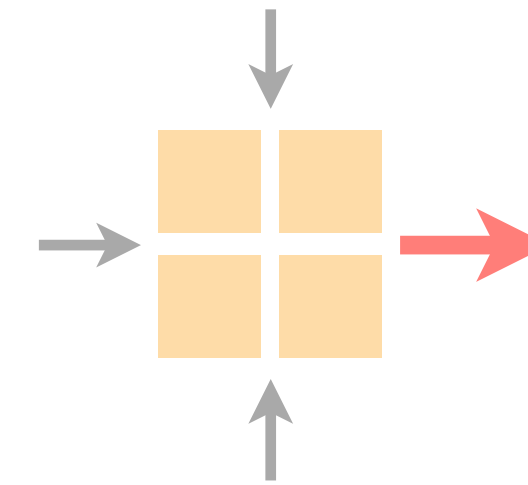


Communication Networks

Spring 2025



Pietro Ronchetti & Laurin Brandner

comm-net.ethz.ch

ETH Zürich

26 Mar 2025

Slides adapted from Lukas Röllin & Georgia Fragkouli

Communication Networks

Exercise 5

Routing Project

Important lecture topics

Introduction to this week's exercise

Time to solve the exercise

Communication Networks

Exercise 5

Routing Project

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Time to solve the exercise

NAT

Network Address Translation

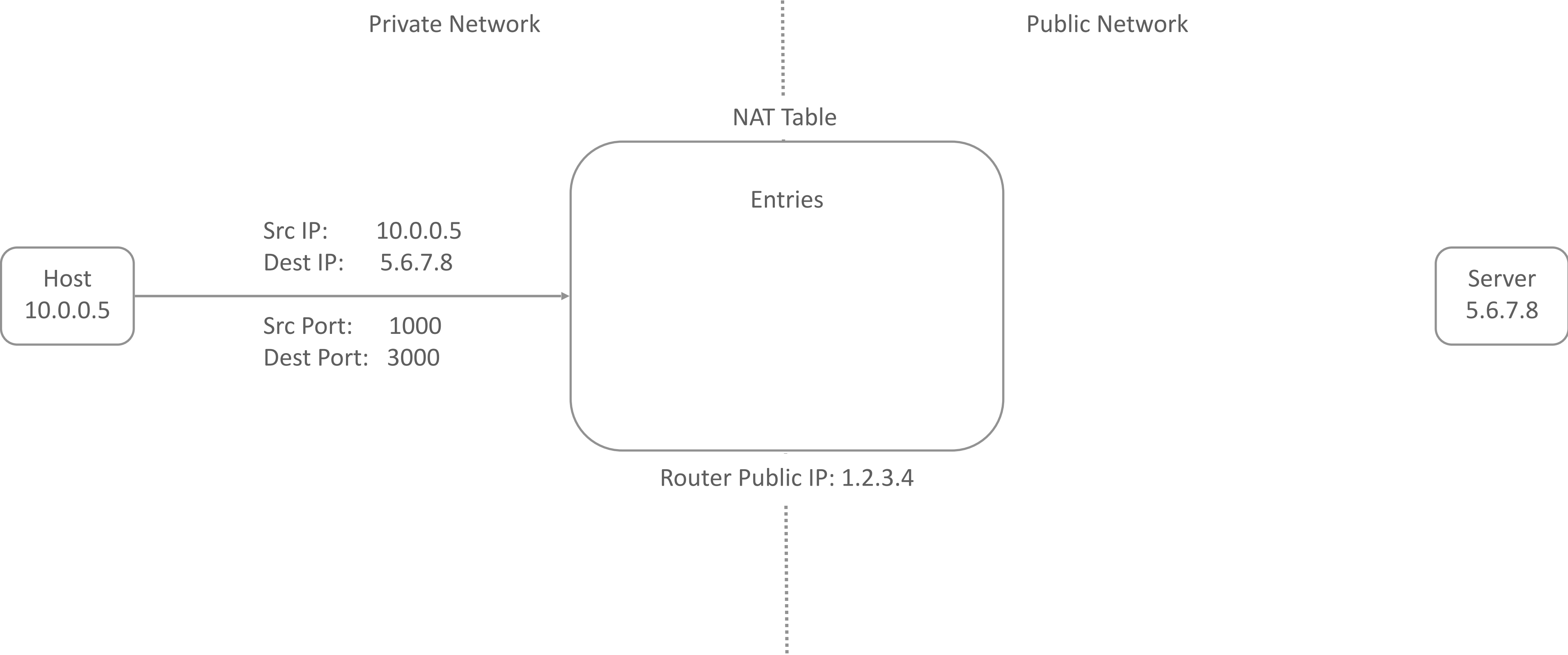
NAT allows one public IP to be shared by multiple hosts



