# ECE 443/518 – Computer Cyber Security
# Lecture 11 Digital Signatures and Authentication

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September 25, 2024

# Outline

# Reading Assignment

- This lecture: UC 10.1 – 10.3
- Next lecture: UC 13

# Midterm Exam

- Lecture 1 $\sim$ Lecture 13, see Homework 1 and 2 for sample.
  - Points may be deducted if key steps are missing.
- Students registered for main campus section: Wed. 10/9, 11:25 AM – 12:40 PM, in class.
  - A physical calculator is allowed. Laptop or any other electronic device or calculator apps running on them are not allowed.
  - Closed book/notes. A letter-size page of cheat sheet is allowed.
- Online students may take the exam as above, or contact Charles Scott (scott@iit.edu) to make arrangement and confirm with me.
  - No make-up exam will be offered if you fail to do so.
- ADA Accommodations: contact Center for Disability Resource (disabilities@iit.edu)
- Emergency/extraordinary reasons for make-up midterm exams are accepted only with documented proof like docter's notes.

# Outline

Digital Signatures

Authentication

# Security Services

- The services we are familiar with
  - Confidentiality
  - Integrity and message authentication
- Nonrepudiation: sender can not deny creation of message.
  - But who is the sender?
- Authentication: who are you?
  - A.k.a. entity/user authentication, or identification
  - Within the context of computer cyber security, shall be built on top of a nonrepudiation service (but usually is not!).
- Services enabled by authentication
  - Access control/authorization: decide who can do what.
  - Auditing: provide a proof of who did what.
- Anonymity/privacy: what if we don't want to be identified?
  - E.g. to guard against potential misuse of identity.
  - Can we authenticate an amonynous user?

# Principle of Digital Signatures

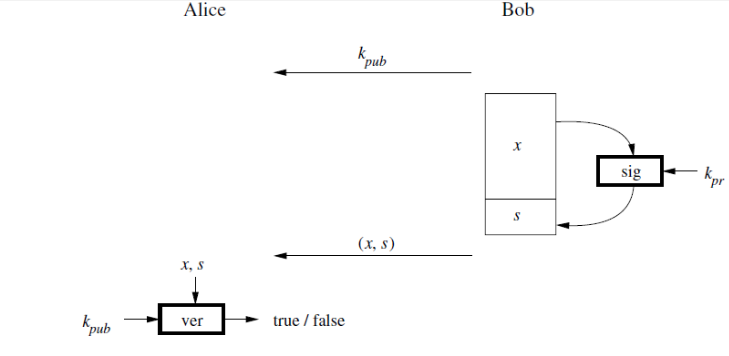
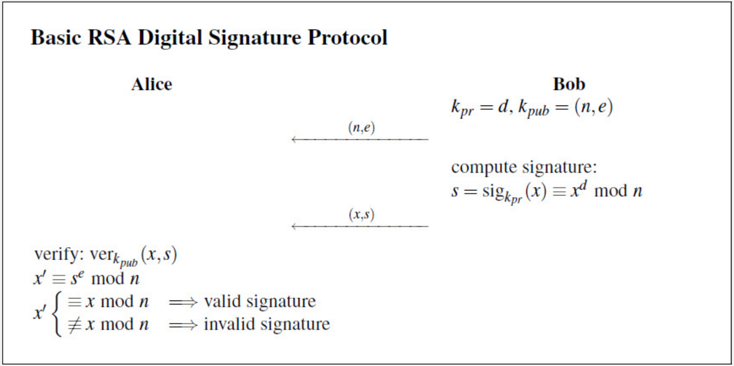



**Fig. 10.1** Principle of digital signatures which involves signing and verifying a message

(Paar and Pelzl)

- Nonrepudiation: no shared secret
  - Bob signs with his private key $k_{pr}$.
  - Alice verifies with Bob's public key $k_{pub}$.
- Sign the hash if the message is too long.

