COMP9332
Network Routing & Switching

IPv4 Addressing

http://www.cse.unsw.edu.au/~cs9332/

Lecture overview

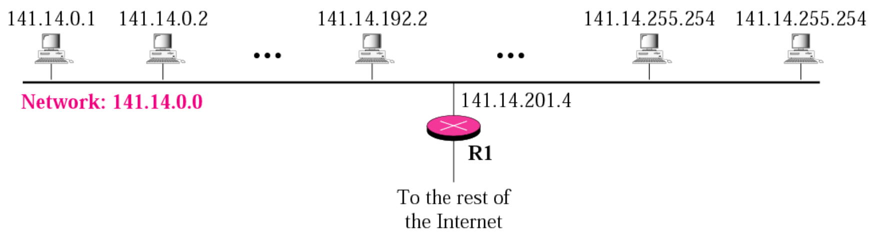
- Key concepts
  - Classful addressing
  - Network mask
  - Subnetting
  - Supernetting
  - Classless addressing
  - Private addressing and Network Address Translation (NAT)

  Reference: Forouzan

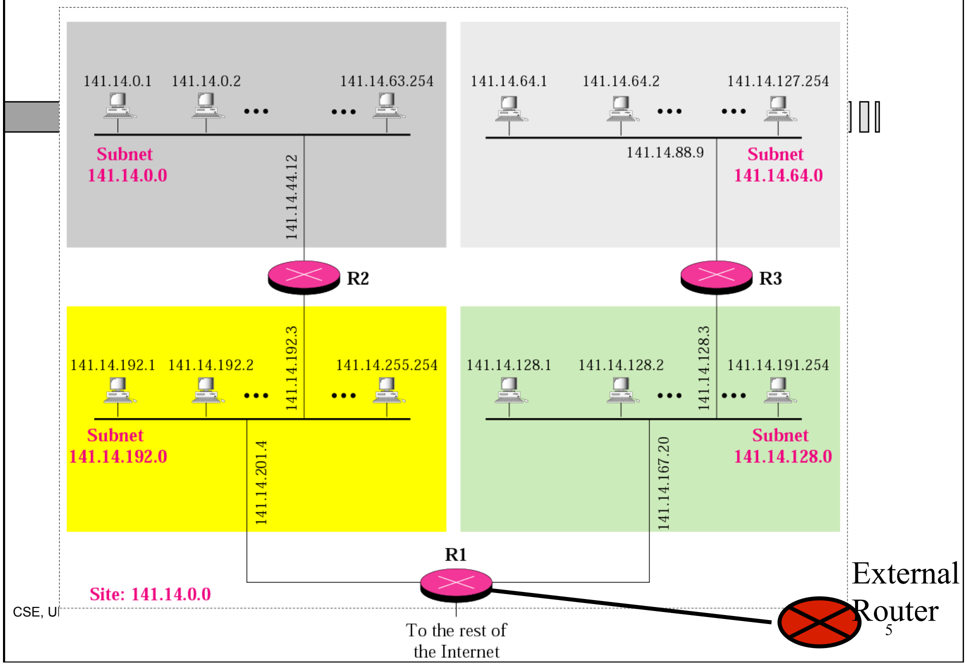
Motivation for subnetting

- Classful addressing means network must be of size: 65536 (2^16) for Class B and 256 (2^8) for Class C
- If an organisation wants to have 4 networks each with 300 hosts, then it needs 4 Class B networks
  - More than 200,000 addresses are wasted
- Subnetting was introduced in 1980s to solve this problem
  - In subnetting, a network is divided into subnets (short for sub-networks)

A network which is not subnetted



Example of a subnetted network



Transparency of subnetting

- In the example on the previous page, only R1, R2 and R3 need to know about the subnets
  - Each subnet requires an entry in their routing table
- Routers external to the network do not need to know about subnetting
  - The external router requires only an entry for the network (i.e. 141.14.0.0) in its routing table