Not physical ports but transport layer ports

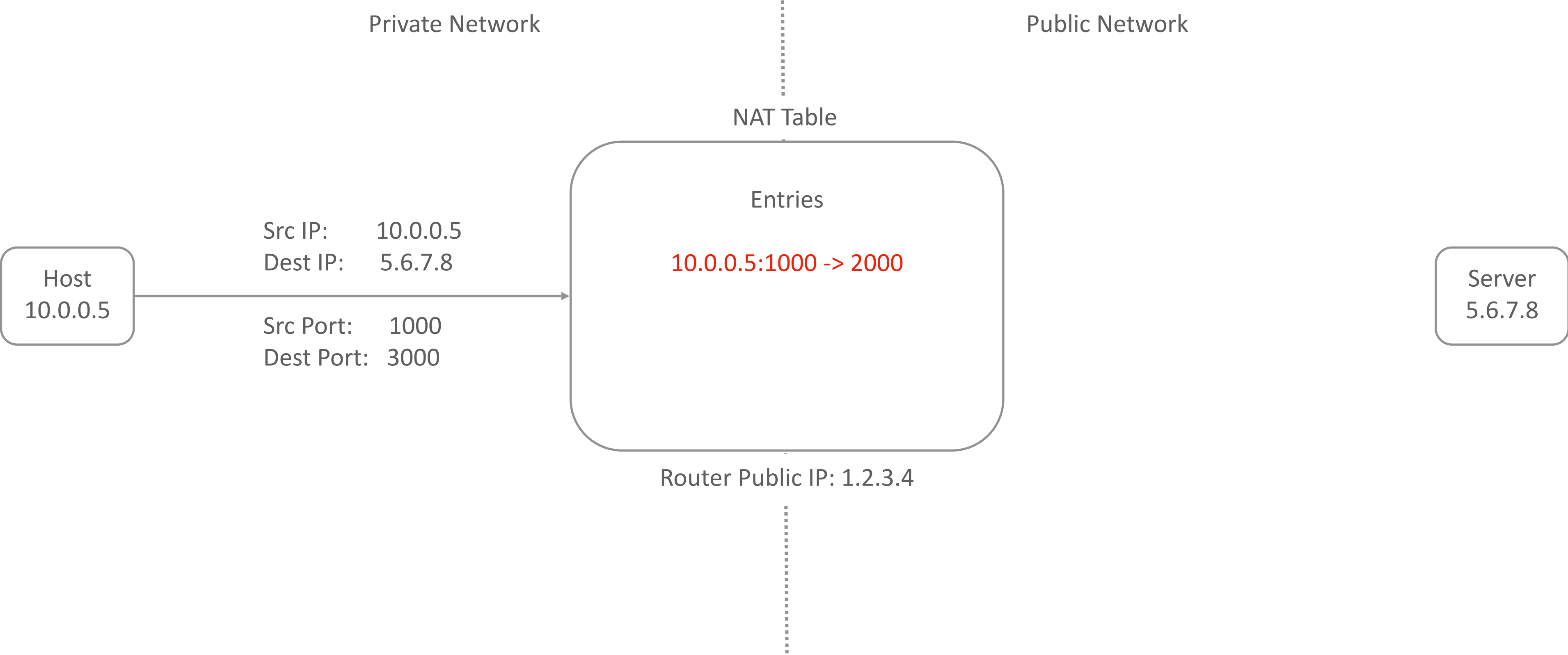
NAT

Network Address Translation



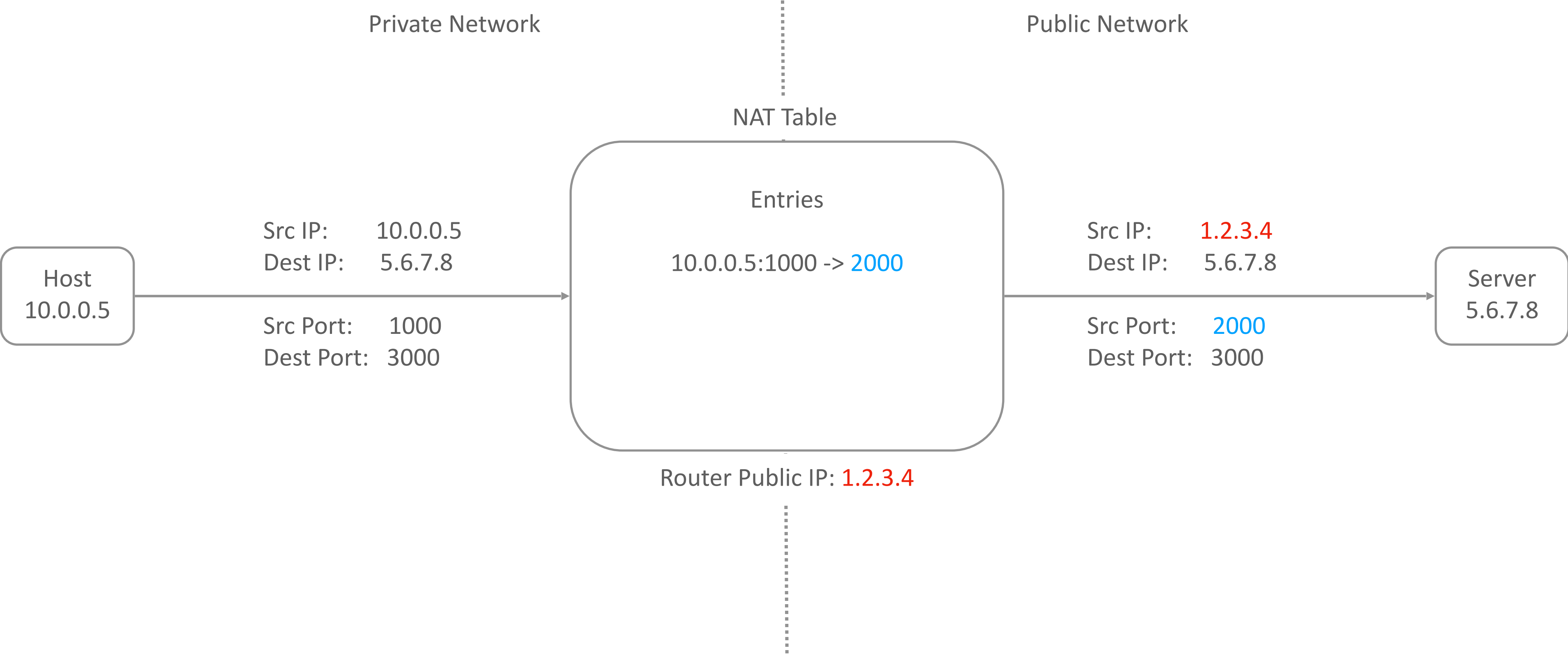
NAT

Network Address Translation



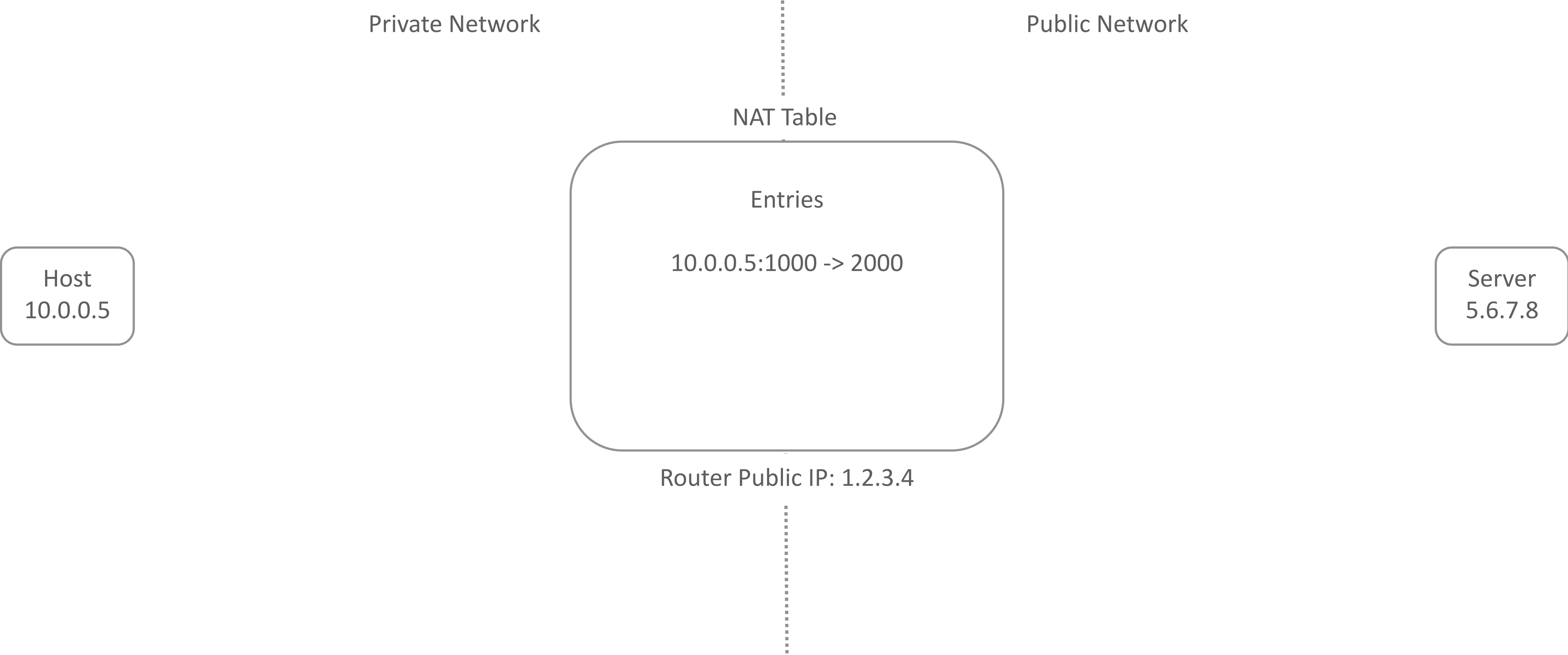
NAT

Network Address Translation



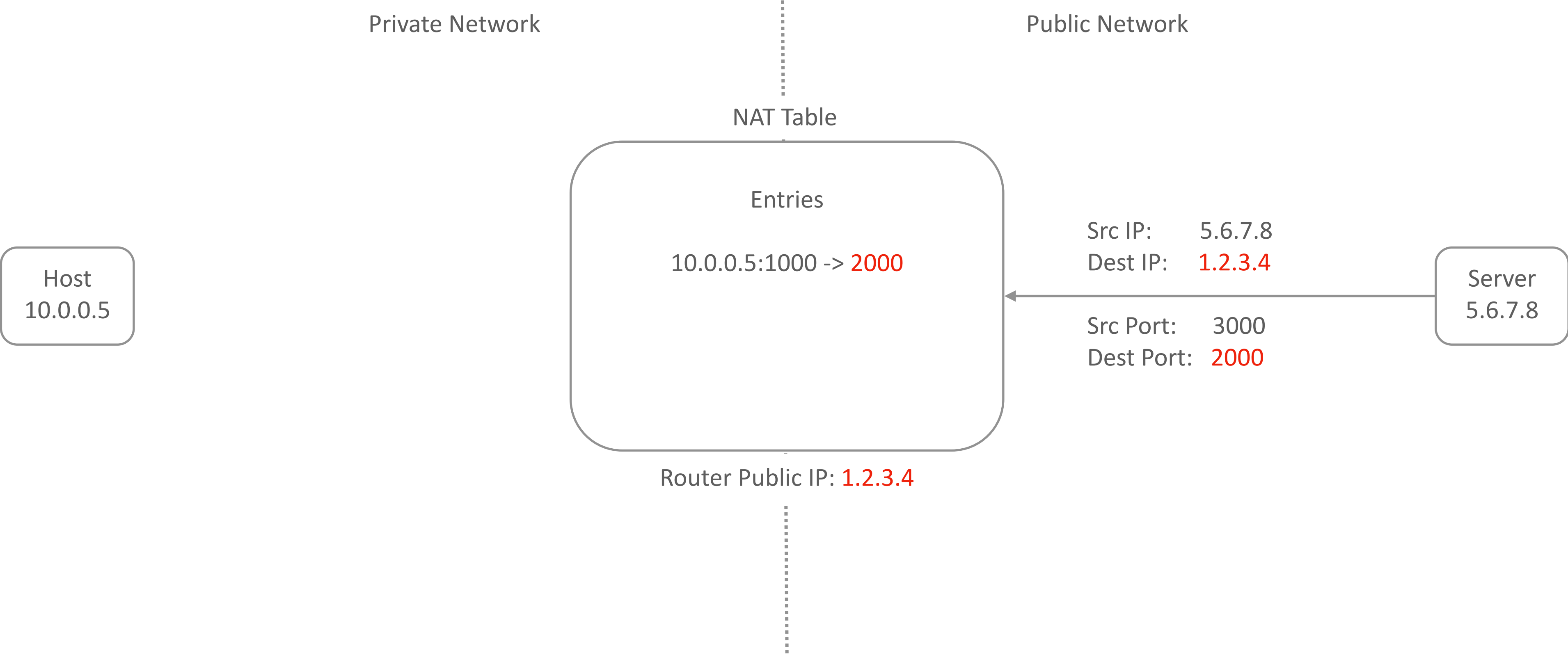
NAT

Network Address Translation



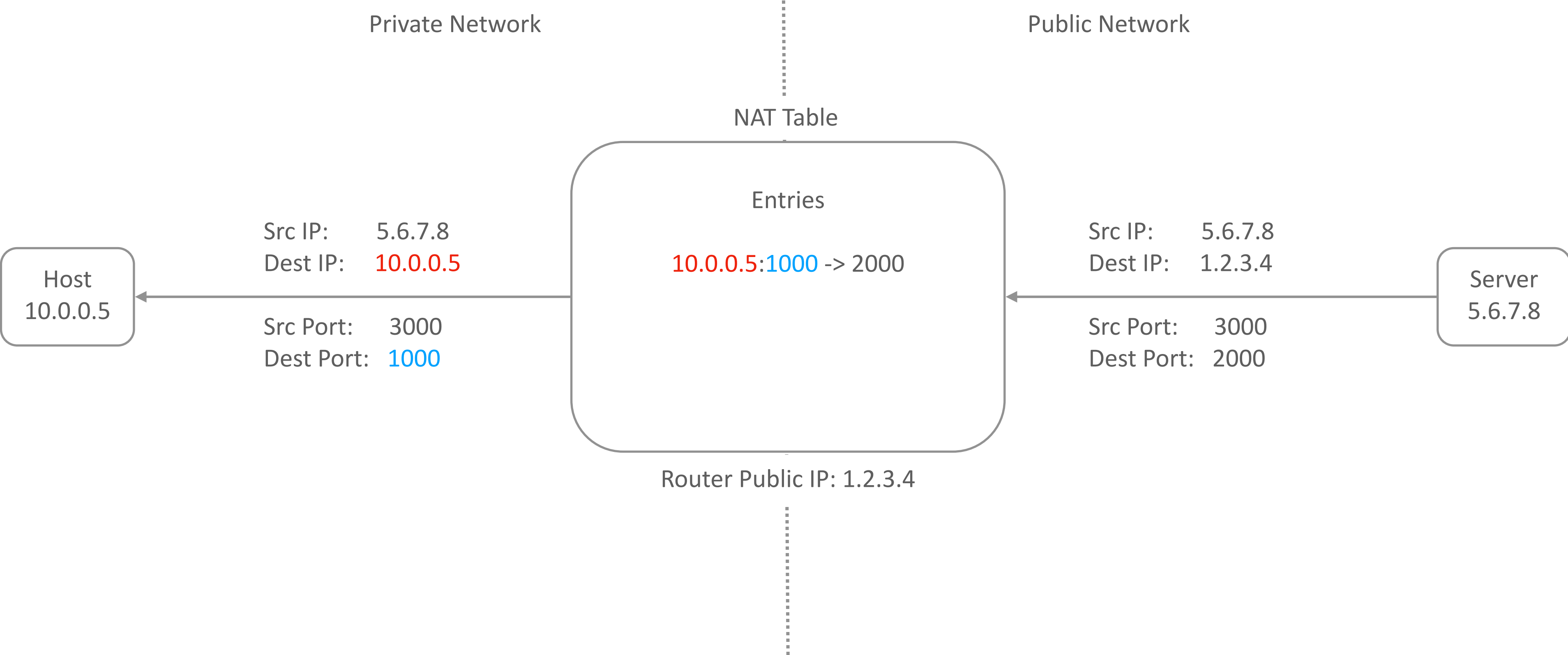
NAT

Network Address Translation



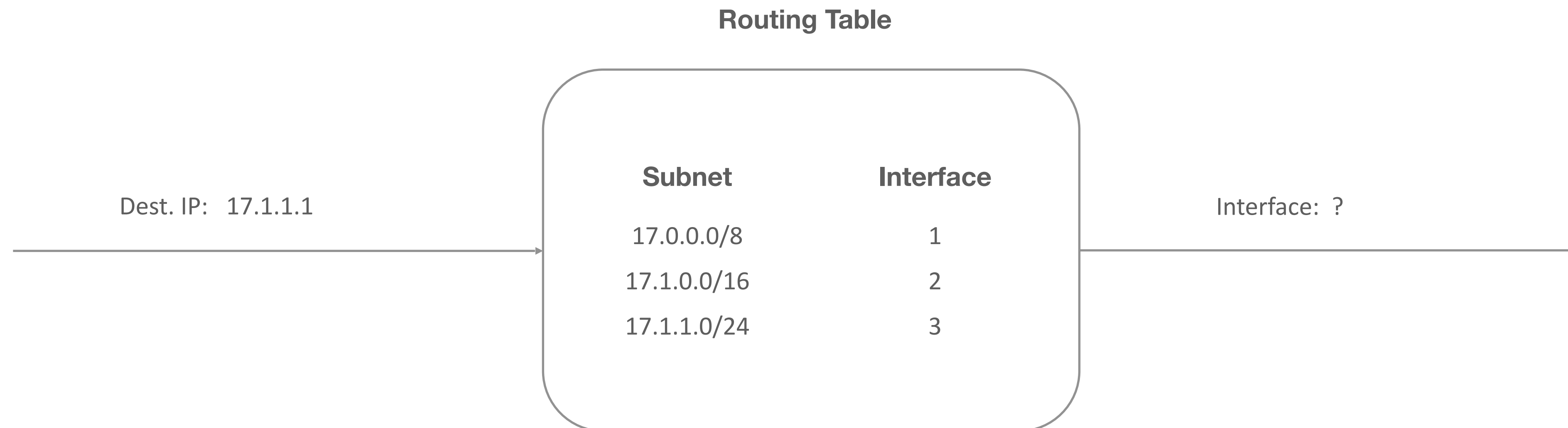
NAT

Network Address Translation



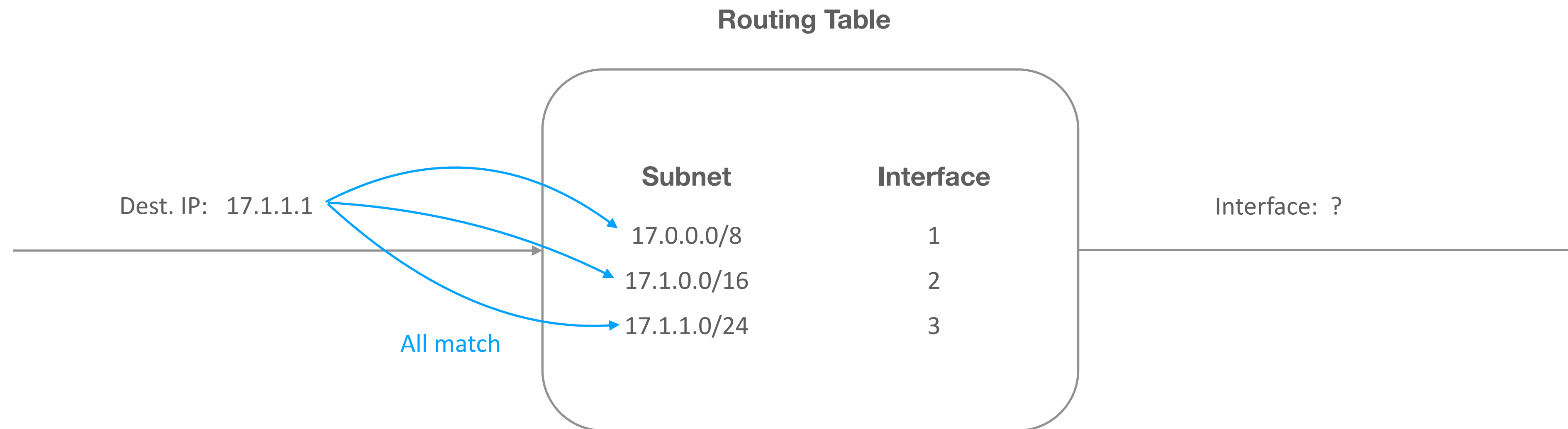
Longest Prefix Matching

IP routers use longest prefix matching to decide where to forward a packet



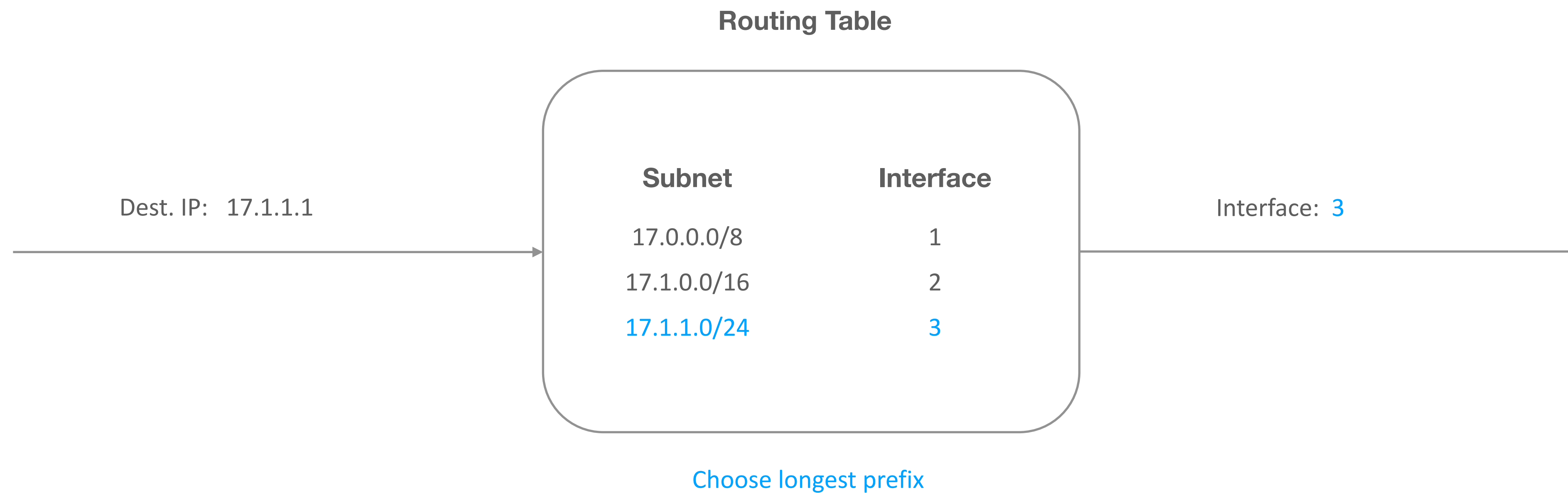
Longest Prefix Matching

IP routers use longest prefix matching to decide where to forward a packet



Longest Prefix Matching

