UNIVERSITÀ DEGLI STUDI
DI TRENTO

Network Security

AA 2015/2016

Network aspects

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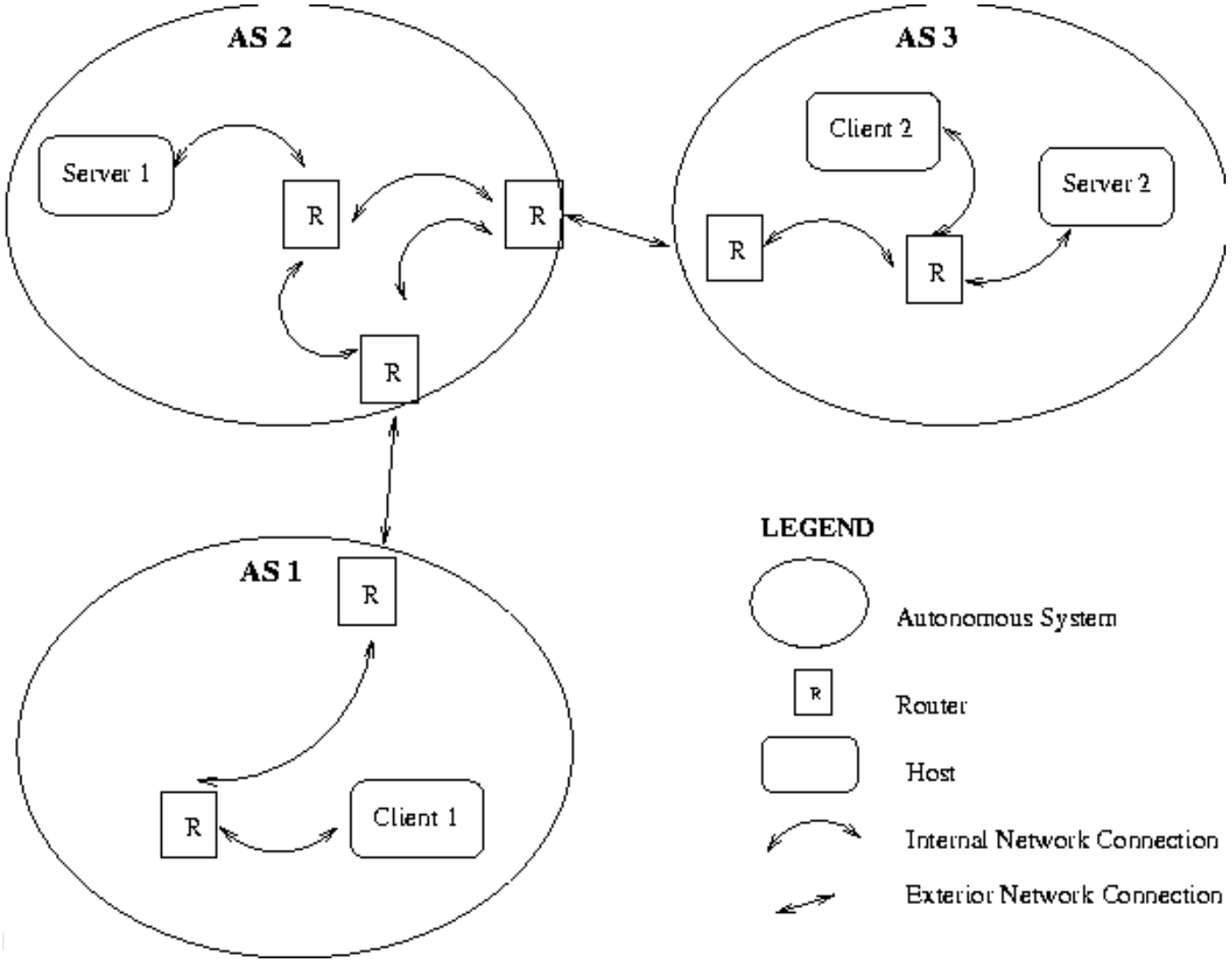
Internet communication

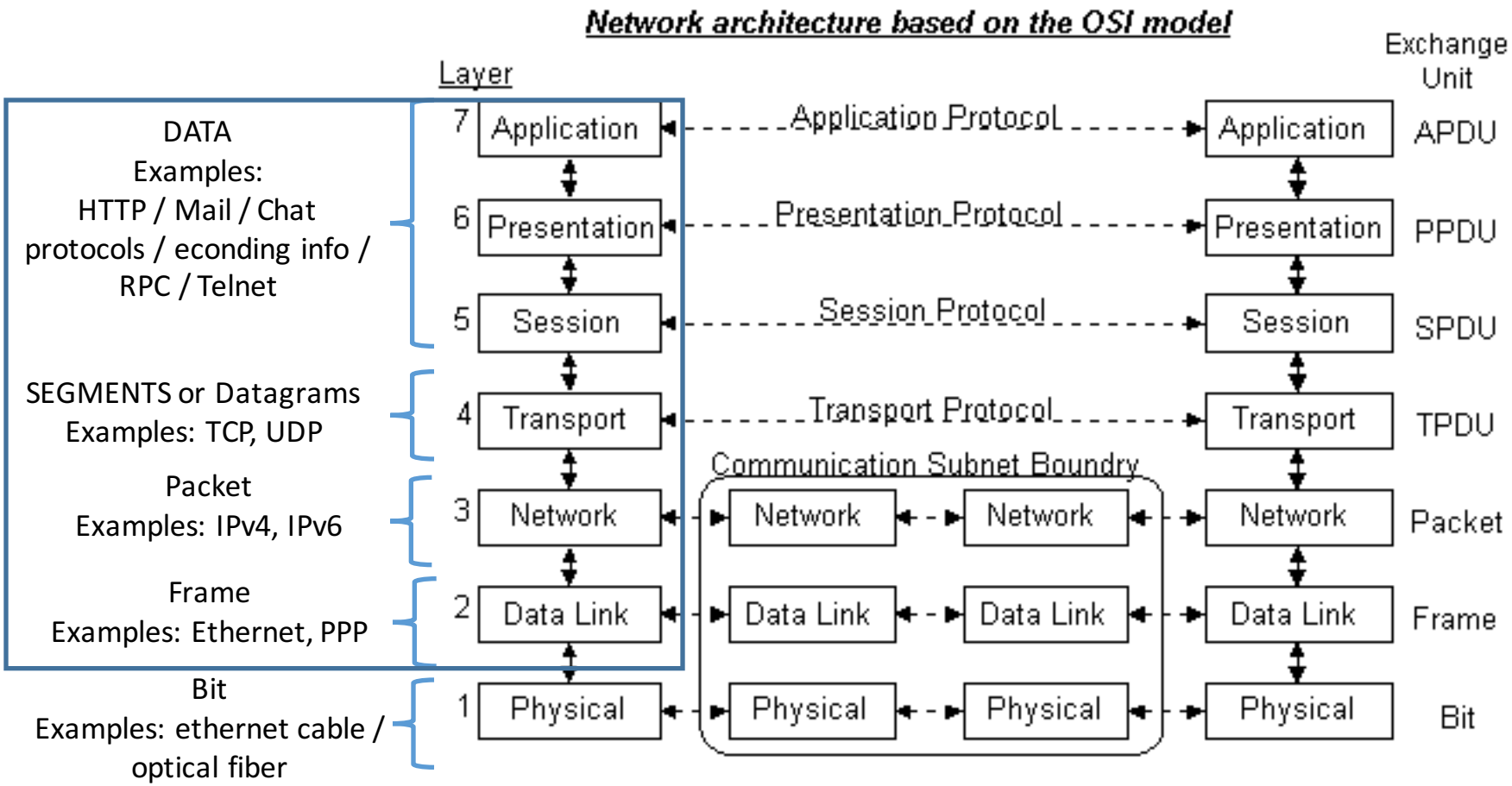
- Internet is made of several logically separated networks → **Autonomous Systems** (AS)
  - Internet= network of networks
- Each AS autonomously manages communications within itself
  - Interior Gateway Protocols (IGP) → route within each AS
  - e.g. Local Area Network
- Each AS can communicate to other AS
  - Exterior Gateways Protocols → route between ASs
    - Border Gateway Protocol

Internet autonomous systems



https://www.usenix.org/legacy/event/lisa98/full_papers/pultar/pultar_html/pultar.html

OSI model


Network architecture based on the OSI model
Layer
Exchange Unit
DATA
Examples:
HTTP / Mail / Chat protocols / econding info / RPC / Telnet
SEGMENTS or Datagrams
Examples: TCP, UDP
Packet
Examples: IPv4, IPv6
Frame
Examples: Ethernet, PPP
Bit
Examples: ethernet cable / optical fiber
7 Application
6 Presentation
5 Session
4 Transport
3 Network
2 Data Link
1 Physical
Application Protocol
Presentation Protocol
Session Protocol
Transport Protocol
Communication Subnet Boundry
Application
Presentation
Session
Transport
Network
Data Link
Physical
APDU
PPDU
SPDU
TPDU
Packet
Frame
Bit

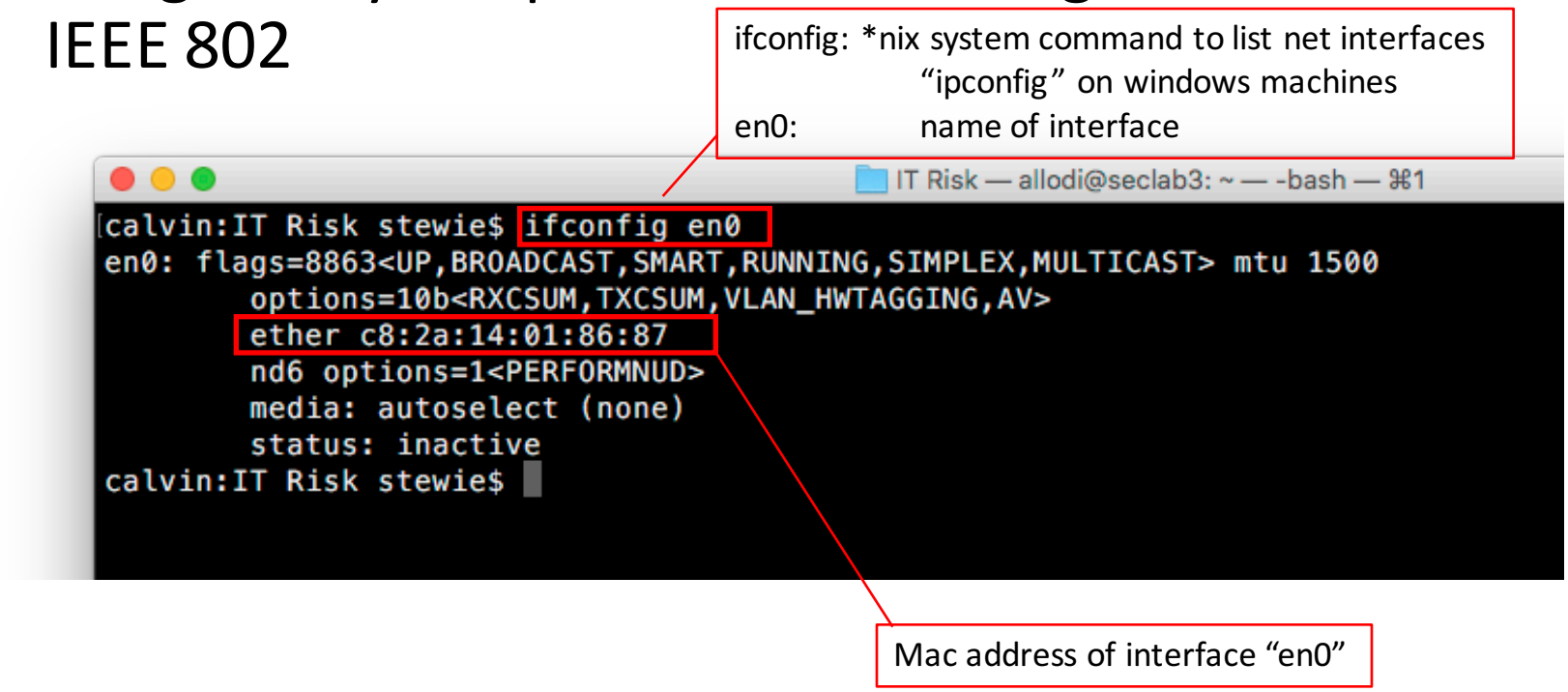
OSI Data Link layer

Data link layer

- Lowest “logical” level
- Data link interconnects physical interfaces
- Each physical interface is identified by a MAC address
  - “Ethernet address”
  - 48-bit Network interface **identifiers**
  - Closest representation of final destination of a frame
  - HEX notation
    - HH-HH-HH-HH-HH-HH
  - Used to route packets in local networks

