Bluetooth

Table of Contents

I. Objectives

The objectives of this work are:

- Understand Bluetooth's *Host Controller Interface* (HCI) interface
- Observe the different phases a Bluetooth device goes during its operation
- Identify main Bluetooth protocols and how there are used and behave

II. Duration

This work should be executed in 2h.

III. Procedures

This Work will use:

a) Students' personal PC with Wireshark installed
b) Previously captured traffic exchanges and downloaded from the course available online materials

IV. Network diagram used (approximate)

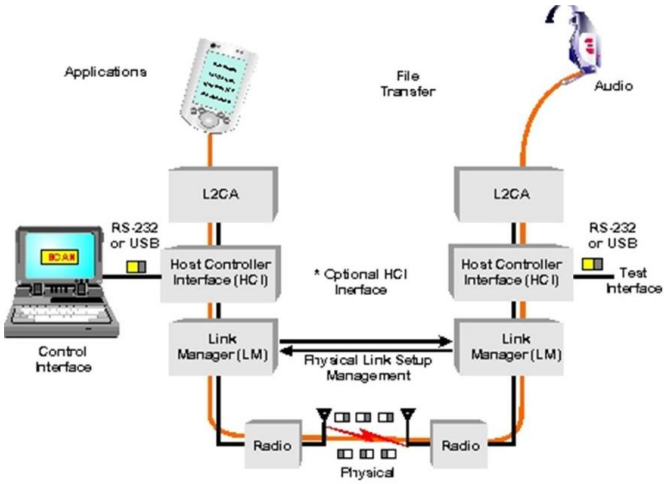


Figure 1: Network diagram used

(http://www.althos.com/tutorial/Bluetooth-tutorial-host-controller-interface-HCI-Layer.html)

V. Used devices

- Master/Controller (left side of the picture)

a) Linux 22.04 PC with TP-Link Archer T5E, AC1200 Wi-Fi Bluetooth 4.2 PCIe Adapter
   - Bluetooth version: 4.2

- Clients/Devices

HP mouse HSA-P007M • Bluetooth version: 4.2	Sony Headphones WF-1000XM4 • Bluetooth version: 5.2 • Bluetooth profiles: A2DP, AVRCP, HFP, HSP • Audio formats: SBC, AAC, LDAC
Sony Headphones WH-1000XM3 • Bluetooth version: 4.2 • Bluetooth profiles: A2DP, AVRCP, HFP, HSP • Audio formats: SBC, AAC, aptX, aptX HD, LDAC	Philips AEA2000/12 adapter • Bluetooth version: 2.1+EDR • Bluetooth profiles: A2DP and AVRCP
RAZER Seiren BT Microphone, RZ19-0415 • Bluetooth Version: 5.0	

VI. Procedures

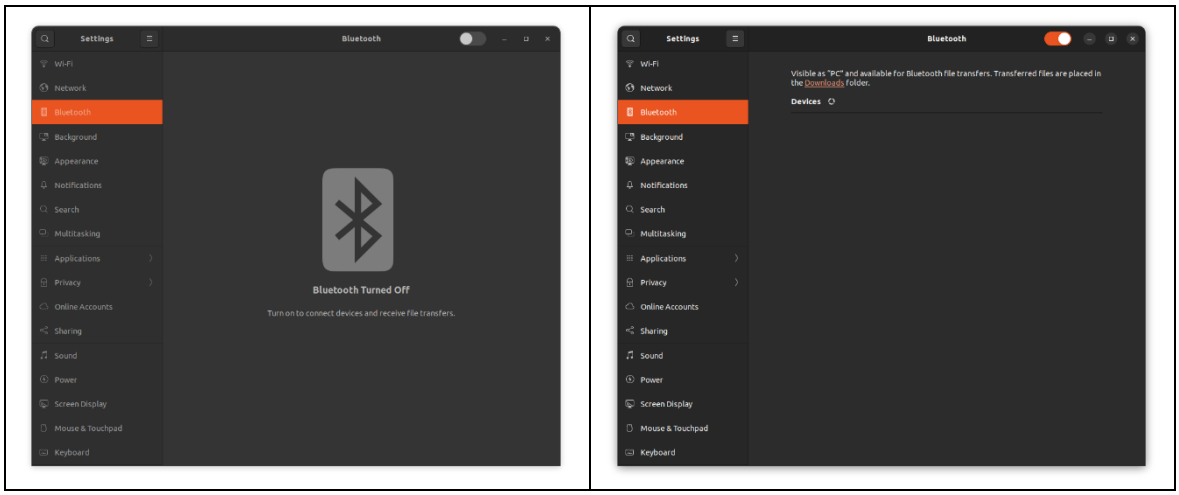
A. Scan

1. Download the Wireshark files, available in eLearning, containing traffic captures taken at an HCI interface for the above listed devices
2. From those, start by opening the capture "**1.PC.BTOn.periodicScanning.pcapng**"