IP routers use longest prefix matching to decide where to forward a packet

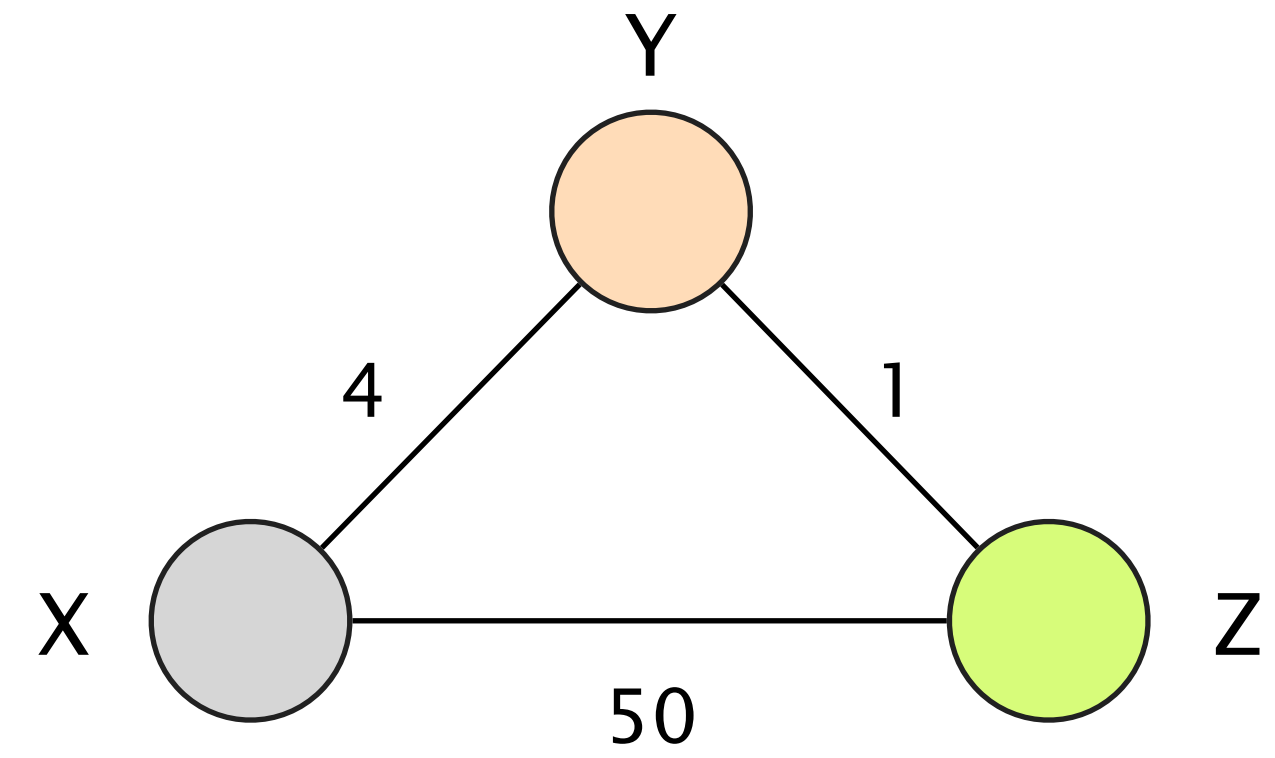


Bellman-Ford

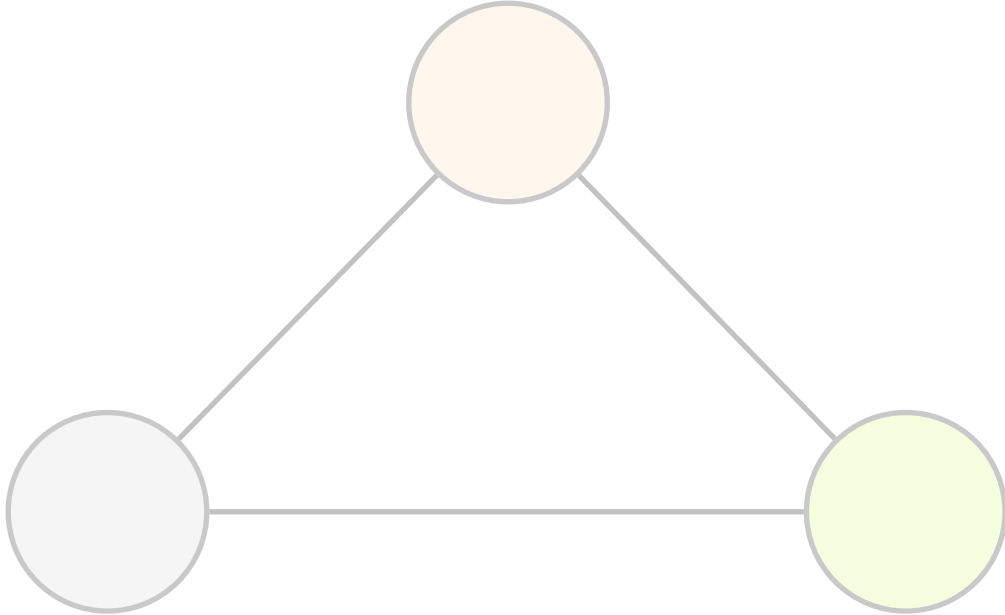
May lead to slow convergence

Bellman-Ford

Consider the following network



Bellman-Ford



leading to the following vectors

Y vector

dest.	via
X	Z

 — Y routes to X directly

X 4 6

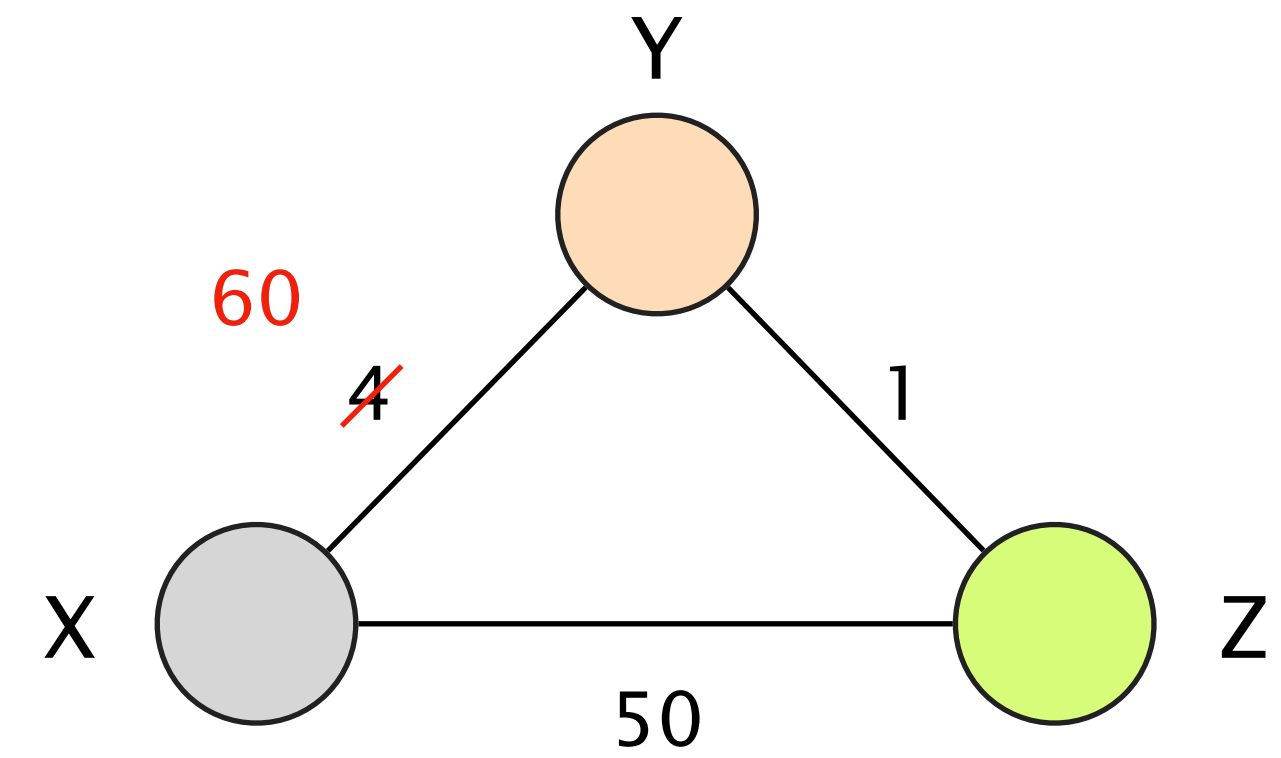
Z vector

dest.	via
X	Y

 — Z routes to X via Y

X 50 5

At $t = 0$
 (X,Y) weight changes from 4 to 60



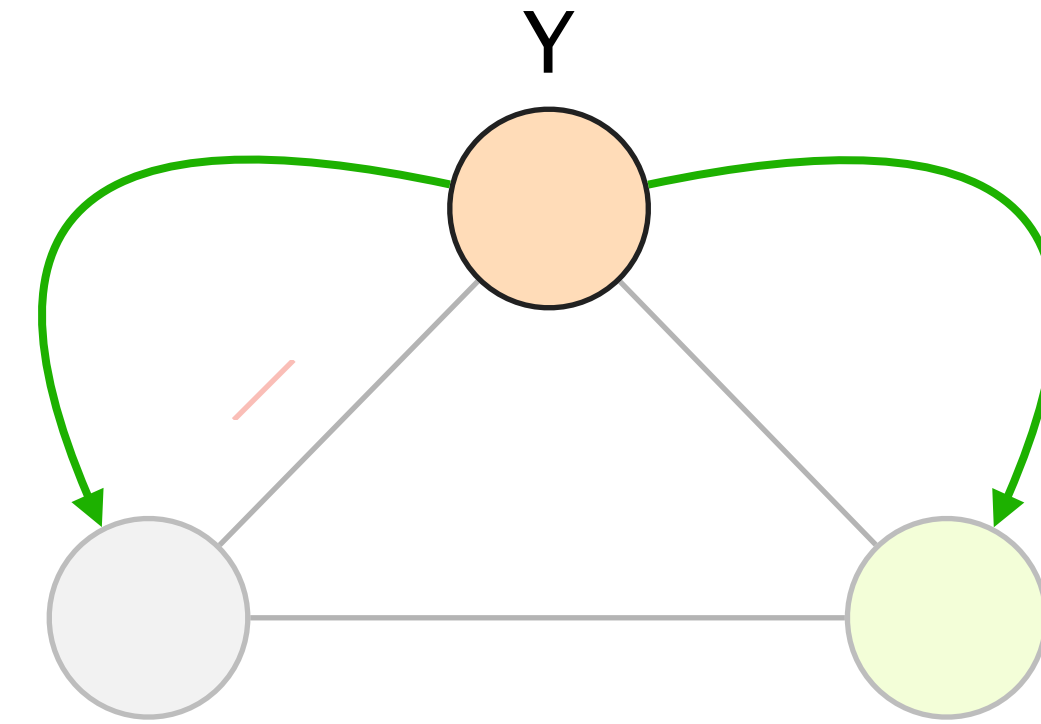
time $t=0$

Y vector	dest.	via	
	X	Z	
	X	4	6

Z vector	dest.	via	
	X	Y	
	X	50	5

At $t = 1$

Y updates its vector, sends it to X and Z



t=0

t=1

Y
vector

dest.	via
X	4
Z	6

X 4 6

dest.	via
X	60
Z	6

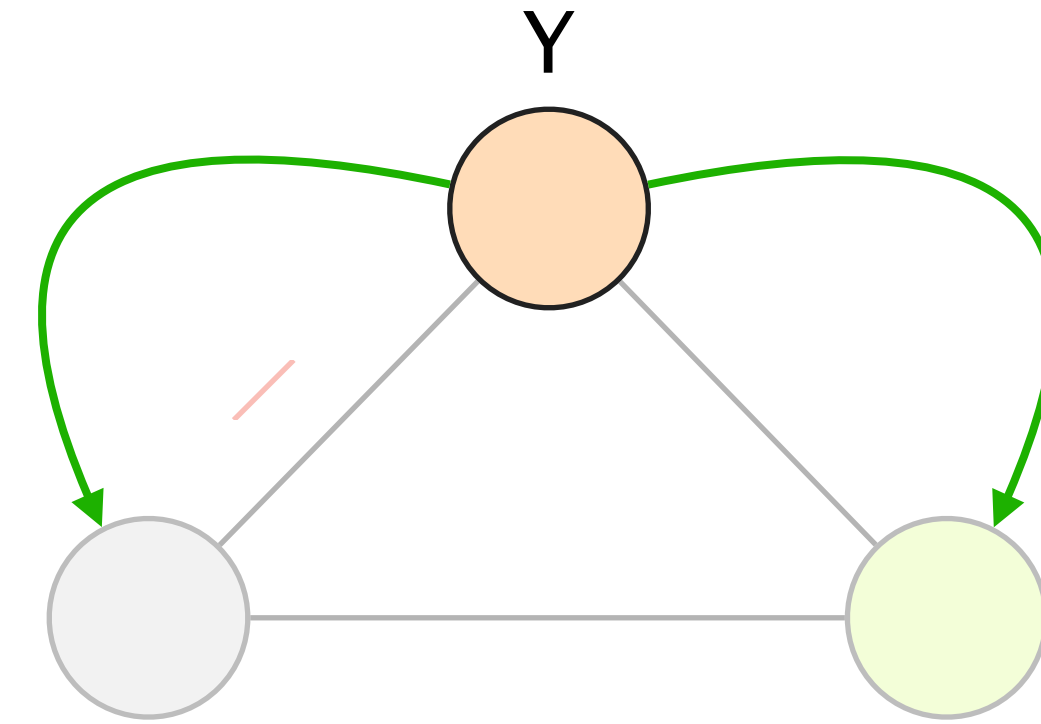
X 60 6

Z
vector

dest.	via
X	50
Y	5

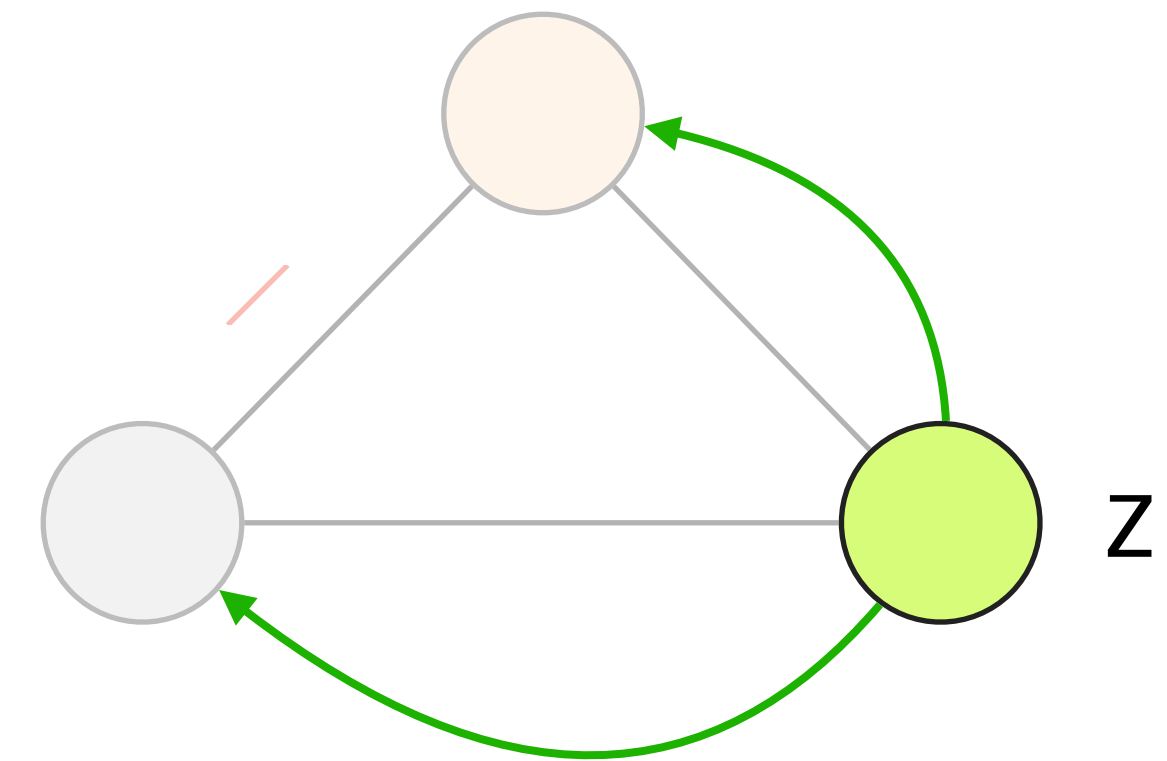
X 50 5

At $t = 1$
