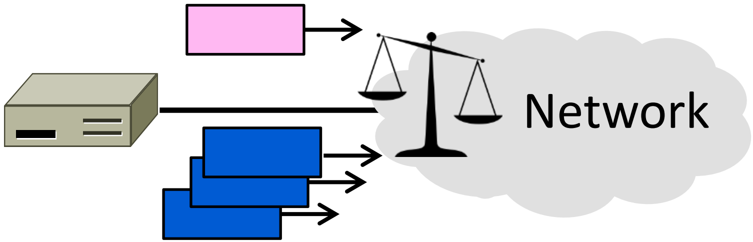
Topic

- Sharing bandwidth between flows
  - WFQ (Weighted Fair Queuing)
  - Key building block for QOS

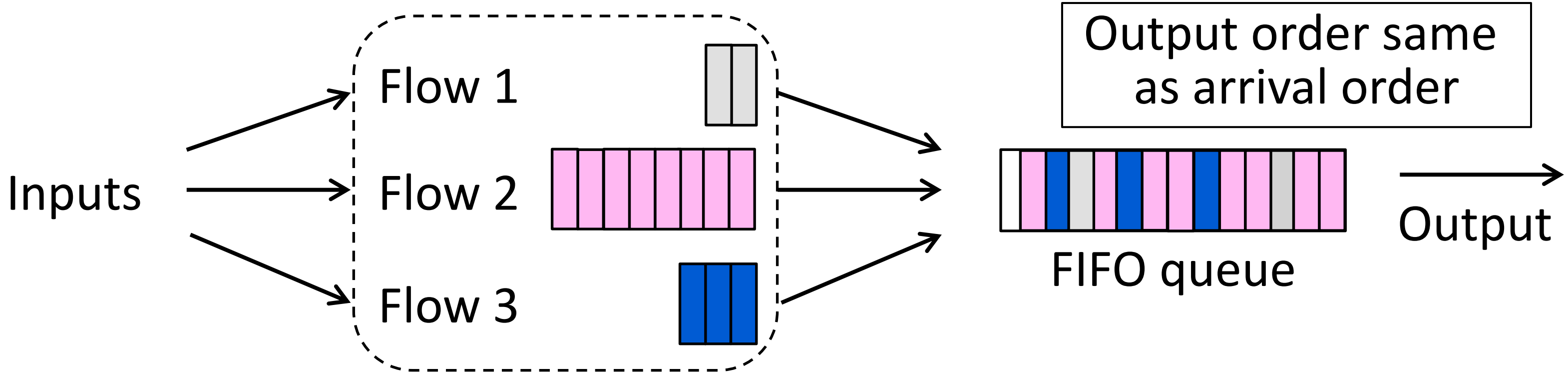


Sharing with FIFO Queuing

- FIFO "drop tail" queue:
  - Queue packets First In First Out (FIFO)
  - Discard new packets when full
  - Typical router queuing model
- Sharing with FIFO queue
  - Multiple users or flows send packets over the same (output) link
  - What will happen?

