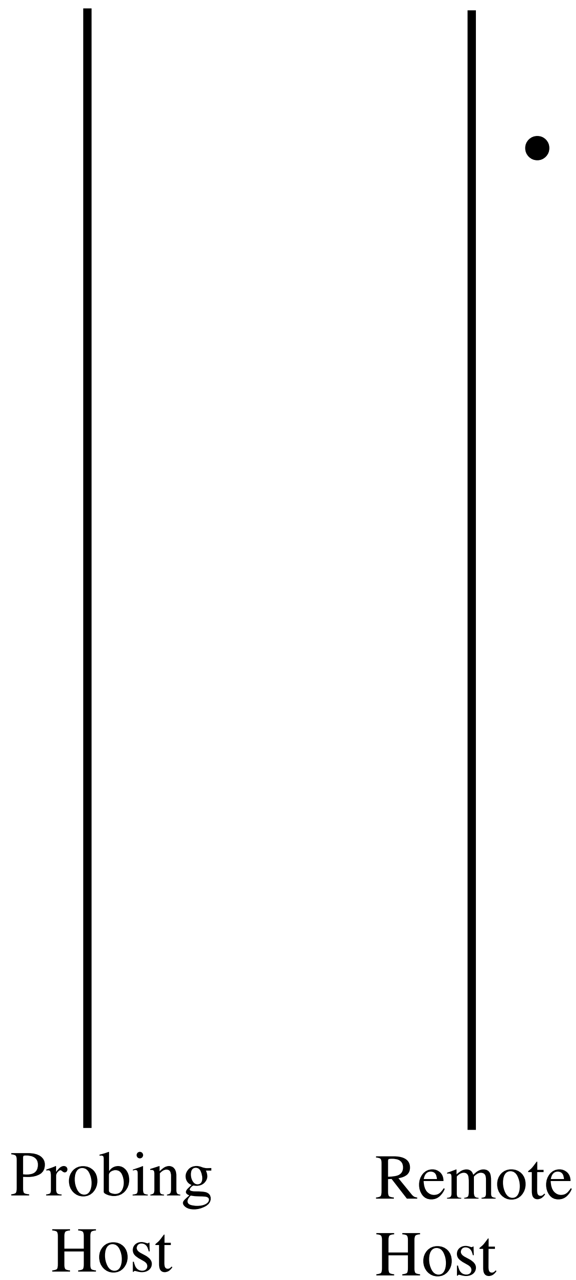


- Packet loss results in unusable samples (*general limitation*)
- ACK parity assumption fails
  - Delayed acknowledgements
  - Need both ACKs to reveal order

Dual Connection Test

- Need two samples to be reliable returned
  - Send **all** packets out of order (ACK not delayed)
  - ACK value useless, so infer order from other fields
    - Use two connections to differentiate samples
    - IPID – "unique" identifier for each datagram in a flow
- New assumptions
  - IPID is strictly increasing per host
    - Dominant implementations do this
  - Both connections are made to the same machine

Dual Connection Test



- Fully establish two TCP sessions (red and black)

