

## **PART IX**

# **INTERNET PROTOCOL: CLASSLESS AND SUBNET ADDRESS EXTENSIONS (CIDR)**

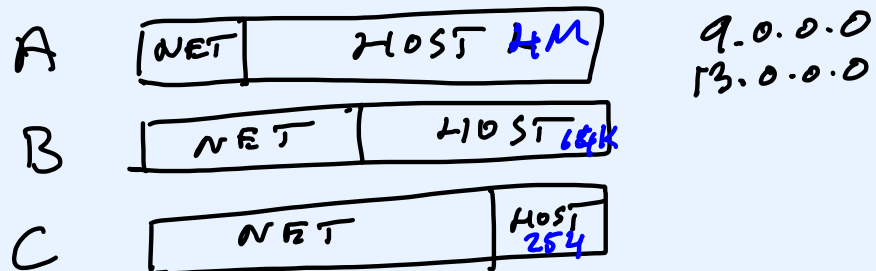
## Recall

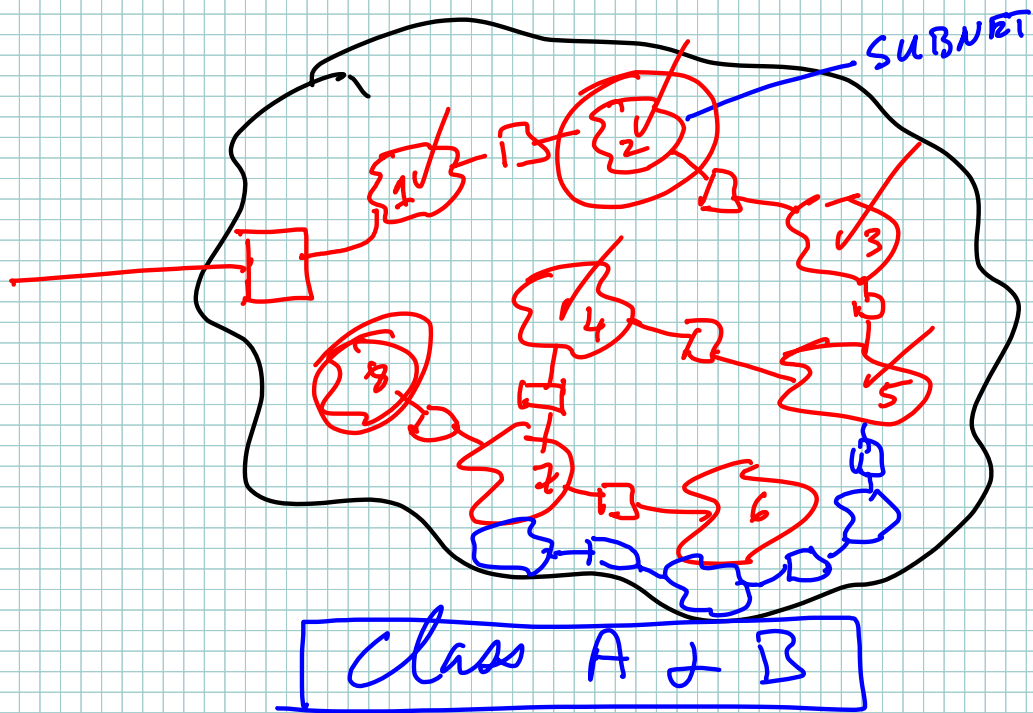
*In the original IP addressing scheme, each physical network is assigned a unique network address; each host on a network has the network address as a prefix of the host's individual address.*

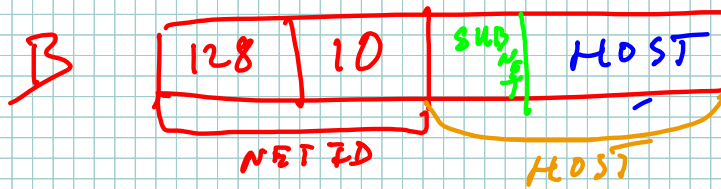
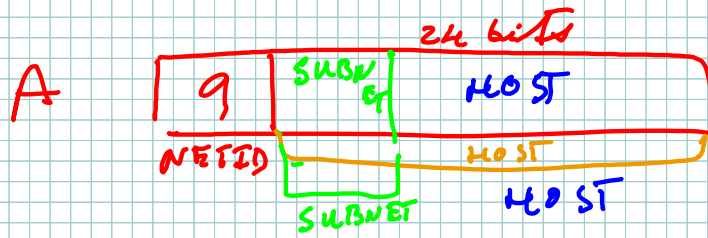
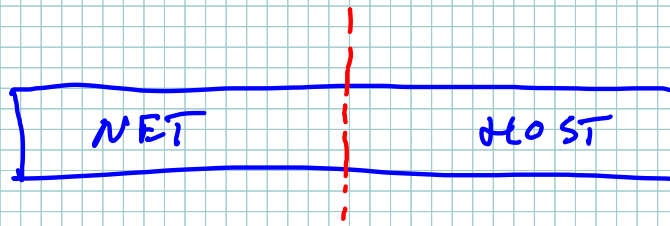
- Routers only examine prefix (small routing tables)

