Relay Attacks on Secure Element-enabled Mobile Devices

Virtual Pickpocketing Revisited

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LAND OBERÖSTERREICH

Outline

- Introduction
  - Card Emulation / Secure Element / Mobile Phone
- Mobile Phone as Target for Attacks
- Software-based Relay Attack
  - Idea
  - Card Emulators
  - Proof of Concept
  - Measurement results
- Conclusion

Card Emulation

- One of three operating modes of NFC devices
- Interaction with existing RFID reader/writer infrastructure
  - E.g. POS terminals, access control readers
- Implementation of card emulation mode
  - Dedicated smartcard chip (secure element)
    - Embedded secure element
    - UICC (“SIM card”)
    - (micro) SD card
  - Software card emulation
    - No secure element
    - Communication is handled by software on the application processor

Secure Element: Current View on Security

- Secure element is as secure as a regular (contactless) smartcard
  - Same security features (secure storage, secure execution environment, hardware-based cryptography, certified high security standard)
  - Same weaknesses
- Main weakness: Relay attack
  - Cannot be prevented by application-layer cryptographic protocols
  - Timing requirements by communication protocol (ISO 14443) are too loose to prevent relay over longer channels
  - Possible countermeasures:
    - Shielding of contactless interface
    - Secondary authentication (PIN codes …)
    - Distance bounding protocols (require additional fast communication channel; not implemented on current smartcards)
  - **BUT: All known relay attacks require physical proximity (< 1 meter) between the attacker and the smartcard!**

Secure Element in a Mobile Phone

- Secure element adds:
  - Security features to a mobile phone
- Mobile phone adds:
  - Over-the-Air management capabilities to the secure element
  - Applications can be added/removed throughout the secure element's whole life-cycle
- Current view:
  - Mobile phone is **not** considered a security risk for the secure element
- **BUT: Mobile phone environment is a significant part of secure element security**
  - Potential host for malicious software
  - (Global) wireless connectivity (GSM, UMTS, WiFi, Bluetooth …)

  ⇒ **Secure element is never isolated from its surrounding world**

Android's Secure Element API

- NFC-Extras API introduced in Android 2.3.4 (com.android.nfc_extras)
  - Not included in public SDK
- Interfaces for APDU-based secure element access and for activation of card emulation
  - Connection to whole smart card and not limited to a single smartcard applet
- Access control:
  - Android 2.3.4: NFC permission required
    - **Any application** with access to NFC has access to the SE
  - Android 2.3.5+: Applications require special permission
    - com.android.nfc.permission.NFCEE_ADMIN, only granted to applications signed with same key as NFC service (**effectively limited to manufacturer** or **root access**)
  - Android 4.0+: Permissions defined in an XML file
    - XML file contains list of allowed application certificates (can only be modified with **OTA updates** or **root access**)

