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# Chapter 10
# ROUTING
# AND
# ADDRESSING

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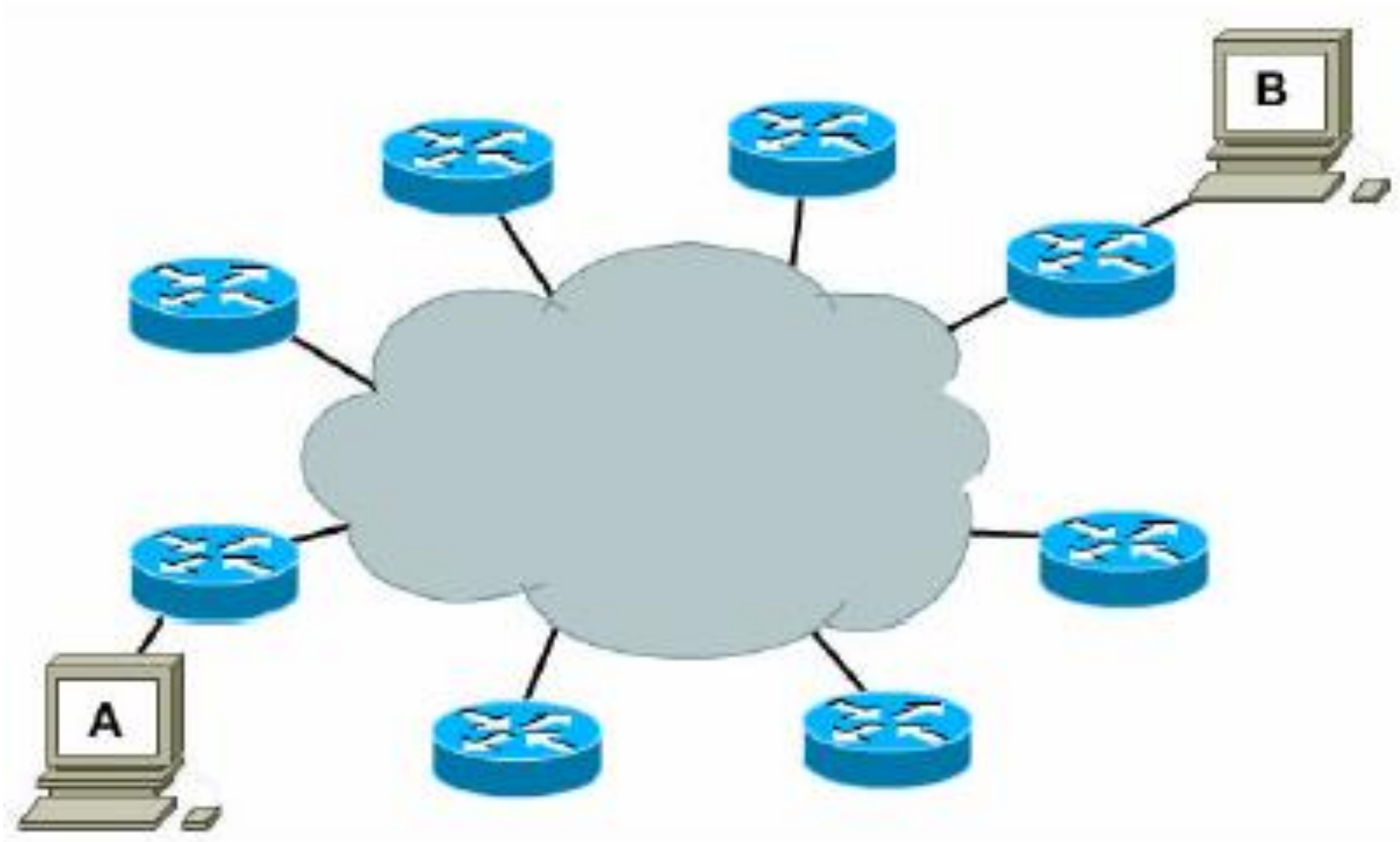
# NETWORK LAYER
# AND
# PATH DETERMINATION

# A network layer. Why?





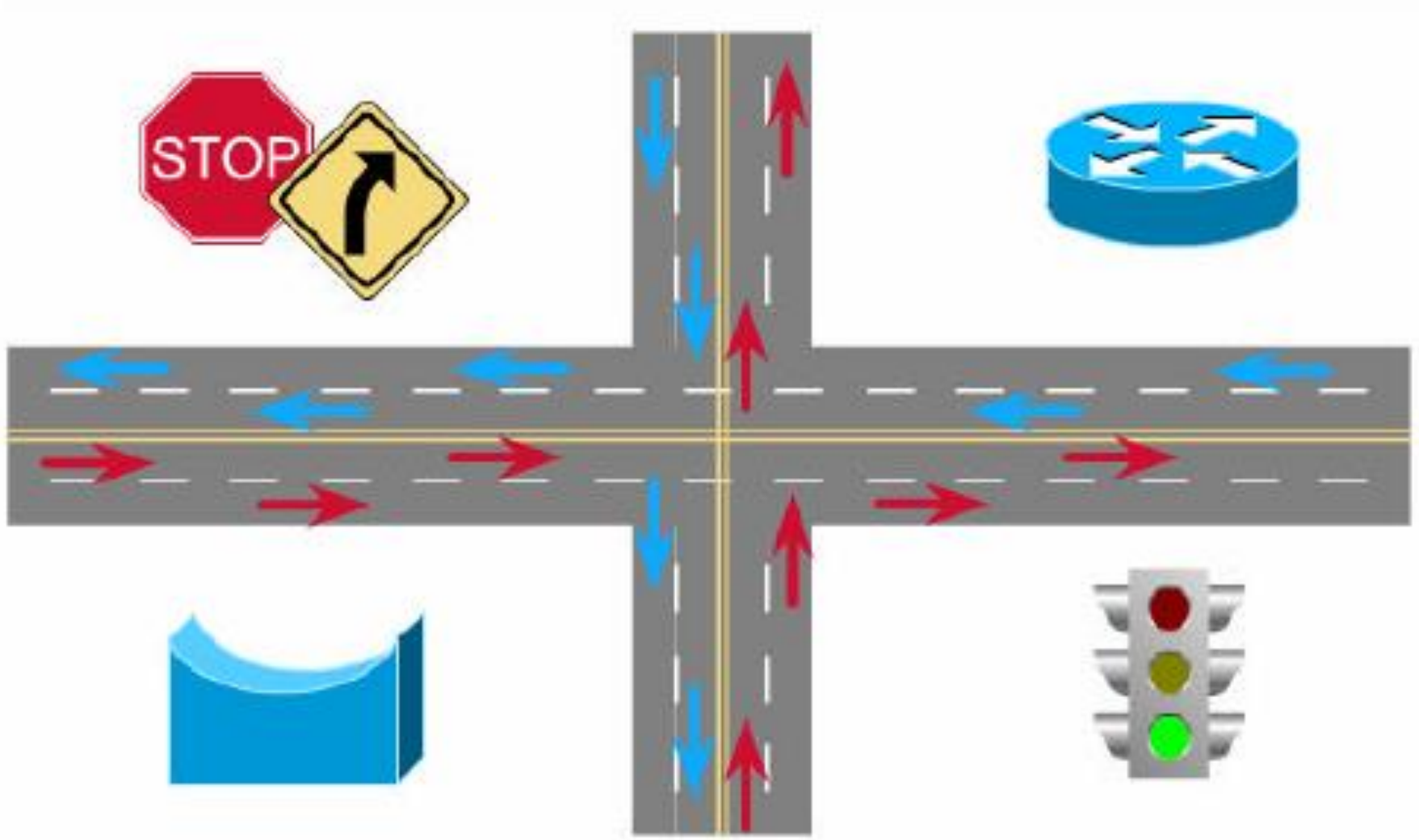
# Network layer



- Segment network and control flow of traffic.
- Move data through a set of networks.
- Logical Addressing, use a hierarchical addressing scheme.

# Network segmentation. Why?





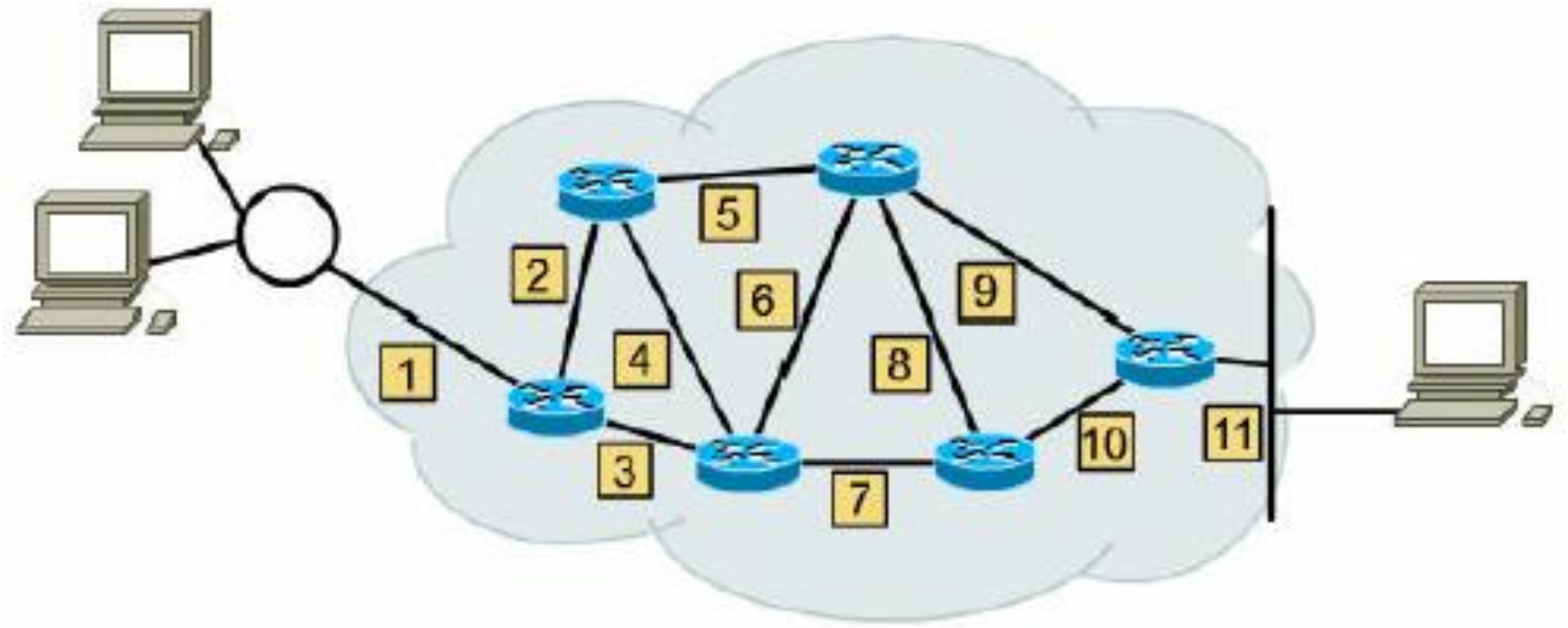
# Network segmentation



- Control network traffics and reduce broadcast traffics.
- Separate computer networks is managed by a single administration - Autonomous systems.

# Communication among networks






- **Networks operate in much the same manner.**

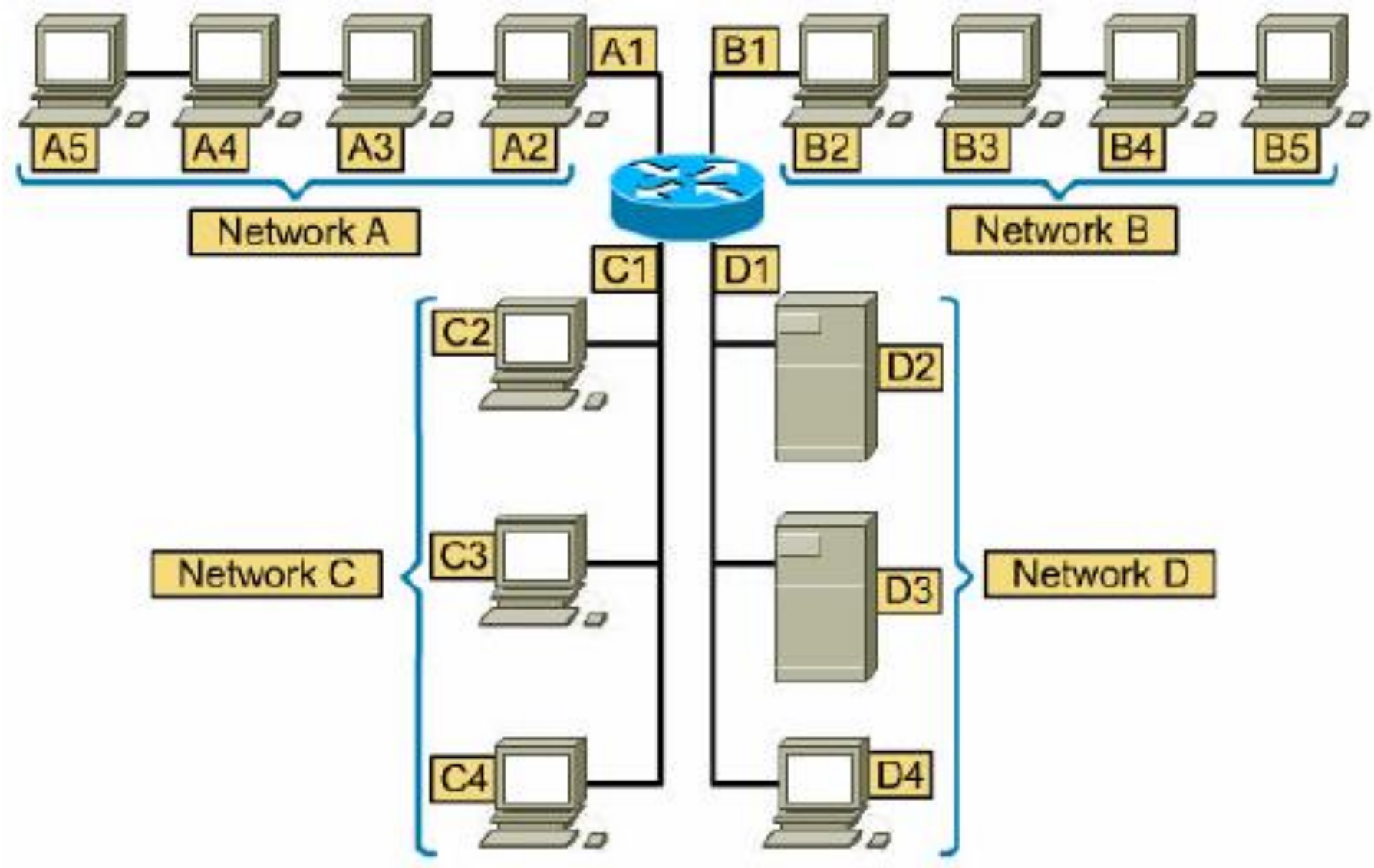
# Router



- Routers connect separate networks.
- Routers make best path decisions based on Layer 3 information.
- Routers actually switch packets from incoming ports to appropriate outgoing ports.

