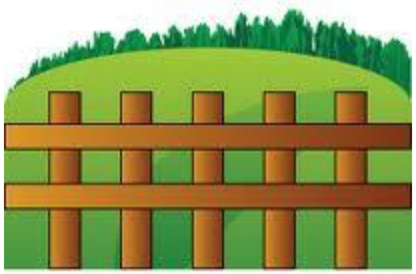
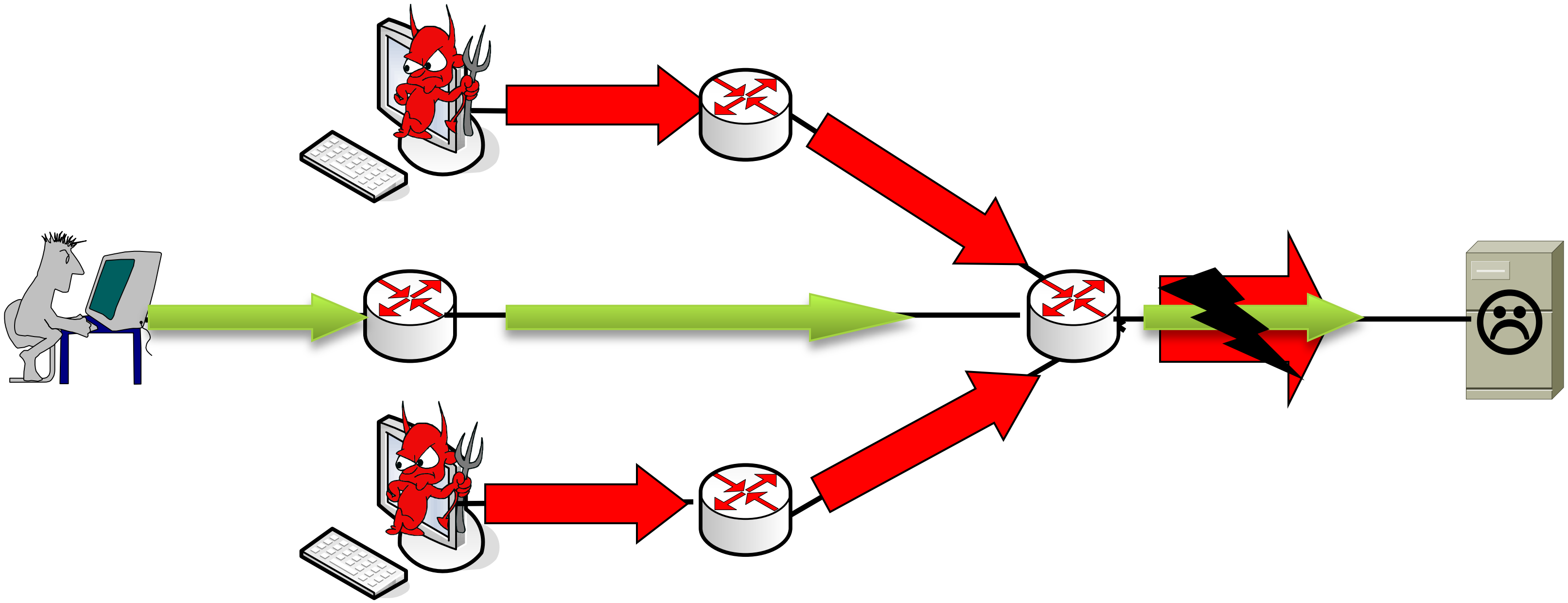


NetFence: Preventing Internet Denial of Service from Inside Out

Xiaowei Yang (Duke University)
with Xin Liu (Duke University)
Yong Xia (NEC Labs China)

Sigcomm 2010
Delhi, India

DoS is a Formidable Threat



- Distributed attacks: many bots send packet floods to exhaust shared resources
  - Bandwidth, memory, or CPU

Largest DDoS Attack
- 49 Gigabits Per Second

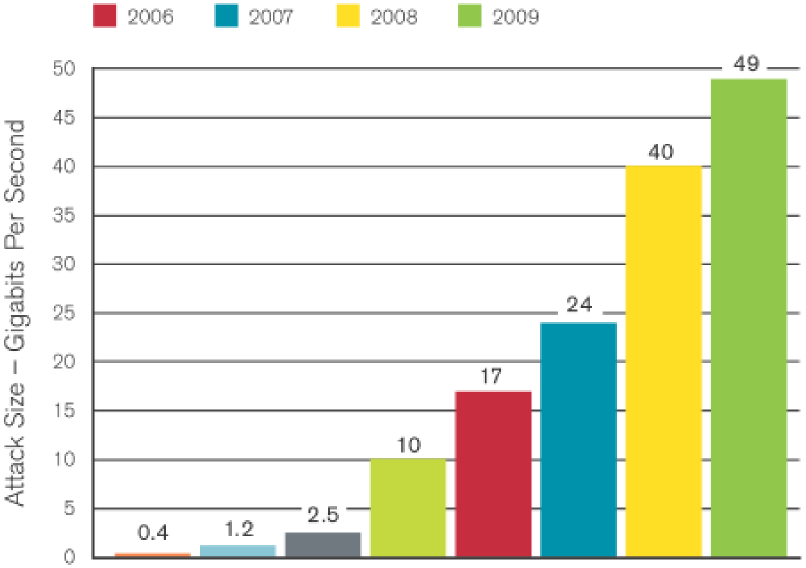


***Figure 1:** Largest DDoS Attack – 49 Gigabits Per Second*

Source: Arbor Networks, Inc.

- *2009 Survey results by Arbor Networks, Inc. among 132 network operators*

Largest Anticipated Threat
– Next 12 Months

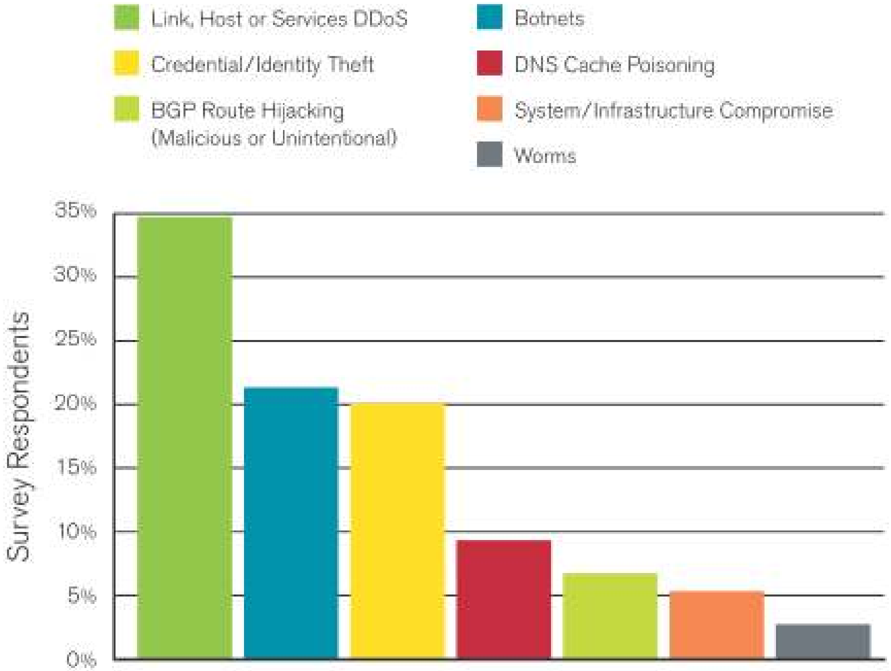


***Figure 4:** Largest Anticipated Threat – Next 12 Months*

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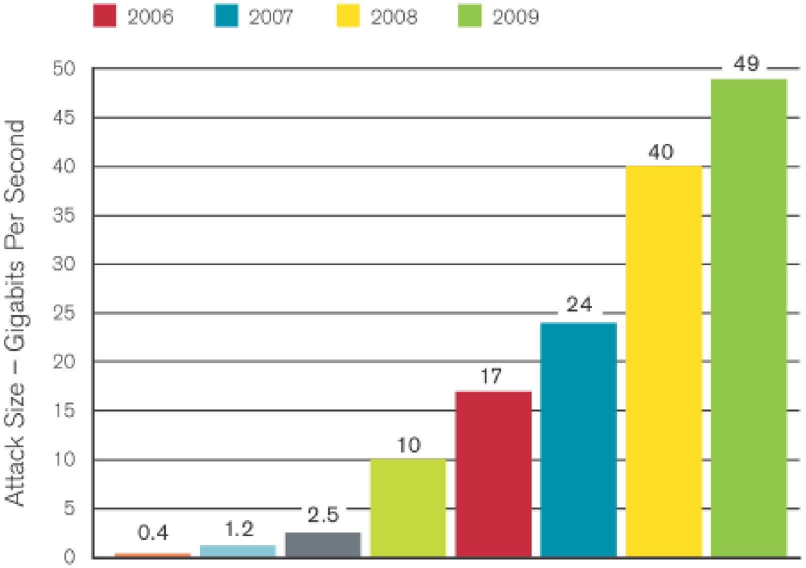

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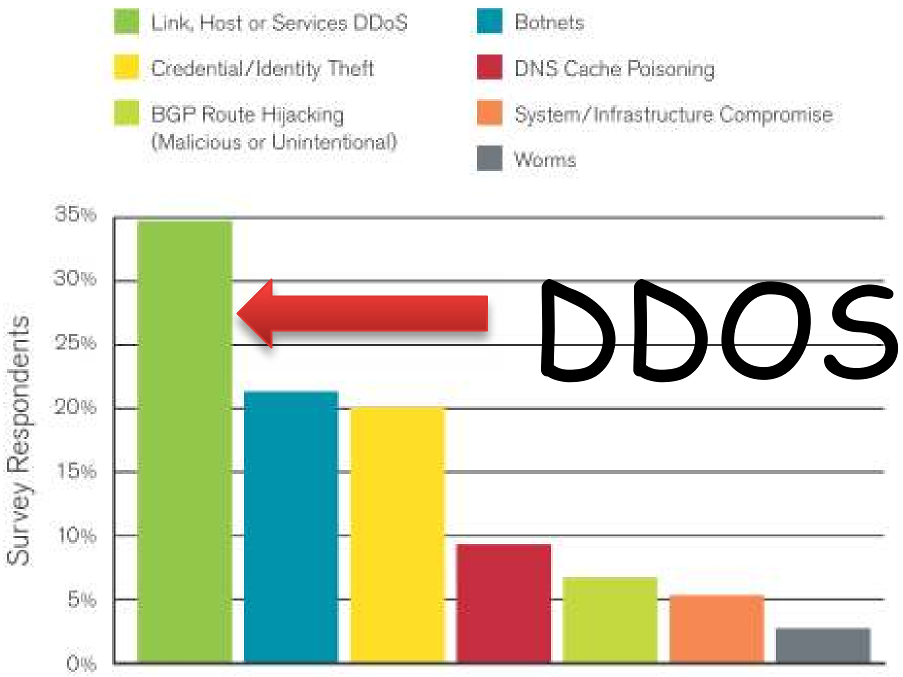

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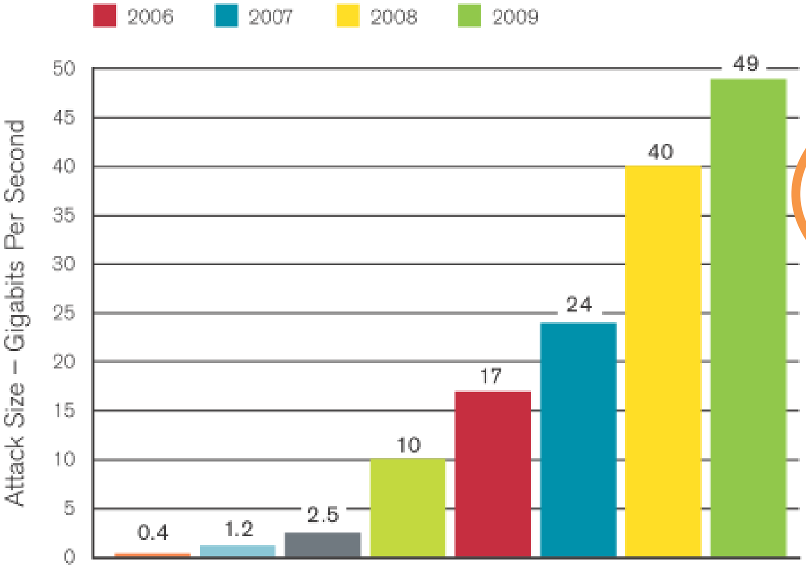

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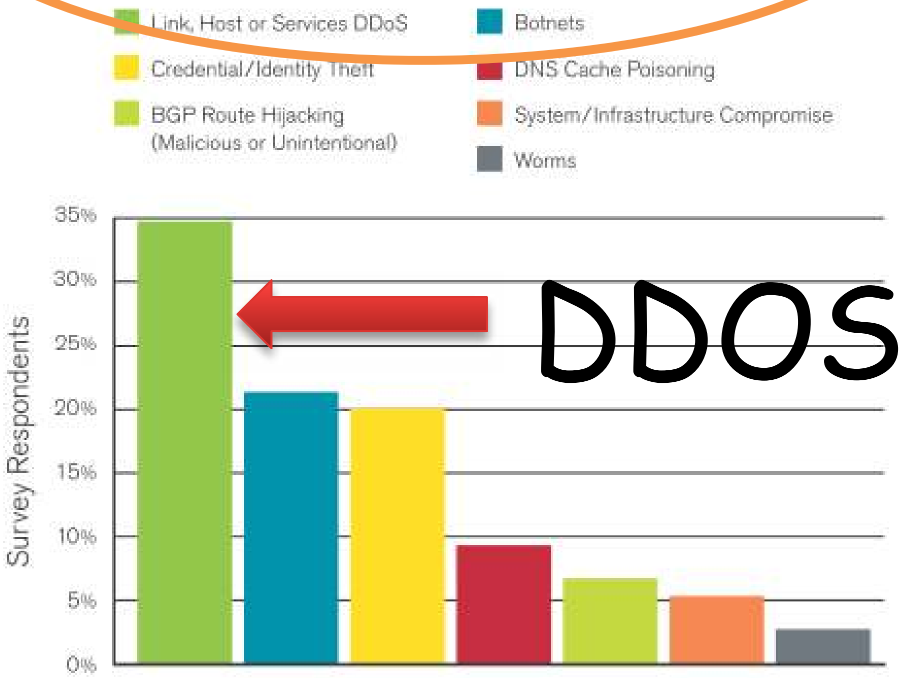

DDOS

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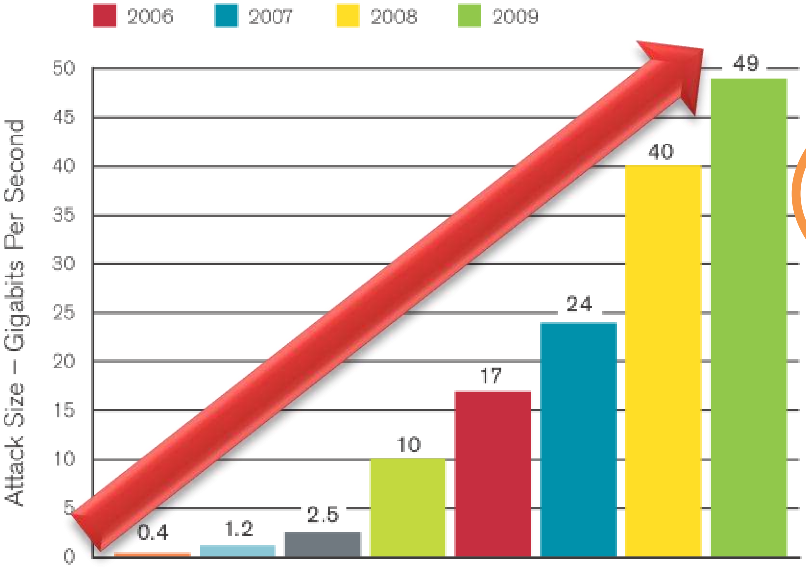

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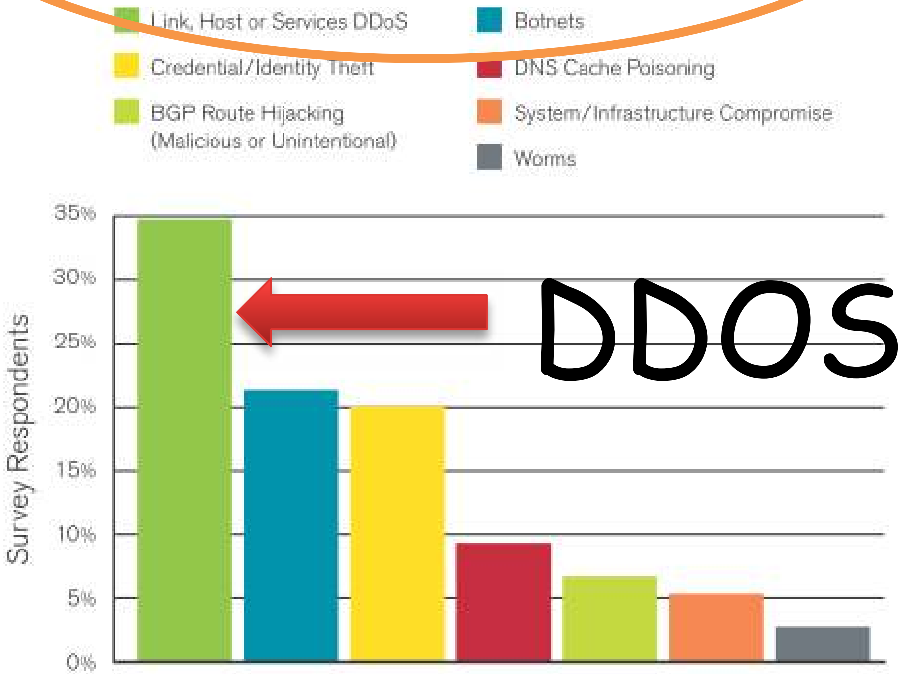

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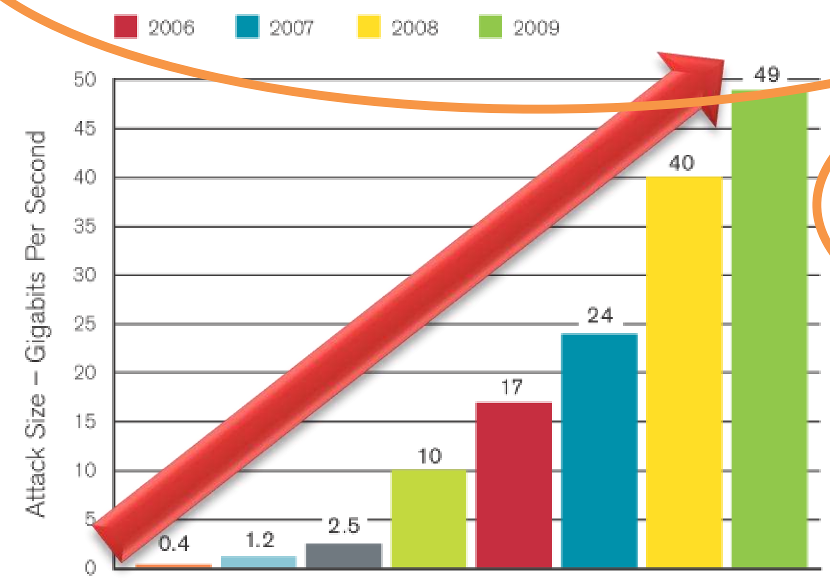

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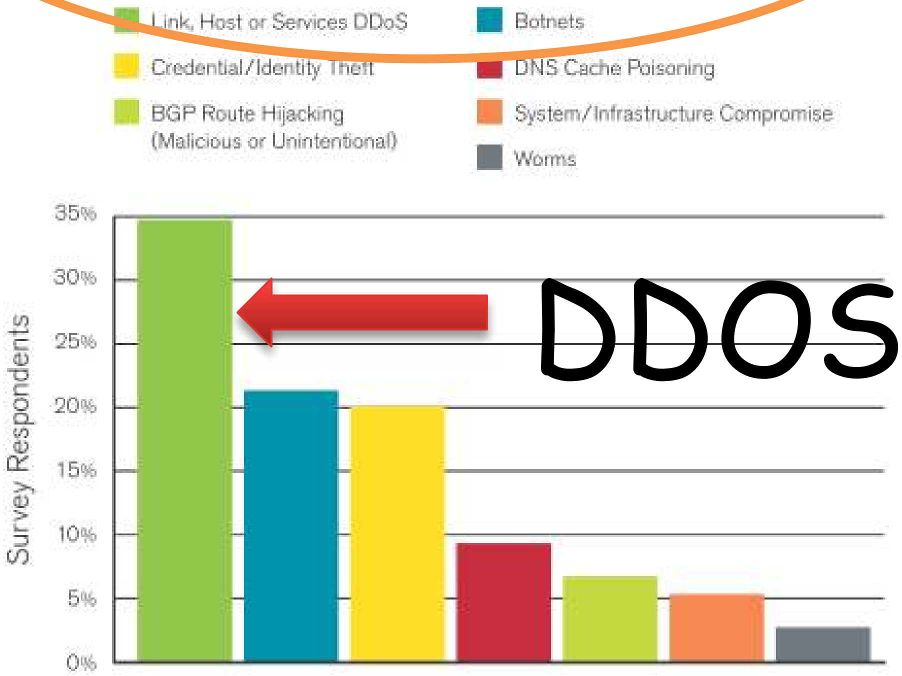


DDOS

***Figure 4:** Largest Anticipated Threat – Next 12 Months*

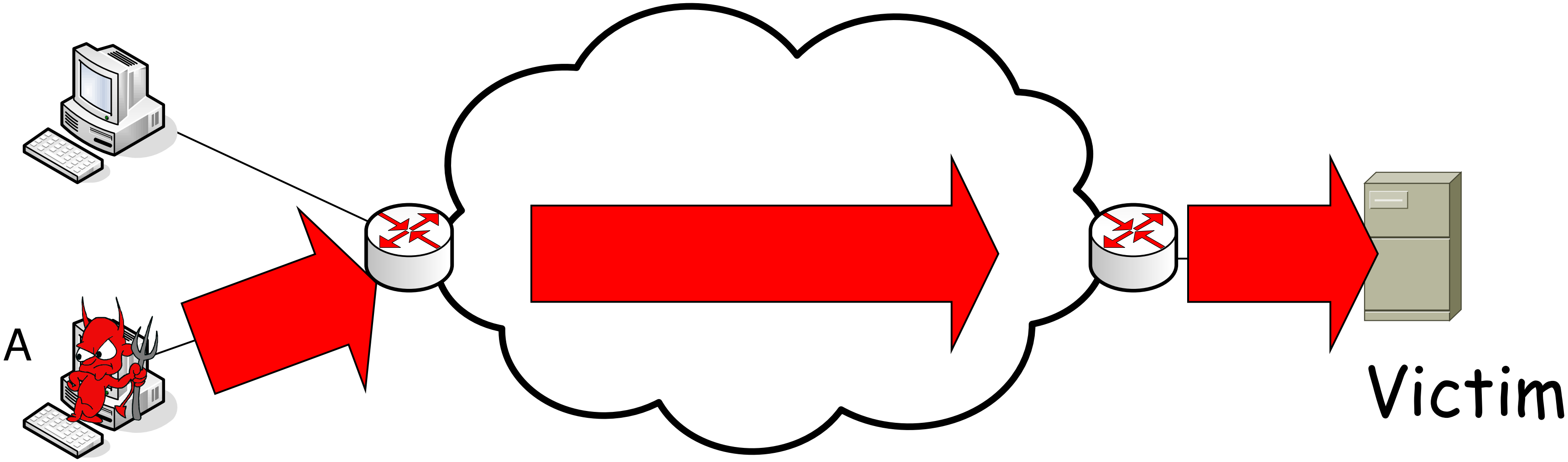
Source: Arbor Networks, Inc.

Combating DoS is Difficult

- A fundamental architecture problem
  1. **Open**: Any to any communication, and new applications
  2. **Robust**: Non-disrupted communications despite compromised hosts and routers

- DoS defense must be built inside out
  - Rethinking the Internet architecture

Previous Work: Receivers as Victims



- **Much work:** AIP, AITF, CenterTrack, dFence, Defense-by-Offense, FastPass, Flow-Cookies, Kill-a-Bot, LazySusan, Mayday, OverDoSe, PacketSymmetry, Phalanx, Pushback, Portcullis, SIFF, SOS, SpeakUp, StopIt, TVA…
- Denial of Edge Service (DoES)
  - Enable receivers to suppress unwanted traffic
  - Network filters, network capabilities

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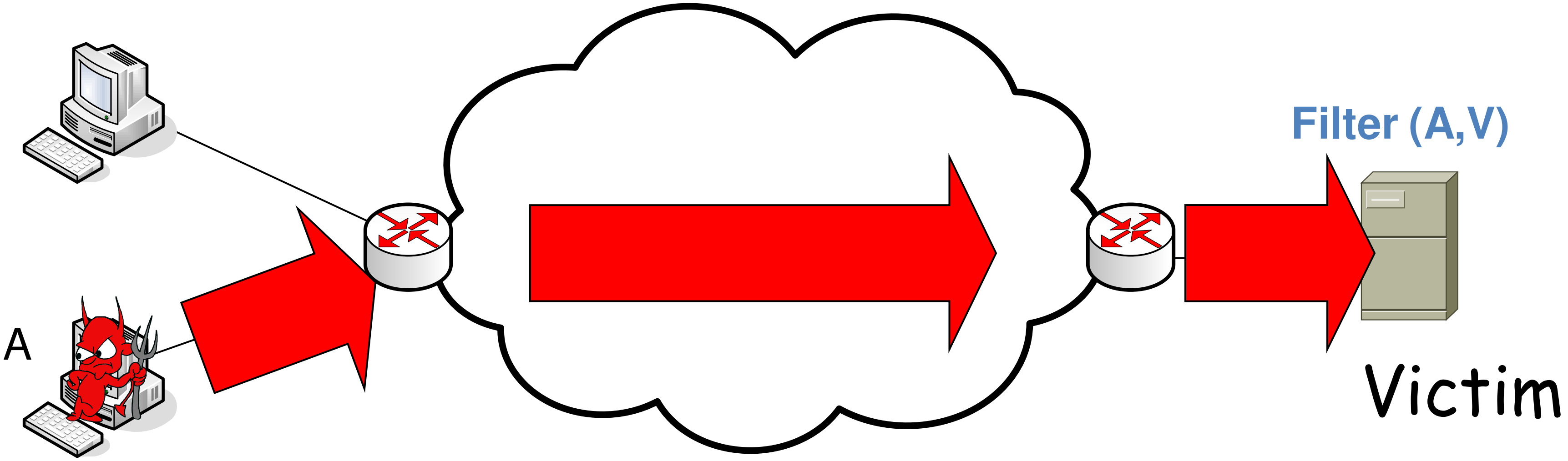

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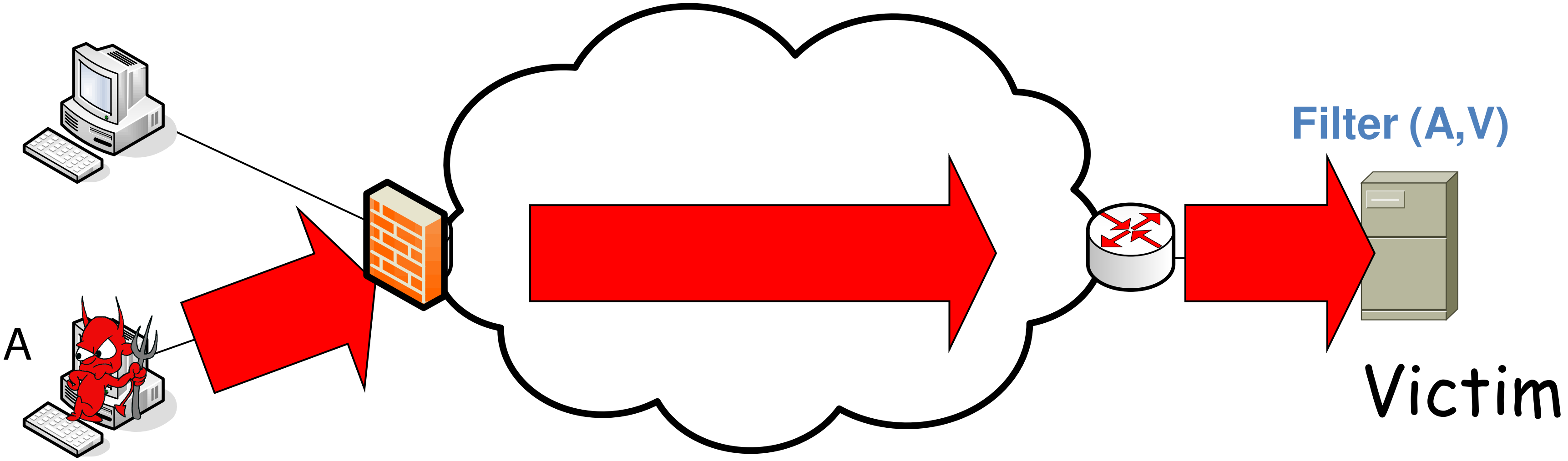

