# Tutorial 1

ID

## 1.1 Identification 1

| **Alice** : $(Alice, pw)$ | | **Bob** : $(Alice, pw)$ |
|---|---|---|
| | $\xrightarrow{(Alice, pw')}$ | |
| | | 1. Alice is verified if $pw' = pw$ |

**Fig. 1.** The simplest Identification Protocol.

Question: explain why this protocol is bad.

# 1

- **Impersonation attack**: An **impersonation attack** is an **attack** in which an adversary successfully assumes the identity of one of the legitimate parties in a system or in a communications protocol. (Adversary logins as the identity Alice)

## 1.2 Identification 2

| **Alice** : $(Alice, pw)$ | | **Bob** : $(Alice, pw)$ |
|---|---|---|
| 1. Compute $H = H(pw)$ | | |
| | $\xrightarrow{(Alice, H)}$ | |
| | | 2. Alice is verified if $H = H(pw)$ |

**Fig. 2.** The Identification Protocol Where $H(pw)$ is transmitted instead of $pw$.

Questions:
Is this protocol secure in terms of identification against the adversary?
Is this protocol more secure in terms of identification compared to the protocol 1?
What is the advantage of this protocol compared to the protocol 1?

## 1.3 Identification 3

| **Alice** : $(Alice, pw)$ | **Bob** : $(Alice, pw)$ |
|---|---|
| 1. Randomly choose $r \in \{0,1\}^n$<br>2. Compute $H = H(r, pw)$ | |
| $\xrightarrow{(Alice, r, H)}$ | |
| | 3. Alice is verified if $H = H(r, pw)$ |

**Fig. 3.** The Identification Protocol Using a Random Salt.

Questions:
Is this protocol secure in terms of identification against the adversary?
Is this protocol more secure in terms of identification compared to the protocol 2?
What is the advantage of this protocol compared to the protocol 2?

## 1.4 Identification 4

| **Alice** : $(Alice, pw)$ | | **Bob** : $(Alice, pw)$ |
|---|---|---|
| | | 1. Randomly choose $r \in \{0,1\}^n$ |
| | $\xleftarrow{r}$ | |
| 2. Compute $H = H(r, pw)$ | | |
| | $\xrightarrow{(Alice, H)}$ | |
| | | 3. Alice is verified if $H = H(r, pw)$ |

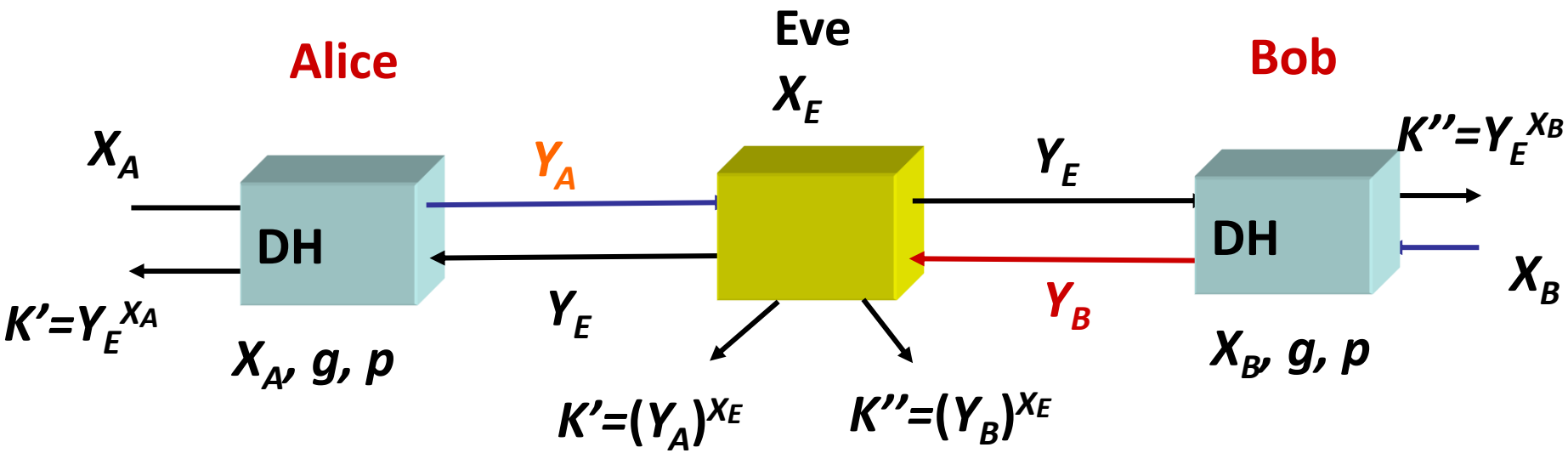
**Fig. 4.** The Identification Protocol Using a Random Salt Chosen by Bob.