## An Observation

- Division into prefix and suffix means: site can assign and use IP addresses in unusual ways provided
  - All hosts and routers at the site honor the site's scheme
  - Other sites on the Internet can treat addresses as a network prefix and a host suffix







## **Classful Addressing**

- Three possible classes for networks
- Class C network limited to 254 hosts (cannot use all-1s or all-0s)
- Personal computers result in networks with many hosts
- Class B network allows many hosts, but insufficient class B prefixes

## Question

- How can we minimize the number of assigned network prefixes (especially class B) without abandoning the 32-bit addressing scheme?

## **Two Answers To The Minimization Question**

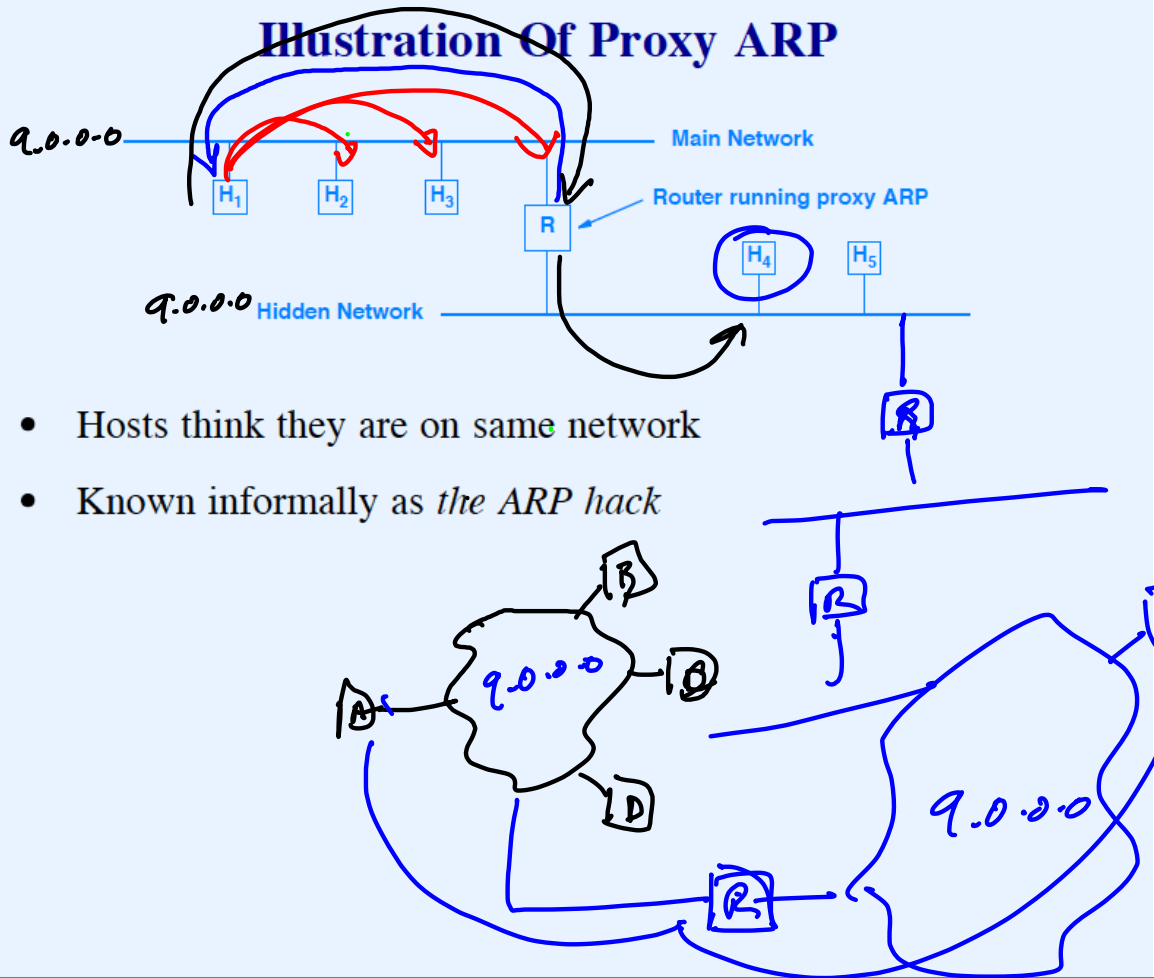
- Proxy ARP
- Subnet addressing



## **Proxy ARP**

- Layer 2 solution
- Allow two physical networks to share a single IP prefix
- Arrange special system to answer ARP requests and forward datagrams between networks