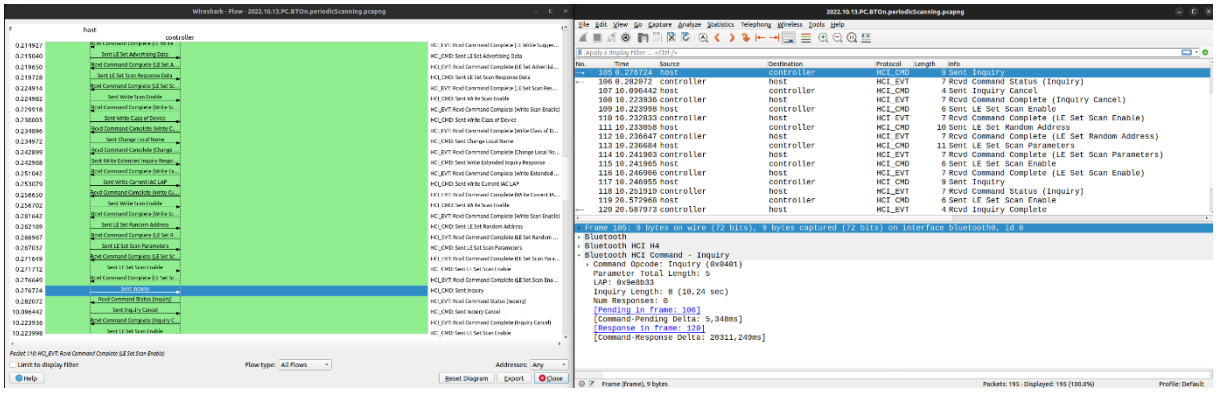
   To better understand this and other captures, go to 'Statistics' → 'Flow Graph' window; when selecting a frame here, it is also selected in Wireshark main window; go to the next frame by pressing 'n'; for the previous one, press 'p'; see each Frame details in Wireshark 'Packed Details' window

   The following procedures were executed while the capture was running:

   a) The PC Bluetooth interface was turned on Bluetooth settings window; the interface starts scanning immediately
   b) After some seconds of frames capture, it was stopped and saved



3. Go to 'Wireshark' → 'Statistics' → 'Flow Graph' and open that new window side-by-side with the main Wireshark window



4. Order the capture by the column 'Protocol'; scrolling down, identify the protocols present in the capture, the actors involved ('Source' and 'Destination') and the direction of the communication

   Têm HCI_CMD (e são sempre host->controller) e HCI_EVT (e são todos controller->host)

5. Reorder the capture by the column 'No.'; Looking into the 'Source', 'Destination' and 'Protocol' columns, observe the sequence of the messages exchange

   Cada HCI_CMD (comando) e respondido com um HCI_EVT (evento)

6. Order the capture using the column 'Info' to see the different messages grouped by its specific type. For instance, check the frequency of the Inquiry process. Look at the 'Read', 'Set' and 'Write' messages used in the start-up and the overall process.

   Observar os 'Sent Inquiry' ou 'Rcvd Inquiry Complete'; Acontece a sensivelmente cada 10 seg.

   Pode usar o filtro: bthci_cmd.opcode == 0x0401 || bthci_evt.code == 0x01

7. Order again by the column 'No.''; Observe and analyse the startup process; see the Read and Write commands sent to controller and the exchanged information; observe via the timing information and the time taken by the process

   Na trama 1 observa-se o host a enviar um reset ao controller.

   A partir daí e até à 105, o host lê (Read) vários parametros do controlador e faz a sua configuração (Write)

   Ver as mensagens de "Send Read …" e "Send LE Read …" e as respectivas respostas

   p.ex. na 7 pede-lhe o MAC Address.

   Ver as respostas 28 (Supported LE Features), 89 (Write Class of Device)

8. Observe and analyse the periodic Inquiry process. Identify the involved messages of the process.

   Na 117 inicia-se o Inquiry que termina na 120.

   Observar os 'Sent Inquiry' ou 'Rcvd Inquiry Complete'; Acontece a sensivelmente cada 10 seg.

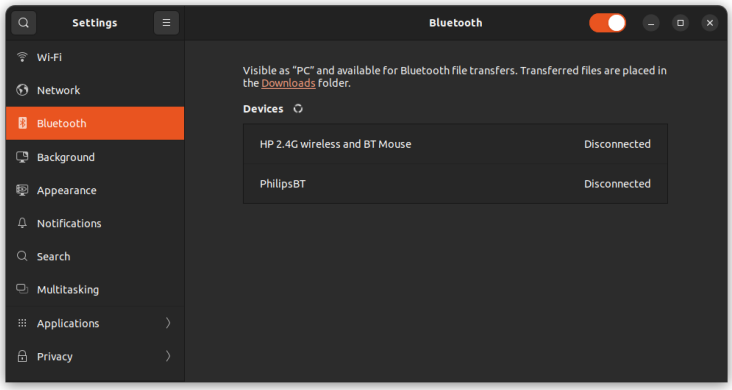
   Pode usar o filtro: bthci_cmd.opcode == 0x0401 || bthci_evt.code == 0x01

B. Pair, connect and use: mouse

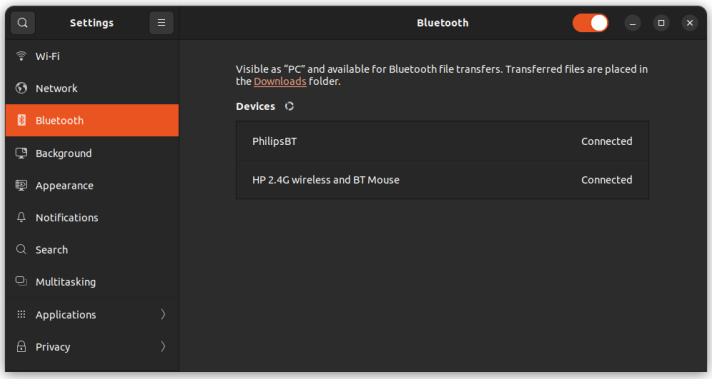
9. Now open the capture "**2.HP.Mouse.pair.move.buttons.switchoff.pcapng**"

