black hat EUROPE 2022

DECEMBER 7-8, 2022

BRIEFINGS

Deep into Android Bluetooth Bug Hunting: New Attack Surfaces and Weak Code Patterns

Zinuo Han

About me

- Senior security experts at OPPO Amber Security Lab
  - Fuzzing and vulnerability research on Android, IoT and Vehicles
  - Development of security defense tools
- Research findings
  - Hundreds of CVEs, Google Bug Hunter No. 7, Qualcomm HackerOne 2022 No. 1
- Previously talked at
  - Ruxcon, Zer0Con, Pacsec, etc
- Contact me
  - ele7enxxh(twitter | gmail)

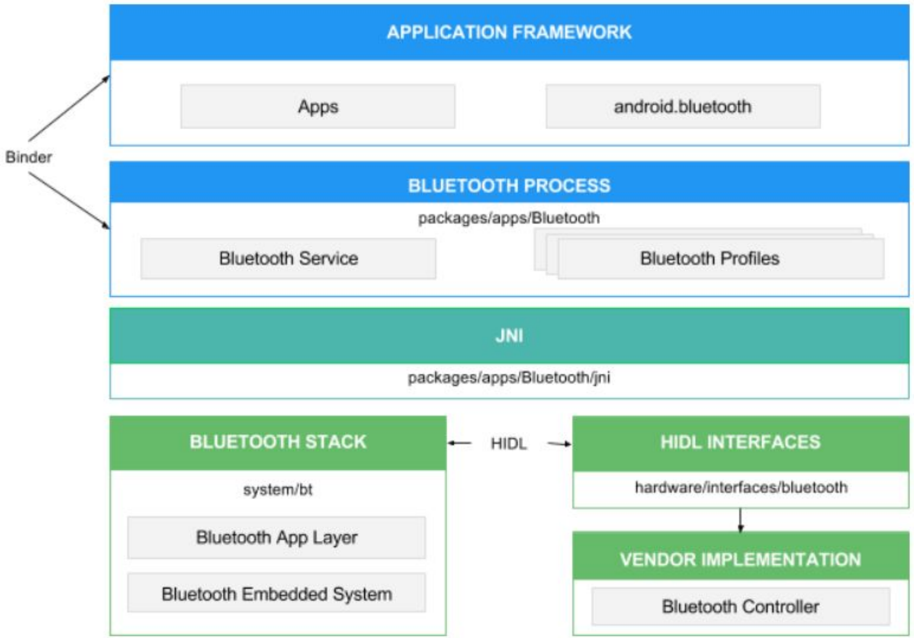
Agenda

- Introduction to Android Bluetooth
- Attack surfaces analysis
- Finding vulnerabilities
- Summary

Android default Bluetooth stack implementation

- Bluez(2.2 - 4.2), Bluedroid(4.2 - 6.0), Fluoride(6.0 - 13), Gabeldorsche(13 -)
  - Architecture changing constantly
- Different scenarios
  - Mobile phone, Android TV, Android Car, etc
- Support multiple protocols and profiles
  - SDP, BNEP, GATT, SMP, AVRCP, AVCTP, HID, RFCOMM, etc
  - Headset, OPP, PBAP, LEAudio, etc

Android Bluetooth architecture



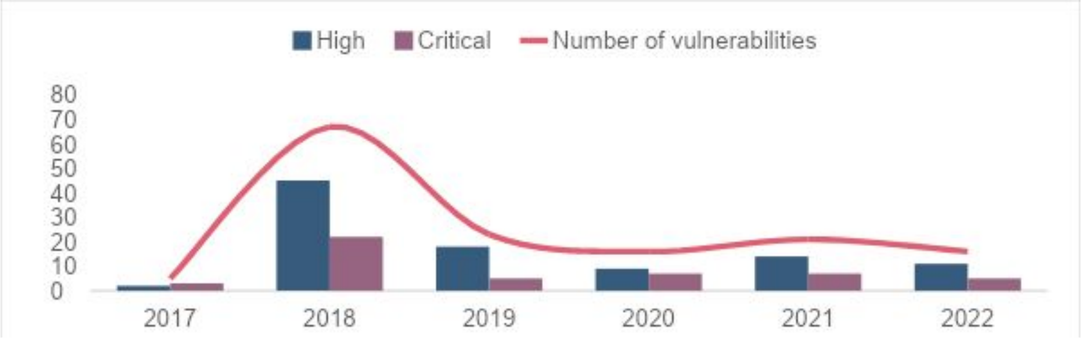
- Application framework
  - User Bluetooth Applications, calls the Bluetooth process through the Binder IPC mechanism
- Bluetooth system service
  - Implements the Bluetooth services and profiles at the Android framework layer, calls into the native Bluetooth stack via JNI
- JNI
  - Implements the Bluetooth services and profiles at the JNI layer, calls into the Bluetooth stack via callbacks
- Bluetooth stack
  - Implements the generic Bluetooth core stack
- Vendor
  - Implements Hardware independent code, interact with the Bluetooth stack using the Hardware Interface Design Language (HIDL)

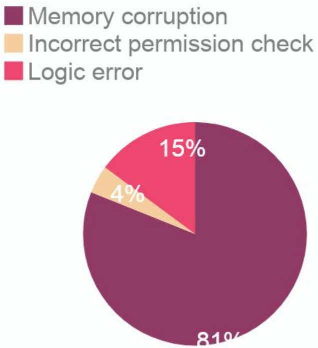
Previous research

- BlueBorne - a series of Bluetooth vulnerabilities endangering multiple operating systems including Android, IOS, Windows and Linux, leading security researchers to pay attention to Bluetooth security
- BadBluetooth - published by Fenghao Xu of the Chinese University of Hong Kong on NDSS, introduced the logic vulnerability in Bluetooth pairing
- BlueFrag - an attacker can use an out of bounds write vulnerability in ACL packet processing to remotely execute code

Historical vulnerability analysis

- From January 2017 to October 2022, at least 148 vulnerabilities have been disclosed, including 99 high vulnerabilities and 49 critical vulnerabilities
- Most are memory corruption types