## Illustration Of Proxy ARP



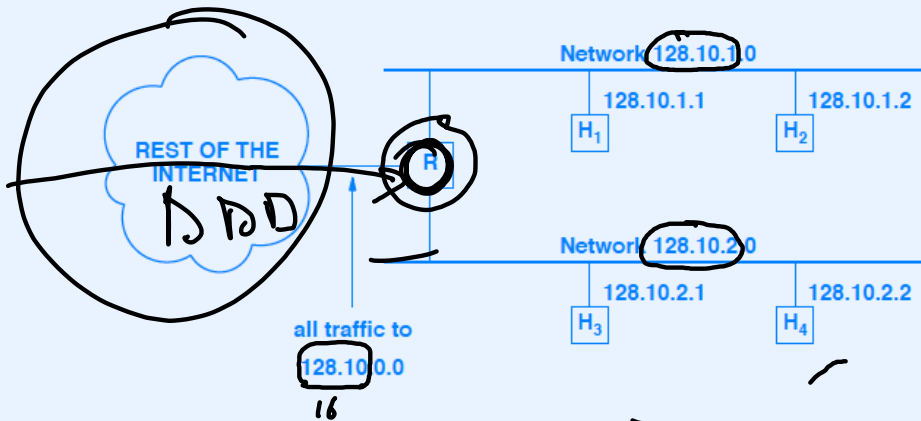
## Assessment Of Proxy ARP

- Chief advantages
  - Transparent to hosts
  - No change in IP routing tables
- Chief disadvantages
  - Does not generalize to complex topology
  - Only works on networks that use ARP
  - Most proxy ARP systems require manual configuration

## **Subnet Addressing**

- Not part of original TCP/IP address scheme
- Allows an organization to use a single network prefix for multiple physical networks
- Subdivides the host suffix into a pair of fields for physical network and host
- Interpreted only by routers and hosts at the site; treated like normal address elsewhere

## Example Of Subnet Addressing

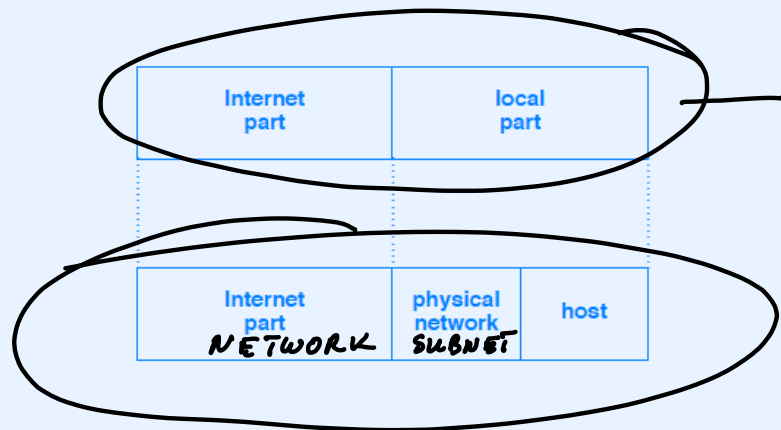


- Both physical networks share prefix 128.10
- Router R uses third octet of address to choose physical net

## **Interpretation Of Addresses**

- Classful interpretation is two-level hierarchy
  - Physical network identified by prefix
  - Host on the net identified by suffix
- Subnetted interpretation is three-level hierarchy
  - Site identified by network prefix
  - Physical net at site identified by part of suffix
  - Host on the net identified by remainder of suffix

## Example Of Address Interpretation (Subnetted Class B Address)



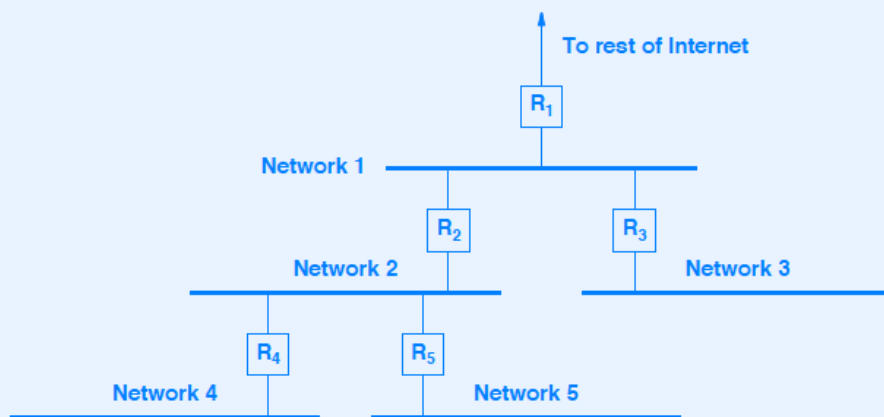
Note: in this case, 16-bit host portion is divided into two 8-bit fields