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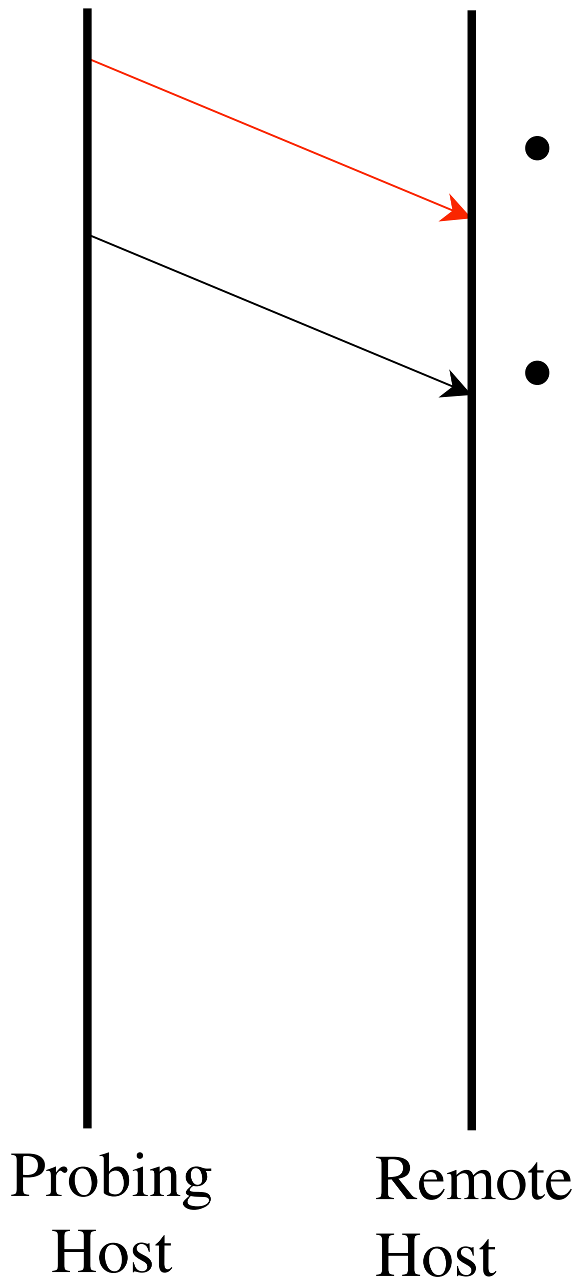
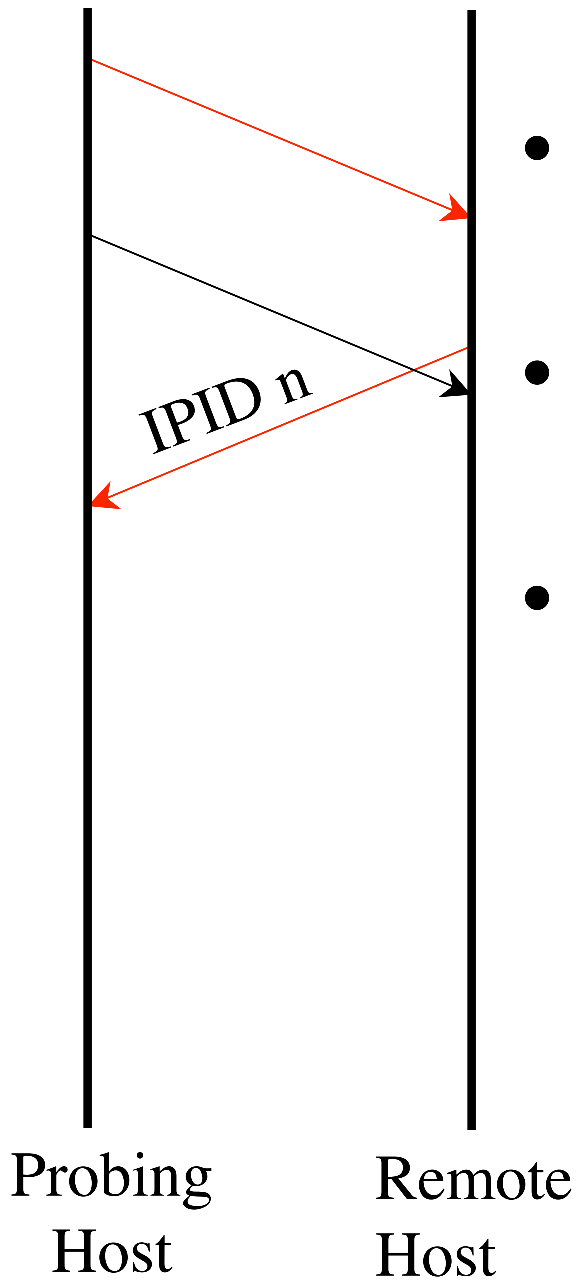