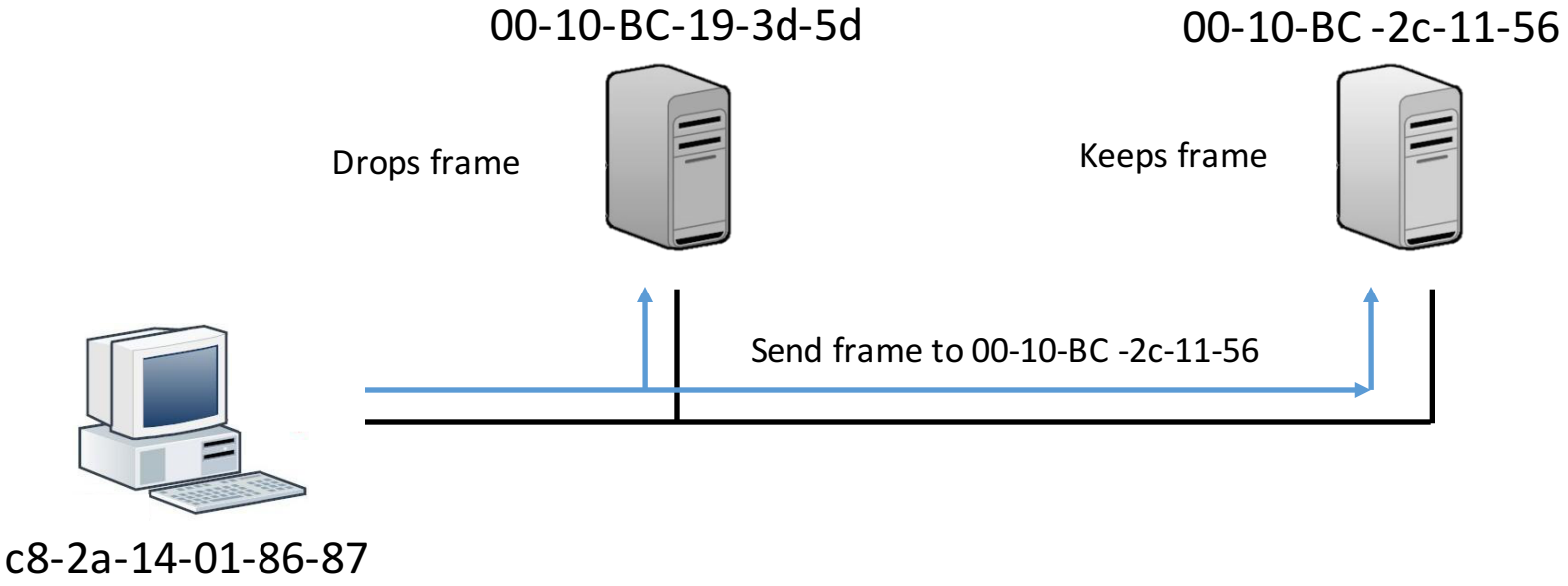
Mac addresses

- Uniquely identify a network interface
- Assigned by the producer according to the standard IEEE 802



Mac addresses example

- First 24 bit are set by IEEE standard
- Identify network interface producer
  - 00-10-BC → Aastra Telecom
  - https://regauth.standards.ieee.org/standards-ra-web/pub/view.html#registries



OSI Network Layer

The Network Layer

- Provides information on how to reach other systems
  - Addressing functionalities
- IP operates at this layer
  - High-level representation of a host's addresses
  - Conveys information to route the datagram
  - IPv4 defined in RFC 791
- IP addresses are dynamically assigned by an authority (e.g. ISP's DHCP server)
  - As opposed to MAC addresses that are fixed by the vendor
  - "**Connectionless**" protocol (stateless)
    - No notion of "established connection" at this stage
    - Only provides the means necessary for a **packet** to reach its destination

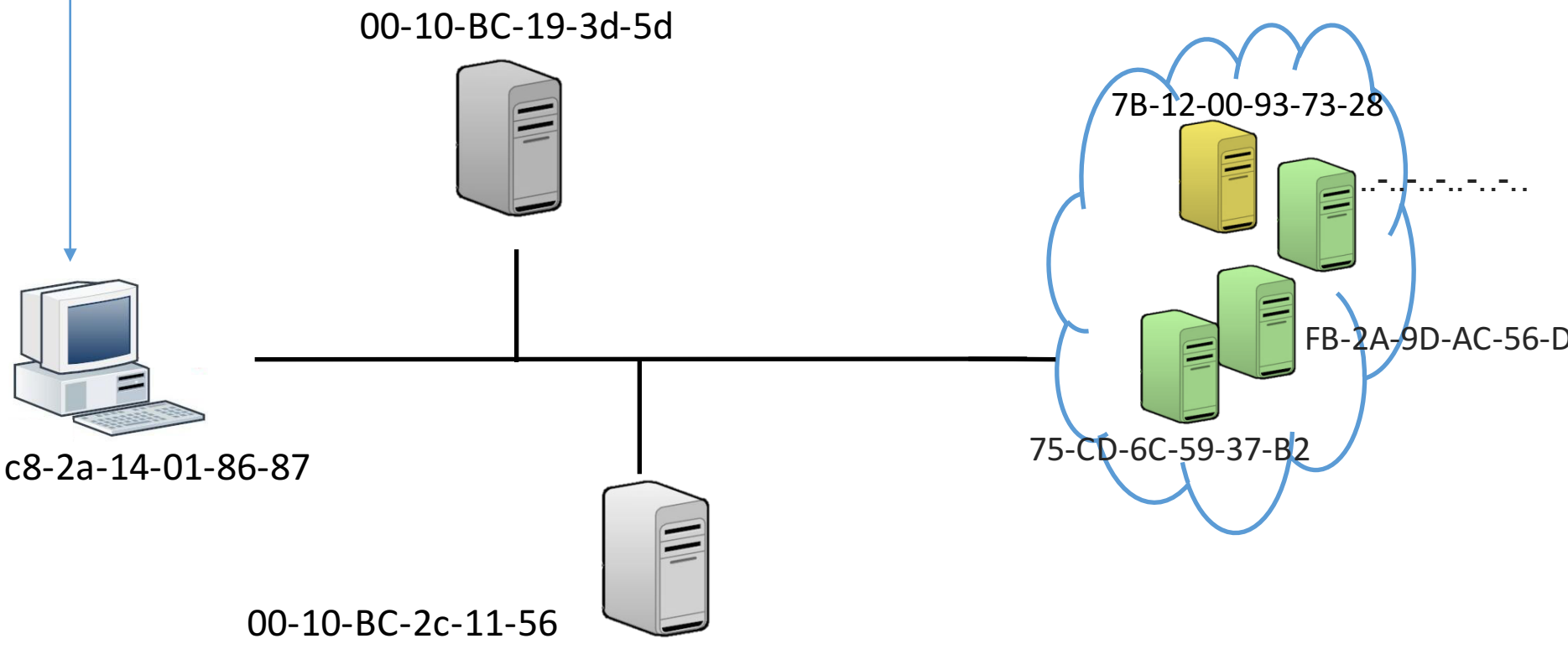
stateless vs stateful

- A communication is made of a number of messagges
- Communications start, develop, and ends
  - Stateful protocols provide means to establish and close a connection
    - e.g. TCP
  - Stateless protocols do not have this notion
    - IP messages are stand-alone packets

IP vs MAC addresses

48 bit → 2^{48} addresses = 281474976710656 → 1536 terabyte

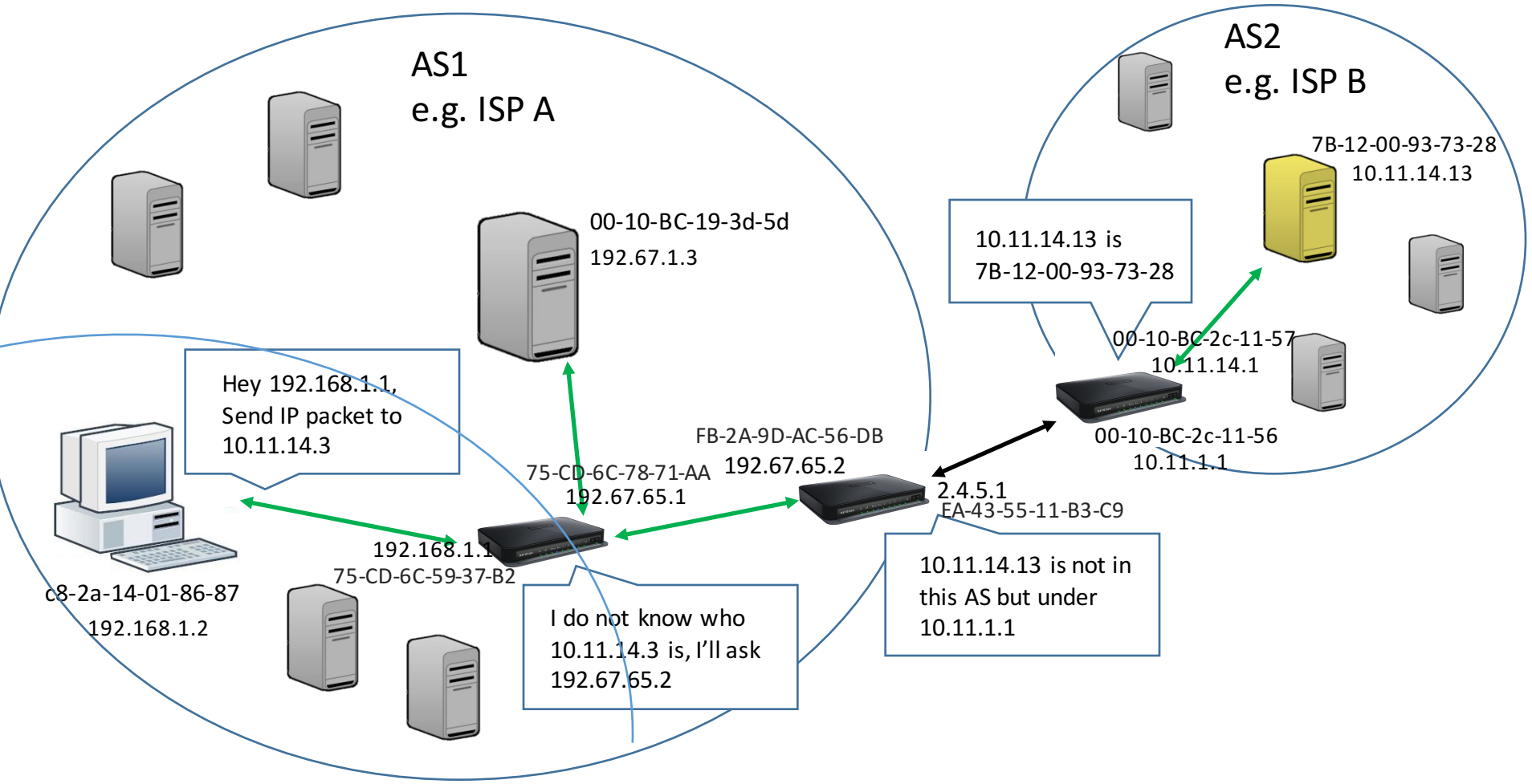
- How to manage revoking? (e.g. One ethernet card gets substituted)
- How to manage routing?



IP addresses

- IP provides a structured way to abstract host addresses away from their physical properties
- Two versions
  - IPv4 → most common, currently used
    - 32 bits
  - IPv6 → early adoption, will be seen commonly in the future
    - 128 bits
- Make it possible to efficiently talk between systems in different AS

IP addresses – routing (simplified)



Details: http://disi.unitn.it/locigno/index.php/teaching-duties/computer-networks/102-reti-aa13-14