## **Choice Of Subnet Size**

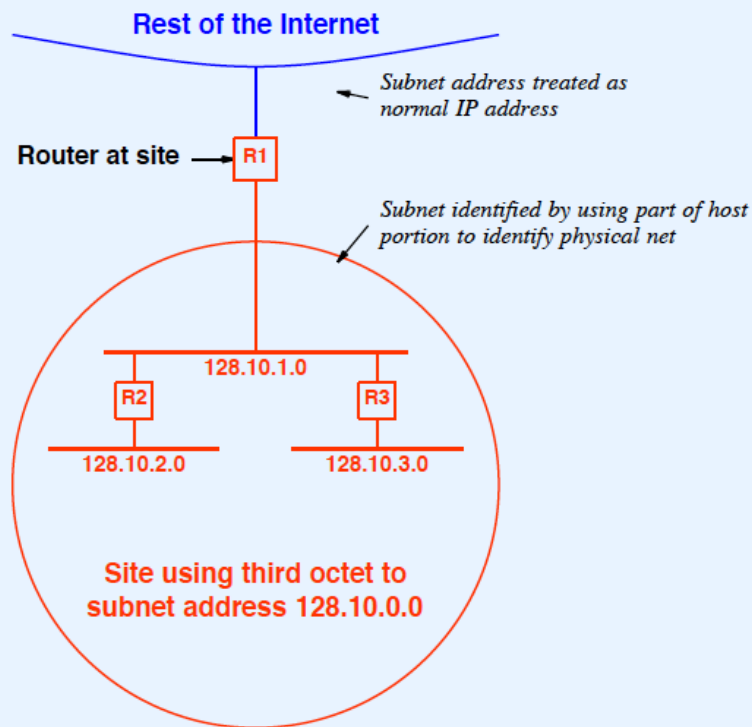
- How should host portion of address be divided?
- Answer depends on topology at site and number of hosts per network



## Example Of Site With Hierarchical Topology



## Illustration Of Subnet Addressing



## Address Mask

- Each physical network is assigned 32-bit *address mask* (also called *subnet mask*)
- One bits in mask cover network prefix plus zero or more bits of suffix portion
- Logical *and* between mask and destination IP address extracts the prefix and subnet portions

|         |     |               |          |
|---------|-----|---------------|----------|
| class A | 18  | 255.0.0.0     | FF000000 |
| class B | 16  | 255.255.0.0   | FFFF0000 |
| class C | 124 | 255.255.255.0 | FFFFFF00 |

## Two Possible Mask Assignments

- Fixed-length subnet masks
- Variable-length subnet masks

## **Fixed-length Subnet Masks**

- Organization uses same mask on all networks
- Advantages
  - Uniformity
  - Ease of debugging / maintenance
- Disadvantages
  - Number of nets fixed for entire organization
  - Size of physical nets fixed for entire organization

## Possible Fixed-Length Subnets For Sixteen Bit Host Address

| Bits in mask | # subnets | # hosts/subnet |
|--------------|-----------|----------------|
| 16           | 1         | 65534          |
| 18           | 2         | 16382          |
| 19           | 6         | 8190           |
| 20           | 14        | 4094           |
| 21           | 30        | 2046           |
| 22           | 62        | 1022           |
| 23           | 126       | 510            |
| 24           | 254       | 254            |
| 25           | 510       | 126            |
| 26           | 1022      | 62             |
| 27           | 2046      | 30             |
| 28           | 4094      | 14             |
| 29           | 8190      | 6              |
| 30           | 16382     | 2              |

- All-0s and all-1s values must be omitted
- Organization chooses one line in table

## **Variable-Length Subnet Masks (VLSM)**

- Administrator chooses size for each physical network
- Mask assigned on per-network basis
- Advantages
  - Flexibility to mix large and small nets
  - More complete use of address space
- Disadvantages
  - Difficult to assign / administer
  - Potential address ambiguity
  - More routes

## Use Of Address Space (Start With 16 Bits Of Host Suffix)

- One possible VLSM assignment (92.9% of addresses used)
  - 11 <sup>SUBNETS</sup> networks of 2046 hosts each
  - 24 networks of 254 hosts each
  - 256 networks of 126 hosts each
- Another possible VLSM assignment (93.1% of addresses used)
  - 9 <sup>SUBNETS</sup> networks of 2046 hosts each
  - 2 networks of 1022 hosts each
  - 40 networks of 510 hosts each
  - 160 networks of 126 hosts each



## Subnet Details

- Two interesting facts
  - *Can* assign all-0's or all-1's subnet
  - *Can* assign noncontiguous subnet mask bits
- In practice
  - Should avoid both
- Discussion question: why does the subnet standard allow the all-1's and all-0's subnet numbers?

