Attacks On And With API: PIN Recovery Attacks

Masaryk University in Brno
Faculty of Informatics

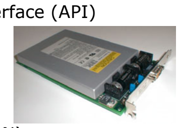
Jan Krhovják
Daniel Cvrček

Roadmap

- Introduction
  - Basic terminology
  - Insufficient checking of function parameters
- Decimalisation table attacks
  - Techniques of PIN generation and verification
  - Attacks utilising known PINs
  - Extended attack without known PINs
- ANSI X9.8 attacks
  - PIN-block formats
  - Attacking PAN with translation&verification functions
  - Attacking PIN translation functions
  - Collision attack
- Conclusion

Introduction

- Basic terminology
  - Hardware Security Module (HSM)
    - Example: IBM 4758 (depicted below)
  - Host device
  - Application Programming Interface (API)
  - Attack
    - PIN Recovery Attacks
  - Clear PIN-block (CPB)
  - Encrypted PIN-block (EPB)
  - Personal Account Number (PAN)
- Insufficient checking of function parameters



PIN Generation and Verification

- Techniques of PIN generation and verification
  - IBM 3624 and IBM 3624 Offset
    - Based on validation data (e.g. account no. – PAN)
    - Validation data encrypted with *PIN derivation key*
    - The result truncated, decimalised => PIN

    - IBM 3624 Offset – decimalised result called IPIN (Intermediate PIN)
    - Customer selects PIN,
      Offset = PIN – IPIN (digits mod 10)
  - Verification process is the same
    - result is compared with decrypted EPB (encrypted PIN from cash-machine)

PIN Verification Function

- Simplified example of verification function and its parameters:
  1. PIN (CPB) encryption/decryption key
  2. PIN derivation key – for PIN generation process
  3. PIN-block format
  4. validation data – for PIN extraction from EPB (e.g. PAN)
  5. encrypted PIN-block
  6. verification method
  7. data array – contains decimalisation table, validation data and offset
- Clear PIN is not allowed to be a parameter of verification function!

PIN Verification – IBM 3624 Offset

- Inputs – (4-digit PIN)
  - PIN in EPB is `7216` (delivered by ATM)
  - Public offset (typically on card) – `4344`
  - Decimalisation table – `0123 4567 8901 2789`
  - Personal Account Number (PAN) is `4556 2385 7753 2239`
- Verification process
  - PAN is encrypted => `3F7C 2201 00CA 8AB3`
  - Truncated to four digits => `3F7C`
  - Decimalised according to the table => `3972`
  - Added offset `4344`, generated PIN => `7216`
  - Decrypt EPB and compare with the correct PIN

Decimalisation Table Attacks I

- Attacks utilising known PINs
  - Assume four-digit PINs and offset `0000`
  - If decim. table (DT) is `0000 0000 0000 0000` generated PIN is always `0000`
  - PIN generation function with *zero* DT outputs EPB with PIN `0000`
  - Let D_{orig} = `0123 4567 8901 2345` is original DT
  - D_i is a *zero* DT with "1" where D_{orig} has *i* e.g. D_5 = `0000 01`**`1`**`00 0000 0001`
  - The attacker calls 10x verification function with EPB of `0000` PIN and with D_0 to D_9
  - If *i* is not in PIN, the "1" will not be used and verification against `0000` will be successful

Decimalisation Table Attacks II

- Results
  - All PIN digits are discovered
  - PIN space reduced from 10^4 to 36 (worst case)
- Extended attack without known PINs
  - Assume, that we obtain customers EPB with correct PIN
  - D_i are DTs containing $i-1$ on positions, where D_{orig} has *i* e.g. D_5 = `0123 `**`4`**`467 8901 234`**`4`**
  - Verification function is called with intercepted EPB and D_i
  - Position of PIN digits is discovered by using *offset* with digits incremented individually by "1"
    - Bold "**4**" changes to "5"

DT Attacks – Example

- Let PIN in EPB be 1492, offset is 1234
- We want to find position of "2"
- Verification function with D_2 results in 1491!=1492 => fails
- Offsets 2234, 1334, 1244, 1235 increment resulting generated PIN (2491,1591,…)
- Eventually the verification is successful with the last offset => 2 is the last digit
- To determine four-digit PIN with different digits is needed at most 6 calls of verification function

Clear PIN Blocks

- Code Book Attacks and PIN-block formats
  - => clear PIN blocks (CPB)
- ECI-2 format for 4 digits PINs
  - ECI-2 CPB = pppprrrrrrrrrrrr
- Visa-3 format for 4–12 digits PINs
  - Visa-3 CPB = ppppFxxxxxxxxxxx
- **ANSI X9.8 format for 4–12 digits PINs**
  - P_1 = ZlppppffffffffFF
  - P_2 = ZZZZaaaaaaaaaaaa
  - ANSI X9.8 CPB = P_1 xor P_2

p – PIN digit
r – random digit
x – arbitrary, all the same
F – 0xF digit

Z – 0x0 digit
l – PIN length
f – either "p" of "F"
a – PAN digit

ANSI X9.8 Attacks I

- Attacking PAN with translation & verification functions – input parameters (key K, EPB, PAN)
  - Functions decrypt EPB & extract PIN
    CPB xor P_2 = 04ppppFFFFFFFFFF => PIN = pppp
  - Extraction tests PIN digits to be 0–9!
  - If a digit of PAN is modified by x
    - P_2' = P_2 xor 0000x00000000000
    - CPB xor P_2'=04ppppFFFFFFFFFF xor
      xor 0000x00000000000
      it means that PIN = pppp xor 00x0
    - If p xor x < 10 function ends successfully, otherwise function fails