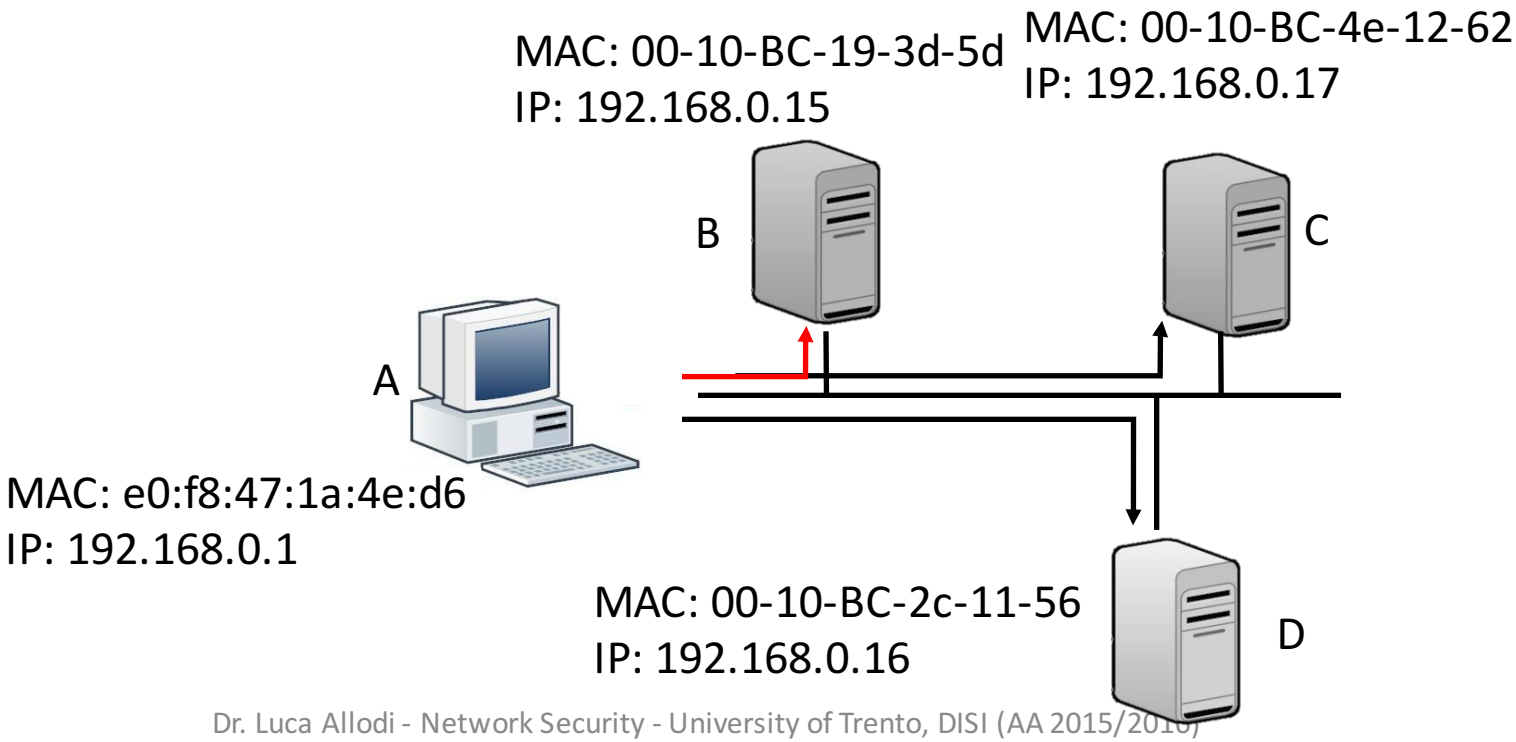
ARP protocol

- ARP = address resolution protocol
  - Allows systems to associate an IP address to a MAC address
  - Allows discovery through broadcast
- ARP tables contain information to translate IP addresses into MAC addresses

```
calvin:IT Risk stewie$ arp -i en1 -a
? (10.196.192.1) at 3c:94:d5:48:25:c1 on en1 ifscope [ethernet]
? (10.196.192.14) at d0:25:98:90:ee:95 on en1 ifscope [ethernet]
? (10.196.192.246) at 2c:1f:23:4f:84:a4 on en1 ifscope [ethernet]
? (10.196.193.5) at 74:e5:b:20:b7:e8 on en1 ifscope [ethernet]
? (10.196.193.162) at 34:36:3b:d4:90:44 on en1 ifscope [ethernet]
? (10.196.193.178) at 4c:25:78:78:f1:e8 on en1 ifscope [ethernet]
? (10.196.193.230) at 94:65:9c:31:55:dd on en1 ifscope [ethernet]
? (10.196.194.52) at 48:50:73:60:3c:1c on en1 ifscope [ethernet]
? (10.196.194.53) at 78:31:c1:c9:81:24 on en1 ifscope [ethernet]
? (10.196.194.223) at 28:5a:eb:17:19:3f on en1 ifscope [ethernet]
? (10.196.195.63) at 64:76:ba:b3:eb:12 on en1 ifscope [ethernet]
```

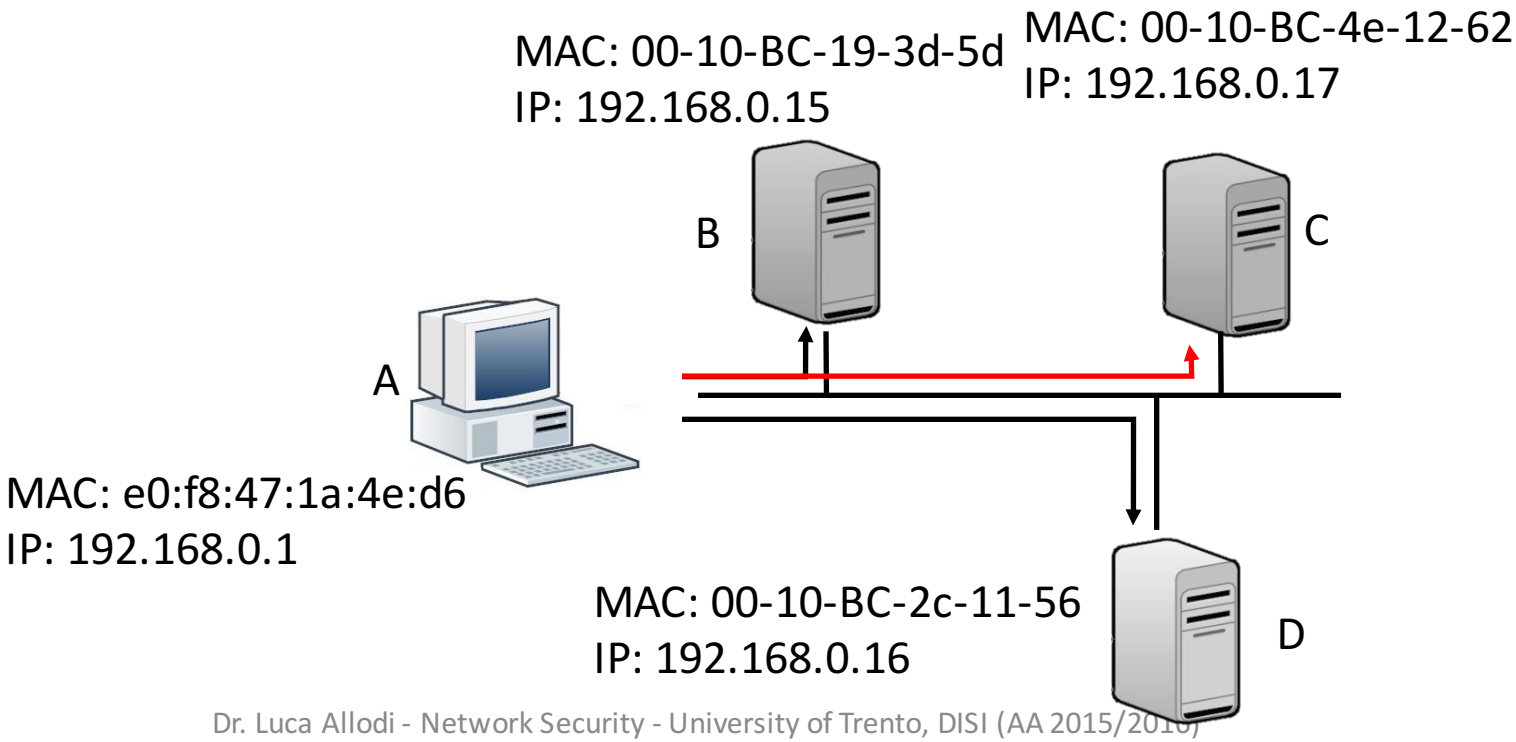
ARP tables A→B

IP address	MAC address	… (e.g. TTL, interfaces..)
192.168.0.15	00-10-BC-19-3d-5d	…
192.168.0.17	00-10-BC-4e-12-62	…



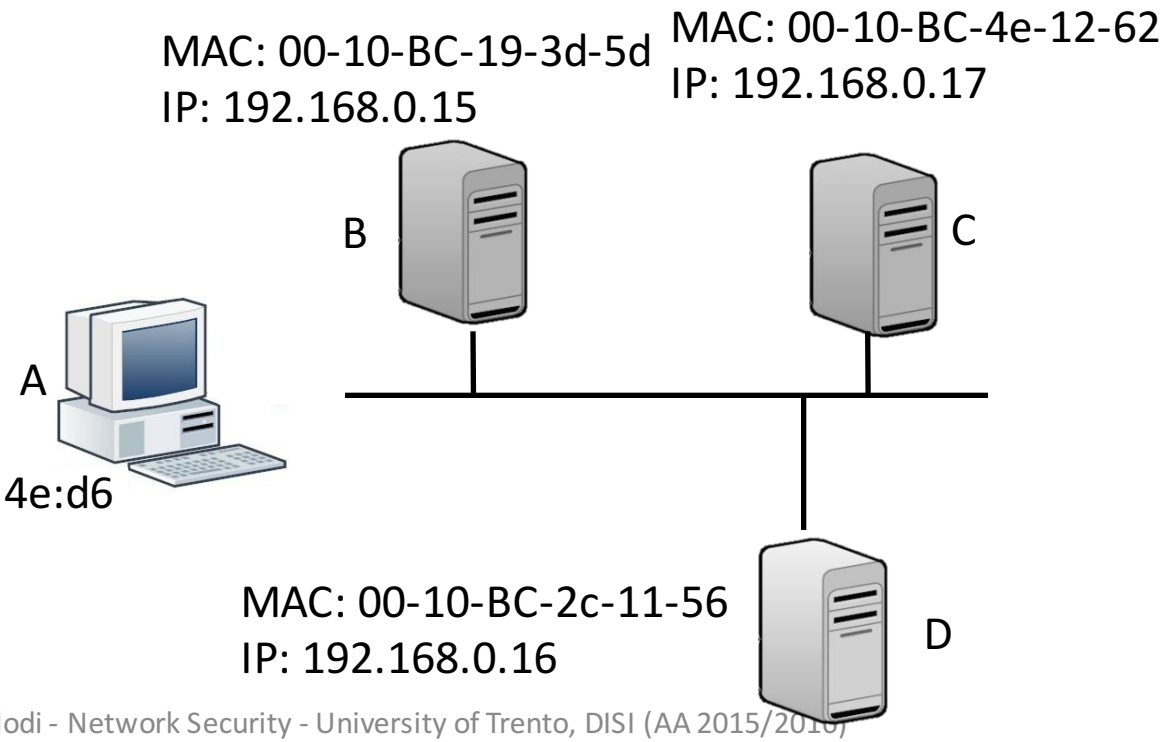
ARP tables A→C

IP address	MAC address	… (e.g. TTL, interfaces..)
192.168.0.15	00-10-BC-19-3d-5d	…
192.168.0.17	00-10-BC-4e-12-62	…



ARP tables A→D

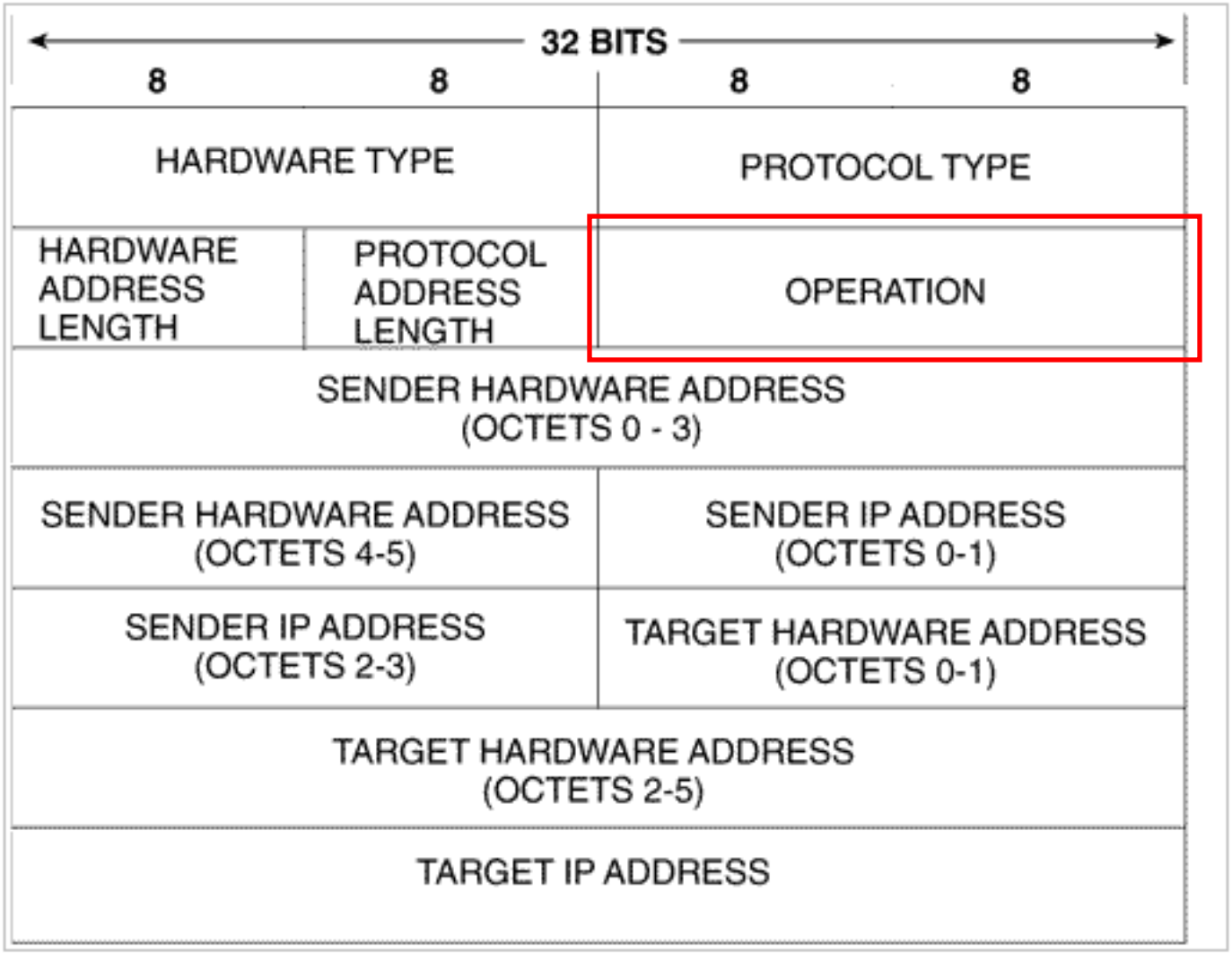
IP address	MAC address	… (e.g. TTL, interfaces..)
192.168.0.15	00-10-BC-19-3d-5d	…
192.168.0.17	00-10-BC-4e-12-62	…
???		



