Alice Who?

Authentication Protocols

Andreas Zeller/Stephan Neuhaus

Lehrstuhl Softwaretechnik
Universität des Saarlandes, Saarbrücken

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- Common Pitfalls

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Meet Alice and Bob:

Alice and Bob want to communicate, but can't really be sure that the other is really who he/she says he/she is. So they exchange a series of messages ⇒ a protocol.

Basics (2)

- May be one-sided: Alice may be a computer and Bob may be a user. Bob logs in to Alice; Alice then knows it’s Bob, but Bob doesn’t (in general) know it’s Alice.

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- There might be an intruder—Trudy—that can listen to and inject messages.

Basics (3): Protocol Notation

$$\text{Alice} \longrightarrow \text{Bob} : N, \{M, N\}_K$$

This notation means that the principal Alice transmits to the principal Bob a message containing a nonce N, and the plaintext M concatenated with N, encrypted under the key K.

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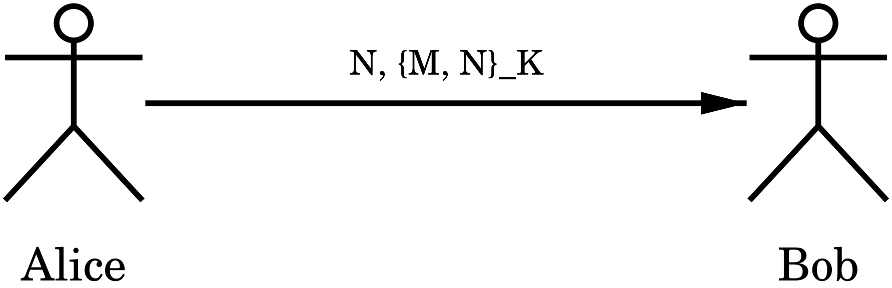
A *nonce* is anything that guarantees the freshness of a message, such as a random number, a serial number, or a challenge received from a third party.

We'll usually distinguish between a principal "Bob" and the identifying information that he sends over the wire, "Bob".

Basics (4)



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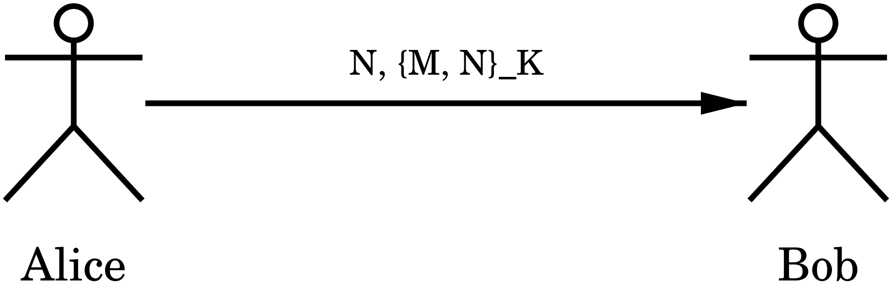

We won't use this often, because it's often easier to see what happens when using the formula notation, especially when there are more than two parties involved.

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- TCP connections are generally not authenticated. This is a problem with mitigating factors, because if you spoof the sender address, you usually won't get the return packets; also, if you are on the same Ethernet, you have to do something about the other party's ARP daemon. But it's possible.

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- Telephone calls are usually not (properly) authenticated; otherwise Kevin Mitnlick couldn't have been as successful as he was. (Remember the very first lecture in this course?)

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As you can see, we'll encounter pretty powerful adversaries.

But we’ll not defend against all threats. For example, we’ll usually not defend against deleted messages (for the practical reason that there’s not much that we can do about it).

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- Alice could be in the posession of a unique token that she presents to Bob. (Who you are is what you have.)
- Alice could agree on submitting to a biometric scan, e.g., a fingerprint scan or face scan. (Who you are is what you are.)

