CS3600 — Systems and Networks

NORTHEASTERN UNIVERSITY

Lecture 26: Security

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Slides used with permissions from Edward W. Knightly,
T. S. Eugene Ng, Ion Stoica, Hui Zhang

Basic Security Requirements

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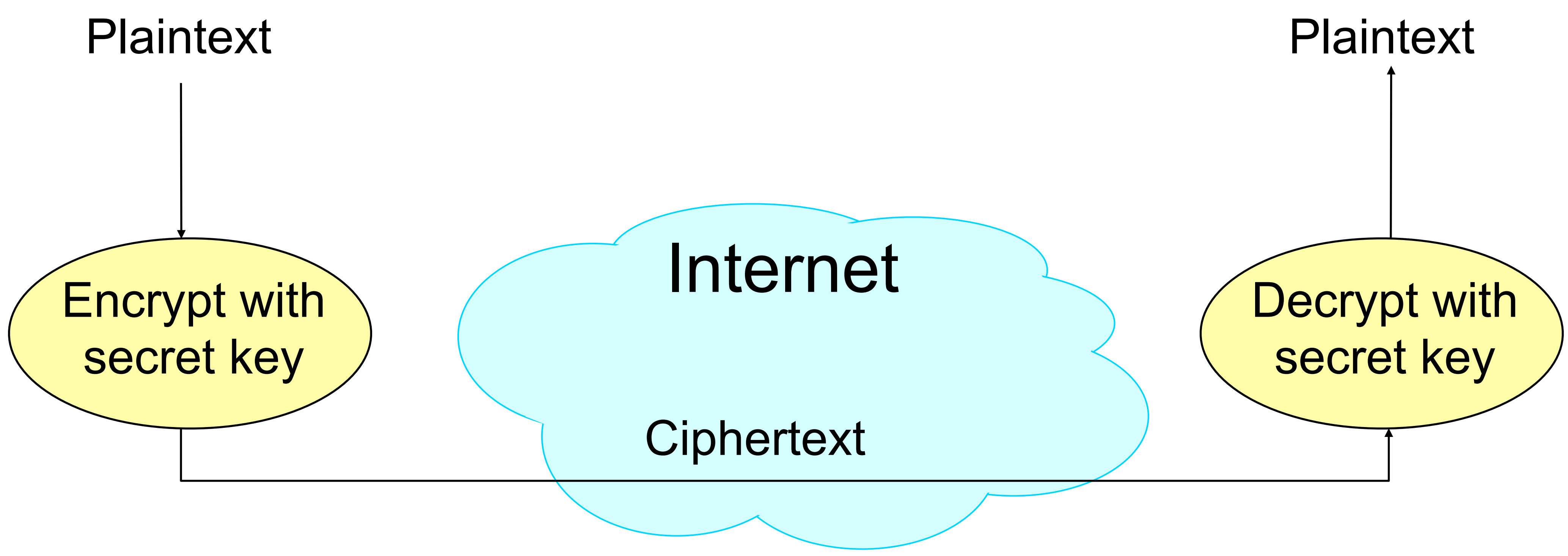
- This is not a crypto course, so we will just skim the surface of the crypto algorithms to give you a rough idea

Cryptographic Algorithms

- Security foundation: cryptographic algorithms
  - Secret key cryptography, e.g. Data Encryption Standard (DES)
  - Public key cryptography, e.g. RSA algorithm
  - Message digest, e.g. MD5

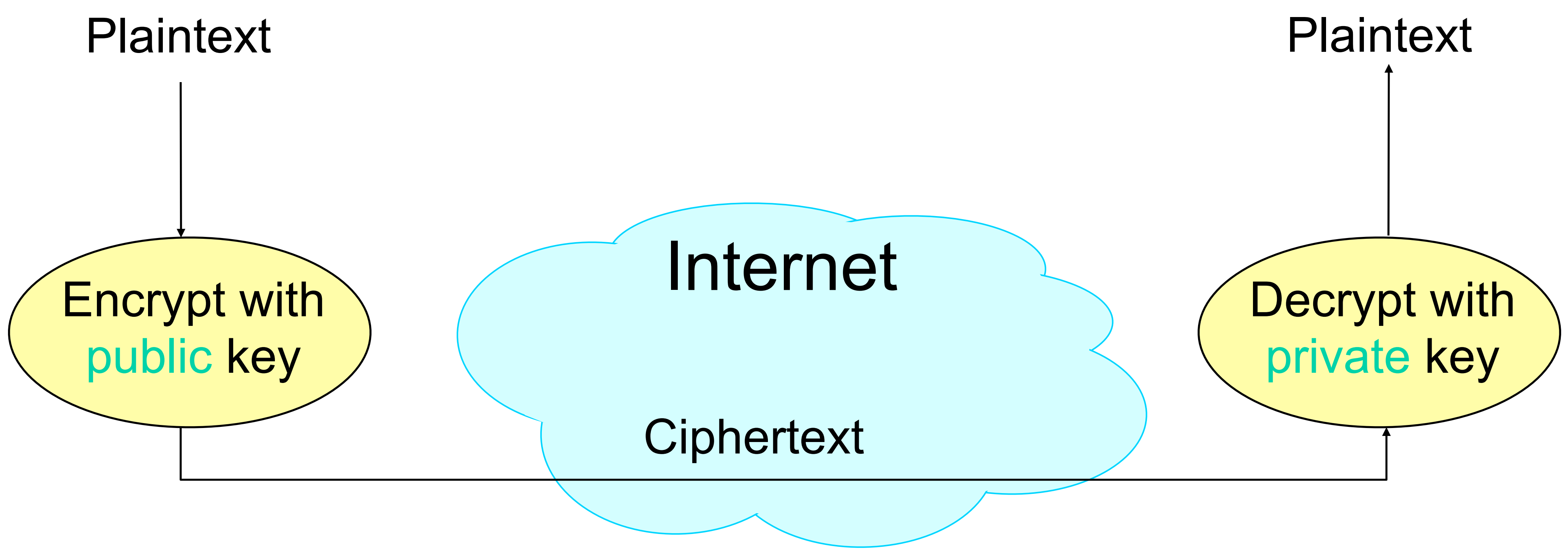
Symmetric Key

- Both the sender and the receiver use the same secret keys



Public-Key Cryptography: RSA (Rivest, Shamir, and Adleman)

- Sender uses a public key
  - Advertised to everyone
- Receiver uses a private key



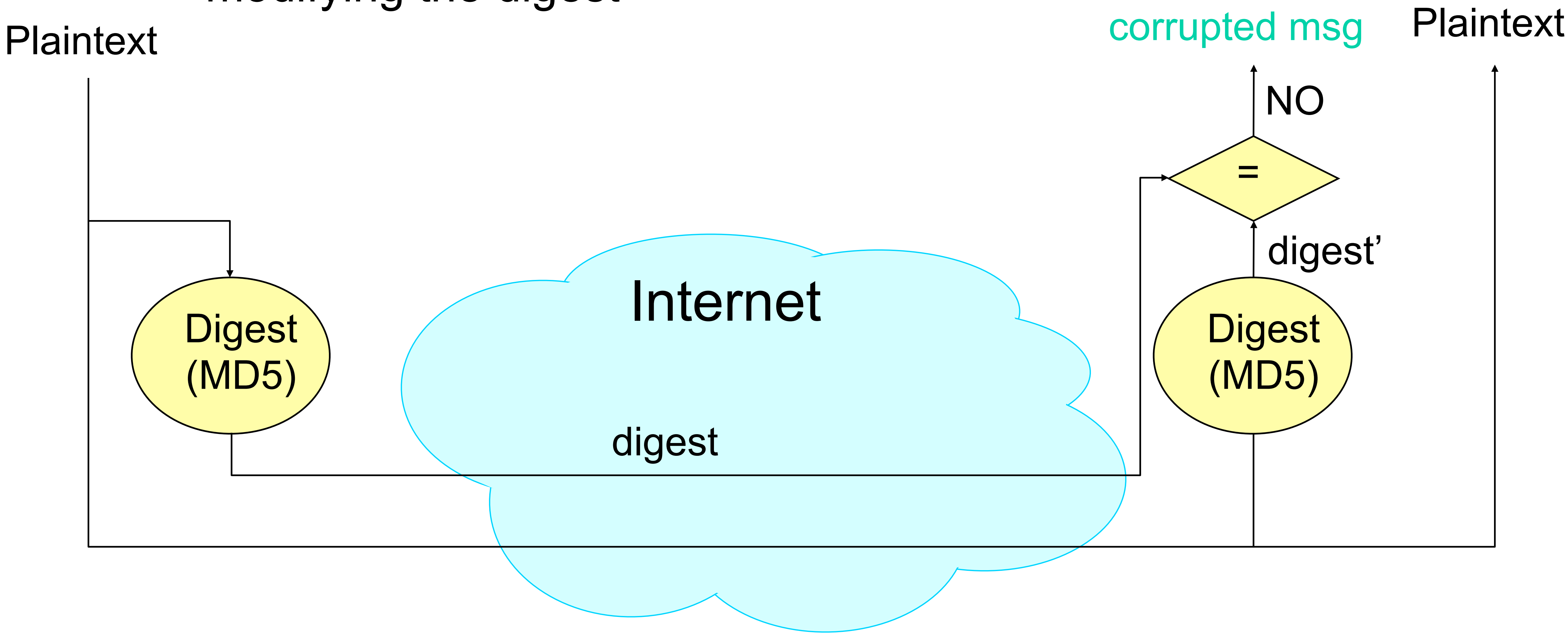
Message Digest (MD) 5

- Can provide data integrity
  - Used to verify the authenticity of a message
- Idea: compute a hash value on the message and send it along with the message
- Receiver can apply the same hash function on the message and see whether the result coincides with the received hash

- Very hard to forge a message that produces the same hash value
  - i.e. Message -> hash is easy
  - Hash -> Message is hard
  - Compare to other error detection methods (CRC, parity, etc)

MD 5 (cont'd)

- Basic property: digest operation very hard to invert
  - Send the digest via a different channel
    - used it in FTP mirrors, user download MD5 digest of file separately from the file, hope no one can forge the MD5 digest before you even download the intended file
  - In practice someone cannot alter the message without modifying the digest



Importance of Network Security

- Internet currently used for important services
  - Financial transactions, medical records
- Could be used in the future for *critical* services
  - 911, surgical operations, energy system control, transportation system control
- Networks more open than ever before
  - Global, ubiquitous Internet, wireless
- Malicious Users
  - Selfish users: want more network resources than you
  - Malicious users: would hurt you even if it doesn't get them more network resources

Network Security Problems

- Host Compromise
  - Attacker gains control of a host
- Denial-of-Service
  - Attacker prevents legitimate users from gaining service
- Attack can be both
  - E.g., host compromise that provides resources for denial-of-service

Host Compromise

- One of earliest major Internet security incidents
  - Internet Worm (1988): compromised almost every BSD-derived machine on Internet
- Today: estimated that a single worm could compromise 10M hosts in < 5 min
- Attacker gains control of a host
  - Reads data
  - Erases data
  - Compromises another host
  - Launches denial-of-service attack on another host

Definitions

- Worm
  - Replicates itself
  - Usually relies on stack overflow attack
- Virus
  - Program that attaches itself to another (usually trusted) program
- Trojan horse
  - Program that gives a hacker a back door
  - Usually relies on user exploitation

Host Compromise: Stack Based Buffer Overflow

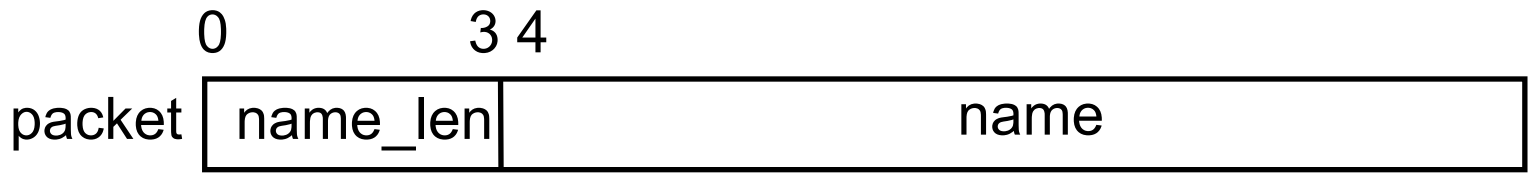
- Typical code has many bugs because those bugs are not triggered by common input
- Network code is vulnerable because it accepts input from the network
- Network code that runs with high privileges (i.e., as root) is especially dangerous
  - E.g., web server

Example

- What is wrong here?

```
#define MAXNAMELEN 64
int offset = OFFSET_USERNAME;
char username[MAXNAMELEN];
int name_len;

name_len = ntohl(*(int *)packet);
memcpy(&username, packet[offset], name_len);
```



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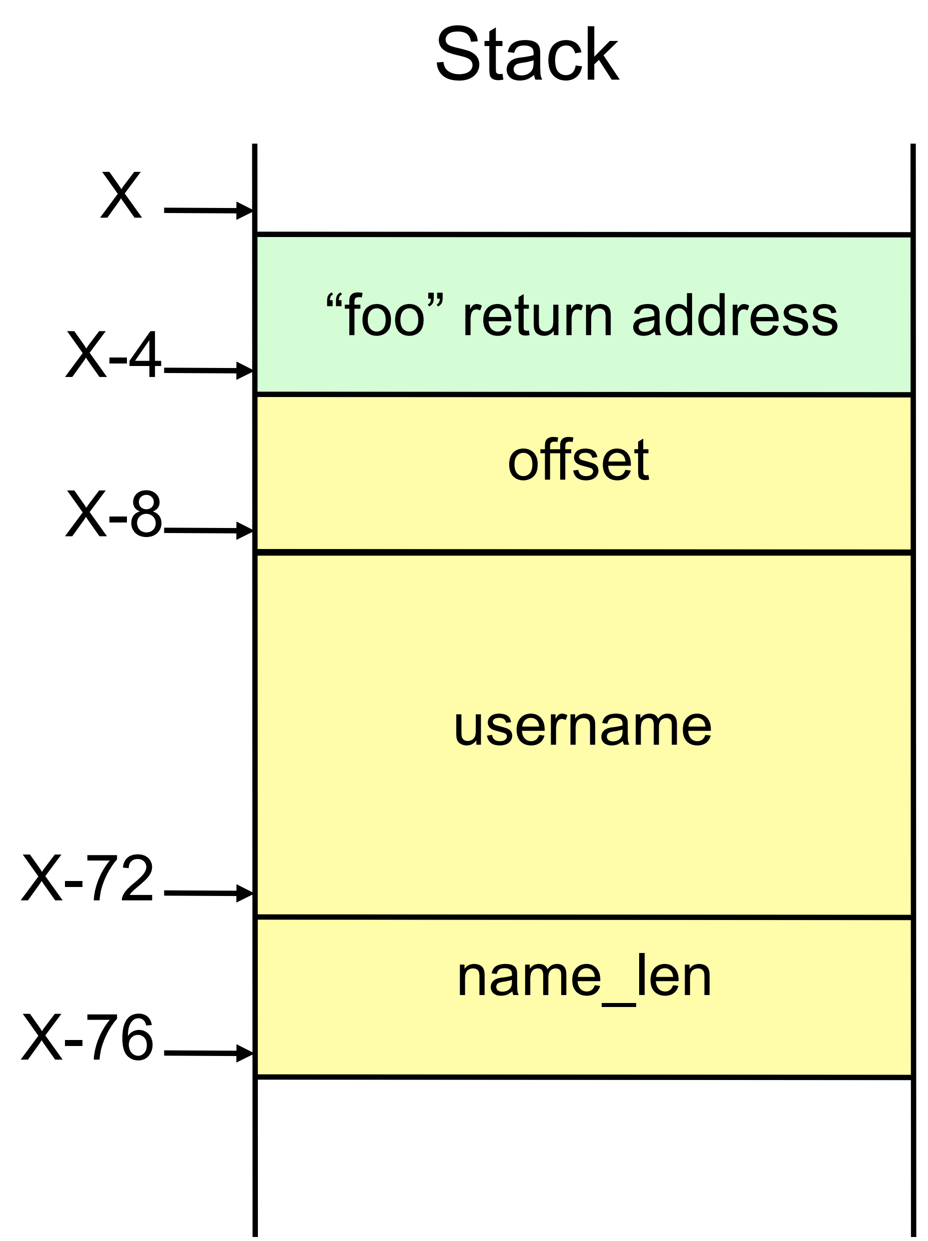