Subnetid

141.14.64.1 is an address in the subnet 141.14.64.0 (subnet number)

Before subnetting

141.14	0100 0000 0000 0001
netid	

After subnetting

141.14	01	00 0000 0000 0001
netid	subnetid	hostid

Subnet mask

- When we configure a host, we need to specify
  - The IP address of the host, and
  - The subnet mask
- The subnet mask has the same role as network mask
  - '1' indicates that bit is a netid or subnetid bit
  - '0' indicates that bit is a hostid bit

Subnet mask example

Given the following netid, subnetid and hostid
(Note: 1st 2 bytes are in dotted decimal, last 2 bytes in binary)

netid	subnetid	hostid
141.14	01	00 0000 0000 0001

The corresponding subnet mask is

255.255	11	00 0000 0000 0000

In dotted decimal notation, it is 255.255.192.0

Subnet mask

- The subnet number is computed from
  Subnet Address =
  IP Address & Subnet Mask
- Exercise: What is the subnet address if the IP address is 200.45.34.56 and the subnet mask is 255.255.240.0?

Solution - Method 1

11001000 00101101 00100010 00111000

11111111 11111111 1111**0000** **00000000**

11001000 00101101 0010**0000** **00000000**

The subnetwork address is **200.45.32.0**.

Short-Cut Method

** If the byte in the mask is 255, copy the byte in the address.

** If the byte in the mask is 0, replace the byte in the address with 0.

** If the byte in the mask is neither 255 nor 0, we write the mask and the address in binary and apply the AND operation.

Exercise

- What is the subnet address if the IP address is 19.30.84.5 and the mask is 255.255.192.0?

Example 2

IP Address

19	30	84	5

Mask

255	255	192	0

19	30	64	0

Subnet Address

84	0	1	0	1	0	1	0	0
192	1	1	0	0	0	0	0	0
64	0	1	0	0	0	0	0	0

Comparison of a default mask and a subnet mask

	255.255.0.0				
Default Mask	11111111	11111111	00000000		00000000
			16		
	255.255.224.0				
Subnet Mask	11111111	11111111	111	00000	00000000
			3	13	

Since subnetid has 3 bits, the number of subnets allowed is 2^3.

Since the hostid has 13 bit, the number of addresses per subnet is 2^13.

Address range in a subnet

- A subnet has an subnet address of 141.14.64.0, find the address range in the subnet if its subnet mask is

1. 255.255.224.0
2. 255.255.240.0

Solution

If the network mask is 255.255.224.0 (netid - 16bits, subnetid - 3bits)
The address range is:

netid	subnetid	hostid
141.14	010	0 0000 0000 0000

to

netid	subnetid	hostid
141.14	010	1 1111 1111 1111

If the network mask is 255.255.240.0 (netid - 16bits, subnetid - 4bits)
The address range is:

netid	subnetid	hostid
141.14	0100	0000 0000 0000

to

netid	subnetid	hostid
141.14	0100	1111 1111 1111

Notes on subnetting

- To define a subnet, you must define both
  - Subnet address and
  - Subnet mask
- It's not enough to give only the subnet address

Example 3

A company is granted the site address 201.70.64.0 (class C). The company needs six subnets. Design the subnets.

Solution

The number of 1s in the default mask is 24 (class C).

Solution (Continued)

The company needs six subnets. This number 6 is not a power of 2. The next number that is a power of 2 is 8 (2^3). We need 3 more 1s in the subnet mask. The total number of 1s in the subnet mask is 27 (24 + 3).

