hexhive

USBFuzz: A Framework for Fuzzing USB Drivers by Device Emulation

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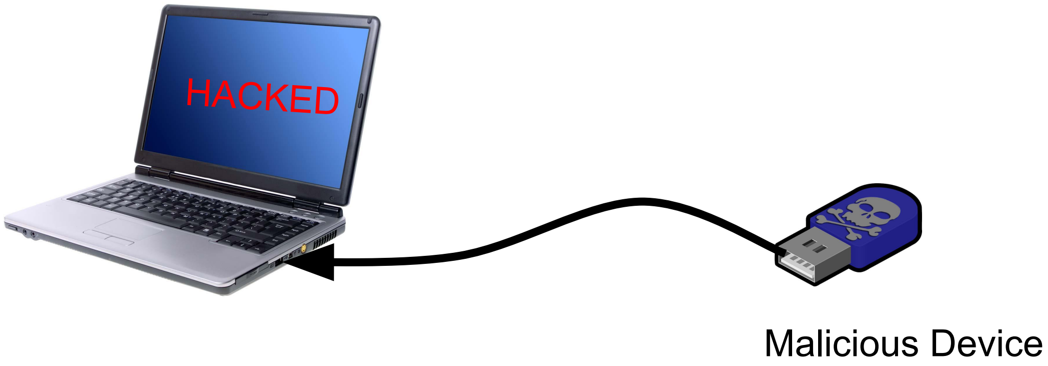
Testing drivers is challenging

- Drivers depend on hardware/devices
- Hard to generate unexpected device inputs
- Many recent attacks/CVEs



Motivation

- Defenses against peripheral attacks are limited
  - Rule-based authorization policy (USBGuard) and USB Firewalls (LBM, USBFilter)
    - Detect only known bugs
  - Isolation based approaches (Cinch)
    - Too expensive, not used in practice
- Fuzzing is a widely used automatic software testing technique
- We propose a framework to apply fuzzing to ***USB drivers***
  - Fixing bugs is better than defending against their exploitation

Threat Model

- Device controlled by attacker via:
  - Prepared device through physical interfaces, or
  - Hijacking networked interfaces (e.g., USBRedir, etc)
- Attack vector
  - Focusing on unexpected data from device side

USB Fuzzing: Challenge & Existing Approaches

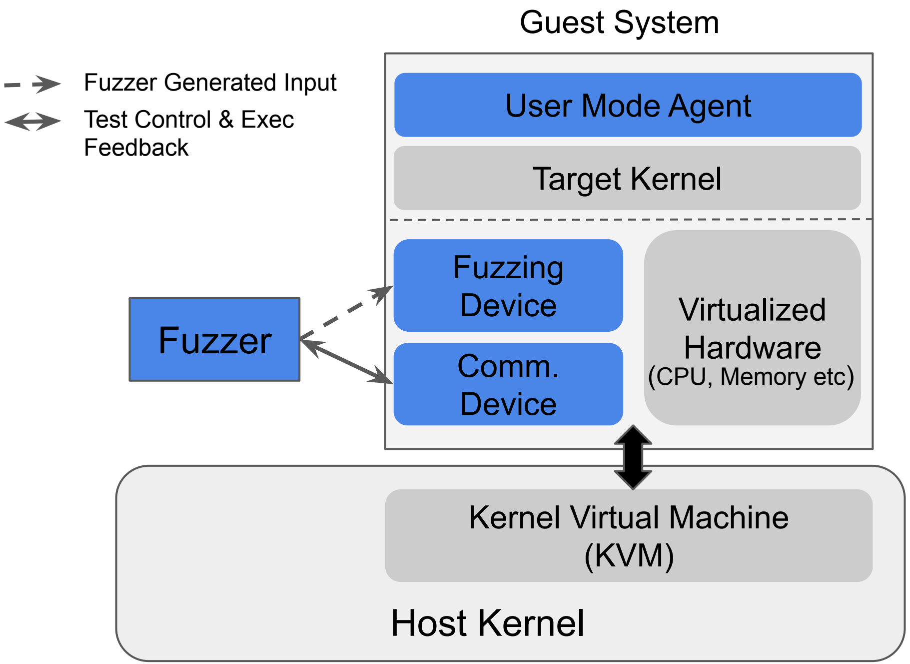
- Challenge
  - ***How to feed random device input to drivers***
- Existing Approaches
  - Dedicated Hardware
    - Umap + FaceDancer
    - Hardware cost, not scalable, etc
  - Data injection in the IO stack
    - Syzkaller usb-fuzz, PeriScope
    - Not portable, some code paths are missed
  - Data injection through networked USB interface
    - vUSBf
    - Only supports dumb fuzzing

