On the Security of two RFID Mutual Authentication Protocols

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OUTLINE

1. RFID Systems Overview
2. HYCLT Protocol
3. Security Analysis of HYCLT
4. HLL Protocol
5. Security Analysis of HLL
6. Conclusion

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EPC C1 G2 RFID Standard

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- EPCglobal Class-1 Gen-2 (EPC C1 G2) is one of the most important standards proposed by EPCglobal .
- This standard was adopted in 2004.
- 18months later (March–April 2006) ratified by ISO.
- It was published as an amendment to 18000-6 standard.

The most important properties of EPC-C1G2 :

- Tags are passive.
- Tags operate on the UHF band (860–960 MHz).
- EPC-C1 G2 tags cannot afford traditional cryptographic primitives.
- Tags include on chip a 16-bit Pseudo-Random Number Generator (PRNG) and a 16-bit Cyclic Redundancy Code (CRC) checksum.

EPC C1 G2 RFID Standard

- Tags have two 32-bit passwords:

- Kill Password: is a 32-bit value stored in reserved memory (00h to 1Fh).

A reader shall use a tag's kill password once, to kill the tag and render it silent there after.

- Access Password : is a 32-bit value stored in reserved memory (20h to 3Fh).

Tags with a nonzero access password shall require a reader to issue this password before transitioning to the secured state, which will allow it to read or write in the password fields.

EPC C1 G2 Security

- Bailey and A. Juels and Peris-Lopez et al. pointed out the weakness in the EPC C1G2 reader-to-tag authentication protocol.
- Konidala et al.'s proposed an alternative scheme which is known to be flawed. In Konidala et al.'s scheme, the *PadGen* function is the key component in constructing the 16-bit pads to mask the password which is transferred over an insecure channel. However, this masking leaks information related to the tag's secrets.

- To solve Konidala et al. protocol's weaknesses two novel protocols have been proposed by Huang *et al.* and Huang, Lin and Li respectively.

- We consider security of these protocols which are denoted by *HYCLT* designed by Huang *et al.* and *HLL* designed by Huang, Lin and Li respectively.

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HYCLT Protocol

R_i :	*RFID* reader *i*
T_i :	*RFID* tag *i*
Req_R :	Reader request
R_{Tx} :	Random numbers generated by the tag.
R_{Mx} :	Random numbers generated by the server.
EPC :	Electronic product code.
Apwd :	*Access password*
Kpwd :	*Kill password*
PAD_x :	*Masking values.*
$CCPwd_{M_1}$:	$Apwd_M \oplus PAD_1$
$CCPwd_{L_1}$:	$Apwd_M \oplus PAD_2$
$X\|_i$:	i^{th} bit of string X
$\oplus$:	Exclusive or operation
$\|\|$:	Concatenation operation
X_{m-n} :	A fraction of X from the m^{th} bit to the n^{th} bit.

HYCLT Protocol

- Huang et al. have proposed (HYCLT) based on a new PadGen and also demonstrated the FPGA hardware implementation of it.

- Any tag in HYCLT protocol have two 32-bit passwords called *Kill* and *Access* password.

- We show that an adversary can determine the complete *Access* password of HYCLT.