. . . What You Know (aka Passwords)

The protocol goes like this: Bob maintains a database of secret passwords. Alice then authenticates herself to Bob like this:

$$\text{Alice} \longrightarrow \text{Bob} : \text{“Hi, I’m } \textit{Alice}\text{, and my password is ‘}\textit{x\&8e;pqA}\text{’.”}$$

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This attack is not always feasible, but it’s feasible enough in so many environments that you *must* abstain from using this protocol.

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But is this really necessary?

No, because Eve can still just capture the entire encrypted message and replay it to Bob.

Challenge-Response

Alice $\longrightarrow$ Bob : “Hi, I’m *Alice*.”

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Alice ⟶ Bob : "Hi, I'm *Alice*."

Bob ⟶ Alice : "Hi *Alice*, please encrypt `0x67f810a762df5e`."

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$$
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\text{Alice} \longrightarrow \text{Bob} &: \text{“Hi, I'm } \textit{Alice}\text{.”} \\
\text{Bob} \longrightarrow \text{Alice} &: \text{“Hi } \textit{Alice}\text{, please encrypt } \texttt{0x67f810a762df5e}\text{.”} \\
\text{Alice} \longrightarrow \text{Bob} &: \{\texttt{0x67f810a762df5e}\}_K
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Or, more formally,

$$\begin{aligned} \text{Alice} \longrightarrow \text{Bob} &: \textit{Alice} \\ \text{Bob} \longrightarrow \text{Alice} &: R \\ \text{Alice} \longrightarrow \text{Bob} &: \{R\}_K, \end{aligned}$$

where R is a random challenge.

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- Somehow Bob needs to maintain a database of secrets *and keep it secure*. In practice, that's bloody difficult.
- Trudy could hijack the connection after the initial exchange.
- If K is derived from a password (that only Alice needs to know), then Eve could mount an offline password-guessing attack.

Variation 1

$$
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\text{Bob} \longrightarrow \text{Alice} &: \ \{R\}_K \\
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- If K is derived from password, and if R is distinguishable from random bits, Eve can mount a password-guessing attack without snooping, by initiating the protocol as *Alice*.

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- Requires reversible cryptography.
- If K is derived from password, and if R is distinguishable from random bits, Eve can mount a password-guessing attack without snooping, by initiating the protocol as *Alice*.
- Authentication is mutual *if* R is a recognizable quantity with a limited lifetime.

Variation 2

$$\text{Alice} \longrightarrow \text{Bob} \ : \ \mathit{Alice}, \{t\}_K,$$

where t is a timestamp.

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- Time setting and login are now coupled.

Mutual Authentication

$$\begin{aligned} \text{Alice} \longrightarrow \text{Bob} &: \textit{Alice} \\ \text{Bob} \longrightarrow \text{Alice} &: R_1 \\ \text{Alice} \longrightarrow \text{Bob} &: \{R_1\}_K, R2 \end{aligned}$$

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\text{Bob} \longrightarrow \text{Alice} &: \{R_2\}_K
\end{aligned}
$$

Mutual Authentication “Optimized”

We attempt to optimize this protocol:

$$
\begin{aligned}
\text{Alice} \longrightarrow \text{Bob} &: \mathit{Alice}, R_2 \\
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We eliminated 25% of all messages. Not bad!

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What's wrong with this protocol?

Reflection Attack

This protocol suffers from a *reflection attack*:

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- Different challenges. Either remember past challenges and decline to encrypt known challenges, or insist that the challenges must be different for Alice and Bob (see exercises).
- Let the initiator of a protocol be the first to prove his identity.

Authentication With Public Key

$$
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\text{Bob} \longrightarrow \text{Alice} &: R \\
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\end{aligned}
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\text{Alice} \longrightarrow \text{Bob} &: [R]_{\text{Alice}}
\end{aligned}$$

- Bob's database doesn't contain secrets anymore ⇒ need not be protected against theft.

Authentication With Public Key

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- Bob’s database doesn’t contain secrets anymore ⇒ need not be protected against theft.
- Database must still be protected against *modification* (*much* easier).

