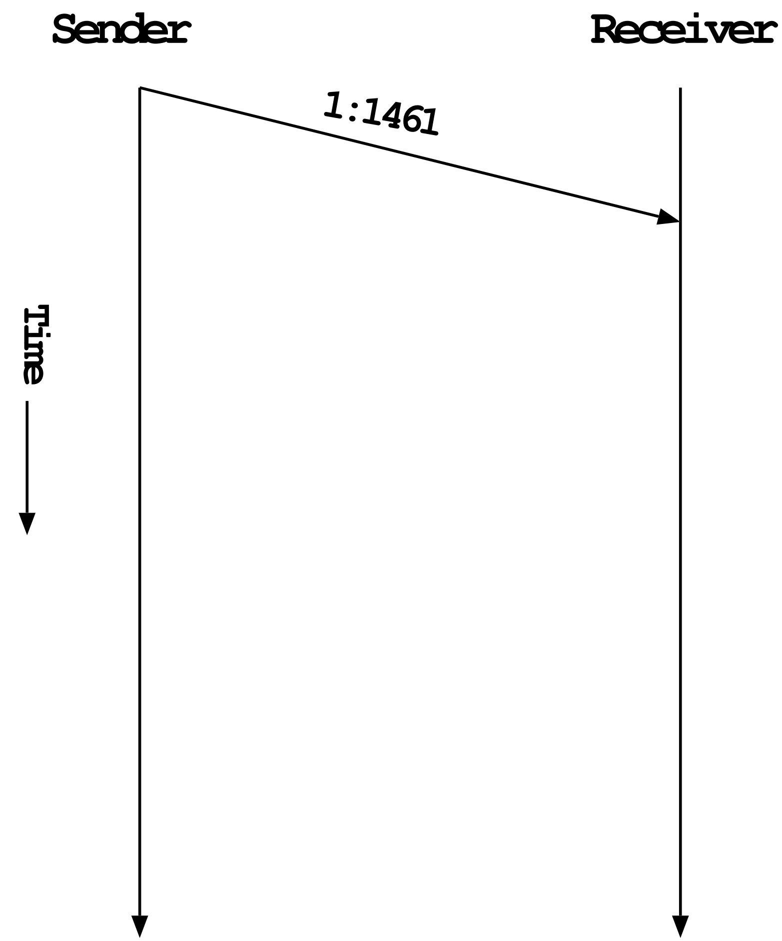
Misbehaving TCP Receivers Can Cause Internet-Wide Congestion Collapse

Rob Sherwood   Bobby Bhattacharjee   Ryan Braud

University of Maryland   UCSD

DoS Using TCP Congestion Control

- Sender transmits packet



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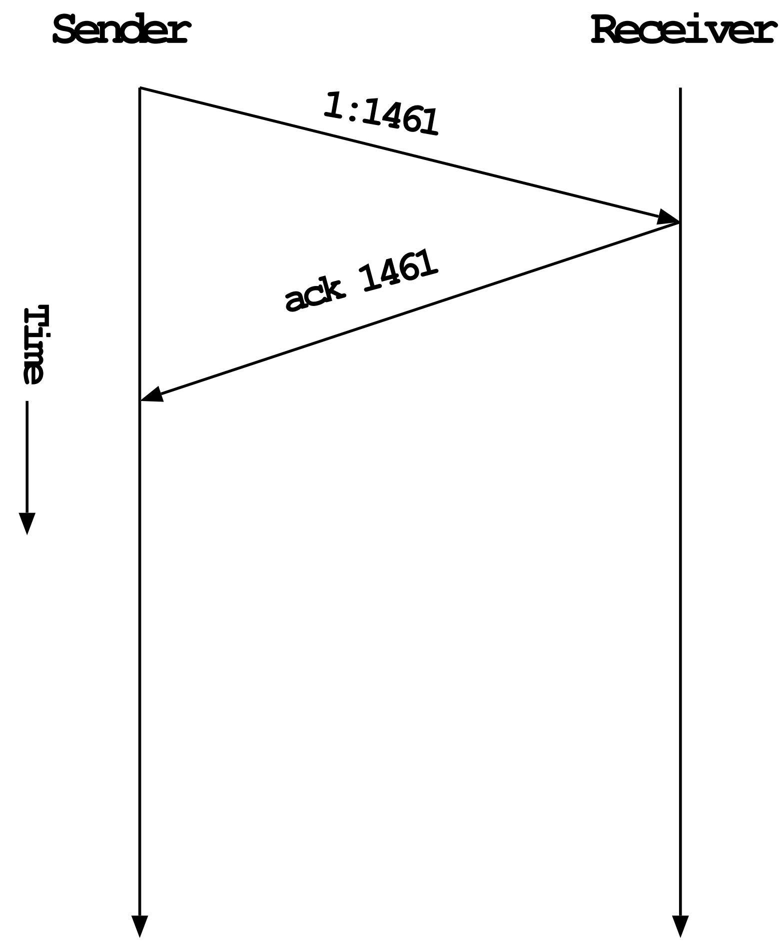

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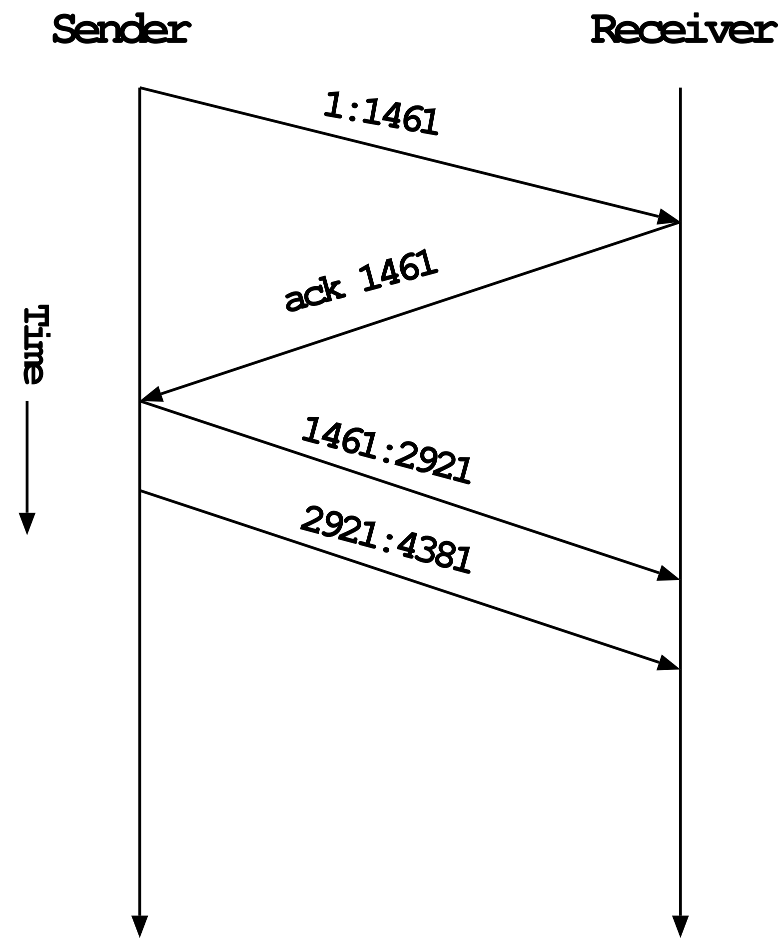

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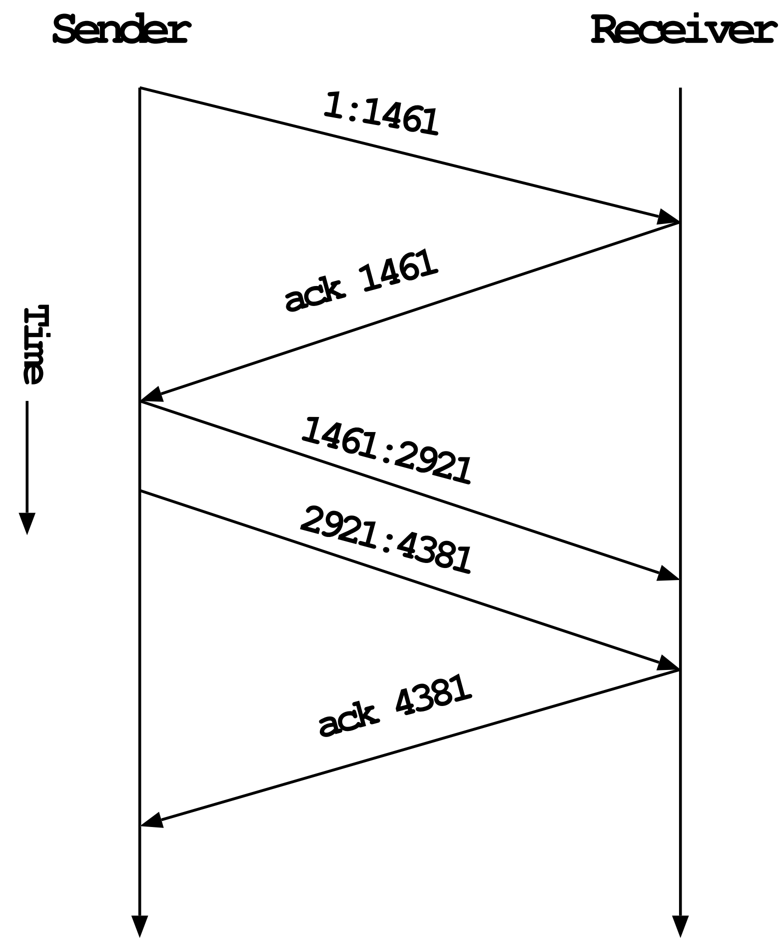