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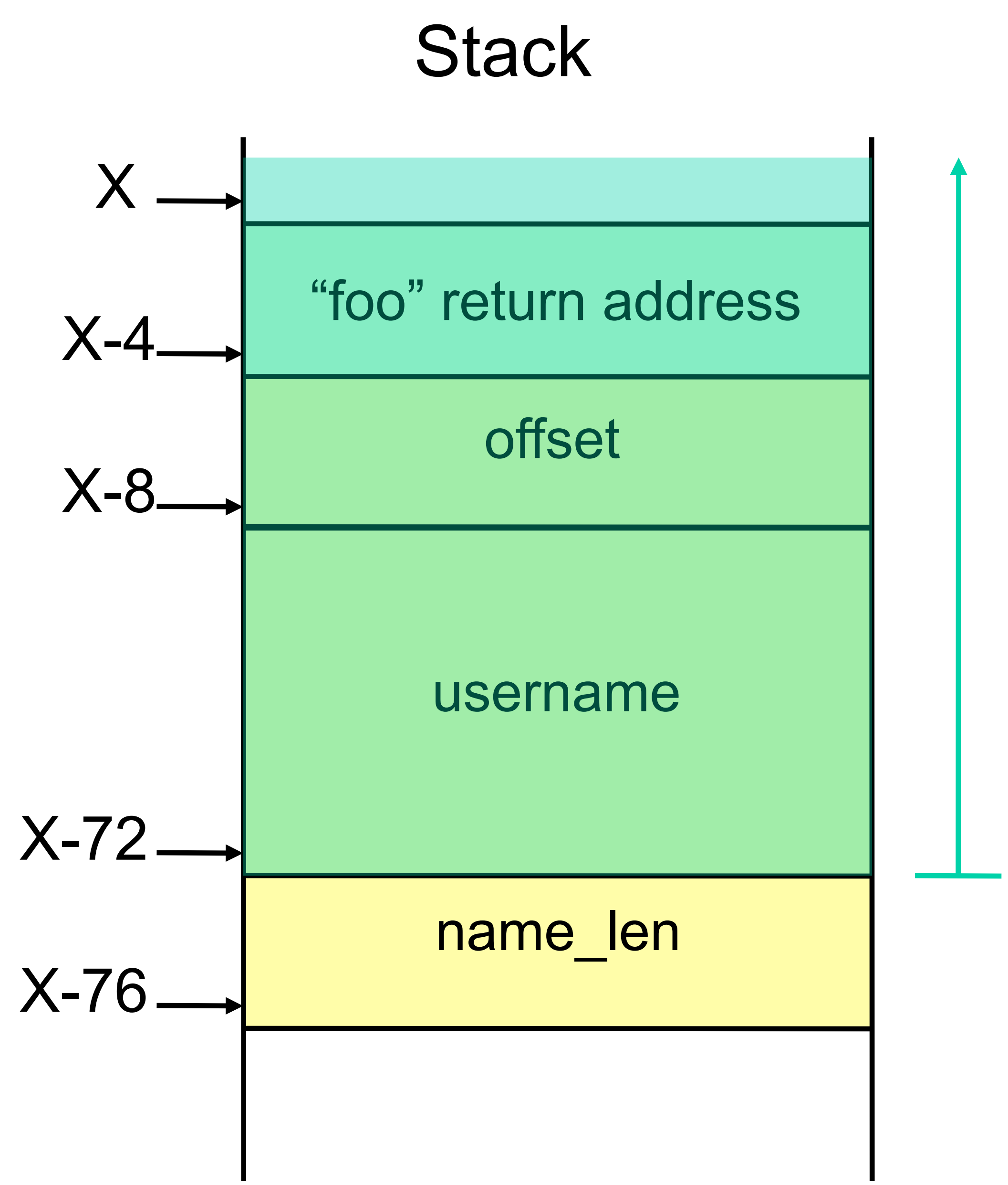


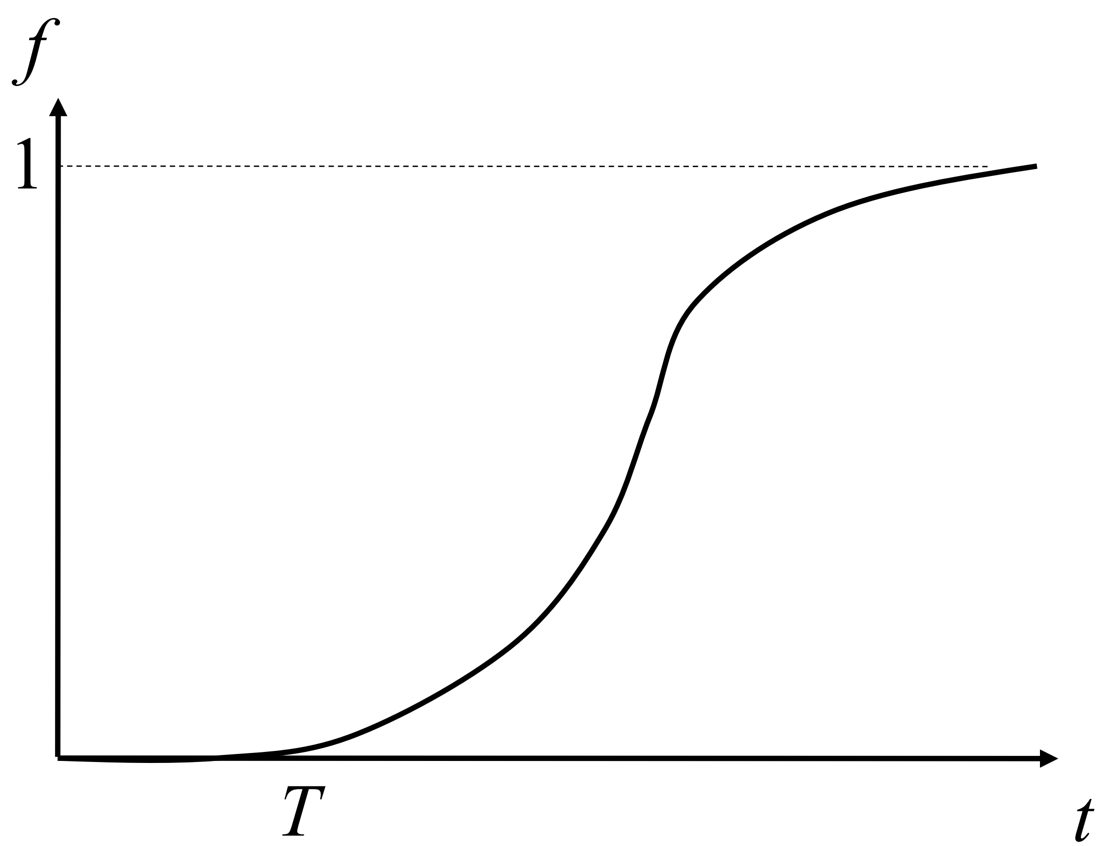
Effect of Stack Based Buffer Overflow

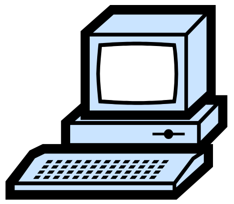
- Write into part of the stack or heap
  - Write arbitrary code to part of memory
  - Cause program execution to jump to arbitrary code
- Worm
  - Probes host for vulnerable software
  - Sends bogus input
  - Attacker can do anything that the privileges of the buggy program allows
    - Launches copy of itself on compromised host
  - Spread at exponential rate
  - 10M hosts in < 5 minutes

Worm Spreading

$f = (e^{K(t-T)} - 1) / (1 + e^{K(t-T)})$

- f – fraction of hosts infected
- K – rate at which one host can compromise others
- T – start time of the attack





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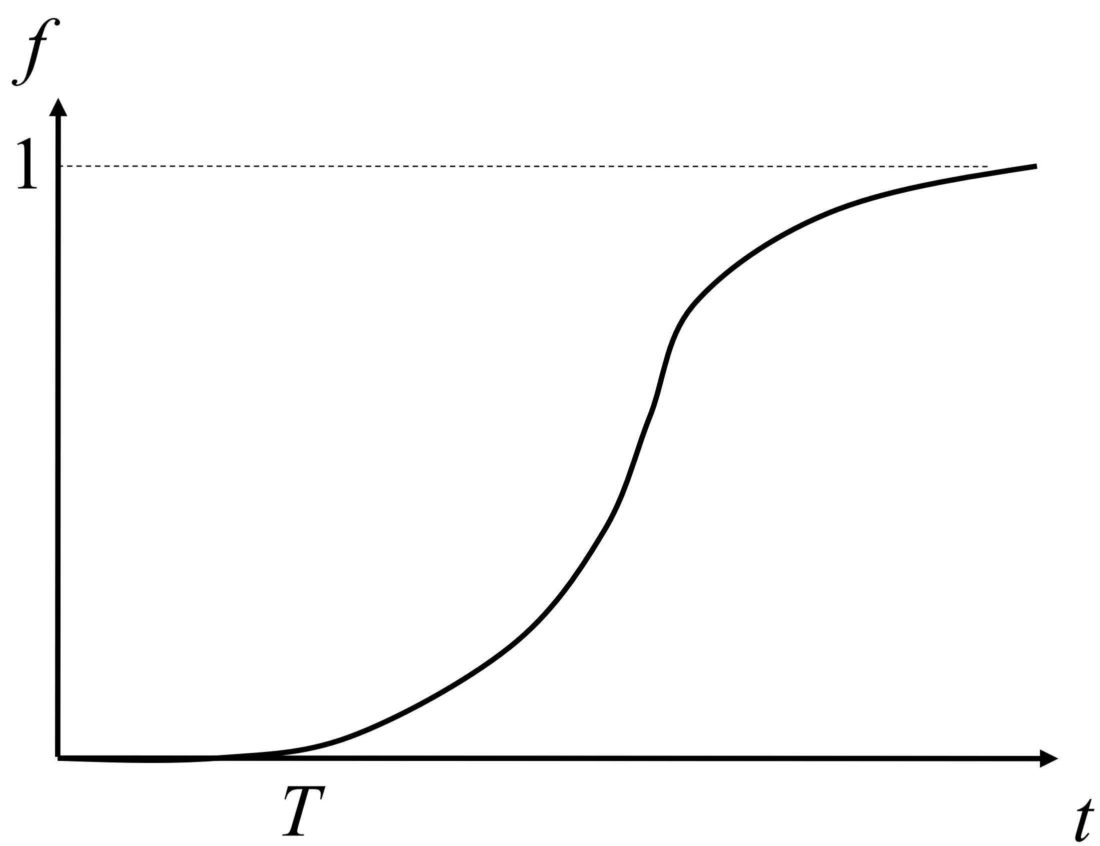

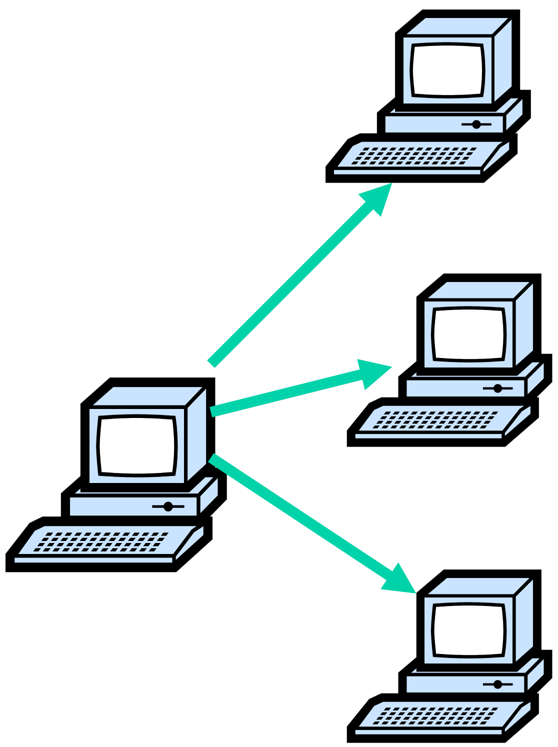

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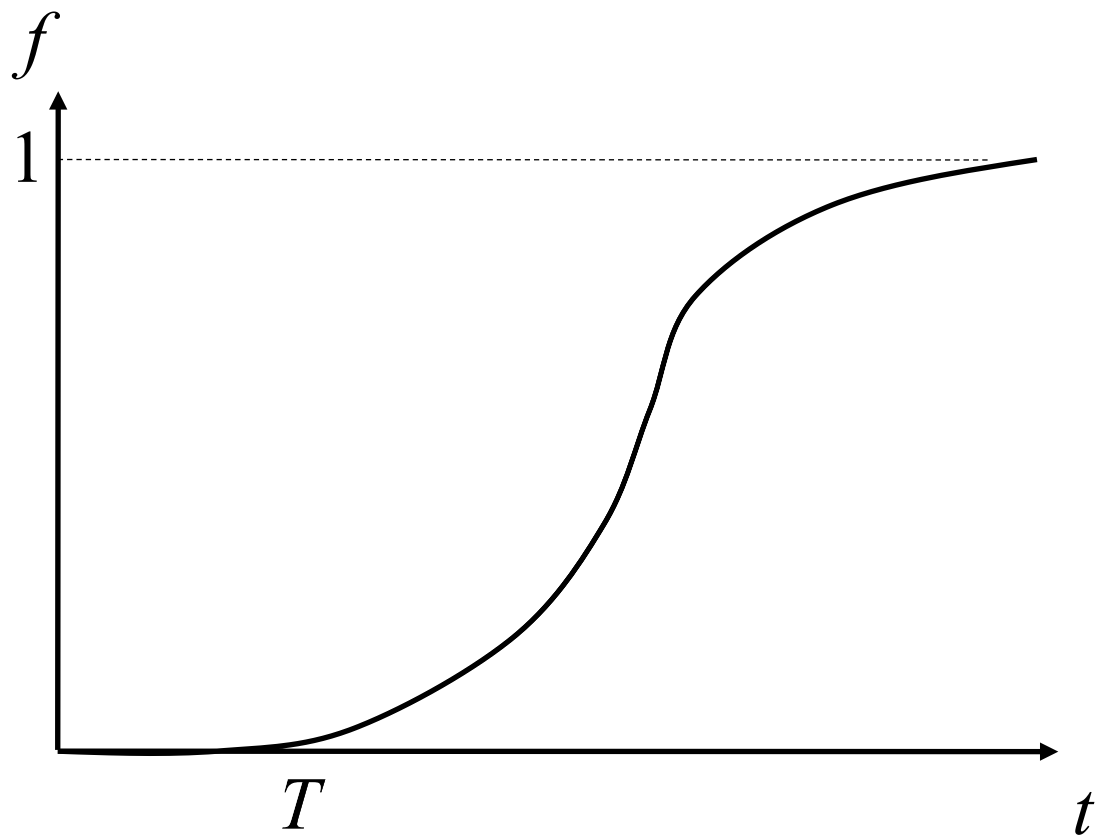
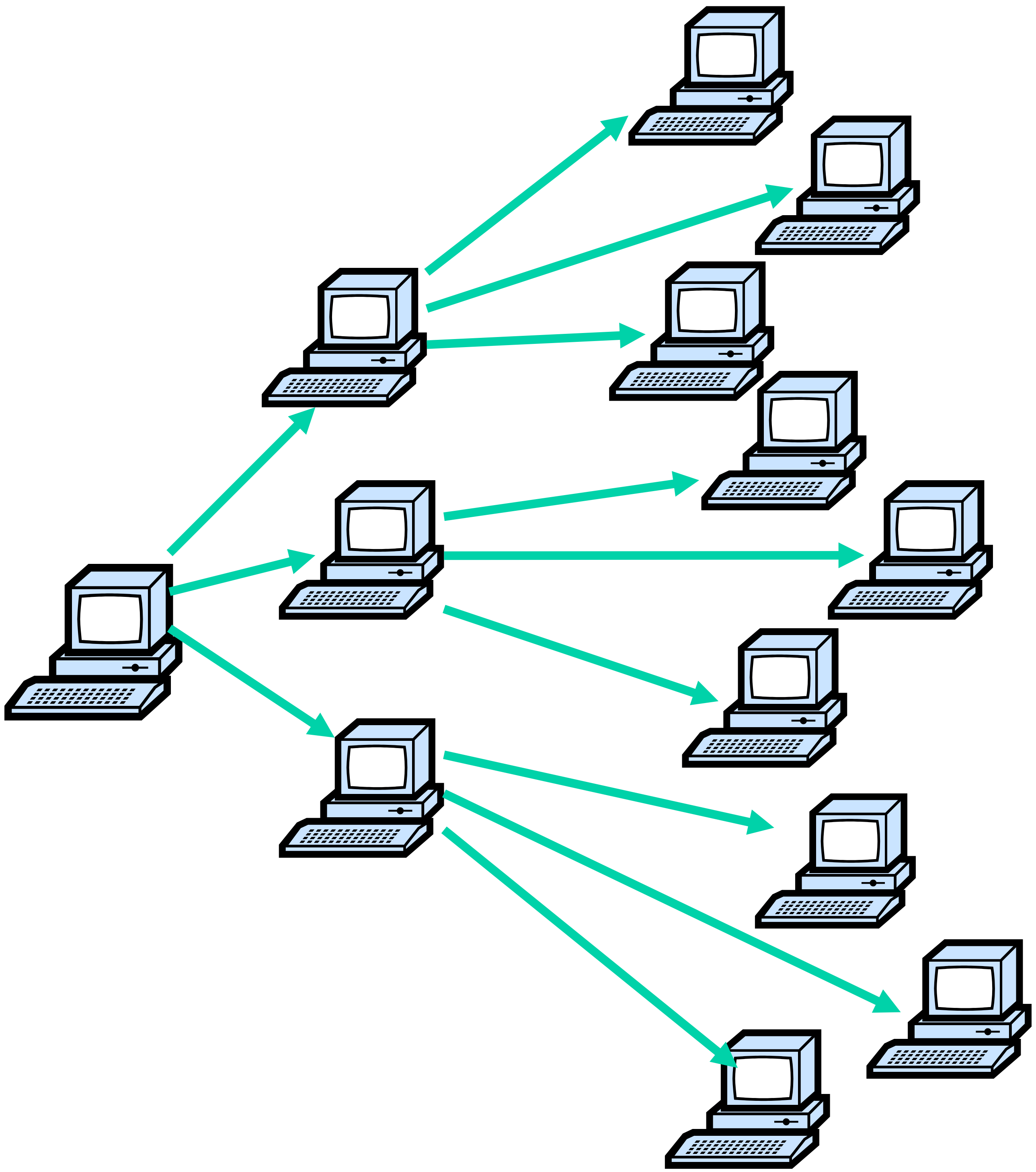




