Breaking Korea Transit Card with Side-Channel Attack -Unauthorized Recharging-

Black Hat Asia 2017

Tae Won Kim, Tae Hyun Kim, and Seokhie Hong

Outline

1. Attack Goal & Scenario
2. Target Device Details
   - Introduction of Target Device
   - Authentication Protocol Analysis
   - Cryptosystem
3. Key Recovery Attack
   - Attack environment & Measurement Set-Up
   - Attack Overview
   - Attack Results
4. Recharging Simulation
5. Conclusion

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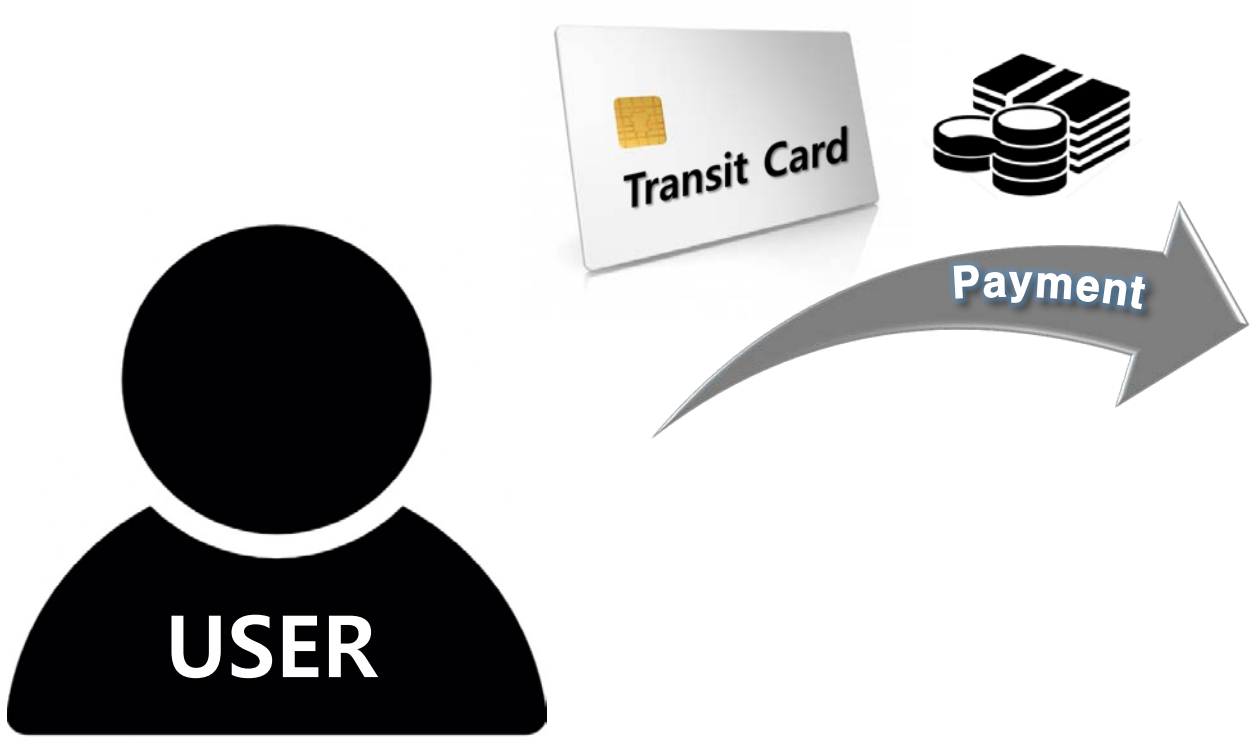
Recharging on Transit Card



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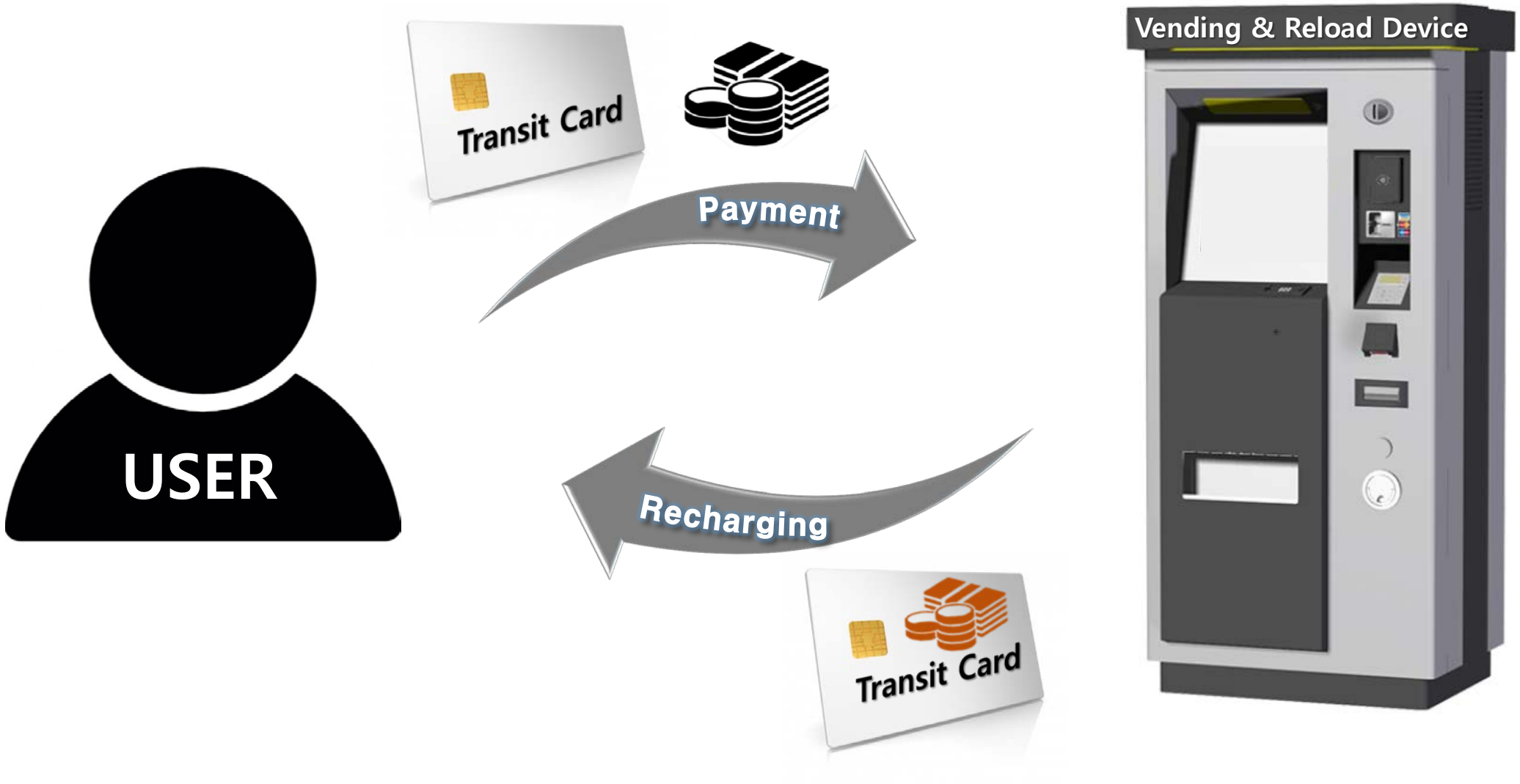
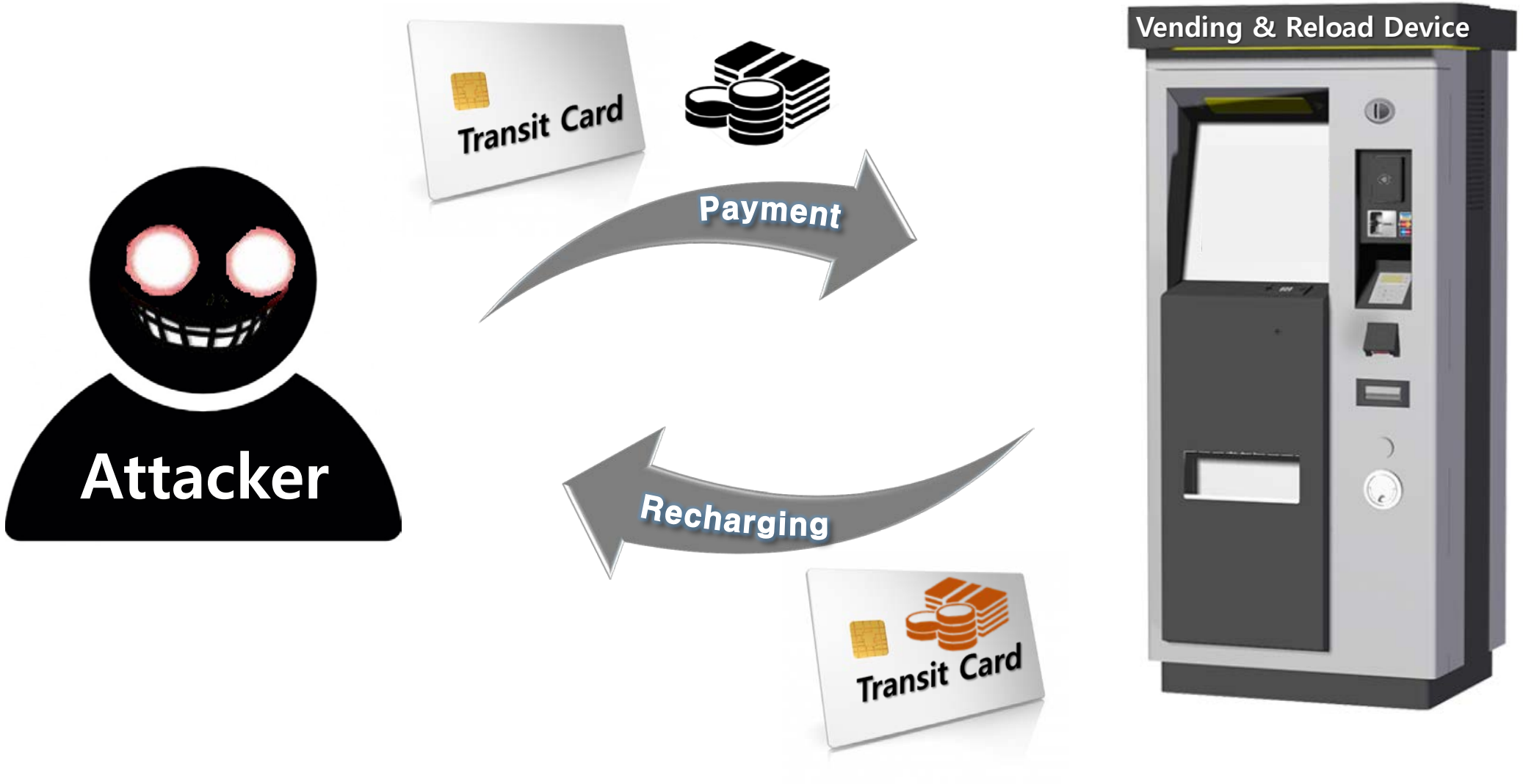


Our Ultimate Goal

Free recharging as much as attacker want



Attack Scenario toward Goal

Phase 1. **Extract authentication key for recharging using side-channel analysis attack**