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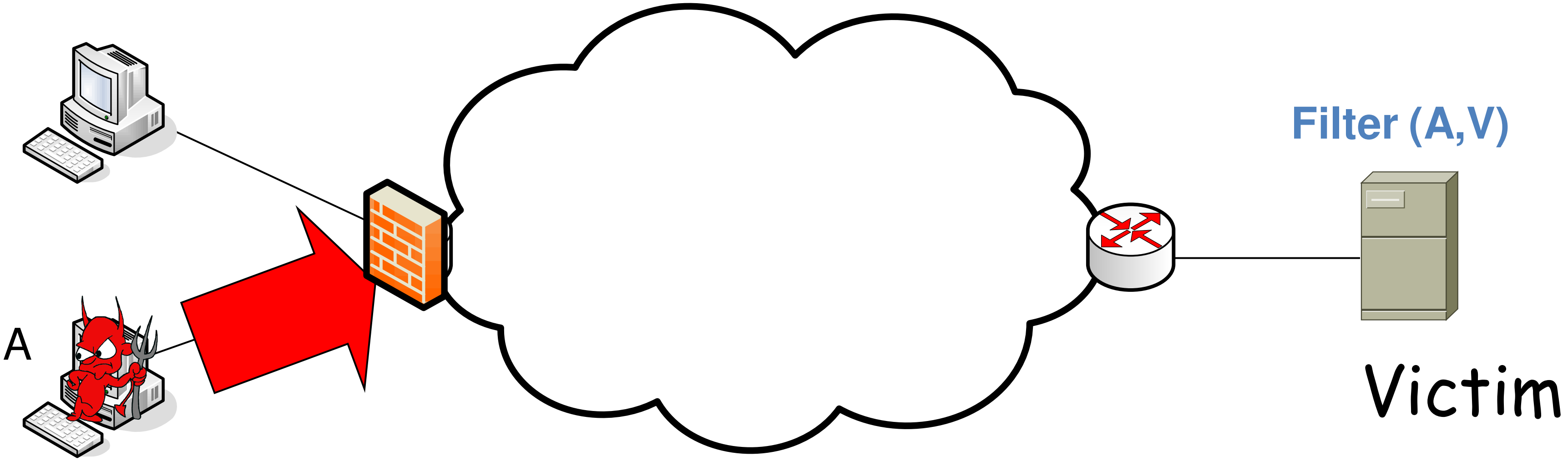

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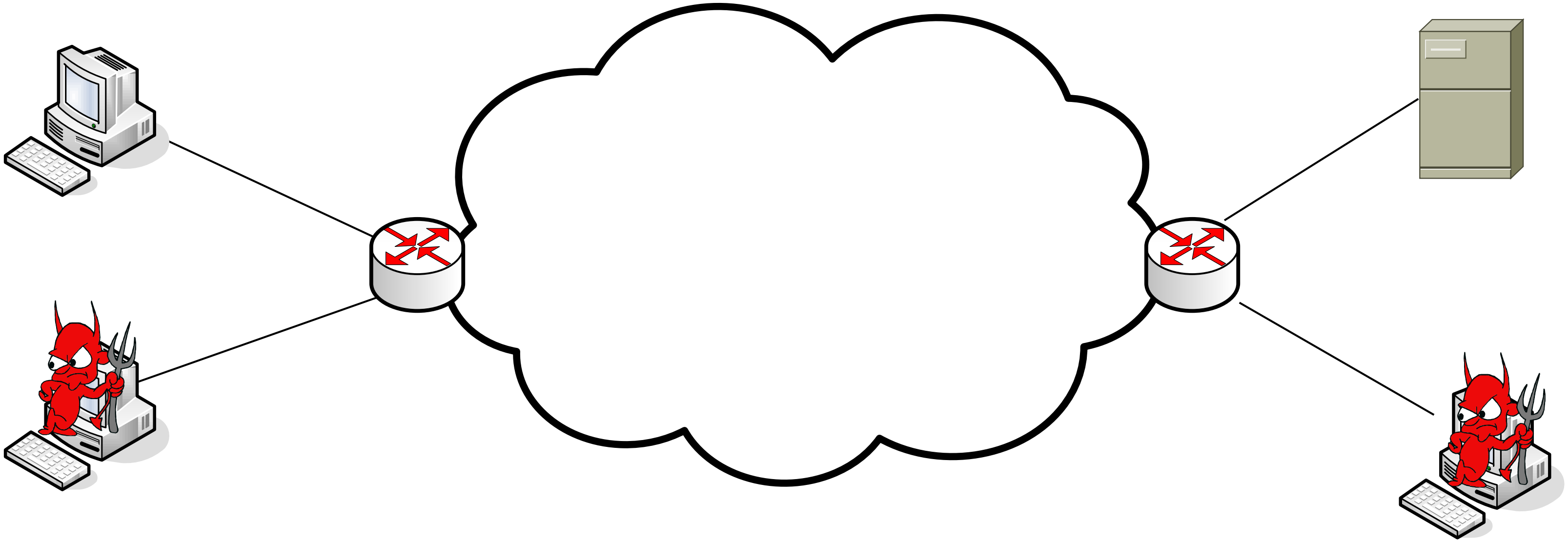
New Threat: Denial of Network Service (DoNS)



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- Incapable of identifying attack traffic

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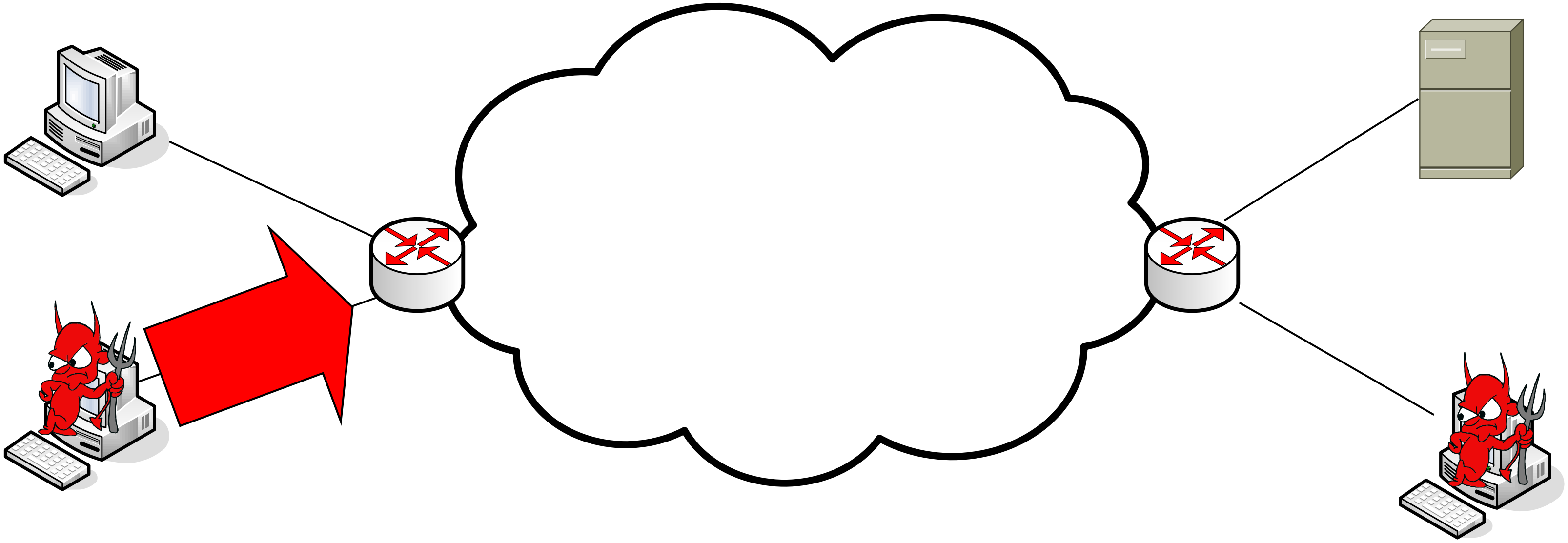

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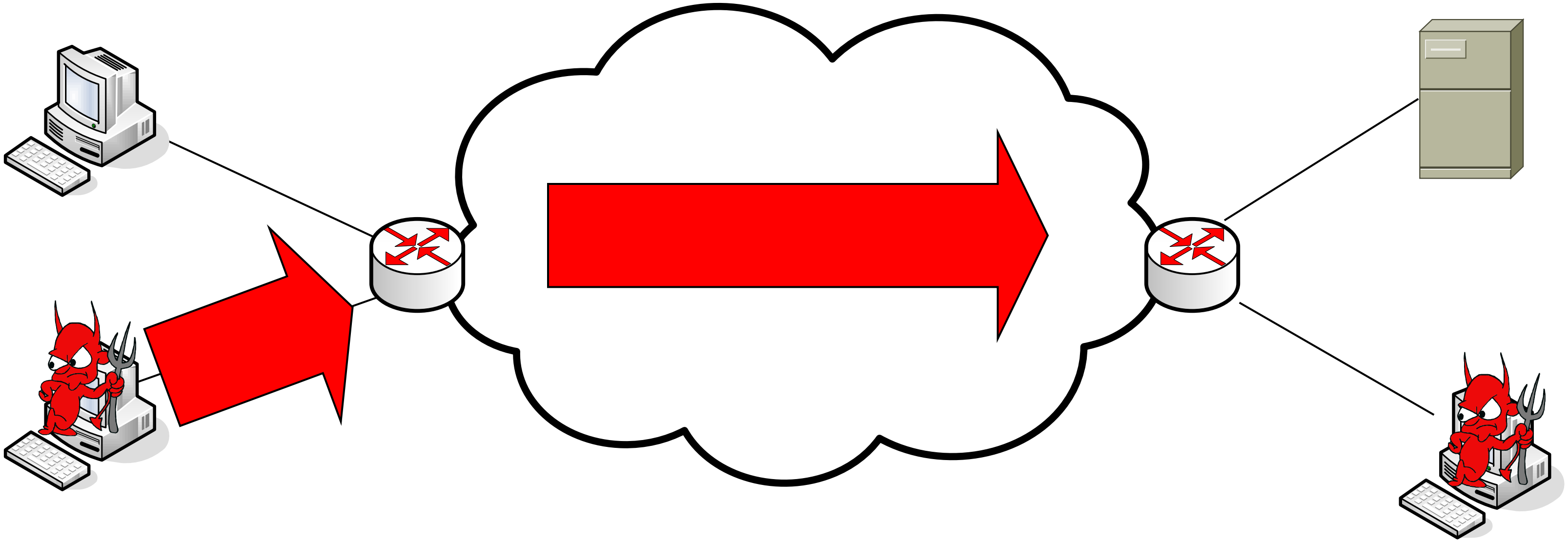

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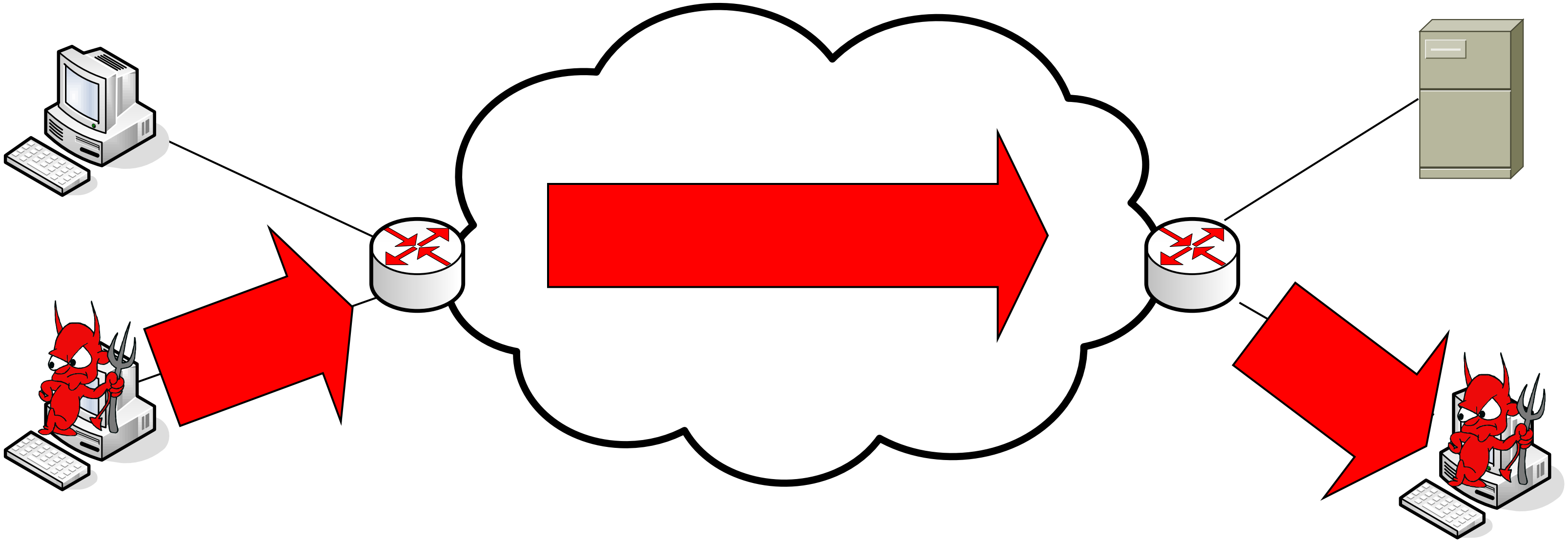

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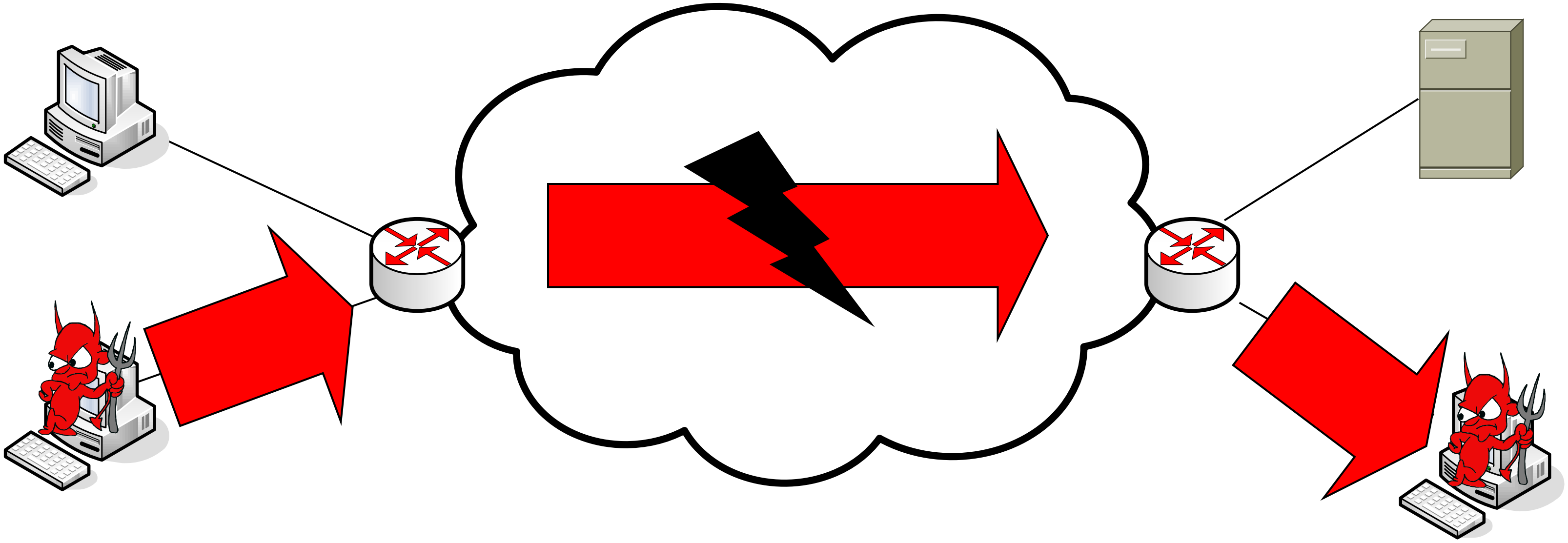

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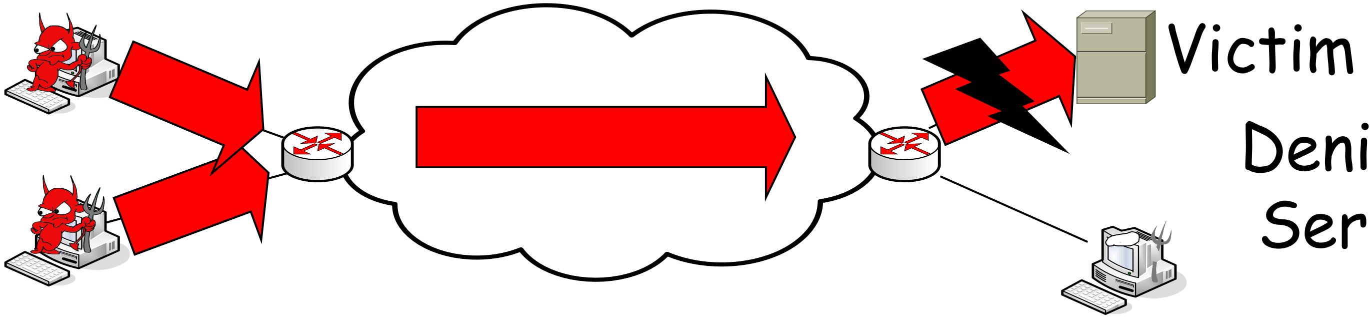
DoS

DoS

=

DoS

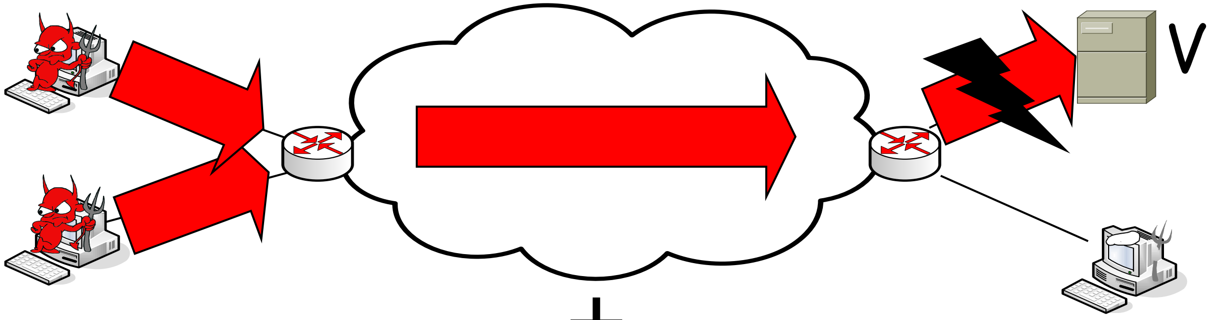
=



Denial of Edge Service (DoES)

DoS

||



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Victim

Denial of Edge Service (DoES)

DoS

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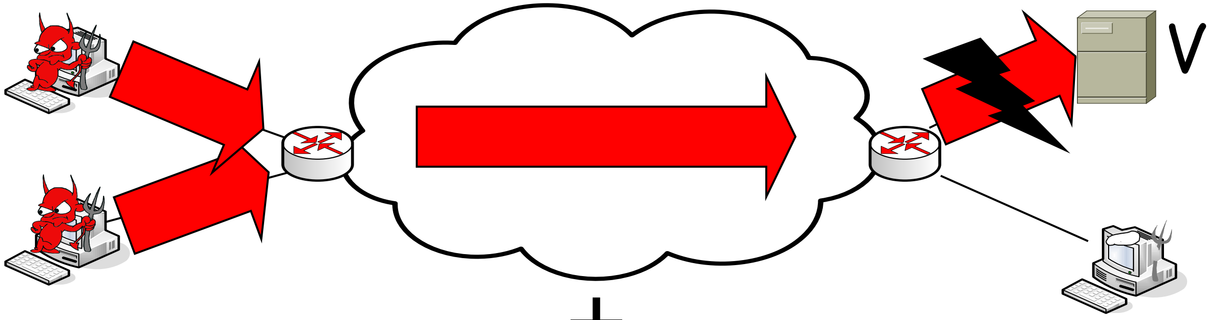

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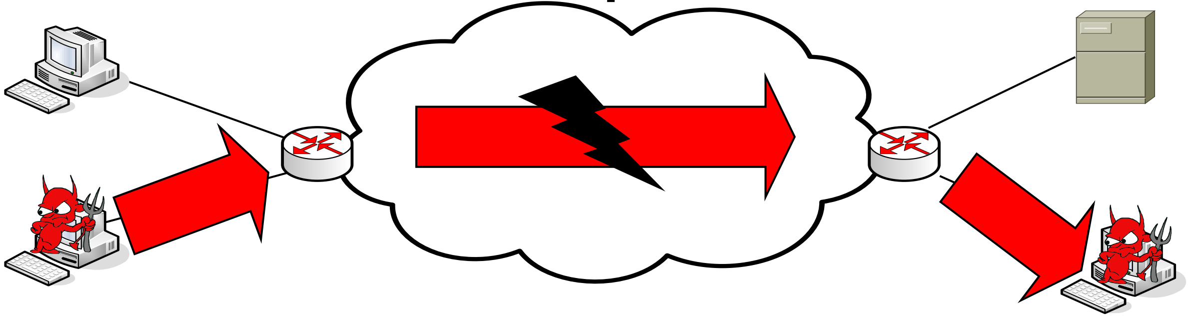

Denial of Network Service (DoNS)

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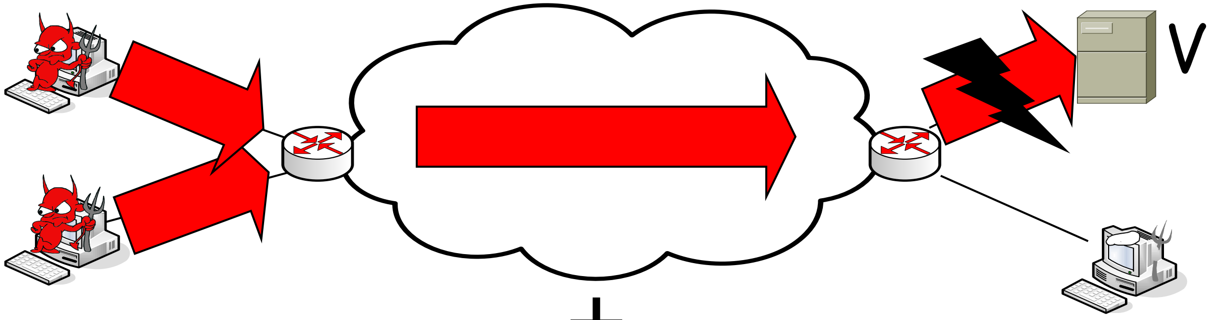

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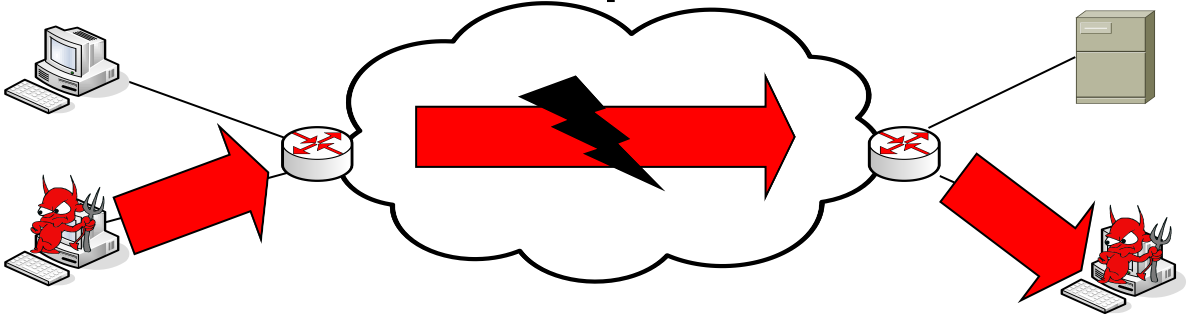

Denial of Network Service (DoNS)

How can we design a network architecture that can combat both DoES and DoNS?

Solution: NetFence

- Design principle: inside-out, network-host joint lines of defense

1. Network controls its resource allocation
   - Combating DoNS

2. End systems controls what they receive
   - Combating DoES

Key Idea

1. Hierarchical,

+

2. Secure congestion policing in the network

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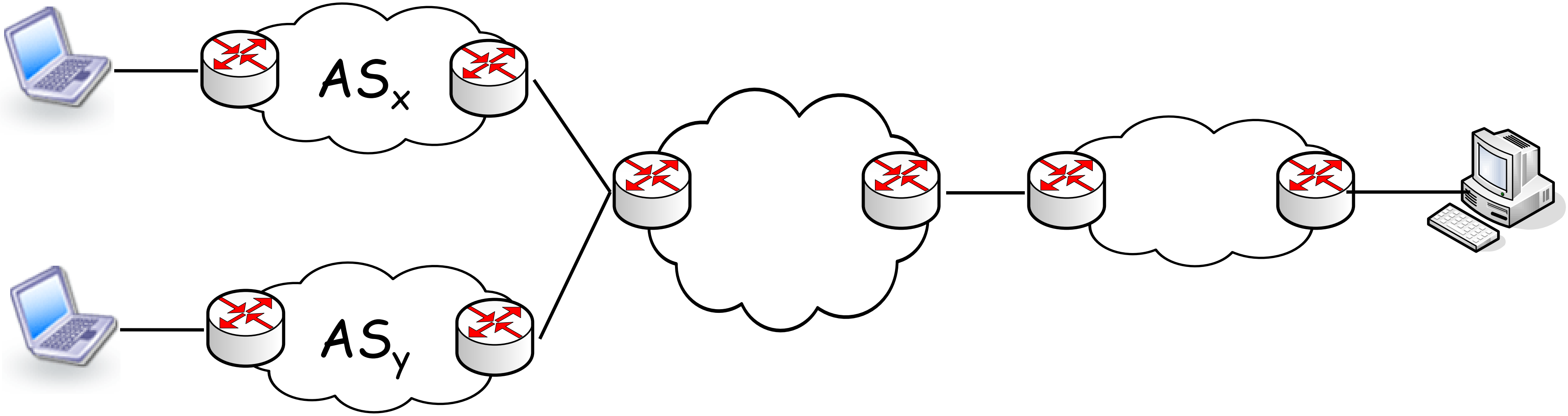
3. Coupled with network capabilities

⇩

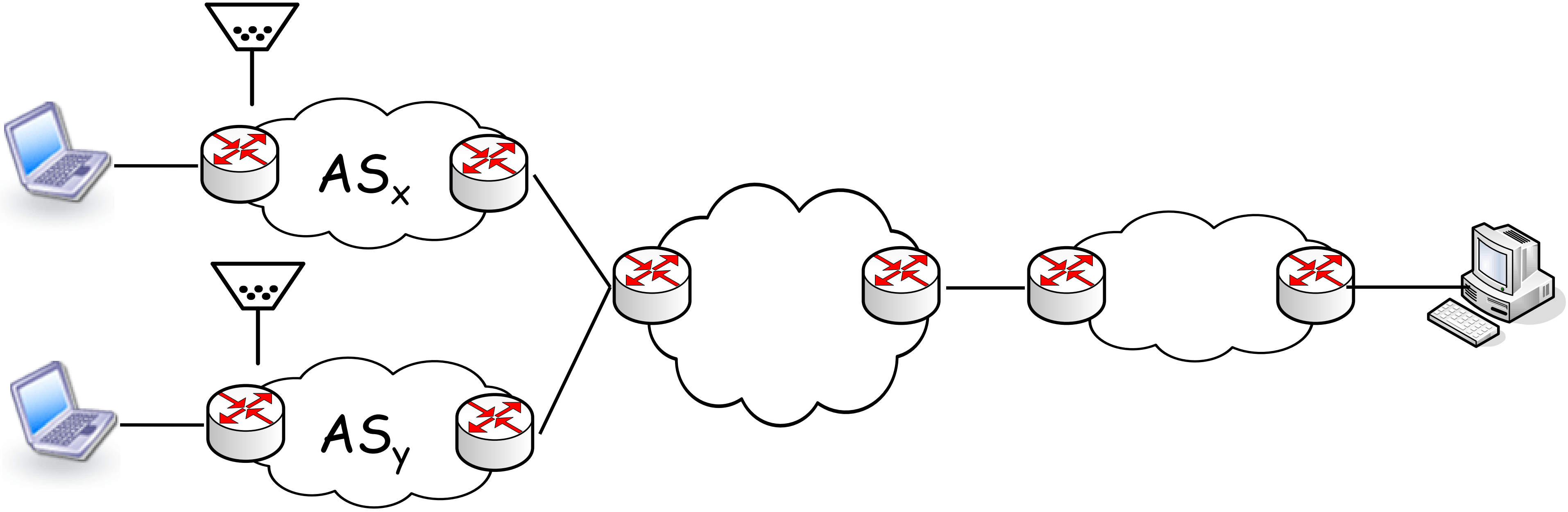
Goals: Scalable, Robust, Open

Hierarchical Congestion Policing



- Scalable: no per-flow state in the core
  1. Aggregate flow policing placed at edge routers [CSFQ]
  2. AS-level policing in the core
     - Fair queuing or rate limiting

