Chapter 3: Review of Important Networking Concepts

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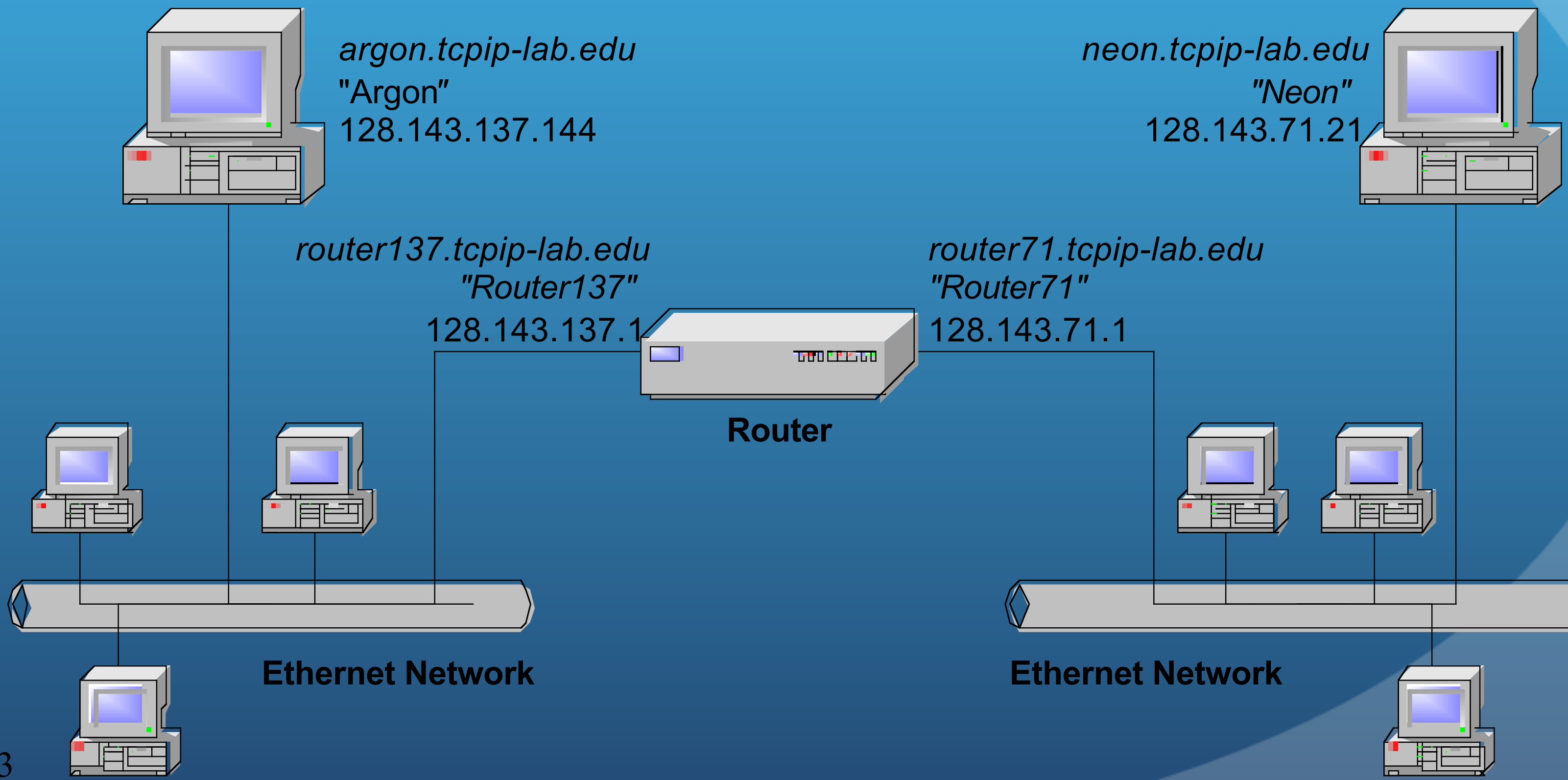
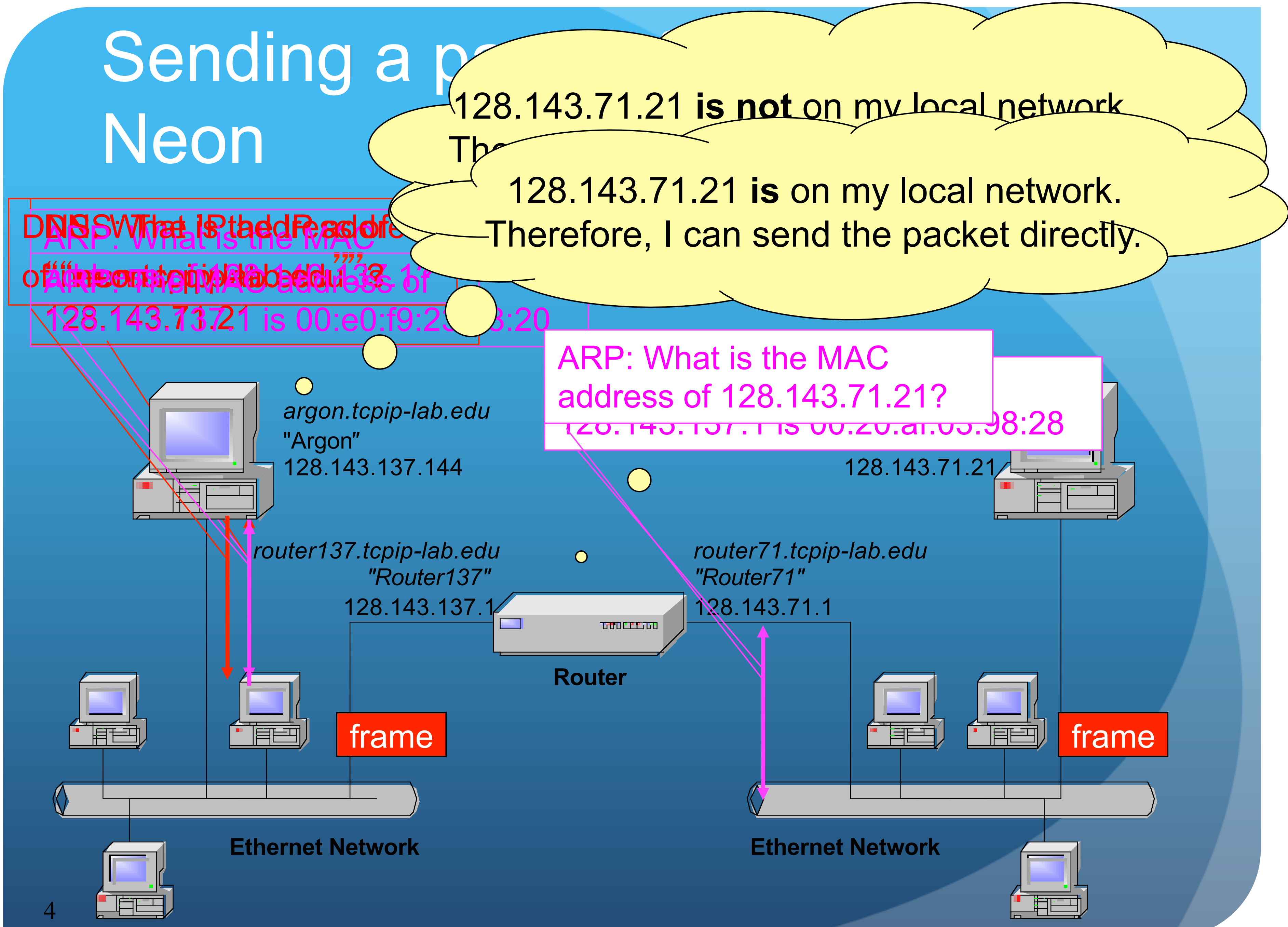
Networking Concepts

- Protocol Architecture
- Protocol Layers
- Encapsulation
- Network Abstractions

Sending a packet from Argon to Neon



Sending a p
Neon

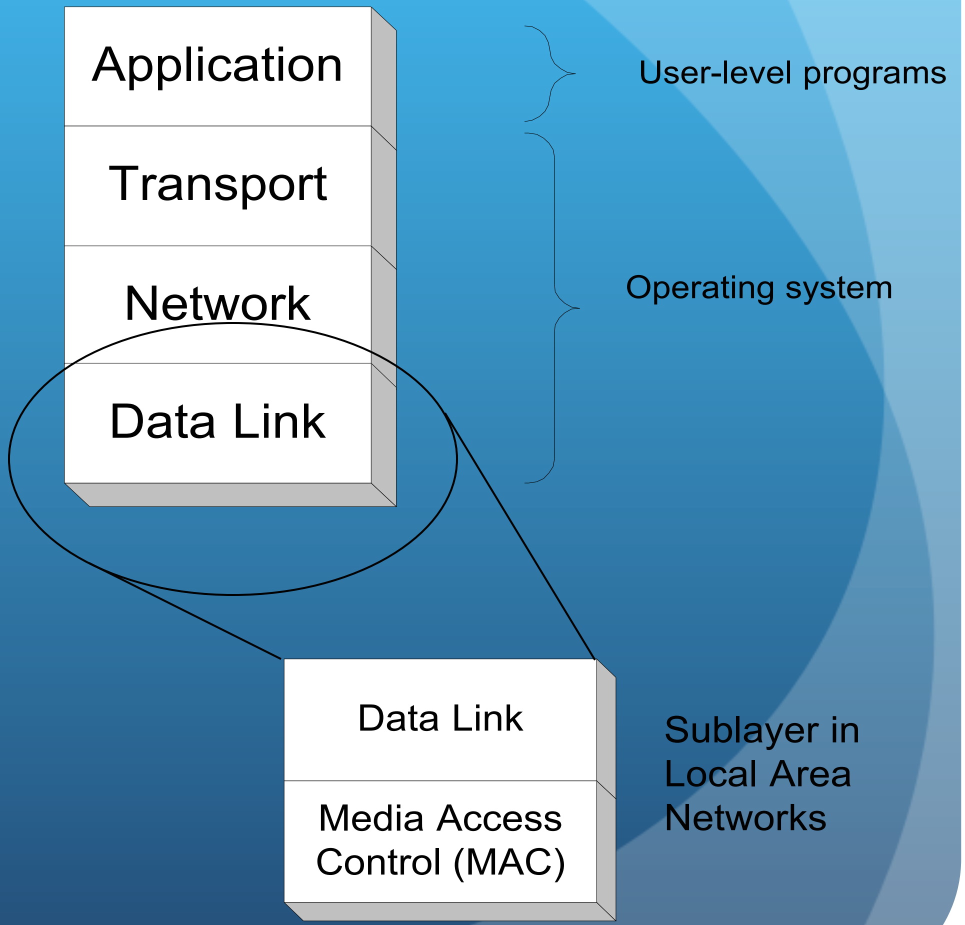


Communications Architecture

- The complexity of the communication task is reduced by using multiple protocol layers:
  - Each protocol is implemented independently
  - Each protocol is responsible for a specific subtask
  - Protocols are grouped in a hierarchy
- A structured set of protocols is called a communications architecture or protocol suite

TCP/IP Protocol Suite

- The TCP/IP protocol suite is the protocol architecture of the Internet
- The TCP/IP suite has four layers: Application, Transport, Network, and Data Link Layer
- End systems (hosts) implement all four layers. Gateways (Routers) only have the bottom two layers.