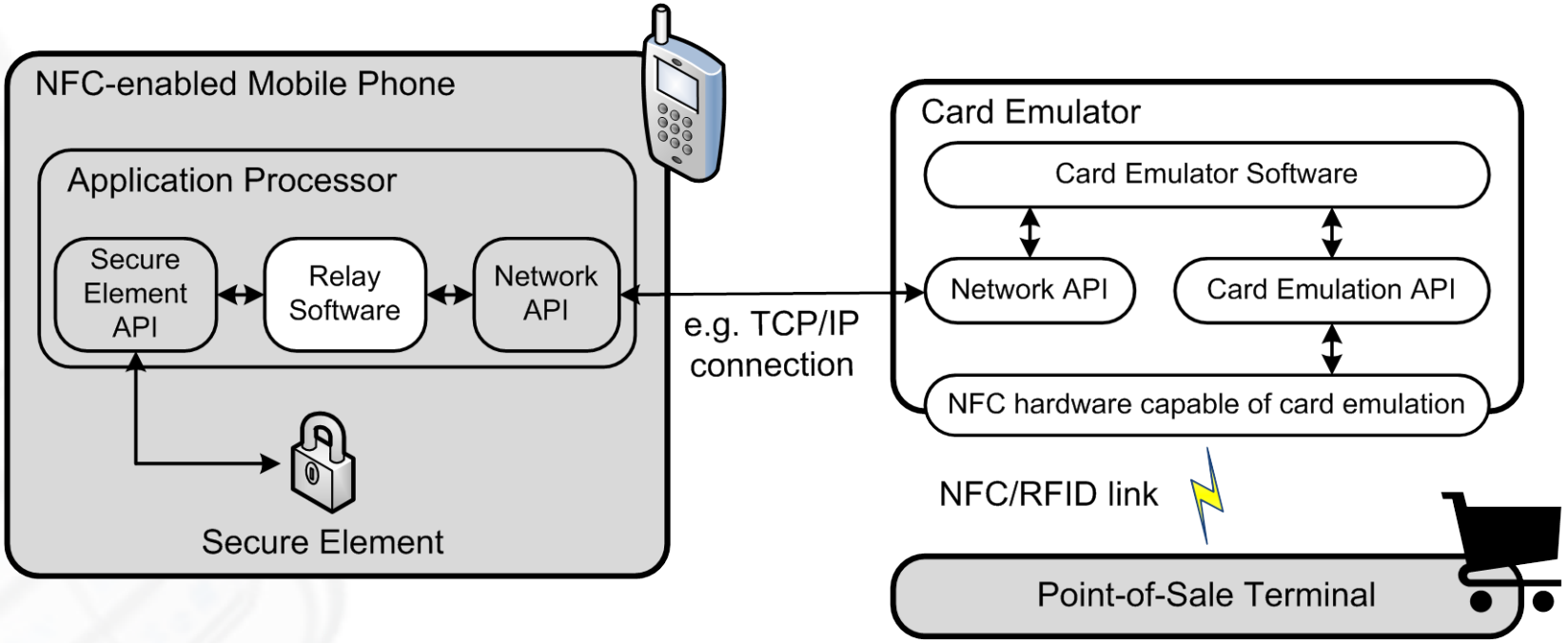
⇒ Access control is enforced by the operating system **on the application processor**

⇒ **Secure Element ultimately trusts the operating system's access control decisions**

Mobile Phone as Target for Attacks

- Threat: Malicious software/privilege escalation exploits
  - Android: Continuous history of privilege escalation exploits
    - mempodroid, Levitator, zergRush, GingerBreak, ZimperLich, KillingInTheName, RageAgainstTheCage, Exploid …
    - Vulnerabilities are fixed quite fast (months), but roll-out of patches takes significantly longer or does not happen at all (many devices still don't run the latest firmware version)
- Threat: User
  - Jail breaking / Rooting
    - Security measures are intentionally circumvented by the user
    - Gain "improved" control over device or bypass DRM
    - **Not** limited to experienced users!
    - Elevated privileges may be used by malicious applications!
  - Carelessness
    - Apps are installed without review of requested permissions
    - Even dangerous combinations of privileges are accepted by users

New: Software-based Relay Attack



- Virtual pickpocketing without physical proximity to the mobile phone
  - Attack only requires an application on victim's mobile phone
  - Application accesses the secure element and relays APDU commands/responses over a network interface (GSM, UMTS, WiFi …)
  - Attackers can use the victims' secure elements as if they were in physical possession of them
  - Relay application may access additional resources (address book, key pad …)