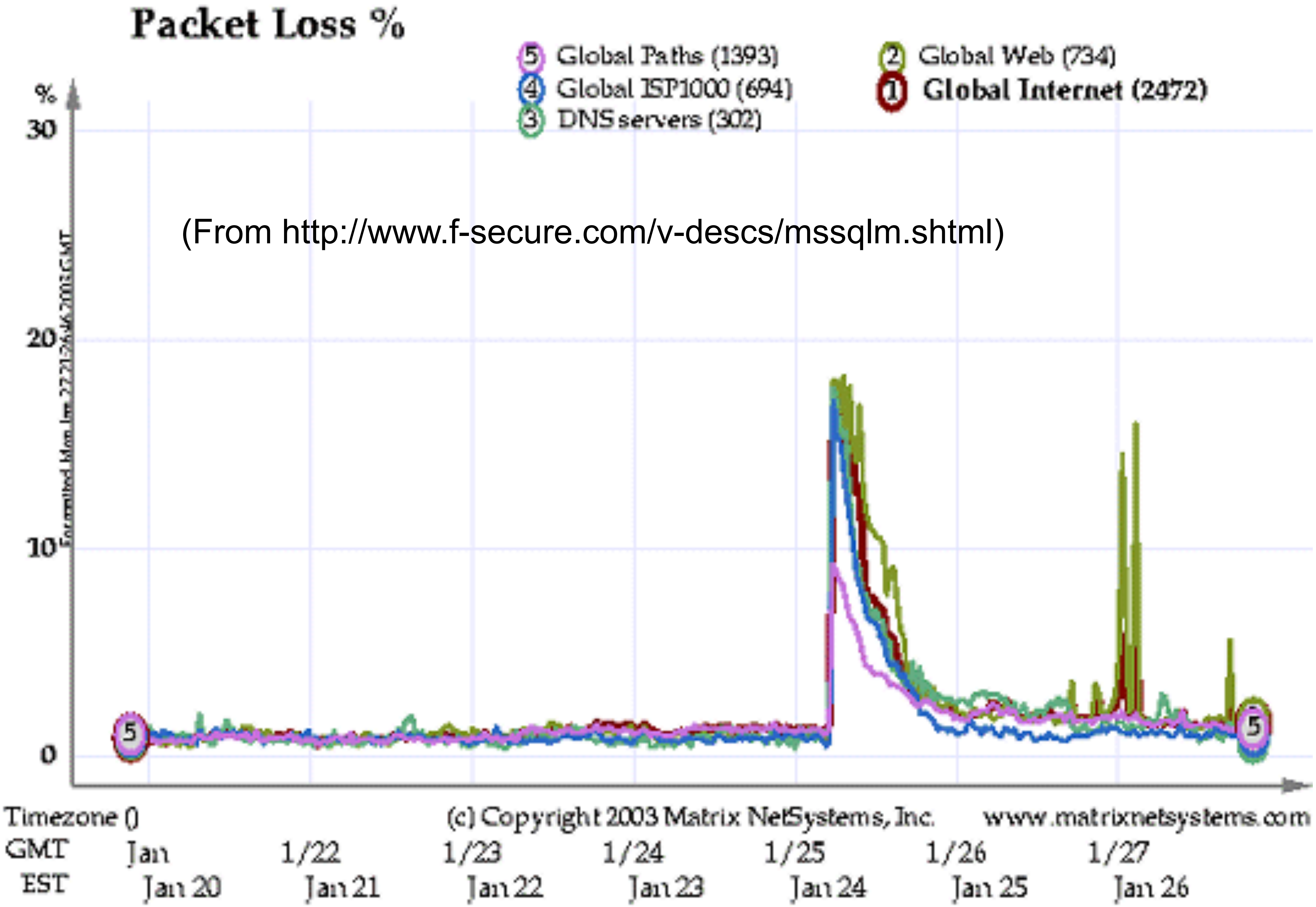
Worm Examples

- Morris worm (1988)
- Code Red (2001)
- MS Slammer (January 2003)
- MS Blaster (August 2003)

MS SQL Slammer (January 2003)

- Uses UDP port 1434 to exploit a buffer overflow in MS SQL server
- Effect
  - Generate massive amounts of network packets
  - Brought down as many as 5 of the 13 internet root name servers
- Others
  - The worm only spreads as an in-memory process: it never writes itself to the hard drive
    - Solution: close UDP port on firewall and reboot

MS SQL Slammer (January 2003)



(From http://www.f-secure.com/v-descs/mssqlm.shtml)

Hall of Shame

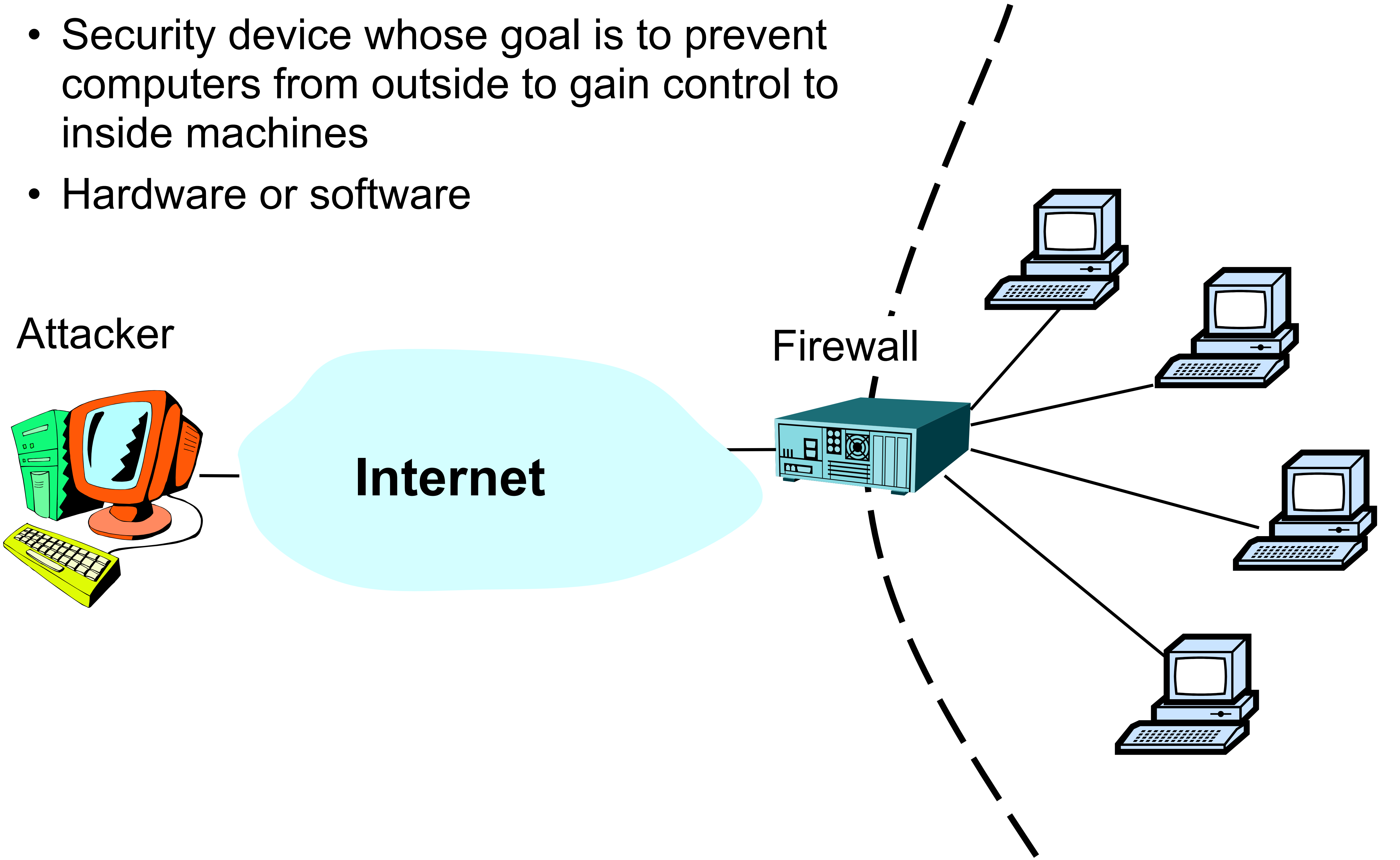
- Software that have had many stack overflow bugs:
  - BIND (most popular DNS server)
  - RPC (Remote Procedure Call, used for NFS)
    - NFS (Network File System)
  - Sendmail (most popular UNIX mail delivery software)
  - IIS (Windows web server)
  - SNMP (Simple Network Management Protocol, used to manage routers and other network devices)

Potential Solutions

- Don’t write buggy software
  - It’s not like people try to write buggy software
- Type-safe Languages
  - Unrestricted memory access of C/C++ contributes to problem
  - Use Java, Perl, or Python instead
- OS architecture
  - Compartmentalize programs better, so one compromise doesn’t compromise the entire system
  - E.g., DNS server doesn’t need total system access
- Firewalls

Firewall

- Security device whose goal is to prevent computers from outside to gain control to inside machines
- Hardware or software



Firewall (cont'd)

- Restrict traffic between Internet and devices (machines) behind it based on
  - Source address and port number
  - Payload
  - Stateful analysis of data
- Examples of rules
  - Block any external packets not for port 80
  - Block any email with an attachment
  - Block any external packets with an internal IP address
    - Ingress filtering

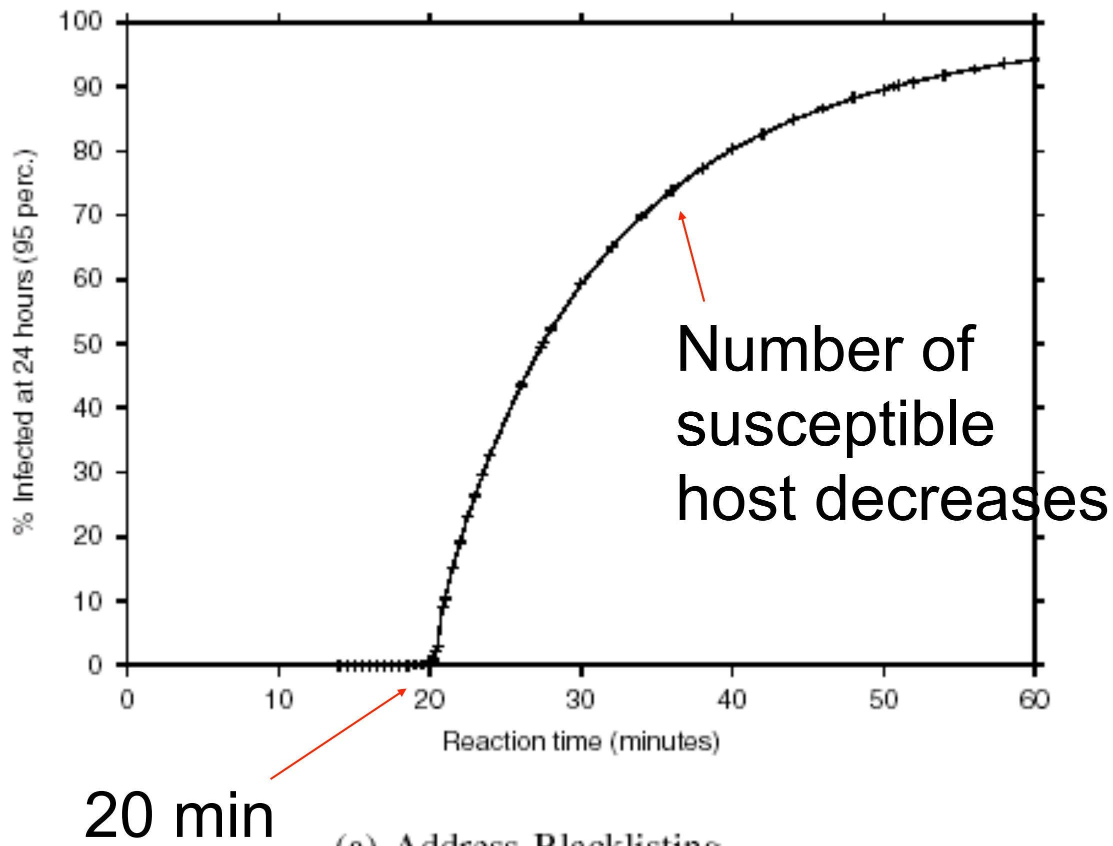
Firewalls: Properties

- Easier to deploy firewall than secure all internal hosts
- Doesn't prevent user exploitation
- Tradeoff between availability of services (firewall passes more ports on more machines) and security
  - If firewall is too restrictive, users will find way around it, thus compromising security
  - E.g., have all services use port 80

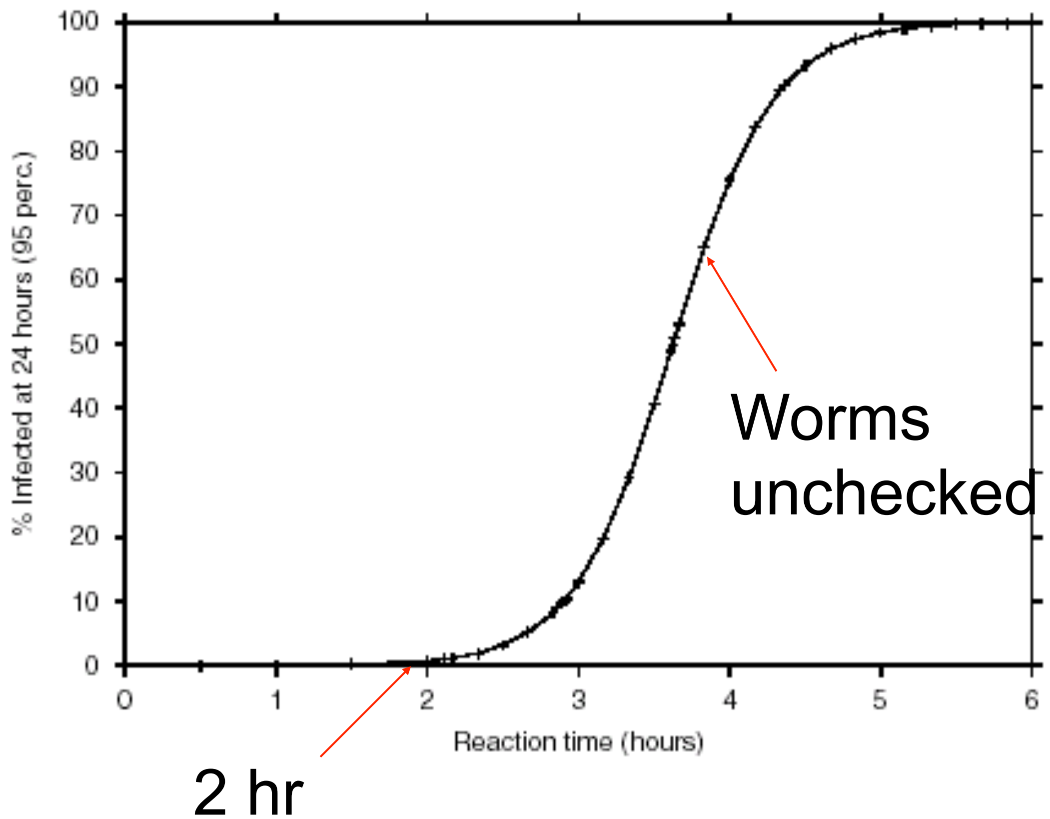
- Can't prevent problem from spreading from within

Address Blacklisting and Content Filtering Solutions against Code Red Worm

- Result: content filtering is more effective.



(a) Address Blacklisting



(b) Content Filtering

Host Compromise: User Exploitation

- Some security architectures rely on the user to decide if a potentially dangerous action should be taken, e.g.,
  - Run code downloaded from the Internet
    - "Do you accept content from Microsoft?"
  - Run code attached to email
    - "subject: You've got to see this!"
  - Allow a macro in a data file to be run
    - "Here is the latest version of the document."

