Network Control

CS 161: Computer Security

Prof. Vern Paxson

TAs: Paul Bramsen, Apoorva Dornadula,
David Fifield, Mia Gil Epner, David Hahn, Warren He,
Grant Ho, Frank Li, Nathan Malkin, Mitar Milutinovic,
Rishabh Poddar, Rebecca Portnoff, Nate Wang

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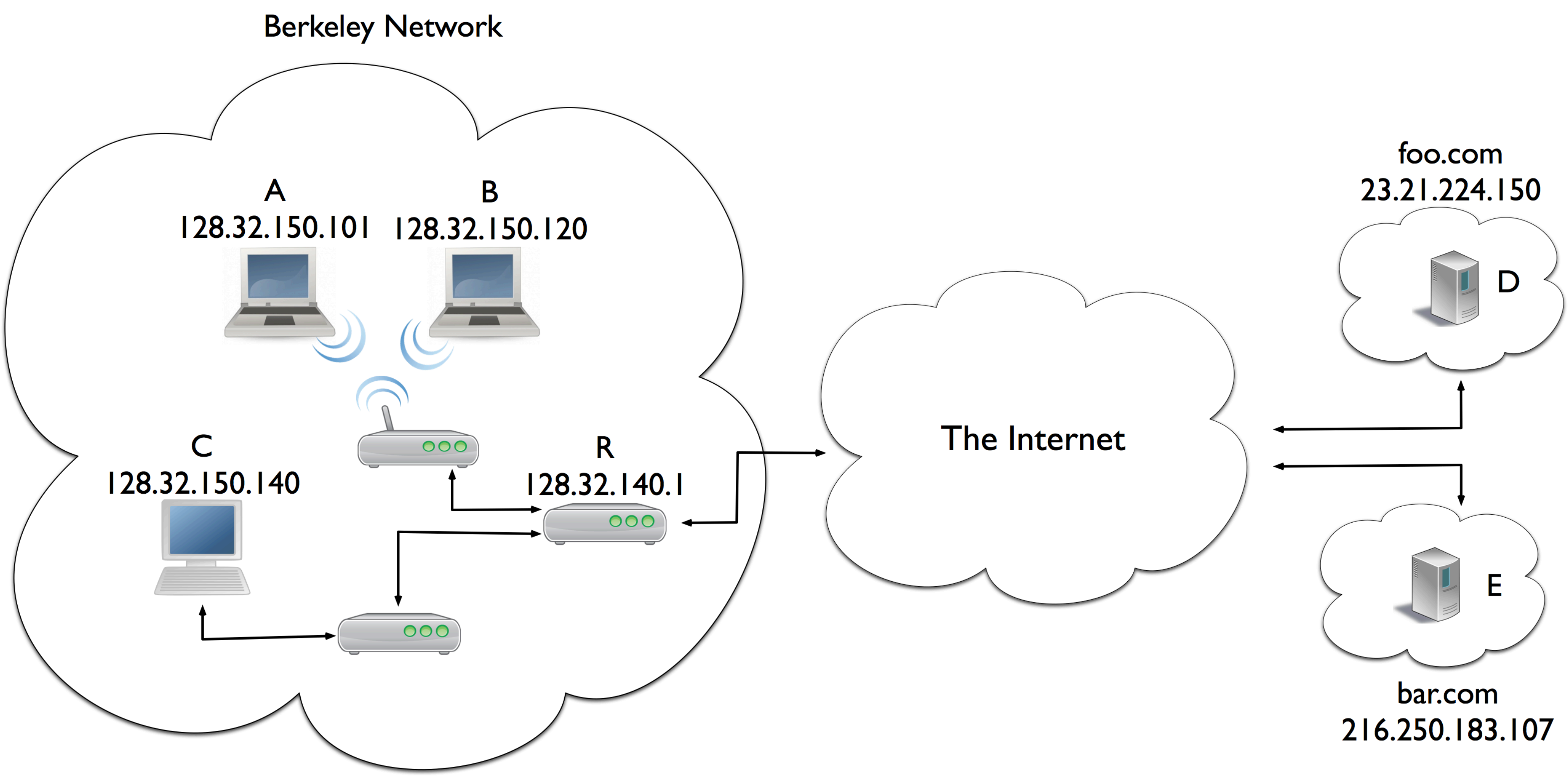
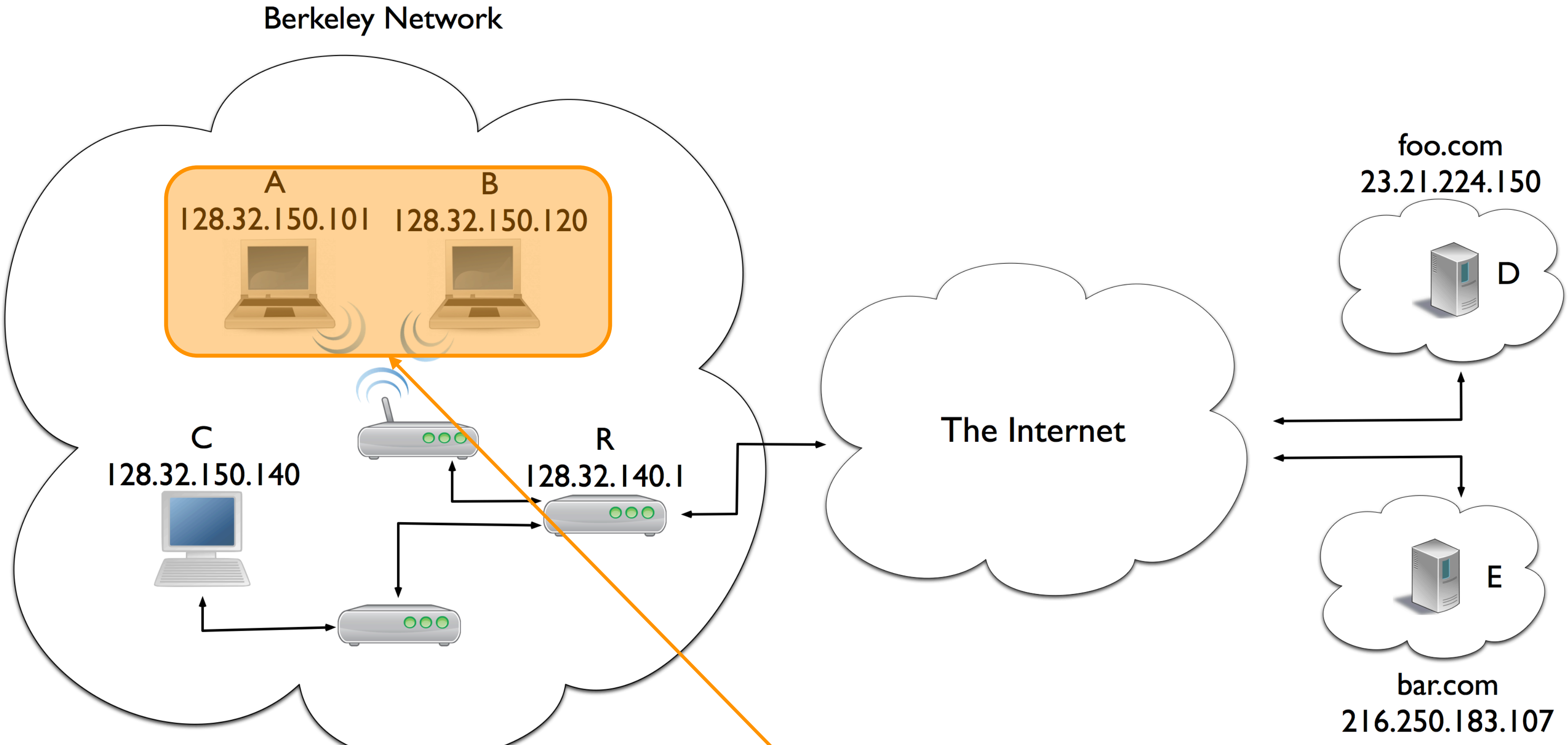
March 21, 2017

Review: Sniffing & Spoofing

Network Diagram

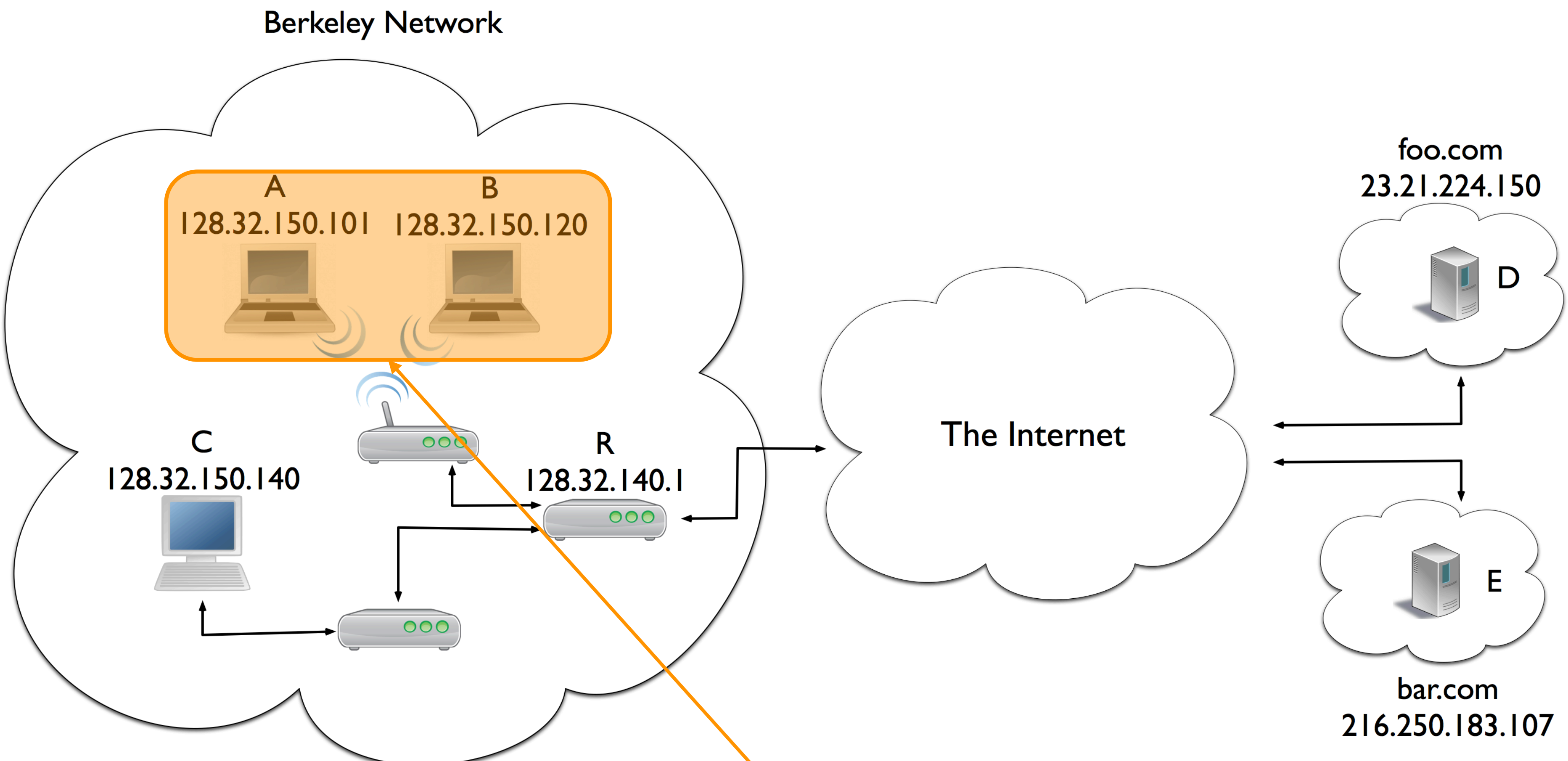


Network Diagram



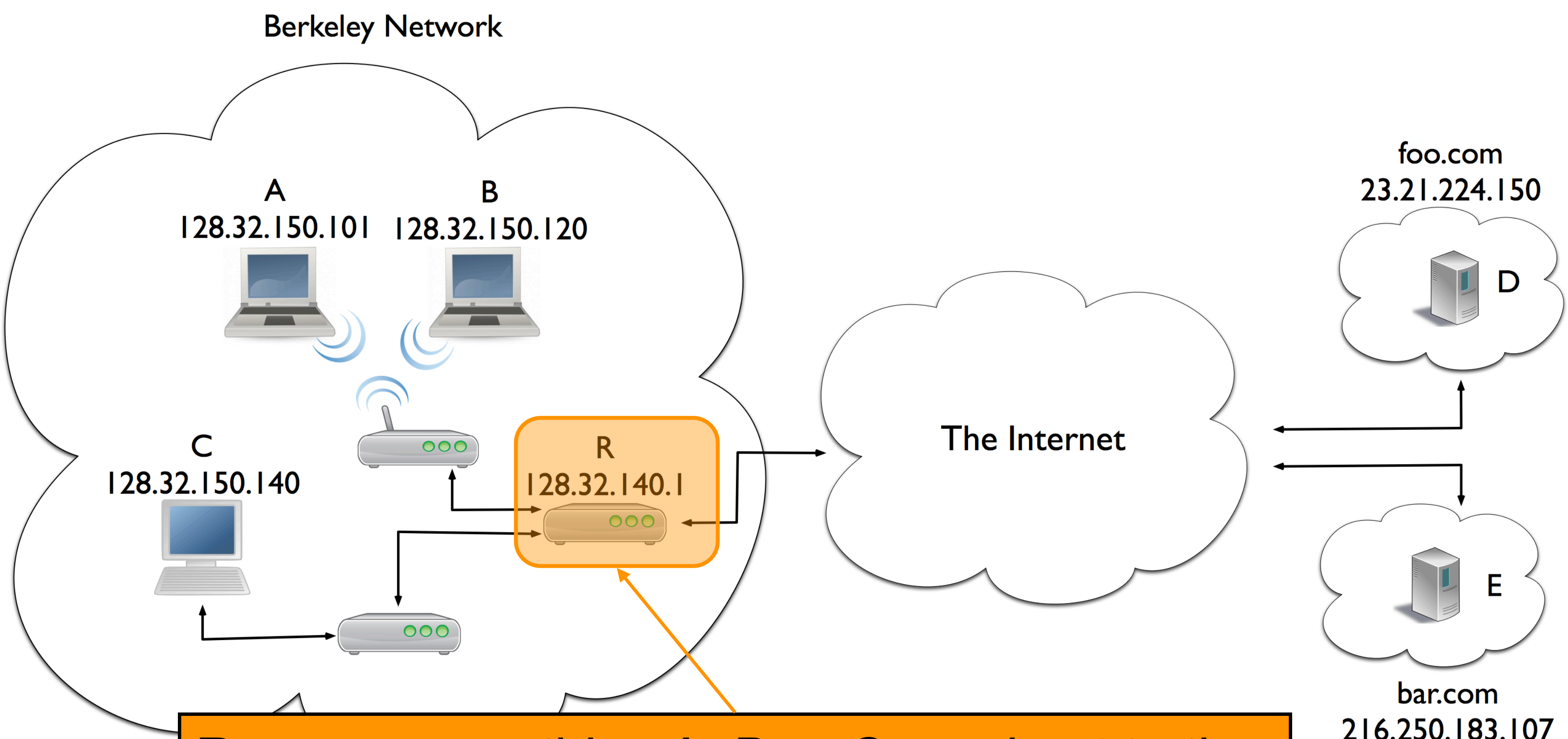
A & B can see everything each other sends if they're on the same open or WPA-Personal WiFi network

Network Diagram



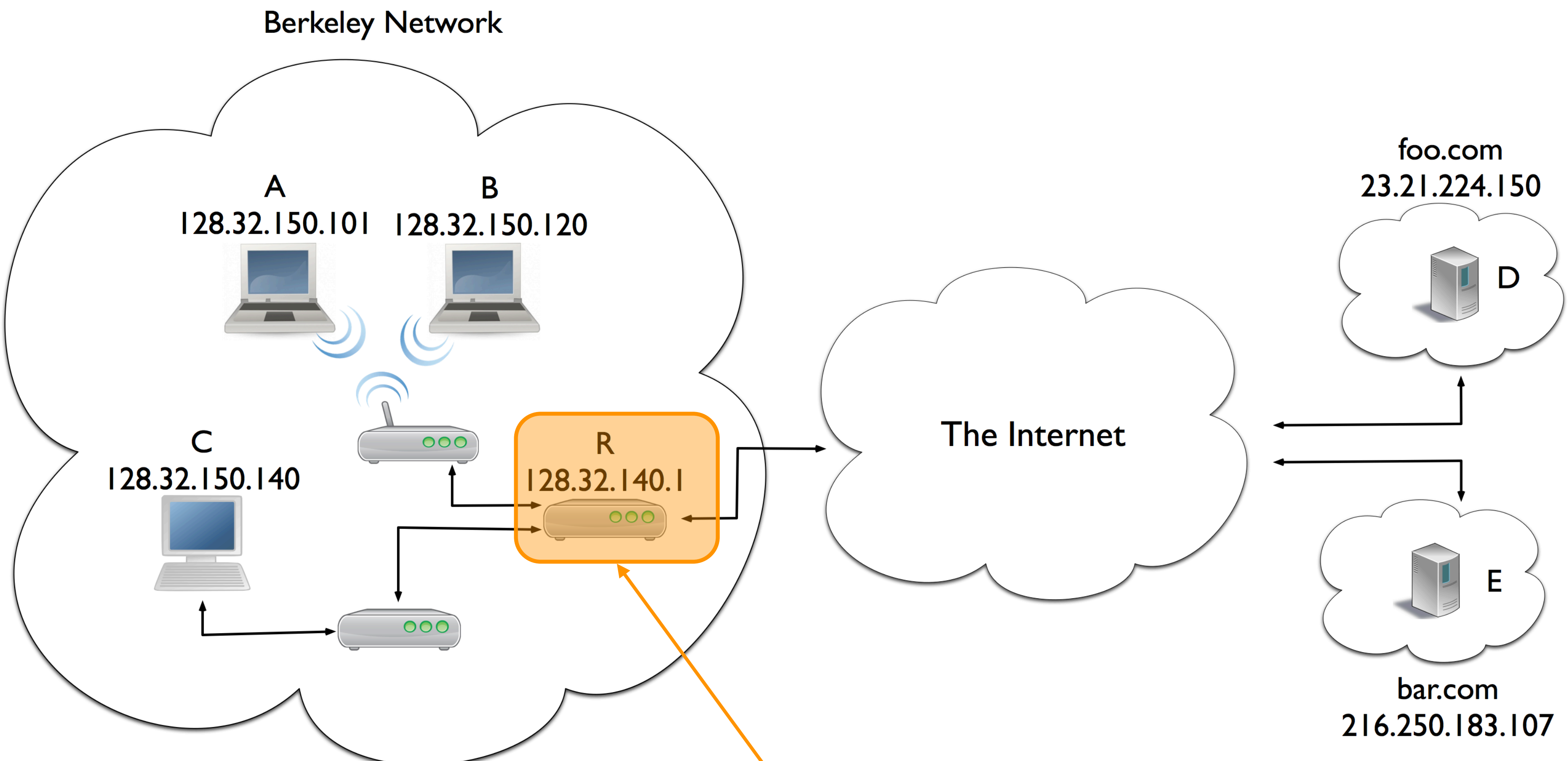
Because of this, B can spoof DHCP offers to A, and vice versa. But no one else can, because the requests stay within A's subnet.

