Chair of Security in Information and Technology
School of Computation, Information and Technology
Technical University of Munich

SmartCard Lab: Final Presentation

Group 2

Mevlüt Yıldırım & Sait Sevban Cander

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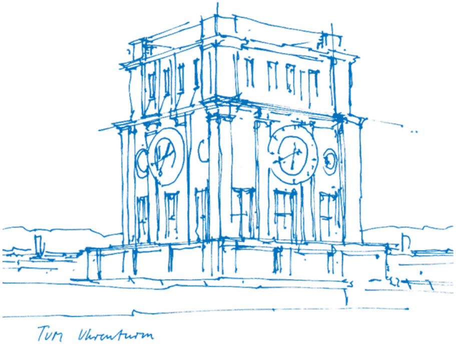


Outline

Task Distribution Among Team Members

Mevlüt Yıldırım

- Implementation of Random Number Generator
- Implementation of AES Countermeasures
- Countermeasure Attacks

Sait Sevban Cander

- Countermeasure Attacks
- Conducting DPA attack benchmarks against countermeasure

Outline

True Random Number Generator (TRNG)

Common entropy sources in STM32 microcontrollers include:

- Measuring jitter between two independent clocks:
  - SysTick timer combined with RTC/Watchdog (WDG).
- Utilizing the noisy internal temperature sensor value of the ADC.

For this implementation, the ADC was chosen as the entropy source for the TRNG.

ADC Setup & Read

ADC Setup:

- Short sampling time (13.5 cycles) for maximum jitter.
- 12-bit resolution.
- Temperature channel selected as the entropy source.

```
adc_enable_temperature_sensor();
adc_set_sample_time_on_all_channels(ADC1, ADC_SMPTIME_013DOT5);
adc_set_resolution(ADC1, ADC_RESOLUTION_12BIT);
adc_set_regular_sequence(ADC1, 1, channel_array2);
```

```
#define CHANNEL_ARRAY2 {1, 1, ADC_CHANNEL_TEMP}
```

ADC Read:

- Extract the least significant bit (LSB) from each conversion and apply an XOR-based correction to enhance randomness.

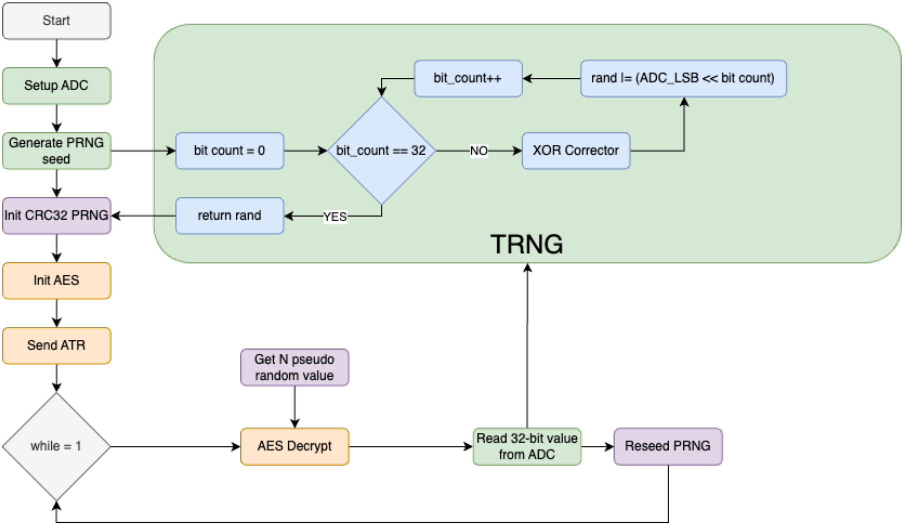
```
// Collect enough valid bits to form a 32-bit random
while (bit_position < 32)
{
    adc_start_conversion_regular(ADC1);
    while (!(adc_eoc(ADC1)))
        ;                                                /
    uint32_t adc_value_1 = adc_read_regular(ADC1); /
    uint32_t lsb_value_1 = adc_value_1 & 0x1;      /
    adc_start_conversion_regular(ADC1);
    while (!(adc_eoc(ADC1)))
        ;                                                /
    uint32_t adc_value_2 = adc_read_regular(ADC1); /
    uint32_t lsb_value_2 = adc_value_2 & 0x1;      /
    // XOR the two LSBs and add to the result
    uint32_t xor_result = lsb_value_1 ^ lsb_value_2;
    rand_value |= (xor_result << bit_position); // A
    bit_position++;
    // delay_cyc(10); // Allow time for jitter
}
return rand_value;
```

Pseudo-Random Number Generator (PRNG)

Overview:

- Cryptographically secure SHA-256 caused delays and timeouts during video stream decryption.
- CRC32 was chosen for its speed and efficiency, despite lacking cryptographic security.
  - Compatible with 32-bit entropy
  - Lightweight and fast
  - Easy to implement and use.
- Base implementation was sourced from GitHub and integrated into the OS (STM32's built-in CRC peripherals were a possible alternative).
- Reseeding after every decryption was used to improve security.

