USB Debugging and Profiling Techniques

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Agenda

- Introduction
- USB Generic Linux System Architecture
- USB Mass Storage Architecture
- Challenges in debugging
- USB Debugging Techniques (sysfs, usbmon, dynamic debug interface, tracepoint, protocol analyzer)
- Gadget Zero
- Other profiling tools

Introduction

- Widespread use of USB in embedded space

  HOST MODE:

  - To connect Ethernet/Hub
  - To connect Modem
  - To connect mass storage devices

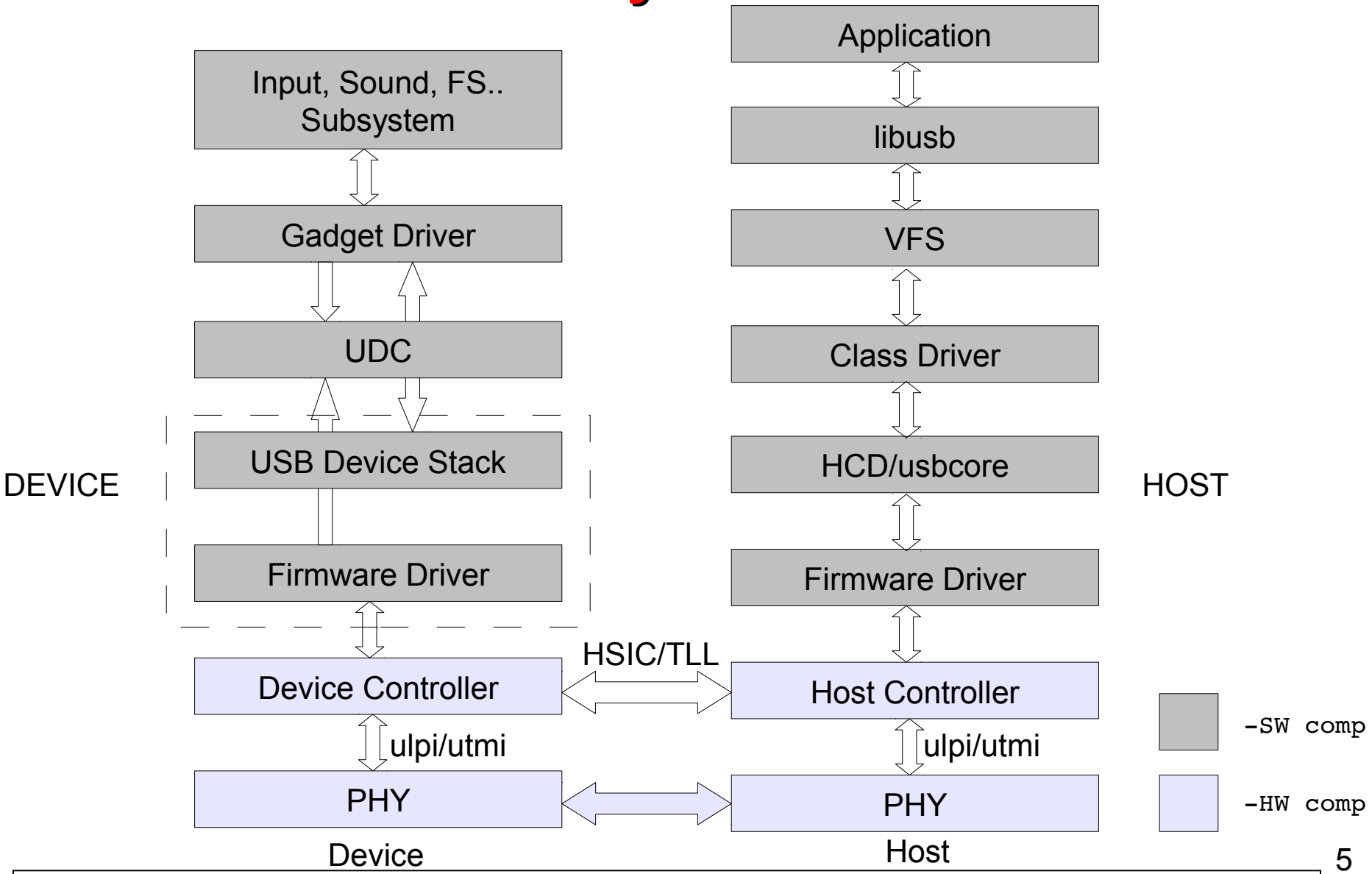
  DEVICE MODE

  - Acts as mass storage device
  - USB Speakers
  - USB serial device
  - USB webcam

