TrustOTP: Transforming Smartphones into Secure One-Time Password Tokens

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Presented by Fengwei Zhang

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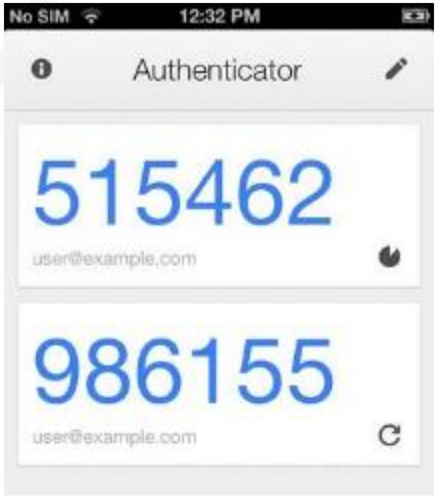
One-time Password (OTP)

- A password that is valid for only one login session or transaction
  - Not vulnerable to reply attacks
  - Widely used in Two-factor Authentication
  - HOTP (Hash-based OTP)
    - Event triggered, key & counter
  - TOTP (Time-based OTP)
    - Time synchronized, key & clock
  - Hardware token & software App

Existing Solutions

- Hardware-based
  - RSA SecurID
  - Yubikey
- Software-based
  - Google authenticator
  - McAfee one-time password


No SIM 12:32 PM

Authenticator

515462
user@example.com

986155
user@example.com

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Limitation

- Hardware-based --- not flexible
  - Unprogrammable
  - Expensive

- Software-based --- not secure
  - Vulnerable to external attacks

Goals

- Confidentiality
  - Malicious mobile OS cannot compromise the keying material (seed) in the OTP generator
  - It cannot read the OTP
- Reliability and Availability
  - Trusted inputs (e.g., clock time) for the OTP genreator
  - Trusted display
  - OTP works even If mobile OS crashes
- Small TCB

TrustZone-related Work

- TrustICE (Sun et al.[1])
  - Isolated Computing Environment in the normal domain
- SeCReT (Jang et al.[2])
  - Secure channel between secure domain and normal application
- Hypervision (Azab et al.[3])
  - Real-time kernel protection in the normal domain
- TrustDump (Sun et al.[4])
  - Reliable Memory Acquisition of the mobile OS
- Smartphone as location verification token for payments (Marforio et al.[5])
- Trusted Language Runtime for trusted applications in the secure domain (Santos et al.[6])

