Computer Security and Cryptography

CS381

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2015-05

Organization

- Week 1 to week 16 (2015-03 to 2014-06)
- 东中院-3-102
- Monday 3-4节; week 9-16
- Wednesday 3-4节; week 1-16
- lecture 10 + exercise 40 + random tests 40 + other 10
- Ask questions in class – counted as points
- Turn ON your mobile phone (after lecture)
- Slides and papers:
  - http://202.120.38.185/CS381
    - computer-security
  - http://202.120.38.185/references
- TA: Geshi Huang gracehgs@mail.sjtu.edu.cn
- Send homework to the TA

Rule: do the homework on your own!

Contents

- Introduction -- What is security?
- Cryptography
  - Classical ciphers
  - Today's ciphers
  - Public-key cryptography
  - Hash functions and MAC
  - Authentication protocols
- Applications
  - Digital certificates
  - Secure email
  - Internet security, e-banking
- Computer and network security
  - Access control
  - Malware
  - Firewall
- Examples: Flame, Router, BitCoin ??

Authentication

- Authentication
  - The provision of assurance of the claimed identity of an entity. [ISO]
- One of 2 main goals of cryptography:
  - Authenticity: "who *wrote* the data"
  - Confidentiality: "who can *read* the data"

Components of Authentication

system: set of users, protocols

1. Claim identity: Alice
2. Submit authentication data by A
   - $A \rightarrow B$: M
3. Verification by B
   - $M \in \{ M_A, \ldots \}$?
4. Conclusion of B
   - accept, reject

Authentic message

- Set of system users: $U=\{A,B,\ldots\}$
- Authentic messages: $\{M_A, A \in U\}$
  - Only legitimate users can have generated the message
  - $M_A= (f_A(X),X)$,
    - f_A : keyed 1-way function with A's secret key, e.g., MAC, cipher, signature.
- Verification: check the correctness of $f_A(X)$.
- Conclusion: after B verifying $M\in\{ M_A, A\in U\}$,
  - If f is cipher or MAC, then $U=\{A,B\}$, B accepts A because B didn't produce M.
  - If f is signature, $U=\{A\}$.
  - B accepts A:
    - A produced the message (authentic)
    - A has sent the message (freshness) ??

Authentic message: MAC

- MAC - shared secrete key k
  - Send: M, $C_K(M)$ //
  - verify computed $C_K(M)$ = received $C_K(M)$
- Security of MAC:
  - If the key k is unknown, it is difficult to find a new message with a valid MAC, even if many valid (M,C_k(M)) are known.
- Only users knowing the key can generate and verify the MAC. (symmetric)

digital signature

- RSA
  - Parameters PK={e,n} , SK={d,p,q}

Alice	(M,S)	Bob
$S \equiv H(M)^{dA} \pmod{n_A}$	$\longrightarrow$	$H(M)\ ? \equiv S^{eA} \pmod{n_A}$

  - only Alice can generate S (asymmetric)
- ElGamal Signature
  - Alice: pri-key x_a; pub-key $y_a=g^{x_a}$
  - Bob: pri-key x_b: pub-key $y_b=g^{x_b}$
  - Signing
    - Alice random r, gcd(r, p–1)=1, and gets $R=g^r$
  - Send: (m, $R=g^r$, $S=r^{-1}(m-x_aR) \pmod{p-1}$)
  - Verification: $g^m=y_a^R R^S \pmod{p}$

Digital Signature Algorithm (DSA)

- NIST Digital Signature Standard (DSS)，FIPS 186 (1991)
- 320-bit signature; with 512-1024 bit security
- signature only, variant of ElGamal & Schnorr schemes

- system public key (p,q,g):
  - large prime p (512-1024 bits) ; Small prime q (160 bits), $q \mid (p-1)$
  - $g = h^{(p-1)/q}$, $1<h<p-1$, $h^{(p-1)/q} \bmod p > 1$
  - Users: private key $x<q$, public key: $y = g^x \bmod p$

  Sign: one-time random signature key k, $k<q$

  $r = (g^k \bmod p) \bmod q$

  $s = [k^{-1}(H(M)+ xr)] \bmod q$
- Send: (M,r,s)
- **verification**

  $u1= [H(M)\ s^{-1}] \bmod q$; $u2= (r\ s^{-1}) \bmod q$

  verify $r = [(g^{u1}\ y^{u2}) \bmod p] \bmod q$

different signatures

User Signer
Message m, random r
blinding mr^e →
← sign$(mr^e)^d$
Message sig m^d

- Blind signature : content of a message is unknown to the signer. publicly verifiable.
  - Untraceable ----voting systems and digital cash
- Undeniable signatures: signer can choose who is allowed to verify
- Group signature: a member of a group to sign a message on behalf of the group anonymously.
  - Ring signature： without group manager
- Threshold signature： Need >t members to sign.
- Proxy signature : signer can delegate the signing power to a proxy (short period)
- Attribute signature –signing power varies according to identity-role……

Authentication protocols

- Protocol: A series of specified actions taken by specified 2 or more entities.