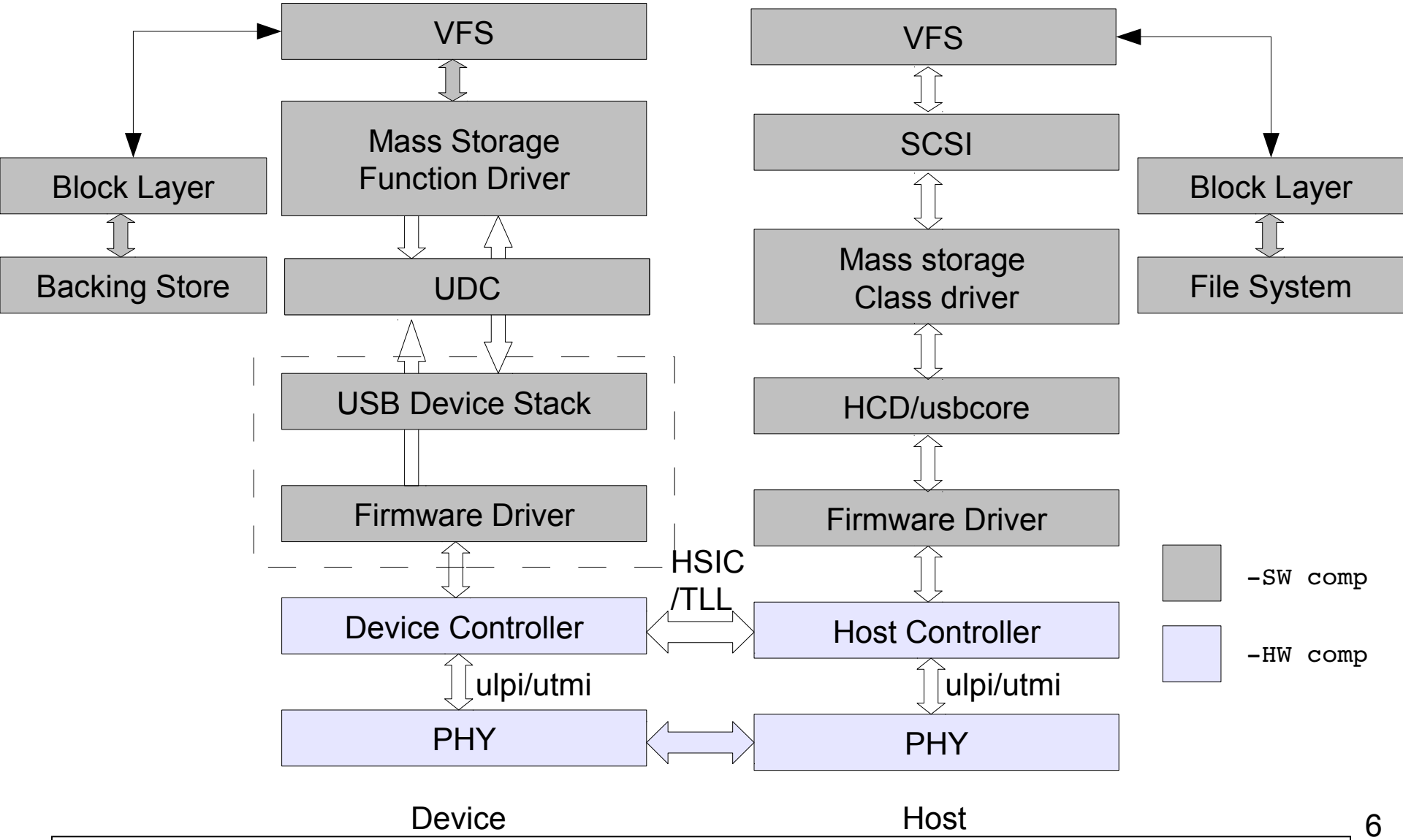
Introduction

- Ease of use
- Hot pluggable
- Speed
- Reliability
- Power devices from the bus
- Bus expansion using hub
- USB On-The-Go

USB Generic Linux System Architecture



USB Mass Storage Architecture



Challenges in debugging

- Data on the bus is encoded
- Timing issues
- Out-of spec signaling errors
- Protocol errors
- Multiple layers makes it difficult to identify where exactly the problem originates
- Too many formatted prints lead to skewed results

USB debugging

- Using linux kernel facilities
  - sysfs/debugfs
  - usbmon
  - Dynamic debug interface
  - Tracepoints
- Using debug tools and Analyzers
  - Elisys/Lecroy/total Phase analyzer tools
  - ETM

Sysfs Entry in host

```
ls /sys/bus/usb/devices/

1-0:1.0    1-1        1-1.1      1-1.1:1.0  1-1:1.0    usb1
```

- The names that begin with "usb" refer to USB controllers
- The devices are named by a scheme

  bus-port.port.port
- The interfaces are indicated by suffixes having this form

  :config.interface
- All information about the device will be under this entry

```
The Documentation information for this entry can be obtained from
http://www.linux-usb.org/FAQ.html#i6
```

