Distance Bounding:
A Countermeasure to Relay Attacks?

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Work presented here is partly issued from collaborations with Muhammed Ali Bingöl, Christian Floerkemeier, Chong-Hee Kim, Cédric Lauradoux, Benjamin Martin, Süleyman Kardaş, and Aslan Tchamkerten.
Summary

- Mise en Bouche.
- Relay Attacks.
- Distance Bounding.
- Hancke and Khun’s Protocol.
- Why are there so many Protocols?
- Where do we go?
MISE EN BOUCHE
RFID Applications

- **Supply chain tracking.**
  - Track boxes, palettes, ...

- **Pet identification.**
  - Replace common tattoos by electronic ones

- **Access control.**
  - Building, Public transportation.

- **Payment.**
  - SpeedPass, PayPass, ....

- **Electronic documents.**
  - ePassports, ...
Variant of ISO 9798-2 Protocol 3

\[ \text{Verifier (secret } k) \]

\[ \text{Pick } N_a \quad \overset{N_a}{\longrightarrow} \quad E_k(N_a, N_b) \quad \overset{E_k(N_a, N_b)}{\longleftarrow} \quad \text{Pick } N_b \]

Protocol \textit{secure} under common assumptions on \( E, k, N_a, \) and \( N_b. \)
Security Particularities of RFID Systems

- **Wireless** communication.
  - Easy access to the channel.

- Tags answer **without agreement** of their holders.
  - Implicit agreement = being in the reader’s field.

- **Low capabilities** of the tags.
  - Lightweight cryptography, no internal clock.
RELAY ATTACKS
Relay Attack

![Diagram showing Prover and Verifier](image)

A.K.A. mafia fraud, chess grandmaster, passive man-in-the-middle, wormhole, relay attack, middleman attack...
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Prover

Verifier

Adversary

10000 km

Adversary

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Do-ability of the Relay Attack

- Successful attacks.
  - Radio link over 50 meters (G. Hancke 05).
  - With some ACR122 (A. Laurie 09).
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- **ISO 14443 “Proximity Cards”.”**
  - Used in most secure applications.
  - Standard on the low-layers (physical, collision-avoidance).
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  - Prover can require more time, up to 4949 ms.
DISTANCE BOUNDING
Protocol Aims in General Framework

Definition (Authentication)

An authentication is a process whereby one party is assured of the identity of a second party involved in a protocol, and that the second has actually participated (i.e. is active at, or immediately prior to, the time evidence is acquired). [Handbook of Crypto]

Definition (Distance Checking)

A distance checking is a process whereby one party is assured that a given property on its distance to a second party involved in a protocol is satisfied at some point in the protocol.

The area where the property is satisfied is called the neighborhood of the verifying party.
Definition (Distance Bounding)

A distance bounding is a process that consists of an authentication combined with a distance-checking, where the considered property is an upper-bound on the distance between the two parties.

- Distance bounding does not avoid relay attacks.
- Distance bounding check that the distance property between the verifier and the claimed prover is verified.
- Proximity check.
- A Distance bounding protocol $P$ is secure if and only if: For all instance of $P$, $P$ succeeds $\Rightarrow$ $V$ authenticated $T$ and the latter is in $V$’s neighborhood.
- In practical RFID systems, distance bounding thwarts the relay attack.
Protocol Aims in RFID Framework

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No Fraud

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From Attack to Fraud

![Diagram of Reader and Adversary]
From Attack to Fraud

Reader → Adversary

Reader → Tag

Reader → Adversary
From Attack to Fraud

- Reader → Adversary
- Reader → Tag
- Reader → Tag
- Reader → Adversary

Gildas Avoine – Distance Bounding: a Countermeasure to Relay Attacks?
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Gildas Avoine – Distance Bounding: a Countermeasure to Relay Attacks?
Measure the **round-trip-time** (RTT) of a given message.

