Plaid Parliament of Pwning 2024 eCTF Team
Carnegie Mellon University

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Presentation Outline

• Design Phase
  • Overview
  • Design Highlight: Zero-Trust Architecture

• Attack Phase
  • I2C Bleed Exploit
  • Supply Chain I2C Bleed
  • Other Attacks + Interesting Defenses

• Project Management + Lessons Learned
## Our Design Highlights

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<th>Encryption At-Rest of <em>Everything</em></th>
<th>Custom Hardened Physical Link Layer</th>
<th>Encrypted Link Layer Wrapper</th>
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<td>Random Nonces to Prevent Replays</td>
<td>ChaCha-Poly AEAD for encryption</td>
<td>Board RNG + von-Neumann</td>
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<td>Minimal External Code Surface</td>
<td>Avoid Interrupts &amp; Async Code</td>
<td>Random Delays + Redundant Checks</td>
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Design Highlight: Zero-Trust Architecture

• Thought Experiment: Assume full hardware compromise
  • How to defend flags? Can we use fun crypto tricks?
• BB Boot / BB Extract: Encrypt comp. secrets w/ key stored in AP
• Op. PIN Extract / SC Extract: Encrypt keys inside AP w/ PIN
  • *Potential for offline brute-force if AP compromised
• Op. Pump Swap: Not defensible, but encrypt the code to make it harder
• SC Boot / Damaged Boot: ??????
  • How to require both components to be present in order to boot?
Design Highlight: Zero-Trust Architecture

• Damaged Boot: Require all components be present in order to boot?

• “Russian Encryption Doll”: Encrypt AP boot data with all component keys

• How to distribute component keys?
  • Comp Key = Hash(Root Key || Comp ID)

• How to do replace component?
  • Keep Root Key encrypted with Replace Token
  • RT is long enough to not be brute-able
Attack Highlight: I2CBleed

- Three vulnerabilities in starter code
  - Read/write indices not reset on repeated start
  - Read index checked for == instead of >=
  - Write index casted to unsigned (overflows)

- Result: Arbitrary Read/Write (!!!)
  (of anything past I2C_REGS)

- Straightforward Attack Process
  1. Write in malicious shellcode
  2. Write a bunch of padding
  3. Overwrite vector table to jump to shellcode
Attack Highlight: Fully-Automated I2CBleed

- **Q:** What to do with a near-universal arbitrary-code-execution exploit?
  - **A:** Make it *full auto*: *4-5 flags in 90 seconds from ZIP download*

- **Step 1: Determine I2C Address of Victim**
  - Scan all addresses, see which ones ACK (like insecure `list_components`)

- **Step 2: Determine I2C_REGS address (shellcode address)**
  - Use arbitrary read until the component crashes (stops ACKing)

- **Step 3: Inject shellcode**
  - Step 3.5 (SC only): Scan until we find the string “ctf{“
  - Locally: Dump all of flash to the UART (including keys and plaintext flags!!)

- **Step 4 (SC only): Bitbang SPI data back to malicious component**
  - Malicious component receives SPI and dumps anything transmitted over UART
Interesting Defenses

• **Defending against I2C-Bleed**
  • Certificate Chain: Provide each component with a ID-unique certificate signed using a deployment-time CA
  • Encrypt component attestation data / boot message with key stored in AP
  • Key pinning to assign unique component keys (bypass deployment hash check...)

• **Other unique defenses**
  • Challenge-response handshake on every message in the system
  • Custom I2C implementation (don’t trust provided libraries...)
  • Use of hardware features / PUFs to prevent emulation
Project Management + Lessons Learned

• **Design Phase**
  - Get everyone set up with insecure example in the first week
  - Design security protocol *before* starting implementation, but can start generic tasks (scripting, infra, comms, crypto library) simultaneously
  - Secure By Design: Drive out the attacker in every possible way

• **Attack Phase**
  - Balance between optimizing conventional attacks and developing novel attacks
  - Track red-team availability for executing rapid attacks for first bloods
  - Be willing to operate at strange hours (sadly)
Project Management + Lessons Learned

• Overall
  • Earning course credit helps offset the time investment
  • Cross-Training: EEs studied crypto, Security students studied electronics
  • If viable, hardware setup for each team member to individually play with

• Lessons Learned
  • Sustainability of having most of the work be done by a few team members?
  • Redundancy to avoid single points of failure (esp. for design phase timeline)
  • Novel attacks require a lot more human-hours than estimated, fine-tuning “standard” attacks can be better
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Thank you!
Extra Slides