   The following procedures were executed while the capture was running:

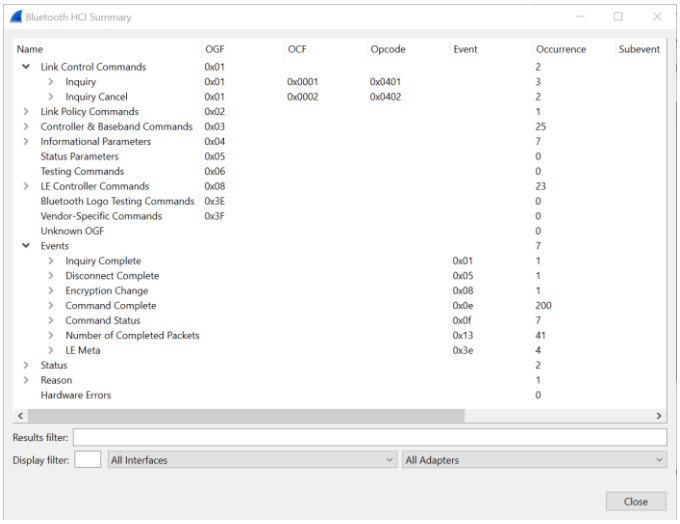
   a) Turn on Bluetooth on the PC on the Settings Menu



   b) Check that no LE Meta (LE Advertising Reports) appear on the capture (no other active devices nearby)
   c) Put the device (mouse) in pairing mode
   d) Observe in Wireshark that LE Meta (LE Advertising Reports) messages start to appear
   e) Order the device to be connected, in the PC's Bluetooth settings menu
   f) Observe that it was successful
   g) Press different buttons in the mouse and move it around
   h) Stop the capture and saved it



10. Go to 'Wireshark' → 'Wireless' → Bluetooth HCI Summary'; you should get the following window:



a) Open the other vertical groups and analyse the information; keep it open and use the information during the next steps

11. Go to 'Wireshark' → 'Statistics' → 'Flow Graph' and open that new window side-by-side with the main Wireshark window

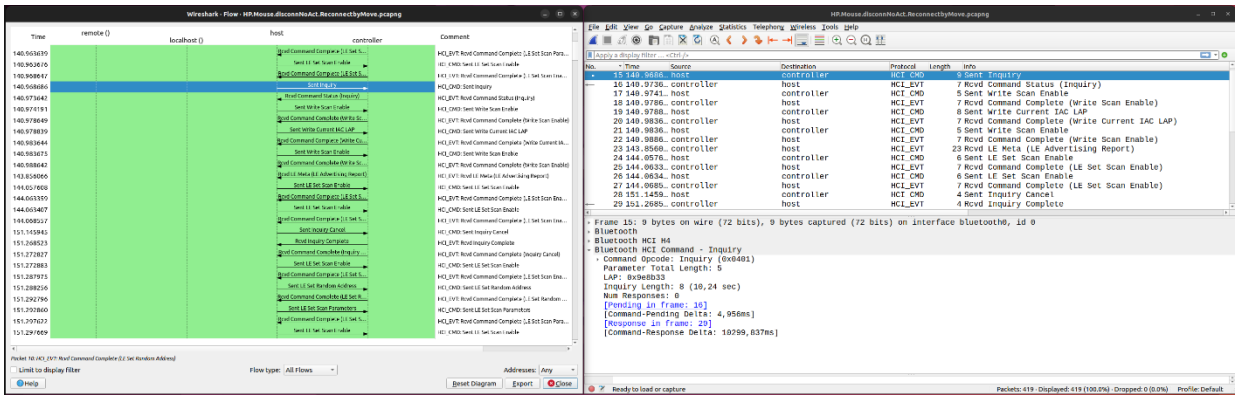


Figure 6: View of the capture file

12. Order capture by the 'Protocol' column and identify the different protocols capture in these interactions.
    a) See their different types by applying the visualization filter hci_h4.type==0x{1|2|3|4} (see table at the end); what type of packets is missing?
    b) Take note of the entities are the messages exchanged ('Source' and 'Destination')

	Type	Protocol	Source	Destination
ATT	2 (ACL DATA)	Attribute Protocol	IntelCor_...(PC) HP 2.4G Wireless ...	HP 2.4G Wireless ... IntelCor_...(PC)
HCI_CMD	1	HCI Commands	host	controller
HCI_EVT	4	HCI Event	controller	host
L2CAP	2	Logical Link Control and Adaptation Protocol	localhost() and MAC of the device (two-way)	Device MAC and localhost() (two-way)
SMP	2	Security Manager Protocol	localhost() and MAC of the device (two-way)	Device MAC and localhost() (two-way)

Controller e host são apenas utilizados para HCI_CMD e HCI_EVT

Faltam pacotes de tipo 3 (Synchronous data)

13. Order again the capture by column 'No.' Observe the pairing and connect procedures that happened after it is requested in the PC Bluetooth Settings window; Identify the following events:
    Note: To better analyse the pairing process, order again by 'Protocol' and see the sequence of exchanged messages of that protocol
    a) LE Create Connection; register the 'Connection handle' value

Create Conn: Frame 566, respondido na 568

Observar o connection handle 0x0e01

b) Pairing Request (*What protocol is used?*)

Pairing req: Frame 572; SMP

c) Start Encryption

Start Encryption: Frame 591

14. Now, observe other events; order again by column 'No.'. Look into captured frames 756 to 1298. See the type of frames exchanged during this period.