HYCLT Protocol

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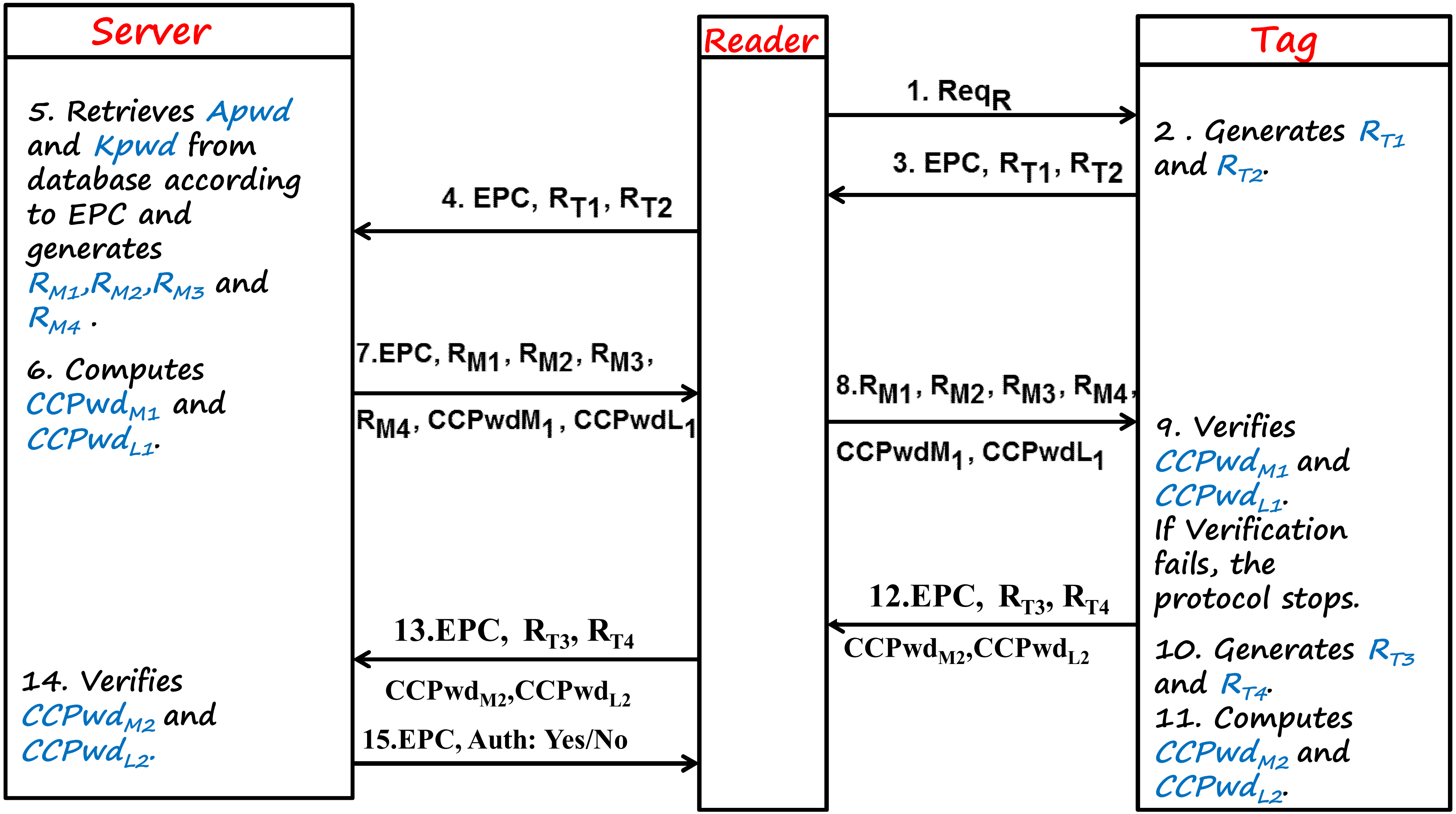

PadGen Function of HYCLT

The simple PadGen function proposed in HYCLT accepts a 32-bit value and two 16-bit values as input and outputs 16 bits.

$X \in \{0,1\}^{32}, Y \in \{0,1\}^{16}, Z \in \{0,1\}^{16}$

$X = X_0 X_1 X_2 X_3 \ldots X_{31} \qquad X_i \in \{0,1\}$

$Y = d_{Y1} d_{Y2} d_{Y3} d_{Y4}$

$Z = d_{Z1} d_{Z2} d_{Z3} d_{Z4} \qquad d_{Zi} \in \{0, 1, \ldots, 15\} \quad i \in \{1, 2, 3, 4\}$ [base 10]

Example,

$Z = 1101\ 0110\ 1000\ 1001$ can be represented as $Z = 13\ 06\ 08\ 09$

which means that

$d_{Z1} = 13;\ d_{Z2} = 06;\ d_{Z3} = 08;\ d_{Z4} = 09$

$Y = h_{Y1} h_{Y2} h_{Y3} h_{Y4}$

$Z = h_{Z1} h_{Z2} h_{Z3} h_{Z4}, \qquad h_{Zi} \in \{0, 1, \ldots, F\} \quad i \in \{1, 2, 3, 4\}$ [base 16]

Example,

$Z = 1101\ 0110\ 1000\ 1001$ can be represented as $Z = C\ 6\ 8\ 9$

which means that

$h_{Z1} = C;\ h_{Z2} = 6;\ h_{Z3} = 8;\ h_{Z4} = 9.$

PadGen Function of HYCLT

$$PadGen(x, y, z)$$
$$= x_{d_{y1}} x_{d_{y1}+16} x_{d_{y2}} x_{d_{y2}+16} \| x_{d_{z1}} x_{d_{z1}+16} x_{d_{z2}} x_{d_{z2}+16} \|$$
$$x_{d_{y3}} x_{d_{y3}+16} x_{d_{y4}} x_{d_{y4}+16} \| x_{d_{z3}} x_{d_{z3}+16} x_{d_{z4}} x_{d_{z4}+16}$$