Variation and Criticism (1)

$$\begin{aligned} \text{Alice} \longrightarrow \text{Bob} &\;:\; \textit{Alice} \\ \text{Bob} \longrightarrow \text{Alice} &\;:\; \{R\}_{\text{Alice}} \\ \text{Alice} \longrightarrow \text{Bob} &\;:\; R \end{aligned}$$

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- Needs encryption in addition to signature.
- Both protocols have the flaw that if Eve can impersonate Bob, she can get arbitrary values signed (or encrypted).
- This is a *serious* flaw if the Alice's key pair is used for things other than authentication (e.g., for signing bank transfers).

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For people who like to sound clever, we can also say that security isn't closed under composition.

Mutual Authentication With Public Key

$$\begin{aligned}
\text{Alice} \longrightarrow \text{Bob} &: \mathit{Alice}, \{R_2\}_{\text{Bob}} \\
\text{Bob} \longrightarrow \text{Alice} &: R_2, \{R_1\}_{\text{Alice}} \\
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In an obvious variation, Alice could send R_2 and Bob could return $[R_2]_{\text{Bob}}$; Bob would then send R_1 and Alice would return $[R_1]_{\text{Alice}}$.

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After this exchange, Alice and Bob can (must) authenticate themselves.

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Therefore, Trent will in general return to Alice not only $\{\text{Use } K_{AB} \text{ for Bob}\}_{\text{Alice}}$, but also $t = \{\text{Use } K_{AB} \text{ for Alice}\}_{\text{Bob}}$, which is called a *ticket*.

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Both will then have to complete a mutual authentication.

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- It's a classic mediated authentication protocol with mutual authentication.
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- It's used in Kerberos and Kerberos is used in Active Directory $\Longrightarrow$ huge installed base.
- We'll analyze this protocol in some detail in order to understand its strengths and weaknesses.

Needham-Schroeder (2)

$$\begin{aligned}
\text{Alice} \longrightarrow \text{Trent} &: N_1, \mathit{Alice} \text{ wants } \mathit{Bob} \\
\text{Trent} &: \text{Invents } K_{AB} \\
\text{Trent} \longrightarrow \text{Alice} &: \{N_1, \mathit{Bob}, K_{AB}, \{K_{AB}, \mathit{Alice}\}_{\text{Bob}}\}_{\text{Alice}} \\
\text{Alice} &: \text{Verifies } N_1\text{, extracts } K_{AB} \text{ and ticket} \\
\text{Alice} \longrightarrow \text{Bob} &: \{K_{AB}, \mathit{Alice}\}_{\text{Bob}}, \{N_2\}_{AB} \\
\text{Bob} &: \text{Extracts } K_{AB} \text{ from ticket} \\
\text{Bob} \longrightarrow \text{Alice} &: \{N_2 - 1, N_3\}_{AB} \\
\text{Alice} \longrightarrow \text{Bob} &: \{N_3 - 1\}_{AB}
\end{aligned}$$

where $\{K_{AB}, \mathit{Alice}\}_{\text{Bob}}$ is Trent's ticket for Alice's conversation with Bob and the N_i are *nonces*, i.e., quantities used only once.

Analysis of Needham-Schroeder (1)

Why the Nonce in the first message?

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Otherwise, the protocol could be susceptibe to a replay attack. Assume that Eve has captured a previous exchange of this modified Needham-Schroeder protocol and has, by some effort, broken K_{AB}:

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$$\begin{aligned} \text{Alice} \longrightarrow \text{Eve} &: \textit{Alice} \text{ wants } \textit{Bob} \\ \text{Eve} \longrightarrow \text{Alice} &: \{Bob, K_{AB}, \{K_{AB}, Alice\}_{\text{Bob}}\}_{\text{Alice}} \end{aligned}$$

and Eve will now be able to decrypt the conversation between Alice and Bob.