# RSA Digital Signature




(page 265, Paar and Pelzl)

- Same key setup as RSA
- RSA digital signature works as inversed RSA encryption!
  - *sig*() is *d*(), *ver*() is essentially *e*().
  - Time complexity is the same as RSA encryption.

# Example

- $k_{pub} = (n = 221, e = 5)$, $k_{pr} = (p = 13, q = 17, d = 77)$
- $x = 35$
- Bob computes the signature:
  $s = x^d \bmod n = 35^{77} \bmod 221 = 120.$
- Alice verifies the signature:
  $x' = s^e \bmod n = 120^5 \bmod 221 = 35.$
  - So $x == x'$ and $x$ is indeed generated by Bob.
- What prevent Oscar to forge Bob's signature?

# Oscar's Attack

- To forge a signature $s$ for $x$, Oscar need to
  - Either compute $d$ and then $s = x^d \bmod n$.
  - Or solve $s^e \equiv x \pmod{n}$
- Both are equivalent to break RSA.

# Elgamal Digital Signature

- Setup Bob's key pair as in DHKE and Elgamal
  - A well-known large prime $p$ and an integer $\alpha$.
  - $k_{pr} = d \in \{2, 3, \ldots, p-2\}$
  - $k_{pub} = \beta = \alpha^d \bmod p$
- To sign a message $x \in \{0, 1, 2, \ldots, p-1\}$ with $(r, s)$,
  - Choose a random ephemeral key $k_E \in \{0, 1, \ldots, p-1\}$ such that $gcd(k_E, p-1) = 1$.
  - Compute $r = \alpha^{k_E} \bmod p$
  - Solve $k_E s \equiv x - dr \pmod{p-1}$ for $s$
- To validate the signature $(r, s)$ for the message $x$,
  - Compute $t = \beta^r r^s \bmod p$
  - Apply Fermat's Little Theorem, $r^s \equiv \alpha^{k_E s} \equiv \alpha^{x-dr} \pmod{p}$
  - So $t \equiv \beta^r r^s \equiv \alpha^{dr} \alpha^{x-dr} \equiv \alpha^x \pmod{p}$ should hold.

# Oscar's Attack

- To forge a signature $(r, s)$ for $x$, Oscar need to solve

$$\alpha^x \equiv \beta^r r^s \pmod{p}$$

- Oscar could first choose any $k_E$ and $r = \alpha^{k_E} \bmod p$, then
  - Either solve $r^s \equiv z \pmod{p}$ directly with some $z$
  - Or find $d$ first and then solve for $s$ as the signature process.
- Both are equivalent to break DHKE.

# Practical Considerations

- For both RSA and Elgamal digital signature, padding is needed to prevent other attacks.
- Elgamal digital signature is rarely used in practice. Instead, a variant named DSA and an ECC generalization named ECDSA are widely used
  - Check FIPS PUB 186-4 (2013) for details.

# Digital Signature vs. MAC

- Digital signatures provide stronger guarantees (nonrepudiation) than MAC (message authentication), and thus can replace MAC.
  - Assume no man-in-the-middle attack.
- Practically, MAC is more efficient.
  - MAC is almost as efficient as hash at both sides.
  - Digital signature need to compute exponentials at both sides in addition to hash.
  - Use MAC if nonrepudiation is not required.
- While we prefer to apply MAC to ciphertext for authenticated encryption, digital signatures are almost always applied to plaintexts if the messages need to be encrypted.