The total number of 0s is 5 (32 - 27). The mask is

Solution (Continued)

11111111 11111111 11111111 11100000

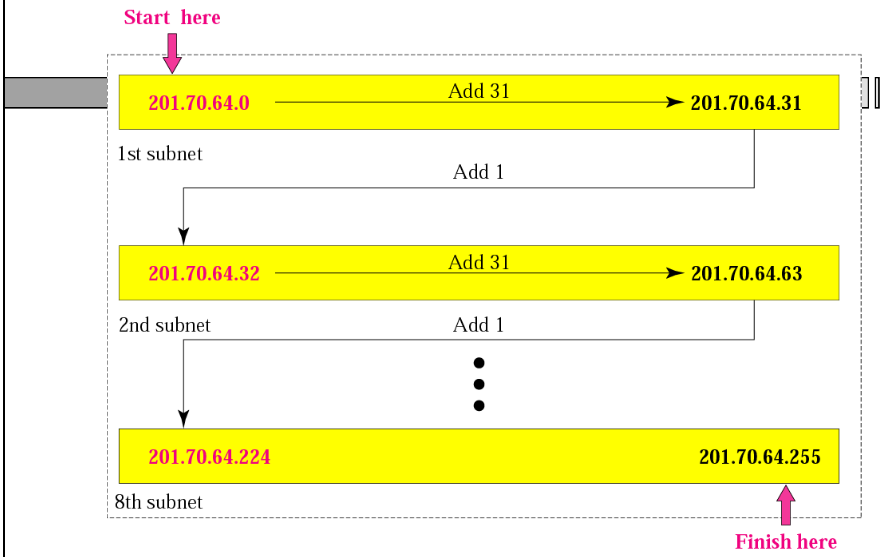
or

255.255.255.224

The number of subnets is 8.

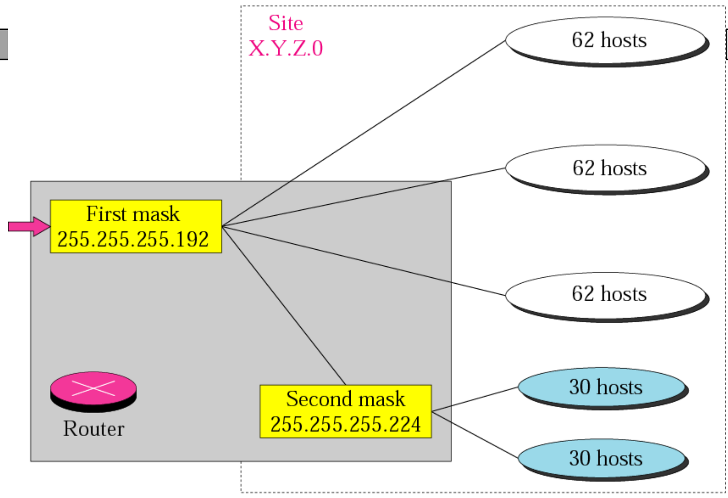
The number of addresses in each subnet is 2^5 (5 is the number of 0s) or 32.

The address range for the subnets are:



The subnet number is the first address in the subnet.