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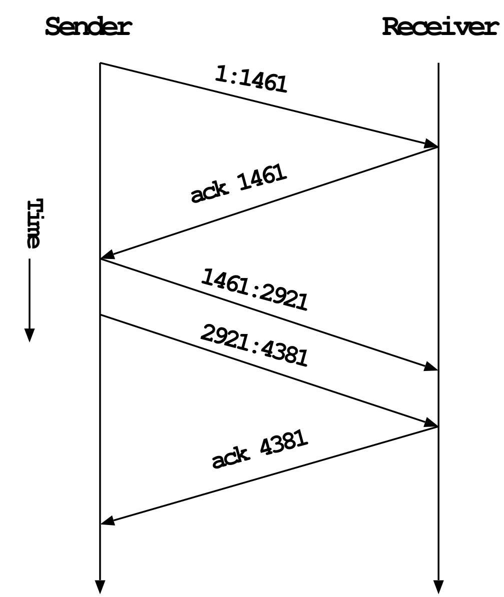

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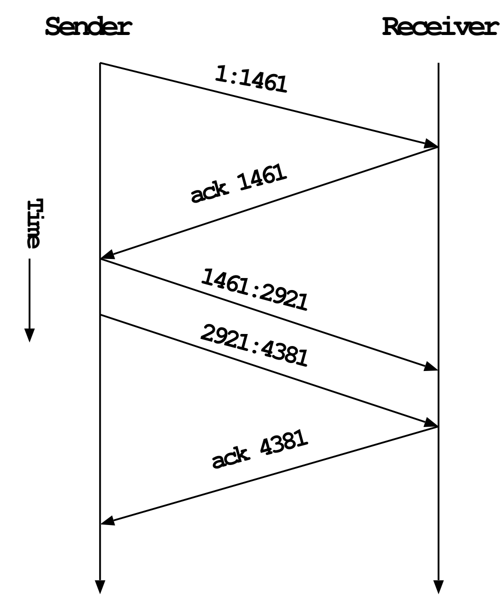

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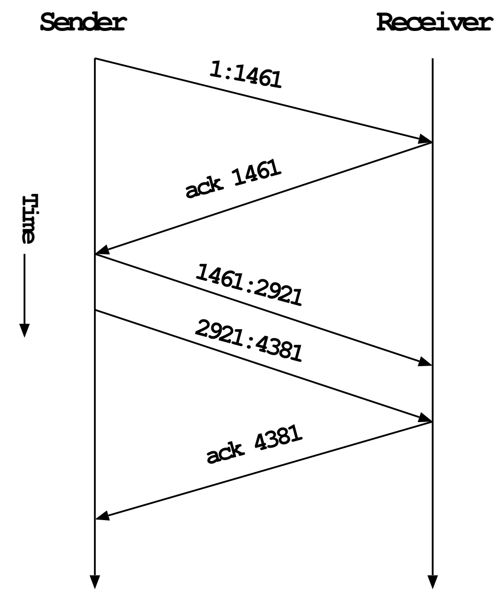

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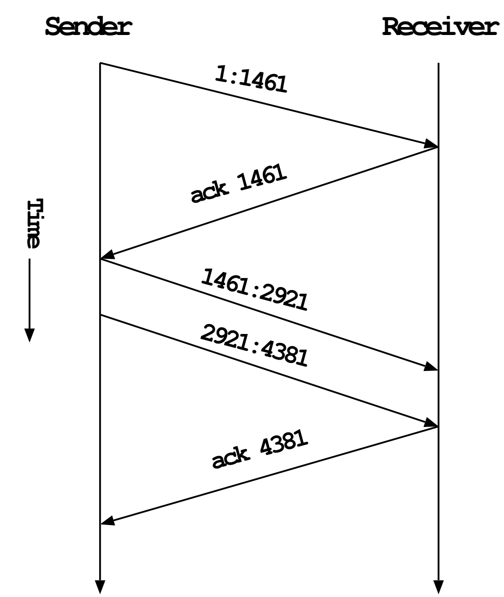

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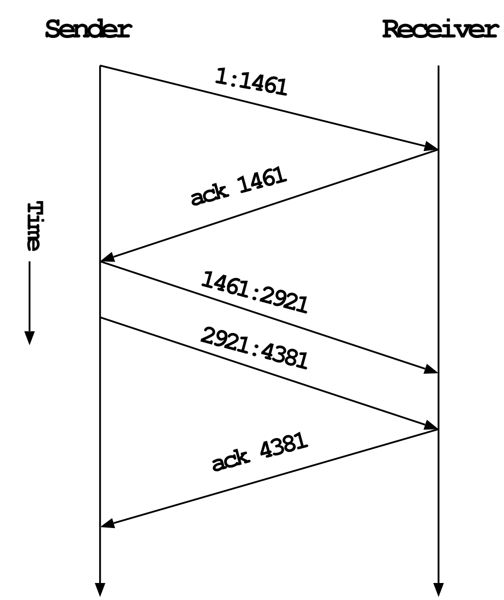
- Assumes honest feedback



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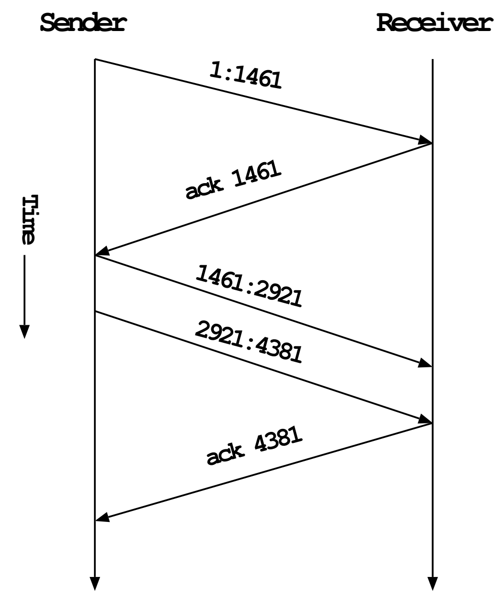
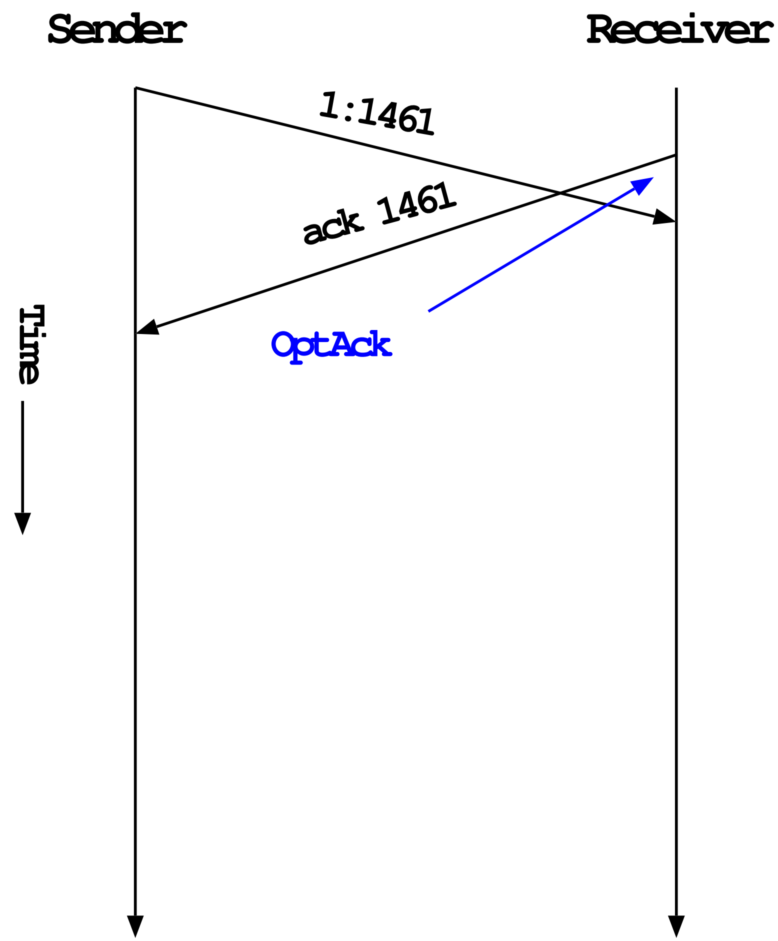
- What if receiver is malicious?



