

Chapter 8

Security I

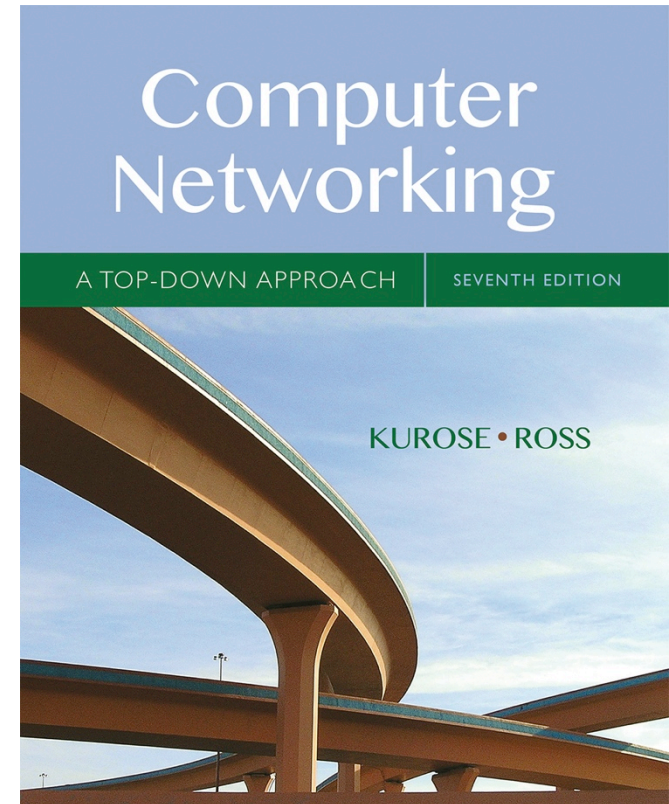
A note on the use of these Powerpoint slides:

We're making these slides freely available to all (faculty, students, readers). They're in PowerPoint form so you see the animations; and can add, modify, and delete slides (including this one) and slide content to suit your needs. They obviously represent a *lot* of work on our part. In return for use, we only ask the following:

- If you use these slides (e.g., in a class) that you mention their source (after all, we'd like people to use our book!)
- If you post any slides on a www site, that you note that they are adapted from (or perhaps identical to) our slides, and note our copyright of this material.

Thanks and enjoy! JFK/KWR

© All material copyright 1996-2016
J.F Kurose and K.W. Ross, All Rights Reserved



*Computer
Networking: A Top
Down Approach*
7th edition

Jim Kurose, Keith Ross
Pearson/Addison Wesley
April 2016

Chapter 8: Network Security

Chapter goals:

- understand principles of network security:
 - cryptography and its *many* uses beyond “confidentiality”
 - authentication
 - message integrity
- security in practice:
 - firewalls and intrusion detection systems
 - security in application, transport, network, link layers

Chapter 8 roadmap

8.1 What is network security?

8.2 Principles of cryptography

8.3 Message integrity

8.4 Authentication

What is network security?

confidentiality: only sender, intended receiver should “understand” message contents

- sender encrypts message
- receiver decrypts message

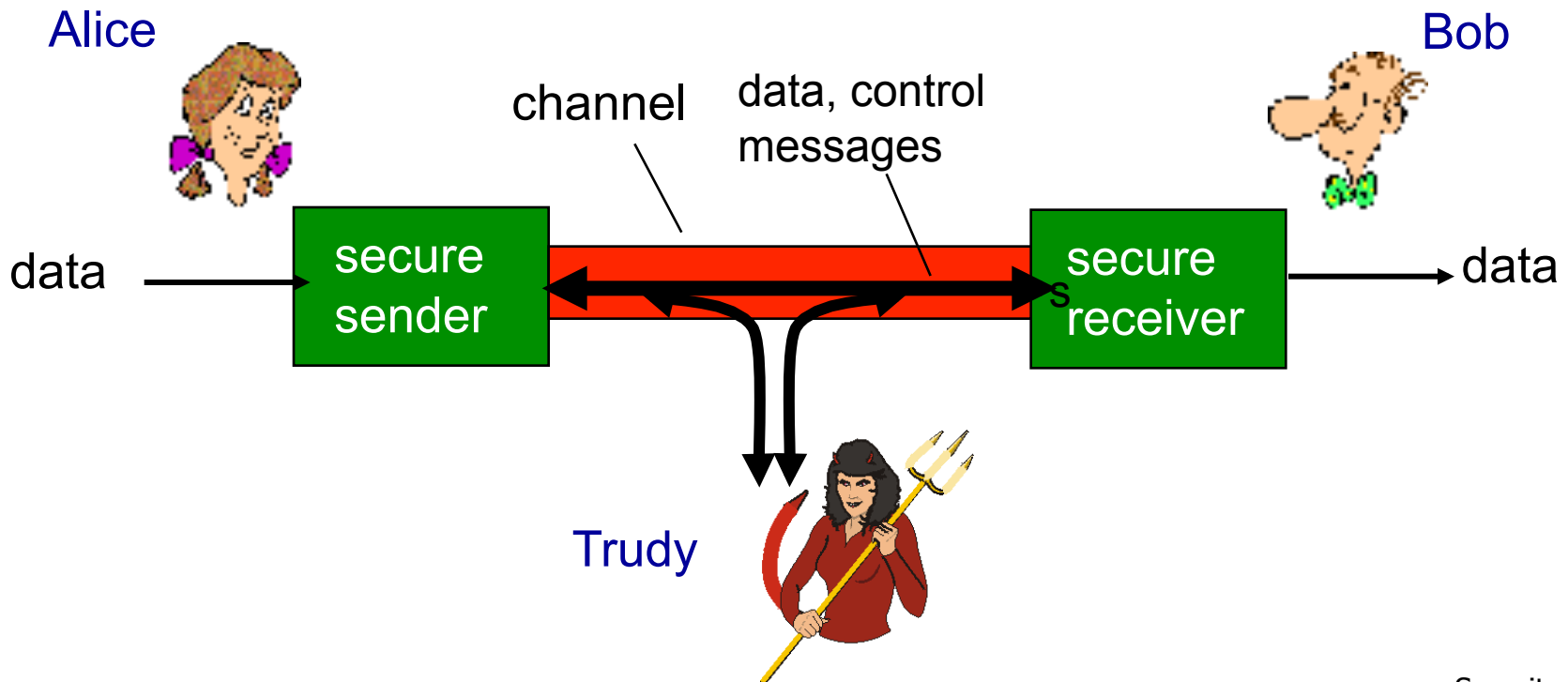
authentication: sender, receiver want to confirm identity of each other

message integrity: sender, receiver want to ensure message not altered (in transit, or afterwards) without detection

access and availability: services must be accessible and available to users

Friends and enemies: Alice, Bob, Trudy

- well-known in network security world
- Bob, Alice (lovers!) want to communicate “securely”
- Trudy (intruder) may intercept, delete, add messages



Who might Bob, Alice be?

- ... well, *real-life* Bobs and Alices!
- Web browser/server for electronic transactions (e.g., on-line purchases)
- on-line banking client/server
- DNS servers
- routers exchanging routing table updates
- other examples?

There are bad guys (and girls) out there!

Q: What can a “bad guy” do?

A: A lot! See section 1.6

- *eavesdrop*: intercept messages
- actively *insert* messages into connection
- *impersonation*: can fake (spoof) source address in packet (or any field in packet)
- *hijacking*: “take over” ongoing connection by removing sender or receiver, inserting himself in place
- *denial of service*: prevent service from being used by others (e.g., by overloading resources)