A protocol specifies how to use cryptographic primitives (encryption, signature…) to provide security services (ex. authentication)

Security

Name	example
applications	Email, payment, PGP, VPN,
services	Confidentiality, authenticity, integrity, non-repudiation, access control
Protocols	DH, SSL, SSH, IPSEC, Kerbros, secret-sharing, ID-based..,
Mechanisms (standards)	Encryption, signature, authentication, key-exchange, non-repudiation
Primitives	Encryption, signature, hash, MAC, RNG,
algorithms	DES, AES, RSA, DH, MD5, SHA, ElGamal,
theory	Math, IT, Number theory, cryptography, complexity

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Example 1 - password

- Password
  - (A→B): Id=Alice
  - (B→A): proof?
  - (A→B): (<u>password</u>)
  - B: check (<u>password</u>)=stored password ?

    If yes, accept A as Alice.
- Attack by replay
  - If enemy intercepted the password, he can reuse it to pretend to be Alice

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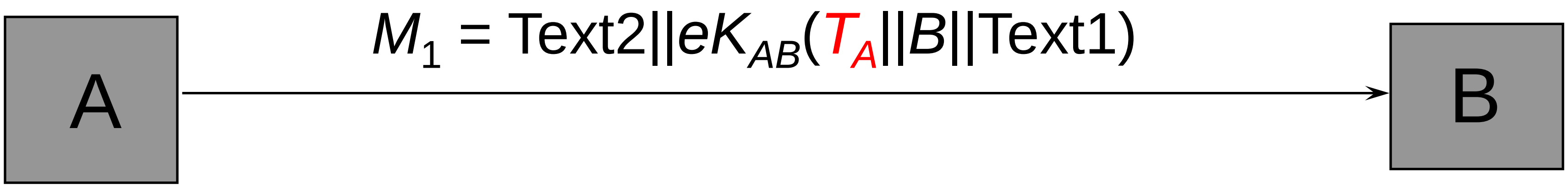
Freshness mechanisms

- Authenticity checking is not enough - also need means of checking 'freshness' of authentic messages, to protect against replays.
- Two main methods:
  - use of time-stamps (clock-based or 'logical' time-stamps),
  - use of 'nonces' or challenges (as in challenge-response protocols).

Example 2. use time-stamp & encryption)



Clause 5.1.1 of ISO/IEC 9798-2.

- use time-stamps T_A for freshness
- eK_{AB} encryption with shared key K_{AB} for origin and integrity checking.
- provides *unilateral authentication* (*B* can check *A*'s identity, but not vice versa).

- Requires **securely** synchronised clocks; Non-trivial to provide such clocks
- need time acceptance 'window' because of clock variations and delays.
- Acceptance window allows for undetectable replays - hence need to store a log of recently received messages.

Logical time - counter

- *A* authenticate to *B:*
  - – *A* maintains counter N_A*,* and B has N_B,
- *A* sends *B* : f(N), ($N>N_A$) and set $N_A=N$*.*
- *B* check
  - – f(N) is authentic; and:
  - – if $N > N_B$ then B accept, and set $N_B=N$,
  - – if $N \leq N_B$ then the message is rejected.

Example 3: e-banking

User input:

- acc. number
- Password
- list number

Then remove the number from the list

Bank check

- acc. number
- Password
- the numbers stored

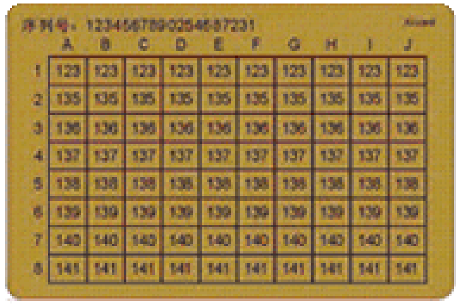
•require synchronization, thus only suitable in well-managed systems.