RNG Architecture



Outline

Shuffling Countermeasure

Permutation Generation:

- A 16-element permutation was generated using the PRNG and Fisher-Yates algorithm.
- Each element represents the index of data in the AES state.

```c
for (uint8_t i = len - 1; i > 0; i--)
{
    uint32_t rand = PRNG_Generate();
    uint8_t j = rand % (i + 1);
    // Swap perm[i] and perm[j]
    uint8_t temp = perm[i];
    perm[i] = perm[j];
    perm[j] = temp;
}
```

Shuffled AES Operations:

- The permutation was used to randomize operations in AES stages.
- Applied to AddRoundKey and InvSubBytes.

```c
static void ShuffledInvSubBytes(state_t *state, uint8_t *perm)
{
  for (uint8_t idx = 0; idx < 16; ++idx)
  {
    // Apply the permutation to access state and round key
    (*state)[perm[idx] / 4][perm[idx] % 4] = getSBoxInvert((*state)[perm[idx] / 4][perm[idx] % 4]);
  }
}
```

```c
static void ShuffledAddRoundKey(uint8_t round, state_t *state, const uint8_t *RoundKey, uint8_t *perm)
{
  uint8_t idx;
  for (idx = 0; idx < 16; ++idx)
  {
    // Apply the permutation to access state and round key
    (*state)[perm[idx] / 4][perm[idx] % 4] ^= RoundKey[(round * Nb * 4) + perm[idx]];
  }
}
```

Dummy Operations Countermeasure

- **Fixed Number of Operations:** 100 dummy operations are added per AES decryption.

Mimic S-Box:
Mimics the S-Box operation to obscure power traces.

```
for (uint8_t i = 0; i < iter_count; i++)
{
  uint8_t random_byte = PRNG_Generate() & 0xFF;
  uint8_t dummy_result = getSBoxInvert(random_byte);

  final_dummy_result ^= dummy_result;
  completed_dumops++;
}
```

Random Distribution:
Distributed randomly across AES rounds.

```
// Randomly distribute dummy operations across rounds
uint8_t dummy_ops_per_round[Nr];
memset(dummy_ops_per_round, 0, sizeof(dummy_ops_per_round));

for (uint8_t i = 0; i < Nr; i++)
{
  // Allocate a random portion of the remaining dummy operations
  if (remaining_dummyops > 0)
  {
    uint8_t allocation = PRNG_Generate() % (remaining_dummyops + 1);
    dummy_ops_per_round[i] = allocation;
    remaining_dummyops -= allocation;
  }
}
```

Random Order:
Inserted with a 50% chance before or after actual operations.

```
if (PRNG_Generate() % 2 == 0)
{
  InvSubBytes(state);
  DummyInvSubBytes(dummy_ops_per_round[round]);
}
else
{
  DummyInvSubBytes(dummy_ops_per_round[round]);
  InvSubBytes(state);
}
```

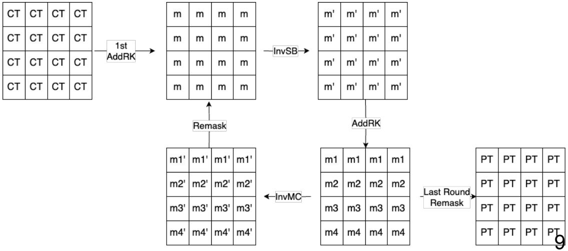
- Results are stored in volatile variables to prevent compiler optimizations.

Masking Countermeasure

- Total of 10 masks: 6 are random ($m1$, $m2$, $m3$, $m4$, m, and m') and 4 are computed ($m1'$, $m2'$, $m3'$, $m4'$).
- m and m' are used as input and output masks in the **InvSubBytes** operation.
- $m1$-$m4$ and $m1'$-$m4'$ are used as input and output masks in the **InvMixColumns** operation.
- **Decryption Flow:** Mask Init $\rightarrow$ Masked AddRK $\rightarrow$ [InvSR $\rightarrow$ Masked InvSB $\rightarrow$ Masked AddRK $\rightarrow$ (InvMC $\rightarrow$ ReMask)] $\rightarrow$ Final ReMask.

Mask Init:

- Precompute the masked invSB.
- Mask the final round key with m.
- Mask all other round keys with $m1 - m4$ & m'.