Chapter 8 roadmap

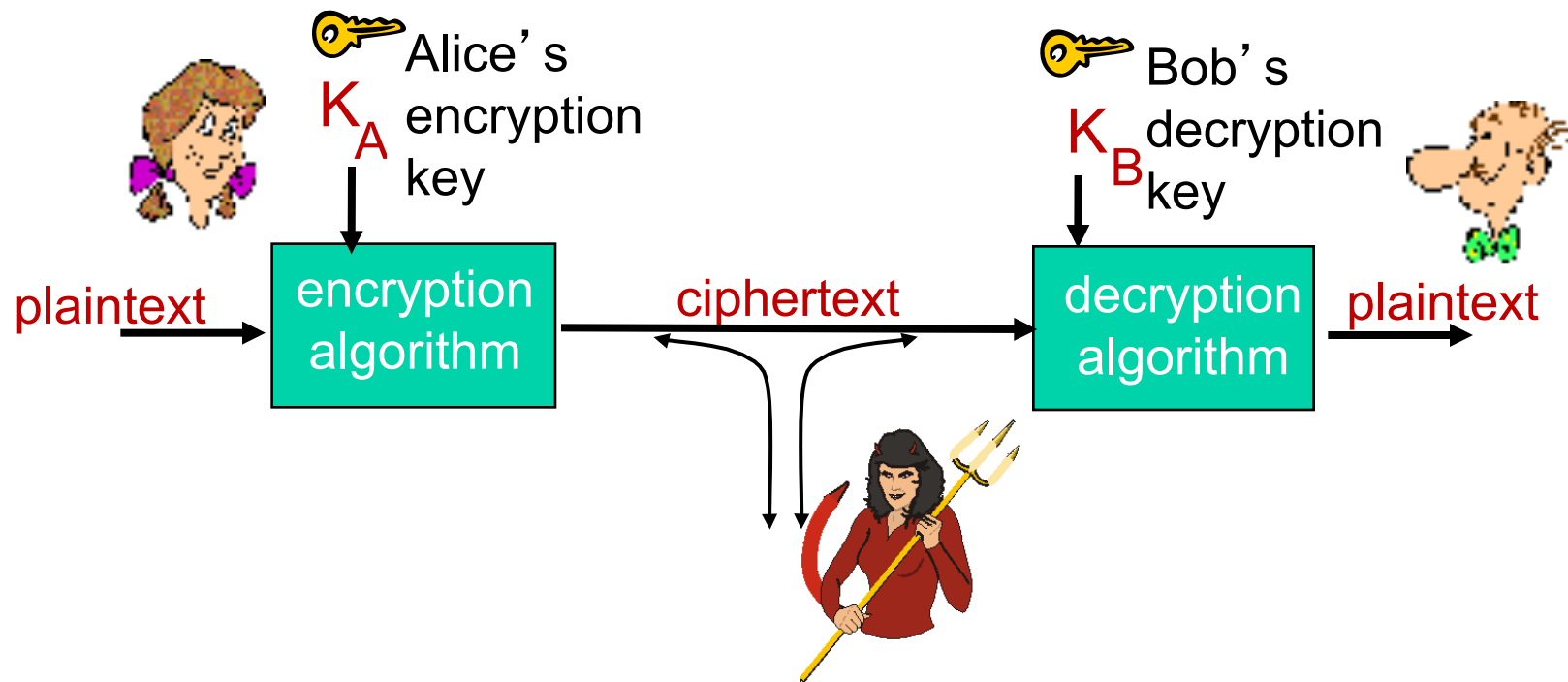
8.1 What is network security?

8.2 *Principles of cryptography*

8.3 Message integrity

8.4 Authentication

The language of cryptography



m plaintext message

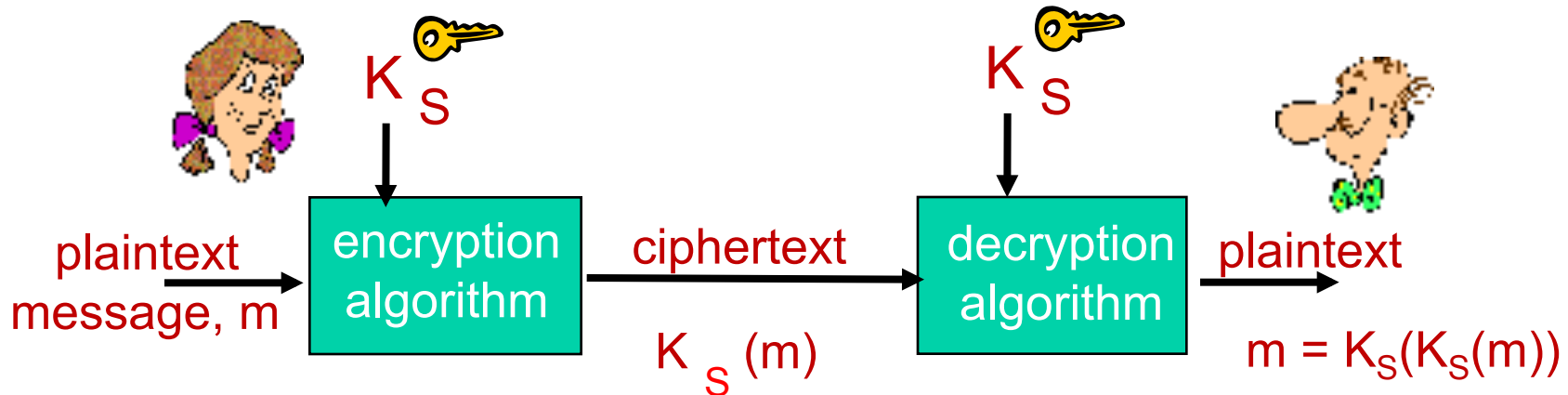
$K_A(m)$ ciphertext, encrypted with key K_A

$m = K_B(K_A(m))$

Breaking an encryption scheme

- **cipher-text only attack:**
Trudy has ciphertext she can analyze
- **two approaches:**
 - brute force: search through all keys
 - statistical analysis
- **known-plaintext attack:**
Trudy has plaintext corresponding to ciphertext
 - e.g., in monoalphabetic cipher, Trudy determines pairings for a,l,i,c,e,b,o,
- **chosen-plaintext attack:**
Trudy can get ciphertext for chosen plaintext

Symmetric key cryptography



symmetric key crypto: Bob and Alice share same (symmetric) key: K_S

- e.g., key is knowing substitution pattern in mono alphabetic substitution cipher

Q: how do Bob and Alice agree on key value?

Simple encryption scheme

substitution cipher: substituting one thing for another

- monoalphabetic cipher: substitute one letter for another

plaintext:	a	b	c	d	e	f	g	h	i	j	k	l	m	n	o	p	q	r	s	t	u	v	w	x	y	z
ciphertext:	m	n	b	v	c	x	z	a	s	d	f	g	h	j	k	l	p	i	o	u	y	t	r	e	w	q

e.g.: Plaintext: bob. i love you. alice
ciphertext: nkn. s gktc wky. mgsbc

🔑 *Encryption key*: mapping from set of 26 letters
to set of 26 letters

A more sophisticated encryption approach

- n substitution ciphers, M_1, M_2, \dots, M_n
- cycling pattern:
 - e.g., $n=4$: M_1, M_3, M_4, M_3, M_2 ; M_1, M_3, M_4, M_3, M_2 ; ..
- for each new plaintext symbol, use subsequent substitution pattern in cyclic pattern
 - dog: d from M_1 , o from M_3 , g from M_4



Encryption key: n substitution ciphers, and cyclic pattern

- key need not be just n-bit pattern

Symmetric key crypto: DES

DES: Data Encryption Standard

- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- block cipher with cipher block chaining
- how secure is DES?
 - DES Challenge: 56-bit-key-encrypted phrase decrypted (brute force) in less than a day
 - no known good analytic attack
- making DES more secure:
 - 3DES: encrypt 3 times with 3 different keys

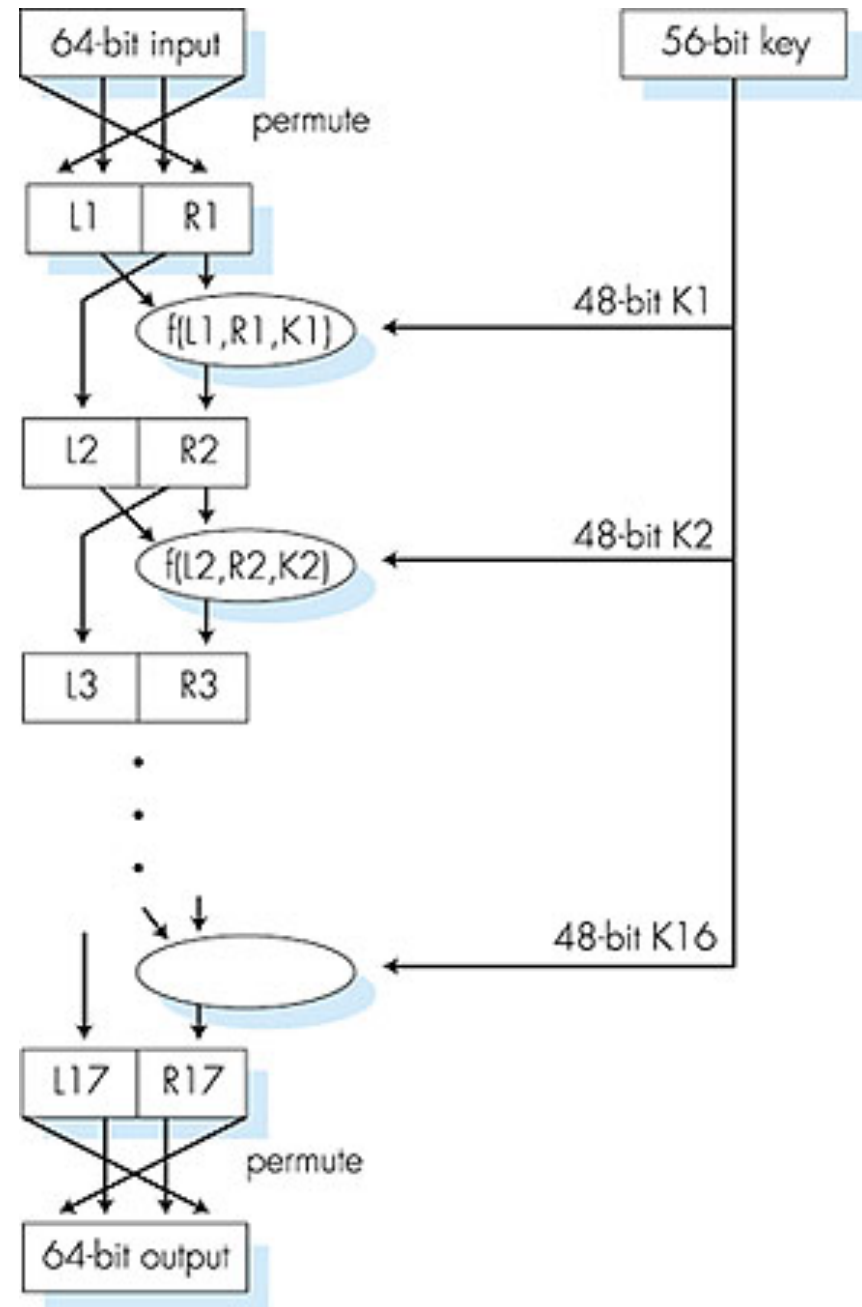
Symmetric key crypto: DES

DES operation

initial permutation

16 identical “rounds” of
function application,
each using different 48
bits of key

final permutation



AES: Advanced Encryption Standard

- symmetric-key NIST standard, replaced DES (Nov 2001)
- processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for AES