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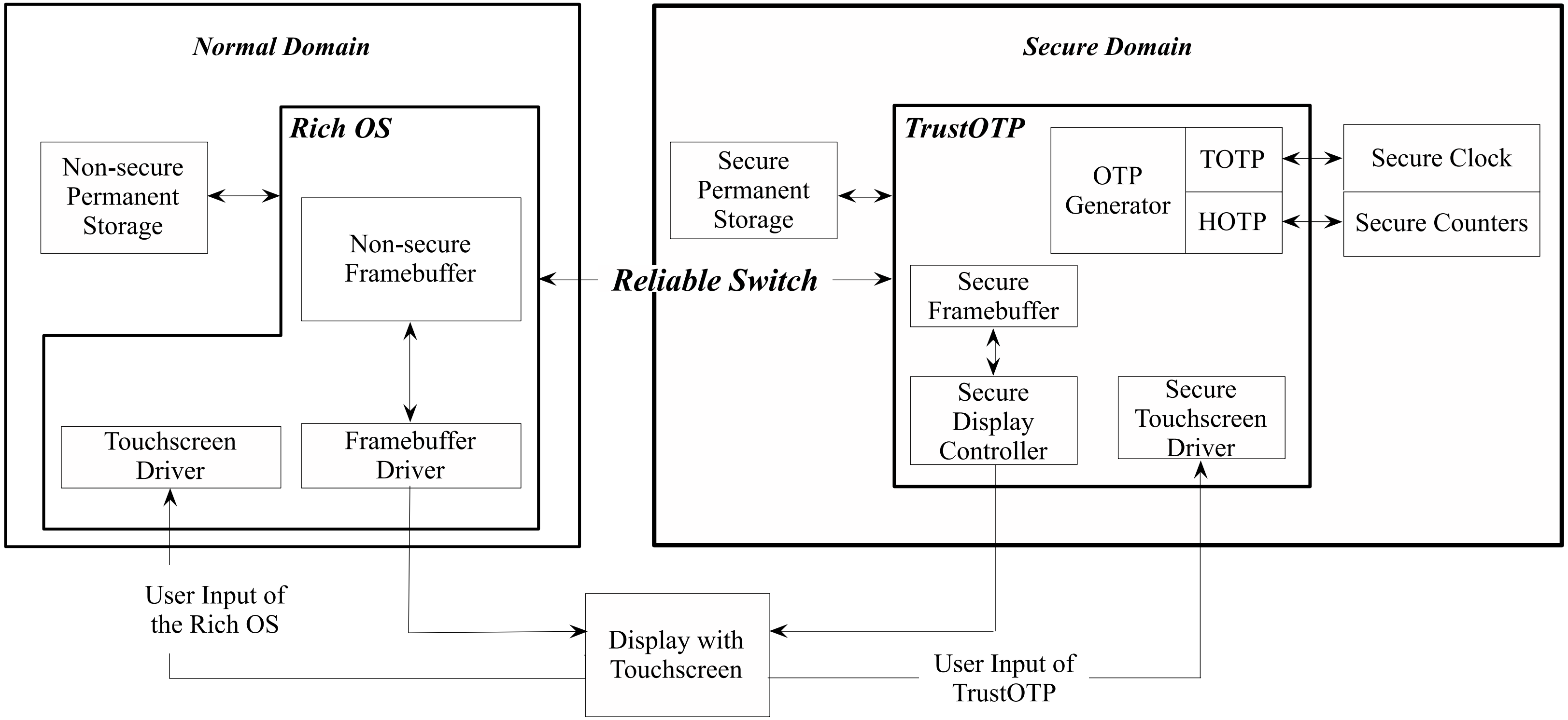
TrustOTP Architecture

- In the secure domain
- Shared I/O device with the rich OS
- Reliable switch between domains



Challenges

- Secure input and display though shared touchscreen
- Reliable switch
- Generator protection
  - Static code
  - Execution environment
- Availability

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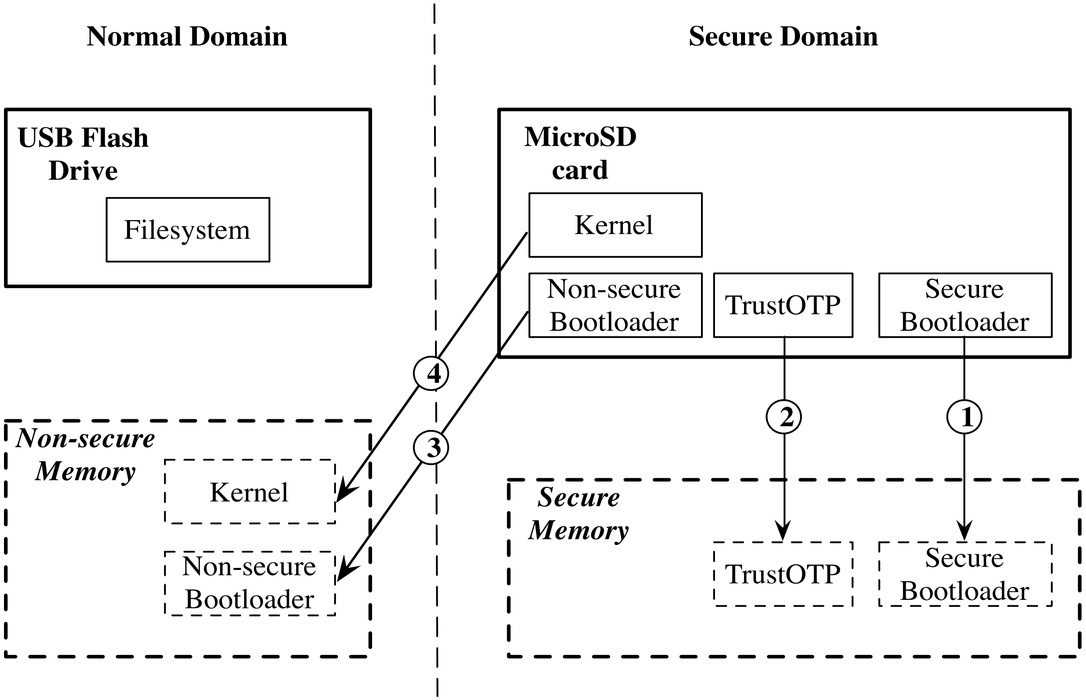
Security Analysis