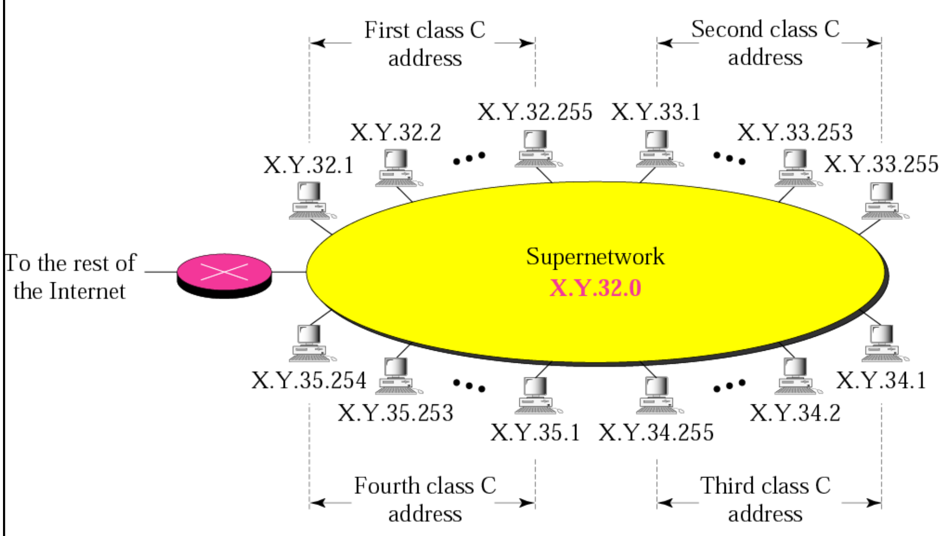
Variable-length subnetting



Supernetting

- Background
  - Class B addresses were running out
  - There were still plenty of class C addresses but each class C network has only 256 addresses
- If an organisation wants 1000 addresses, supernetting allows 4 class C networks to be merged to form a supernet with 1024 addresses

A supernetwork



Address assignment

- If a subnet consists of 100 Class C networks and if these addresses are randomly chose
  - The routers external to the supernet requires 100 entries (one for each Class C network) for the supernet
- It would be desirable if only 1 entry is required
- This can be achieved by carefully assigning addresses

Address assignment rules

- The number of blocks must be a power of 2 (1, 2, 4, 8, 16, . . .).
- The blocks must be contiguous in the address space (no gaps between the blocks).
- The third byte of the first address in the superblock must be evenly divisible by the number of blocks. In other words, if the number of blocks is N, the third byte must be divisible by N.

Exercise

A company needs 600 addresses. Which of the following set of class C blocks can be used to form a supernet for this company?

a)198.47.32.0 198.47.33.0 198.47.34.0

b)198.47.32.0 198.47.42.0 198.47.52.0 198.47.62.0

c)198.47.31.0 198.47.32.0 198.47.33.0 198.47.34.0

d)198.47.32.0 198.47.33.0 198.47.34.0 198.47.35.0

Solution

a)198.47.32.0 198.47.33.0 198.47.34.0

Not acceptable. #blocks not a power of 2.

b)198.47.32.0 198.47.42.0 198.47.52.0 198.47.62.0

Not acceptable. Not contagious.

c)198.47.31.0 198.47.32.0 198.47.33.0 198.47.34.0

Not acceptable. 3rd byte of 1st address not divisible by 4.

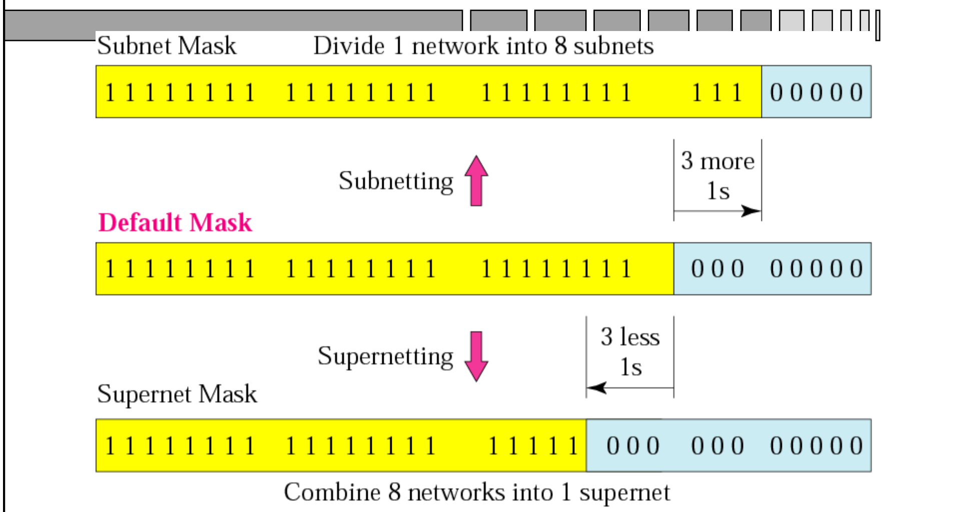
d)198.47.32.0 198.47.33.0 198.47.34.0 198.47.35.0

Acceptable.