Network Diagram



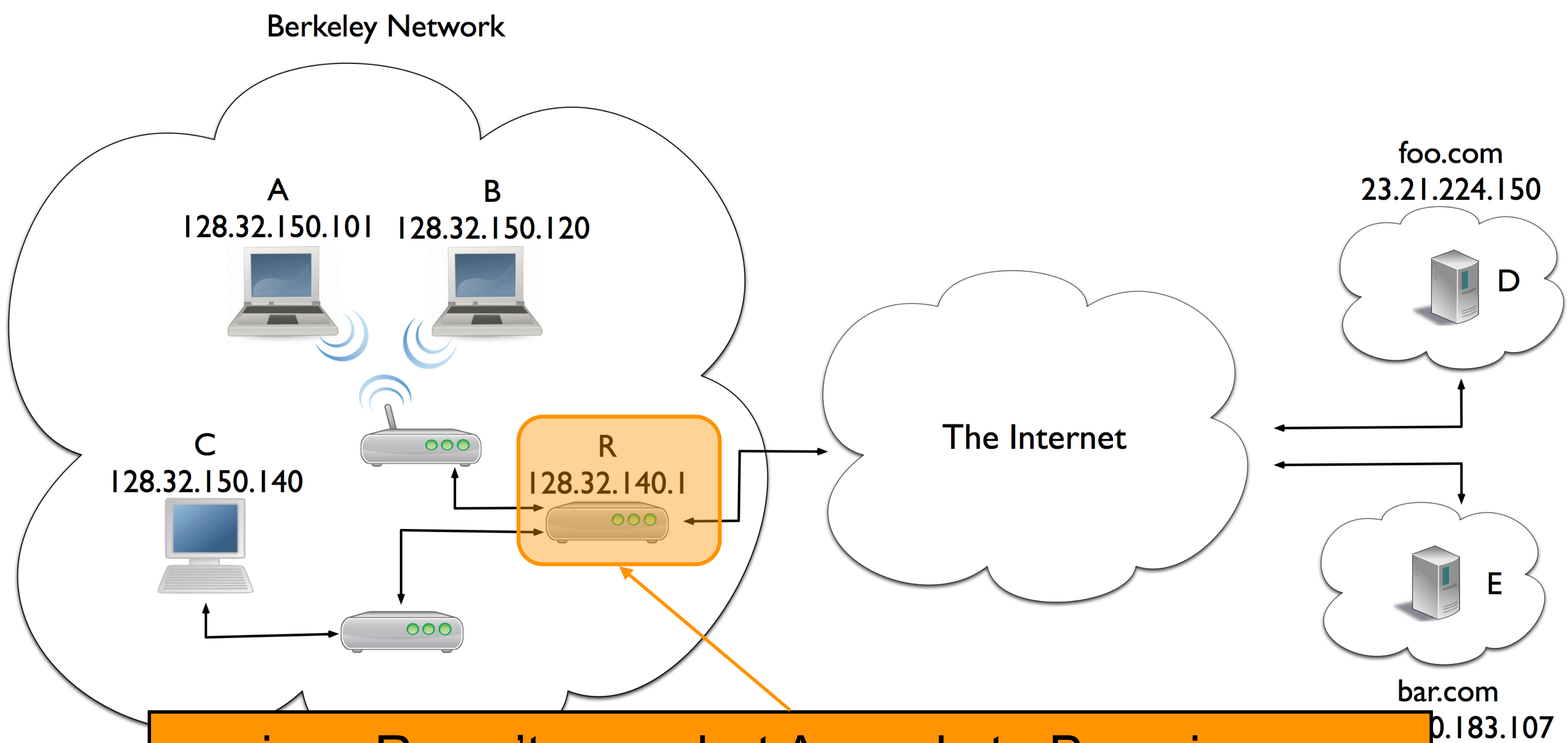
R can see anything A, B or C send out to the Internet … and any replies sent back to them

Network Diagram



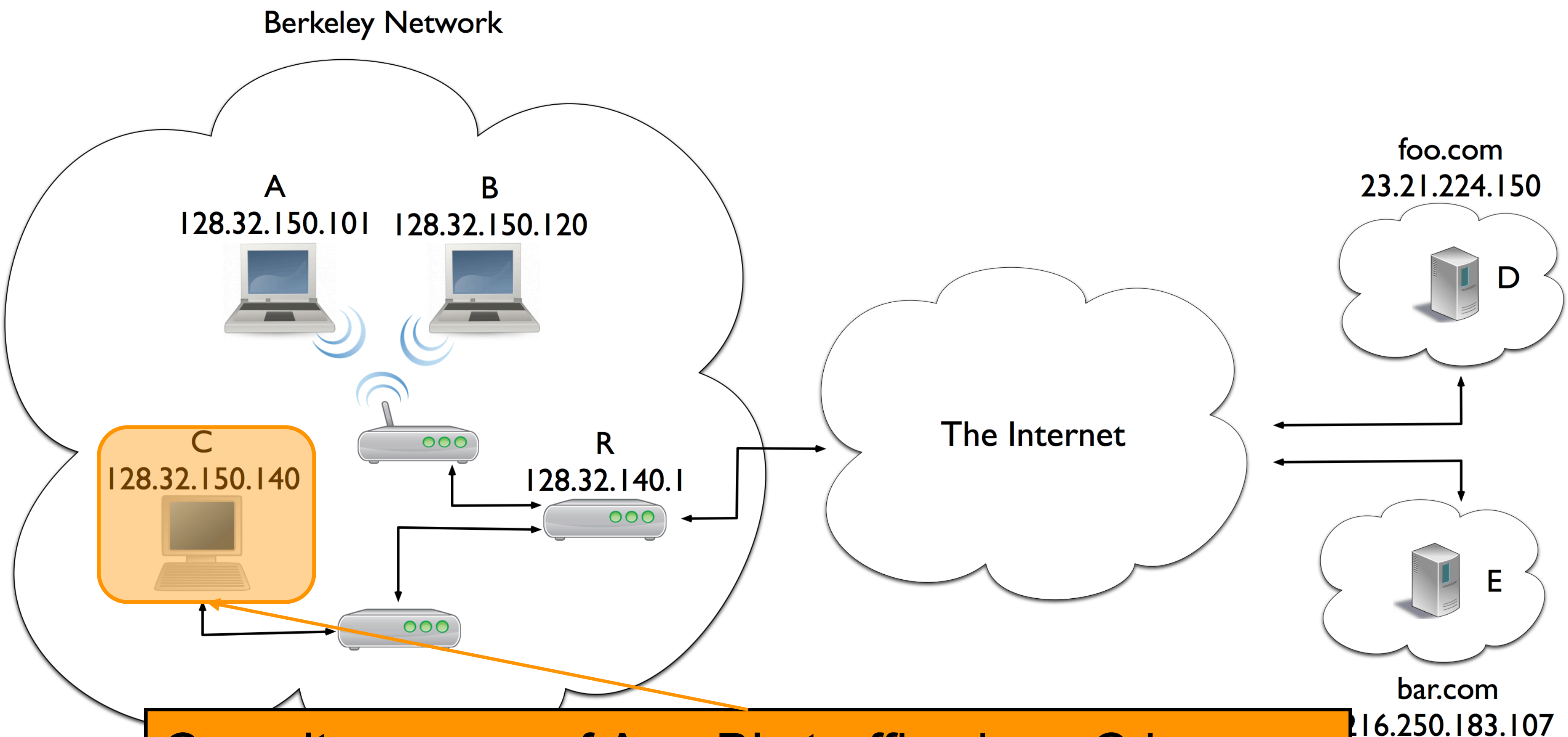
Thus, R can do successful TCP or DNS injection on them …
… other than for local traffic such as between A & B

Network Diagram



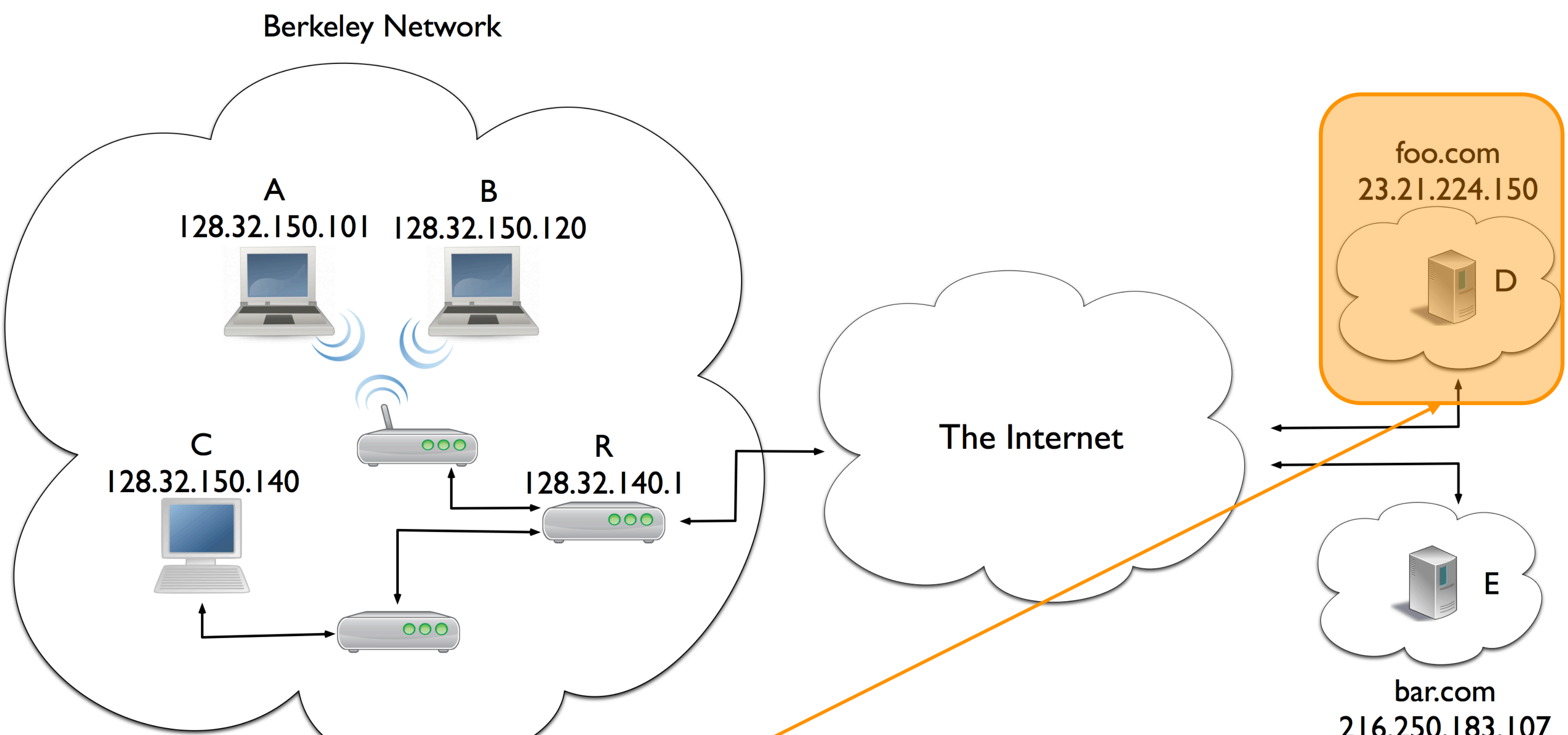
… since R can't see what A sends to B or vice versa

Network Diagram



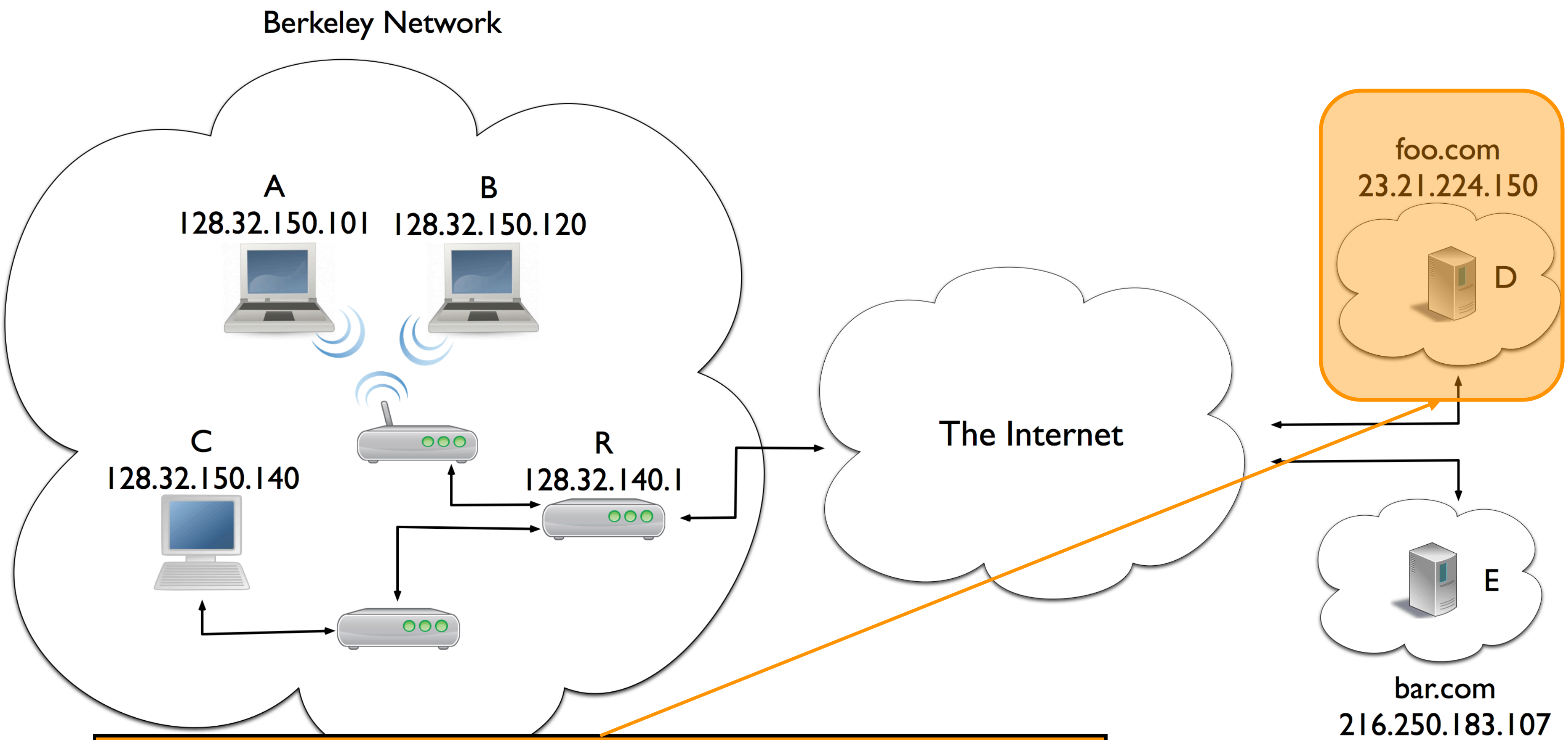
C can’t see any of A or B’s traffic since C is on a different subnet. C likewise can’t see R’s traffic.

Network Diagram



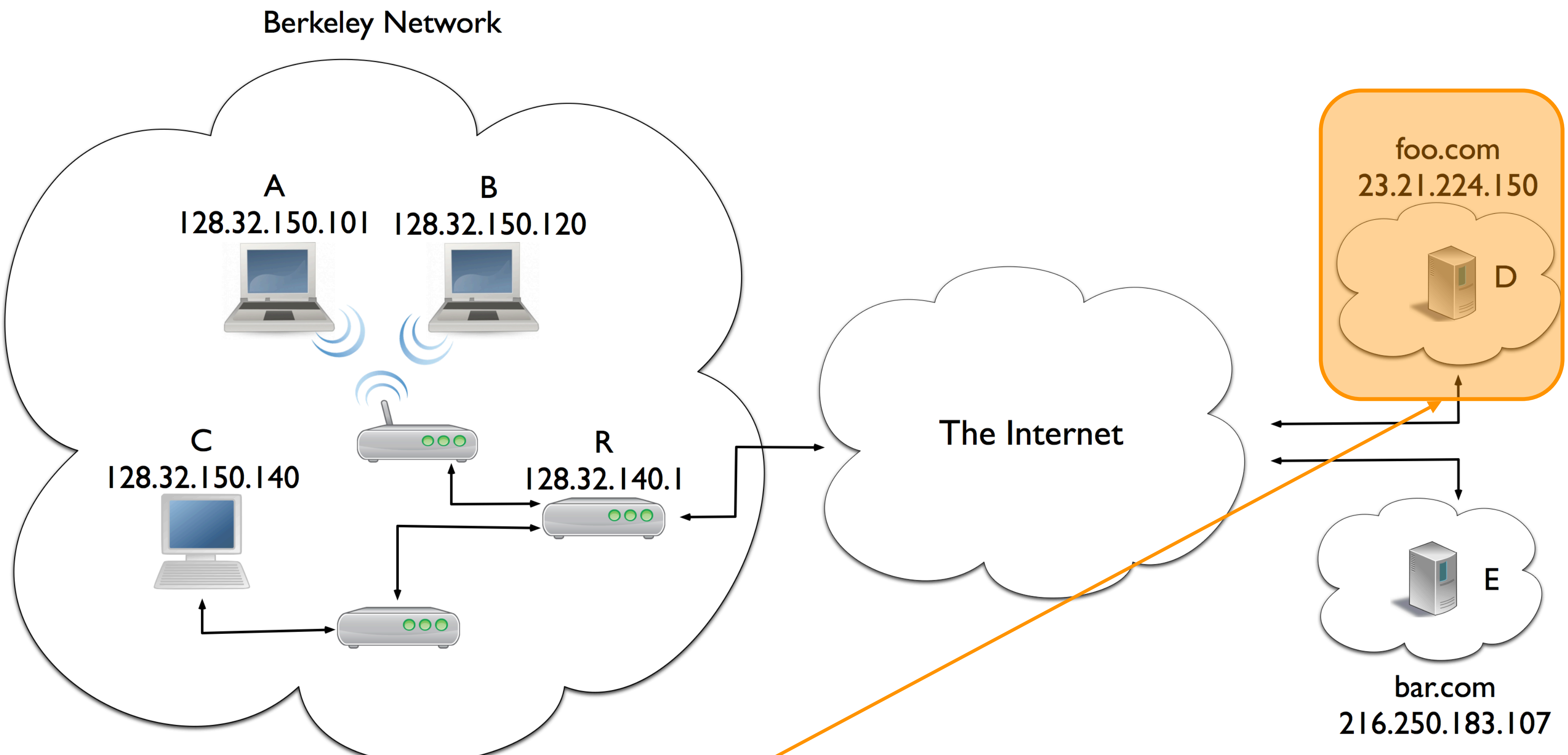
D can’t see E’s traffic nor any traffic from the Berkeley Network unless it happens to be directed to D

Network Diagram



Like all Internet hosts, D can spoof whatever packet fields D desires … **BUT**

Network Diagram



BUT it's a separate question whether those spoofs will succeed. The use of randomized fields in TCP & DNS make this very hard.