Karte gültig ab 17.10.2005

51	8QBN	61	YBHB	71	TRPB	81	KC6F	91	HEQL
52	87D3	62	AE97	72	L6DQ	82	M747	92	VWTP
53	XTXN	63	SDWB	73	UZMK	83	XU23	93	SXBE
54	CGJT	64	X5U2	74	PERX	84	4SKB	94	VNY7
55	ARMM	65	AYQE	75	2KWA	85	V9HG	95	9QXU
56	AS2V	66	7X9P	76	BSY5	86	B7RV	96	6XJG
57	P8TB	67	S5V5	77	JBG6	87	9VBA	97	UNHZ
58	RNXP	68	V96J	78	EW4B	88	F6CR	98	LGHN
59	X4WU	69	5RNU	79	JR9E	89	Y7NS	99	39P8
60	VKQW	70	Q2G9	80	27CN	90	ZPUX	100	4HKZ

电子银行口令卡

电子银行口令卡正面



电子银行口令卡背面（覆膜刮开后的示意图）

- use 2 numbers each time (A1,C8)
- 80X79/4 choices

图1 中国工商银行的电子银行口令卡

中国工商银行、中国建设银行的电子口令卡的使用次数、支付限额

	是否有口令卡	使用次数	借记卡支付限额	信用卡支付限额
中国工商银行	√	1000次	单 笔：1000元 日累计：5000元	单 笔：1000元与信用卡本身限额相比低者 日累计：5000元与信用卡本身限额相比低者

Example 4: time – secureID

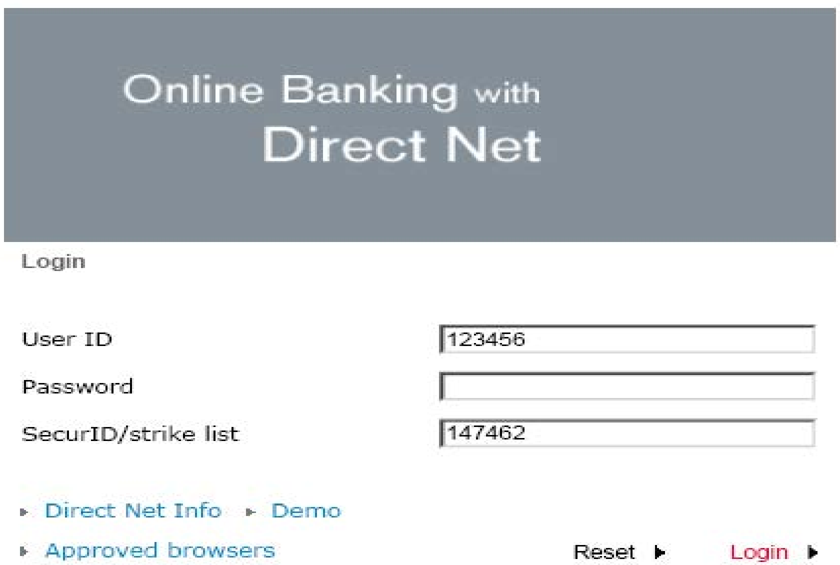
Who you are
What you know
What you have

One-time password, change every 60 sec.

User supply:
- Acc. number
- Password
- SecureID number

Bank check
- acc. Number
- Password
- the numbers computed from local time

CREDIT SUISSE



- SID=h(userID,key,T0)
- T0 $\in$[T0-a,T0+b]

Example 4: nonces – secureID

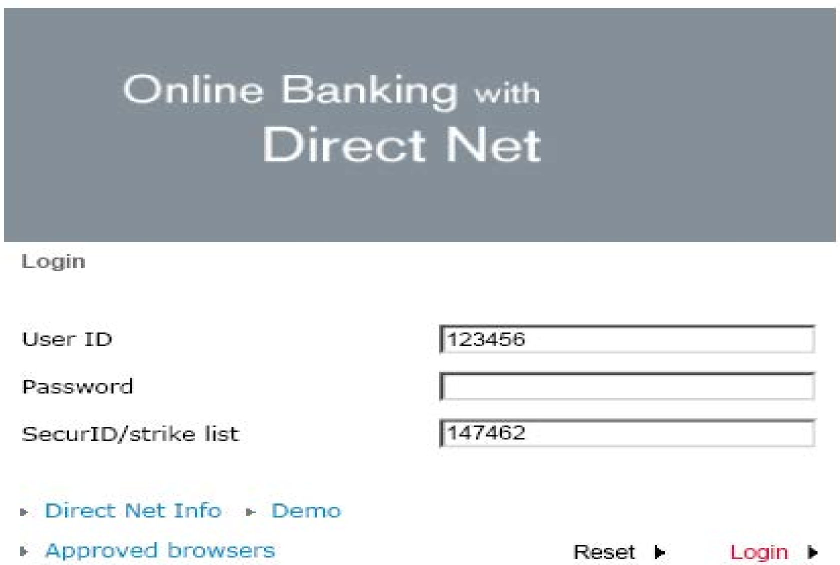
One-time password, change every 60 sec.