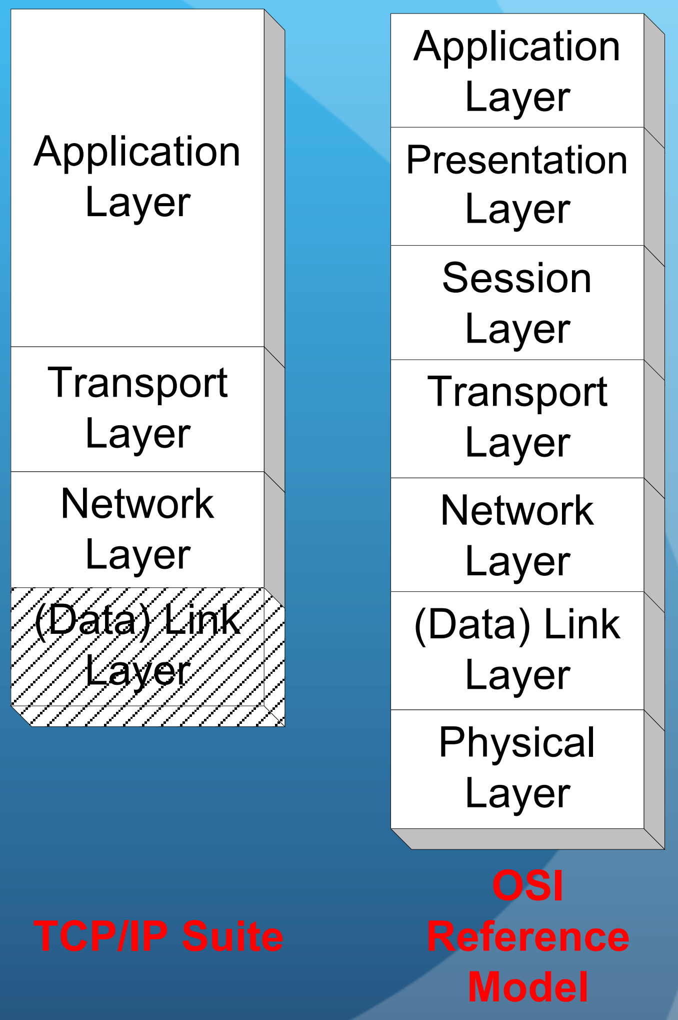


Functions of the Layers

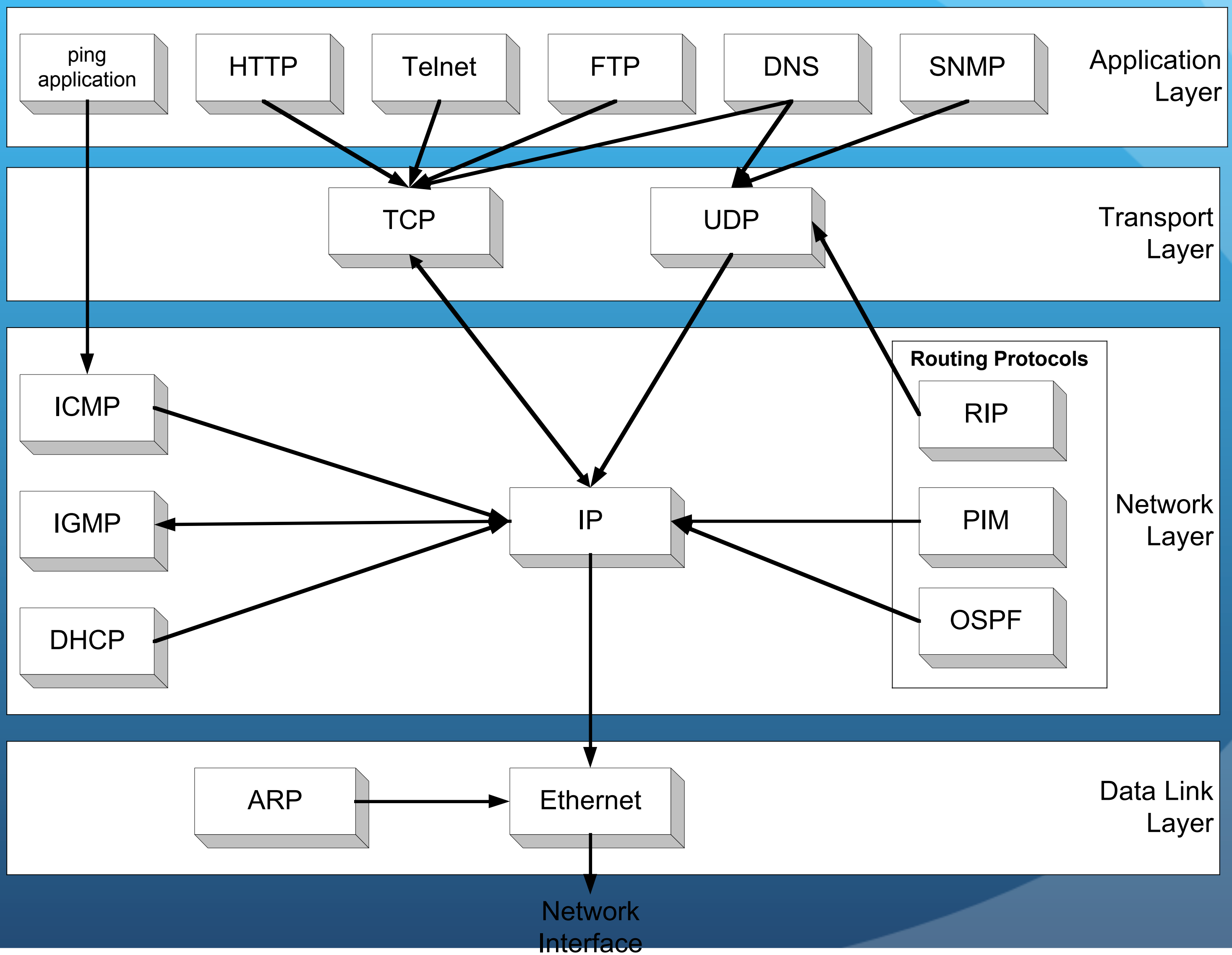
- Data Link Layer:
  - Service: Reliable transfer of frames over a link Media Access Control on a LAN
  - Functions: Framing, media access control, error checking
- Network Layer:
  - Service: Move packets from source host to destination host
  - Functions: Routing, addressing
- Transport Layer:
  - Service: Delivery of data between hosts
  - Functions: Connection establishment/termination, error control, flow control
- Application Layer:
  - Service: Application specific (delivery of email, retrieval of HTML documents, reliable transfer of file)
  - Functions: Application specific

TCP/IP Suite and OSI Reference Model

The TCP/IP protocol stack does not define the lower layers of a complete protocol stack

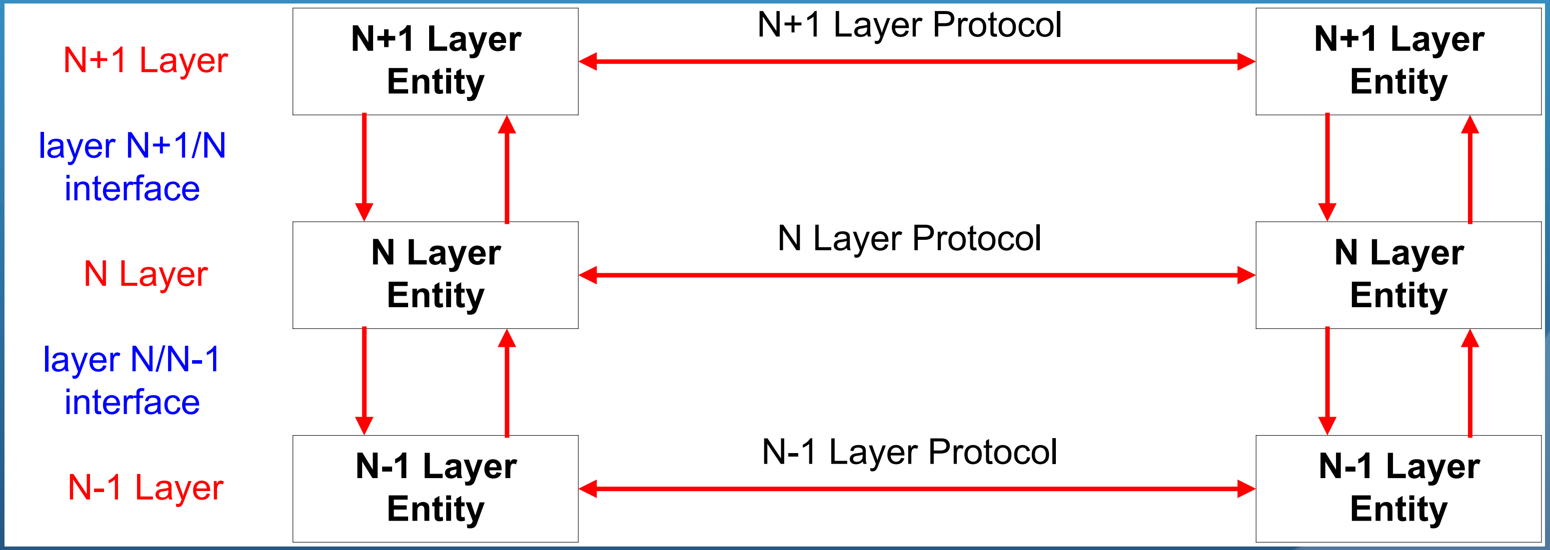


Assignment of Protocols to Layers



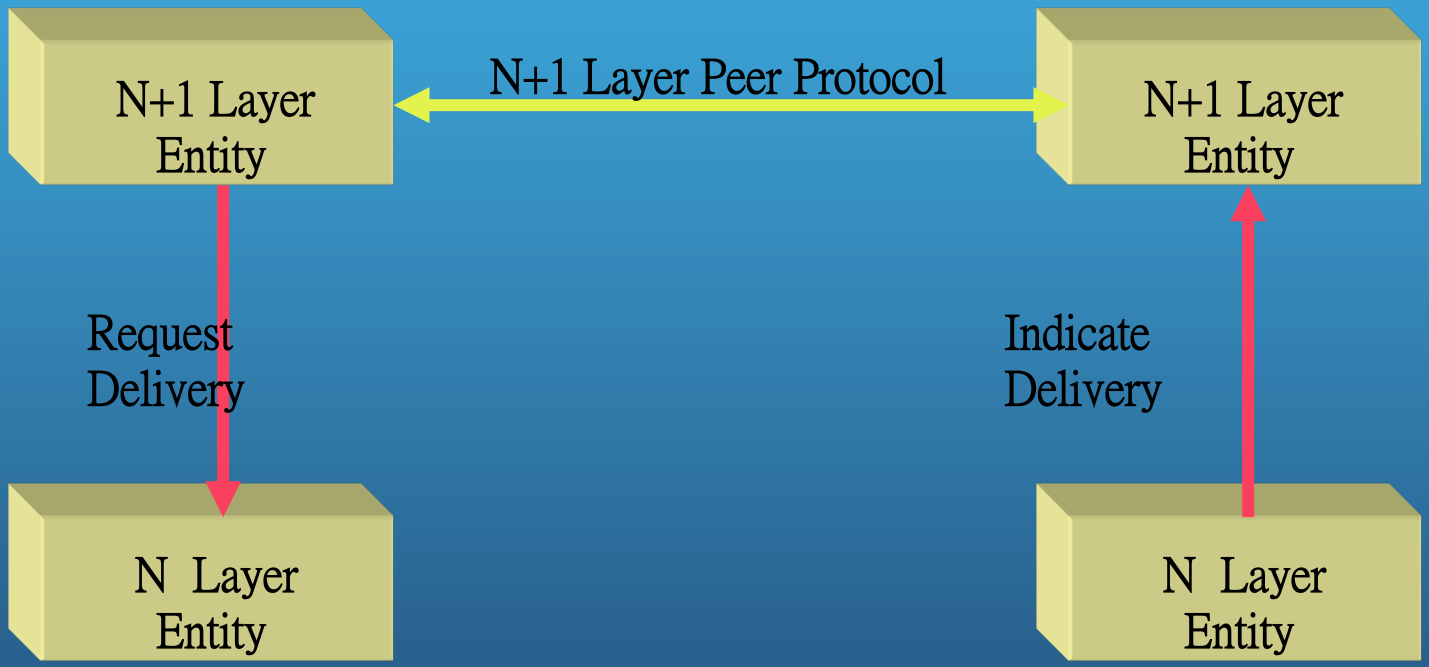
Layered Communications

- An entity of a particular layer can only communicate with:
  1. a peer layer entity using a common protocol (**Peer Protocol**)
  2. adjacent layers to provide services and to receive services



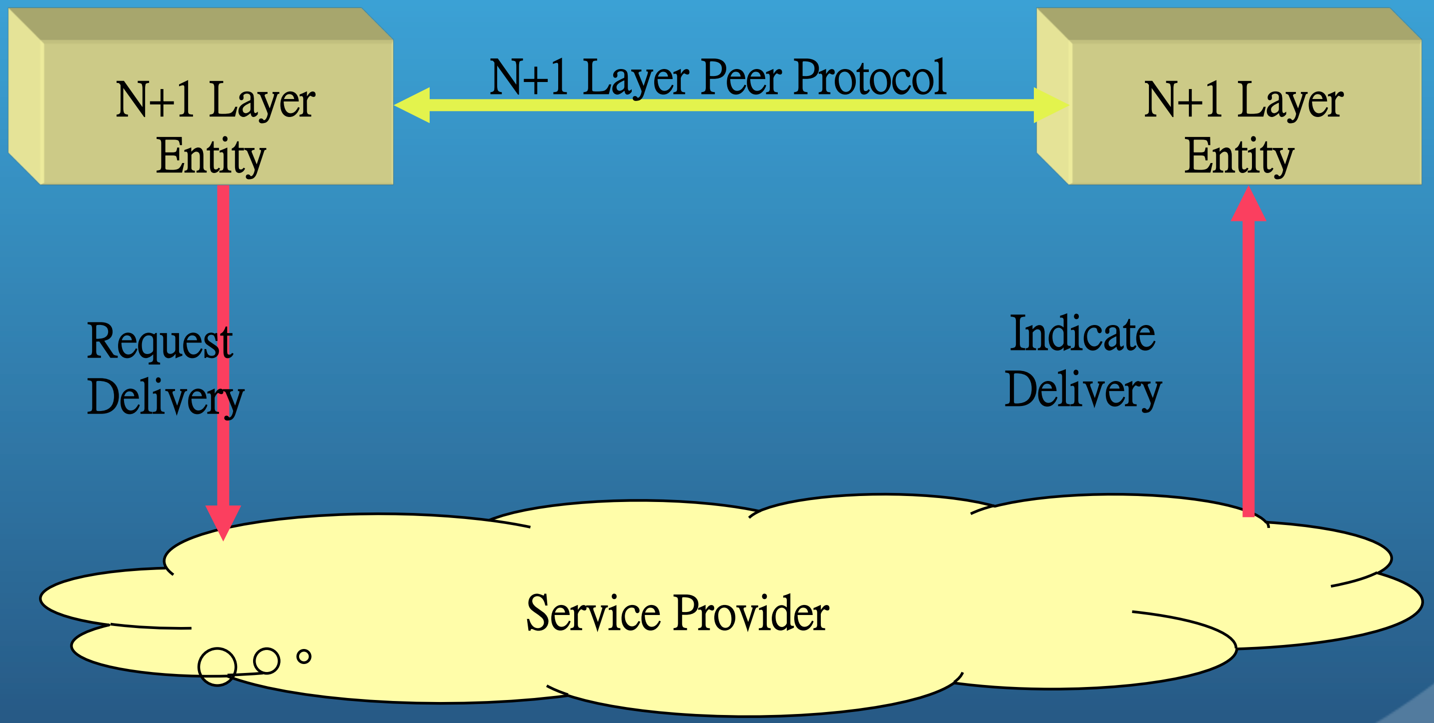
Service Primitives

Communication services are invoked via function calls. The functions are called **service primitives**



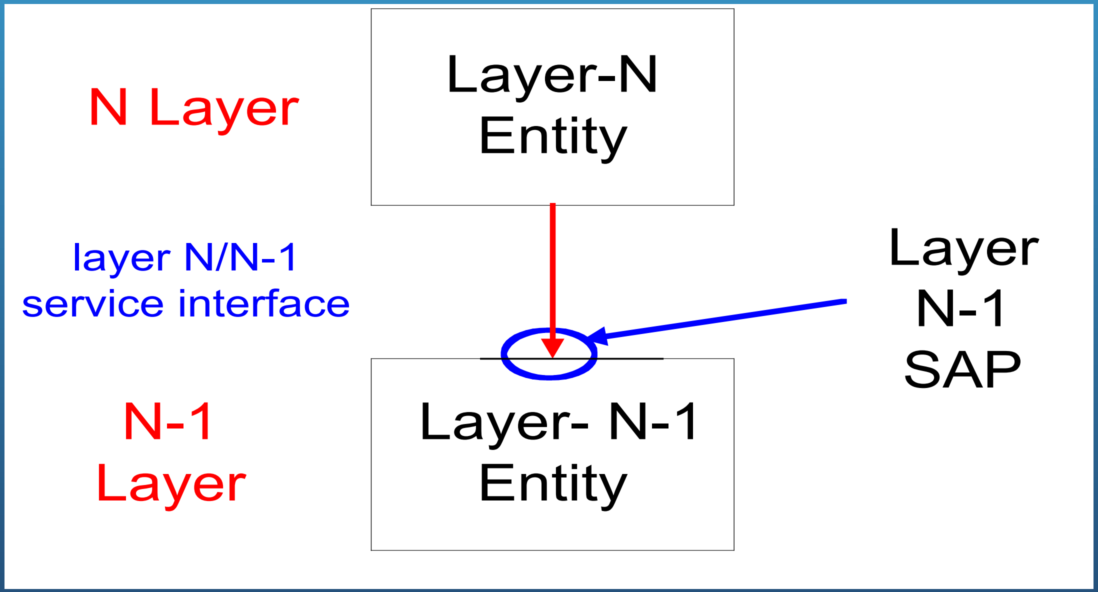
Service Primitives

Recall: A layer N+1 entity sees the lower layers only as a service provider



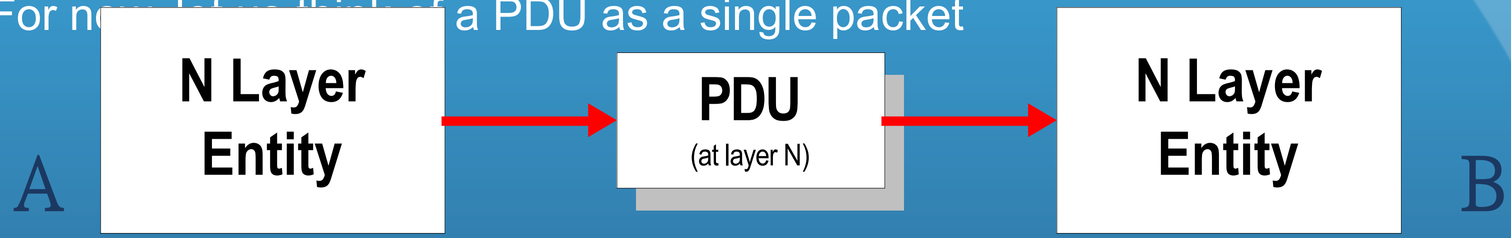
Service Access Points

- A service user accesses services of the service provider at Service **Access Points (SAPs)**
- A SAP has an address that uniquely identifies where the service can be accessed