Controlling Networks Using *Firewalls*

Controlling Networks … On The Cheap

- Motivation: How do you harden a set of systems against external attack?
  - *Key Observation:*
    - *The more network services your machines run, the greater the risk*
  - Due to larger attack surface
- One approach: on each system, turn off unnecessary network services
  - But you have to know ***all*** the services that are running
  - And sometimes some trusted remote users still require access
- Plus key question of scaling
  - What happens when you have to secure 100s/1000s of systems?
  - Which may have different OSs, hardware & users …
  - Which may in fact not all even be identified …

Taming Management Complexity

- Possibly more scalable defense: Reduce risk by blocking *in the network* outsiders from having unwanted access your network services
  - Interpose a **firewall** that traffic to/from the outside must traverse
  - Chokepoint can cover 1000s of hosts

Selecting a Security Policy

- Effectiveness of firewall relies on deciding what policy it should implement:
  - *Who is allowed to talk to whom, accessing what service?*
- Distinguish between inbound & outbound connections
  - Inbound: attempts by external users to connect to services on internal machines
  - Outbound: internal users to external services
  - Why? Because fits with a common ***threat model***

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  - *Who is allowed to talk to whom, accessing what service?*
- Distinguish between inbound & outbound connections
  - Inbound: attempts by external users to connect to services on internal machines
  - Outbound: internal users to external services
  - Why? Because fits with a common ***threat model***
- Conceptually simple *access control policy*:
  - Permit inside users to connect to any service
  - External users restricted:
    - Permit connections to services meant to be externally visible
    - Deny connections to services not meant for external access

How To Treat Traffic Not Mentioned in Policy?

- **Default Allow**: start off permitting external access to services
  - Shut them off as problems recognized

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- **Default Allow**: start off permitting external access to services
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- **Default Deny**: start off permitting just a few known, well-secured services
  - Add more when users complain (and mgt. approves)

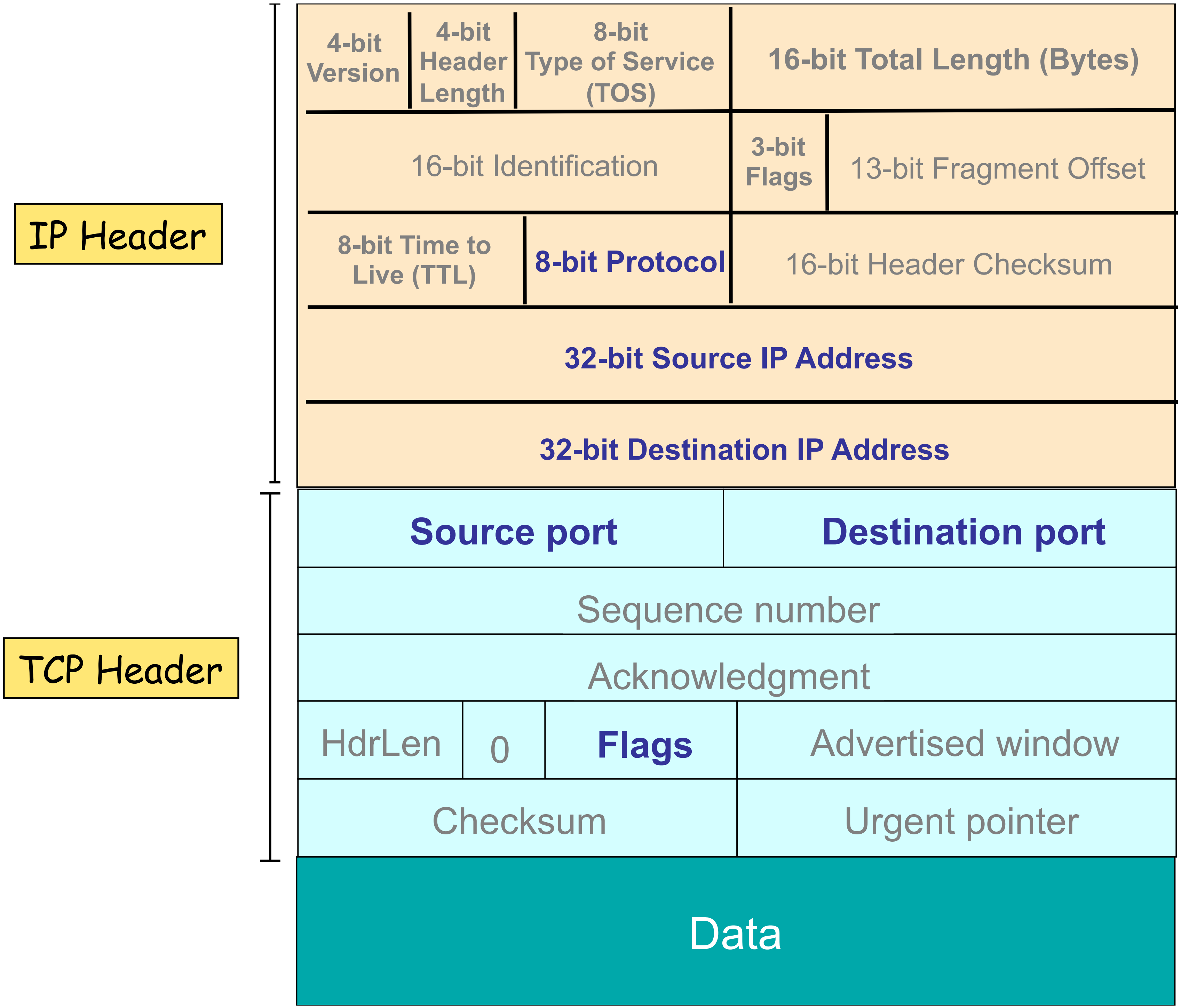
How To Treat Traffic Not Mentioned in Policy?

- **Default Allow**: start off permitting external access to services
  - Shut them off as problems recognized
- **Default Deny**: ✓ off permitting just a few known, well-secured services
  - Add more when users complain (and mgt. approves)
- Pros & Cons?
  - Flexibility vs. conservative design
  - Flaws in Default Deny get noticed more quickly / less painfully

In general, use Default Deny

Packet Filters

- Most basic kind of firewall is a *packet filter*
  - Router with list of *access control rules*
  - Router checks each received packet against security rules to decide to forward or drop it
  - Each rule specifies which packets it applies to based on a packet's header fields (stateless)
    - Specify source and destination IP addresses, port numbers, and protocol names, or wild cards


IP Header
4-bit Version
4-bit Header Length
8-bit Type of Service (TOS)
16-bit Total Length (Bytes)
16-bit Identification
3-bit Flags
13-bit Fragment Offset
8-bit Time to Live (TTL)
8-bit Protocol
16-bit Header Checksum
32-bit Source IP Address
32-bit Destination IP Address
TCP Header
Source port
Destination port
Sequence number
Acknowledgment
HdrLen
0
Flags
Advertised window
Checksum
Urgent pointer
Data

Packet Filters

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  - Each rule specifies which packets it applies to based on a packet's header fields (stateless)
    - Specify source and destination IP addresses, port numbers, and protocol names, or wild cards
    - Each rule specifies the *action* for matching packets: **ALLOW** or **DROP** (aka DENY)

    ```
    <ACTION> <PROTO> <SRC:PORT> -> <DST:PORT>
    ```
  - First listed rule has *precedence*

Examples of Packet Filter Rules

```
allow tcp 4.5.5.4:1025 -> 3.1.1.2:80
```

- States that the firewall should **permit** any TCP packet that's:
  - from Internet address `4.5.5.4` **and**
  - using a source port of `1025` **and**
  - destined to port `80` of Internet address `3.1.1.2`

```
deny tcp 4.5.5.4:* -> 3.1.1.2:80
```

- States that the firewall should **drop** any TCP packet like the above, regardless of source port

Examples of Packet Filter Rules

```
deny tcp 4.5.5.4:* -> 3.1.1.2:80
allow tcp 4.5.5.4:1025 -> 3.1.1.2:80
```

- *In this order*, the rules won't allow *any* TCP packets from `4.5.5.4` to port `80` of `3.1.1.2`

```
allow tcp 4.5.5.4:1025 -> 3.1.1.2:80
deny tcp 4.5.5.4:* -> 3.1.1.2:80
```

- *In this order*, the rules allow TCP packets from `4.5.5.4` to port `80` of `3.1.1.2` ***only*** if they come from source port `1025`

Firewall Considerations

- Firewalls can have 1000s of filtering rules like these
  - Easy to introduce subtle errors 😕
- Provide not only security but also *policy enforcement*
  - E.g. do not allow company systems to access file-sharing sites

- Modern firewalls operate in a stateful fashion
  - Make Yes/No decisions upon establishment of a connection/flow
    - For Yes decisions, add 4-tuple to a *connection table* consulted for future traffic
    - Drop arriving non-establishment packet if not in table
- An important example of a *reference monitor*

Security Principle: *Reference Monitors*

- Firewalls embody useful principles that are applicable elsewhere in computer security
  - Optimized for enforcing particular kind of *access control policy*
  - Chokepoint notion makes enforcement possible
- A *reference monitor* examines every request to access a controlled resource (an *object*) and determines whether to allow request

Reference Monitor Security Properties

- *Always invoked*
  - *Complete mediation* property: all security-relevant operations must be mediated by RM
  - RM should be invoked on every operation controlled by access control policy
- *Tamper-resistant*
  - Maintain RM integrity (no code/state tampering)
- *Verifiable*
  - Can verify RM operation (correctly enforces desired access control policy)
    - Requires extremely **simple** RM
    - We find we can't verify correctness for systems with any appreciable degree of complexity

Considering Firewalls as Reference Monitors

- Always invoked?
  - Place Packet Filter as an *in-path* element on chokepoint link for all internal-external communications
  - Packets only forwarded across link if firewall explicitly decides to do so after inspection

Potential Problems?

- What if a user hooks up an unsecured wireless access point to their internal machine?
- Anyone who drives by with wireless-enabled laptop can gain access to internal network
  - Bypasses packet filter!
- Or: what if user brings an infected device onto the premises?
- To use a firewall safely, must ensure we've covered all links between internal and external/untrusted networks with firewalls
  - Set of links known as the ***security perimeter***

RM Property: *Tamper-Resistant*

- Will this hold?
- Do not allow management access to firewall other than from specific hosts
  - I.e., firewall itself needs firewalling
- Protect firewall's physical security
- Must also secure storage & propagation of configuration data

RM Property: *Verifiable*

- Will this hold?
- Current practice:
  - Packet filter software too complex for feasible systematic verification …
  - … and rulesets with 1,000s (!) of rules
- Result:
  - *Bugs* that allowed attackers to defeat intended security policy by sending unexpected packets that packet filter doesn't handle as desired
- In addition: challenging to ensure network topology does not allow internal access by untrusted devices

Why Have Firewalls Been Successful?

- *Central control – easy administration and update*
  - Single point of control: update one config to change security policies
  - Potentially allows rapid response
- *Easy to deploy – transparent to end users*
  - Easy incremental/total deployment to protect 1,000's
- *Addresses an important problem*
  - Security vulnerabilities in network services are rampant
  - Easier to use firewall than to directly secure code …

Firewall Disadvantages?

- *Functionality loss* – *less connectivity, less risk*
  - May reduce network's usefulness
  - Some applications don't work with firewalls
    - Two peer-to-peer users behind different firewalls
- *The malicious insider problem*
  - Deployment assumes insiders are trusted
    - Malicious insider (or *anyone gaining control of internal machine*) can wreak havoc
- Firewalls establish a *security perimeter*
  - Like *Eskimo Pies*: "hard crunchy exterior, soft creamy center"
  - Threat from travelers with laptops, cell phones, …

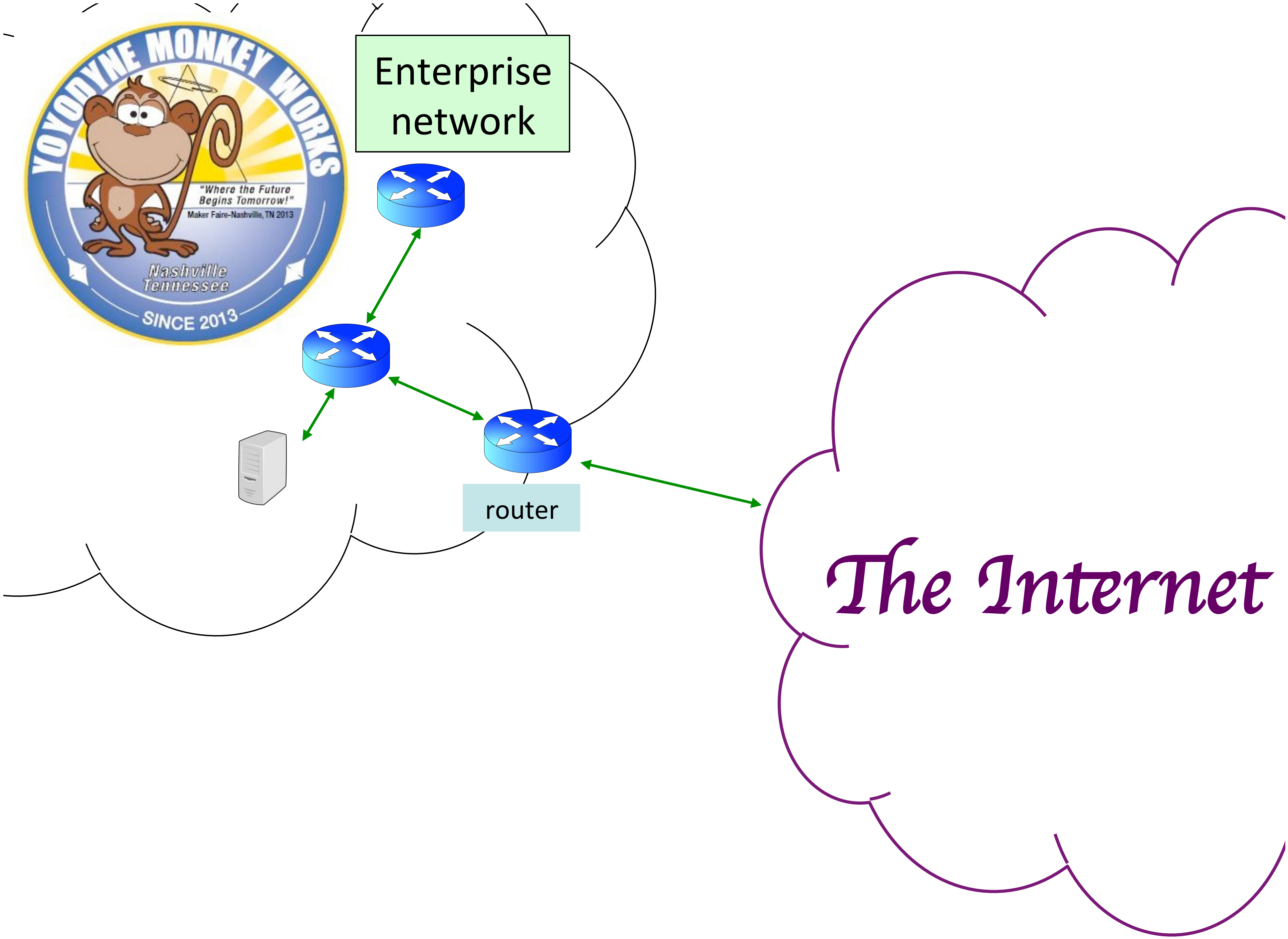
5 Minute Break

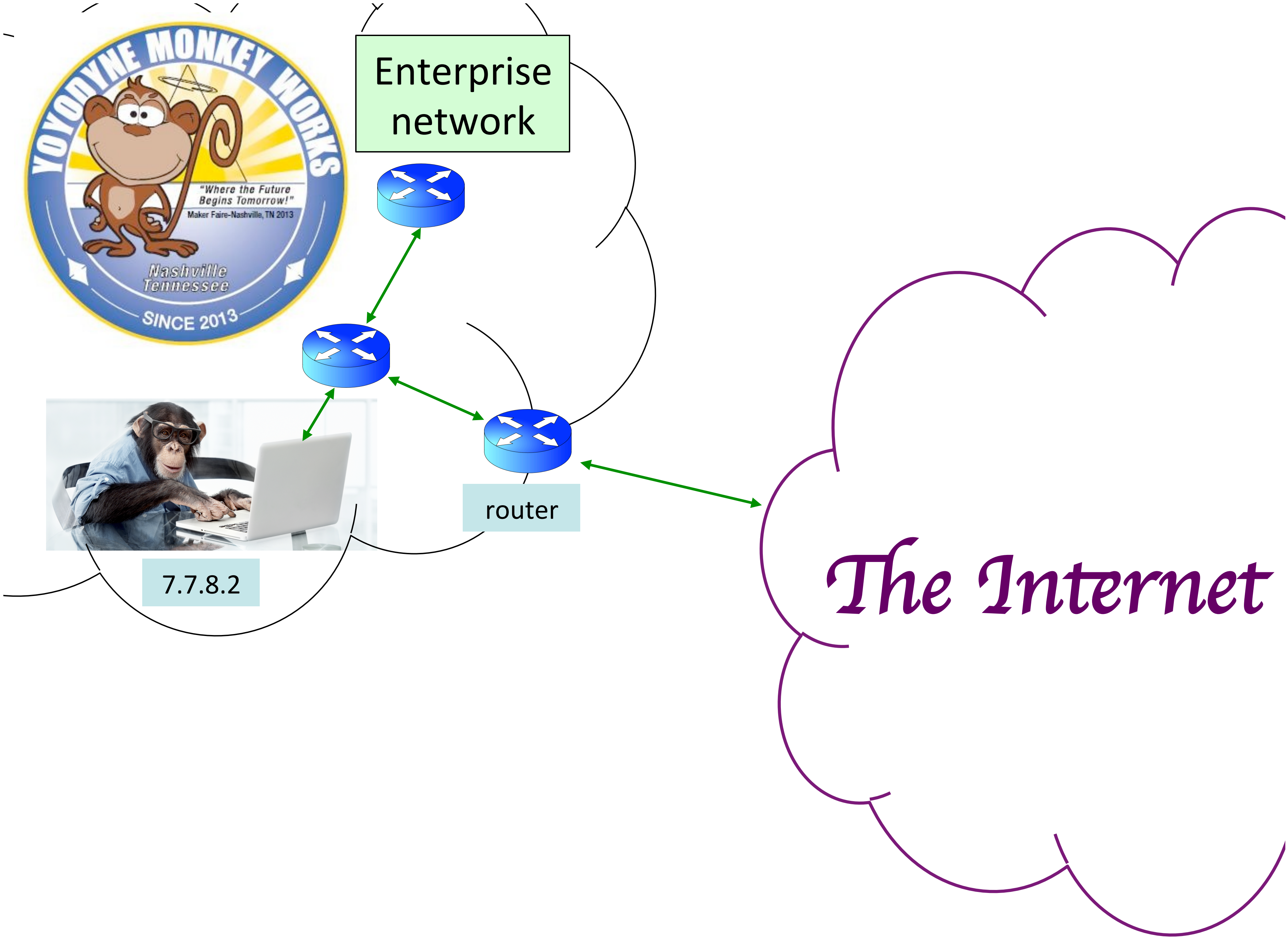
Questions Before We Proceed?