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and Eve will now be able to decrypt the conversation between Alice and Bob. This can't happen with N_1 used in the first step, because Eve can't encrypt N_1.

Analysis of Needham-Schroeder (2)

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To make it impossible for Trudy to substitute her own name for Bob's:

$$
\begin{aligned}
\text{Alice} \longrightarrow \text{Trudy} &: \textit{Alice} \text{ wants } \textit{Bob} \\
\text{Trudy} &: \text{Intercepts and changes the message} \\
\text{Trudy} \longrightarrow \text{Trent} &: \textit{Alice} \text{ wants } \textit{Trudy} \\
\text{Trent} \longrightarrow \text{Trudy} &: \{K_{AB}, \{K_{AB}\}_{\text{Trudy}}\}_{\text{Alice}} \\
\text{Trudy} \longrightarrow \text{Alice} &: \{K_{AB}, \{K_{AB}\}_{\text{Trudy}}\}_{\text{Alice}} \\
\text{Trudy} &: \text{Impersonates Bob}
\end{aligned}
$$

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Nonce types are:

- a timestamp;
- a sequence number; and
- a large random number.

Large Random Numbers as Nonces (1)

Why can we use a random number as a nonce when there is a chance that it would be reused?

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Why can we use a random number as a nonce when there is a chance that it would be reused?

Back-of-envelope-calculation: Assume n-bit random numbers; there are $N = 2^n$ of them. The probability that k independent draws out of N numbers yield all different numbers is $N(N-1)\cdots(n-k+1)/N^k$.

The relative difference between N and $N-k+1$ is $\delta = (k-1)/N$. (I.e., $N-k+1 = (1-\delta)N$.) Let's assume we generate a 128-bit nonce every millisecond for 1000 years. That will be $1000 \cdot 366 \cdot 24 \cdot 3600 \cdot 1000 = 31622400000000$ or about 2^{45} nonces. With $N = 2^{128}$ and $k = 2^{45}$, we have $\delta \approx 2^{45}/2^{128} = 2^{-83}$.

Large Random Numbers as Nonces (2)

$N - k + 1 \approx (1 - 2^{-83})N$; therefore

$$\begin{aligned} N(N-1)\cdots(N-k+1)/N^k &\geq (N-k+1)^k/N^k \\ &\approx (1-2^{-83})^k N^k/N^k \\ &\approx (1-2^{-83})^k \\ &\approx 1 - k \cdot 2^{-83} \\ &\approx 1 - 2^{45} \cdot 2^{-83} \\ &= 1 - 2^{-38}. \end{aligned}$$

Therefore, it is practically certain that all nonces are different. ($2^{-38} \approx 3.6 \cdot 10^{-12}$.)

Timestamps and Sequence Numbers

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\text{Bob} \longrightarrow \text{Alice} &: \{R\}_{AB} \\
\text{Alice} \longrightarrow \text{Bob} &: R
\end{aligned}
$$

Breaking The Protocol

If Bob used sequence numbers, Eve could listen in to only one exchange between Alice and Bob. Then she would know the current value of R and could impersonate Alice:

$$\begin{aligned} \text{Eve} \longrightarrow \text{Bob} &: \textit{Alice} \\ \text{Bob} \longrightarrow \text{Eve} &: \{R+1\}_{AB} \\ \text{Eve} \longrightarrow \text{Bob} &: R+1 \end{aligned}$$

Eve can answer "$R+1$" in step 3, even though she can't decrypt $\{R+1\}_{AB}$, because she can *predict* what the challenge will be.

Random Numbers

If you use random numbers for nonces, be sure to pick good ones. We've had two lectures on how to do that, so we won't talk about that any further.

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- Number of connection buildups and teardowns

Checklist

A checklist can be found in Charlie Kaufman, Radia Perlman, Mike Speciner, *Network Security*, Prentice-Hall. (The second edition has the list on p. 285f.)

Summary

- Simple Authentication Protocols

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Resources

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