Hierarchical Congestion Policing



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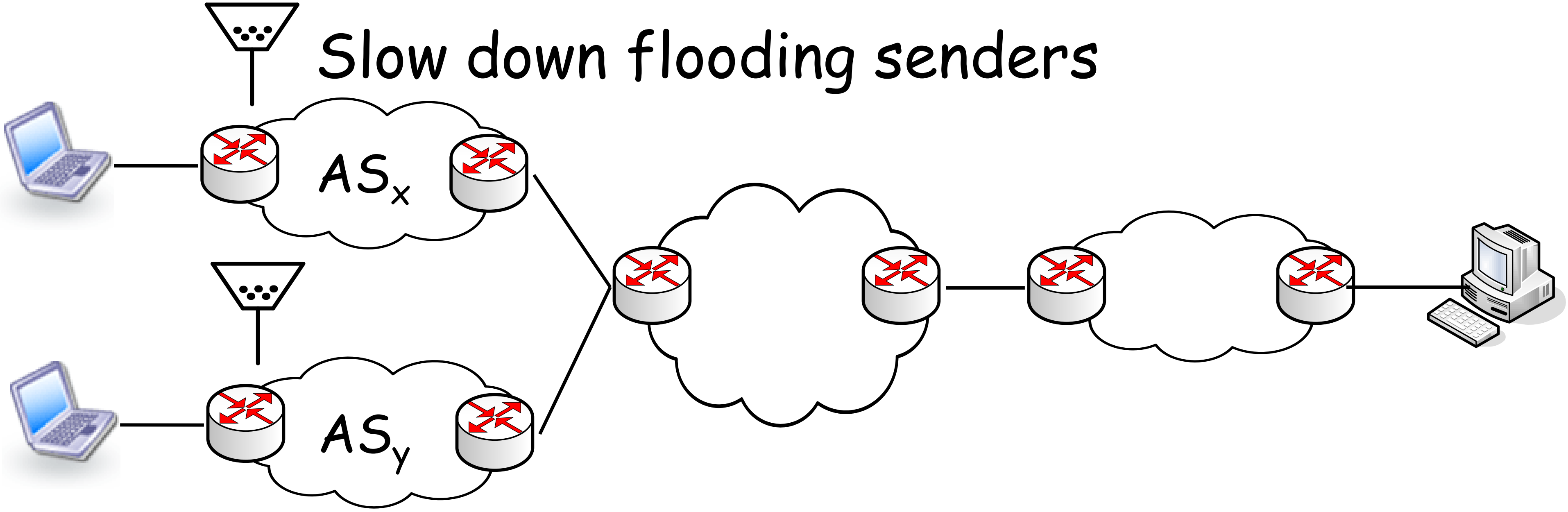

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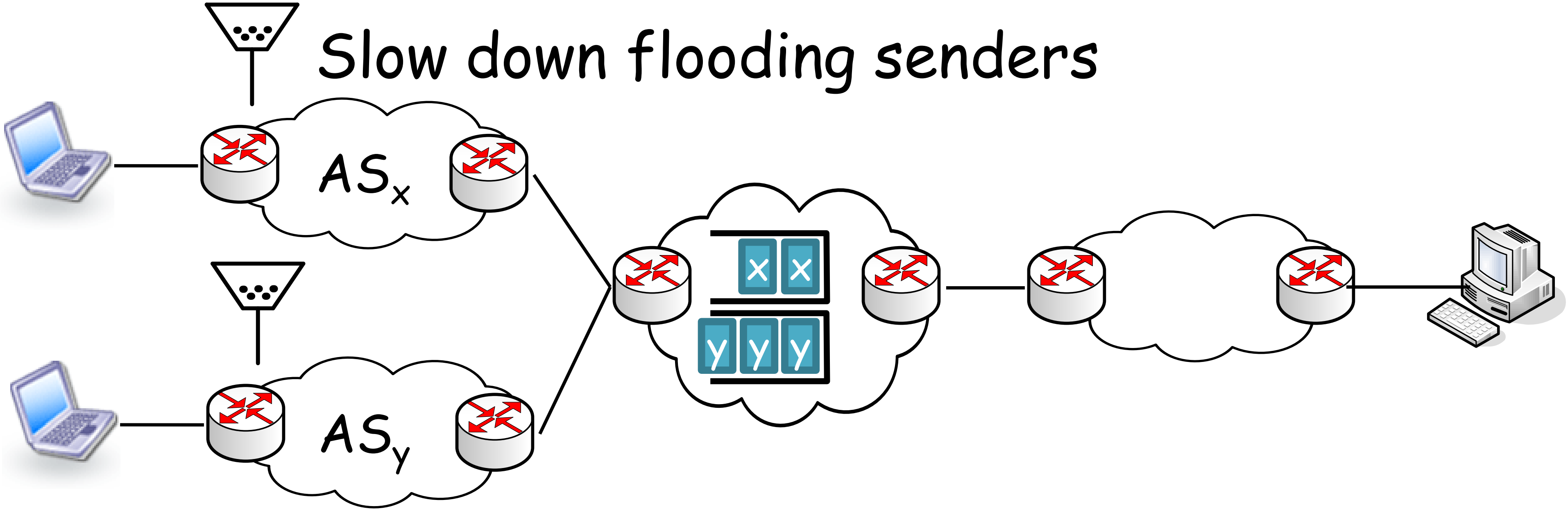

Slow down flooding senders

- Scalable: no per-flow state in the core
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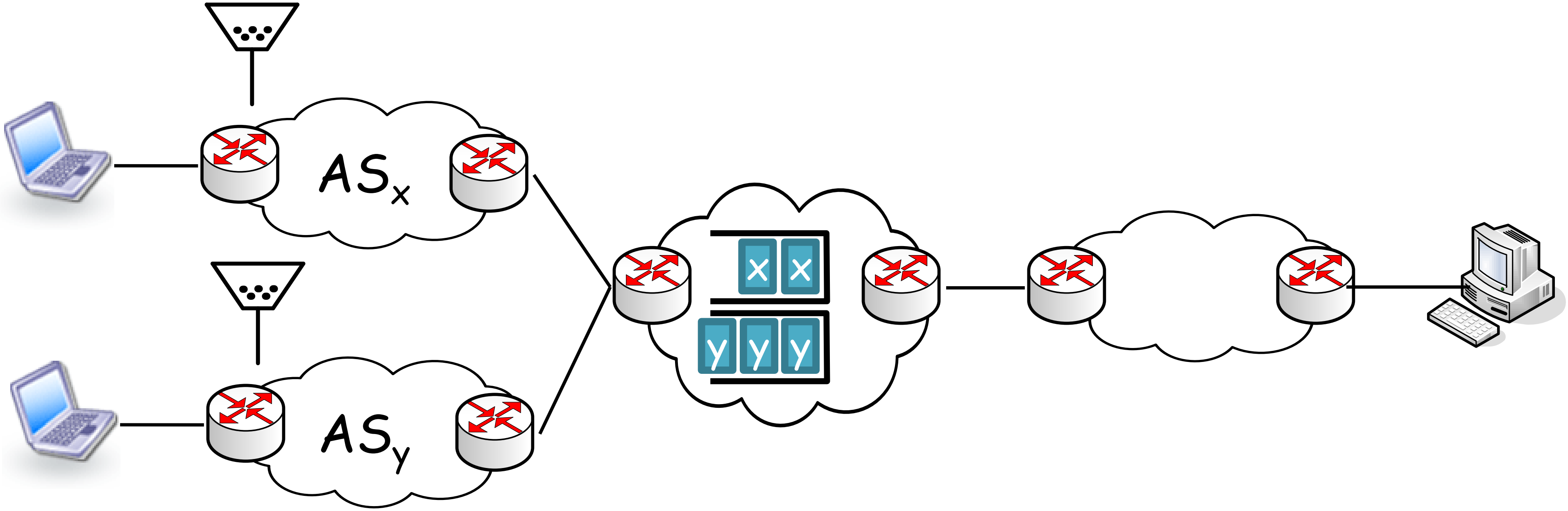
Secure Congestion Policing



- Robust to compromised routers and hosts
  - Efficient symmetric key cryptography
  - Packets carry secure tokens
    - Source AS authenticators [Passport,NSDI08] → AS Accountability
    - Secure congestion policing feedback

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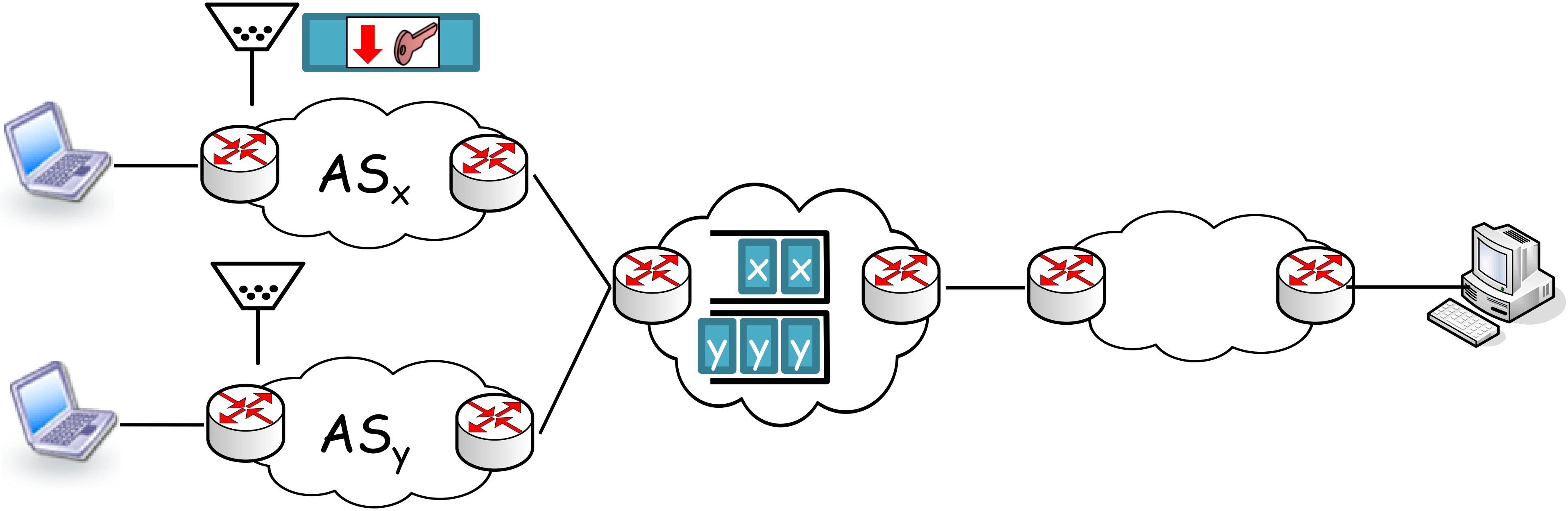

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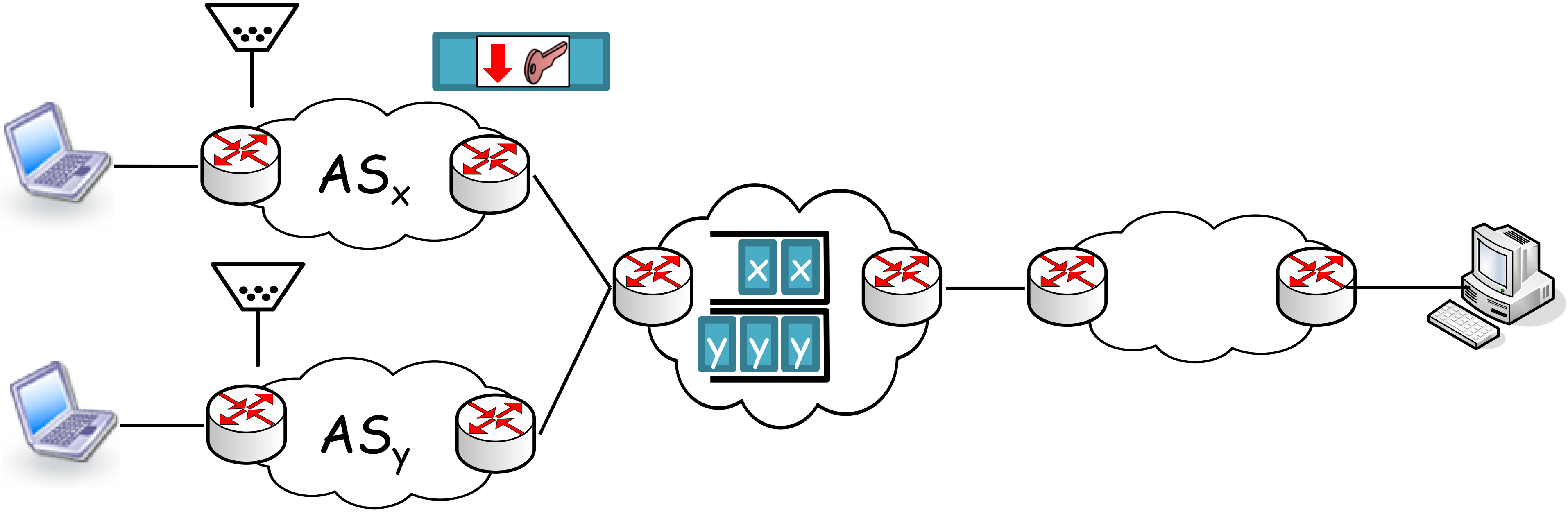
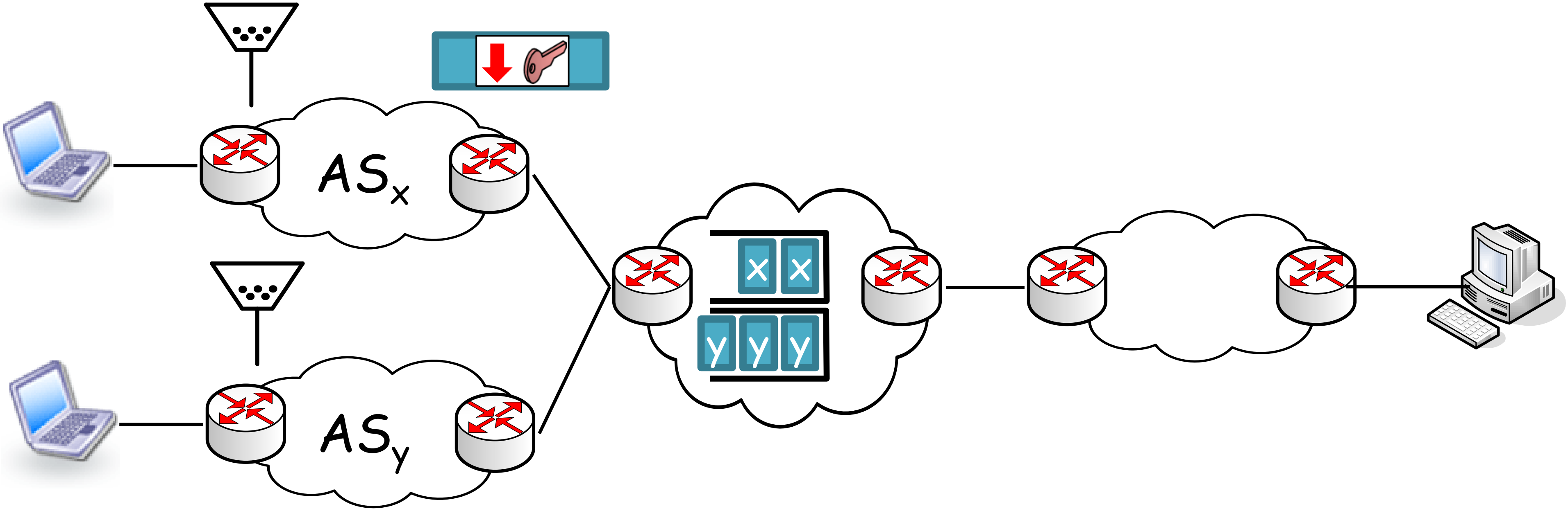
Secure Congestion Policing Feedback as Network Capabilities



- Open
  - Receiver explicitly authorizes desired traffic
    - Return if wants to receive
    - Not, otherwise

Secure Congestion Policing Feedback as Network Capabilities



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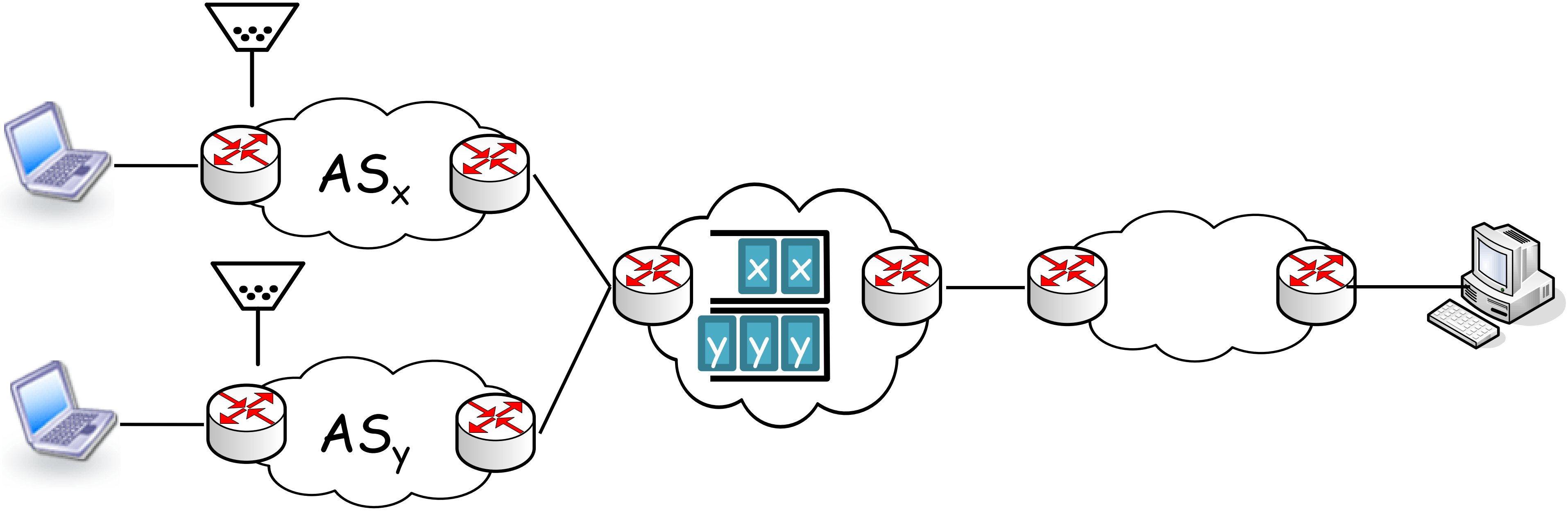

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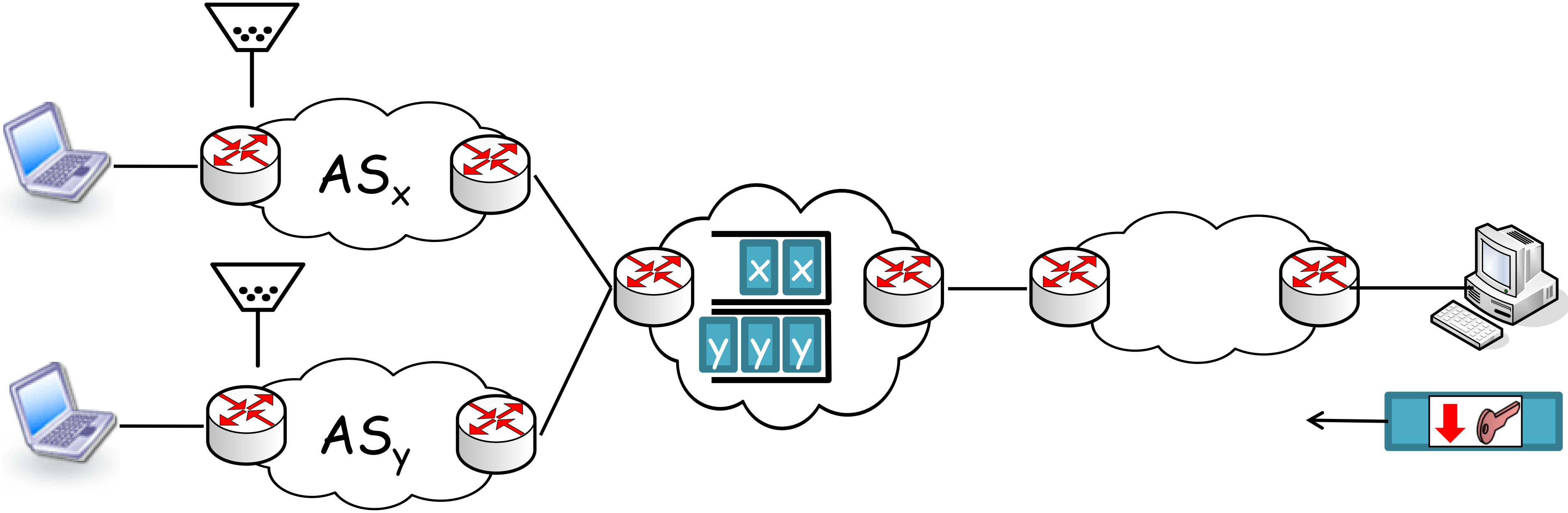

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Now the Details…

How does NetFence Work?

- A sender sends two types of packets

Request

Regular

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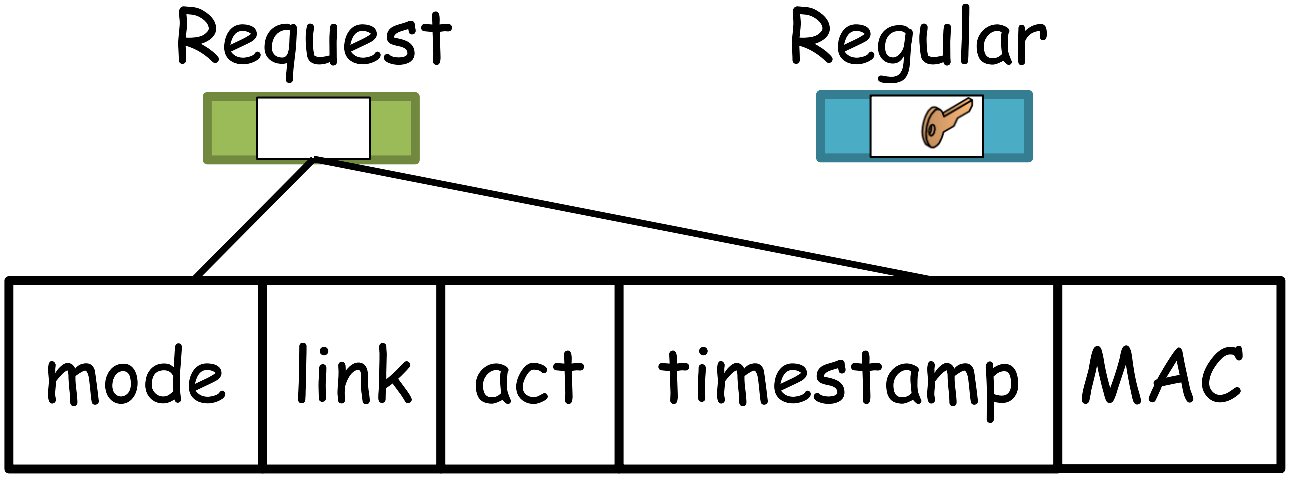

Request

Regular

mode | link | act | timestamp | MAC

NetFence Header

How does NetFence Work?

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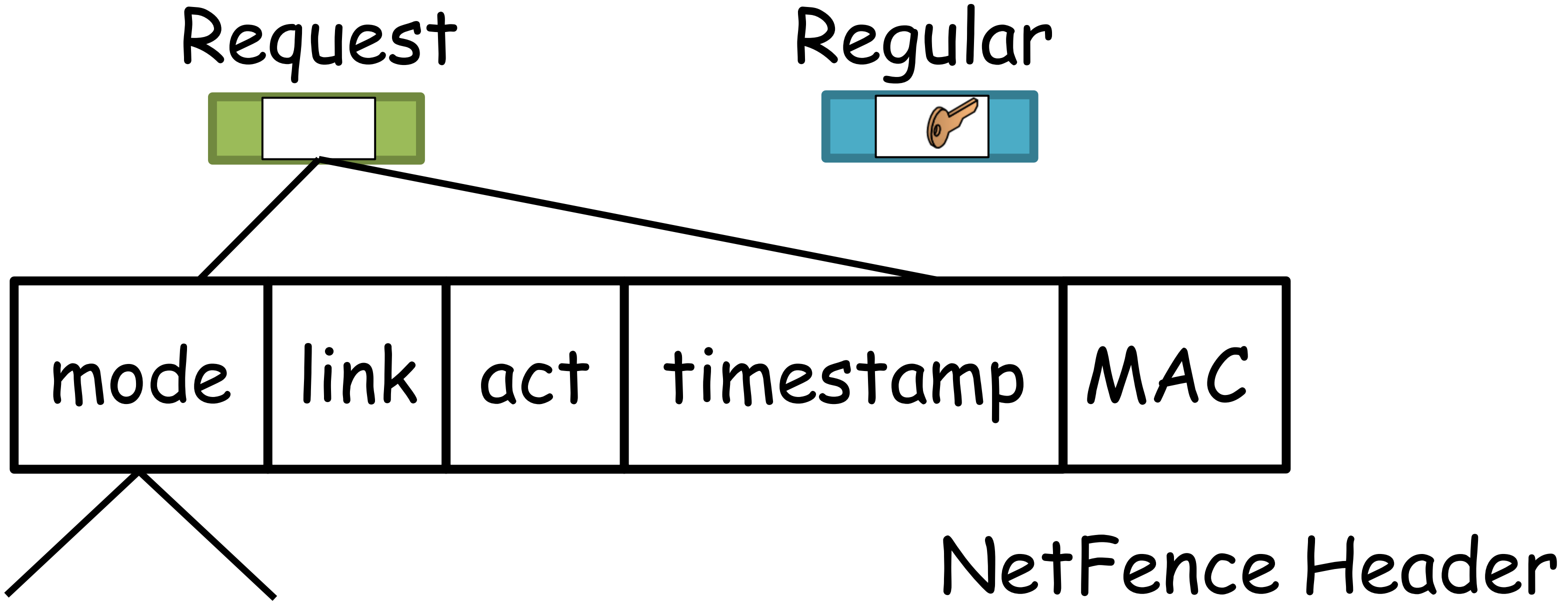

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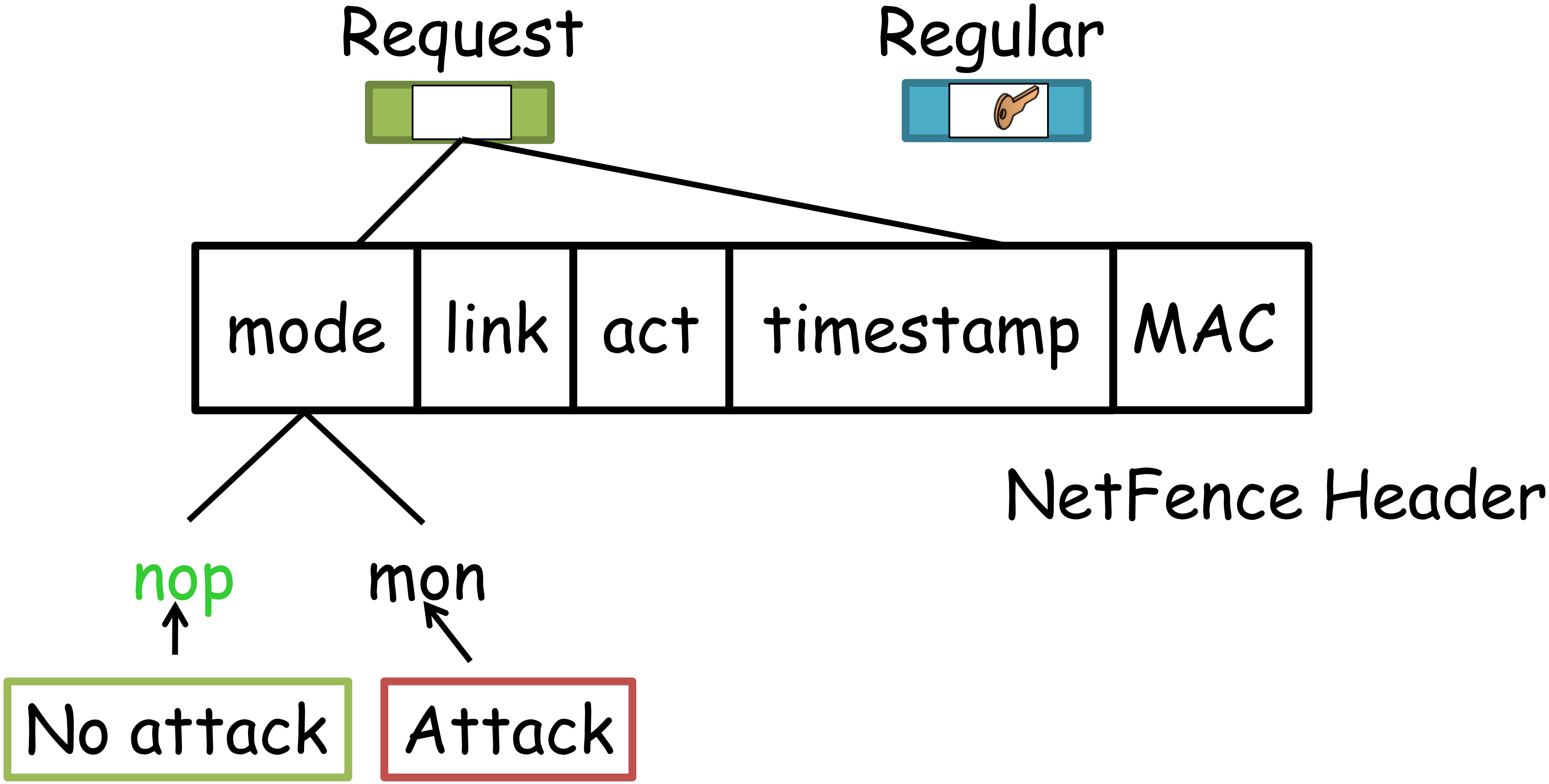