$$X = 1001\ 1111\ 0011\ 1011\ 0000\ 0011\ 1100\ 0101$$

The location of the extracted bits

$$Y = 0111\ 0100\ 0110\ 1011$$
$$Z = 1101\ 0110\ 1000\ 1001$$

$$PadGen(x, y, z)$$
$$= x_7\ x_{7+16} x_4\ x_{4+16} \| x_{13}\ x_{13+16} x_6\ x_{6+16} \|$$
$$x_6\ x_{6+16} x_{11}\ x_{11+16} \| x_8\ x_{8+16} x_9\ x_{9+16}$$

$$= 1110\ 0011\ 1110\ 0101$$

PadGen Function of HYCLT

$$Apwd = a_0\, a_1\, a_2\, a_3\, \ldots a_{31} \qquad a_i \in \{0, 1\}$$

$$Apwd_L = a_0\, a_1\, a_2\, a_3\, \ldots a_{15}$$

$$Apwd_M = a_{16}\, a_{17}\, a_{18}\, a_{19}\, \ldots a_{31}$$

$$Kpwd = k_0\, k_1\, k_2\, k_3\, \ldots k_{31} \qquad k_i \in \{0, 1\}$$

$$R_{Tx} = d_{t1} d_{t2} d_{t3} d_{t4}$$

$$R_{Mx} = d_{m1} d_{m2} d_{m3} d_{m4} \qquad x \in \{1, 2, 3, 4\} \quad \text{[base 10]}$$

$$R_{Tx} = h_{t1} h_{t2} h_{t3} h_{t4}$$

$$R_{Mx} = h_{m1} h_{m2} h_{m3} h_{m4} \qquad h_{mj} \in \{0, \ldots, F\} \quad j \in \{1, 2, 3, 4\} \quad \text{[base 16]}$$

PadGen Function of HYCLT

PadGen function is used to compute masking values PAD_x**, where** $x \in \{1, 2, 3, 4\}$

$$
\begin{aligned}
R_{Vx} &= PadGen(Apwd, R_{TX}, R_{MX}) \\
&= a_{d_{t1}} a_{d_{t1}+16} a_{d_{t2}} a_{d_{t2}+16} \| a_{d_{m1}} a_{d_{m1}+16} a_{d_{m2}} a_{d_{m2}+16} \| \\
&\quad a_{d_{t3}} a_{d_{t3}+16} a_{d_{t4}} a_{d_{t4}+16} \| a_{d_{m3}} a_{d_{m3}+16} a_{d_{m4}} a_{d_{m4}+16} \\
&= d_{v1} d_{v2} d_{v3} d_{v4}
\end{aligned}
$$

$$
\begin{aligned}
PAD_X &= PadGen(Kpwd, R_{Vx}, R_{Tx}) \\
&= k_{d_{v1}} k_{d_{v1}+16} k_{d_{v2}} k_{d_{v2}+16} \| k_{d_{t1}} k_{d_{t1}+16} k_{d_{t2}} k_{d_{t2}+16} \| \\
&\quad k_{d_{v3}} k_{d_{v3}+16} k_{d_{v4}} k_{d_{v4}+16} \| k_{d_{t3}} k_{d_{t3}+16} k_{d_{t4}} k_{d_{t4}+16} \\
&= h_{p1} h_{p2} h_{p3} h_{p4}
\end{aligned}
$$

PadGen Function of HYCLT

To increase the security level of HYCLT, authors also proposed a more complex way to use R_{Tx} and R_{Mx} as follows:

$$R_{Vx} = PadGen(Apwd, R_{Tx}, R_{Mx}) = a_{w1}a_{w2}a_{w3}a_{w4} \| a_{w5}a_{w6}a_{w7}a_{w8} \| a_{w9}a_{w10}a_{w11}a_{w12} \| a_{w13}a_{w14}a_{w15}a_{w16} = d_{v1}\, d_{v2}\, d_{v3}\, d_{v4}$$

$$PAD_X = PadGen(Kpwd, R_{Vx}, R_{Tx}) = k_{z1}k_{z2}k_{z3}k_{z4} \| k_{z5}k_{z6}k_{z7}k_{z8} \| k_{z9}k_{z10}k_{z11}k_{z12} \| k_{z13}k_{z14}k_{z15}k_{z16} = h_{p1}\, h_{p2}\, h_{p3}\, h_{p4}$$