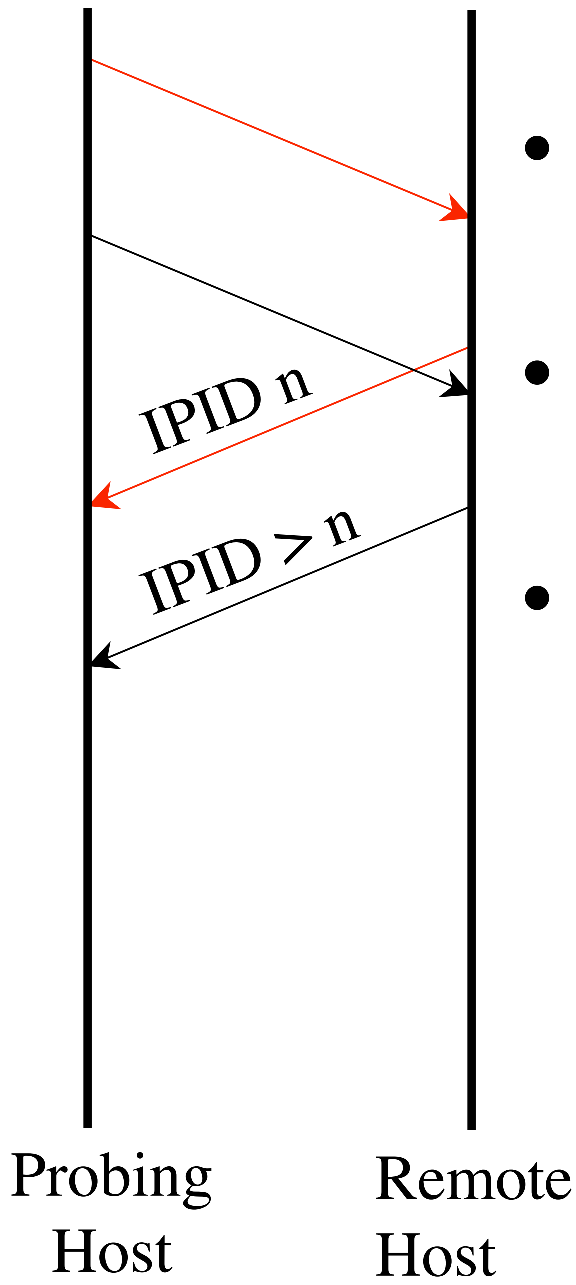
- Fully establish two TCP sessions (red and black)
- Send two sample packets: one in each connection

Dual Connection Test



- Fully establish two TCP sessions (red and black)
- Send two sample packets: one in each connection
- If no reordering
  - IPID of first response packet…

Dual Connection Test



- Fully establish two TCP sessions (red and black)
- Send two sample packets: one in each connection
- If no reordering
  - IPID of first response packet, is strictly less than IPID of response packet

