TREAD: A generic construction for provably TF resistant distance bounding

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FutureDB

This talk : Outline

TREAD

- Family of protocols
- Provably secure
- Modular : several possible instances
  - Lightweight
  - Private vs eavesdropper
  - Anonymous vs verifiers
- New mechanism for TF resistance

The DFKO framework

- Another security model for DB
- Dürholz, Fischlin, Kasper, Onete (2011)
- Overview of the proofs for TREAD

Why provable ?

- Too many broken protocols
- A 2015 survey on 40+ protocols found only 9 survivors
- New attack statregies appear regularly
  - TF against noise resistant protocols
  - MF via key recovery/bit flipping
  - PRF programming attacks
  - ...

Why anonymous ?

- User tracking has become pervasive
- Location history reveal a lot :
  - Work address
  - Home address
  - Social links
- DB is a good candidate for tracking

Why a new approach for TF resistance ?

- TF resistance : if P helps $\mathcal{A}$ once, then $\mathcal{A}$ can impersonnate P at will
- Generally done by forcing P to leak his key for $\mathcal{A}$ to succeed
- $r^0 = a, r^1 = a \oplus X$
- P can give $\mathcal{A}$ a noisy version of his secret : proving it is enough to pass is difficult

Previous solutions :

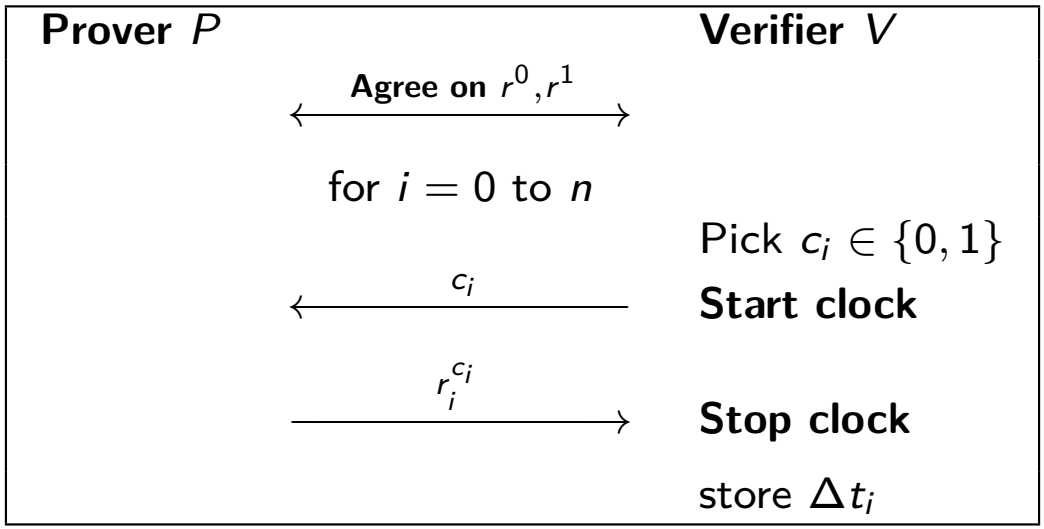
- FO, SPADE : Backdoor
- SKI, DBopt : Leakage scheme
- Proprox : Extractor

Additionally, it helped with anonymity

Combining TF resistance and anonymity

- **Challenging** (with a revocation mechanism)
- Metro access system
  - Anonymity for location privacy
  - DF/DH/TF resistance to prevent access subletting
  - MF for obvious reasons

TREAD : Design



Everything is in the setting of r^0 and r^1
(Usually PRF)

One problem : PRF programming

- PRF securiy : $PRF_X(input) \equiv random$ if x random and hidden
- $\neq$ unpredictible if the key is known : $Enc_x(input)$ is a PRF
- DF : $PRF_X(NP, NV) =$
  - $Cste$ if $NP = H(X)$
  - $f_x(NP, NV)$ otherwise

  is a PRF
- Not safe if combined with the key either
- MF : $PRF_X(NP, NV, a) =$
  - X if $a = f_X(NP, NV) \oplus X$
  - $f_x(NP, NV, a)$ otherwise

  is a PRF

Let's remove the PRF !