São Attribute Protocol, transportados em L2CAP

15. In the details view, check for 'Connection Handle' (ACL), 'Method' (ATT) and 'Value' (ATT) fields. Find the following:
    a) Report on battery level

Frames ATT 744, 1000, 1272 and 1298

    b) Mouse movements (happens from 60sec to 92.4sec of the capture) and Buttons pressed (happens from 78.1sec to 83.9sec of the capture);

Buttons: 1273 a 1286

16. At the end the device is physically switch off, in the built-in button. See what happens at the HCI interface.

Há uma única frame do controller ao host com o mesmo connection handle (0x0e01) estabelecido na frame 568.

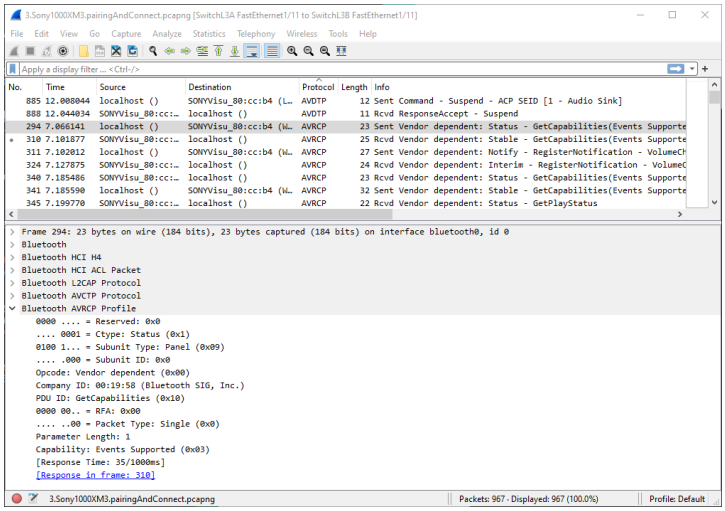
C. Pair, connect and use, phones

17. Open the capture "**3.0.Sony1000XM3.pairingAndConnect.pcapng**"

    The following procedures were executed while the capture was running:

    a) Turn on Bluetooth on the PC on the Settings Menu
    b) Check that no LE Meta (LE Advertising Reports) appear on the capture (no other active devices nearby)
    c) Put the device (phones) in pairing mode
    d) Observe in Wireshark that LE Meta (LE Advertising Reports) messages start to appear
    e) Order the device to be connected, in the PC's Bluetooth settings menu
    f) Observe that it was successful
    g) Stop the capture and saved it

18. Order by Protocol and list the protocols involved
    a) By selecting a frame of each protocol, observe the protocol stack in the details window (see example).
    b) Also chech the order there are used



Types and Order: HCI_EVT (0.00/1)

HCI_CMD (0.20/3)

L2CAP (6.54/70) sem outros protos dentro (signalling channel)

SDP (6.56/86) in L2CAP

RFCOMM (6.76/147) in L2CP in ACL

HFP (6.80/171) in RFCOMM in L2CAP in ACL

AVDTP (6.81/181) in L2CAP in ACL

SBC (7.00/276) in RTP in A2DP Profile in L2CAP in ACL

AVRPC (7.06/294) in AVCTP in L2CAP in ACL

19. Identify the start of the pairing and connect process (it is useful at this step to order again by 'No.')

    Frame 33, Send Create Connection

20. Observe the presence of the protocol RFCOMM; check what parameters are exchanged and the configuration done with it. Also look into HFP.

    Radio Frequency Communication; Transporte para outras coisas. Começa por estabelecer o canal 10 (UIH Channel =10) onde depois passa o HFP

    HFP: coisas relacionadas com ser auricular (handsfree) p chamadas de voz

21. Observe the presence of the protocol AVDTP; check what parameters are exchanged and configuration done with it. Check Frame 217

    Controla os canais de audio utilizados; ver as frames 236, 256 e 885

22. Observe the presence of the protocol AVRPC; check what parameters are exchanged and configuration done with it.

    Utilizado para controlar o playback; ver a Frame 346, p.ex.

D. Connect and unpair, phones

23. Open the capture "**3.1.Sony1000XM3.powerOn.Connect.unPair.pcapng**"

    The following procedures were executed while the capture was running:

    a) Switch on the device
    b) Wait to see the device switching to Sniff Mode (Frame 745)
    c) In the PC Bluetooth Setting remove the device
    d) Wait a few seconds, stop the capture and save it

24. Observe the immediate connect requested by the device

    O dispositivo faz um pedido de ligação que traz o seu endereço (BD_ADDR) e uns parametros de caracterização; depois o processo é identico

    São estabelecidos 3 signalling channels; Frames:

    1. *151: PSM: AVDTP*
    2. *185: PSM: AVDTP*
    3. *196: PSM: AVCTP_Control*

25. Observe the disconnect process

    O disconnect da Frame 851, vem do connect da Frame 196; tem SCID 0x0041

    O disconnect da Frame 864, vem do connect da Frame 185; tem SCID 0x0042

    O disconnect da Frame 865, vem do connect da Frame 151; tem SCID 0x0043

E. Audio call (Messenger), phones

26. Open the capture "**4.Sony1000XM3.MessengerCall.pcapng**"; also open 'Statistics → 'Flow Graph'; this capture was obtained in the scope of a Messenger call.