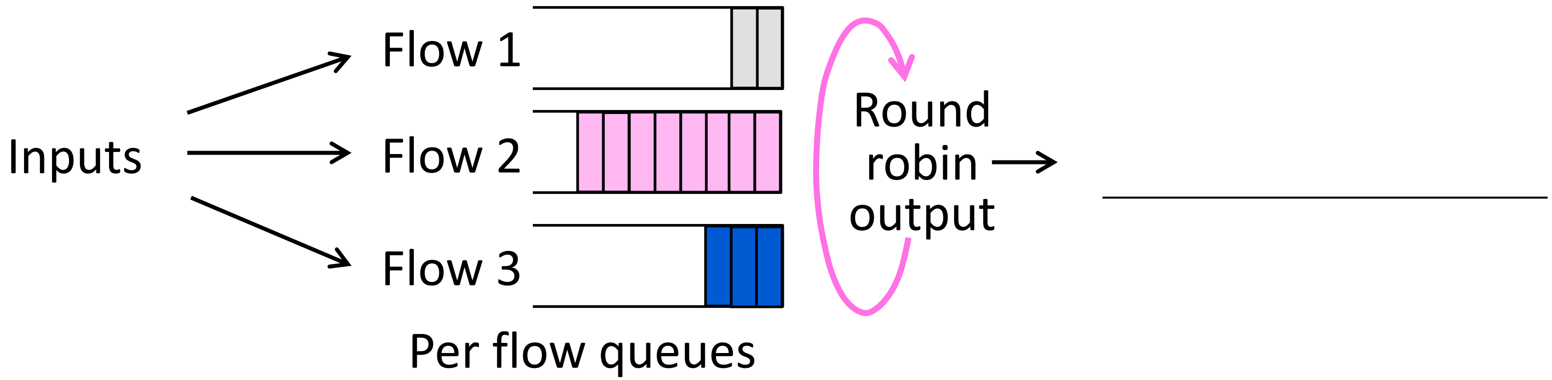
Sharing with FIFO Queuing (2)

- Bandwidth allocation depends on behavior of all flows
  - TCP gives long-term sharing – with delay/loss, and RTT bias
  - Aggressive user/flow can crowd out the others



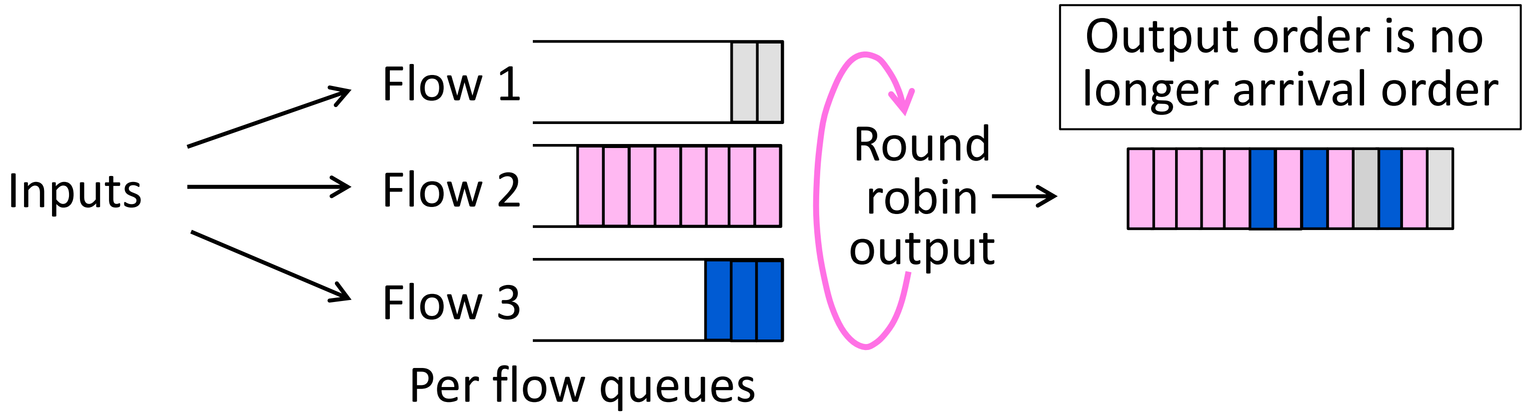
Round-Robin Queuing

- Idea to improve fairness:
  - Queue packets separately for each flow; take one packet in turn from each non-empty flow at the next output time