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NetFence Header

nop

mon

No attack

Attack

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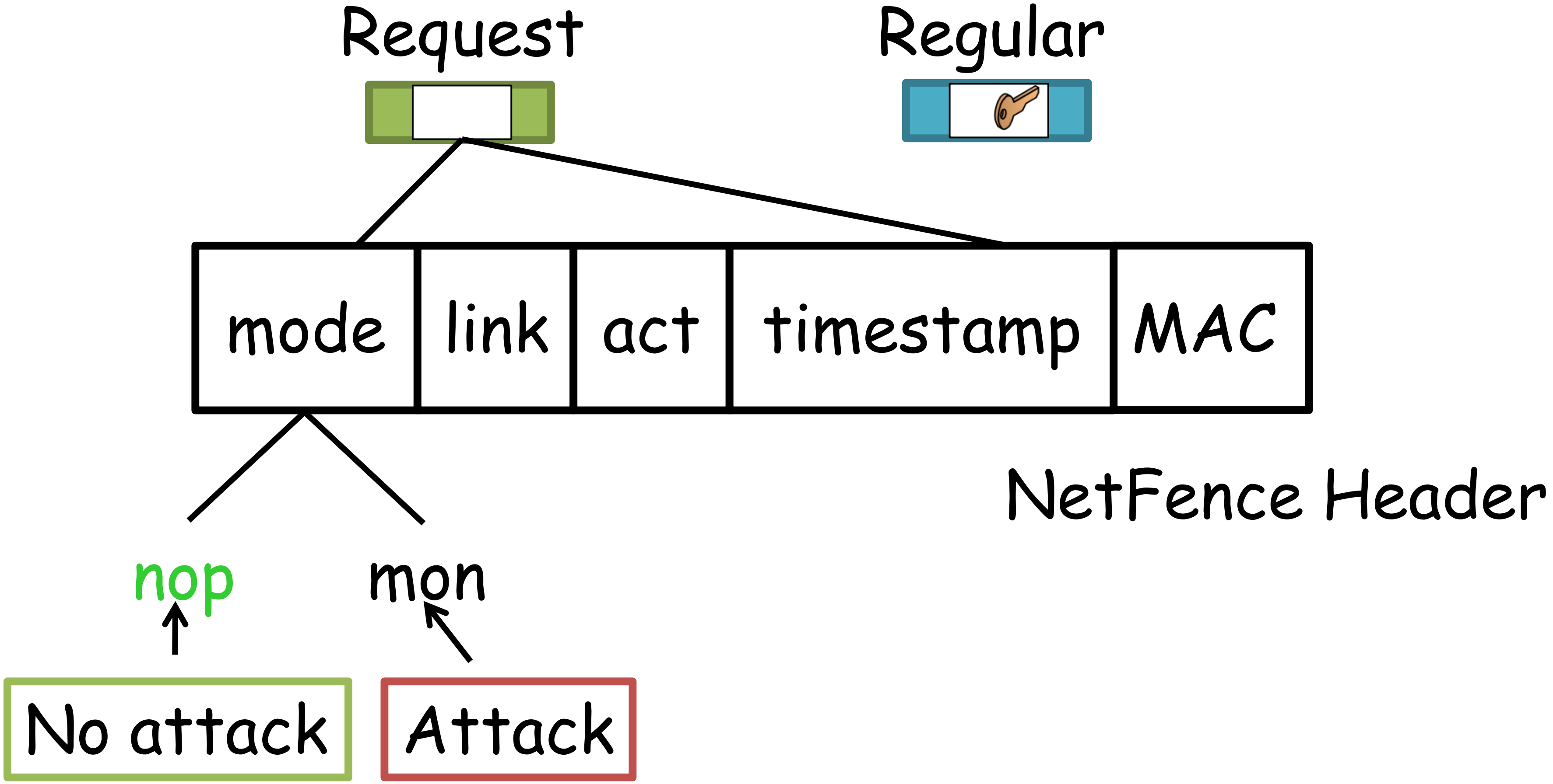

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NetFence Header

nop ← No attack

mon ← Attack

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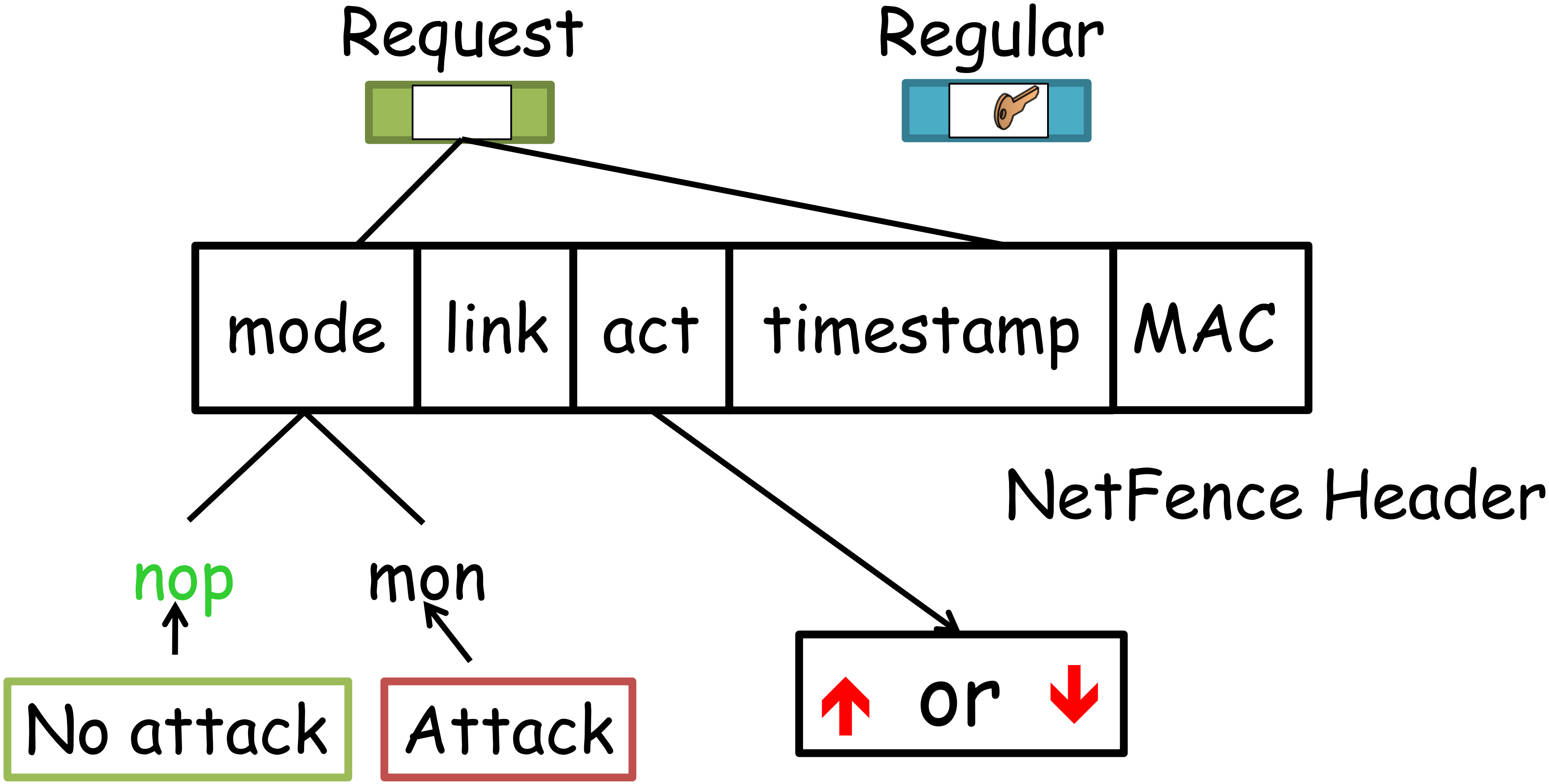

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nop

mon

No attack

Attack

↑ or ↓

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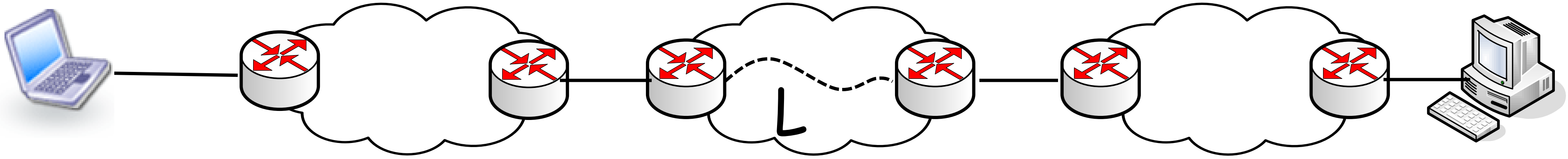
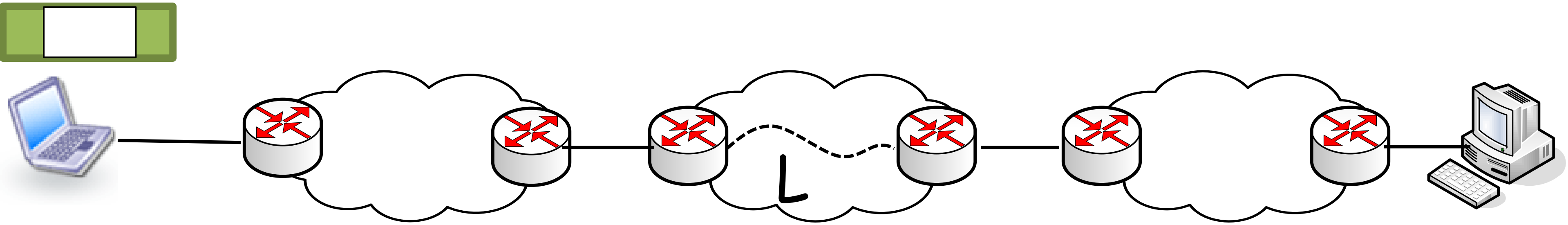


- A sender first sends a request packet
- Its access router stamps nop
  - now → ts (timestamp), null → link, nop → mode
  - ▬🔑 = MAC🔑(src, dst, ts, null, nop)

How does NetFence Work?



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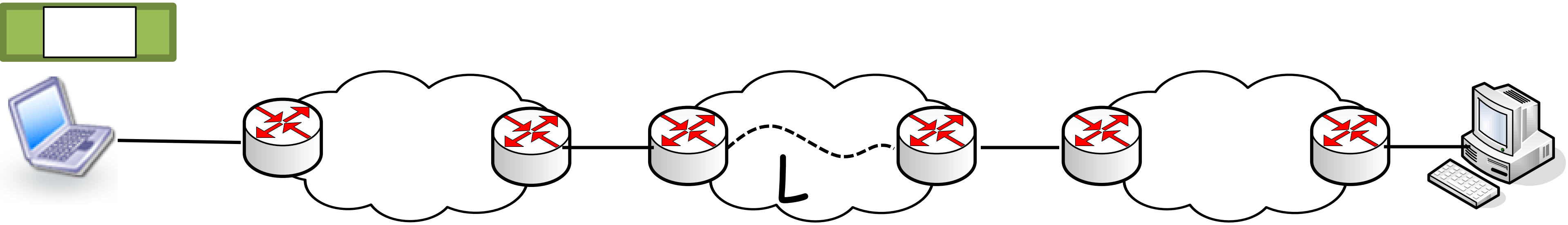

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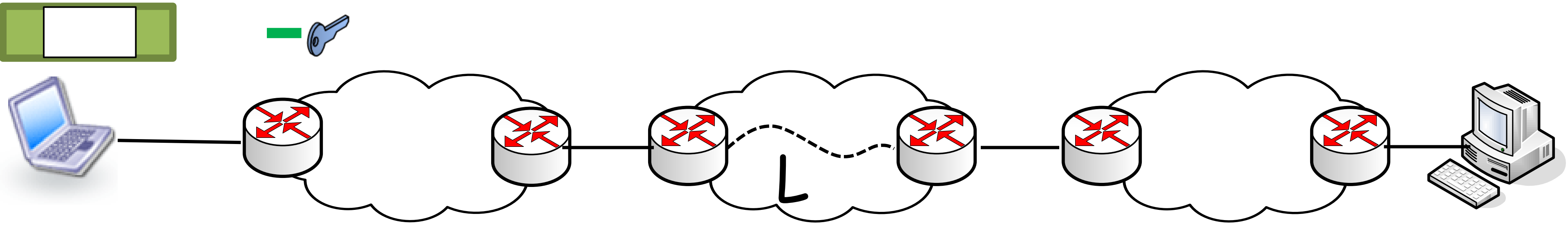

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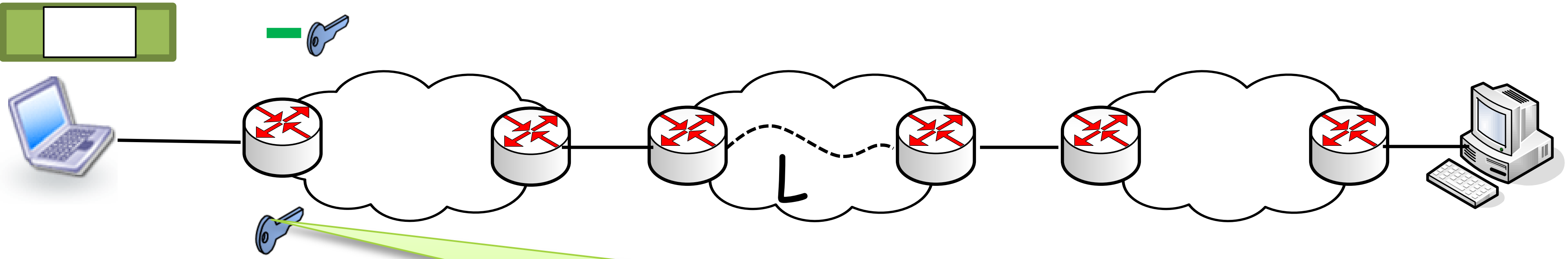

A time-varying secret key

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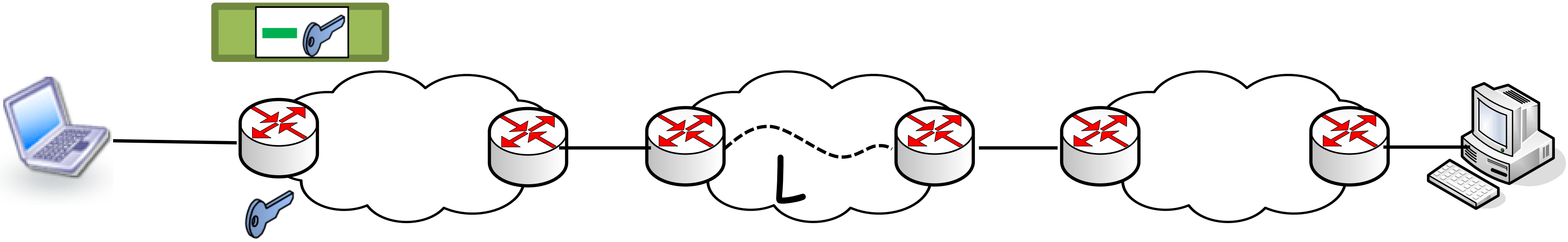
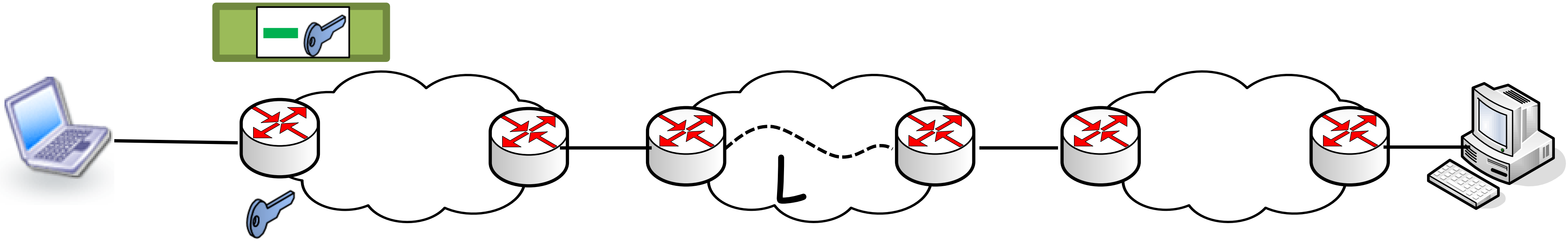


- A router under attack replaces nop with L↓
  - All traffic
  - Signal congestion to access router
  - L→ link, ↓ → act, mon → mode
  - ↓🔑 = MAC🔑(src, dst, ts, L, mon, ↓, —🔑)
  - No downstream overwrite

How does NetFence Work?



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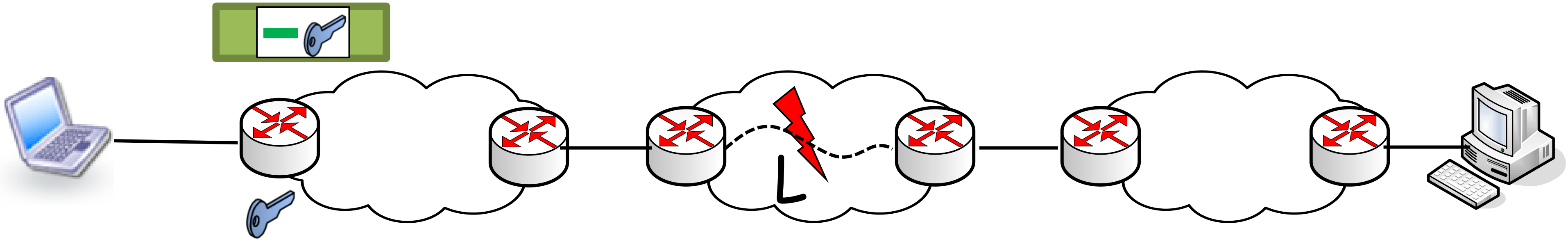

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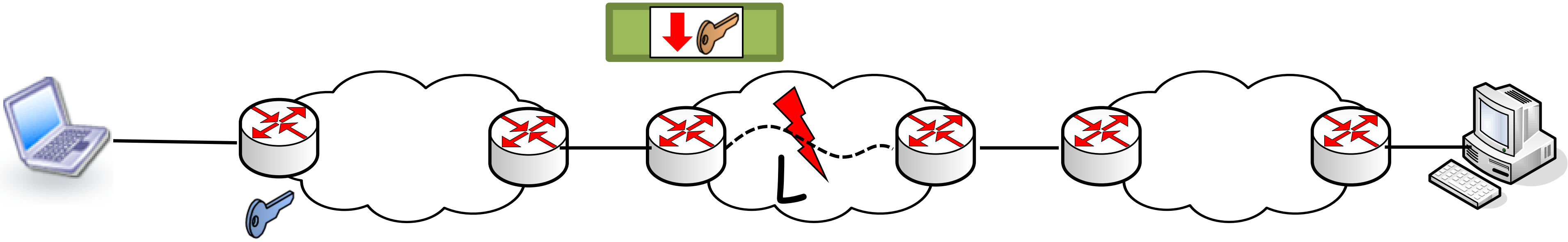

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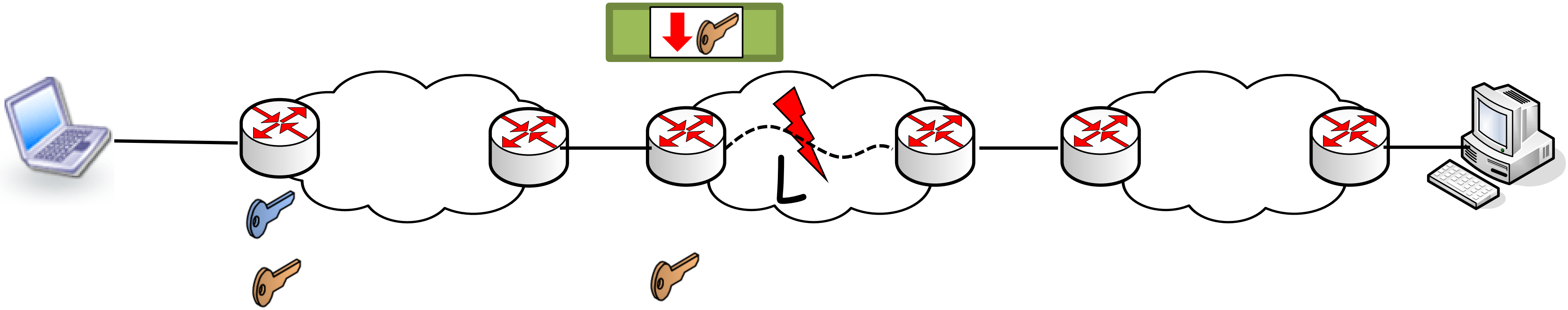

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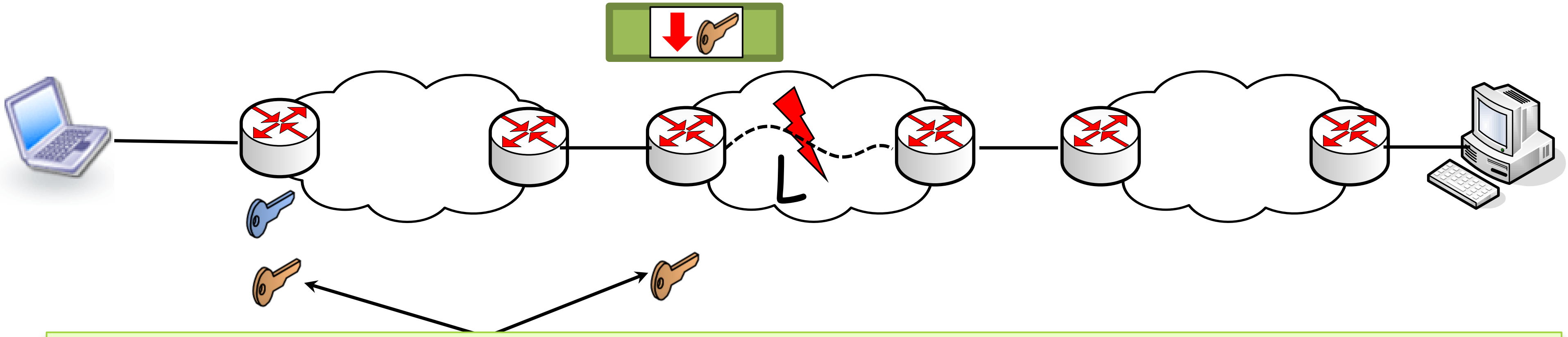

A shared time-varying secret key
via distributed Diffie-Hellman via BGP [Passport]

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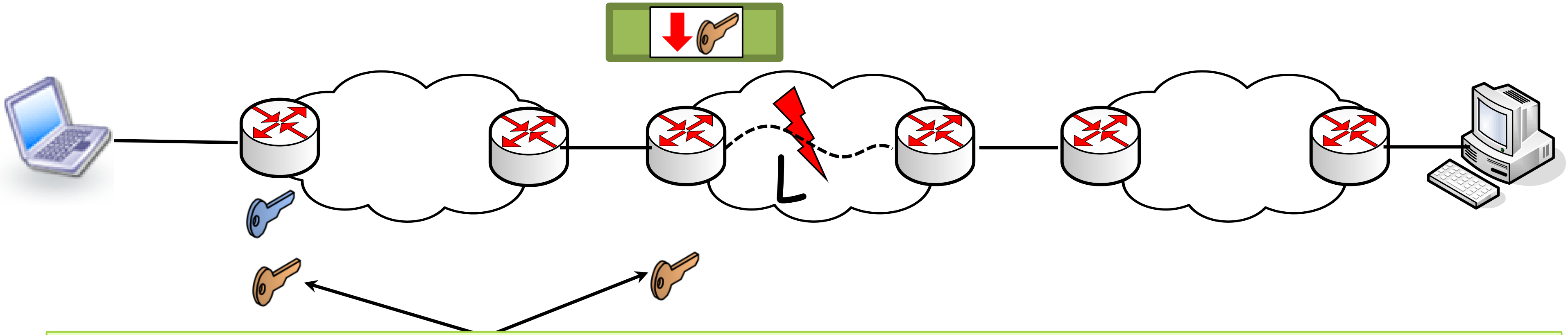

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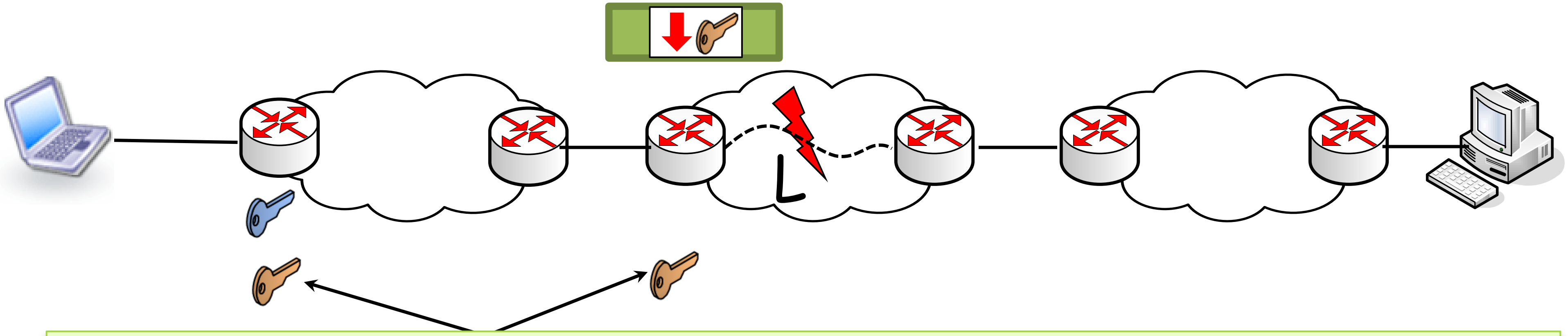

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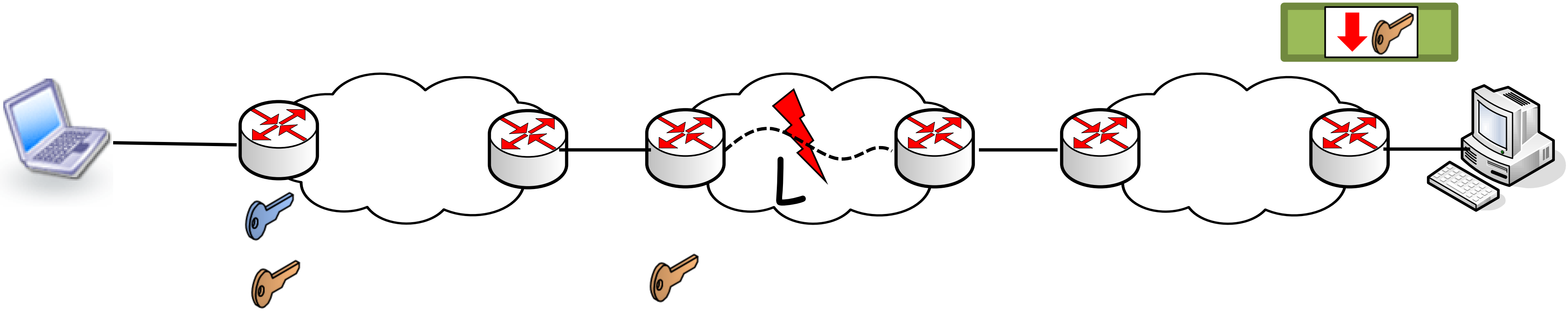

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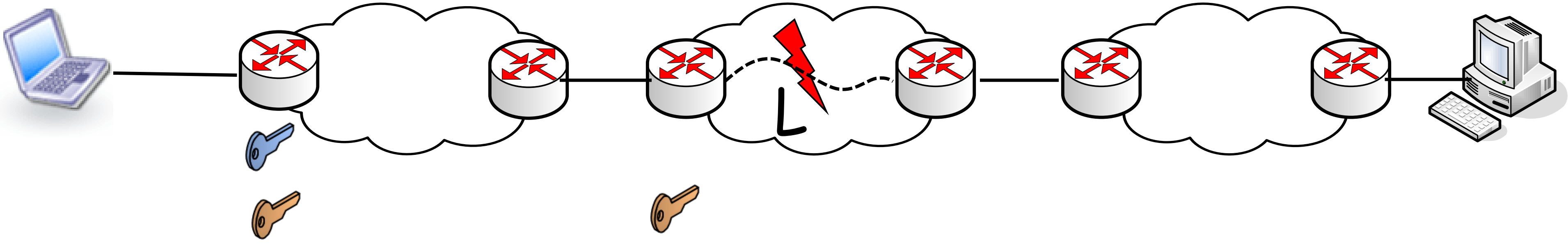

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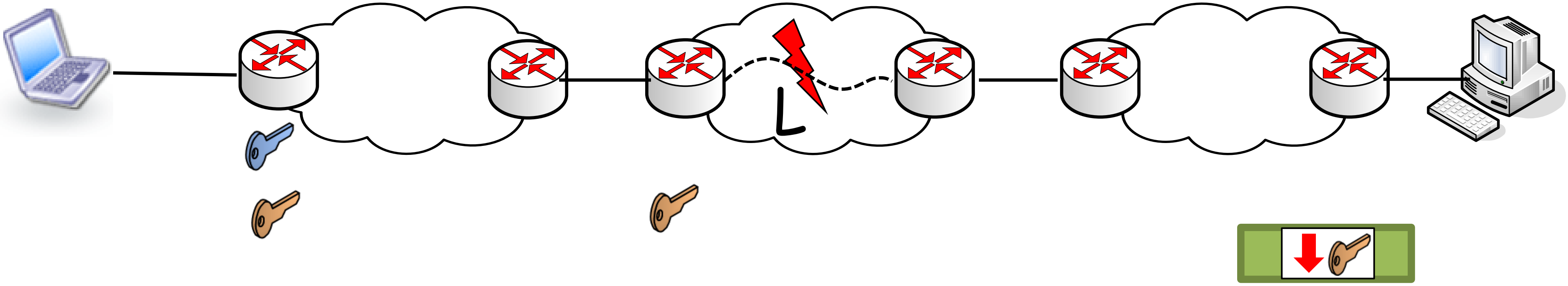