User Exploitation

- Users are not good at making this decision
  - Which of the following is the real name Microsoft uses when you download code from them?
    - Microsoft
    - Microsoft, Inc.
    - Microsoft Corporation
- Typical email attack
  - Attacker sends email to some initial victims
  - Reading the email / running its attachment / viewing its attachment opens the hole
  - Worm/trojan/virus mails itself to everyone in address book

Solutions

- OS architecture
- Don’t ask the users questions which they don’t know how to answer anyway
- Separate code and data
  – Viewing data should not launch attack
- Be very careful about installing new software

Denial of Service

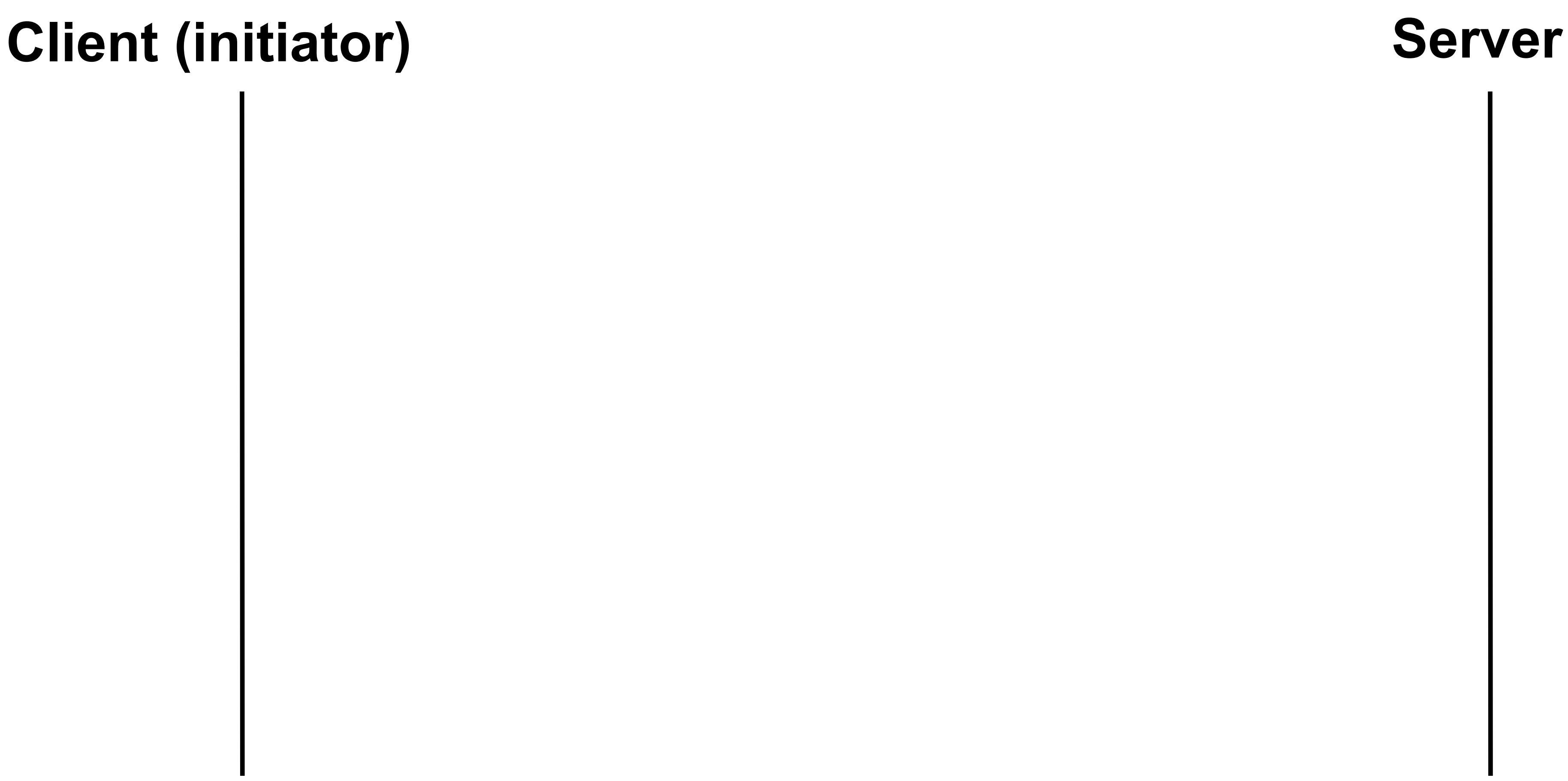
- Huge problem in current Internet
  - Major sites attacked: Yahoo!, Amazon, eBay, CNN, Microsoft
  - 12,000 attacks on 2,000 organizations in 3 weeks
  - Some more that 600,000 packets/second
    - More than 192Mb/s
  - Almost all attacks launched from compromised hosts
- General form
  - Prevent legitimate users from gaining service by overloading or crashing a server
  - E.g., SYN attack

Effect on Victim

- Buggy implementations allow unfinished connections to eat all memory, leading to crash
- Better implementations limit the number of unfinished connections
  - Once limit reached, new SYNs are dropped
- Effect on victim's users
  - Users can't access the targeted service on the victim because the unfinished connection queue is full → DoS

SYN Attack (Recap: 3-Way Handshaking)

- Goal: agree on a set of parameters: the start sequence number for each side
  - Starting sequence numbers are random.



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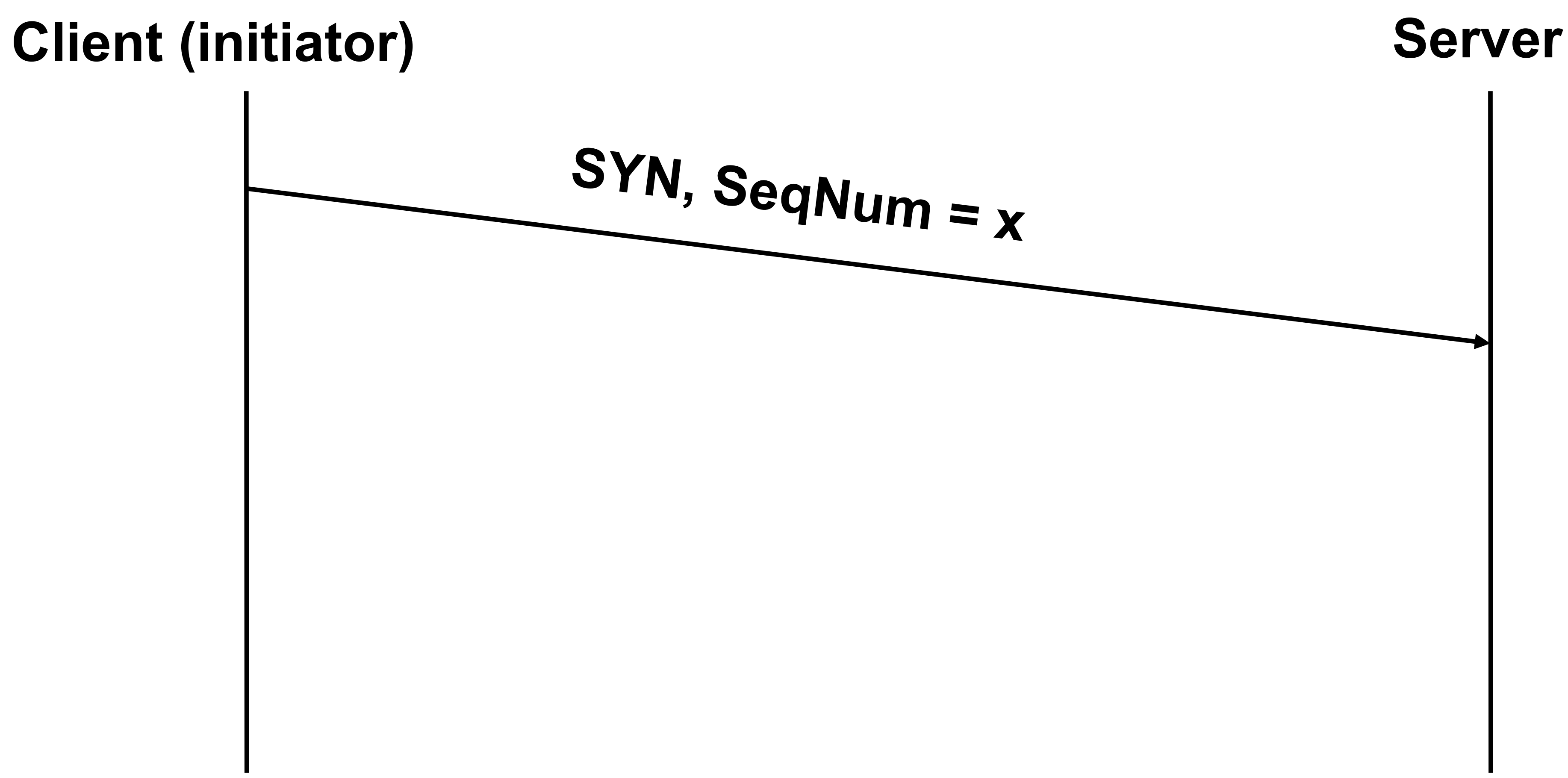

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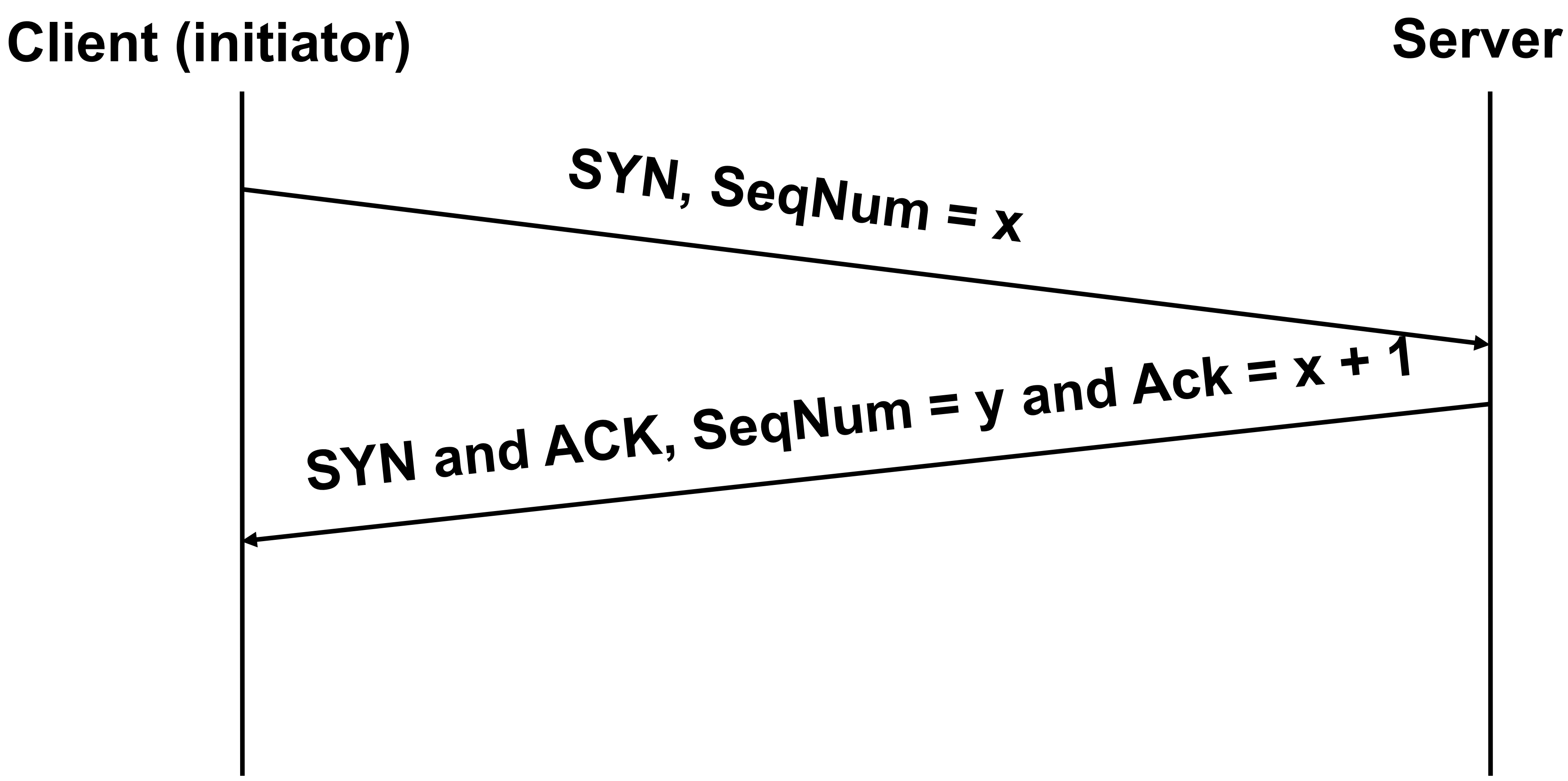

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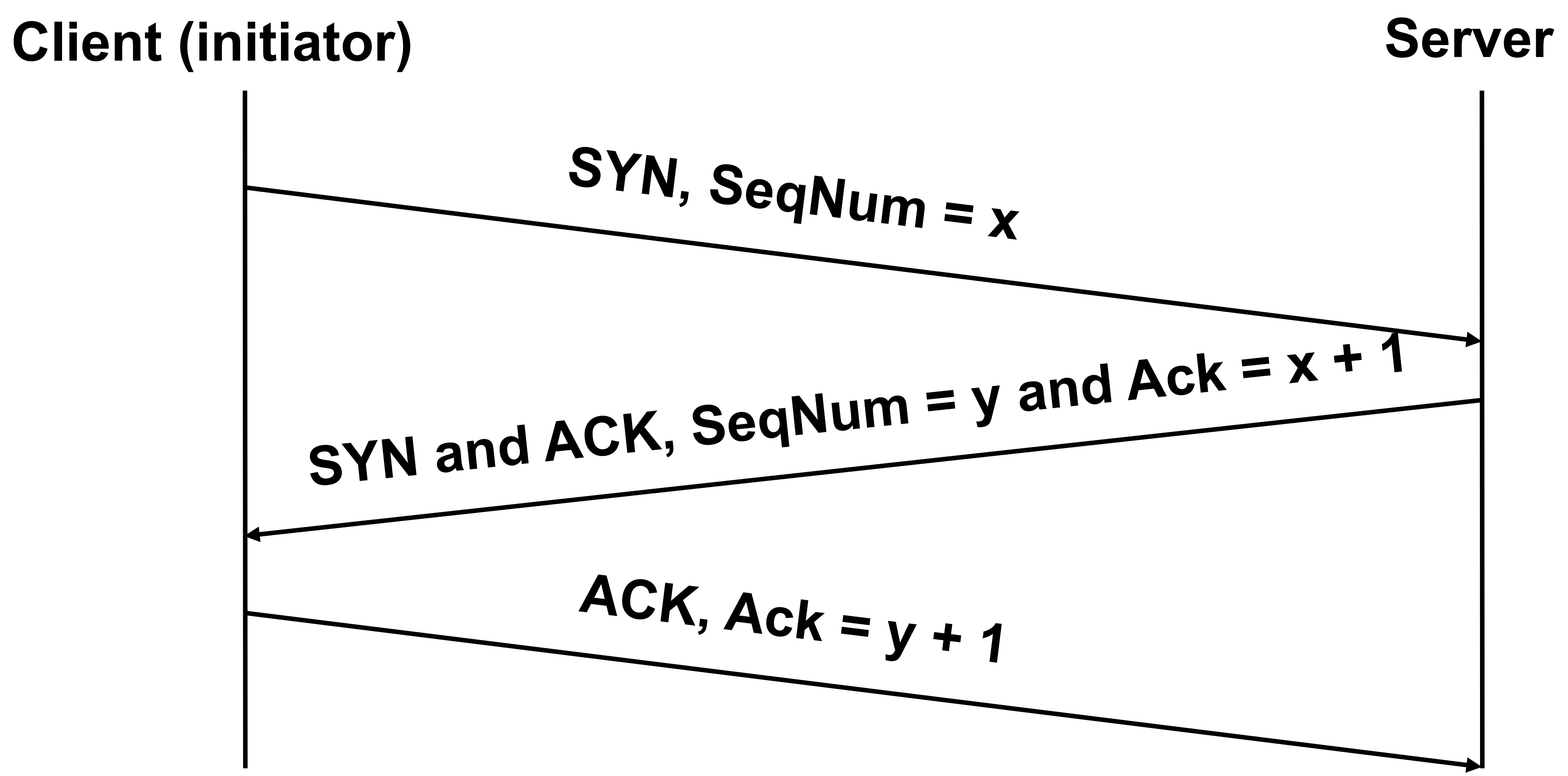


SYN Attack

- Attacker: send at max rate TCP SYN with random spoofed source address to victim
  - Spoofing: use a different source IP address than own
  - Random spoofing allows one host to pretend to be many
- Victim receives many SYN packets
  - Send SYN+ACK back to spoofed IP addresses
  - Holds some memory until 3-way handshake completes
    - Usually never, so victim times out after long period (e.g., 3 minutes)

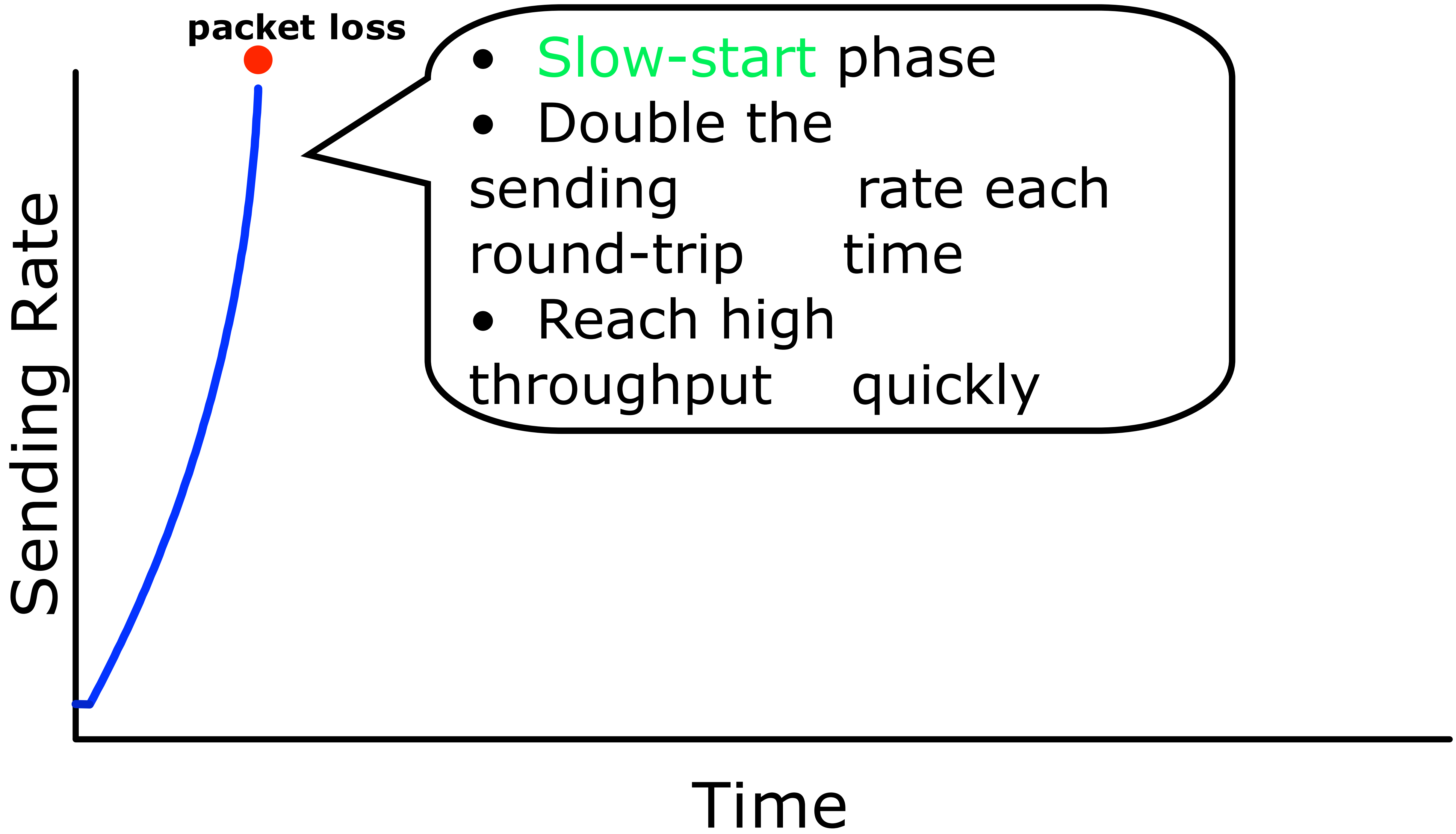
Solution: SYN Cookies

- Server: send SYN-ACK with sequence number y, where
  - y = H(client_IP_addr, client_port, server_secret)
  - H(): one-way hash function
- Client: send ACK containing y+1
- Sever:
  - verify if y = H(client_IP_addr, client_port, server_secret)
  - If verification passes, allocate memory
- Note: server doesn't allocate any memory if the client's address is spoofed