Questions:
Is this protocol secure if the adversary cannot compute pw from the communication?
Is this protocol still secure if $r$ chosen by Bob is always the same?

# Key Establishment

# Diffie-Hellman Key Agreement

- **Man-in-the-Middle Attack**




1: A $\rightarrow$ E: $Y_A$

2: E $\rightarrow$ B: $Y_E$

3: B $\rightarrow$ E: $Y_B$

4: E $\rightarrow$ A: $Y_E$

**Remark: all the computation should involve the "mod p" operation, we omit this operation to simplify the presentation**

# 1.MITM attack

What is the cause for the MITM attack?

- Lack of authentication
- Alice cannot be assured that she performed the key exchange with Bob
  - In the attack, Alice actually performed the Diffie-Hellman key exchange with Eve

# 2.MITM attack

How to prevent the MITM attack?

# 3.MTI Families of KE Protocols

- Matsumoto, Takashima, Imai (MTI, 1986)
- Incorporate ***authentication*** into Diffie-Hellman exchange by combining the

  ***long-term keys and ephemeral keys***

  into a single equation.
- Three families of protocols
  - A(k), B(k), C(k) (k: any integer)
  - Only look at A(0) here

# MTI Families of Protocols

- p: a large prime number (e.g. 1024-bit)
- q: a large prime number (e.g. 160-bit) such that q divides (p-1)
  - Z*p has a cyclic subgroup G which has order q
- g is a generator $G=\{g^1, g^2, g^3, ..., g^q\}$
- All the computation will be done under G

*(G, g, p, q)*

# Cyclic group $Z_{11}^*$

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 1 | | | | | | | | |
| **2** | **2** | **4** | **8** | **5** | **10** | **9** | **7** | **3** | **6** | **1** |
| 3 | 3 | 9 | 5 | 4 | 1 | 3 | | | | |
| 4 | 4 | 5 | 9 | 3 | 1 | 4 | | | | |
| 5 | 5 | 3 | 4 | 9 | 1 | 5 | | | | |
| **6** | **6** | **3** | **7** | **9** | **10** | **5** | **8** | **4** | **2** | **1** |
| **7** | **7** | **5** | **2** | **3** | **10** | **4** | **6** | **9** | **8** | **1** |
| **8** | **8** | **9** | **6** | **4** | **10** | **3** | **2** | **5** | **7** | **1** |
| 9 | 9 | 4 | 3 | 5 | 1 | 9 | | | | |
| 10 | 10 | 1 | 10 | | | | | | | |

# MTI A(0)

Certified Long-term keys (in the form of digital certificates)
Alice: $(PK_A, SK_A) = (g^{x_A}, x_A)$
Bob: $(PK_B, SK_B) = (g^{x_B}, x_B)$

Key agreement
1: $A \rightarrow B: g^{r_A}$

2: $B \rightarrow A: g^{r_B}$

Note: $r_A$ and $r_B$ are ephemeral secret keys randomly chosen in each session

Shared Key $Z_{AB} = g^{r_A x_B + r_B x_A}$

- How does each party derive the key?
- Does the MITM attack still work?
- Does this protocol have key freshness?
- Does this protocol have key authentication?

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- Does the MITM attack still work?
  - Suppose that Eve replaces $g^{r_B}$ in the key agreement protocol by $g^{r_E}$, as in the MITM attack shown at the beginning, what is the session key computed by Alice?
  - Can Eve still compute Alice's session key?

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- Does the MITM attack still work?
  - Suppose that Eve replaces $g^{r_B}$ in the key agreement protocol by $g^{r_E}$, as in the MITM attack shown at the beginning, what is the session key computed by Alice?
  - Alice's session key: $Z = (g^{x_B})^{r_A} (g^{r_E})^{x_A}$
  - Eve can't compute this key since Eve can't produce $(g^{x_B})^{r_A}$

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- Key freshness?

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- Key authentication?
  - No, due to the triangle attack (next slide)

# Triangle Attack on MTI A(0)

1: $A \rightarrow B: g^{r_A}$

2: $B \rightarrow A: g^{r_B}$ Shared key $Z_{AB} = g^{r_A x_B + r_B x_A}$

1': $E \rightarrow B: g^{r_A}$

2': $B \rightarrow E: g^{r'_B}$ Shared key $Z_{EB} = g^{r_A x_B + r'_B x_E}$

1'': $E \rightarrow A: g^{r_B}$

2'': $A \rightarrow E: g^{r'_A}$ Shared key $Z_{EA} = g^{r'_A x_E + r_B x_A}$

$$\mathbf{Z_{AB} = (Z_{EB}/(g^{r'_B})^{x_E}) \bullet (Z_{EA}/(g^{r'_A})^{x_E})}$$