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SAT-based Verifiction of NSPKT Protocol Including Delays in the Network

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Importance of Security Protocols

- Key point of security systems
- Used in many areas
- Errors in: structure, operations, security
- Specification and verification importance
- Need for the complete formal model
- IT market development sets new requirements

New Challenges

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- Detailed analysis of the protocol
- "Tailor-made" security
- The importance of time

World Leaders

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- AVISPA
- ProVerif
- Scyther
- VerIcs
- PRISM

Basic elements

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Protocol definition (with time aspect)

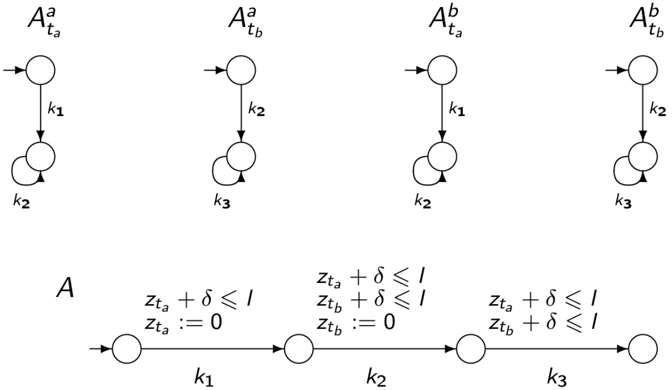
$$\begin{aligned} \alpha^1 &= (S_{\rightarrow}, R_{\leftarrow}, L), \\ \alpha^2 &= (\tau, D, X, G, tc) \end{aligned} \tag{1}$$

Example: Needham-Schroeder Public Key Protocol

$$
\begin{aligned}
\alpha_1 &= (\alpha_1^1, \alpha_1^2),\\
\alpha_1^1 &= (\mathcal{A}; \mathcal{B}; \langle \tau_\mathcal{A} \cdot \mathcal{I}_\mathcal{A} \rangle_{\mathcal{K}_\mathcal{B}}),\\
\alpha_1^2 &= (\tau_1; D_1; \{\tau_\mathcal{A}, \mathcal{I}_\mathcal{A}, \mathcal{K}_\mathcal{B}\}; \{\tau_\mathcal{A}\}; \tau_1 + \mathcal{D}_1 - \tau_\mathcal{A} \leqslant \mathcal{L}),\\
\\
\alpha_2 &= (\alpha_2^1, \alpha_2^2),\\
\alpha_2^1 &= (\mathcal{B}; \mathcal{A}; \langle \tau_\mathcal{B} \cdot \tau_\mathcal{A} \rangle_{\mathcal{K}_\mathcal{A}}),\\
\alpha_2^2 &= (\tau_2; \mathcal{D}_2; \{\tau_\mathcal{B}, \tau_\mathcal{A}, \mathcal{K}_\mathcal{A}\}; \{\tau_\mathcal{B}\}; \tau_2 + \mathcal{D}_2 - \tau_\mathcal{A} \leqslant \mathcal{L} \wedge \tau_2 + \mathcal{D}_2 - \tau_\mathcal{B} \leqslant \mathcal{L}),\\
\\
\alpha_3 &= (\alpha_3^1, \alpha_3^2),\\
\alpha_3^1 &= (\mathcal{A}; \mathcal{B}; \langle \tau_\mathcal{B} \rangle_{\mathcal{K}_\mathcal{B}}),\\
\alpha_3^2 &= (\tau_3; \mathcal{D}_3; \{\tau_\mathcal{A}, \mathcal{K}_\mathcal{B}\}; \{\emptyset\}; \tau_3 + \mathcal{D}_3 - \tau_\mathcal{A} \leqslant \mathcal{L} \wedge \tau_3 + \mathcal{D}_3 - \tau_\mathcal{B} \leqslant \mathcal{L}).
\end{aligned}
$$

Automata Model

Network of synchronized timed automata for NSPK protocol



Automata Model

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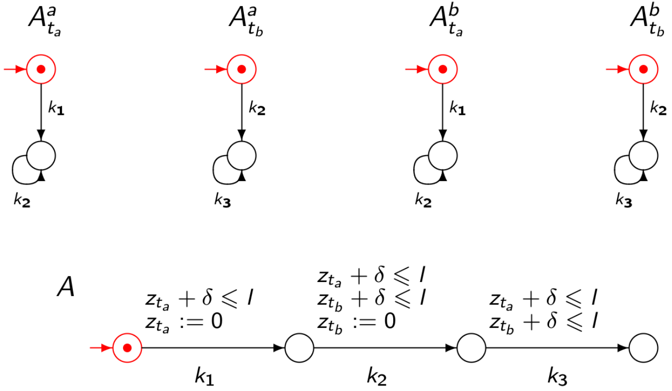

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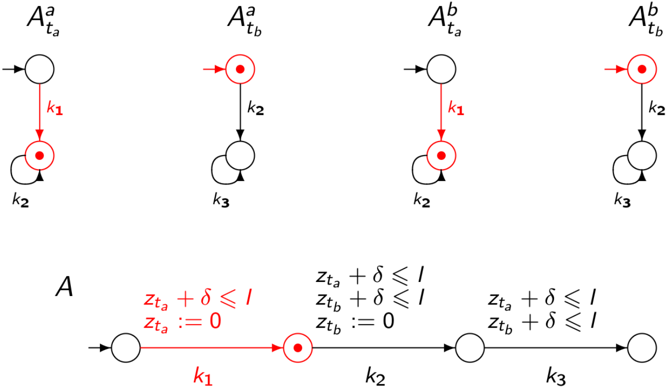

