EM Analysis in the IoT Context: Lessons Learned from an Attack on Thread

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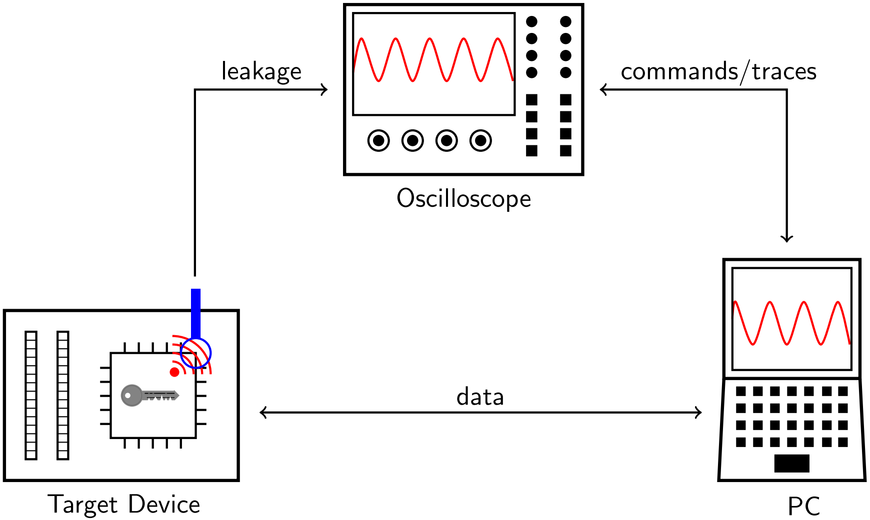
Outline

EM Analysis


leakage
commands/traces
Oscilloscope
data
Target Device
PC

Thread

- Networking protocol for the IoT
- Simple for consumer
- Built-in security
- Power efficient
- IPv6 connectivity
- Robust mesh network
- Runs on IEEE 802.15.4 radio silicon

More than 100 members

Motivation

- Numerous low-cost hardware and software tools for side-channel attacks
- Evaluate the effort required to apply an EM attack in the IoT context

Do cryptographic implementations in the network layer need protection against side-channel attacks?

Outline

Communication Security

- Security is enforced at two layers:
  - Medium Access Control (MAC) — AES–CCM using key K_{MAC}
  - Mesh Link Establishment (MLE) — AES–CCM using key K_{MLE}

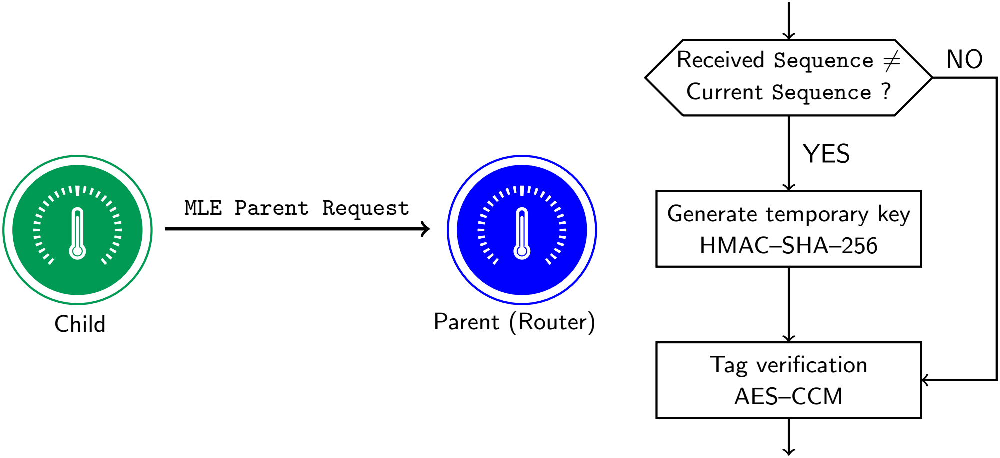
- A node gets the master key K when it is commissioned to a Thread network

- Fresh keys are generated from the 16-byte K and 4-byte `Sequence` number:

$$K_{MAC} \mathbin{||} K_{MLE} = \mathit{HMAC\text{–}SHA\text{–}}256(K, \texttt{Sequence} \mathbin{||} \text{“}\mathit{Thread}\text{”})$$