How to pick the response vectors

- $\forall i, r_i^0 = r_i^1$: DF, MF
- $\forall i, r_i^0 \neq r_i^1$: DF, MF
- $\forall i, r_i^1 = r_i^0 \oplus X_i$: TF, MF

Solution : P pick a, b, V picks m, $r^0 = a, r^1 = b \oplus m$
P authenticates a, b with a signature S and an encryption scheme E

TREAD...almost

Prover P		**Verifier** V
ek : encryption key		dk : decryption key
sk : signature key		vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$		
$\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b)$		
$e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\sigma_p)$	$\xrightarrow{e}$	$(a\|\|b\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$
		if $\mathsf{S.ver}_{\mathsf{vk}}(\sigma_p, a\|\|b\|\|\mathsf{idprv}(P)) = 0$ then abort
	$\xleftarrow{m}$	$m \xleftarrow{\$} \{0,1\}^n$
	$r^0 = a, r^1 = b \oplus m$ for $i = 0$ to n	
		Pick $c_i \in \{0,1\}$
	$\xleftarrow{c_i}$	**Start clock**
	$\xrightarrow{r_i^{c_i}}$	**Stop clock**
		store Δt_i

TREAD with identities

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$ if $\mathsf{S.ver}_{\mathsf{vk}}(\sigma_p, a\|\|b\|\|\mathsf{idprv}(P)) = 0$ then abort
	$\xleftarrow{m}$	$m \xleftarrow{\$} \{0,1\}^n$
	$r^0 = a, r^1 = b \oplus m$ for $i = 0$ to n	
		Pick $c_i \in \{0,1\}$
	$\xleftarrow{c_i}$	**Start clock**
	$\xrightarrow{r_i^{c_i}}$	**Stop clock**
		store Δt_i

Security of TREAD

If E is a CCA-2 secure encryption scheme, and S is unforgeable, then TREAD is

- DF/DH resistant, and $Pr^{DF} = (\frac{3}{4})^n$
- MF resistant, and $Pr^{MF} = (\frac{3}{4})^n + negl.$ (signature+encryption)
- And SimTF Resistant

Proofs in the DFKO (Dürholz, Fischlin, Kasper, Onete) model

The DFKO model

- Session based (P-V, P-$\mathcal{A}$, $\mathcal{A}$-V)
- A strictly increasing clock $marker(sid, m)$ per session
- $\mathcal{A}$ quantified in terms of t, q_{obs}, q_P, q_V
- Notion of tainted session
- $\mathcal{A}$ wins if he is accepted in an untainted session

DFKO : DF/DH

A malicious, far away prover P^* tries to be accepted by V, possibly in the presence of honest provers near the verifier.

- $CommitTo(r_i) \equiv$ send in advance
- $Prompt(r_i) \equiv$ use P's response
- In practice, two dummy sessions

A session is tainted if during the time critical part

- P^* does not either commit or prompt for one round
- P^* changes his response after receiving the challenge

P^* wins if $\exists pid$ such that

- pid is not tainted
- P^* is accepted in pid

TREAD : DH resistance

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$
	$r^0 = a, r^1 = b \oplus m$	

- $r_i^0 \neq r_i^1$ for half the rounds due to m
- commit correct with probability $\frac{3}{4}$ for each round
- For DH-like attacks :
- $Pr\left[r_i^{P^*} = r_i^P\right] = \frac{1}{2}$

The best strategy is to guess r_i in advance

DFKO : MF

$\mathcal{A}$ is between a far away P and V
A session is tainted if $\mathcal{A}$ performs *pure relaying* during the time critical phase, *ie* :

$P \xleftarrow{c_i'} \mathcal{A} \xleftarrow{c_i} V$
$P \xrightarrow{r_i} \mathcal{A} \xrightarrow{r_i'} V$

- $c_i = c_i'$
- $r_i = r_i'$
- $\mathcal{A}$ receives c_i before sending c_i'
- $\mathcal{A}$ receives r_i before sending r_i'