Specifying a supernet

- Analogous to a subnet, a supernet is specified by
  - A supernet address
  - A supernet mask

Comparison of subnet, default, and supernet masks



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Example

We need to make a supernetwork out of 16 class C blocks. What is the supernet mask?

Solution

We need 16 blocks. For 16 blocks we need to change four 1s to 0s in the default mask. So the mask is

11111111 11111111 1111**0000** 00000000

or

255.255.240.0

Example

A supernet has a first address of 205.16.32.0 and a supernet mask of 255.255.248.0. How many blocks are in this supernet and what is the range of addresses?

Solution

The supernet mask has 21 1s. The default mask has 24 1's. Since the difference is 3, there are 2^3 or 8 blocks in this supernet.

The blocks are 205.16.32.0, 205.16.33.0, …, 205.16.39.0.

The first address is 205.16.32.0. The last address is 205.16.39.255.

Classless addressing

- Classful addressing: The number of addresses in a network can only be 2^8, 2^16 or 2^24
- A supernet consisting of multiple Class C networks can have 256 * 2^n (n=2,…7) addresses
- The number of addresses in a *classless network* can be any number as long as it is a power of 2
  - Classless network is part of the Classless Interdomain Routing Protocol (CIDR)

Beginning address

- The addresses in a classless network must be chosen carefully so that only one entry in the routing table is required
- The beginning address of a classless network must be divisible by the number of addresses in the network

Beginning address (cont'd)

- The IP address in dotted decimal a.b.c.d is actually the decimal number:

  $$a\ 256^3 + b\ 256^2 + c\ 256 + d$$

- E.g. to check whether an IP address is divisible by 16, we only need to check whether the last byte is divisible by 16

Example 9

Which of the following can be the beginning address of a block that contains 16 addresses?

205.16.37.32
190.16.42.44
17.17.33.80
123.45.24.52

Solution

The address 205.16.37.32 is eligible because 32 is divisible by 16. The address 17.17.33.80 is eligible because 80 is divisible by 16.

Example 10

Which of the following can be the beginning address of a block that contains 1024 addresses?

205.16.37.32
190.16.42.0
17.17.32.0
123.45.24.52

Solution

To be divisible by 1024, the rightmost byte of an address should be 0 and the second rightmost byte must be divisible by 4. Only the address 17.17.32.0 meets this condition.

Classless networks

- A classless network is specified by
  - A network address
  - A mask
- Since a mask consists of a number of 1's at the left followed by a number of 0's, instead of specifying the mask in dotted decimal, we can specify the number of 1's

CIDR notation

- A classless network is usually written as

  A.B.C.D/n
  - 'n' specifies the number of 1's in the mask
  - This is known as slash notation or CIDR notation
  - The first n bits of A.B.C.D is known as the prefix and n is known as the prefix length
  - The last (32-n) bits are known as the suffix

Example

A small organization has the network **205.16.37.24/29**. What is the range of the block?

Solution

The beginning address is 205.16.37.24. To find the last address we keep the first 29 bits and change the last 3 bits to 1s.

Beginning:**11001111 00010000 00100101 00011**000
Ending : **11001111 00010000 00100101 00011**111

There are only 8 addresses in this block.

Example 13

What is the network address if one of the addresses is 167.199.170.82/27?

Solution

The prefix length is 27, which means that we must keep the first 27 bits as is and change the remaining bits (5) to 0s. The 5 bits affect only the last byte. The last byte is 01010010. Changing the last 5 bits to 0s, we get 01000000 or 64. The network address is 167.199.170.64/27.

Subnetting classless network

- A classless network also be subnetted
- Example:

  An organization is granted the block 130.34.12.64/26. The organization needs to have four subnets. What are the subnet addresses and the range of addresses for each subnet?

Solution

Since the prefix length is 26. This means the last 6 bits are available as hostid, the total number of addresses in the block is 64 (2^6). If we create four subnets, each subnet will have 16 addresses.