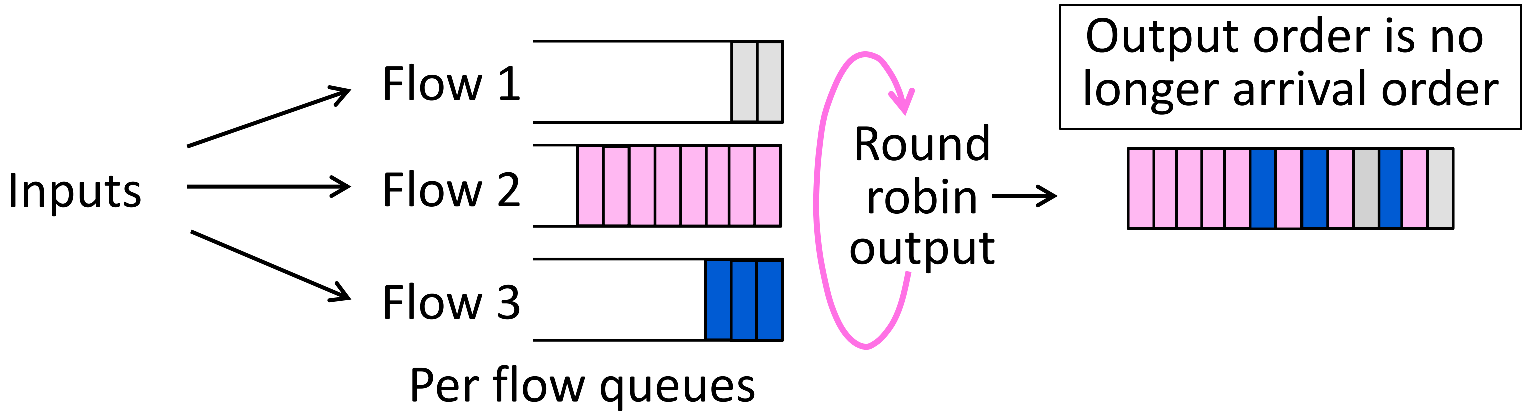
Round-Robin Queuing (2)

- Idea to improve fairness:
  - Queue packets separately for each flow; take one packet in turn from each non-empty flow at the next output time
  - How well does this work?



Round-Robin Queuing (3)

- Flows don't see uncontrolled delay/loss from others!
- But different packet sizes lead to bandwidth imbalance
  - Might be significant, e.g., 40 bytes vs 1500 bytes



Fair Queuing

- Round-robin but approximate bit-level fairness:
  - Approximate by computing virtual finish time
  - Virtual clock ticks once for each bit sent from all flows
  - Send packets in order of their virtual finish times, $Finish(j)_F$
  - Not perfect – don't preempt packet being transmitted

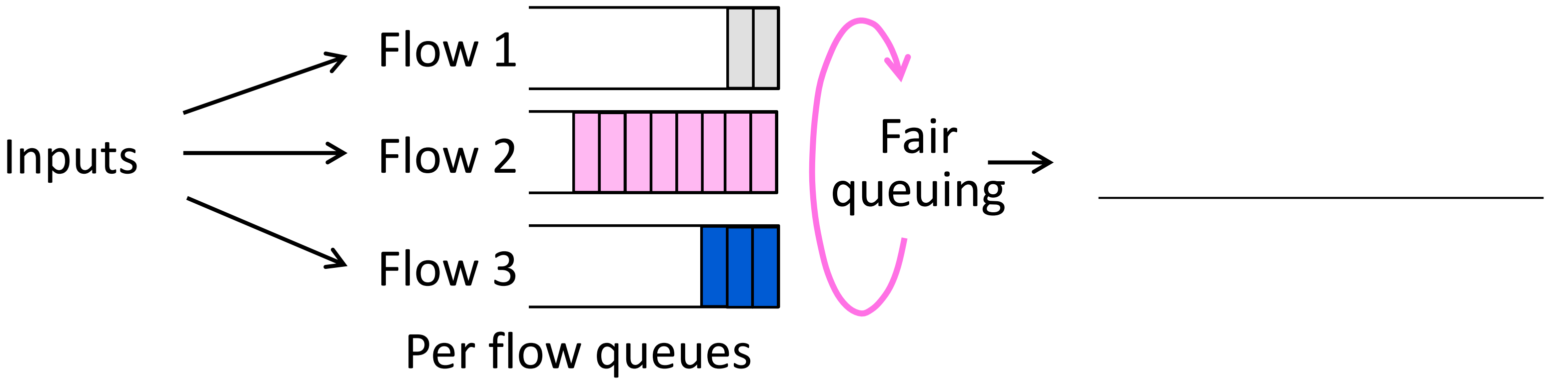
$Arrive(j)_F$ = arrival time of j-th packet of flow F