 We have a **routing loop**
 Packets to X ping-pong between Y-Z



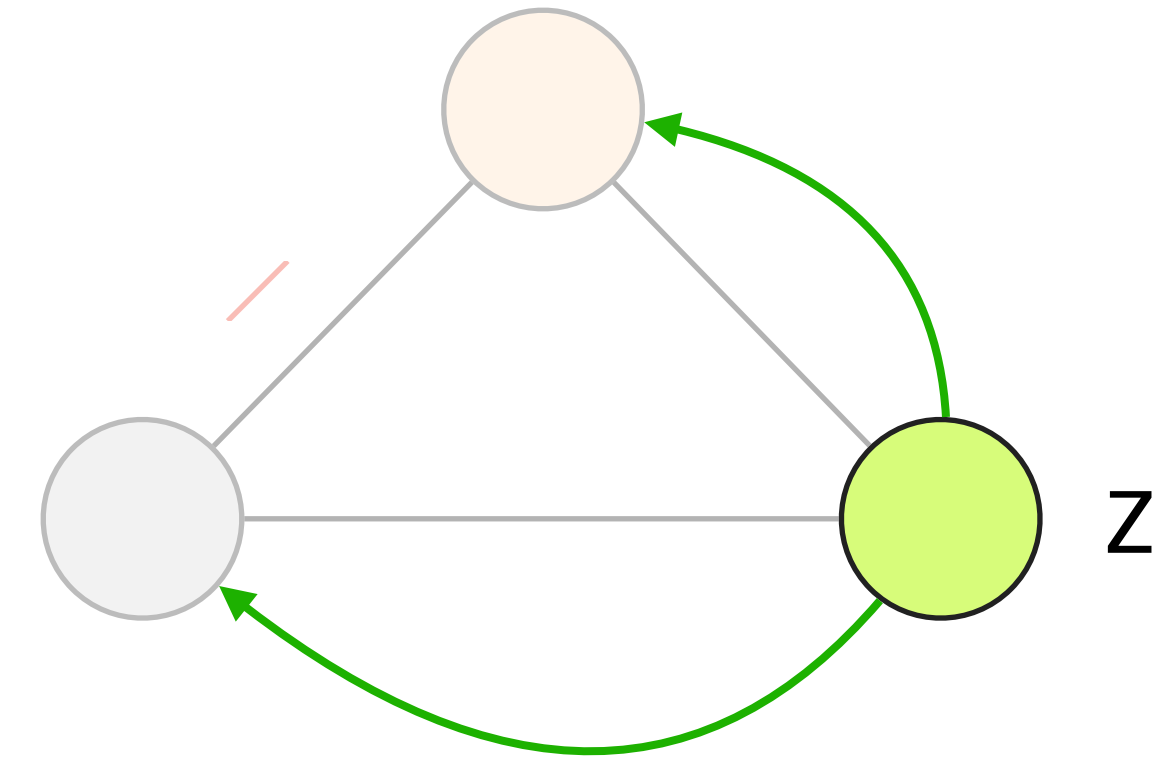
	t=0	t=1													
Y vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> </tr> <tr> <td>X</td> <td>X Z</td> </tr> <tr> <td></td> <td>4 6</td> </tr> </table>	dest.	via	X	X Z		4 6	<table border="1"> <tr> <td>dest.</td> <td>via</td> </tr> <tr> <td>X</td> <td>X Z</td> </tr> <tr> <td></td> <td>60 6</td> </tr> </table>	dest.	via	X	X Z		60 6	Y routes to X via Z
dest.	via														
X	X Z														
	4 6														
dest.	via														
X	X Z														
	60 6														
Z vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> </tr> <tr> <td>X</td> <td>X Y</td> </tr> <tr> <td></td> <td>50 5</td> </tr> </table>	dest.	via	X	X Y		50 5		Z routes to X via Y						
dest.	via														
X	X Y														
	50 5														