USBFuzz: Device Emulation

- Using emulated USB device in a virtualized kernel
  - Feeding random device inputs to USB drivers
  - A host memory area exported to the guest system
    - Can be used for coverage collection
- Advantages
  - Cheap, scalable, portable
  - Supports coverage guided fuzzing

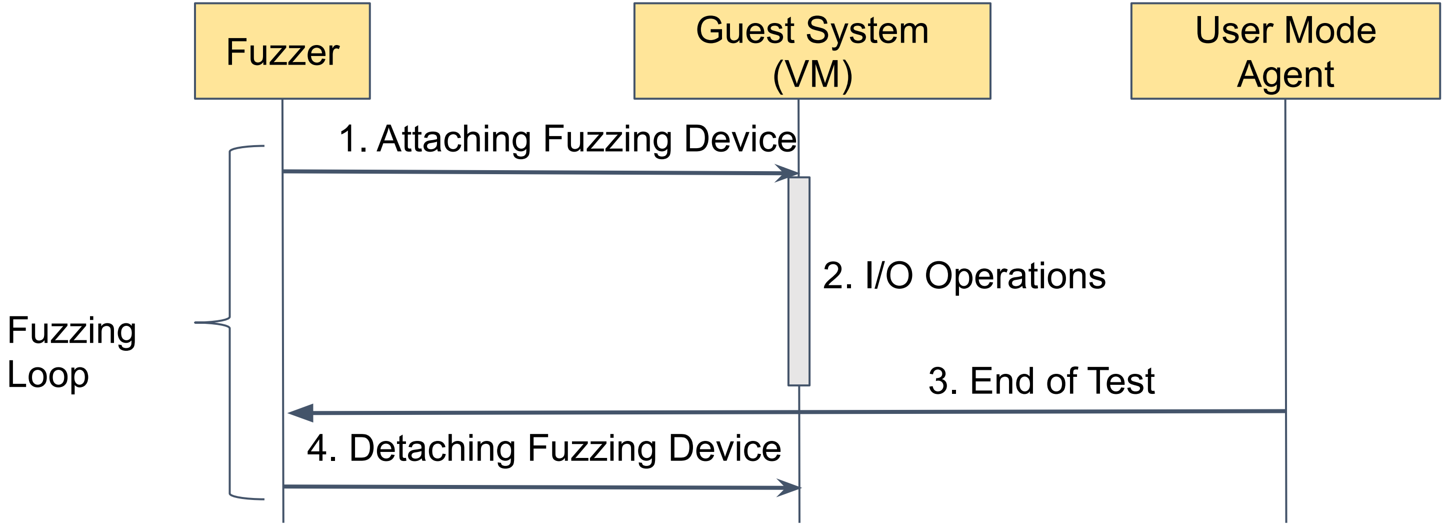
USBFuzz Design

- Guest system
  - Runs target system
  - Fuzzing device
  - Communicating device
  - User Mode Agent
- Fuzzer
  - Runs in host system
  - Controls test execution
  - Collect coverage info



Test Execution

- A test starts from attaching the fuzzing device to guest system
- Drivers are tested while performing IO ops on the fuzzing device
- User Mode Agent detects end of a test by scanning kernel logs



Evaluation

- Coverage guided fuzzing on Linux kernel
  - Adapted KCOV to collect coverage info
- Dumb fuzzing on FreeBSD, Windows and MacOS
  - Seeded by inputs generated when fuzzing Linux kernel

Bugs and CVEs

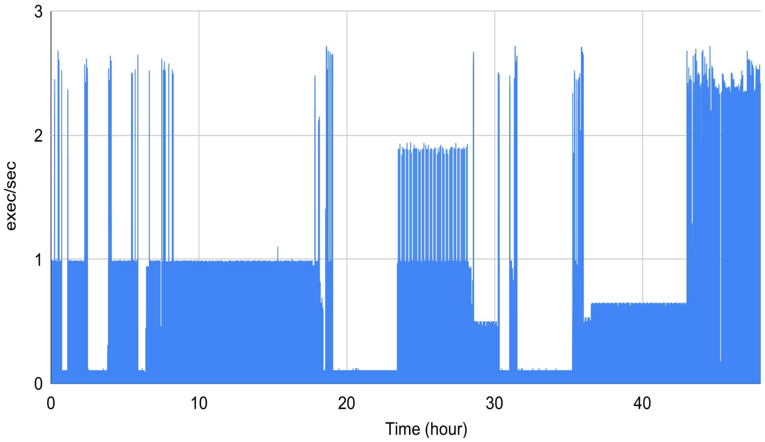
- Bugs

OS/Kernel	Details
Linux	26 new bugs, 16 of them are memory bugs
FreeBSD	One in a USB bluetooth dongle driver
Windows	4, resulting Bluescreen on Windows 8 and Windows 10
MacOS	3, two resulting unplanned restart and one resulting freeze

