Securing statically-verified communications protocols against timing attacks

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Outline

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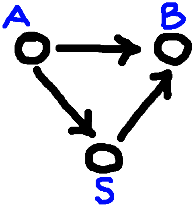
1. Secure communications protocols
   - Timing attacks
   - Remote timing attacks
2. Static analysis for security properties using LySa
   - LySa process calculus
   - LySa model of the Wide-Mouthed Frog protocol
   - Static analysis with the LySatool
3. Dynamic analysis for performance properties using PEPA
   - The PEPA stochastic process algebra
   - PEPA model of the Wide-Mouthed Frog protocol
   - Dynamic analysis with IPC/DNAmaca
4. Summary

Purpose of a secure communications protocol

- Allows sender and receiver to exchange confidential messages.
- Authenticates the principals to confirm their identity.

An example: the Wide-Mouthed Frog protocol



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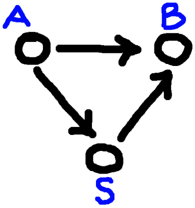

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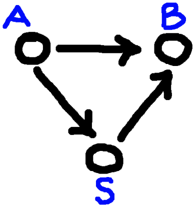

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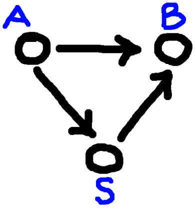

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3. A sends a message to B encrypted under K_{AB}.

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- Secure communications protocols depend on encryption algorithms which take a measureable time to execute.
- If security-sensitive operations can be repeatedly timed then information about the secret keys used for decryption can be gained bit by bit until they are entirely known.
- When secret keys become known then the confidentiality and authenticity offered by secure protocols are entirely lost.

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    - Attack applies in networked, inter-process and virtual machine environments.
    - Found that many crypto libraries completely ignore the timing attack.

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$P_1 \mid P_2$	Parallel
$!P$	Replication
0	Nil
$(\nu\, n)\, P$	New
$\langle t_1, \ldots, t_k \rangle.P$	Output
$(t_1, \ldots, t_j;\ x_{j+1}, \ldots x_k).P$	Input
decrypt t as $\{t_1, \ldots, t_j;\ x_{j+1}, \ldots, x_k\}_{t_0}$ in P	Decrypt

Structure of a LySa packet

LySa packet

$$\langle \; \underbrace{A, S,}_{\text{header}} \quad \underbrace{A, \{ \, B, K_{AB} \, \}_{K_{AS}}}_{\text{payload}} \quad \underbrace{[\mathrm{at}\ a1\ \mathrm{dest}\ s1]}_{\text{metadata}} \; \rangle$$

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- Payload: The name A is sent in the clear and the name B and the key K_{AB} are sent encrypted under K_{AS}.
- Metadata: This is encrypted at $a1$ to be decrypted at $s1$.

LySa model of the Wide-Mouthed Frog protocol

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Principal A

$$!(\nu\, K_{AB})\, \langle A, S, A, \{B, K_{AB}\}_{K_{AS}} [\text{at } a1 \text{ dest } s1\,] \rangle.$$
$$(\nu\, message)\, \langle A, B, \{message\}_{K_{AB}} [\text{at } a2 \text{ dest } b2\,] \rangle.0$$

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Server S

$$!(A, S, A;\, z).\text{decrypt } z \text{ as } \{B;\, zk\}_{K_{AS}}[\text{at } s1 \text{ orig } a1\,] \text{ in}$$
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Principal B

$$!(S, B;\, x).\text{decrypt } x \text{ as } \{A;\, xk\}_{K_{BS}} [\text{at } b1 \text{ orig } s2\,] \text{ in}$$
$$(A, B;\, y).\text{decrypt } y \text{ as } \{;\, ym\}_{xk} [\text{at } b2 \text{ orig } a2\,] \text{ in } 0$$

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    - Reporting too many errors does not pose a big problem in practice.
- The LySatool reports no errors in the WMF protocol.

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Performance Evaluation Process Algebra

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$(\alpha, r).P$	Prefix
$P_1 + P_2$	Choice
$P_1 \bowtie_L P_2$	Co-operation
P/L	Hiding
X	Variable

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$$P_A \stackrel{def}{=} (as, r_{as}).(ab, r_{ab}).P_A$$

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- Rates can be chosen to represent communication cost, computation cost, or an aggregate of these.
- We can modify the protocol by adding delays to mask the difference between a faster interaction and a slower one.
- Finally, we wish to determine whether or not two versions of the PEPA model of the protocol are sufficiently close that we would believe that a timing attack is impractical.