$CCPwd_{M_1} = Apwd_M \oplus PAD_1$ **and** $CCPwd_{L_1} = Apwd_L \oplus PAD_2$

PadGen Function of HYCLT

$$w_{1-4} = d_{t1} + d_{m1},\ d_{t1} + d_{m2},\ d_{t1} + d_{m3},\ d_{t1} + d_{m4}$$
$$w_{5-8} = d_{t2} + d_{m1},\ d_{t2} + d_{m2},\ d_{t2} + d_{m3},\ d_{t2} + d_{m4}$$
$$w_{9-12} = d_{t3} + d_{m1},\ d_{t3} + d_{m2},\ d_{t3} + d_{m3},\ d_{t3} + d_{m4}$$
$$w_{13-16} = d_{t4} + d_{m1},\ d_{t4} + d_{m2},\ d_{t4} + d_{m3},\ d_{t4} + d_{m4}$$

$$z_{1-4} = d_{t1} + d_{v1},\ d_{t1} + d_{v2},\ d_{t1} + d_{v3},\ d_{t1} + d_{v4}$$
$$z_{5-8} = d_{t2} + d_{v1},\ d_{t2} + d_{v2},\ d_{t2} + d_{v3},\ d_{t2} + d_{v4}$$
$$z_{9-12} = d_{t3} + d_{v1},\ d_{t3} + d_{v2},\ d_{t3} + d_{v3},\ d_{t3} + d_{v4}$$
$$z_{13-16} = d_{t4} + d_{v1},\ d_{t4} + d_{v2},\ d_{t4} + d_{v3},\ d_{t4} + d_{v4}$$

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Security Analysis of Complex HYCLT

Passive Adversary:

Assume that an adversary impersonates the target tag and sends $R_{Tx} = d_{t1}d_{t2}d_{t3}d_{t4}$ to the reader such that $d_{t1}=d_{t2}=d_{t3}=d_{t4}$ e.g. $R_{Tx}=0$

$$w_{1-4} = w_{5-8} = w_{9-12} = w_{13-16}$$
$$d_{v1} = d_{v2} = d_{v3} = d_{v4}$$

$$Z_1 = Z_2 = \ldots = Z_{16} = Z$$

$$PAD_X = PadGen(Kpwd, d_{v1}d_{v2}d_{v3}d_{v4}, R_{Tx}) = k_Z \| k_Z \| k_Z \| k_Z$$
$$Z \in \{0,1,\ldots,F\}$$

$$PAD_X = PadGen(Kpwd, d_{v1}d_{v2}d_{v3}d_{v4}, R_{Tx}) \in \{0000, FFFF\}$$

$CCPwd_{M_1} = Apwd_M \oplus PAD_1$ **and** $CCPwd_{L_1} = Apwd_L \oplus PAD_2$

The adversary can determine $Apwd_M \| Apwd_L$ **with the probability of** 2^{-2}

Security Analysis of Complex HYCLT

Active Adversary

Assume that an active adversary intercepts the message from the tag to the reader in step 2 and replaces R_{T1} by $R_{T1} = d_{t1} \| d_{t2} \| d_{t3} \| d_{t4}$

where $d_{t1} = d_{t2} = d_{t3} = d_{t4} = X$

$$\Rightarrow R_{T1} = i \| i \| i \| i \,, \quad 0 \le i \le 15$$

$$R_{V1} = PadGen(Apwd, R_{T1}, R_{M1})$$
$$= a_x \; a_{x+16} a_x \; a_{x+16} \| a_{d_{m1}} \; a_{d_{m1}+16} a_{d_{m2}} \; a_{d_{m2}+16} \|$$
$$a_x \; a_{x+16} a_x \; a_{x+16} \| a_{d_{m3}} \; a_{d_{m3}+16} a_{d_{m4}} \; a_{d_{m4}+16}$$
$$= d_{v1} d_{v2} d_{v1} d_{v4}$$

$d_{v1} = d_{v3}$

$$PAD_1 = PadGen(Kpwd, R_{V1}, R_{T1})$$
$$= k_{d_{v1}} \; k_{d_{v1}+16} k_{d_{v2}} \; k_{d_{v2}+16} \| k_{d_{t1}} \; k_{d_{t1}+16} k_{d_{t2}} \; k_{d_{t2}+16} \|$$
$$k_{d_{v1}} \; k_{d_{v1}+16} k_{d_{v4}} \; k_{d_{v4}+16} \| k_{d_{t3}} \; k_{d_{t3}+16} k_{d_{t4}} \; k_{d_{t4}+16}$$
$$= h_{p1} h_{p2} h_{p3} h_{p4}$$

Security Analysis of Complex HYCLT

Given that $CCPwd_{M1} = Apwd_M \oplus PAD_1$ and $APwd_M = a_{16}a_{17}...a_{31}$, we can extract:

$$(CCPwd_{M1})|_0 \oplus (CCPwd_{M1})|_8 = a_{16} \oplus a_{24}$$
$$(CCPwd_{M1})|_1 \oplus (CCPwd_{M1})|_9 = a_{17} \oplus a_{25}$$

which used to recognize a target tag with the success probability of $1-2^{-4}$.