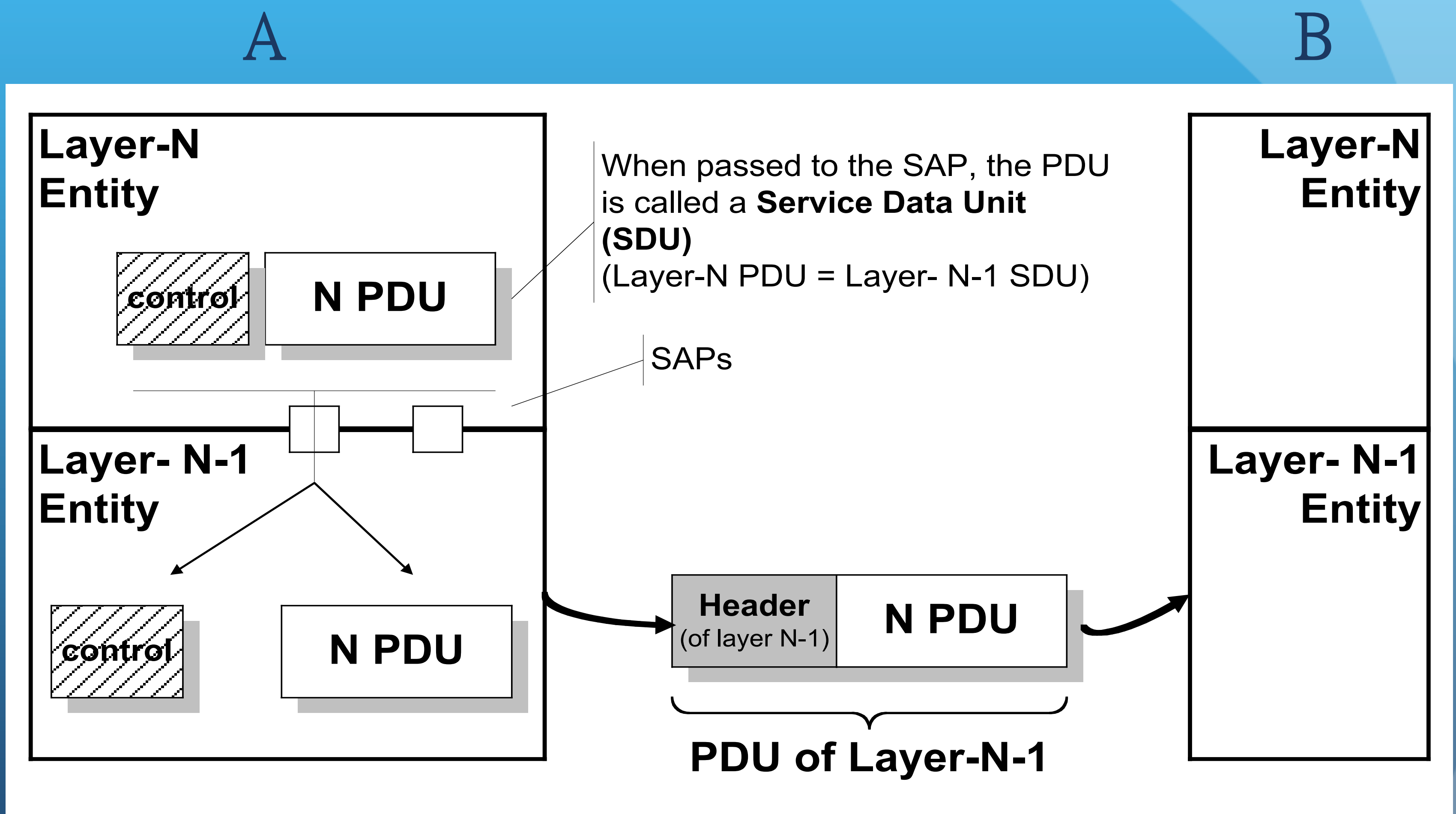
Exchange of Data

- Assume a layer-N entity at A wants to send data to a layer-N peer entity to B
- The unit of data sent between peer entities is called a **Protocol Data Unit (PDU)**
- For now, let us think of a PDU as a single packet

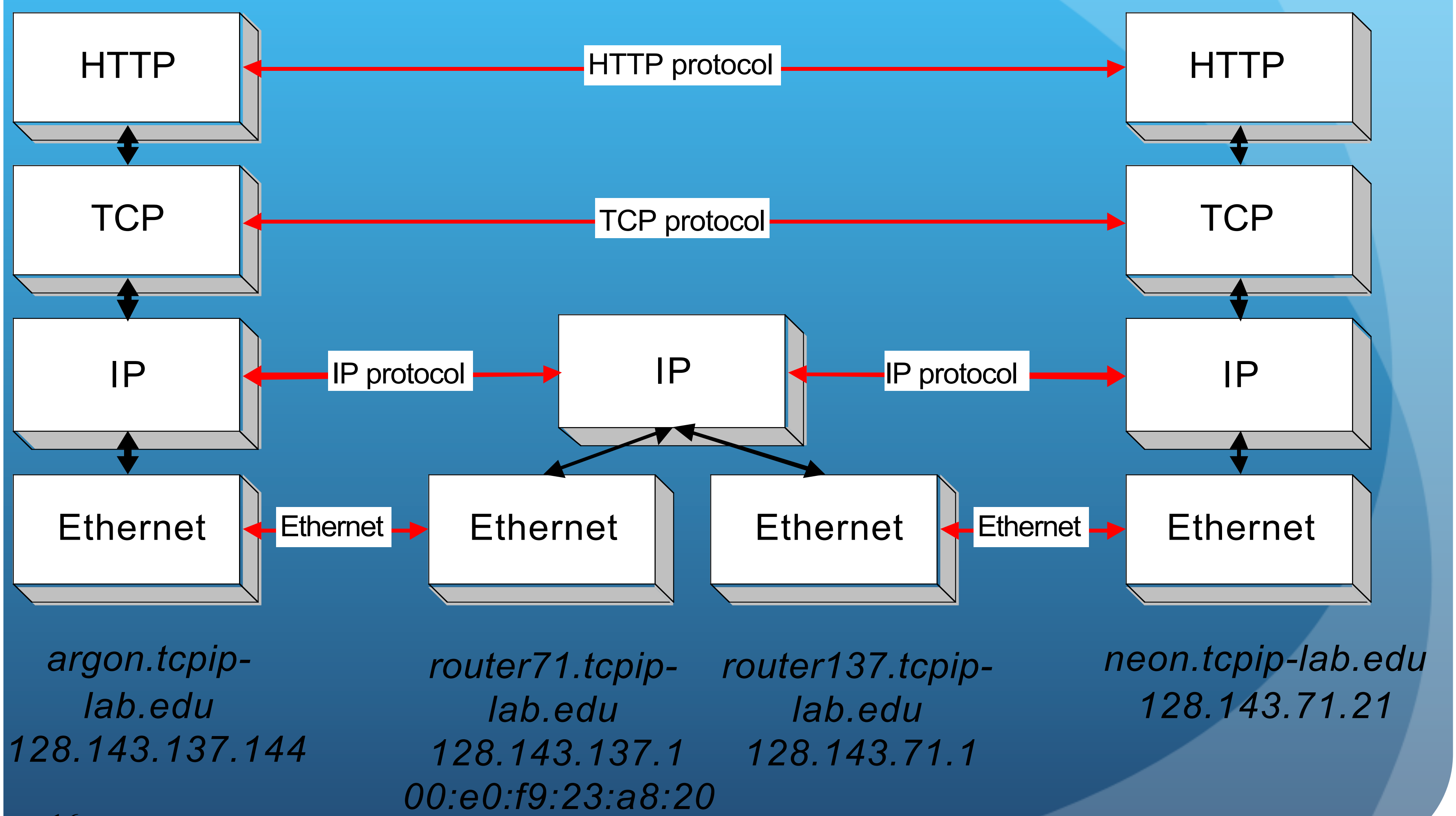


- What actually happens: Layer N passes the PDU to one of A's SAPs at layer N-1
- The layer N-1 entity (at A) then constructs its own PDU which it sends to the layer N-1 entity at B
- Note: PDU at layer N-1 = Header + PDU at layer N

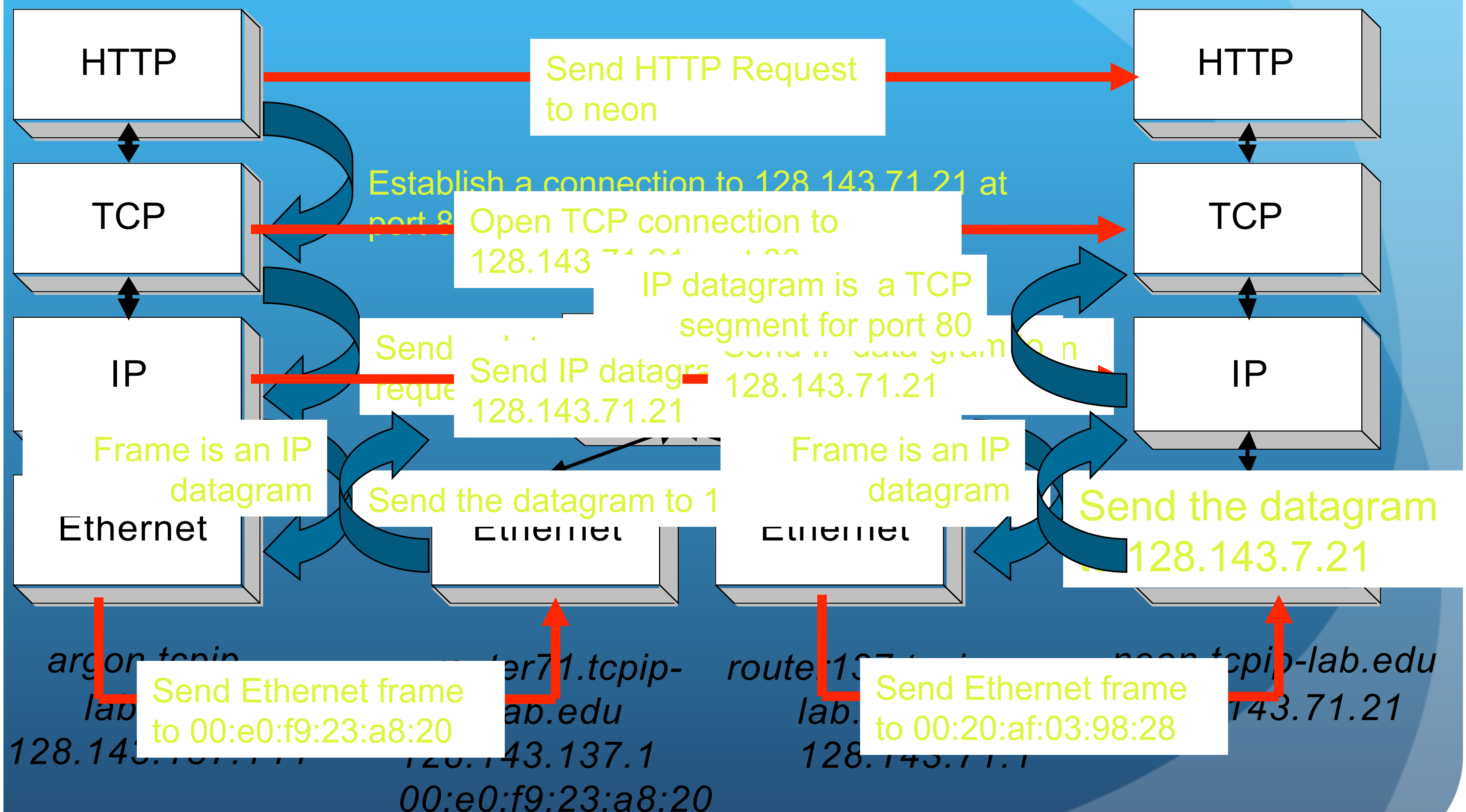
Exchange of Data



Layers in the Example



Layers in the Example



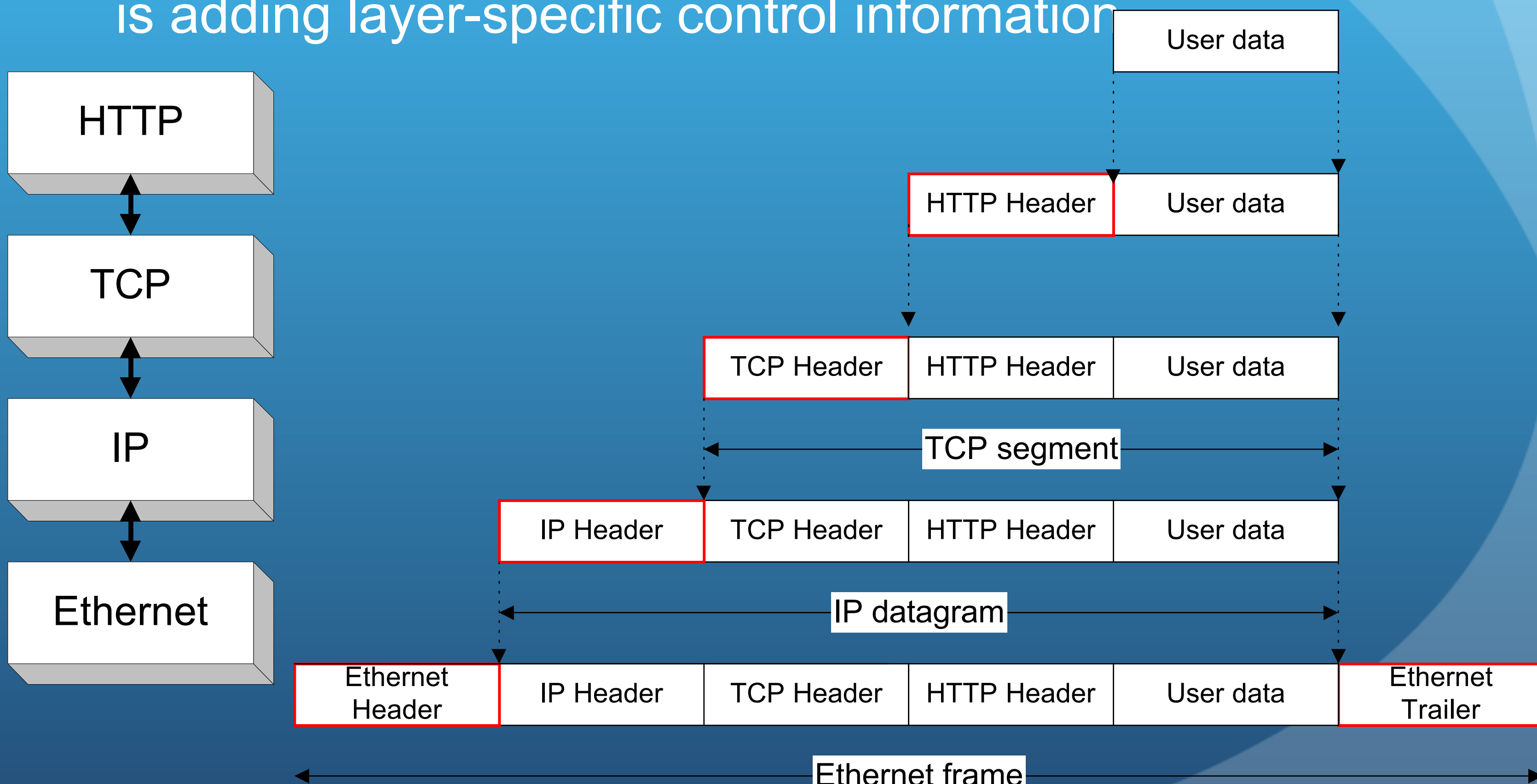
Layers and Services

- Service provided by TCP to HTTP:
  - reliable transmission of data over a logical connection
- Service provided by IP to TCP:
  - unreliable transmission of IP datagrams across an IP network
- Service provided by Ethernet to IP:
  - transmission of a frame across an Ethernet segment