Public Key Cryptography



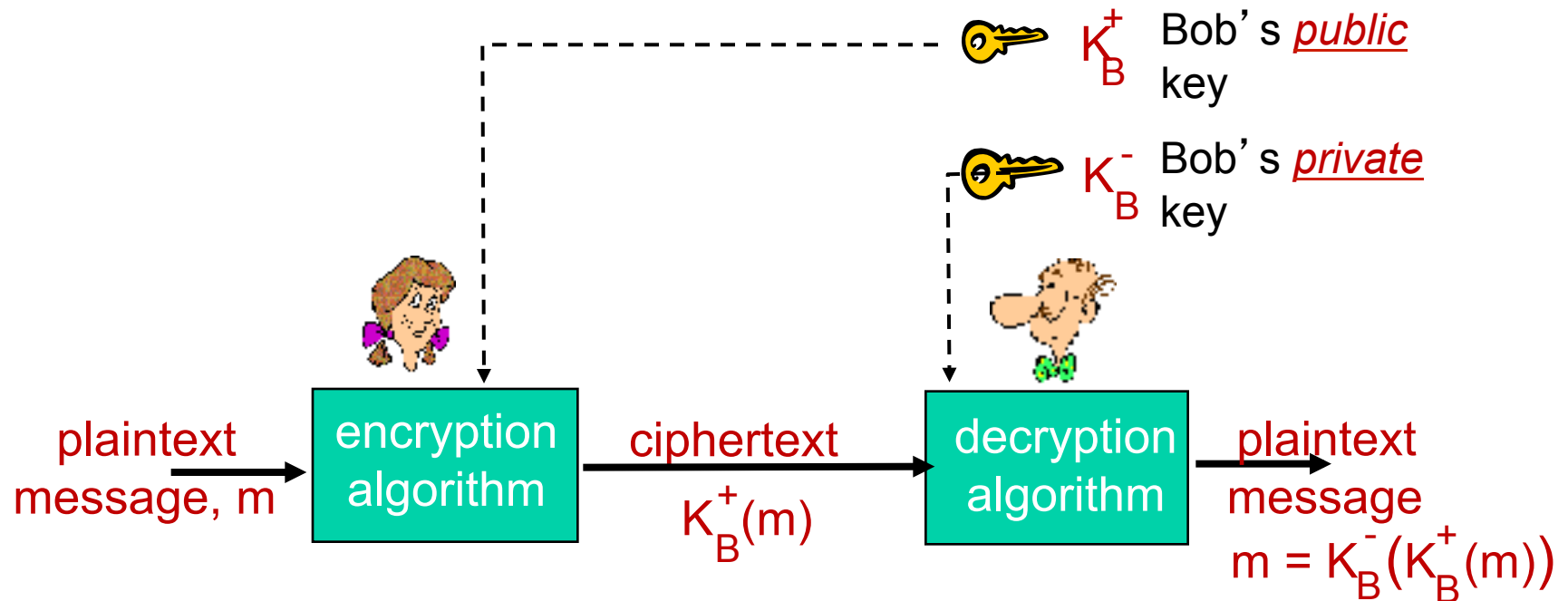
symmetric key crypto

- requires sender, receiver know shared secret key
- Q: how to agree on key in first place (particularly if never “met”)?

public key crypto

- radically different approach [Diffie-Hellman76, RSA78]
- sender, receiver do *not* share secret key
- *public* encryption key known to *all*
- *private* decryption key known only to receiver

Public key cryptography



Public key encryption algorithms

requirements:

- ① need $K_B^+(\cdot)$ and $K_B^-(\cdot)$ such that
$$K_B^-(K_B^+(m)) = m$$
- ② given public key K_B^+ , it should be impossible to compute private key K_B^-

RSA: Rivest, Shamir, Adelson algorithm

Prerequisite: modular arithmetic

- $x \bmod n$ = remainder of x when divide by n

- facts:

$$[(a \bmod n) + (b \bmod n)] \bmod n = (a+b) \bmod n$$

$$[(a \bmod n) - (b \bmod n)] \bmod n = (a-b) \bmod n$$

$$[(a \bmod n) * (b \bmod n)] \bmod n = (a*b) \bmod n$$

- thus

$$(a \bmod n)^d \bmod n = a^d \bmod n$$

- example: $x=14, n=10, d=2$:

$$(x \bmod n)^d \bmod n = 4^2 \bmod 10 = 6$$

$$x^d = 14^2 = 196 \quad x^d \bmod 10 = 6$$

RSA: getting ready

- message: just a bit pattern
- bit pattern can be uniquely represented by an integer number
- thus, encrypting a message is equivalent to encrypting a number

example:

- $m = 10010001$. This message is uniquely represented by the decimal number 145.
- to encrypt m , we encrypt the corresponding number, which gives a new number (the ciphertext).

RSA: Creating public/private key pair

1. choose two large prime numbers p, q .
(e.g., 1024 bits each)
2. compute $n = pq$, $z = (p-1)(q-1)$
3. choose e (with $e < n$) that has no common factors with z (e, z are “relatively prime”).
4. choose d such that $ed-1$ is exactly divisible by z .
(in other words: $ed \bmod z = 1$).
5. public key is $\underbrace{(n, e)}_{K_B^+}$. private key is $\underbrace{(n, d)}_{K_B^-}$.

RSA: encryption, decryption

0. given (n,e) and (n,d) as computed above

1. to encrypt message m ($<n$), compute

$$c = m^e \bmod n$$

2. to decrypt received bit pattern, c , compute

$$m = c^d \bmod n$$

magic happens!

$$m = \underbrace{(m^e \bmod n)}_c^d \bmod n$$

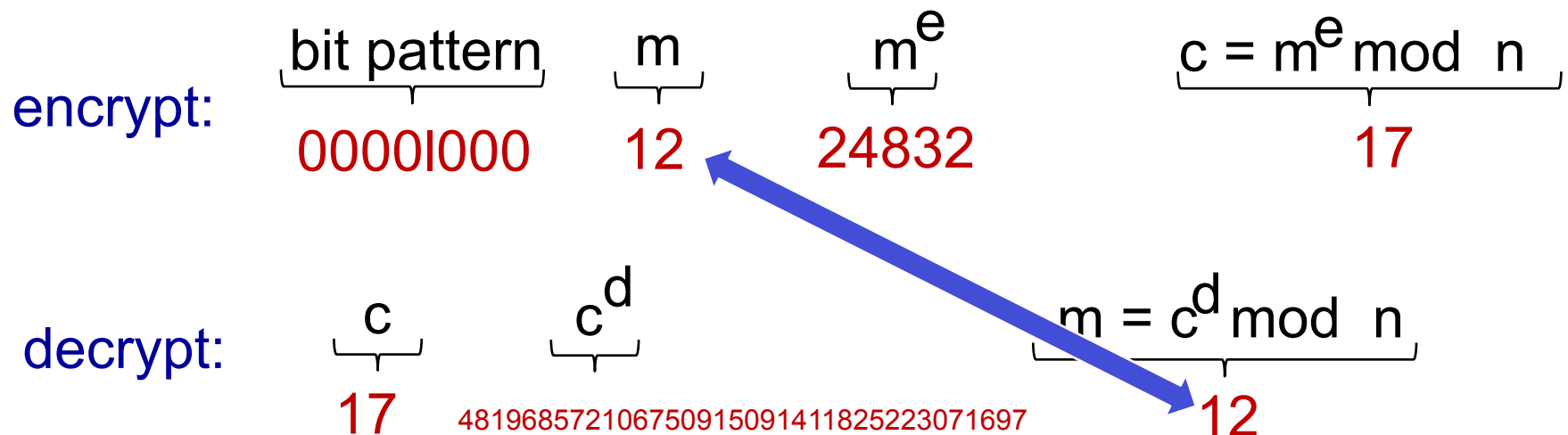
RSA example:

Bob chooses $p=5$, $q=7$. Then $n=35$, $z=24$.

$e=5$ (so e , z relatively prime).