Getting Around Firewalls

Subverting Firewalls

- Along with possible bugs, packet filters have a fundamentally limited semantic model
  - They lack a full understanding of the meaning of the traffic they carry
    - In part because operate only at layers 3 & 4; not 7
- How can a local user who wants to get around their site's firewall exploit this?
  - *(**Note**: we're not talking about how an external attacker can escape a firewall's restrictions)*
- One method of subversion: **abuse ports**
  - Who says that e.g. port 53/udp = DNS?
    - Why couldn't it be say Skype or BitTorrent?
    - Just requires that client & server agree on application protocol


YOYODYNE MONKEY WORKS
"Where the Future Begins Tomorrow!"
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
Enterprise network
router
The Internet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7.7.8.2
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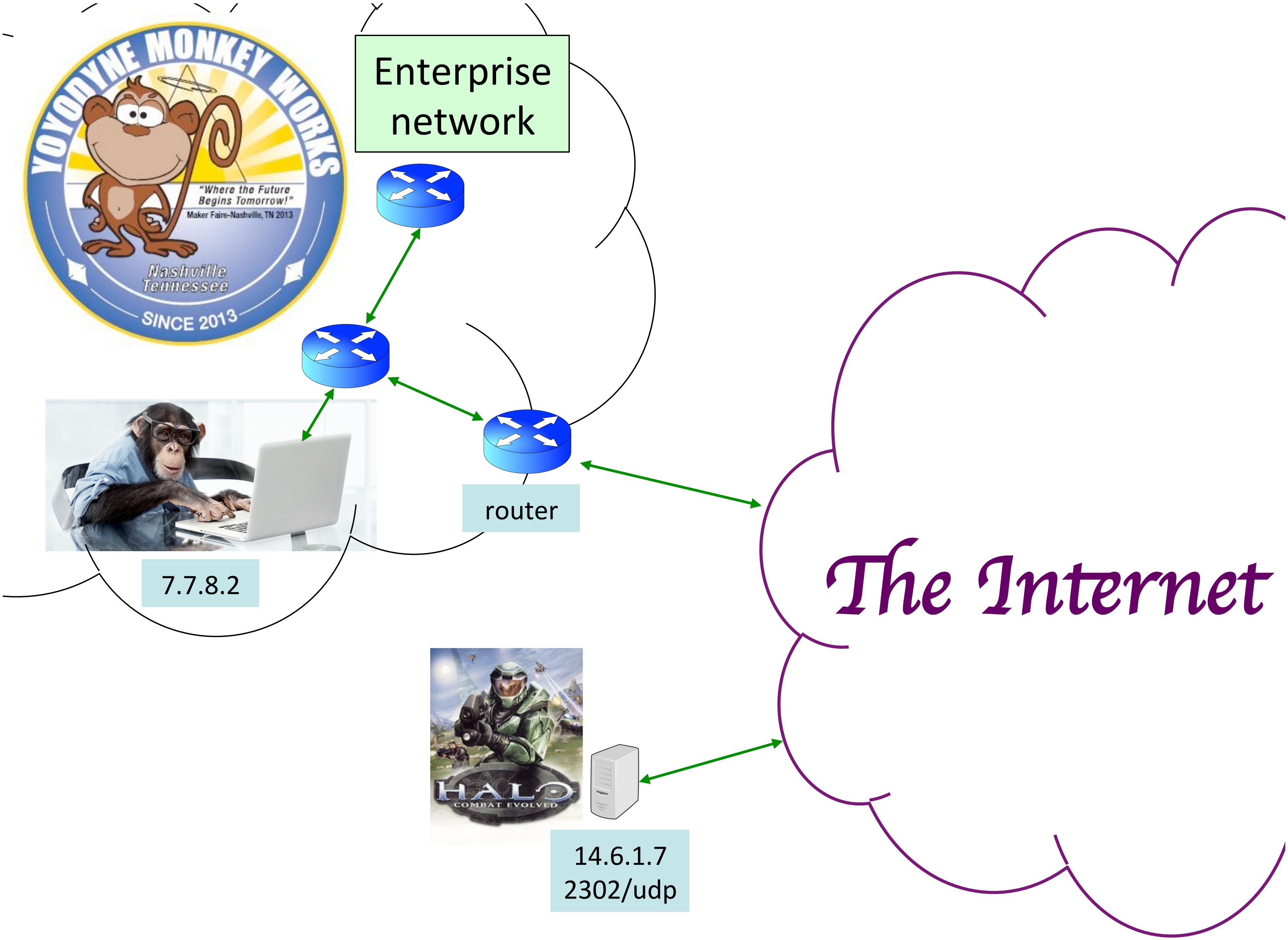
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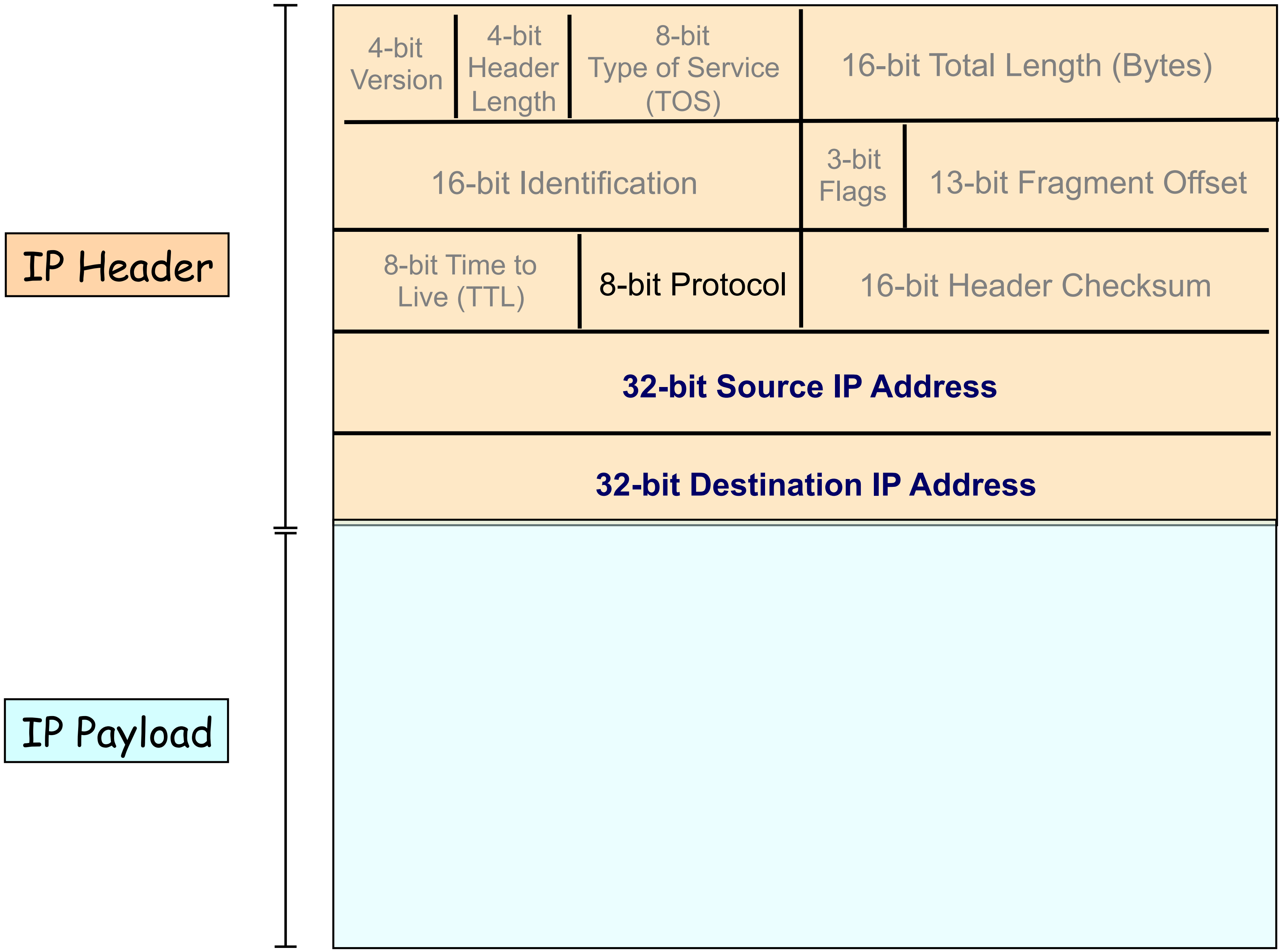
router
7.7.8.2
HALO
COMBAT EVOLVED
14.6.1.7
2302/udp
The Internet

Packet Sent to Halo Server



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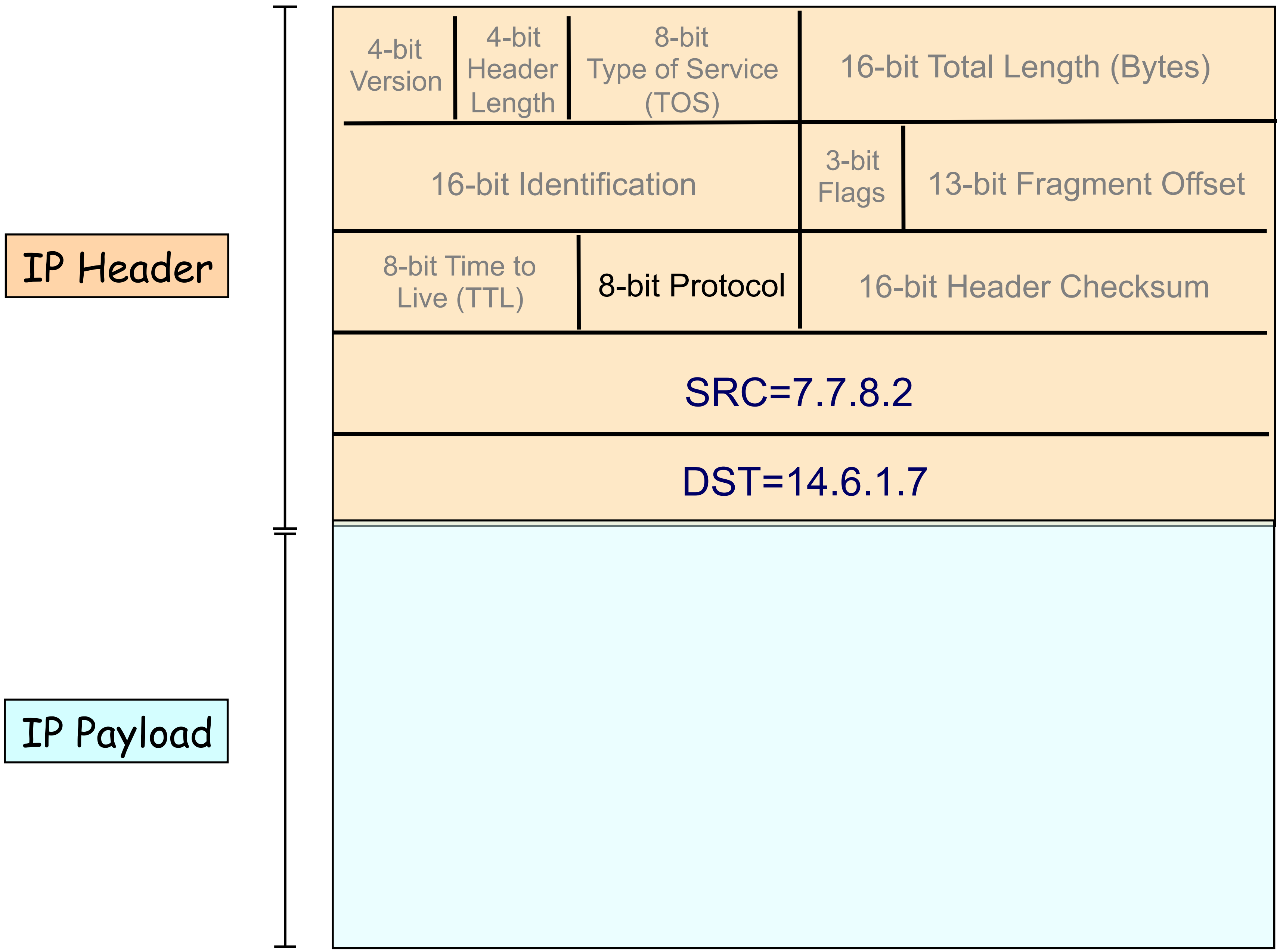

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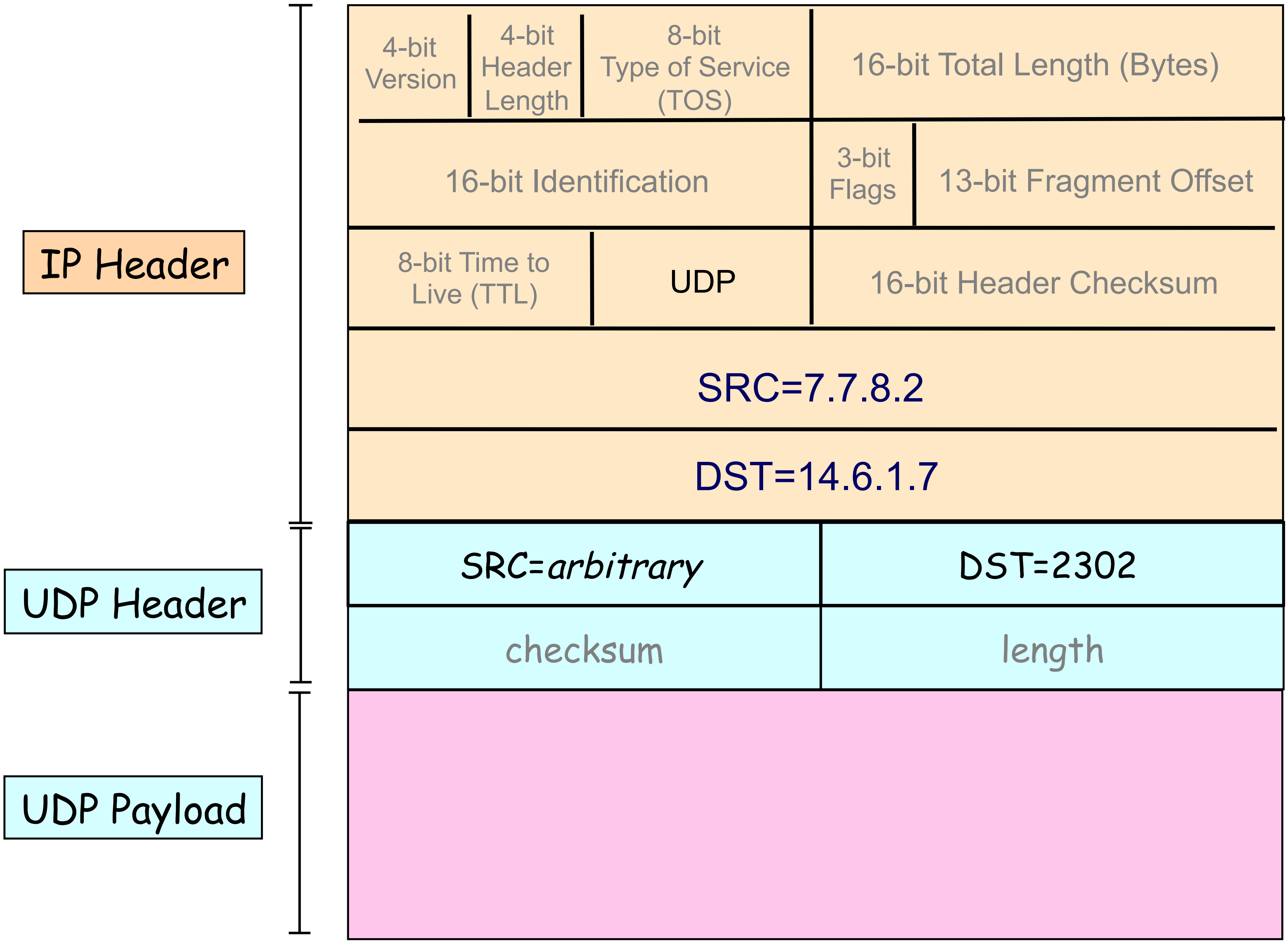
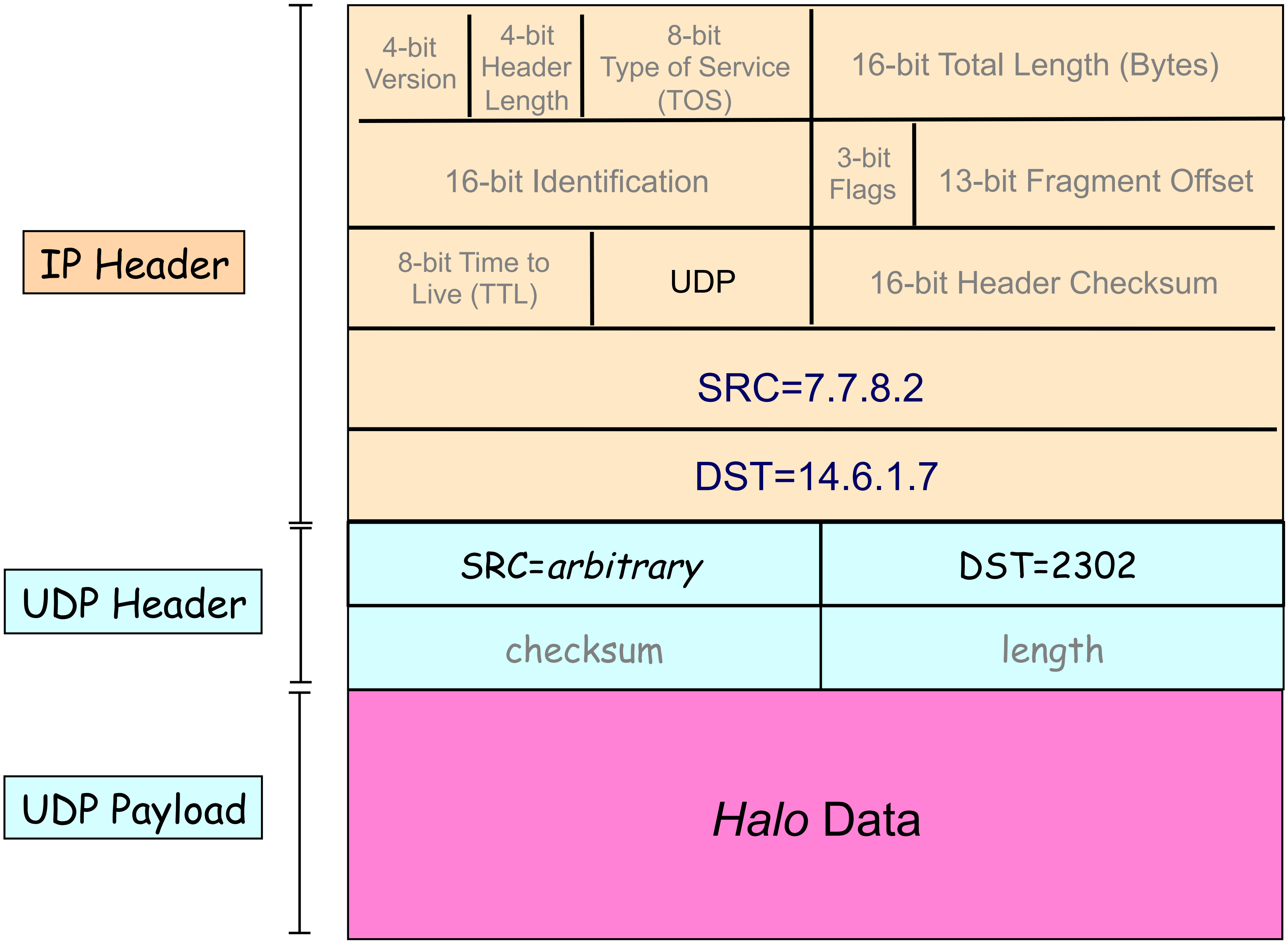
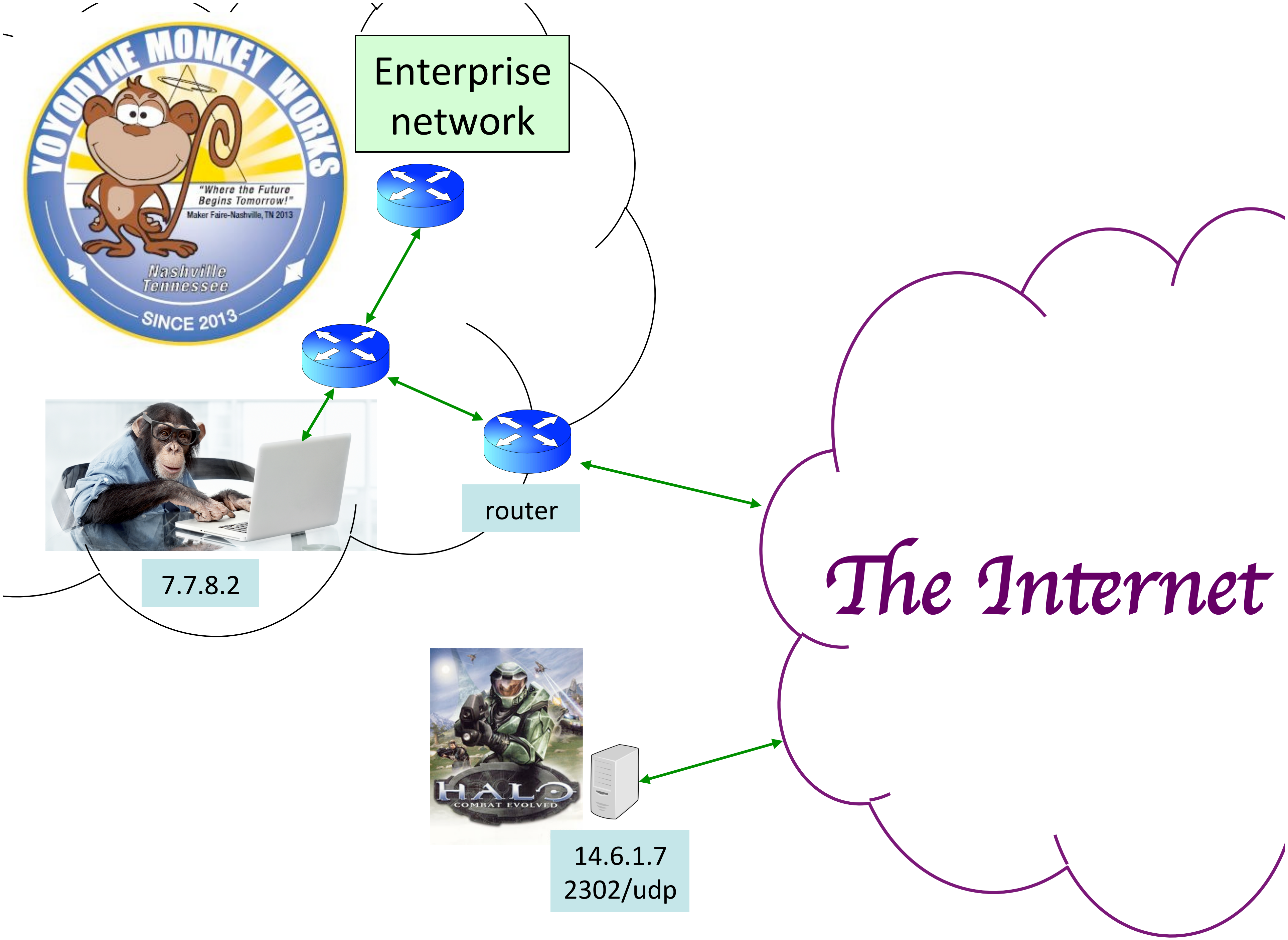