ARP query

- All addresses in an ARP table are added by one of two mechanisms
  - ARP request-reply
    - → **who is** 192.168.0.16 **tell** 192.168.0.1
    - → 192.168.0.16 **is at** 00-10-BC-2c-11-56
  - Gratuitous ARP
    - → 192.168.0.16 **is at** 00-10-BC-2c-11-56
- The discovery process happens through queries to neighbor devices
  - Broadcast message to the desired IP
    - L2 ethernet address FF-FF-FF-FF-FF-FF
- The system with the requested IP replies back with its correct mac address

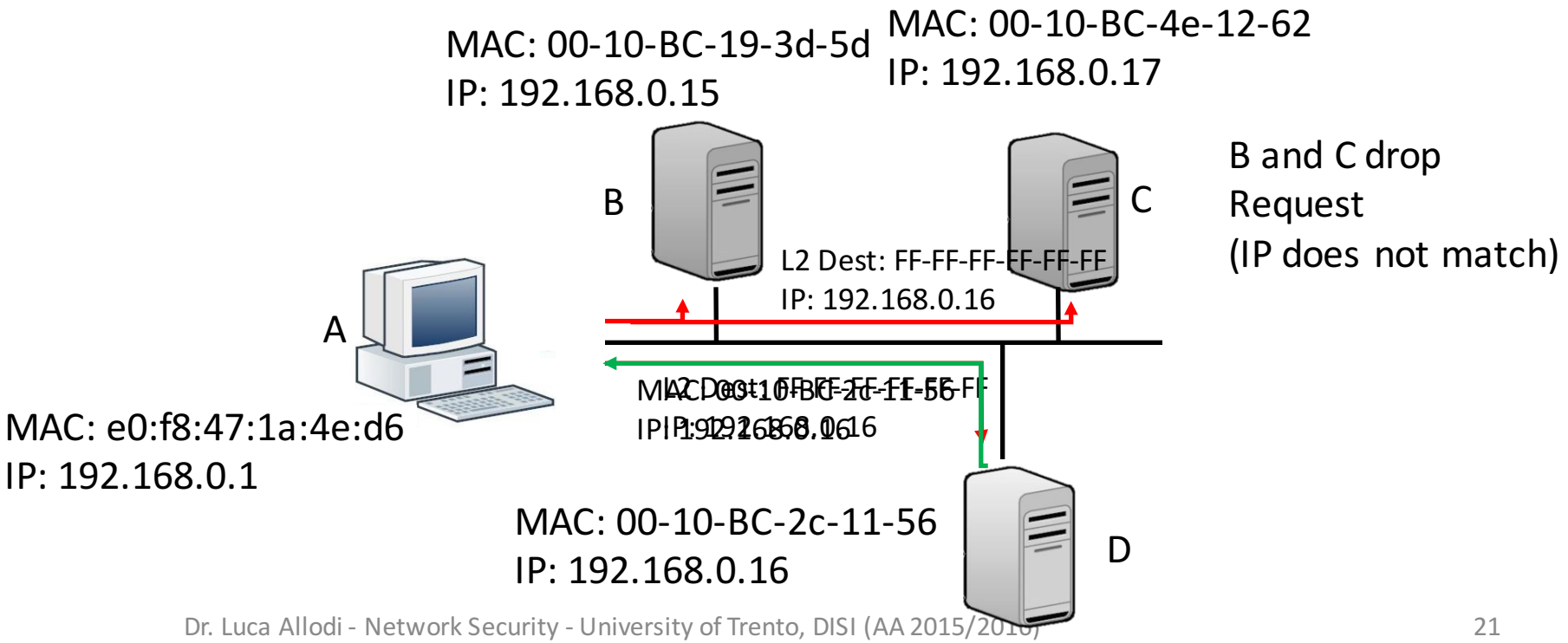
ARP frame header



1=request
2=reply

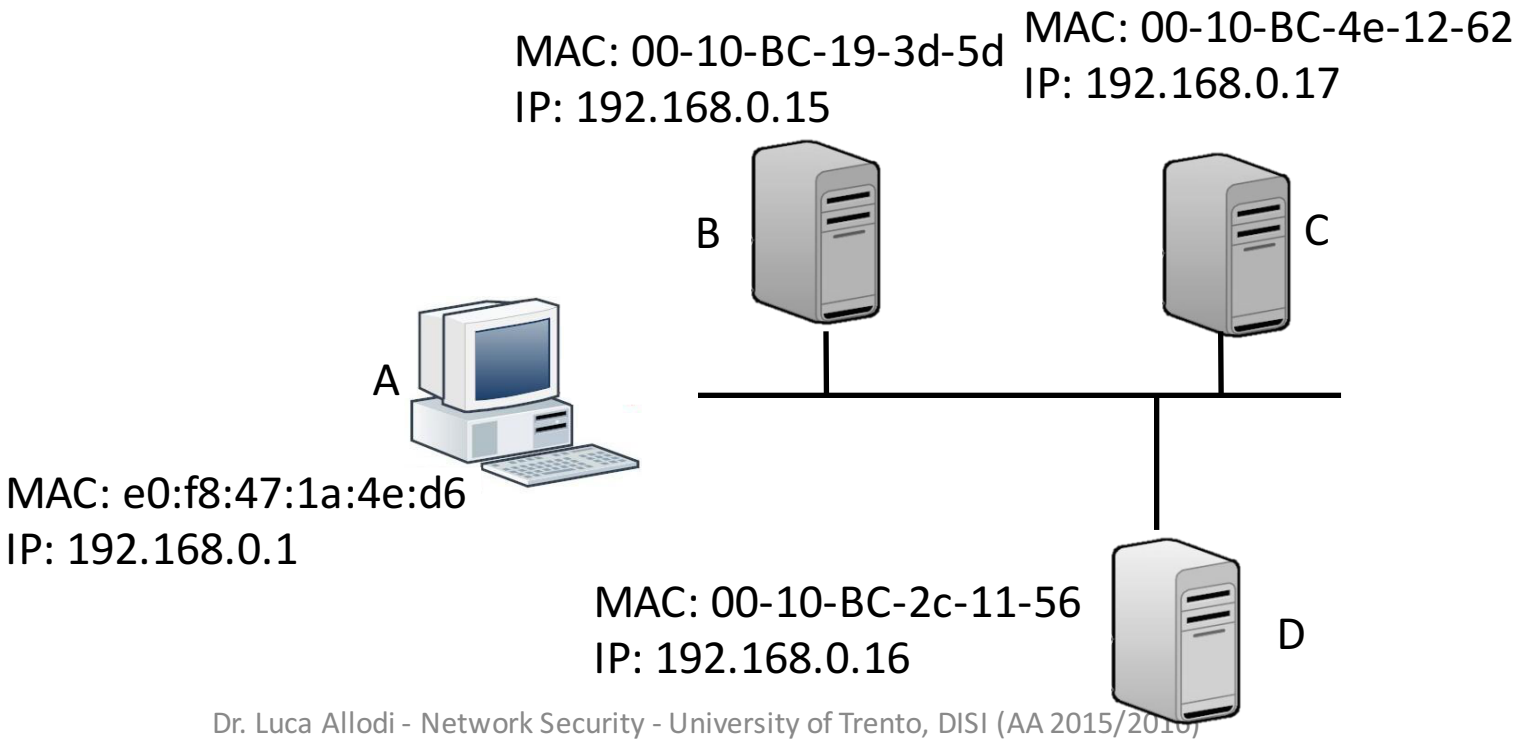
ARP tables A→D

IP address	MAC address	… (e.g. TTL, interfaces..)
192.168.0.15	00-10-BC-19-3d-5d	…
192.168.0.17	00-10-BC-4e-12-62	…



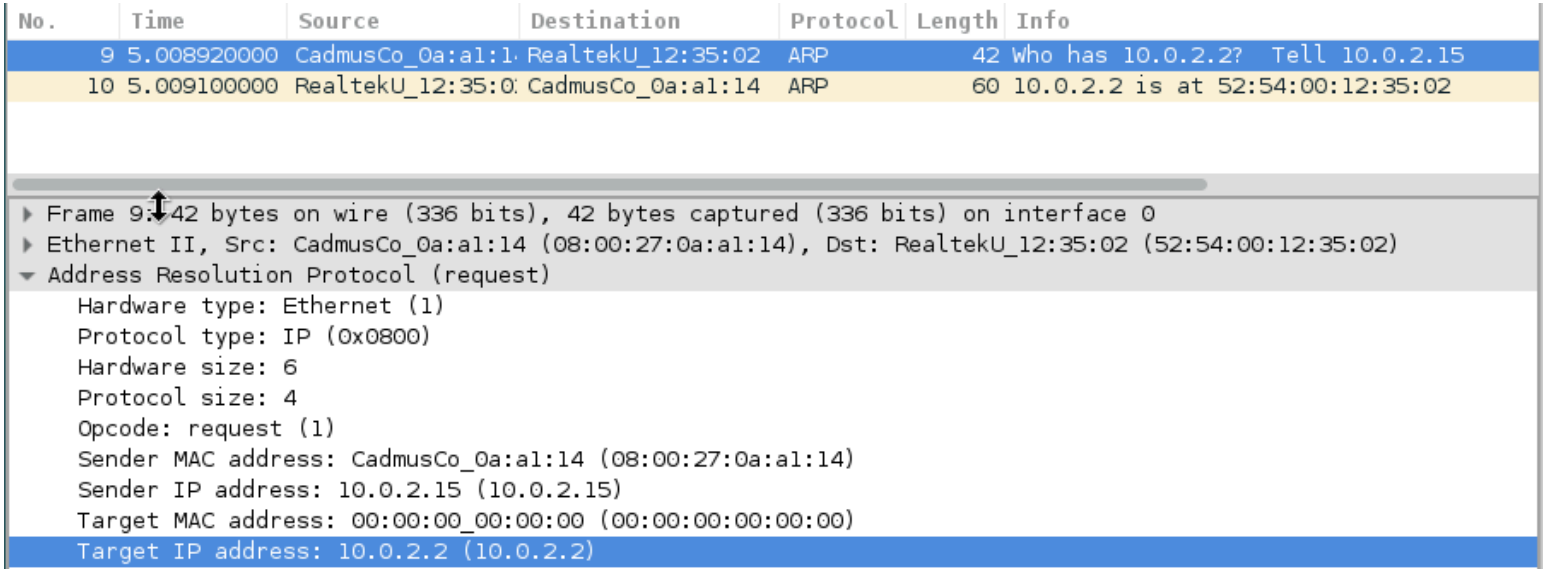
ARP tables A→D

IP address	MAC address	… (e.g. TTL, interfaces..)
192.168.0.15	00-10-BC-19-3d-5d	…
192.168.0.17	00-10-BC-4e-12-62	…
192.168.0.16	00-10-BC-2c-11-56	

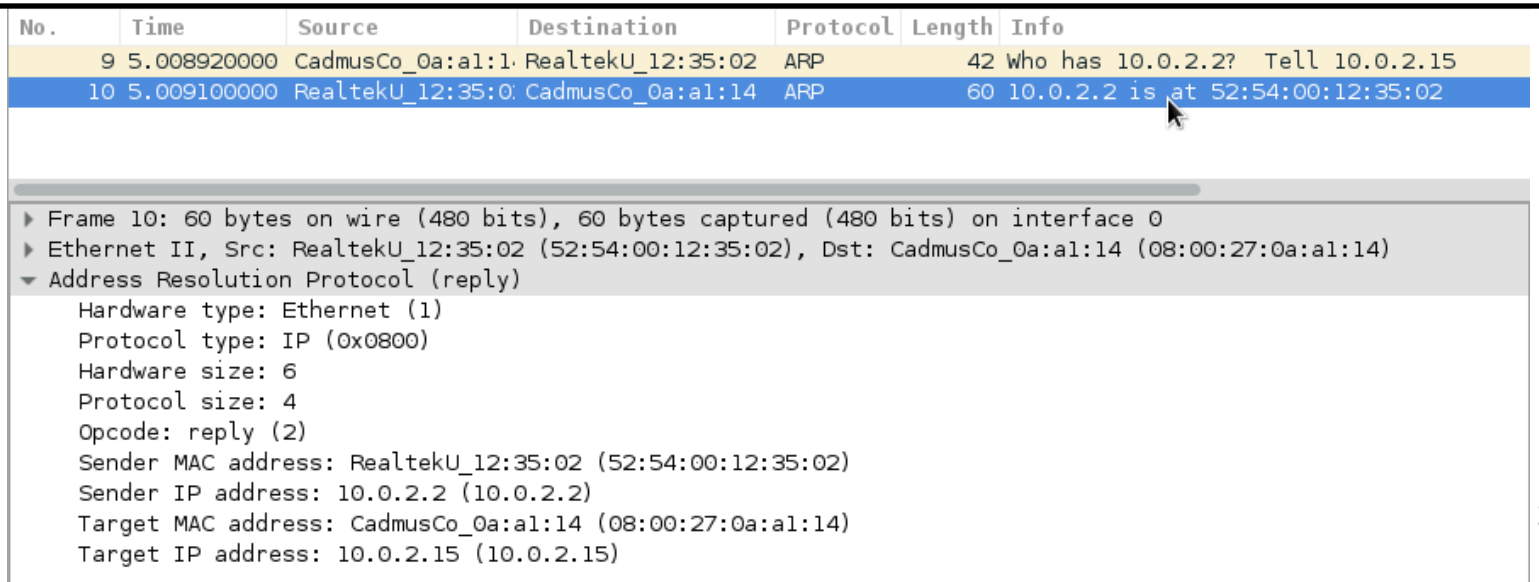


Example of ARP request-reply

request



reply



ARP broadcast example

No.	Time	Source	Destination	Protocol	Length	Info
2	0.997964000	CadmusCo_0a:a1:1	Broadcast	ARP	42	Who has 10.0.2.5? Tell 10.0.2.15
3	1.997994000	CadmusCo_0a:a1:1	Broadcast	ARP	42	Who has 10.0.2.5? Tell 10.0.2.15
4	3.017323000	CadmusCo_0a:a1:1	Broadcast	ARP	42	Who has 10.0.2.5? Tell 10.0.2.15
5	4.014031000	CadmusCo_0a:a1:1	Broadcast	ARP	42	Who has 10.0.2.5? Tell 10.0.2.15