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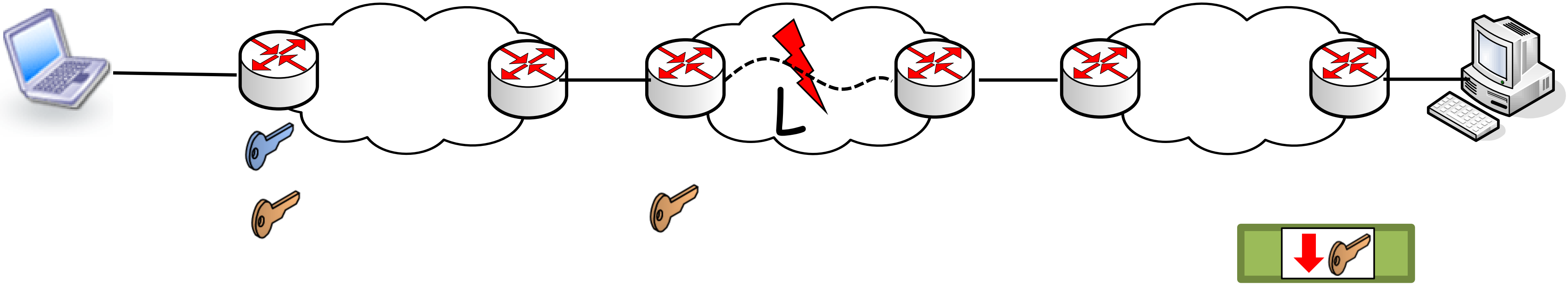

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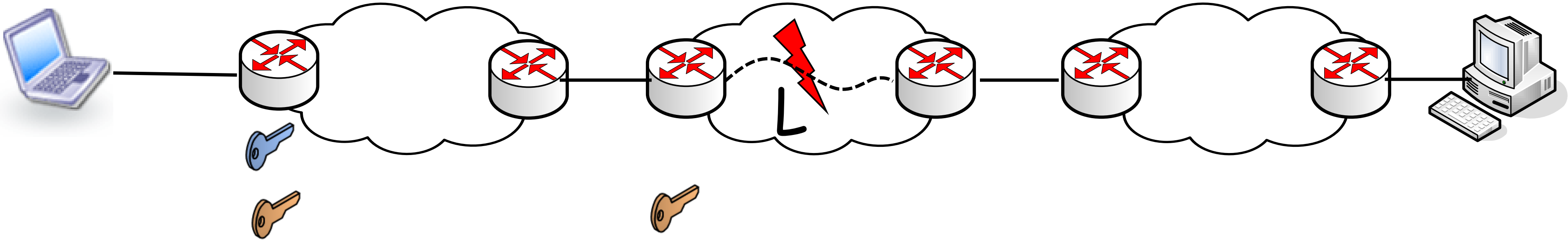

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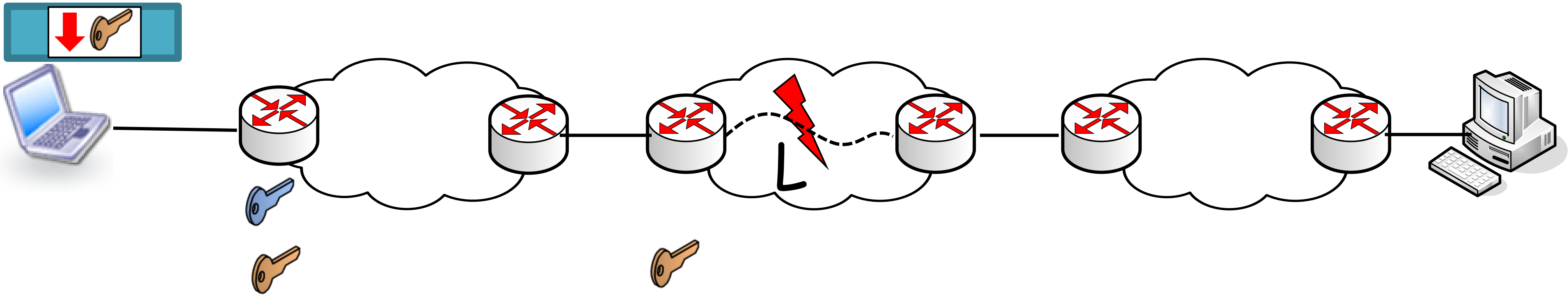

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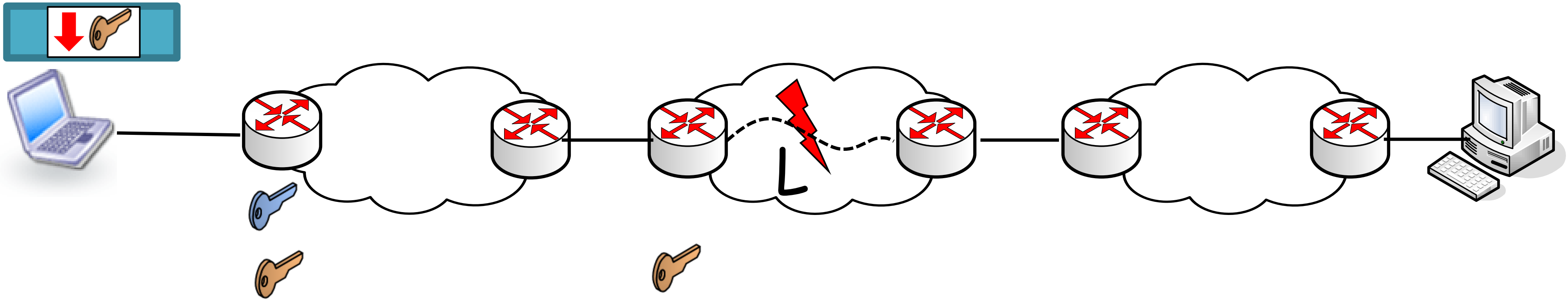

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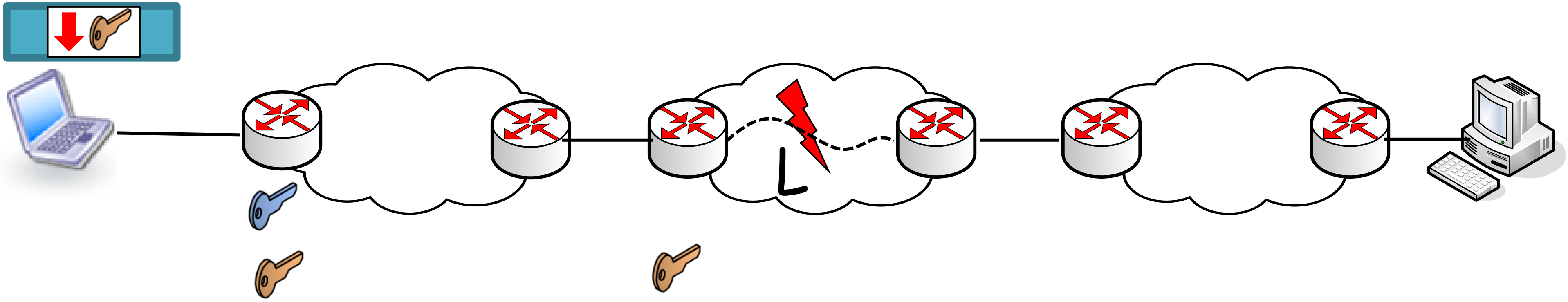

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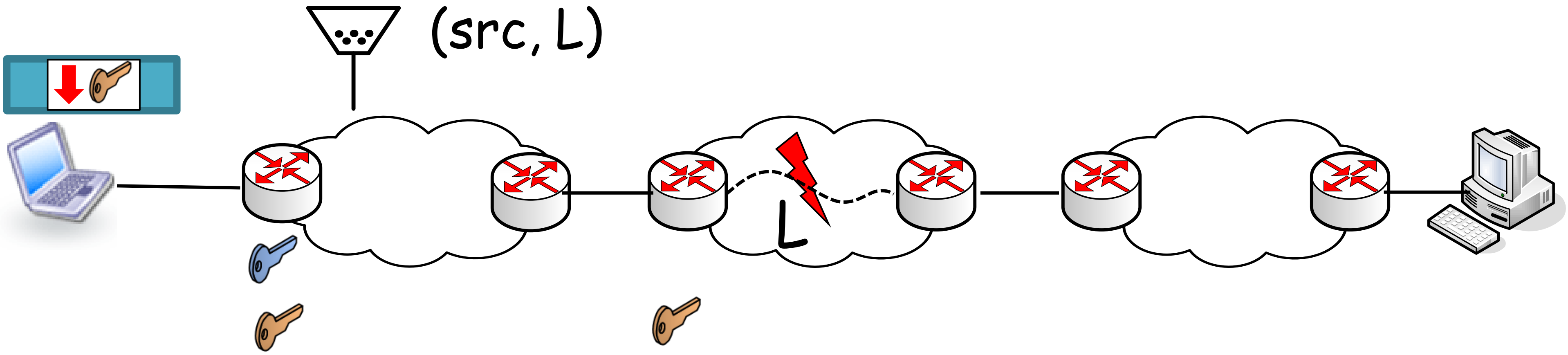

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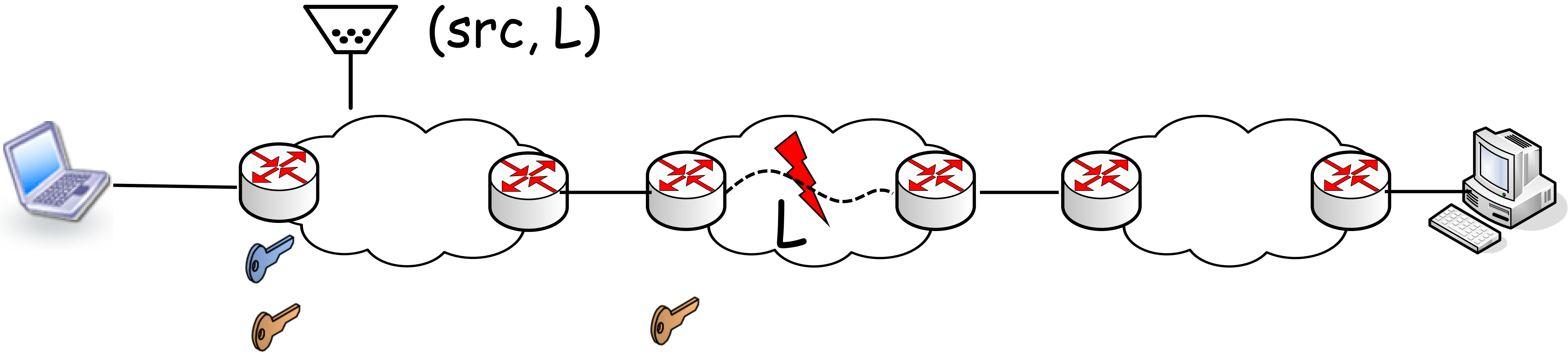

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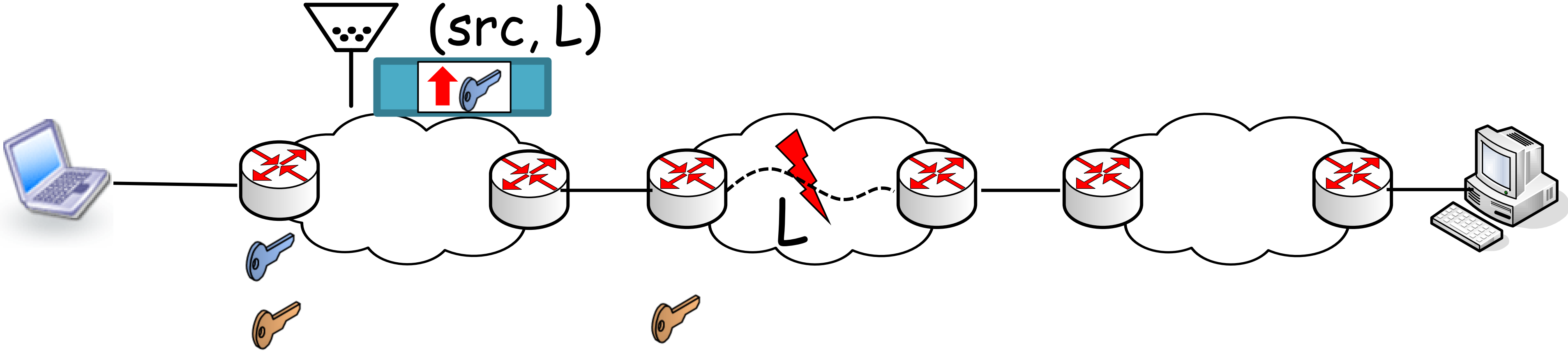

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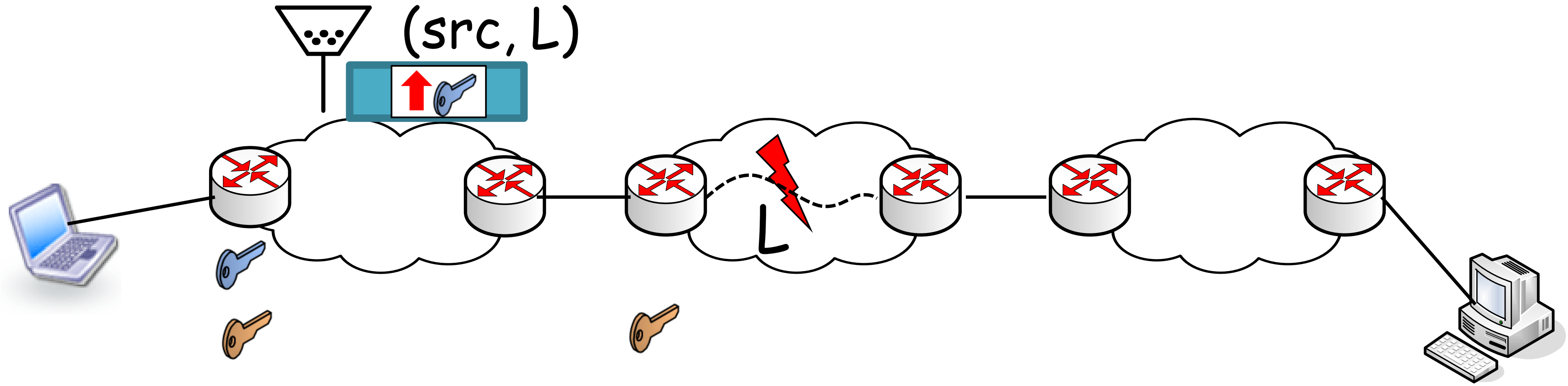

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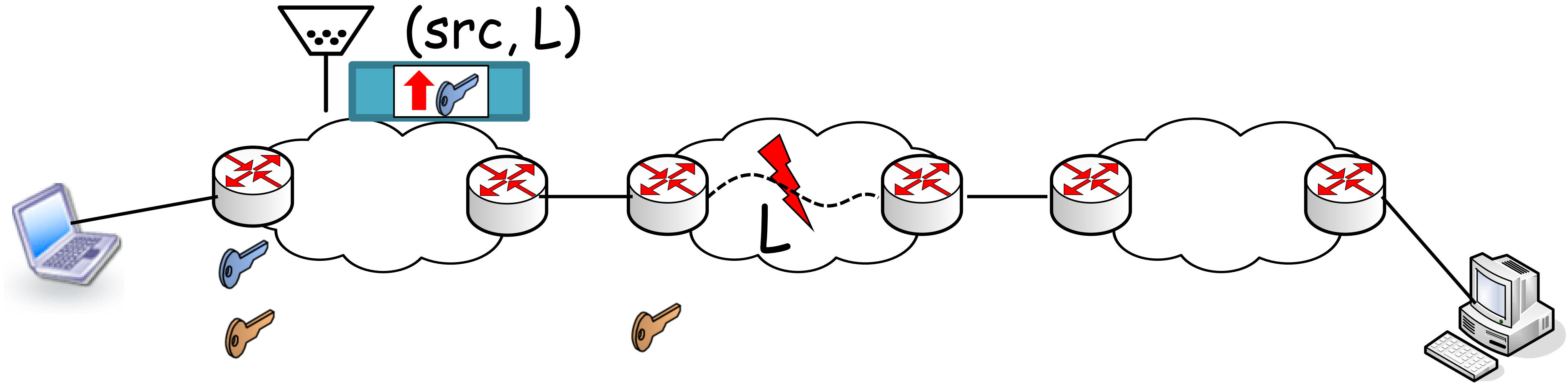

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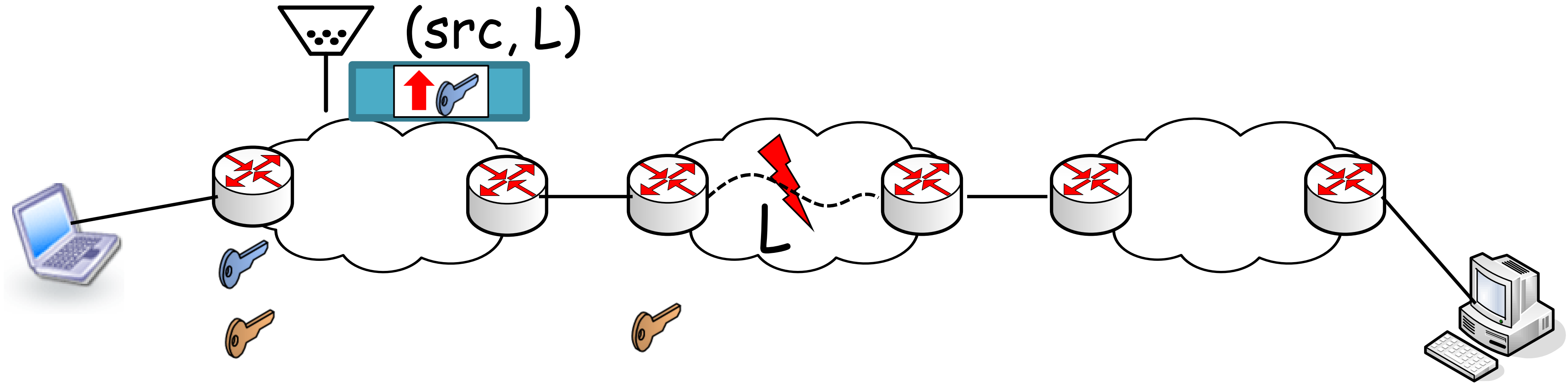

- Establishes a congestion policing loop
  - Bottleneck router signals
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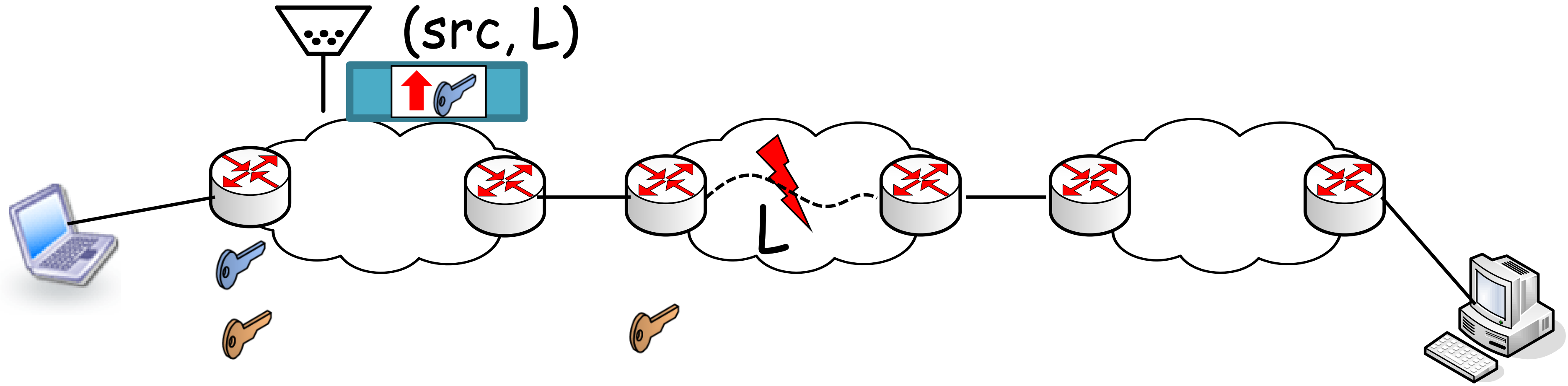

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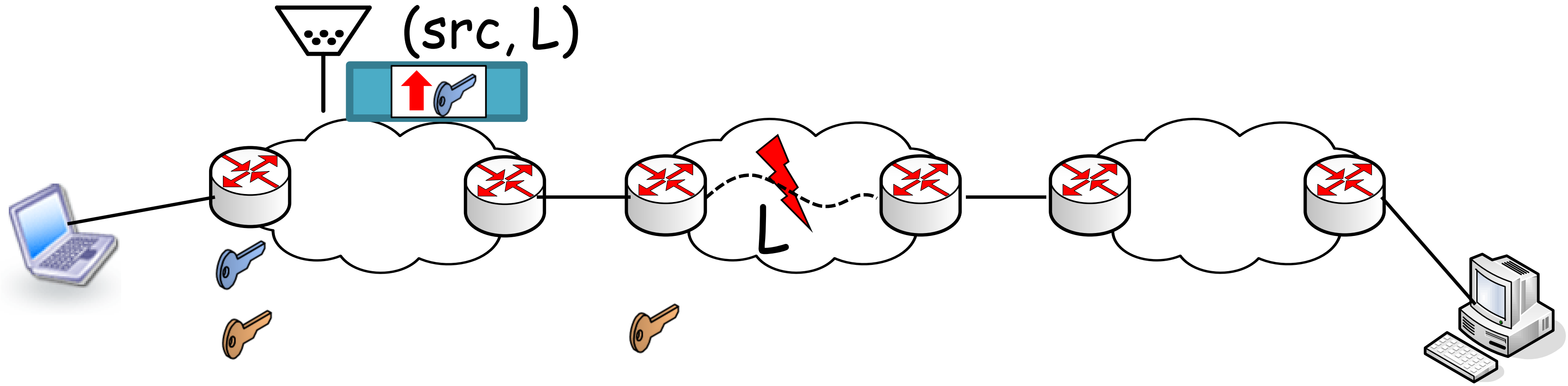

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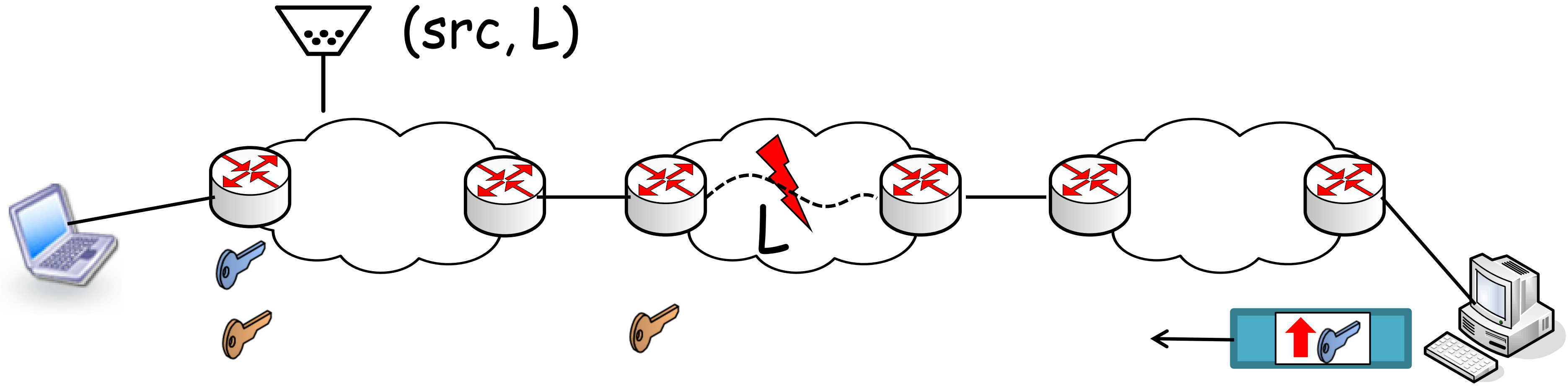

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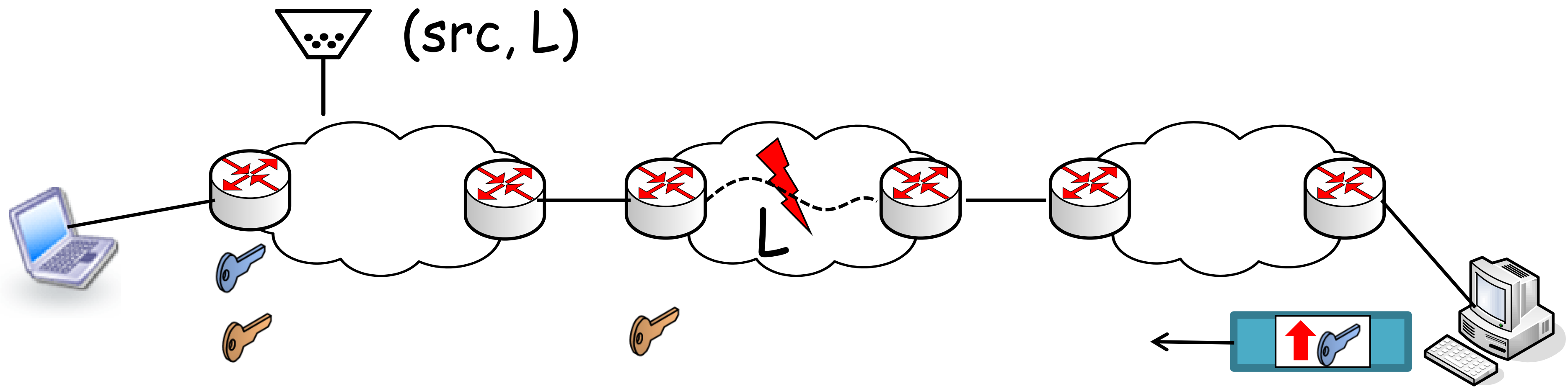

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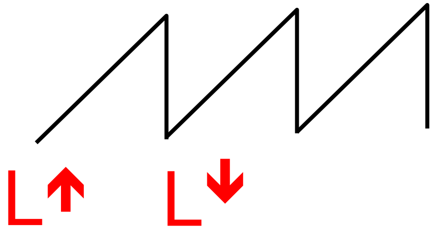


How does NetFence Work?