Who you are
What you know
What you have

User supply:
- Acc. number
- Password
- SecureID number

Bank check
- acc. Number
- Password
- the numbers stored

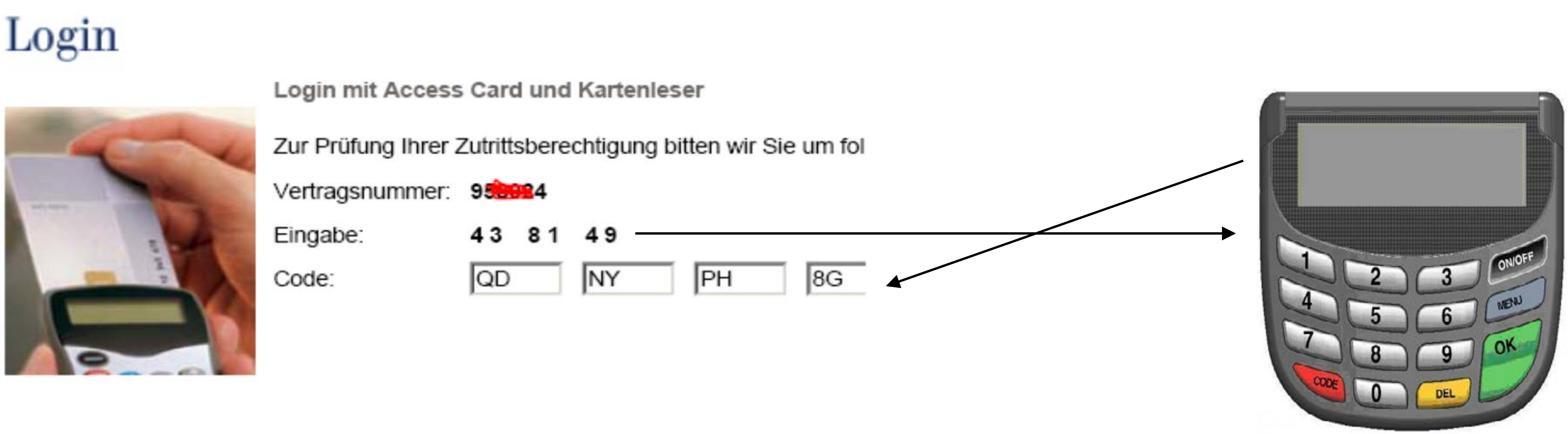
CREDIT SUISSE



• $SID = h(userID, key, N)$ $N > N_0$

Hash, AES

Example 4: nonces–challenge/response



Who you are --- name/account number

What you know --- password

What you have --- device generating valid response

2 basic elements in authentication protocols

- Authentic message
  - – a message that the receiver can verify that it can only be originated by the sender.
- Freshness of the authentic message:
  - – To prevent "replay" attack by using the previously used authentic message.

Example 5 (nonce & integrity mechanism)

A $\xleftarrow{M_1 = R_B || \text{Text1}}$ B

A $\xrightarrow{M_2 = \text{Text3} || fK_{AB}(R_B || B || \text{Text2})}$ B

clause 5.1.2 of ISO/IEC 9798-4.