Debugfs Entry in host

```
cat /sys/kernel/debug/usb/devices

T:  Bus=01 Lev=00 Prnt=00 Port=00 Cnt=00 Dev#=  1 Spd=480  MxCh= 3
B:  Alloc=  0/800 us ( 0%), #Int=  1, #Iso=  0
D:  Ver= 2.00 Cls=09(hub  ) Sub=00 Prot=00 MxPS=64 #Cfgs=  1
P:  Vendor=1d6b ProdID=0002 Rev= 3.06
S:  Manufacturer=Linux 3.7.0-rc2-next-20121026-00003-g72580a5 ehci_hcd
S:  Product=OMAP-EHCI Host Controller
S:  SerialNumber=ehci-omap.0
C:* #Ifs= 1 Cfg#= 1 Atr=e0 MxPwr=  0mA
I:* If#= 0 Alt= 0 #EPs= 1 Cls=09(hub  ) Sub=00 Prot=00 Driver=hub
E:  Ad=81(I) Atr=03(Int.) MxPS=   4 Ivl=256ms

T:  Bus=01 Lev=01 Prnt=01 Port=00 Cnt=01 Dev#=  2 Spd=480  MxCh= 5
D:  Ver= 2.00 Cls=09(hub  ) Sub=00 Prot=02 MxPS=64 #Cfgs=  1
P:  Vendor=0424 ProdID=9514 Rev= 2.00
C:* #Ifs= 1 Cfg#= 1 Atr=e0 MxPwr=  2mA
I:  If#= 0 Alt= 0 #EPs= 1 Cls=09(hub  ) Sub=00 Prot=01 Driver=hub
E:  Ad=81(I) Atr=03(Int.) MxPS=   1 Ivl=256ms
I:* If#= 0 Alt= 1 #EPs= 1 Cls=09(hub  ) Sub=00 Prot=02 Driver=hub
E:  Ad=81(I) Atr=03(Int.) MxPS=   1 Ivl=256ms
```

The Documentation information for this entry can be obtained from Documentation/usb/proc_usb_info.txt

Debugfs Entry in host contd..

```
T:  Bus=01 Lev=02 Prnt=02 Port=00 Cnt=01 Dev#=  3 Spd=480  MxCh= 0
D:  Ver= 2.00 Cls=ff(vend.) Sub=00 Prot=01 MxPS=64 #Cfgs=  1
P:  Vendor=0424 ProdID=ec00 Rev= 2.00
C:* #Ifs= 1 Cfg#= 1 Atr=e0 MxPwr=  2mA
I:* If#= 0 Alt= 0 #EPs= 3 Cls=ff(vend.) Sub=00 Prot=ff Driver=smsc95xx
E:  Ad=81(I) Atr=02(Bulk) MxPS= 512 Ivl=0ms
E:  Ad=02(O) Atr=02(Bulk) MxPS= 512 Ivl=0ms
E:  Ad=83(I) Atr=03(Int.) MxPS=  16 Ivl=1ms
```

The Documentation information for this entry can be obtained from Documentation/usb/proc_usb_info.txt

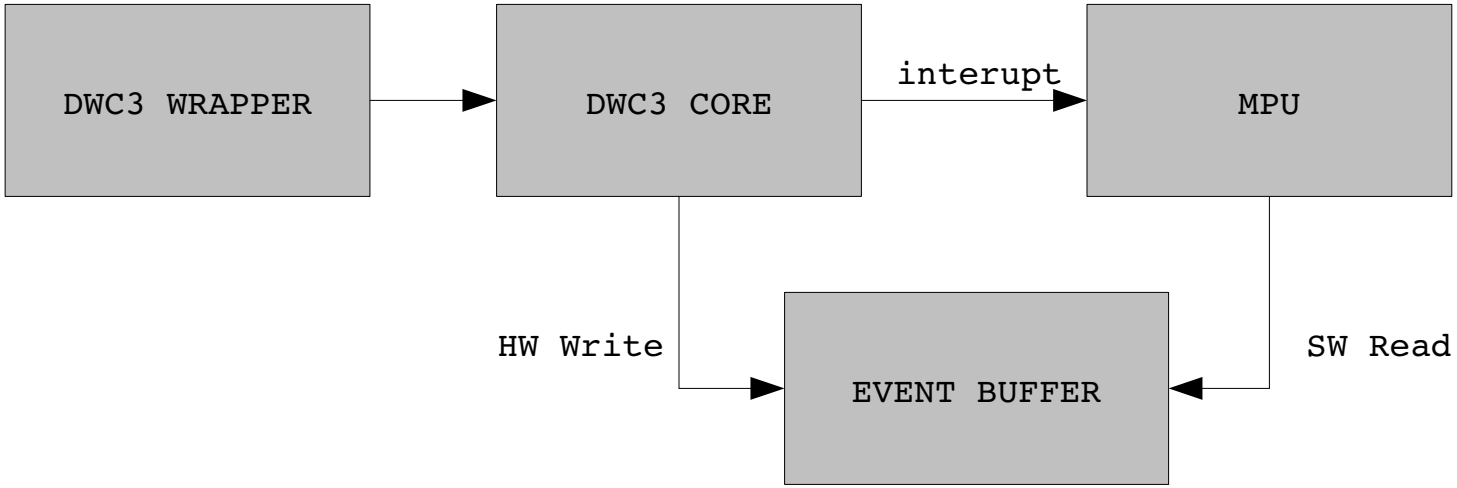
Debugfs (in device controller)

- drivers/usb/dwc3/debugfs.c
- Show the entire register dump
- Change the port mode (device, host, OTG)
- Force the controller to work at a particular speed (super, high..)