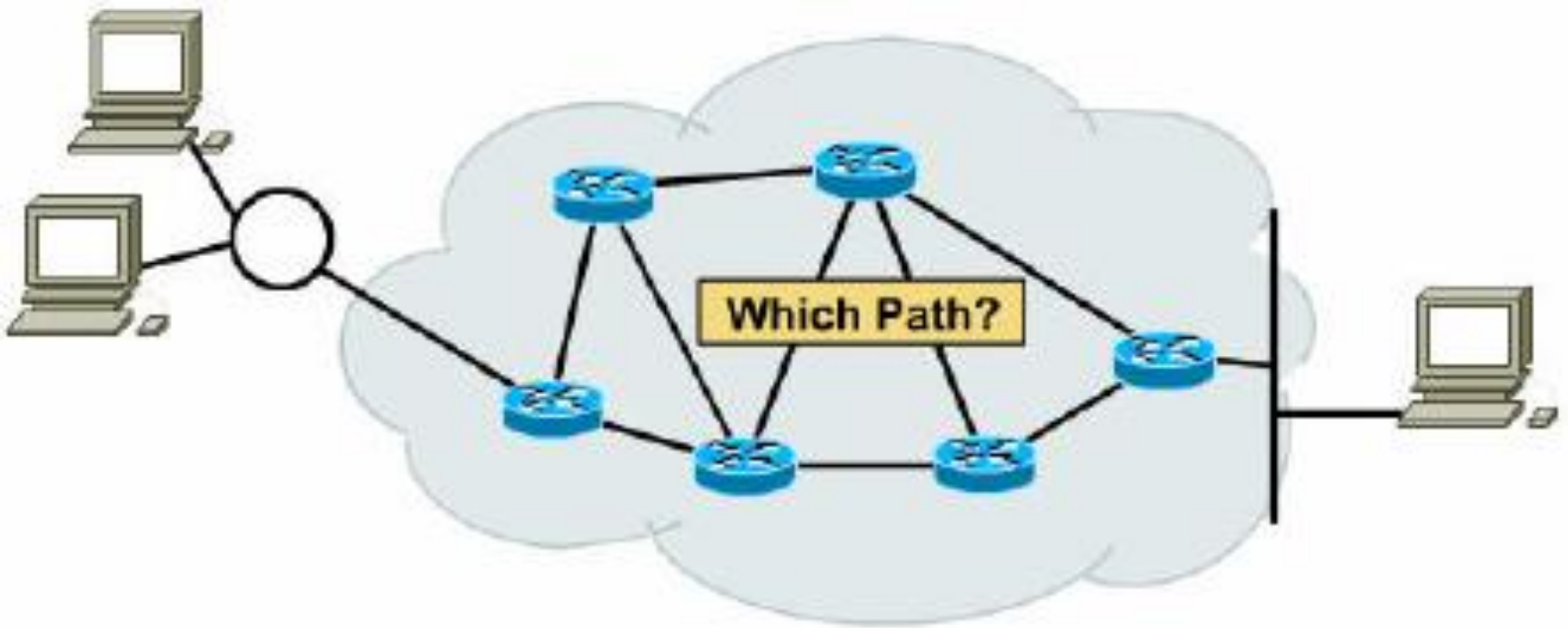
# Data relaying





# Path determination



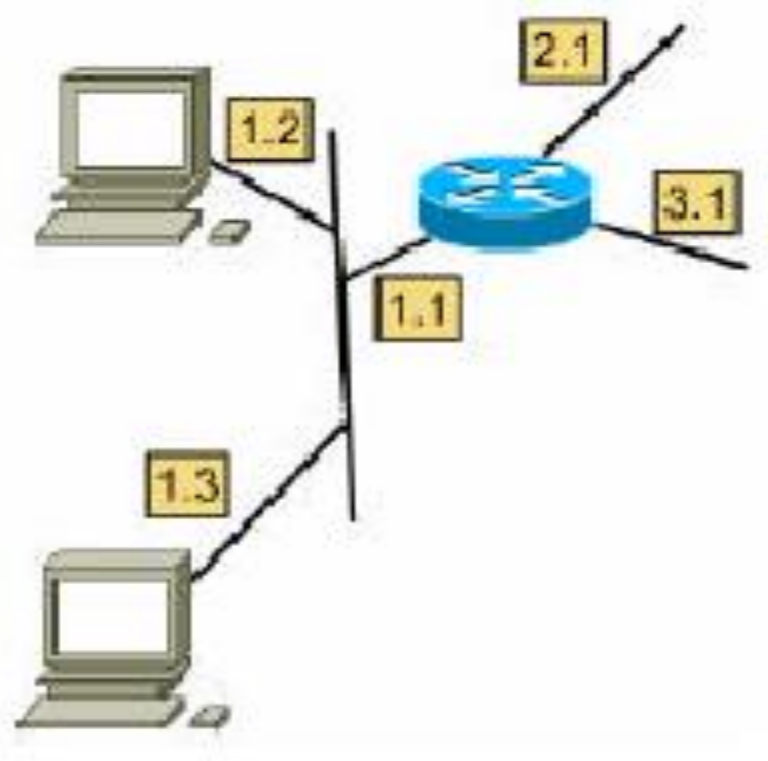



- **Path determination is the process that the router uses to choose the next hop in the path for the packet to travel to its destination based on the link bandwidth, hop, delay ...**

# Network layer addressing



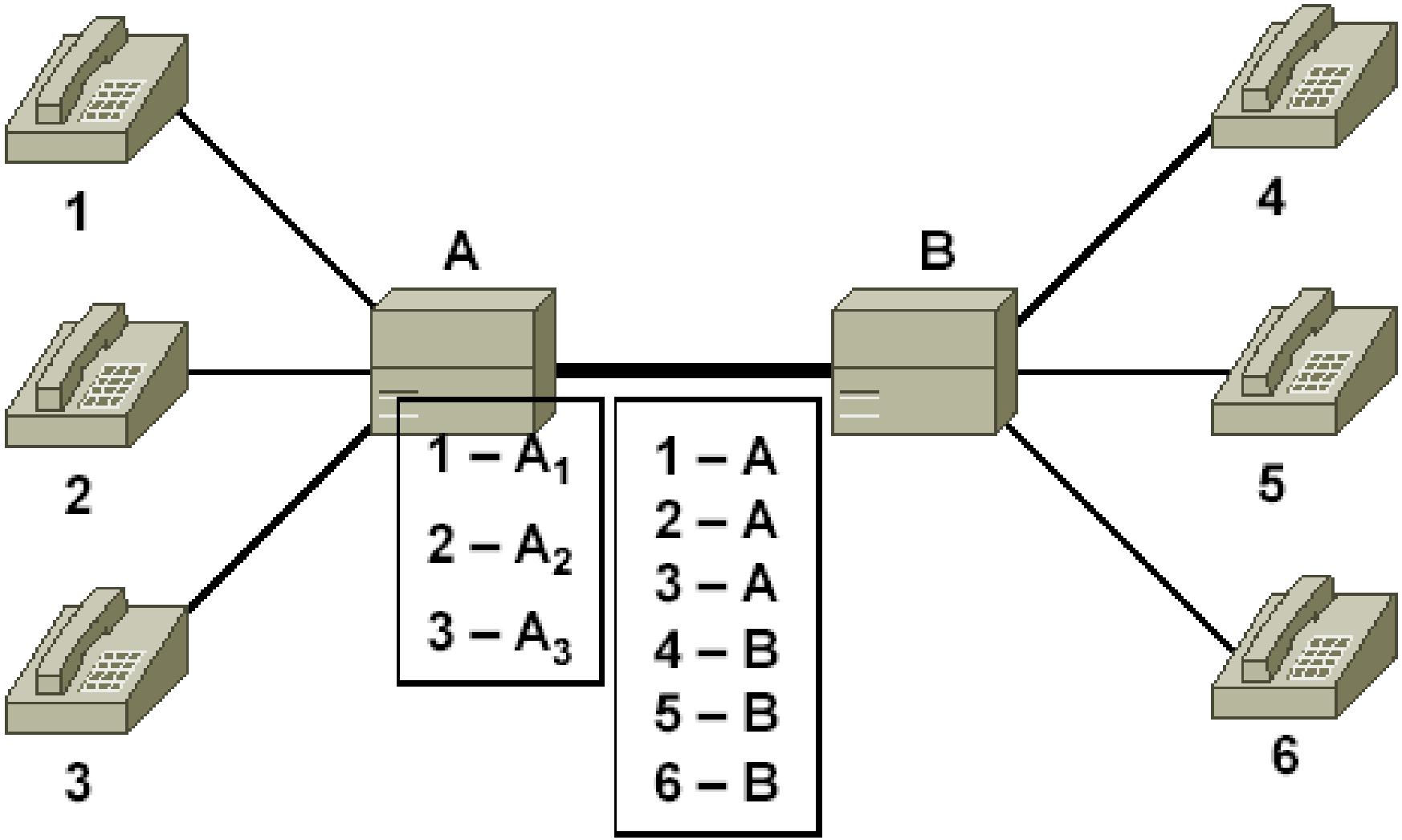
| Network | Host |
|---|---|
| 1 | 1 |
| | 2 |
| | 3 |
| 2 | 1 |
| 3 | 1 |




- **Network address + Host address: Hierarchical Addressing Schemes.**

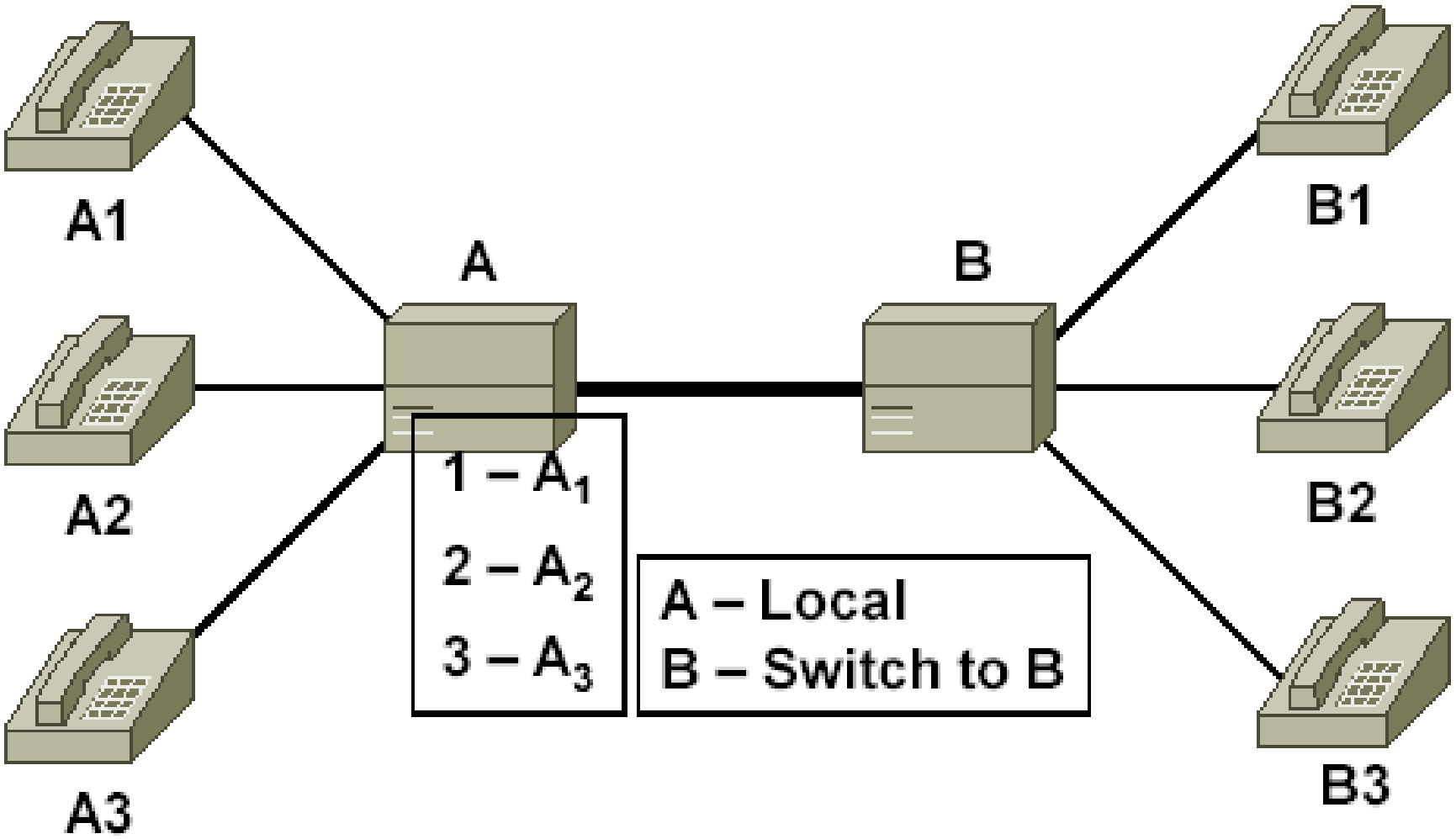
# Flat Addressing Scheme





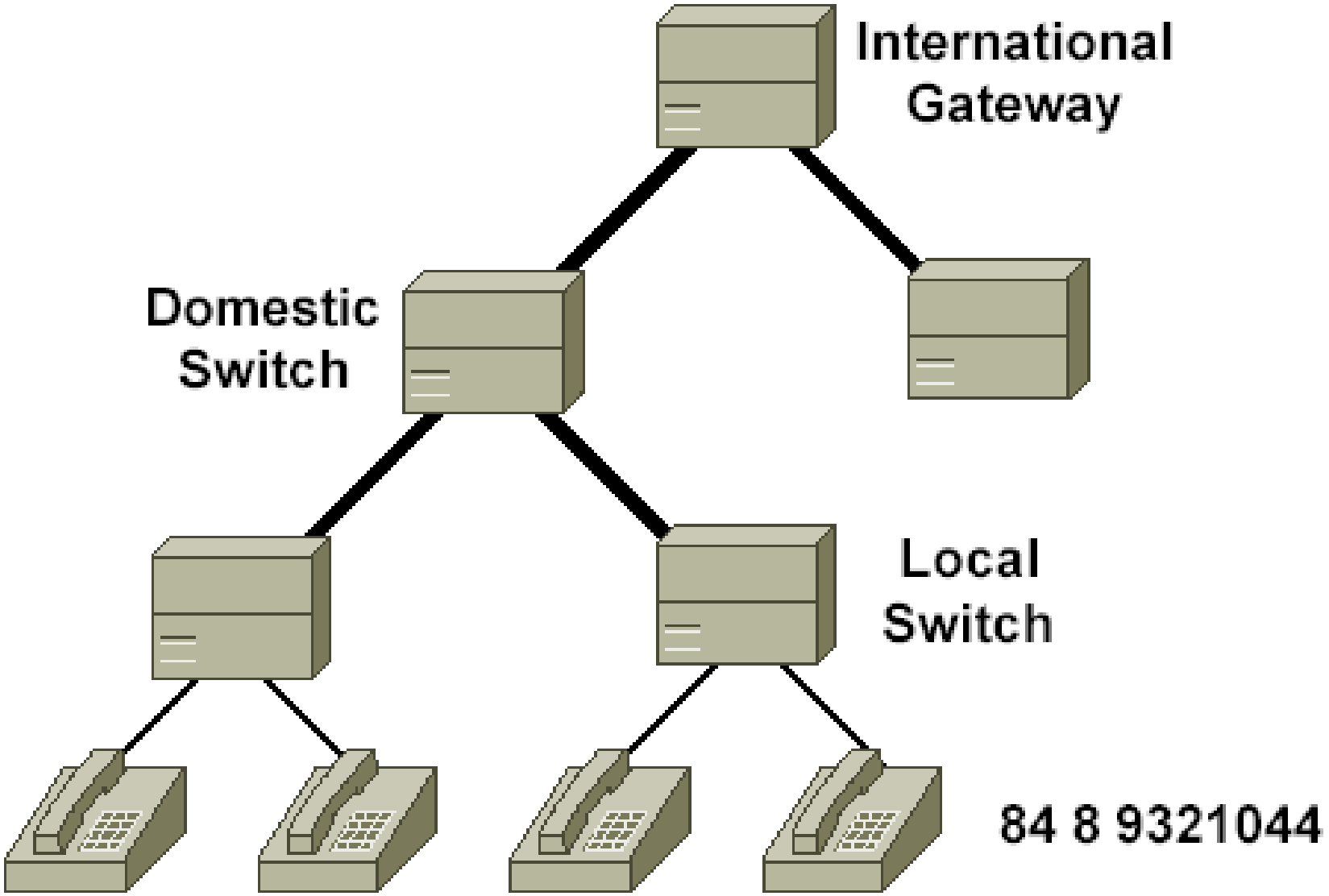
# Hierarchical Addressing Scheme





# Hierarchical Addressing Scheme





# Network address



- The network address helps the router identify a path within the network cloud.
- The router uses the network address to identify the destination network of a packet within an internetwork.
- Network address is assigned by higher-level administrator. Host address is assigned manually or automatically by manager of that network.