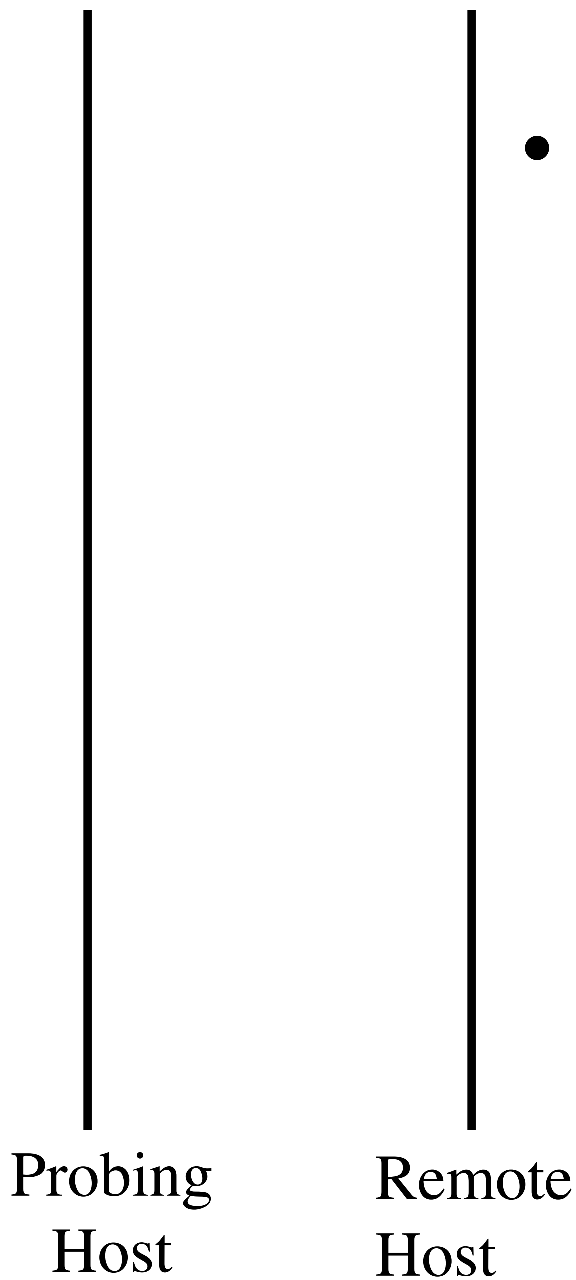
Dual Connection Test Pitfalls

- Connection assumption violations
  - **Load balancer** can direct two connections to different hosts
- IPID assumption violations
  - Random IPID values (e.g., OpenBSD)
  - Zero IPID after MTU discovery (e.g., Linux)

SYN Test

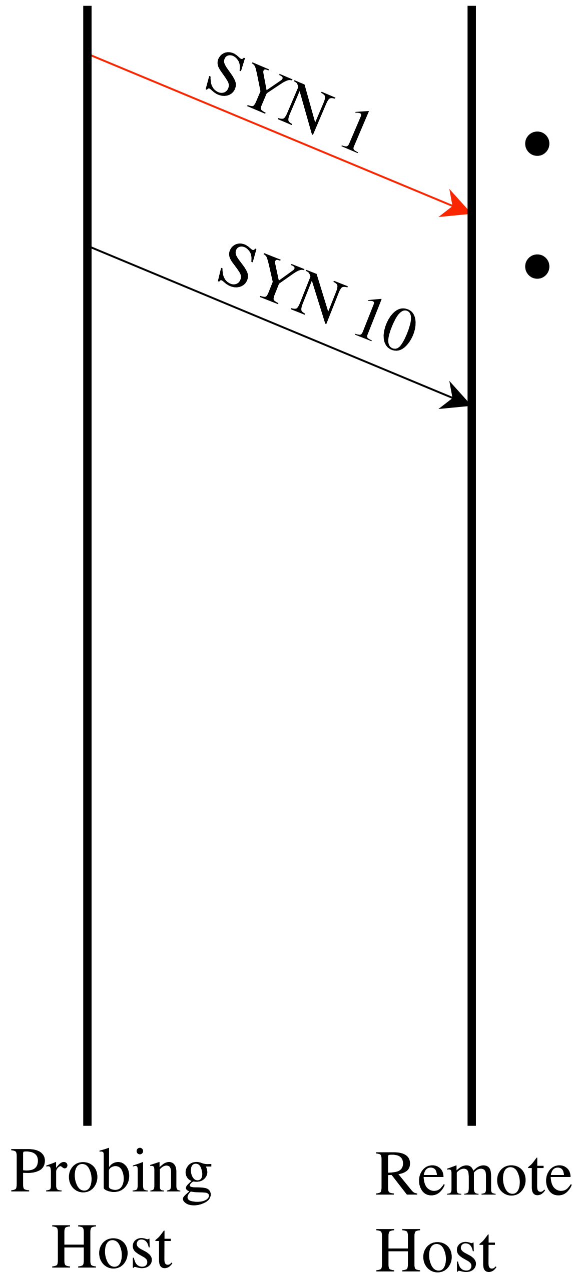
- Trick load balancers by starting "identical" connections
  - Appear to belong to same flow (but different seq #'s)
- Use TCP connection state machine to infer order
  - No assumptions about IPID
- Assumptions
  - Duplicate SYN's with different seq cause ACK or RST packets

SYN Test



- Uses no pre-established sessions

SYN Test



- Uses no pre-established sessions
- Send two SYN packets to remote host
  - Different starting sequence number
  - Other than that, identical