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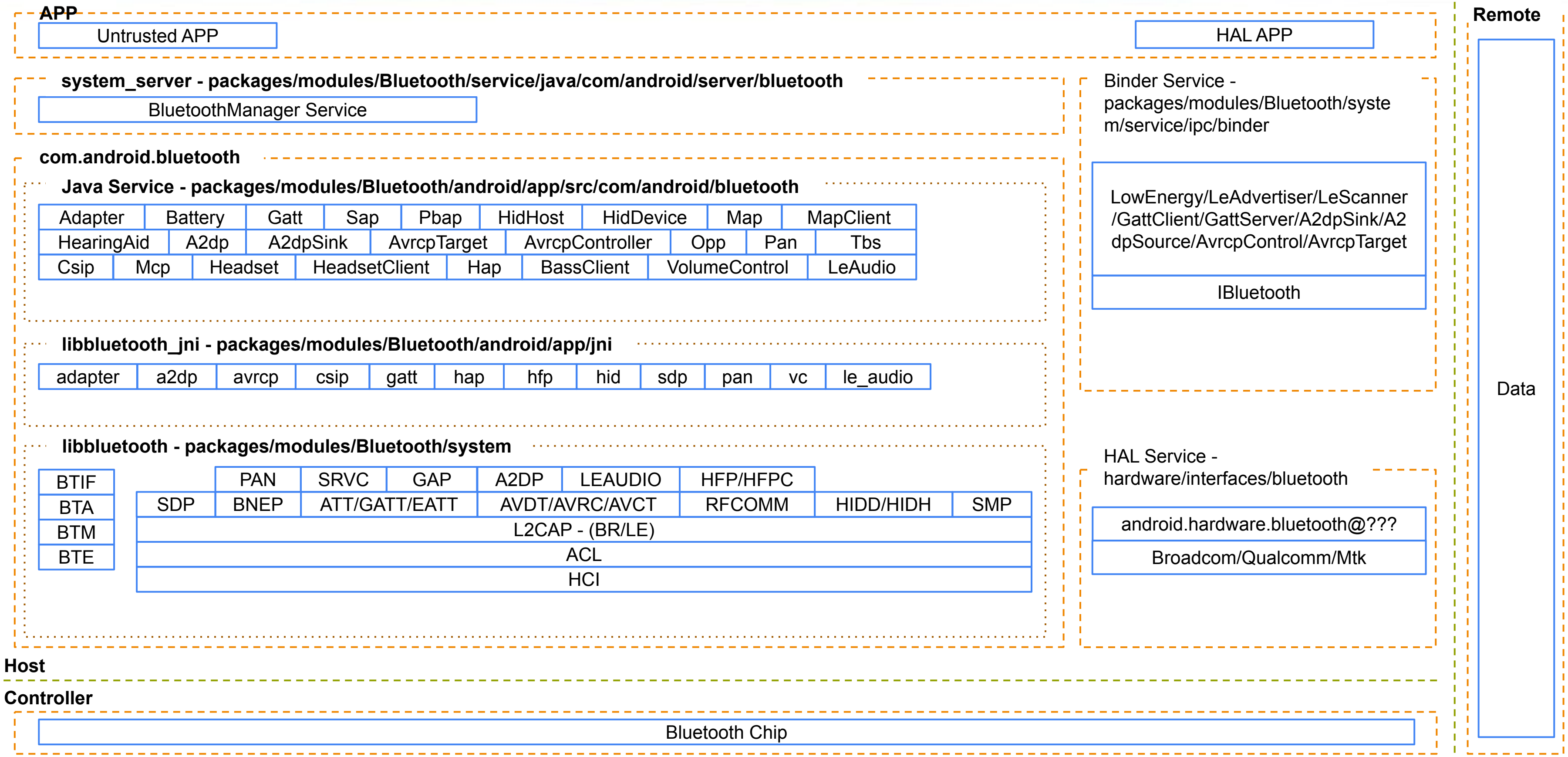
APP
Untrusted APP
HAL APP
Remote
system_server - packages/modules/Bluetooth/service/java/com/android/server/bluetooth
BluetoothManager Service
Binder Service - packages/modules/Bluetooth/system/service/ipc/binder
LowEnergy/LeAdvertiser/LeScanner/GattClient/GattServer/A2dpSink/A2dpSource/AvrcpControl/AvrcpTarget
IBluetooth
com.android.bluetooth
Java Service - packages/modules/Bluetooth/android/app/src/com/android/bluetooth
Adapter
Battery
Gatt
Sap
Pbap
HidHost
HidDevice
Map
MapClient
HearingAid
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Opp
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a2dp
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csip
gatt
hap
hfp
hid
sdp
pan
vc
le_audio
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BTIF
BTA
BTM
BTE
PAN
SRVC
GAP
A2DP
LEAUDIO
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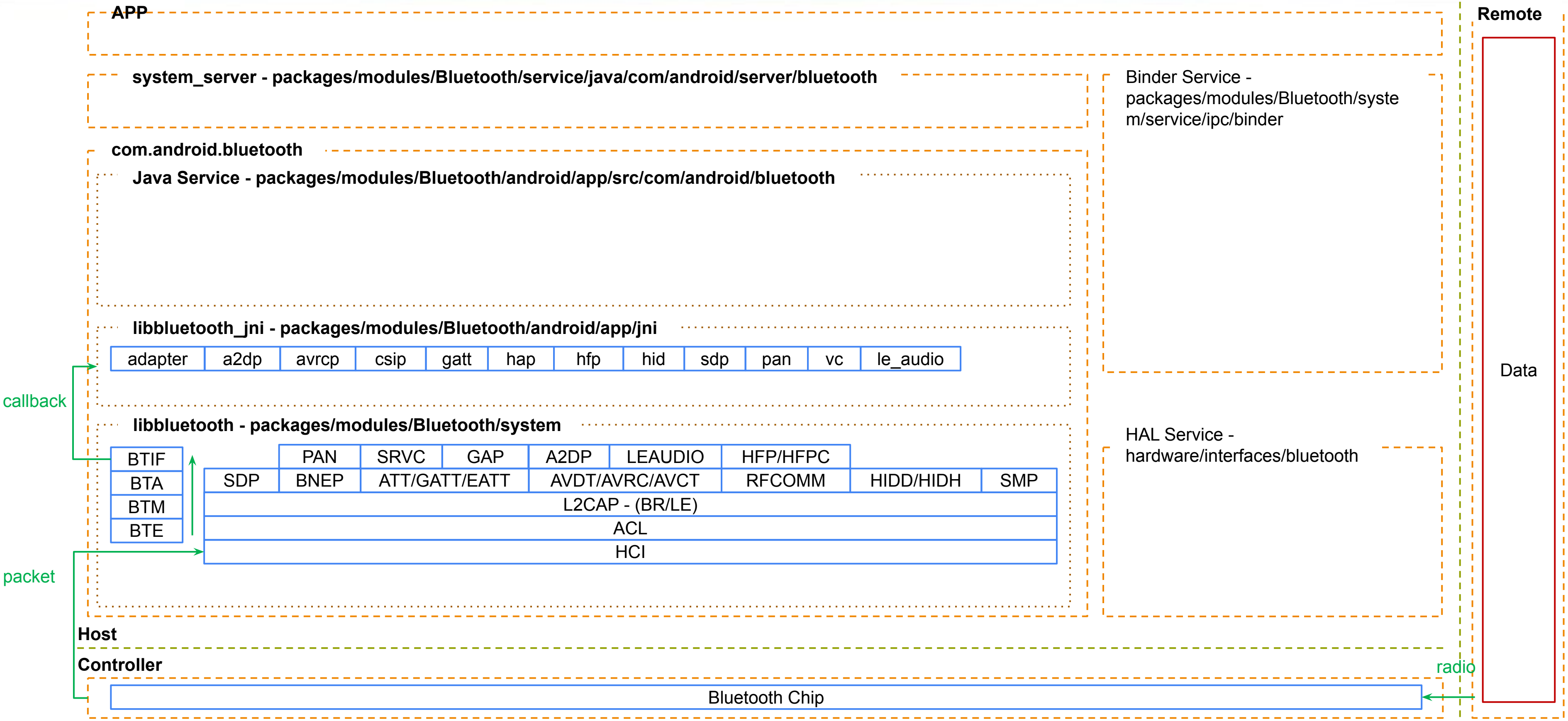
SDP
BNEP
ATT/GATT/EATT
AVDT/AVRC/AVCT
RFCOMM
HIDD/HIDH
SMP
L2CAP - (BR/LE)
ACL
HCI
HAL Service - hardware/interfaces/bluetooth
android.hardware.bluetooth@???
Broadcom/Qualcomm/Mtk
Data
Host
Controller
Bluetooth Chip