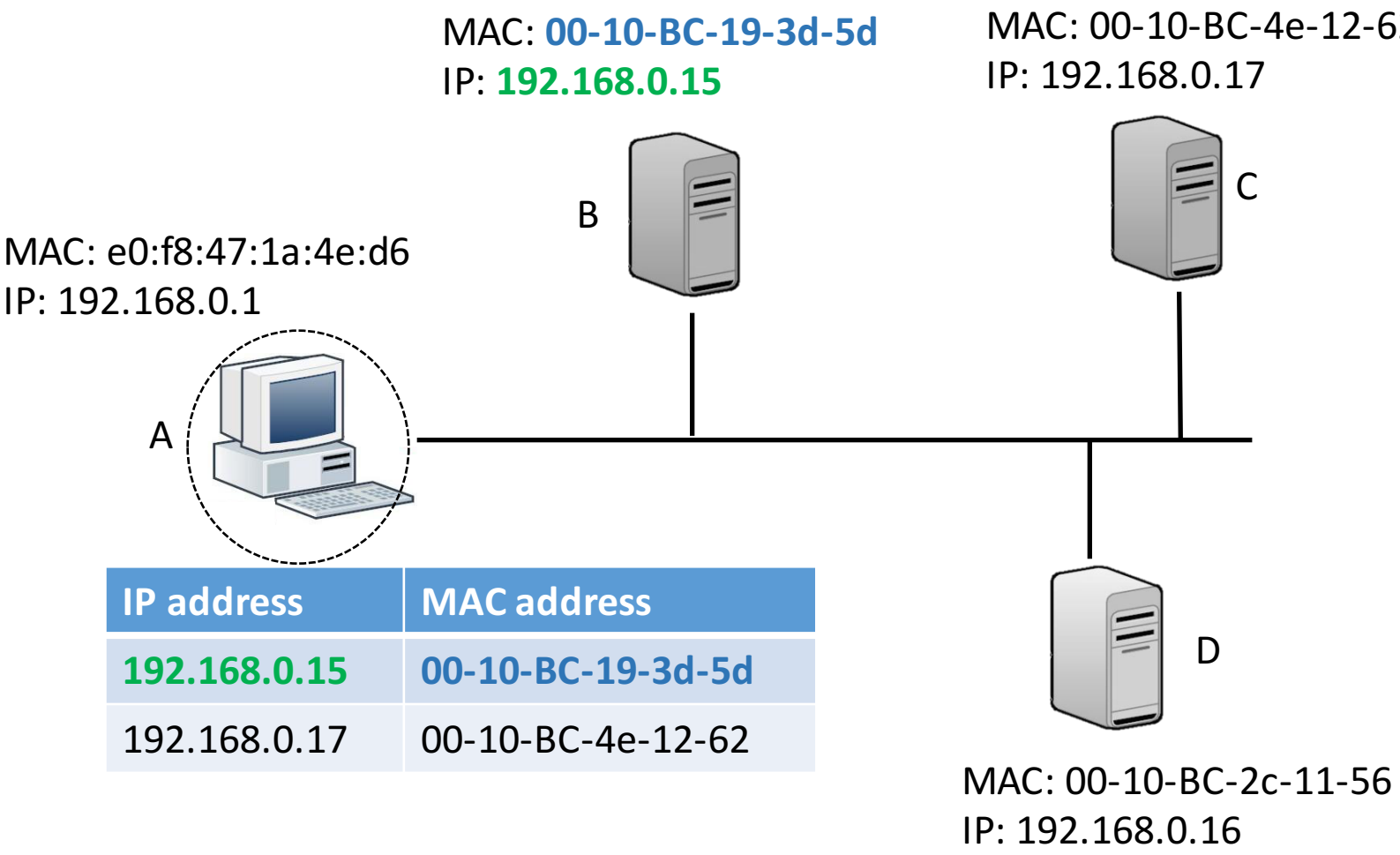
```
▸ Frame 2: 42 bytes on wire (336 bits), 42 bytes captured (336 bits) on interface 0
▾ Ethernet II, Src: CadmusCo_0a:a1:14 (08:00:27:0a:a1:14), Dst: Broadcast (ff:ff:ff:ff:ff:ff)
  ▸ Destination: Broadcast (ff:ff:ff:ff:ff:ff)
  ▸ Source: CadmusCo_0a:a1:14 (08:00:27:0a:a1:14)
    Type: ARP (0x0806)
▾ Address Resolution Protocol (request)
    Hardware type: Ethernet (1)
    Protocol type: IP (0x0800)
    Hardware size: 6
    Protocol size: 4
    Opcode: request (1)
    Sender MAC address: CadmusCo_0a:a1:14 (08:00:27:0a:a1:14)
    Sender IP address: 10.0.2.15 (10.0.2.15)
    Target MAC address: 00:00:00_00:00:00 (00:00:00:00:00:00)
    Target IP address: 10.0.2.5 (10.0.2.5)
```

L2 dest

ARP poisoning

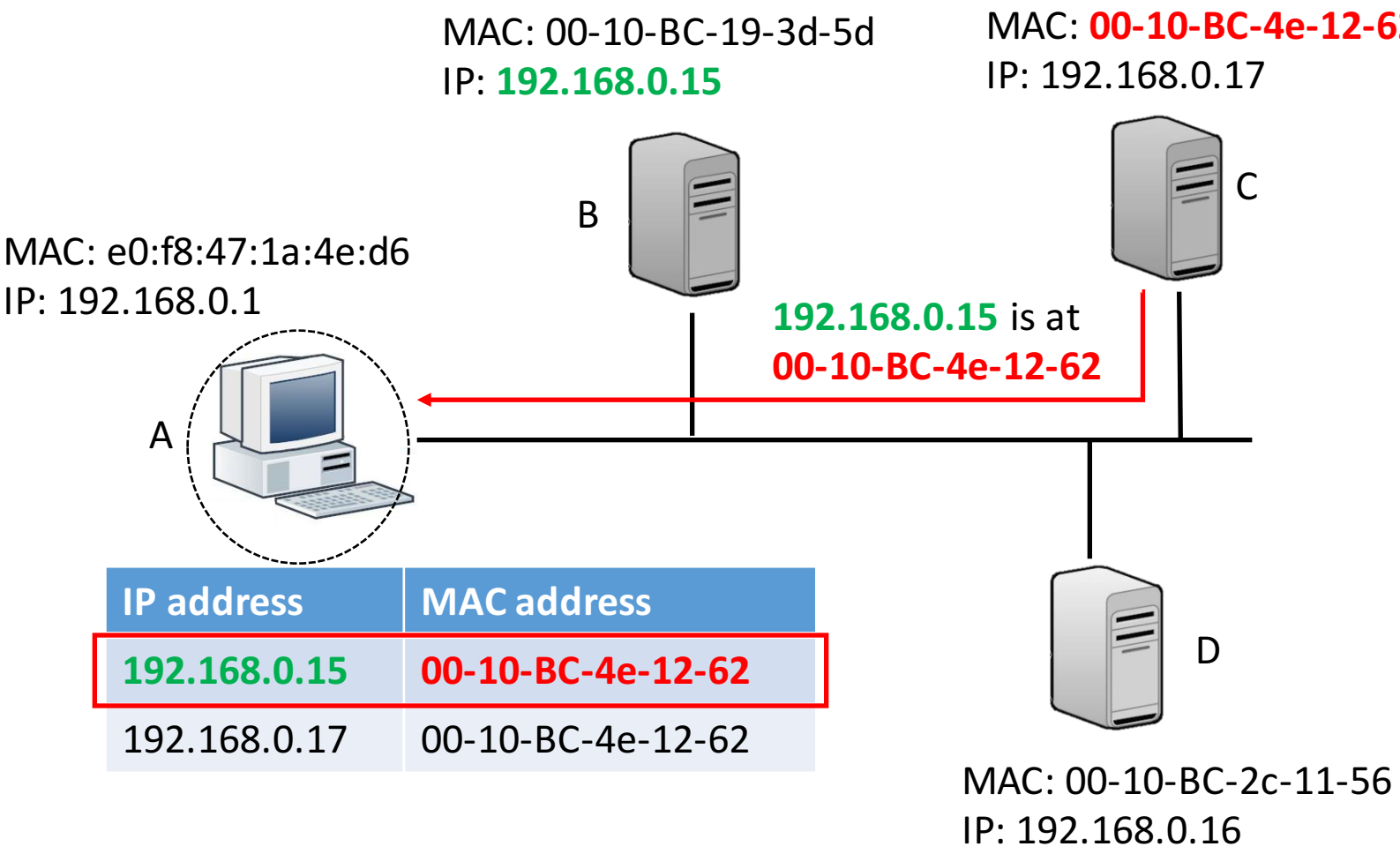
- ARP answers or Gratuitous ARP frames do not require an (additional) answer/confirmation
  - It's a *declarative* protocol
- Nodes are not authenticated
  - Whomever can say I am x.x1.x2.x3, my mac address is hh.hh1.hh2.hh3.hh4.hh5
- C can tell B "D is at [C mac address]"
- C can tell D "B is at [C mac address]"
- As a result every communication between B and D will pass by C

ARP poisoning



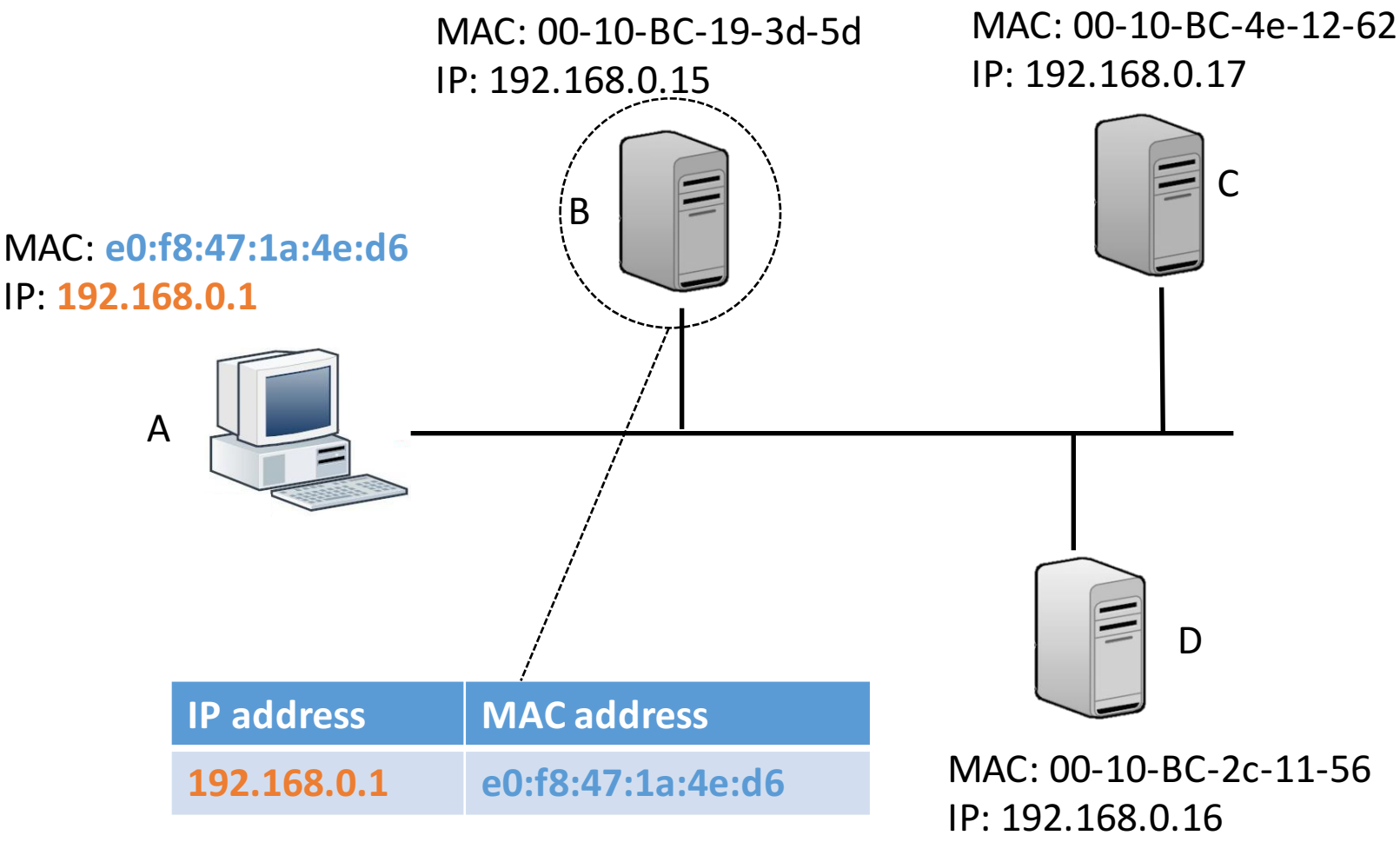
IP address	MAC address
192.168.0.15	00-10-BC-19-3d-5d
192.168.0.17	00-10-BC-4e-12-62