At $t = 2$
 Z updates its vector, sends it to X and Y



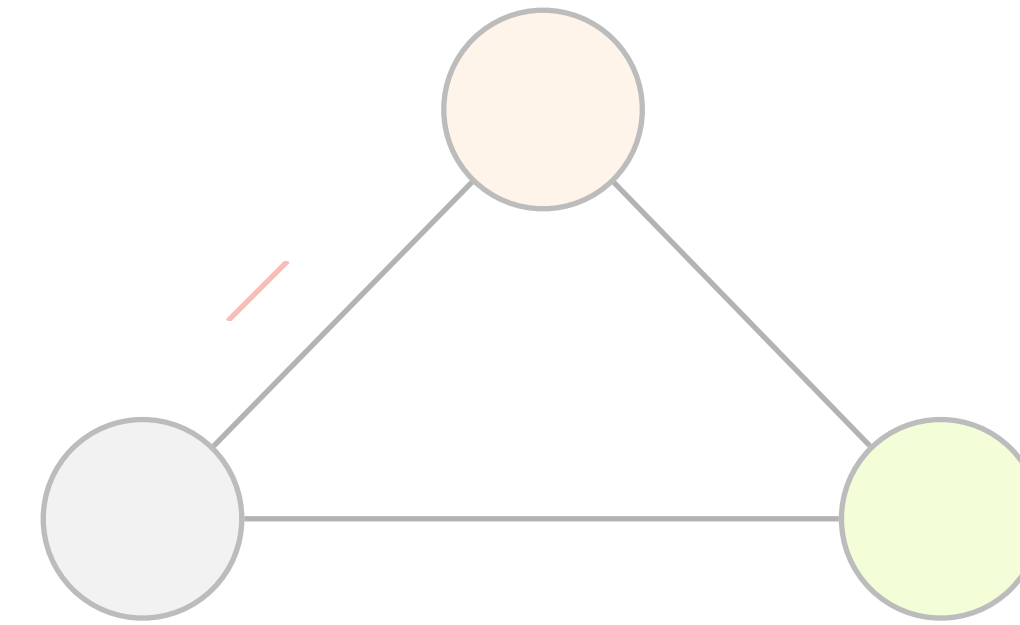
	t=0	t=1	t=2																		
Y vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>4</td> <td>6</td> </tr> </table>	dest.	via		X	X	Z		4	6	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>60</td> <td>6</td> </tr> </table>	dest.	via		X	X	Z		60	6	
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dest.	via																				
X	X	Y																			
	50	5																			
dest.	via																				
X	X	Y																			
	50	7																			

At $t = 2$
 The **routing loop** continues



	t=0	t=1	t=2																		
Y vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>4</td> <td>6</td> </tr> </table>	dest.	via		X	X	Z		4	6	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>60</td> <td>6</td> </tr> </table>	dest.	via		X	X	Z		60	6	Y routes to X via Z
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dest.	via																				
X	X	Y																			
	50	5																			
dest.	via																				
X	X	Y																			
	50	7																			

At $t = 46$
The routing loop finishes



t=45

t=46

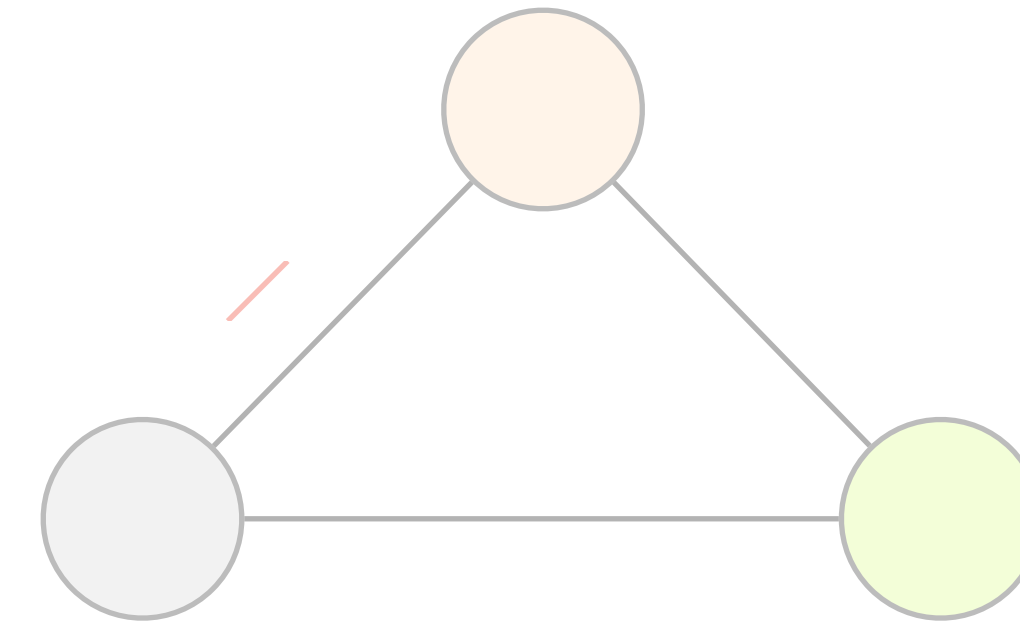
Y
vector

dest.	via
X	X Z
60	50

Z
vector

dest.	via
X	X Y
50	51

At $t = 48$
The network converges

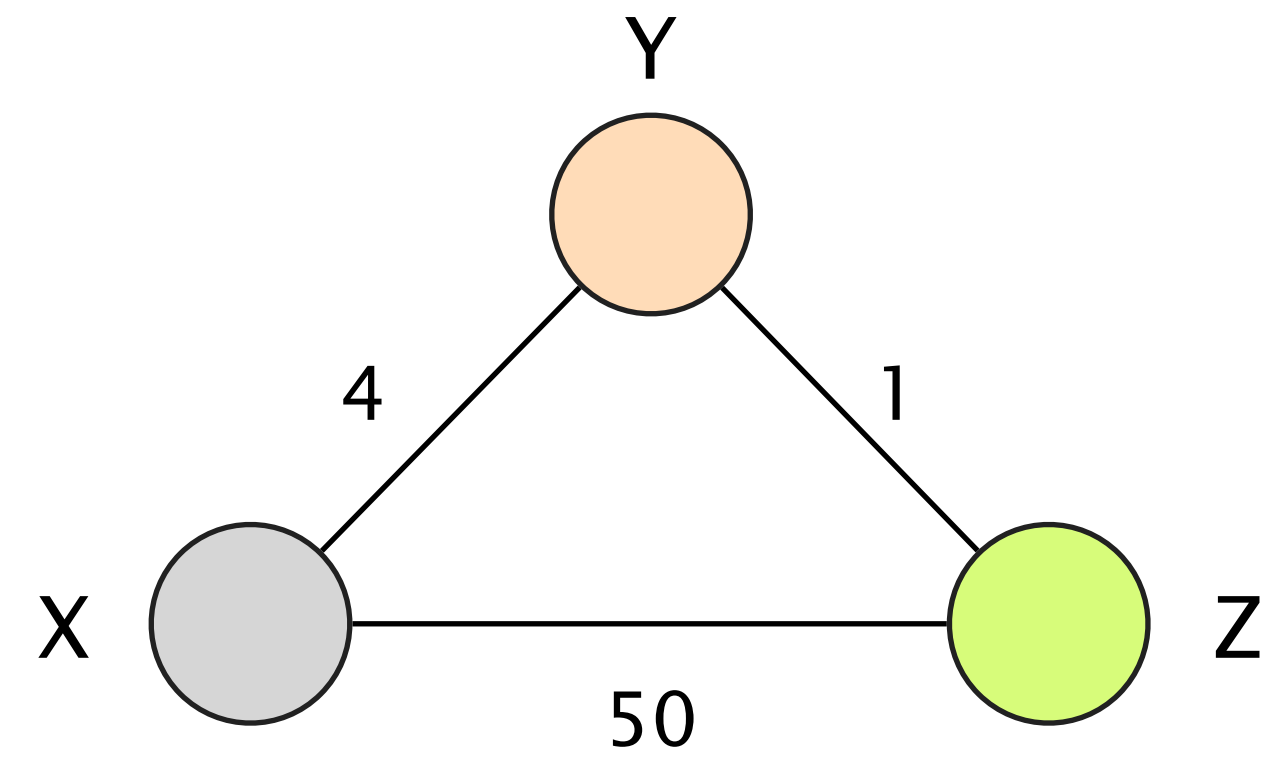


	t=45	t=46	t=47	t=48									
Y vector	<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>Z</td></tr></table> X 60 50	dest.	via	X	Z		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>Z</td></tr></table> X 60 51	dest.	via	X	Z		
dest.	via												
X	Z												
dest.	via												
X	Z												
Z vector		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>Y</td></tr></table> X 50 51	dest.	via	X	Y		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>Y</td></tr></table> X 50 52	dest.	via	X	Y	
dest.	via												
X	Y												
dest.	via												
X	Y												

Let's try to
fix routing loops and slow convergence

Whenever a router (say X) uses another one (say Y),
X will announce to Y an infinite cost