- Other services:
  - DNS: translation between domain names and IP addresses
  - ARP: Translation between IP addresses and MAC addresses

Encapsulation and Demultiplexing

- As data is moving down the protocol stack, each protocol is adding layer-specific control information



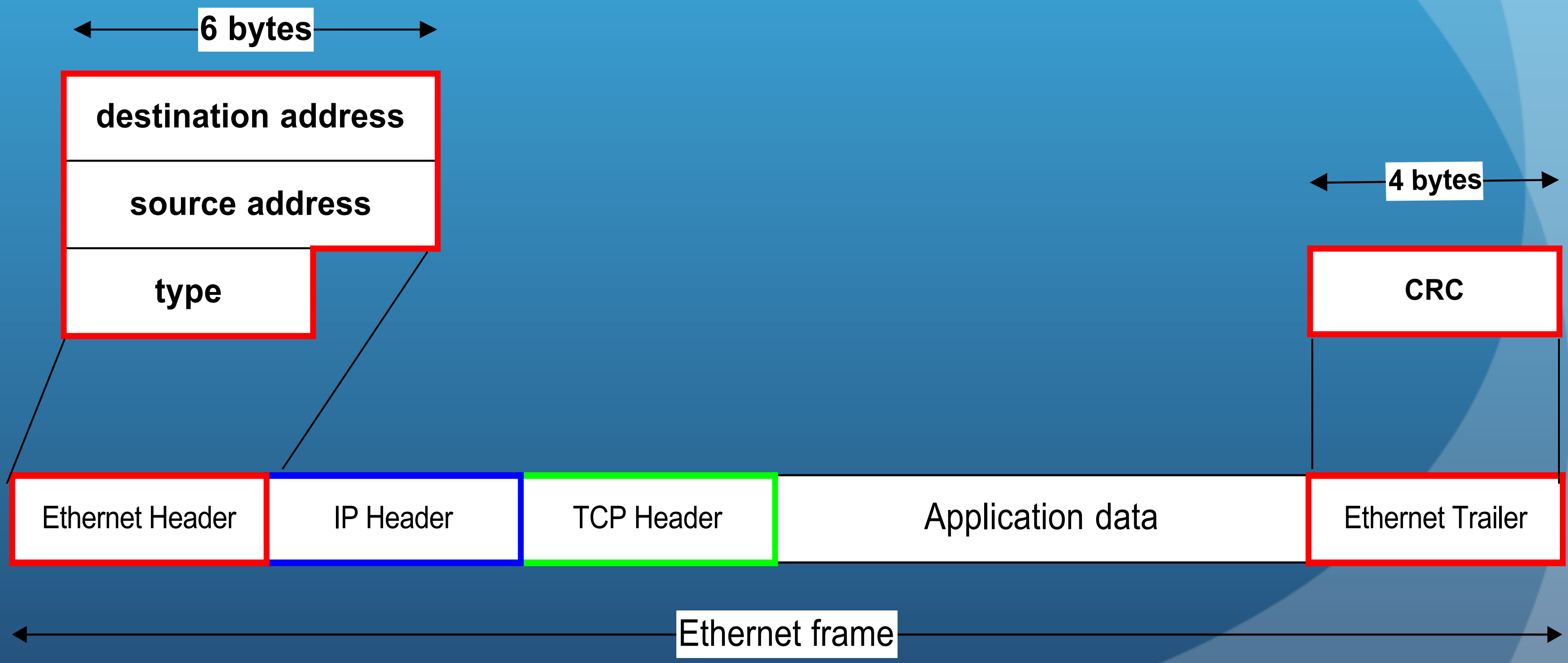
Encapsulation and Demultiplexing in our Example

- Let us look in detail at the Ethernet frame between Argon and the Router, which contains the TCP connection request to Neon.

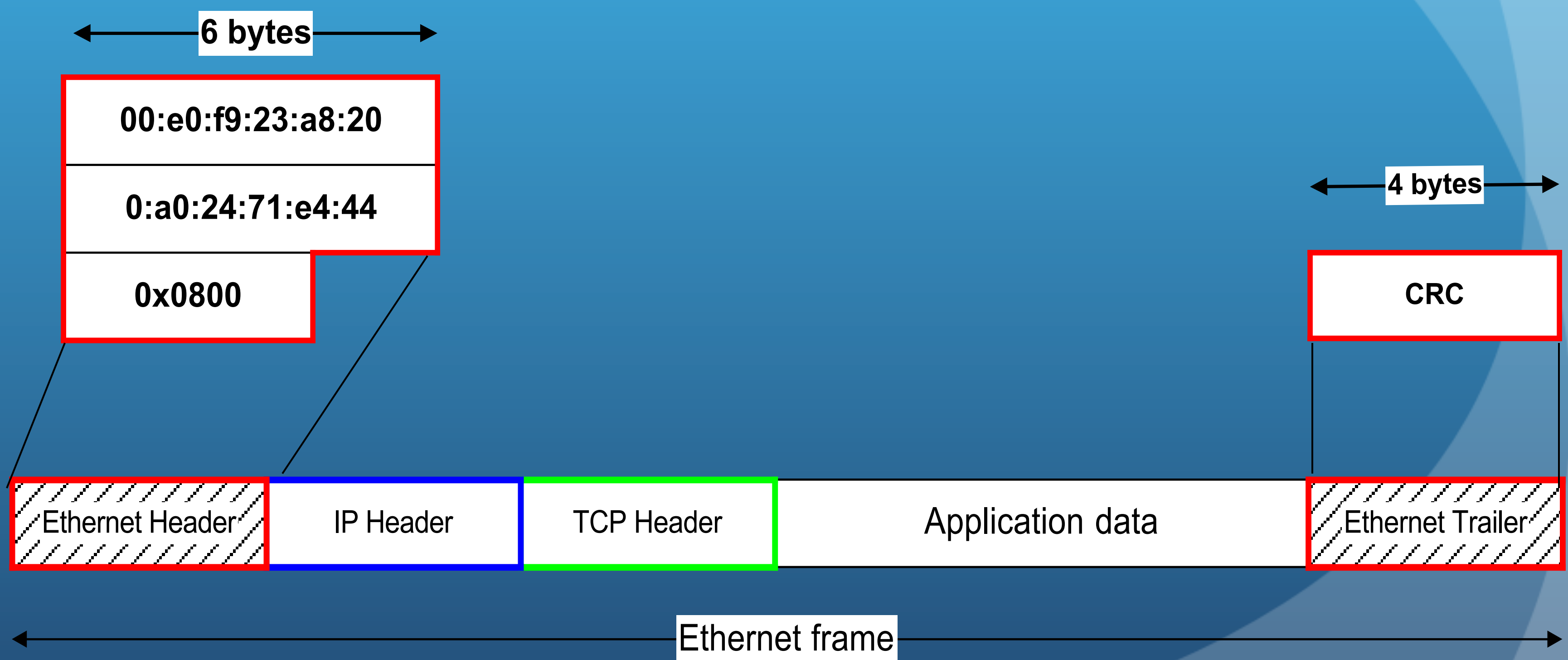
- This is the frame in hexadecimal notation.

```
00e0 f923 a820 00a0 2471 e444 0800 4500
002c 9d08 4000 8006 8bff 808f 8990 808f
4715 065b 0050 0009 465b 0000 0000 6002
2000 598e 0000 0204 05b4
```

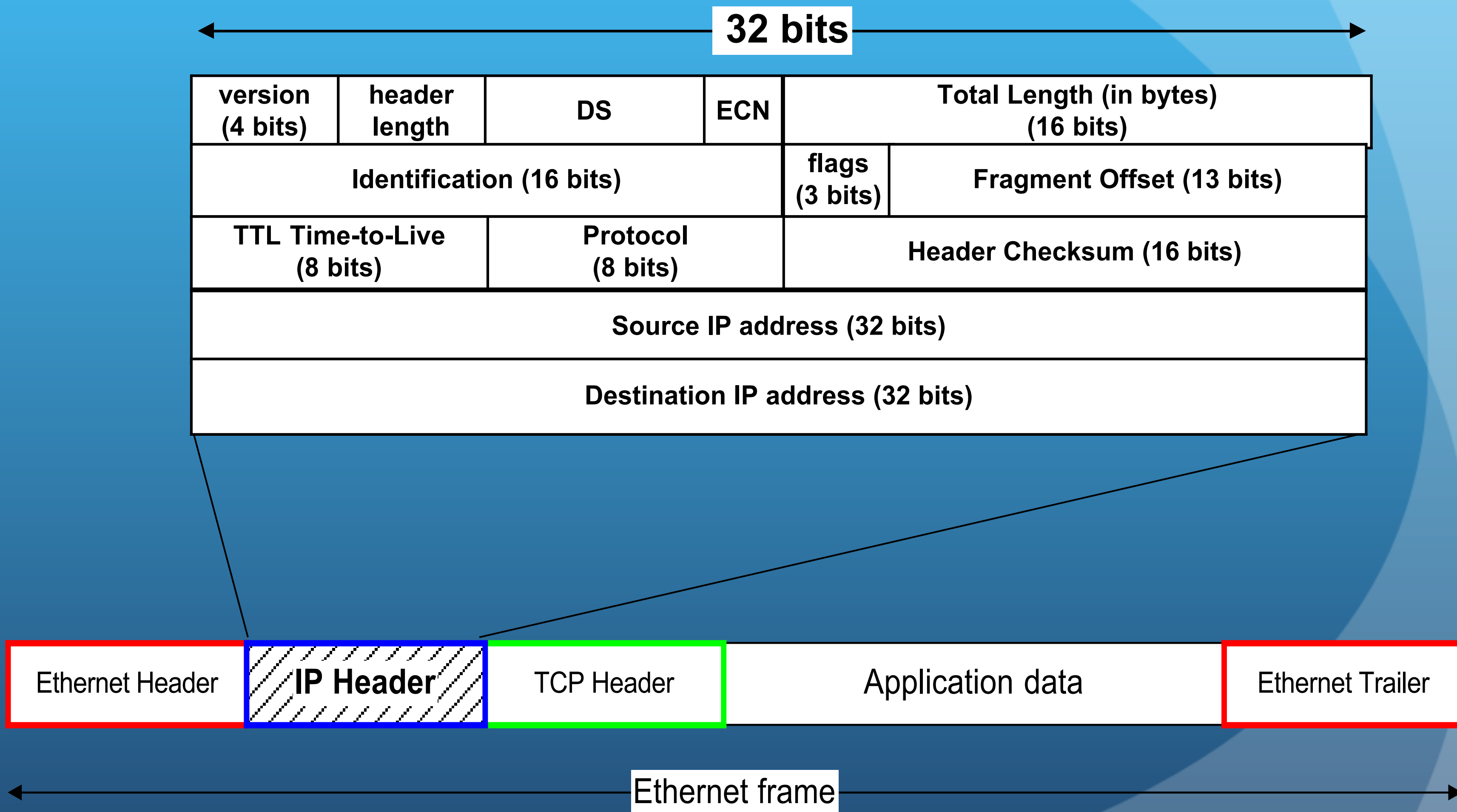
Encapsulation and Demultiplexing



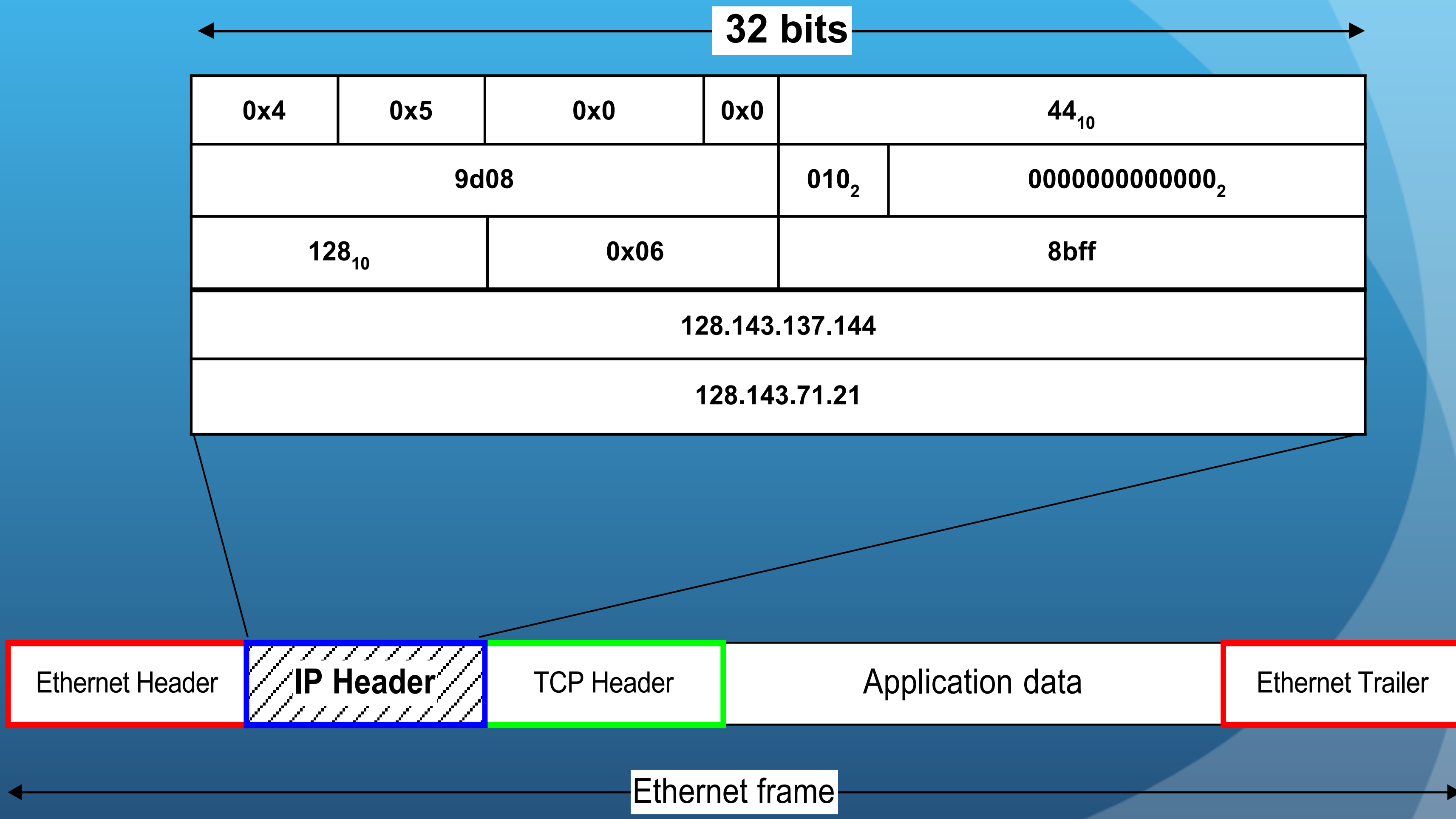
Encapsulation and Demultiplexing: Ethernet Header