Debug example using debugfs

- PROBLEM STATEMENT

Added PM support for dwc3 and realized once the system goes to off mode and comes back the device is not enumerating. Adding some debug prints showed the we are not getting any interrupts in dwc3.



Configuration Diagram

Debug example using debugfs

- Took the register dump before the system goes to suspend and after resuming using “cat /debug/dwc3.0/regdump”

```
GEVNTADRLO(0) = 0xae802000
GEVNTADRHI(0) = 0x00000000
GEVNTSIZ(0) = 0x00001000
GEVNTCOUNT(0) = 0x00000000
GHWPARAMS8 = 0x00000786
DCFG = 0x00480804
DCTL = 0x800000a0
DEVTEN = 0x00001e1f
```

Working Regdump
(Before Suspend)

```
GEVNTADRLO(0) = 0x93040000
GEVNTADRHI(0) = 0x00000000
GEVNTSIZ(0) = 0x00001000
GEVNTCOUNT(0) = 0x00000000
GHWPARAMS8 = 0x00000786
DCFG = 0x00480804
DCTL = 0x800000a0
DEVTEN = 0x00000000
```

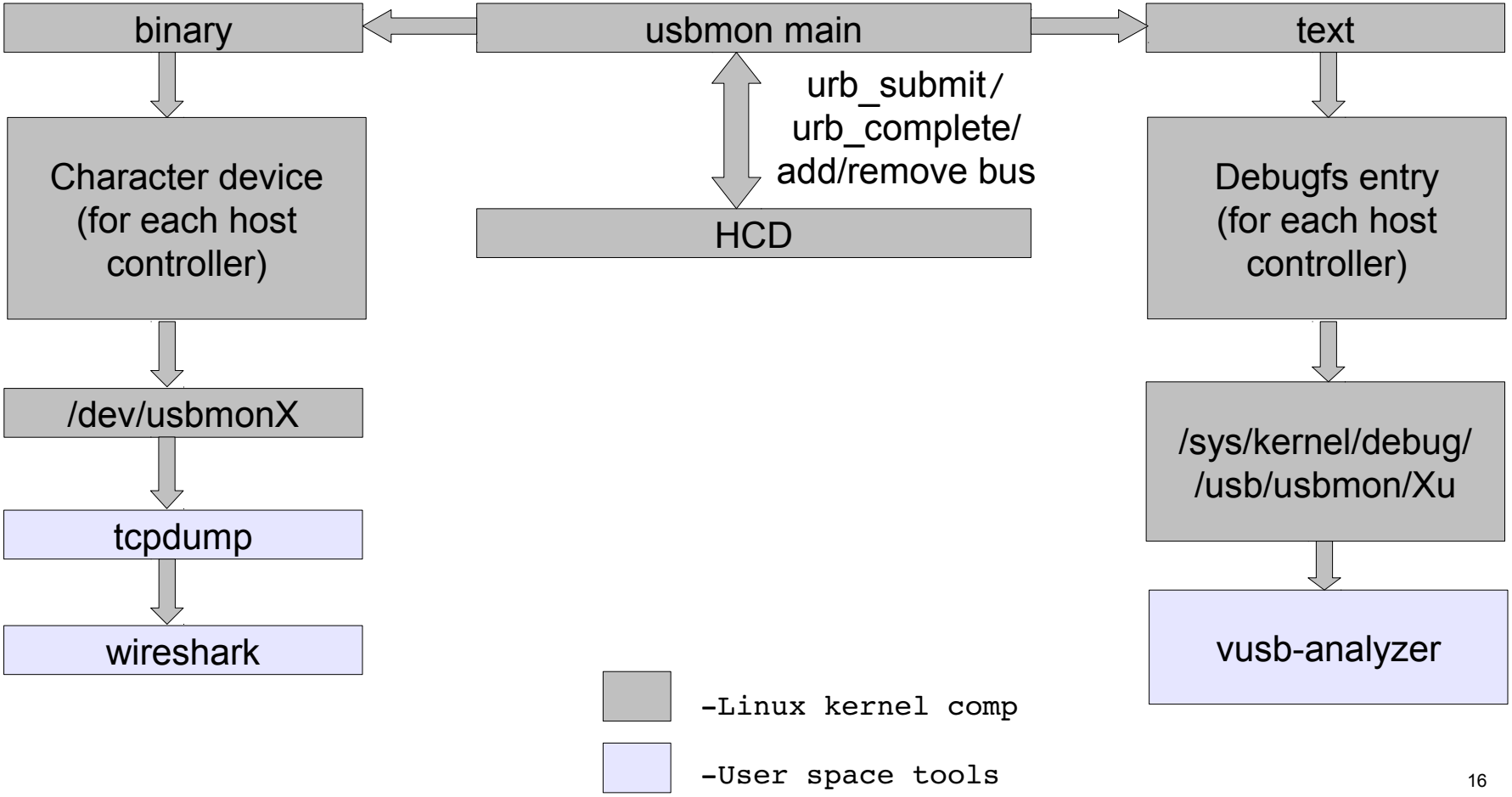
Non Working Regdump
(After Resume)