- The default key rotation period is set to 28 days

Processing a `MLE Parent Request` Message



AES–CCM

- Combines CBC–MAC mode and CTR mode
- The execution of both modes of operation can be attacked
- The attacker can control up to 12 input bytes of the first block:
  - `Source MAC Address` – 8 bytes
  - `Frame Counter` – 4 bytes
- Known attack: Jaffe [CHES'07], O'Flynn and Chen [COSADE'16]

AES-CBC	49	`Source MAC Address`	`Frame Counter`	05	00	15
AES-CTR	01	`Source MAC Address`	`Frame Counter`	05	00	01

Relationship between K and K_{MLE}

Master key to MLE key ($K \longrightarrow K_{MLE}$)

- Key derivation using HMAC

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- The `MLE Child ID Response` includes the master key

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Master key and MLE key are equivalent!

$$K \longleftrightarrow K_{MLE}$$

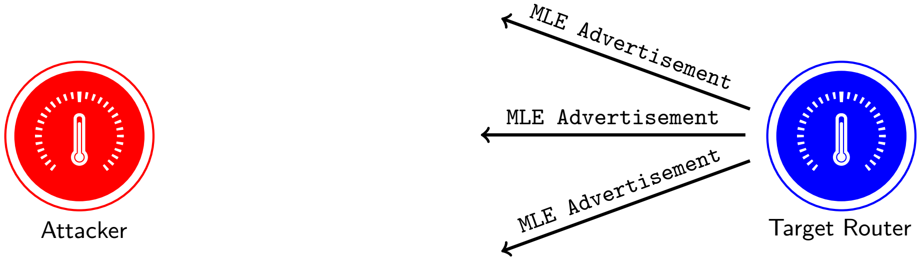
Outline

The Most Feasible Attack

Attacker

Target Router

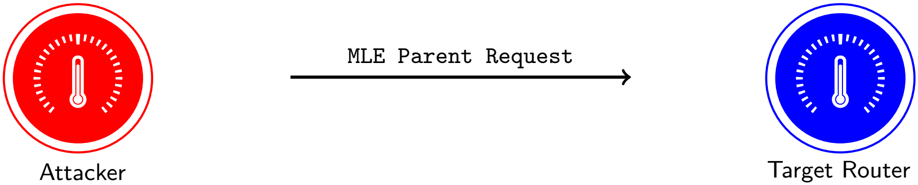
The Most Feasible Attack



Step 1: Observe an `MLE Advertisement` message

- Record the `Sequence` number

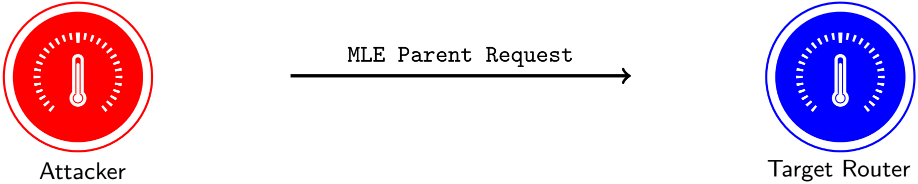
The Most Feasible Attack



Step 2: Inject `MLE Parent Request` messages

- Recorded `Sequence` number
- Random `Source MAC Address` and `Frame Number`

The Most Feasible Attack



Step 3: Observe the EM leakage

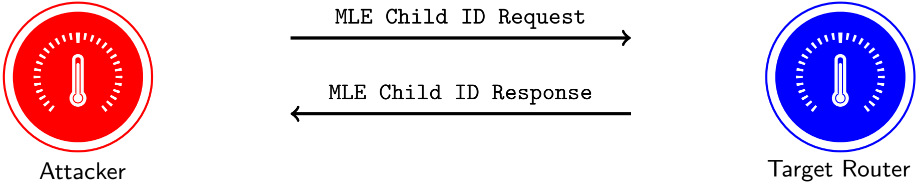
- Save the injected inputs and corresponding EM traces