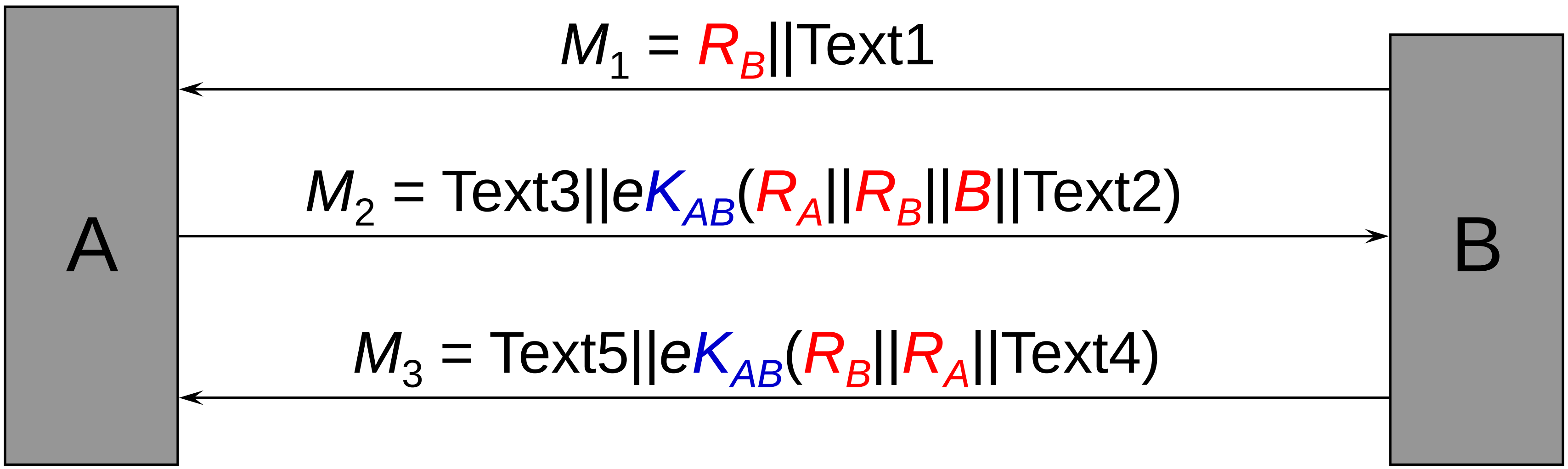
- use of nonces R_B (for freshness) and MAC for origin and integrity checking.

  It provides *unilateral authentication* (*B* can check *A*'s identity)

fK_{AB} denotes a cryptographic check (MAC) function with shared key K_{AB}

This is a challenge-response protocol

Example 6 (nonce & encryption)

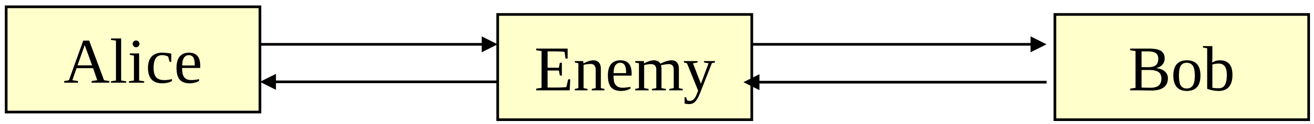


clause 5.2.2 of ISO/IEC 9798-2.

use nonces (for freshness) and encryption (for origin and integrity checking).

It provides *mutual authentication*

Model



Model for authentication.

- 3 parties: Alice, Bob and Enemy
- All communication between A and B are under the control of Enemy (read, relay, modify, insert)
- Assumption: crypto-algorithms (cipher, MAC, hash..) used in the protocols are secure, so we concentrate on protocol.

- Protocol: A series of specified actions taken by specified 2 or more entities.

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Examples

- Password. (A→B): (Alice, <u>password</u>)
  - – Enemy can replay the message.
- Timestamp. (*(A→B)-authentic message)*$_{time}$
  - – require universal clock
- Serial number. n-th message is (*(A→B)-authentic message)*$_{n}$
  - – require synchronization
- Random number (nonces)
  - – challenge B→A: C
  - – response A→B: f(C)

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Key-Exchange protocol

- In most cases, only authentication is not enough.
- it is often used to establish a shared key (“session key”)
- this session key is used to protect the real application.
- Security requirements

1. Authenticity: they both know who the other party is
2. Secrecy: only they know the resultant shared key

Also crucial (yet easy to overlook):

3. Consistency: if two honest parties establish a common session key then both have a consistent view of who the peers to the session are

A: (B,K) and B: (x,K) ➔ x=A

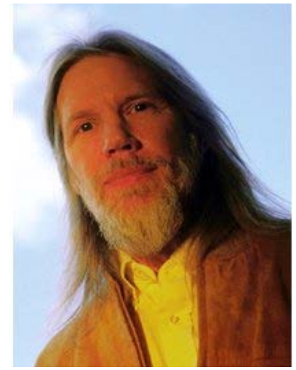
One description of secure key exchange protocol [Krawczyk]

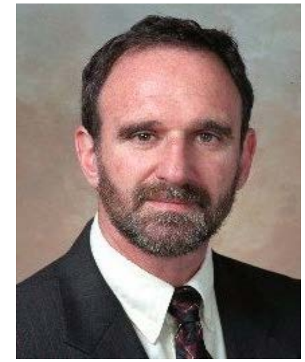
Key management standards

- ISO SC27 generic Key management standard: 11770.
- US banking community - ANSI X9.17, X9.24, 9.28, X9.30, X9.31.
- ISO TC68, banking standards committee for ISO, leading to ISO 8732 (≈ X9.17), ISO 11568, ISO 11649 (≈ X9.28) and ISO 11166 (≈ X9.30/9.31).
- IEEE P1363.2 (Specifications for Password-based Public Key Cryptographic Techniques, used in ISO 11770-4)
- Note: Key management is the most difficult part in use of cryptography