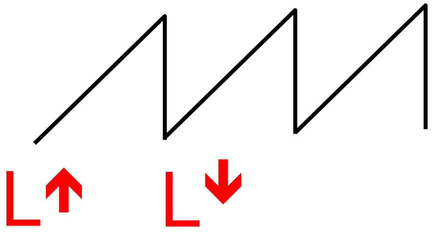
- Bottleneck router
  1. Detect attack to start a policing cycle
     - Loss or load based

  2. Signal congestion within a cycle
     - Random Early Detection (RED)

Recap: Why It Works

1. Secret keys to secure congestion policing feedback

2. Periodic AIMD based on secure congestion police feedback



3. Secure congestion feedback as network capabilities

Properties

- Provable fairness
  - Denial of Service → Predictable Delay of Service

Theorem: Given *G* good and *B* bad senders sharing a bottleneck link of capacity *C*, regardless of the attack strategies, any good sender *g* with sufficient demand eventually obtains a fair share

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Now the Trickier Stuff

More Challenges

- A broad range of attacks
  - Flood request packets (with no feedback)
  - Hide $L^{\downarrow}$
  - Evade attack detection
  - On/Off
  - …

- Multiple bottlenecks
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  - Low overhead
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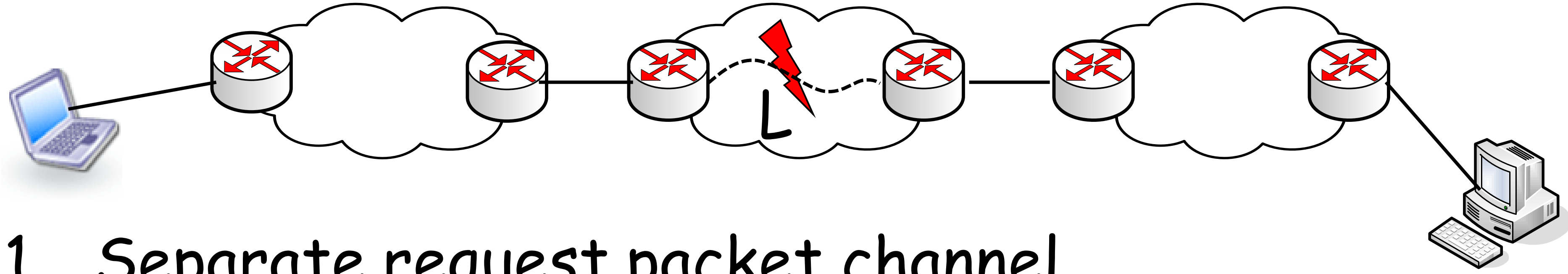

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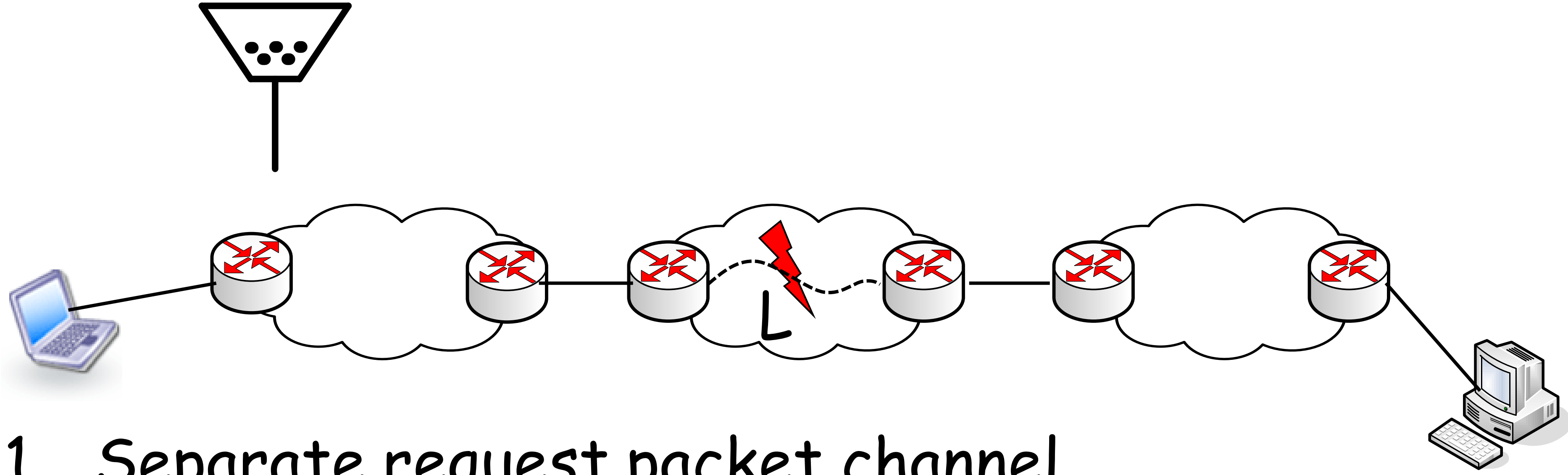

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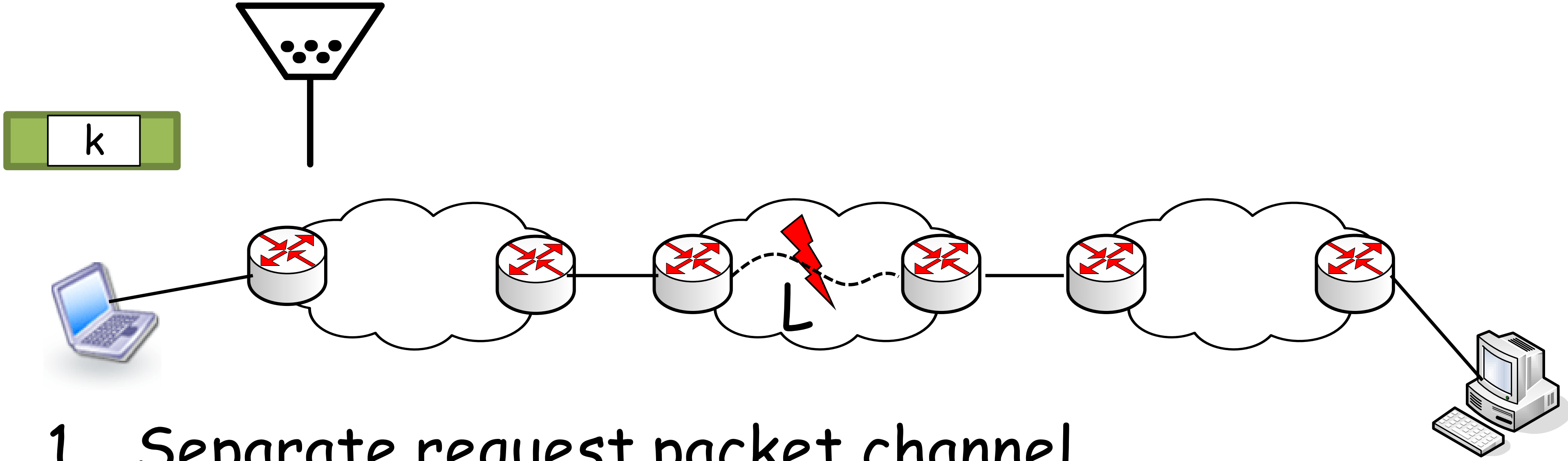

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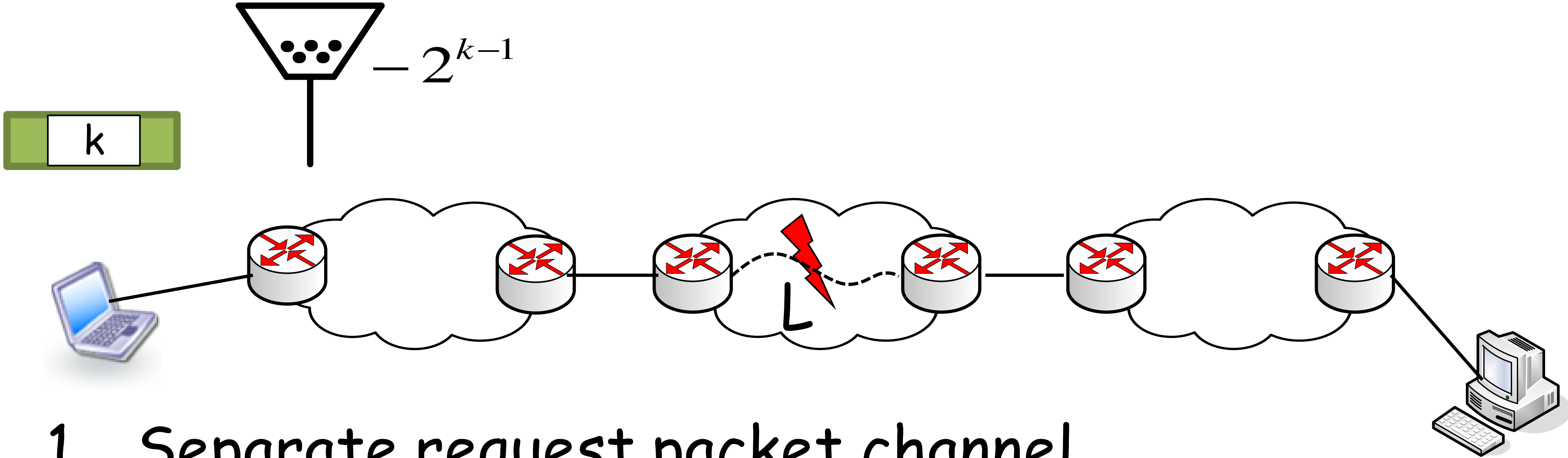

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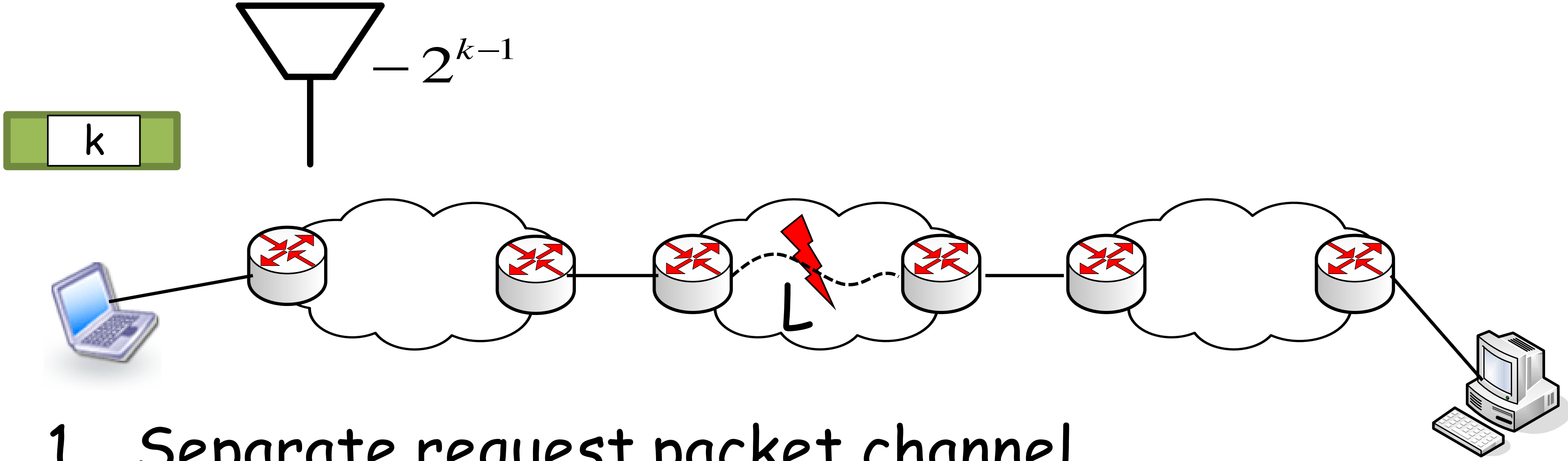

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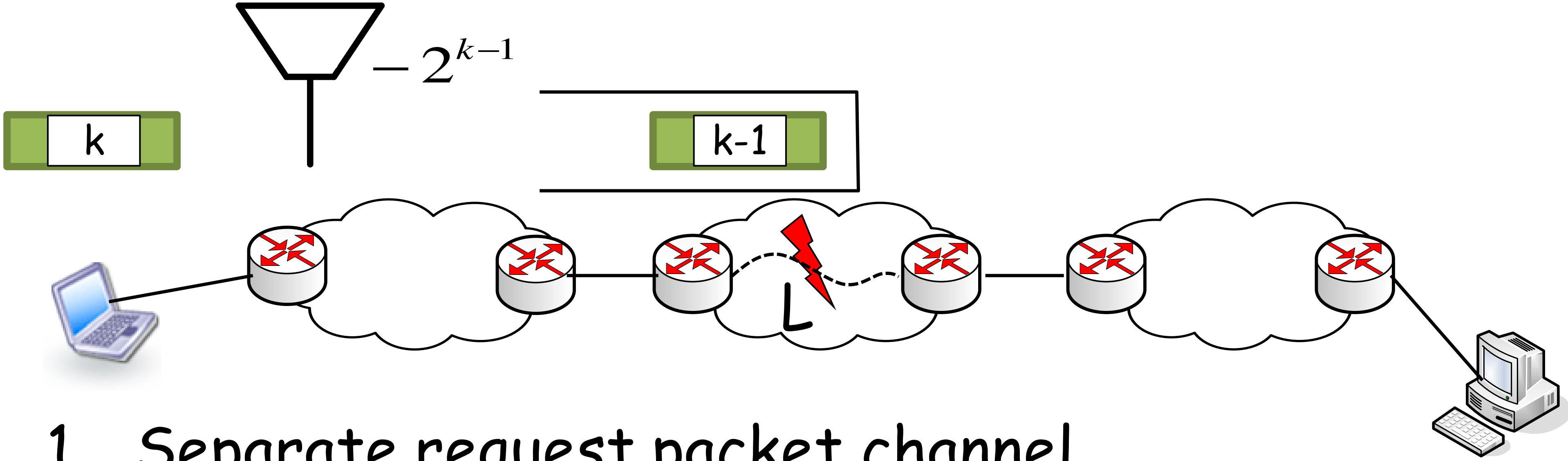

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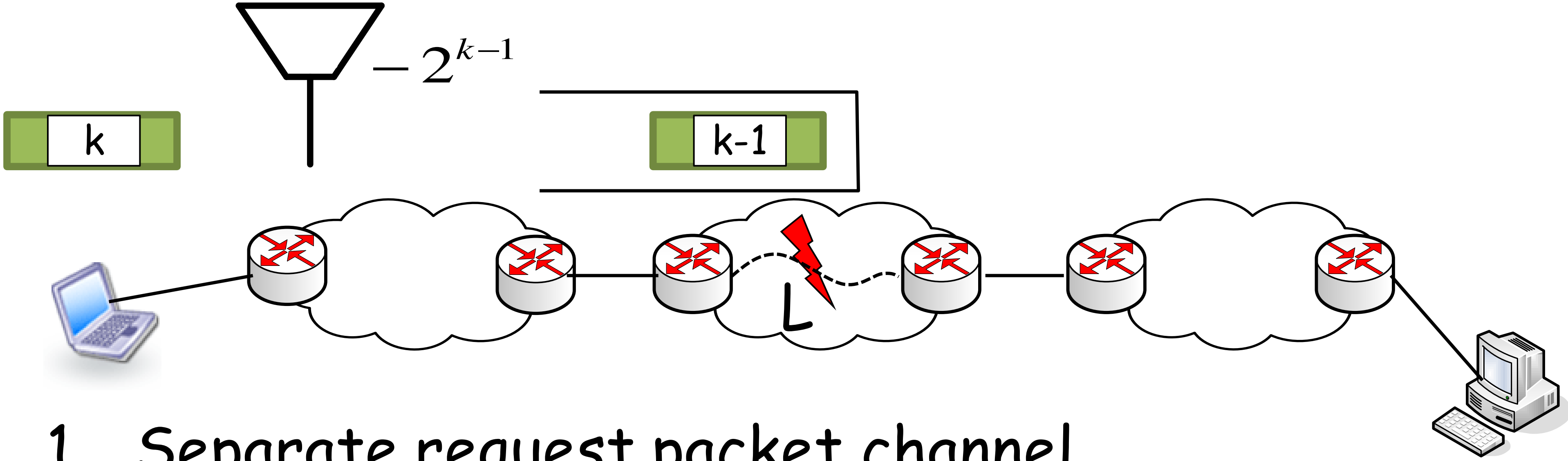

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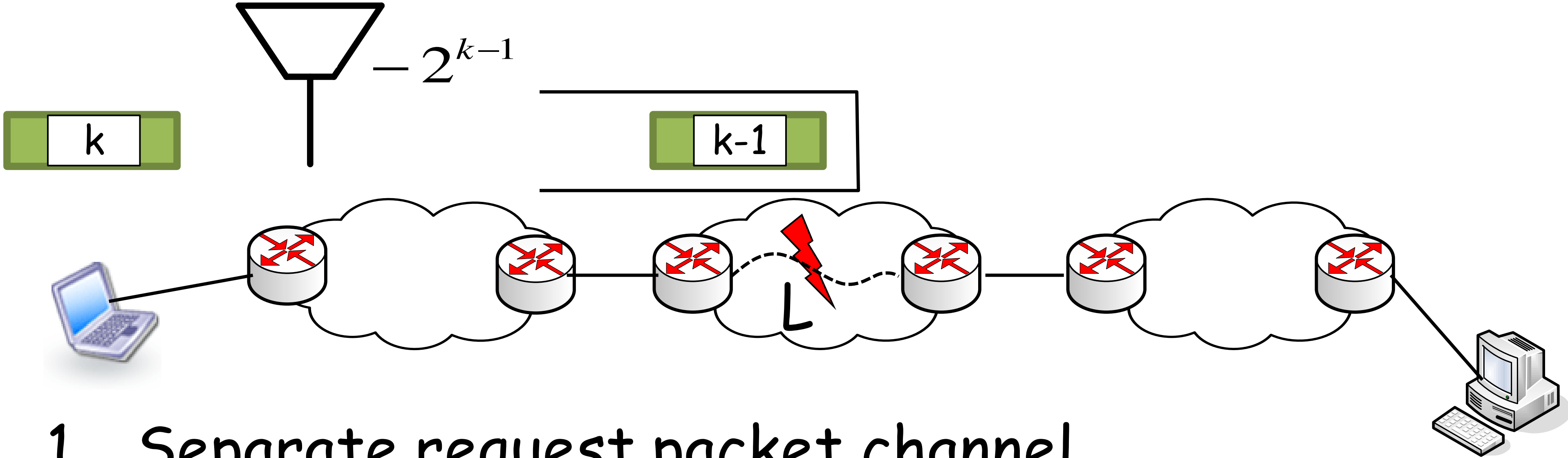

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1. Eventual success
2. Efficient: waiting replaces proof of work

Making hiding L↓ ineffective

- Robust signaling rate increase with L↑
  1. Treating the absence of L↑ as L↓
  2. Stamping no L↑ for sufficiently long after congestion ends

Making hiding L↓ ineffective

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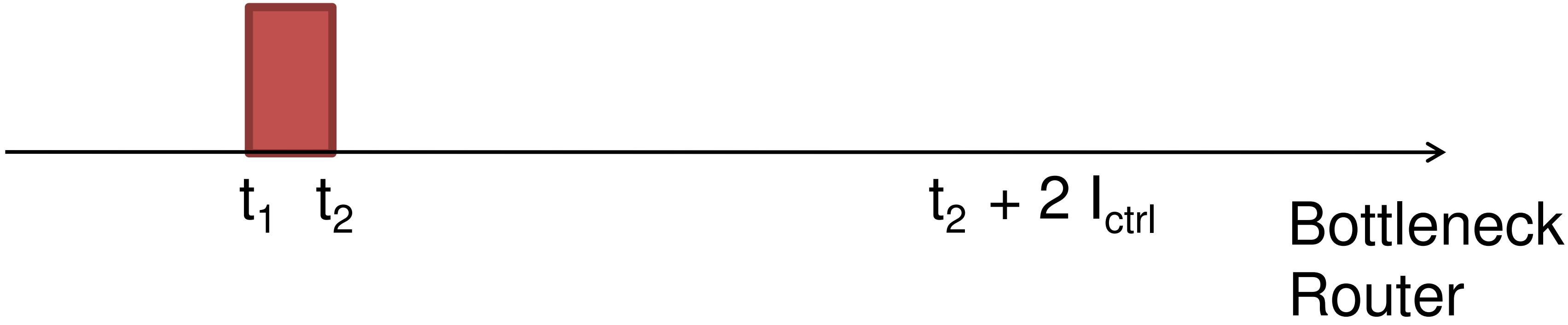

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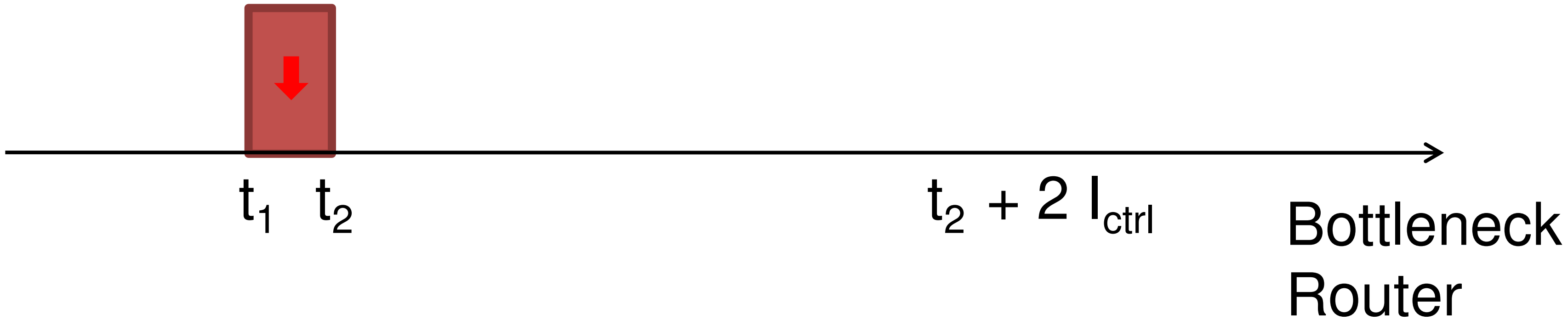

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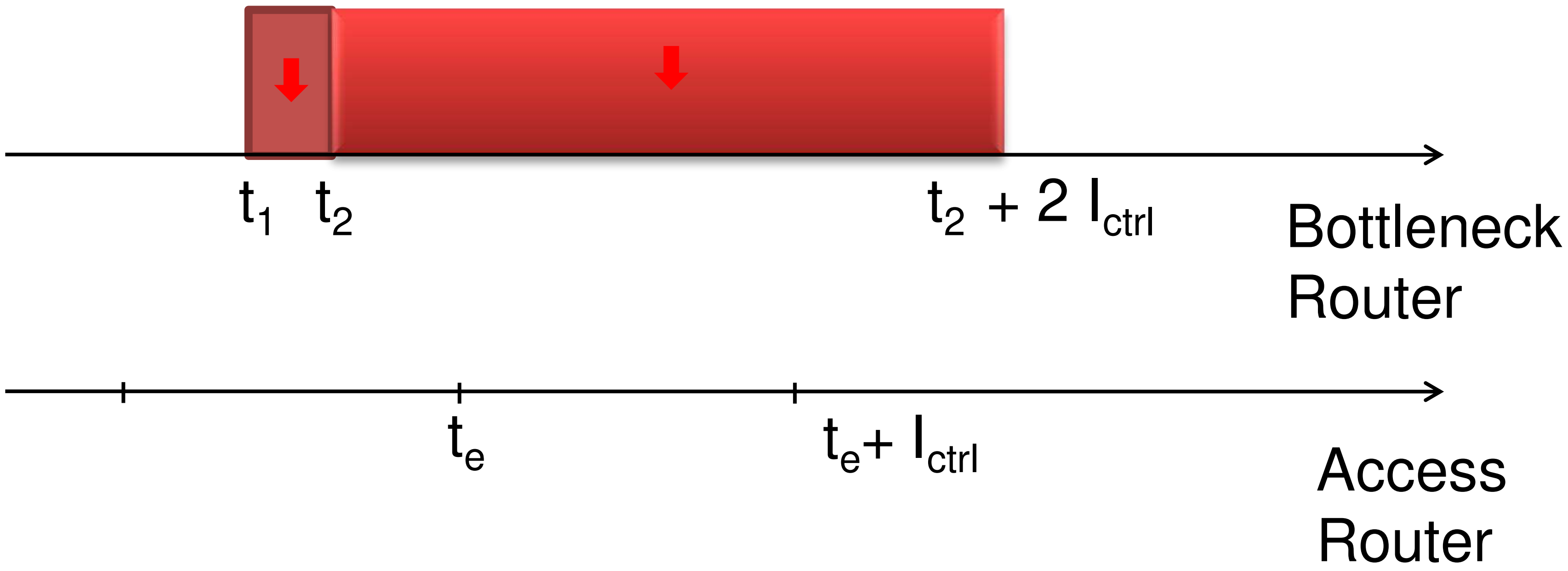

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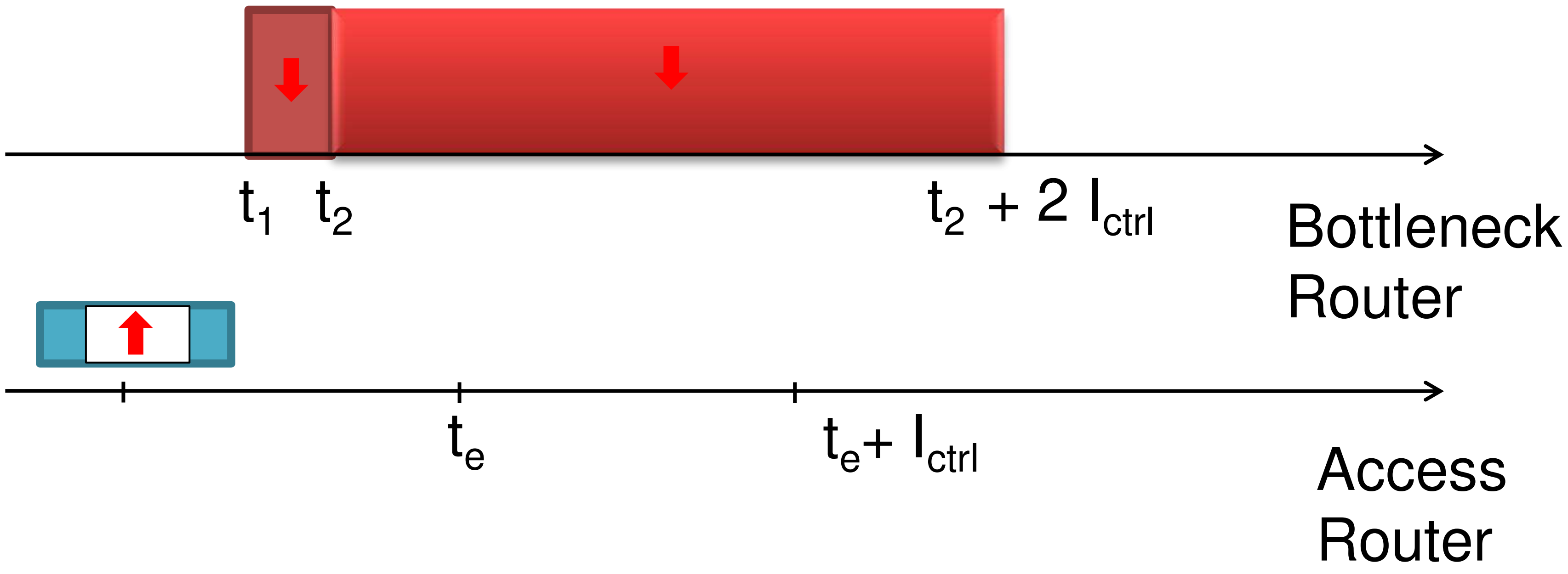

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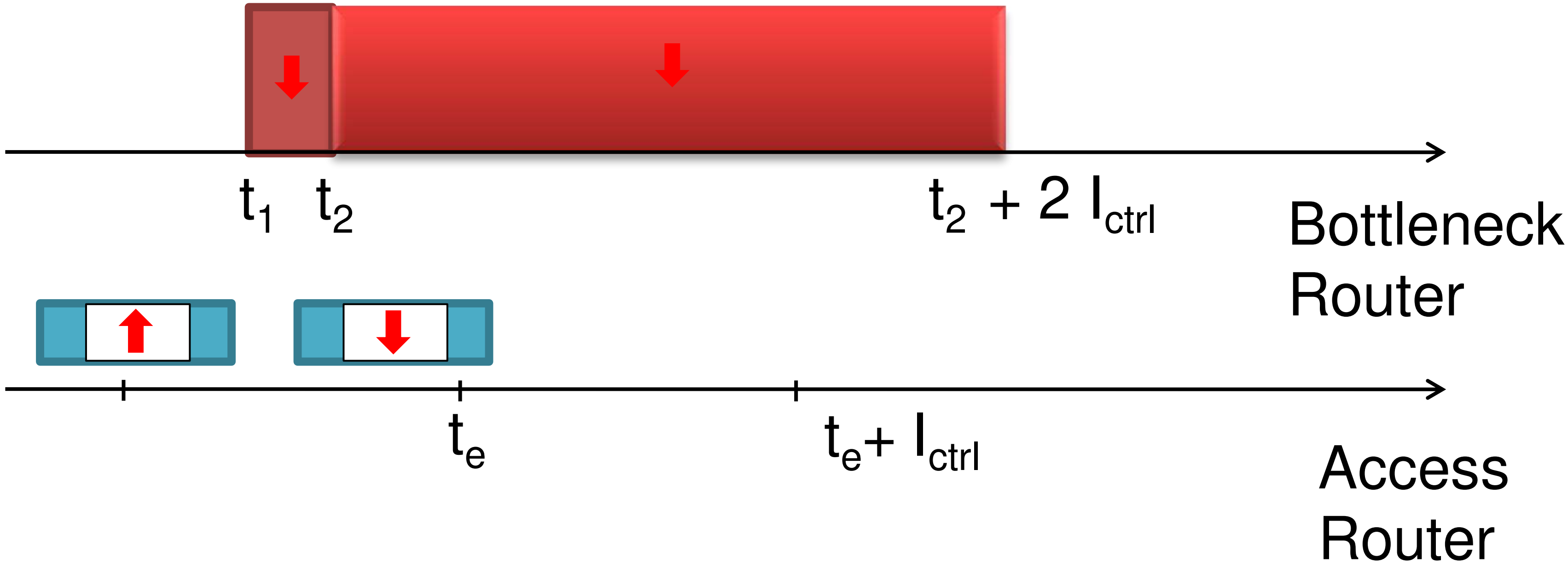

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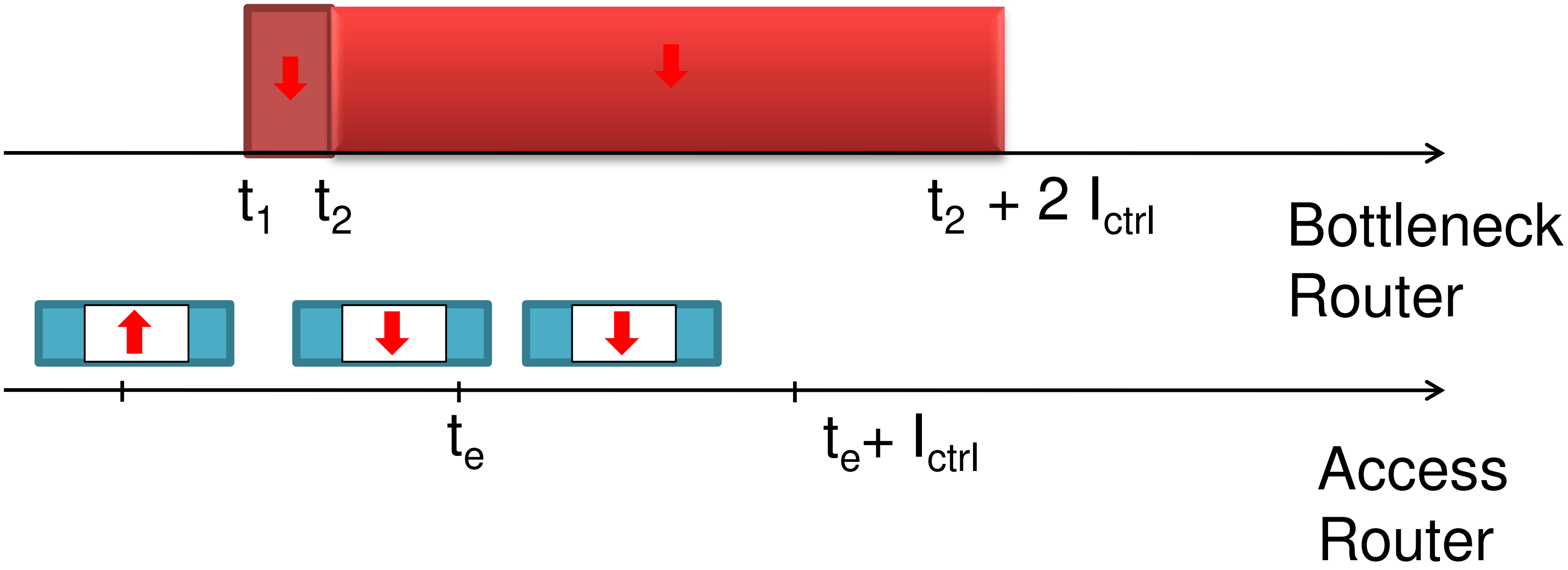