- Information leakage
  - Generated OTPs
  - Shared keys
- Control flow tampering
  - Code integrity
  - Execution integrity (e.g., Interrupt)
- Denial-of-service
  - Switch between domains
  - Static & dynamic code
  - Display

Boot Sequence

- Secure storage
  - MicroSD card
- Memory Isolation
  - TZASC (TrustZone Address Space Controller)
  - Watermark mechanism
  - Secure boot
- Secure bootloader
  - Non-secure bootloader
  - Rich OS



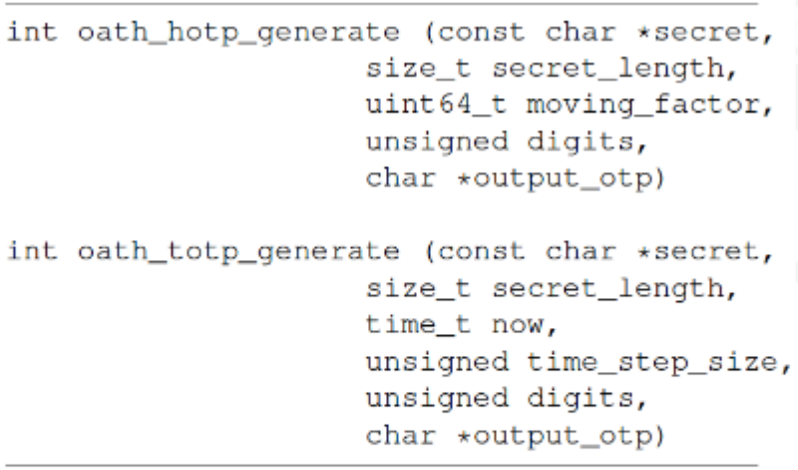
TrustOTP Triggering

- Reliable switch
  - Non-maskable interrupt (NMI)
    - The rich OS cannot block or intercept
  - Secure Interrupt (FIQ)
    - The rich OS cannot manipulate
  - Interrupt source (configurable)
    - Physical button
    - Timer

OTP Generation

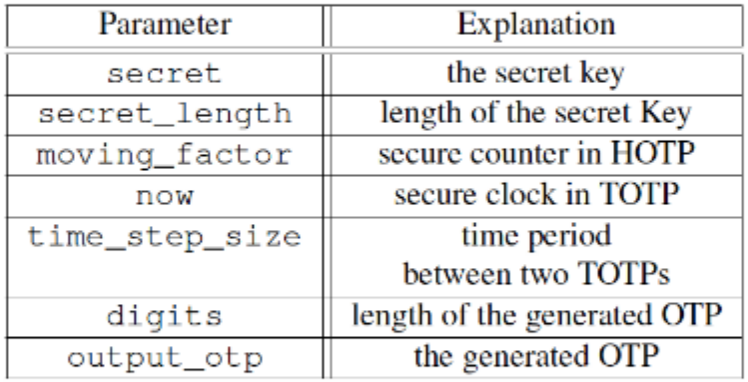
- Hash-based one-time password (HOTP)
  - Key, counter
- Time-based one-time password (TOTP)
  - Key, Clock

Listing 1: OTP Generation Functions



```
int oath_hotp_generate (const char *secret,
                        size_t secret_length,
                        uint64_t moving_factor,
                        unsigned digits,
                        char *output_otp)

int oath_totp_generate (const char *secret,
                        size_t secret_length,
                        time_t now,
                        unsigned time_step_size,
                        unsigned digits,
                        char *output_otp)
```



Parameter	Explanation
`secret`	the secret key
`secret_length`	length of the secret Key
`moving_factor`	secure counter in HOTP
`now`	secure clock in TOTP
`time_step_size`	time period between two TOTPs
`digits`	length of the generated OTP
`output_otp`	the generated OTP