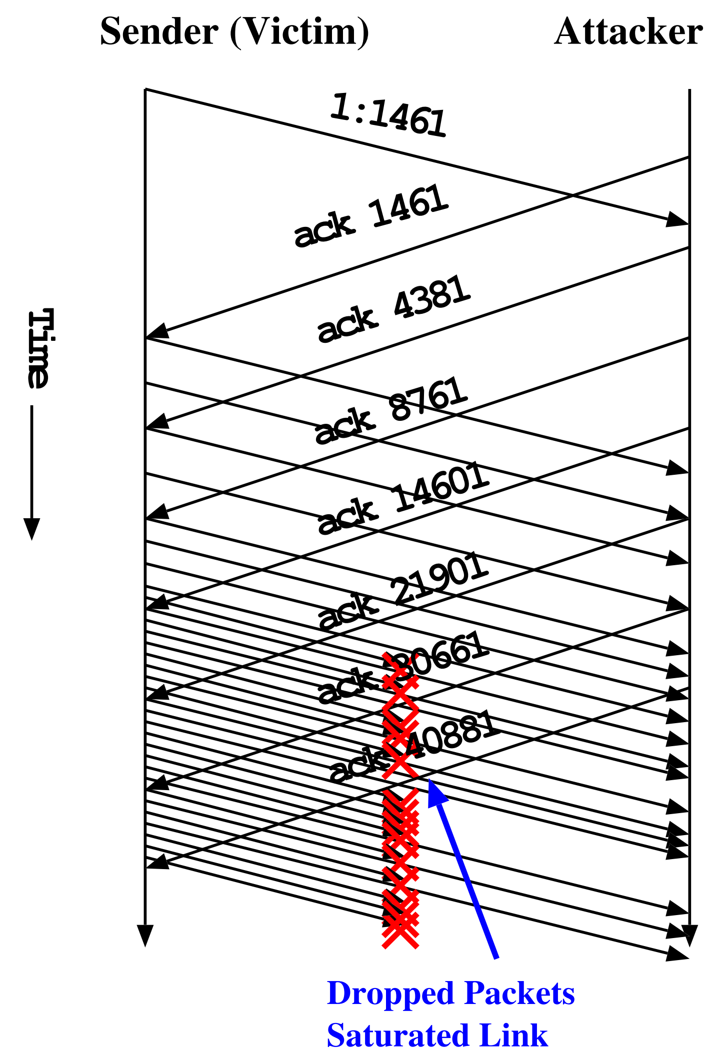
DoS Using TCP Congestion Control

- Misbehaving receiver can send *optimistic* ACKs for packets before they are received
- Faster performance [Savage99]



DoS Using TCP Congestion Control

- Malicious receiver can ACK data that is never received
- Force sender to congest the network (DoS)



Amplification

- Measure of DoS severity
- Amplification = $\frac{\text{traffic generated}}{\text{traffic sent}}$
  - Flooding : x1
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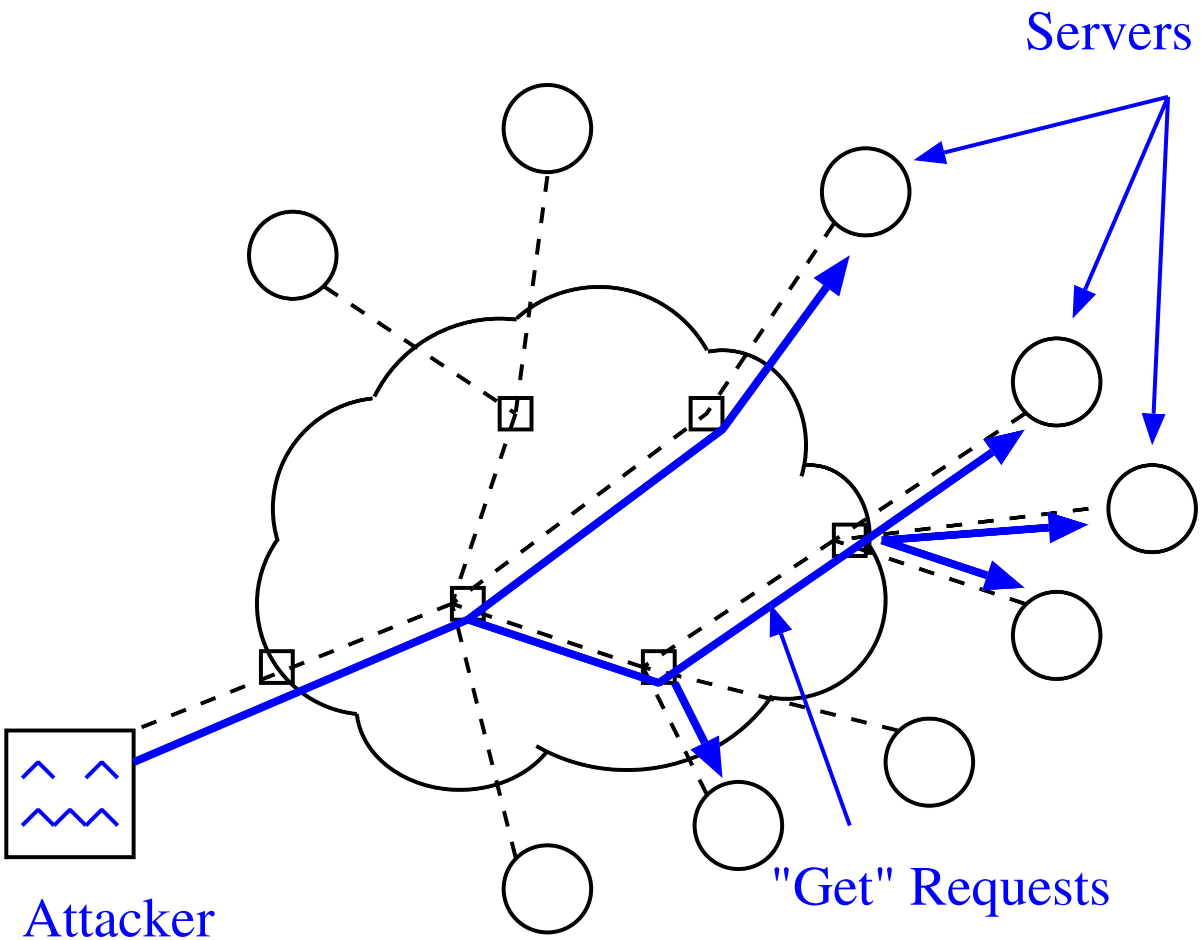
- OptAck: x1683
  - With window scaling: x32×10^6

Talk Outline

- Contributions
  - Discuss attack and amplification
  - Implementation techniques
    - Simulated and real world experiments
  - Solution: randomly skipped segments
    - Validate efficiency of implementation
- Conclusions

Attack Overview



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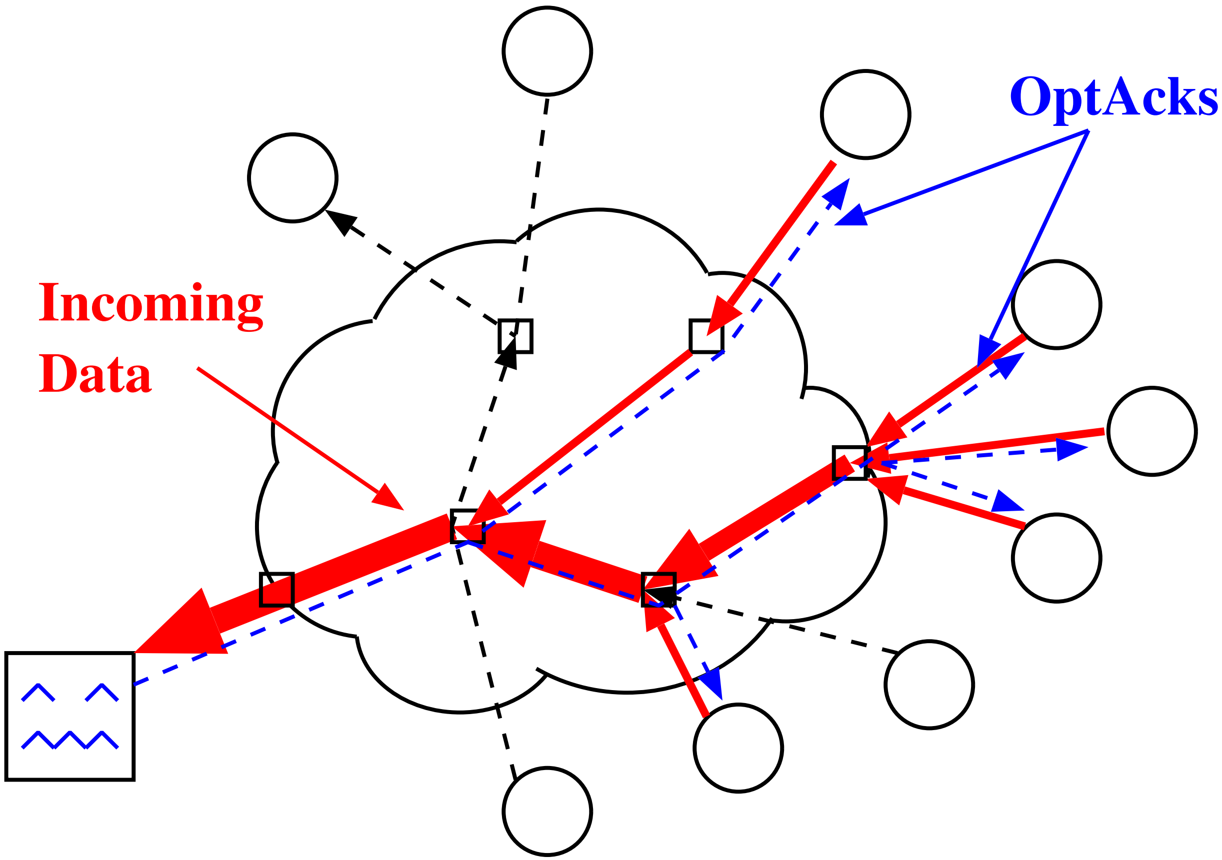

