On the Provable Security of the Dragonfly protocol

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Outline

1. PAKEs
2. Dragonfly
3. Results
4. Conclusion

Password Authenticated Key Exchange

PAKE Problem:

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3. "J-PAKE-style"

$$\xrightarrow{\qquad (D_1)^{xpw},\ \pi_1 \qquad}$$

$$\xleftarrow{\qquad (D_2)^{ypw},\ \pi_2 \qquad}$$

Security Models for PAKE

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Find-then-Guess BPR Model

Queries available to PPT adversary $\mathcal{A}$:

- **Send**(U^i, M) - message exchange
- **Execute**(C^i, S^j) - eavesdropping
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Definition

Protocol P is forward secure PAKE if for all PPT adversaries $\mathcal{A}$ making at most n_{se} online attempts, where N is the size of the dictionary and C is a constant

$$\mathbf{Adv}_{\mathrm{P}}^{ake}(\mathcal{A}) \leq \frac{C \cdot n_{se}}{N} + \varepsilon \ . \tag{1}$$

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    - Dragonfly PAKE
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- Without security proof
- Stirred some controversy

Dragonfly draft specifications

Client	**Initialization**	Server

Public: $\mathbb{G}$, p, q; $H_0, H_2 : \{0,1\}^* \rightarrow \{0,1\}^k$; $H_1 : \{0,1\}^* \rightarrow \{0,1\}^{2k}$;

$\pi \in Passwords$; $seed := H_0(C, S, \pi, c)_{max,min}$; $PW := H\&P(seed, l_1)$.

$m_1, r_1 \leftarrow \mathbb{Z}_q$		$m_2, r_2 \leftarrow \mathbb{Z}_q$
$s_1 := r_1 + m_1$		$s_2 := r_2 + m_2$
$E_1 := PW^{-m_1}$		$E_2 := PW^{-m_2}$
	$\xrightarrow{C, E_1, s_1}$	
	$\xleftarrow{S, E_2, s_2}$	
abort if $\neg\mathrm{Good}(E_2, s_2)$		abort if $\neg\mathrm{Good}(E_1, s_1)$
$\sigma := (PW^{s_2} \times E_2)^{r_1}$		$\sigma := (PW^{s_1} \times E_1)^{r_2}$
$kck \vert sk_C := H_1(\sigma, l_2)$		$kck \vert sk_S := H_1(\sigma, l_2)$
$\kappa := H_2(kck, C, s_1, s_2, E_1, E_2)$		$\tau := H_2(kck, S, s_2, s_1, E_2, E_1)$
$\hat{\tau} := H_2(kck, S, s_2, s_1, E_2, E_1)$		$\hat{\kappa} := H_2(kck, C, s_1, s_2, E_1, E_2)$
	$\xrightarrow{\kappa}$	
	$\xleftarrow{\tau}$	
abort if $\tau \neq \hat{\tau}$		abort if $\kappa \neq \hat{\kappa}$

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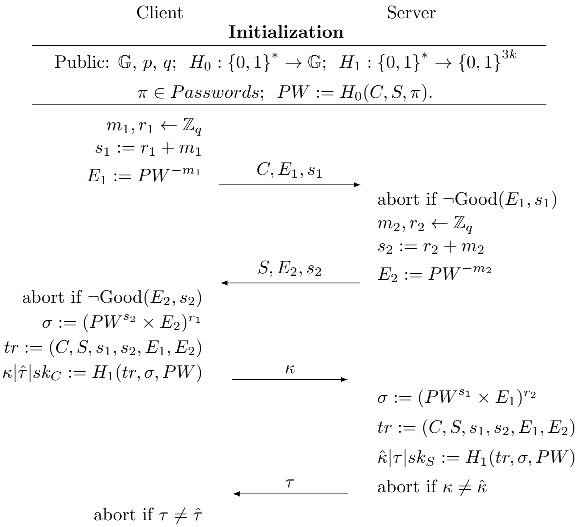
Provable Secure Dragonfly

Our Dragonfly



Client Server

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$tr := (C, S, s_1, s_2, E_1, E_2)$

$\kappa | \hat{\tau} | sk_C := H_1(tr, \sigma, PW)$ $\xrightarrow{\kappa}$

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$\xleftarrow{\tau}$ abort if $\kappa \neq \hat{\kappa}$