OTP Display

- Secure I/O
  - – Display: IPU (Image Processing Unit) + LCD
  - – Input: 4-wire resistive touchscreen
- User-friendly manner
  - – Rich OS and TrustOTP run concurrently
  - – Watchdog timer
  - – 1.5 seconds / cycle
    - 0.5 second for display
    - 1 second for input 2~3 numbers

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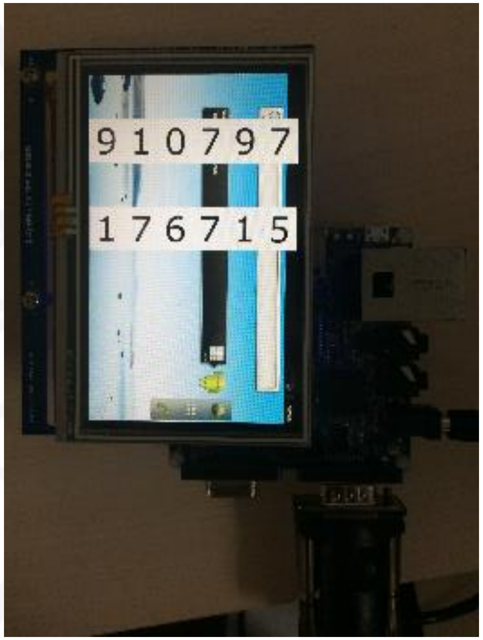
Evaluation

- Freescale i.MX53 QSB
  - A Cortex-A8 1GHz processor
  - 1GB DD3 RAM
  - 4GB microSD card
- Monsoon power monitor
  - Power measurement
  - Power logging



TrustOTP Performance

- Before OTP display (60.48 ms)

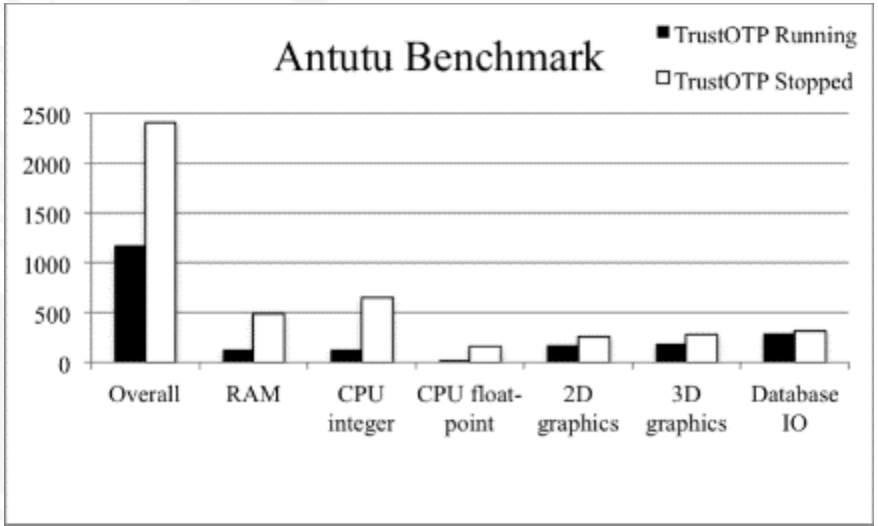
Step	Operation	Time (ms)
1	Domain Switching	0.002
2	Context Saving	0.0006
3	TOTP/HOTP Generation	0.048/0.044
4	Background Matching	49.85
5	OTP Drawing	8.029
6	IPU Check	2.22
7	Framebuffer Replacement	0.28

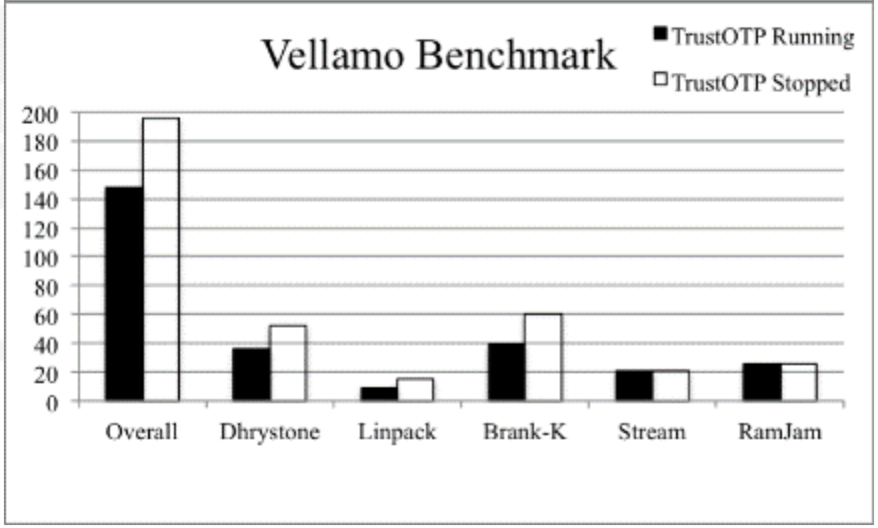
- After OTP display (7.52 ms)