The technique is known as **poisoned reverse**



Y vector

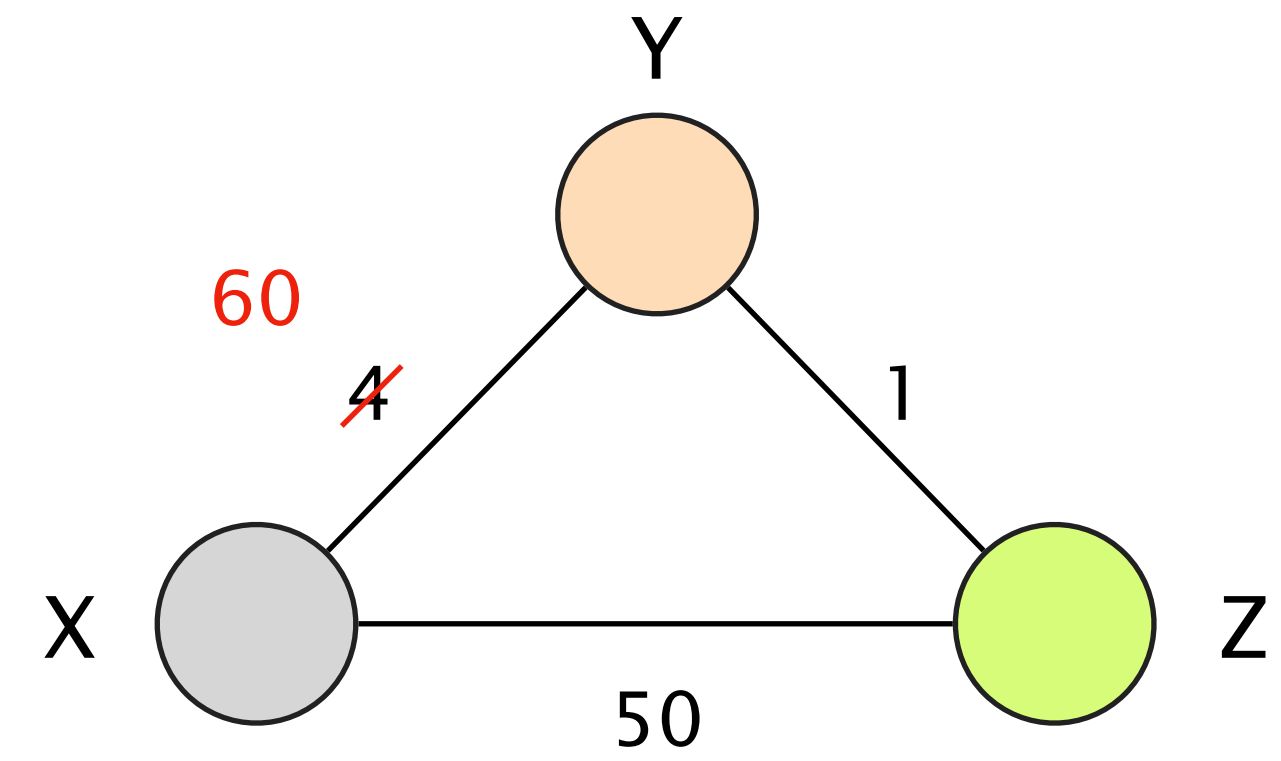
dest.	via	
X	Z	
X	4	∞

As Z routes to X via Y,
Z announces to Y an infinite cost

Z vector

dest.	via	
X	Y	
X	50	5

At $t = 0$
 (X,Y) weight changes from 4 to 60



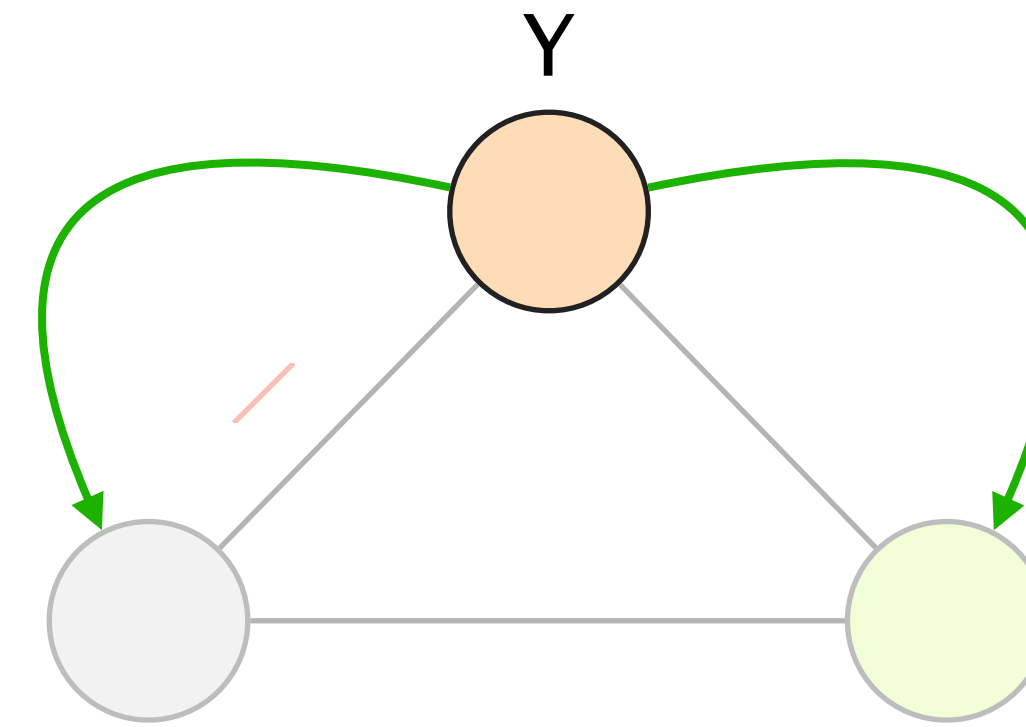
$t=0$

Y vector	dest.	via	
	X	Z	
	X	4	∞

Z vector	dest.	via	
	X	Y	
	X	50	5

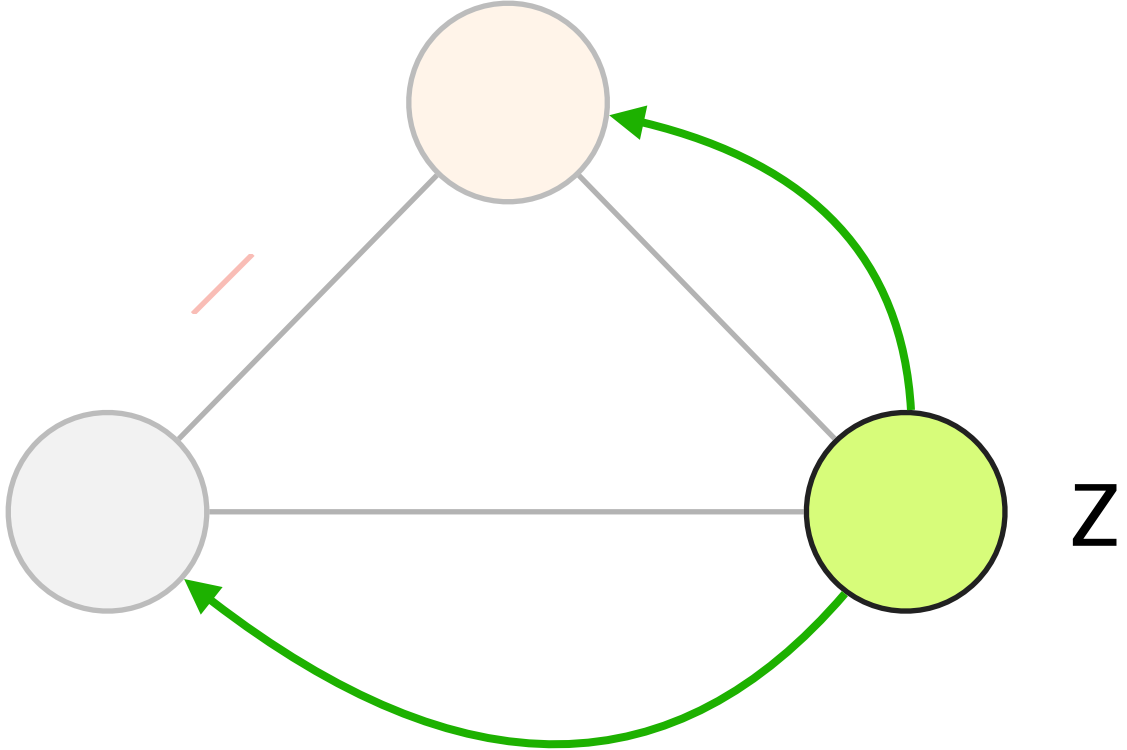
At $t = 1$

Y updates its vector, sends it to X and Z



	t=0	t=1																		
Y vector	<table><thead><tr><th>dest.</th><th>via</th><th></th></tr><tr><td>X</td><td>X</td><td>Z</td></tr></thead><tbody><tr><td>X</td><td>4</td><td>∞</td></tr></tbody></table>	dest.	via		X	X	Z	X	4	∞	<table><thead><tr><th>dest.</th><th>via</th><th></th></tr><tr><td>X</td><td>X</td><td>Z</td></tr></thead><tbody><tr><td>X</td><td>60</td><td>∞</td></tr></tbody></table>	dest.	via		X	X	Z	X	60	∞
dest.	via																			
X	X	Z																		
X	4	∞																		
dest.	via																			
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X	60	∞																		
Z vector	<table><thead><tr><th>dest.</th><th>via</th><th></th></tr><tr><td>X</td><td>X</td><td>Y</td></tr></thead><tbody><tr><td>X</td><td>50</td><td>5</td></tr></tbody></table>	dest.	via		X	X	Y	X	50	5										
dest.	via																			
X	X	Y																		
X	50	5																		

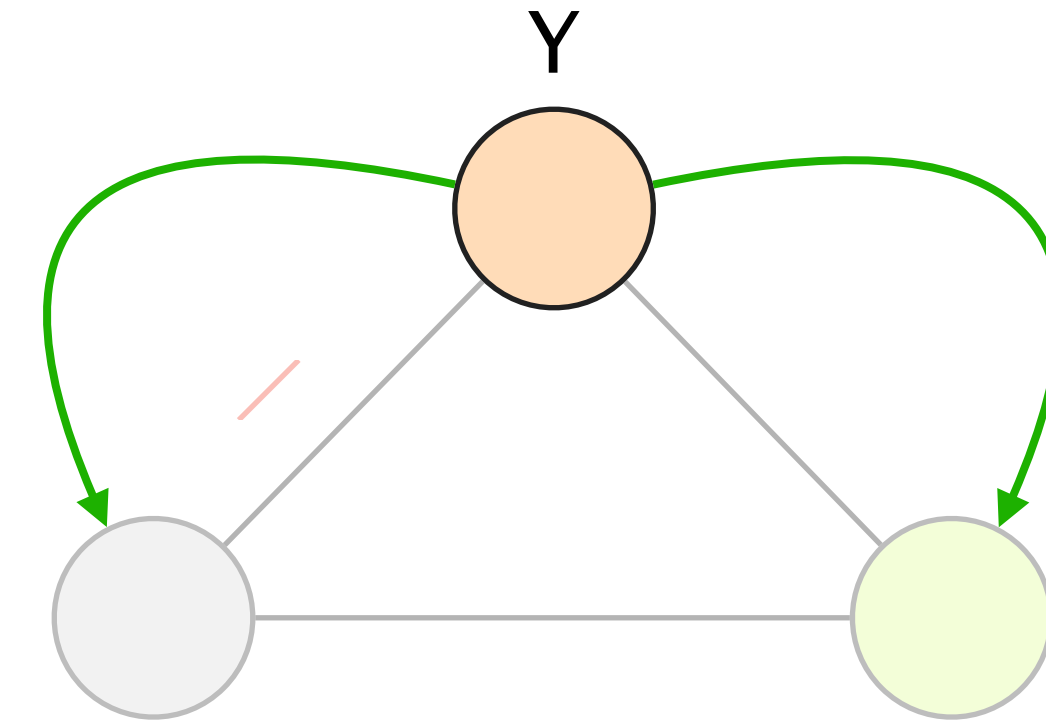
At $t = 2$
 Z updates its vector, sends it to X and Y



	t=0	t=1	t=2																		
Y vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>4</td> <td>∞</td> </tr> </table>	dest.	via		X	X	Z		4	∞	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Z</td> </tr> <tr> <td></td> <td>60</td> <td>∞</td> </tr> </table>	dest.	via		X	X	Z		60	∞	
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Z vector	<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Y</td> </tr> <tr> <td></td> <td>50</td> <td>5</td> </tr> </table>	dest.	via		X	X	Y		50	5		<table border="1"> <tr> <td>dest.</td> <td>via</td> <td></td> </tr> <tr> <td>X</td> <td>X</td> <td>Y</td> </tr> <tr> <td></td> <td>50</td> <td>61</td> </tr> </table>	dest.	via		X	X	Y		50	61
dest.	via																				
X	X	Y																			
	50	5																			
dest.	via																				
X	X	Y																			
	50	61																			