Attack scenario 1 - malicious Bluetooth radio


APP
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BTA
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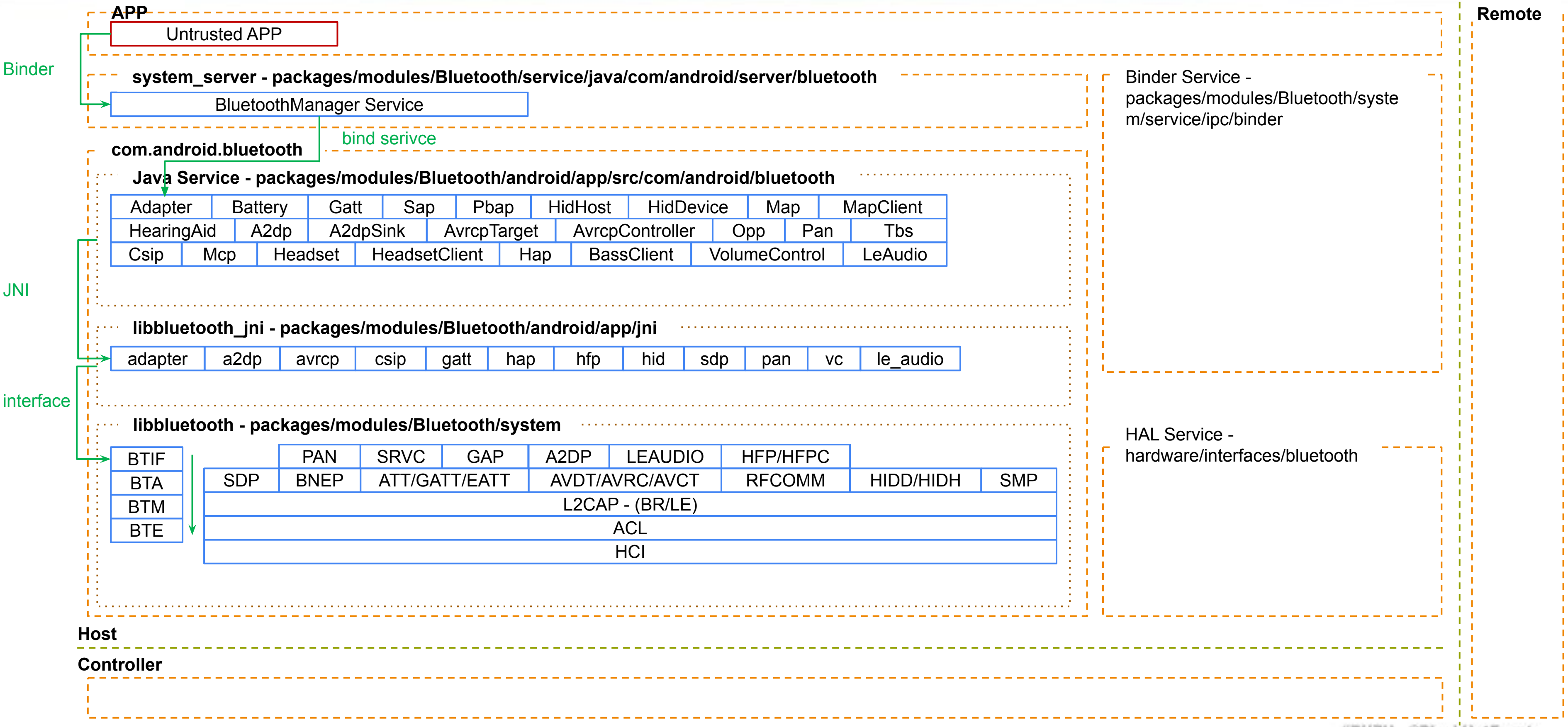
ACL
HCI
packet
HAL Service - hardware/interfaces/bluetooth
Host
Controller
Bluetooth Chip
radio
Remote
Data

Attack scenario 2 - malicious untrusted APP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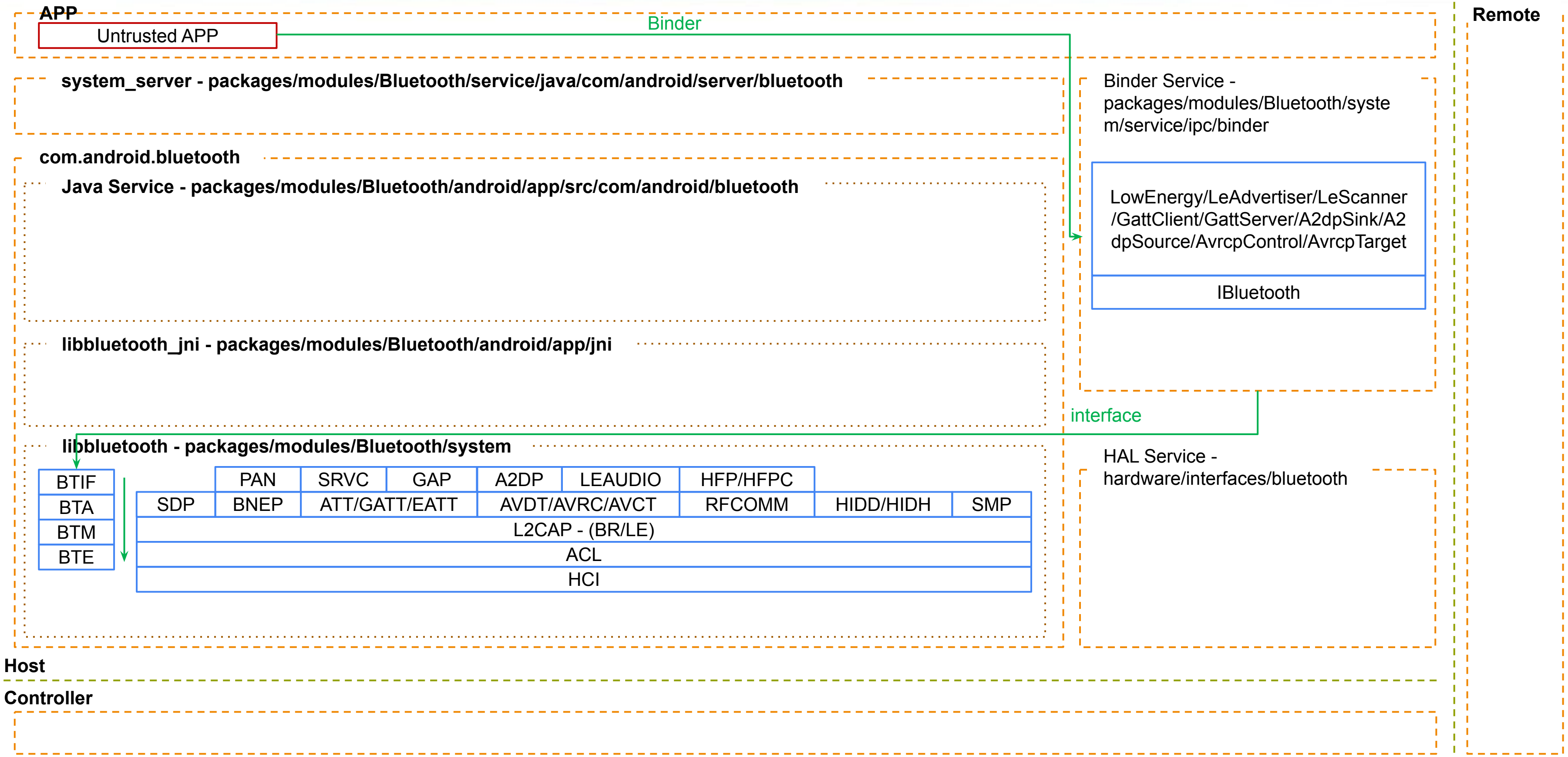
Untrusted APP
Binder
system_server - packages/modules/Bluetooth/service/java/com/android/server/bluetooth
BluetoothManager Service
bind serivce
com.android.bluetooth
Java Service - packages/modules/Bluetooth/android/app/src/com/android/bluetooth
Adapter | Battery | Gatt | Sap | Pbap | HidHost | HidDevice | Map | MapClient
HearingAid | A2dp | A2dpSink | AvrcpTarget | AvrcpController | Opp | Pan | Tbs
Csip | Mcp | Headset | HeadsetClient | Hap | BassClient | VolumeControl | LeAudio
JNI
libbluetooth_jni - packages/modules/Bluetooth/android/app/jni
adapter | a2dp | avrcp | csip | gatt | hap | hfp | hid | sdp | pan | vc | le_audio
interface
libbluetooth - packages/modules/Bluetooth/system
BTIF
BTA
BTM
BTE
PAN | SRVC | GAP | A2DP | LEAUDIO | HFP/HFPC
SDP | BNEP | ATT/GATT/EATT | AVDT/AVRC/AVCT | RFCOMM | HIDD/HIDH | SMP
L2CAP - (BR/LE)
ACL
HCI
Binder Service - packages/modules/Bluetooth/system/service/ipc/binder
HAL Service - hardware/interfaces/bluetooth
Host
Controller
Remote