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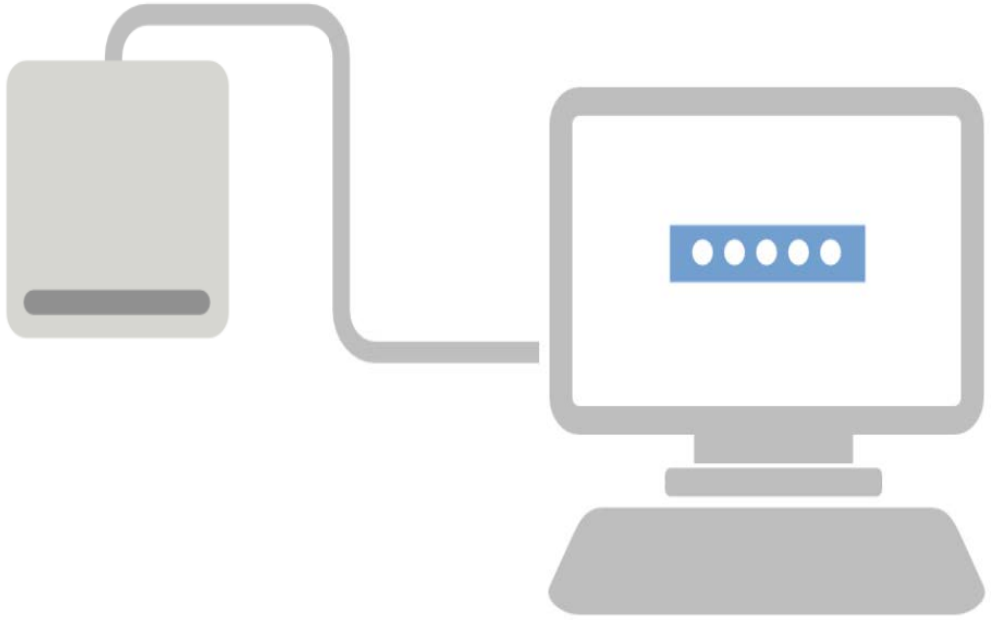

Phase 2. Design free recharging tool with restored key

Attack Scenario toward Goal

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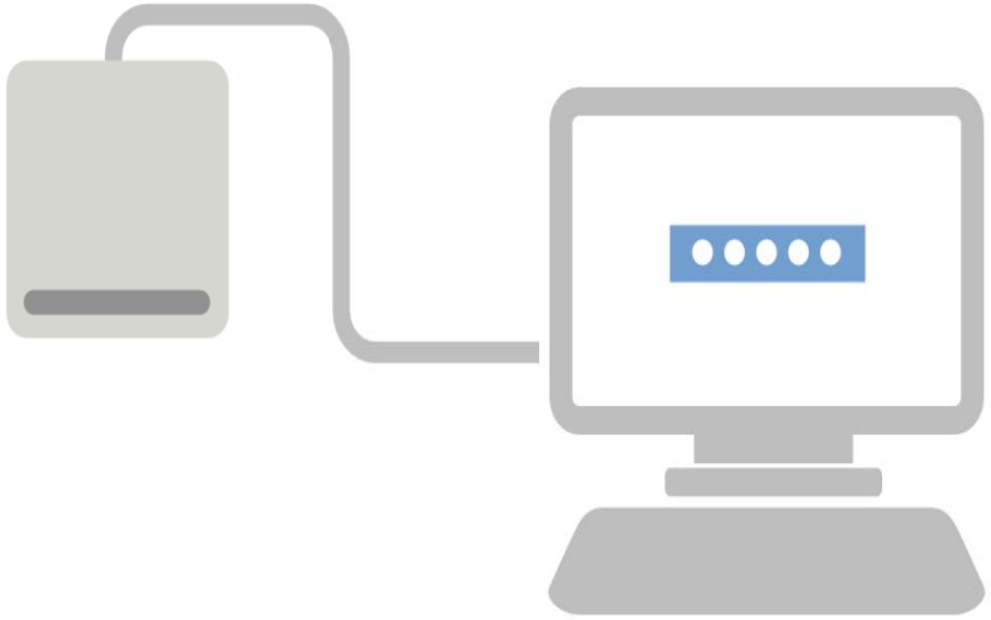

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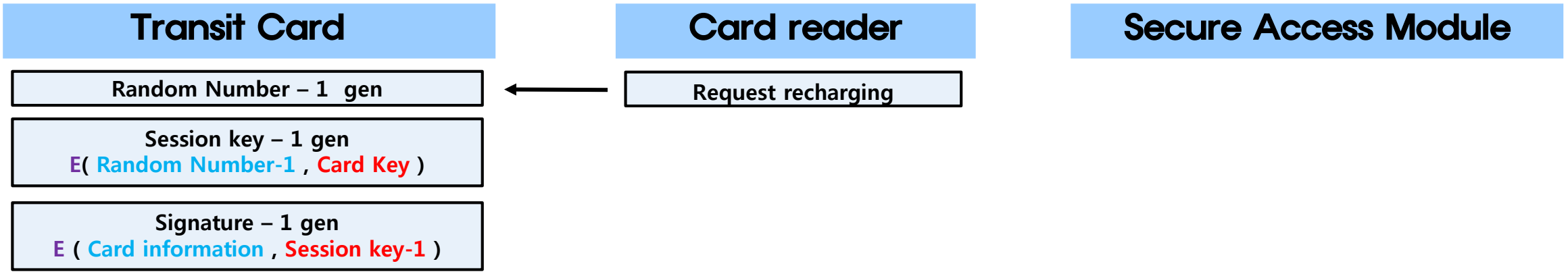
Target device

- Transit card
  - Pre-paid transit card for the freeway in Korea
  - Over 800 million cards were issued and used
  - Cafeteria and convenience store in the freeway service area
  - Movie theater, Airport car park etc...
- Contact Smartcard
  - Equipped with cryptographic engine in hardware level
  - Countermeasure employed against side-channel attacks
  - Support ISO/IEC 7816 standard and KS X 6924 Korea standard

Authentication protocol for recharging

Public information
Secret information
Crypto algorithm



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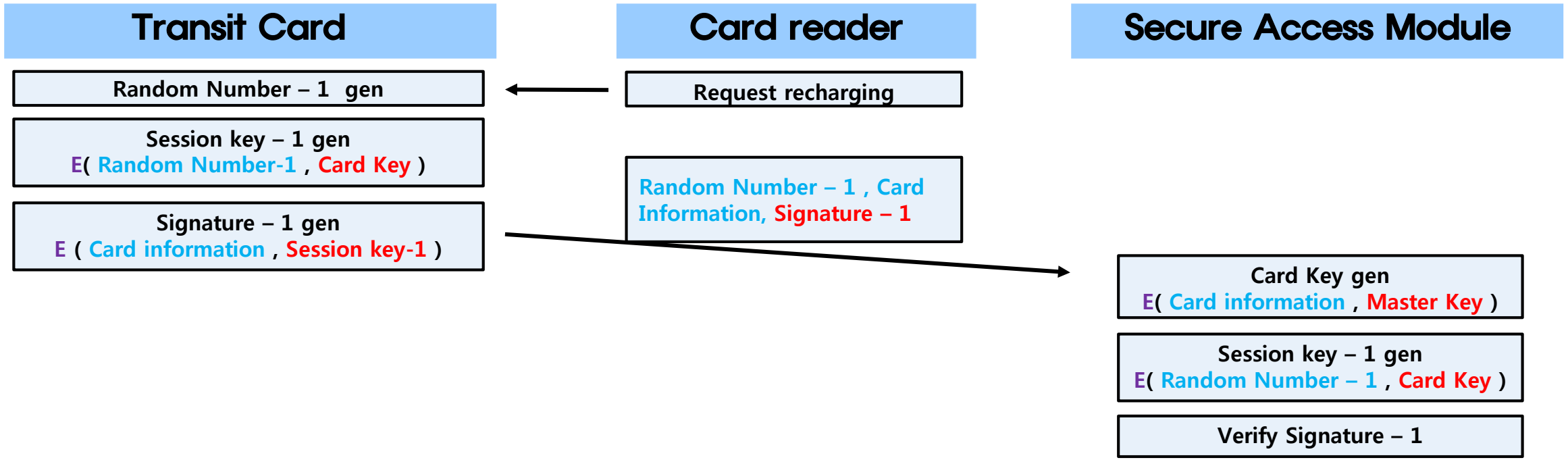

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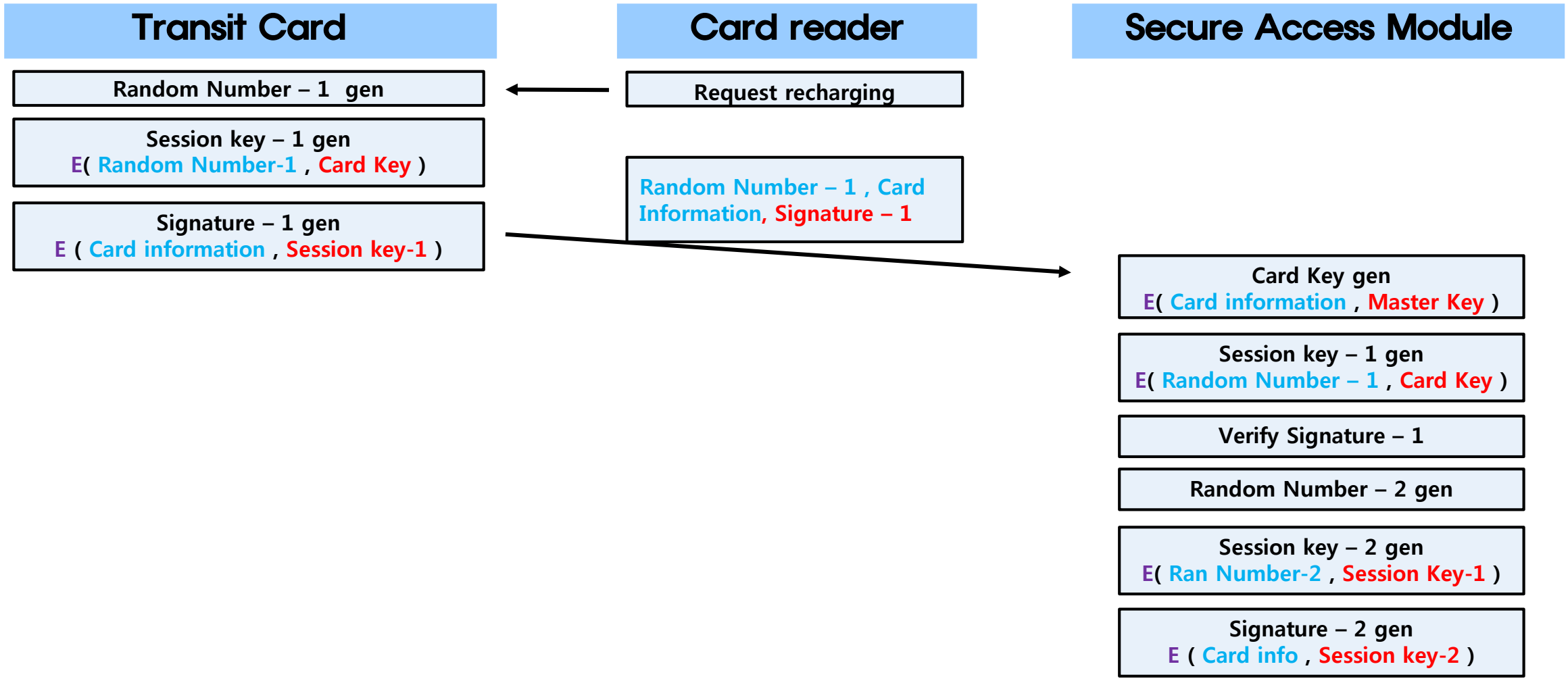