$d=29$ (so $ed-1$ exactly divisible by z).

encrypting 8-bit messages.



Why does RSA work?

- must show that $c^d \bmod n = m$
where $c = m^e \bmod n$
- fact: for any x and y : $x^y \bmod n = x^{(y \bmod z)} \bmod n$
 - where $n = pq$ and $z = (p-1)(q-1)$
- thus,
$$\begin{aligned} c^d \bmod n &= (m^e \bmod n)^d \bmod n \\ &= m^{ed} \bmod n \\ &= m^{(ed \bmod z)} \bmod n \\ &= m^1 \bmod n \\ &= m \end{aligned}$$

RSA: another important property

The following property will be *very* useful later:

$$\underbrace{K_B^-(K_B^+(m))}_{\text{use public key first, followed by private key}} = m = \underbrace{K_B^+(K_B^-(m))}_{\text{use private key first, followed by public key}}$$

use public key
first, followed by
private key

use private key
first, followed by
public key

result is the same!

Why $K_B^-(K_B^+(m)) = m = K_B^+(K_B^-(m))$?

follows directly from modular arithmetic:

$$\begin{aligned}(m^e \bmod n)^d \bmod n &= m^{ed} \bmod n \\ &= m^{de} \bmod n \\ &= (m^d \bmod n)^e \bmod n\end{aligned}$$

Why is RSA secure?

- suppose you know Bob's public key (n,e) . How hard is it to determine d ?
- essentially need to find factors of n without knowing the two factors p and q
 - fact: factoring a big number is hard

RSA in practice: session keys

- exponentiation in RSA is computationally intensive
- DES is at least 100 times faster than RSA
- use public key crypto to establish secure connection, then establish second key – symmetric session key – for encrypting data

session key, K_S

- Bob and Alice use RSA to exchange a symmetric key K_S
- once both have K_S , they use symmetric key cryptography

Chapter 8 roadmap

8.1 What is network security?

8.2 Principles of cryptography

8.3 *Message integrity*

8.4 Authentication

Digital signatures

cryptographic technique analogous to hand-written signatures:

- sender (Bob) digitally signs document, establishing he is document owner/creator.
- *verifiable, nonforgeable*: recipient (Alice) can prove to someone that Bob, and no one else (including Alice), must have signed document


Digital signatures

simple digital signature for message m :

- Bob signs m by encrypting with his private key K_B^- , creating “signed” message, $K_B^-(m)$

Bob's message, m

Dear Alice
Oh, how I have missed
you. I think of you all the
time! ... (blah blah blah)
Bob

 K_B^- Bob's private
key

Public key
encryption
algorithm

$m, K_B^-(m)$

Bob's message,
 m , signed
(encrypted) with
his private key

Digital signatures

- suppose Alice receives msg m , with signature: $m, K_B^-(m)$
- Alice verifies m signed by Bob by applying Bob's public key K_B^+ to $K_B^-(m)$ then checks $K_B^+(K_B^-(m)) = m$.
- If $K_B^+(K_B^-(m)) = m$, whoever signed m must have used Bob's private key.

Alice thus verifies that:

- Bob signed m
- no one else signed m
- Bob signed m and not m'

non-repudiation:

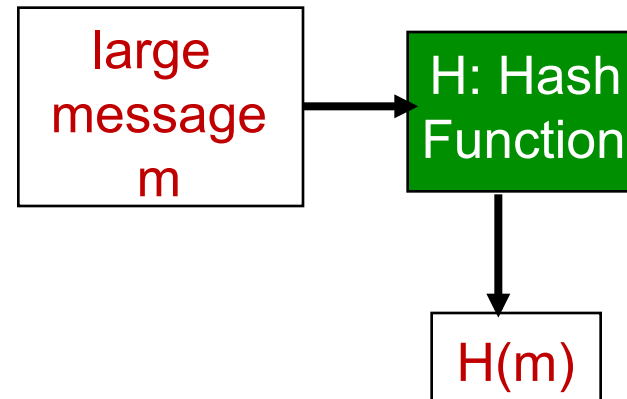
- ✓ Alice can take m , and signature $K_B^-(m)$ to court and prove that Bob signed m

Message digests

computationally
expensive to public-key-
encrypt long messages

goal: fixed-length, easy-
to-compute digital
“fingerprint”

- apply hash function H to m , get fixed size message digest, $H(m)$.

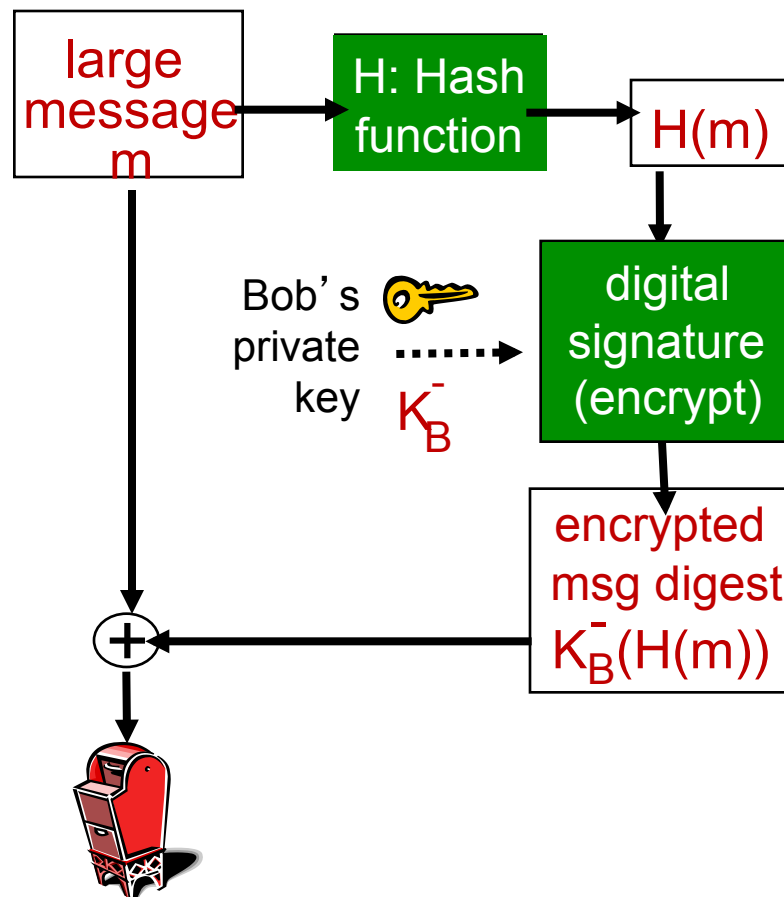


Hash function properties:

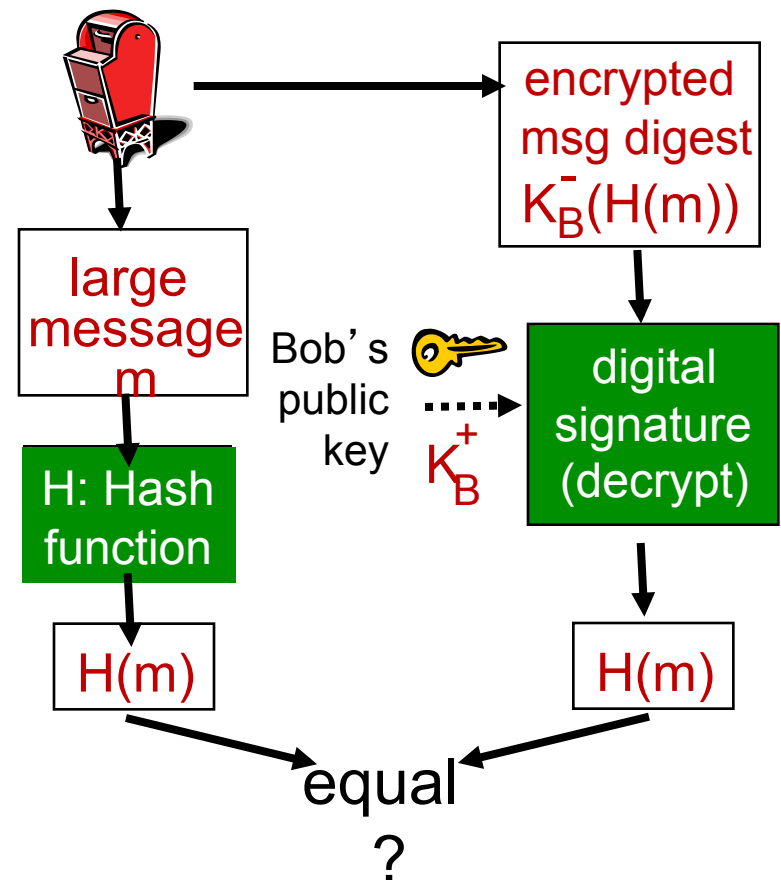
- many-to-1
- produces fixed-size msg digest (fingerprint)
- given message digest x , computationally infeasible to find m such that $x = H(m)$

Digital signature = signed message digest

Bob sends digitally signed message:



Alice verifies signature, integrity of digitally signed message:



Internet checksum: poor crypto hash function

Internet checksum has some properties of hash function:

- produces fixed length digest (16-bit sum) of message
- is many-to-one

But given message with given hash value, it is easy to find another message with same hash value:

<u>message</u>	<u>ASCII format</u>		<u>message</u>	<u>ASCII format</u>
I O U 1	49 4F 55 31		I O U <u>9</u>	49 4F 55 <u>39</u>
0 0 . 9	30 30 2E 39		0 0 . <u>1</u>	30 30 2E <u>31</u>
9 B O B	39 42 D2 42		9 B O B	39 42 D2 42
	<u>B2 C1 D2 AC</u>	different messages		<u>B2 C1 D2 AC</u>
		but identical checksums!		