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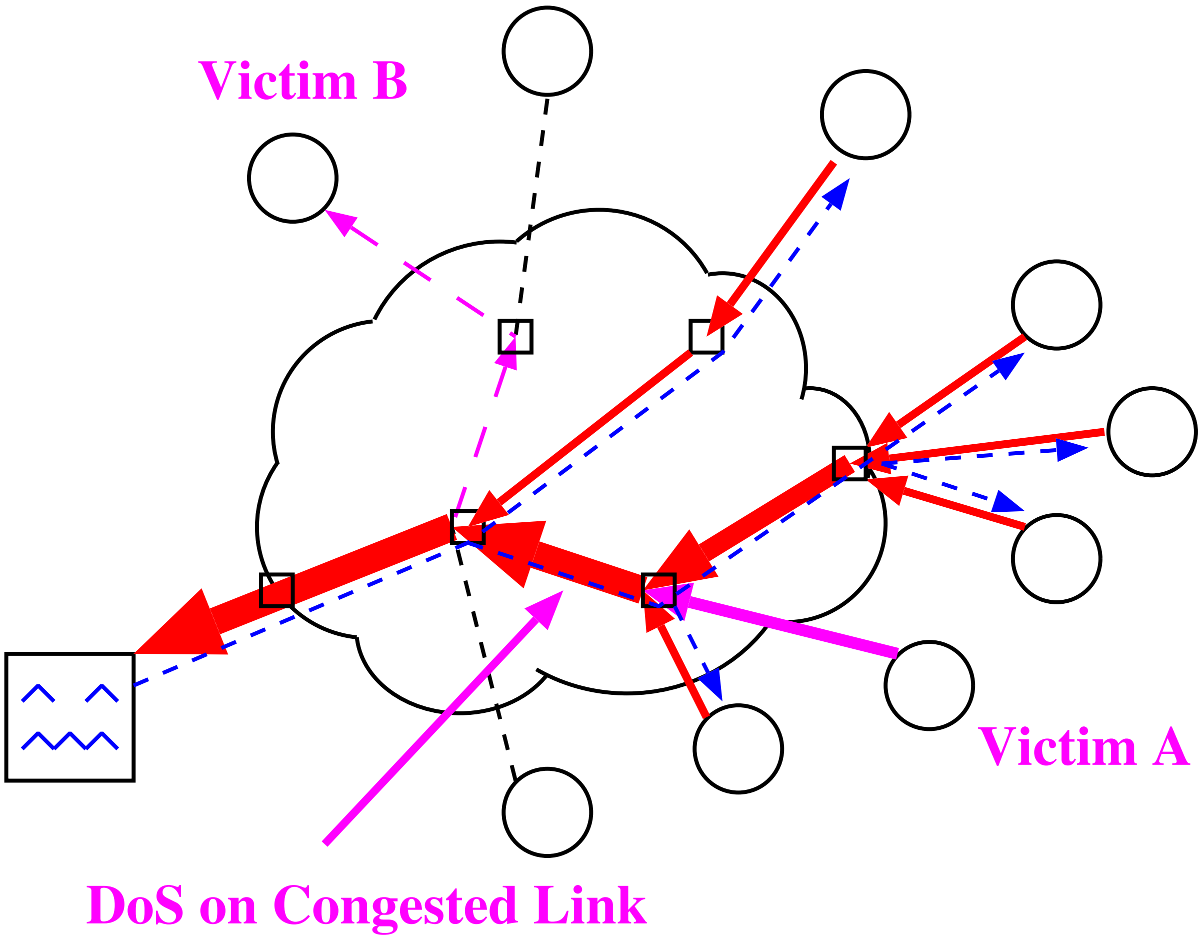

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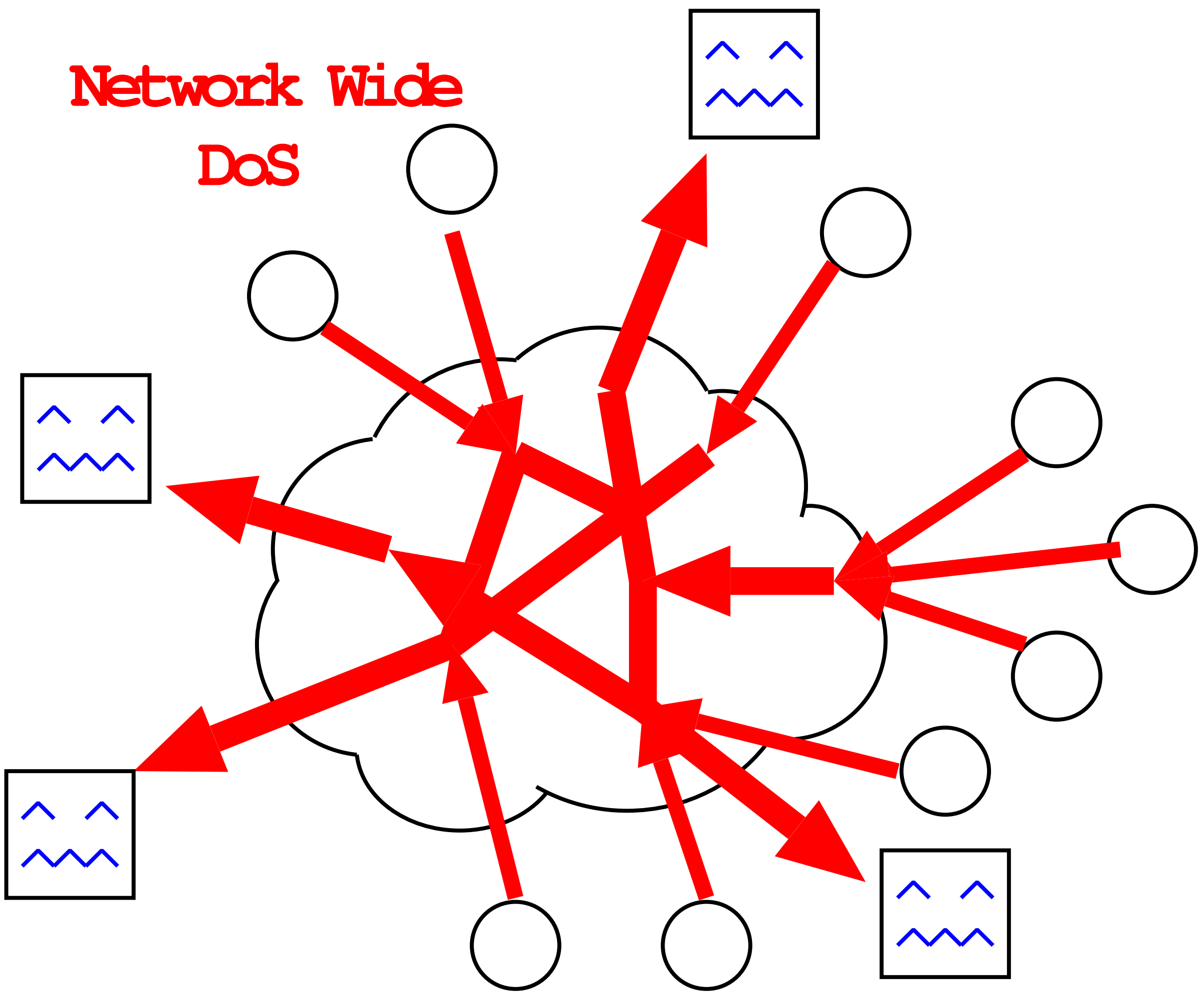

Amplification Factor Analysis

$$\frac{\text{traffic generated}}{\text{traffic sent}}$$

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$$\frac{\text{\# packets} \times \text{packet size}}{1 \text{ ACK}}$$

OptAck:

Send 1 ACK $\rightarrow$ Get entire window of packets

Amplification Factor Analysis

$$\frac{\frac{\text{cwnd}}{\text{mss}} \times (40 + \text{mss})}{40}$$

- cwnd: Size of window
- mss: Packet payload size
- 40 bytes: TCP header size

Amplification Factor Analysis

$$\text{cwnd} \times \left[\frac{1}{\text{mss}} + \frac{1}{40}\right]$$

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- wscale=14, mss=88 $\rightarrow$ x32×10^6