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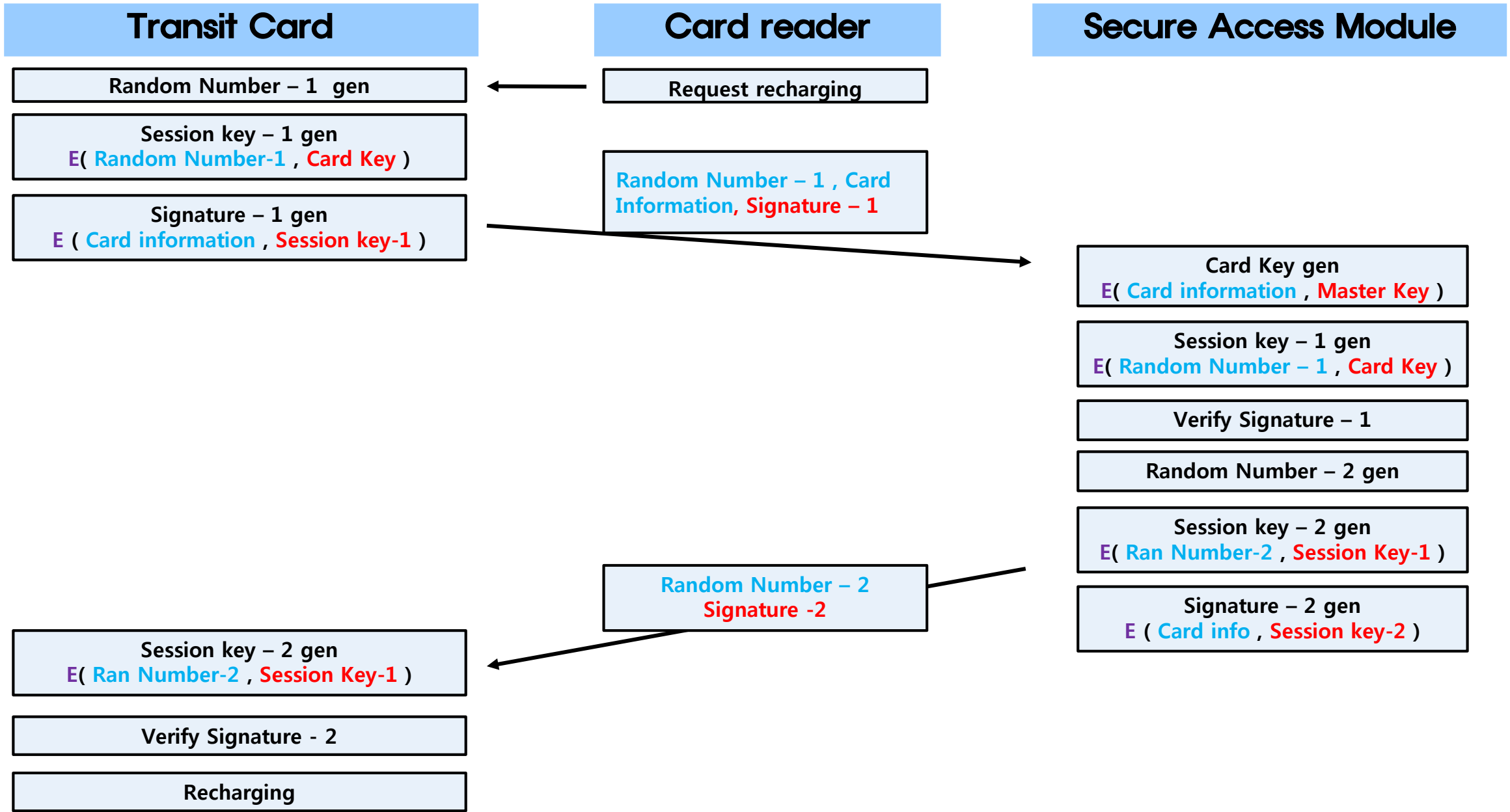

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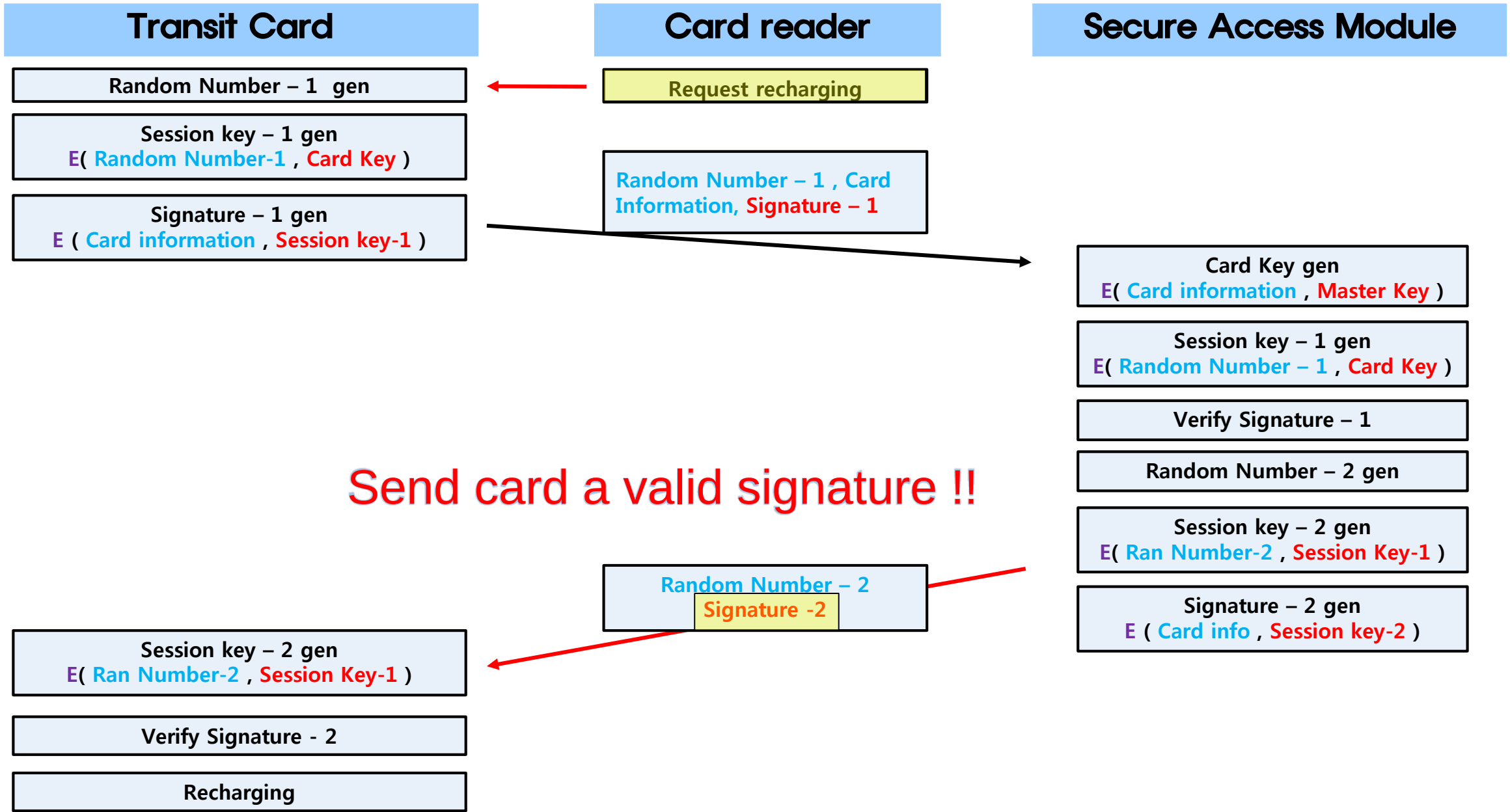

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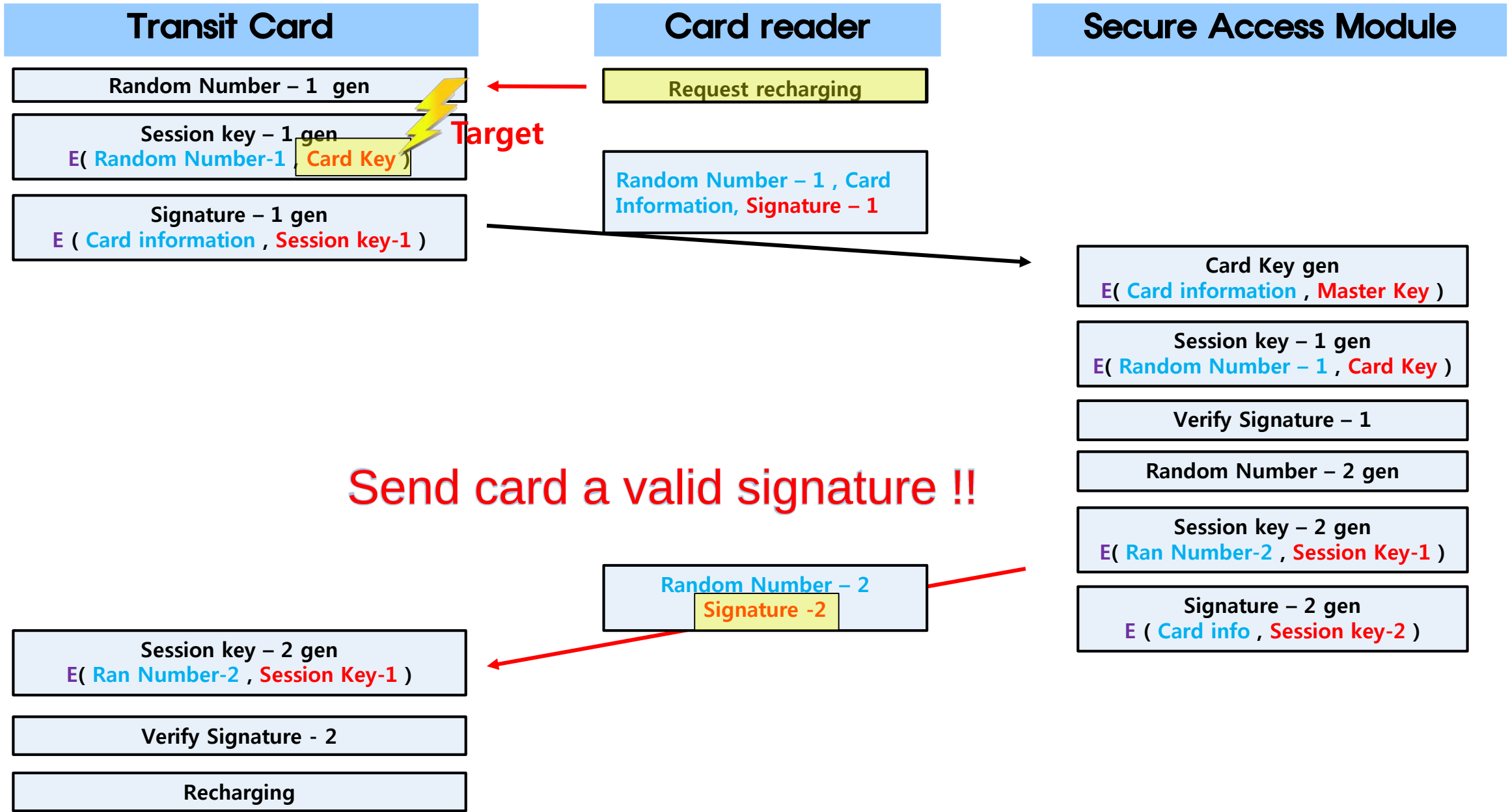