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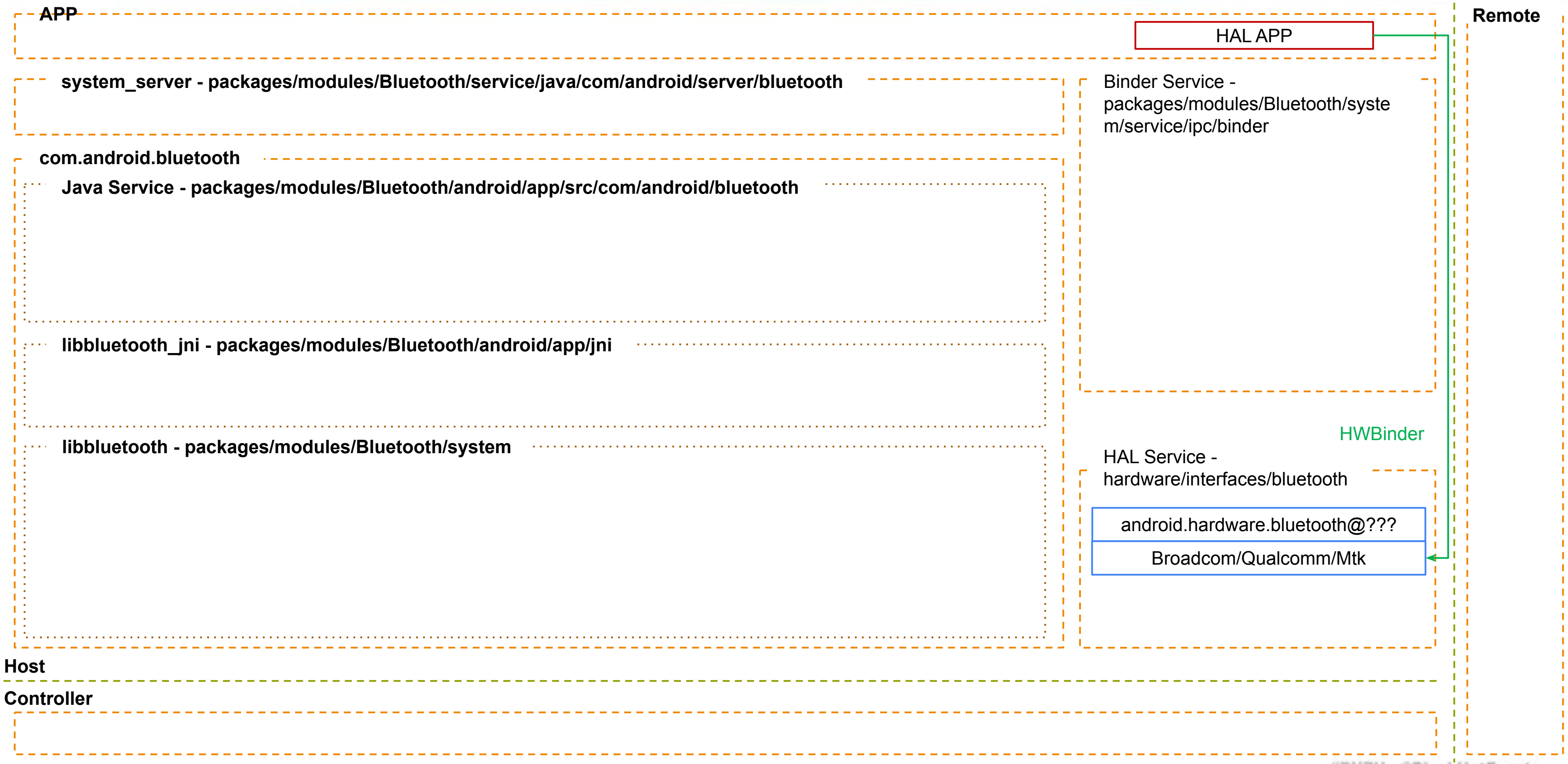
HCI
HAL Service - hardware/interfaces/bluetooth
Host
Controller