Hash function algorithms

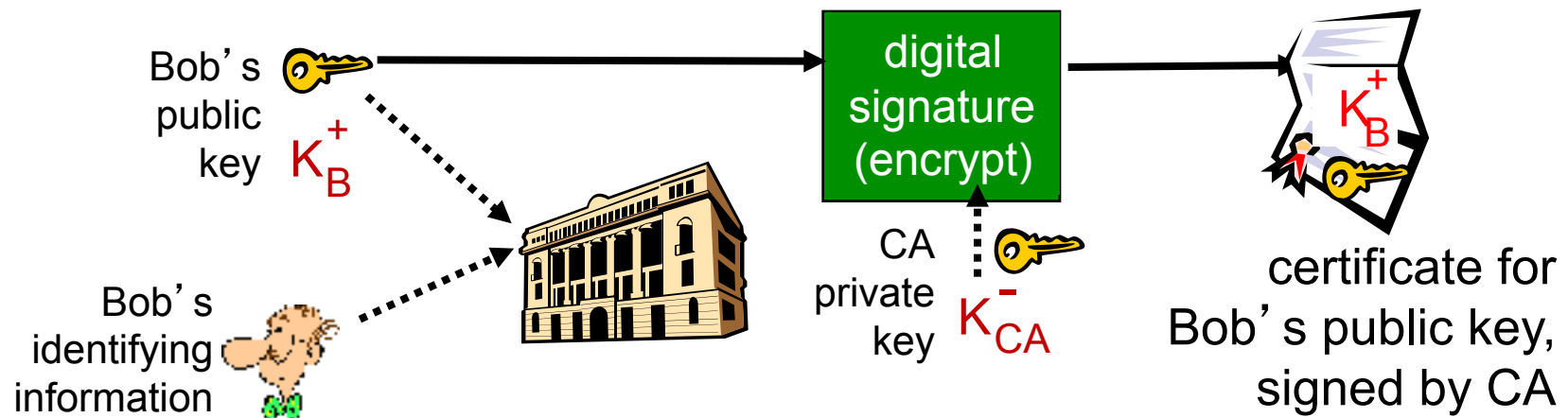
- **MD5 hash function widely used (RFC 1321)**
 - computes 128-bit message digest in 4-step process.
 - arbitrary 128-bit string x , appears difficult to construct msg m whose MD5 hash is equal to x
- **SHA-0 and SHA-1**
 - 160-bit message digest
 - Have not been considered secure since 2005 and is not supported by major browsers
- **SHA-2**
 - Up to 512-bit message digest
 - Can theoretically be attacked
- **SHA-3**
 - Best security

Public-key certification

- motivation: Trudy plays pizza prank on Bob
 - Trudy creates e-mail order:
Dear Pizza Store, Please deliver to me four pepperoni pizzas. Thank you, Bob
 - Trudy signs order with her private key
 - Trudy sends order to Pizza Store
 - Trudy sends to Pizza Store her public key, but says it's Bob's public key
 - Pizza Store verifies signature; then delivers four pepperoni pizzas to Bob
 - Bob doesn't even like pepperoni

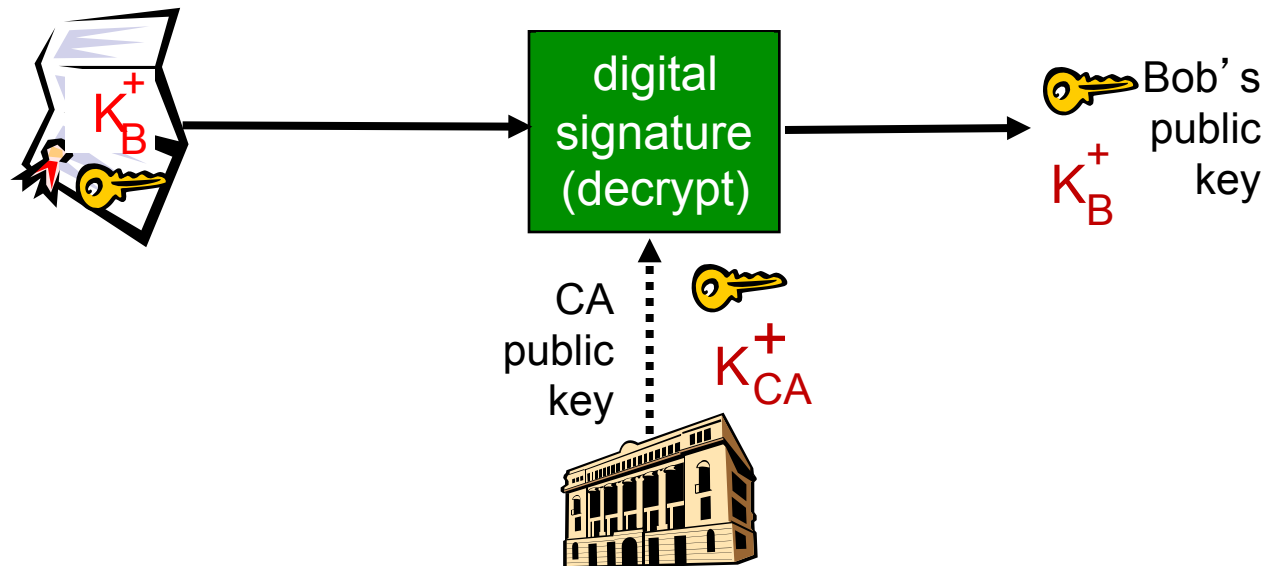
Certification authorities

- **certification authority (CA)**: binds public key to particular entity, E.
- E (person, router) registers its public key with CA.
 - E provides “proof of identity” to CA.
 - CA creates certificate binding E to its public key.
 - certificate containing E’s public key digitally signed by CA – CA says “this is E’s public key”



Certification authorities

- when Alice wants Bob's public key:
 - gets Bob's certificate (Bob or elsewhere).
 - apply CA's public key to Bob's certificate, get Bob's public key



Chapter 8 roadmap

8.1 What is network security?

8.2 Principles of cryptography

8.3 Message integrity

8.4 Authentication

Authentication

Goal: Bob wants Alice to “prove” her identity to him

Protocol ap1.0: Alice says “I am Alice”



Failure scenario??



Authentication

Goal: Bob wants Alice to “prove” her identity to him

Protocol ap1.0: Alice says “I am Alice”

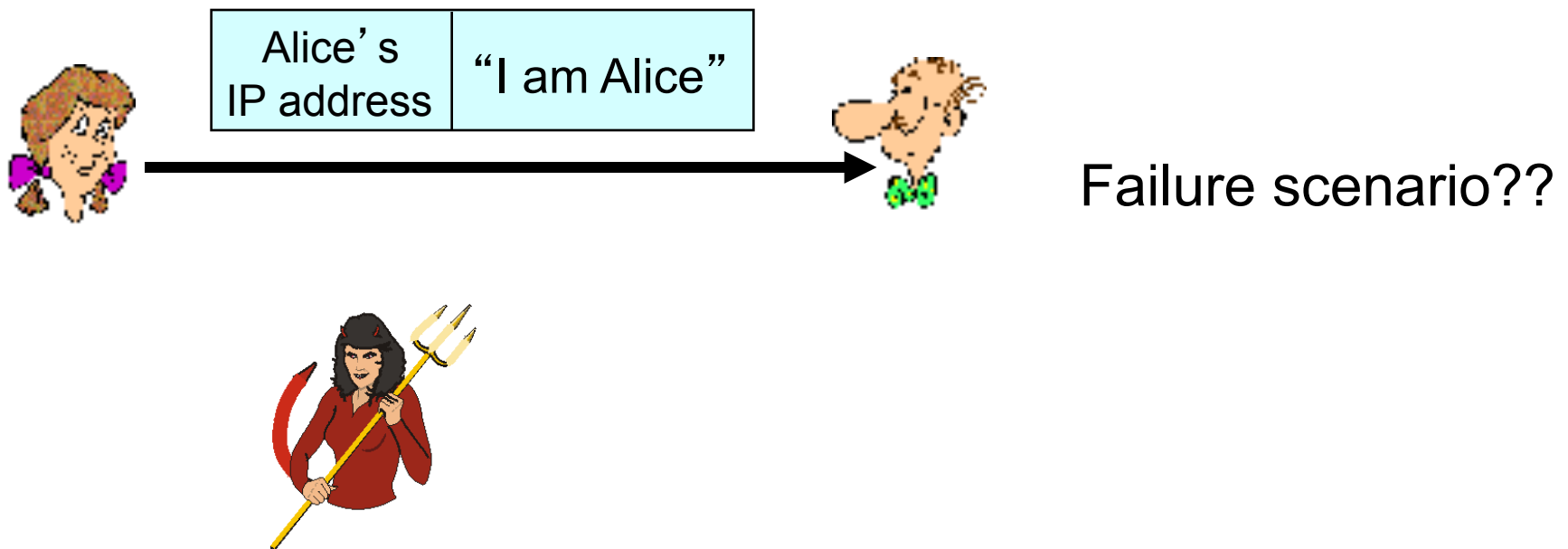


“I am Alice”

in a network,
Bob can not “see” Alice,
so Trudy simply declares
herself to be Alice