- After going to OFF mode and coming back, DEVTEN register lost the contents.
- DEVTEN controls the generation of device specific events.
- The fix is to restore the contents of DEVTEN after coming back from OFF mode.

usbmon

- Facility in kernel to be used to collect URB traces
- USB monitoring facilities for Linux consists of a kernel part and user part
- Reports requests made by peripheral-specific drivers to Host Controller Drivers (HCD)
- Requires a reliable working HCD
- Has a "text" and "binary" API

usbmon Architecture



usbmon ASCII capture

- `mount -t debugfs none_debugs /sys/kernel/debug`
- `modprobe usbmon`
- `ls /sys/kernel/debug/usb/usbmon/`

  `0s  0u  1s  1t  1u`
- `cat /sys/kernel/debug/usbmon/1u > usbmon.mon`
- `./vusb-analyzer usbmon.mon`

usbmon binary capture

- `modprobe usbmon`
- `ls /dev/usbmon<TAB>`

  `usbmon0 usbmon1`
- `sudo tcpdump -i usbmon1 -w usbmon.pcap &`
- `./wireshark usbmon.pcap`

Decoding usbmon captures

- Usbmon trace

```
d2263780 469874560 S Ci:3:003:0 s 80 06 0100
0000 0008 8 <

d2263780 469875939 C Ci:3:003:0 0 8 = 12010002
ef020140
```

URB Address	Time stamp	Urb Event	Transfer & Direction	Bus Number	Device Number	Endpoint Number	URB Status	bmRequest type	bRequest
d2263780	469874560	S	Ci	3	003	0	s	80	06

wValue	wIndex	wLength
1	0	8

URB Address	Time stamp	Urb Event	Transfer & Direction	Bus Number	Device Number	Endpoint Number	URB Status	Length		data
d2263780	469875939	C	Ci	3	003	0	0	8	=	12010002 ef020140

Debug examples using usbmon

- PROBLEM STATEMENT1

  usb stick works fine under older kernels (tested on 2.6.34 and 2.6.37) but stopped working for 3.0 and 3.1

- Obtain usbmon traces for working and non working setup
- Filter the usbmon traces for only the required devices

```
cat usb_nw.mon | grep 2:011 > usb_nw_dev.mon

cat usb_w.mon | grep 1:019 > usb_w_dev.mon
```

- `./vusb-analyzer usb_nw_dev.mon usb_w_dev.mon`
- The non working log has some additional commands compared to working log

Debug examples using usbmon contd.

2011	0x002C		00 80 02 02 1F 00 00 00 55 44 49 53 4B 20 20 20 ....UDISK
2011	0x000D		
2011	0x000D		55 53 42 53 5D 00 00 00 00 00 00 00 00 USBS]........
2011	0x001F		55 53 42 43 5E 00 00 00 10 02 00 00 80 00 0C 06 USBC^...........
2011	0x001F		
2011	0x0210		
2011	0x0000		Status: -32
2011	0x0000	02 01 00 00 00 82 00 00	

NON WORKING LOG

- From the diff, there are additional commands in the non-working case like the UDISK shown in the command
- Then the URB return status shows broken PIPE error.
- The host sends CLEAR ENDPOINT HALT and this happens again and again
- So it's concluded some user space program send bogus commands causing the issue.

Debug examples using usbmon

- PROBLEM STATEMENT2

  Webcam does not work when connected to USB 2 port but works on USB 3

- Obtain usbmon traces for working and non working setup
- Filter the usbmon traces for only the required devices

```
cat usb2.mon | grep 1:006 > usb2_nw.mon

cat usb3.mon | grep 3:003 > usb3_w.mon
```

- `./vusb-analyzer usb2_nw.mon usb3_w.mon`

Debug examples using usbmon contd.

EP0	5.615865s :10089	1006	0x0000	01 0B 00 00 00 01 00 0
EP0	5.615913s :10090	1006	0x0000	
EP6 IN	5.616535s :10091	1006	0x0001	
EP6 IN	5.617533s :10092	1006	0x0001	
EP6 IN	5.618533s :10093	1006	0x0001	
EP6 IN	5.619533s :10094	1006	0x0001	
EP6 IN	5.620533s :10095	1006	0x0001	
EP6 IN	5.621533s :10096	1006	0x0001	
EP6 IN	5.622533s :10097	1006	0x0001	
EP6 IN	5.623534s :10098	1006	0x0001	
EP0	48.720184s :10099	1006	0x0000	80 00 00 00 00 00 00 0
EP0	48.724142s :10100	1006	0x0000	