$\mathcal{A}$ wins if $\exists pid$ such that

- *pid* is not tainted
- P is accepted in *pid*

$\mathcal{A}$ can perform impure relaying
(equivalent to the learning phase of BMV)

TREAD : MF resistance

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$ $r^0 = a, r^1 = b \oplus m$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$

- $r_i^0 \neq r_i^1$ for half the rounds due to m
- a, b protected by E
- $\mathcal{A}$ cannot forge e
- a, b are never reused, $\mathcal{A}$ only learns the responses for one set of challenges (or slightly more)

DFKO : SimTF

P^* helps $\mathcal{A}$, the protocol is resistant if after one success, a simulator with the view of $\mathcal{A}$ Pr_{sim} can pass with probability at least $Pr_{\mathcal{A}}$.
A session is tainted if $\mathcal{A}$ and P^* communicate *at all* during the time critical phase.
Other notions :

- GameTF : $Pr_{sim} \geq Pr^{MF}$
- strSimTF : like simTF, but $\mathcal{A}$ and P^* can communicate during the time critical phase

TREAD : TF resistance

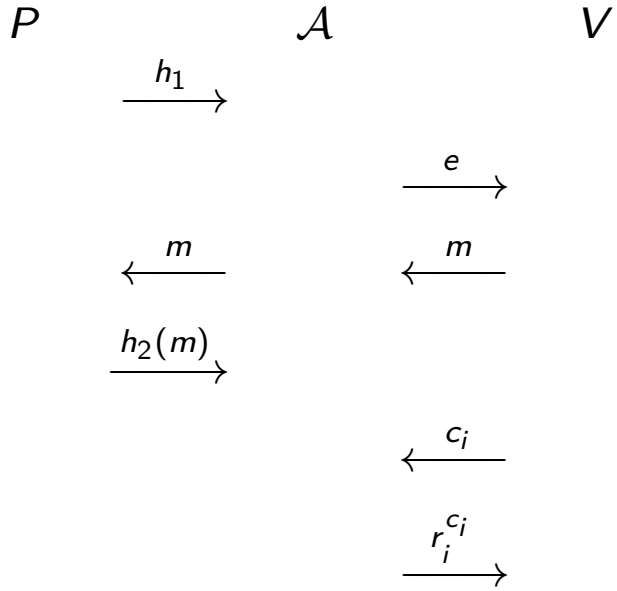
Counter intuitive

- Combining r^0 and r^1 gives no key
- No full secret vector recovery
- No backdoor/extractor/leakage scheme

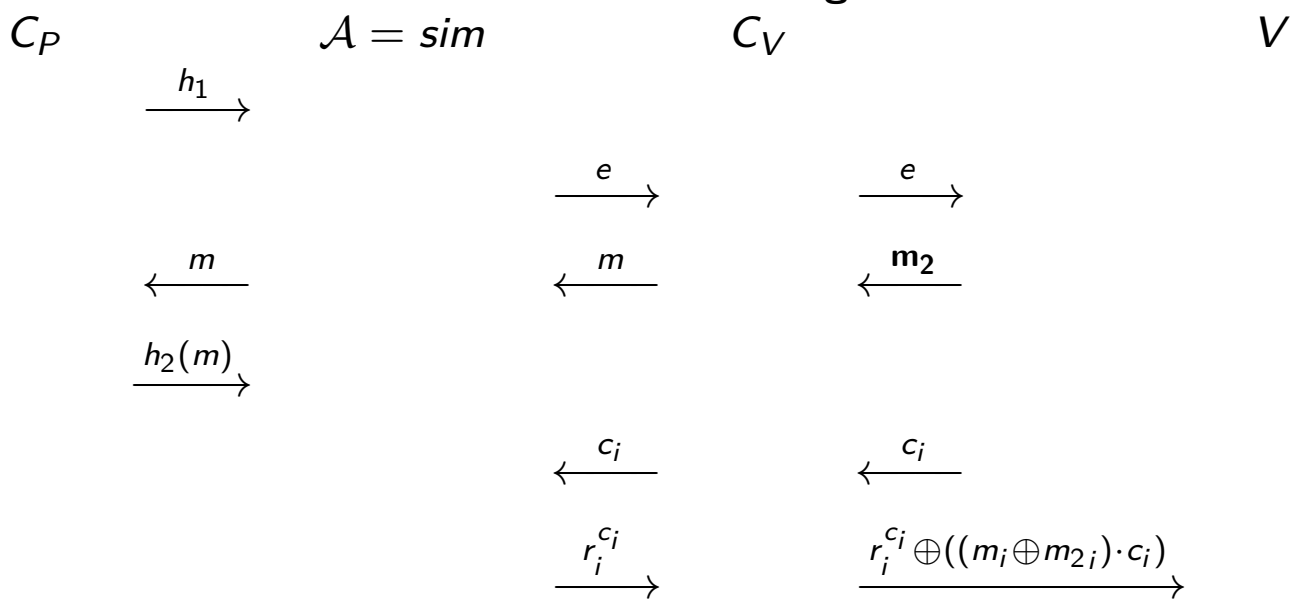
Key idea : $\mathcal{A}$ can replay e
Rewind $\mathcal{A}$ and make him play again