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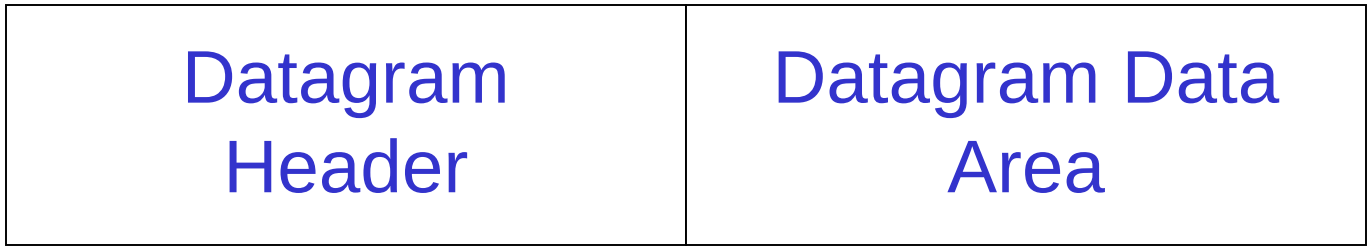
# IP ADDRESS WITHIN THE IP HEADER

# Network layer datagram

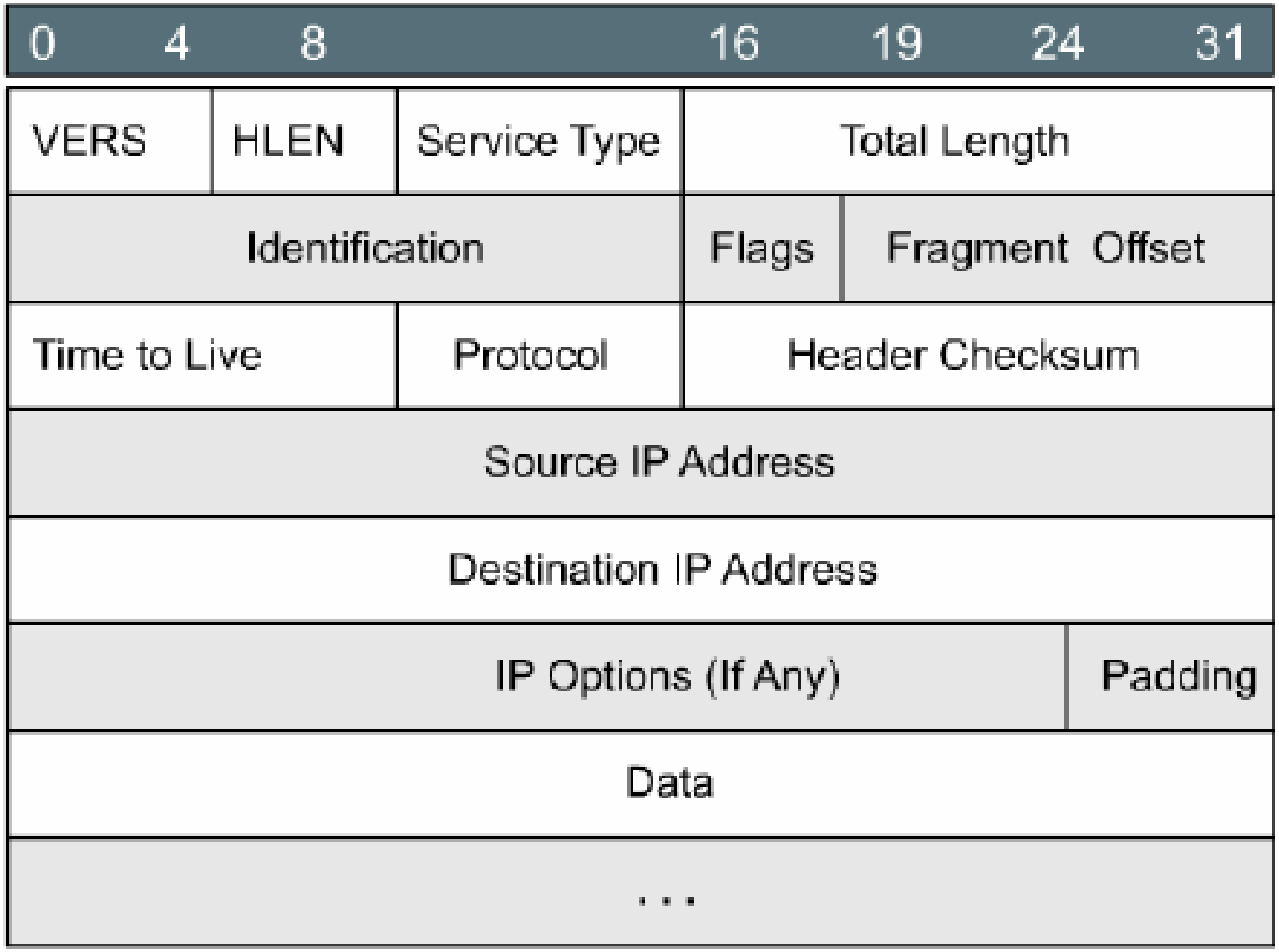





- **At the network layer, the data is encapsulated within packets (also known as datagrams).**
- **Packet includes header – addressing and other control information – and actual data - whatever is passed down from the higher layers.**

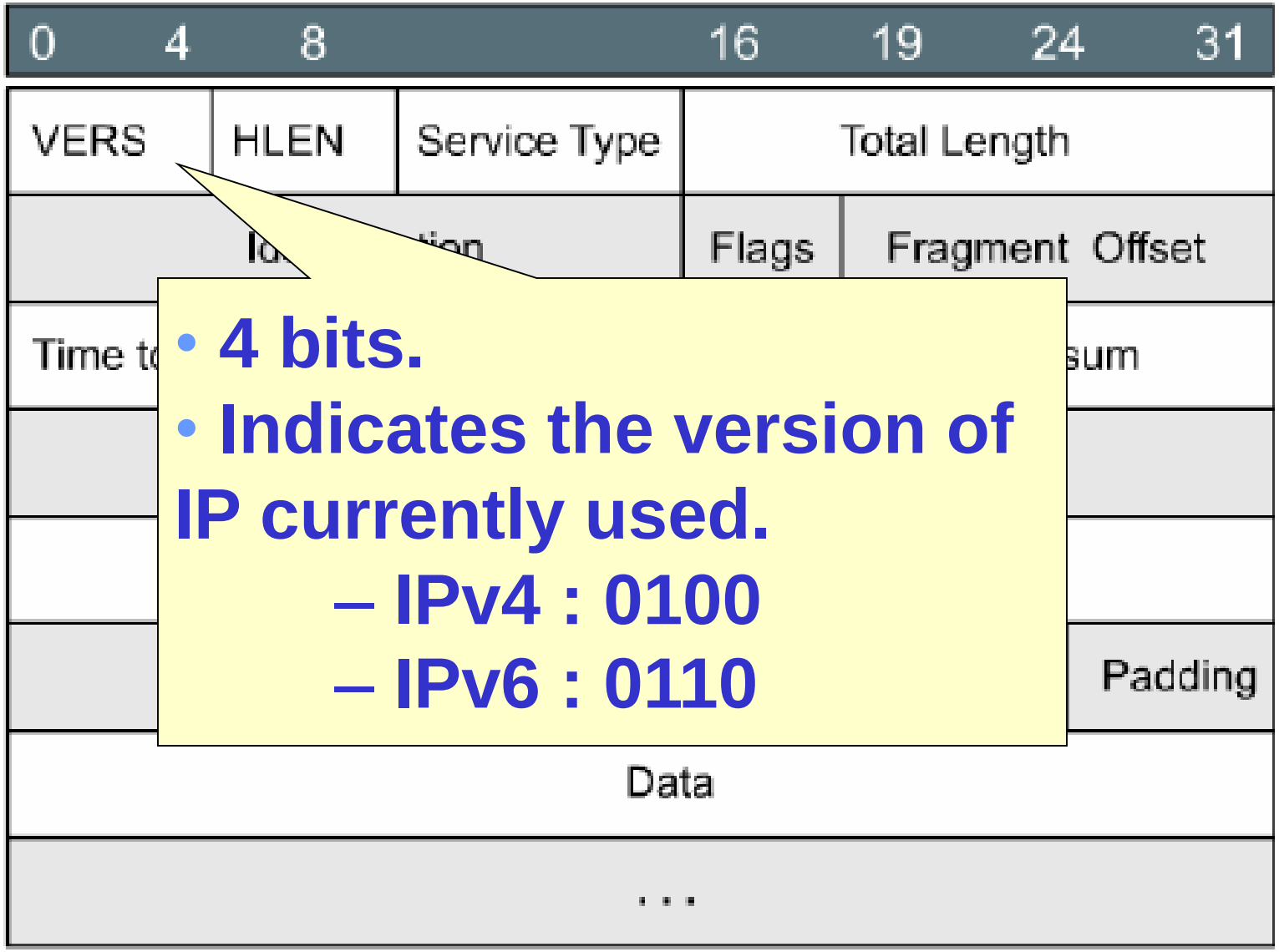
# IP header format





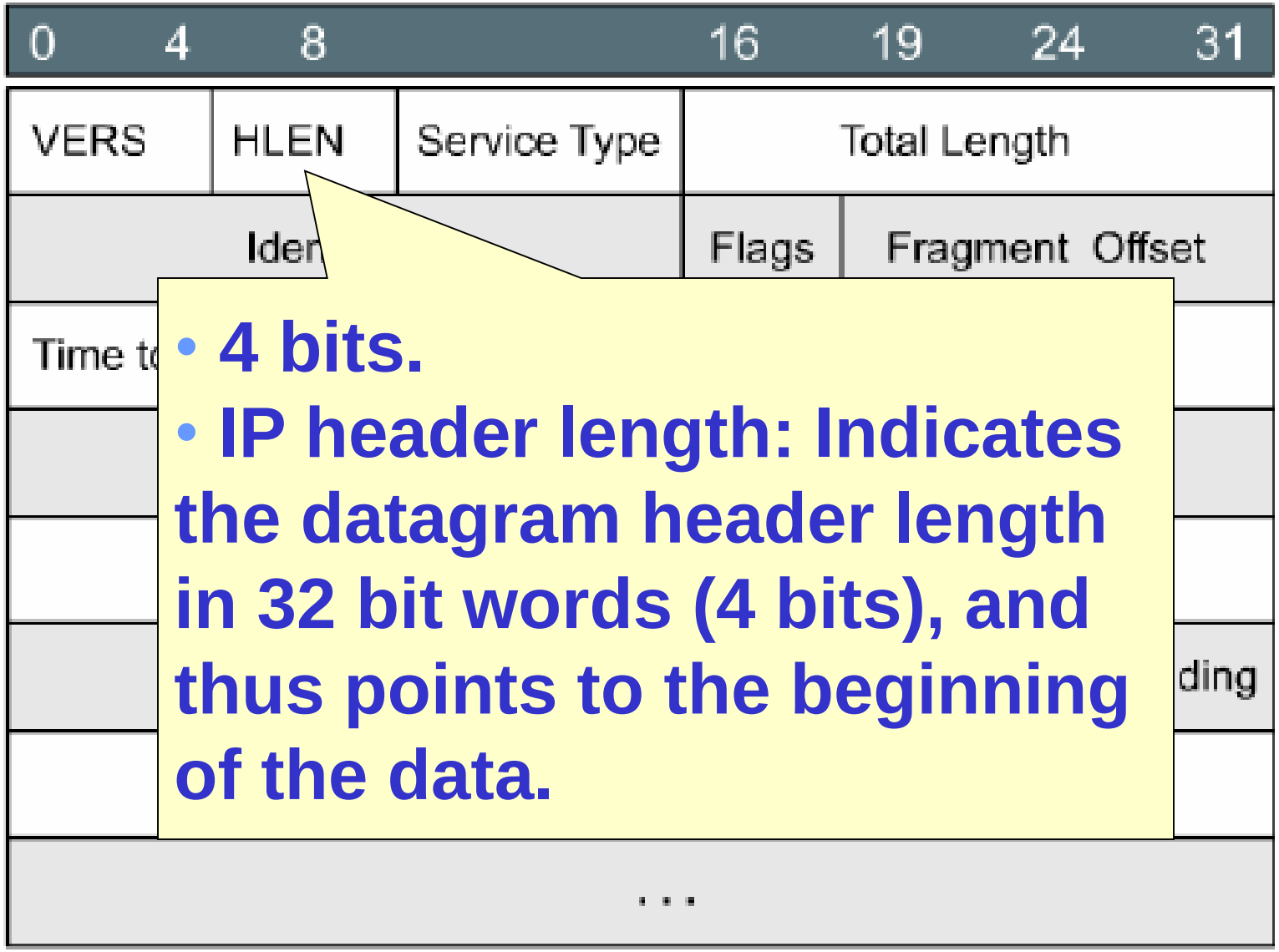
# IP header format: Version





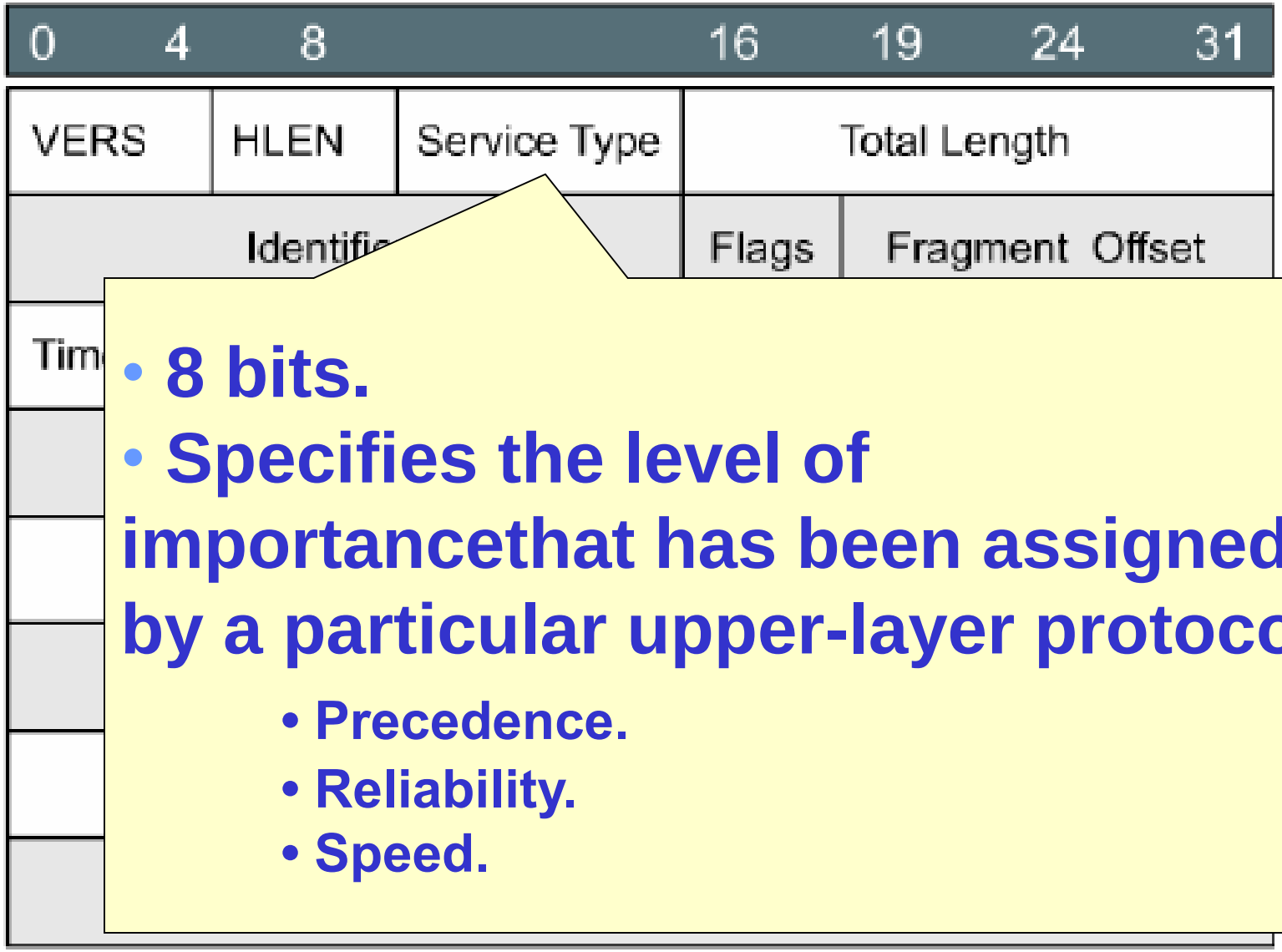

- **4 bits.**
- **Indicates the version of IP currently used.**
  - **IPv4 : 0100**
  - **IPv6 : 0110**