Shrew

- Very small but aggressive mammal that ferociously attacks and kills much larger animals with a venomous bite

TCP Congestion Control



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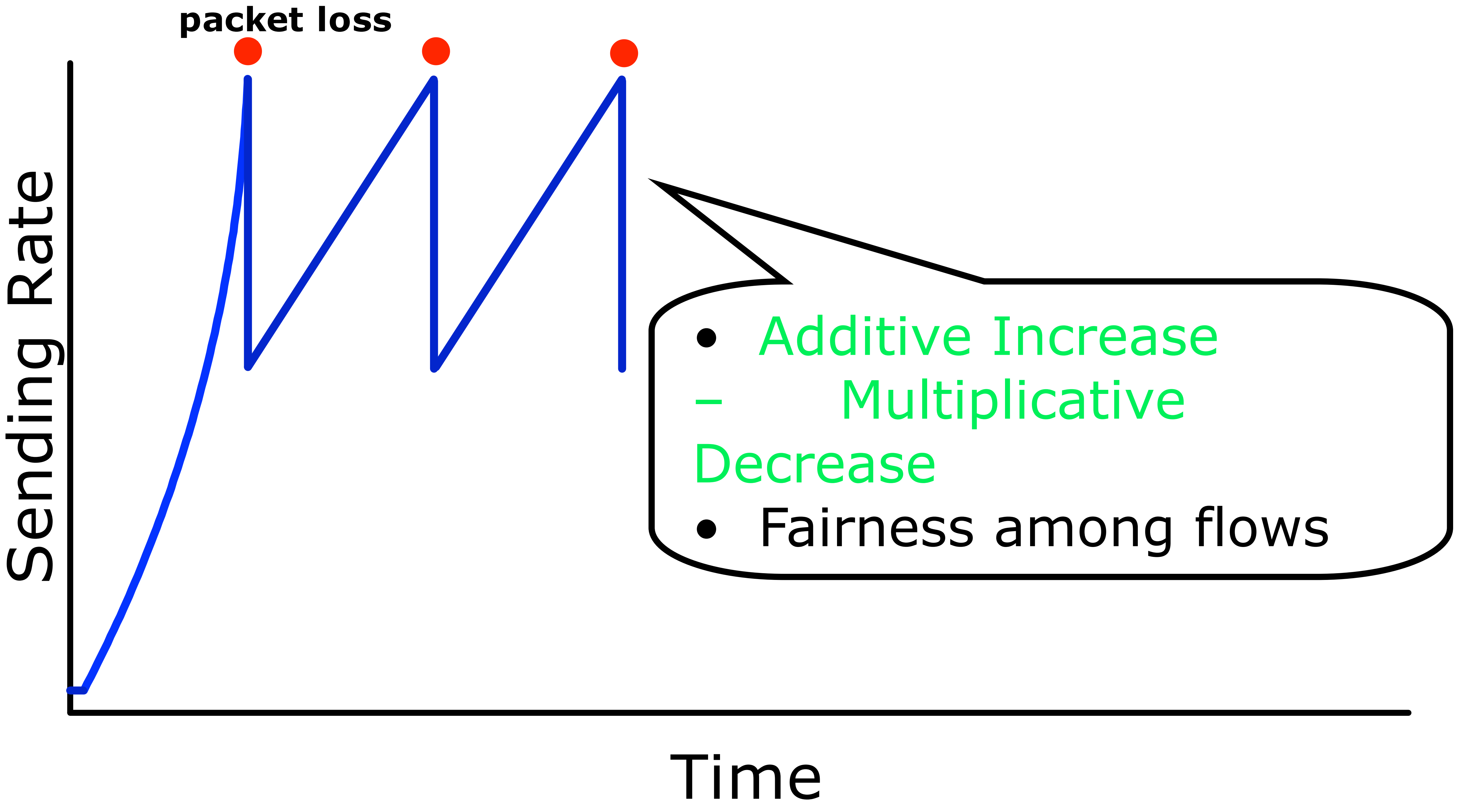

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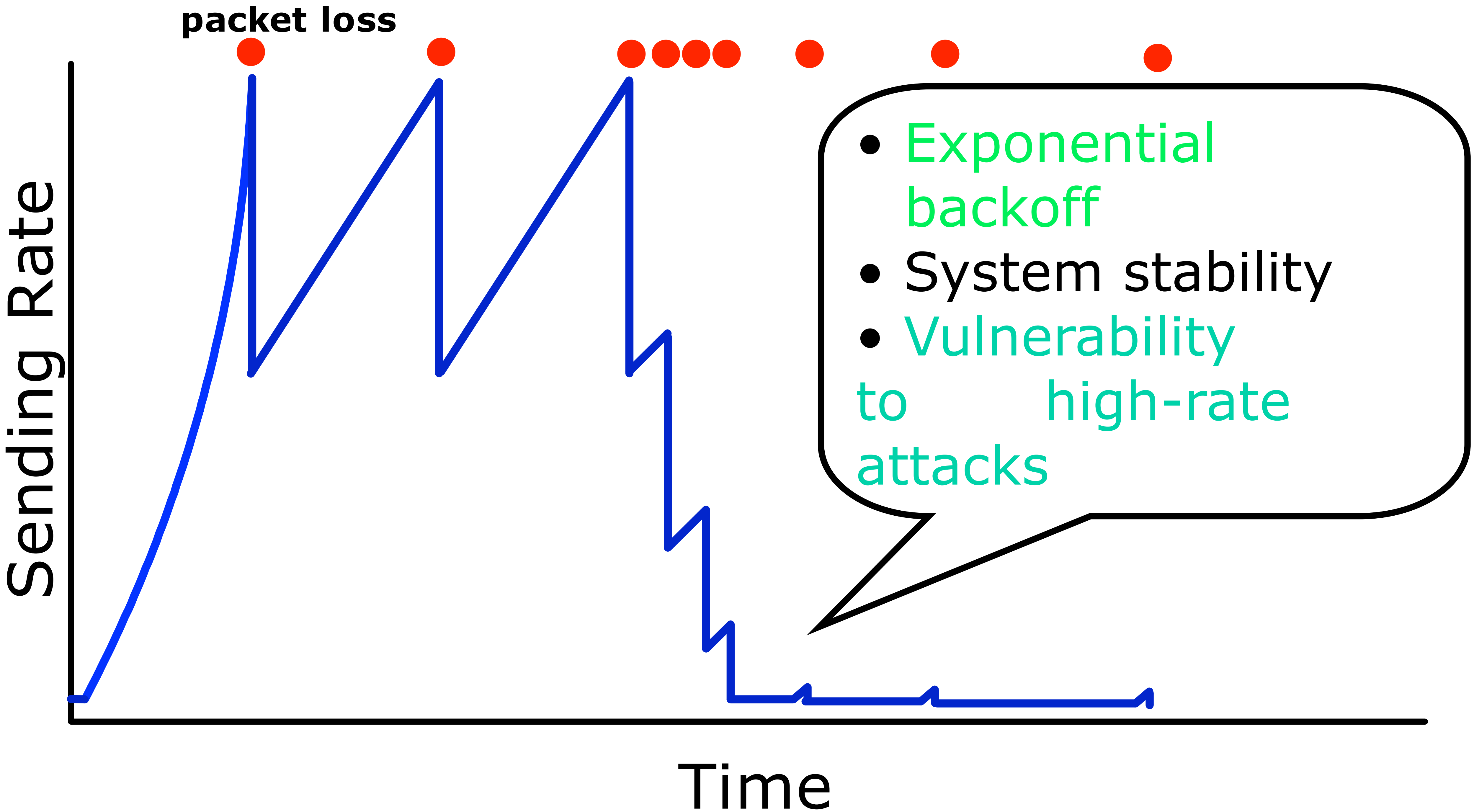
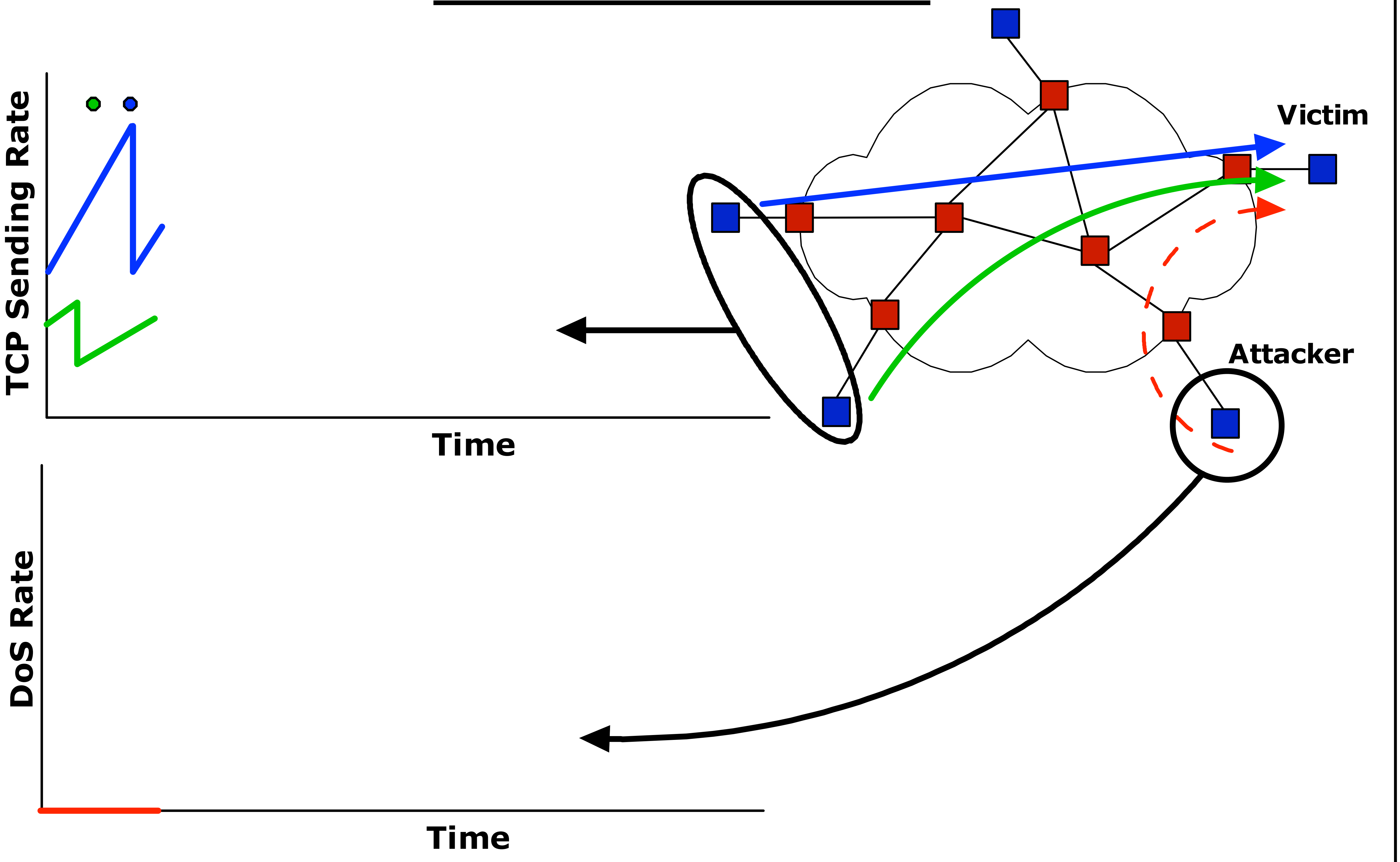


TCP: a Dual Time-Scale Perspective

- Two time-scales **fundamentally** required
  - RTT time-scales (~10-100 ms)
    - AIMD control
  - RTO time-scales (*RTO=SRTT+4*RTTVAR*)
    - Avoid congestion collapse
- Lower-bounding the RTO parameter:
  - [AllPax99]: minRTO = 1 sec
    - to avoid spurious retransmissions
  - RFC2988 recommends minRTO = 1 sec

Discrepancy between RTO and RTT time-scales is a **key source of vulnerability** to low rate attacks

The Shrew Attack



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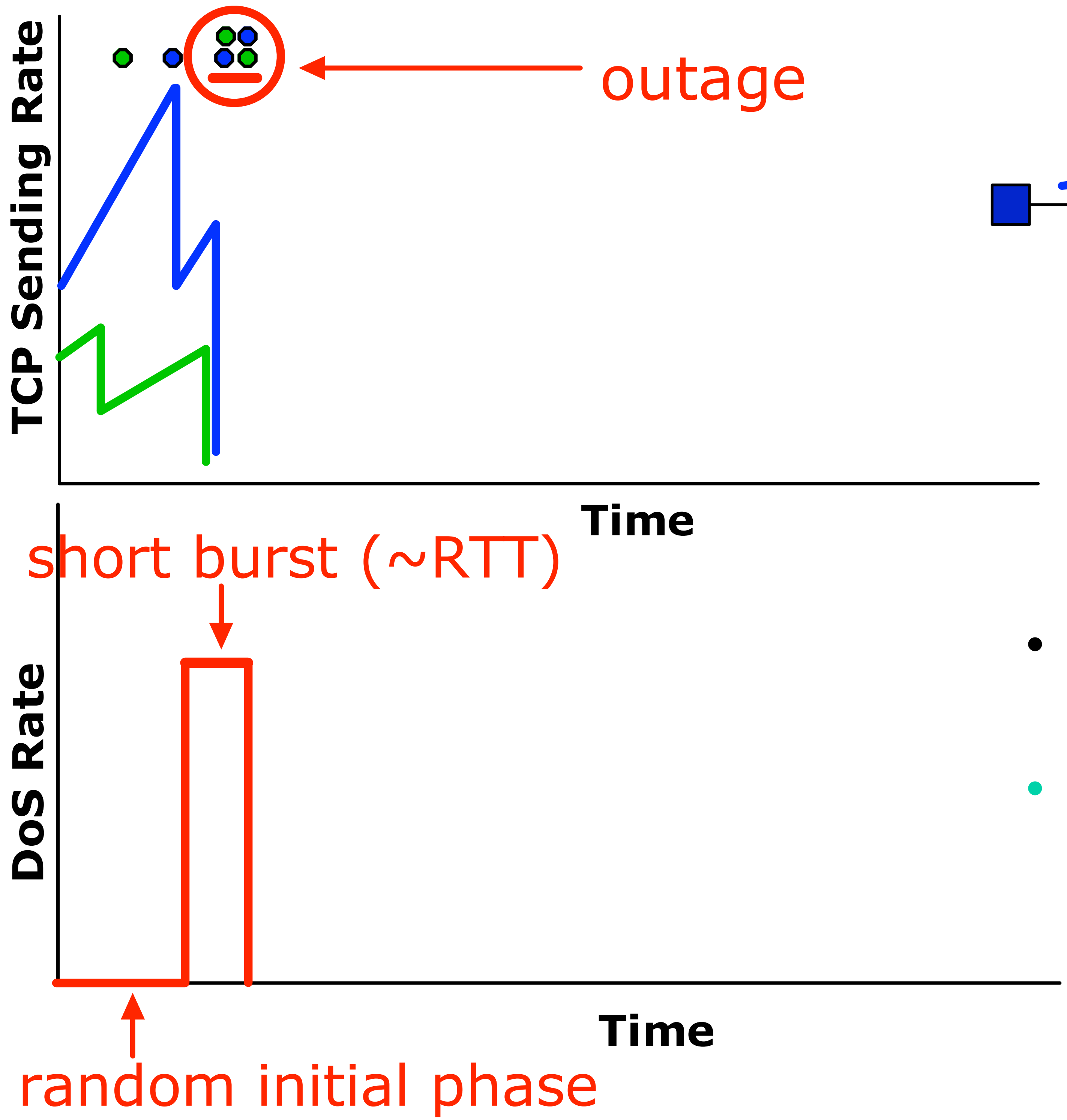