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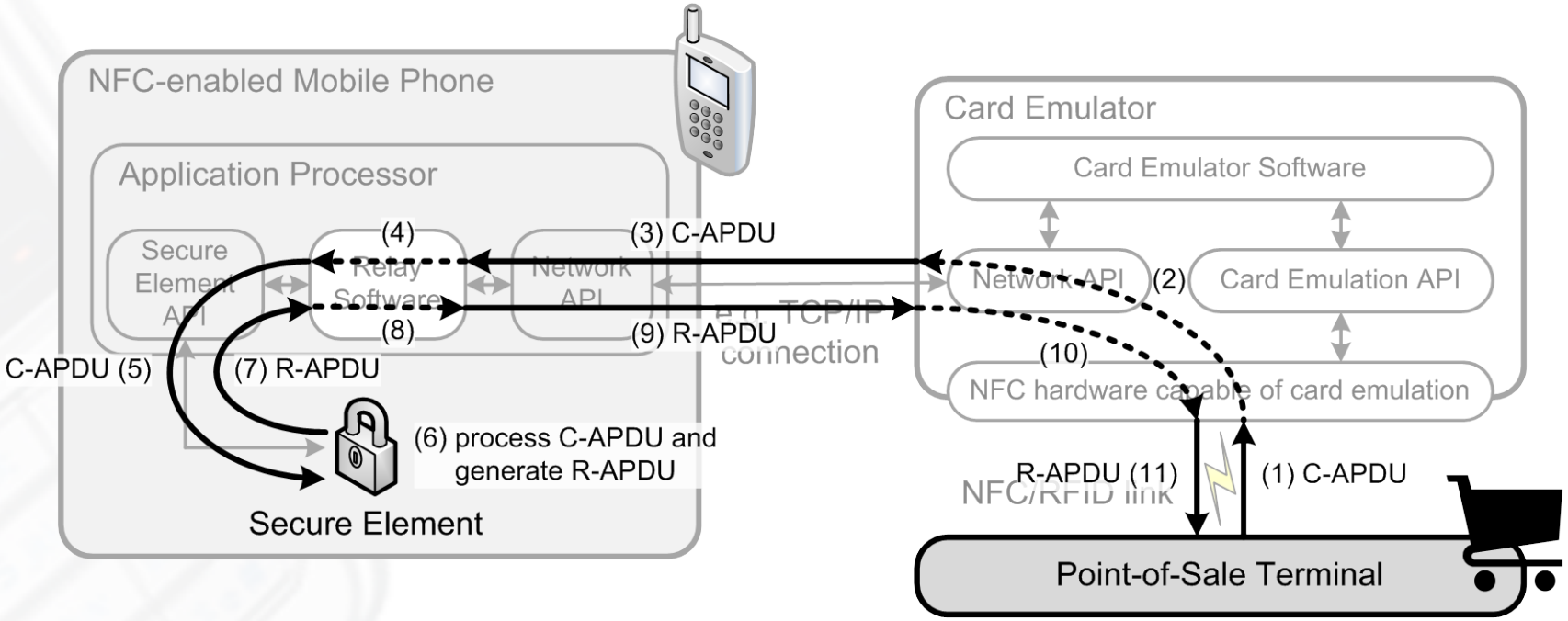