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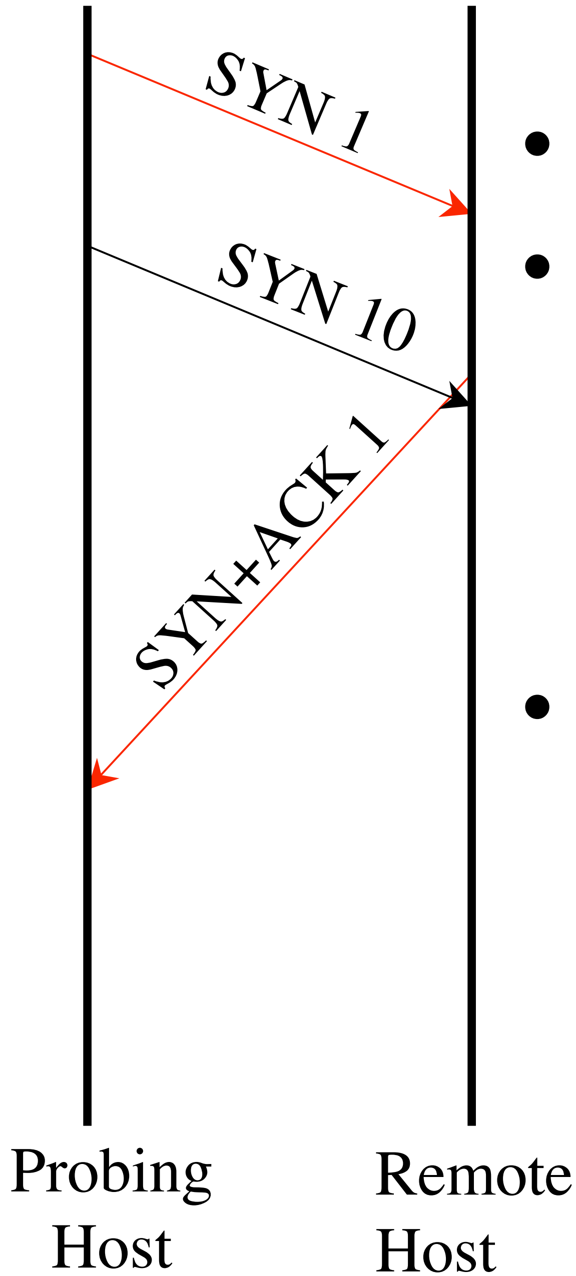

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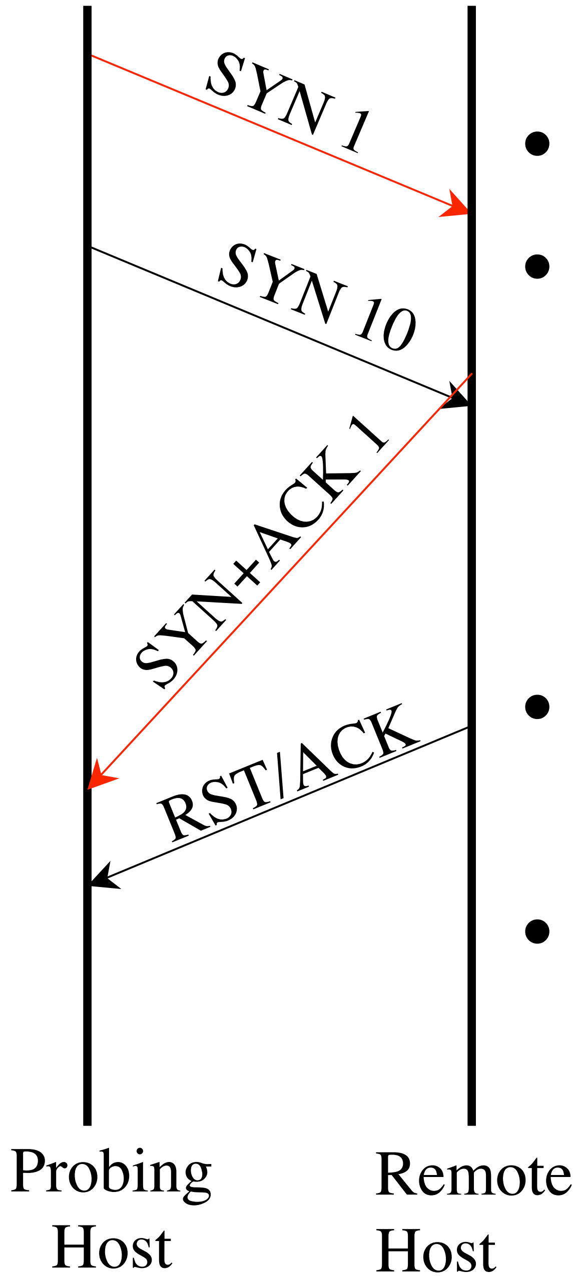