Replay

With the prover



Later, with a challenger



No extraction

- No assumptions on h_1 or $h_2(m)$
- No assumption on how much bits $\mathcal{A}$ knows
- If $\mathcal{A}$ wins once, he can replay the same game and win again
- But : proof more difficult if no SimTF

Some instances : symmetric

E : Symmetric encryption, S : Mac, idpub=P

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
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- No anonymity, no privacy
- Lightweight

Some instances : public key

E : Public key encryption, idpub=$\emptyset$, idpriv=P

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$

- Privacy vs eavesdroppers
- Requires public key

Some instances : group signature

E : Public key encryption, S : Group signature, idpub=$\emptyset$, idpriv=GroupID

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$

- Privacy vs eavesdroppers
- Anonymous wrt verifiers
- Requires group signatures

e can be precomputed

Other options

Prover P		**Verifier** V
ek : encryption key sk : signature key idpub(P) : public identity idprv(P) : private identity		dk : decryption key vk : verification key
$a\|\|b \xleftarrow{\$} \{0,1\}^{2\cdot n}$ $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a\|\|b\|\|\mathsf{idprv}(P))$ $e = \mathsf{E.enc}_{\mathsf{ek}}(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p)$	$\xrightarrow{e\|\|\mathsf{idpub}(P)}$	$(a\|\|b\|\|\mathsf{idprv}(P)\|\|\sigma_p) = \mathsf{E.dec}_{\mathsf{dk}}(e)$

- More lightweight : E : Symmetric encryption, S : MAC, idpub=$\emptyset$, idpriv=P
- Identity based encryption
- idpub=group, idpriv=identity
- Any combination, as long as E is CCA2-secure and S is unforgeable.

e can be precomputed

The anonymous version

- Anonymity directly comes from the group signature
- We extend the model to perform the proofs
- Join, corrupt, revoke...

A note on recent attacks

Distance-Bounding Protocols : Verification without Time and Location

and

Sjouke Mauw, Zach Smith, Jorge Toro-Pozo, Rolando Trujillo-Rasua

Proving physical proximity using symbolic models

Alexandre Debant, Stéphanie Delaune, Cyrille Wiedling

- Multible, possibly dishonest verifiers
- Not possible in our model, but still very relevant
- V^* deciphers e, and gets $a, b, \sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a||b)$
- V^* can use $a, b, \sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a||b)$ with another verifier and impersonate P

Possible solutions

- Authenticating the verifier (*eg* certificate)
- Setting $\sigma_p = \mathsf{S.sig}_{\mathsf{sk}}(a, b, V)$ and $e = \mathsf{E.enc}_{\mathsf{ek}}(a, b, V, \mathsf{idprv}(P), \sigma_p)$
- **But** then TF resistance only for one verfiier
- (needs to be verified)

Thank you for your attention !

Questions ?