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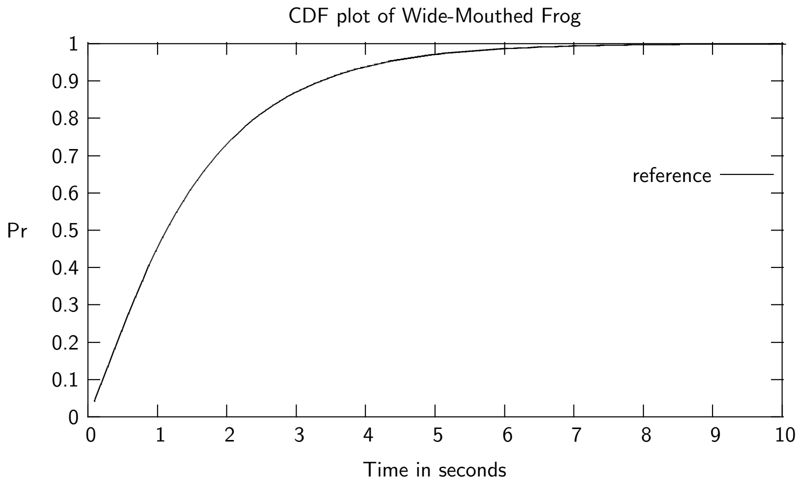
- IPC allows the modeller to attach stochastic probes to a PEPA model to mark the start and end of passages through the model.
- Via uniformisation, DNAmaca computes passage-time densities for this, allowing them to be presented as a cumulative density function (CDF) for the passage.

CDF plot of the WMF protocol



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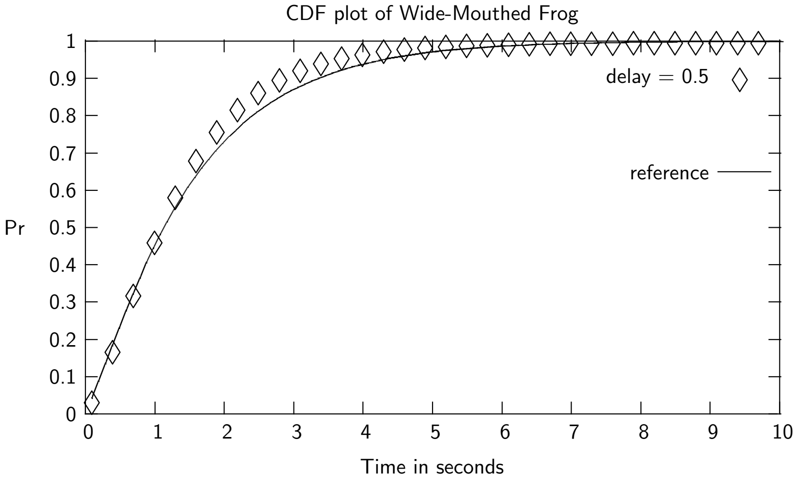

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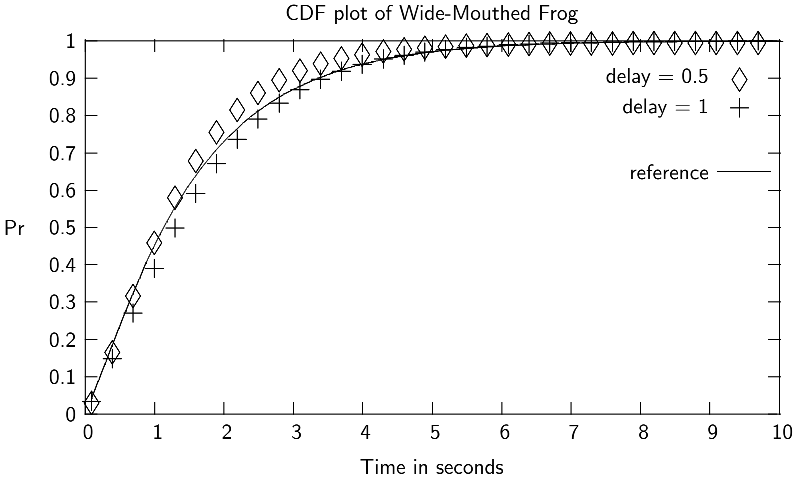

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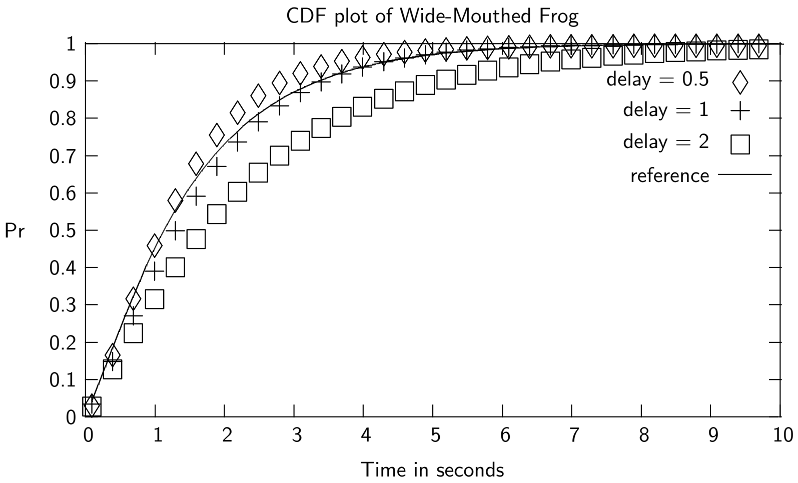

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- Security and performance are interrelated issues:
  - Time-dependent behaviour can be used to attack a protocol.
  - Developers who are concerned with achieving peak performance view security measures as an overhead.
- By using the LySatool to check origination and destination of messages and the Imperial PEPA Compiler and DNAmaca for the computation of passage-time quantiles we have been able to guard against certain types of network-based attacks.