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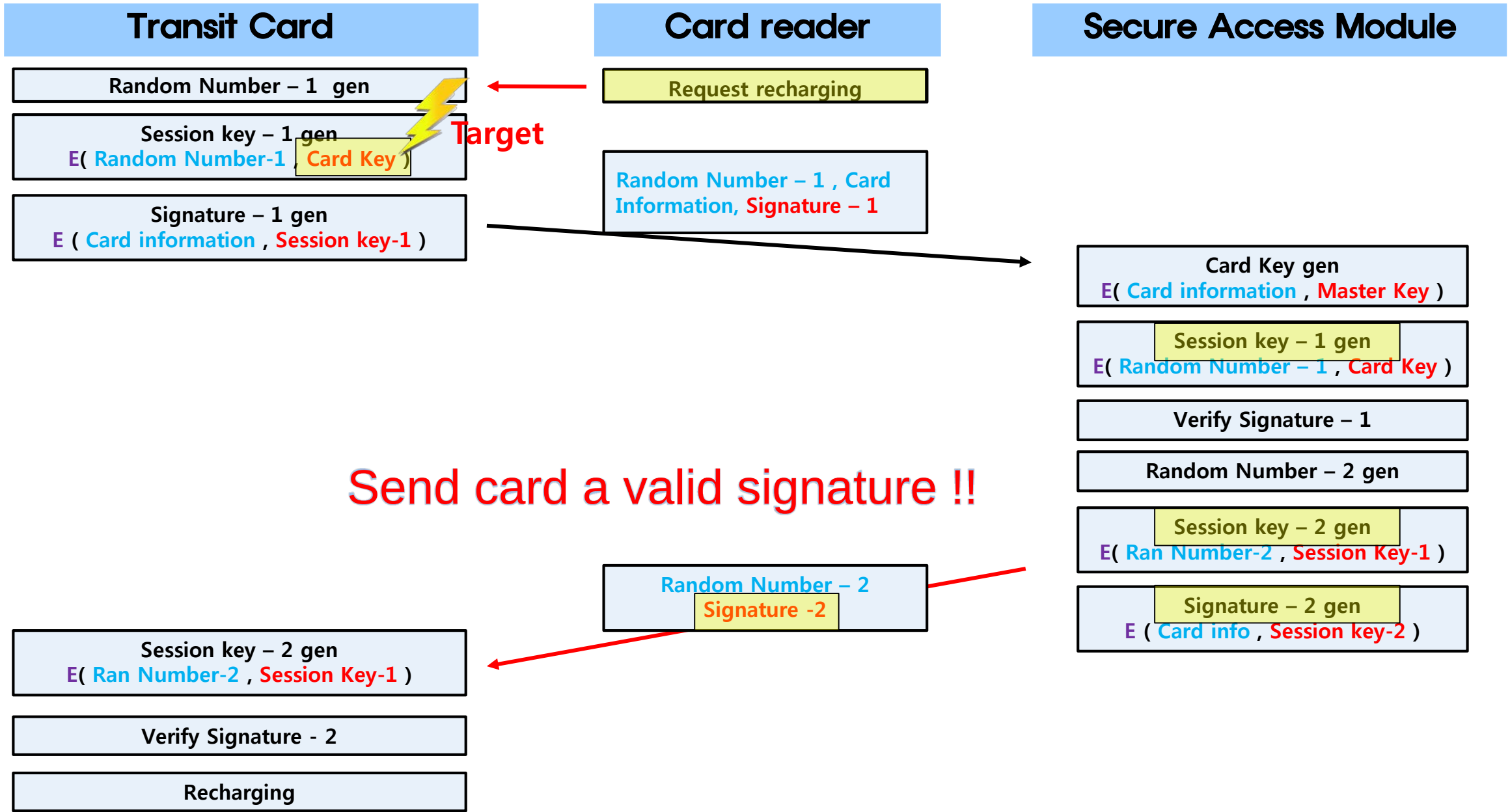
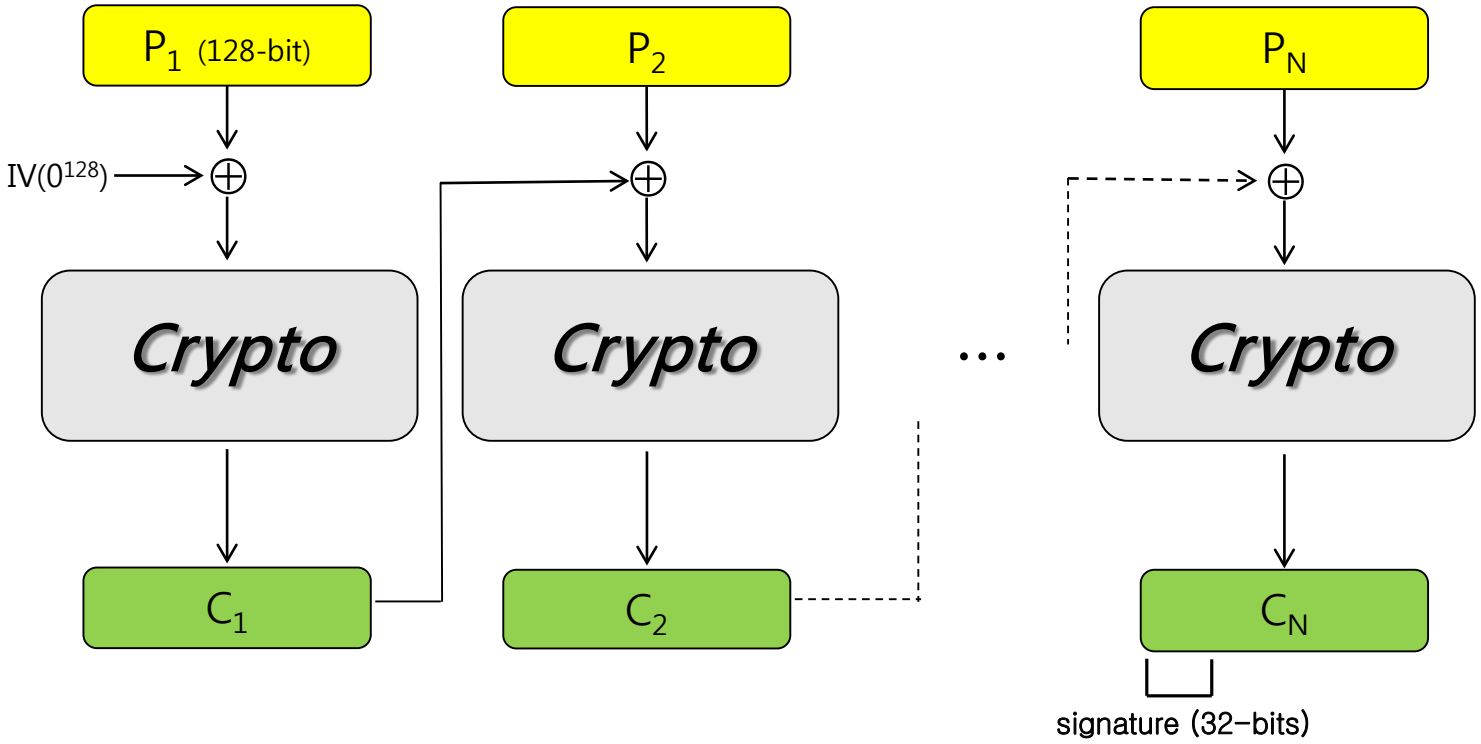


Crypto Algorithm Analysis



- Sign & verify

  => performs crypto Algorithm

- 128-bit Block cipher & operation mode
  - Crypto function => Two Triple-DES
  - Cipher Block Chaining (CBC) mode
- Initial Vector
  - 0^{128}
- Signature value
  - Most significant 32-bit of last ciphertext block
- Padding rule
  - 80 00 00 00 …

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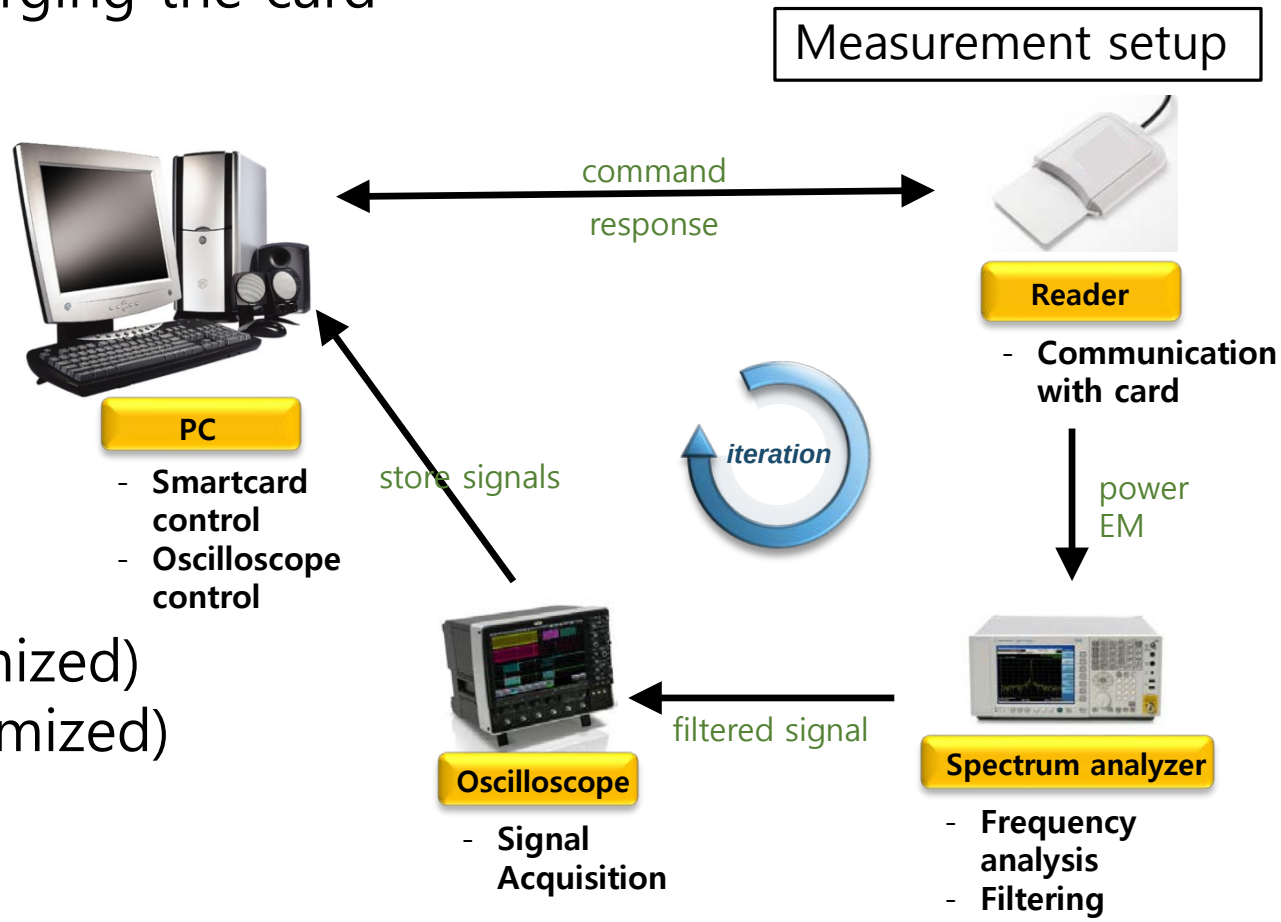
Attack Environment

- Attack under the secure transit card
  - APDU commands for recharging the card
- Hardware
  - Board
  - Card reader
  - Oscilloscope
  - Spectrum Analyze
- Software
  - For the acquisitions(Customized)
  - Signal preprocessing(Customized)
  - Analysis(Customized)
  - Matlab

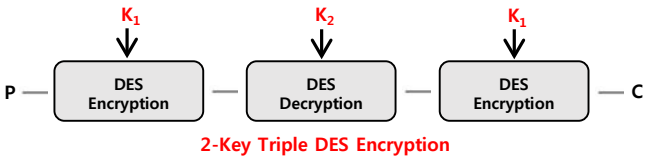


Attack Overview

Phase 1 : Locate the positon of T-DES

1. I/O signal analysis
2. Visual Inspection
   - Find similar patterns
3. Plaintext CPA
   - Find location of relating plaintext
   - Can deduce location of target operation from plaintext location