## VLSM Example

- Use low-order sixteen bits of 128.10.0.0
- Create seven subnets
- Subnet 1
  - Up to 254 hosts
  - Subnet mask is 24 bits
- Subnets 2 through 7
  - Up to 62 hosts each
  - Subnet mask is 26 bits

## Example VLSM Prefixes

- Subnet 1 (up to 254 hosts)

mask: 11111111 11111111 11111111 00000000

prefix: 10000000 00001010 00000001 00000000

- Subnet 2 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000000 10000000

- Subnet 3 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000000 11000000

## Example VLSM Prefixes (continued)

- Subnet 4 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 00000000

- Subnet 5 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 01000000

- Subnet 6 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 10000000

## Example VLSM Prefixes (continued)

- Subnet 7 (up to 62 hosts)

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 11000000

## Address Ambiguity

- Address of host 63 on subnet 1 is

mask: 11111111 11111111 11111111 00000000

prefix: 10000000 00001010 00000001 00000000

host: 10000000 00001010 00000001 00111111

128.10.1.63

- Directed broadcast address on subnet 4 is

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 00000000

bcast: 10000000 00001010 00000001 00111111

128.10.1.63

## Address Ambiguity

- Address of host 63 on subnet 1 is

mask: 11111111 11111111 11111111 00000000

prefix: 10000000 00001010 00000001 00000000

host: 10000000 00001010 00000001 00111111

- Directed broadcast address on subnet 4 is

mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 00000000

bcast: 10000000 00001010 00000001 00111111

- Same value!

## More Address Ambiguity

- Directed broadcast address on subnet 1 is

```
mask:      11111111 11111111 11111111 00000000
prefix:    10000000 00001010 00000001 00000000
broadcast: 10000000 00001010 00000001 11111111
```

- Directed broadcast address on subnet 7 is

```
mask:      11111111 11111111 11111111 11000000
prefix:    10000000 00001010 00000001 11000000
broadcast: 10000000 00001010 00000001 11111111
```



## More Address Ambiguity

- Directed broadcast address on subnet 1 is

mask: 11111111 11111111 11111111 00000000

prefix: 10000000 00001010 00000001 00000000

broadcast: 10000000 00001010 00000001 11111111

- Directed broadcast address on subnet 7 is

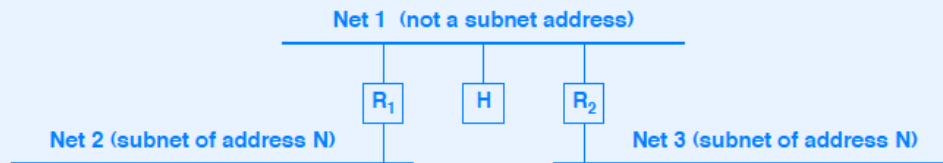
mask: 11111111 11111111 11111111 11000000

prefix: 10000000 00001010 00000001 11000000

broadcast: 10000000 00001010 00000001 11111111

- Same value!

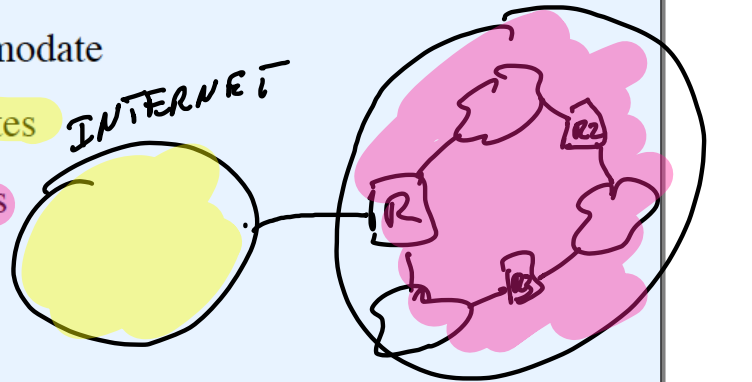
## Example Of Illegal Subnet Assignment



- Host cannot route among subnets
- Rule: subnets *must* be contiguous!

