Understanding Bluetooth® Low Energy

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Raffaele Riva – RF Application Manager

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Agenda

Time	Presentation	Speaker
11:10	Bluetooth Low Energy Introduction	Hary Radakichenane
	• Bluetooth Low Energy Power Consumption • Maximize Bluetooth Low Energy Application Throughput • Voice over Bluetooth Low Energy • Over The Air (OTA) FW Upgrade over Bluetooth Low Energy	Raffaele Riva
12:00	ST Bluetooth Low Energy Roadmap	Hary Radakichenane

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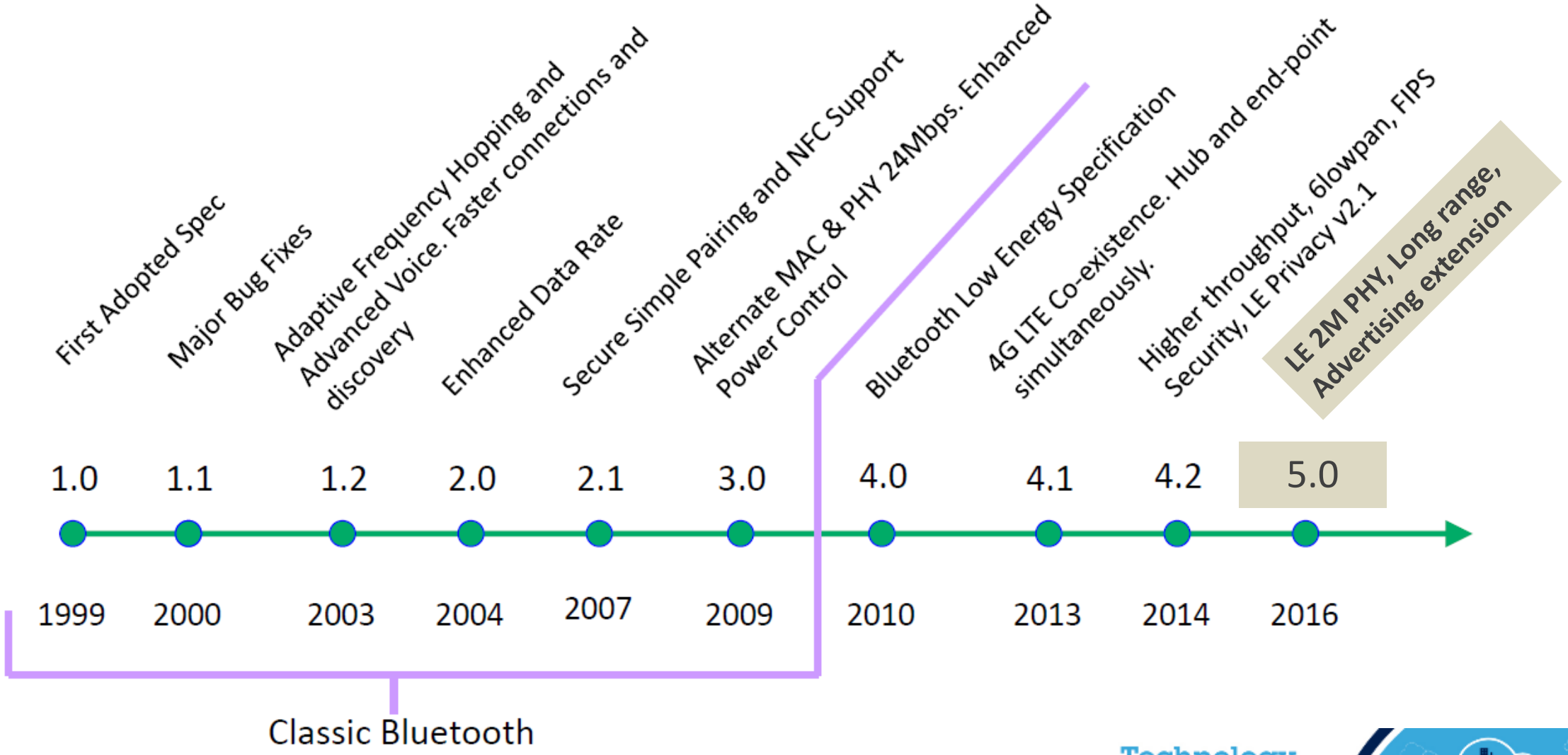
Bluetooth Evolution



Bluetooth Low Energy: Designed for Success

- Lower power than Bluetooth “Classic” (or Bluetooth 3.0)
  - Lower duty cycle
  - Faster connection
  - Lower peak power (relaxed RF parameters)

- Compatible with all major platforms (iOS, Android, Windows, Linux)
- Able to discover thousands of devices in local area
- Unlimited number of slaves connected to a master
- Unlimited number of masters
- State of the Art encryption
- Security including privacy/authentication/authorization

Bluetooth Low Energy Branding

2011 Two flavors

Bluetooth SMART

- Ultra low power consumption being a pure low energy implementation
- Months to years of lifetime on a standard coin cell battery