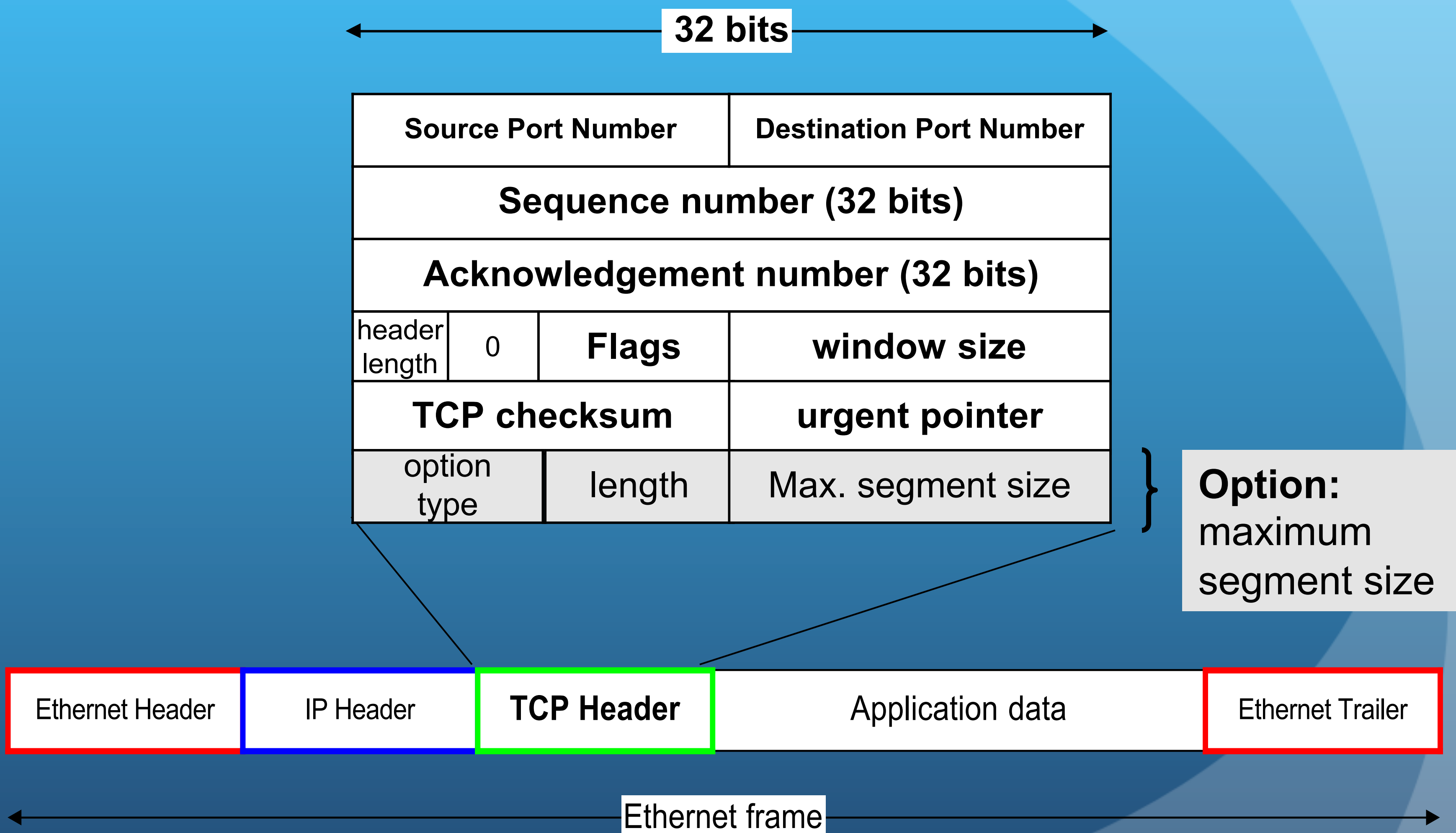
Encapsulation and Demultiplexing: IP Header



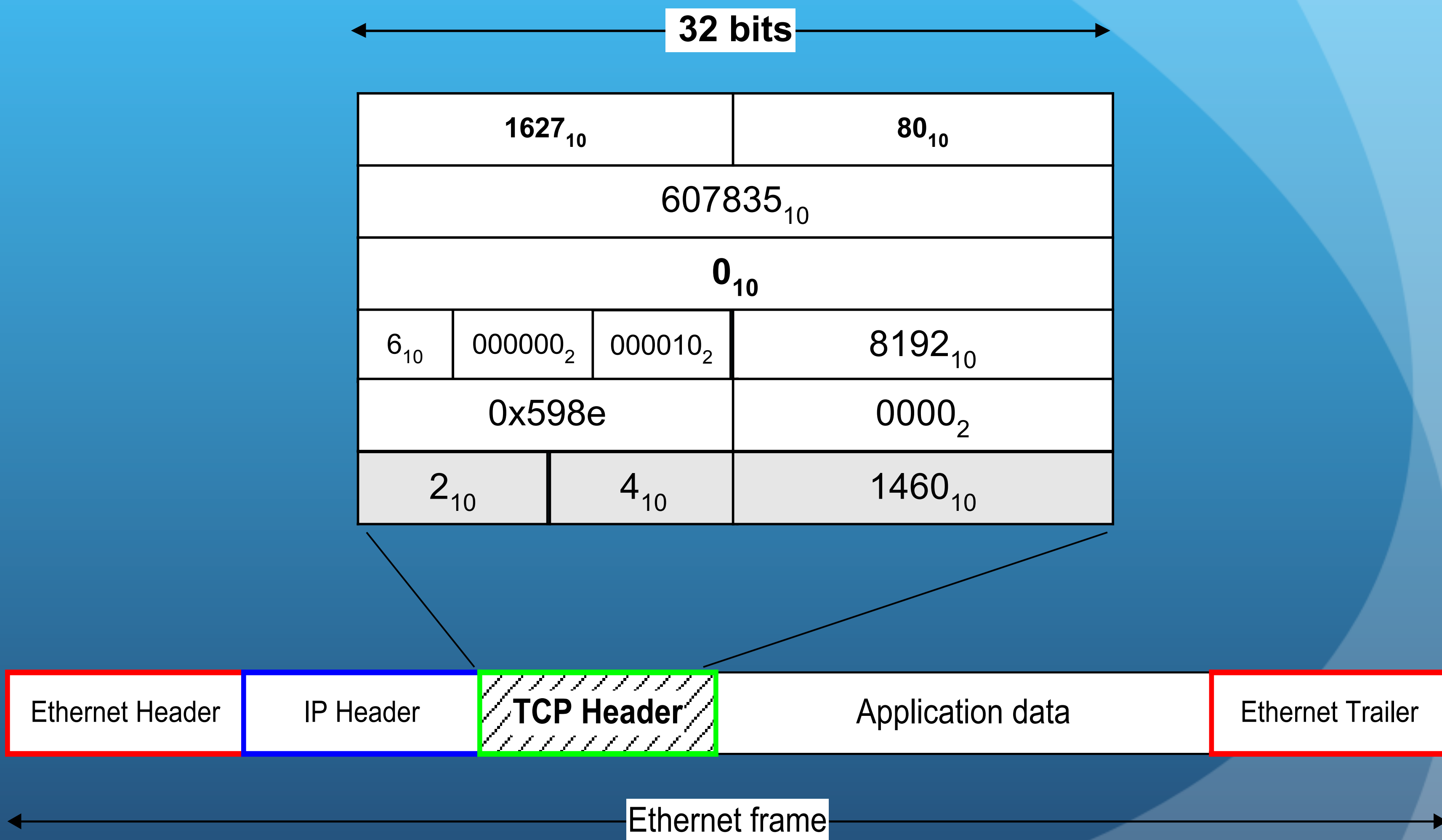
Encapsulation and Demultiplexing: IP Header



Encapsulation and Demultiplexing: TCP Header

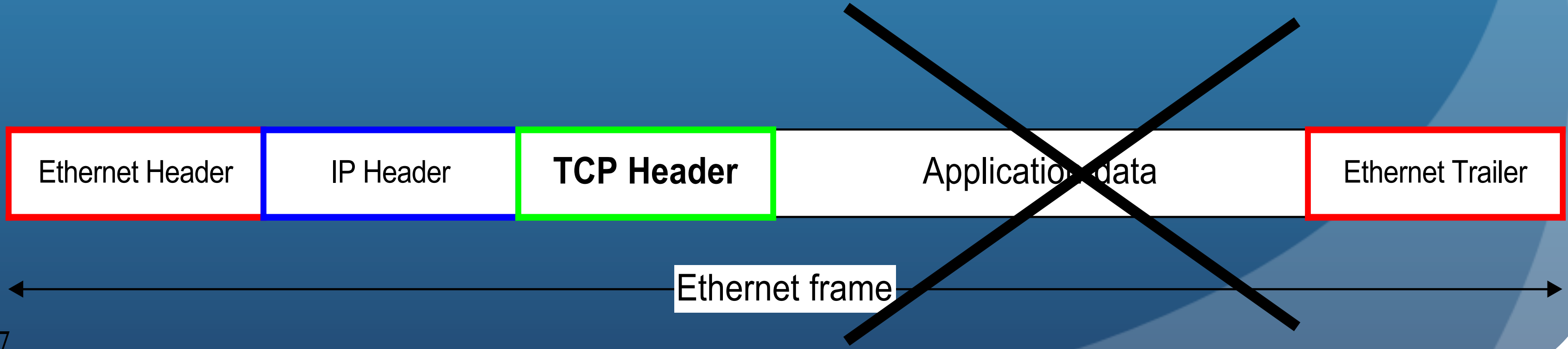


Encapsulation and Demultiplexing: TCP Header



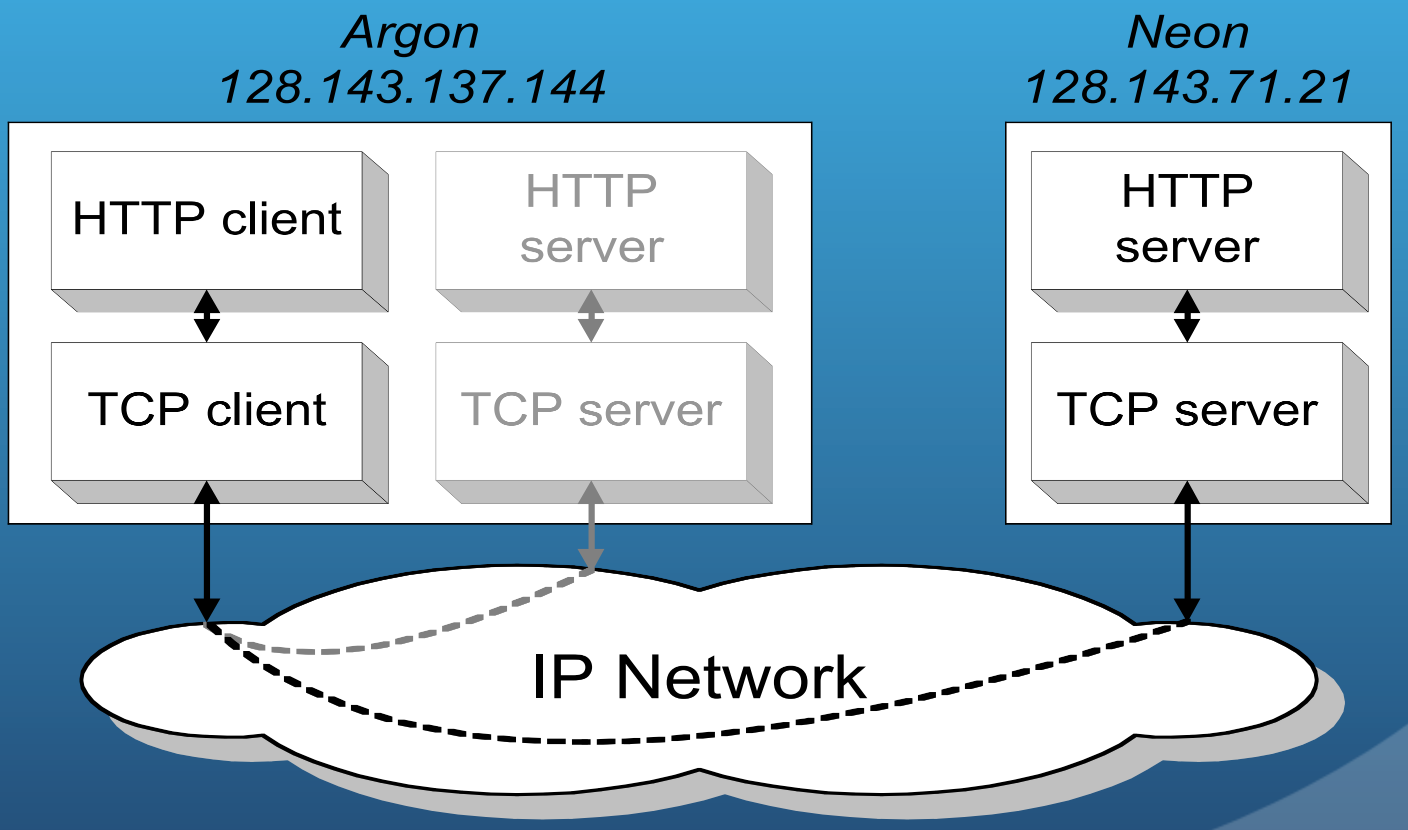
Encapsulation and Demultiplexing: Application data