At $t = 3$

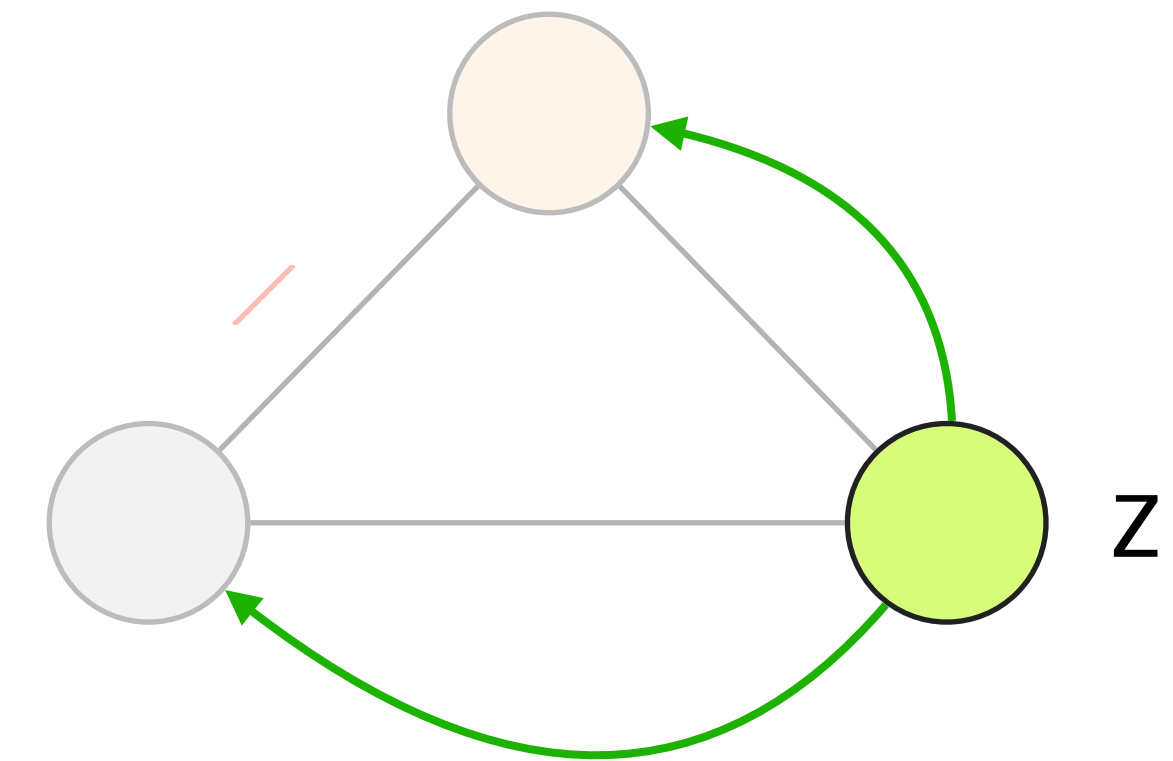
Y updates its vector, sends it to X and Z



	t=0	t=1	t=2	t=3																		
Y vector	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr><tr><td>X</td><td>Z</td></tr></thead><tbody><tr><td>4</td><td>∞</td></tr></tbody></table>	dest.	via	X	Z	4	∞	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr><tr><td>X</td><td>Z</td></tr></thead><tbody><tr><td>60</td><td>∞</td></tr></tbody></table>	dest.	via	X	Z	60	∞		<table border="1"><thead><tr><th>dest.</th><th>via</th></tr><tr><td>X</td><td>Z</td></tr></thead><tbody><tr><td>60</td><td>51</td></tr></tbody></table>	dest.	via	X	Z	60	51
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X	Z																					
4	∞																					
dest.	via																					
X	Z																					
60	∞																					
dest.	via																					
X	Z																					
60	51																					
Z vector	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr><tr><td>X</td><td>Y</td></tr></thead><tbody><tr><td>50</td><td>5</td></tr></tbody></table>	dest.	via	X	Y	50	5		<table border="1"><thead><tr><th>dest.</th><th>via</th></tr><tr><td>X</td><td>Y</td></tr></thead><tbody><tr><td>50</td><td>61</td></tr></tbody></table>	dest.	via	X	Y	50	61							
dest.	via																					
X	Y																					
50	5																					
dest.	via																					
X	Y																					
50	61																					

At $t = 4$

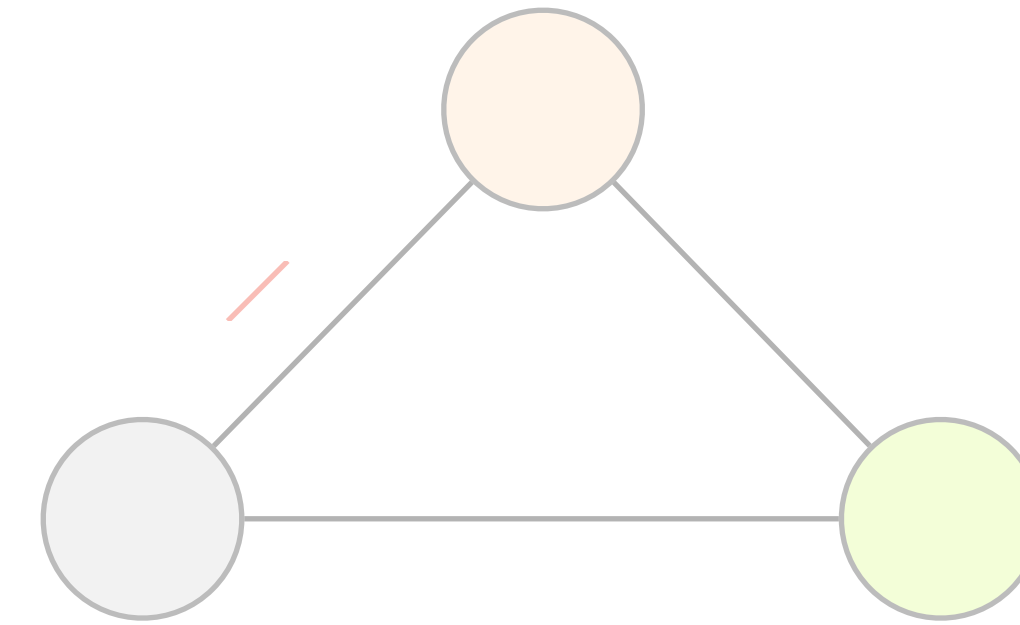
Z updates its vector, sends it to X and Y



	t=0	t=1	t=2	t=3	t=4												
Y vector	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Z</td></tr></tbody></table> X 4 ∞	dest.	via	X	Z	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Z</td></tr></tbody></table> X 60 ∞	dest.	via	X	Z		<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Z</td></tr></tbody></table> X 60 51	dest.	via	X	Z	
dest.	via																
X	Z																
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X	Z																
Z vector	<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Y</td></tr></tbody></table> X 50 5	dest.	via	X	Y		<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Y</td></tr></tbody></table> X 50 61	dest.	via	X	Y		<table border="1"><thead><tr><th>dest.</th><th>via</th></tr></thead><tbody><tr><td>X</td><td>Y</td></tr></tbody></table> X 50 ∞	dest.	via	X	Y
dest.	via																
X	Y																
dest.	via																
X	Y																
dest.	via																
X	Y																

For $t > 4$

No more updates: **network has converged!**



	t=0	t=1	t=2	t=3	t=4	t>4																								
Y vector	<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Z</td></tr><tr><td>4</td><td>∞</td></tr></table>	dest.	via	X	X Z	4	∞	<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Z</td></tr><tr><td>60</td><td>∞</td></tr></table>	dest.	via	X	X Z	60	∞		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Z</td></tr><tr><td>60</td><td>51</td></tr></table>	dest.	via	X	X Z	60	51		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Z</td></tr><tr><td>60</td><td>51</td></tr></table>	dest.	via	X	X Z	60	51
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Z vector	<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Y</td></tr><tr><td>50</td><td>5</td></tr></table>	dest.	via	X	X Y	50	5		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Y</td></tr><tr><td>50</td><td>61</td></tr></table>	dest.	via	X	X Y	50	61		<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Y</td></tr><tr><td>50</td><td>∞</td></tr></table>	dest.	via	X	X Y	50	∞	<table border="1"><tr><td>dest.</td><td>via</td></tr><tr><td>X</td><td>X Y</td></tr><tr><td>50</td><td>∞</td></tr></table>	dest.	via	X	X Y	50	∞
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dest.	via																													
X	X Y																													
50	∞																													
dest.	via																													
X	X Y																													
50	∞																													

While poisoned reverse solved this case,
it does **not** solve converge issues in general