Attack Overview



2-Key Triple DES Encryption

Phase 2 : DPA Attack for key recovery

1. Pre-processing
   - Compression
   - Alignment
2. First Round attack in the DES
   - 48-bit Key recovery
   - 6-bitwise CPA
3. Correction of error
   - Prevent error propagation
   - Method based on BS-CPA
4. 2-15 Round attack
   - 56-bit full-key recovery
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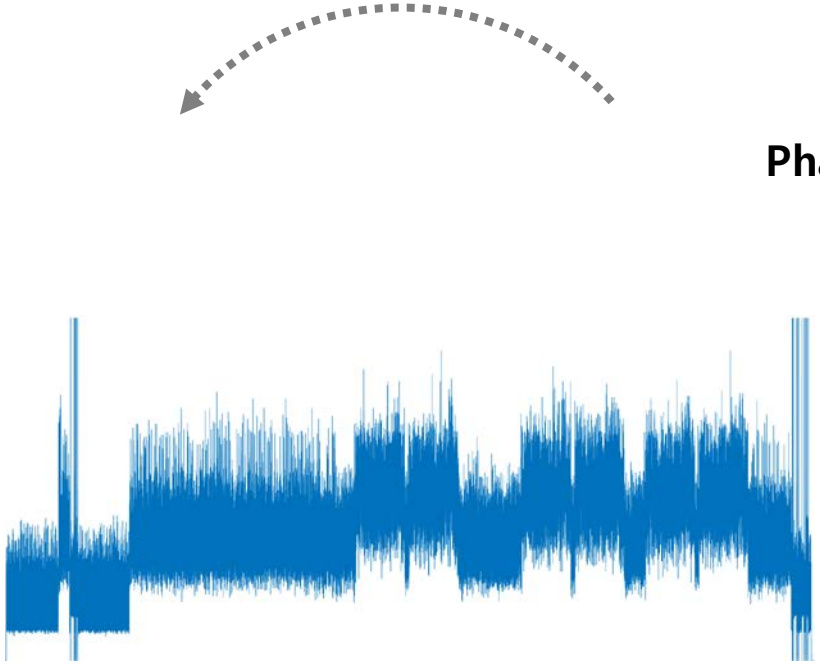

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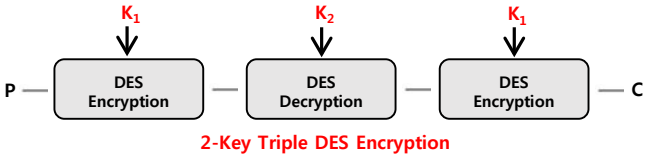

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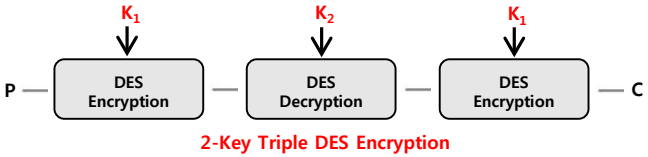

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If fail, return to the beginning

Repeat until the key is found

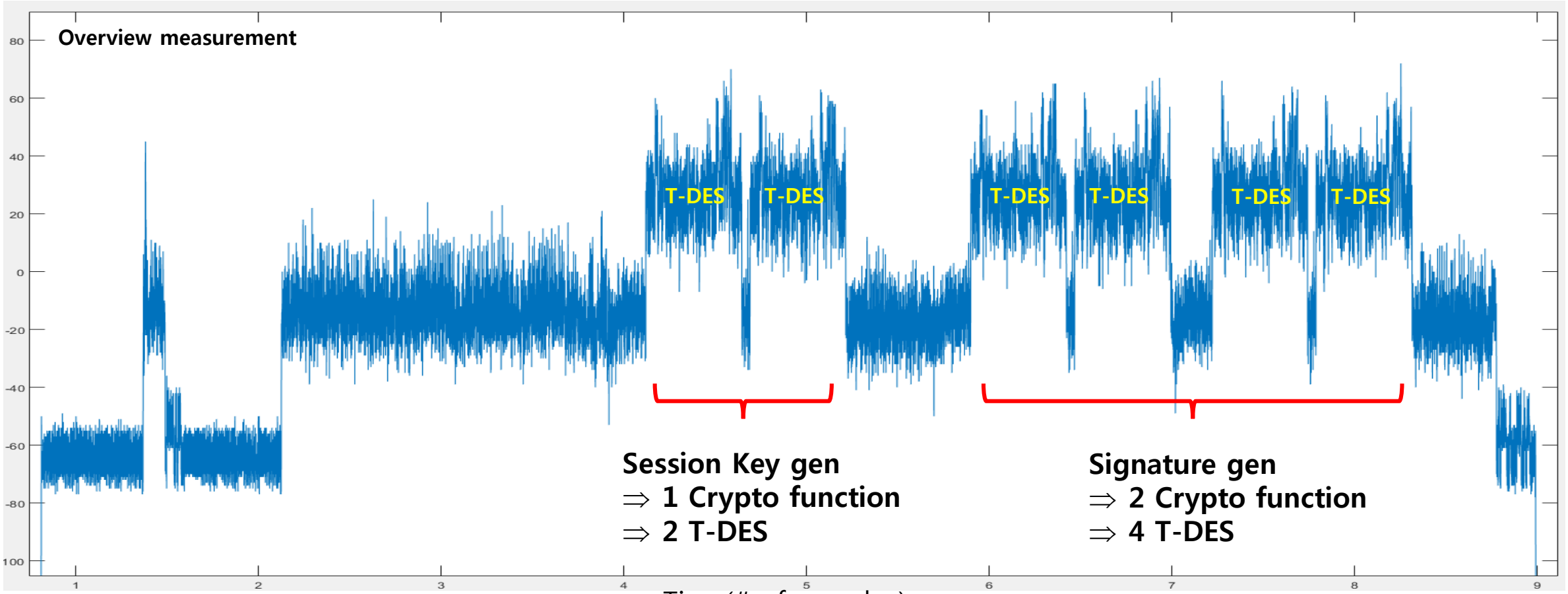
Tremendous trials and errors!!

Some Problems for Key Recovery

- Hiding Countermeasure
  - Pre-processing for mitigation
    - Filtering, Alignment
  - Increases the number of traces
- Alignment
  - Align, whenever guess the location of target operation
  - There is no good reference pattern
    - By effect of hiding countermeasure
  - Need elaborated work
    - One or two point of misalignment leads to attack failure
- More requirement of time cost, memory
  - Compression of trace
  - Parallel processing

Visual Inspection

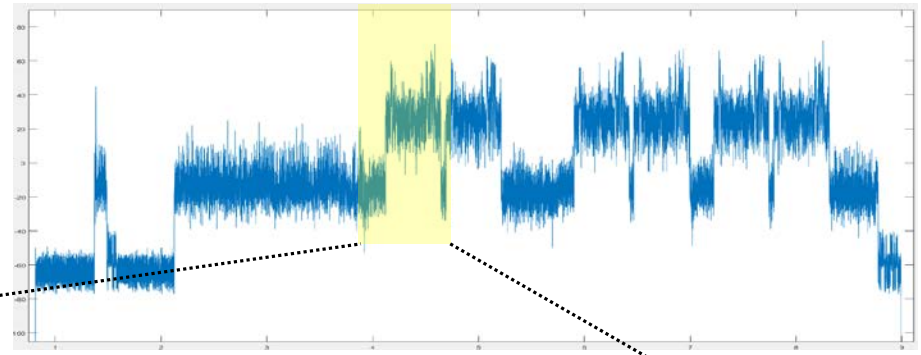
- Search for similar patterns
- Execution of three crypto function
  =>6 T-DES