- Uses no pre-established sessions
- Send two SYN packets to remote host
  - Different starting sequence number
  - Other than that, identical
- First received packet will generate a SYN+ACK
- Other packet causes a RST or ACK

SYN Test Pitfalls

- SYN behavior assumption violations
  - Poorly understood/implemented part of spec.
  - Some TCP stacks send SYN+ACK or nothing in response to a bad duplicate SYN
- A series of SYN-based probes may be interpreted as a DoS attack
  - Implementation is good about cleaning up state

Implementation

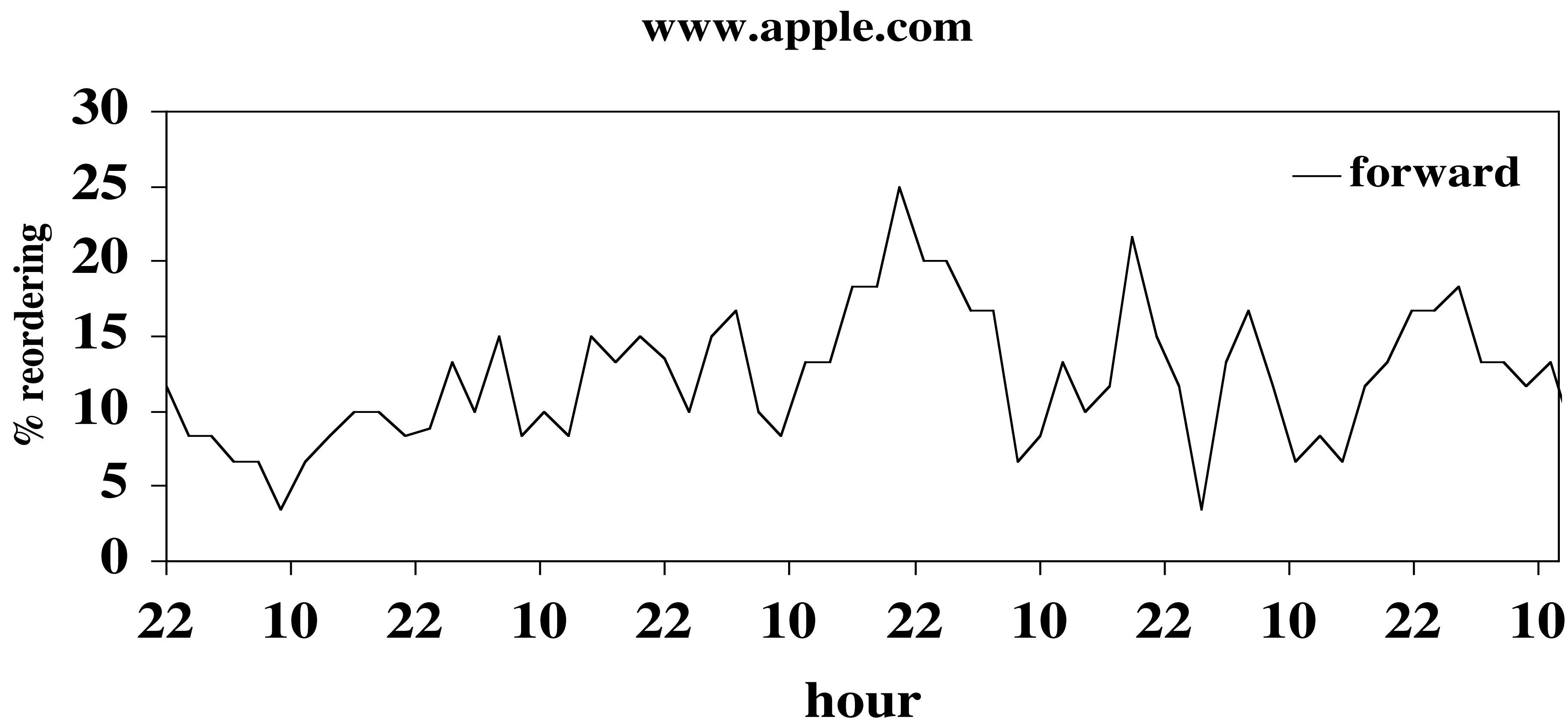
- User-level subset of TCP stack
  - Shared origin w/Sting, TBit, Sprobe and Alpine
  - Raw socket for sending frames
  - Packet filters (via libpcap) to capture response
  - Firewall filters to prevent host OS from seeing response
  - Detect assumption failures
- Runs on stock FreeBSD and Linux