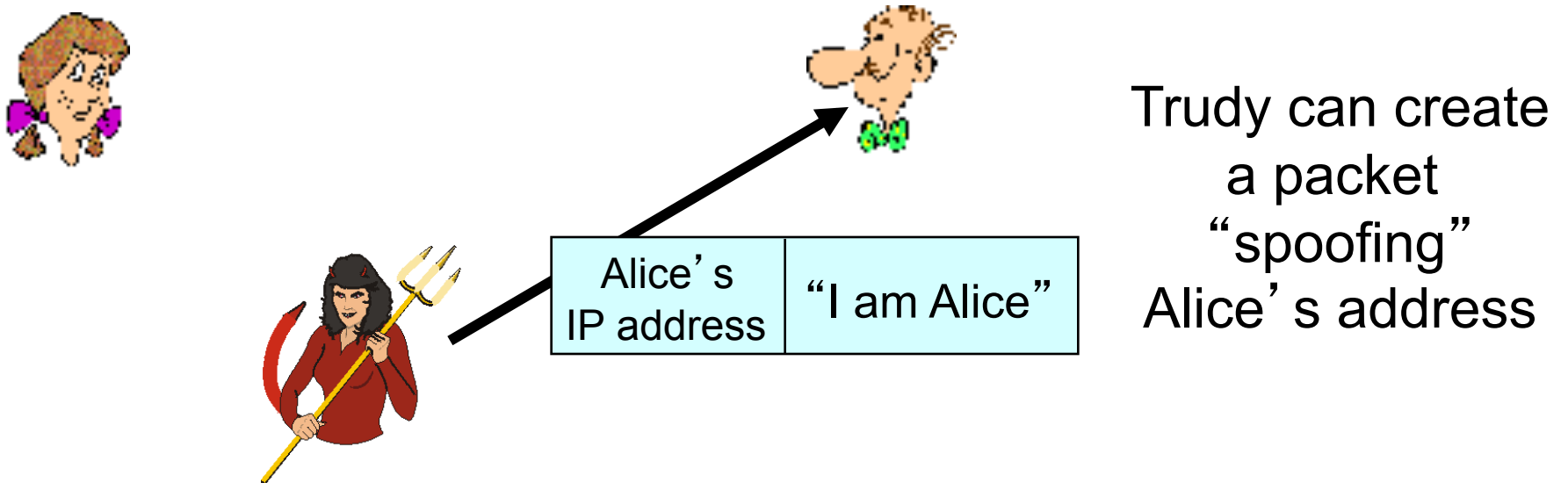
Authentication: another try

Protocol ap2.0: Alice says “I am Alice” in an IP packet containing her source IP address



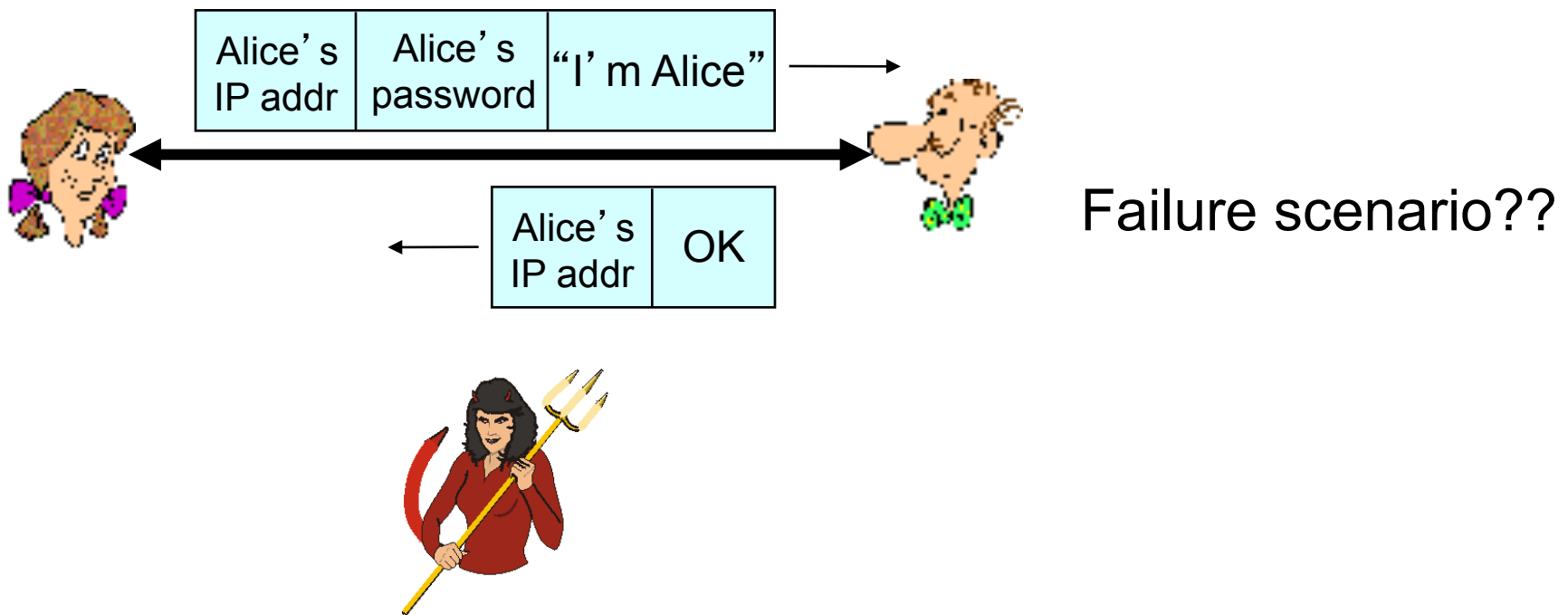
Authentication: another try

Protocol ap2.0: Alice says “I am Alice” in an IP packet containing her source IP address



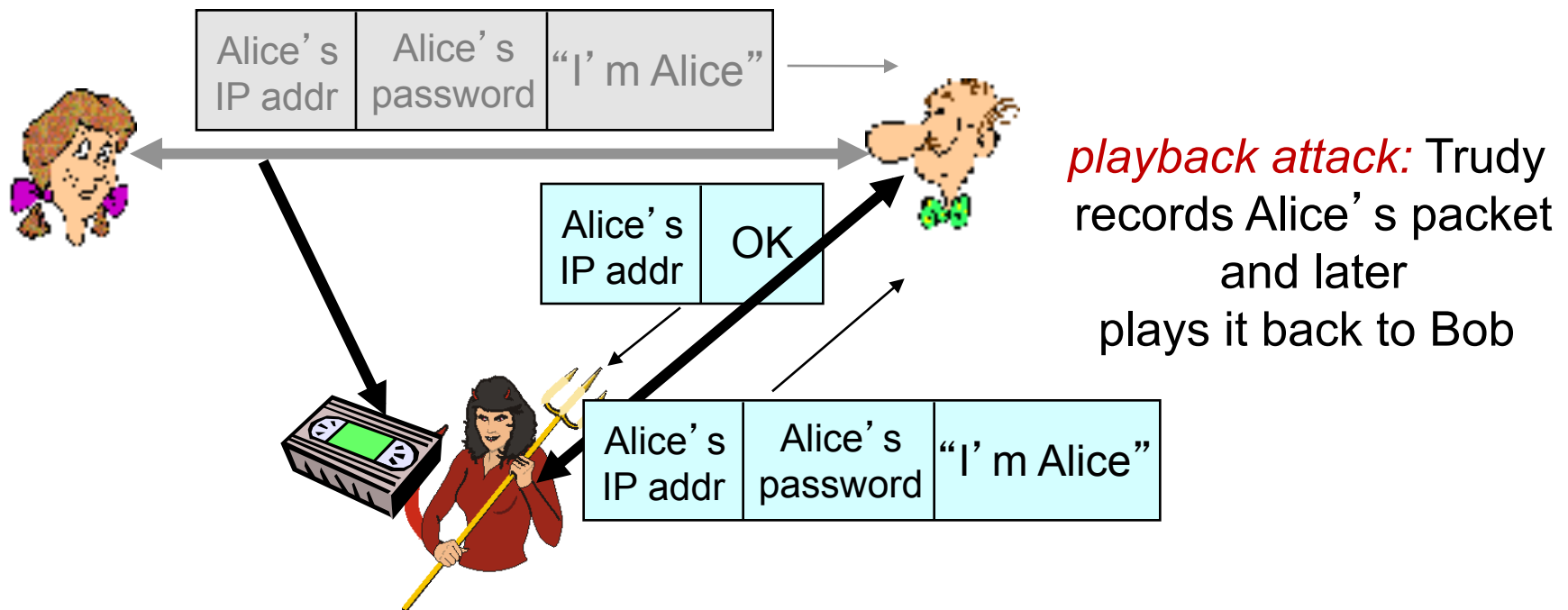
Authentication: another try

Protocol ap3.0: Alice says “I am Alice” and sends her secret password to “prove” it.