No Application Data in this frame

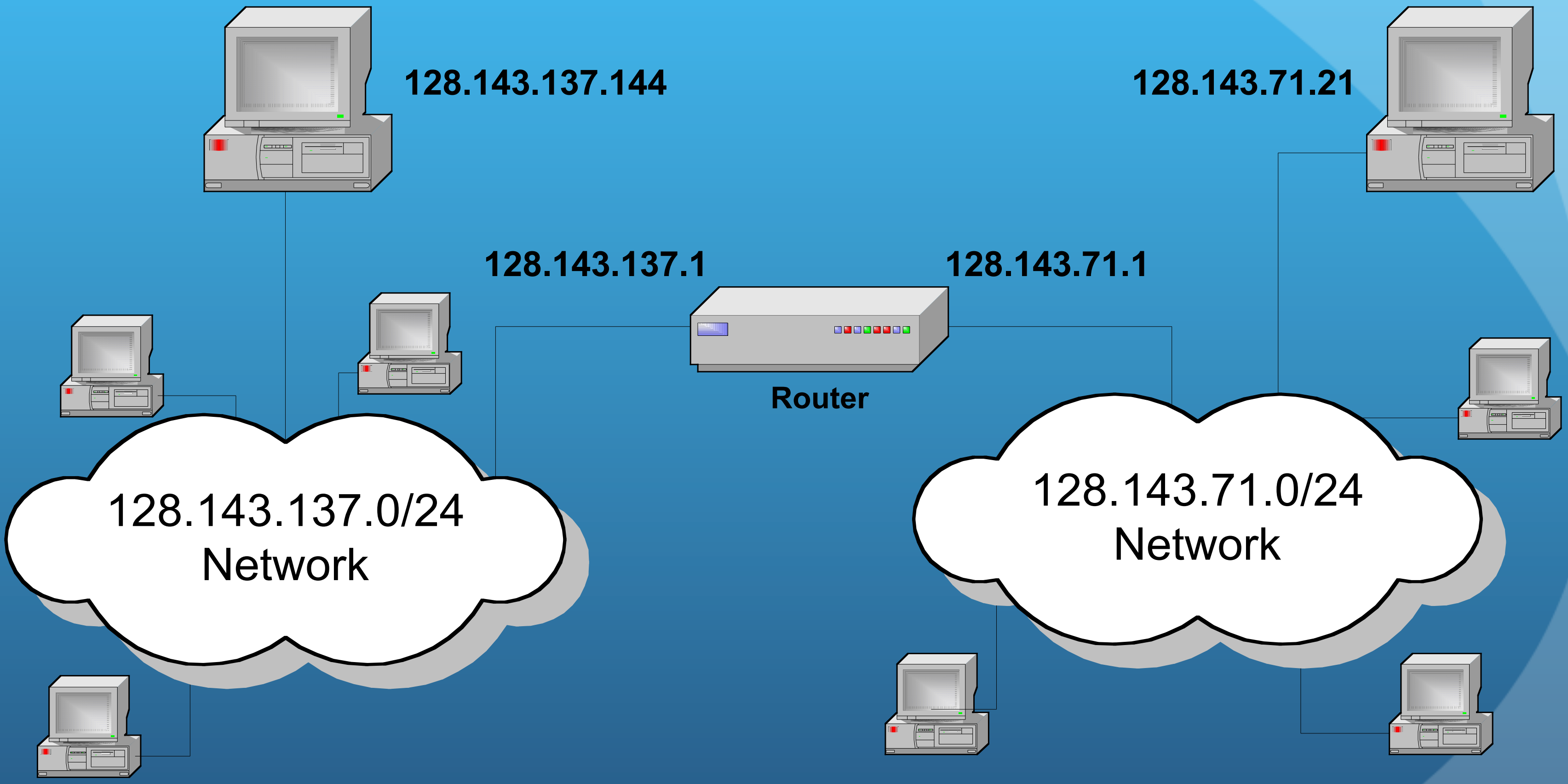


Different Views of Networking

- Different Layers of the protocol stack have a different view of the network. This is HTTP' s and TCP' s view of the network.

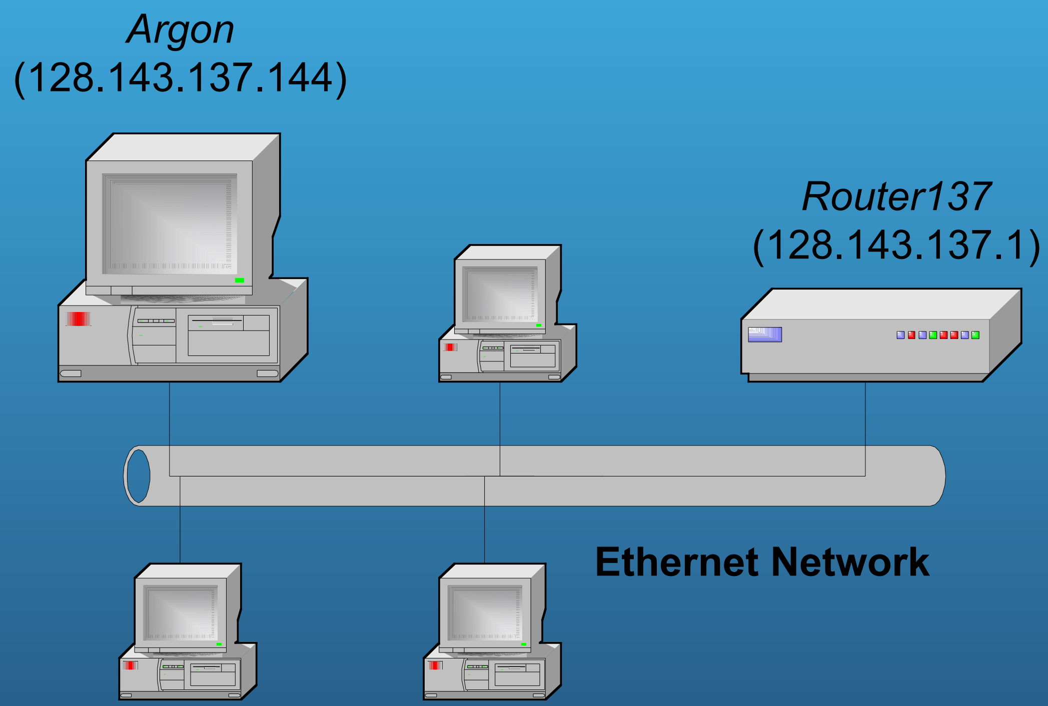


Network View of IP Protocol



Network View of Ethernet

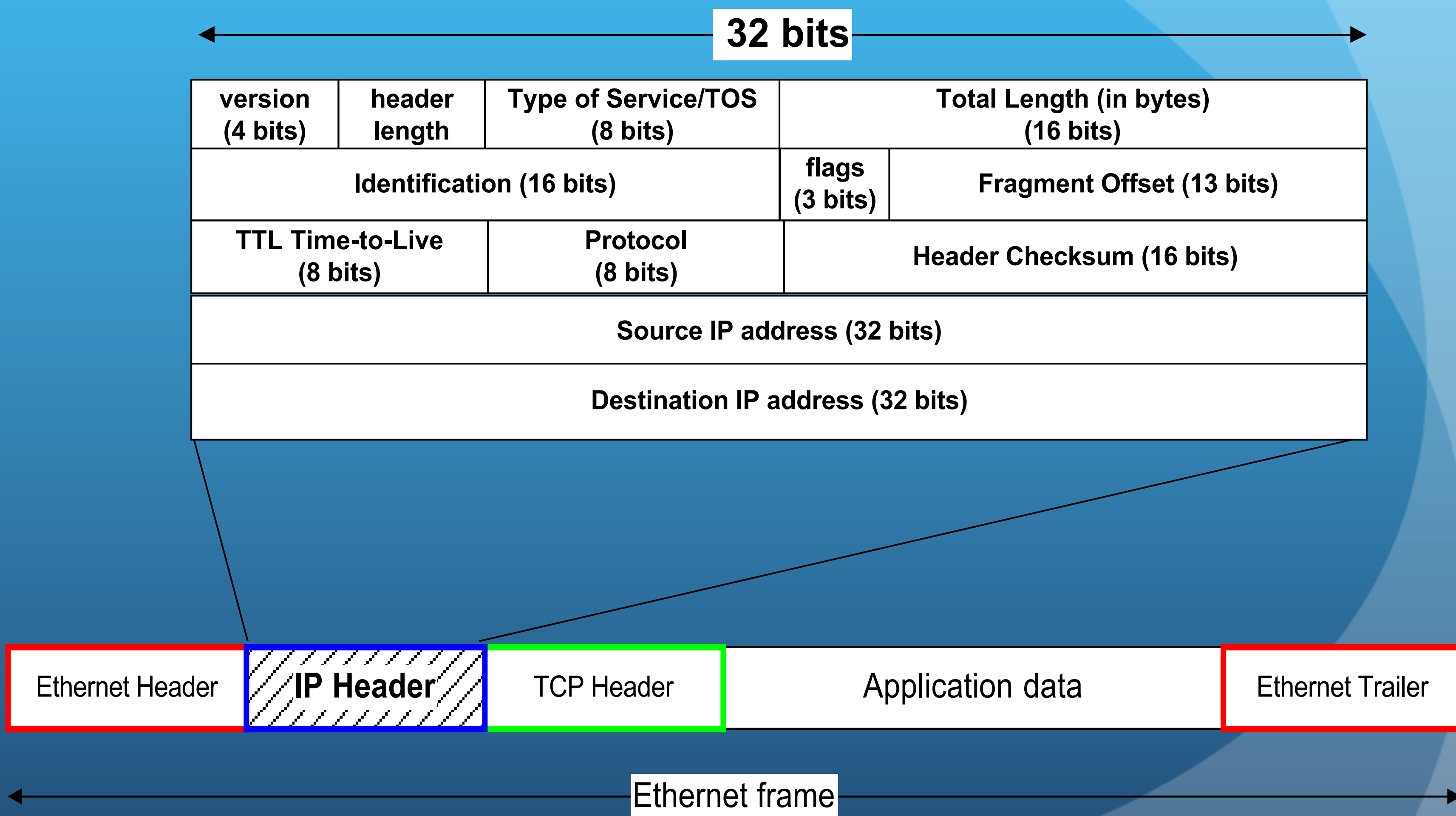
- Ethernet's view of the network



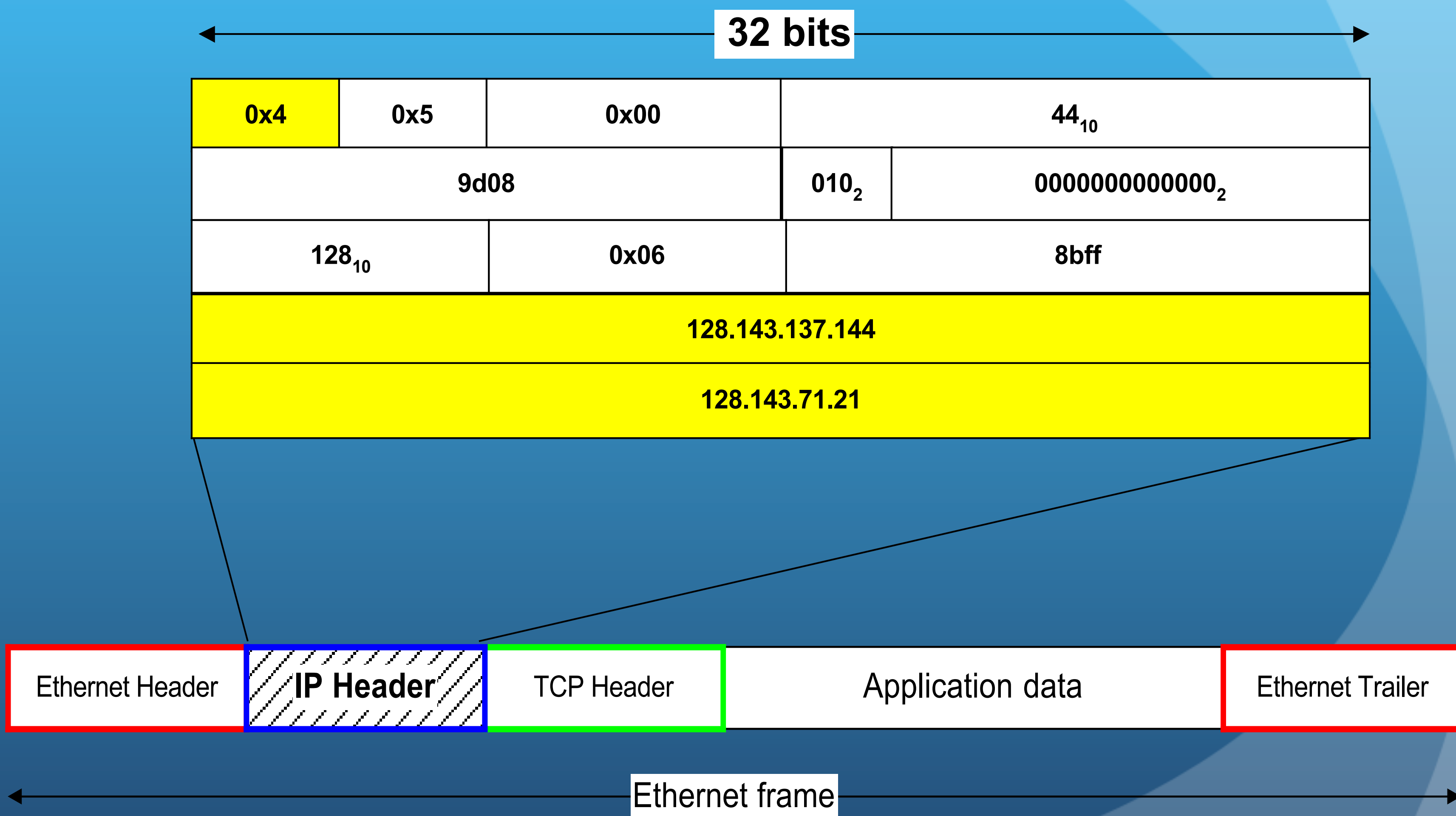
IP Addresses

- Structure of an IP address
- Subnetting
- CIDR

IP Addresses



IP Addresses



What is an IP Address?