$Length(j)_F$ = length of j-th packet of flow F

$Finish(j)_F = \max(Arrive(j)_F, Finish(j-1)_F) + Length(j)_F$

Fair Queuing (2)

- Suppose:
  - Flow 1 and 3 use 1000B byte packets, flow 2 uses 300B packets
  - What will fair queuing do?



Fair Queuing (3)

- Suppose:
  - Flow 1 and 3 use 1000B packets, flow 2 uses 300B packets
  - What will fair queuing do?

Let $\text{Finish}(0)_F=0$, queues backlogged $[\text{Arrive}(j)_F < \text{Finish}(j-1)_F]$

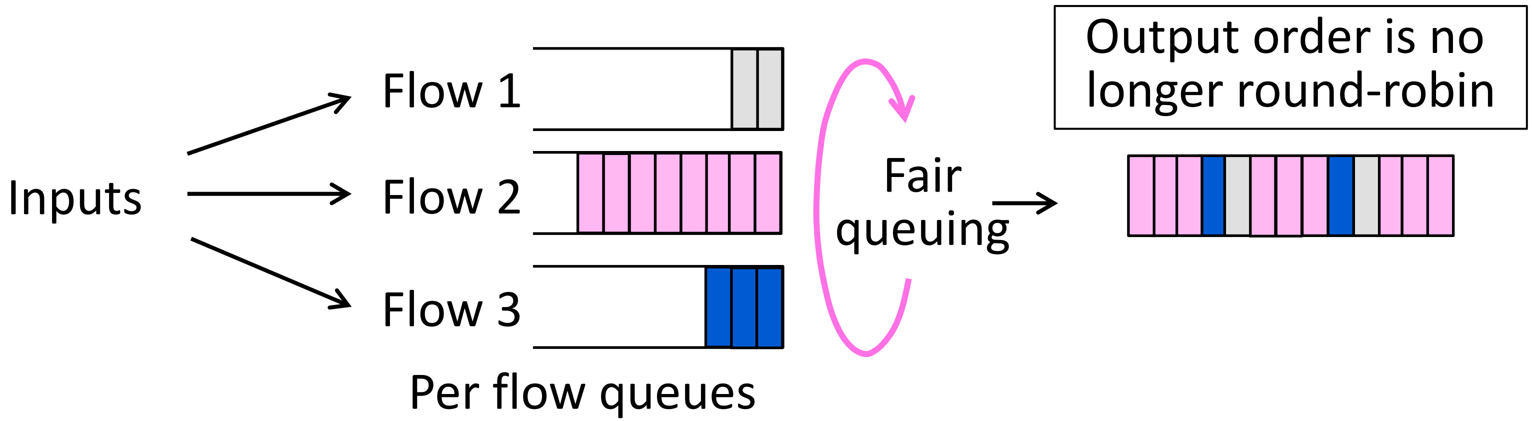
$\text{Finish}(1)_{F1}=1000$, $\text{Finish}(2)_{F1}=2000$, …

$\text{Finish}(1)_{F2}=300$, $\text{Finish}(2)_{F2}=600$, $\text{Finish}(3)_{F2}=900$, 1200, 1500, …

$\text{Finish}(1)_{F3}=1000$, $\text{Finish}(2)_{F3}=2000$, …

Fair Queuing (4)

- Suppose:
  - Flow 1 and 3 use 1000B byte packets, flow 2 uses 300B packets
  - What will fair queuing do?