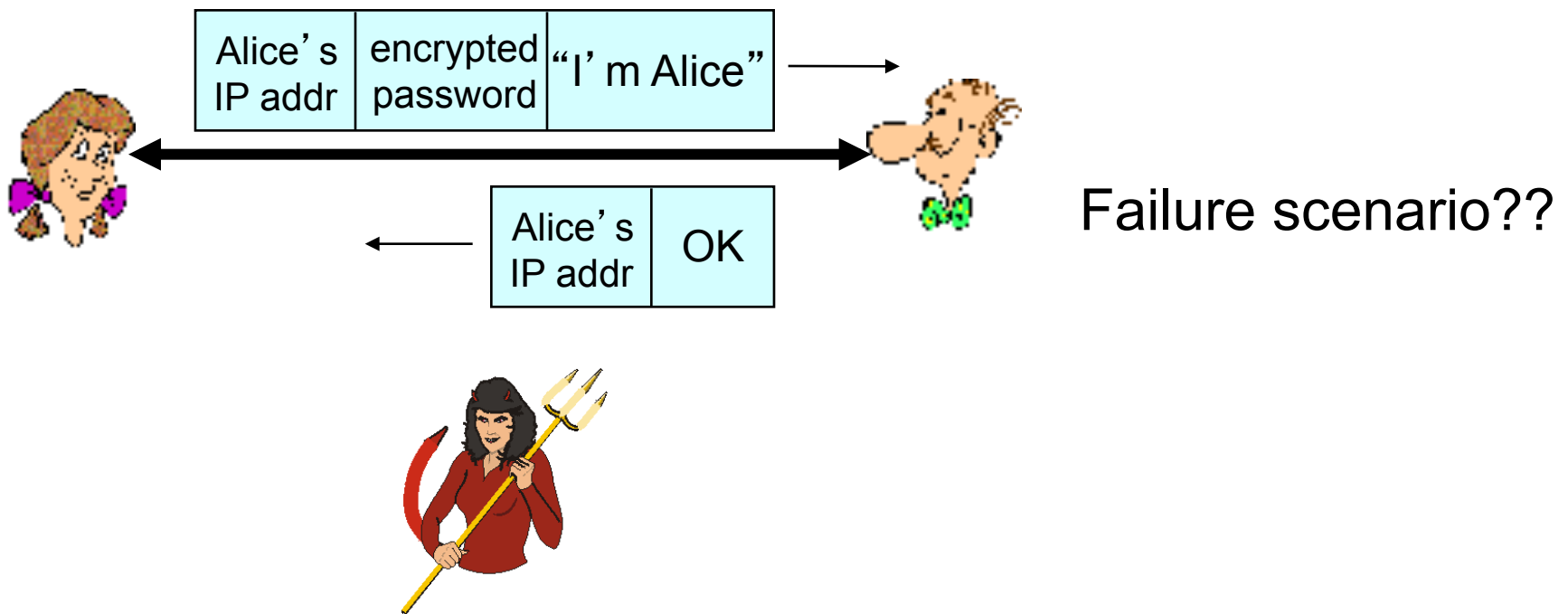
Authentication: another try

Protocol ap3.0: Alice says “I am Alice” and sends her secret password to “prove” it.



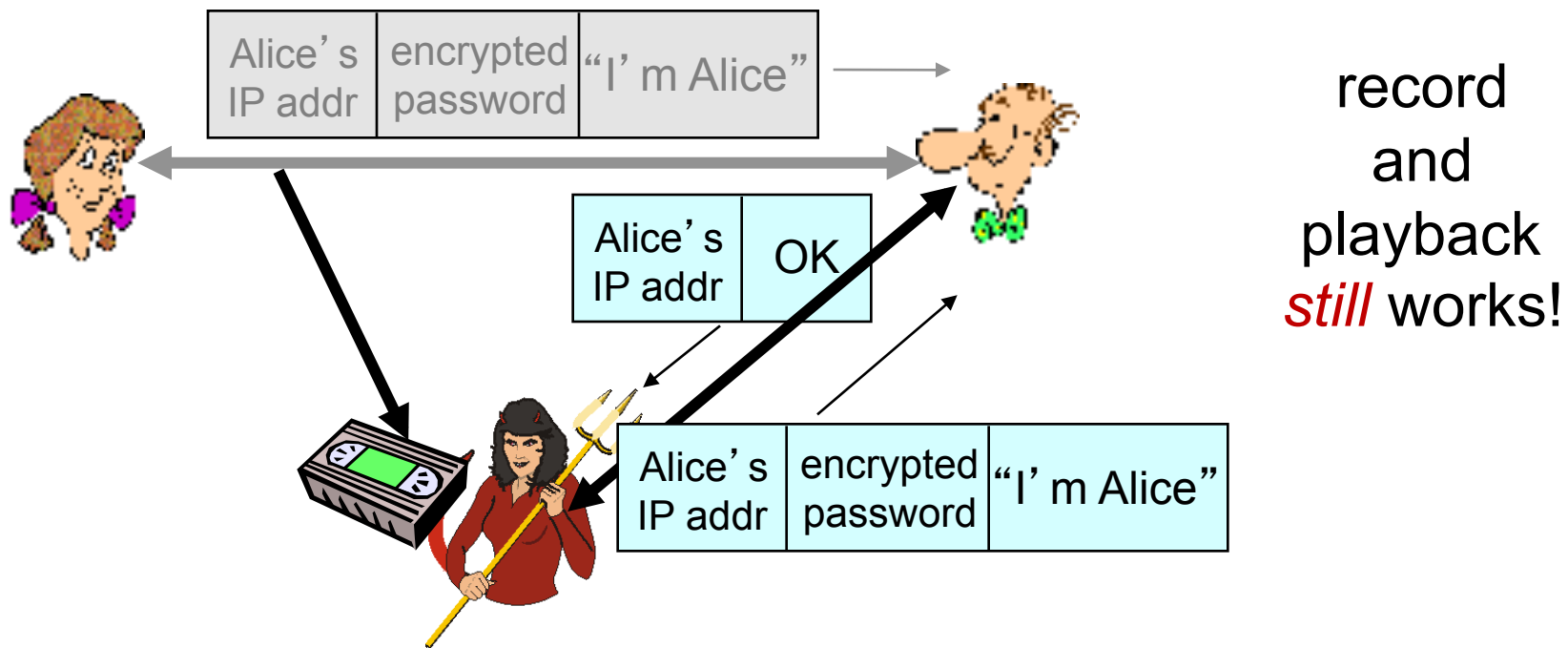
Authentication: yet another try

Protocol ap3.1: Alice says “I am Alice” and sends her *encrypted* secret password to “prove” it.



Authentication: yet another try

Protocol ap3.1: Alice says “I am Alice” and sends her *encrypted* secret password to “prove” it.

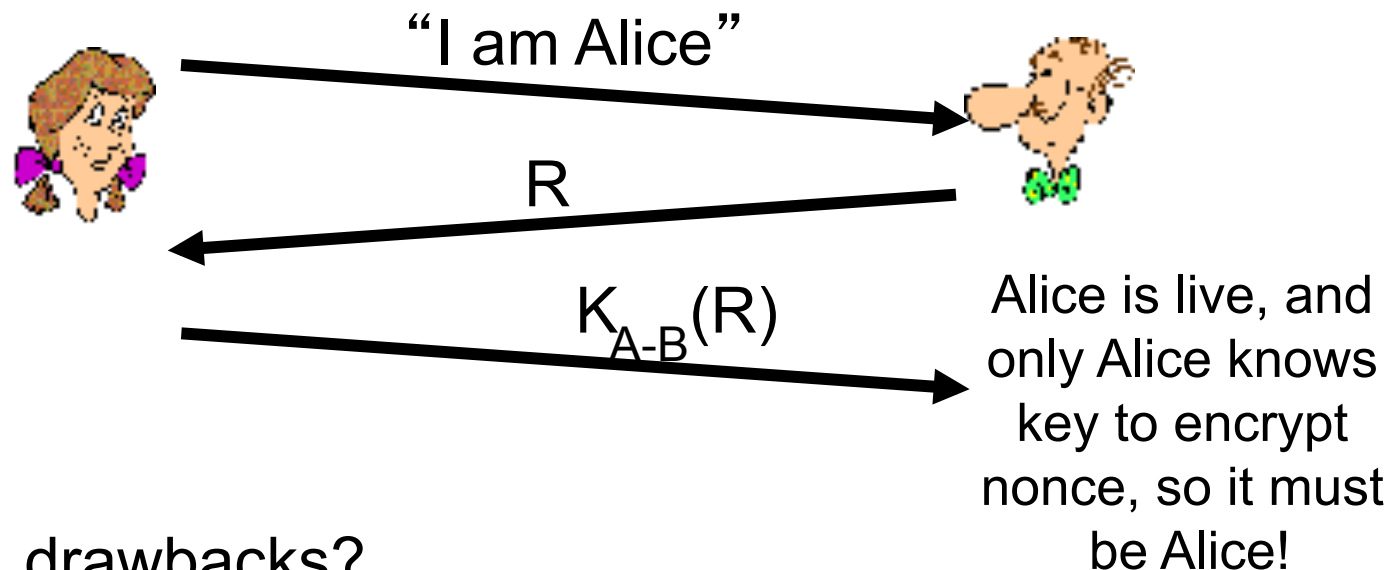


Authentication: yet another try

Goal: avoid playback attack

nonce: number (R) used only *once-in-a-lifetime*

ap4.0: to prove Alice “live”, Bob sends Alice *nonce*, R. Alice must return R, encrypted with shared secret key