## Variety Of Routes

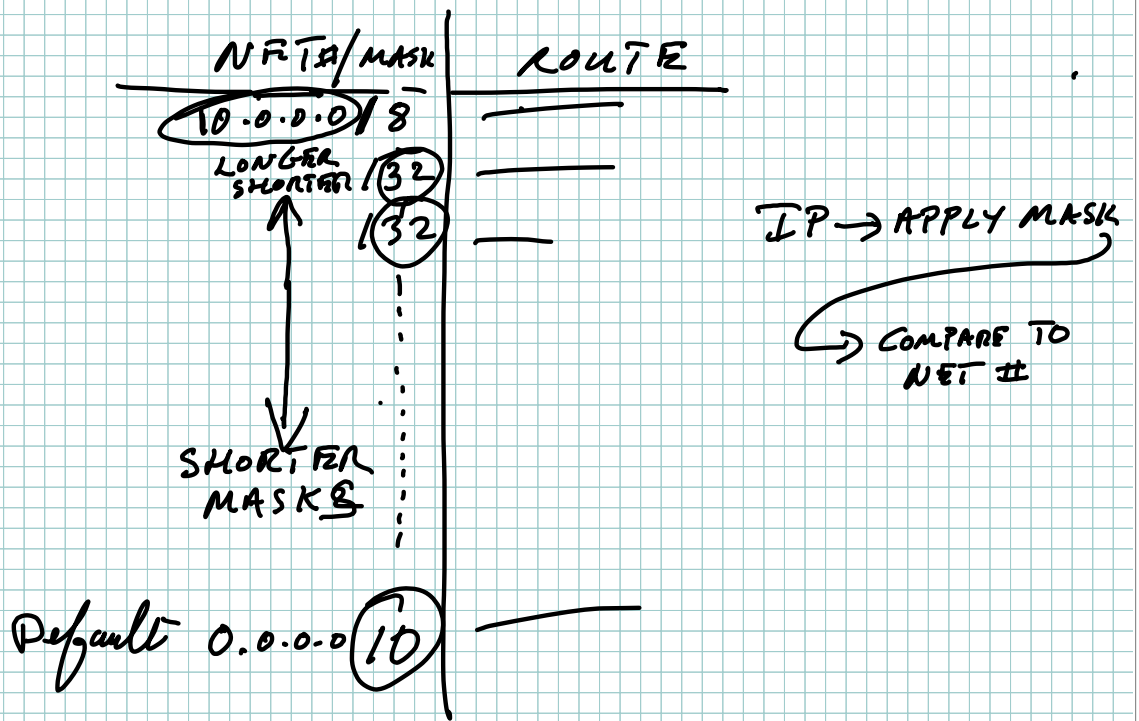
- Forwarding must accommodate
  - Network-specific routes
  - Subnet-specific routes
  - Host-specific routes
  - Default route
  - Limited broadcast
  - Directed broadcast to network
  - Directed broadcast to specific subnet
- Single algorithm with address masks can accommodate all the above



## Use Of Address Masks

- Each entry in routing table also has address mask
- All-1s mask used for host-specific routes
- Network mask used for network-specific routes
- Subnet mask used for subnet-specific routes
- All-0s mask used for default route

| NET      | ROUTE |
|----------|-------|
| NET1 /24 |       |
| NET2 /22 |       |
| NET3 /20 |       |



## Unified Forwarding Algorithm

### Algorithm:

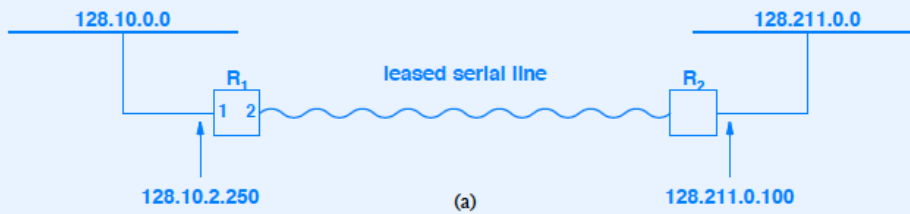
Forward\_IP\_Datagram (datagram, routing\_table)

```
Extract destination IP address,  $D$ , from datagram;
If prefix of  $D$  matches address of any directly connected
network send datagram to destination over that network
(This involves resolving  $D$  to a physical address,
encapsulating the datagram, and sending the frame.)
else
  for each entry in routing table do
    Let  $N$  be the bitwise-and of  $D$  and the subnet mask
    If  $N$  equals the network address field of the entry then
      forward the datagram to the specified next hop address
    endforloop
If no matches were found, declare a forwarding error;
```

## **Special Case: Unnumbered Serial Network**

- Only two endpoints
- Not necessary to assign (waste) network prefix
- Trick: use remote IP address as next hop

## Example Unnumbered Serial Network



| TO REACH HOSTS<br>ON NETWORK | ROUTE TO<br>THIS ADDRESS | USING THIS<br>INTERFACE |
|------------------------------|--------------------------|-------------------------|
| 128.10.0.0                   | DELIVER DIRECT           | 1                       |
| default                      | 128.211.0.100            | 2                       |



## Classless Inter-Domain Routing (CIDR)

- Problem
  - Continued exponential Internet growth
  - Subnetting insufficient
  - Limited IP addresses (esp. Class B)
- Dire prediction made in 1993:

We will exhaust the address space “in a few years”.