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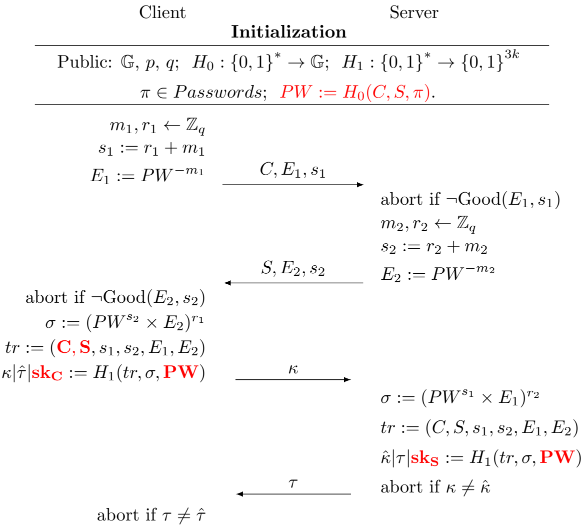

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Differences between draft and proven variant

Differences:

- "Hunting-and-Pecking" procedure
- Session key computation (sid, PW)
- Confirmation codes (recipient’s identity)
- Symmetric nature:
    - Ordered message exchange
    - Min/Max

The proof of security for Dragonfly

The theorem statement

Theorem

*We consider **Dragonfly** protocol, with a password set of size N. Let $\mathcal{A}$ be an adversary that runs in time at most t, and makes at most n_{se} **Send** queries, n_{ex} **Execute** queries, and n_{h0} and n_{h1} RO queries to H_0 and H_1, resp. Then there exist two algorithms $\mathcal{B}$ and $\mathcal{D}$ running in time t' such that **Adv**$^{ake}_{\texttt{dragonfly}}(\mathcal{A}) \leq T$ where*

$$T := \frac{\mathbf{6n_{se}}}{\mathbf{N}} + \frac{4(n_{se}+n_{ex})(2n_{se}+n_{ex}+n_{h1})}{q^2} + \frac{n_{h0}^2 + 2n_{h1}}{q} + \frac{n_{h1}^2 + 2n_{se}}{2^k} +$$

$$2n_{h1}(1+{n_{se}}^2) \times Succ^{cdh}_{PW,\mathbb{G}}(\mathcal{B}) + 4n_{h0}^3 \times \left(\textbf{\textit{Adv}}^{didh}_{g,\mathbb{G}}(\mathcal{D}) + \frac{n_{h1}^3 + 3n_{se}}{q} \right) \quad (2)$$

and where $t' = O(t + (n_{se}+n_{ex}+n_{ro})t_{exp})$ with t_{exp} being a time required for exponentiation in $\mathbb{G}$.

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AskH1$_3$ event:
$\mathcal{A}$ has to make "correct" combo of H_0 and H_1 queries to win.

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DIDH

Security Assumptions

DIDH assumption

Let $IDH_g(X,Y) = g^{1/(x+y)}$.
An algorithm $\mathcal{D}$ is a (t,ε)-DIDH solver if $\mathbf{Adv}^{didh}_{g,\mathbb{G}}(\mathcal{D})$

$$\begin{aligned}\mathbf{Adv}^{didh}_{g,\mathbb{G}}(\mathcal{D}) :=& \\ &\Pr[x,y \leftarrow \mathbb{Z}_q^*, X \leftarrow g^{1/x}; Y \leftarrow g^{1/y}; Z \leftarrow IDH_g(X,Y) : \\ &\qquad\qquad\qquad\qquad \mathcal{D}(X,Y,Z)=1] \\ &\quad - \Pr[x,y,z \in \mathbb{Z}_q^*, X \leftarrow g^{1/x}; Y \leftarrow g^{1/y}; Z \leftarrow g^{1/z} : \\ &\qquad\qquad\qquad\qquad \mathcal{D}(X,Y,Z)=1] \ ,\end{aligned}$$

is bigger than negligible.

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$$\Pr[\mathsf{Coll}_C] \leq 2n_{h0}^3 \times \left(\mathsf{Adv}_{g,\mathbb{G}}^{didh}(\mathcal{D}) + \frac{n_{h1}^3 + 3n_{se}}{2q} \right) \quad . \tag{3}$$

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$$\Pr[\textsf{AskH1-withC}_4] \leq \frac{\mathbf{2}n_{se}}{N} \quad . \tag{4}$$

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Summary of results

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- Recommendations: sid in sk and ID in authenticators.