    The following procedures were executed while the capture was running (Phones were already paired and connect):

    a) Started the capture in Wireshark

    b) Started a call in the PC Messenger client to another client

    c) Stop the call in the PC Messenger

    d) Wait to see the last Mode Change

    e) Stop the capture (PC)

27. See Frames 1 to 3; What do they mean?

    O dispositivo estava em 'Sniff Mode' e passou a 'Active Mode'

28. See Frame 4 to 7; check the type of connection being established. Why that?

    Chamada messenger, requer tempo real, estabelece uma ligação síncrona

29. From 8 to 19170, in 29 seconds, audio frames are exchanged bidirectionally.
    a) Apply the visualization filter "hci_h4.type==0x03".
    b) Check on the table at the end of the manual the type of these frame.

    Synchronous Connection Oriented Link (Data)

    c) Based on that, conclude about frequency and size of the frames

    São frames de 'Synchronous Data". São muito frequentes e com poucas amostras para haver baixa latencia. Erros/perdas tb têm menor impacto.

30. Check one of those frames in the 'Packet Details' window. See the protocol stack and 'HCI Packet Type'; see where this exchange fits in the HCI protocol stack present at the end of this manual

    SCO Data; trocado directo da App ao Voice Codec

31. The call is finished; see what happens in and after Frame 19171 (you have to clear the visualization filter).

    Há um Disconnect e o dispositivo reporta ter entrado em Sniff Mode

    Ver o Connection Handle utilizado aqui e na Frames 7 (0x0101)

F. Audio streaming (Spotify), phones

32. Open the capture "**5.Sony1000XM3.Spotify.pcapng**"

    The following procedures were executed while the capture was running (Phones were already paired and connect):

    a) Started the capture in Wireshark

    b) Start streaming on PC (Spotify)

    c) Stop streaming on PC (Spotify)

    d) Start streaming on phones (Frame 835, 8.62s)

    e) Stop streaming on phones (Frame 1380, 23.925s)

    f) Stop the capture (PC)

33. Identity the type of established connection and see the initial mode change

    Frame 1: Connection oriented request: localhost to remote (remote evice)

    Frame 2: Exit sniff mode: host to controller (local)

34. Identity the messages exchange for the audio exchange; observe the direction of the messages

35. Observe what happens when resuming audio stream at the phones.

    Ligação é estabelecida desde os phones

G. Uni and bidirecctional audio, microfone (with line-out functionality)

36. Open the capture "**6.RaizerMicroph.switchOn.changeToSychroAudio.switchToOff.pcapng**"

    The following procedures were executed while the capture was running (the device has been already paired and connected):

    a) Start Capture

    b) Switch on the device

    c) Select the device as Output Device in the Linux Settings window

    d) Wait for change mode notification (in Wireshark)

    e) Start streaming on Spotify

    f) Pause streaming on Spotify

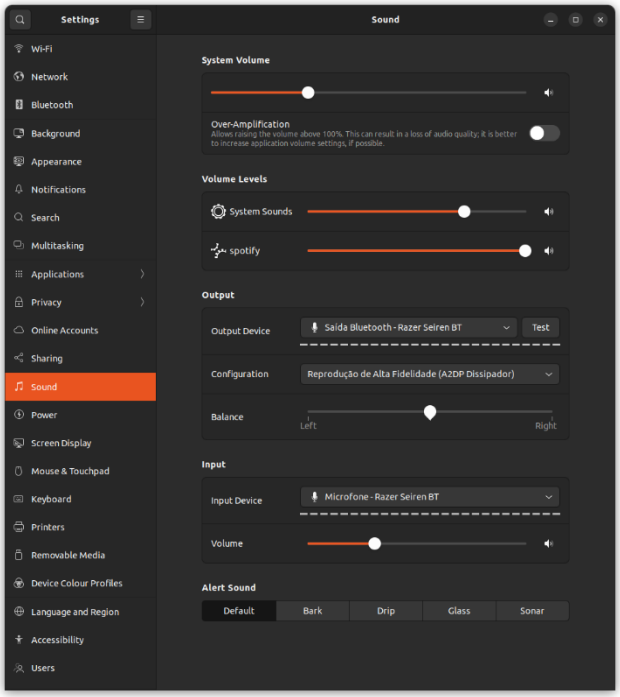
    g) Wait for change mode notification (in Wireshark)

    h) Resume streaming on Spotify

    i) Change audio input device in the Linux Settings window to the Raizen device (see figure)

    j) Switch off device

    k) Stop the capture



37. Has with previous analysis, identify the involved protocols and their stack

    AVDTP in L2CAP (dynamically allocated channel) in ACL – fase inicial

    AVRPC in AVCTP in L2CAP (dynamically allocated channel) in ACL – fase inicial

    HCI_CMD

    HCI_EVT

    HCI_SCO

    HFP in RFCOMM – fase inicial

    L2CAP sem qq outro protocol dentro (signalling channel)