# IP header format: Header length



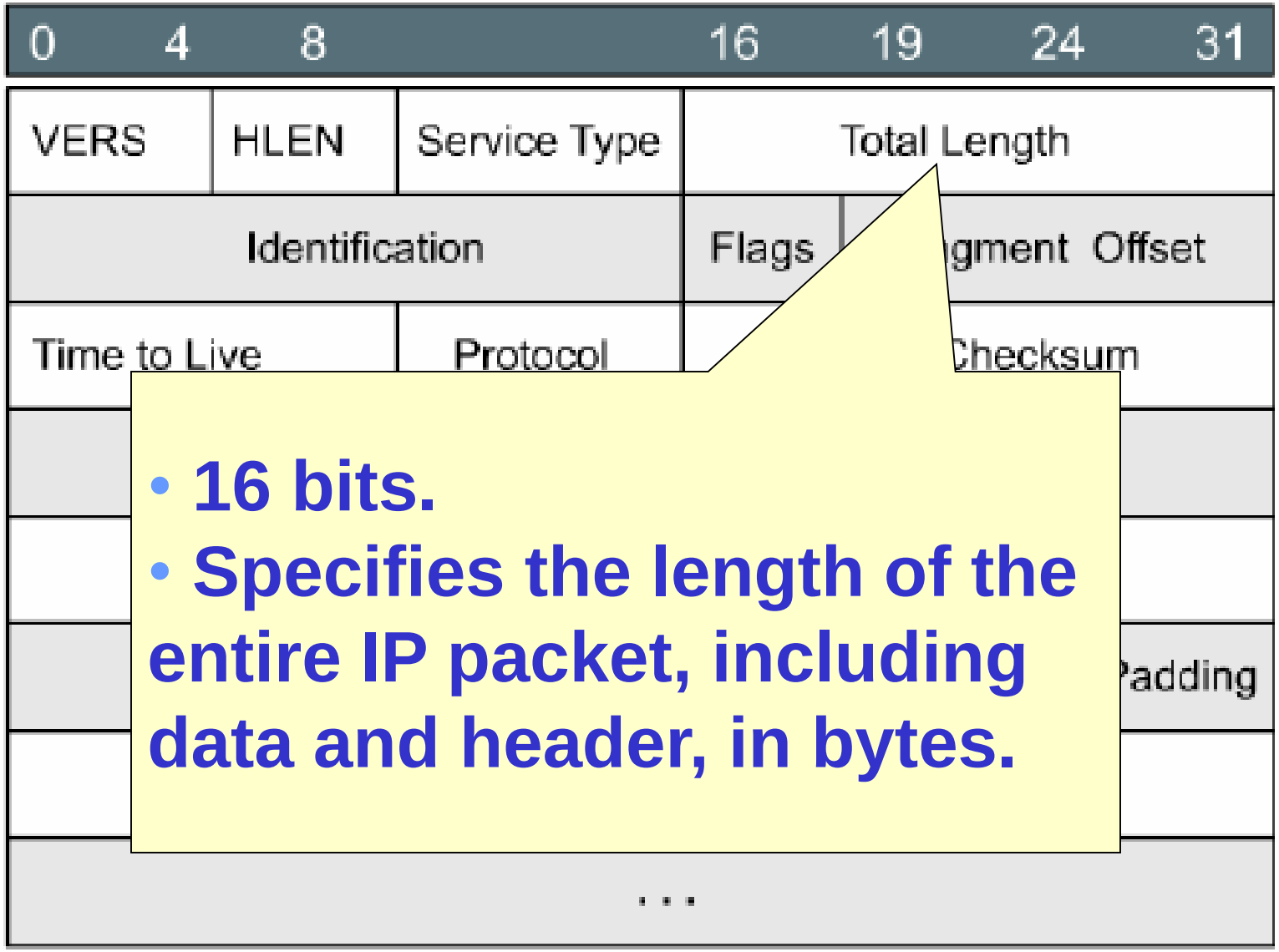

- **4 bits.**
- **IP header length: Indicates the datagram header length in 32 bit words (4 bits), and thus points to the beginning of the data.**

# IP header format: Service type



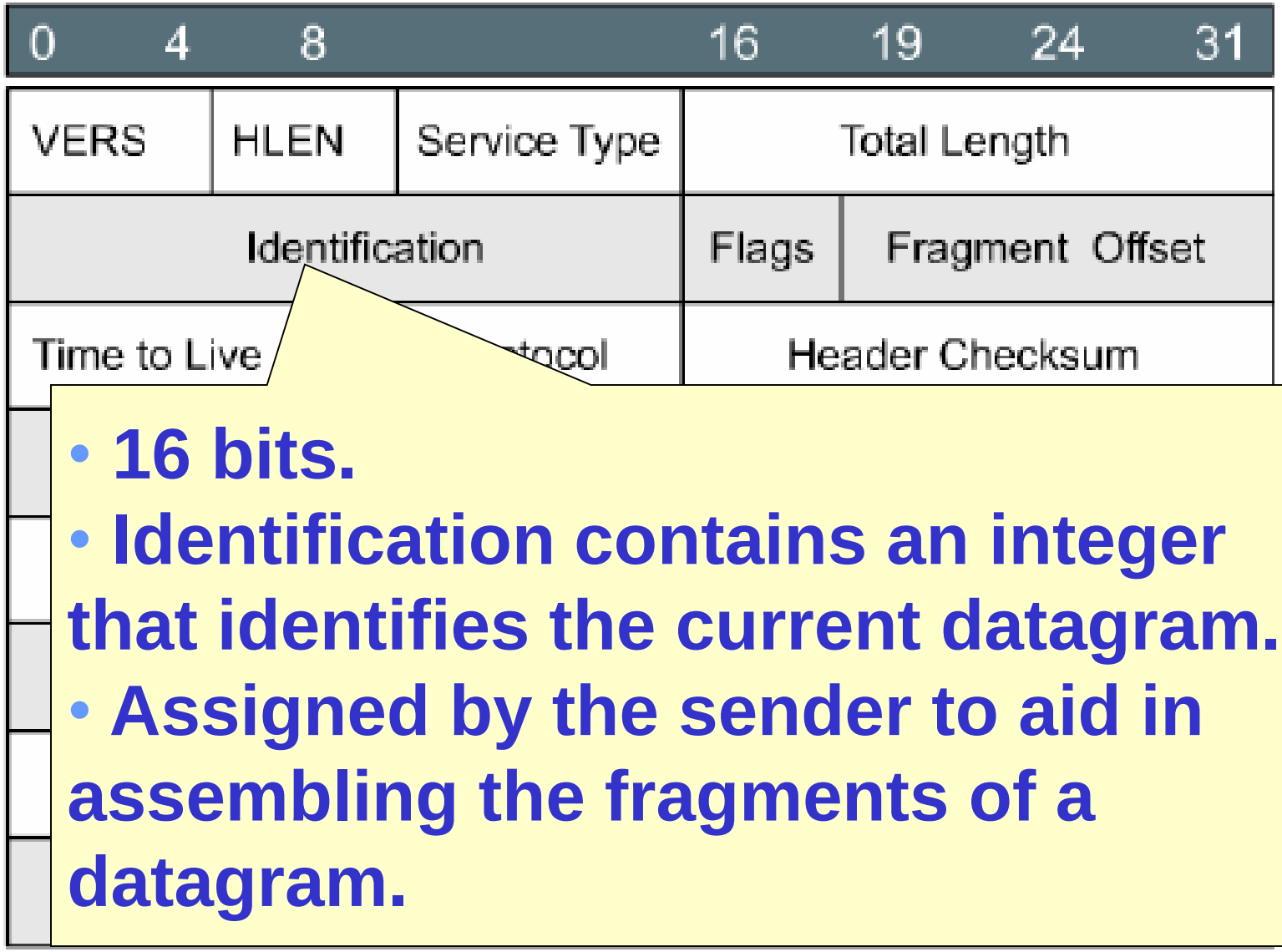

- 8 bits.
- Specifies the level of importancethat has been assigned by a particular upper-layer protocol.
  - Precedence.
  - Reliability.
  - Speed.

# IP header format: Total length



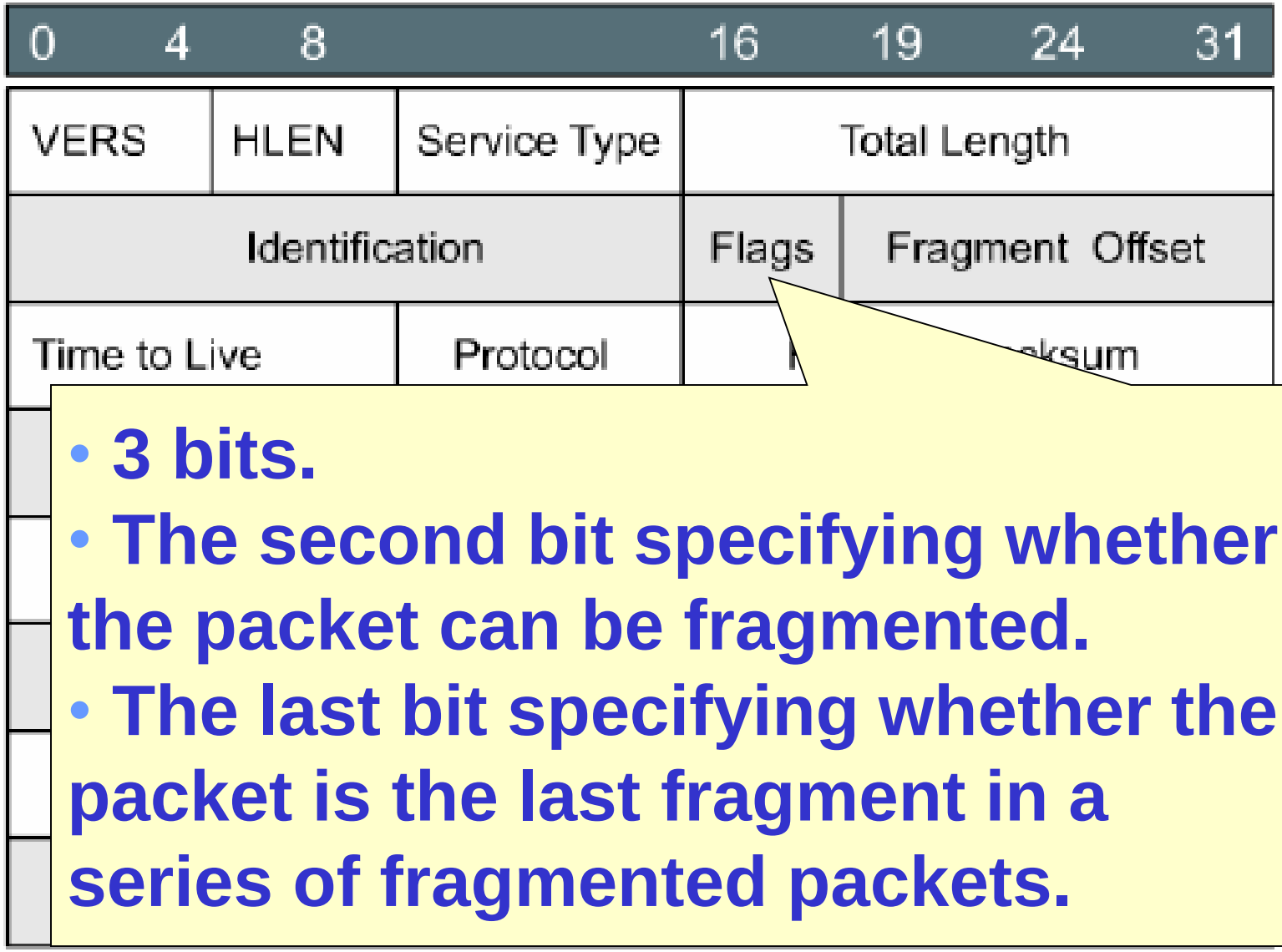

- 16 bits.
- Specifies the length of the entire IP packet, including data and header, in bytes.

# IP header format: Identification




- 16 bits.
- Identification contains an integer that identifies the current datagram.
- Assigned by the sender to aid in assembling the fragments of a datagram.

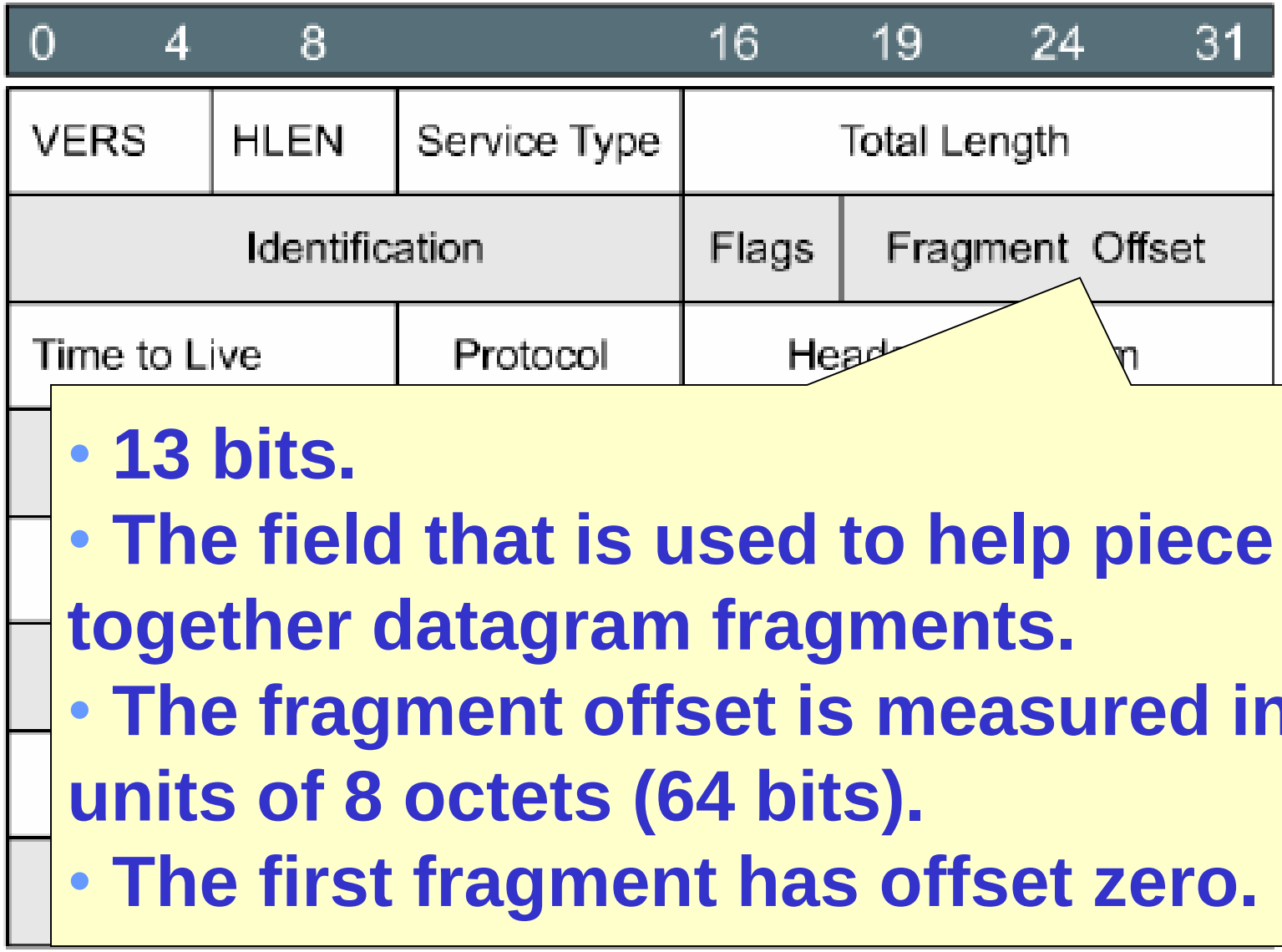
# IP header format: Flags




- 3 bits.
- The second bit specifying whether the packet can be fragmented.
- The last bit specifying whether the packet is the last fragment in a series of fragmented packets.