- An IP address is a unique global address for a network interface

- An IP address:
  - is a **32 bit long** identifier
  - encodes a network number (**network prefix**) and a **host number**

Dotted Decimal Notation

- IP addresses are written in a so-called ***dotted decimal* notation**
- Each byte is identified by a decimal number in the range [0..255]:

10000000	10001111	10001001	10010000
1st Byte	2nd Byte	3rd Byte	4th Byte
= 128	**= 143**	**= 137**	**= 144**

128.143.137.144

Network prefix and Host number

- The network prefix identifies a network and the host number identifies a specific host (actually, interface on the network).

network prefix	host number

- **How do we know how long the network prefix is?**
  - The network prefix is implicitly defined (**class-based addressing**)
  - The network prefix is indicated by a **netmask.**

Example

- **Example**: ellington.cs.virginia.edu

128.143	137.144

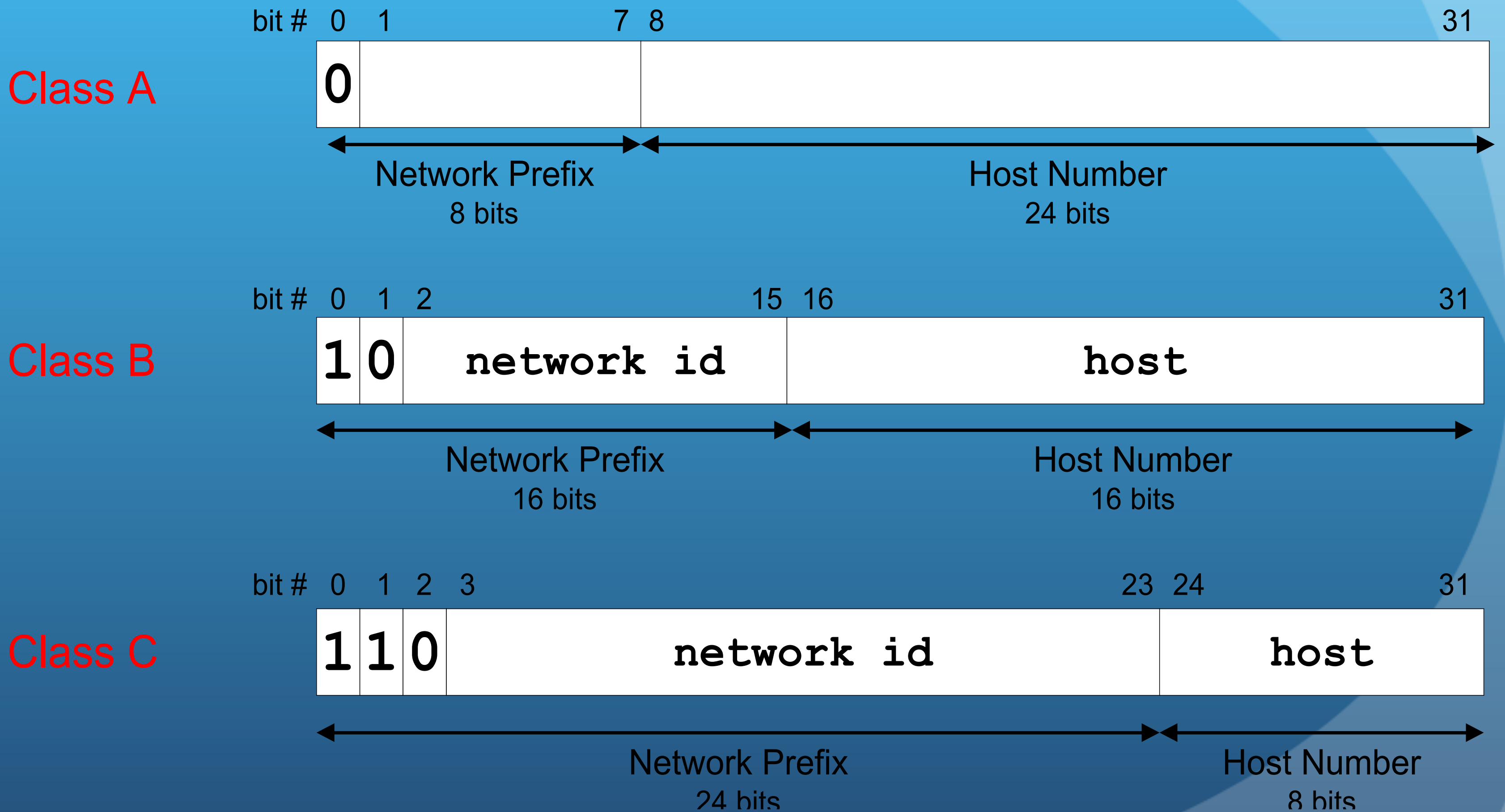
- Network id is: `128.143.0.0`
- Host number is: `137.144`
- Network mask is: `255.255.0.0` or `ffff0000`
- Prefix notation: `128.143.137.144/16`
- Network prefix is 16 bits long

The old way: Classful IP Adresses

- When Internet addresses were standardized (early 1980s), the Internet address space was divided up into classes:
  - **Class A:** Network prefix is 8 bits long
  - **Class B:** Network prefix is 16 bits long
  - **Class C:** Network prefix is 24 bits long

- Each IP address contained a key which identifies the class:
  - **Class A:** IP address starts with "0"
  - **Class B:** IP address starts with "10"
  - **Class C:** IP address starts with "110"

The old way: Internet Address Classes



The old way: Internet Address Classes

Class D

bit #	0	1	2	3	4 … 31
	1	1	1	0	multicast group id

Class E

bit #	0	1	2	3	4	5 … 31
	1	1	1	1	0	(reserved for future use)

- We will learn about multicast addresses later in this course.

Problems with Classful IP Addresses

- The original classful address scheme had a number of problems

Problem 1. Too few network addresses for large networks

- Class A and Class B addresses are gone

Problem 2. Two-layer hierarchy is not appropriate for large networks with Class A and Class B addresses.

- **Fix #1: Subnetting**

Problems with Classful IP Addresses

Problem 3. **Inflexible.** Assume a company requires 2,000 addresses

- Class A and B addresses are overkill
- Class C address is insufficient (requires 8 Class C addresses)

- **Fix #2:** **Classless Interdomain Routing (CIDR)**

Problems with Classful IP Addresses

Problem 4: Exploding Routing Tables: Routing on the backbone Internet needs to have an entry for each network address. In 1993, the size of the routing tables started to outgrow the capacity of routers.

- **Fix #2: Classless Interdomain Routing (CIDR)**

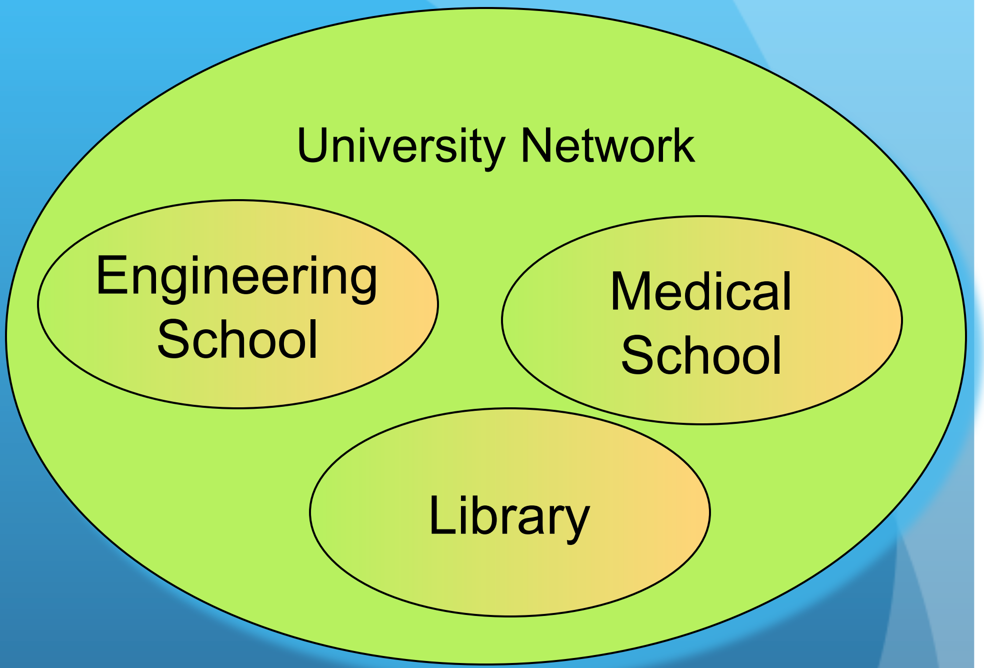
Problems with Classful IP Addresses

Problem 5. The Internet is going to outgrow the 32-bit addresses

- **Fix #3: IP Version 6**

Subnetting

- **Problem**: Organizations have multiple networks which are independently managed
  - **Solution 1:** Allocate one or more addresses for each network
    - Difficult to manage
    - -> From the outside of the organization - each network must be addressable.



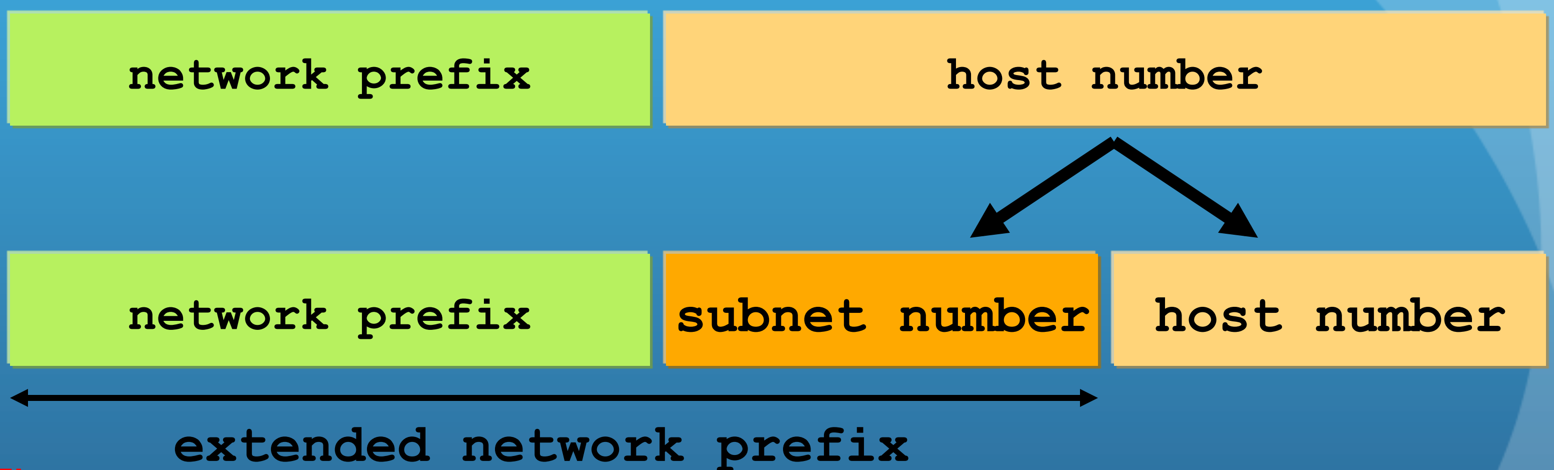
- **Solution 2:** Add another level of hierarchy to the IP addressing structure

→ **Subnetting**

Basic Idea of Subnetting

- Split the host number portion of an IP address into a **`subnet number`** and a (smaller) **`host number`**.

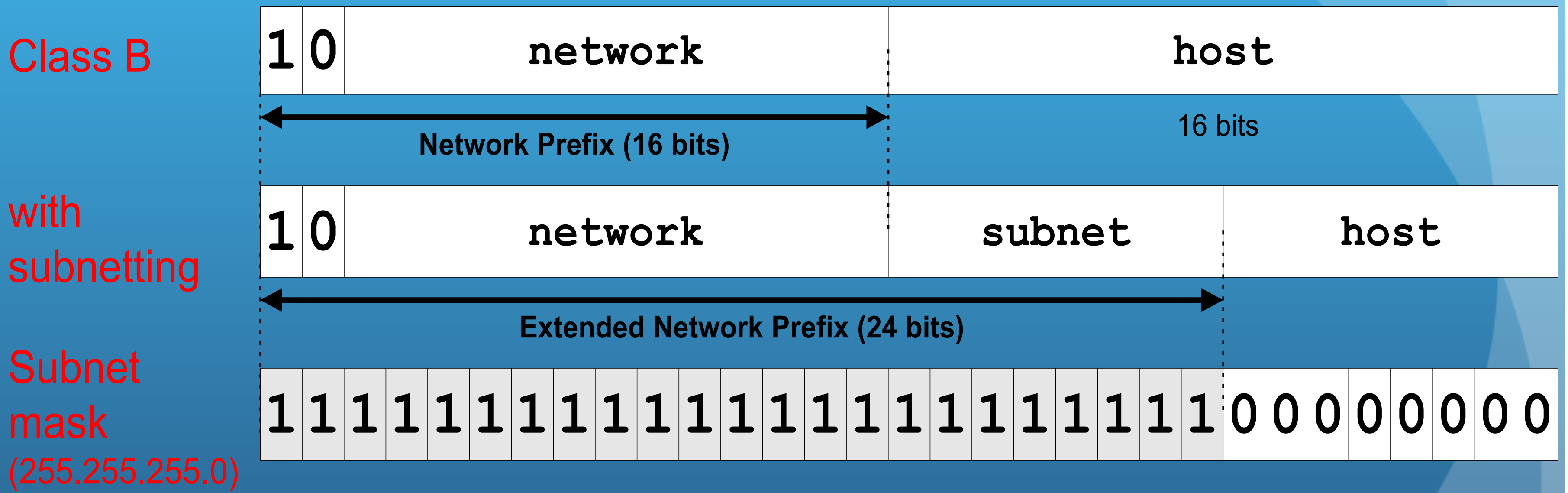
- Result is a 3-layer hierarchy



- Then:
    - Subnets can be freely assigned within the organization
    - Internally, subnets are treated as separate networks
    - Subnet structure is not visible outside the organization