The Most Feasible Attack

Step 4: Recover the MLE key K_{MLE}

- Mount a DEMA attack

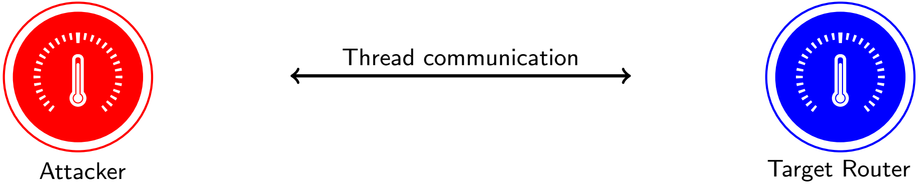
The Most Feasible Attack



Step 5: Get the master key K

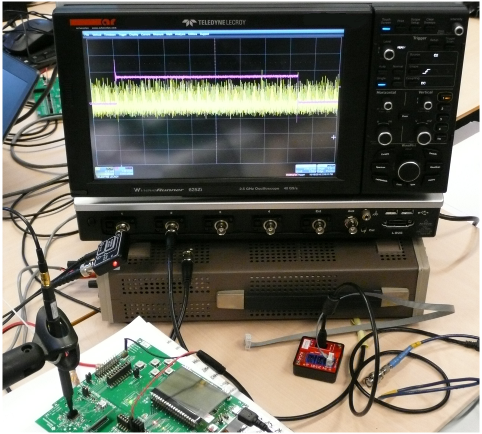
- Send a `MLE Child ID Request` message
- The `MLE Child ID Response` message contains K

The Most Feasible Attack



Full network access!

Experimental Setup



- Target: TI CC2538 (Cortex-M3, 32 MHz)
- Thread stack: OpenThread
- Oscilloscope: LeCroy waveRunner 625Zi
- Langer EM probes
- No trigger signal from target!

Results

- Sampling rate set to 1 GS/s
- 10,000 EM traces acquired in about 3 hours
- Full recovery of the MLE key K_{MLE}
- Two key bytes were much more difficult to recover than the rest
- Message fragmentation prevented recovery of the master key
- The attack may succeed on other implementations of the stack

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Countermeasures

- Shielding & tamper resistance
- Protected cryptographic implementations
- Protocol level mitigations
- Security certification scheme

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A combination of the above countermeasures
is recommended for high security!

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Lessons learned from our evaluation
can be applied to other IoT systems and protocols.

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Side-channel attacks are a real threat for the IoT!


SECURE

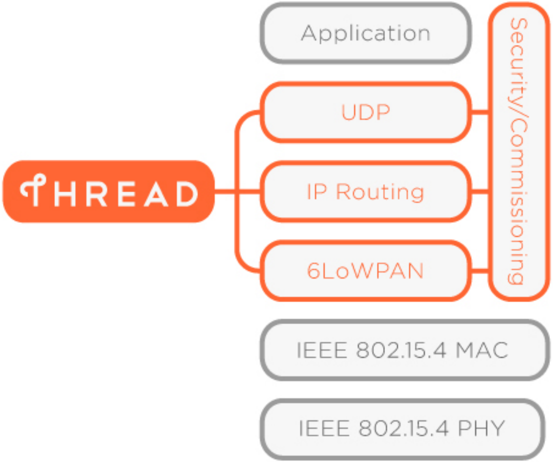
Thank you!

Appendix

References

- Joshua Jaffe. *A first-order DPA attack against AES in counter mode with unknown initial counter*. In Cryptographic Hardware and Embedded Systems - CHES 2007.
- Colin O'Flynn and Zhizhang Chen. *Power analysis attacks against IEEE 802.15.4 nodes*. In Constructive Side-Channel Analysis and Secure Design - COSADE 2016.

Thread Stack

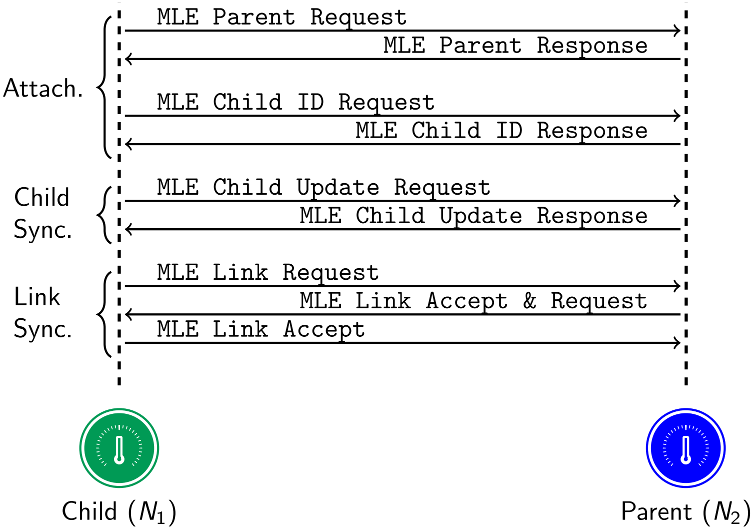


Source: https://www.threadgroup.org/

Mesh Link Establishment (MLE)