# IP header format: Fragment offset

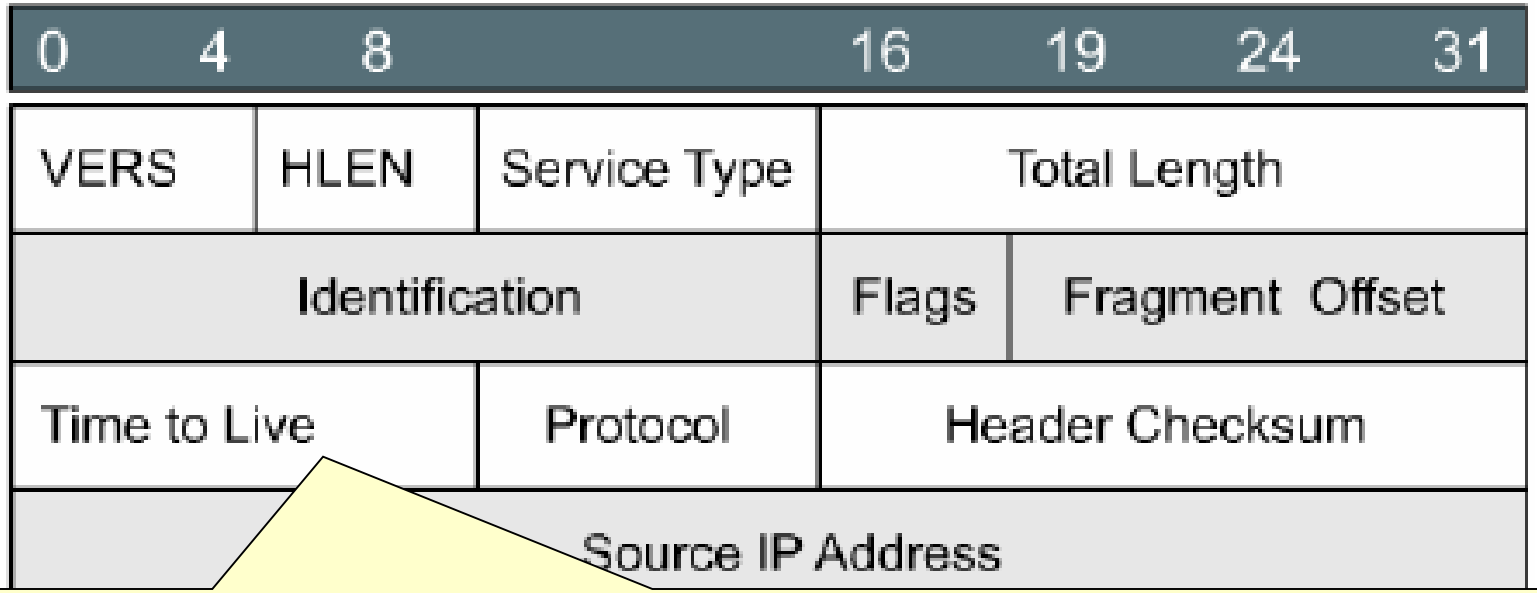





- 13 bits.
- The field that is used to help piece together datagram fragments.
- The fragment offset is measured in units of 8 octets (64 bits).
- The first fragment has offset zero.

# IP header format: Time to Live

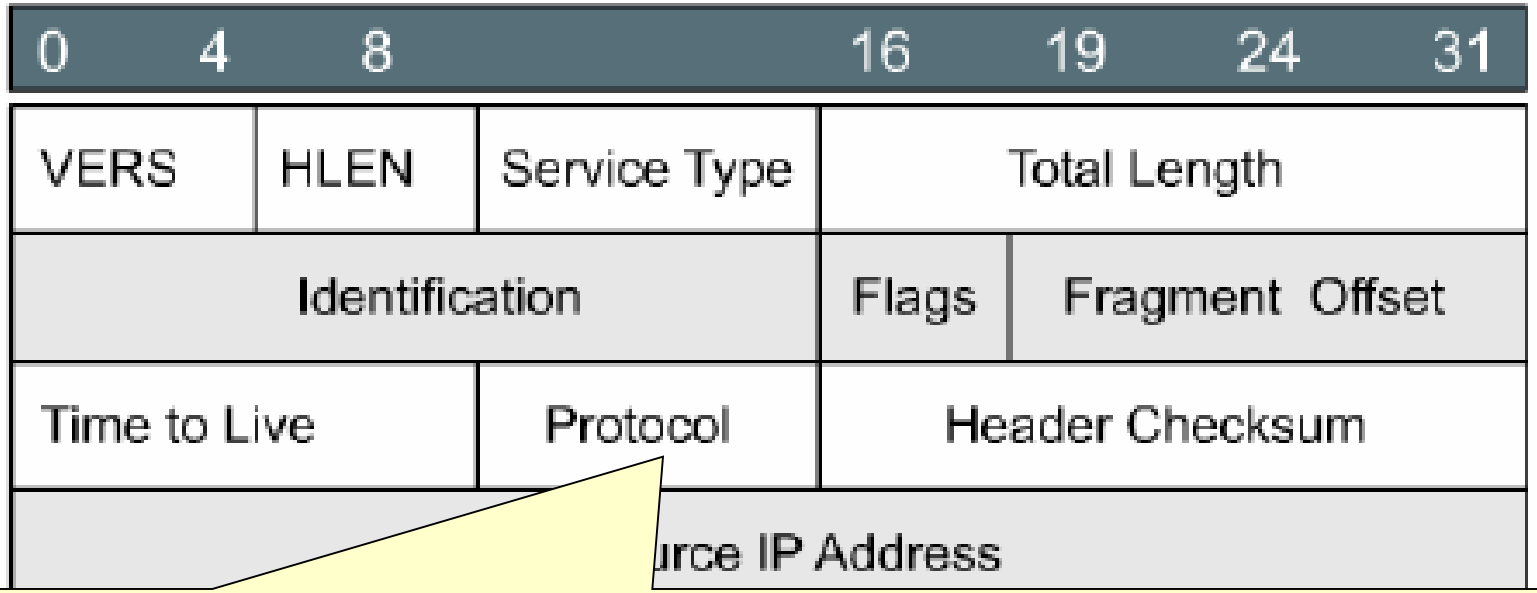





- 8 bits.
- Time-to-Live maintains a counter that gradually decreases to zero, at which point the datagram is discarded, keeping the packets from looping endlessly.

# IP header format: Protocol

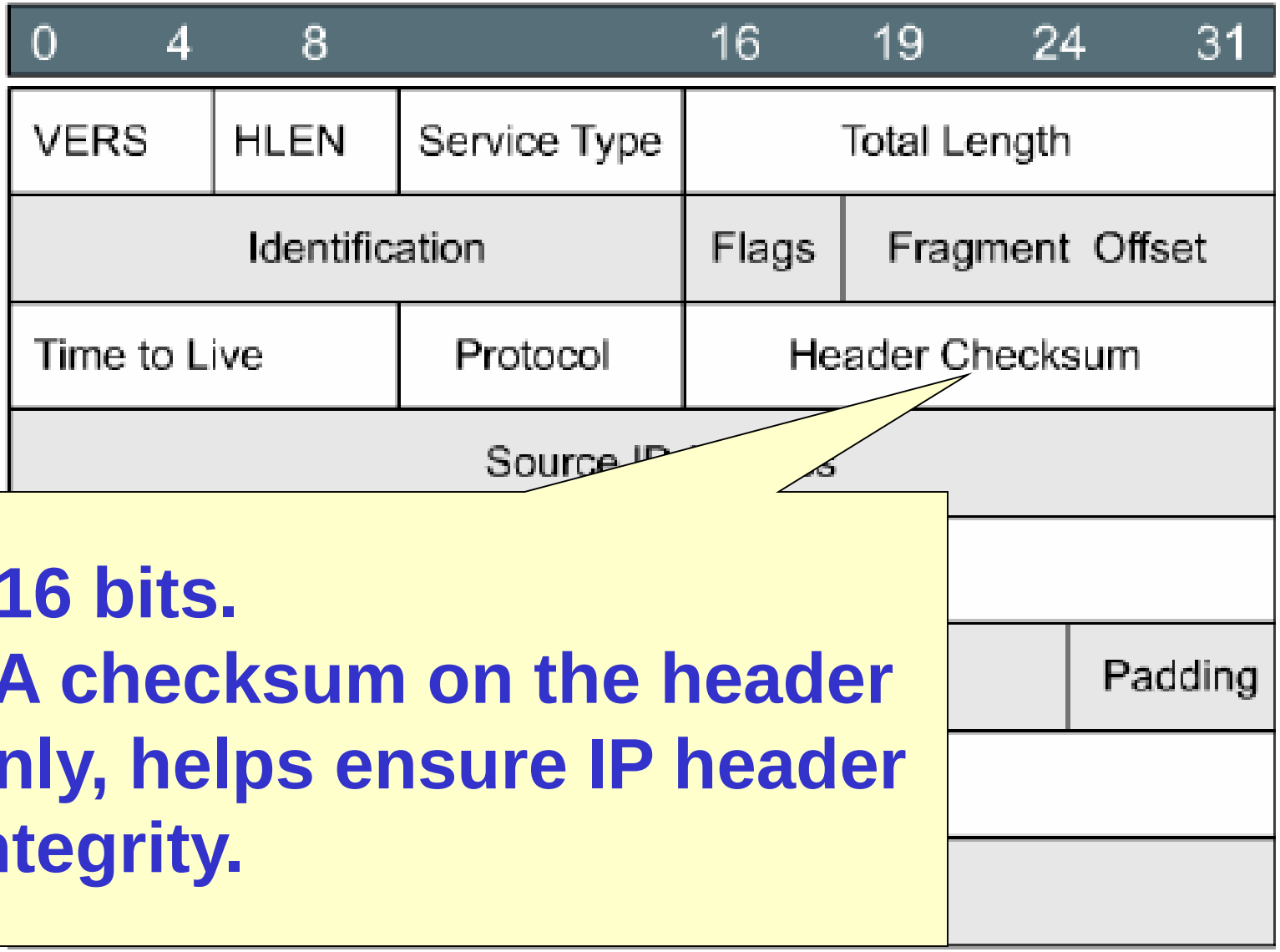





- 8 bits.
- Indicates which upper-layer protocol receives incoming packets after IP processing has been completed
  - 06 : TCP
  - 17 : UDP

# IP header format: Header checksum



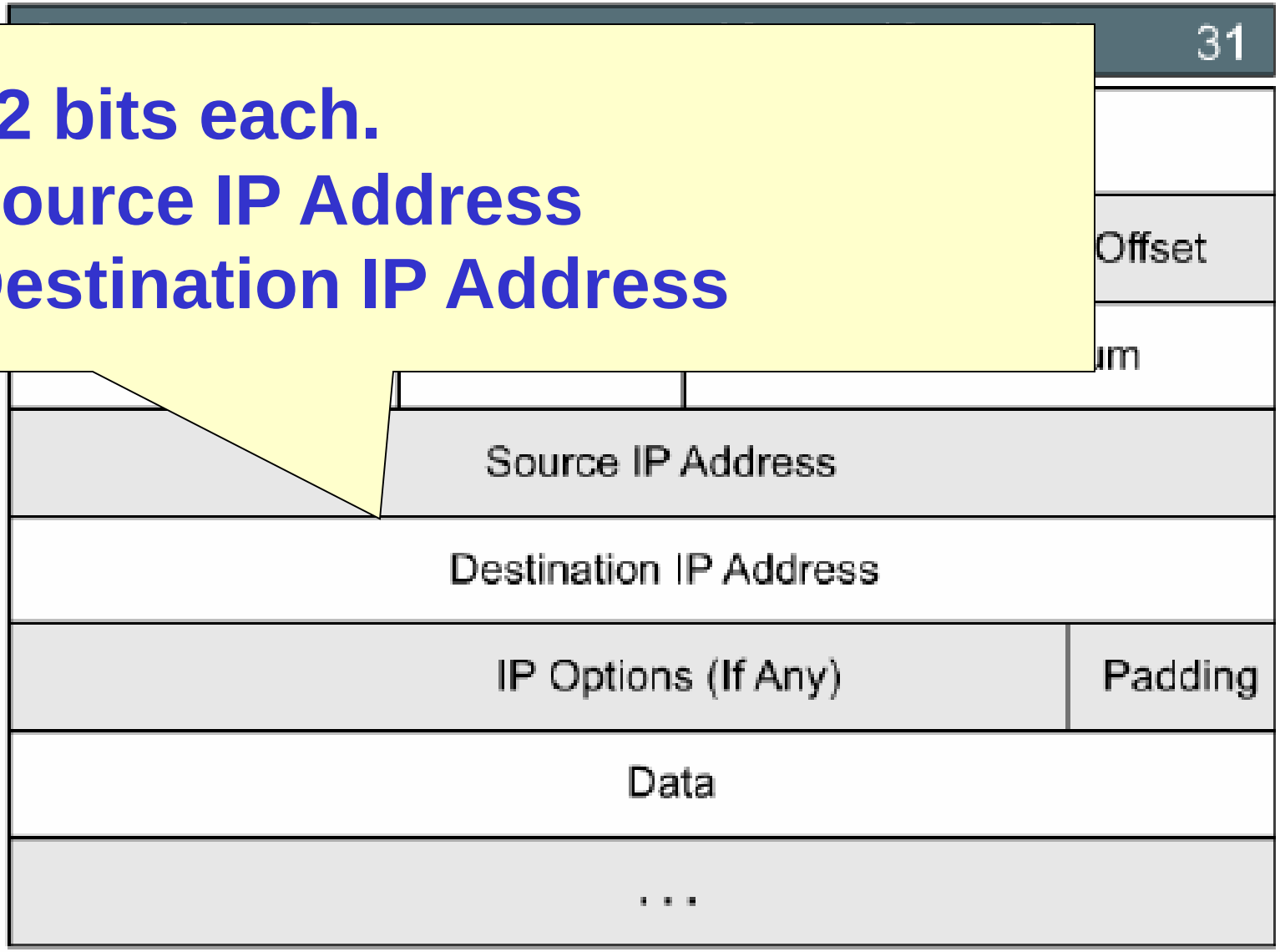



- 16 bits.
- A checksum on the header only, helps ensure IP header integrity.