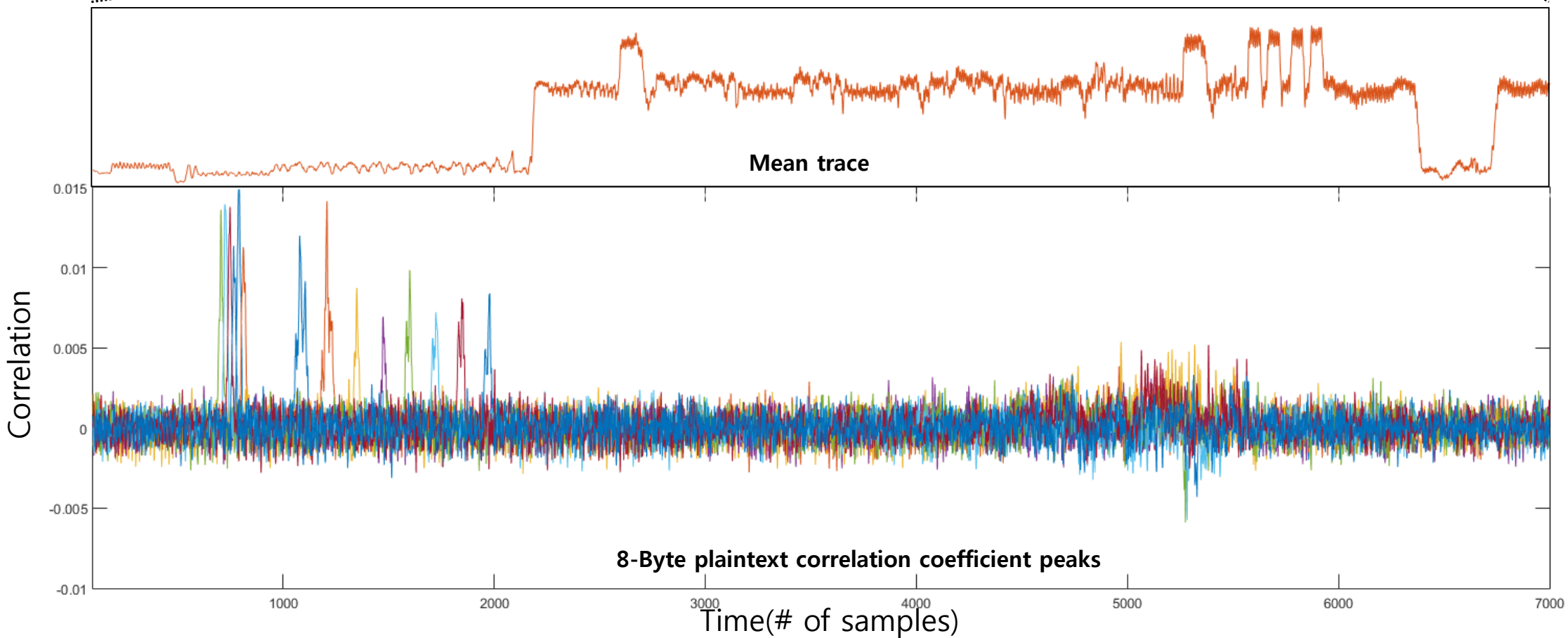


Plaintext CPA

- Perform after alignment
- Result of CPA

  => Indicate location relating to plaintext





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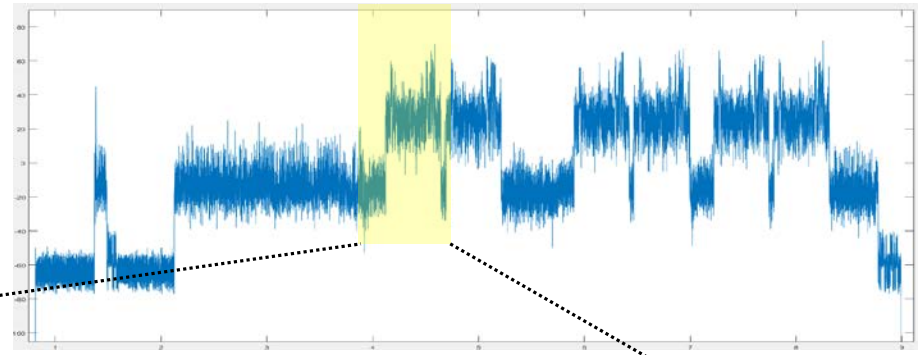
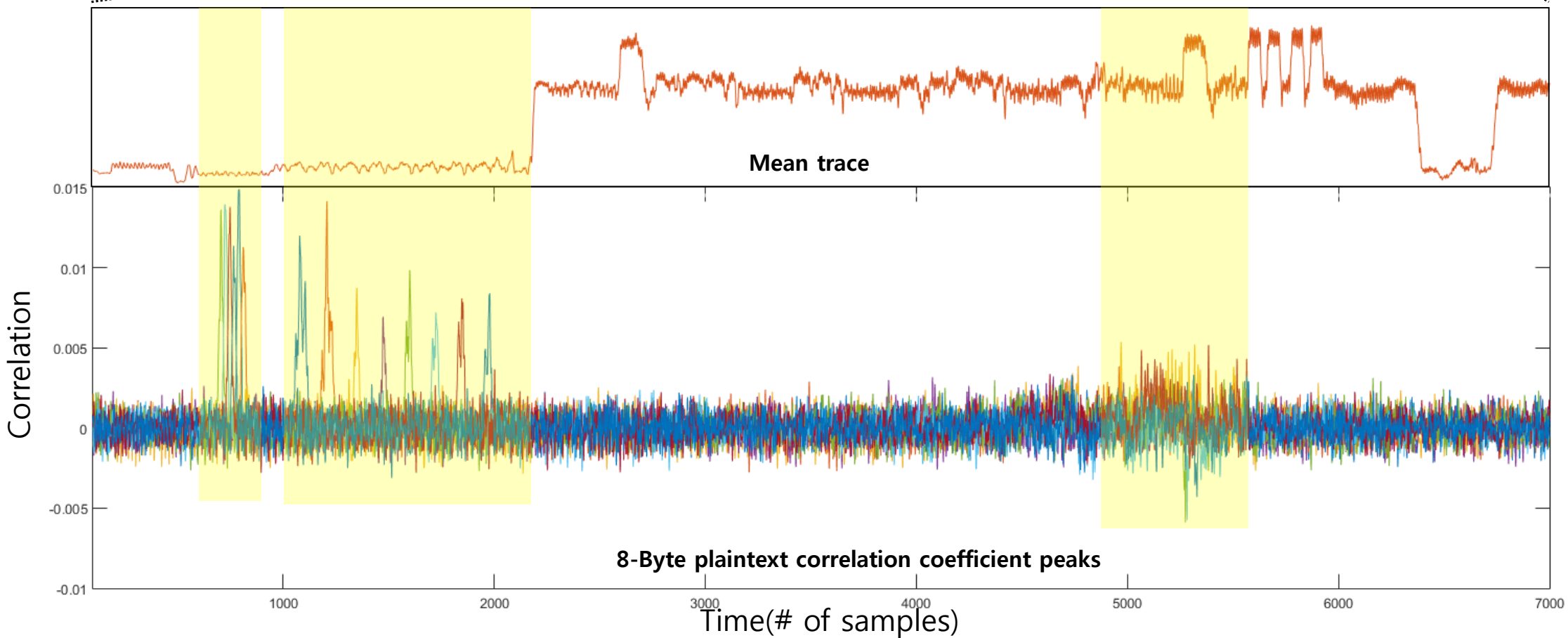
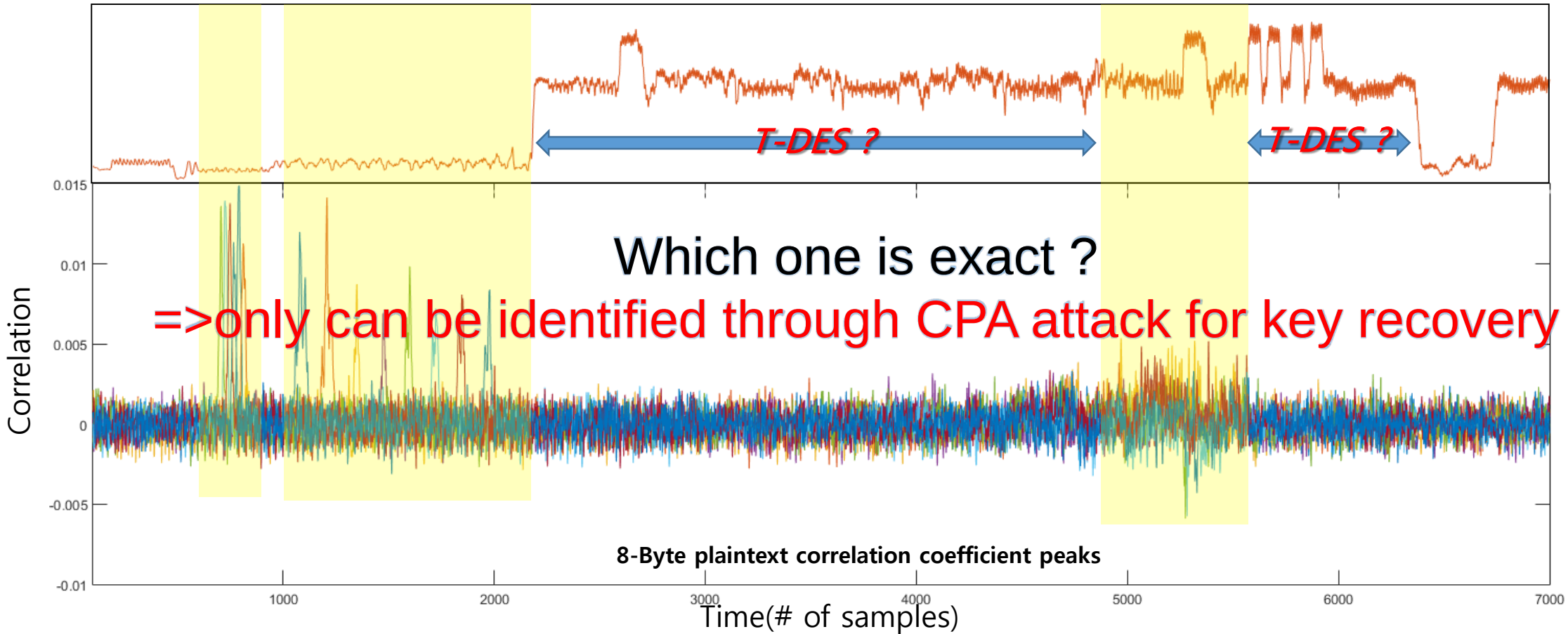




Plaintext CPA

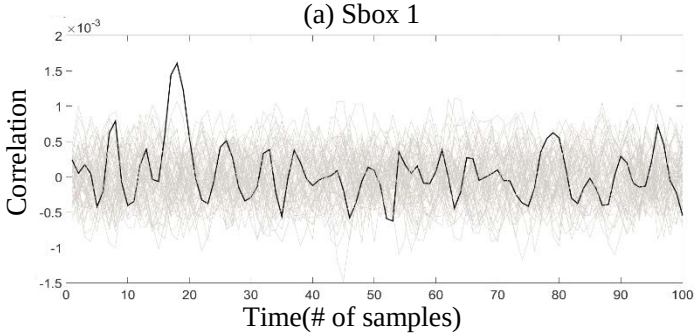
- Two possible intervals for target operation