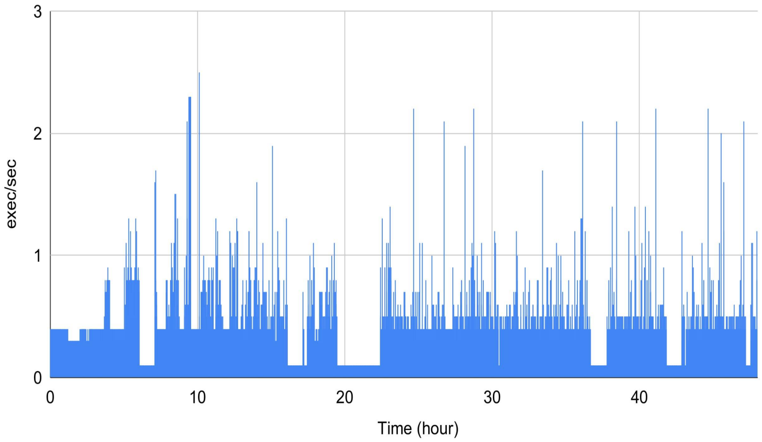
- CVEs
    - CVE-2018-20169, CVE-2018-19824, CVE-2019-15098, CVE-2019-15099, CVE-2018-19985, CVE-2018-20344, CVE-2019-15117, CVE-2019-15118, CVE-2019-15504, CVE-2019-15505

Fuzzing throughput

- 0.1 ~ 3.0 exec/sec
- Most of the execution time is spent on OS-device interaction
- Similar throughput observed in syzkaller usb-fuzz



A sample of execution speed of USBFuzz



A sample of execution speed of syzkaller usb-fuzz

Case Study (1)

- USB devices are described by ***Device Descriptors***
- USB standard defines the first 2 bytes
  - The first byte indicates the length
  - The second byte indicates the type
- Descriptors are read from the device side

```
struct usb_descriptor_header {
    __u8  bLength;
    __u8  bDescriptorType;
} __attribute__ ((packed));
```

Data structure representing the first 2 bytes of a descriptor

```
struct usb_otg_descriptor {
    __u8  bLength;
    __u8  bDescriptorType;
    __u8  bmAttributes;
} __attribute__ ((packed));
```

Descriptor for USB On-The-Go

Case Study (2)

- Bug detected in case of malicious descriptors
- Attackers can masquerade long descriptors using short ones

```
int __usb_get_extra_descriptor(char *buffer, unsigned size, unsigned char type, void **ptr) {
    struct usb_descriptor_header *header;
    while (size >= sizeof(struct usb_descriptor_header)) {
        header = (struct usb_descriptor_header *)buffer;
        if (header->bLength < 2) { return -1; }
        if (header->bDescriptorType == type) {
            *ptr = header;
            return 0;
        }
        buffer += header->bLength;
        size -= header->bLength;
    }
    return -1;
}
```

check on untrusted data

Case Study (3)

- Security Impact
  - Allowing Out-Of-Bounds Access

```
struct usb_otg_descriptor {
        __u8  bLength;
        __u8  bDescriptorType;
        __u8  bmAttributes;
} __attribute__ ((packed));
```

```
static int usb_enumerate_device_otg(struct usb_device * udev) {
  // ......
  struct usb_otg_descriptor * desc = NULL;
  err = __usb_get_extra_descriptor( udev->rawdescriptors[0] ,
              le16_to_cpu( udev->config[0].desc.wTotalLength ), USB_DT_OTG, (void **) &desc);
  if (err||!(desc->bmAttributes & USB_OTG_HNP))
    return 0;

  // ......
}
```

0x3, USB_DT_OTG

OOB Access

Demo/Windows - Bluescreen of Death

Demo/MacOS - Unplanned Restart

Conclusion

- Testing drivers is challenging
- USBFuzz provides a device emulation based approach fuzz USB drivers
- USBFuzz is cheap, portable and flexible
- So far USBFuzz has found:
  - 26 bugs in Linux
  - one bug in FreeBSD
  - 4 bugs in Windows
  - 3 bugs in MacOS

https://github.com/HexHive/USBFuzz

EOF

Data injection in syzkaller usb-fuzz