ANSI X9.8 Attacks II

- The sequence of (un)successful function calls can be used by attacker to identify p as a digit from set {p, p xor 1}
- For example if PIN digit is 8 or 9, then this sequence will be PPFFFFFFPPPPPPPP, where P is PASS, F is FAIL and x is incremented from 0 to 15

- Only last two PIN digits can be attacked
- PIN space is reduced from 10^4 to 400
- This attack can be extended to all PIN digits

ANSI X9.8 Attacks III

- Attack against PIN translation functions
  - Input/output PIN-block format can be modified
  - Consider ANSI X9.8 EPB with null PAN (wlog)
    - Attacker specifies input format as VISA-3 and output as ANSI X9.8
    - PIN is then extracted from `04ppppFFFFFFFFFF` as `04pppp`
    - `04pppp` is formatted into ANSI CPB as `0604ppppFFFFFFFF` and encrypted
  - Attacker has EPB with six-digit PIN and can use previous attack to determine all 4 digits of original PIN
- PIN space is reduced from 10^4 to 16

ANSI X9.8 Attacks IV

- PIN can be also determined exactly
- The attacker needs to be able to modify PAN
  - This is impossible if input format is Visa-3
  - PAN modification must be done earlier (in EPB)
- Let's modify second digit of PAN by `x`
  - Input format is VISA-3 and output ANSI X9.8
  - PIN is decrypted from ANSI X9.8 EPB and extracted as `04pppp xor 00000x`
  - If `x = p xor F` (i.e. `x xor p = F`) then PIN is extracted as `04ppp` and formatted into ANSI X9.8
  - This can be detected by/during translation back to VISA-3 format EPB

ANSI X9.8 Attacks – Collision Attack

- Assuming well designed API (e.g. DT is fixed)
- Attack allows to partially identify last two PIN digits
  - Basic idea (simple example with one-digit PIN&PAN)

PAN	PIN	xor	EPB	PAN	PIN	xor	EPB
0	0	0	21A0	7	0	7	2F2C
0	1	1	73D2	7	1	6	345A
0	2	2	536A	7	2	5	0321
0	3	3	FA2A	7	3	4	FF3A
0	4	4	FF3A	7	4	3	FA2A
0	5	5	0321	7	5	2	536A
0	6	6	345A	7	6	1	73D2
0	7	7	2F2C	7	7	0	21A0
0	8	8	**4D0D**	7	8	F	**AC42**
0	9	9	**21CC**	7	9	E	**9A91**

  - Attacker knows for each PAN only the set of EPBs

ANSI X9.8 Attacks – Collision Attack

- Looking collisions in output of PIN generation function
- Remember PIN generation & ANSI X9.8 CPB
- Formalizing PIN generation function
  - So EPB = $Encrypt(Pad(U_a, U_b, U_c, U_d))$, where
    $U_a = (F_a(e,f)+a) \bmod 10$
    $U_b = (F_b(e,f)+b) \bmod 10$
    $U_c = ((F_c(e,f)+c) \bmod 10) \text{ xor } e$
    $U_d = ((F_d(e,f)+d) \bmod 10) \text{ xor } f$
  - e, f are first two digits of PAN
  - $F_x(e,f)$ is respective digit of IPIN
  - a, b, c, d are digits of offset

ANSI X9.8 Attacks – Collision Attack

- The whole function is $Gen(a,b,c,d,e,f)$
- Desired IPIN digits are $F_c(e,f)$ and $F_d(e,f)$
  - To get $F_c(e,f)$, the attacker must choose a fixed value $DELTA$
  - She modifies offset and to get collisions:
    $Gen(a,b,c,d,e,f) = Gen(a',b',c',d',e \text{ xor } DELTA,f)$
  - When a collision is found: $U_c=U_{c'}$ and $DELTA = ((F_c(e,f)+c) \bmod 10) \text{ xor } ((F_c(e \text{ xor } DELTA,f)+c) \bmod 10)$
  - Certain DELTA can be obtained only by a few combinations (e.g F=6 xor 9 or 7 xor 8)
    $=> (F_c(e,f)+c) \bmod 10$ is 6, 7, 8 or 9
  - Next collision for DELTA=7 leaves only 6 and 7
  - Because c is known, we simply get $F_c(e,f)$

Conclusion

- The security of current generation banking APIs is really bad with respect to **insider attacks**
- Function parameters can be arbitrarily changed – **controls not sufficient**
- PIN-block formats do not ensure sufficient **entropy**
- Number of standards implemented ensures **interoperatibility** but also **causes errors**
- Can asymmetric cryptography help? See an attack on Chrysalis Luna CA3 module!
- Other attacks ☺
  - Master's thesis (in czech): http://www.fi.muni.cz/~xkrhovj/apinf/sdipr/DP_upravena_v1.pdf
  - Mike Bond's research: http://www.cl.cam.ac.uk/~mkb23/research.html
  - Jolyon Clulow's research: http://www.cl.cam.ac.uk/~jc407/