WFQ (Weighted Fair Queuing)

- WFQ is a useful generalization of Fair Queuing:
  - Assign a weight, Weight_F, to each flow
  - Higher weight gives more bandwidth, e.g., 2 is 2X bandwidth
  - Change computation of $\text{Finish}(j)_F$ to factor in Weight_F

$\text{Arrive}(j)_F$ = arrival time of j-th packet of flow F

$\text{Length}(j)_F$ = length of j-th packet of flow F

$\text{Finish}(j)_F = \max(\text{Arrive}(j)_F, \text{Finish}(j-1)_F) + \text{Length}(j)_F / \text{Weight}_F$

Using WFQ

- Lots of potential!
  - Can prioritize and protect flows
  - A powerful building block
- Not yet a complete solution
  - Need to determine flows (user? application? TCP connection?)
  - Difficult to implement at high speed for many concurrent flows
  - Need to assign weights to flows

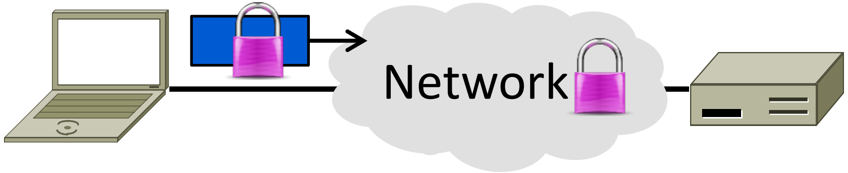
Where we are in the Course

- Revisiting the layers
  - Network security affects all layers because each layer may pose a risk

Application
Transport
Network
Link
Physical

Topic

- Network security designs to protect against a variety of threats
  - Often build on cryptography
  - Just a brief overview. Take a course!



Security Threats

- “Security” is like “performance”
  - Means many things to many people
  - Must define the properties we want
- Key part of network security is clearly stating the threat model
  - The dangers and attacker’s abilities
  - Can’t assess risk otherwise

Security Threats (2)

- Some example threats
  - It's not all about encrypting messages

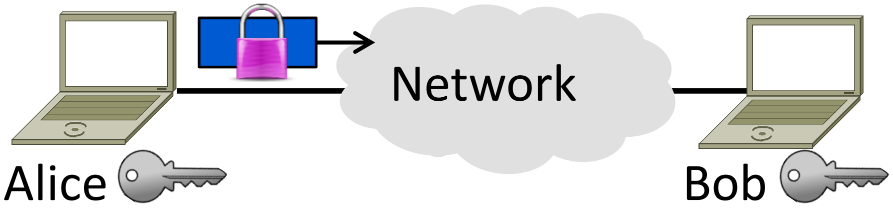
Attacker	Ability	Threat
Eavesdropper	Intercept messages	Read contents of message
Intruder	Compromised host	Tamper with contents of message
Impersonator	Remote social engineering	Trick party into giving information
Extortionist	Remote / botnet	Disrupt network services

Uses of Cryptography

- Encrypting information is useful for more than deterring eavesdroppers
  - Prove message came from real sender
  - Prove remote party is who they say
  - Prove message hasn't been altered
- Designing a secure cryptographic scheme is full of pitfalls!
  - Use approved design in approved way

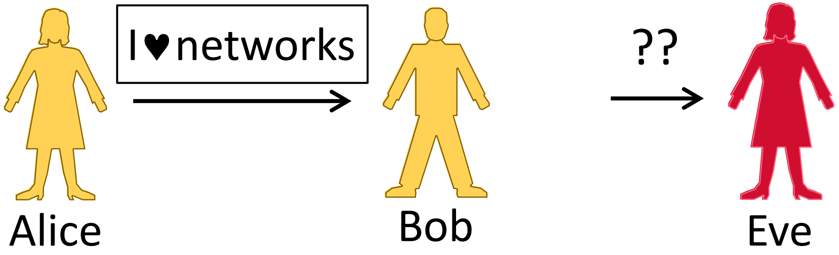
Topic

- Encrypting information to provide confidentiality
  - Symmetric and public key encryption
  - Treat crypto functions as black boxes