Solution (Continued)

Let us first find the subnet prefix (subnet mask). We need four subnets, which means we need to add two more 1s to the site prefix. The subnet prefix is then /28.

Subnet 1: 130.34.12.64/28 to 130.34.12.79/28.

Subnet 2 : 130.34.12.80/28 to 130.34.12.95/28.

Subnet 3: 130.34.12.96/28 to 130.34.12.111/28.

Subnet 4: 130.34.12.112/28 to 130.34.12.127/28.

Private addresses and Network Address Translation

IP addressing

- Evolution of IP addressing
  - Original classful addressing: Network id, hostid
  - Subnetting: Network id, subnet id, host id
  - Classless addressing (CIDR): Network prefix, hostid
- The evolution is driven by
  - Waste in address assignment
  - Greater demand for addresses
- A method to conserve IP address is to use private addresses together with Network Address Translation (NAT)
  - Note: Private addresses are also used for private networks

Private addresses

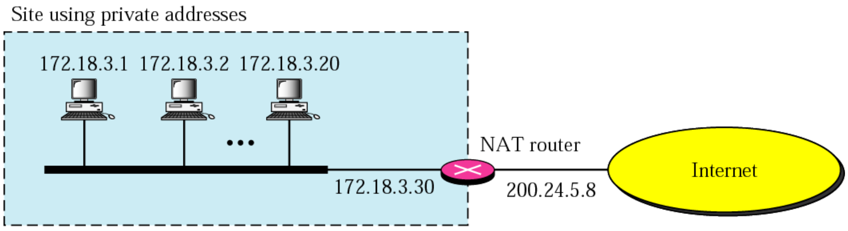
- Some IPv4 addresses are designated as private addresses, they are

Prefix	Range	#Addresses
10/8	10.0.0.0-10.255.255.255	2^24
172.16/12	172.16.0.0-172.31.255.255	2^20
192.168/16	192.168.0.0-192.168.255.255	2^16

Use of private addresses

- Public IP addresses are assigned to ensure that every host connected to the Internet has a unique public IP address
- A host with a private address cannot be connected to the Internet *directly*
  - It requires Network Address Translation (NAT)
  - Multiple hosts, as long as they are not in the same network, can use the same private address
- Private addresses together with NAT can be used to reduce the rate of public IP address consumption

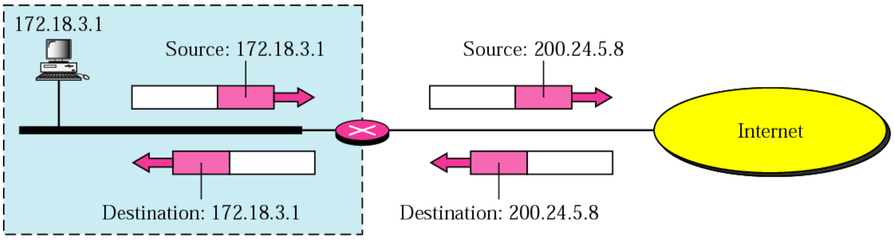
NAT



(Also known as a private network.)

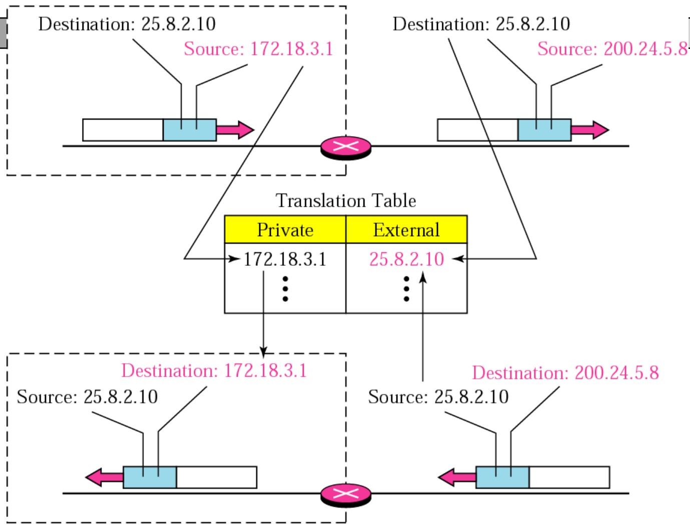
In this example, only one public IP address is used.