Packet Sent to Halo Server





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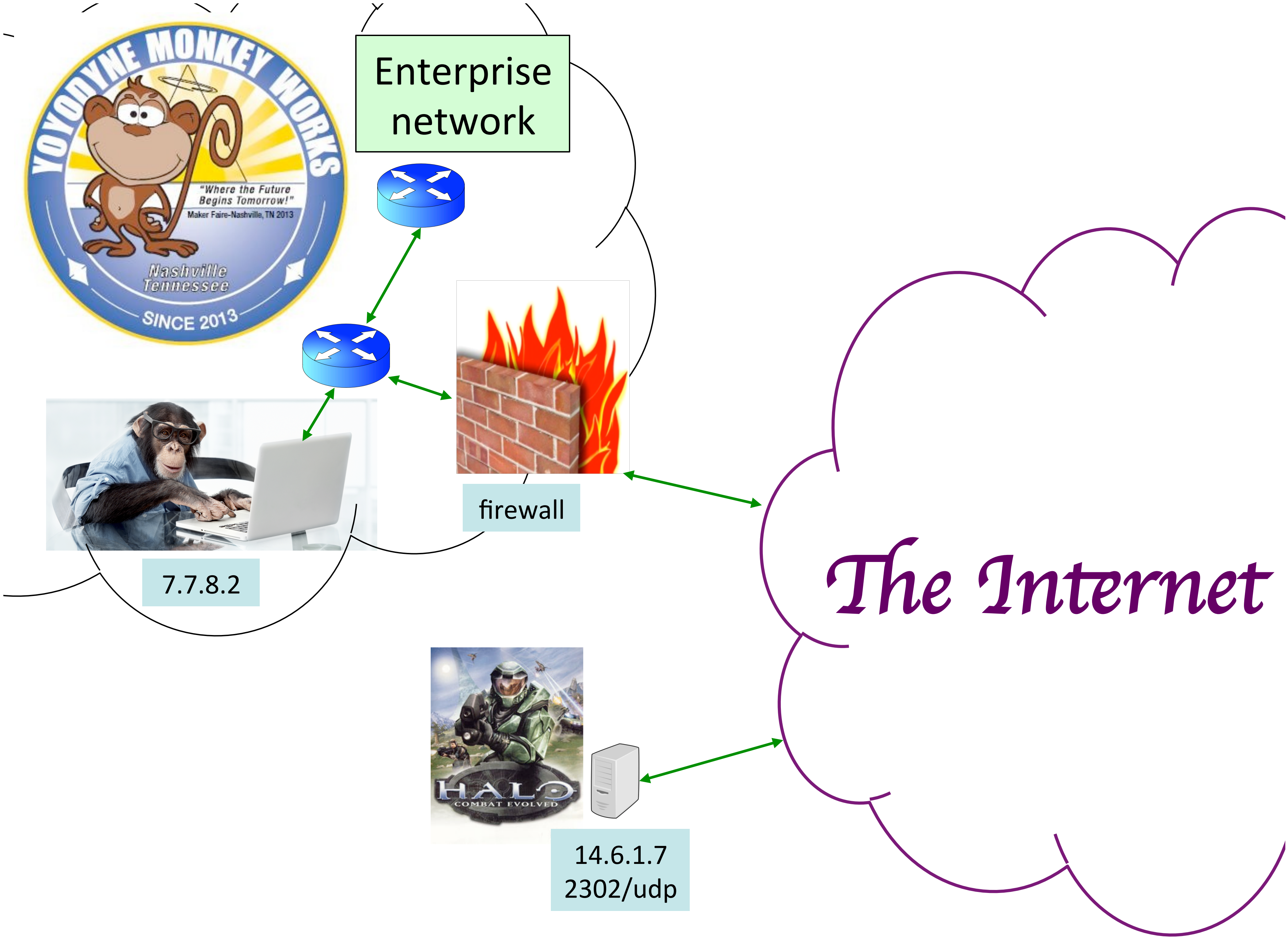
Enterprise network
router
7.7.8.2
HALO
COMBAT EVOLVED
14.6.1.7
2302/udp
The Internet



Enterprise network
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SINCE 2013
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
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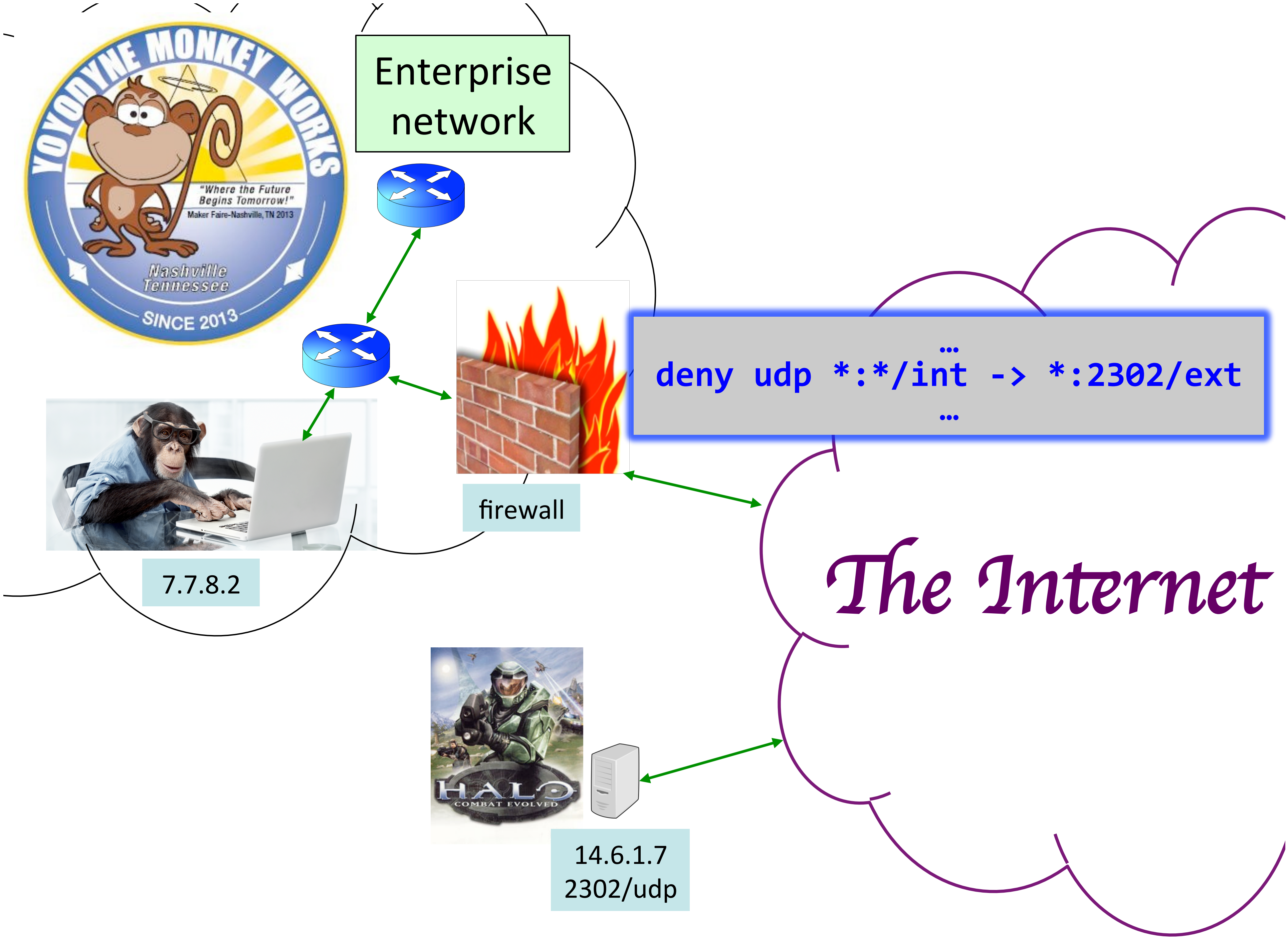
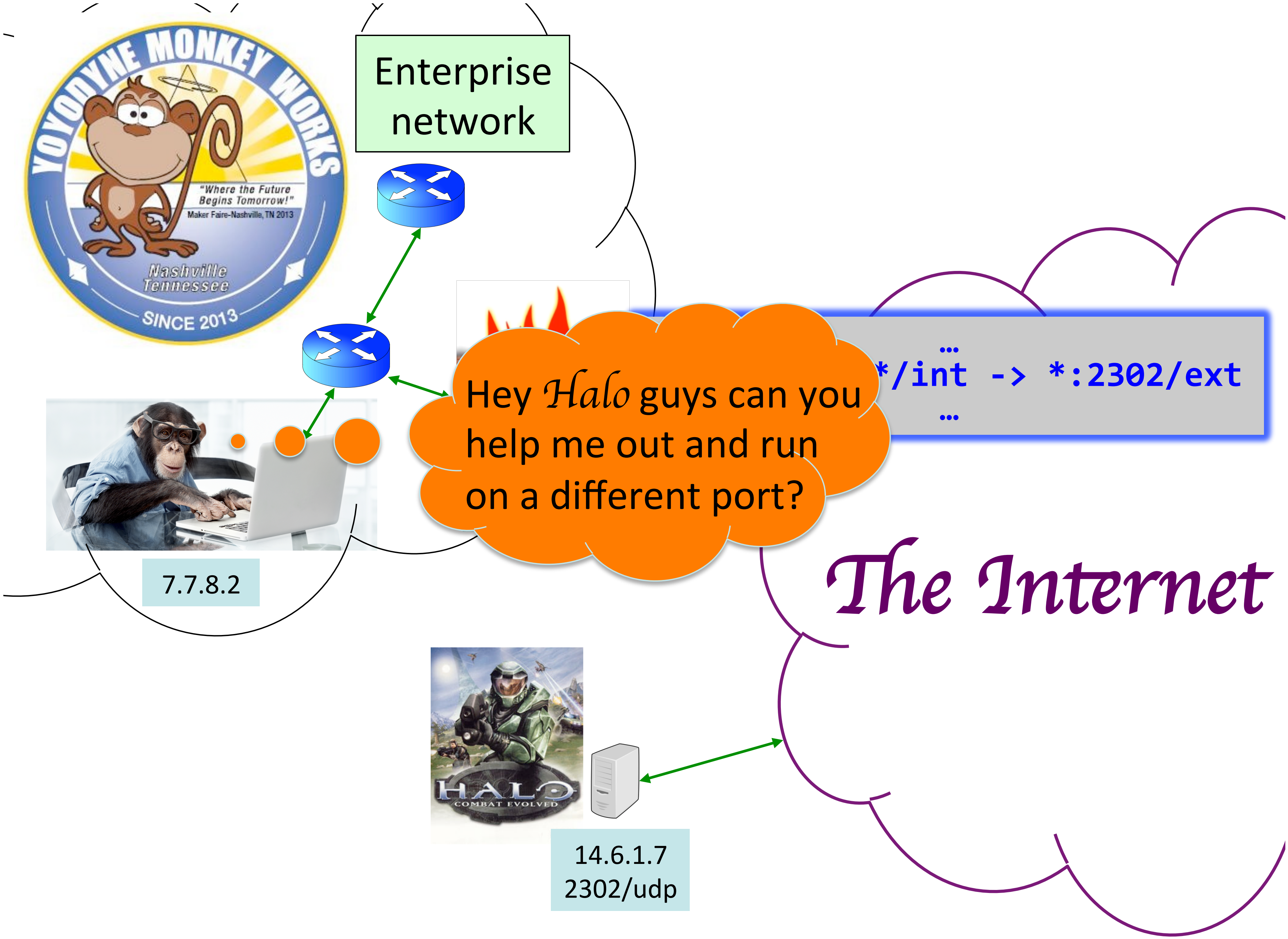
2302/udp