    SBC in RTP in A2DP profile in L2CAP in ACL – fase inicial

    SDP in L2CAP

38. Observe the overall process captured in Wireshark and analyse, considering the following guidelines:

    a) Initial connection and configuration process between the two devices. It goes from Frame 1 to Frame 181

    b) There is an initial exchange of empty audio packets (to be confirmed in following steps) that stop in Frame 899

    c) Frame 901 results from Spotify start

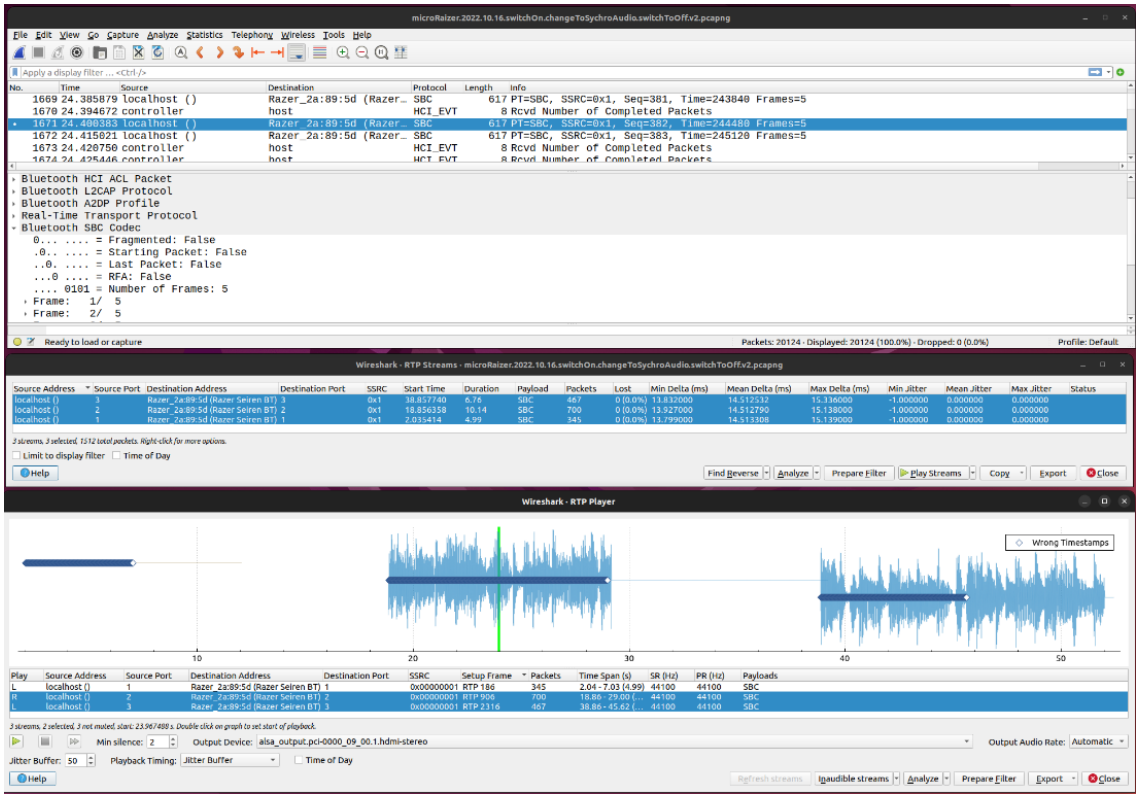
    d) Frame 2306 results from Spotify pause

    e) Frame 2311 results from Spotify resuming streaming

    f) Frame 3254 results from the device being added also as audio input device

    g) Frame 20088 results from the device being switched off

39. Go to 'Telephony' → 'RTP' → 'RTP Streams' and observed that three RTP were identified. Select then and press 'Play Streams'. With an audio device in your PC you should be able to listen to the 2nd and 3rd streams!



As can be seen in the figure (and in your screen), the first sequence has no audio. The samples with "Wrong timestamps" correspond to audio sent with RTP+SBC (initial setup and unidirectional audio streaming). The last samples correspond the direct, bidirectional audio.

H. Other devices

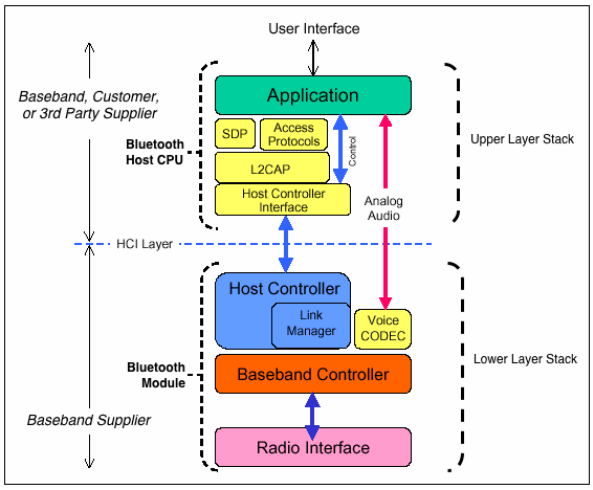
40. Analyse the two other captures:

    7.PhilipsBTaudio.pairing.pcapng and

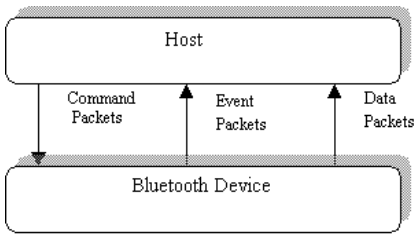
    8.Sony1000XM4.pairing.pcapng

    and do similar analysis to the previous ones.