Bluetooth SMART READY

- Classic Bluetooth + Bluetooth low energy on a single chip
- These are the hub devices of the Bluetooth ecosystem

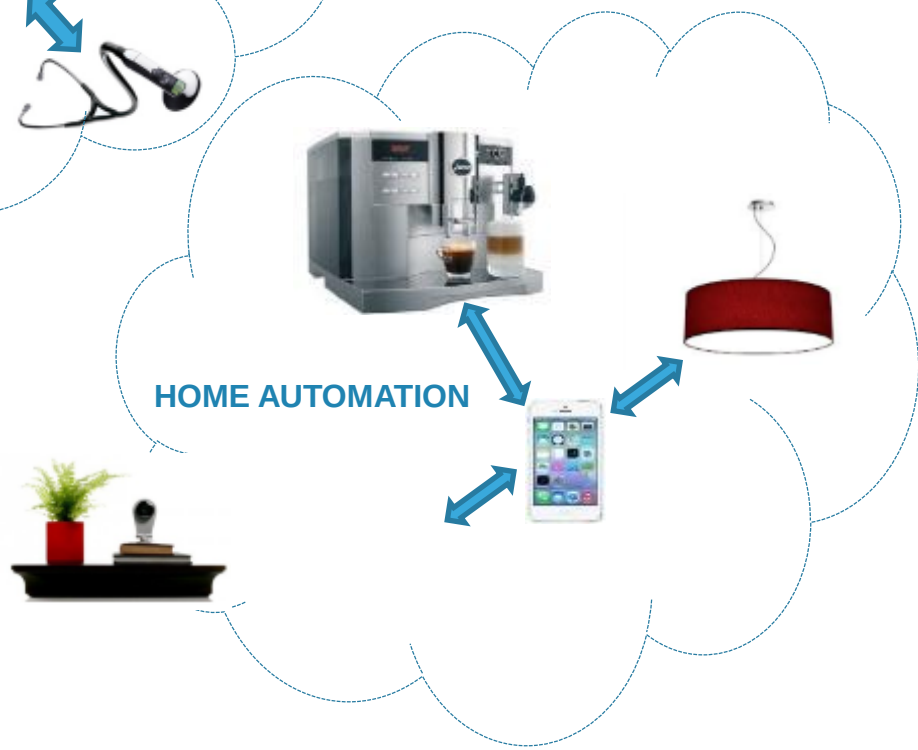
2017 Back to one flavor

Bluetooth

- An implementation of the Bluetooth core system has only one Primary Controller which may be one of the following configurations:
  - BR/EDR Controller (3.0 and earlier)
  - LE (low energy) Controller (4.0 and newer)
  - Combined BR/EDR Controller portion and LE controller portion into a single Controller (4.0 and newer)