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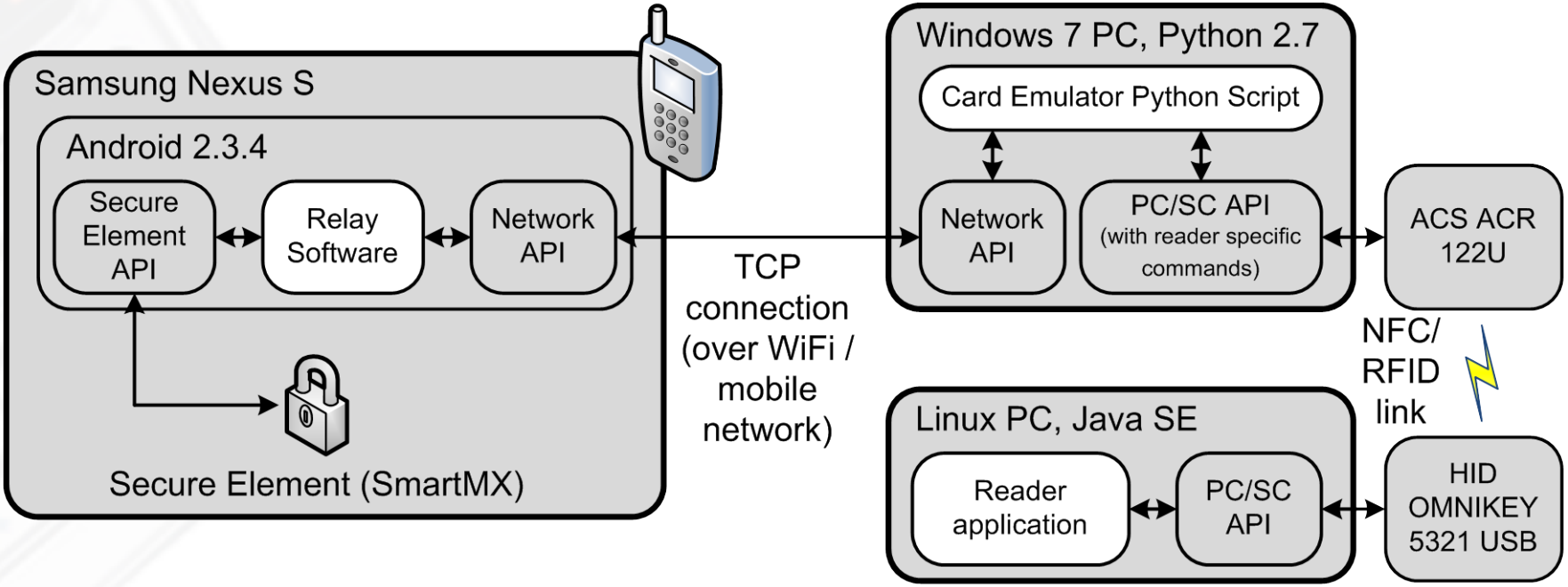
Card Emulator

- Building a new device from scratch:
  - Full control over whole design process
  - Any (inconspicuous looking) shape possible
  - All parameters of the RFID protocol stack can be controlled (e.g. emulation of any UID value)
  - Highest design cost & effort
- Using a ready-made RFID card emulation device: (e.g. Proxmark)
  - All parameters of the RFID protocol stack can be controlled (e.g. emulation of any UID value)
  - Reduced design cost & effort
  - Fixed shape
  - Additional hardware for network interface necessary
- Using an NFC reader with card emulation support: (e.g. ACR 122U)
  - A PC is necessary to control the NFC reader and for network communication
  - ACR 122U restricts some protocol parameters:
    - Only ISO/IEC 14443 Type A protocol can be emulated
    - UID restricted to random UID range (i.e. UID must start with 0x08)

  → *This is sufficient for many applications*
- Using an NFC-enabled mobile phone
  - BlackBerry NFC phones support software card emulation
    - ISO/IEC 14443 Type A and Type B protocol
    - Only random UIDs are supported (auto-generated by the firmware)
  - Nexus S & Galaxy Nexus support software card emulation through CyanogenMod 9 after-market firmware
  - Mobile phone has expected form-factor for NFC contactless transactions
  - Mobile phone has the same network interfaces as the device under attack

Proof of concept: Test setup



Test setup: Limitations

- At the time of our research:
  - Mobile phone‘s secure element did not contain an actual application!
- Instead:
  - Access the GlobalPlatform card manager application (OPEN/ISD)
  - Custom reader application
  - Tested APDUs:
    - SELECT card manager by AID
      - Command: 00A4040008A000000003000000 (13 bytes)
      - Response: File control information template (105 bytes)
    - GET_DATA object '65'
      - Command: 00CA006500 (5 bytes)
      - Response: Reference data not found error (2 bytes)
    - GET_DATA object '66'
      - Command: 00CA006600 (5 bytes)
      - Response: Card data/security domain management data (78 Byte)

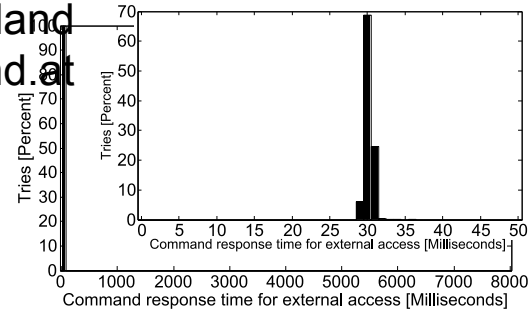
Comparison of different access scenarios