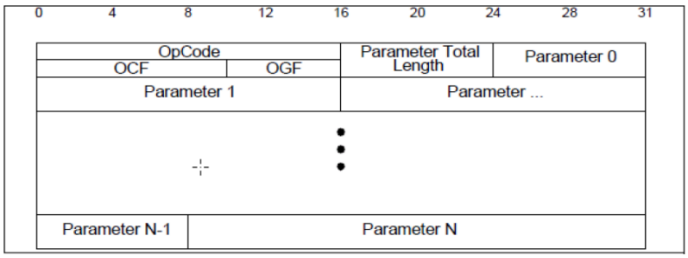
VII. Interface HCI



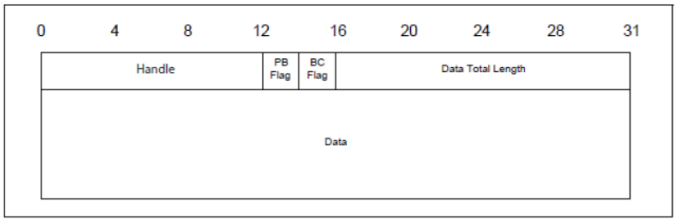
https://hearinghealthmatters.org/wp-content/uploads/sites/9/files/2014/01/BT-Stack.gif



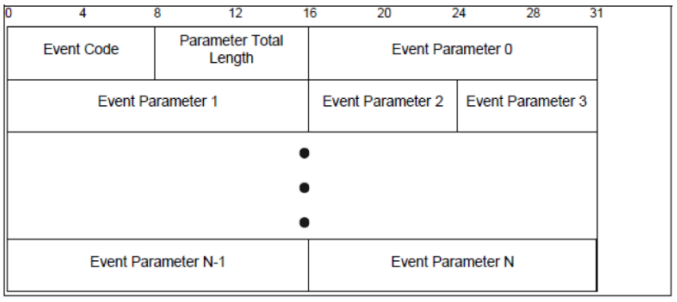
Command Packet



Asynchronous Data Packet



Event Packet



VIII. Bluetooth states

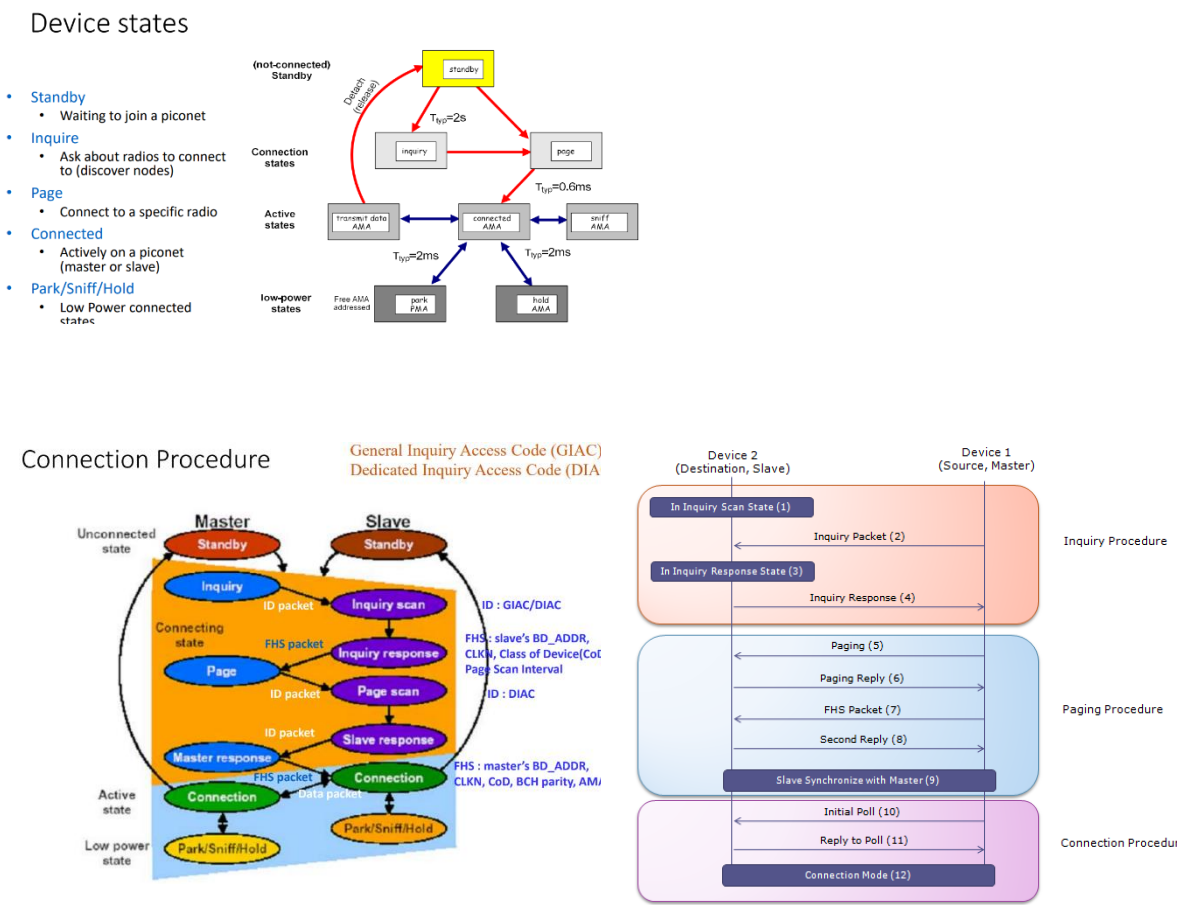
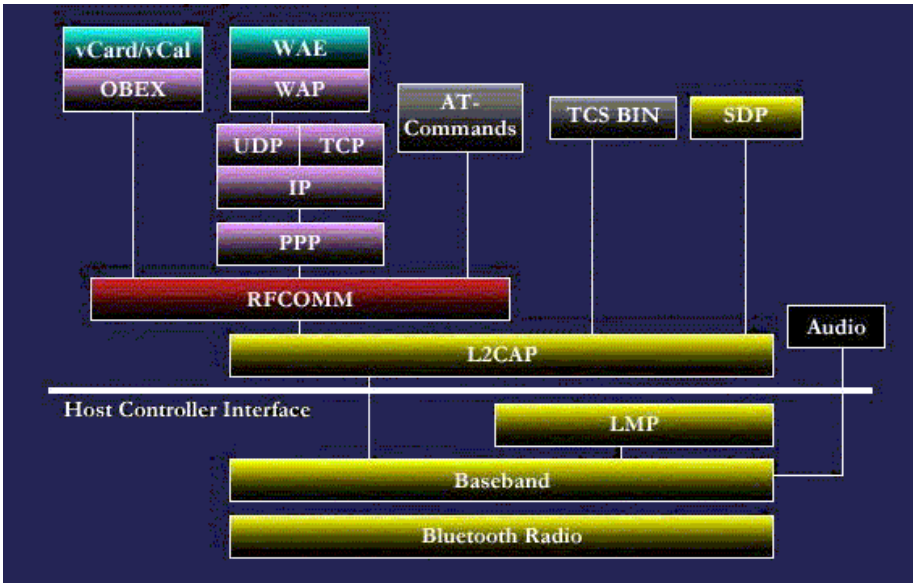