# IP header format: Addresses

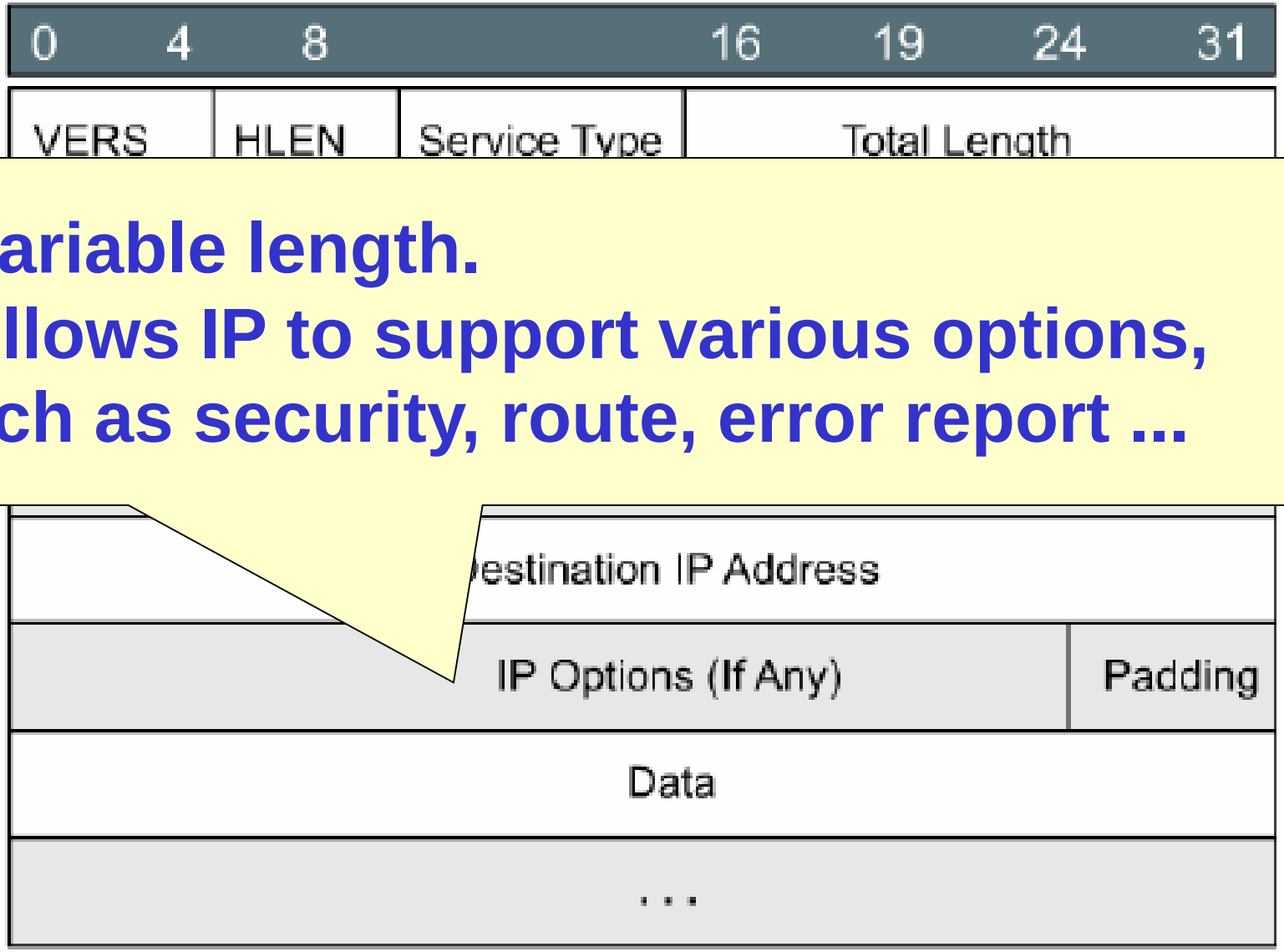


- 32 bits each.
- Source IP Address
- Destination IP Address



# IP header format: Options

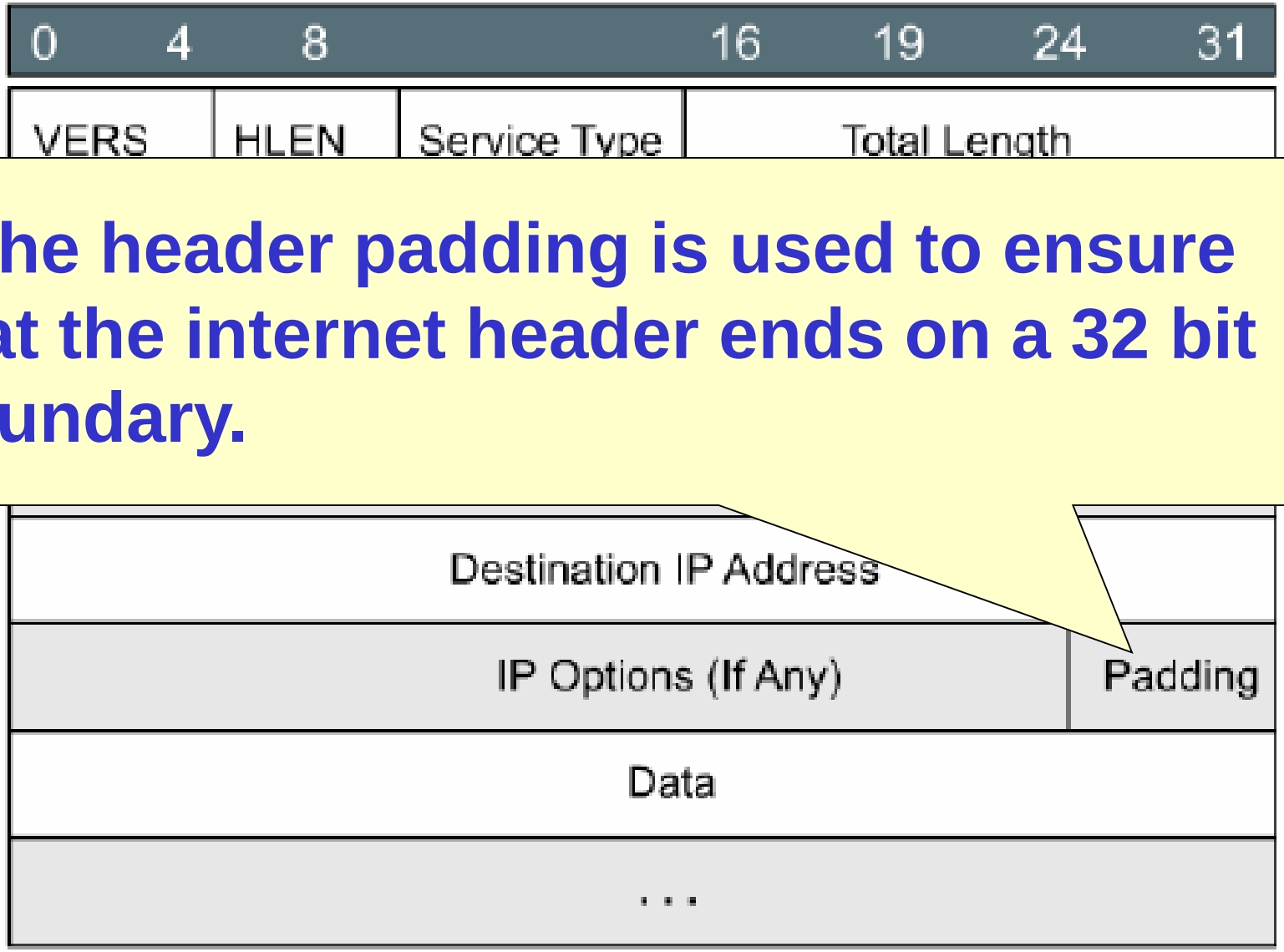





- Variable length.
- Allows IP to support various options, such as security, route, error report ...

# IP header format: Padding






- The header padding is used to ensure that the internet header ends on a 32 bit boundary.

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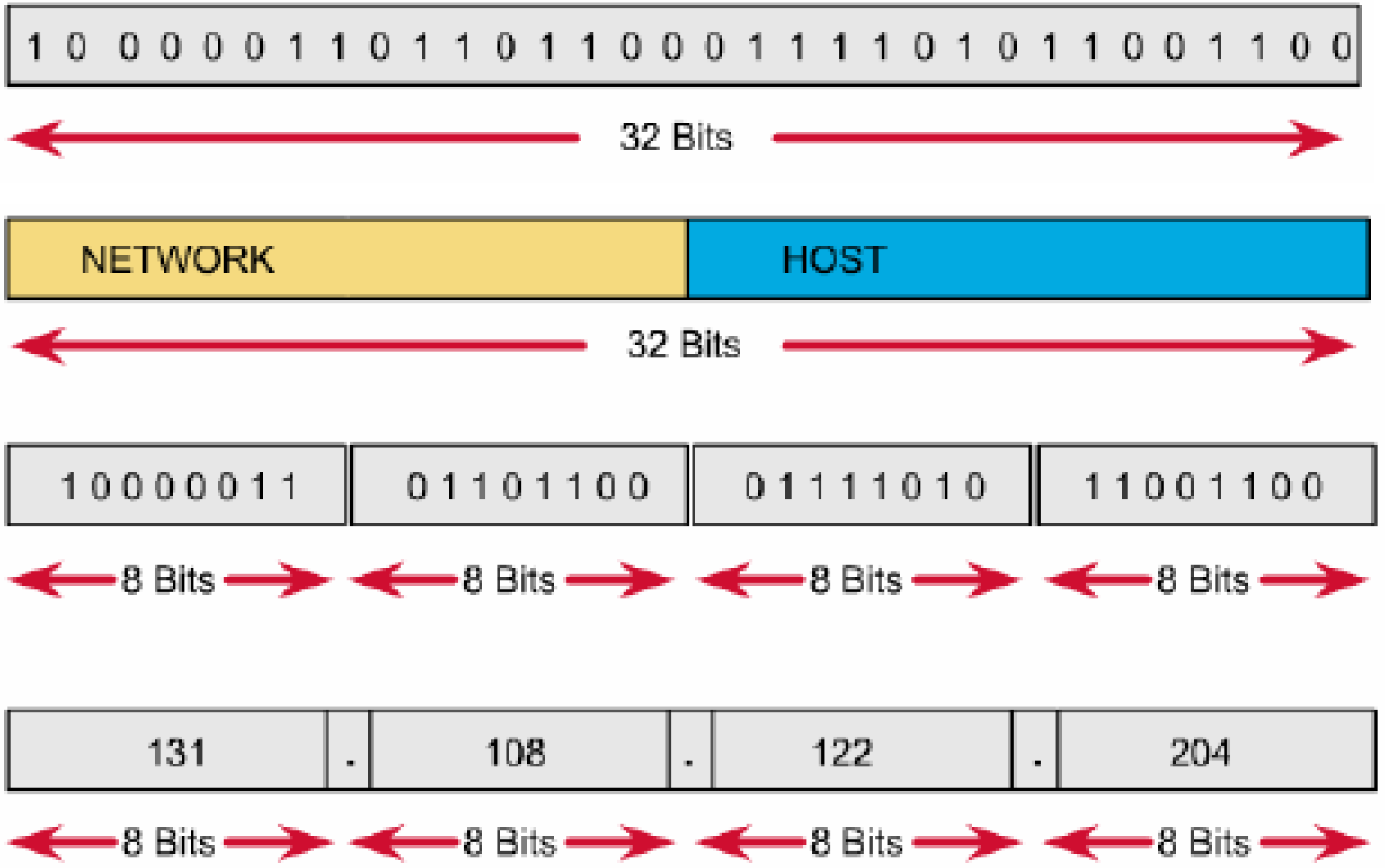
# IP ADDRESS CLASSES

# IP network address



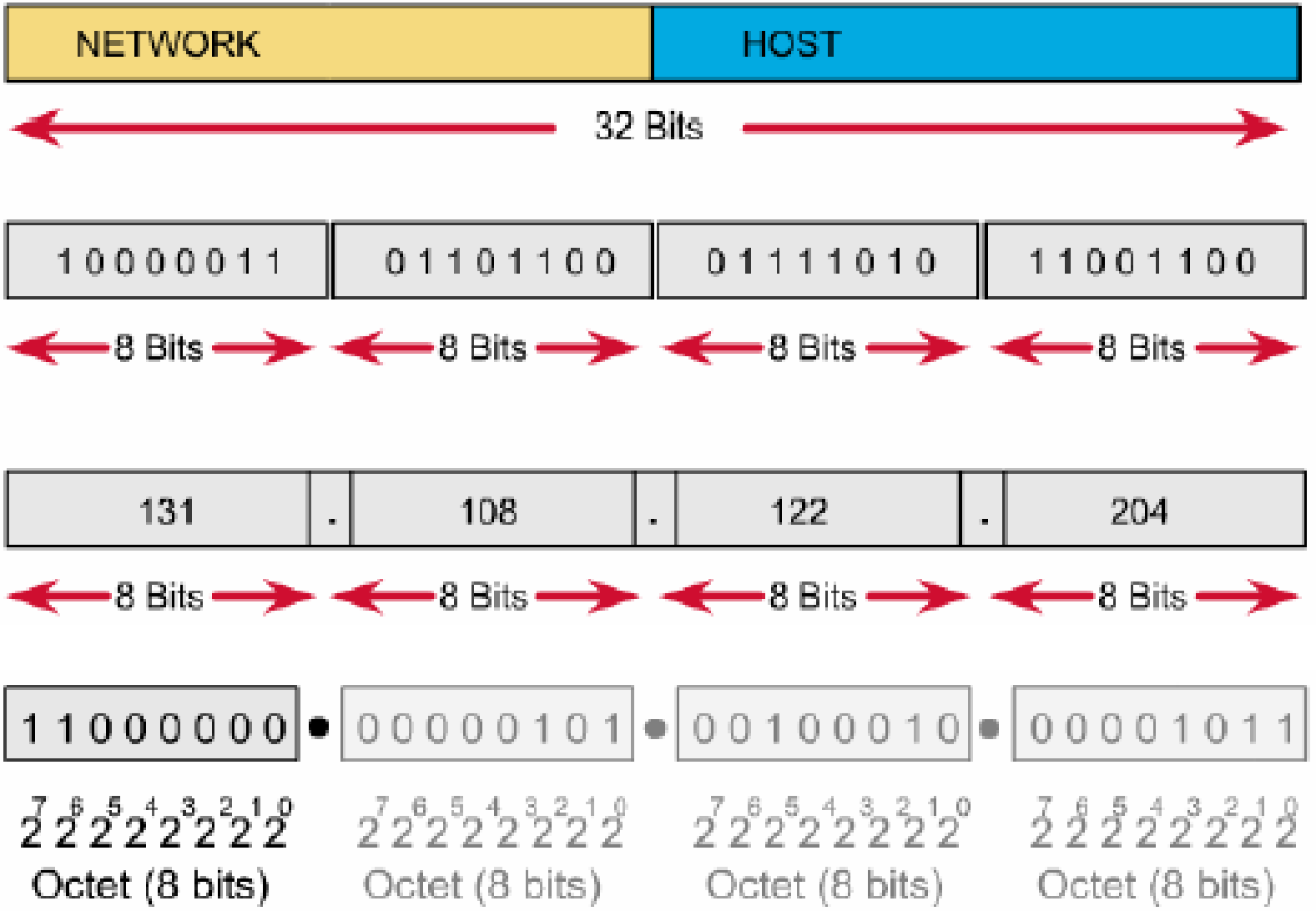
- Network layer addresses are 32 bits long.
- The are presented as four octets in dotted decimal format.
- The IP address has two components: Network ID and Host ID.

# IP address format



# Binary and decimal conversion





# Why we need to know B-D conversion



- **Use of calculators is discouraged for two reasons :**
  - **First, practitioners of networking often need to make quick.**
  - **Second, no calculators are allowed on the CCNA exam.**

# Network ID and host ID



- **Network ID**:
  - Assigned by **Internet Network Information Center**.
  - Assigned by upper organization.
  - Identifies the network to which a devices is attached.
- **Host ID**:
  - Assigned by a network administrator.
  - Identifies the specific device on that network.