Note: address space is *not* near exhaustion

# CLASSLESS INTER DOMAIN ROUTING

## CIDR Addressing

- Solution to problem
  - Temporary fix until next generation of IP
  - Backward compatible with classful addressing
  - Extend variable-length subnet technology to prefixes
- CIDR was predicted to work “for a few years”
  - Extremely successful!
  - Will work for at least 25 years!

# class C networks:

193.162.0.0  
 193.162.1.0  
 193.162.2.0  
 193.162.3.0  
 193.162.4.0

⋮  
 193.162.15.0

1100 0001 1010 0010 0000 0000  
 1100 0001 1010 0010 0000 0001 0000 0000  
 1100 0001 1010 0010 0000 0010  
 0000 0011  
 0000 0100

0000 0101  
 0110  
 0111  
 1000  
 1001  
 1010  
 1011  
 1100  
 1101  
 1110  
 1111

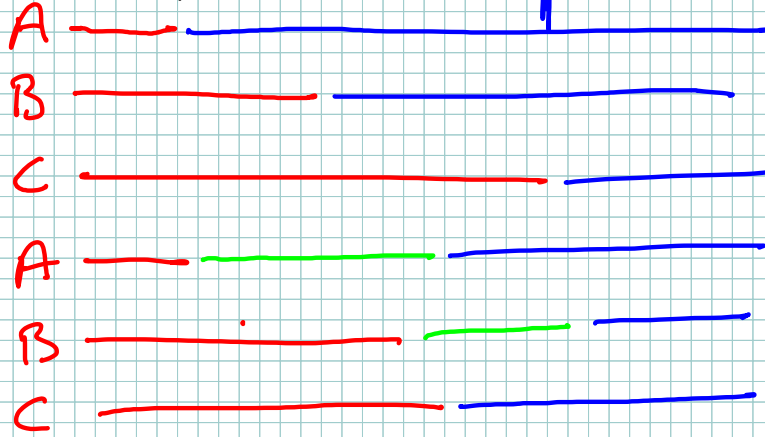
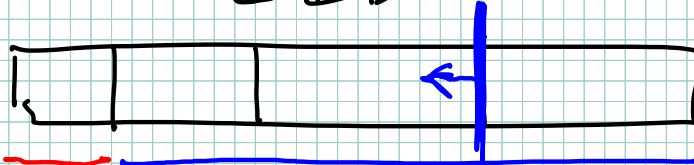
193.162.0.0 /20

193.162.5.17 /20

193.162.0.0

255.255.240.0 /20

CIDR



## **One Motivation For CIDR: Class C**

- Fewer than seventeen thousand Class B numbers (total)
- More than two million Class C network numbers
- No one wants Class C (too small)
- CIDR allows
  - Merging 256 Class C numbers into a single prefix that is equivalent to Class B
  - Splitting a Class B along power of two boundaries

## CIDR Notation

- Addresses written *NUMBER/m*
  - *NUMBER* is IP prefix
  - *m* is “address mask” length
- Example

214.5.48.0/20

  - Prefix occupies 20 bits
  - Suffix occupies 12 bits
- Mask values must be converted to dotted decimal when configuring a router (and binary internally)

## Route Proliferation

- If classful forwarding used, CIDR addresses result in more routes
- Example:
  - Single CIDR prefix spans 256 Class C network numbers (*supernetting*)
  - Classful routing table requires 256 separate entries

## Route Condensation

- Solution: change forwarding as well as addressing
- Store address mask with each route
- Send pair of (address, mask) whenever exchanging routing information
- Known as a *CIDR block*



## Example Of A CIDR Block

|         | <u>Dotted Decimal</u> | <u>32-bit Binary Equivalent</u>     |
|---------|-----------------------|-------------------------------------|
| lowest  | 128.211.168.0         | 10000000 11010011 10101000 00000000 |
| highest | 128.211.175.255       | 10000000 11010011 10101111 11111111 |

## Dotted Decimal Equivalents

| CIDR Notation | Dotted Decimal | CIDR Notation | Dotted Decimal  |
|---------------|----------------|---------------|-----------------|
| /1            | 128.0.0.0      | /17           | 255.255.128.0   |
| /2            | 192.0.0.0      | /18           | 255.255.192.0   |
| /3            | 224.0.0.0      | /19           | 255.255.224.0   |
| /4            | 240.0.0.0      | /20           | 255.255.240.0   |
| /5            | 248.0.0.0      | /21           | 255.255.248.0   |
| /6            | 252.0.0.0      | /22           | 255.255.252.0   |
| /7            | 254.0.0.0      | /23           | 255.255.254.0   |
| /8            | 255.0.0.0      | /24           | 255.255.255.0   |
| /9            | 255.128.0.0    | /25           | 255.255.255.128 |
| /10           | 255.192.0.0    | /26           | 255.255.255.192 |
| /11           | 255.224.0.0    | /27           | 255.255.255.224 |
| /12           | 255.240.0.0    | /28           | 255.255.255.240 |
| /13           | 255.248.0.0    | /29           | 255.255.255.248 |
| /14           | 255.252.0.0    | /30           | 255.255.255.252 |
| /15           | 255.254.0.0    | /31           | 255.255.255.254 |
| /16           | 255.255.0.0    | /32           | 255.255.255.255 |