For the simple version of PadGen in HYCLT protocol, we can recover both Apwd and Kpwd.

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HLL Protocol

- Huang, Lin and Li presented another protocol with a different *PadGen* function based on a set of values i.e. (R_V, R_W), which is not under the direct control of the adversary.

- Any tag in HLL have two 32-bit passwords called *Kill* and *Access* passwords.

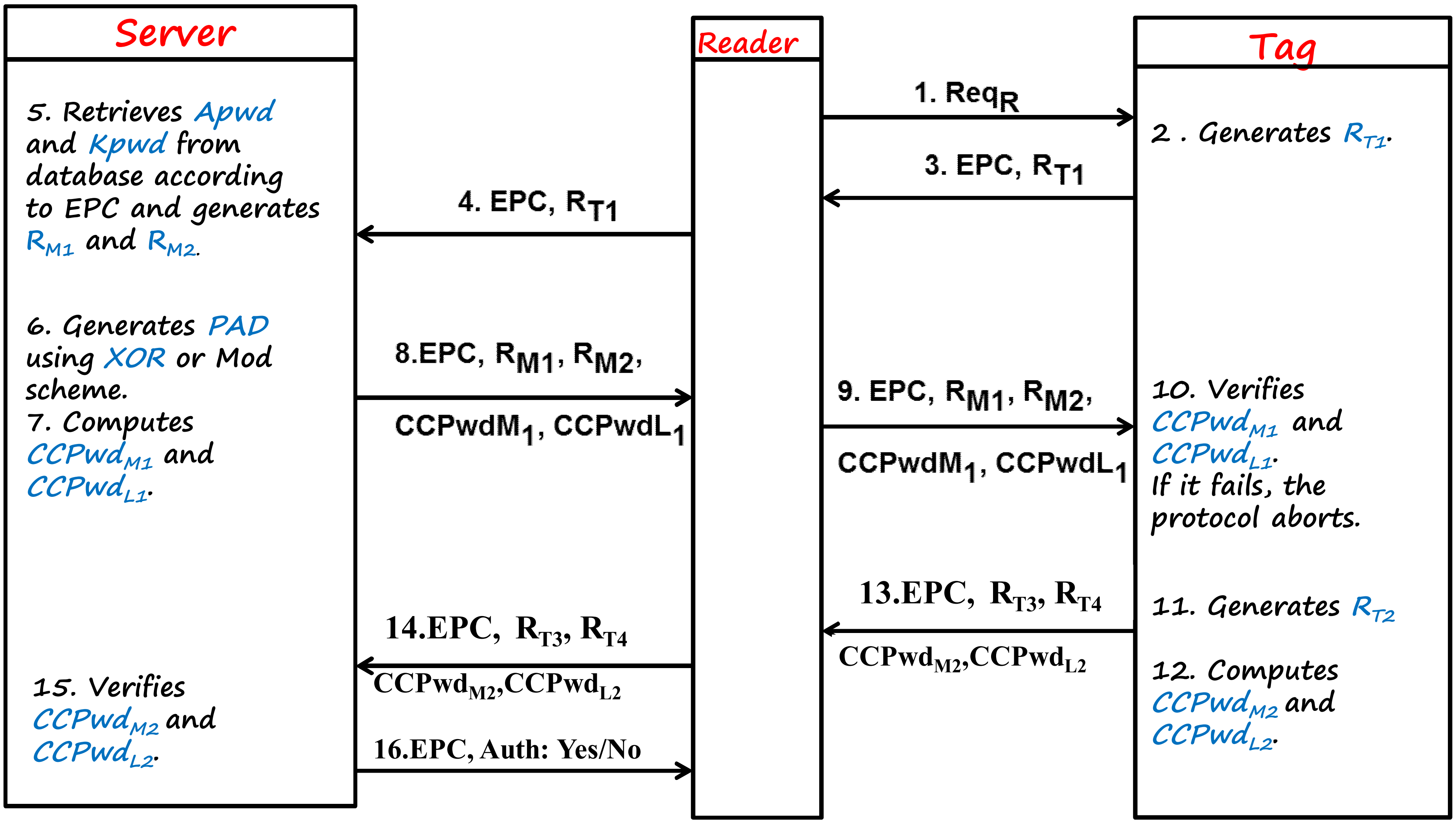
- The main difference between HYCLT and HLL is their *PadGen* function calculations.