Figure 9: Bluetooth state machine

(http://www.sharetechnote.com/html/Bluetooth_Protocol.html)

IX. Bluetooth protocols and profiles



http://www.tutorial-reports.com/wireless/bluetooth/protocolstack.php

X. Acronyms (with some additional information)

NOT Complete. For sure you will find many more on the capture files.

Acronym	Name	Notes
A2DP	Advanced Audio Distribution Profile	
ACP	Acceptor	
ACL	Asynchronous Connection Less	
AVCTP	Audio/Video Control Transport Protocol	Transported in L2CAP
AVDTP	Audio/Video Distribution Transport Protocol	Specifies the transport protocol for audio and video distribution and streaming; Transported in L2CAP
AVRCP	Audio/Video Remote Control Profile	Transported in AVCTP (in L2CAP)
ATT	Attribute Protocol	
CID	Channel Identifier	A channel identifier (CID) is the local name representing a logical channel endpoint on the device
DCID	Destination CID	
GATT	Generic ATTribute Profile	
HCI	host controller interface	
HFP	Hands-Free Profile	
L2CAP	Logical Link Control and Adaptation Protocol	Supports connection-oriented as well as connectionless services Supports *Synchronous Connection-Oriented* (SCO) links for real-time voice traffic using reserved bandwidth and *Asynchronous Connection-Less* (ACL) links for best-effort traffic
LE	Low Energy	
PSM	Protocol Service Multiplexor	
RFCOMM	Radio Frequency Communication	reliable stream-based protocol providing emulated RS-232 serial ports
RTP	Real-time Transport Protocol	
SBC	Sub-band Coding	Transported in RTP
SCID	Source Channel Identifier	
SCO	Synchronous Connection Oriented Link	
SDP	Service Discovery Protocol	
SEID	Stream End-point IDentifier	
SMP	Security Management Protocol	
UIH	Unnumbered Information with Header check	
UUID	Universally Unique IDentifier	

XI. Using Wireshark

Preview filters

- hci_h4.direction == 0x00 / 0x01
- hci_h4.type == see table

Packet	Packet Type
Command	0x01
Asynchronous Data	0x02
Synchronous Data	0x03
Event	0x04

- bthci_cmd.opcode == *Command Opcode* (Opcode Group Field + Opcode Command Field)
- bthci_cmd.opcode.ocf == *Opcode Command Field*
- bthci_cmd.opcode.ogf == *Opcode Group Field*
- bthci_evt.code == *Event Code*

The opcode is subdivided into two parts:

1. a 10-bit Opcode Command Field (OCF) and
2. a 6-bit Opcode Group Field (OGF)

XII. Useful links

- https://www.bluetooth.com/specifications/specs/
- https://lisha.ufsc.br/teaching/shi/ine5346-2003-1/work/bluetooth/hci_commands.html
- http://oscar.iitb.ac.in/onsiteDocumentsDirectory/Bluetooth/Bluetooth/Help/Host%20Controller%20Interface.htm
- https://gitlab.com/wireshark/wireshark/-/wikis/Bluetooth
- https://software-dl.ti.com/simplelink/esd/simplelink_cc13x2_sdk/1.60.00.29_new/exports/docs/ble5stack/vendor_specific_guide/BLE_Vendor_Specific_HCI_Guide/hci_interface.html
- https://www.wireshark.org/docs/dfref/h/hci_h4.html
- http://www.althos.com/tutorial/Bluetooth-tutorial-title-slide.html