Diffie-Hellman Key Agreement

W.Diffie and M.E.Hellman, “New Directions in Cryptography”, IEEE Transaction on Information Theory, V.IT-22.No.6, Nov 1976, PP.644-654





Parameters: p, g

Alice

Choose a

Compute $g^a \bmod p$

$$\xrightarrow{g^a \bmod p}$$

$$\xleftarrow{g^b \bmod p}$$

Compute $g^{ab} \bmod p$

Bob

Choose b

Compute $g^b \bmod p$

Compute $g^{ab} \bmod p$

g^{ab} is the secrete key shared by Alice and Bob

Man-in-the middle attack

Parameters: p, g

Alice

Choose a

Compute $g^a \bmod p$

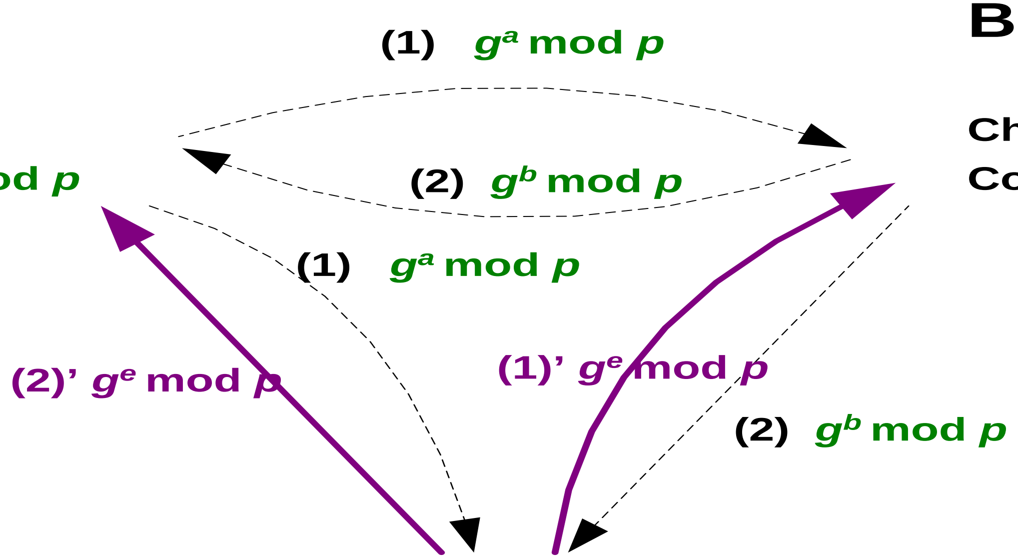
Compute $g^{ae} \bmod p$

Bob

Choose b

Compute $g^b \bmod p$

Compute $g^{be} \bmod p$



Eve

Choose e

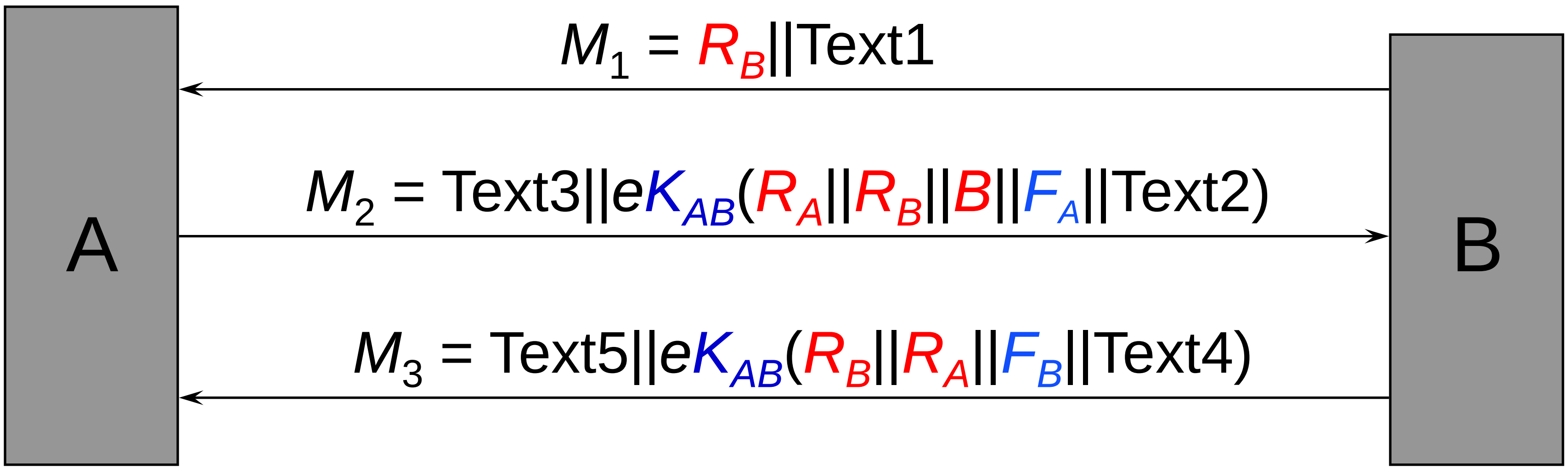
Compute $g^e \bmod p$

Compute $g^{ae} \bmod p$, g^{be} $\bmod p$,

DH provide no authentication,

is also called anonymous key agreement

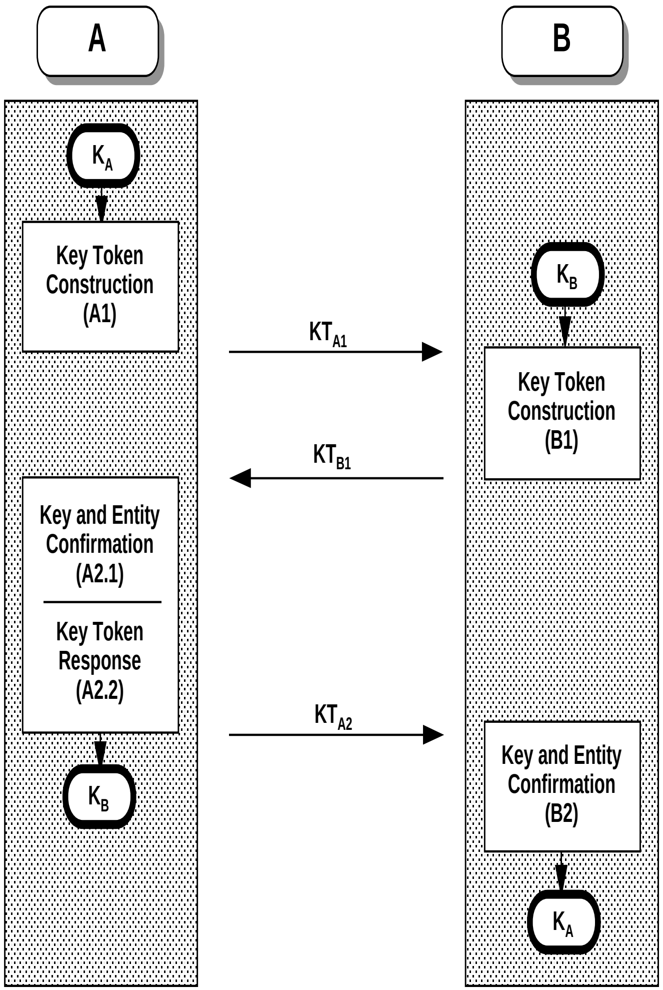
ISO 11770-2 mechanism 6



- *A,B share K_{AB} (master key)*
- R_A and R_B denote nonces, and F_A and F_B are keying material.
- The key K established between A and B is a non-invertible function of F_A and F_B.

clause 5.2.2 of ISO/IEC 9798-2. It provides mutual authentication

ISO 11770-3: Key transport mechanism 6



$KT_{A1} = E_B\,(A||K_A\,||r_A\,||Text1)||Text2$

$KT_{B1} = E_A\,(B||K_B\,||r_A\,||r_B\,||Text3)||Text4$

$KT_{A2} = r_B\,||Text5.$

- Use public-key