YOYODYNE MONKEY WORKS
"Where the Future Begins Tomorrow!"
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
Enterprise network
…
deny udp *:*/int -> *:2302/ext
…
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
2302/udp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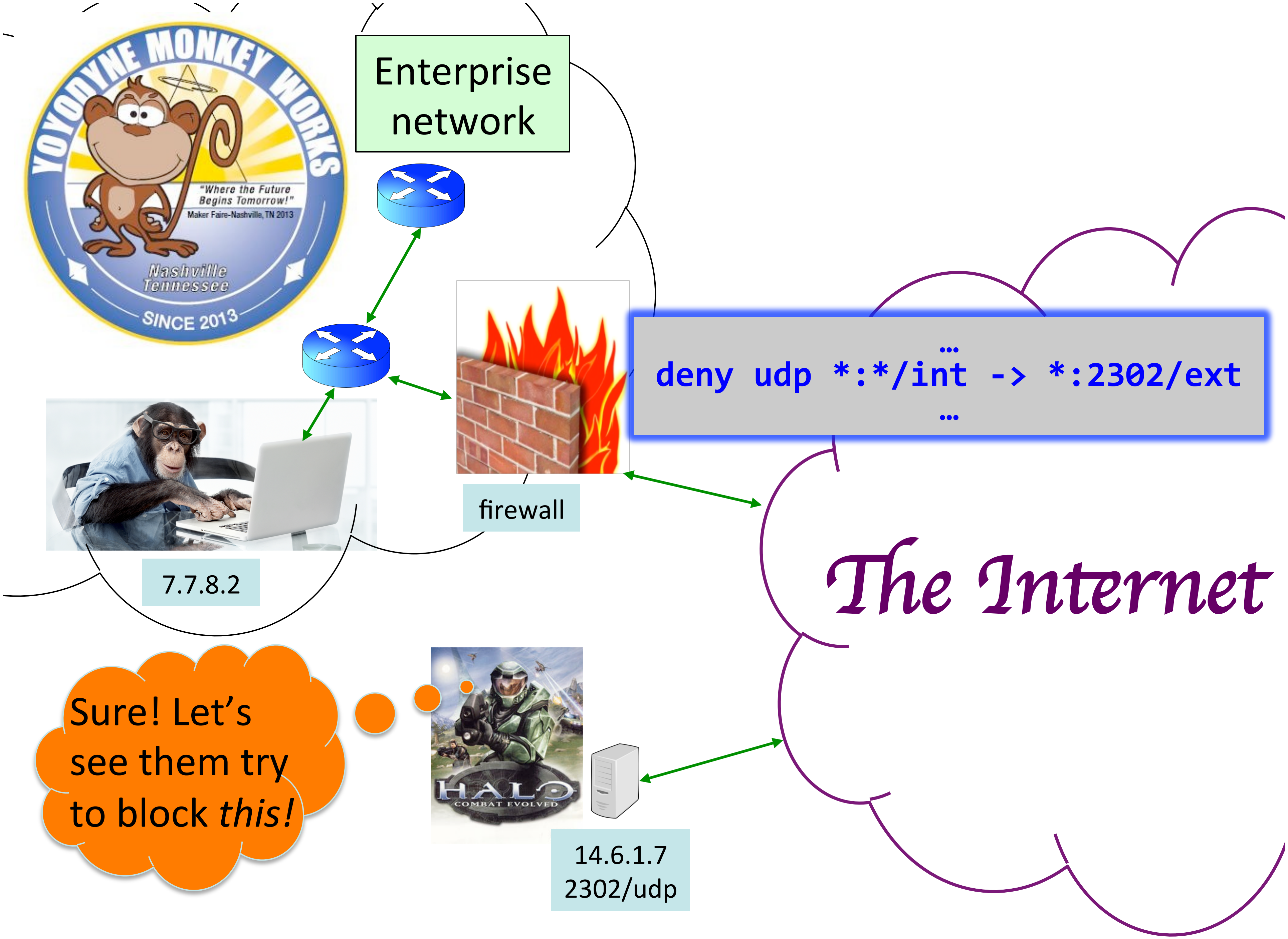
Nashville Tennessee
SINCE 2013
Enterprise network
…
*/int -> *:2302/ext
…
Hey Halo guys can you help me out and run on a different port?
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
2302/udp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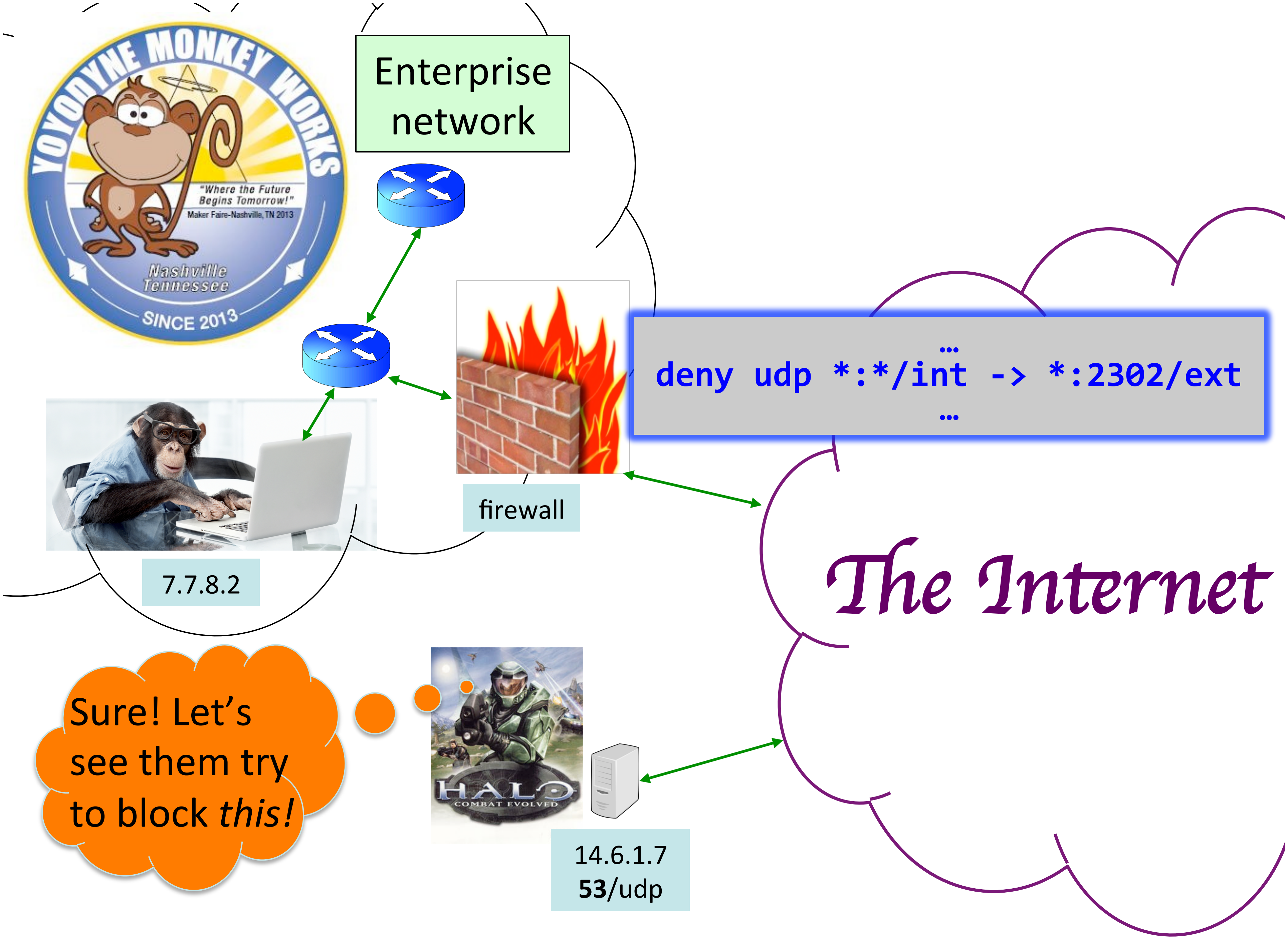
SINCE 2013
Enterprise network
firewall
…
deny udp *:*/int -> *:2302/ext
…
7.7.8.2
The Internet
Sure! Let's see them try to block *this!*
HALO
COMBAT EVOLVED
14.6.1.7
2302/udp



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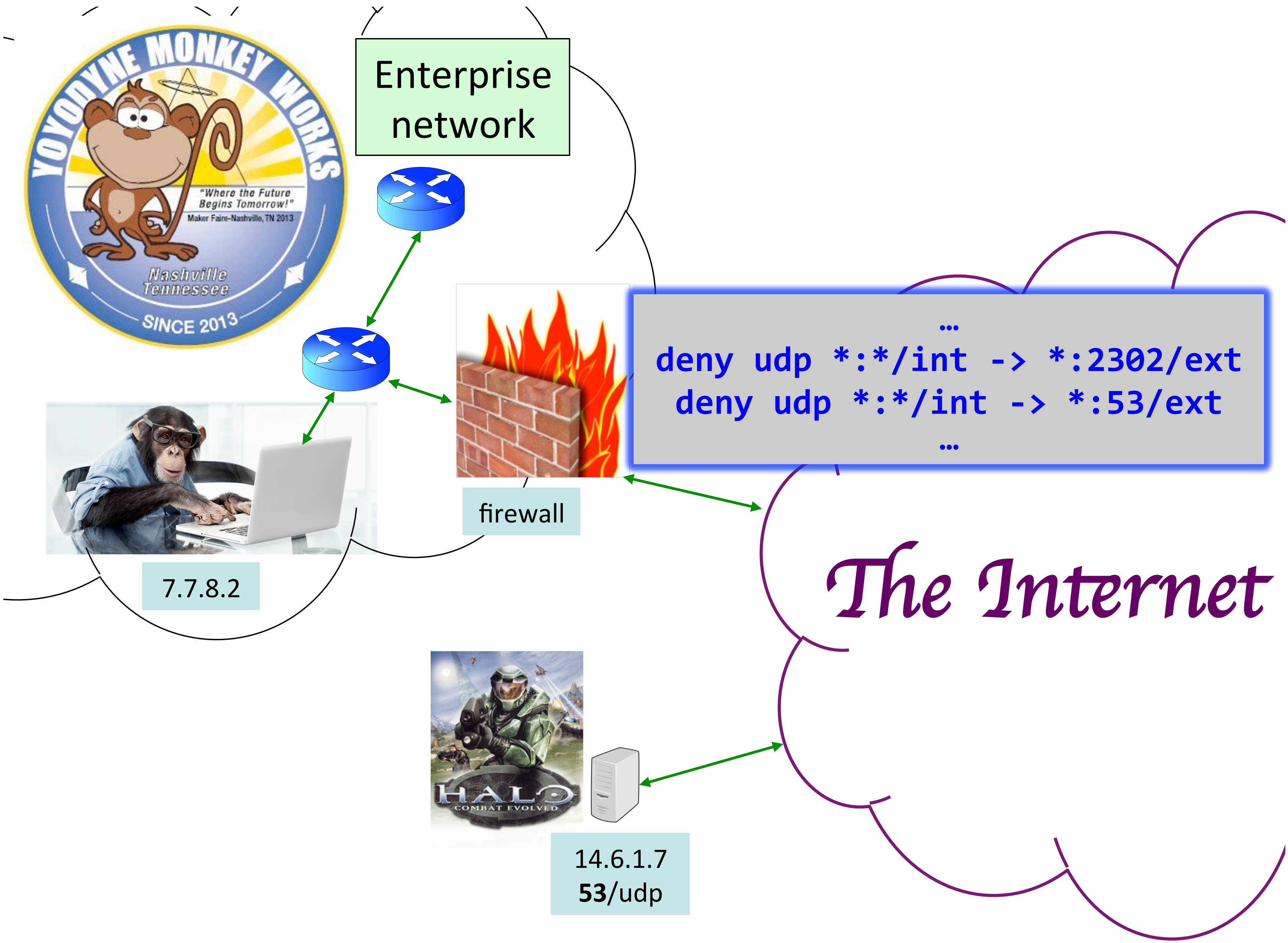
Nashville Tennessee
SINCE 2013
Enterprise network
firewall
7.7.8.2
…
deny udp *:*/int -> *:2302/ext
…
The Internet
Sure! Let's see them try to block *this!*
HALO
COMBAT EVOLVED
14.6.1.7
53/udp



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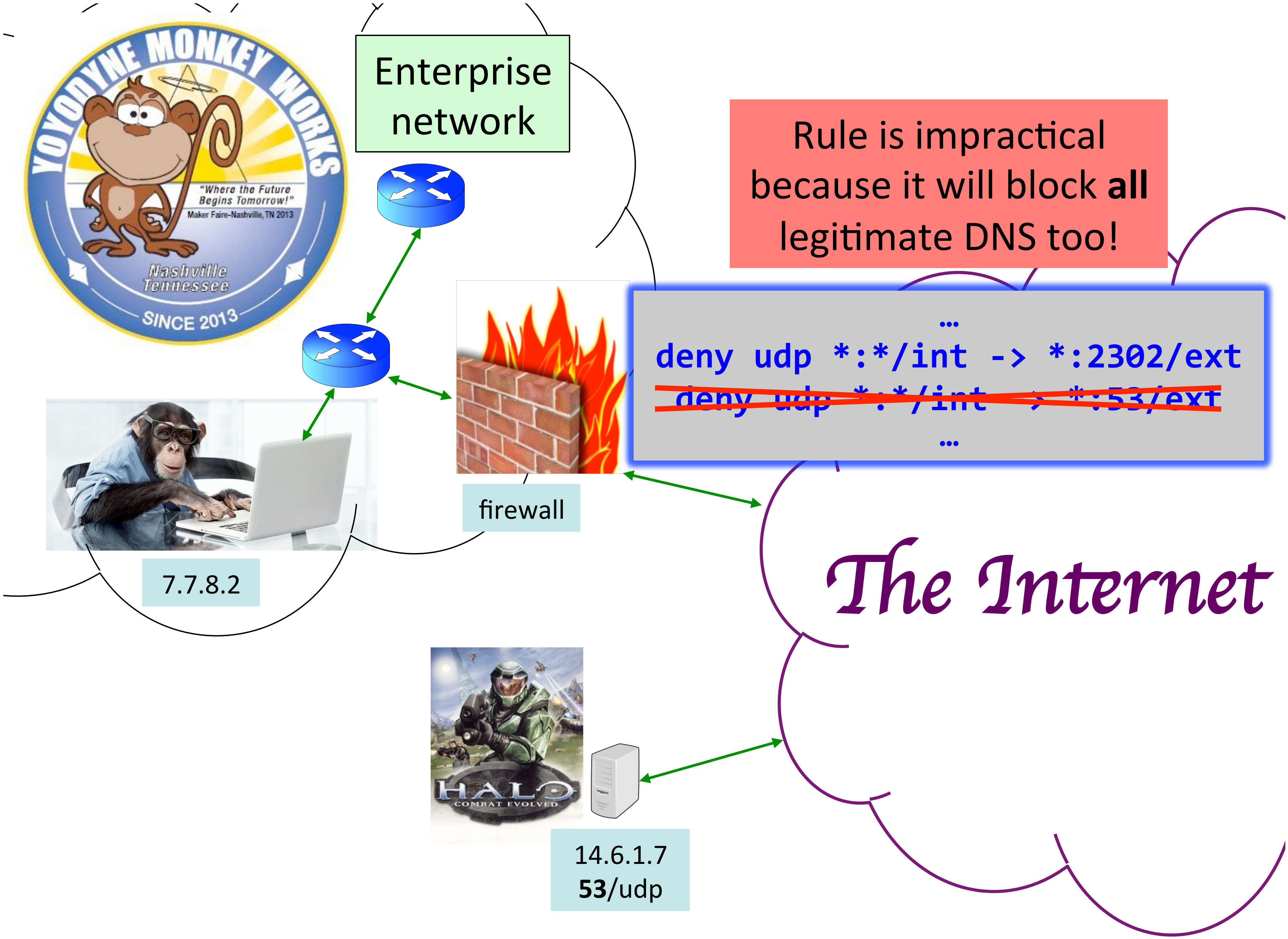
Nashville Tennessee
SINCE 2013
Enterprise network
…
deny udp *:*/int -> *:2302/ext
deny udp *:*/int -> *:53/ext
…
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp


Enterprise network
YOYODYNE MONKEY WORKS
"Where the Future Begins Tomorrow!"
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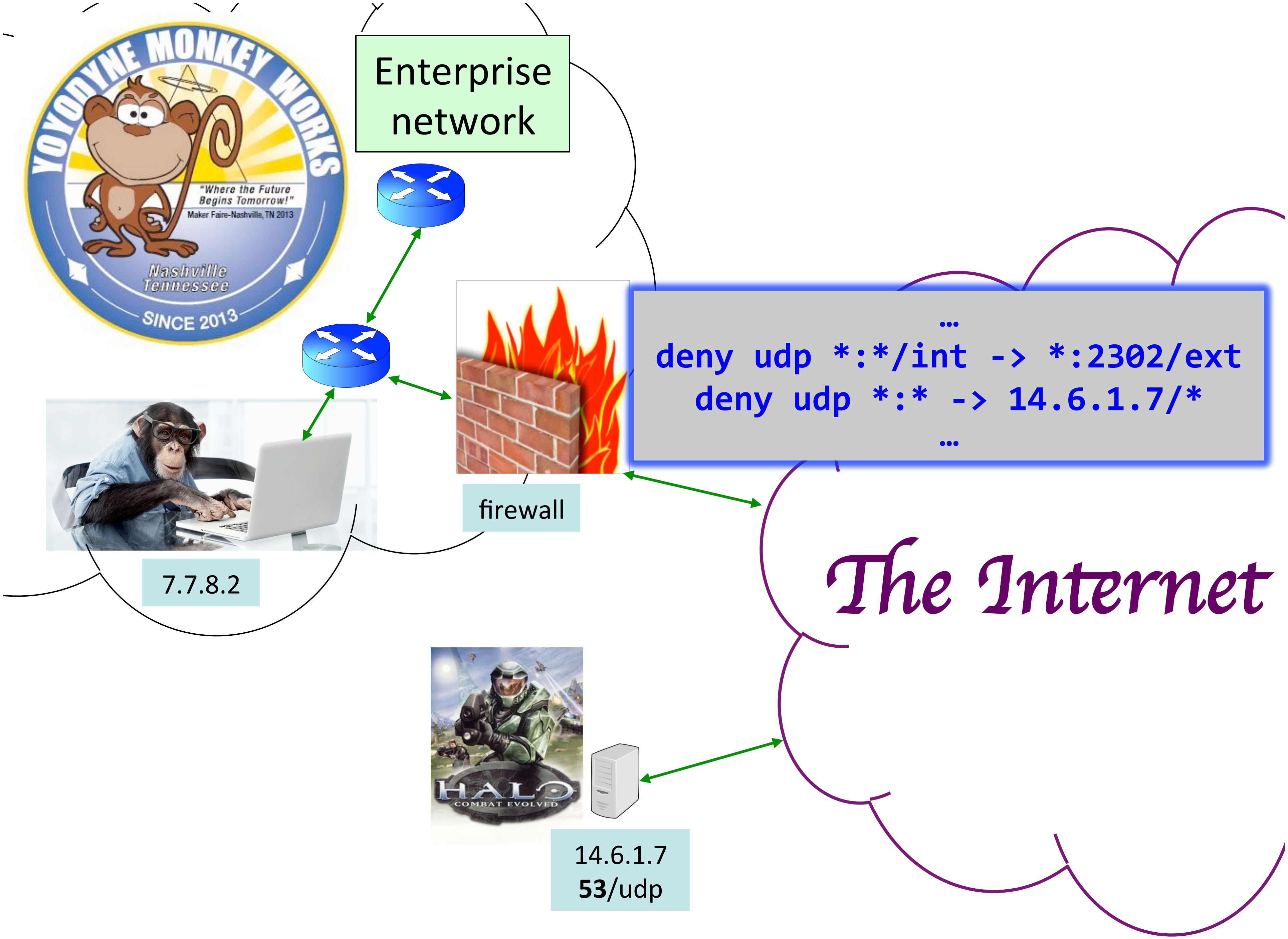
Nashville Tennessee
SINCE 2013
Rule is impractical because it will block **all** legitimate DNS too!
…
deny udp *:*/int -> *:2302/ext
~~deny udp *:*/int -> *:53/ext~~
…
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp



YOYODYNE MONKEY WORKS
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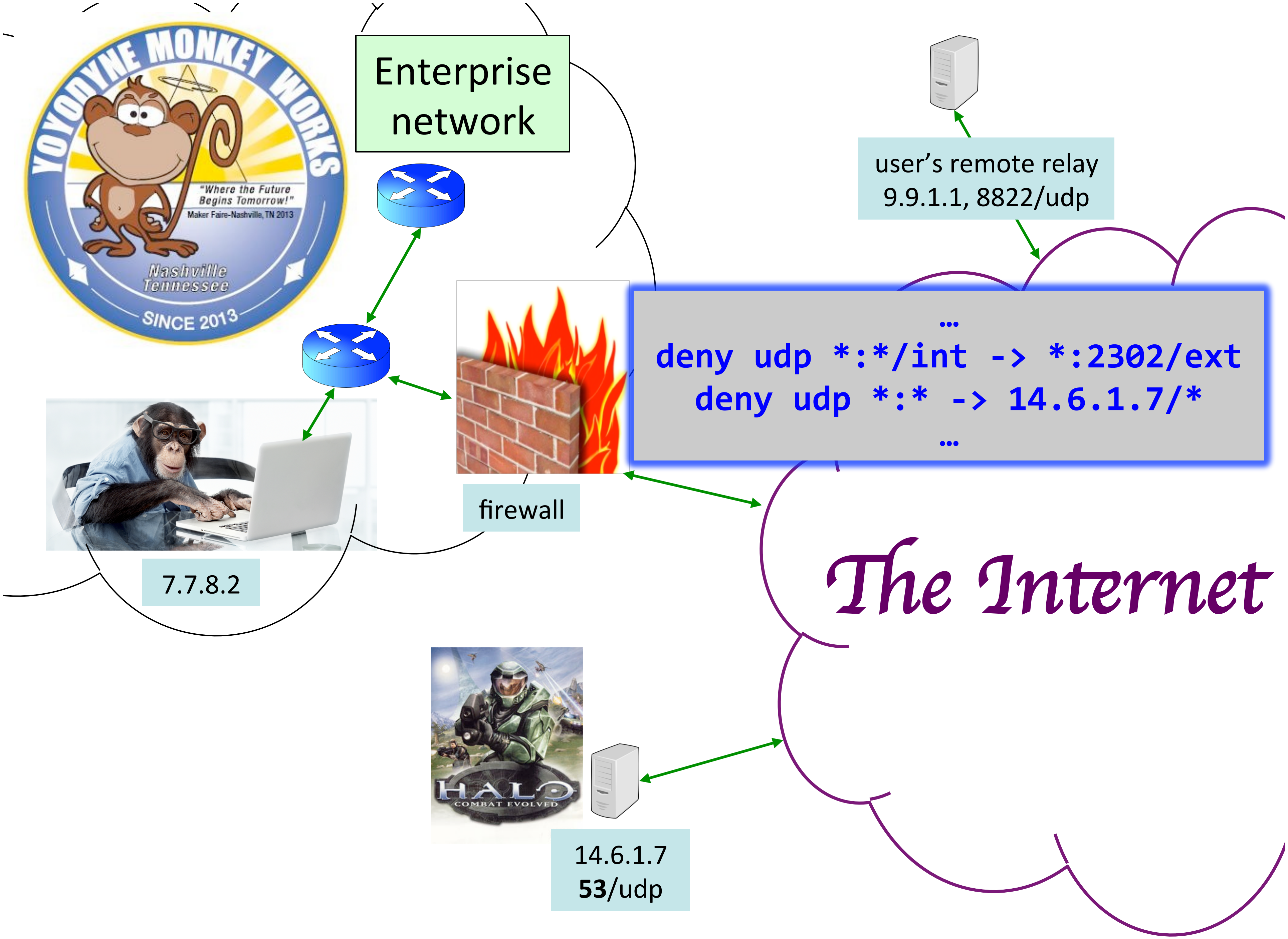
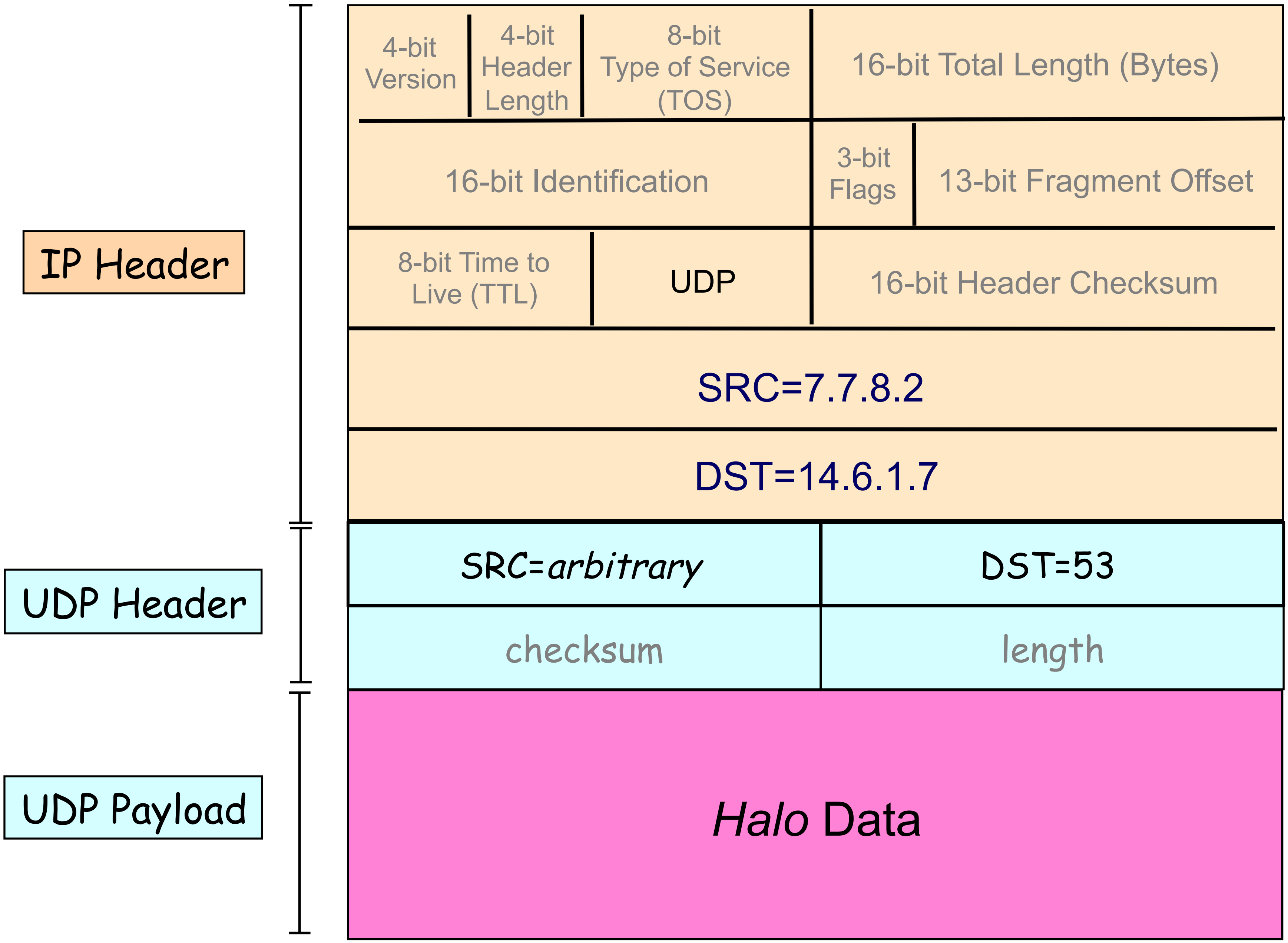
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
Enterprise network
firewall
…
deny udp *:*/int -> *:2302/ext
deny udp *:* -> 14.6.1.7/*
…
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp

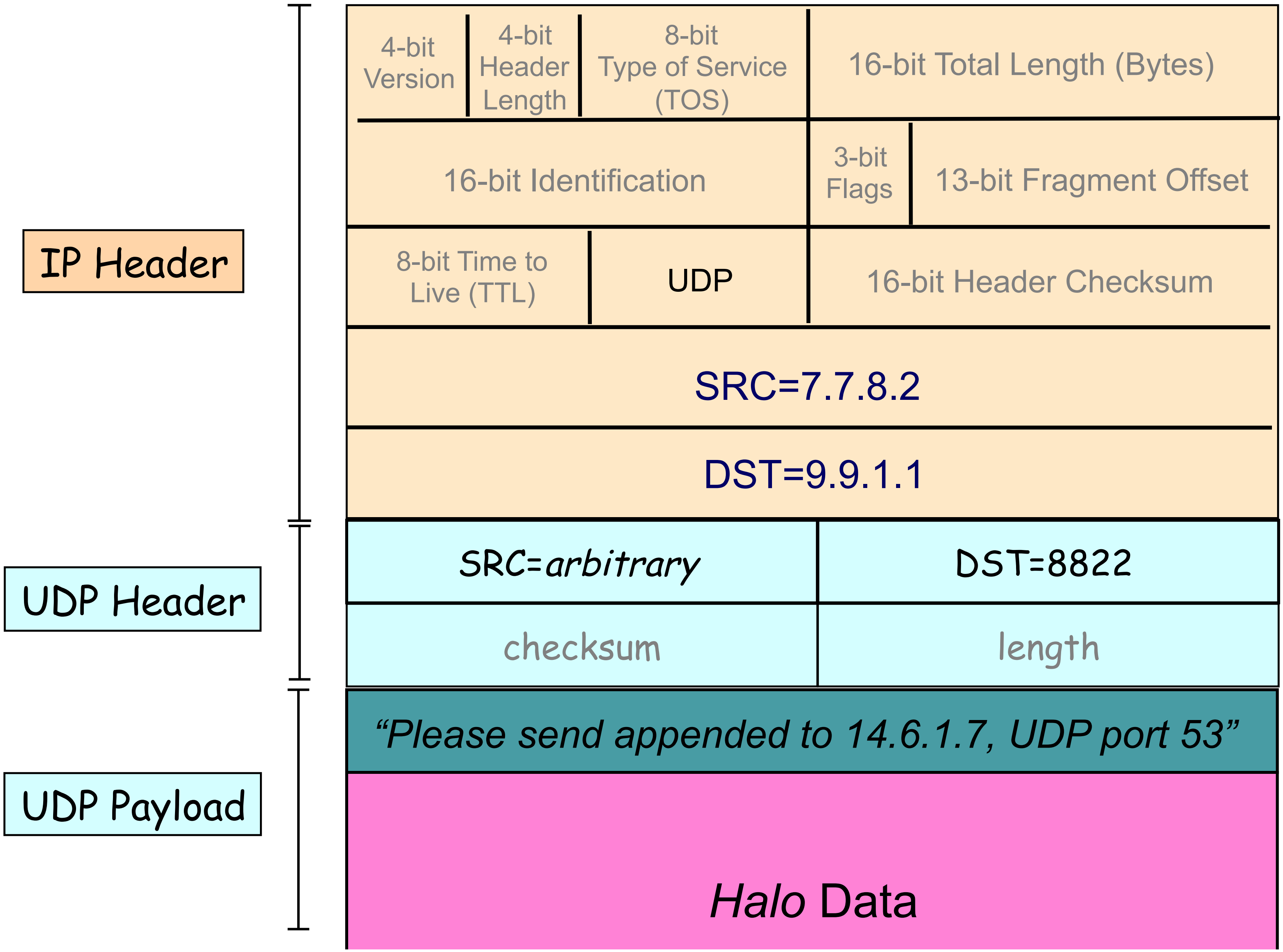


Enterprise network
YOYODYNE MONKEY WORKS
"Where the Future Begins Tomorrow!"
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
user's remote relay
9.9.1.1, 8822/udp
…
deny udp *:*/int -> *:2302/ext
deny udp *:* -> 14.6.1.7/*
…
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp

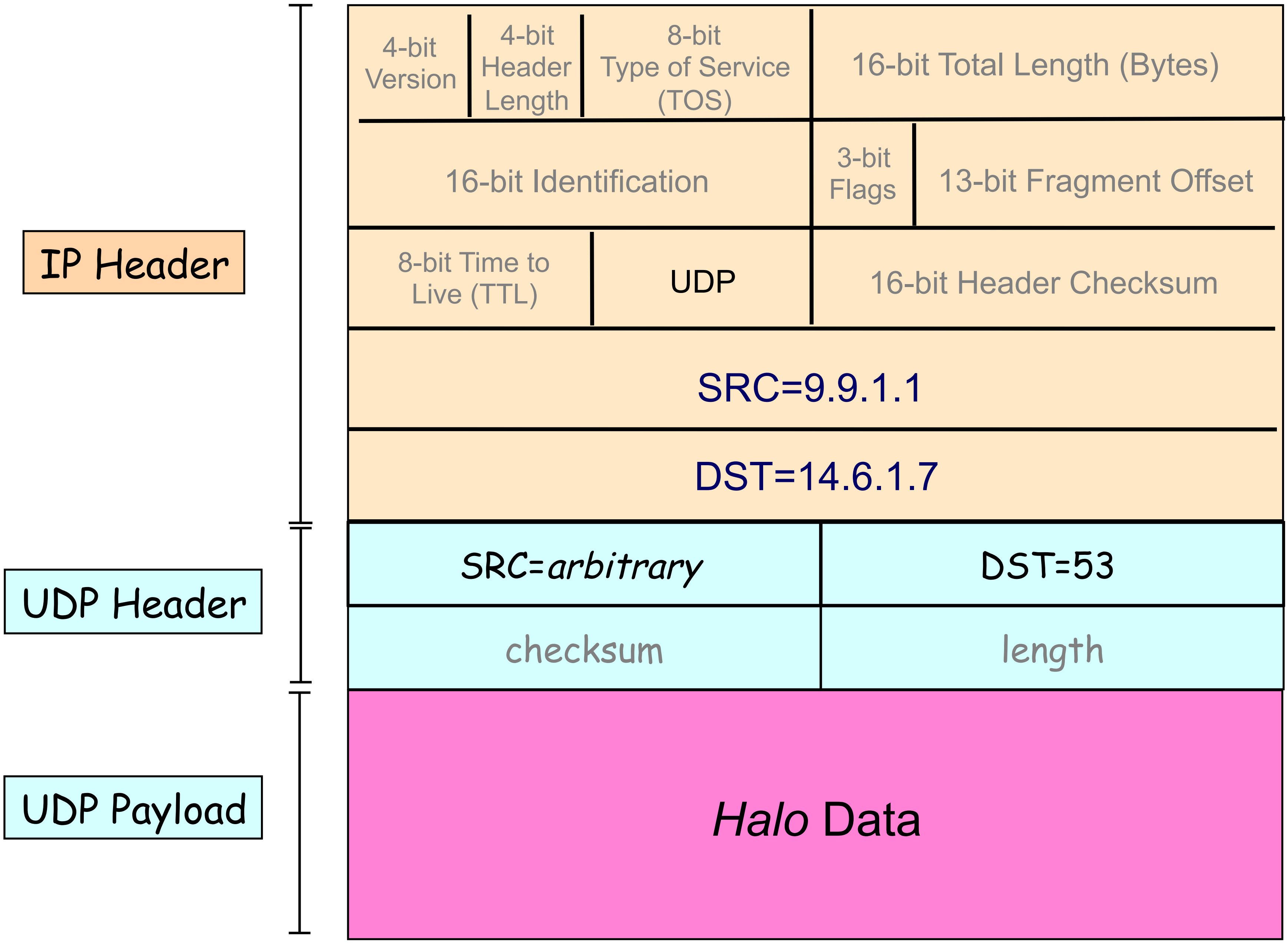
Packet Sent to Halo Server

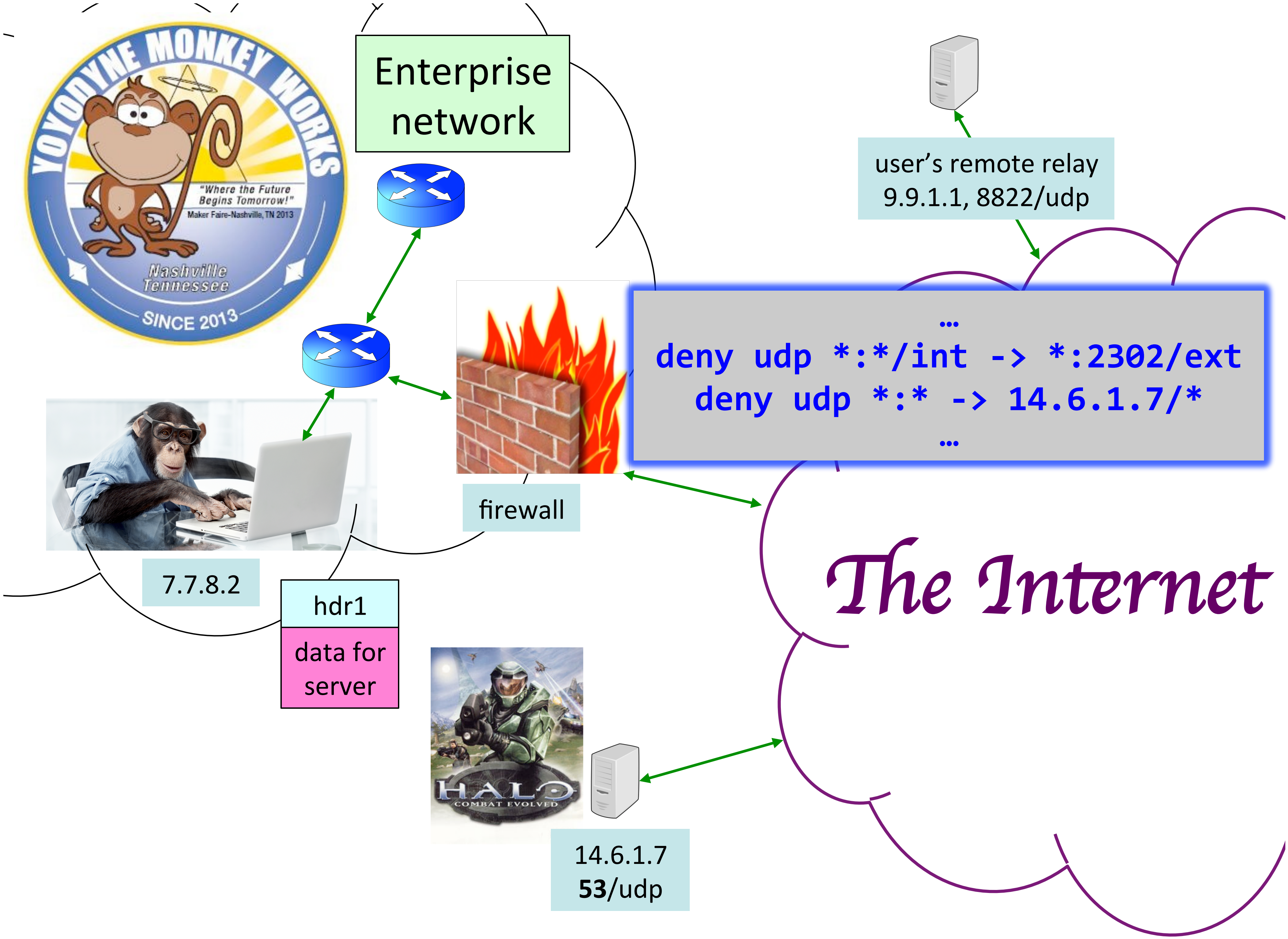


Packet Sent to Remote Relay



Packet Sent *by* Remote Relay




YOYODYNE MONKEY WORKS
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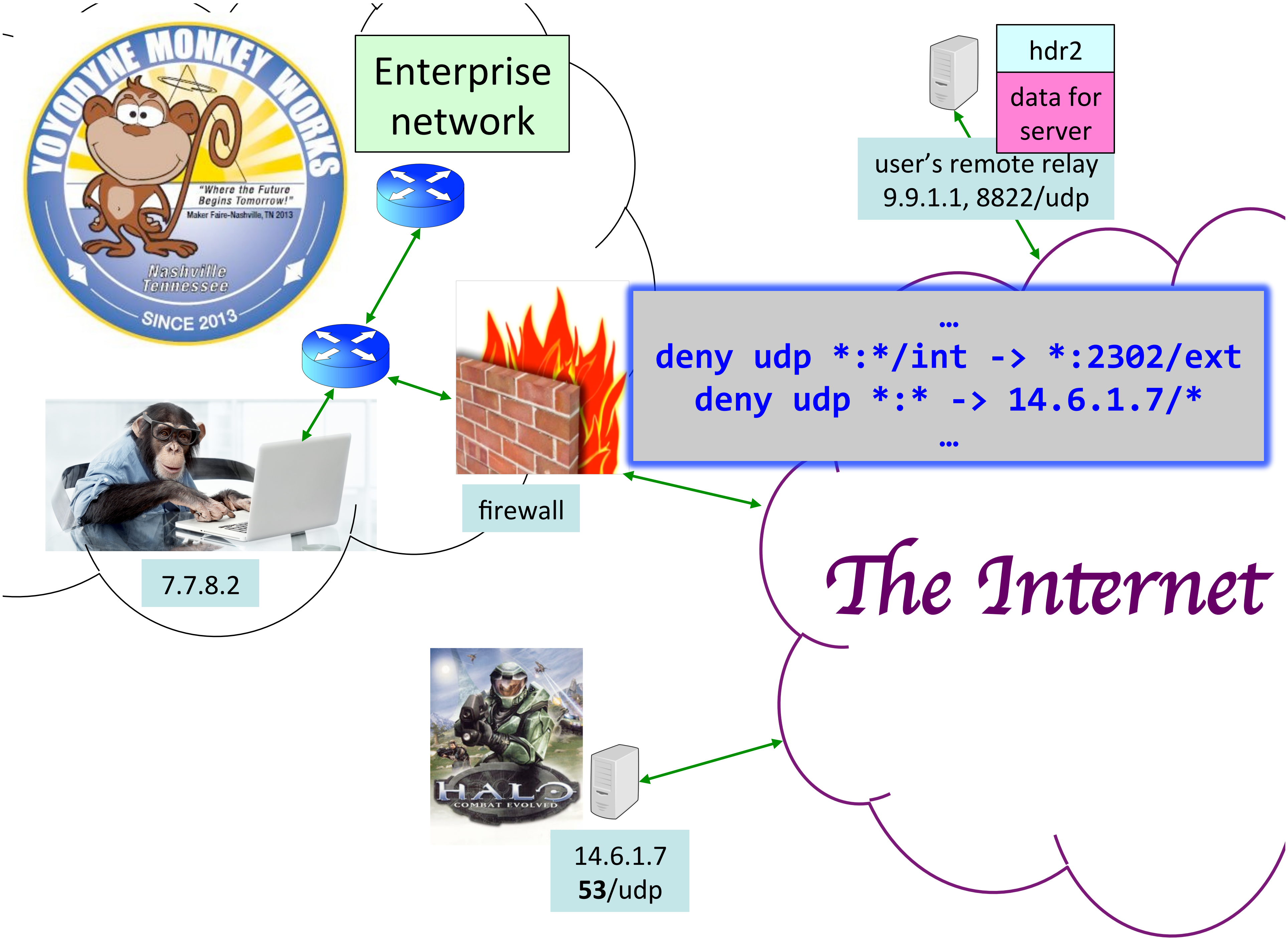
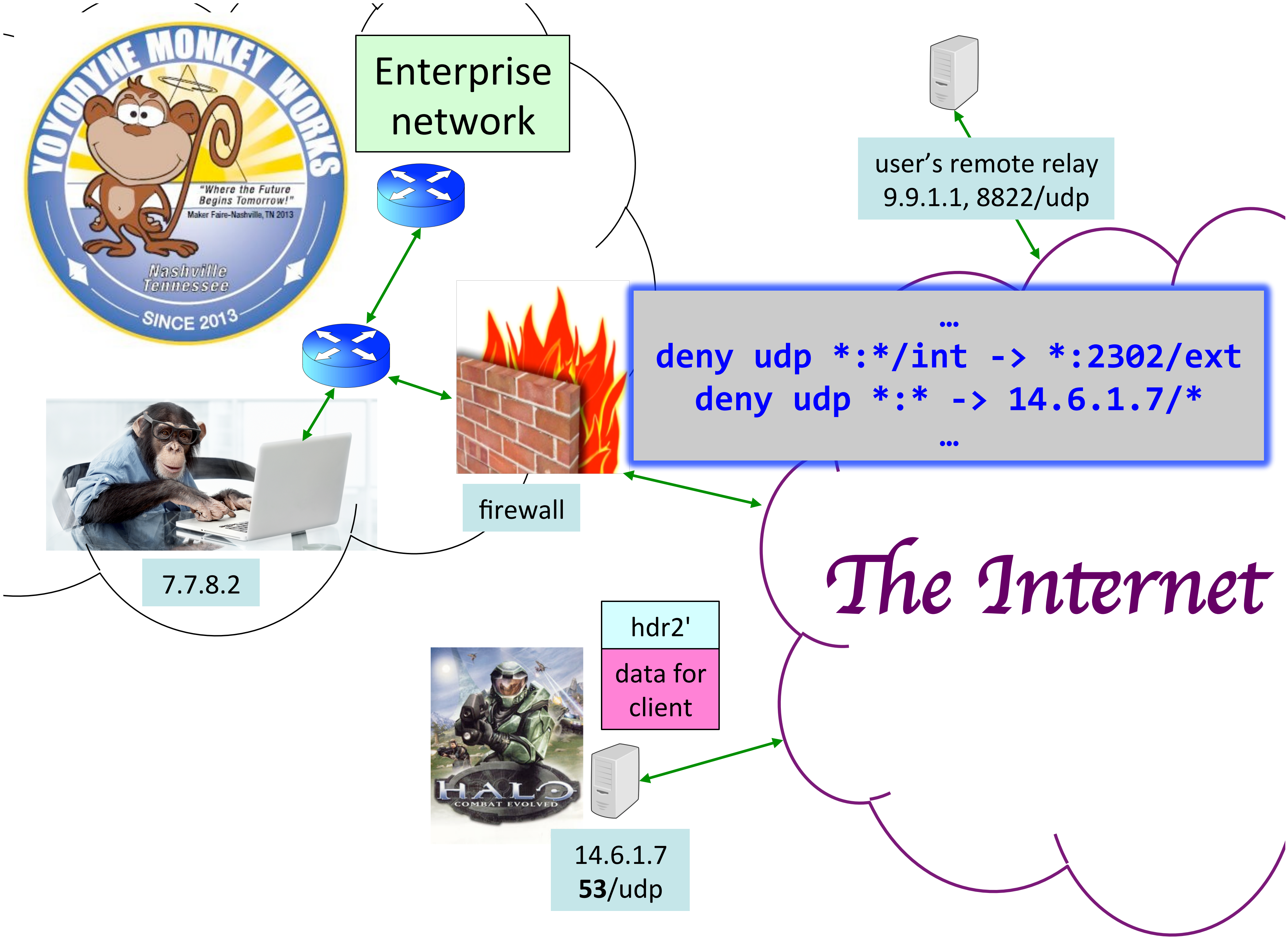
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
Enterprise network
user's remote relay
9.9.1.1, 8822/udp
…
deny udp *:*/int -> *:2302/ext
deny udp *:* -> 14.6.1.7/*
…
firewall
7.7.8.2
hdr1
data for server
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp



YOYODYNE MONKEY WORKS
"Where the Future Begins Tomorrow!"
Maker Faire-Nashville, TN 2013
Nashville Tennessee
SINCE 2013
Enterprise network
firewall
7.7.8.2
hdr2
data for server
user's remote relay
9.9.1.1, 8822/udp
…
deny udp *:*/int -> *:2302/ext
deny udp *:* -> 14.6.1.7/*
…
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp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9.9.1.1, 8822/udp
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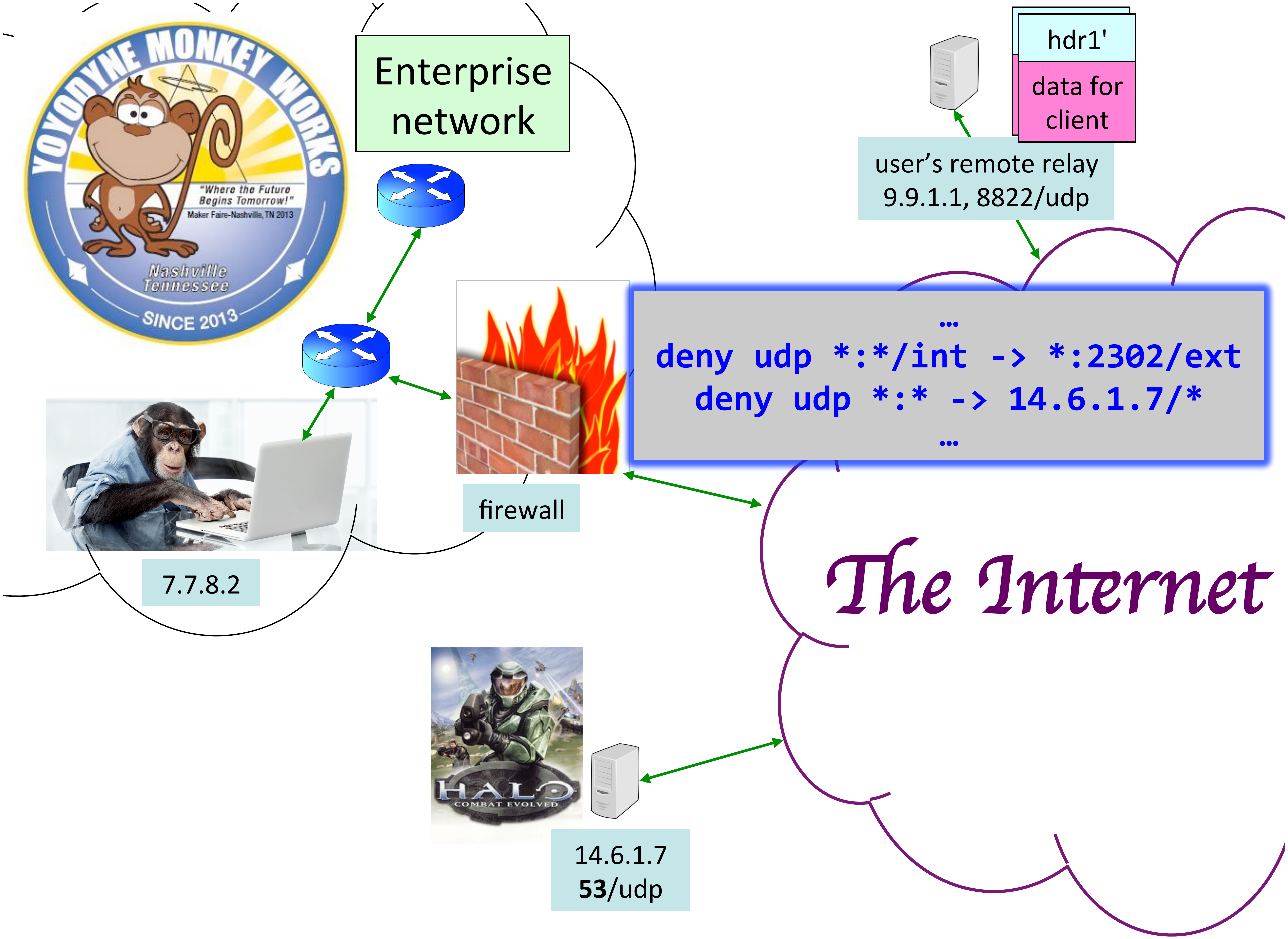
firewall
7.7.8.2
The Internet
hdr2'
data for client
HALO
COMBAT EVOLVED
14.6.1.7
53/udp



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Enterprise network
hdr1'
data for client
user’s remote relay
9.9.1.1, 8822/udp
…
deny udp *:*/int -> *:2302/ext
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…
firewall
7.7.8.2
The Internet
HALO
COMBAT EVOLVED
14.6.1.7
53/udp

Hiding on Other Ports

- Method #1: use port allocated to another service
  (how can this be detected?)
- Method #2: **tunneling**
  - Encapsulate one protocol inside another
  - Receiver of "outer" protocol *decapsulates* interior tunneled protocol to recover it
  - Pretty much **any** protocol can be tunneled over another (with enough effort)
- E.g., tunneling IP over SMTP (email)
  - Just need a way to code an IP datagram as an email message (either mail body or just headers)

Example: Tunneling IP over Email

From: halo-nut@yoyodyne.com
To: my-buddy@tunnel-decapsulators.R.us
Subject: Here's my IP datagram

IP-header-version: 4
IP-header-len: 5
IP-proto: 17 (UDP)
IP-src: 7.7.8.2
IP-dst: 14.6.1.7
IP-payload: 0xa144bf2c0102…

This operator of this email server has chosen to *cooperate* with the email sender to help them tunnel

Remote email server receives this legal email, **builds** an IP packet corresponding to description in email body …
… and **injects** it into the network

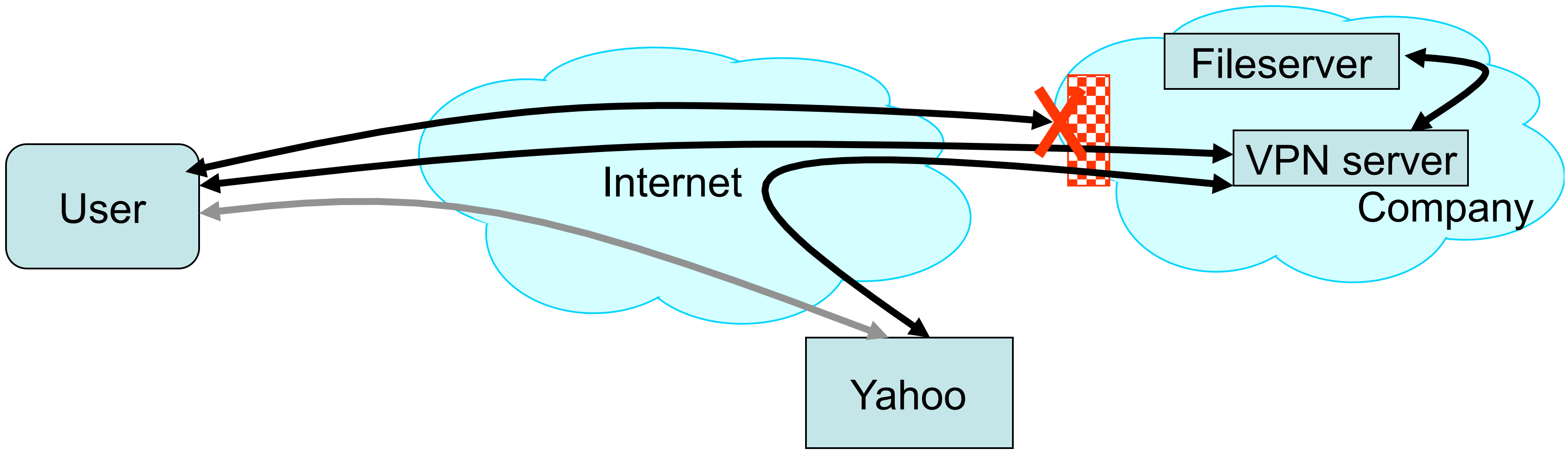
How can a firewall detect this??

Network Control & Tunneling

- *Tunneling* = embedding one protocol inside another
  - Sender and receiver at each side of the tunnel both cooperate (so it's not useful for initial attacks)
- Traffic takes on properties of outer protocol
  - Including for firewall inspection, which generally can't analyze inner protocol (due to complexity)
- Tunneling has legitimate uses
  - E.g., Virtual Private Networks (VPNs)
    - Tunnel server relays remote client's packets
    - Makes remote machine look like it's local to its home network
    - Tunnel encrypts traffic for privacy & to prevent meddling

Other Ways of Securing Network Access

Secure External Access to Inside Machines



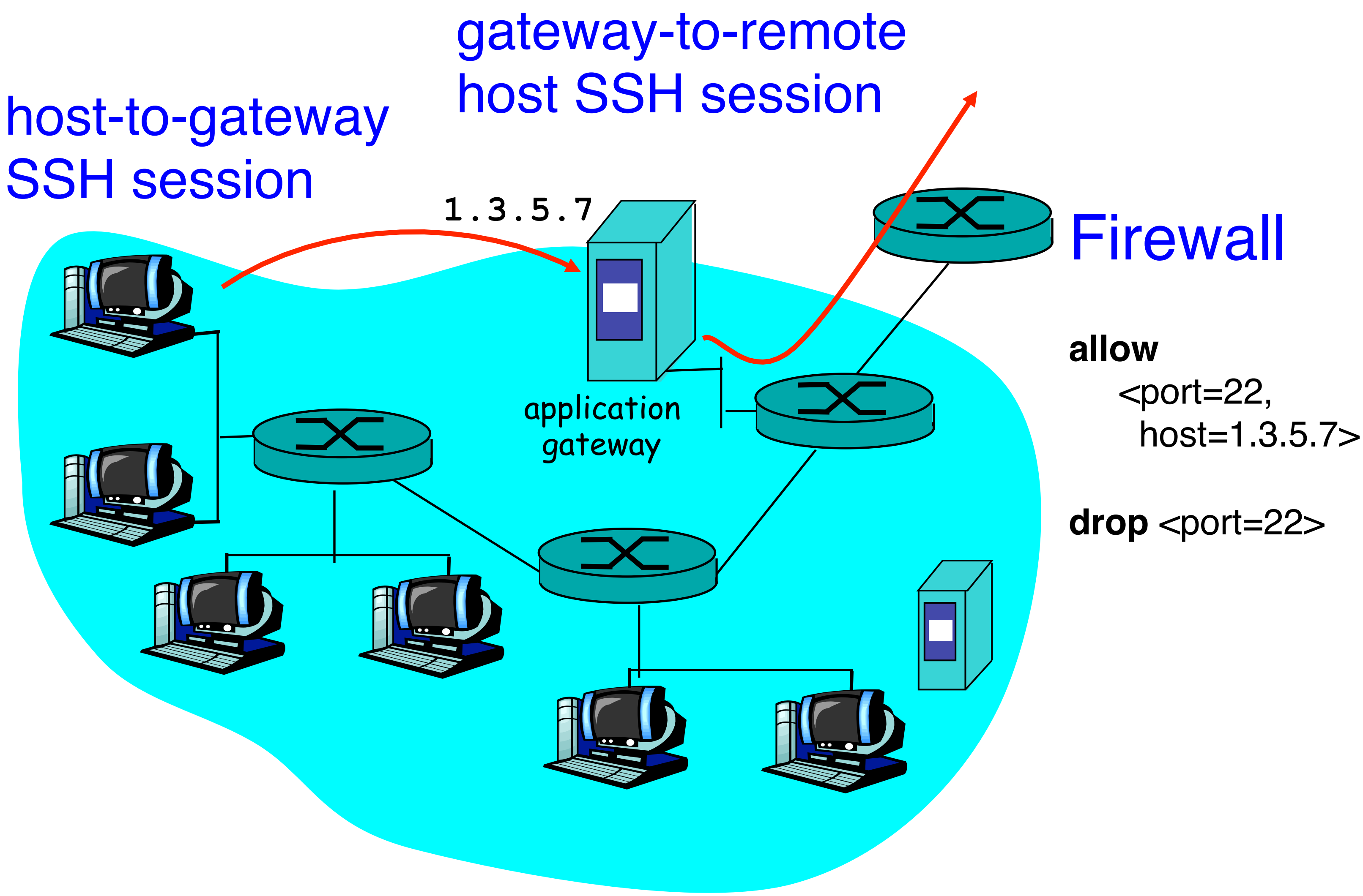
- Often need to provide secure remote access to a network protected by a firewall
  - Remote access, telecommuting, branch offices, …
- Create secure channel (*Virtual Private Network*, or **VPN**) to tunnel traffic from outside host/network to inside network
  - Provides Authentication, Confidentiality, Integrity
    - Requires some form of key management to set up
  - However, also raises *perimeter issues*

  (Try it yourself at http://www.net.berkeley.edu/vpn/)

Application Proxies

- Can more directly control applications by requiring them to go through a proxy for external access
  - Proxy doesn't simply forward, but acts as an application-level middleman
- Example: SSH gateway
  - Require all SSH in/out of site to go through gateway
  - Gateway logs authentication, inspects decrypted text
  - Site's firewall configured to *prohibit any other* SSH access

SSH Gateway Example



Application Proxies

- Can more directly control applications by requiring them to go through a proxy for external access
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- Example: SSH gateway
  - Require all SSH in/out of site to go through gateway
  - Gateway logs authentication, inspects decrypted text
  - Site's firewall configured to prohibit any other SSH access
- Provides a powerful degree of monitoring/control
- Costs?
  - Need to run extra server(s) per app (possible *bottleneck*)
  - Each server requires careful hardening