Attack scenario 3 - malicious HAL APP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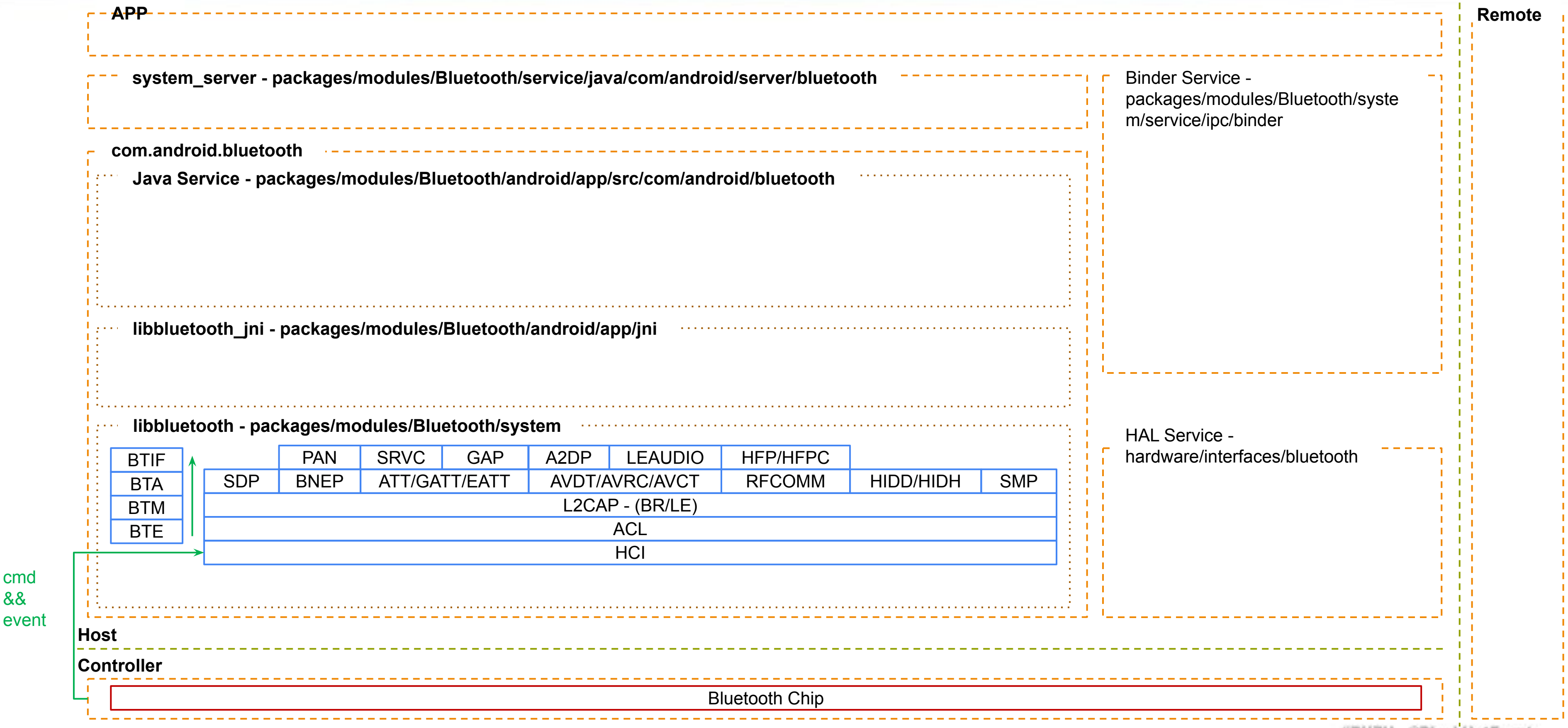
libbluetooth - packages/modules/Bluetooth/system
HWBinder
HAL Service - hardware/interfaces/bluetooth
android.hardware.bluetooth@???
Broadcom/Qualcomm/Mtk
Host
Controller

Attack scenario 4 - malicious Bluetooth chip


APP
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SRVC
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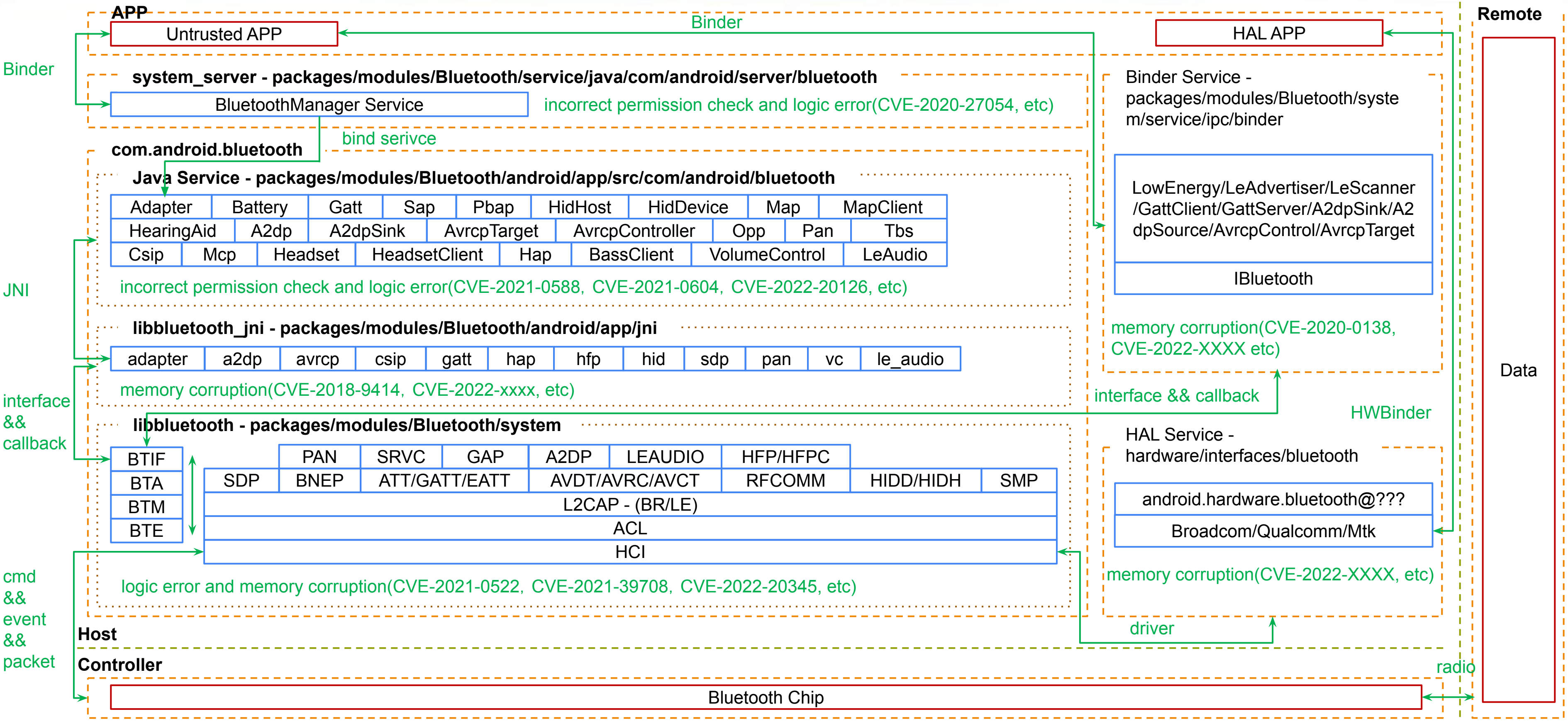
A2DP
LEAUDIO
HFP/HFPC
SDP
BNEP
ATT/GATT/EATT
AVDT/AVRC/AVCT
RFCOMM
HIDD/HIDH
SMP
L2CAP - (BR/LE)
ACL
HCI
HAL Service - hardware/interfaces/bluetooth
cmd
&&
event
Host
Controller
Bluetooth Chip

