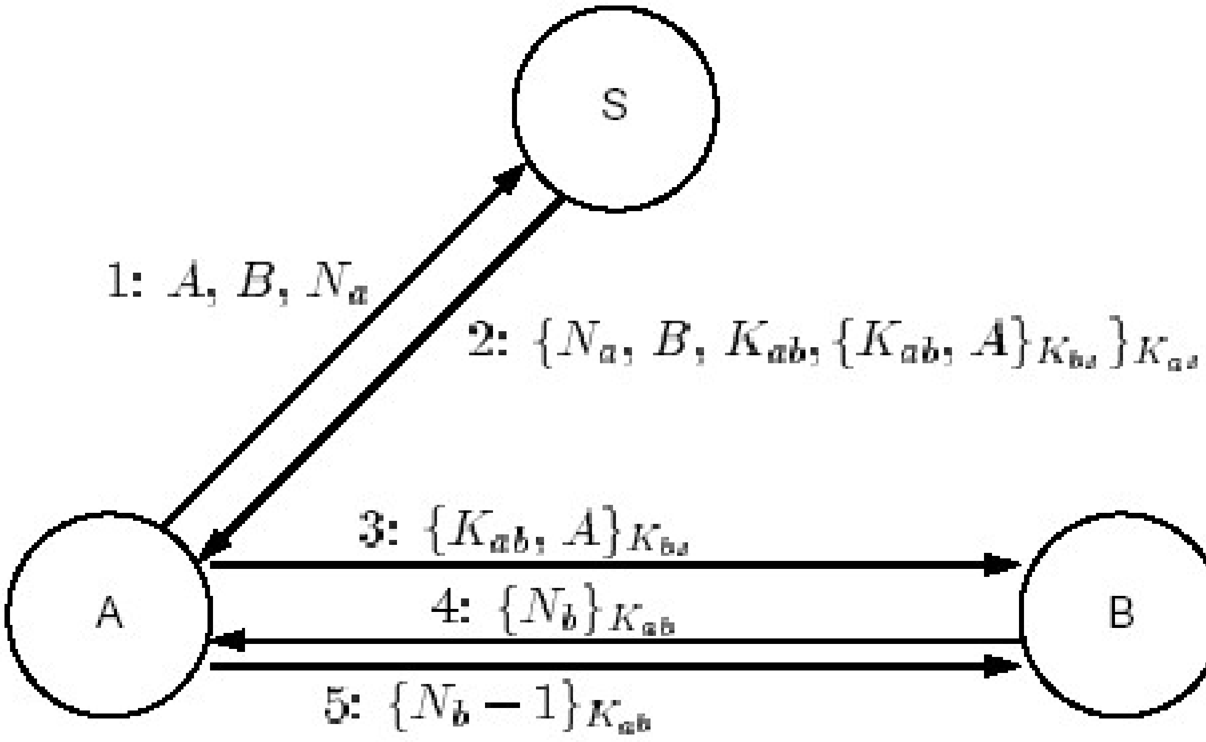
Needham-Schroeder authentication protocol and its formal analysis

Needham-Schroeder protocol

- The goal of the protocol is to establish mutual authentication between two parties A and B in the presence of adversary, who can
  - Intercept messages;
  - Delay messages;
  - Read and copy messages;
  - Generate messages,

  But who does not know
  - secret keys of principals, which they share with the authentication server S.
- A and B obtain a secret shared key though authentication server S.
- The protocol uses shared keys encryption/decryption

Needham-Schroeder protocol



The Needham-Schroeder Protocol (with shared keys)

Needham-Schroeder protocol

- Message 1 $A \rightarrow S: A, B, N_A$
- Message 2 $S \rightarrow A: \{N_A, B, K_{AB}, \{K_{AB}, A\}_{K_B}\}_{K_A}$
- Message 3 $A \rightarrow B: \{K_{AB}, A\}_{K_B}$
- Message 4 $B \rightarrow A: \{N_B\}_{K_{AB}}$
- Message 5 $A \rightarrow B: \{N_B - 1\}_{K_{AB}}$

- Here K_A and K_B are keys of *A* and *B* shared with S, resp.
- N_A and N_B are nonces, introduced by *A* and *B*, resp.
- K_{AB} is a secret session key for *A* and *B* provided by *S*

How it works

- A makes contact with the authentication server S, sending identities A and B and *nonce* N_A;
- S responds with a message encrypted with the key of A. The message contains session key K_{AB} (to be used by A and B) and certificate encrypted with B's key conveying the session key and A's identity;
- A sends the certificate to B;
- B decrypts the certificates and sends his own nonce encrypted by the session key to A; (*nonce handshake*);
- A decrypts the last message and sends *modified nonce* back to B.

By the end of the message exchange both A and B share the secret key and both are assured in the presence of each other.