## Example Of /30 CIDR Block

|         | <u>Dotted Decimal</u> | <u>32-bit Binary Equivalent</u>     |
|---------|-----------------------|-------------------------------------|
| lowest  | 128.211.176.212       | 10000000 11010011 10110000 11010100 |
| highest | 128.211.176.215       | 10000000 11010011 10110000 11010111 |

- Useful when customer of ISP has very small network

## Implementation Of CIDR Route Lookup

- Each entry in routing table has address plus mask
- Search is organized from most-specific to least-specific (i.e., entry with longest mask is tested first)
- Known as *longest-prefix lookup* or *longest-prefix search*

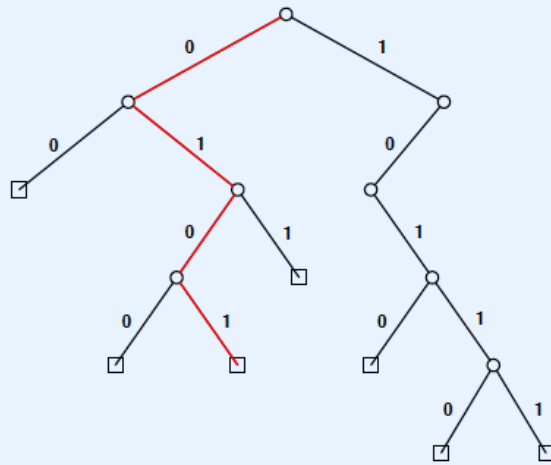
## Implementing Longest-Prefix Matching

- Cannot easily use hashing
- Data structure of choice is *binary trie*
- Identifies unique prefix needed to match route

## Example Of Unique Prefixes

| <u>32-Bit Address</u>               | <u>Unique Prefix</u> |
|-------------------------------------|----------------------|
| 00110101 00000000 00000000 00000000 | 00                   |
| 01000110 00000000 00000000 00000000 | 0100                 |
| 01010110 00000000 00000000 00000000 | 0101                 |
| 01100001 00000000 00000000 00000000 | 011                  |
| 10101010 11110000 00000000 00000000 | 1010                 |
| 10110000 00000010 00000000 00000000 | 10110                |
| 10111011 00001010 00000000 00000000 | 10111                |

## Example Binary Trie For The Seven Prefixes



- Path for 0101 is shown in red

## **Modifications And Extensions**

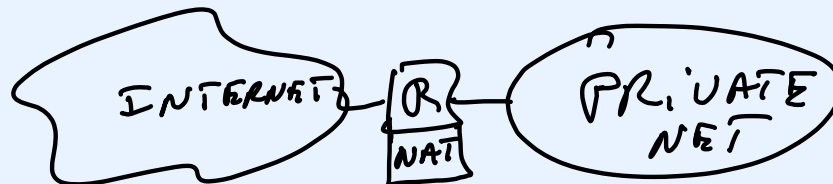
- Several variations of trie data structures exist
  - PATRICIA trees
  - Level-Compressed tries (LC-tries)
- Motivation
  - Handle longest-prefix match
  - Skip levels that do not distinguish among routes



## Nonroutable Addresses

- CIDR blocks reserved for use within a site
- Must never appear on the Internet
- ISPs do not maintain routes
- Also called *private addresses*

| Prefix     | Lowest Address | Highest Address |
|------------|----------------|-----------------|
| 10/8       | 10.0.0.0       | 10.255.255.255  |
| 172.16/12  | 172.16.0.0     | 172.31.255.255  |
| 192.168/16 | 192.168.0.0    | 192.168.255.255 |
| 169.254/16 | 169.254.0.0    | 169.254.255.255 |



## Summary

- Original IP addressing scheme was classful
- Two extensions added
  - Subnet addressing
  - CIDR addressing
- Subnetting used only within a site
- CIDR used throughout the Internet
- Both use 32-bit address mask
  - CIDR mask identifies division between network prefix and host suffix
  - Subnet mask identifies boundary between subnet and individual host

## **Summary (continued)**

- Single unified forwarding algorithm handles routes that are
  - Network-specific
  - Subnet-specific
  - Host-specific
  - Limited broadcast
  - Directed broadcast to network
  - Directed broadcast to subnet
  - Default
- Longest-prefix match required
  - Typical implementation: binary trie