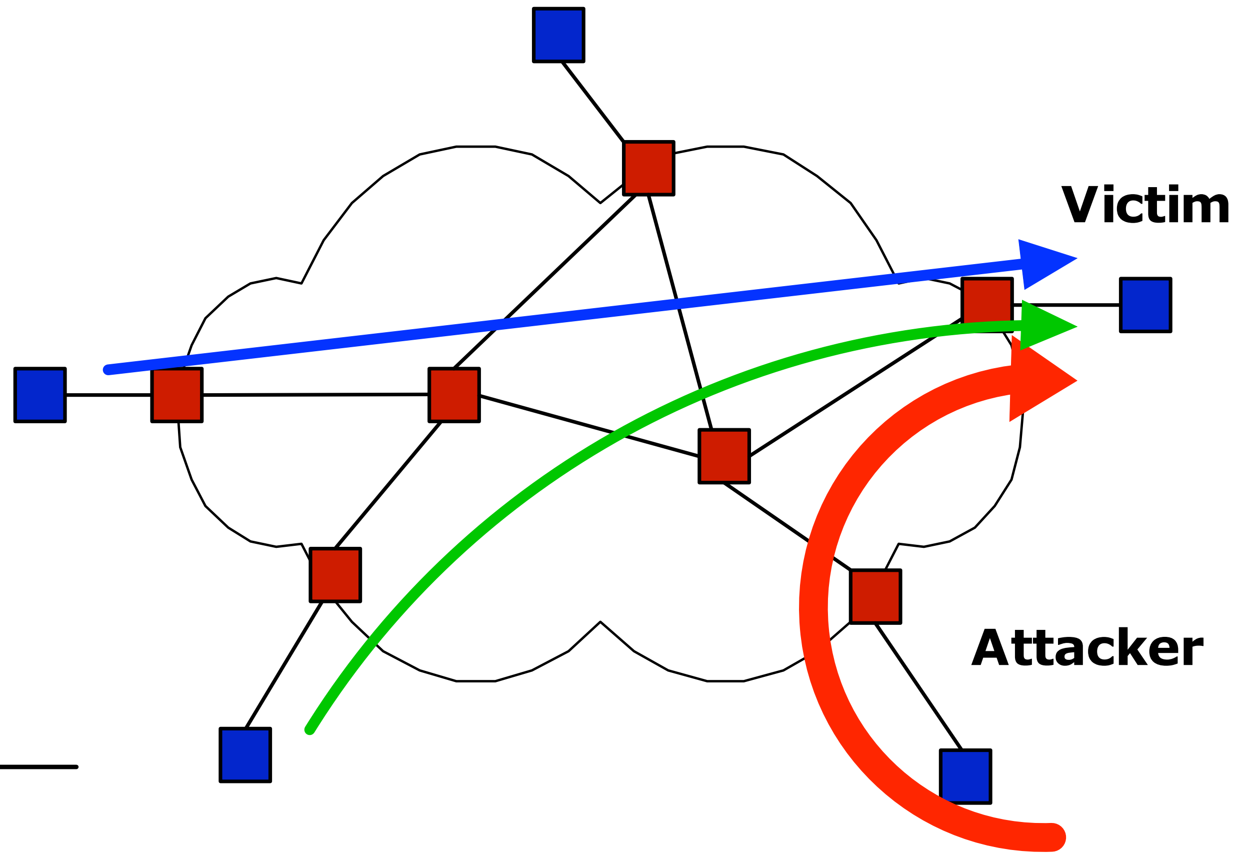

- A short burst (~RTT) sufficient to create outage
- Outage – event of correlated packet losses that forces TCP to enter RTO mechanism

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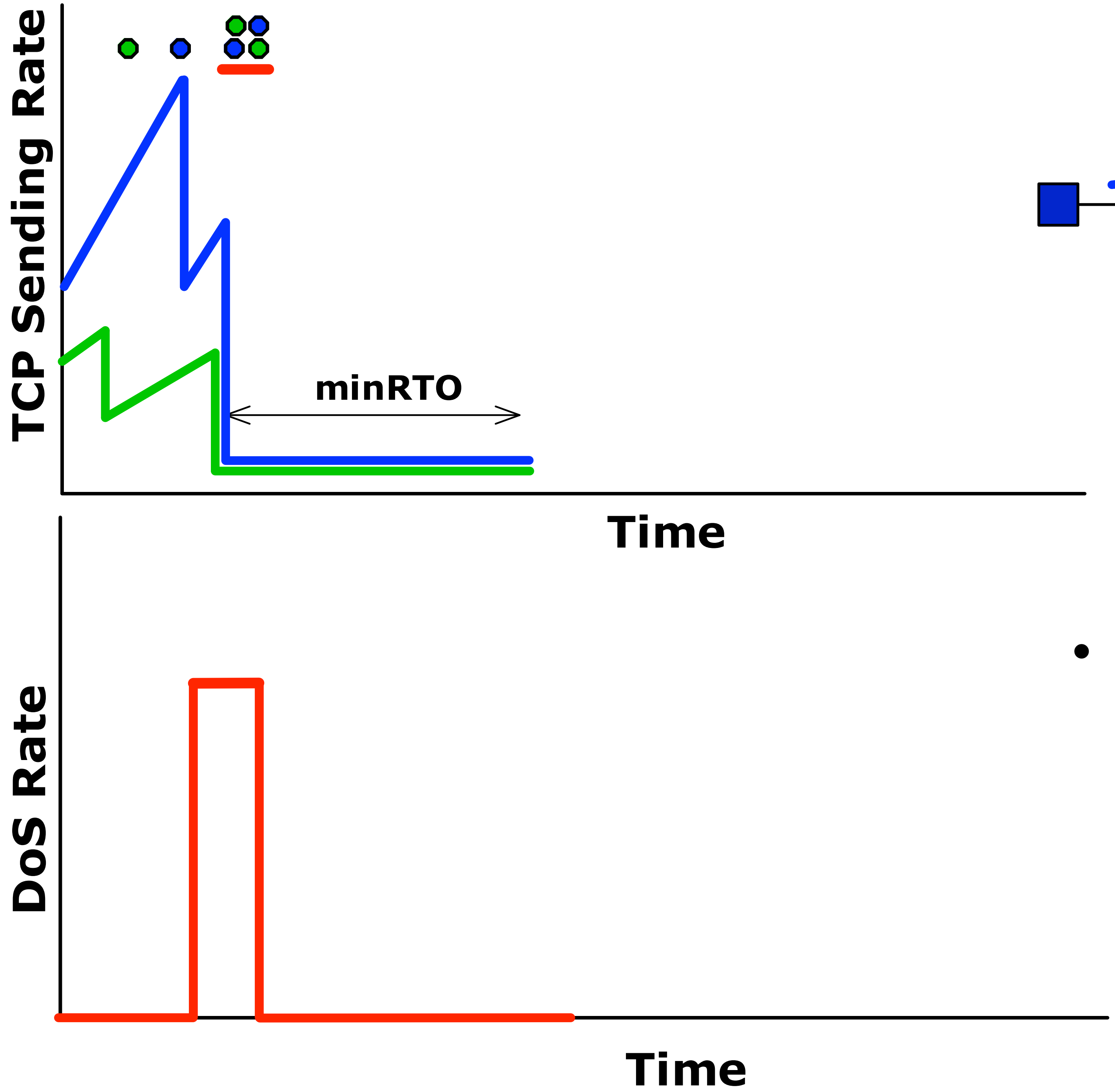
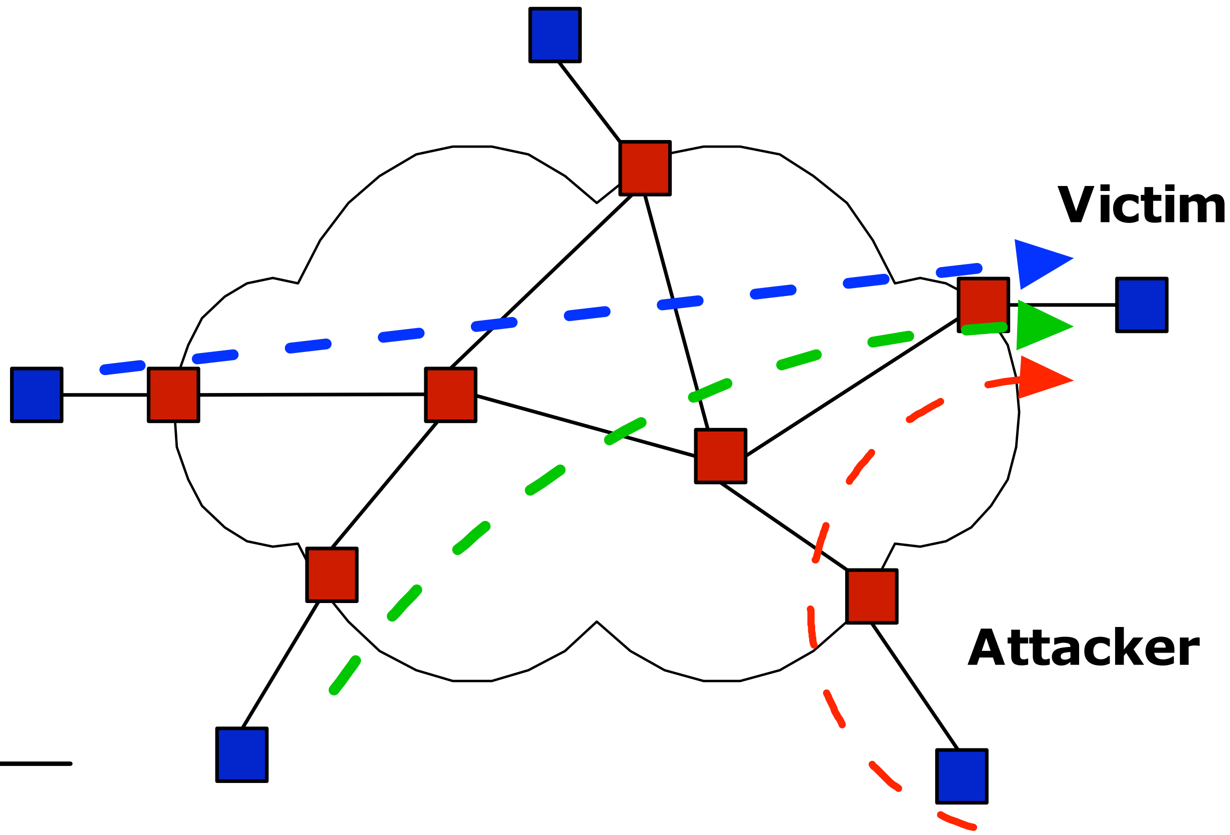
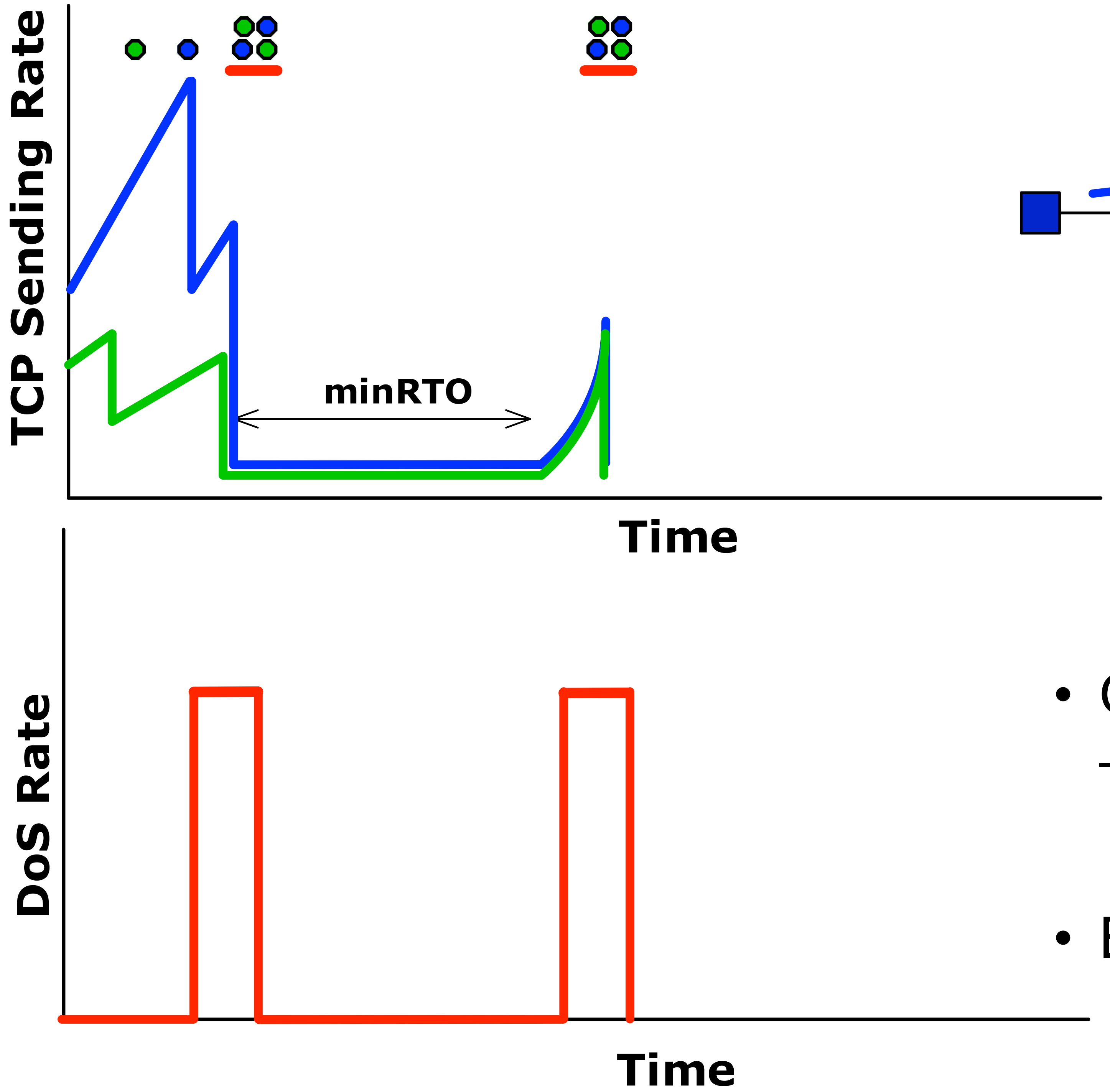
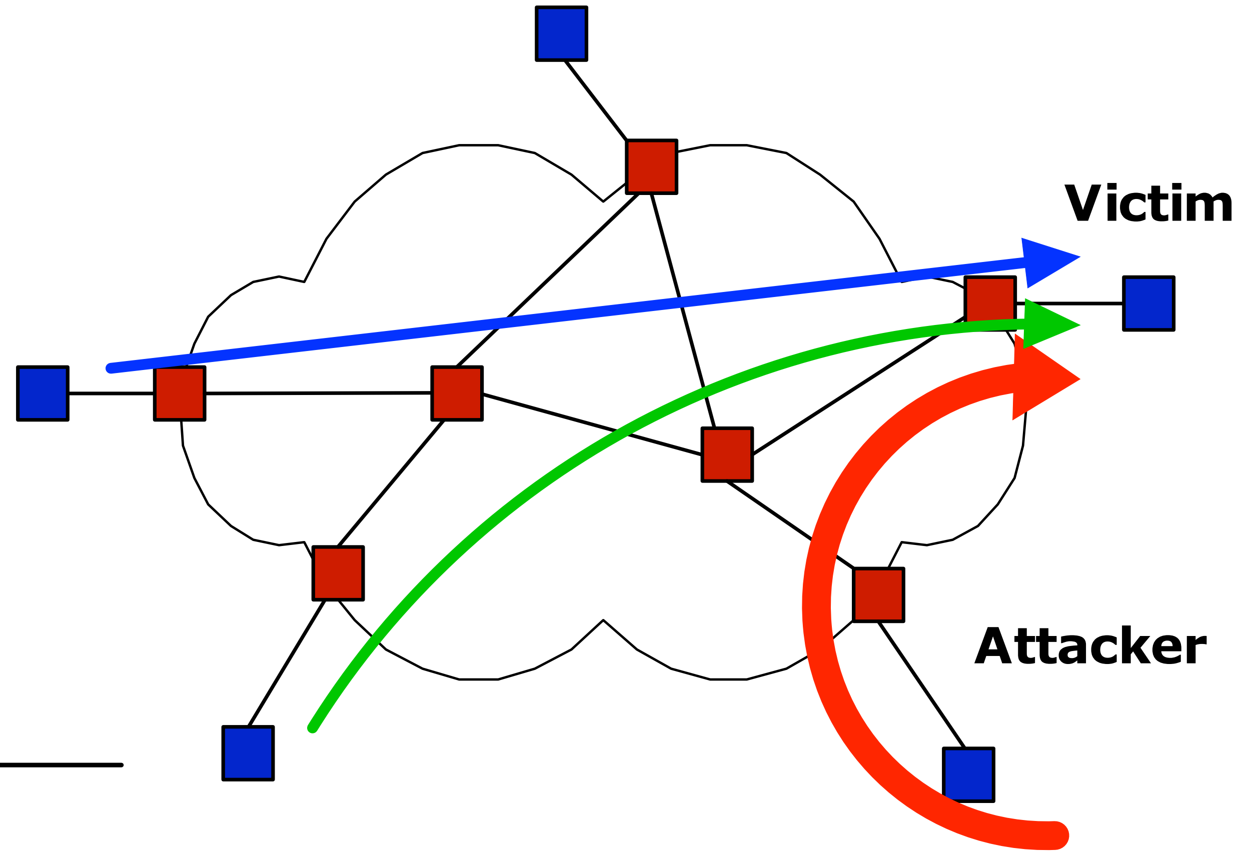