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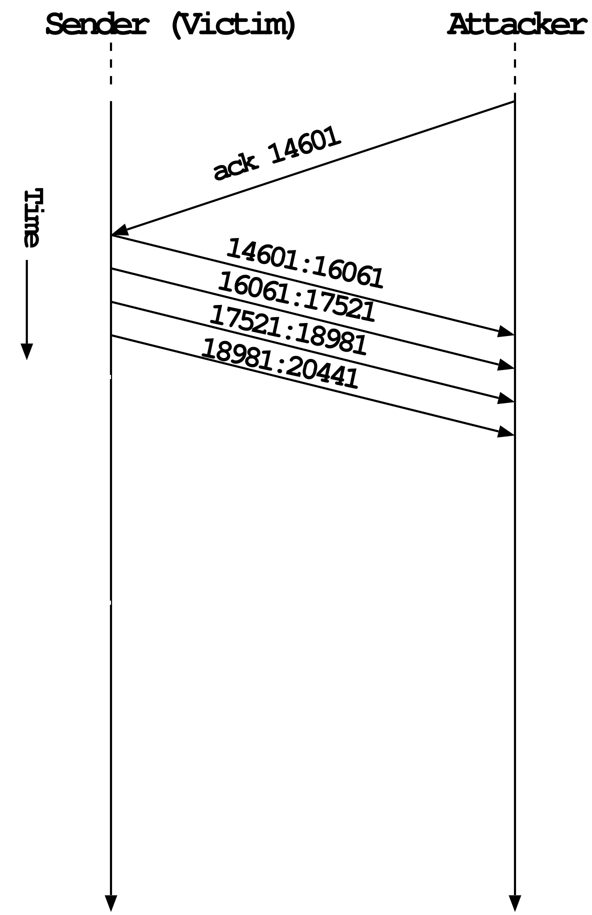
  - Data point: Slammer worm generated 31GB/s at peak [CAIDA03]
    - Equal to traffic generated by 5 OptAck attackers on T3s, wscale=0, mss=1460

Attack Implementation

- Is attack practical?
- How vulnerable are deployed TCP Stacks?
- Discovered effective solution
- We implement the attack
  - approx. 1200 lines of code
- Main challenge: ACK overruns

ACK overruns

- Attacker becomes unsynchronized



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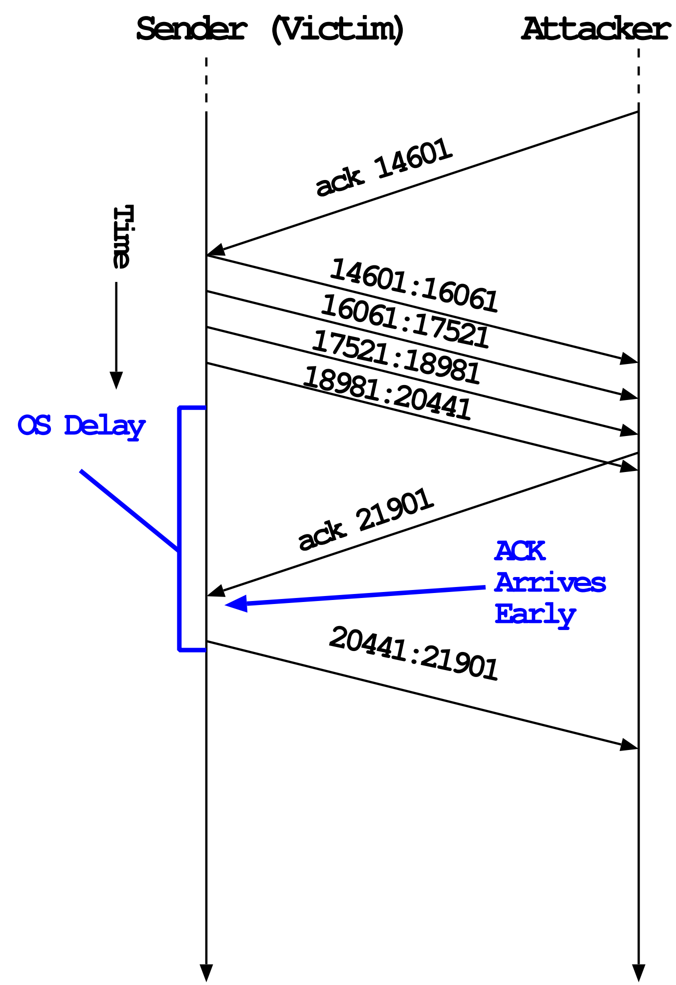

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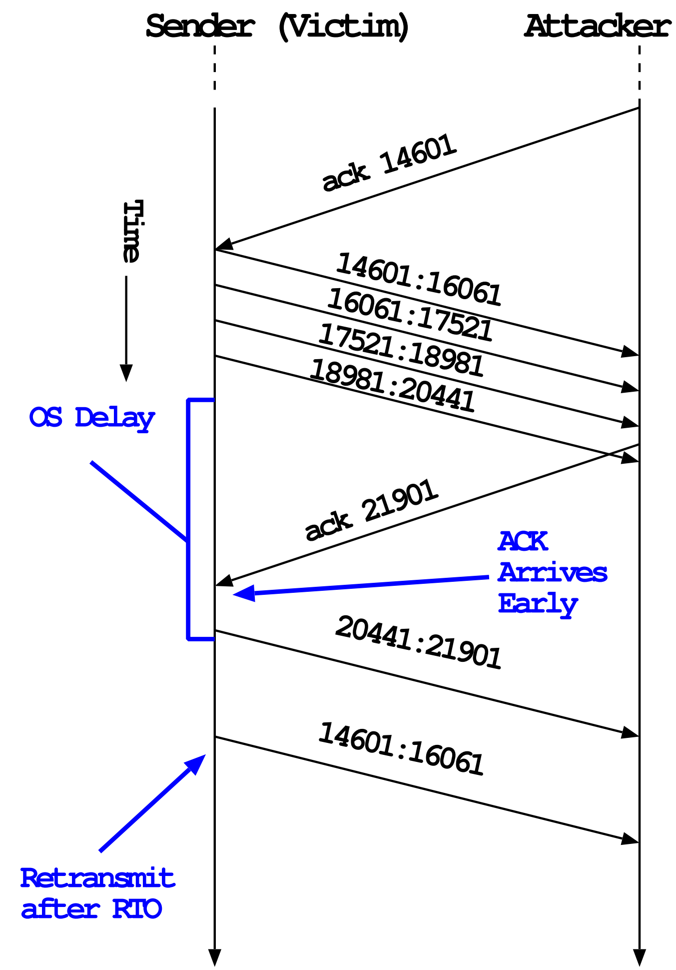

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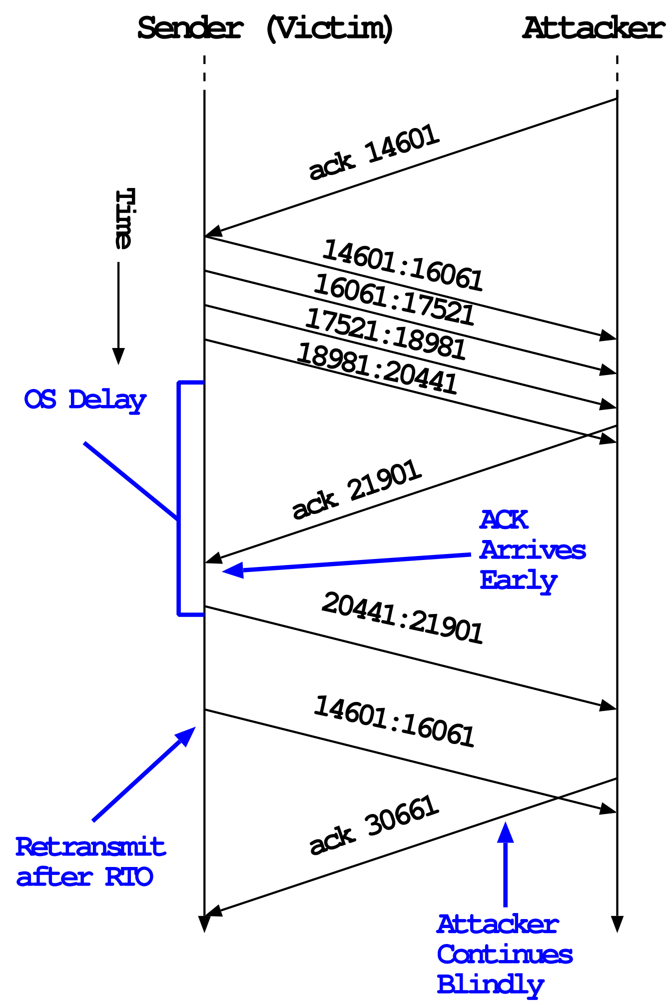