ARP poisoning

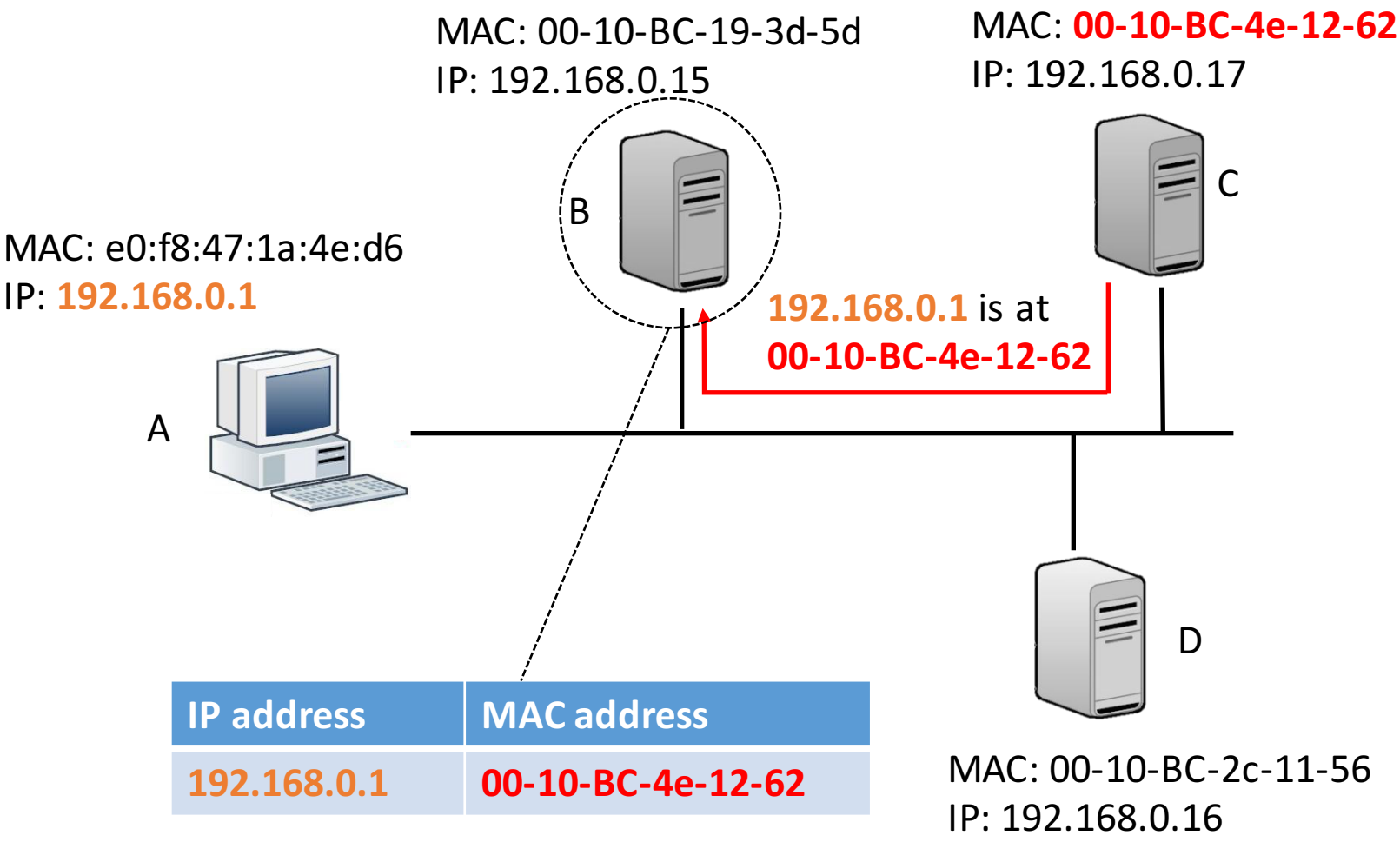


IP address	MAC address
192.168.0.15	00-10-BC-4e-12-62
192.168.0.17	00-10-BC-4e-12-62