- The outage synchronizes all TCP flows
  - All flows react simultaneously and identically
    - backoff for minRTO

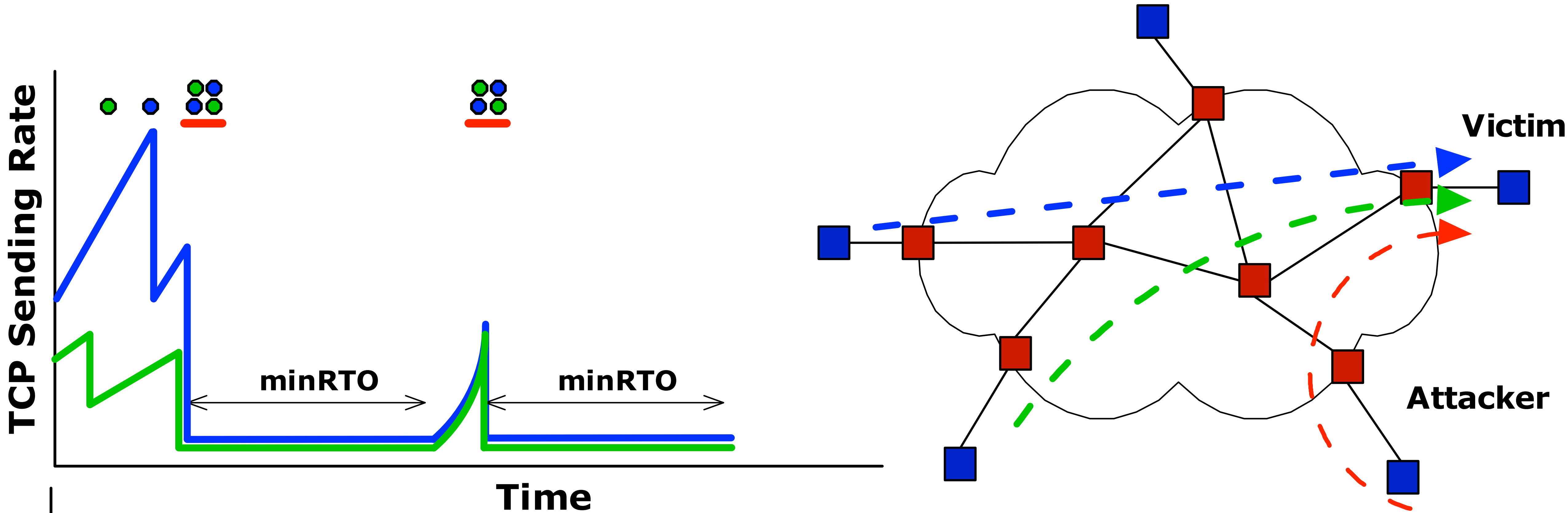
The Shrew Attack

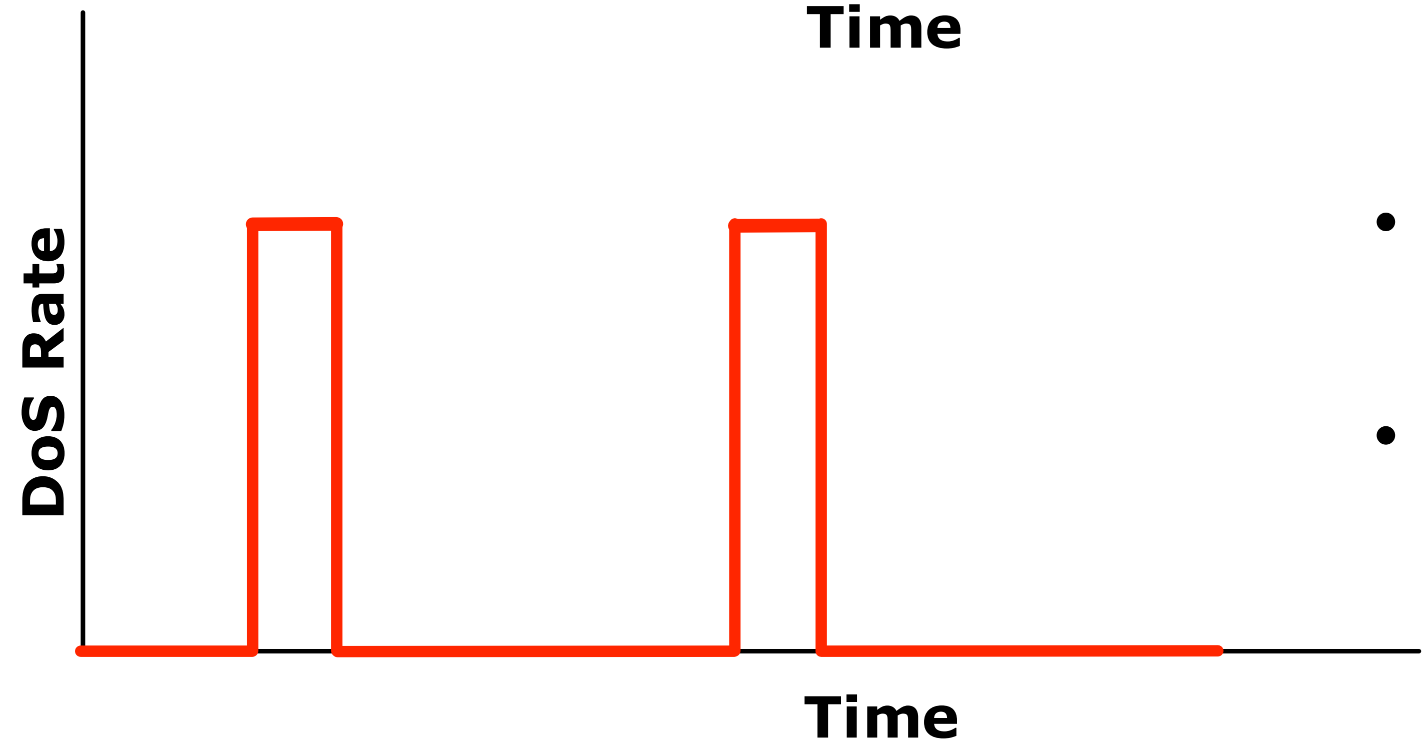




- Once the TCP flows try to recover – hit them again
- Exploit protocol determinism

The Shrew Attack



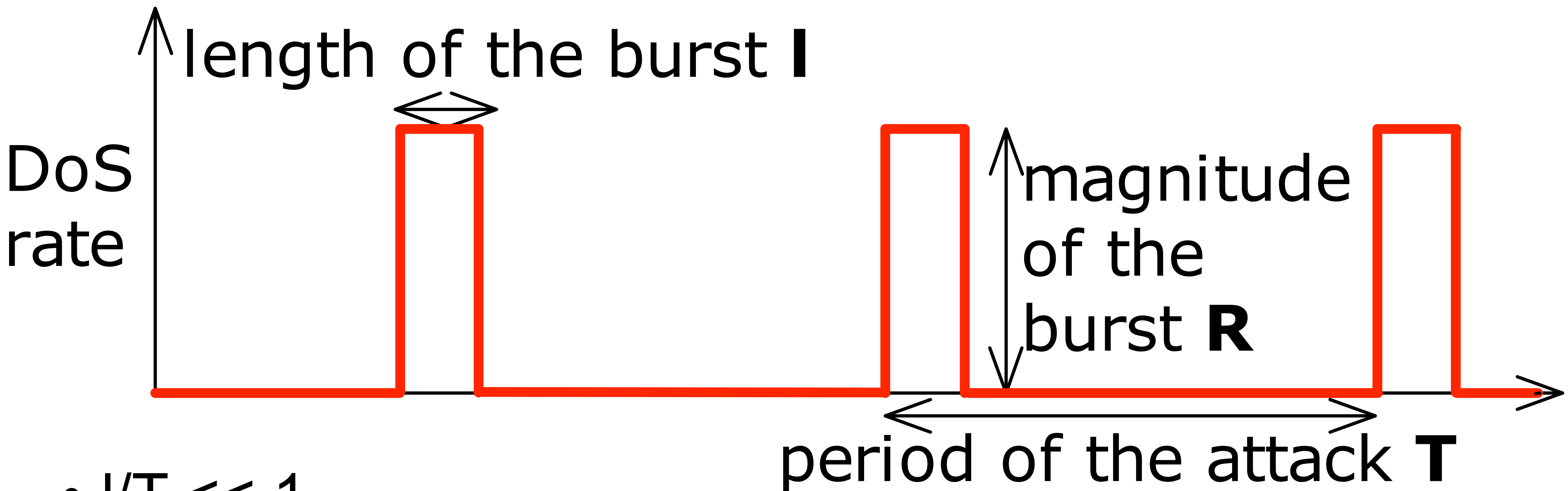


- And keep repeating…
- RTT-time-scale outages inter-spaced on minRTO periods can deny service to TCP traffic

Shrew Principles

- A single RTT-length outage forces all TCP flows to *simultaneously* enter timeout
  - All flows respond *identically* and backoff for the minRTO period
- Shrews exploit protocol *determinism*, and repeat the outage after each minRTO period
- Periodic outages *synchronize* TCP flows and deny their service
- Outages occur relatively slowly (RTO-scale) and can be induced with low average rate

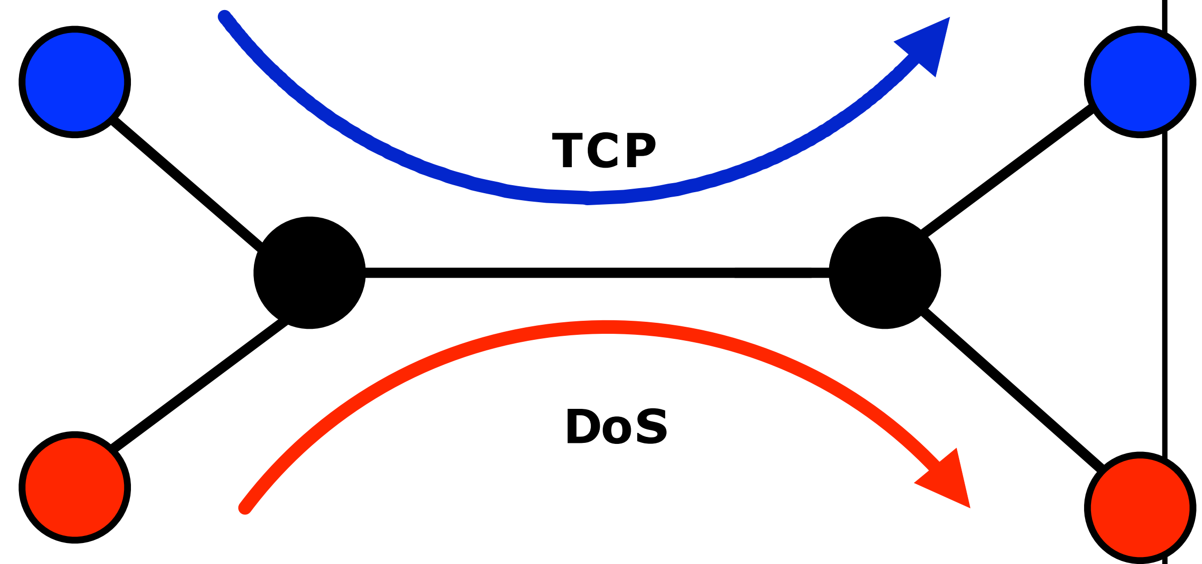
Shrews are Hard to Detect

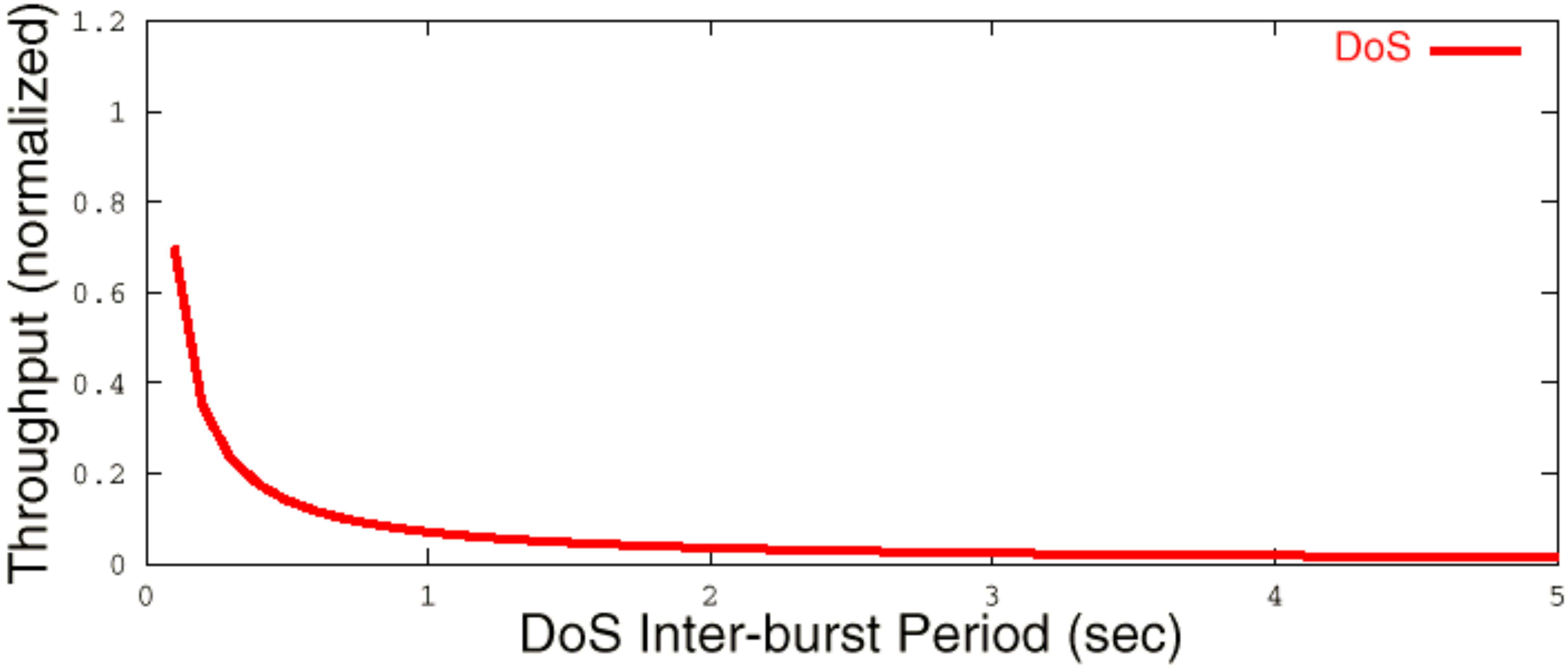


- l/T << 1
- **Low-rate flow is hard to detect**
  - Most counter-DOS mechanisms tuned for high-rate attacks
  - Detecting Shrews may have unacceptably many *false alarms* (due to legitimate bursty flows)

The Shrew in Action

- How much is TCP throughput degraded?
- **DoS** stream:
  - **R=C=**1.5Mb/s;
  - **l**=70ms (~TCP RTT)