# Outline

Digital Signatures

Authentication

# Digital Signatures Revisited

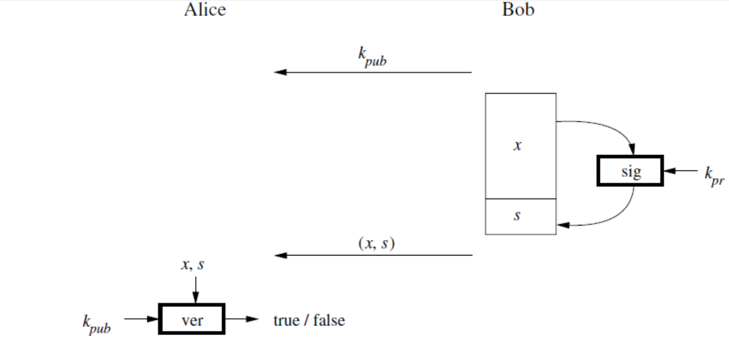



**Fig. 10.1** Principle of digital signatures which involves signing and verifying a message

(Paar and Pelzl)

- What should be sent over an authentic channel?
  - $k_{pub}$, if Alice need a proof that $k_{pub}$ is indeed Bob's public key.
- What if $k_{pub}$ is sent over an insecure channel?
  - Nonrepudiation still works in some sense: Alice can confirm that $x$ is created by someone who owns $k_{pr}$.

# Public Key and Identity

- Authentication: Bob need to decide if Alice is Alice.
  - For recurring activities.
  - Two steps: Alice first leaves Bob some information for her identity, and then everytime Bob uses such information to verify that Alice is Alice.
- Public key is identity.
  - Without an authentic channel: Bob receives a public key and names it Alice.
  - "Anonymous": this identity associates to no real-world entity.
- Public key as a representation of identity.
  - With an authentic channel: Alice need to prove she is Alice to Bob, e.g. via a passport, before she can provide a public key for Bob to store.
  - The public key could be revoked, e.g. when Alice lost her private key.
- Which one is better? Depending on the application.

# Authetication with Digital Signatures

- With Alice's public key on file, Bob authenticates by asking whoever claims to be Alice to sign a message with Alice's private key.
- This seems to be very secure.
  - Assume Alice keeps her private key as a secret, and Bob stores Alice's public key in a way no one can modify it.
  - Oscar cannot forge digital signatures.
  - Even if Oscar steals Alice's public key from Bob, he/she cannot use it to prove he/she is Alice to another party.
- Replay attack: but Oscar may record the message with Alice's signature and replay it to Bob at a later time.
  - Bob need to ask Alice to sign a chosen message!
- Challenge-response authentication.
  - Challenge: Bob generates a nonce and sends it to Alice.
  - Response: Alice signs the nonce and replies to Bob.
  - Any possibility of man-in-the-middle attack?

# Mutual Authentication

- In many cases Alice also need to be sure that Bob is Bob.
- Alice may authenticate Bob by Bob's public key.
  - Same as how Bob setups Alice's public key.
- Complications
  - The two channels Alice-to-Bob and Bob-to-Alice could be different.
    - Both are authentic.
    - Both are not authentic.
    - One is authetic and the other is not authentic.
  - The need for confidentiality.

# Practical Applications and Considerations

- Common people used to have limited access to public-key cryptography.
  - Due to sophiscated/costly hardware/software, patents, business practices etc.
- Servers usually identify themselves via digital signatures.
  - Mostly via HTTPS.
  - Still, people with little knowledge about cyber security and digital signatures are subject to phishing scams.
- For professionals nowadays, adoption of Linux makes authentication with digital signatures widely available.
  - Mostly via SSH, e.g. GitHub.
  - Sometimes even enforced, e.g. AWS EC2.

# Summary

- RSA digital signature
  - Key generation: by Bob, $k_{pub} = (n, e)$, $k_{pr} = (p, q, d)$
  - Sign: Bob only, $s = d_{k_{pr}}(x) = x^d \bmod pq$.
  - Verify: everyone, $x' = e_{k_{pub}}(s) = s^e \bmod n$, $x == x'$?
  - Assumption: Oscar cannot factorize $n$ into $p$ and $q$ in polynomial time.
- Other digital signature algorithms like DSA and ECDSA.
- Identification/authentication: solutions exist, but need to make trade-offs.