NON-Working usbmon log

EP0	5.621055s :10119	3003	0x0000	01 0B 00 00 00 01 00 0
EP0	5.621079s :10120	3003	0x0000	
EP0	10.132004s :10121	3003	0x0000	80 00 00 00 00 00 00 0
EP0	10.132030s :10122	3003	0x0002	80 00 00 00 00 00 00 0
EP0	10.132044s :10123	3003	0x0000	21 01 02 00 00 03 00 1
EP0	10.135614s :10124	3003	0x001A	
EP0	16.884006s :10125	3003	0x0000	80 00 00 00 00 00 00 0
EP0	16.884034s :10126	3003	0x0002	80 00 00 00 00 00 00 0
EP0	16.884049s :10127	3003	0x0000	21 01 02 00 00 03 00 1
EP0	16.887552s :10128	3003	0x001A	

Working usbmon log

- Both traces show that the webcam stopped being used for a short time and was suspended
- when it was resumed again, it worked okay in USB3 but did not work in USB-2
- The workaround was to disable auto-suspend (and debug the device)

Dynamic Debug Interface

- Extended version of printk
- Use dev_dbg and dev_vdbg to control debug messages
- Enabled using DDEBUG and DVERBOSE_DEBUG compiler options
- If CONFIG_DYNAMIC_DEBUG is **NOT** set, everything under dev_dbg turns to normal printk
- If CONFIG_DYNAMIC_DEBUG is set
  - a new debugfs entry /sys/kernel/debug/dynamic_debug/control gets created
  - Writing to this file will enable or disable specific debugging functions
  - e.g., echo file gadget.c line 269 +p > .../dynamic_debug/control

Debug Example using Dynamic Debug Interface

GOOD: out transfer on dwc3 device mode:

```
[  274.694458] =>>>queing request ed7cdea0 to ep2out-bulk length 512
[  274.694458] dwc3 dwc3.0: ep2out-bulk: req ed7cdea0 dma ac9f0000
length 512 last
[  274.713378] dwc3 dwc3.0: ep2out-bulk: cmd 'Start Transfer' params
00000000 ad5ab110 00000000
[  274.713378] dwc3 dwc3.0: Command Complete --> 0
[  274.726989] dwc3 dwc3.0: ep2out-bulk: Transfer Complete
[  274.732482] =>>request ed7cdea0 from ep2out-bulk completed 16/512
===> 0
```

BAD: out transfer on dwc3 device mode:

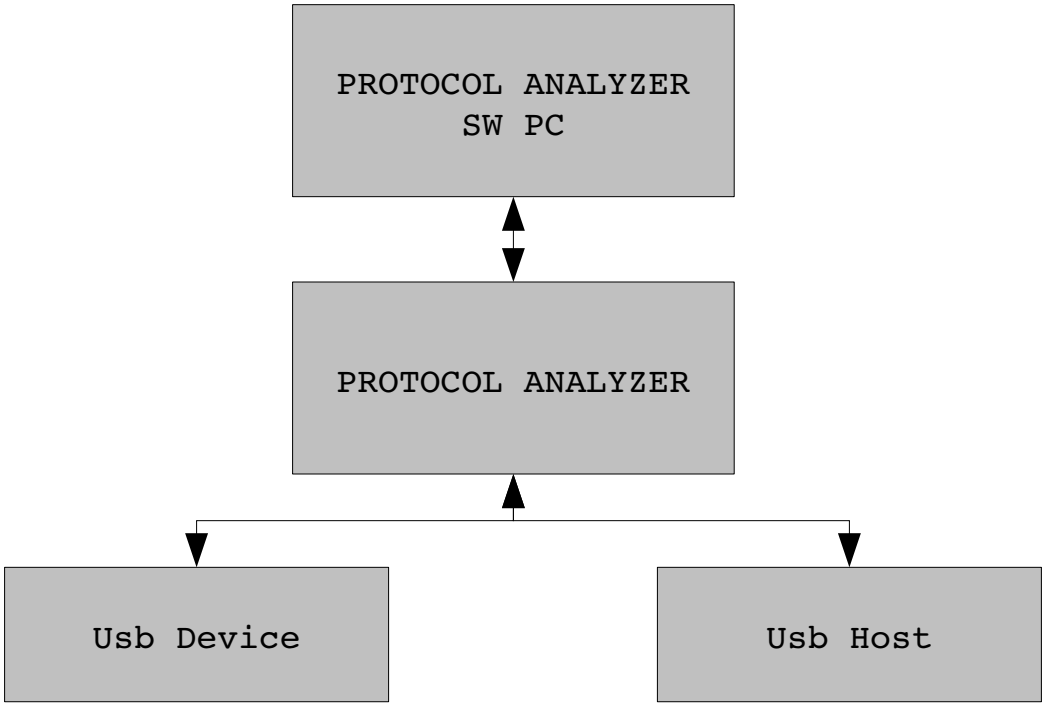
```
[  217.927062] =>>>queing request ecb1ecc0 to ep1out-bulk length 24
[  219.333374] dwc3 dwc3.0: ep1out-bulk: req ecb1ecc0 dma aca1b000
length 24 last
[  219.333374] dwc3 dwc3.0: ep1out-bulk: cmd 'Start Transfer' params
00000000 ad55e000 00000000
[  219.349822] dwc3 dwc3.0: Command Complete --> 0
[  219.360168] dwc3 dwc3.0: ep1out-bulk: endpoint busy
```

Debug Example using Dynamic Debug Interface

- The log shows OUT transfers of 512bytes is getting succeeded but OUT transfer of size 24 is failing
- Confirms maxpacket aligned transfers for out direction are succeeded and there is a problem with short packet transfer
- The problem is that the controller requires OUT transfers to be aligned on wMaxPacketSize, even if we *know* the correct size
- So the fix is done in the gadget driver to give maxpacket aligned buffers to the controller.