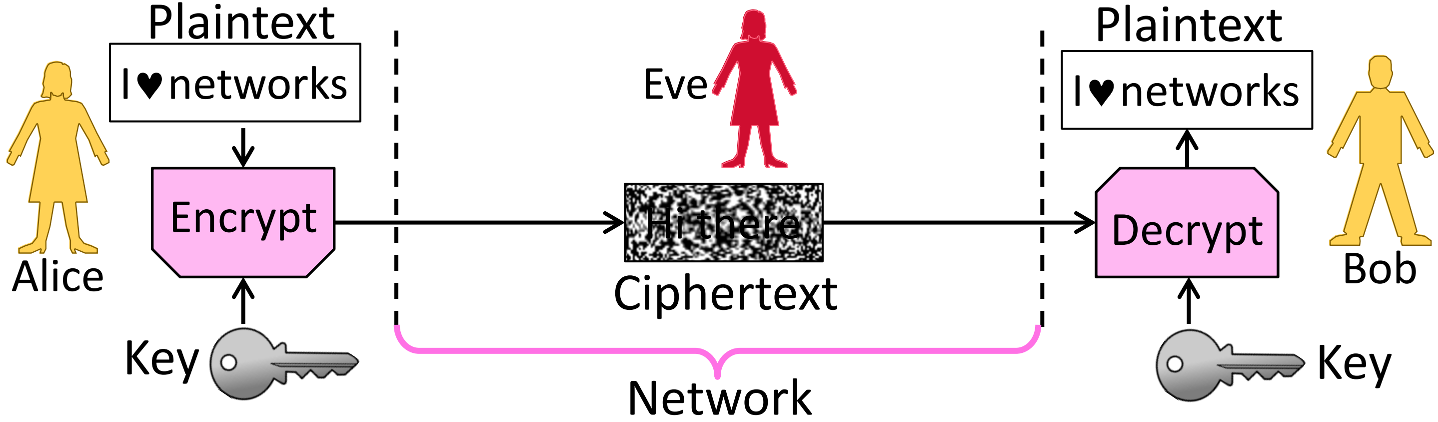
Goal and Threat Model

- Goal is to send a private message from Alice to Bob
  - This is called confidentiality
- Threat is Eve will read the message
  - Eve is a passive adversary (observes)



Encryption/Decryption Model

- Alice encrypts private message (plaintext) using key
- Eve sees ciphertext but can't relate it to private message
- Bob decrypts using key to obtain the private message



Encryption/Decryption (2)

- Encryption is a reversible mapping
  - Ciphertext is confused plaintext
- Assume attacker knows algorithm
  - Security does not rely on its secrecy
- Algorithm is parameterized by keys
  - Security does rely on key secrecy
  - Must be distributed (Achilles' heel)

Encryption/Decryption (3)