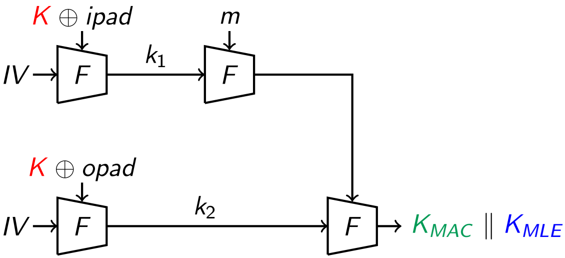
- Facilitates the secure configuration of radio links
- Allows exchange of network parameters
- MLE messages are sent inside UDP datagrams
- Routers periodically multicast `MLE Advertisement` messages
- Link configuration is initiated by a `MLE Parent Request` message

Establishing a Communication Link



HMAC–SHA–256

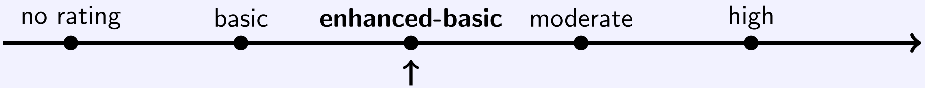
- $m = \texttt{Sequence} \parallel \text{“}\mathit{Thread}\text{”} \parallel \texttt{0x80 0x00} \ldots \texttt{ 0x00} \parallel \mathit{len}$
- The attacker targets k_1 and k_2
- k_1, k_2, and Sequence give K_{MAC} and K_{MLE}
- Not enough control of the input!



Attack Feasibility

Attack Effort

- Adaptation of the rating for smart cards from the Joint Interpretation Library
- Last step of the attack is feasible ⇒ **enhanced-basic**



Equipment Cost

Cost	Oscilloscope	Attack Success
HIGH	**LeCroy WaveRunner 6Zi**	✓
MEDIUM	PicoScope, ChipWhisperer-Pro	✓
LOW	ChipWhisperer-Lite	✗

Guessing Entropy

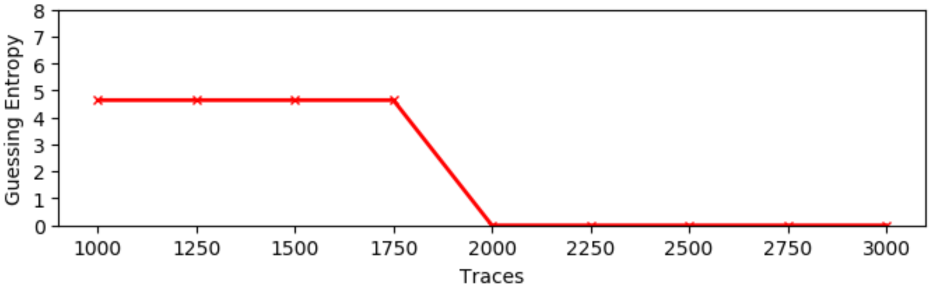


Figure: Evolution of the guessing entropy for the second key byte.

Correlation Matrix

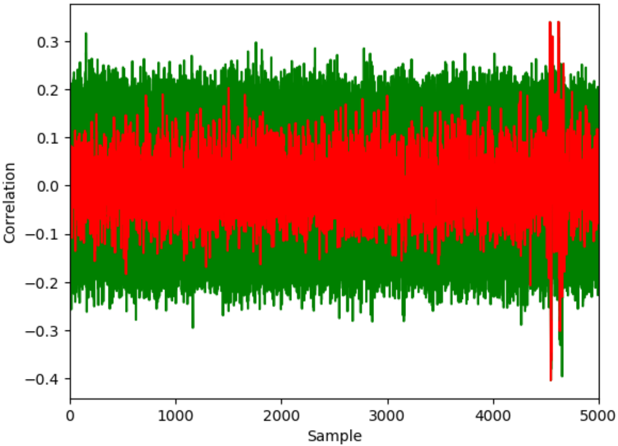


Figure: Correlation of all key candidates for the second key byte when using 3,000 traces.