Automatic Generation of HCCA Resistant Scalar Multiplication Algorithm by Proper Sequencing of Field Multiplier Operands

Poulami Das, **Debapriya Basu Roy** and, Debdeep Mukhopadhyay
Indian Institute of Technology Kharagpur

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- Public Key Cryptography (PKC) was introduced to address key issues of Key Distribution Problem and Digital Signature Verification problems.
- The two most widely used primitives of PKC are RSA and Elliptic Curve Cryptography.
- Elliptic Curve Cryptography (ECC) has emerged as a strong alternative to RSA due to its property of more security per key bit.

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- Scalar Blinding, Point Coordinate Randomization: Countermeasure against Differential Power Analysis

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- It involves few (single) number of traces to break the entire secret key.
- Thus imposes a serious threat to ECC implementations.

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- *property* 3*:* Given a set S of n field multiplications $(m_1,\ m_2,\ \ldots,\ m_n)$, if there exists at least one pair $(m_i,\ m_j)$, where m_i and $m_j \in S$, $i \neq j$, sharing property 1.

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- *condition* 1*:* Only one of the sets set_a and set_d satisfies property 3.

HCCA scenario 1

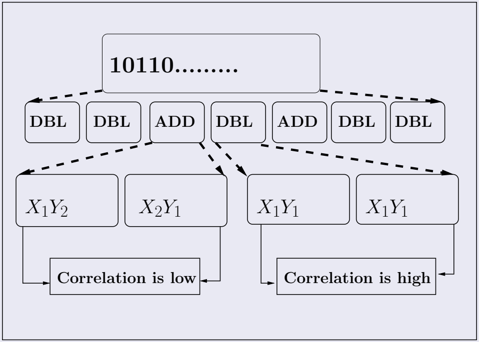

Figure: HCCA scenario 1

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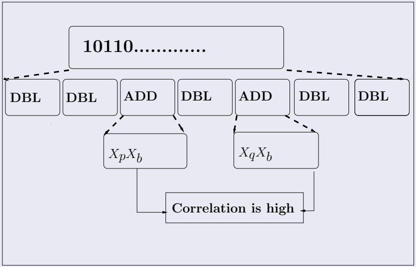

Figure: HCCA scenario 2

Long Integer Multiplication

Algorithm 1: Long Integer Multiplication algorithm(LIM)

Data: : $\{X = (X[t], X[t-1], ..., X[1])_{2^w}\}$, $\{Y = (Y[t], Y[t-1], ..., Y[1])_{2^w}\}$
Result: : $\{X.Y\}$

begin
  for $i \leftarrow 1$ **to** $2t$ **do**
    $R[i] = 0$
  end
  for $i \leftarrow 1$ **to** t **do**
    $C = 0$;
    for $j \leftarrow 1$ **to** t **do**
      $(U, V)_{2^w} = X[i] \times Y[j]$;
      $(U, V)_{2^w} = (U, V)_{2^w} + C$;
      $(U, V)_{2^w} = (U, V)_{2^w} + R[i + j - 1]$;
      $R[i + j - 1] = V$;
      $C = U$;
    end
    $R[i + t] = C$;
  end
  return R ;
end

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- Let C_i be the operation leaking information at each iteration.
- The output of the calculation C_i is denoted as O_i
- At each iteration output O_i leaks an information $l(O_i)$
- The leakage $l(O_i)$ is approximated by the Hamming Weight power model.
- A long integer multiplication LIM(A, B) leads to a leakage vector $< l_{(a_0 b_0)}, l_{(a_0 b_1)}, \ldots, l_{(a_i b_j)}, \ldots, l_{(a_{t-1} b_{t-1})} >$

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- $\rho_3 = Corr(LIM(A, B), LIM(C, D))$
- *Lemma* 1*:* $std(LIM(A, B)) = std(LIM(B, A))$
- *Lemma* 2*:* $cov(LIM(A, B), cov(LIM(C, B)) \neq cov(LIM(A, B), LIM(B, C))$.

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- With the help of the Lemmas following observations are made:
- *Observation 1:* $\rho_1 \neq \rho_2$
- *Observation 2:* $\rho_2 \approx \rho_3$
- *Observation 3:* $\rho_1 > \rho_2$, when C=A (i.e. both the operands are shared).

Safe sequence formation for Edward curve formula

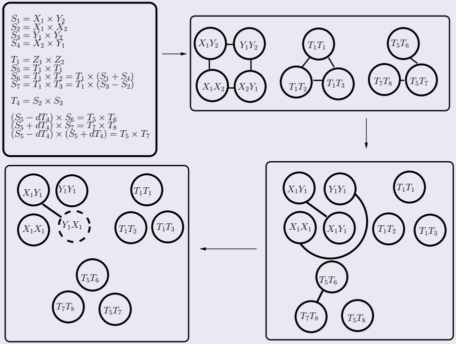

Figure: Safe sequence transformation of Edward unified formula

Countermeasure Design: Safe Sequence

Safe sequence formation for Brier-Joye unified formula

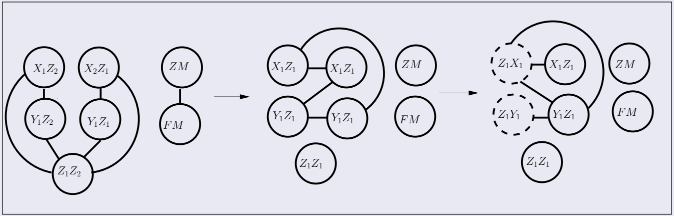

Figure: Safe sequence transformation of Brier-Joye unified formula

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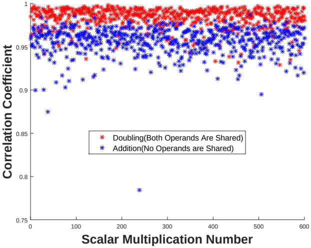
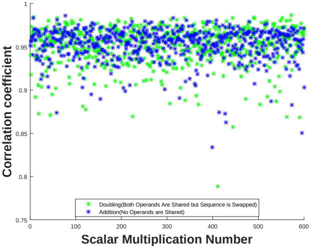


(a) Evaluation of HCCA on Edwards Curve Scalar Multiplier



(b) Evaluation of proposed countermeasure on Edwards Curve Scalar Multiplier

HCCA Scenario 2 and Other Collision Attacks

- HCCA scenario 2: Same input point is used in all addition steps
- Re-randomization: Use randomize input point at each stage of addition steps
- After the end of scalar multiplication loop, de-randomize the results[1].
- Similar re-randomization can be used to mitigate other single trace collision attacks [2].

[1] Poulami Das, Debapriya Basu Roy, Debdeep Mukhopadhyay: Exploiting the Order of Multiplier Operands: A Low Cost Approach for HCCA Resistance. IACR Cryptology ePrint Archive 2015: 925 (2015)

[2] N. Hanley, H. Kim, and M. Tunstall, Exploiting collisions in addition chain-based exponentiation algorithm using a single trace, Cryptography ePrint Archive: Report 2012/485.

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- We show how a unified addition (doubling) formula can be converted into a safe sequence where, the information leakage from sharing of operands among field multipliers have been hidden. Once the sequence have been determined through Algorithm 1 there is no runtime overhead requirement for the step 1 of our countermeasure.
- We have validated HCCA and our proposed countermeasure scheme on a SASEBO platform.

Thank You