Validation

- Controlled
  - Added reordering to FreeBSD Dummynet
  - Independently varied forward and reverse reordering
  - Match between network trace and reports from tool
- Experimental
  - Probed 50 hosts over 20 days with all tests
  - Each host probed approx. every 30 minutes
  - Probe results similar for hosts across tests (where different tests were compatible)

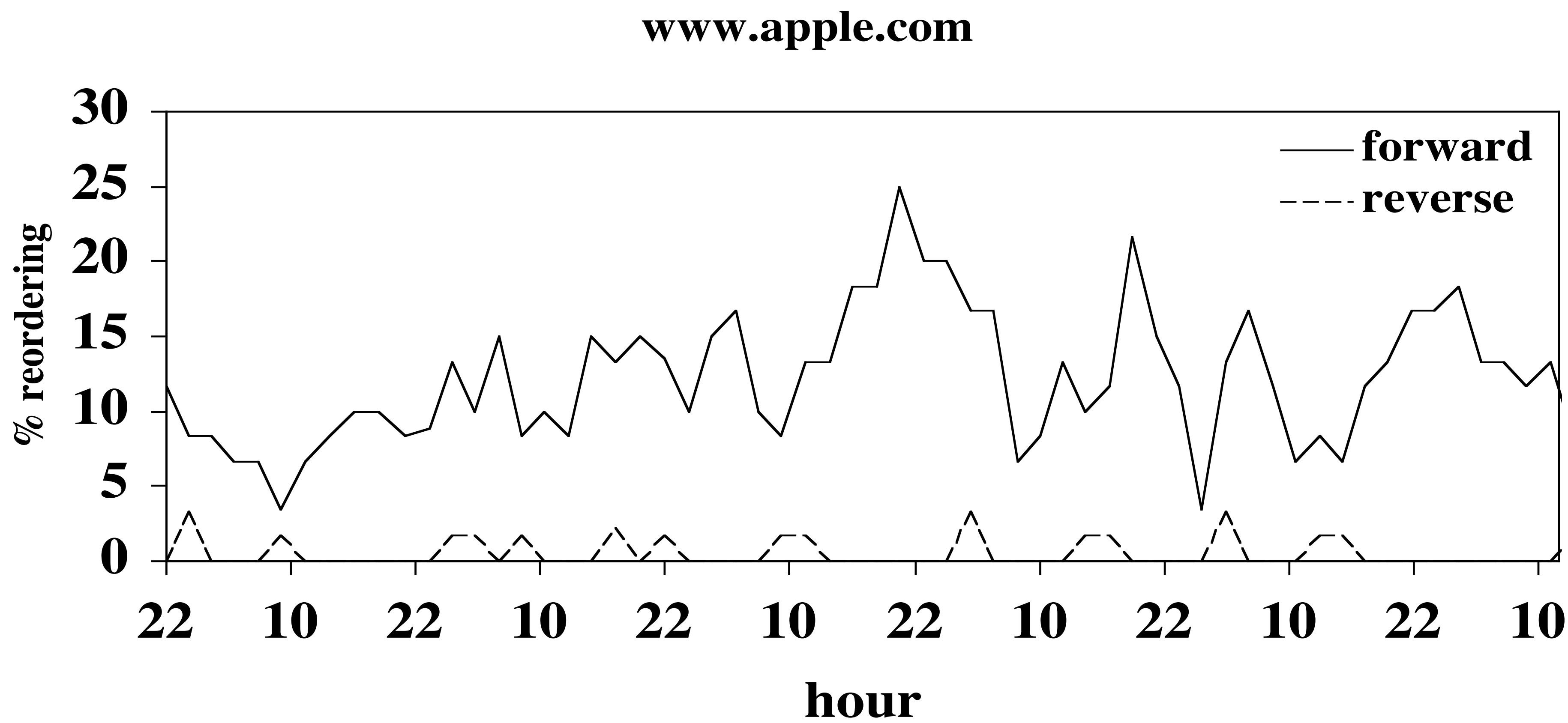
Observations (1)