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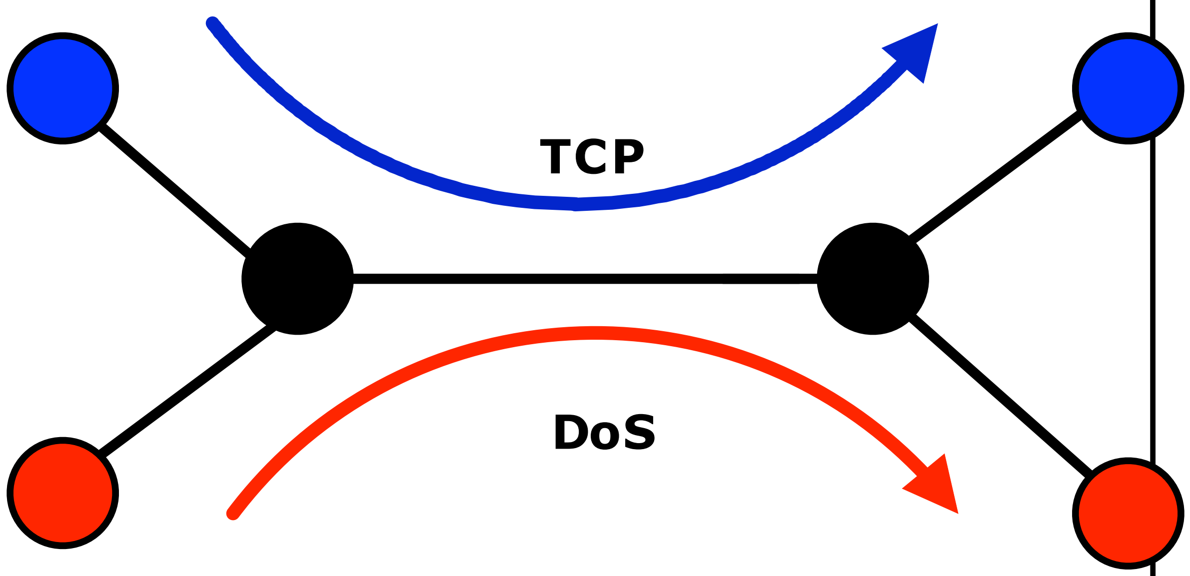
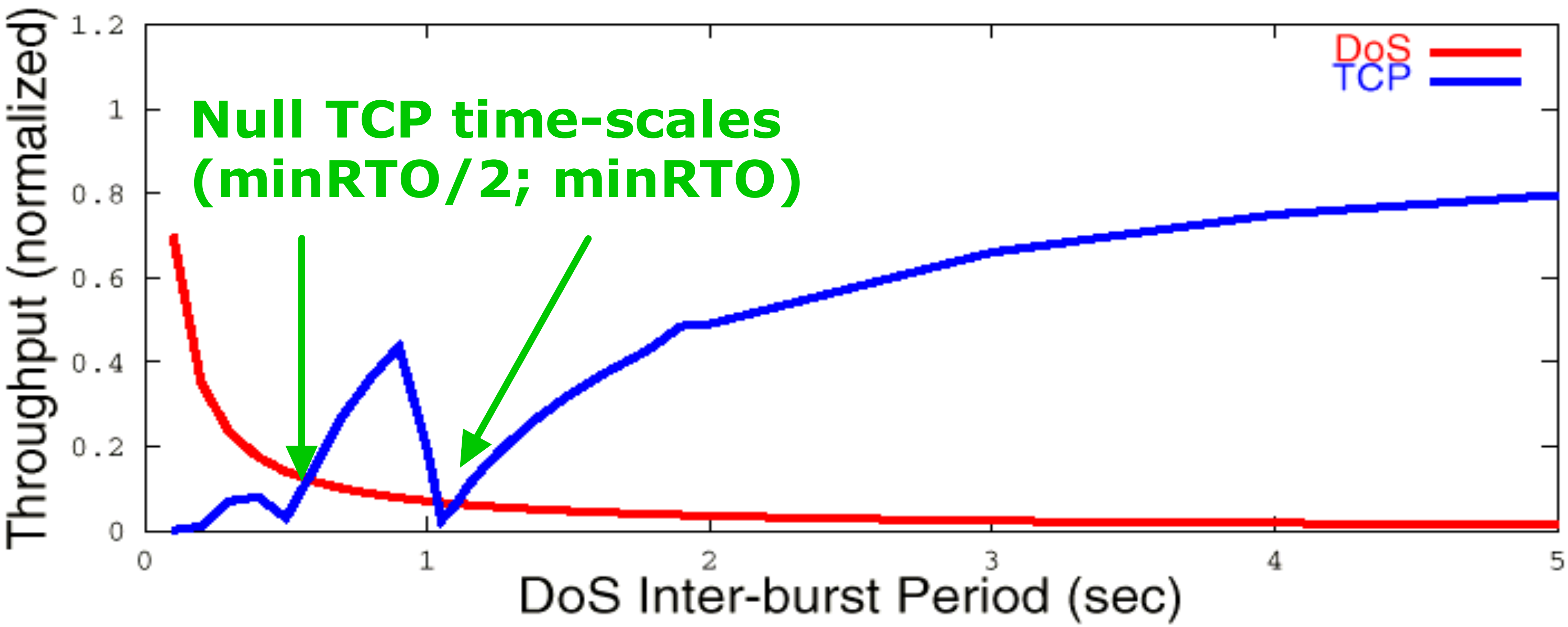
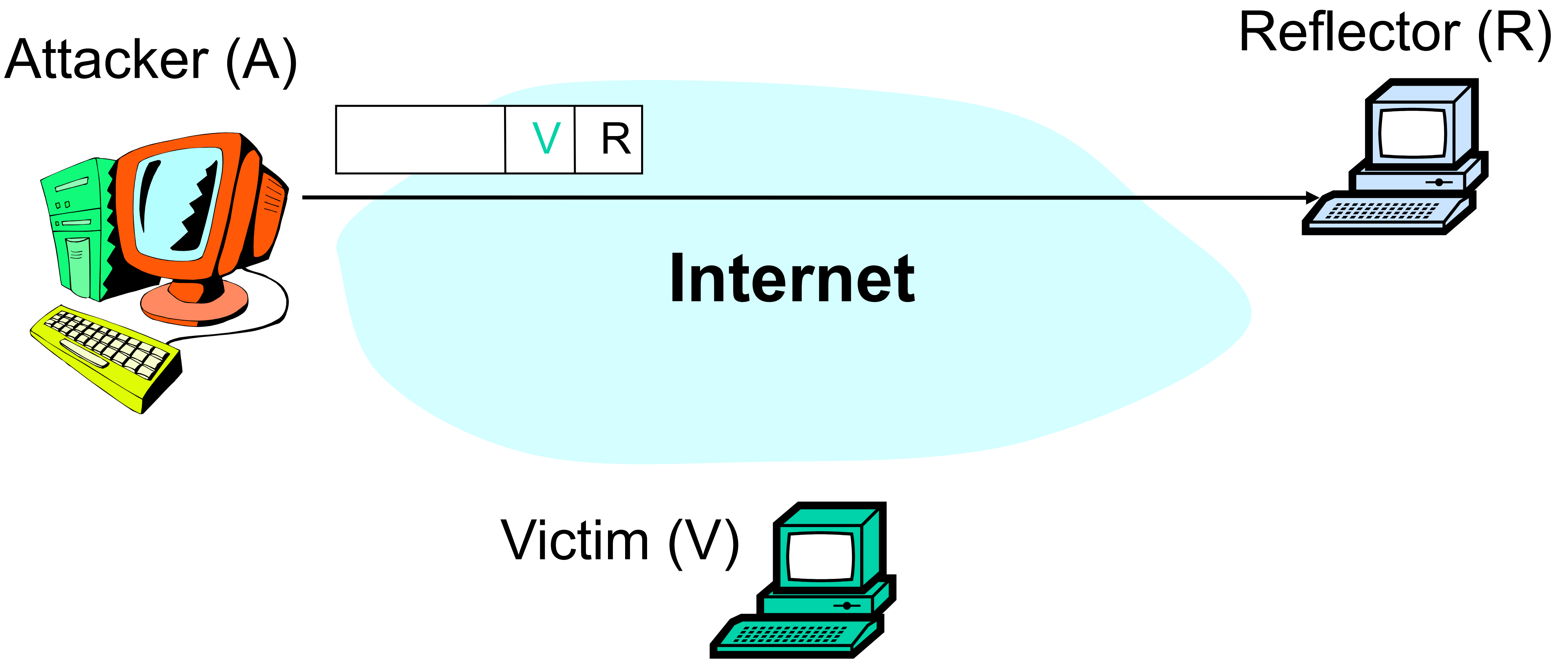




Other Denial-of-Service Attacks

- Reflection
  - Cause one non-compromised host to attack another
  - E.g., host A sends DNS request or TCP SYN with source V to server R. R sends reply to V



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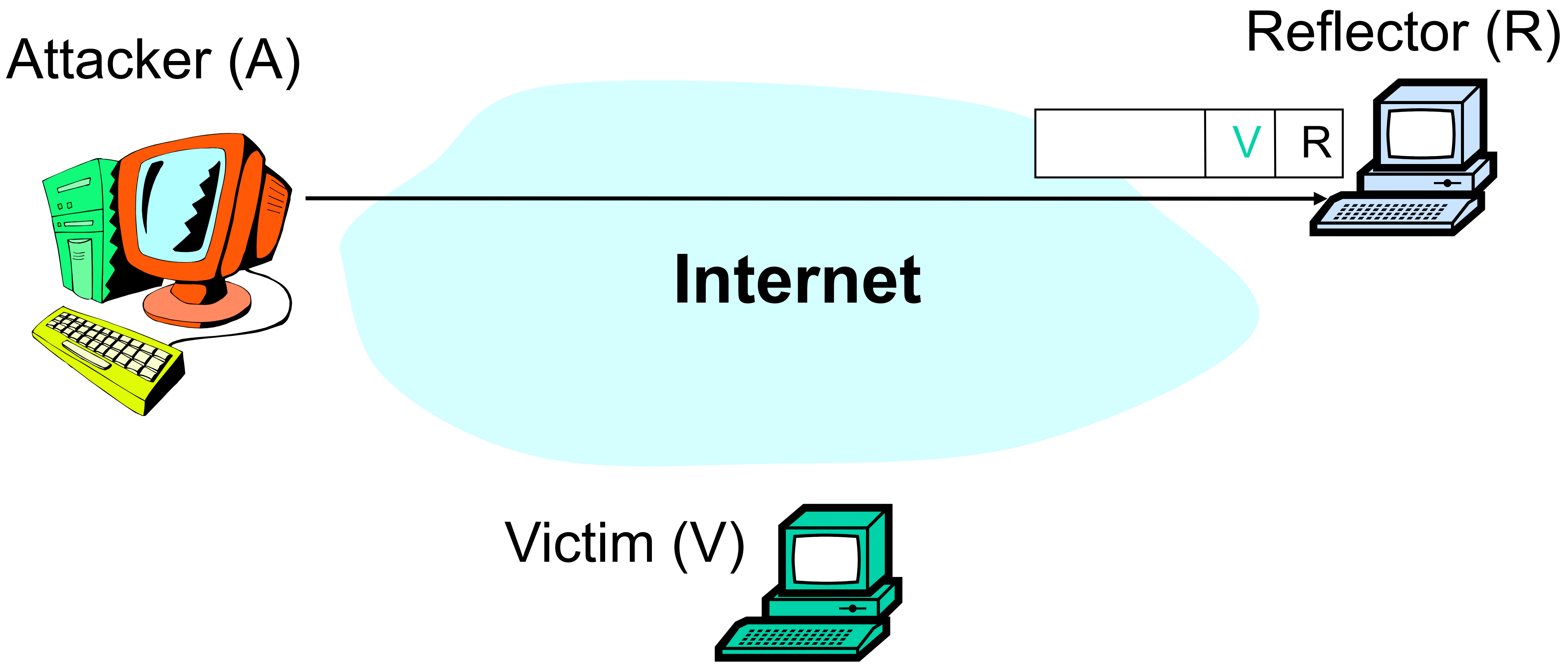

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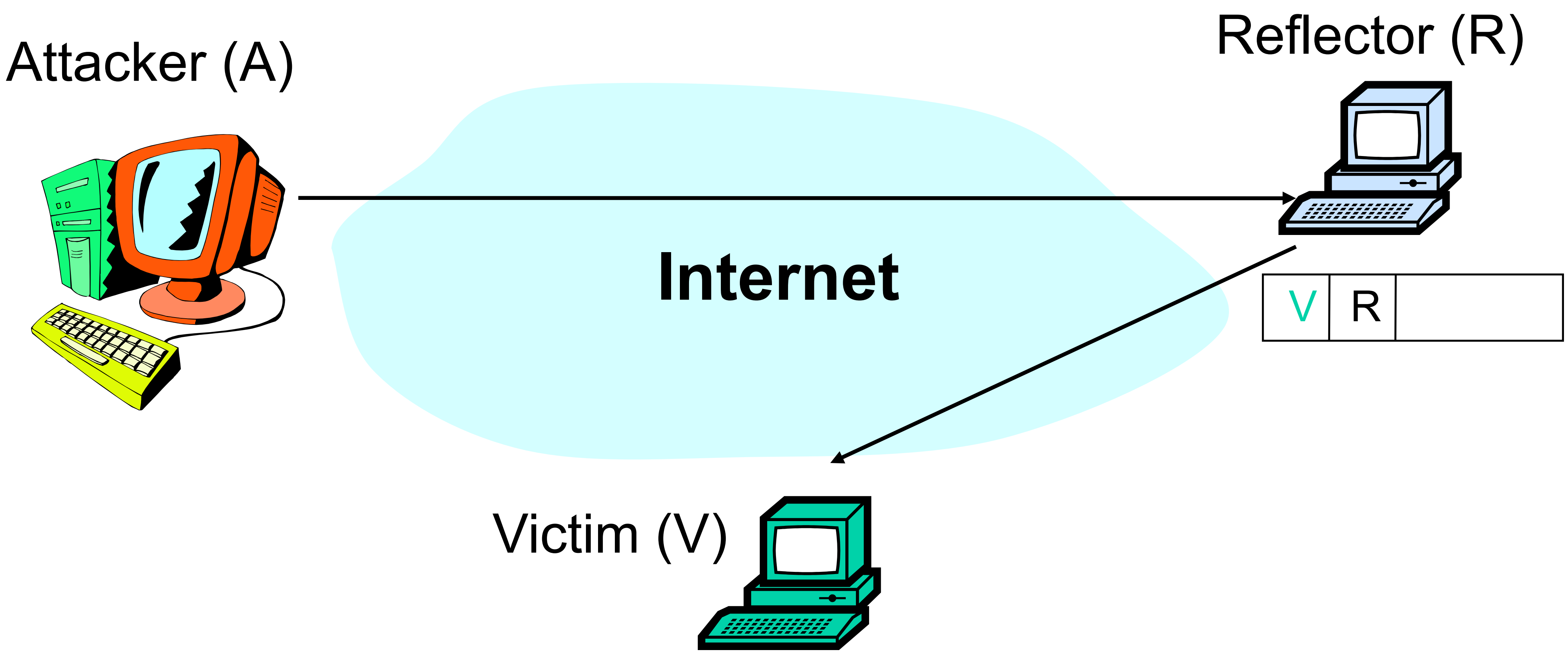
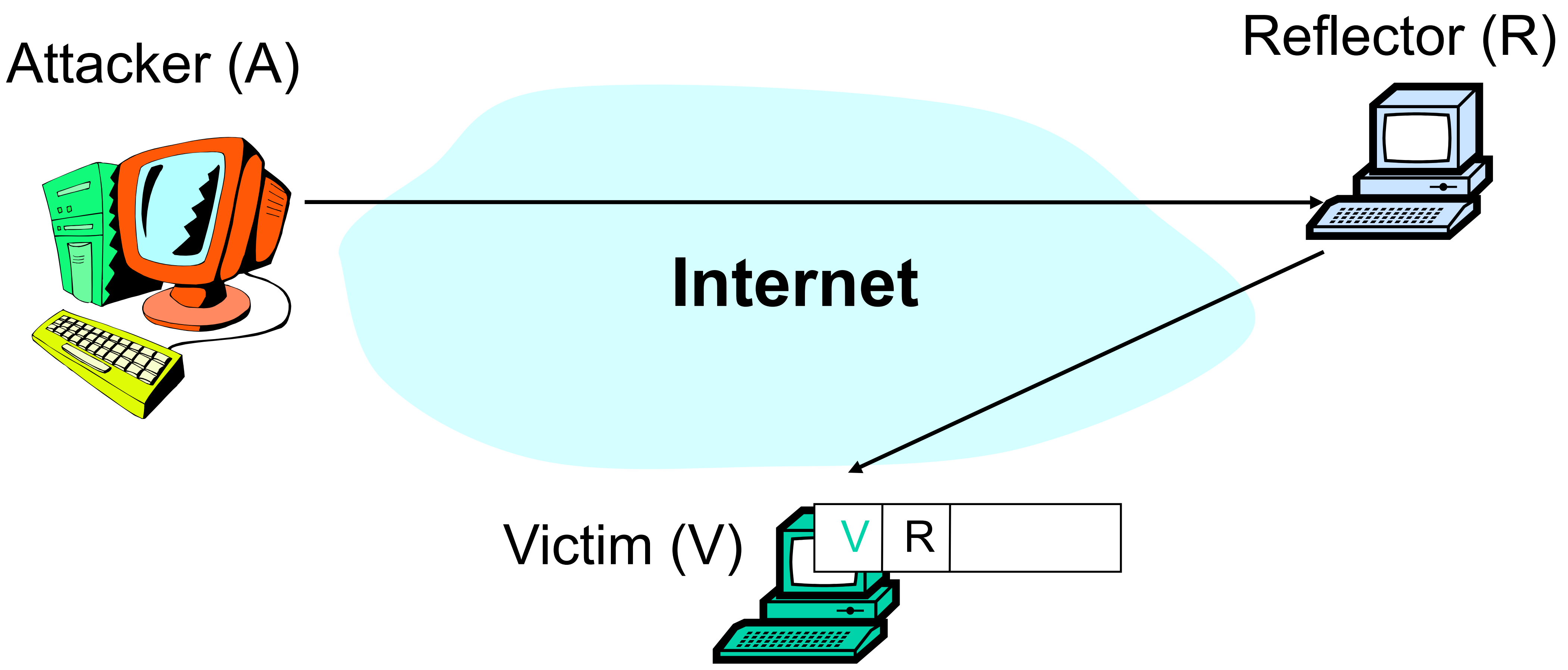


Other Denial-of-Service Attacks

- Reflection
  - Cause one non-compromised host to attack another
  - E.g., host A sends DNS request or TCP SYN with source V to server R. R sends reply to V



Dealing with Attacks

- Distinguish attack from flash crowd
- Prevent damage
  - Distinguish attack traffic from legitimate traffic
  - Rate limit attack traffic
- Stop attack
  - Identify attacking machines
  - Shutdown attacking machines
  - Usually done manually, requires cooperation of ISPs, other users
- Identify attacker
  - Very difficult, except
  - Usually brags/gloats about attack on IRC
  - Also done manually, requires cooperation of ISPs, other users

Incomplete Solutions

- Fair queueing, rate limiting (e.g., token bucket)
- Prevent a user from sending at 10Mb/s and hurting a user sending at 1Mb/s
- Does not prevent 10 users from sending at 1Mb/s and hurting a user sending a 1Mb/s

Identify and Stop Attacking Machines

- Defeat spoofed source addresses
- Does not stop or slow attack
- Ingress filtering
  - A domain's border router drop outgoing packets which do not have a valid source address for that domain
  - If universal, could abolish spoofing
- IP Traceback
  - Routers probabilistically tag packets with an identifier
  - Destination can infer path to true source after receiving enough packets

Summary

- Network security is possibly the Internet's biggest problem
  - Preventing Internet from expanding into critical applications
- Host Compromise
  - Poorly written software
  - Solutions: better OS security architecture, type-safe languages, firewalls
- Denial-of-Service
  - No easy solution: DoS can happen at many levels