ARP poisoning

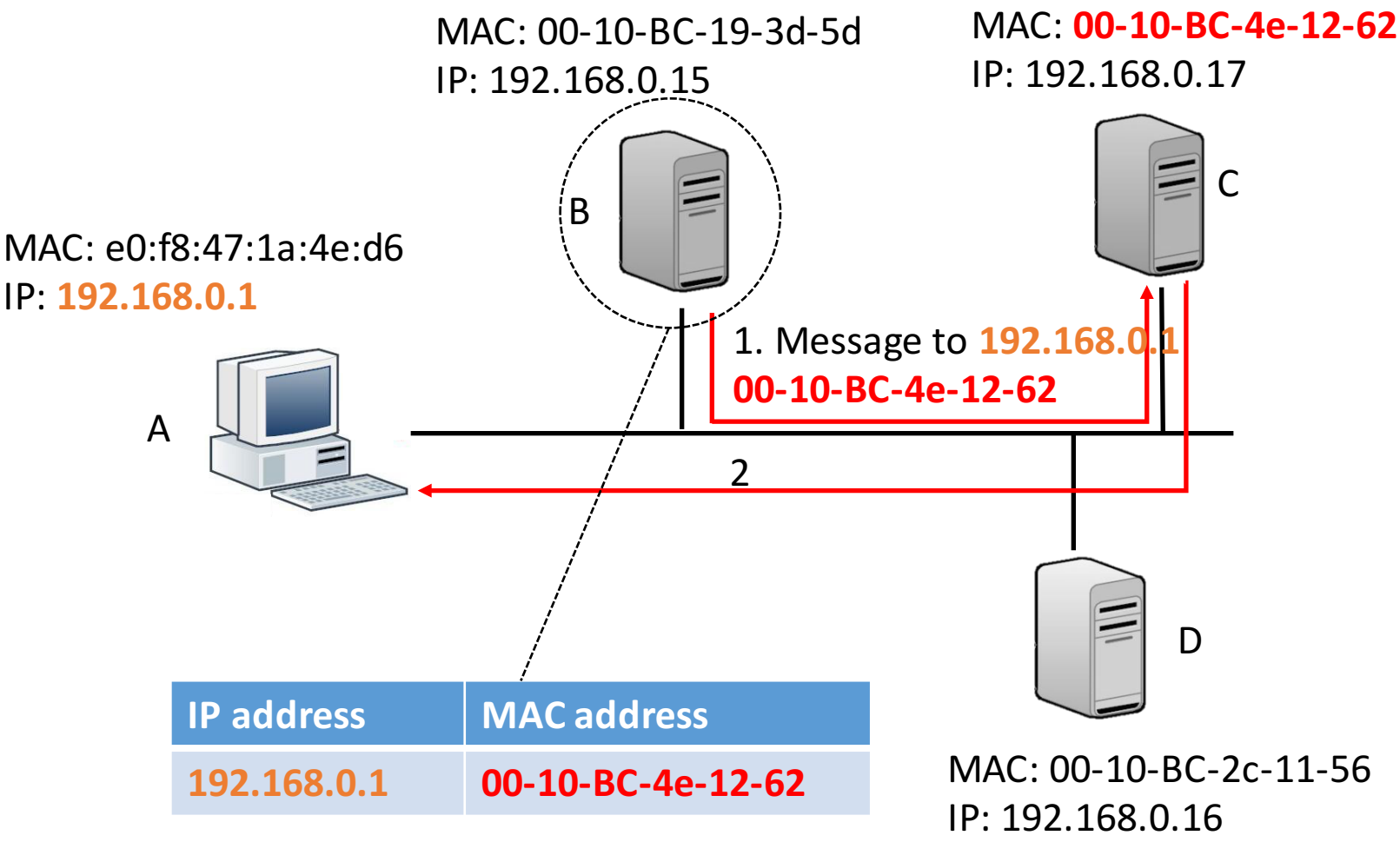


ARP poisoning

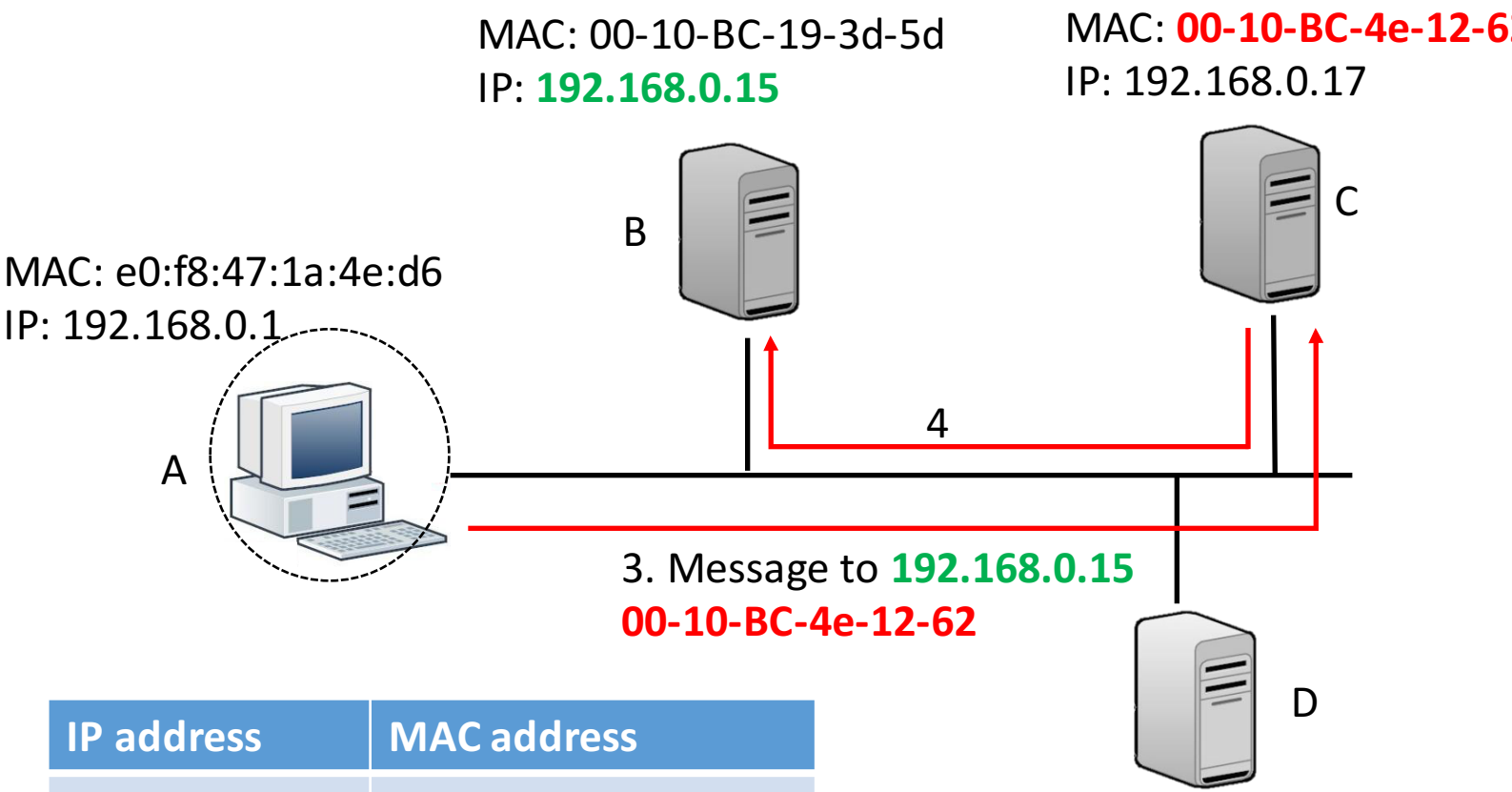


IP address	MAC address
192.168.0.1	00-10-BC-4e-12-62

ARP poisoning



ARP poisoning

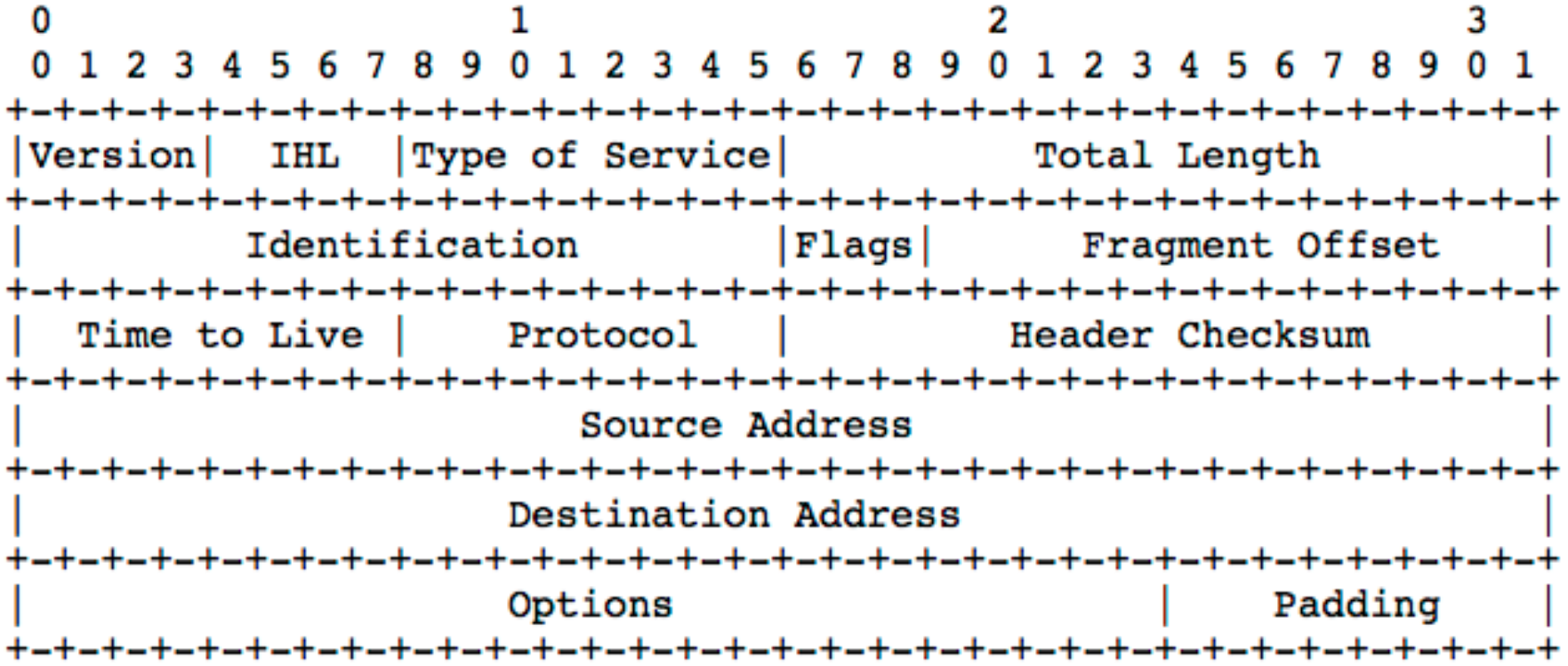


IP address	MAC address
192.168.0.15	00-10-BC-4e-12-62

ARP poisoning - limitations

- Works only on local networks, where MAC addresses are actually meaningful
  - When communication is targeted to different network, IP addresses are used
- Routers and DNSs have MAC addresses too..
- The poisoning works because systems are not authenticated
  - Some implementations/third party tools can mitigate the problem
    - Check for anomalies
  - Can you think of a possible mitigation?

IP Header


0 1 2 3
0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1 2 3 4 5 6 7 8 9 0 1
Version
IHL
Type of Service
Total Length
Identification
Flags
Fragment Offset
Time to Live
Protocol
Header Checksum
Source Address
Destination Address
Options
Padding

Subnets and CIDR

- Subnets are logical divisions of IP addresses
  - Possible to split a network in multiple sub-networks
- IP bits are divided in
  - x network bits
  - y subnet bits
  - z host bits
- Subnet mask indicates sections of IP addresses meant for network+subnet
  - 255.255.255.0 → 24 bits to network+subnet, 8 bits to hosts
- CIDR → synthetic way to represent subnet masks
  - **Classless Inter-Domain Routing**
  - Indicates number of bits covered by the mask
  - 192.168.10.1/24 = 192.168.10.1/255.255.255.0

Subnet example

	NETWORK	SUBNET	HOST
binary	10000100	10000110	00001111 01100000
decimal	132	134	15 96

- Ip address → 132.134.15.96

- Network mask?
  - 255.255.0.0
- CIDR representation?
  - 132.134.15.96/16
- How many hosts?
  - 2^16 = 65,536 - 1

Subnet example

- Ip address → 132.134.15.96

	NETWORK	SUBNET	HOST
Binary IP	10000100	10000110	00001111 01100000
Binary Subnet mask	11111111	11111111	00000000 00000000
Network= IP AND Subnet	10000100	10000110	00000000 00000000
Host=IP AND complement(subnet)	00000000	00000000	00001111 01100000

IP classes

- IPv4 has several classes
- Defined over
  - Range of IP
  - Number of referenceable hosts
- Classes:
  - A : 0.0.0.0/8 → 127.255.255.255/8
  - B: 128.0.0.0/16 → 191.255.255.255/16
  - C: 192.0.0.0/24 → 223.255.255.255/24
  - D: 224.0.0.0 → 239.255.255.255
  - E: 240.0.0.0 → 254.255.255.254

Standard communications

Multicast

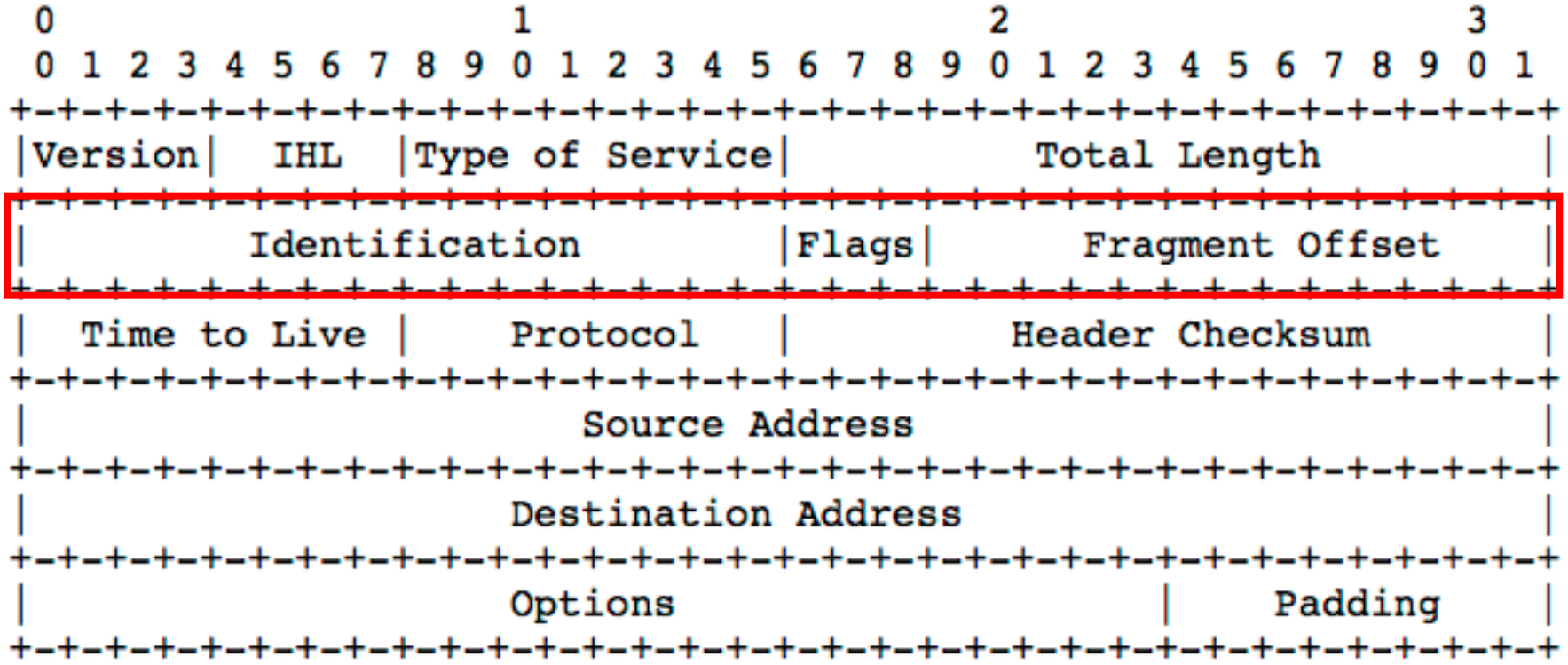
Experimental

IP addresses – private addresses

- Some IPs are reserved for private networks
  - 10.0.0.0 → 10.255.255.255
  - 192.168.0.0 → 192.168.255.255
  - 172.16.0.0 → 172.31.255.255

- These should not be routed on the internet
  - Gateway should **drop** the datagram

IP fragmentation (datagram size > MTU)

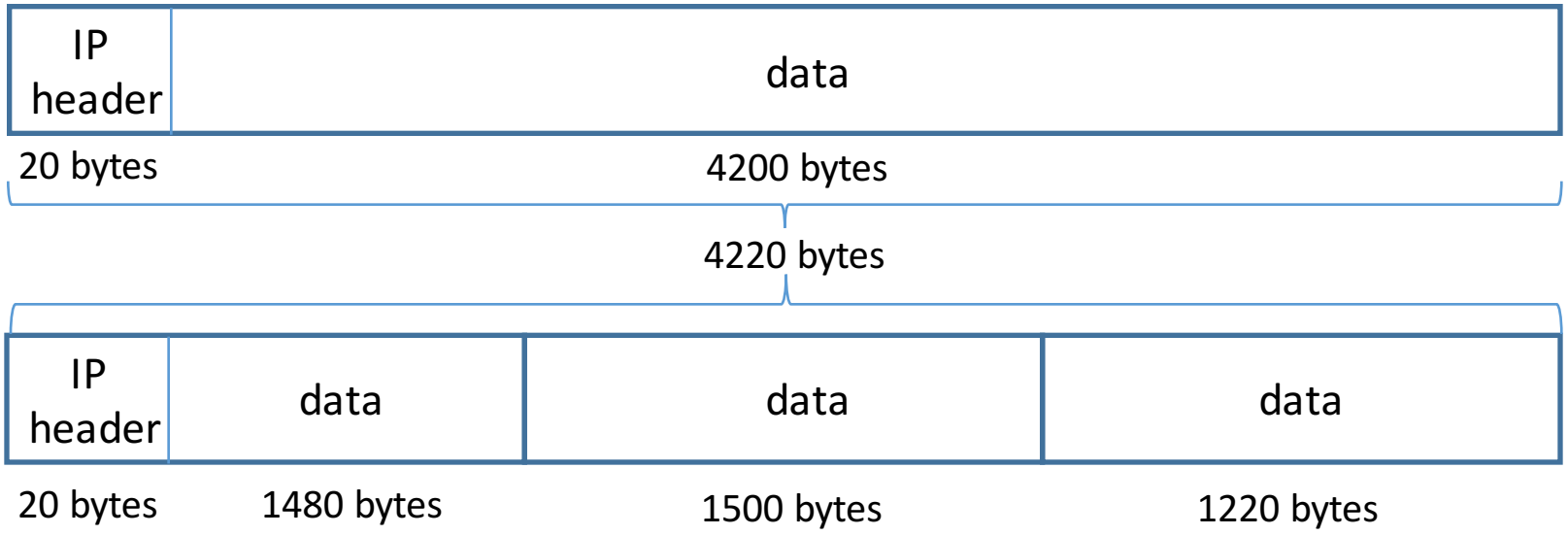


IP Fragments

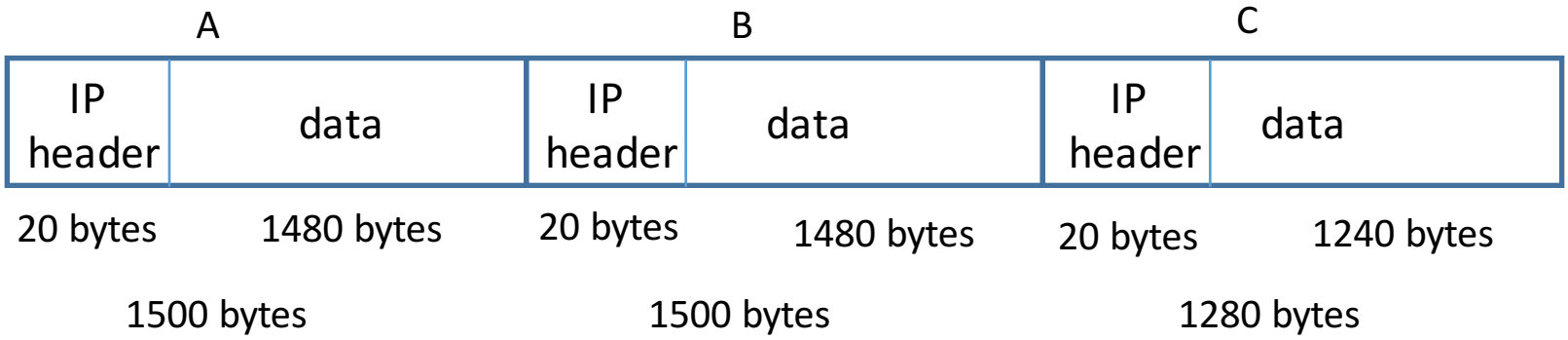
- **Identification**, 16 bit: unique identifier of the fragmented datagrams
  - All fragments have the same identification number
- **Flags**, 3 bit
  - 0 → Reserved, must be 0
  - DF → Don't fragment
    - 0 = there may be fragments
    - 1 = don't fragment. If must be fragmented, drop datagram
  - MF → More fragments
    - 0 = last fragment
    - 1 = there are more fragments
- **Offset**, 13 bits: offset of this datagram w.r.t first fragment with that ID.