Step	Operation	Time (ms)
1	Flushing IPU & Rich OS Recovery	7.47
2	Domain Switching	0.05

Impact on the Rich OS

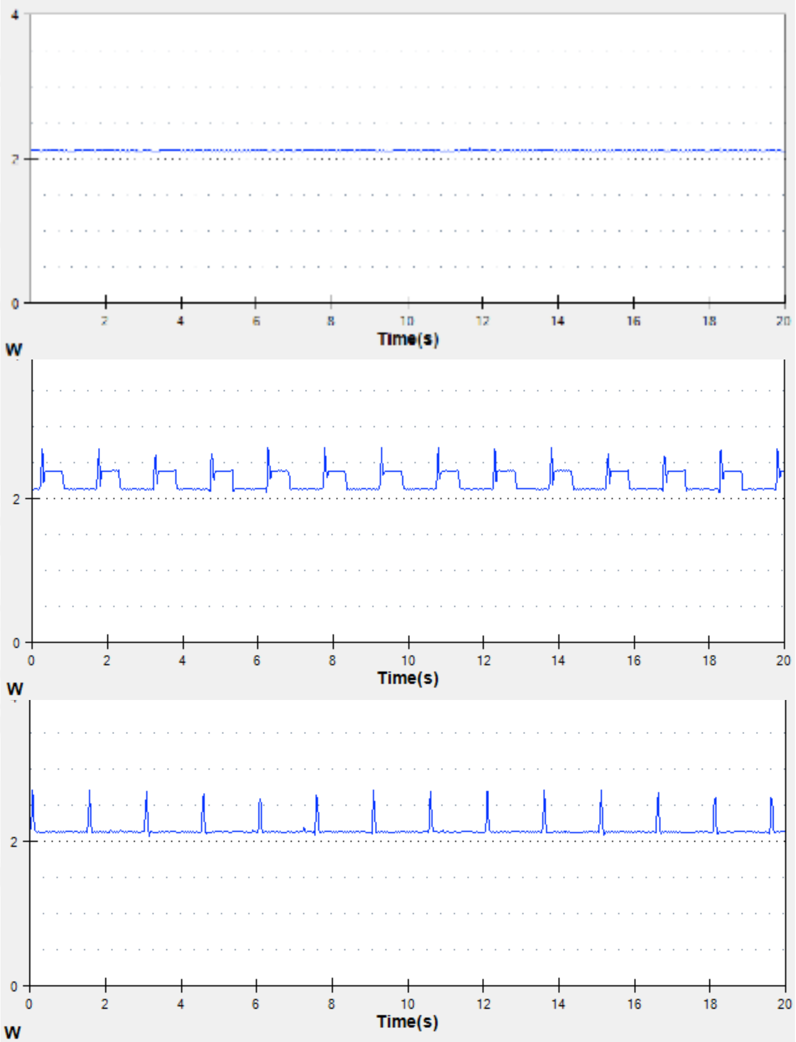
- Rich OS vs. TrustOTP
- Anutu
  - CPU & RAM
  - I/O devices
- Vellamo





Power Consumption

- Rich OS
  - Average = 2,128 mW
- TrustOTP running
  - Average =2,230 mW
- TrustOTP without display



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Summary

- TrustOTP: Hardware-assisted OTP Token on smartphones
  - Security (confidentiality, integrity, availability)
  - Flexibility (various and multiple OTPs)
- Low performance overhead on the Rich OS
  - No need to modify the Rich OS
  - Low power consumption

References

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