Full attack scenarios


APP
Untrusted APP
Binder
HAL APP
Remote
Binder
system_server - packages/modules/Bluetooth/service/java/com/android/server/bluetooth
BluetoothManager Service
incorrect permission check and logic error(CVE-2020-27054, etc)
Binder Service - packages/modules/Bluetooth/system/service/ipc/binder
bind serivce
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incorrect permission check and logic error(CVE-2021-0588, CVE-2021-0604, CVE-2022-20126, etc)
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hfp
hid
sdp
pan
vc
le_audio
memory corruption(CVE-2018-9414, CVE-2022-xxxx, etc)
memory corruption(CVE-2020-0138, CVE-2022-XXXX etc)
Data
interface && callback
interface && callback
HWBinder
libbluetooth - packages/modules/Bluetooth/system
HAL Service - hardware/interfaces/bluetooth
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RFCOMM
HIDD/HIDH
SMP
L2CAP - (BR/LE)
ACL
HCI
android.hardware.bluetooth@???
Broadcom/Qualcomm/Mtk
memory corruption(CVE-2022-XXXX, etc)
logic error and memory corruption(CVE-2021-0522, CVE-2021-39708, CVE-2022-20345, etc)
cmd && event && packet
driver
Host
Controller
radio
Bluetooth Chip

Agenda

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How to discover the bugs

- Code audit
  - Goal - focus on full life cycle of data event/commands/packets in different scenarios, including receiving, subcontracting, packaging, parsing, handling, circulation, storage, recycling, etc
  - Disadvantage - take significant investment
  - Solution - combine with CodeQL
- Fuzz
  - Goal - focus on some complex code fragments, avoid missing some ignored issues
  - Disadvantage - remote fuzzing can handle various complex state machines, but inefficient and costly
  - Solution - local fuzzing with simulated state machine

Basic knowledge

- BT_HDR
  - define the header of each buffer used in the Bluetooth stack

```
typedef struct {
    uint16_t event;
    uint16_t len; // packet length
    uint16_t offset;
    uint16_t layer_specific;
    uint8_t data[]; // packet data
} BT_HDR;

BT_HDR* p_msg;
uint8_t* p_req = (uint8_t*) (p_msg + 1) + p_msg->offset;
uint8_t* p_req_end = p_req + p_msg->len;
```

- *_STREAM_TO*
  - Used to read values from input packet data

```
#define BE_STREAM_TO_UINT8(u8, p) \
  {                               \
    (u8) = (uint8_t)(*(p));       \
    (p) += 1;                     \
  }
#define BE_STREAM_TO_UINT16(u16, p)
#define BE_STREAM_TO_UINT24(u32, p)
#define BE_STREAM_TO_UINT32(u32, p)
#define BE_STREAM_TO_UINT64(u64, p)
#define BE_STREAM_TO_ARRAY(p, a, len)
```

Weak code patterns - integer overflow in stream deserialization

- A simple example

```
int xxx_data_ind(uint8_t* data, size_t len) {
    uint16_t num;
    BE_STREAM_TO_UINT16(num, data); // source - num is read via BE_STREAM_TO_UINT16
    uint16_t size = num * sizeof(int); // sink - num is used in arithmetic operation, and result maybe larger
than the maximum value of the storage variable
    int* dst = (int*) malloc(size); // allocated memory size is smaller than expected
    for (uint16_t i = 0; i < num; ++i) BE_STREAM_TO_UINT32(dst[i], data); // out of bounds write
}
```

- Code is possible vulnerable if tainted data flows from theses macros source to a sink in the arithmetic expression

Weak code patterns - integer overflow in stream deserialization

- Step 1 - find all calls of BE_STREAM_TO* or STREAM_TO*

```
// CodeQL code
class BTStreamMacroInvocationExpr extends AssignExpr {
    BTStreamMacroInvocationExpr() {
        // BE_STREAM_TO_UINT8 or STREAM_TO_UINT8
        this.getRValue()
            .(PointerDereferenceExpr)
            .getOperand()
            .(VariableAccess)
            .getTarget()
            .getName()

.regexpMatch("p|pp|p_data|p_req|p_reply|p_buf|p_stream|value|stream|data")
        or
        // BE_STREAM_TO_UINT16 or STREAM_TO_UINT16
    }
}
```

```
// c++ code
BE_STREAM_TO_UINT8(id, p);
BE_STREAM_TO_UINT32(u32, value);
STREAM_TO_UINT16(num, p_req);
STREAM_TO_UINT24(u24, data);
```

Weak code patterns - integer overflow in stream deserialization

- Step 2 - check the source corresponds to this expression

```
// CodeQL code
override predicate isSource(DataFlow::Node source) {
    exists(AssignExpr ae |
        ae instanceof BTStreamMacroInvocationExpr and
        source.asExpr() = ae
    )
}
```

Weak code patterns - integer overflow in stream deserialization

- Step 3 - check the sink corresponds to an arithmetic expression, and the maximum value of the result is greater than the maximum value of the lvalue

```
// CodeQL code
override predicate isSink(DataFlow::Node sink) {
    exists(AssignAddExpr aae |
        aae.getRValue() = sink.asExpr() and
        aae.getLValue().getType().getSize() <=
        aae.getRValue().getExplicitlyConverted().getType().getSize()
    ) or
    exists(AddExpr ae |
    ) or
    exists(MulExpr me |
    ) or
    // ...
}
```

```
// c++ code
uint16_t len, size;
BE_STREAM_TO_UINT16(len, p);
// possible integer overflow
size += len;
```

```
// c++ code
uint16_t len, size;
BE_STREAM_TO_UINT8(len, p);
// ingore this
size += len;
```

Weak code patterns - integer overflow in stream deserialization

- Step 4 - run query,analysis results and report issue
  - 100+ results in 5 seconds
  - Most are false positives

```
// calculation logic of the right value is complex, the ql script can't properly handle
min_len += MIN(p_result->get_caps.count, AVRC_CAP_MAX_NUM_COMP_ID) * 3;
```

  - After analysis, discovered 4 security bugs

Weak code patterns - integer overflow in stream deserialization

- CVE-2022-20445
  - Triple integer overflow causes heap buffer overflow read bug

```
static void process_service_search_rsp(tCONN_CB* p_ccb, uint8_t* p_reply, uint8_t* p_reply_end) {
    uint16_t cur_handles, orig;

    // cur_handles can take on any value from 0 to UINT16_MAX
    BE_STREAM_TO_UINT16(cur_handles, p_reply);
    orig = p_ccb->num_handles;
    // p_ccb->num_handles is uint16_t type, thus if cur_handles is sufficiently large, can result in an integer
overflow causing p_ccb->num_handles to be less than orig
    p_ccb->num_handles += cur_handles;
    // double integer overflow in "p_ccb->num_handles - orig" and "p_reply + ((p_ccb->num_handles - orig) * 4) +
1", causing this check to be bypassed
    if (p_reply + ((p_ccb->num_handles - orig) * 4) + 1 > p_reply_end) return;
    for (uint16_t xx = orig; xx < p_ccb->num_handles; xx++) BE_STREAM_TO_UINT32(p_ccb->handles[xx], p_reply);
}
```