- HLL against HYCLT is based on *XOR* or *MOD* operation to generate *PadGen* function.

- We show several attacks on *XOR* based.

- Our attack does not work for the *MOD* mode.

HLL Protocol



PadGen Function of HLL

$R_{T_i} \quad i \in \{1,2\}$ → R_T $\qquad$ $R_{M_i} \quad i \in \{1,2\}$ → R_M

in HLL defined that $R_T \oplus R_M = R_{T\oplus M} = d_{x1} d_{x2} d_{x3} d_{x4}$

$$R_W = PadGen(Apwd, R_T, R_{T\oplus M})$$

$$= a_{d_{t1}} a_{d_{t2}} a_{d_{t3}} a_{d_{t4}} \| a_{d_{t1}+16} a_{d_{t2}+16} a_{d_{t3}+16} a_{d_{t4}+16} \|$$

$$a_{d_{x1}} a_{d_{x2}} a_{d_{x3}} a_{d_{x4}} \| a_{d_{x1}+16} a_{d_{x2}+16} a_{d_{x3}+16} a_{d_{x4}+16}$$

$$= d_{w1} d_{w2} d_{w3} d_{w4}$$

$$R_V = PadGen(Apwd, R_{T_x}, R_{M_x})$$

$$= a_{d_{t1}} a_{d_{t2}} a_{d_{t3}} a_{d_{t4}} \| a_{d_{t1}+16} a_{d_{t2}+16} a_{d_{t3}+16} a_{d_{t4}+16} \|$$

$$a_{d_{m1}} a_{d_{m2}} a_{d_{m3}} a_{d_{m4}} \| a_{d_{m1}+16} a_{d_{m2}+16} a_{d_{m3}+16} a_{d_{m4}+16}$$

$$= d_{v1} d_{v2} d_{v3} d_{v4} \qquad \text{[base10]}$$

PadGen Function of HLL

$$PAD_1 = PadGen(Kpwd, R_V, R_W)$$
$$= k_{d_{v1}} k_{d_{v2}} k_{d_{v3}} k_{d_{v4}} \| k_{d_{v1}+16} k_{d_{v2}+16} k_{d_{v3}+16} k_{d_{v4}+16} \|$$
$$k_{d_{w1}} k_{d_{w2}} k_{d_{w3}} k_{d_{w4}} \| k_{d_{w1}+16} k_{d_{w2}+16} k_{d_{w3}+16} k_{d_{w4}+16}$$
$$= h_{q1} h_{q2} h_{q3} h_{q4}$$

in HLL defined that $R_V \oplus R_W = R_{V \oplus W} = d_{s1} d_{s2} d_{s3} d_{s4}$

$$PAD_2 = PadGen(Kpwd, R_V, R_{V \oplus W})$$
$$= k_{d_{v1}} k_{d_{v2}} k_{d_{v3}} k_{d_{v4}} \| k_{d_{v1}+16} k_{d_{v2}+16} k_{d_{v3}+16} k_{d_{v4}+16} \|$$
$$k_{d_{s1}} k_{d_{s2}} k_{d_{s3}} k_{d_{s4}} \| k_{d_{s1}+16} k_{d_{s2}+16} k_{d_{s3}+16} k_{d_{s4}+16}$$
$$= h_{r1} h_{r2} h_{r3} h_{r4}$$

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Security Analysis of HLL

Observation 1: It can be seen that :

$$d_{v1} = d_{w1} = a_{d_{t1}}\ a_{d_{t2}} a_{d_{t3}}\ a_{d_{t4}}$$

$$d_{v2} = d_{w2} = a_{d_{t1}+16}\ a_{d_{t2}+16} a_{d_{t3}+16}\ a_{d_{t4}+16}$$

Observation 2: Following Observation 1

$$k_{d_{v1}} = k_{d_{w1}}, k_{d_{v2}} = k_{d_{w2}}$$

$$k_{d_{v1}+16} = k_{d_{w1}+16}$$

$$k_{d_{v2}+16} = k_{d_{w2}+16}$$

Security Analysis of HLL

Following Observation 2:

$$PAD_1 = k_{d_{v1}} k_{d_{v2}} k_{d_{v3}} k_{d_{v4}} \| k_{d_{v1}+16} k_{d_{v2}+16} k_{d_{v3}+16} k_{d_{v4}+16} \|$$
$$k_{d_{v1}} k_{d_{v2}} k_{d_{w3}} k_{d_{w4}} \| k_{d_{v1}+16} k_{d_{v2}+16} k_{d_{w3}+16} k_{d_{w4}+16}$$
$$= h_{q1} h_{q2} h_{q3} h_{q4}$$