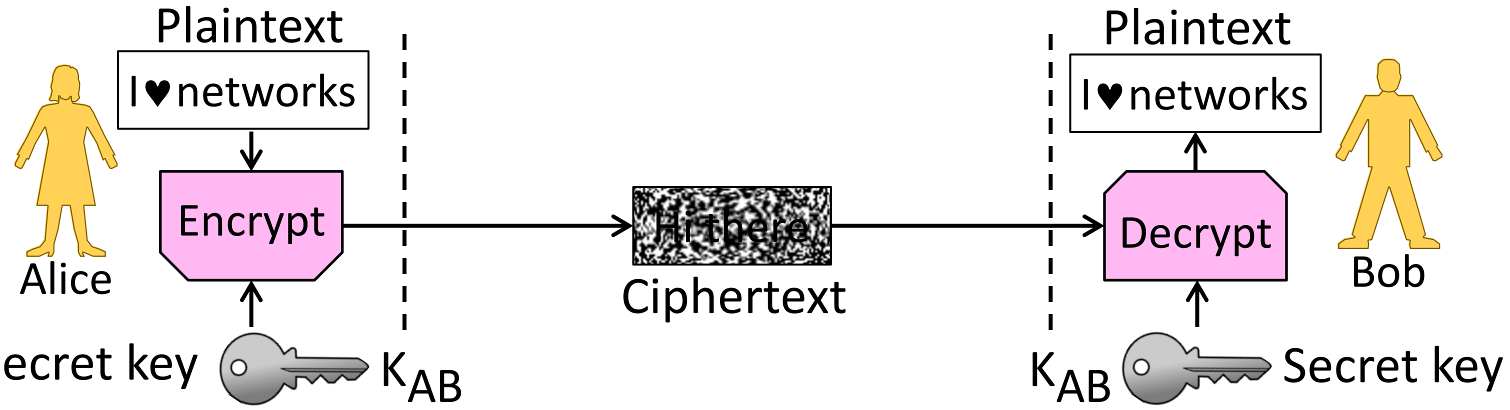
Two main kinds of encryption:

1. Symmetric key encryption », e.g., AES
   - Alice and Bob share secret key
   - Encryption is a bit mangling box

2. Public key encryption », e.g., RSA
   - Alice and Bob each have a key in two parts: a public part (widely known), and a private part (only owner knows)
   - Encryption is based on mathematics (e.g., RSA is based on difficulty of factoring)

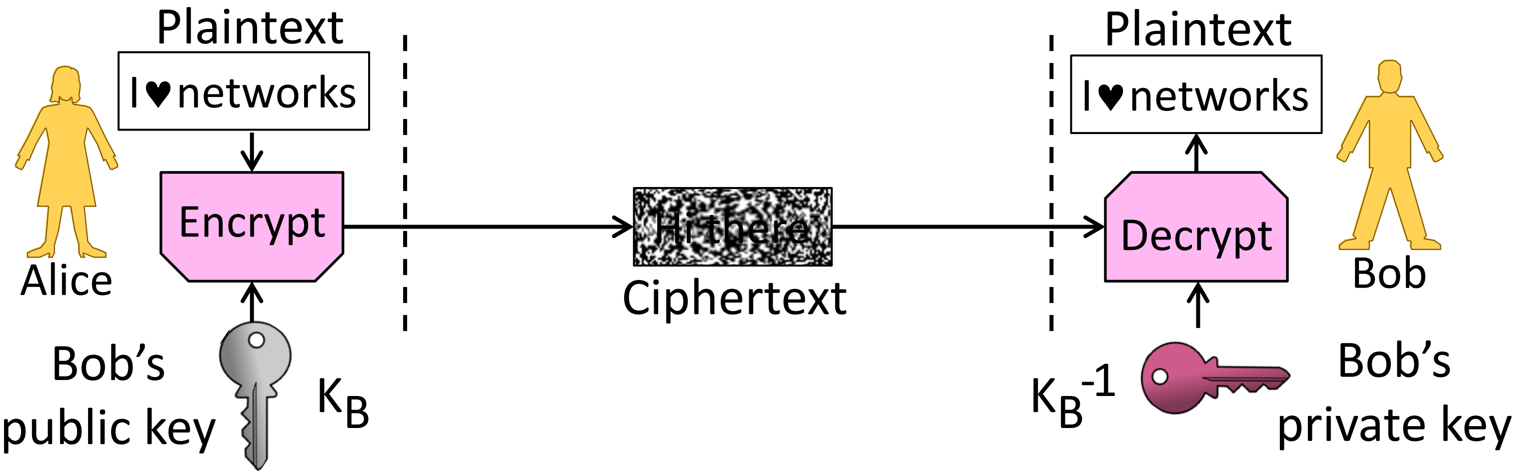
Symmetric (Secret Key) Encryption

- Alice and Bob have the same secret key, K_{AB}
  - Anyone with the secret key can encrypt/decrypt