- 4 scenarios:
  1. Direct, external access through the phone‘s contactless interface
  2. Direct, internal access through the secure element API (measured by an app on the device)
  3. Access through the relay system using a WiFi link
  4. Access through the relay system using the cellular network/Internet
- For every scenario:
  - Measurement of the command-response delay at the reader side
  - Test with 5000 repetitions
    - Scenario 1, 3 & 4:
      - Card emulator/phone was removed from the reader‘s RF field between every repetition (automated with test robot)
    - Scenario 2:
      - Connection to the secure element was re-established using the API‘s close() and open() methods

Measurement results

- Command-response delay for SELECT APDU
  - Command: 13 bytes / Response: 105 bytes
  - Scenario 1: (direct, external access)
    - ~30 ms
  - Scenario 2: (direct, internal access)
    - ~50 to 80 ms
    - Significantly slower than external access!
  - Scenario 3: (relay over WiFi)
    - ~190 to 260 ms
    - WiFi adds about 100 to 210 ms of delay
  - Scenario 4: (relay over cellular network/Internet)
    - > 200 ms, significant peak at 300 ms
    - ~45% of measured delays below 1 second
    - ~80% of measured delays below 4 seconds
    - ~97% of measured delays below 10 seconds
- Similar results for all three APDU commands
  - Results only differ in delays due to command and response lengths
- Usability of relay attack
  - ISO 14443 has no strict timeout requirements
    - Max. timeout of 4.9 seconds can be extended through “Waiting Time Extension”
  - EMV has no timeout requirements for credit card terminals
    - EMV defines only timings for maintaining user experience
    - Some terminals interrupt a transaction after several seconds
  - Payment transactions in the order of 20 to 30 seconds will not raise any suspicions (especially while the technology is new)

1.



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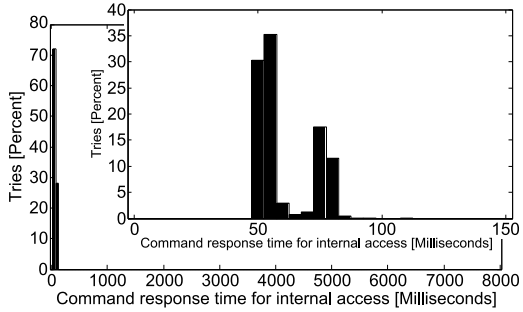

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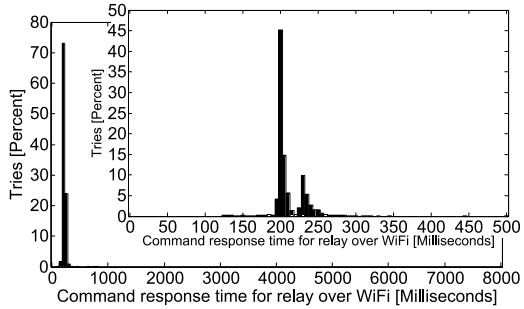

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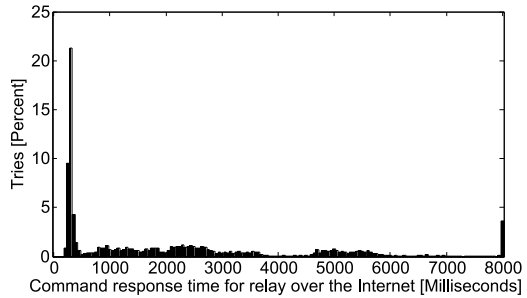

Conclusion

- New attack: Software-based Relay Attack
  - Access to a secure element without physical proximity
  - Software on victim's device is sufficient
- Secure Element delegates access control enforcement to insecure component (application processor)
  - An app only needs to bypass the operating system's access control mechanisms
- Measurement's show that communication can even be relayed over long distances through the Internet
  - An attacker could create a world-wide network of infected mobile phones that could later be used for payment, …

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http://congress.nfc-research.at/

Thank You!

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