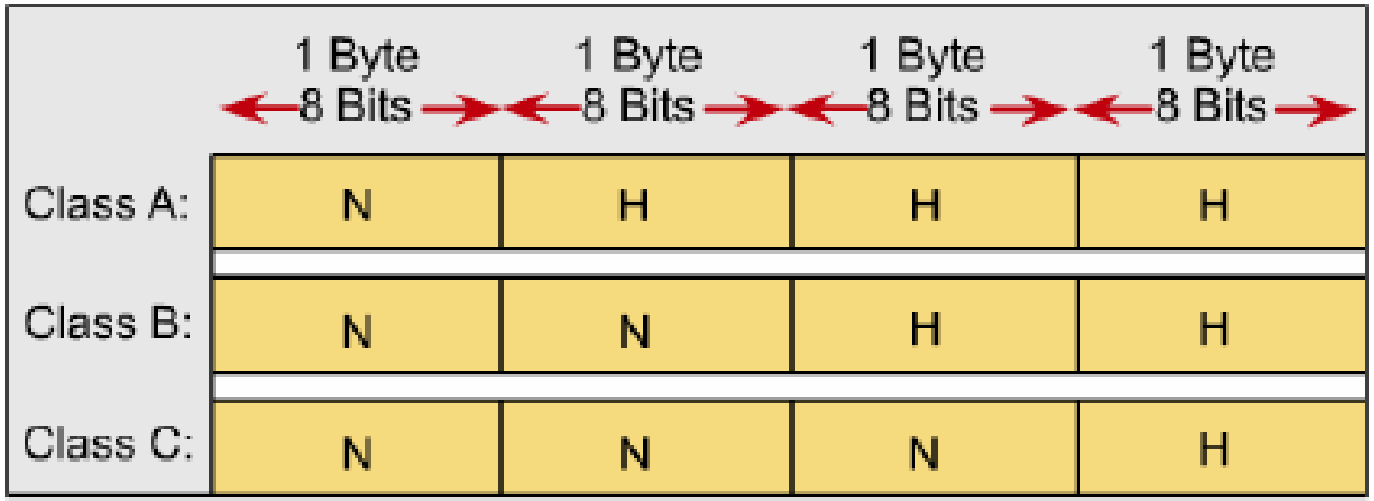
# Bits on the IP address



- **Network Bits**:
  - Identifies network ID
  - Identifies class of the IP address
  - All of bits are 0: not allowed
- **Host Bits**:
  - Identifies host ID
  - All of bits are 0: reserved for network address
  - All of bits are 1: reserved for broadcast address

# IP address classes

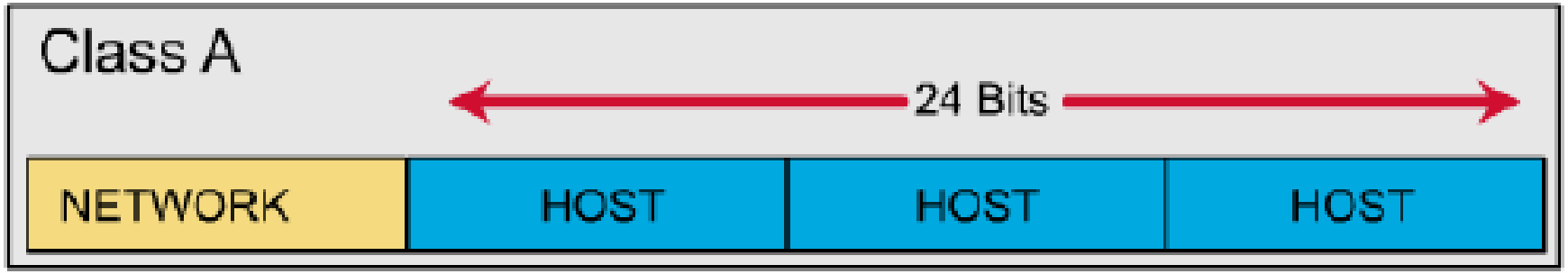





- **Different class addresses reserve different amounts of bits for the Network and Host portions of the address**
- **Provide the flexibility required to support different size networks**

# IP address classes: Class A






| # Bits | 1 | 7 | 24 |
|---|---|---|---|
| Class A: | 0 | NETWORK# | HOST# |

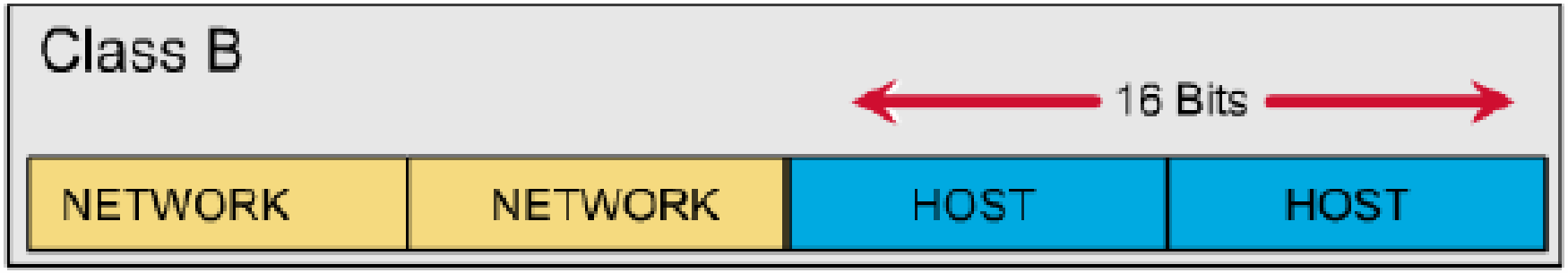
# IP address classes: Class A



- The first bit of a Class A address is always 0.
- The first 8 bits to identify the network part of the address.
- Possible network address from 1.0.0.0 to 127.0.0.0.
- The remaining three octets can be used for the host portion of the address.
- Each class A network have up to 16,777,214 possible IP addresses.

# IP address classes: Class B






| # Bits | 1 | 1 | 14 | 16 |
|---|---|---|---|---|
| Class B: | 1 | 0 | NETWORK# | HOST# |

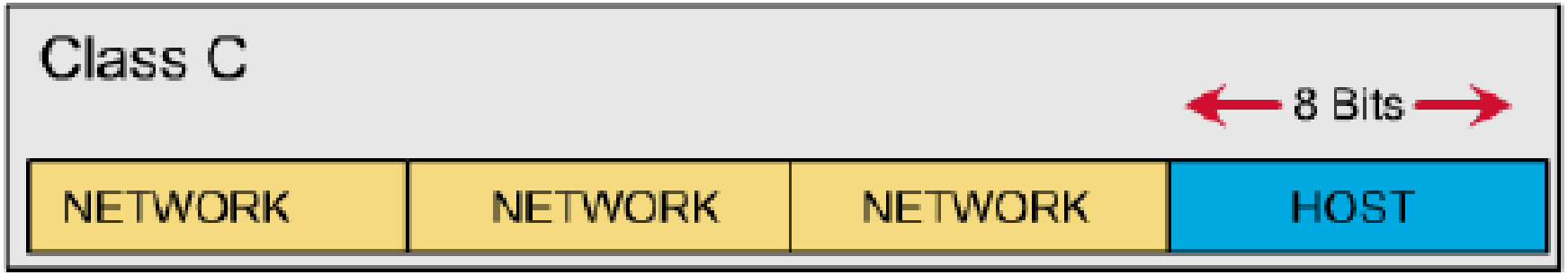
# IP address classes: Class B



- The first 2 bits of a Class B address is always 10.
- The first two octets to identify the network part of the address.
- Possible network address from 128.0.0.0 to 191.255.0.0.
- The remaining two octets can be used for the host portion of the address.
- Class B network have up to 65.534 possible IP addresses.

# IP address classes: Class C






| # Bits | 1 | 1 | 1 | 21 | 8 |
|---|---|---|---|---|---|
| Class C: | 1 | 1 | 0 | NETWORK# | HOST# |

# IP address classes: Class C



- The first 3 bits of a Class C address is always 110.
- The first three octets to identify the network part of the address.
- Possible network address from 192.0.0.0 to 223.255.255.0.
- The remaining last octet can be used for the host portion of the address.
- Class C network have up to 254 possible IP addresses.

# IP address classes: Summary



- 1.0.0.0 - 126.0.0.0 : Class A.
- 127.0.0.0 : Loopback network.
- 128.0.0.0 - 191.255.0.0 : Class B.
- 192.0.0.0 - 223.255.255.0 : Class C.
- 224.0.0.0 < 240.0.0.0 : Class D, multicast.
- >= 240.0.0.0 : Class E, reserved.

# Network address



- Network address provide a convenient way to refer to all of the addresses on a particular network or subnetwork.
- Two hosts with differing network address require a device, typically a router, in order to communicate.
- An IP address that ends with binary 0s in all host bits is reserved for the network address.

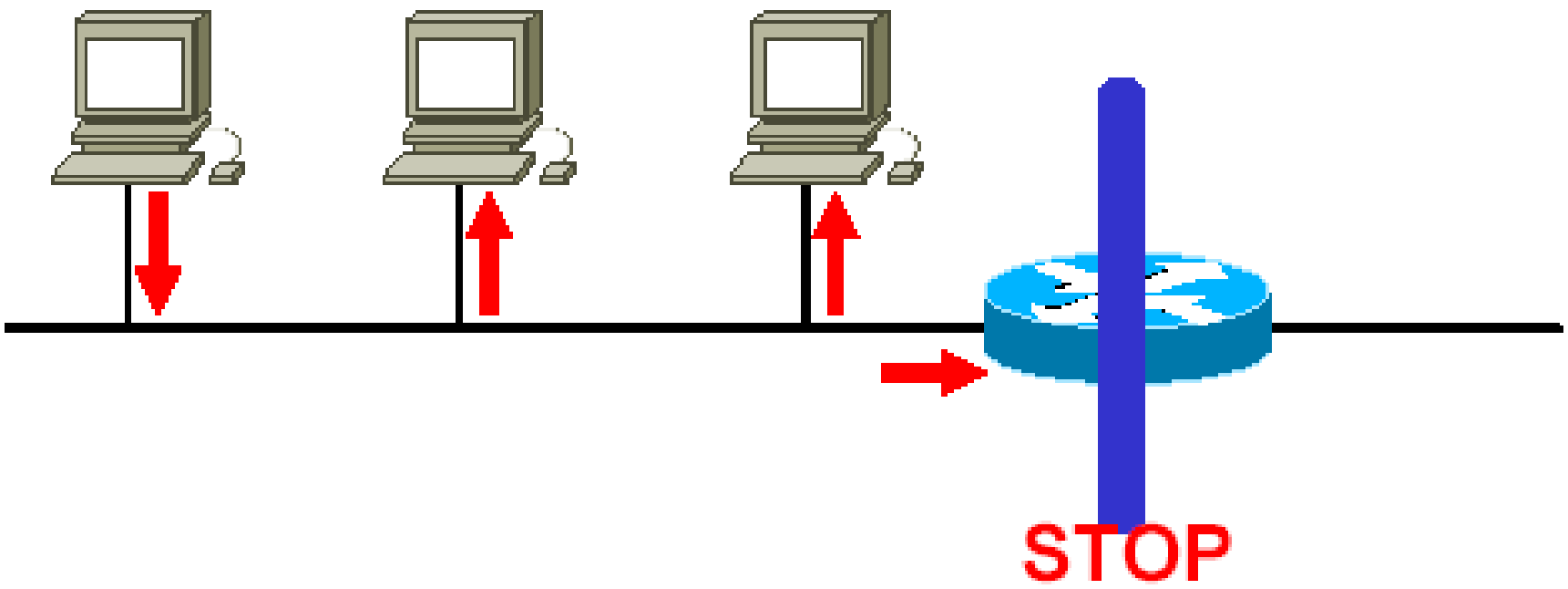
# Broadcast address



- Broadcast goes to every host with a particular network ID number.
- An IP address that ends with binary 1s in all host bits is reserved for the directed broadcast address.
- An IP address with binary 1s in all network bits and host bits is reserved for the local broadcast address.

# Local broadcast address



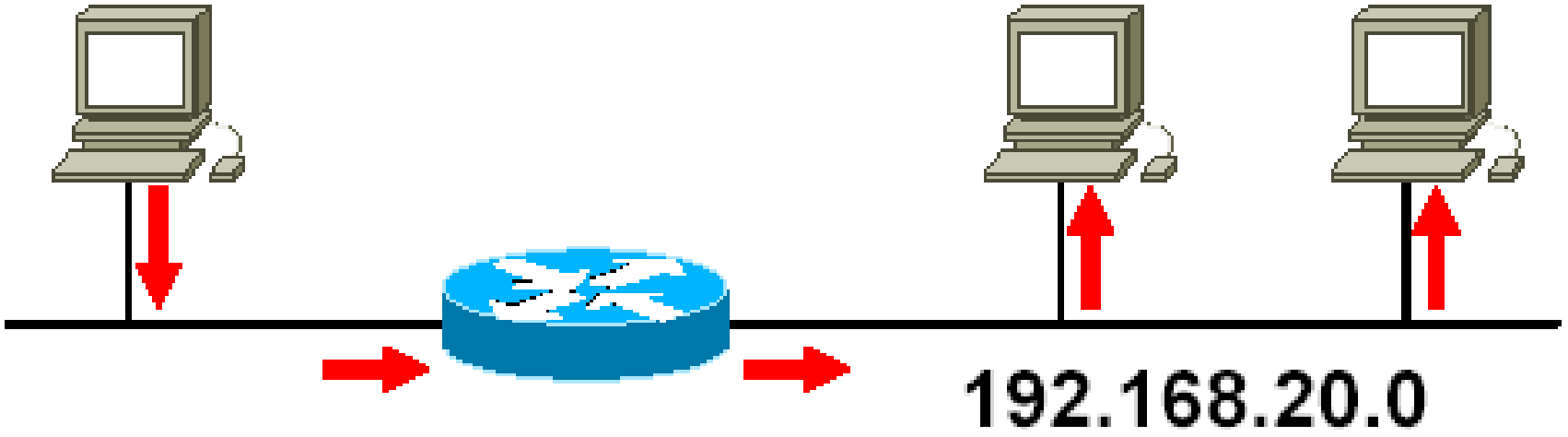



**Broadcast address**

**255.255.255.255**

# Directed broadcast address






**Broadcast address**

**192.168.20.255**

# Example: 172.16.20.200



- 172.16.20.200 is Class B address
- Network portion: 172.16
- Host portion: 20.200
- Network address: 172.16.0.0
- Broadcast address: 172.16.255.255

# Private addresses



- According to RFC-1918.
- Organizations make use of the private Internet address space for hosts that require IP connectivity within their enterprise network, but do not require external connections to the global Internet.
- Class A: 10.0.0.0
- Class B: 172.16.0.0 - 172.31.0.0
- Class C: 192.168.0.0 - 192.168.255.0

# Preparation for LAB



- **Lab companion:**
  - **10.4.1: IP address classes.**

# Lab 10.4.1: Step 1



- **Review IP address classes and their characteristics.**

# Lab 10.4.1: Step 2



1. What is the decimal and binary range of the first octet of class B IP addresses?
   - Decimal: 128 – 191
   - Binary: 10000000 – 10111111
2. Which octet(s) represent the network portion of a class C IP address?
   - The first three octets
3. Which octet(s) represent the host portion of a class A IP address?
   - The last three octets

# Lab 10.4.1: Step 3



| Host IP Address | Address Class | Network Address | Host Address | Broadcast Address |
|---|---|---|---|---|
| 218.14.55.137 | C | 218.14.55 | 137 | 218.14.55.255 |
| 123.1.1.15 | A | 123 | 1.1.15 | 123.255.255.255 |
| 150.127.221.244 | B | 150.127 | 221.244 | 150.127.255.255 |
| 194.125.35.199 | C | 194.125.35 | 199 | 194.125.35.255 |
| 175.12.239.244 | B | 175.12 | 239.244 | 175.12.255.255 |

# Lab 10.4.1: Step 4 – Valid address



- 150.100.255.255
- 175.100.255.18
- 195.234.253.0
- 100.0.0.23
- 188.258.221.176
- 127.34.25.189
- 224.156.217.73