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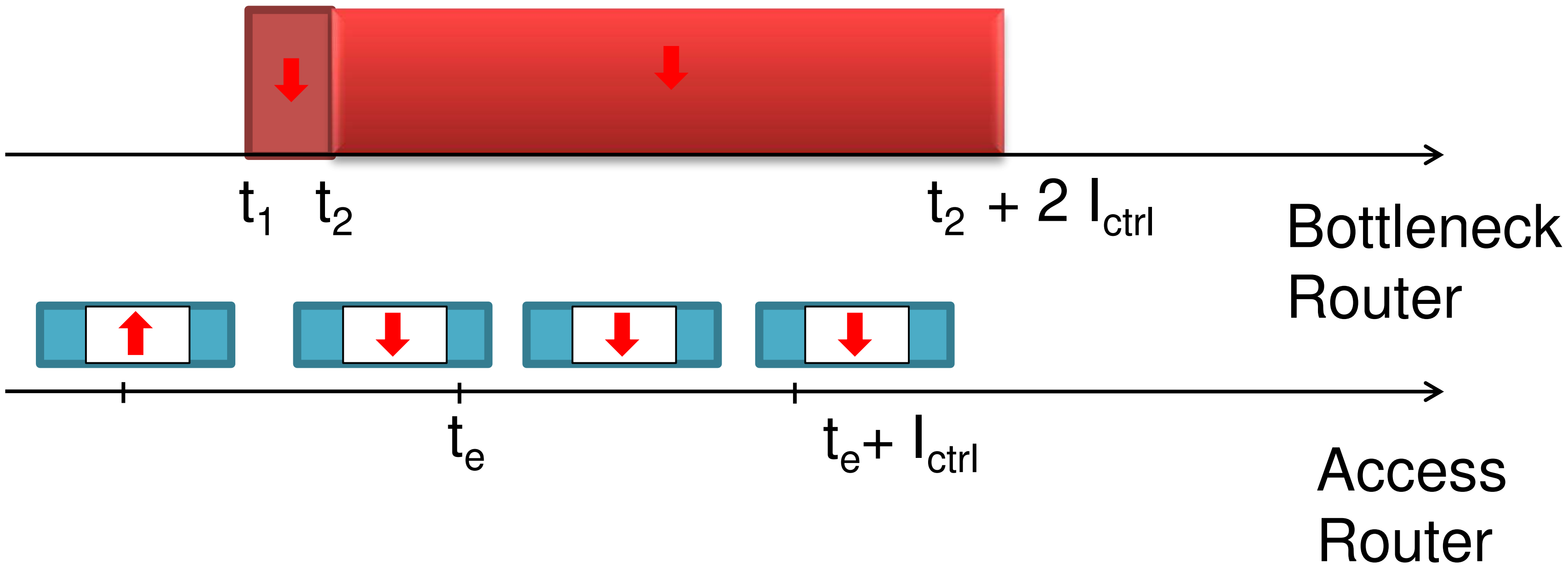

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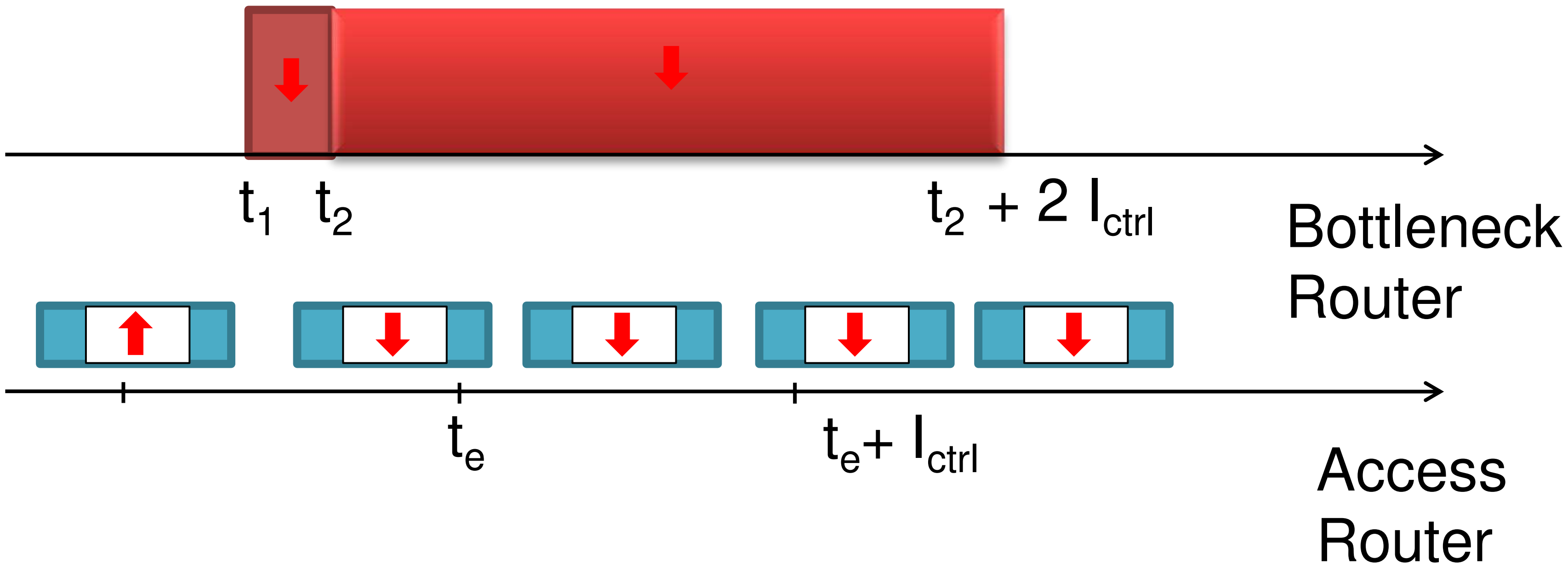
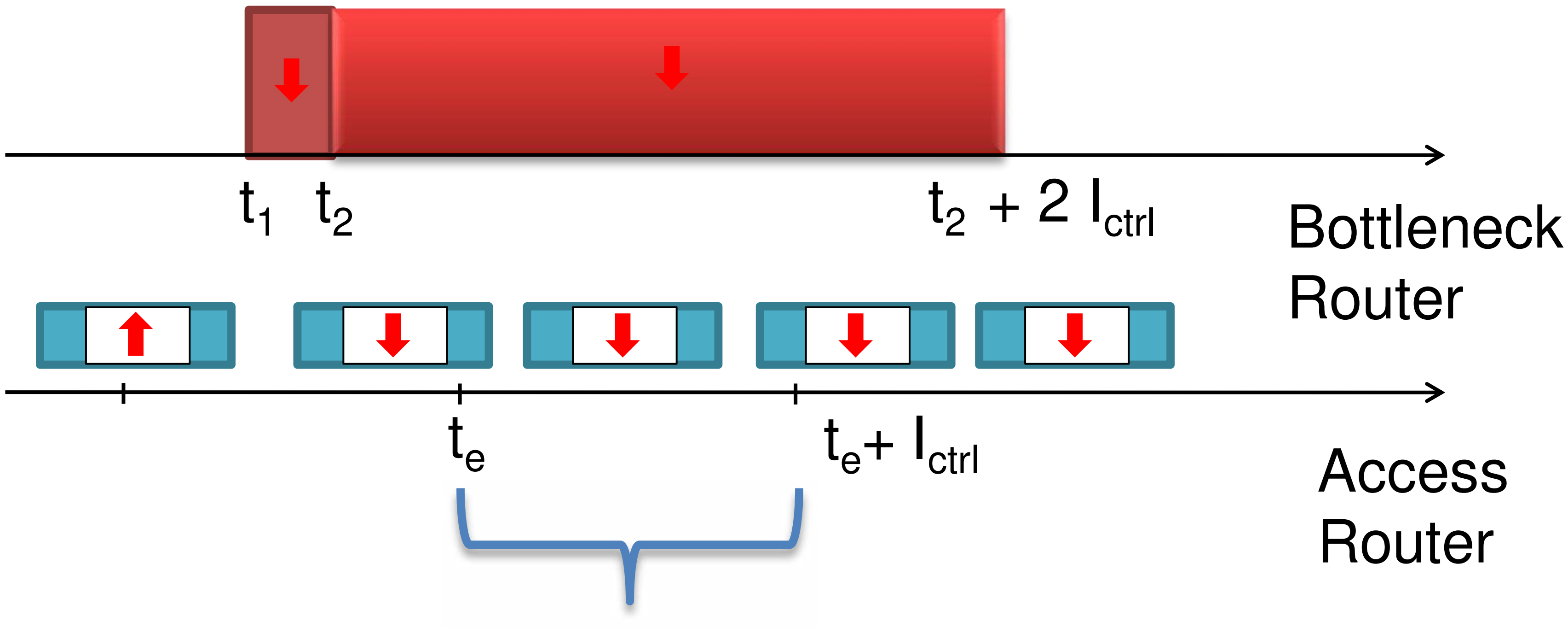


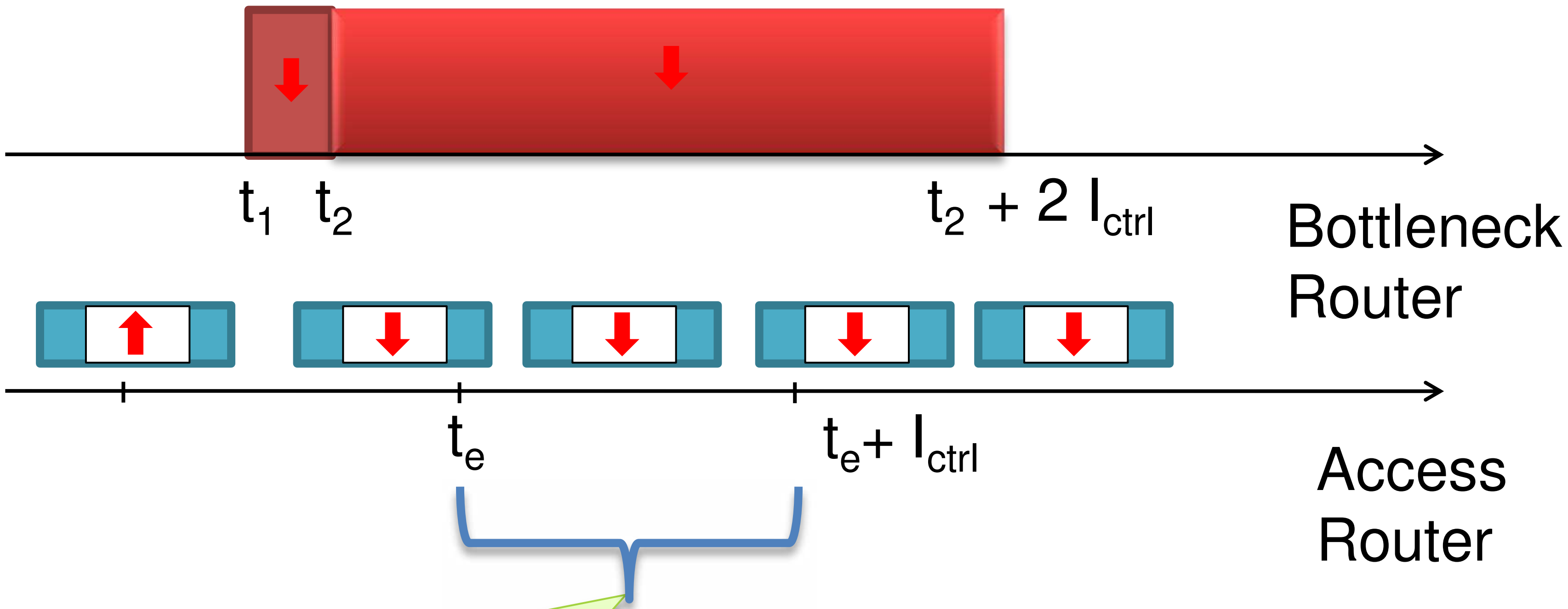
- Robust signaling rate increase with $L^{\uparrow}$
  1. Treating the absence of $L^{\uparrow}$ as $L^{\downarrow}$
  2. Stamping no $L^{\uparrow}$ for sufficiently long after congestion ends

Making hiding $L^{\downarrow}$ ineffective



- Robust signaling rate increase with $L^{\uparrow}$
  1. Treating the absence of $L^{\uparrow}$ as $L^{\downarrow}$
  2. Stamping no $L^{\uparrow}$ for sufficiently long after congestion ends

Making hiding L↓ ineffective



➔ $t_e+I_{ctrl} \le t_2 + 2I_{ctrl}$

➔ A sender can't present L↑

➔ Rate limit is reduced

- Rob … with L↑

1. T …
2. S … ong after congestion ends

Performance

Implementation

- A software implementation in Linux
  - XORP and Click
  - AES-128 as the MAC function

- DeterLab experiments
  - Dual-core Intel Xeon 3GHz CPUs
  - 2GB memory

Implementation

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Encrypting the Internet!

- DeterLab
  - Dual-core Intel Xeon 3GHz CPUs
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- A software implementation in Linux
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  - AES-128 as the MAC function

- DeterLab experiments
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Processing overhead

	Packet type	**Access router**	**Bottleneck router**
No Attack	Request	546 ns/pkt	0
	Regular	781 ns/pkt	0
Attack	Request	546 ns/pkt	492 ns/pkt
	Regular	1267 ns/pkt	554 ns/pkt

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One AES computation
Tput ~ 2mpps

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≤ 3AES computation.
Parallelizable

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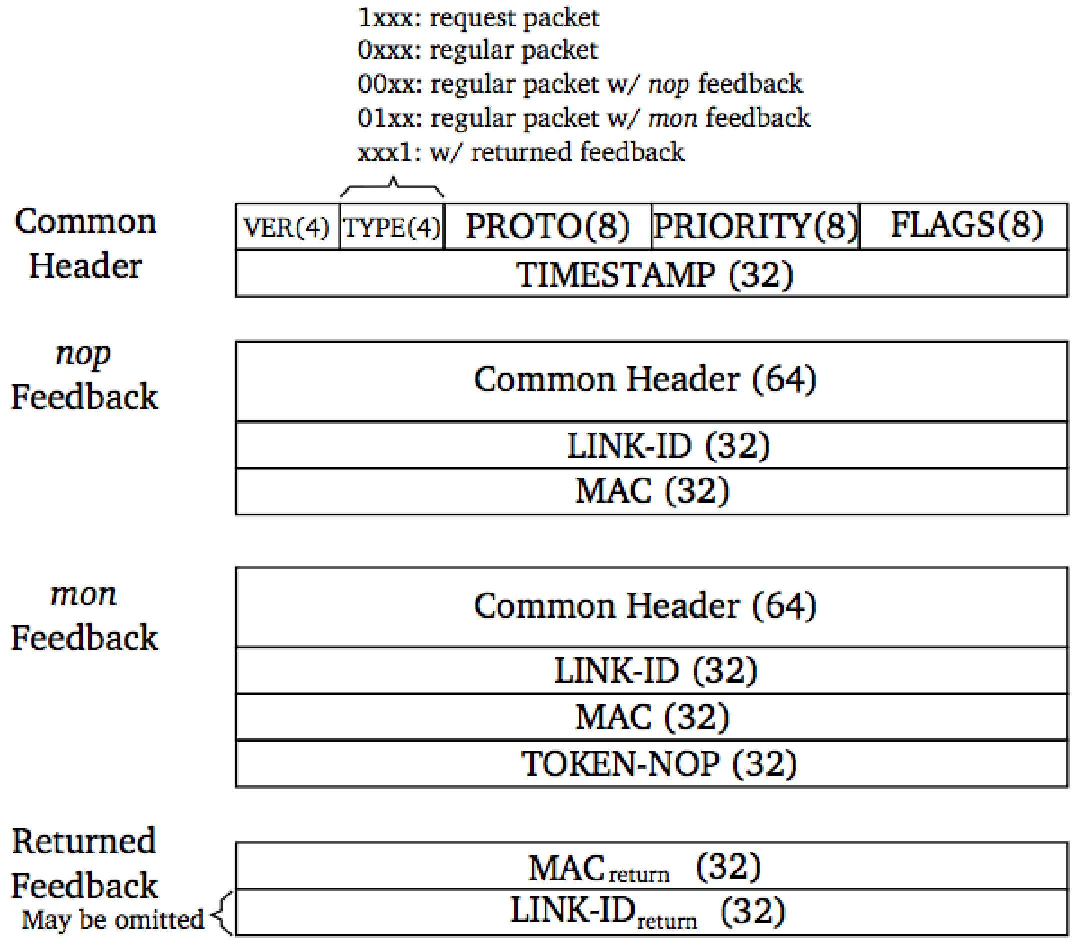
≤ 3AES computation.
Parallelizable

One AES
computation
Tput ~ 2mpps

NetFence is suitable for high-speed implementation

Header overhead



1xxx: request packet
0xxx: regular packet
00xx: regular packet w/ *nop* feedback
01xx: regular packet w/ *mon* feedback
xxx1: w/ returned feedback

Common Header

VER(4)	TYPE(4)	PROTO(8)	PRIORITY(8)	FLAGS(8)
TIMESTAMP (32)				

nop Feedback

Common Header (64)
LINK-ID (32)
MAC (32)

mon Feedback

Common Header (64)
LINK-ID (32)
MAC (32)
TOKEN-NOP (32)

Returned Feedback

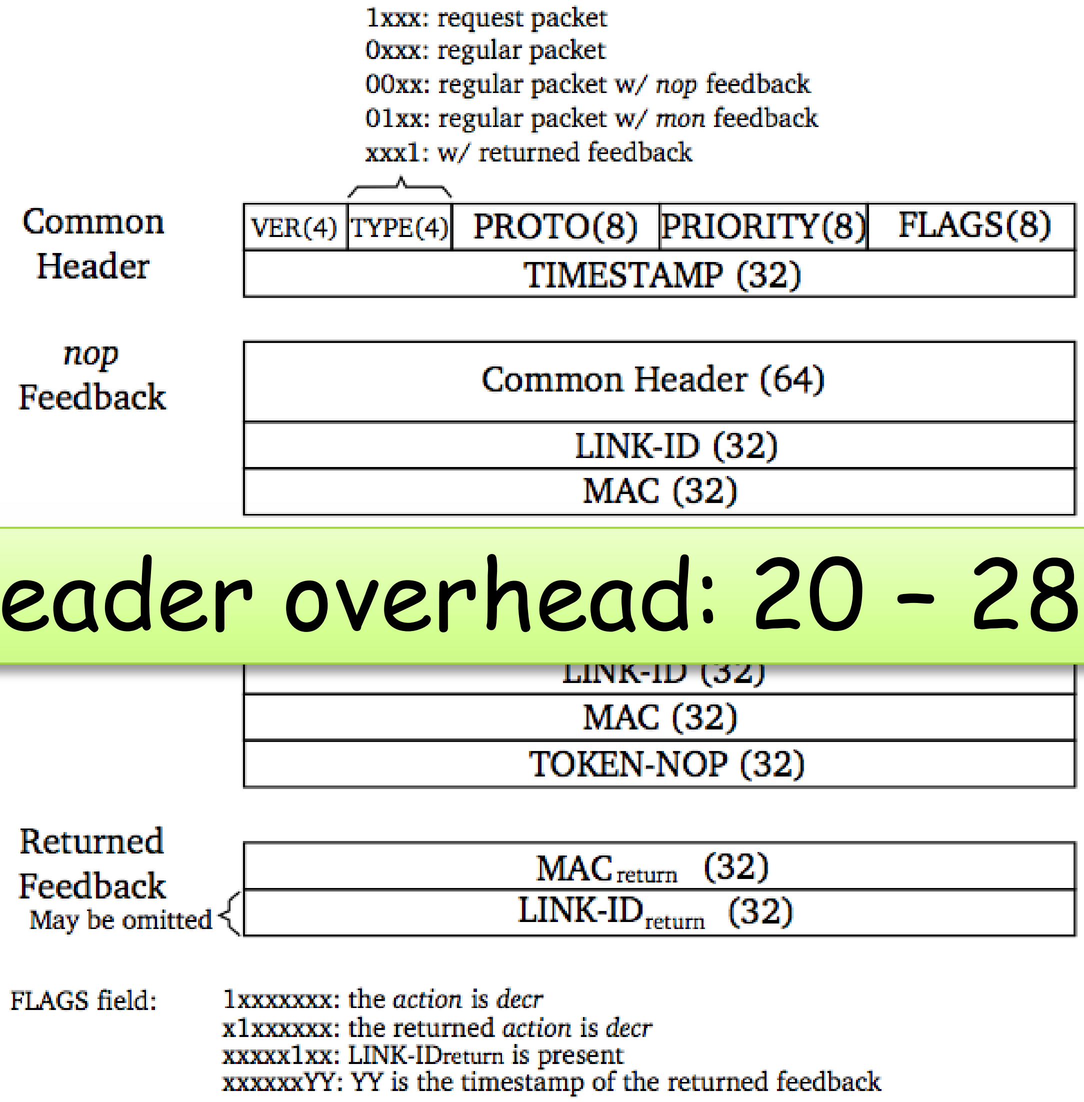
$\text{MAC}_{\text{return}}$ (32)
$\text{LINK-ID}_{\text{return}}$ (32)

May be omitted

FLAGS field:

1xxxxxxx: the *action* is *decr*
x1xxxxxx: the returned *action* is *decr*
xxxxx1xx: $\text{LINK-ID}_{\text{return}}$ is present
xxxxxxYY: YY is the timestamp of the returned feedback

Header overhead



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Common Header

VER(4)	TYPE(4)	PROTO(8)	PRIORITY(8)	FLAGS(8)
TIMESTAMP (32)				

nop Feedback

Common Header (64)
LINK-ID (32)
MAC (32)

Header overhead: 20 - 28 bytes

LINK-ID (32)
MAC (32)
TOKEN-NOP (32)

Returned Feedback

May be omitted

$\text{MAC}_{\text{return}}$ (32)
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Simulations

- Extensive ns-2 simulations
- Systems compared: more state in core
  - Per-sender Fair Queuing (FQ)
  - TVA+: capability + per-sender/receiver FQ
  - StopIt: filter + per-sender FQ

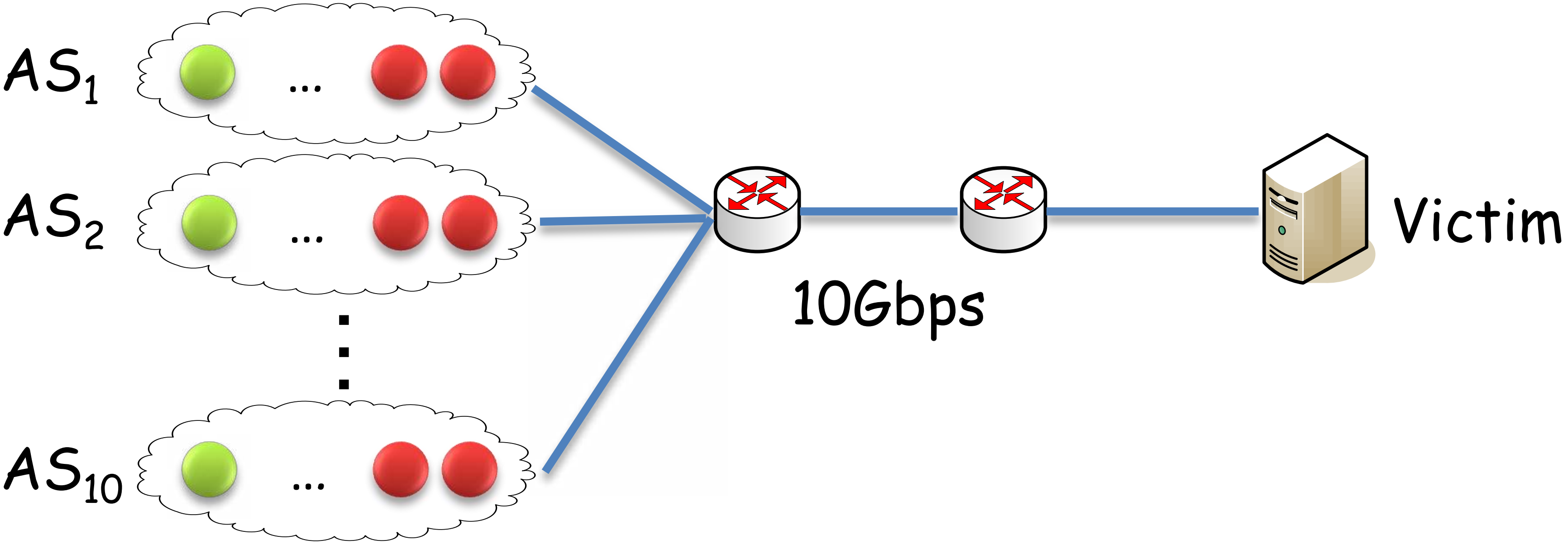
NetFence

- Enables receivers to suppress unwanted traffic
- Effectively polices malicious flows