Formal analysis using BAN logic

- Explicit assumptions:

A believes:	*B believes:*	*S believes:*
$A \overset{K_A}{\leftrightarrow} S$	$B \overset{K_B}{\leftrightarrow} S$	$A \overset{K_A}{\leftrightarrow} S$, $B \overset{K_B}{\leftrightarrow} S$
S **controls** $A \overset{K_{AB}}{\leftrightarrow} B$	S **controls** $A \overset{K_{AB}}{\leftrightarrow} B$	$A \overset{K_{AB}}{\leftrightarrow} B$
S **controls** **fresh**($A \overset{K_{AB}}{\leftrightarrow} B$)		**fresh**($A \overset{K_{AB}}{\leftrightarrow} B$)
fresh(N_A)	**fresh**(N_B)	

Authentication goals

- Main: $A \textbf{ believes } A \overset{K_{AB}}{\longleftrightarrow} B$ and $B \textbf{ believes } A \overset{K_{AB}}{\longleftrightarrow} B$

- Subsidiary: $A \textbf{ believes } B \textbf{ believes } A \overset{K_{AB}}{\longleftrightarrow} B$ and

  $B \textbf{ believes } A \textbf{ believes } A \overset{K_{AB}}{\longleftrightarrow} B$

Protocol steps formalized

- Transform each message into an idealized message, containing only nonces and statements (implicitly asserted by a sender)

Message	*Idealized Message*
1. $A \rightarrow S: A, B, N_A$	–
2. $S \rightarrow A: \{N_A, B, K_{AB}, \{K_{AB}, A\}_{K_B}\}_{K_A}$	$\{N_A, A \overset{K_{AB}}{\leftrightarrow} B, \textbf{fresh}(A \overset{K_{AB}}{\leftrightarrow} B), \{A \overset{K_{AB}}{\leftrightarrow} B\}_{K_B}\}_{K_A}$
3. $A \rightarrow B: \{K_{AB}, A\}_{K_B}$	$\{A \overset{K_{AB}}{\leftrightarrow} B\}_{K_B}$
4. $B \rightarrow A: \{N_B\}_{K_{AB}}$	$\{N_B, A \overset{K_{AB}}{\leftrightarrow} B\}_{K_{AB}}$
5. $A \rightarrow B: \{N_B - 1\}_{K_{AB}}$	$\{N_B, A \overset{K_{AB}}{\leftrightarrow} B\}_{K_{AB}}$

First step of analysis

- Let $M = (N_A, A \overset{K_{AB}}{\leftrightarrow} B, \textbf{fresh}(A \overset{K_{AB}}{\leftrightarrow} B))$
- Then we have
  - $A \ \textbf{believes} \ A \overset{K_A}{\leftrightarrow} S,$ licit assumption)
  - $A \ \textbf{sees} \ \{M\}_{K_A}$ (upon receiving Message 2)
- Apply message-meaning rule:

$$\frac{A \ \textbf{believes} \ A \overset{K_A}{\leftrightarrow} S, \ A \ \textbf{sees} \ \{M\}_{K_A}}{A \ \textbf{believes} \ (S \ \textbf{said} \ M)}$$

Further steps

- We have
- A **believes** **fresh**(N_A) (explicit assumption)
- N_A is a part of $M = (N_A, A \overset{K_{AB}}{\leftrightarrow} B, \textbf{fresh}(A \overset{K_{AB}}{\leftrightarrow} B))$

By application of second decomposition rule we deduce:

$$A \textbf{ believes fresh}(M)$$

Further steps

- By nonce-verification rule:

$$\frac{A \textbf{ believes fresh } (M),\ A \textbf{ believes } (S \textbf{ said } M)}{A \textbf{ believes } (S \textbf{ believes } M)}$$

- By the third decomposition rule

$$\frac{A \textbf{ believes } (S \textbf{ believes } (N_A,\ A \overset{K_{AB}}{\leftrightarrow} B,\ \textbf{fresh}(A \overset{K_{AB}}{\leftrightarrow} B)))}{A \textbf{ believes } (S \textbf{ believes } A \overset{K_{AB}}{\leftrightarrow} B)}$$

Final step

- By jurisdiction rule:

$$\frac{A \textbf{ believes } (S \textbf{ controls } A \overset{K_{AB}}{\leftrightarrow} B),\ A \textbf{ believes } (S \textbf{ believes } A \overset{K_{AB}}{\leftrightarrow} B)}{A \textbf{ believes } A \overset{K_{AB}}{\leftrightarrow} B}$$

- The first authentication goal is achievable!

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Remaining authentication goals

- The statement $B \textbf{ believes } A \overset{K_{AB}}{\longleftrightarrow} B$. is not derivable!

- One needs one extra assumption to derive it:

$$B \textbf{ believes fresh}(A \overset{K_{AB}}{\longleftrightarrow} B).$$

- Derivation of subsidiary goals is left as an exercise:

Conclusion

- The formal analysis we have just done should not be
- neither underestimated:
  - We have shown that the protocol is **correct** under explicit assumptions and concrete formalization;
- nor overestimated:
  - The analysis is as good as formal (idealized) model and explicit assumptions are;
  - The adequacy of the model and assumptions may be an issue here.