- Provide a bound on the distance (proximity check).
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Existing Protocols

- Brands and Chaum (Eurocrypt 1993)
- Hancke and Kuhn (SecureComm 2005)
- Munilla, Ortiz, and Peinado (RFIDsec 2006)
- Reid, Neito, Tang, and Senadji (ASIACCS 2007)
- Singelée and Preneeld (ESAS 2007)
- Tu and Piramuthu (EURASIP RFID Technologie 2007)
- Munilla and Peinado (Wireless Com. and Mobile Comp. 2008)
- Kim, Avoine, Koeune, Standaert, and Pereira (ICISC 2008)
- Nikov and Vauclair (eprint 2008)
- Avoine and Tchamkerten (ISC 2009)
- Kim and Avoine (CANS 2009)
- Avoine, Floerkemeier and Martin (Indocrypt 2009)
- ...
HANCKE AND KUHN’S PROTOCOL
Hancke and Kuhn’s Protocol

**Reader**
(secret $K$)

Pick a random $N_a$

$\rightarrow N_a$

$\leftarrow N_b$

**Tag**
(secret $K$)

Pick a random $N_b$

$h(K, N_a, N_b) = \begin{cases} v^0 = & 110110010 \\ v^1 = & 0111100100 \end{cases}$

Start of fast bit exchange

for $i = 1$ to $n$

Pick $C_i \in_R \{0, 1\}$

Start Clock

$\rightarrow C_i$

$R_i = \begin{cases} v^0_i, & \text{if } C_i = 0 \\ v^1_i, & \text{if } C_i = 1 \end{cases}$

Stop Clock

$\leftarrow R_i$

Check: $\Delta t_i \leq t_{max}$

Check: correctness of $R_i$

End of fast bit exchange
Mafia Fraud: \( \left( \frac{3}{4} \right)^n \).

Terrorist Fraud: 1

Distance Fraud: \( \left( \frac{3}{4} \right)^n \).
Adversary’s Success Probabilities

- Mafia Fraud: \( \left( \frac{3}{4} \right)^n \).
- Terrorist Fraud: 1
- Distance Fraud: \( \left( \frac{3}{4} \right)^n \).
Adversary’s Success Probabilities

- Mafia Fraud: \(\left(\frac{3}{4}\right)^n\).
- Terrorist Fraud: 1
- Distance Fraud: \(\left(\frac{3}{4}\right)^n\).
WHY ARE THERE SO MANY PROTOCOLS?
Why so Many Protocols?

- Goal is to decrease the adversary’s success probabilities.
- Goal is to add new features.
Goal is to add new features

- Resistance to noise.
- Avoid a final signature.
- Separate authentication and distance checking.
- And probably more...
Decrease Adversary Success Probability

- Trade-off prob. vs computation complexity.
- Trade-off prob. vs memory (eg. Avoine-Tchamkerten).
- Trade-off prob. vs symbol size (bits) (eg. Munilla-Peinado).
- And probably more...
WHERE DO WE GO?
Goal is to add new features

“I believe this puts an end to RFID distance bounding protocol” (anonymous reviewer).

Not the end of the story, just the beginning!
Goal is to add new features

- “I believe this puts an end to RFID distance bounding protocol” (anonymous reviewer).
- Not the end of the story, just the beginning!
The Future

- Are distance bounding protocols **practicable**?
- Can we reach a unified **framework**?
- Which **parameters** can be modified?
Prover Model

Definition (Black-box model)
In a black-box model, the prover cannot observe or tamper with the execution of the algorithm.

Definition (White-box model)
In the white-box model, the prover has full access to the implementation of the protocol and a complete control over the execution environment.
An arrow from \( A \) to \( B \) (scenario,model) means: if there exists an attack in \( A \) that succeeds with probability \( p_A \), then there exists an attack in \( B \) that succeeds with probability \( p_B \) s.t. \( p_B \geq p_A \).

A crossed out arrow means that the implication is false.
Adversary Strategies

- **No-ask strategy.** The adversary does not interact with the prover during the attack.

- **Pre-ask strategy.** The adversary queries the prover before he starts the fast phase with the legitimate verifier.

- **Post-ask strategy.** The adversary queries the prover after the verifier stops the fast phase. This strategy only makes sense if a final slow phase exists.
The parameters

- What is the practical radius of the neighborhood?
- Why sending only one bit?
- Is it more expensive to send $1 \times n$ bits than $n \times 1$ bit?
- Shall noise really taken into account?
- And many many other practical questions...
CONCLUSION
Distance Bounding: a Countermeasure to Relay Attacks?

- Unified framework needed.
- Move to practice.
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Unified framework needed.

Move to practice.
Distance Bounding: a Countermeasure to Relay Attacks?

Unified framework needed.

Move to practice.
Going Further

- RFID Security and Privacy **Lounge:**
  - [http://sites.uclouvain.be/security/](http://sites.uclouvain.be/security/)

- RFID Security and Privacy **Training Week:**