Fragmentation example

- Need to send a 4200 bytes of data over IP
  - Maximum Transmission Unit on ethernet channel is 1500 bytes
  - The datagram does not fit in the MTU

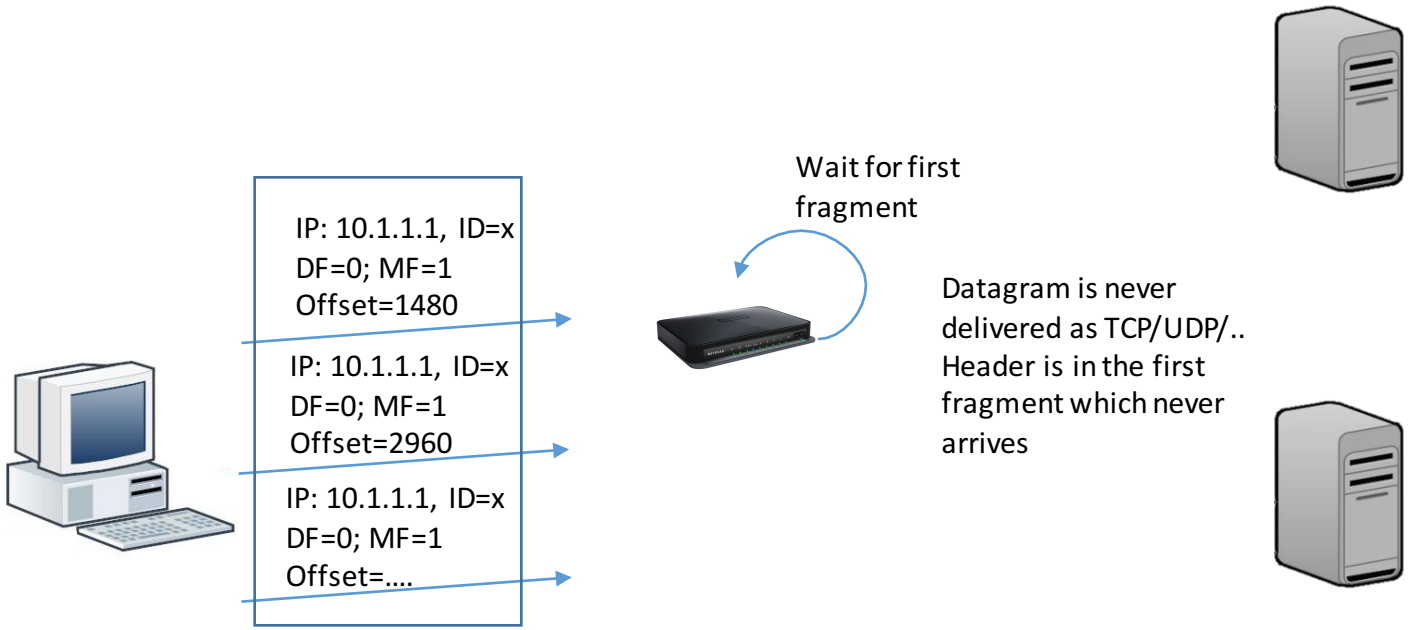


Fragmentation example (cntd)



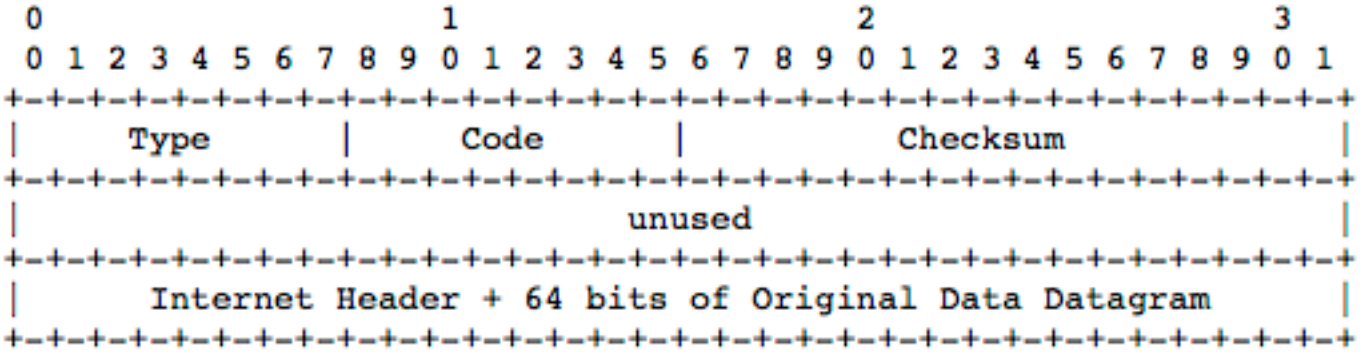
	A	B	C
Identification	4452	4452	4452
Flags	• DF=0 • MF=1	• DF=0 • MF=1	• DF=0 • MF=0
Offset	0	1480	2960

Denial of service with IP fragments



Internet Control Message Protocol

- Defined in RFC 792
- Relies on IP
  - However, it is an **integral** part of the Internet Protocol
  - All IP modules must have ICMP support



Some ICMP Message types

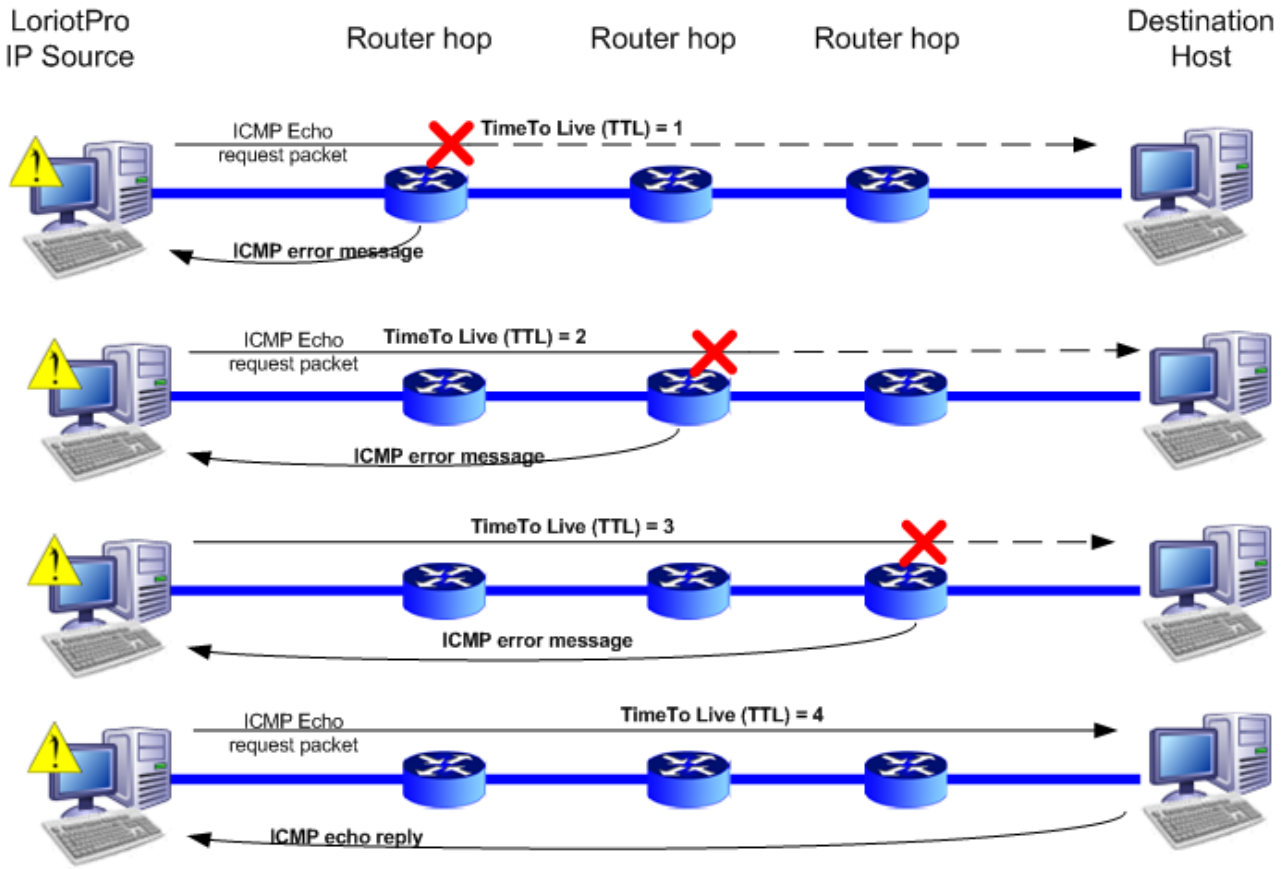
- **Destination Unreachable Message (Type 3)**
- Code
  - 0 = net unreachable;
  - 1 = host unreachable;
  - 2 = protocol unreachable;
  - 3 = port unreachable;
  - 4 = fragmentation needed and DF set;
  - 5 = source route failed.

- **Time Exceeded Message (Type 11)**
- Code
  - 0 = net unreachable;
  - 1 = host unreachable;

- **Echo or Echo Reply Message**
- Type
  - 8 = echo message;
  - 0 = echo reply;
- Code
  - 0

Traceroute (slide added from class)

See for example:
http://www.cisco.com/c/en/us/support/docs/ios-nx-os-software/ios-software-releases-121-mainline/12778-ping-traceroute.html



Picture from: http://www.loriotpro.com/Products/On-line_Documentation_V5/LoriotProDoc_EN/J10-Loriotpro_tools/J10-U21_Trace_Route_EN.htm (no affiliation)

List of all message types

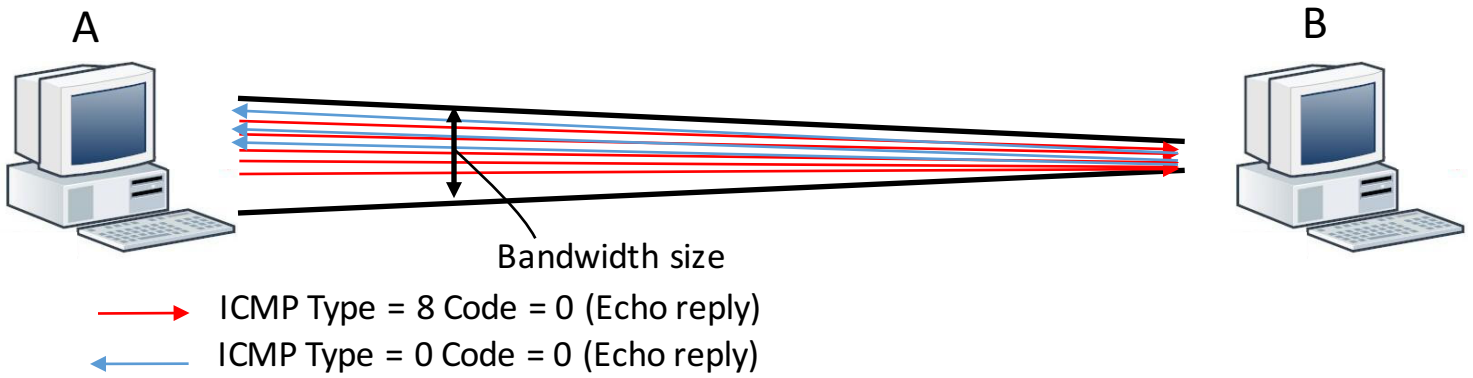
- 0 Echo Reply
- 3 Destination Unreachable
- 4 Source Quench
- 5 Redirect
- 8 Echo
- 11 Time Exceeded
- 12 Parameter Problem
- 13 Timestamp
- 14 Timestamp Reply
- 15 Information Request
- 16 Information Reply

Denial of Service

- Denial of service (DoS) is a type of attack that aims at congesting or overpowering a system's capacity by generating requests the system will have to answer
  - Can affect the performance of the attacked system or its channels
  - Can lead to a system crash due to resource consumption
- DoS can be operated
  - Locally
  - Over the network

A simple DoS (Ping Flood)

- Network DoS attacks usually exploit protocol features



- A can exploit its wider bandwidth to flood B with ICMP echo requests
- B's bandwidth gets (quickly, relatively to A's) exhausted with
  - A's requests
  - B's replies
- B can no longer operate on its network channel

A more advanced DoS – Ping of Death

- ICMP packets are typically 64 bytes in size including IP headers and data
- IP datagram can extend up to 65,535 bytes
  - Data Length field is 16 bit
- Early implementations of Internet modules were strictly implementing RFC directives
  - Not handling exceptions properly
- Ping of Death
  - Generate large ICMP packet
  - Fragment in 1024 IP packets of 64 Bytes
  - Destination receives regular packet
    - IP module compose fragments
    - ICMP module tries to read datagram bigger than assigned buffer size
  - Destination crashes
    - "buffer overflow" → possible execution of code in memory (more on this in this course)

Ping of death → visualisation