OS and AES Results

AES Execution Time

Implementation	Time [ms]	Difference [%]
Reference card (no countermeasure)	54.1	N/A
Own OS No Countermeasure	51.5	-4.8%
Own OS Dummy Ops.	53.9	+4.66%
Own OS Shuffling	51.8	+0.58%
Own OS Masking	53.7	+4.27%
Own OS All 3	56.6	+9.90%

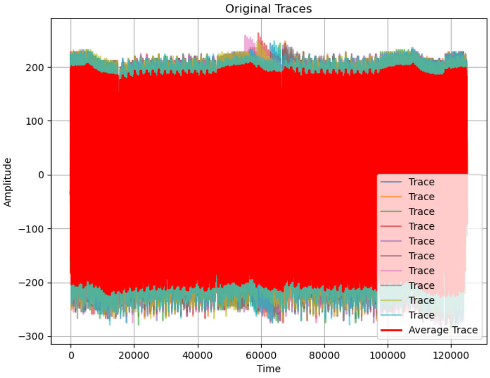
Memory Usage

Implementation	Text [kB]	Data [B]	BSS [B]	Total [B]	Difference [%]
Own OS No Countermeasure	3.8	8	176	3952	N/A
Own OS Dummy Ops.	5.856	28	192	6036	+52.77
Own OS Shuffling	5.716	28	192	5972	+51.15
Own OS Masking	6372	28	448	6848	+173.27
Own OS All 3	6660	28	452	7140	+180.66

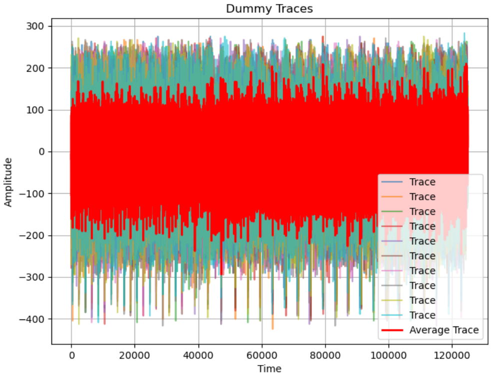
Outline

Attacking Own Card

No protection

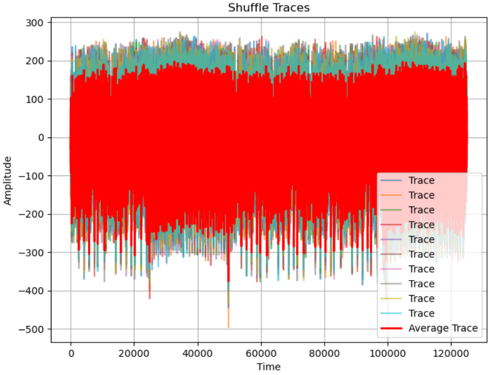


Dummy Operations

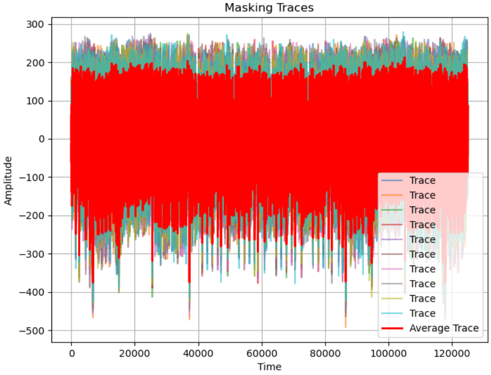


Attacking Own Card

Shuffling



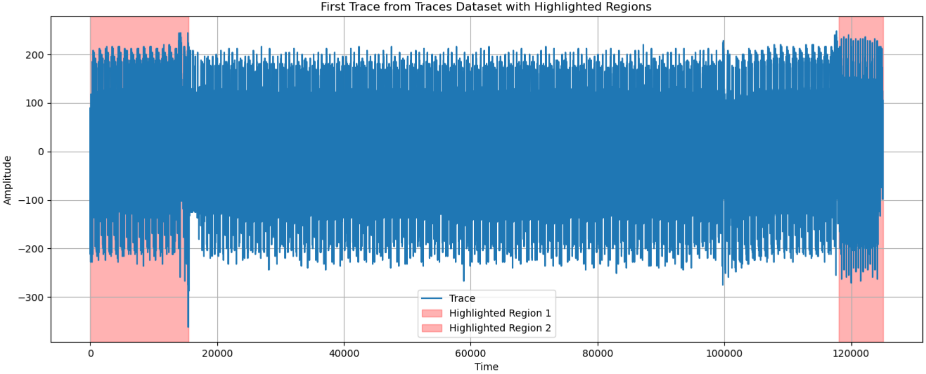
Masking



Possible Reasons

- Too many traces are required
- Problems due to misalignment
- Need of a more advanced attack (2nd order)
- Sample count uncertainty

Attack on Reference Card + Shuffling



DPA Attack Benchmark Results

Implementation	Broken [yes/no]	Min. # of Traces	Duration [s]	Compression Method	Window Size
Own Card (no countermeasure)	Yes	250	0.91	Squared	7
Own Card + Dummy Operations	X	X	X	X	X
Own Card + Shuffling	Yes	400	0.65	Absolute	13
Own Card + Masking	X	X	X	X	X
Reference Card (no countermeasure)	Yes	200	0.86	Max	9
Reference Card + Dummy Operations	X	X	X	X	X
Reference Card + Shuffling	Yes	7050	0.7	Absolute	17
Reference Card + Masking	X	X	X	X	X