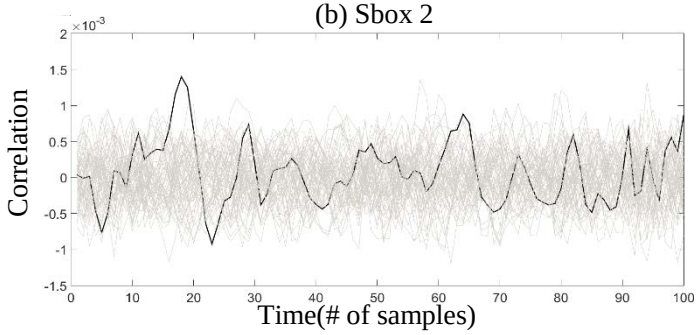
48-bit key recovery

- Correlation Coefficients for the first Round of DES

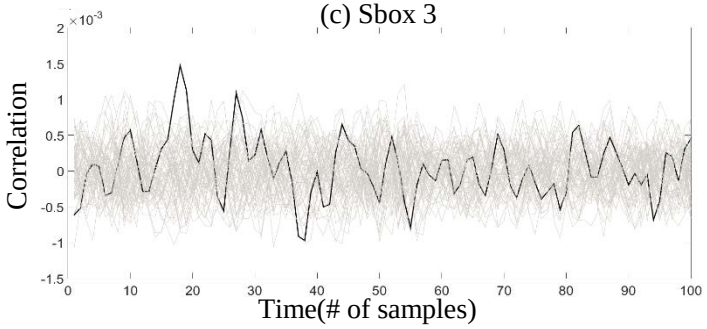
(a) Sbox 1



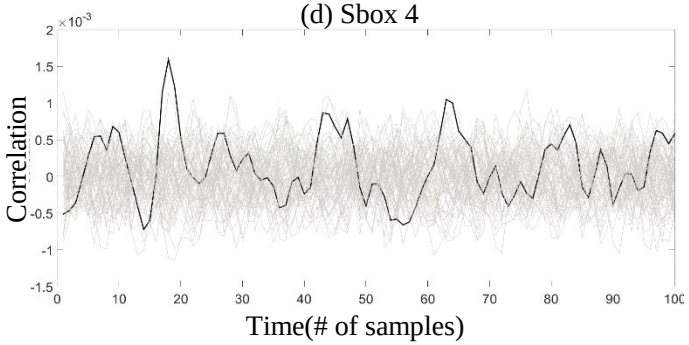
(b) Sbox 2



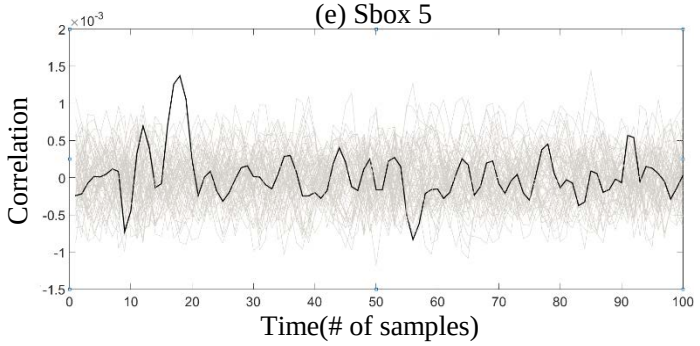
(c) Sbox 3



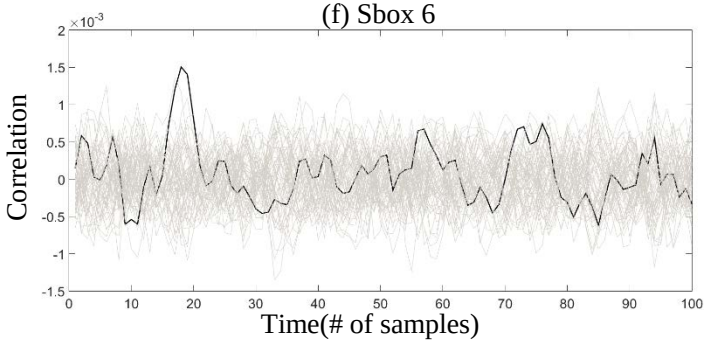
(d) Sbox 4



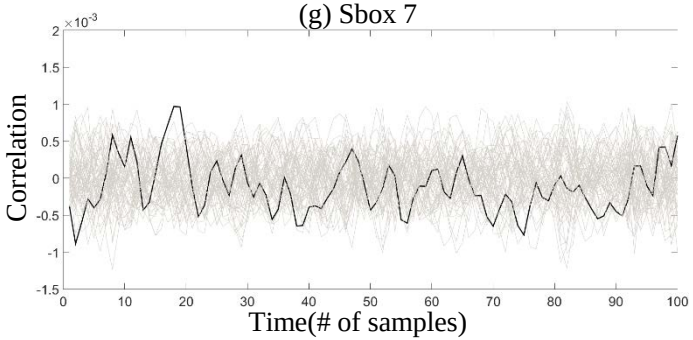
(e) Sbox 5



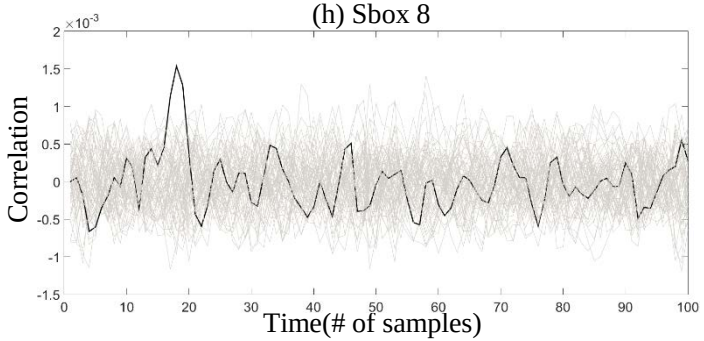
(f) Sbox 6



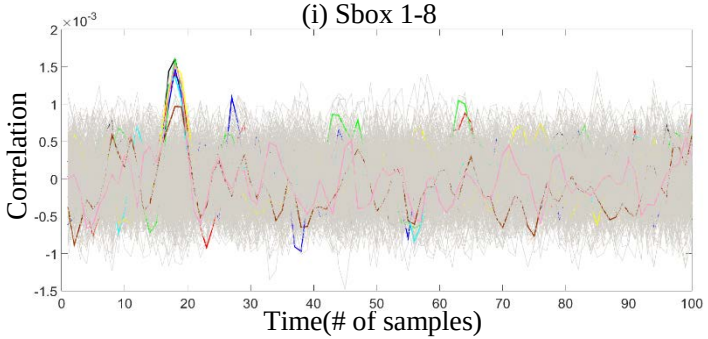
(g) Sbox 7



(h) Sbox 8

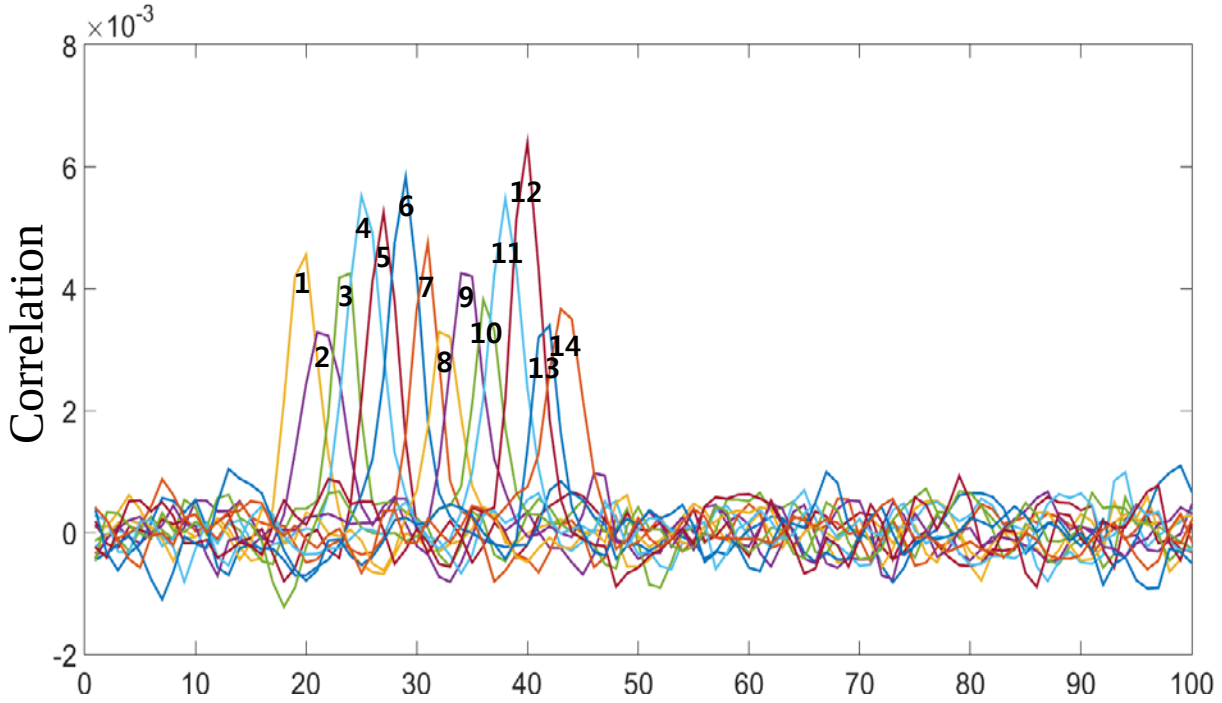


(i) Sbox 1-8

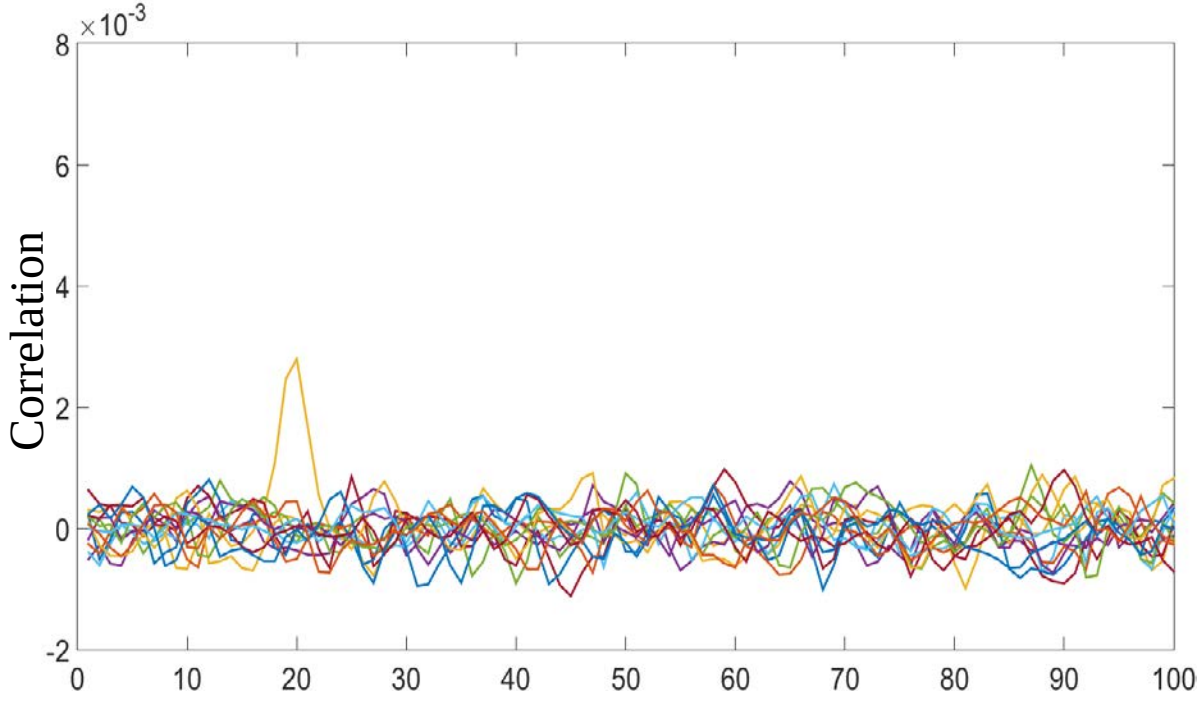


Full Key Recovery

- Correlation coefficients for the Hamming distances between rounds(2-15) of the T-DES
- Correct key guess => Observe 14 peaks