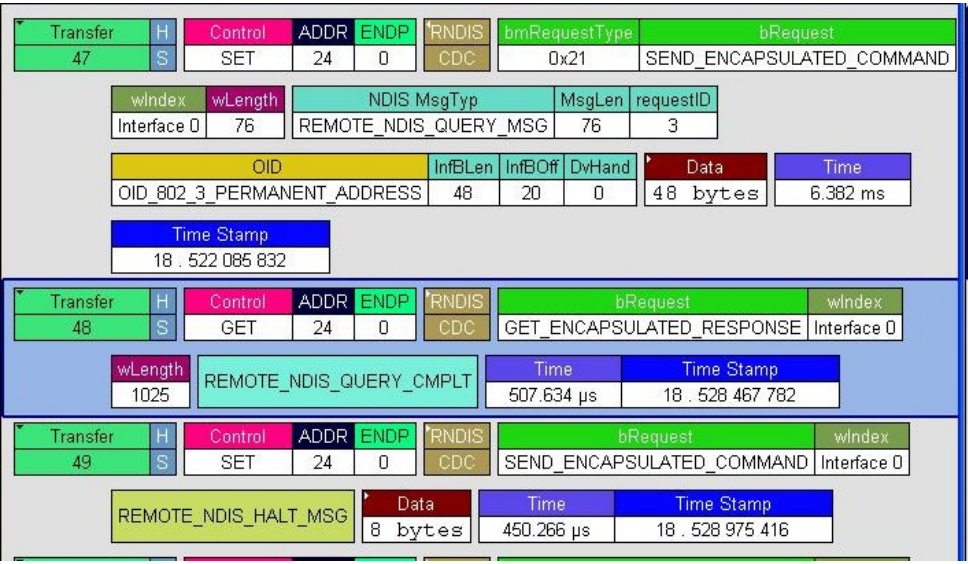
Protocol Analyzer

- A protocol analyzer decodes, filters, and displays USB data
- Some analyzers also have an exerciser along with it that can generate data on the bus

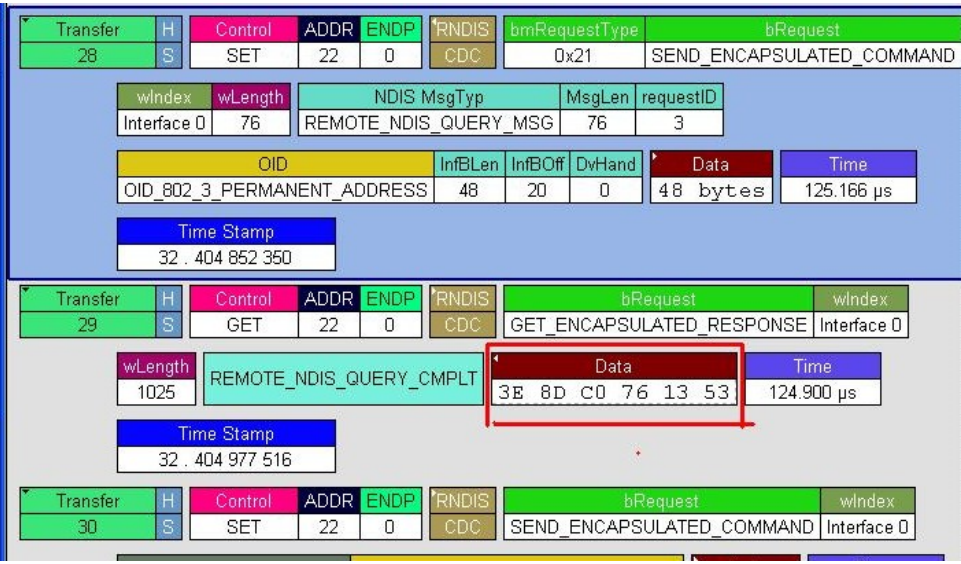


Debug Example using Protocol Analyzer

- USB tethering is not working on omap5
- Captured CATC trace in omap4(working) and in omap5(non-working)



Non Working (OMAP5)



Working (OMAP4)

Debug Example using Protocol Analyzer

- The host sends a QUERY message for OID_802_3_PERMANENT_ADDRESS
- In the working case the device responds with a QUERY_COMPLT message with some DATA in it.
- In the non working case the device responds with a QUERY_COMPLT without any DATA in it.
- So the host sends a HALT message
- The issue was around copying data from the bounce buffer to the gadget layer.