See exercise task 3

Communication Networks

Exercise 5

Routing Project

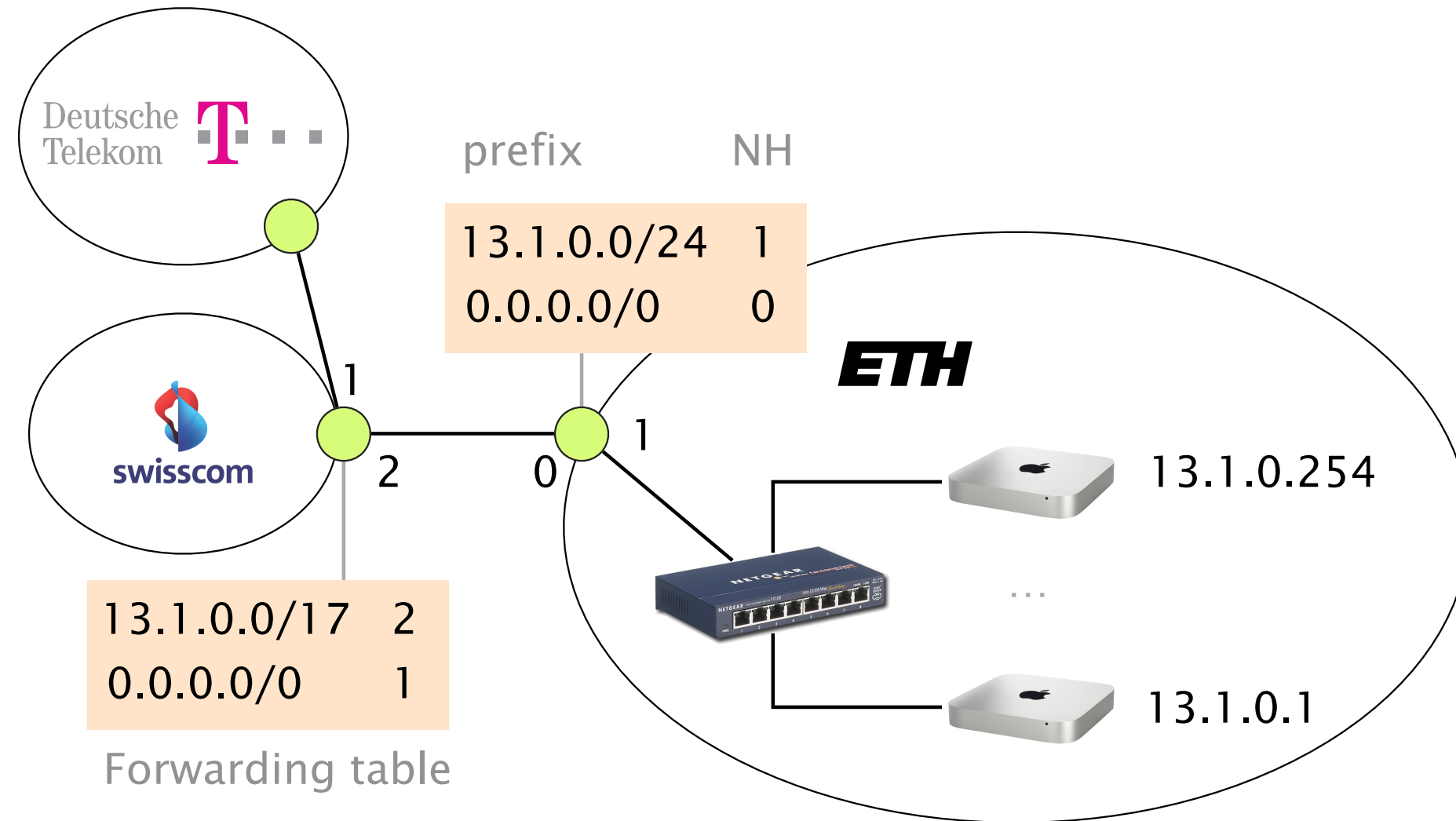
Important lecture topics

Introduction to this week's exercise

Time to solve the exercise

Task 5.1

Forwarding

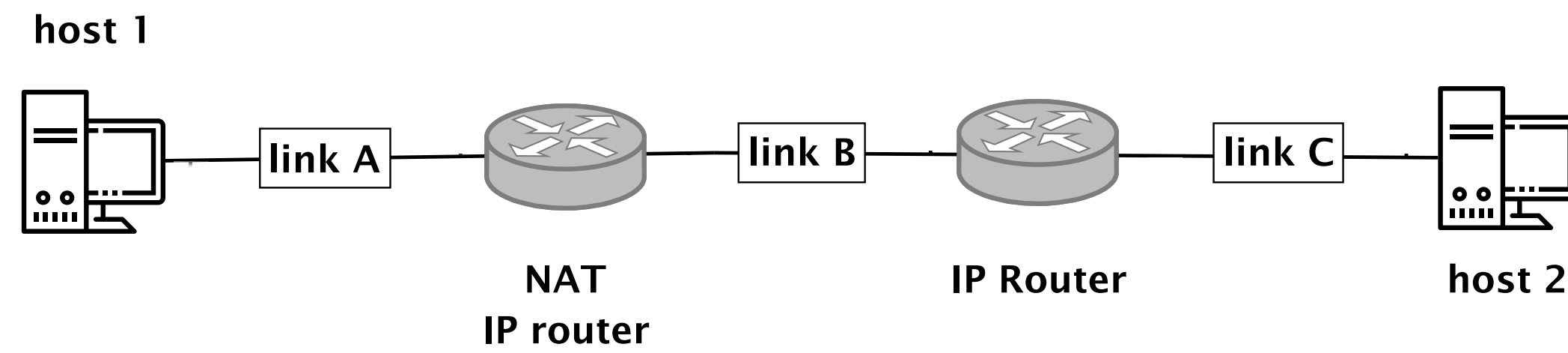


Number of IPs available for devices

Longest prefix matching

Task 5.2

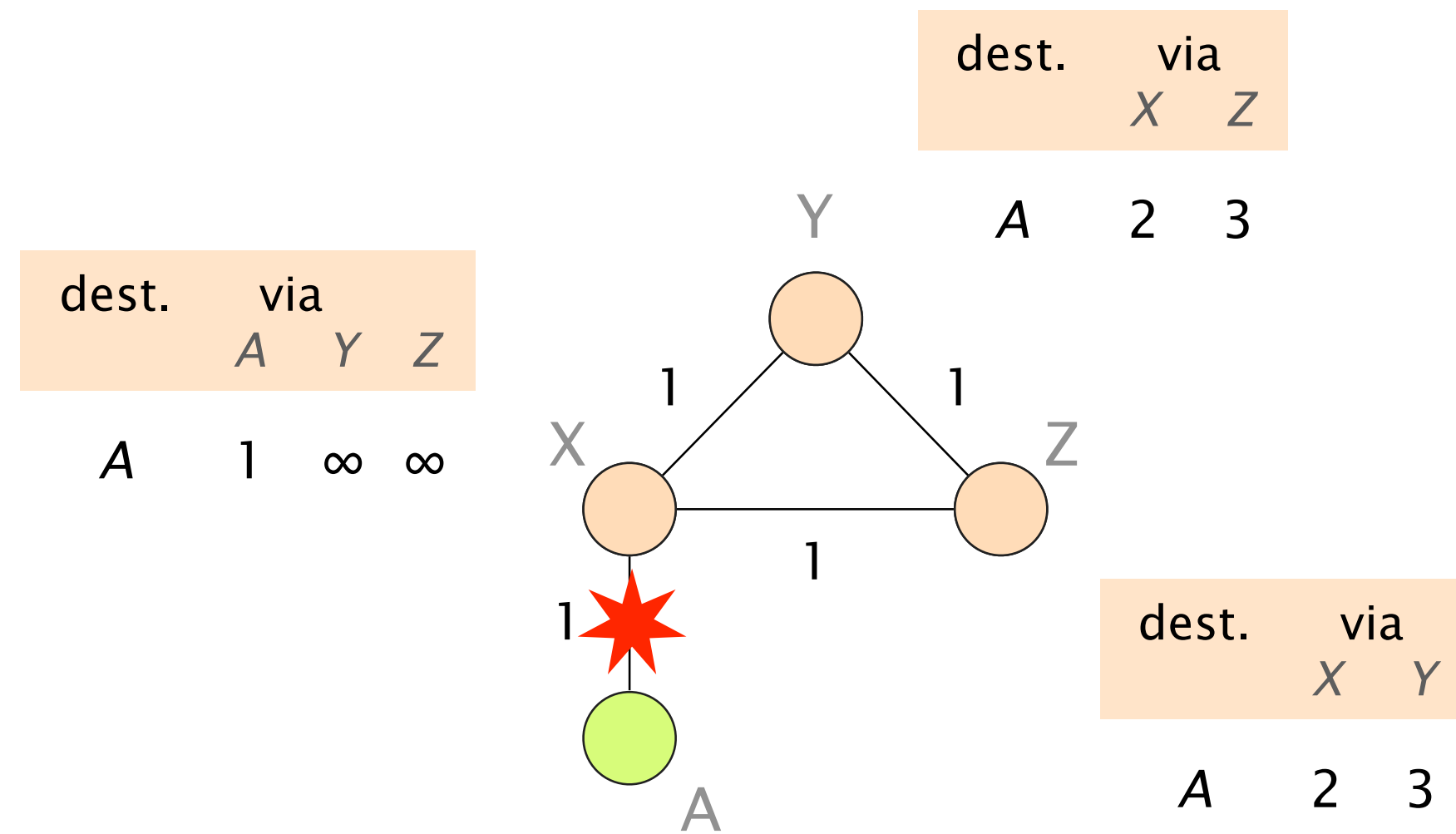
Network Address Translation



What information is needed for routing?

Task 5.3

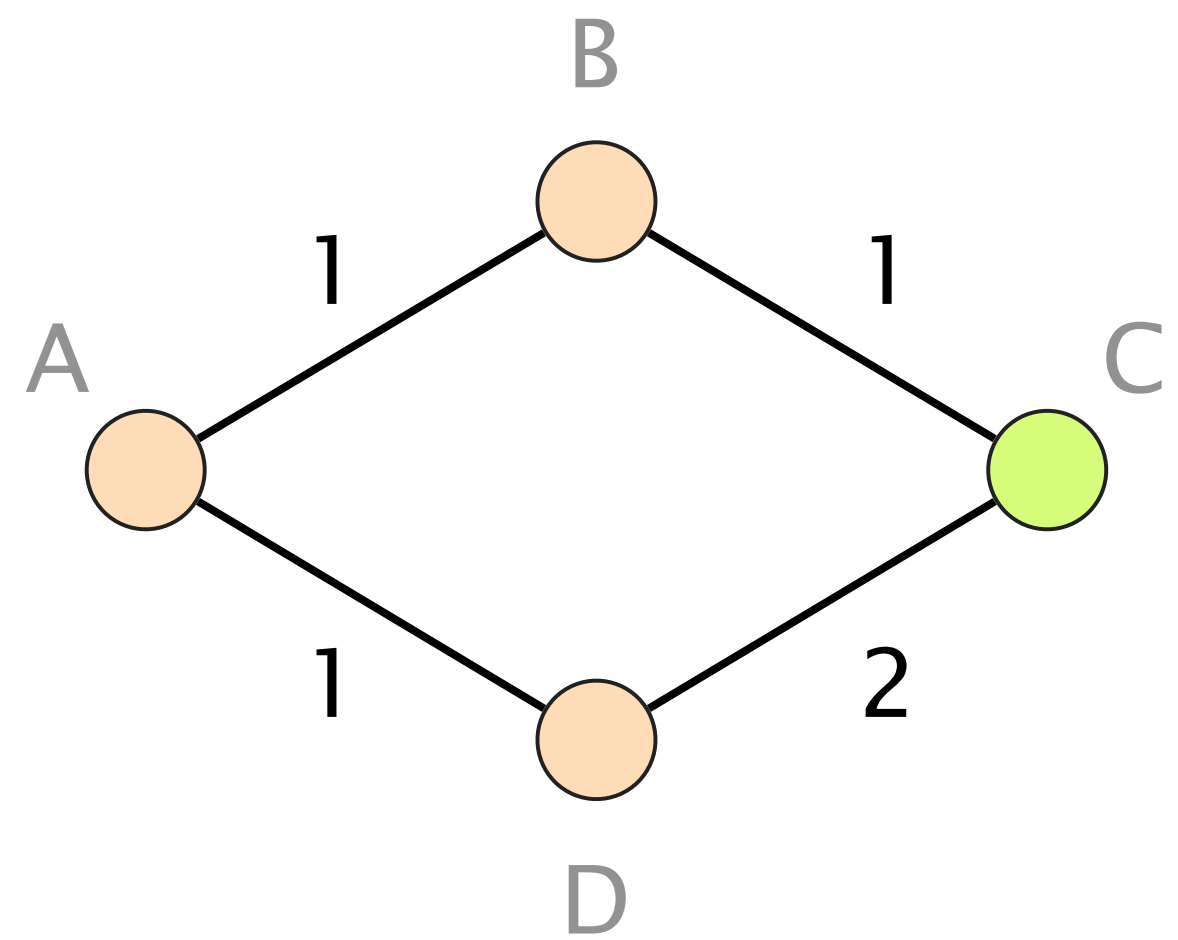
Convergence with Poisoned Reverse



What we have talked about today

Task 5.4

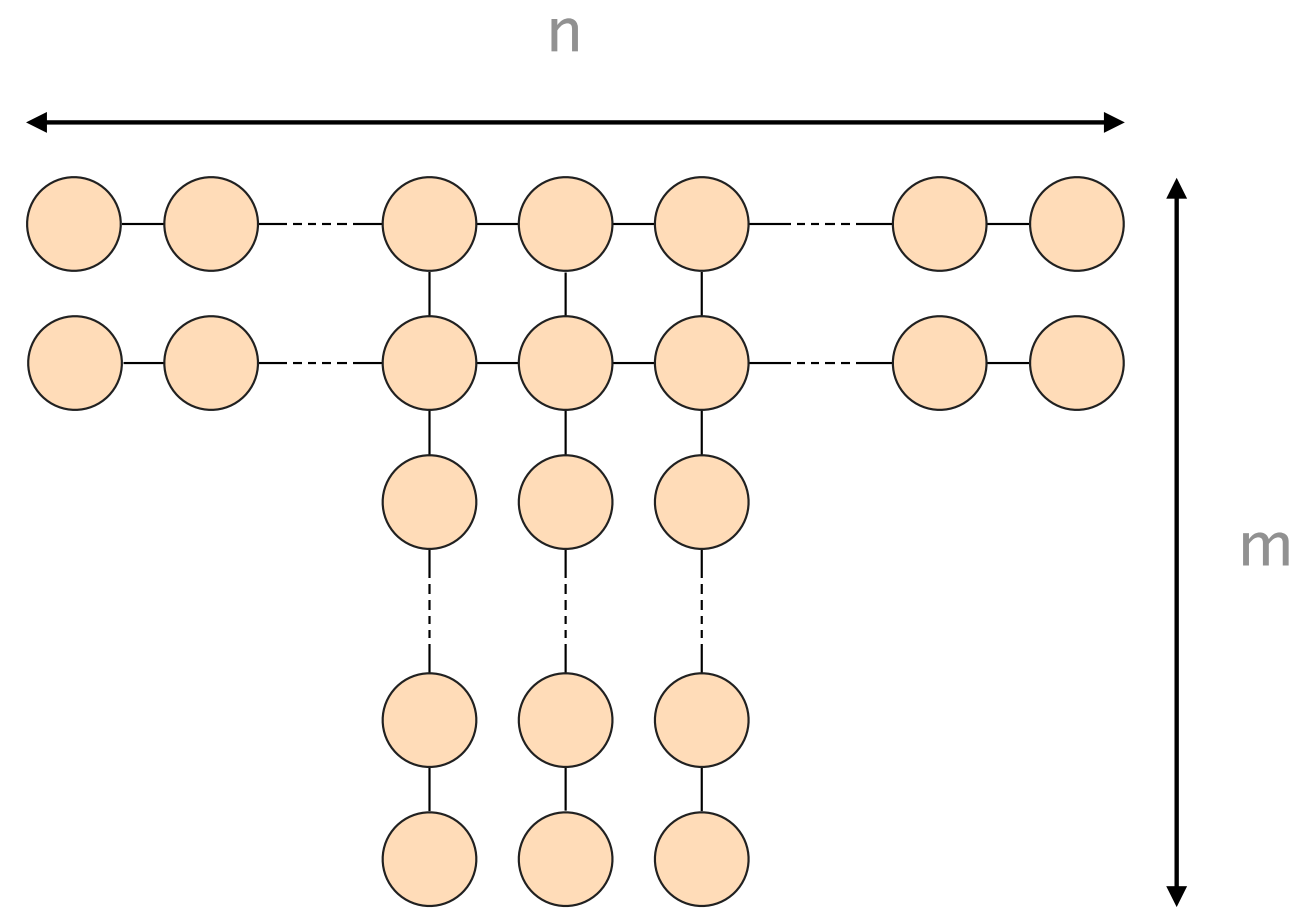
Link-State Protocol Convergence



Come up with weight changes that only affect the forwarding behavior of one node at a time

Task 5.5

Convergence of General Topologies



Think about how long it takes to propagate information along the diameter of this network.

Communication Networks

Exercise 5

Routing Project

Important lecture topics

Introduction to this week's exercise

Time to solve the exercise