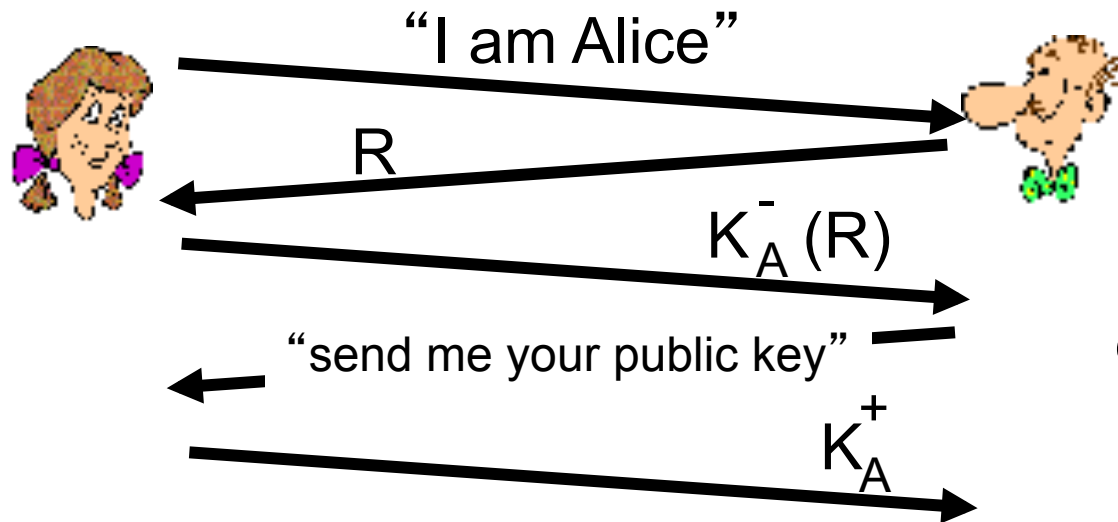
Failures, drawbacks?

Authentication: ap5.0

ap4.0 requires shared symmetric key

- can we authenticate using public key techniques?

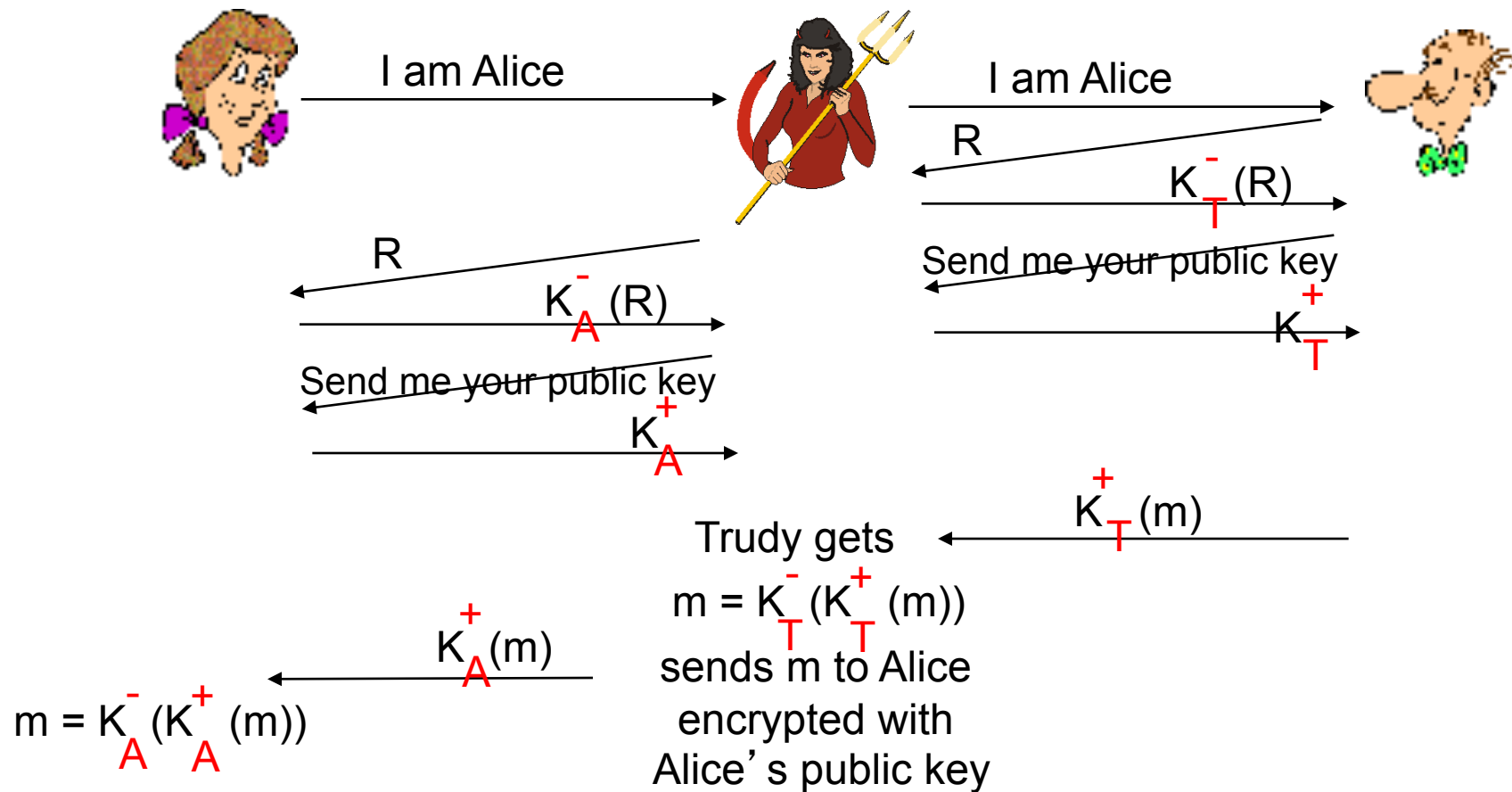
ap5.0: use nonce, public key cryptography



Bob computes
 $K_A^+(K_A^-(R)) = R$
and knows only Alice
could have the private
key, that encrypted R
such that
 $K_A^+(K_A^-(R)) = R$

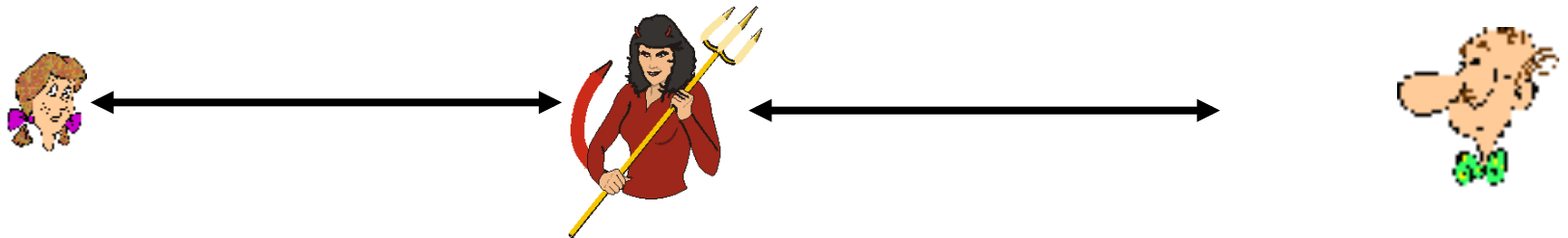
ap5.0: security hole

man (or woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



ap5.0: security hole

man (or woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)



difficult to detect:

- Bob receives everything that Alice sends, and vice versa. (e.g., so Bob, Alice can meet one week later and recall conversation!)
- problem is that Trudy receives all messages as well!
- CA can partly solve this

Network Security (summary)

basic techniques.....

- cryptography (symmetric and public)
 - Note the differences between the two!
- message integrity
 - How does it work!
- end-point authentication
 - Secure protocols are important!

Next lecture used in many different security scenarios

- secure email
- secure transport (SSL)
- IP sec, 802.11

operational security: firewalls and IDS