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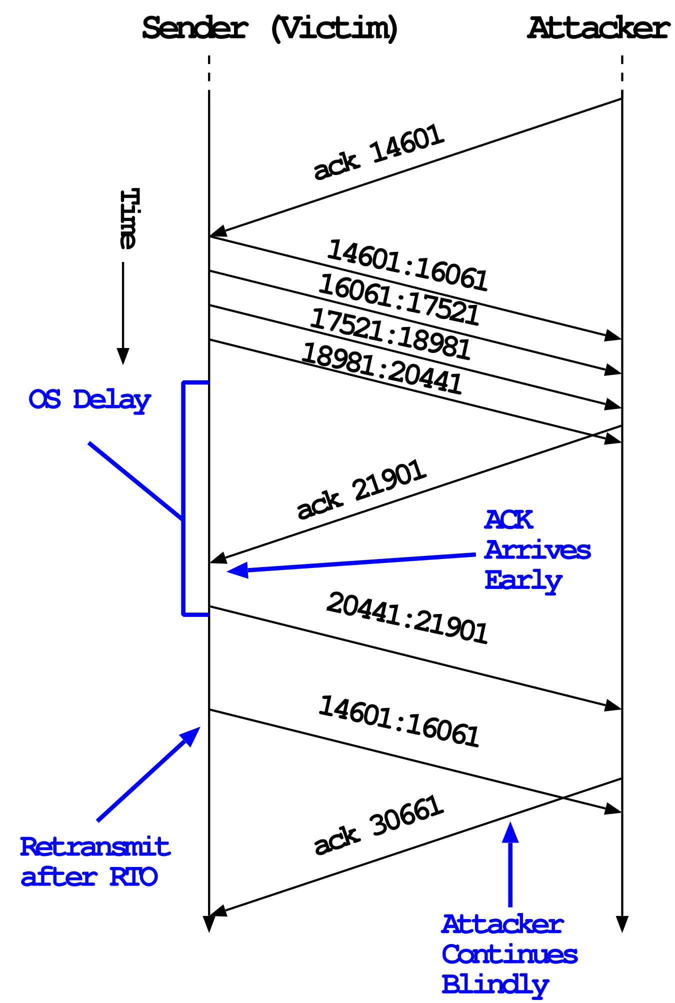

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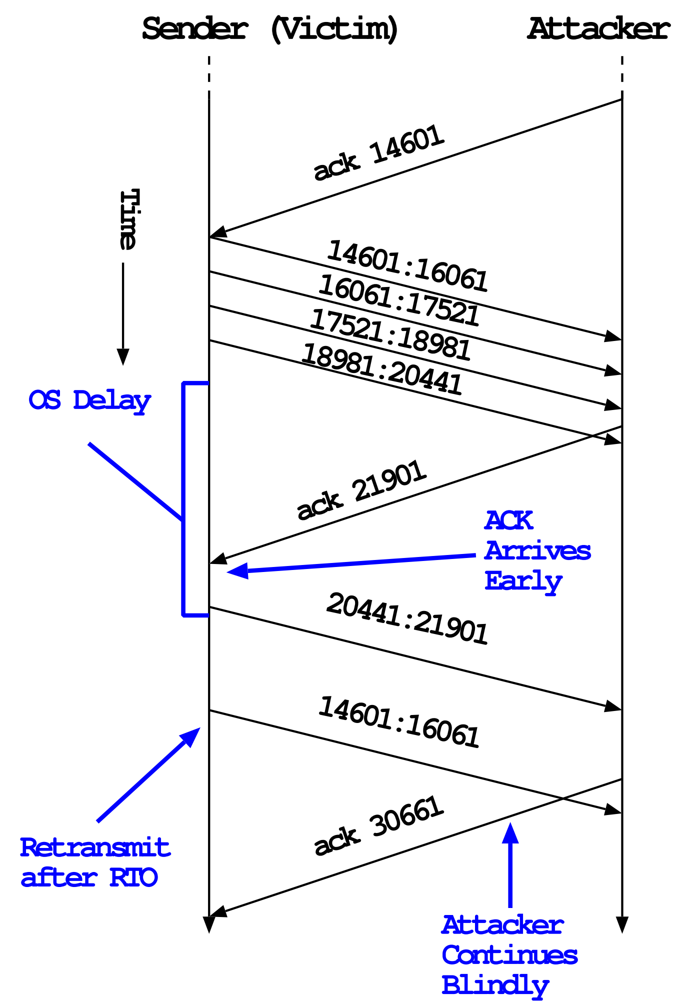

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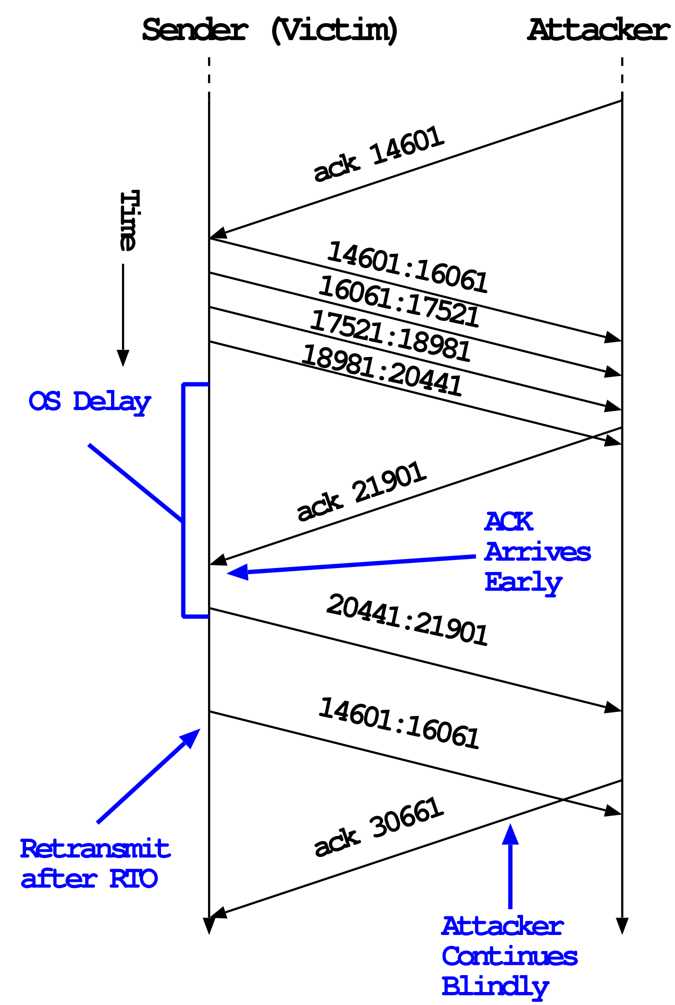

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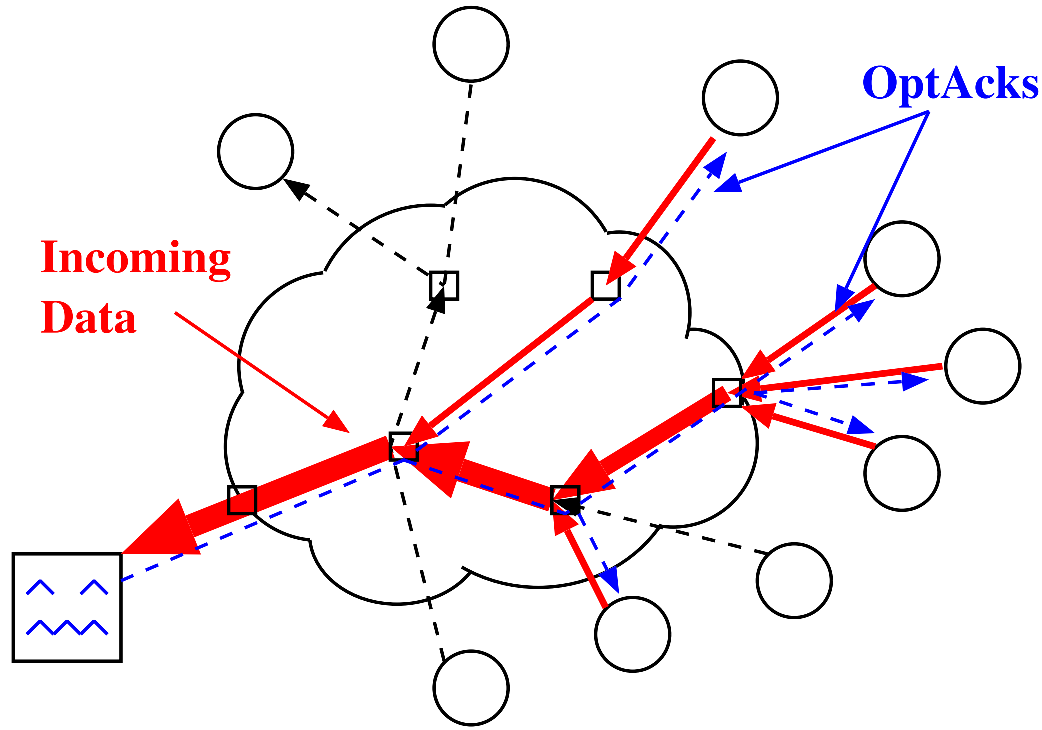
- Recovery details in paper

Attack Validation

- Experiment: How much traffic does OptAck generate?