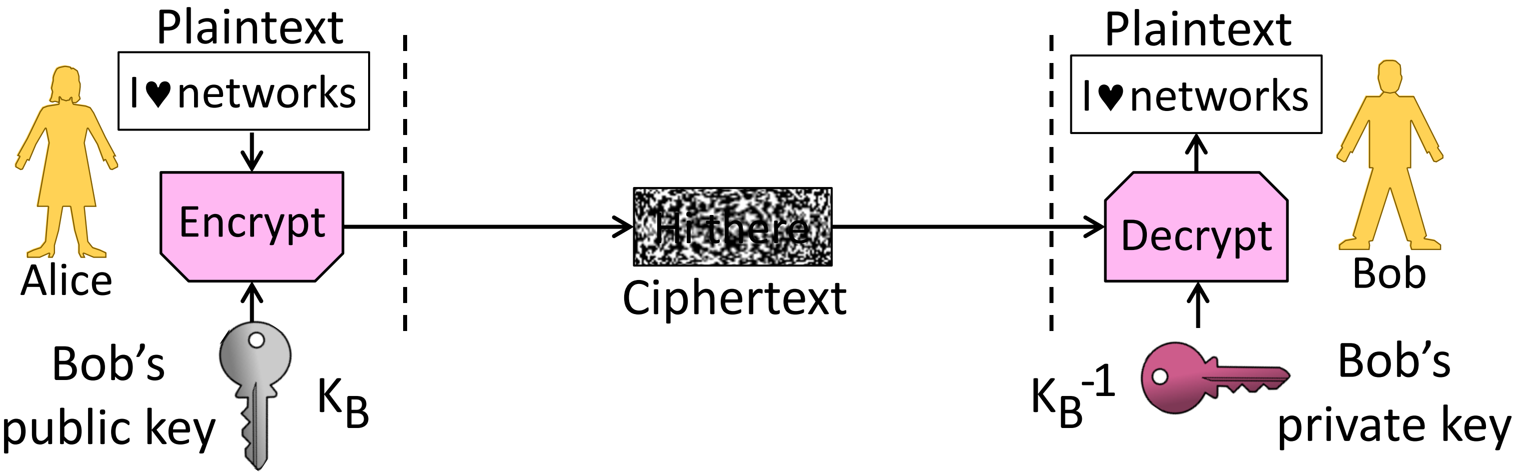
Public Key (Asymmetric) Encryption

- Alice and Bob each have public/private key pair (K_B / K_B^{-1})
  - Public keys are well-known, private keys are secret to owner

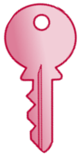


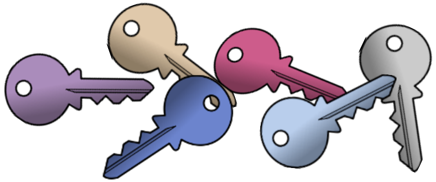
Public Key Encryption (2)

- Alice encrypts with Bob's public key K_B; anyone can send
- Bob decrypts with his private key K_B^{-1}; only he can do so



Key Distribution





- This is a big problem on a network!
  - Often want to talk to new parties
- Symmetric encryption problematic
  - Have to first set up shared secret
- Public key idea has own difficulties
  - Need trusted directory service
  - We'll look at <u>certificates</u> later

Symmetric vs. Public Key

- Have complementary properties
  - Want the best of both!

Property	Symmetric	Public Key
Key Distribution	Hard – share secret per pair of users	Easier – publish public key per user
Runtime Performance	Fast – good for high data rate	Slow – few, small, messages

Winning Combination

- Alice uses public key encryption to send Bob a small private message
  - It’s a key! (Say 256 bits.)
- Alice and Bob send large messages with symmetric encryption
  - Using the key they now share
- The key is called a <u>session key</u>
  - Generated for short-term use