- mutual authentication and implicit key authentication
- mutual key confirmation
- known as COMSET
- based on zero-knowledge techniques (clause 9.1 in 9798-5).

Properties of ZK Proofs

Properties of ZK Proofs:

– completeness

prover who knows the secret convinces the verifier with overwhelming probability (always accept)

– soundness (is a proof of knowledge)

no one who doesn't know the secret can convince the verifier with non-negligible probability (random guess, $p=2^{-t}$)

– zero knowledge

the proof does not leak any additional information (verifier can simulate the protocol)

Fiat-Shamir ZK protocol

Fiat-Shamir ID protocol (ZK Proof of knowledge of square root modulo n)

- System parameter: n=pq,
- Private authenticator: s
- Public identity: $v = s^2 \bmod n$
- Protocol (repeat t times)

1. A: picks random r in Z_n^*, sends $x=r^2 \bmod n$ to B
2. B checks $x \neq 0$ and sends random c in {0,1} to A
3. A sends y to B, where If c=0, y=r, else y=rs mod n.
4. B accept if $y^2 \equiv xv^c \bmod n$

Properties of ZK Proofs

- completeness

  honest prover who knows the secret convinces the verifier with overwhelming probability (always accept)

- soundness (is a proof of knowledge)

  no one who doesn’t know the secret can convince the verifier with non-negligible probability (random guess, $p=2^{-t}$). Correct answers to both 0 and 1 implies knowing s.