Results - NS Simulations

Connections:

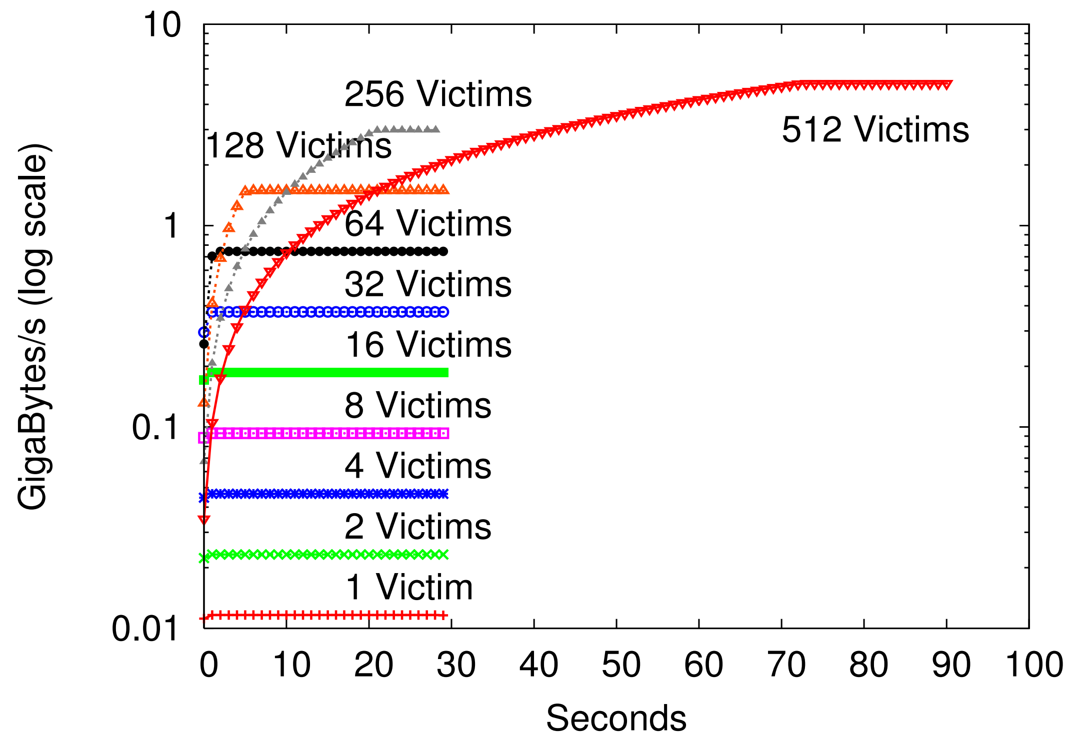
1 Attacker: 1.5Mbps

Victims: 100Mbps

Parameters:

wscale=4

mss=1460



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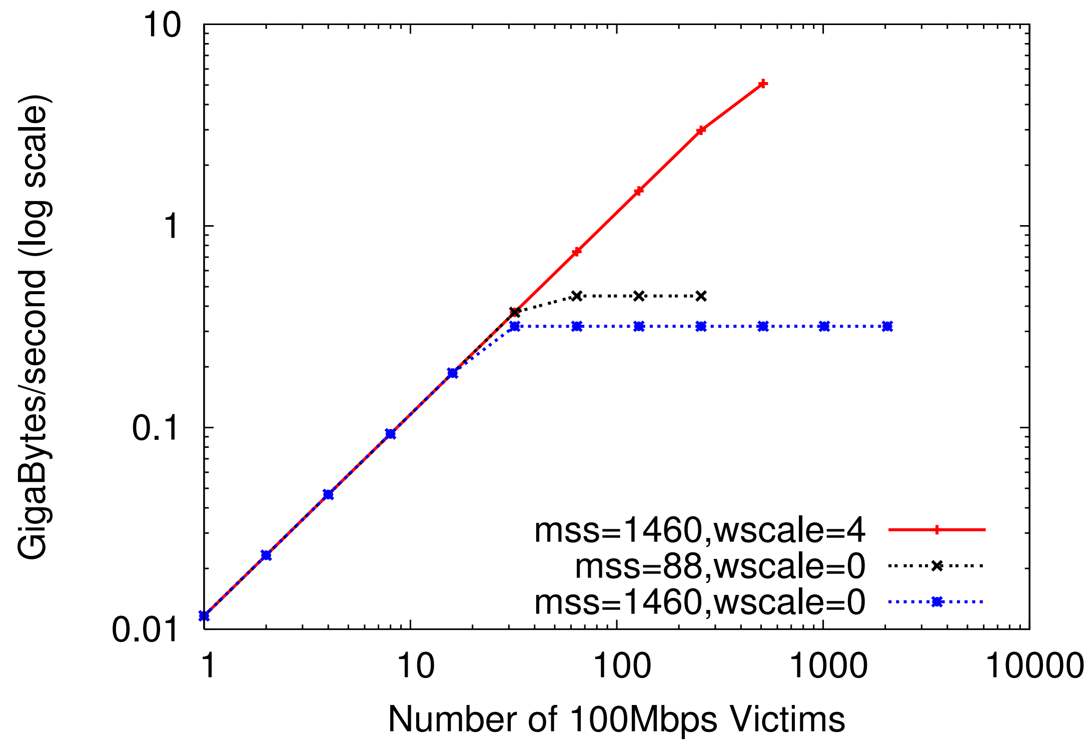
Max traffic:

99.9% of predicted

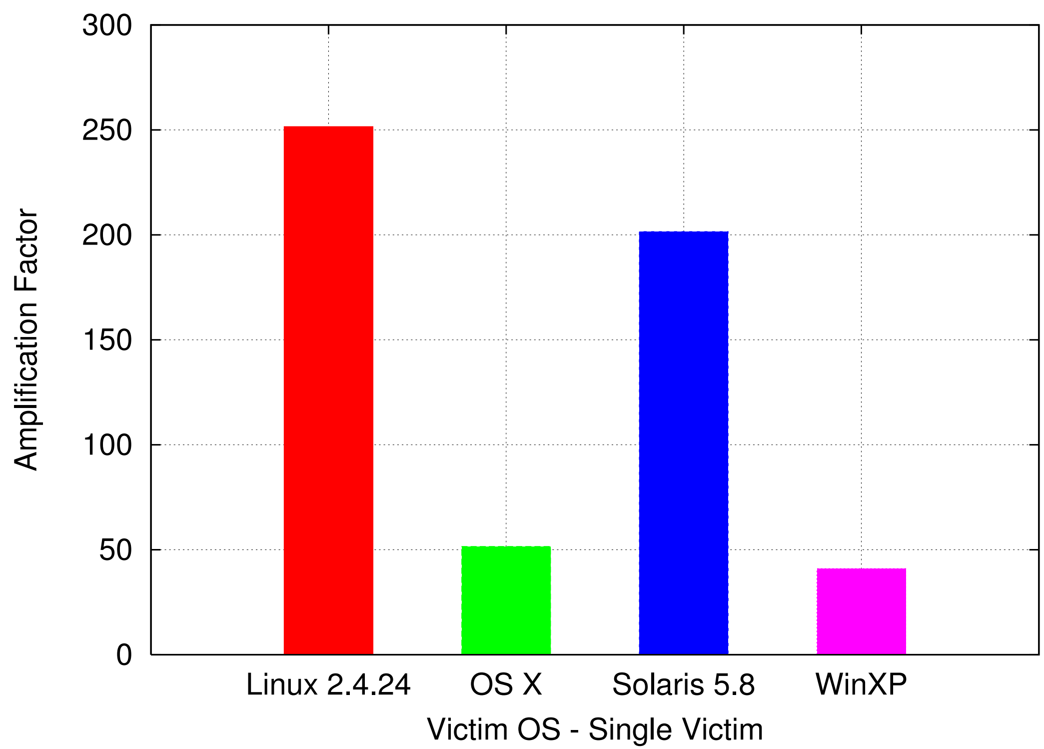
Conclusion:

Model is accurate



Results - Implementation

- 1 Attacker on LAN w/ 1 victim
- wscale=0, mss=1460
- No multi-victim overrun avoidance



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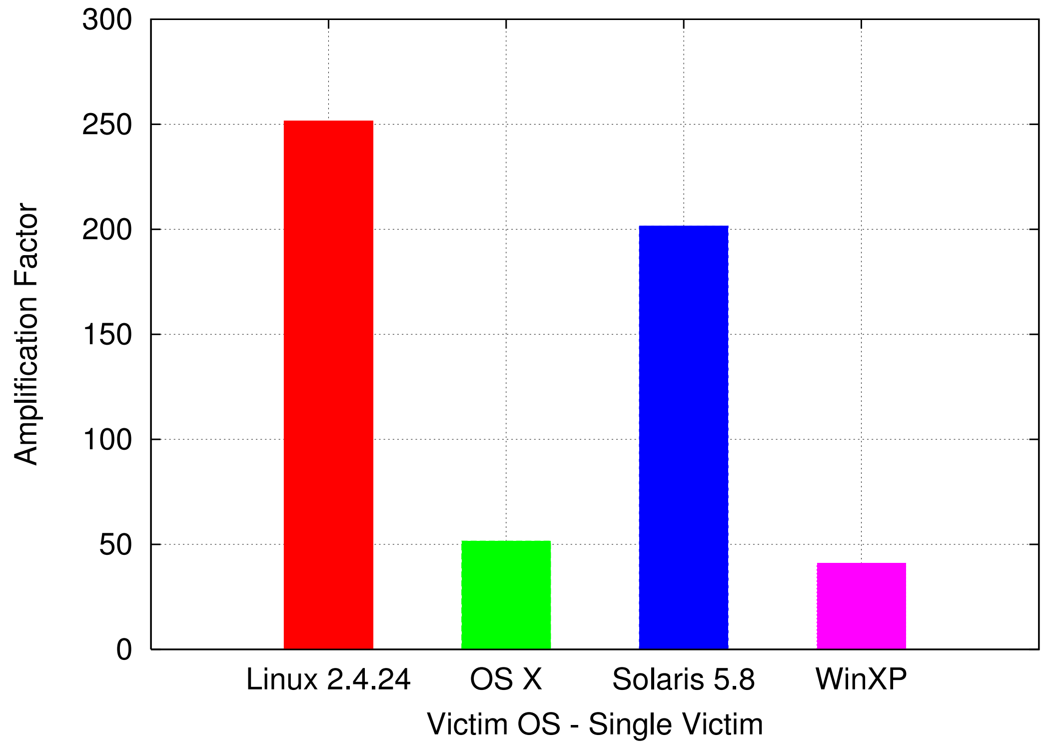
- Conclusion: Works on deployed TCP stacks