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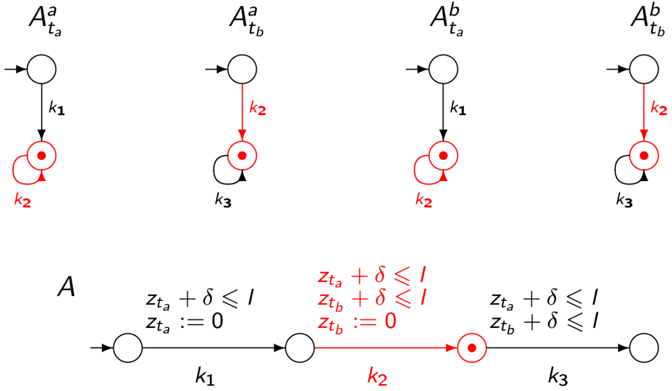

Automata Model

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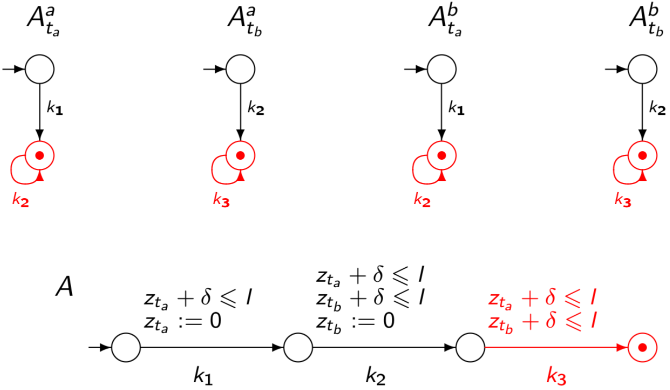

Time dependencies

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Message composing time

$$T_c = T_{sz} + T_g \tag{2}$$

Duration of k-step

$$T_k = T_{sz} + T_g + D + T_{dsz} \tag{3}$$

$$T_k^{min} = T_{sz} + T_g + D_{min} + T_{dsz} \tag{4}$$

$$T_k^{max} = T_{sz} + T_g + D_{max} + T_{dsz} \tag{5}$$

Time dependencies

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Session time

$$T_{ses} = \sum_{k=1}^{n} T_k \tag{6}$$

$$T_{ses}^{min} = \sum_{k=1}^{n} T_k^{min} \tag{7}$$

$$T_{ses}^{max} = \sum_{k=1}^{n} T_k^{max} \tag{8}$$

Time dependencies

Lifetime in single step

$$T_k^{out} = \sum_{i=k}^{n} T_i^{max} \tag{9}$$

where:

- k – step number,
- n – number of all steps in protocol,
- T_i^{max} – maximum time of step execution.

Steps of Procedure

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- Writing protocol in ProToc language.
- Generating a set of protocol executions.
- Generating a network of timed automata.
- Generating a formulas for SAT-Solver.
- SAT-Solver testing.
- Saving results to a file.

Selected SAT-solvers

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Protocols	Mini-SAT	Lingeling	Clasp	Glucose	Treengeling
Memory [MB]					
NSPK	2,95	2,99	3,01	3,2	4
$NSPK_{Lowe}$	3,95	4,4	4,02	4,23	5
Time [ms]					
NSPK	48	56	60	200	260
$NSPK_{Lowe}$	360	400	370	560	430

Experimental results for NSPK protocol

Length of path	Variables	Clauses	Memory [MB]	Time [ms]	Result
2	6087	15781	2,19	8	UNSAT
3	7322	18829	2,19	8	UNSAT
4	13873	34298	2,48	20	UNSAT
5	15051	37188	2,55	28	UNSAT
6	21849	53246	2,95	48	SAT

Time assumptions:

- Delays in $D = 0,15[tu]$,
- lifetime $Lf = 2[tu]$

Susceptibility to Attack

Protocol NSPK will be vulnerable to attack if

- in the first step: $D \leqslant Lf$
- in the second step: $D \leqslant Lf/4$
- in the last step: $D \leqslant Lf/5$

Experimental results for NSPK protocol, with time restrictions

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Length of path	Variables	Clauses	Memory [MB]	Time [ms]	Result
2	6216	16118	2,19	8	UNSAT
3	7533	19366	2,18	12	UNSAT
4	14177	35054	2,48	32	UNSAT
5	15431	38130	2,55	28	UNSAT
6	22334	54435	2,95	80	UNSAT

Time assumptions:

- Delay in the following steps $D_1 = 10,1[tu]$, $D_2 = 2,6[tu]$, $D_3 = 2,1[tu]$,
- lifetime $Lf = 10[tu]$

Summary

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- Presented method can be used for fast and simple protocol verification.
- With the implemented tool, we can not only find the attack on the protocol, but also check if the protocol makes sense.
- Shown time constraints, enable us to determine the protocol time frame in which it is vulnerable to attack.
- This is one of the steps to accurately show the strengths and weaknesses of security protocols.

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