- zero knowledge

  the proof does not leak any additional information (verifier can simulate the protocol):

  – Repeat the following: pick random $c \in \{0,1\}$,

  • if c=0, pick random r and outputs $(r^2, 0, r)$

  • if c=1, pick random y, and outputs $(y^2 v^{-1}, 1, y)$

ZK Proofs

probability of forgery: $1/2^t$

soundness (proof of knowledge):

– if A can successfully answer two challenges d1 and d2, i.e., A can output D1 and D2 such that $W=g^{D1}G^{d1}=g^{D2}G^{d2}$, then $g^{D1-D2}=G^{d2-d1}$ and thus the secret $Q=(D1-D2)(d2-d1)^{-1} \bmod q$

zero knowledge (the proof does not leak any additional information):

Pick a random d, random D, let $W=G^d g^D$,

Outputs (W, d, D)

Key management with a trusted third party

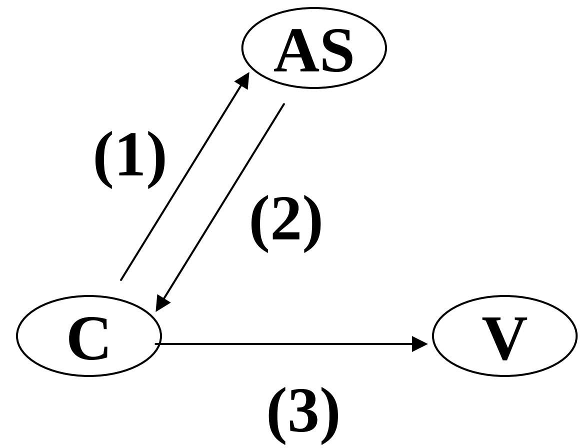
- Beside the 2-party protocols, we can use a trusted third party (TTP) to exchange keys
- Ex. a trusted Key Distribution Center (KDC)
  - each party shares own master key with KDC
  - KDC generates session keys used for connections between parties
  - master keys used to distribute these to them

Denning AS Protocol

(1) $C \rightarrow AS$: $ID_C \| P_C \| ID_V$

(2) $AS \rightarrow C$: Ticket

(3) $C \rightarrow V$: $ID_C \|$ Ticket



$$Ticket = E_{K_V}[ID_C \| AD_C \| ID_V]$$

C : client

AS : Authentication Server

V : server

ID_C : identifier of user on C

ID_V : identifier of V

P_C : password of user on C

AD_C : network address of C

K_V : secret key shared between AS and server V

Key management and password

- Cryptographic keys are formed as binary digits
  - Symmetric: 128-bit
  - RSA,DL: 1024, 2048,.., bits
  - Elliptic curve: 256, 512,...,bits
- Human uses memorized password
  - 4-digit numbers
  - Text password
  - Pass phrases
- Vulnerable to brute-force attacks (guess, dictionary attack)
- Protection methods: policy, slow hash, restrict verification trials, CAPTCHA,…

CAPTCHA

- CAPTCHA (Completely Automated Public Turing Test to Tell Computers and Humans Apart)
  - a type of challenge-response test used in computing to ensure that the response is not generated by a computer.
  - A common type of CAPTCHA requires that the user type the letters or digits of a distorted image that appears on the screen.
- 验证码

Secure use of password

- A: Password π, verifier B knows $k=H(\pi)$
- A sends e_k(data) to B, B check e_k(data) .
  - Brute-force attack: guess π', check $e_{k'}$(data)
  - Could be easier than breaking the cipher.
- Solution
  - B generates a public key p_B, send to A.
  - A send $e_{p_B}(\pi$, nonce) to B
  - Brute-force attack becomes difficult (need to break the public-key cipher)

- ISO 11770-4, IEEE P1363.2

Summary

- Authentication protocols
  - Authentic messages
    - MAC
    - signatures Math
  - Freshness mechanisms
    - Time / counter / Challenge-response
- Key-management
  - Protocols
  - password
- Next lecture: Kerberos, PKI