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- Rate limiting
  - Target more servers; use more attackers
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  - Trivial DoS
- Network Policing
- Insight: attacker cannot tell where in the network a packet is dropped

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- Sender only modification: deployable

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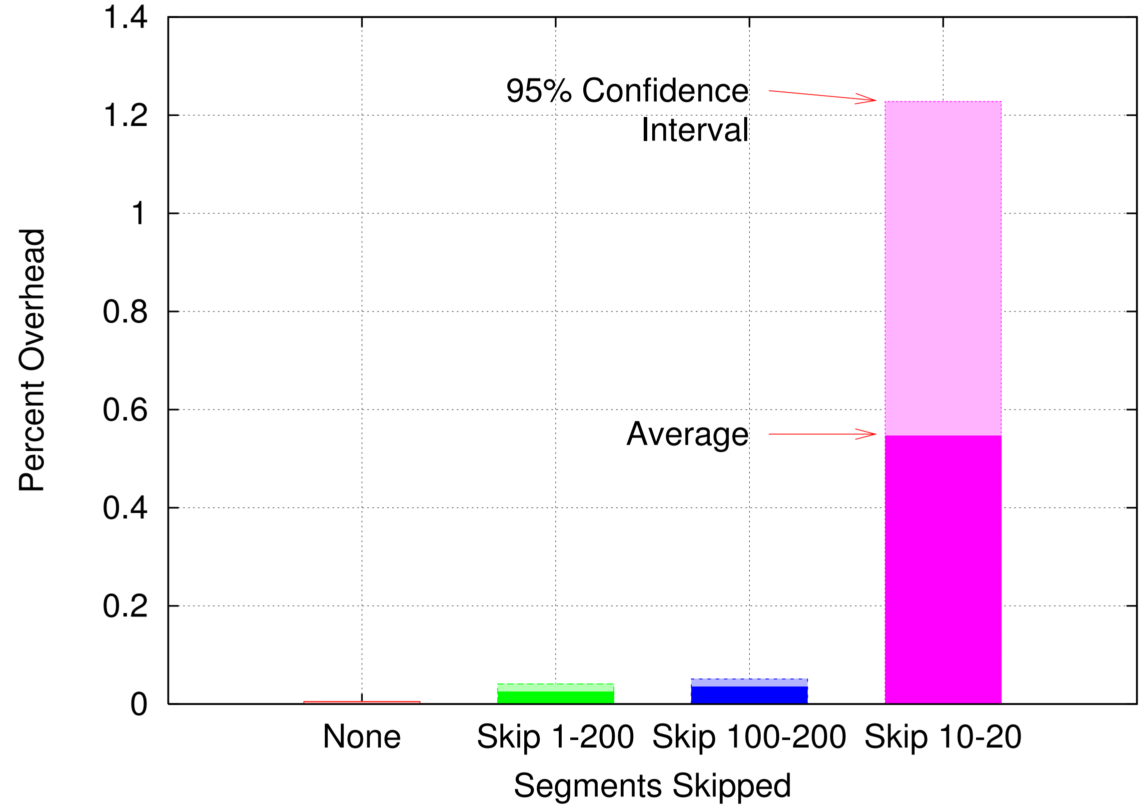
- TCP optimized to recover from packet loss
- Linux implementation:
  - 30 lines of code
  - 5 bytes per connection

Skipped Segments Efficiency

- Download 100MB file
- No attack
- Vary skip rate



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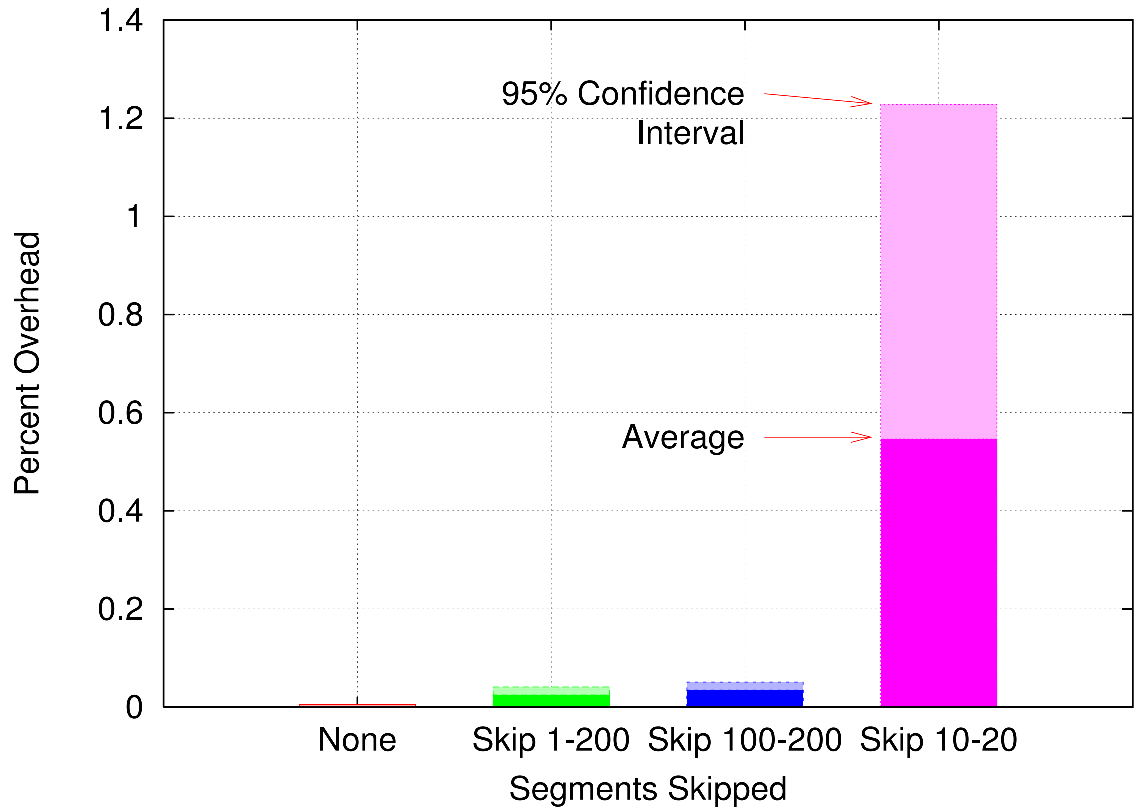
- Conclusion: Overhead is trivial
  - $< 0.1\%$



Related Work

- [Savage99]
  TCP Congestion Control with a Misbehaving Receiver.
  Stefan Savage, Neal Cardwell, David Wetherall, and Tom Anderson.
  CCR 1999.
  - Original optimistic acknowledgment
  - Defense requires receiver side modifications - inhibits deployment

Related Work (more)

- [Azcorra04] (Expired) Draft RFC: DoS vulnerability of TCP by acknowledging not received segments. A. Azcorra, C. Bernardos, and I. Soto. draft-azcorra-tcpm-tcp-blind-ack-dos-01
  - Proposed solutions already discussed in paper

Related Work (more)

- [CAIDA03]: Inside the Slammer Worm: David Moore, Vern Paxson, Stefan Savage, Colleen Shannon, Stuart Staniford, Nicholas Weaver. http://www.caida.org/outreach/papers/2003/sapph
- [HONEYNET04]: Know your Enemy: Tracking Botnets. The Honeynet Project Research Alliance. http://www.honeynet.org/papers/bots.

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- Future work: DETER?
- Questions?

This talk was written in $\LaTeX$ with Prosper: http://prosper.sourceforge.net/

Defense Categories

- bandwidth caps
  - just use more victims or more attackers
- nonces
  - non-cumulative nonces are not robust
  - cumulative nonces require client deployment
- ACK alignment/timestamps
  - requires CPU for strong random numbers
  - timestamps are optional
  - not robust to lazy attack

More Defenses

- In network support
  - not currently deployed
- Random Pauses
  - inefficient
- segment reordering
  - allows false positives from network reordering, dropped ACKs
  - no performance penalty