Weak code patterns - integer overflow in stream deserialization

- CVE-2022-20410
  - Bypass length check due to integer overflow, leading to heap buffer overflow read

```
uint16_t min_len = 0;
min_len += 8;
// "p_attrs[i].name.str_len" can take any value form 0 to UINT16_MAX
BE_STREAM_TO_UINT16(attr_entry->name.str_len, p);
// possible integer overflow, "min_len" may less than expected
min_len += attr_entry->name.str_len;
// bypass this length check
if (pkt_len < min_len) goto browse_length_error;
attr_entry->name.p_str = (uint8_t*) osi_malloc(attr_entry->name.str_len * sizeof(uint8_t));
// oob read due to "attr_entry->name.str_len" could be larger than real size of input data
BE_STREAM_TO_ARRAY(p, attr_entry->name.p_str, attr_entry->name.str_len);
```

Weak code patterns - use after free due to ignoring error status

- A simple example

```
int some_function(BT_HDR* p_msg) {
    if (/*...*/) {
        osi_free(p_msg); // free p_msg
        return -1;
    }
    return 0;
}
BT_HDR* p_msg = (BT_HDR*) osi_malloc(sizeof(BT_HDR) + 4096);
some_function(p_msg); // missing check the return value
uint8_t* p = (uint8_t*) (p_msg + 1) + p_msg->len; // uaf
```

- Code is possible vulnerable if there is reachability flow between deallocation function call source and dereference sink

Weak code patterns - use after free due to ignoring error status

- Step 1 - define osi_free function

```
// CodeQL code
private class SpecialDeallocationFunction extends DeallocationFunction {
    int freedArg;

    SpecialDeallocationFunction() {
        hasGlobalOrStdOrBslName([
            // --- AOSP Bluetooth library allocation
            "osi_free", "osi_free_and_reset"
        ]) and freedArg = 0
    }

    override int getFreedArg() { result = freedArg }
}
```

```
// C++ code
void osi_free(void* ptr);
```

Weak code patterns - use after free due to ignoring error status

- Step 2 - find all calls that direct or possible call to deallocation function

```
// CodeQL code
predicate deallocCallOrIndirect(FunctionCall fc, VariableAccess va) {
    // direct free call
    fc.(DeallocationExpr).getFreedExpr() = va or
    // direct free call with assigned value
    fc.(DeallocationExpr).getFreedExpr()
    .(VariableAccess).getTarget().getInitializer().getExpr() = va or
    // // indirect free call
    exists(FunctionCall midcall, Function mid, int arg |
        fc.(Call).getArgument(arg) = va and
        mayCallFunction(fc, mid) and
        midcall.getEnclosingFunction() = mid and
        deallocCallOrIndirect(midcall, mid.getParameter(arg).(Variable).getAnAccess())
    )
}
```

```
// C++ code
// direct free call
osi_free(p_msg);

// direct free call with assigned value
void* p_buf = p_msg;
osi_free(p_buf);

// indirect free call
do_some_work(p_buf);
void do_some_work(BT_HDR* p_buf) {
    osi_free(p_buf);
}
```

Weak code patterns - use after free due to ignoring error status

- Step 3 - check an expression that may dereference variable

```
// CodeQL code
predicate isDerefByCallExpr(Call c, int i, VariableAccess va,
StackVariable v) {
    v.getAnAccess() = va and
    va = c.getAnArgumentSubExpr(i) and
    not c.passesByReference(i, va) and
    (c.getTarget().hasEntryPoint() implies
    isDerefExpr(_, c.getTarget().getParameter(i)))
}

predicate isDerefExpr(Expr e, StackVariable v) {
    v.getAnAccess() = e and dereferenced(e) or
    isDerefByCallExpr(_, _, e, v)
}
```

```
// C++ code
// example 1
uint16_t len = p_msg->len;

// example 2
p_msg->offset += 4;

// example 3
uint8_t* p_start =
    (uint8_t*) (p_msg + 1) + p_msg->offset;
```

Weak code patterns - use after free due to ignoring error status

- Step 4 - do reachability analysis

```
// CodeQL code
class UseAfterFreeReachability extends StackVariableReachability {
    UseAfterFreeReachability() {
        this = "UseAfterFreeDueToIgnoringErrorStatusInAospBluetooth"
    }
    override predicate isSource(ControlFlowNode node, StackVariable v) {
        deallocCallOrIndirect(node, v.getAnAccess())
    }
    override predicate isSink(ControlFlowNode node, StackVariable v) {
        isDerefExpr(node, v) and not deallocCallOrIndirect(_, node)
    }
    override predicate isBarrier(ControlFlowNode node, StackVariable v) {
        definitionBarrier(v, node) or deallocCallOrIndirect(node, v.getAnAccess())
    }
}
```

Weak code patterns - use after free due to ignoring error status

- Step 5 - run query, analysis results and report issue
  - 30+ results in 5 seconds
  - Some are false positives due to complex condition judgment between edges
  - After analysis, discovered 3 security bugs

Weak code patterns - use after free due to ignoring error status

- CVE-2022-20447
  - Use after free due to the code ignores the possibility that the bnepu_check_send_packet function may release the p_buf object

```
// in special case, p_buf will be freed bu result is still BNEP_SUCCESS
result = BNEP_WriteBuf(pcb->handle, dst, p_buf, protocol, &src, ext);
if (result == BNEP_IGNORE_CMD) {
   PAN_TRACE_DEBUG("PAN ignored data buf write to PANU");
   pcb->write.errors++;
   return PAN_IGNORE_CMD;
} else if (result != BNEP_SUCCESS) {
   PAN_TRACE_ERROR("PAN failed to send data buf to the PANU");
   pcb->write.errors++;
   return (tPAN_RESULT)result;
}
pcb->write.octets += p_buf->len;
pcb->write.packets++;
```

```
tBNEP_RESULT BNEP_WriteBuf(uint16_t handle, const RawAddress& p_dest_addr,
BT_HDR* p_buf,
   uint16_t protocol, const RawAddress* p_src_addr, bool fw_ext_present) {
   // no return value
   bnepu_check_send_packet(p_bcb, p_buf);
   return (BNEP_SUCCESS);
}
```

```
void bnepu_check_send_packet(tBNEP_CONN* p_bcb, BT_HDR* p_buf) {
   if (p_bcb->con_flags & BNEP_FLAGS_L2CAP_CONGESTED) {
      if (fixed_queue_length(p_bcb->xmit_q) >= BNEP_MAX_XMITQ_DEPTH) {
         // in this case, p_buf will be freed
         osi_free(p_buf);
      }
   }
}
```

Weak code patterns - others

- Double free due to ignoring error status
- Out of bounds read due to missing length check in *STREAM_TO_*
- Out of bounds write due to ignoring check of return value
- Deadloop due to index integer underflow
- And more...