Subnet Masks

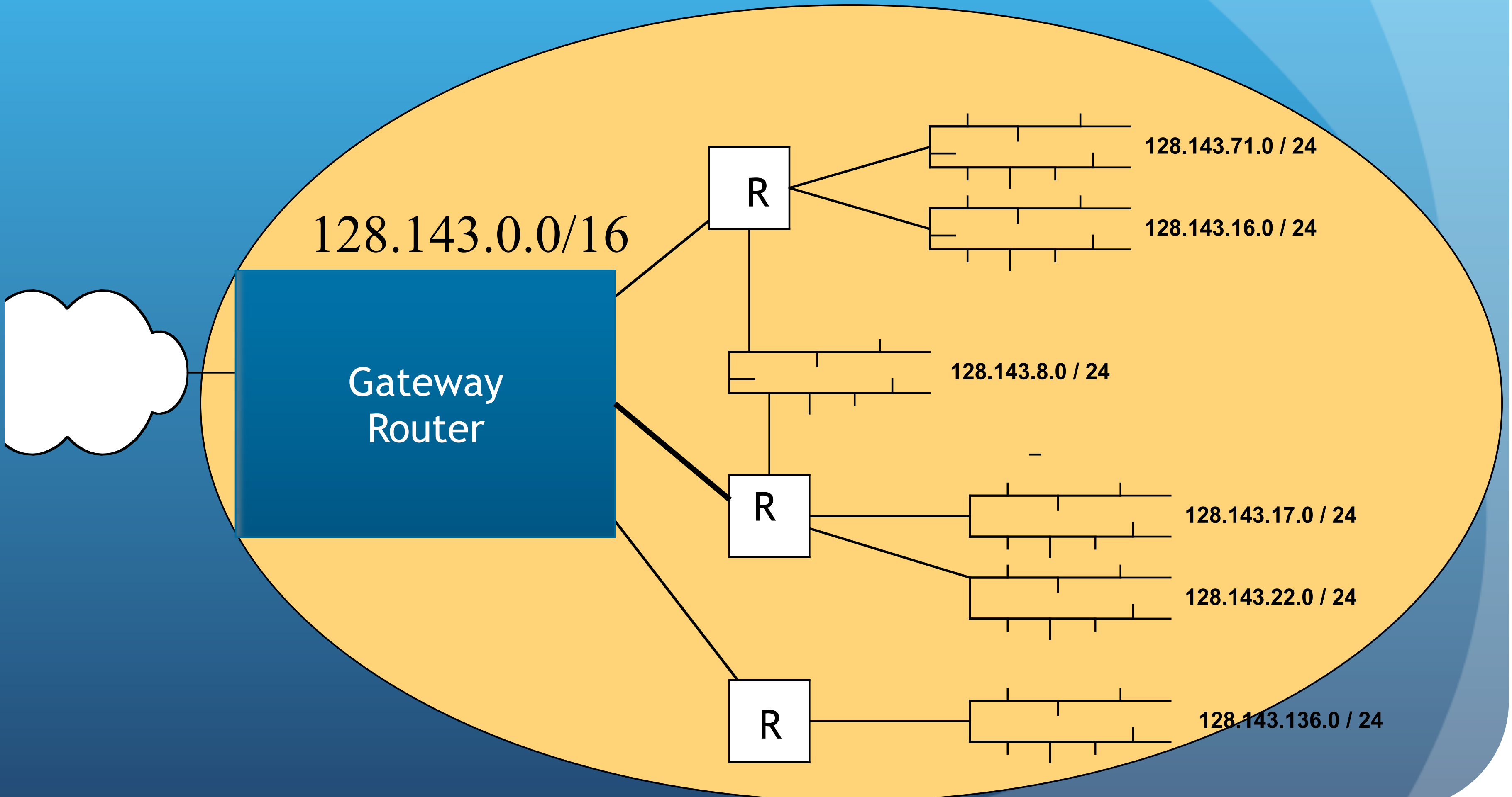
- Routers and hosts use an **extended network prefix** (**subnet mask)** to identify the start of the host numbers



* There are different ways of subnetting. Commonly used netmasks for university networks with /16 prefix (Class B) are 255.255.255.0 and 255.255.0.0

Typical Addressing Plan for an Organization that uses subnetting

- Each layer-2 network (Ethernet segment, FDDI segment) is allocated a subnet address when connected to a router.



Advantages of Subnetting

- With subnetting, IP addresses use a 3-layer hierarchy:
  - Network
  - Subnet
  - Host
- Improves efficiency of IP addresses by not consuming an entire address space for each physical network.
- Reduces router complexity. Since external routers do not know about subnetting, the complexity of routing tables at external routers is reduced.
- Note: Length of the subnet mask need not be identical at all subnetworks.

CIDR - Classless Interdomain Routing

- IP backbone routers have one routing table entry for each network address:
  - With subnetting, a backbone router only needs to know one entry for each network
  - This is acceptable for Class A and Class B networks
    - 2^7 = 128 Class A networks
    - 2^{14} = 16,384 Class B networks
  - But this is not acceptable for Class C networks
    - 2^{21} = 2,097,152 Class C networks

- In 1993, the size of the routing tables started to outgrow the capacity of routers

- Consequence: The Class-based assignment of IP addresses had to be abandoned

CIDR - Classless Interdomain Routing

- **Goals:**
  - Restructure IP address assignments to increase efficiency
  - Hierarchical routing aggregation to minimize route table entries

Key Concept: The length of the network id (prefix) in the IP addresses is kept arbitrary

- Consequence: Routers advertise the IP address and the length of the prefix

CIDR Example

- CIDR notation of a network address:

  192.0.2.0/18

  - "18" says that the first 18 bits are the network part of the address (and 14 bits are available for specific host addresses)

- The network part is called the prefix

- Assume that a site requires a network address with 1000 addresses

- With CIDR, the network is assigned a continuous block of 1024 addresses with a 22-bit long prefix

CIDR: Prefix Size vs. Network Size

CIDR Block Prefix	# of Host Addresses
/27	32 hosts
/26	64 hosts
/25	128 hosts
/24	256 hosts
/23	512 hosts
/22	1,024 hosts
/21	2,048 hosts
/20	4,096 hosts
/19	8,192 hosts
/18	16,384 hosts
/17	32,768 hosts
/16	65,536 hosts
/15	131,072 hosts
/14	262,144 hosts
/13	524,288 hosts

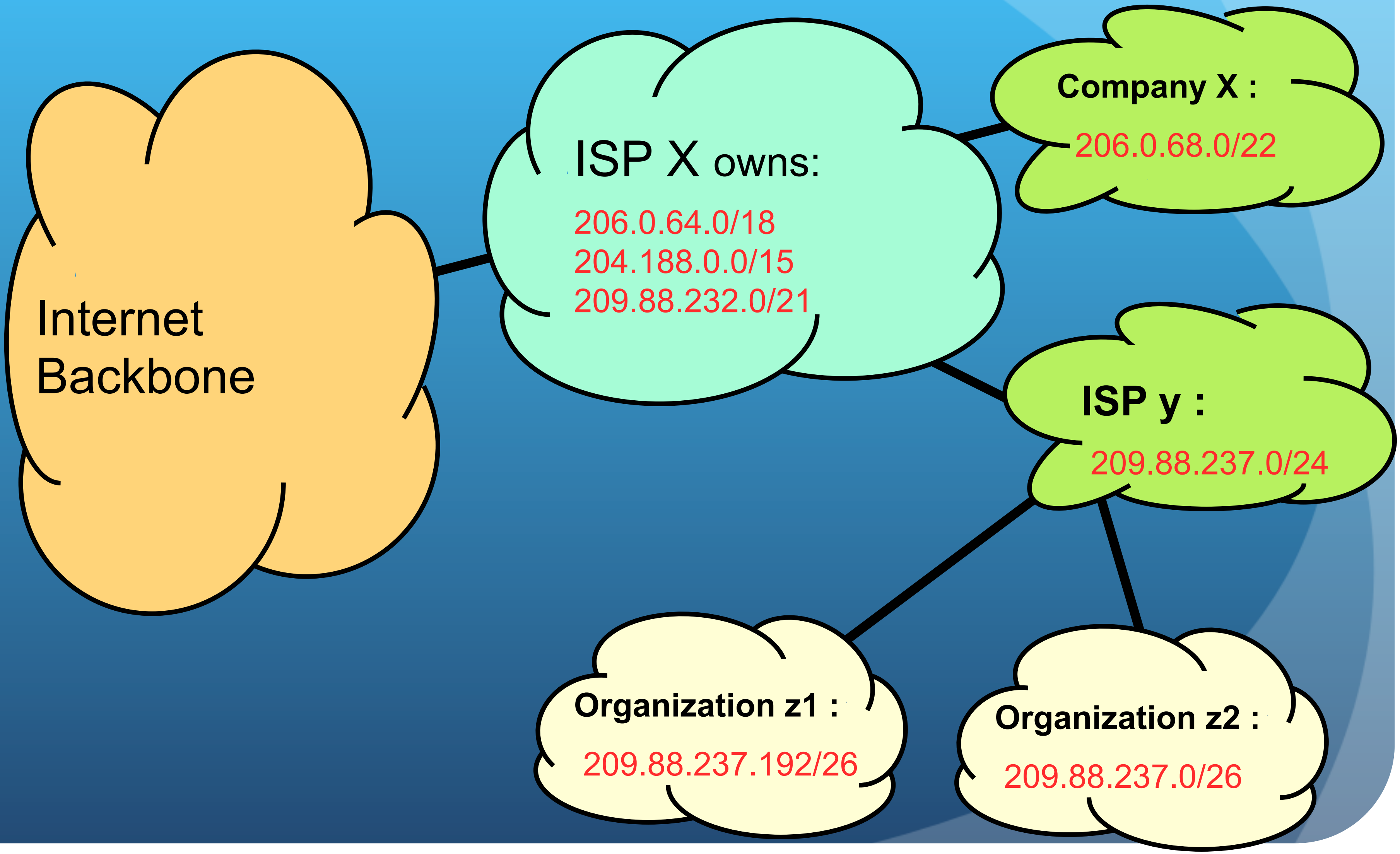
CIDR and Address assignments

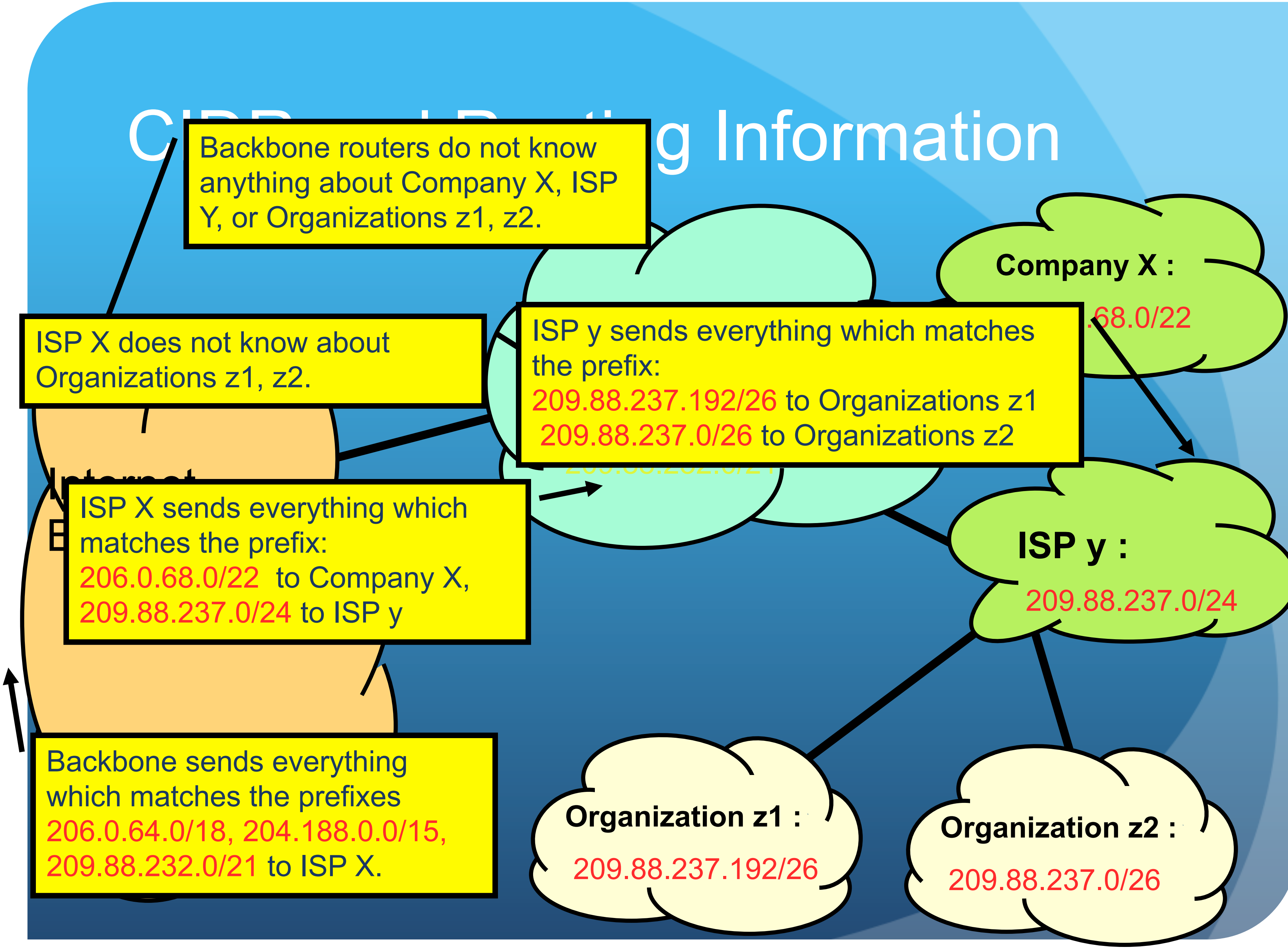
- Backbone ISPs obtain large block of IP addresses space and then reallocate portions of their address blocks to their customers.

Example:

- Assume that an ISP owns the address block 206.0.64.0/18, which represents 16,384 ($2^{32-18}=2^{14}$) IP addresses
- Suppose a client requires 800 host addresses
- With CIDR: Assign a /22 block ($512=2^9<800<1024=2^{10}$ -> 32-10=22), i.e., 206.0.68.0/22 gives a block of 1,024 (2^{10}) IP addresses.

CIDR and Routing Information




g Information
Backbone routers do not know anything about Company X, ISP Y, or Organizations z1, z2.
ISP X does not know about Organizations z1, z2.
ISP X sends everything which matches the prefix:
206.0.68.0/22 to Company X,
209.88.237.0/24 to ISP y
Backbone sends everything which matches the prefixes
206.0.64.0/18, 204.188.0.0/15,
209.88.232.0/21 to ISP X.
ISP y sends everything which matches the prefix:
209.88.237.192/26 to Organizations z1
209.88.237.0/26 to Organizations z2
Company X :
.68.0/22
ISP y :
209.88.237.0/24
Organization z1 :
209.88.237.192/26
Organization z2 :
209.88.237.0/26

Example

- The IP Address: 207.2.88.170

207	2	88	170
11001111	00000010	01011000	10101010

Belongs to:
City of Charlottesville, VA: 207.2.88.0 - 207.2.92.255

11001111	00000010	01011000	00000000

Belongs to:
Cable & Wireless USA 207.0.0.0 - 207.3.255.255

11001111	00000000	00000000	00000000

CIDR and Routing

- **Aggregation** of routing table entries:
  - 128.143.0.0/16 and 128.142.0.0/16 are represented as 128.142.0.0/15
- **Longest prefix match**: Routing table lookup finds the routing entry that matches the longest prefix

What is the outgoing interface for

128.143.137.0 ?

Prefix	Interface
128.0.0.0/4	interface #5
128.128.0.0/9	interface #2
128.143.128.0/17	interface #1

Routing table