Address translation



- Source (destination) IP address is translated
  - o Checksum and other fields may need adjustment
- The operation is transparent to the hosts

Translation



Limitation and extension (1)

- This NAT scheme uses only one public IP address
  - Advantage: One public IP address for many hosts
  - Limitation: No two hosts within the private network can talk to the same external host at the same time
- A solution to this is for the NAT router to use a pool of IP addresses
- Exercise: For the same NAT scheme, if the NAT router has 4 public IP addresses available, what is the maximum number of hosts in the network that can talk to an external host at the same time?

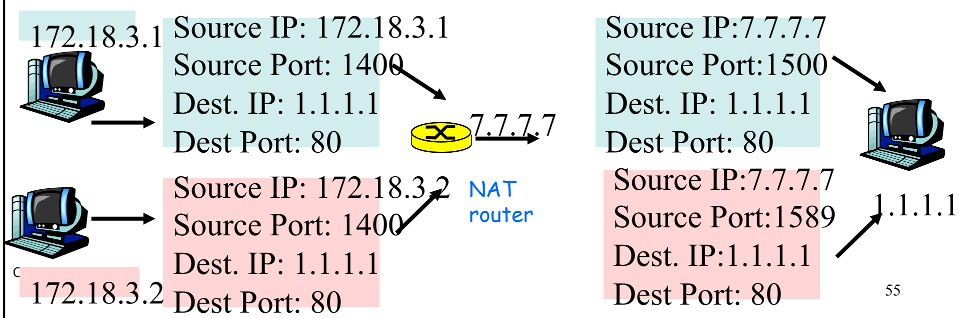
Limitation and extension (2)

- Answer: 4
- This method identifies a connection by using
  - Private address,
  - The public IP address selected for that connection
  - External destination IP address
- An alternative: NAT router has only one public IP address but uses the TCP/UDP port number to identify the connection

Port mapped NAT

Example: NAT router maintains the following translation table

Private address	Private port	External address	External port	NAT port	Protocol
172.18.3.1	1400	1.1.1.1	80	1500	TCP
172.18.3.2	1400	1.1.1.1	80	1589	TCP



Port mapped NAT (cont.)

- Two fields are translated
- Outgoing translation (private→public)
  - Source IP address, source port number
- Incoming translation (public→private)
  - Dest IP addr, dest port number

Problems with NAT

- NAT is complex
  - Requires router to do lots of packet processing
- Both IP and TCP header fields need adjustments
  - changes to checksum, sequence number, acknowledgement are required (why?)
- NAT may need to change the *data stream* (packet payload) too e.g. in FTP
  - Why?
- External client cannot initiate communication with internal server (why?)
  - Any positive side of this? ..... Home network security?

Popular NAT Software

- Internet Connection Sharing (ICS)
  - MS Windows 98
  - Completely software-based (any laptop can be a NAT)
- Slirp
  - BSD based
  - implements port mapped NAT
  - for dialup environment
- Masquerade
  - Linux based
  - port mapped NAT
  - non dialup

Twice NAT

- *Connects networks where address space in one network overlaps, partially or fully, with that of another (how can it happen?)*
- *Twice NAT helps networks already connected to Internet with a routable public address space to switch to another address space without requiring address renumbering*
- Described in RFC2663, August 1999
  - Available in current products (e.g. CISCO and Juniper routers)
- With Twice NAT, external clients *can* initiate communication with internal servers (unlike traditional NATs)