Given that $CCPwd_{M1} = Apwd_M \oplus PAD_1$ and $APwd_M = a_{16} a_{17} \ldots a_{31}$, we extract:

$$(CCPwd_{M1})|_0 \oplus (CCPwd_{M1})|_8 = a_{16} \oplus a_{24}$$
$$(CCPwd_{M1})|_1 \oplus (CCPwd_{M1})|_9 = a_{17} \oplus a_{25}$$
$$(CCPwd_{M1})|_4 \oplus (CCPwd_{M1})|_{12} = a_{20} \oplus a_{28}$$
$$(CCPwd_{M1})|_5 \oplus (CCPwd_{M1})|_{13} = a_{21} \oplus a_{29}$$

which is used to recognize a target tag with the success probability of $1-2^{-4}$.

Security Analysis of HLL

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Observation 3: Following Observation 1

One can state that $d_{s1} = d_{s2} = 0$ **and** $R_{V \oplus W} = 00 d_{s3} d_{s4}$

Hence, we can rewrite PAD_2 as :

$$PAD_2 = Kpwd - PadGen(R_V, R_{V \oplus W})$$
$$= k_{d_{v1}} k_{d_{v2}} k_{d_{v3}} k_{d_{v4}} \| k_{d_{v1}+16} k_{d_{v2}+16} k_{d_{v3}+16} k_{d_{v4}+16} \|$$
$$k_0 k_0 k_{d_{s3}} k_{d_{s4}} \| k_{16} k_{16} k_{d_{s3}+16} k_{d_{s4}+16} = h_{r1} h_{r2} h_{r3} h_{r4}$$

$$CCPwd_{L1} = XXXX \| XXXX \| (k_0 \oplus a_8)(k_0 \oplus a_9) XX \|$$
$$(k_{16} \oplus a_{12})(k_{16} \oplus a_{13}) XX$$

Which is used to recognize a target tag with the success probability of $1-2^{-4}$.

Security Analysis of HLL

Comparing PAD_1 and PAD_2 , we can see:

$$h_{q1}h_{q2} = h_{r1}h_{r2}$$
$$PAD_1 = h_{q1}h_{q2}h_{q3}h_{q4}$$
$$PAD_2 = h_{r1}h_{r2}h_{r3}h_{r4}$$
$$CCPwd_{M1} = Apwd_M \oplus PAD_1$$
$$CCPwd_{L1} = Apwd_L \oplus PAD_2$$
$$PAD_1 \oplus PAD_2 = 0000 \| 0000 \| XXXX \| XXXX, \quad \text{(Observation 4)}$$
$$Apwd_L = a_0a_1 \ldots a_{15} \quad , \quad Apwd_M = a_{16}a_{17} \ldots a_{31}$$
$$CCPwd_{L1} \oplus CCPwd_{M1} = (a_0 \oplus a_{16})(a_1 \oplus a_{17})(a_2 \oplus a_{18})(a_3 \oplus a_{19}) \|$$
$$(a_4 \oplus a_{20})(a_5 \oplus a_{21})(a_6 \oplus a_{22})(a_7 \oplus a_{23}) \| XXXX \| XXXX$$

- 8- LSB of $CCPwd_{M1} \oplus CCPwd_{L1}$ is independent of the random values, R_T and R_M
- These 8 bits of $CCPwd_{M1} \oplus CCPwd_{L1}$ are only dependent on $Apwd_L \oplus Apwd_M$.
- Adversary can use these 8- LSB of $CCPwd_{M1} \oplus CCPwd_{L1}$ as a measure to trace a tag.

Secret Disclosure Attack on HLL

Active Adversary

Assume that an active adversary intercepts the message from the tag to the reader in step 2 and replaces R_{T1} by $R^i_{T1} = d^i_{t1} \| d^i_{t2} \| d^i_{t3} \| d^i_{t4} = i \| i \| i \| i$, $0 \geq i \geq 15.$

Then, one can state that $d^i_{v1} = d^i_{w1} = a_i a_i a_i a_i \in \{0000,1111\}$

If $d^i_{v1} = d^i_{w1}$ then $k_{d^i_{v1}} \oplus k_{d^i_{w1}} = 0$

If $d^i_{v1} \neq d^i_{w1}$ then $k_{d^i_{v1}} \oplus k_{d^i_{w1}} = k_0 \oplus k_{15}$