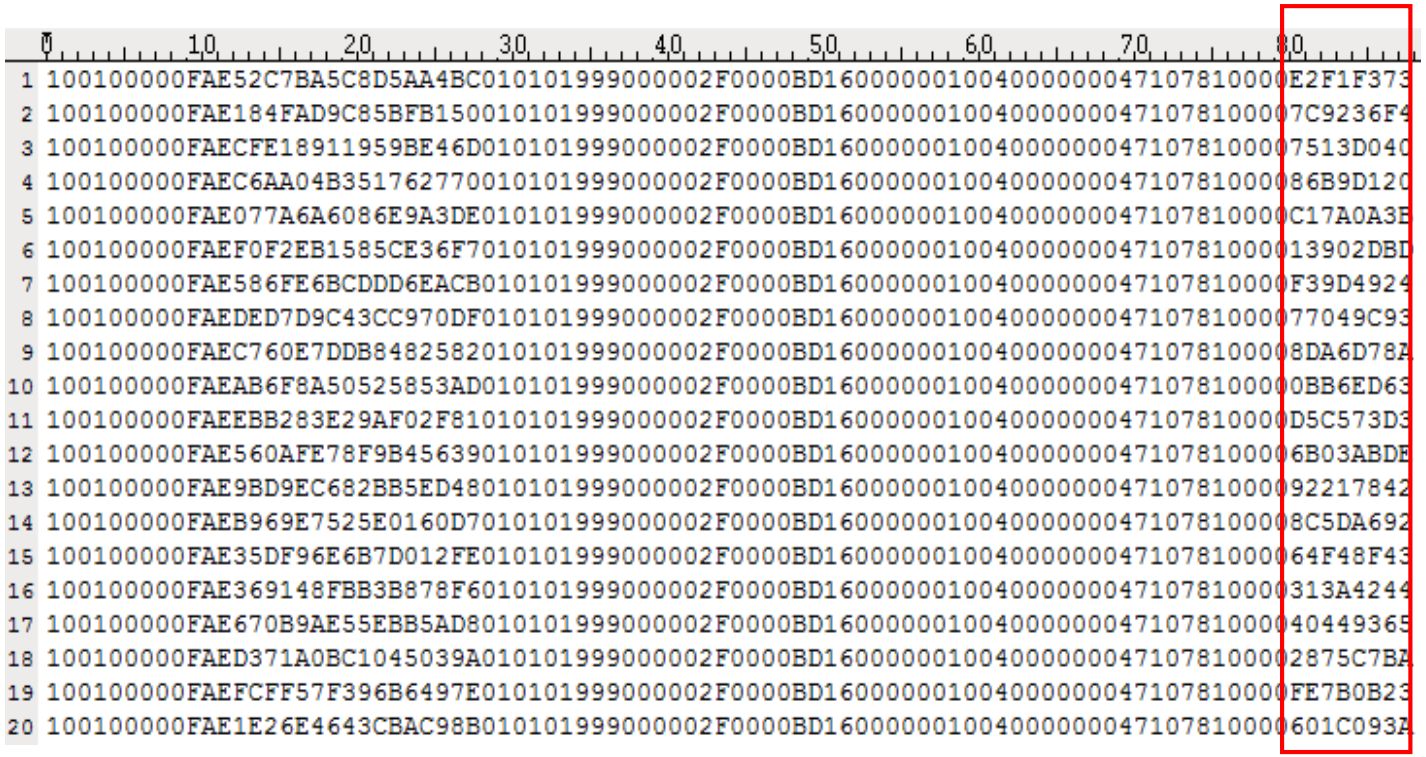


correct key guess



incorrect key guess

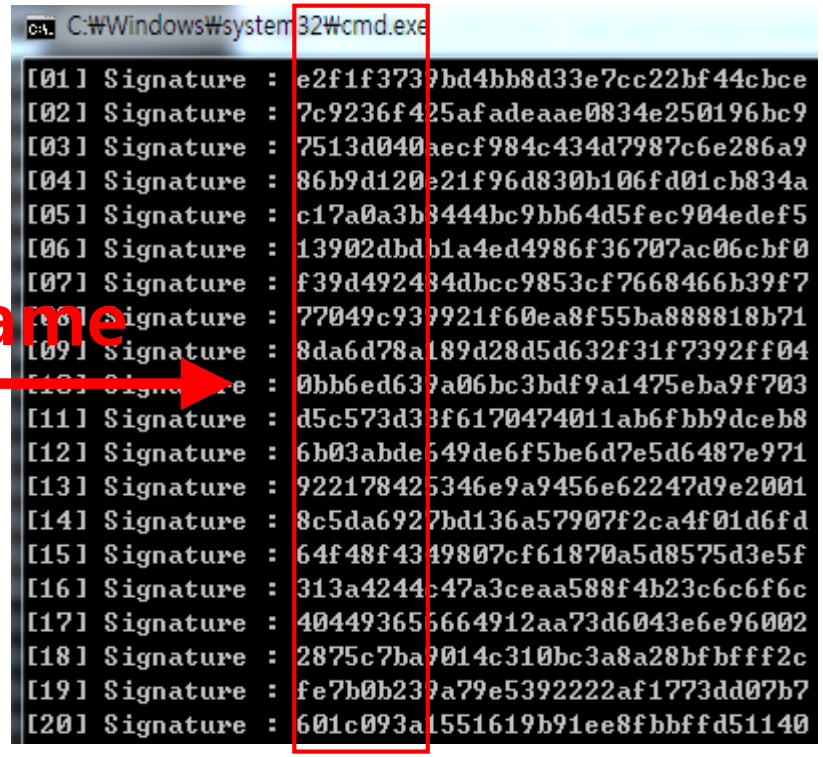
Verification of Restored Entire Key



```
1  100100000FAE52C7BA5C8D5AA4BC010101999000002F0000BD160000001004000000047107810000E2F1F373
2  100100000FAE184FAD9C85BFB150010101999000002F0000BD160000001004000000047107810000 7C9236F4
3  100100000FAECFE18911959BE46D010101999000002F0000BD160000001004000000047107810000 7513D040
4  100100000FAEC6AA04B3517627700101019990000002F0000BD160000001004000000047107810000 86B9D120
5  100100000FAE077A6A6086E9A3DE010101999000002F0000BD160000001004000000047107810000 C17A0A3B
6  100100000FAEF0F2EB1585CE36F7010101999000002F0000BD160000001004000000047107810000 13902DBD
7  100100000FAE586FE6BCDDD6EACB010101999000002F0000BD160000001004000000047107810000 F39D4924
8  100100000FAEDED7D9C43CC970DF010101999000002F0000BD160000001004000000047107810000 77049C93
9  100100000FAEC760E7DDB84825820101019990000002F0000BD160000001004000000047107810000 8DA6D78A
10 100100000FAEAB6F8A50525853AD010101999000002F0000BD160000001004000000047107810000 0BB6ED63
11 100100000FAEEBB283E29AF02F8101010199900002F0000BD160000001004000000047107810000 D5C573D3
12 100100000FAE560AFE78F9B4563901010199900002F0000BD160000001004000000047107810000 6B03ABDE
13 100100000FAE9BD9EC682BB5ED4801010199900002F0000BD160000001004000000047107810000 92217842
14 100100000FAEB969E7525E0160D7010101999000002F0000BD160000001004000000047107810000 8C5DA692
15 100100000FAE35DF96E6B7D012FE010101999000002F0000BD160000001004000000047107810000 64F48F43
16 100100000FAE369148FBB3B878F6010101999000002F0000BD160000001004000000047107810000 313A4244
17 100100000FAE670B9AE55EBB5AD8010101999000002F0000BD160000001004000000047107810000 40449365
18 100100000FAED371A0BC1045039A010101999000002F0000BD160000001004000000047107810000 2875C7BA
19 100100000FAEFCFF57F396B6497E010101999000002F0000BD160000001004000000047107810000 FE7B0B23
20 100100000FAE1E26E4643CBAC98B010101999000002F0000BD160000001004000000047107810000 601C093A
```

Response values from the card including signatures

Same



```
C:¥Windows¥system32¥cmd.exe
[01] Signature : e2f1f3739bd4bb8d33e7cc22bf44cbce
[02] Signature : 7c9236f425afadeaae0834e250196bc9
[03] Signature : 7513d040aecf984c434d7987c6e286a9
[04] Signature : 86b9d120e21f96d830b106fd01cb834a
[05] Signature : c17a0a3b8444bc9bb64d5fec904edef5
[06] Signature : 13902dbdb1a4ed4986f36707ac06cbf0
[07] Signature : f39d492484dbcc9853cf7668466b39f7
[08] Signature : 77049c939921f60ea8f55ba888818b71
[09] Signature : 8da6d78a189d28d5d632f31f7392ff04
[10] Signature : 0bb6ed639a06bc3bdf9a1475eba9f703
[11] Signature : d5c573d38f6170474011ab6fbb9dceb8
[12] Signature : 6b03abde649de6f5be6d7e5d6487e971
[13] Signature : 922178425346e9a9456e62247d9e2001
[14] Signature : 8c5da6927bd136a57907f2ca4f01d6fd
[15] Signature : 64f48f4349807cf61870a5d8575d3e5f
[16] Signature : 313a4244c47a3ceaa588f4b23c6c6f6c
[17] Signature : 4044936565664912aa73d6043e6e96002
[18] Signature : 2875c7ba9014c310bc3a8a28bfbfff2c
[19] Signature : fe7b0b239a79e5392222af1773dd07b7
[20] Signature : 601c093a1551619b91ee8fbbffd51140
```

Generated signatures by ourselves

1. Attack Goal & Scenario
2. Target Device Details
   - Introduction of Target Device
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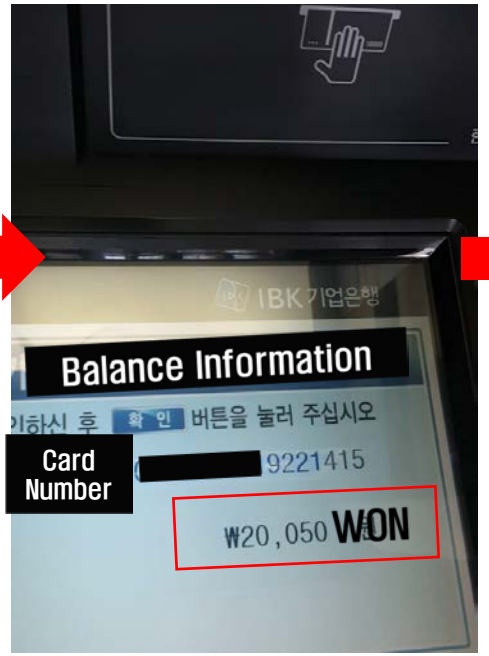
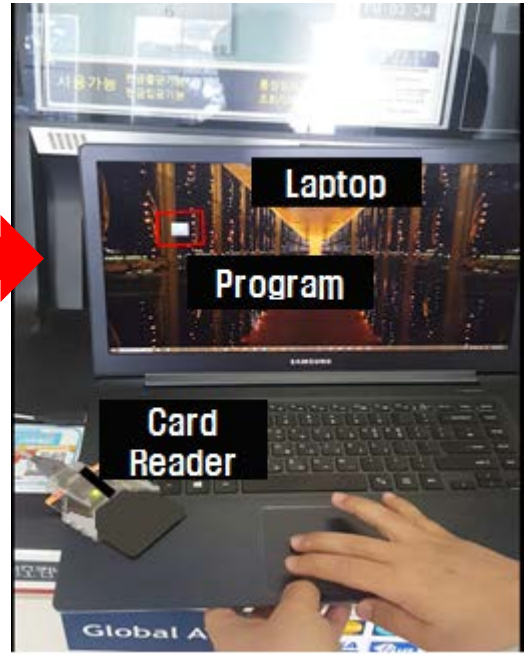
   - Cryptosystem
3. Key Recovery Attack
   - Attack environment & Measurement Set-Up
   - Attack Overview
   - Attack Results
4. Recharging Simulation
5. Conclusion

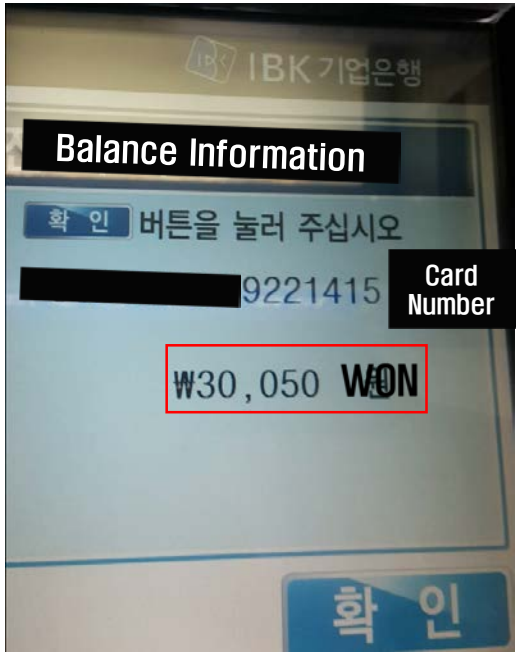
(a) Before recharging,
check balance with ATM



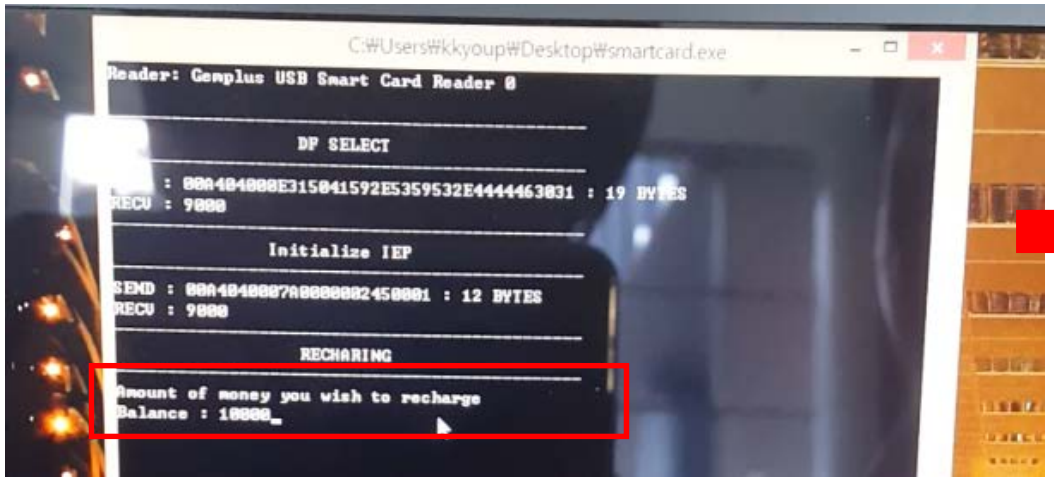
(b) Balance : 20,050 (₩)



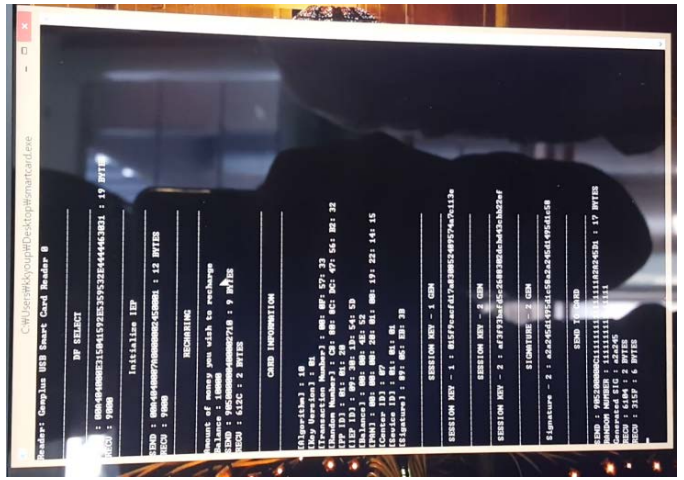
(c) Recharging Tool



(f) After recharging,
Balance : 30,050 (₩)



(d) Execution of our recharging program.
Insert amount of money you wish to recharge => 10,000 (₩)



(e) Completion of recharging

1. Attack Goal & Scenario
2. Target Device Details
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   - Attack Results
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5. Conclusion

Conclusion

- Demonstrated that side-channel analysis attack is serious threat in real-world
  - Hacking the Korea transit card in a black-box manner
  - Showing financial damage through unauthorized recharging balance
- Practical attack
  - Trials and errors
    - Approx. six months
  - Current extracting key in same device
    - Approx. 63 hours (trace collection : 58 hours + Attack : 5 hours)
- Further works
  - For black box attack, combination of reverse engineering and side-channel attack
  - Go on attack for any commercial devices!

More details ?

Could please see white paper

&

Questions ?

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Thank you ☺

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