Purpose of Twice NAT is quite different than standard NAT

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Twice NAT Challenge

- Consider the concept of *twin networks*
  - Two networks with identical publicly routable address space (fully overlap case)
- We would not face this twin-network scenario if physical *address renumbering* was done in the original network during address space switching

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Dealing with Twin Network Problem

- Problem - *Both original and twin networks have the same physical address space*
- *Solution*
  - *Twin network should know the original network by its new address space (public DNS update)*
  - *Original network should know the twin network by a "fake" address space (local DNS update)*
  - *Twice NAT router should do more advanced translations*

Public DNS Update

(in the Internet)

- DNS servers in the Internet map original network hosts to the *new* address space
  - How DNS works is pre-req knowledge
- Hosts in twin network (and in any network in the Internet) obtain new IP addresses of original hosts from Internet DNS servers

Local DNS Update

(in original network)

- Local DNS at original network maps twin network hosts to a different (fake) address space (to avoid collision)
- hosts in original network obtain (fake) IP addresses of twin hosts from the local DNS

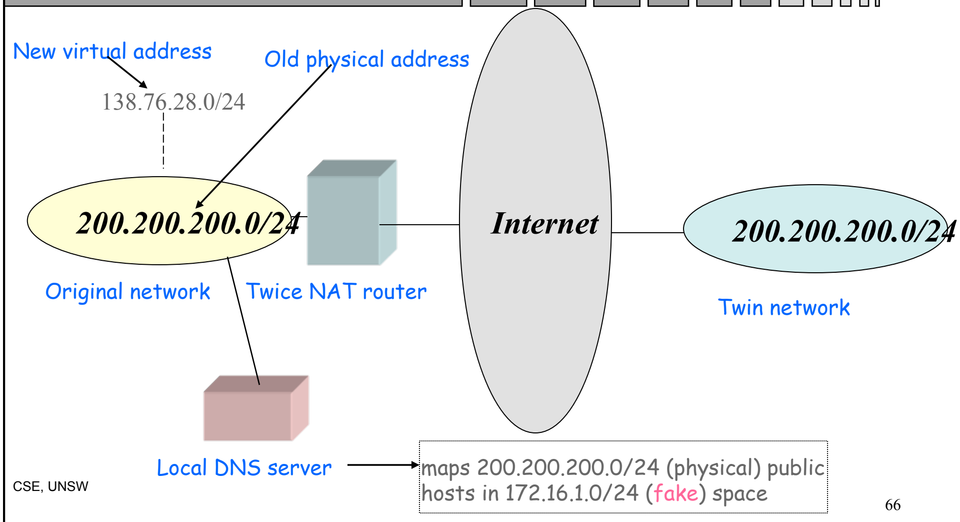
Twice NAT Translation

- Standard NAT translates only source (outgoing) or destination (incoming)
- Twice NAT translates both source and destination addresses (hence called *twice*) in each direction (outgoing and incoming)

Twice NAT Translation Example Address Mapping

- *Original* to *twin* 200.200.200.0/24 -> 138.76.28.0/24
  - NAT box is configured with this mapping
  - 138.76.28.0/24 is new (but virtual) space for private network
  - 200.200.200.0/24 is old (but physical) space for private network
- *Twin* to *original* 200.200.200.0/24 -> 172.16.1.0/24
  - NAT box is configured with this mapping
  - Local DNS maps 200.200.200.0/24 (physical) public hosts in 172.16.1.0/24 (fake) space

Twice NAT Example



Twice NAT Translation Example HostA (original)--> HostX (twin)

- Within original network (before translation)
  - Obtain (fake) destination address from local DNS
  - DA: 172.16.1.100   SA: 200.200.200.1
- After twice NAT translation
  - DA 200.200.200.100   SA: 138.76.28.1

Twice NAT Translation Example HostX (twin)--> HostA (original)

- Within twin network
  - Obtain destination address from DNS
  - DA: 138.76.28.1   SA: 200.200.200.100
- After twice NAT translation
  - DA 200.200.200.1   SA: 172.16.1.100