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# SUBNETTING

# AND

# CREATING A SUBNET

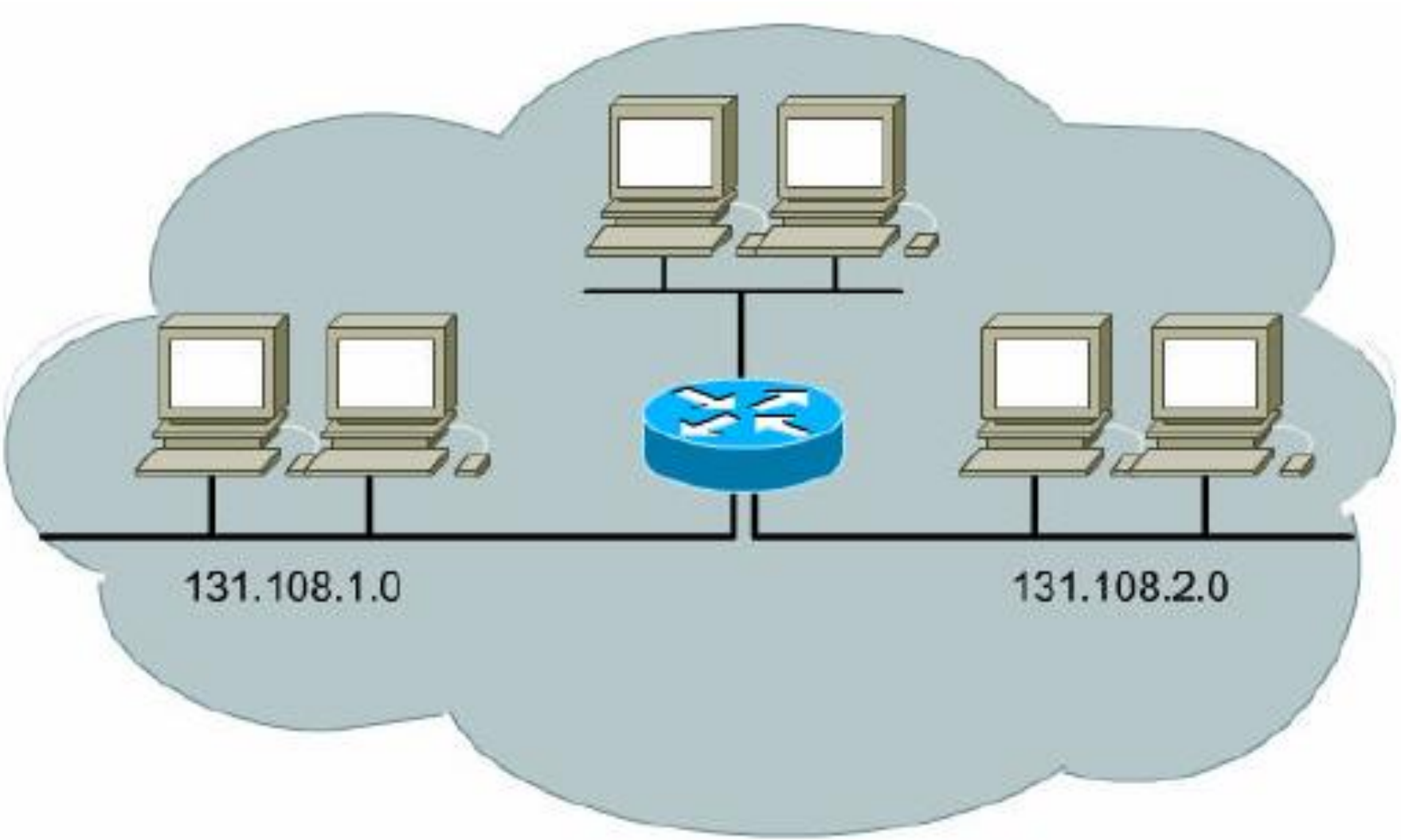
# Why we need to divide network?



- **Network administrators sometimes need to divide networks, especially large ones, into smaller networks:**
  - **Reduce the size of a broadcast domain.**
  - **Improve network security.**
  - **Implement the hierarchical managements.**
- ***So we need more network addresses for your network. But I want the outside networks see our network as a single network.***

# Divide network by three





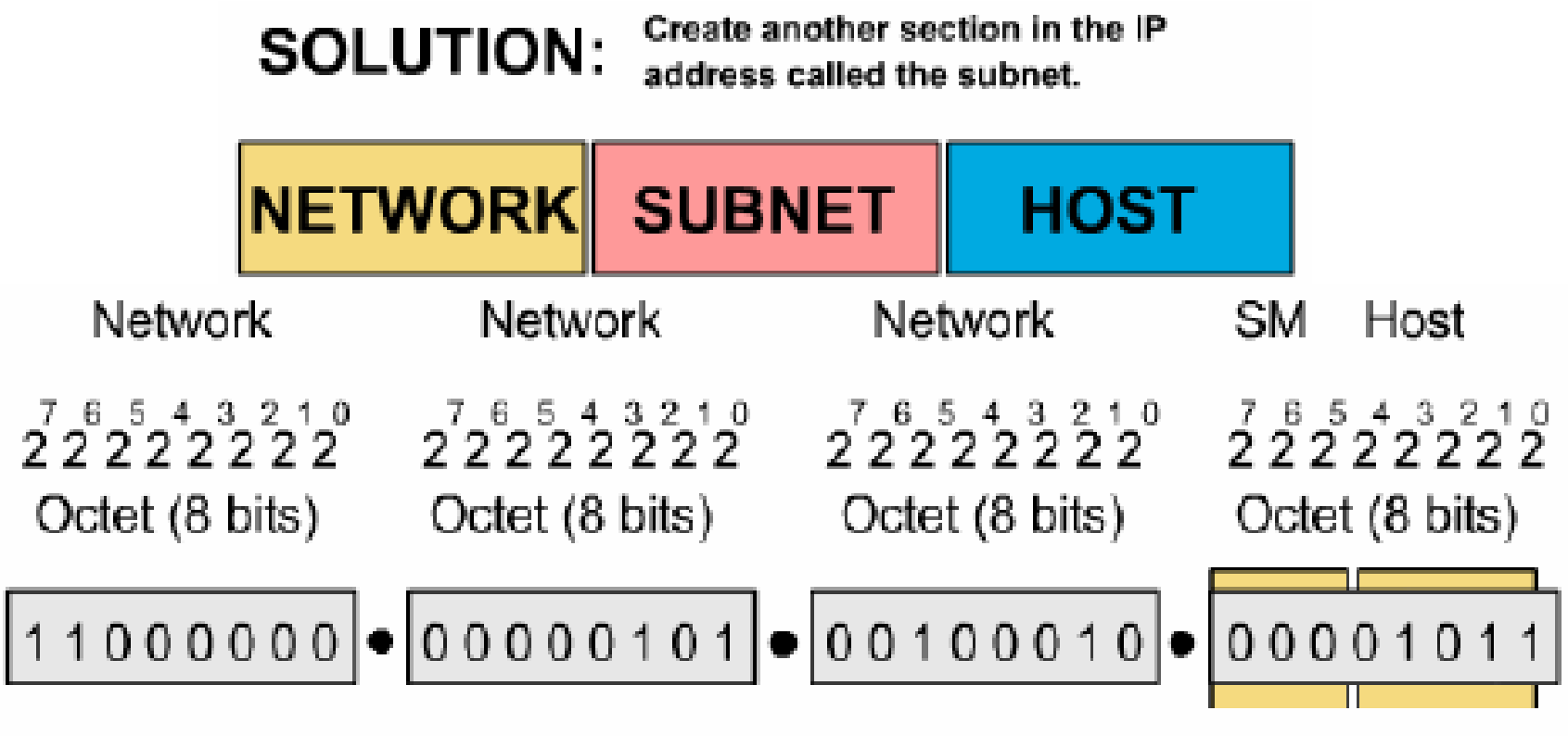
# Subnetting



- Subnetworks are smaller divisions of network.
- Subnet addresses include the Class A, Class B, or Class C network portion, plus a subnet field and a host field.
- To create a subnet address, a network administrator borrows bits from the original host portion and designates them as the subnet field.
- Subnet addresses are assigned locally, usually by a network administrator.

# Subnetting






**HOW???**

**By using a SUBNET MASK**

# Subnet mask



- “Extended Network Prefix”.
- Determines which part of an IP address is the network field and which part is the host field.
- 32 bits long.
- Divided into four octets.
- Network and Subnet portions all 1’s.
- Host portions all 0’s.

# Default subnet mask: Example



- 192.168.2.100 / 255.255.255.0
- 11000000.10101000.00000010.01100100
- 11111111.11111111.11111111.00000000
- 11000000.10101000.00000010.00000000
- Class C network:
  - 24 bits for network portion.
  - 0 bits for subnet portion.
  - 8 bits for host portion.
- Subnet address: 192.168.2.0

# Subnet mask: Example



- 172.16.65.100 / 255.255.240.0
- 10101100.00010000.01000001.01100100
- 11111111.11111111.11110000.00000000
- 10101100.00010000.01000000.00000000
- Class B network:
  - 16 bits for network portion.
  - 4 bits for subnet portion.
  - 12 bits for host portion.
- Subnet address: 172.16.64.0

# How many bits can I borrow?



- All of subnet bits are:
  - 0 : reserved for network address.
  - 1 : reserved for broadcast address.
- The minimum bits you can borrow is: 2 bits.
- The maximum bits you can borrow is:
  - A: 22 bits ~ $2^{22}$ - 2 = 4.194.302 subnets.
  - B: 14 bits ~ $2^{14}$ - 2 = 16.382 subnets.
  - C: 06 bits ~ $2^{06}$ - 2 = 62 subnets.

# Boolean algebra review



- **Boolean operators:**
  - **AND**
  - **OR**
  - **NOT**

# AND operator



1 AND 1 = 1

1 AND 0 = 0

0 AND 1 = 0

0 AND 0 = 0

# OR operator



1 OR 1 = 1

1 OR 0 = 1

0 OR 1 = 1

0 OR 0 = 0

# NOT operator



NOT 1 = 0

NOT 0 = 1

# Boolean algebra examples



1010 AND 0110 = 0010

1010 OR 0110 = 1110

# Why we need to know Boolean ops?



| IP Address | AND | Subnet Mask | = | Network and Subnet address |
|---|---|---|---|---|

- Network layer performs the Boolean operations in order to find the network ID of a subnet
- Example:
  - 172.16.65.100 AND 255.255.240.0
  - Network address: 172.16.64.0

# Subnetting example



- Given network 172.16.0.0.
- We need 8 usable subnets and up to 1000 hosts on each subnet.

# Calculating a subnet



1. Determine the class of network and default subnet mask.
2. Determine how many bits to borrow. Determine the subnet mask and the actual number of subnets and hosts.
3. Determine the ranges of host address for each subnet. Choose the subnets that you want to use.

# Calculating a subnet: STEP 1



- Determine the Class of network
  - ➔ Class B
- Determine the default subnet mask
  - ➔ 255.255.0.0

# Calculating a subnet: STEP 2



- Number of subnets <= $2^n$ - 2 with n is number of bits that are borrowed.
- Number of hosts <= $2^m$ - 2 with m is number of bits that are remained.
- Determine how many bits to borrow from the host portion from requirement:
  - 8 subnets.
  - 1000 hosts on each subnet.

# Calculating a subnet: STEP 2 (Cont.)



- Choose n = 4:
  - Number of possible subnets is:

    $2^4 - 2 = 14$

  - Number of possible hosts on each subnet is:

    $2^{(16-4)} - 2 = 4094$

- *Other choice n = 5 , n = 6 ?*

# Calculating a subnet: STEP 2 (Cont.)



| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 | |
|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | = 128 |
| 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | = 192 |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | = 224 |
| 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | = 240 |
| 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | = 248 |
| 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | = 252 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | = 254 |
| 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | = 255 |

- **The subnet mask: 255.255.240.0.**

# Calculating a subnet: STEP 3



- Determine the subnets and the ranges of host address for each subnet. Including:
  - Sub-network addresses
  - Range of usable IP addresses
  - Sub-network broadcast addresses

# Calculating a subnet: STEP 3 (Cont.)



- Determine the subnets from 4 borrowed bits from the host portion (last 2 bytes):
  - 1st subnet: .00000000.00000000
  - 2nd subnet: .00010000.00000000
  - 3rd subnet: .00100000.00000000
  - …
  - 15th subnet: .11110000.00000000

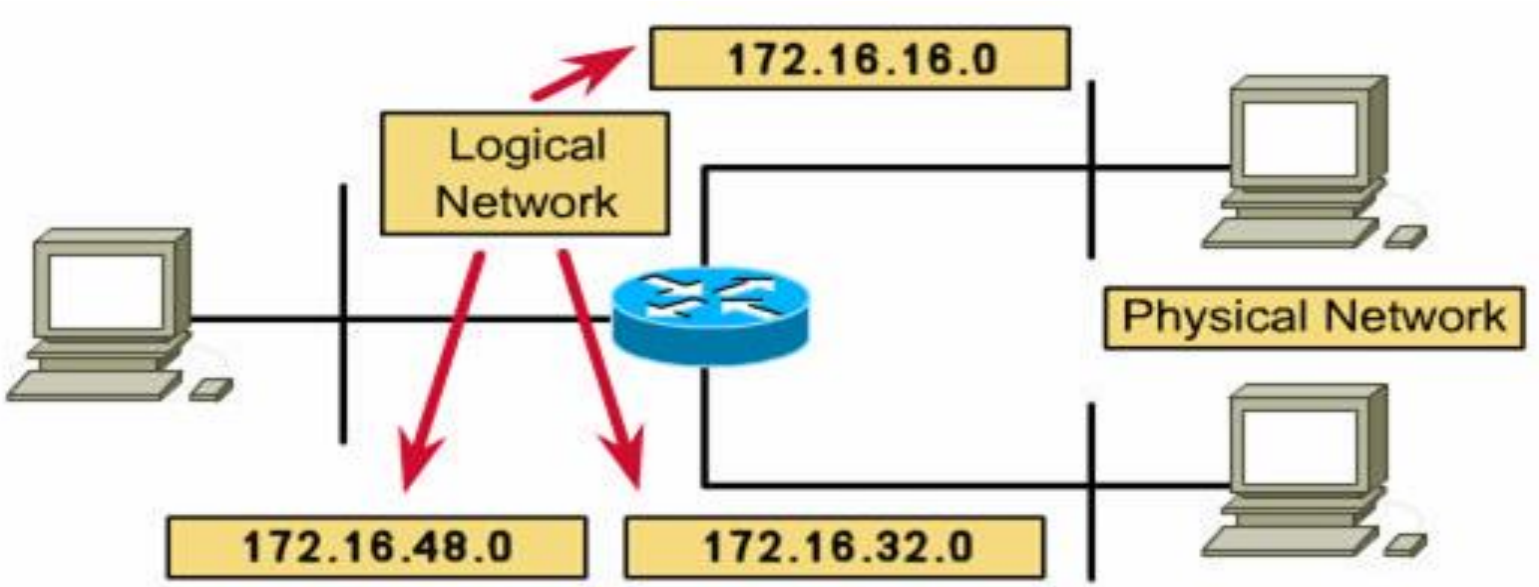
# Calculating a subnet: STEP 3 (Cont.)



| No | Sub-network address | Possible host address | Broadcast address | Use ? |
|---|---|---|---|---|
| 0 | 172.16.0.0 | 172.16.0.1 – 172.16.15.254 | 172.16.15.255 | N |
| 1 | 172.16.16.0 | 172.16.16.1 – 172.16.31.254 | 172.16.31.255 | Y |
| 2 | 172.16.32.0 | 172.16.32.1 – 172.16.47.254 | 172.16.47.255 | Y |
| .. | .. | .. | .. | .. |
| .. | .. | .. | .. | .. |
| 13 | 172.16.208.0 | 172.16.208.1 – 172.16.223.254 | 172.16.223.255 | Y |
| 14 | 172.16.224.0 | 172.16.224.1 – 172.16.239.254 | 172.16.239.255 | Y |
| 15 | 172.16.240.0 | 172.16.240.1 – 172.16.255.254 | 172.16.255.255 | N |

# Calculating a subnet: STEP 3 (Cont.)






- Using subnets No.1 to No.8.
- Assign IP addresses to hosts and interfaces on each network. IP address configuration.

# Addresses are loose by subnetting.



| Number of Bits Borrowed | Number of Subnets Created | Number of Hosts Per Subnet | Total Number of Hosts | Percent Used |
|---|---|---|---|---|
| 2 | 2 | 62 | 124 | 49% |
| 3 | 6 | 30 | 180 | 71% |
| 4 | 14 | 14 | 196 | 77% |
| 5 | 30 | 6 | 180 | 71% |
| 6 | 62 | 2 | 124 | 49% |

- **Network administrator must strike a balance between the number of subnets required, the hosts per subnet that is acceptable, and the resulting waste of addresses.**

# Teaching topology (10.7.6)