- Significant reordering seen on some paths



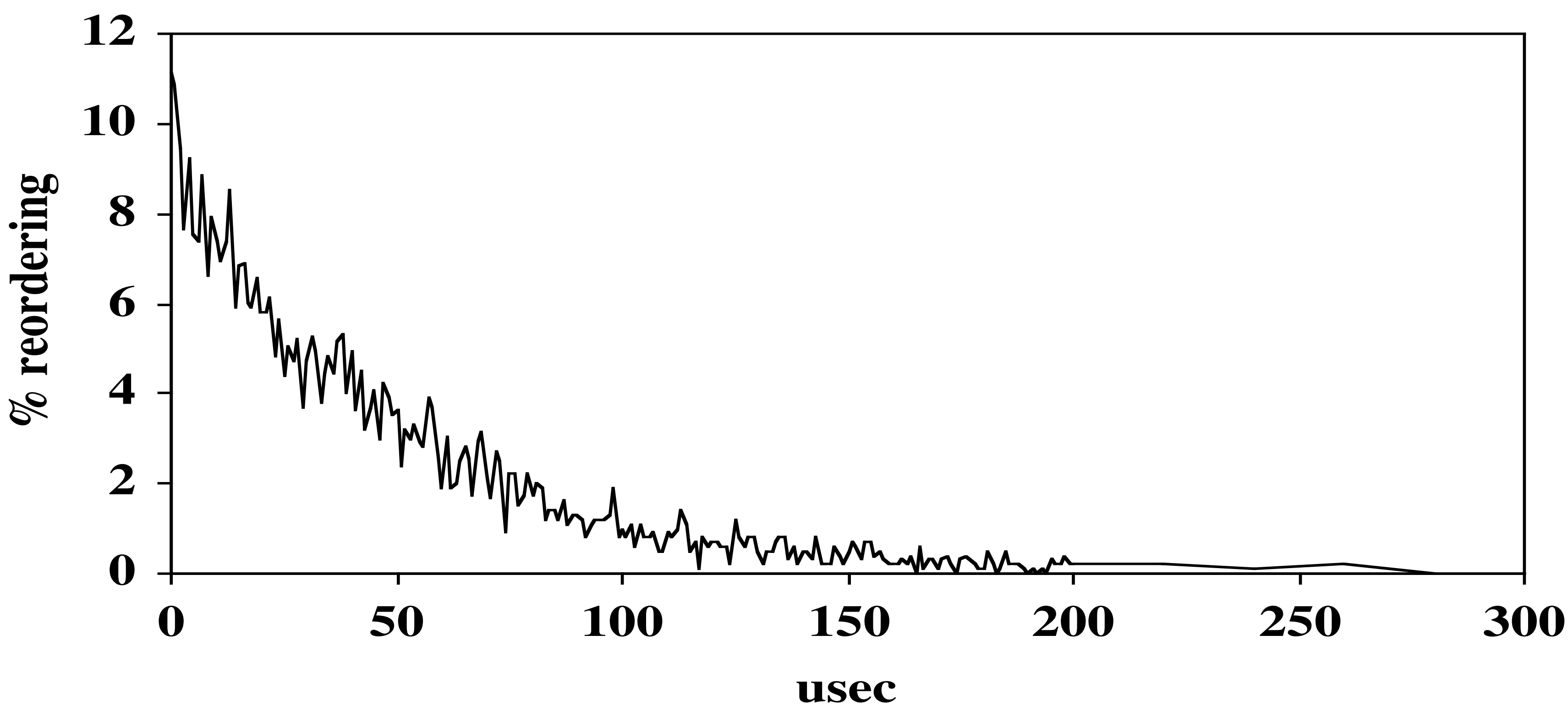
Observations (2)

- Reordering can be highly asymmetric



Observations (3)

- Small changes in packet spacing can have large changes on reordering (on same path)



Conclusion

- We can measure unidirectional reordering from a single endpoint
- This matters
  - Reordering does happen
  - Asymmetry is common on reordered paths
- We still need a precise metric for reordering
  - Results currently not comparable between studies
- Source code will be available shortly at: http://ramp.ucsd.edu/reorder