tracepoint

- Used to record data at a specific point in the kernel for later retrieval
- Light weight hooks added to the kernel
- Two types: static tracepoint and dynamic tracepoint
- can be used by a number of tools for kernel debugging and performance problem diagnosis
- They have zero overhead when disabled and minimal overhead when enabled

Defining Static tracepoint

- Macros existing to create a static tracepoint include
  - TRACE_EVENT()
  - TP_PROTO()
  - TP_ARGS()
  - TP_STRUCT__entry()
  - TP_fast_assign()
  - TP_printk()
- The TRACE_EVENT() is created by

  TRACE_EVENT(name, proto, args, struct, assign, print)

Defining Static tracepoint

- Macros existing to create a static tracepoint to do more than printing
  - DECLARE_TRACE()
  - DECLARE_TRACE_NOARGS()
  - DEFINE_TRACE()
- To hook into the tracepoints

  register_trace_[tracepoint_func]()
- To unregister the hook

  unregister_trace_[tracepoint_func]()

Tracepoint Sample

- Patch to log usb_request from gadget layer

  http://gitorious.org/linux-usb/linux-usb/commit/a7e7fb69808

- Patch to log every read/write in dwc3

  http://comments.gmane.org/gmane.linux.usb.general/64821
  ([PATCH] usb: dwc3: add trace support)

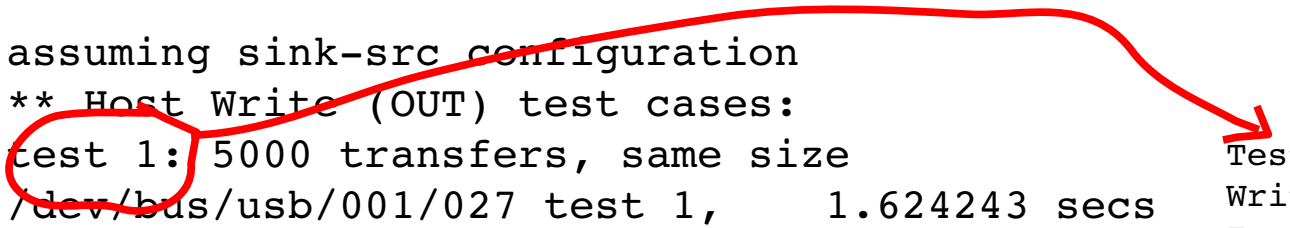
Gadget Zero

- Obtain performance characteristics
- Two configuration device
  - sinks and sources bulk data
  - loops back a configurable number of transfers
- A kernel driver (host), drivers/usb/misc/usbtest.c, where the actual test cases live
- Userland software to call that driver, such as testusb.c and test.sh
- Can't be used for class or vendor-specific functionality

Sample test.sh output

```
** Control test cases:
test 9: ch9 postconfig
/dev/bus/usb/001/027 test 9,    64.183046 secs
test 10: control queueing
/dev/bus/usb/001/027 test 10,    11.738630 secs
test 14: control writes
/dev/bus/usb/001/027 test 14,     5.432296 secs

assuming sink-src configuration
** Host Write (OUT) test cases:
test 1: 5000 transfers, same size
/dev/bus/usb/001/027 test 1,     1.624243 secs
test 3: 5000 transfers, variable/short size
/dev/bus/usb/001/027 test 3,     1.090523 secs
test 5: 2000 scatterlists, same size entries
/dev/bus/usb/001/027 test 5,    13.404251 secs
test 7a: 2000 scatterlists, variable size/short entries
/dev/bus/usb/001/027 test 7,     8.839292 secs
```



Test Case No 1,3,5,7 are Write test cases
Test Case No 2,4,6,8 are read test cases

Sample test.sh output contd.

```
test 7b: 2000 scatterlists, variable size/bigger entries
/dev/bus/usb/001/027 test 7,    6.701336 secs
test 7c: 2000 scatterlists, variable size/micro entries
/dev/bus/usb/001/027 test 7,    4.173024 secs

** Host Read (IN) test cases:
test 2: 5000 transfers, same size
/dev/bus/usb/001/027 test 2,    0.803351 secs
test 4: 5000 transfers, variable size
/dev/bus/usb/001/027 test 4,    0.784580 secs
test 6: 2000 scatterlists, same size entries
/dev/bus/usb/001/027 test 6,    5.442718 secs
test 8: 2000 scatterlists, variable size entries
/dev/bus/usb/001/027 test 8,    3.621307 secs
```

Other Profiling Tools

- Iozone
  - Can be used to profile mass-storage devices
  - Iozone can perform 13 types of test: Read, write, re-read, re-write, read backwards, read strided, fread etc.,
  - Sudo iozone -Rab massstorage.xls -i0 -i1 -e -f /dev/sdb
- FFSB
- dd
  - Copy a file, converting and formatting according to the operands
  - dd if=/dev/zero of=/dev/sdb bs=128 count=1024

References

- Documentation/usb/*
- Documentation/trace/*
- Drivers/usb/*
- lwn.net
- Bootstrap Yourself with Linux-USB Stack
- linux-usb list
- http://vusb-analyzer.sourceforge.net/

THANK YOU

For Queries and Feedback

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