We assume that $k_0 \oplus k_{15} = k_{16} \oplus k_{31} = 1$ *to disitinguish* $d^i_{v1} = d^i_{w1}$ from $d^i_{v1} \neq d^i_{w1}$ given $k_{d^i_{v1}} \oplus k_{d^i_{w1}}$ .it is valid with the probability of 2^{-2}

Secret Disclosure Attack on HLL

Some details, given $CCPwd^{i}_{M1}$ and $CCPwd^{j}_{M1}$:

$$CCPwd^{i}_{M1} \oplus CCPwd^{j}_{M1} = Apwd_{M} \oplus PAD^{i}_{1} \oplus Apwd_{M} \oplus PAD^{j}_{1}$$

$$= PAD^{i}_{1} \oplus PAD^{j}_{1}$$

$$= (k_{d^{i}_{v1}} \oplus k_{d^{j}_{v1}})(k_{d^{i}_{v2}} \oplus k_{d^{j}_{v2}})(k_{d^{i}_{v3}} \oplus k_{d^{j}_{v3}})(k_{d^{i}_{v4}} \oplus k_{d^{j}_{v4}})||$$

$$(k_{d^{i}_{v1}+16} \oplus k_{d^{j}_{v1}+16})(k_{d^{i}_{v2}+16} \oplus k_{d^{j}_{v2}+16})(k_{d^{i}_{v3}+16} \oplus k_{d^{j}_{v3}+16})(k_{d^{i}_{v4}+16} \oplus k_{d^{j}_{v4}+16})||$$

$$(k_{d^{i}_{w1}} \oplus k_{d^{j}_{w1}})(k_{d^{i}_{w2}} \oplus k_{d^{j}_{w2}})(k_{d^{i}_{w3}} \oplus k_{d^{j}_{w3}})(k_{d^{i}_{w4}} \oplus k_{d^{j}_{w4}})||$$

$$(k_{d^{i}_{w1}+16} \oplus k_{d^{j}_{w1}+16})(k_{d^{i}_{w2}+16} \oplus k_{d^{j}_{w2}+16})(k_{d^{i}_{w3}+16} \oplus k_{d^{j}_{w3}+16})(k_{d^{i}_{w4}+16} \oplus k_{d^{j}_{w4}+16})||$$

Secret Disclosure Attack on HLL

$\left(CCPwd_{M1}^{0} \oplus CCPwd_{M1}^{1}\right)\Big|_{0} = k_{d_{v1}^{0}} \oplus k_{d_{v1}^{1}}$ and $d_{v1}^{0} = a_0a_0a_0a_0$ and $d_{v1}^{1} = a_1a_1a_1a_1$;

$\left(CCPwd_{M1}^{0} \oplus CCPwd_{M1}^{2}\right)\Big|_{0} = k_{d_{v1}^{0}} \oplus k_{d_{v1}^{2}}$ and $d_{v1}^{2} = a_2a_2a_2a_2$;

$\left(CCPwd_{M1}^{0} \oplus CCPwd_{M1}^{i}\right)\Big|_{0} = k_{d_{v1}^{0}} \oplus k_{d_{v1}^{i}}$ and $d_{v1}^{2} = a_ia_ia_ia_i$;

Given that $k_0 \oplus k_{15} = 1$ if $k_{d_{v1}^{0}} \oplus k_{d_{v1}^{i}} = 0$ then $a_0 = a_i$ otherwise $a_0 \neq a_i$;

In this way we receive 16 equations that each of them includes a_0 and another bit of $Apwd_L$.

We guess a_0 (with the probaility of 0.5) and determine $a_1, ..., a_{15}$ which gives $Apwd_L$;

A similar approach is use to determine $Apwd_M$;

Given $Apwd$ We can also determine $KPwd$;

The total success probability of this attack is $2^{-2} \times 2^{-1} \times 2^{-1}$.

OUTLINE

1. RFID Systems Overview
2. HYCLT Protocol
3. Security Analysis of HYCLT
4. HLL Protocol
5. Security Analysis of HLL
6. **Conclusion**

Conclusion

- We considered the security of two RFID mutual authentication protocols conforming to the EPC-C1G2 standard.
- We showed that an attacker can obtain the *Access* and *Kill* passwords with high probability.
- We showed that for HYCLT protocol an adversary can determine the *Access* password with a probability of 2^{-2}
- We showed in HLL scheme, the passive adversary can trace a tag with a probability of $1-2^{-4}$
- We showed in HLL scheme the active adversary can determine all bits of *Access* password with a probability of 2^{-4}

THANK YOU