Fuzzing - find the target function

- L2CA_Register(), L2CA_Register2(), L2CA_RegisterLECoc()
  - Used to register all L2CAP based profile data callback functions

```
extern uint16_t L2CA_Register(uint16_t psm, const tL2CAP_APPL_INFO& p_cb_info,
                              bool enable_snoop, tL2CAP_ERTM_INFO* p_ertm_info,
                              uint16_t my_mtu, uint16_t required_remote_mtu,
                              uint16_t sec_level);
uint16_t L2CA_Register2(uint16_t psm, const tL2CAP_APPL_INFO& p_cb_info,
                        bool enable_snoop, tL2CAP_ERTM_INFO* p_ertm_info,
                        uint16_t my_mtu, uint16_t required_remote_mtu,
                        uint16_t sec_level);
```

Fuzzing - find the target function

- pL2CA_DataInd_Cb

```
typedef struct {
 tL2CA_CONNECT_IND_CB* pL2CA_ConnectInd_Cb;
 tL2CA_CONNECT_CFM_CB* pL2CA_ConnectCfm_Cb;
 tL2CA_CONFIG_IND_CB* pL2CA_ConfigInd_Cb;
 tL2CA_CONFIG_CFM_CB* pL2CA_ConfigCfm_Cb;
 tL2CA_DISCONNECT_IND_CB* pL2CA_DisconnectInd_Cb;
 tL2CA_DISCONNECT_CFM_CB* pL2CA_DisconnectCfm_Cb;
 tL2CA_DATA_IND_CB* pL2CA_DataInd_Cb;
 tL2CA_CONGESTION_STATUS_CB* pL2CA_CongestionStatus_Cb;
 tL2CA_TX_COMPLETE_CB* pL2CA_TxComplete_Cb;
 tL2CA_ERROR_CB* pL2CA_Error_Cb;
 tL2CA_CREDIT_BASED_CONNECT_IND_CB* pL2CA_CreditBasedConnectInd_Cb;
 tL2CA_CREDIT_BASED_CONNECT_CFM_CB* pL2CA_CreditBasedConnectCfm_Cb;
 tL2CA_CREDIT_BASED_RECONFIG_COMPLETED_CB*
     pL2CA_CreditBasedReconfigCompleted_Cb;
 tL2CA_CREDIT_BASED_COLLISION_IND_CB* pL2CA_CreditBasedCollisionInd_Cb;
} tL2CAP_APPL_INFO;
```

https://cs.android.com/

- packages/modules/Bluetooth/system/stack/avct/avct_l2c_br.cc (1 occurrence)
  58: avct_l2c_br_data_ind_cback,
- packages/modules/Bluetooth/system/stack/avct/avct_l2c.cc (1 occurrence)
  57: avct_l2c_data_ind_cback,
- packages/modules/Bluetooth/system/stack/avdt/avdt_l2c.cc (1 occurrence)
  59: avdt_l2c_data_ind_cback,
- packages/modules/Bluetooth/system/stack/bnep/bnep_main.cc (1 occurrence)
  85: bnep_cb.reg_info.pL2CA_DataInd_Cb = bnep_data_ind;
- packages/modules/Bluetooth/system/stack/eatt/eatt.cc (1 occurrence)
  47: reg_info_.pL2CA_DataInd_Cb = eatt_data_ind;
- packages/modules/Bluetooth/system/stack/gap/gap_conn.cc (1 occurrence)
  123: conn.reg_info.pL2CA_DataInd_Cb = gap_data_ind;
- packages/modules/Bluetooth/system/stack/gatt/gatt_main.cc (1 occurrence)
  81: gatt_l2cif_data_ind_cback,
- packages/modules/Bluetooth/system/stack/hid/hidd_conn.cc (1 occurrence)
  57: hidd_l2cif_data_ind,
- packages/modules/Bluetooth/system/stack/hid/hidh_conn.cc (1 occurrence)
  76: .pL2CA_DataInd_Cb = hidh_l2cif_data_ind,
- packages/modules/Bluetooth/system/stack/include/l2c_api.h (1 occurrence)
  326: typedef struct {
- packages/modules/Bluetooth/system/stack/rfcomm/rfc_l2cap_if.cc (1 occurrence)
  71: p_l2c->pL2CA_DataInd_Cb = RFCOMM_BufDataInd;
- packages/modules/Bluetooth/system/stack/sdp/sdp_main.cc (1 occurrence)
  91: sdp_cb.reg_info.pL2CA_DataInd_Cb = sdp_data_ind;

Fuzzing - SDP

- sdp_data_ind
  - Handle SDP data received from L2CAP
- sdp_disc_server_rsp
  - Handle response data from server
- sdp_server_handle_client_req
  - Handle request data from client

```c
static void sdp_data_ind(uint16_t l2cap_cid, BT_HDR* p_msg) {
  tCONN_CB* p_ccb;

  /* Find CCB based on CID */
  p_ccb = sdpu_find_ccb_by_cid(l2cap_cid);
  if (p_ccb != NULL) {
    if (p_ccb->con_state == SDP_STATE_CONNECTED) {
      if (p_ccb->con_flags & SDP_FLAGS_IS_ORIG)
        sdp_disc_server_rsp(p_ccb, p_msg);
      else
        sdp_server_handle_client_req(p_ccb, p_msg);
    } else {
      SDP_TRACE_WARNING(
          "SDP - Ignored L2CAP data while in state: %d, CID: 0x%x",
          p_ccb->con_state, l2cap_cid);
    }
  } else {
    SDP_TRACE_WARNING("SDP - Rcvd L2CAP data, unknown CID: 0x%x", l2cap_cid);
  }

  osi_free(p_msg);
}
```

Fuzzing - SDP

- Write a test harness
  - Init sdp stack
  - Init sdp connection control block to simulate a real sdp connection
  - Generate some sdp databases
  - Generate some states
  - Generate sdp packet data
  - Continuously fuzz sdp server and client interfaces

```
extern "C" int LLVMFuzzerTestOneInput(const uint8_t* data, size_t size)
{
   FuzzedDataProvider fdp(data, size);

   sdp_init();
   init_ccb();
   init_sdp_db(fdp);

   size_t count = fdp.ConsumeIntegralInRange<int>(1, 20);
   while (count-- && sdp_db_vect.size() && fdp.remaining_bytes()) {
       if (fdp.ConsumeBool()) {
           sdp_disc_server_rsp_fuzzer(fdp);
       } else {
           sdp_server_handle_client_req_fuzzer(fdp);
       }
   }

   SDP_DeleteRecord(0);
   sdp_db_vect.clear();
   sdpu_release_ccb(p_ccb);
   sdp_free();

   return 0;
}
```

Results

- Since 2022, total 33 vulnerabilities have been found
  - 3 are duplicate
  - 8 have been fixed
  - others are still in process
- Found with CodeQL
  - 15 vuls, including CVE-2022-20445, CVE-2022-20222, CVE-2022-20362, CVE-2022-20283, CVE-2022-20447, CVE-2022-20410
- Found with fuzzing
  - 9 vuls, including CVE-2022-20224, CVE-2022-20229, CVE-2022-20140

Agenda

- Introduction to Android Bluetooth
- Attack surfaces analysis
- Finding vulnerabilities
- Summary

Conclusion

- Some basic information about Android Bluetooth
- Historical vulnerability analysis
- Full attack surfaces and vectors
- How to find the bugs
  - Weak code patterns
  - Fuzzing tricks
- CVE cases

Future work

- Write more CodeQL scripts to catch more vulnerable patterns
  - Dangling pointers nullification in C++ smart pointers
  - Race condition in JNI/main/hci threads
  - Type confusion in message queue
- Focus on new protocols and profiles implemented on Android 13
  - LeAudio
- Other vendors Bluetooth stack implementation
  - Qualcomm
  - Mediatek

Reference

- https://source.android.com/docs/core/connect/bluetooth
- https://source.android.com/security/bulletin/
- https://codeql.github.com/
- https://bughunters.google.com/leaderboard
- https://hackerone.com/qualcomm/thanks/2022

Thanks