➔ A robust and scalable DoS solution

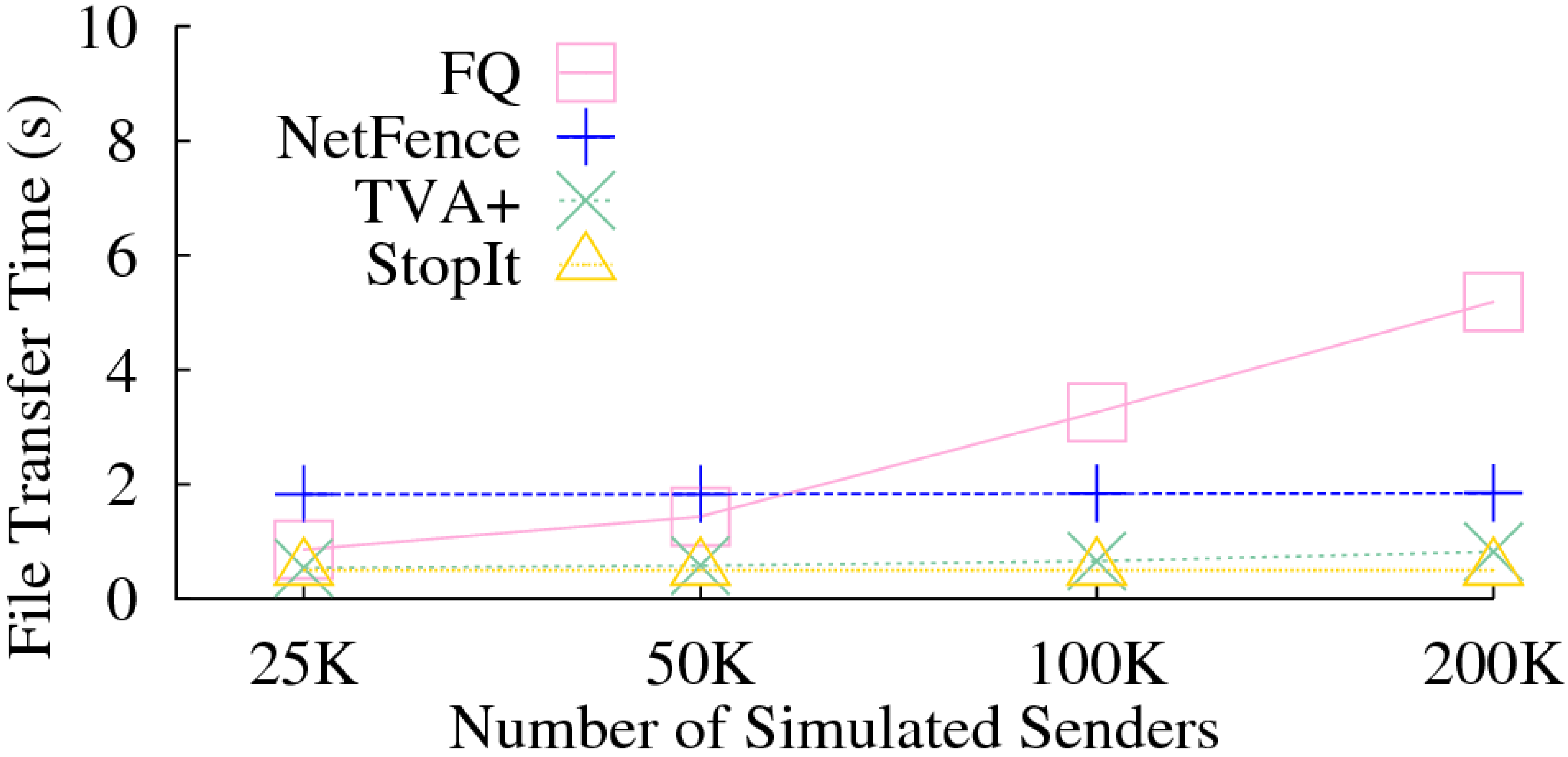
A Subset of Results

Expr 1: DoES Attacks



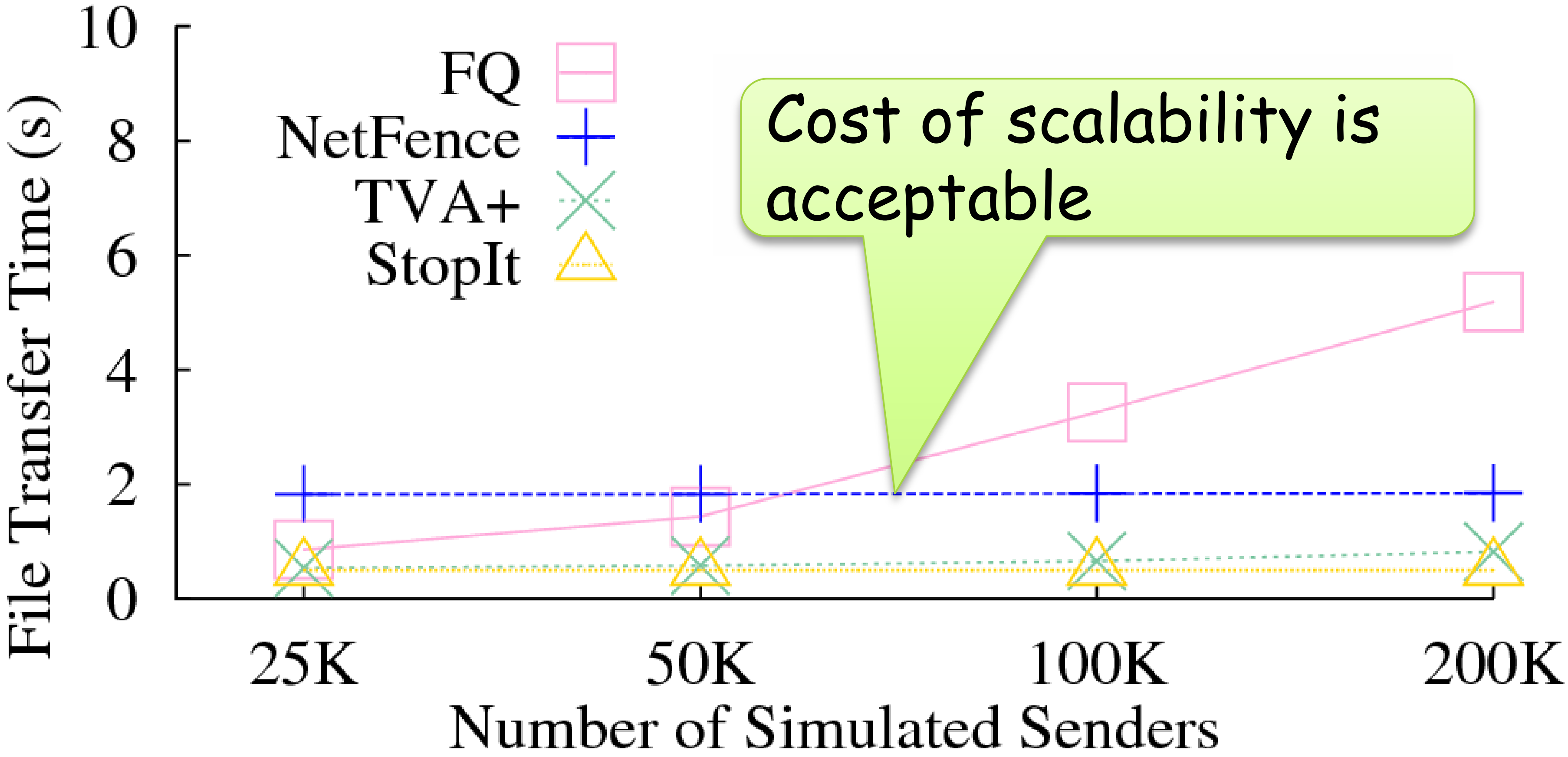
- In each source AS
  - 1 user sends a 20KB file to a victim via TCP
  - 99 attackers each send 1Mbps UDP traffic to the victim

NetFence Limits DoES



- All transfer finishes despite attackers >> users
- No per-sender queues

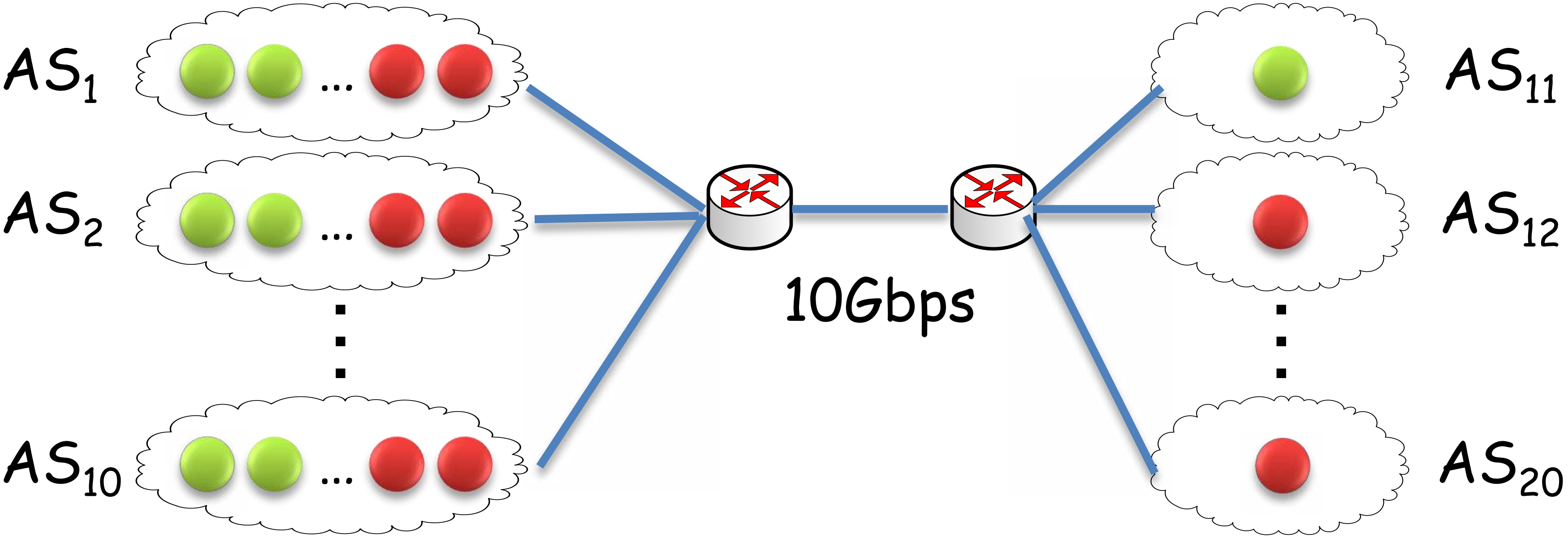
NetFence Limits DoES



Cost of scalability is acceptable

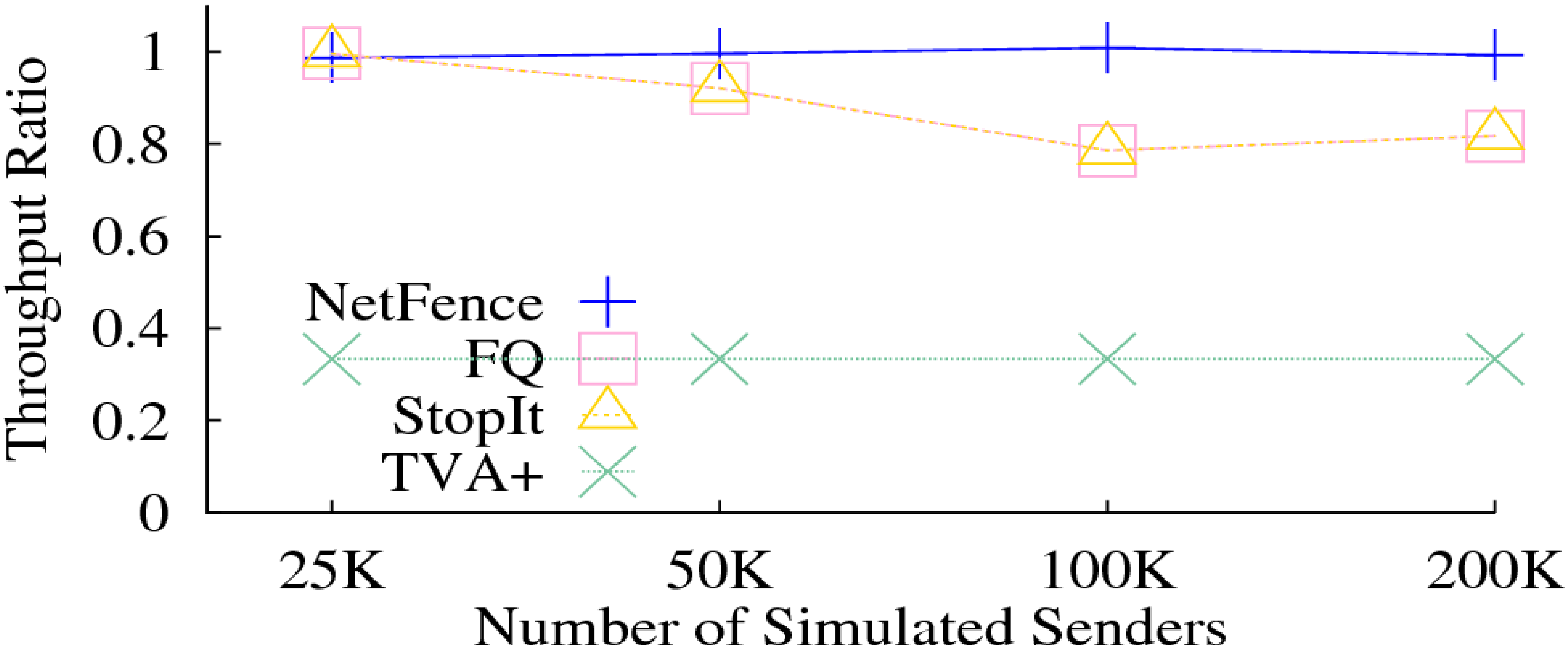
- All transfer finishes despite attackers >> users
- No per-sender queues

Expr 2: DoNS Attacks



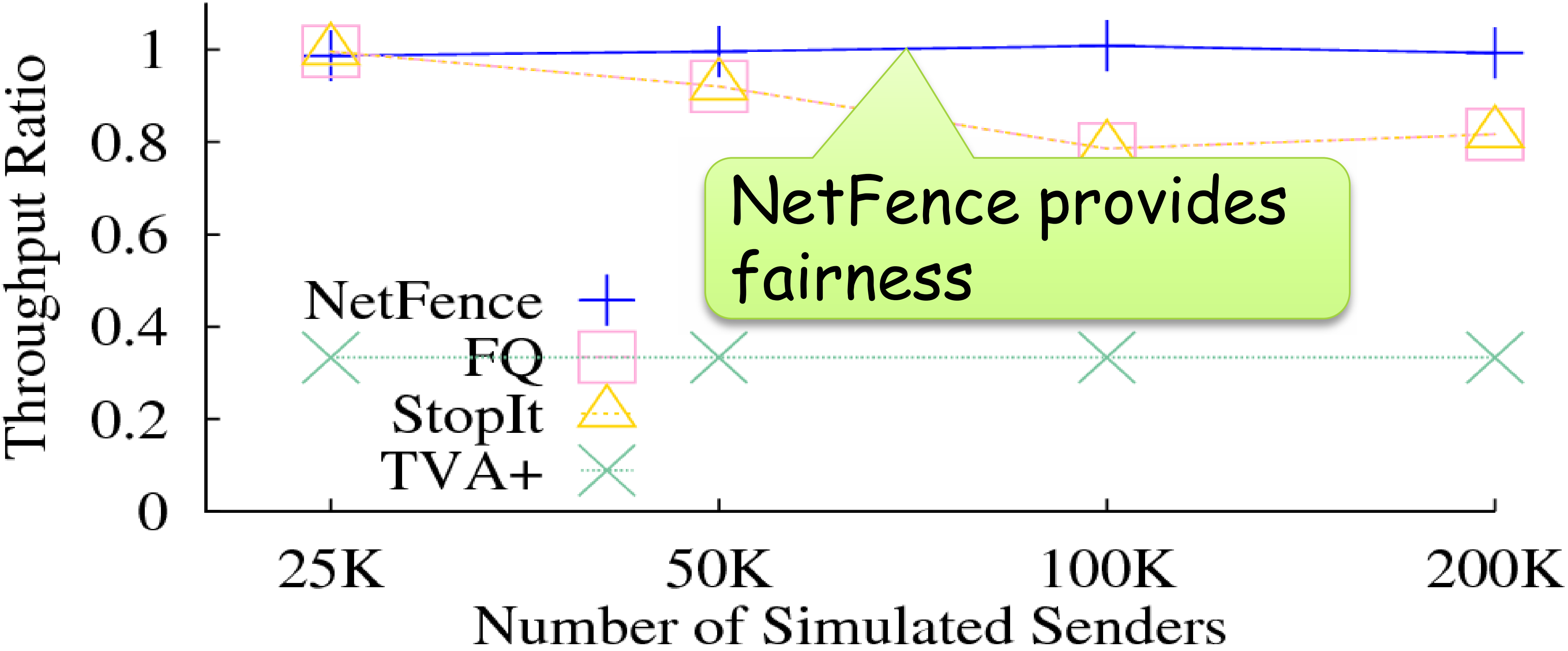
- In each source AS
  - 25% legitimate users and 75% attackers
- In each destination AS
  - One legitimate receiver or one colluding attacker

NetFence Limits DoNS



- Throughput ratio = avg(user)/avg(attacker)

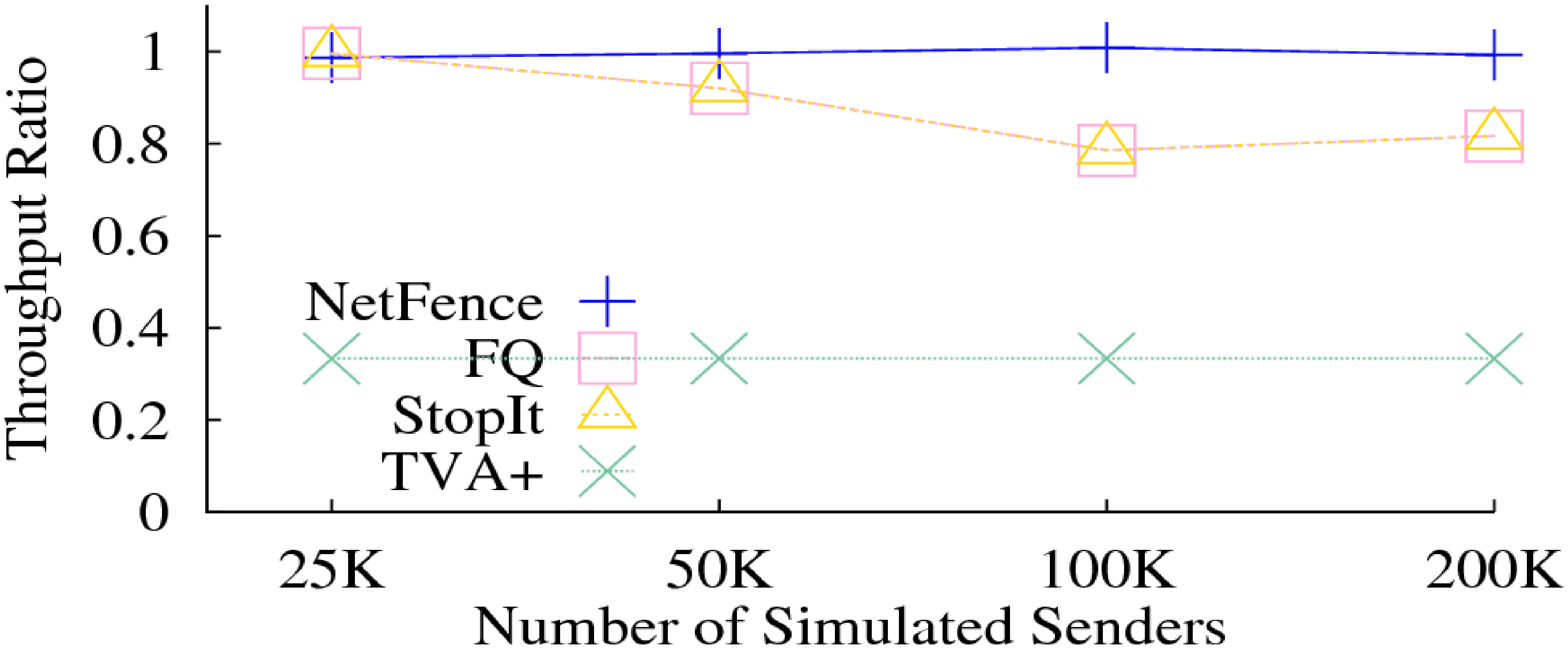
NetFence Limits DoNS



NetFence provides fairness

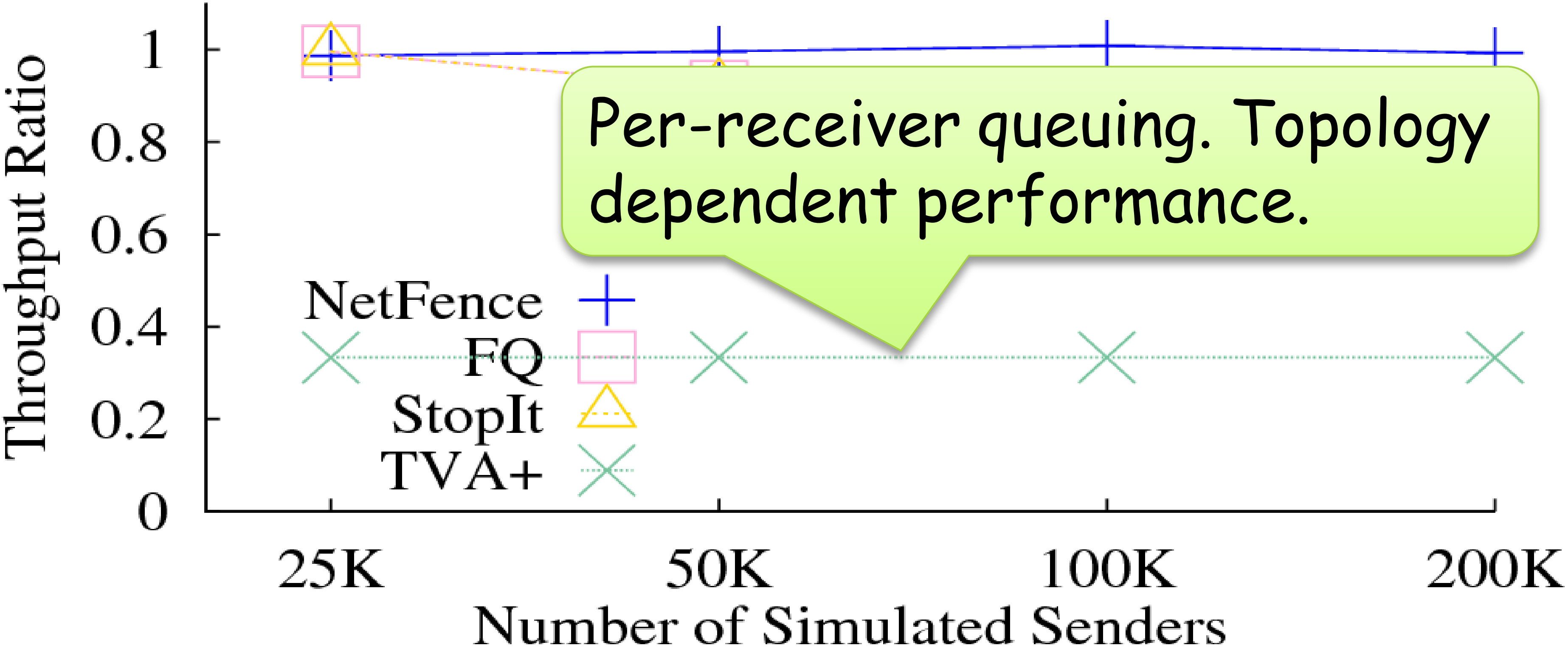
- Throughput ratio = avg(user)/avg(attacker)

NetFence Limits DoNS



- Throughput ratio = avg(user)/avg(attacker)

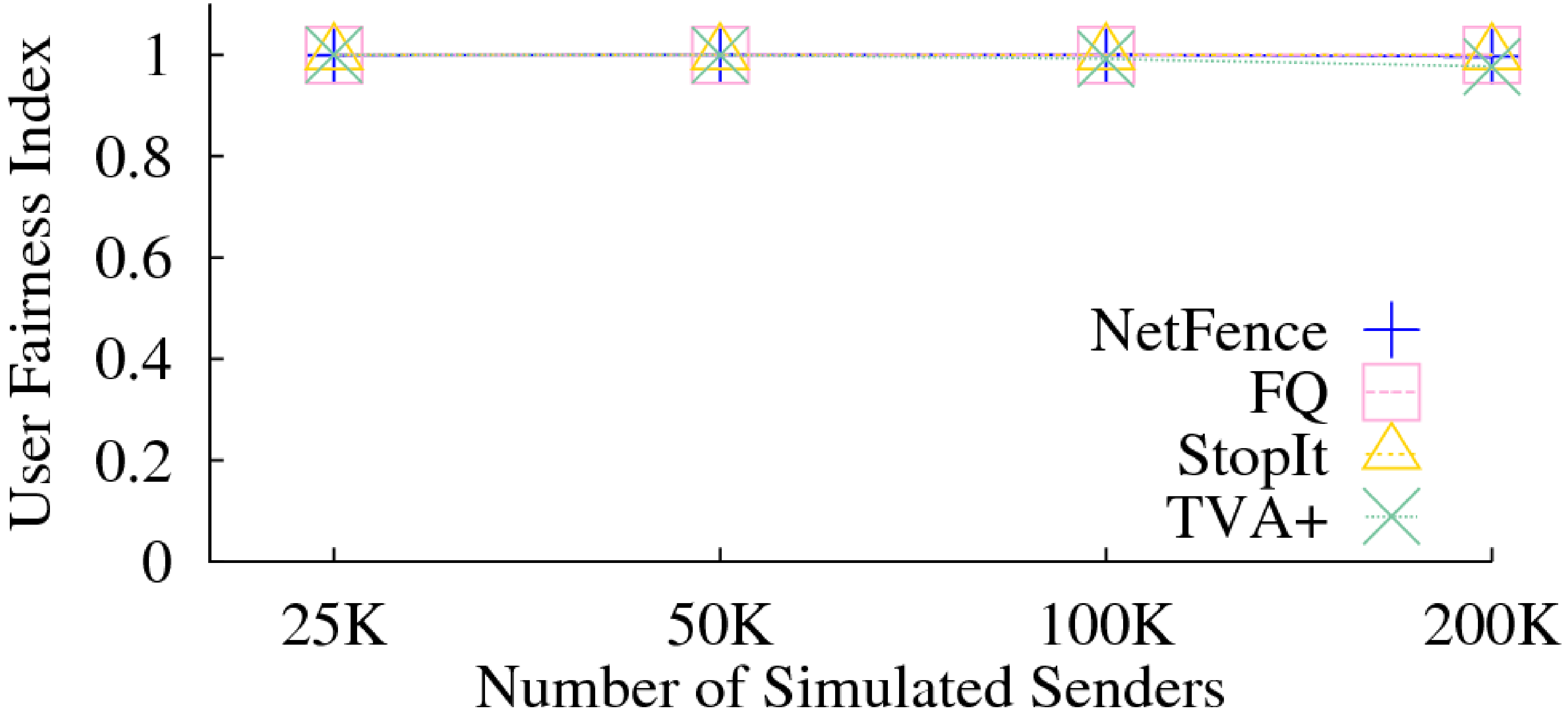
NetFence Limits DoNS



Per-receiver queuing. Topology dependent performance.

- Throughput ratio = avg(user)/avg(attacker)

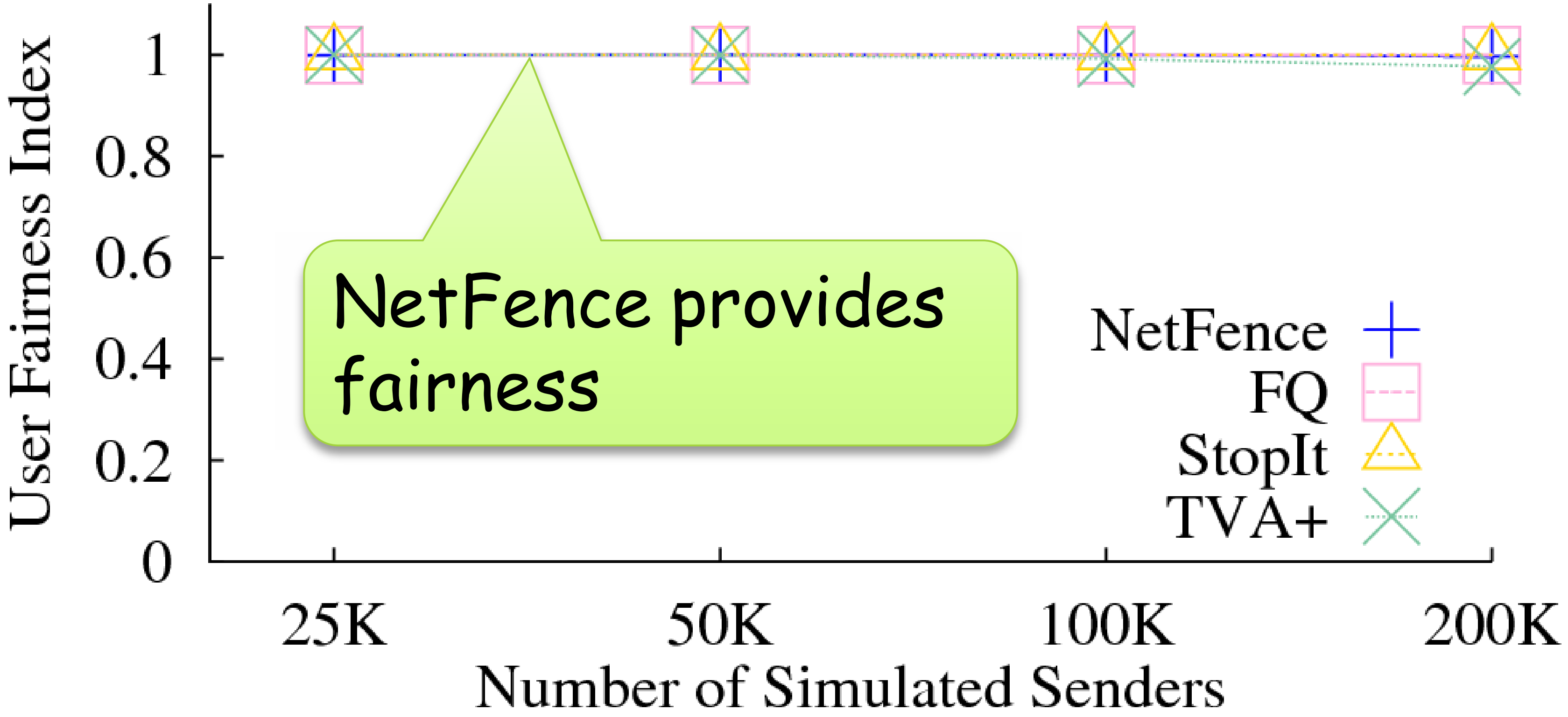
NetFence Limits DoNS



- Fairness index among legitimate users

$$(\sum x_i)^2 / n \sum x_i^2$$

NetFence Limits DoNS



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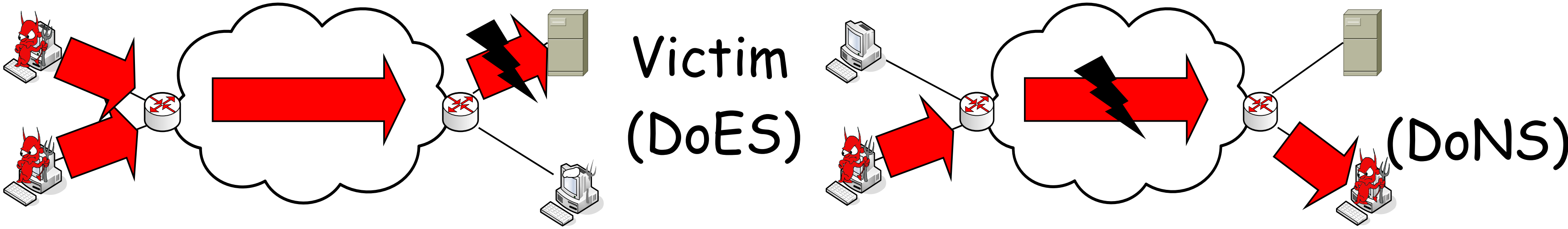
Conclusion



- NetFence
  - First comprehensive solution combating DoES and DoNS attacks scalably
  - Design principle: inside-out, network-host joint lines of defense
  - Goals: Scalable, robust, and open
  - Key idea: Hierarchical, secure congestion policing coupled with network capabilities

Thank you!

- Questions
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