Source: Bluetooth SIG

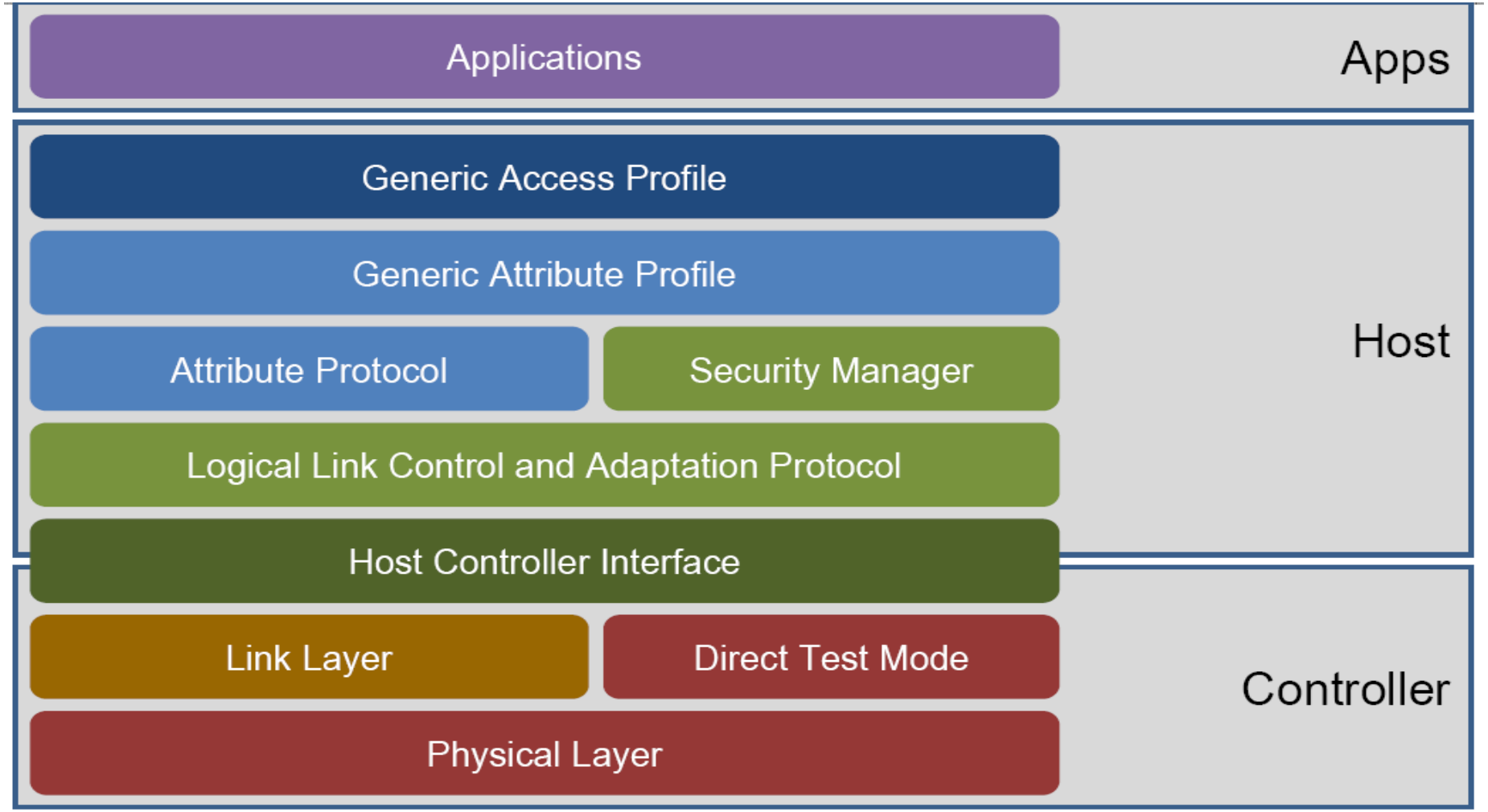
Bluetooth Low Energy Main Applications



Bluetooth Certification

- Is a requirement
- Logo or not, technology is IP of the Bluetooth SIG
- Must be a member of the Bluetooth SIG
  - Adopter: FREE
  - Associate: $7,500 -$35,000 Annual FEE
- Use of pre-certified Components are beneficial
  - Bluetooth Stack
  - Profiles/Services
  - RF Modules
- Listing FEE minimum required

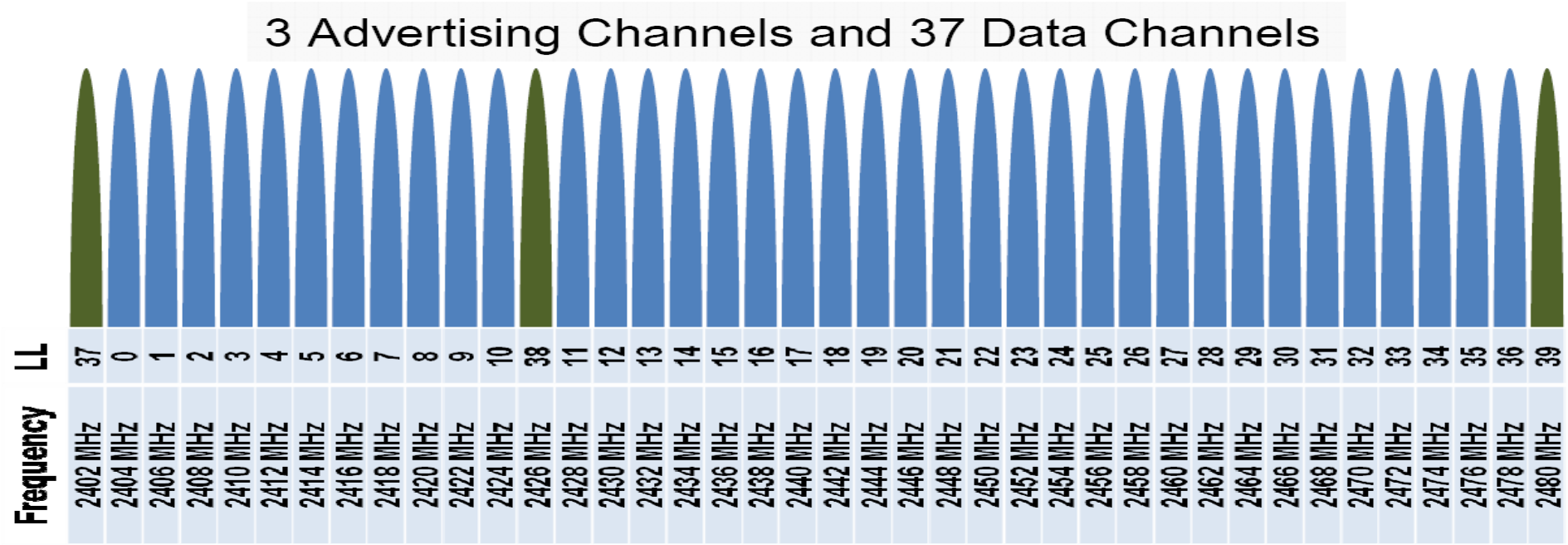
Bluetooth Low Energy Protocol Stack



Source : Bluetooth® SIG

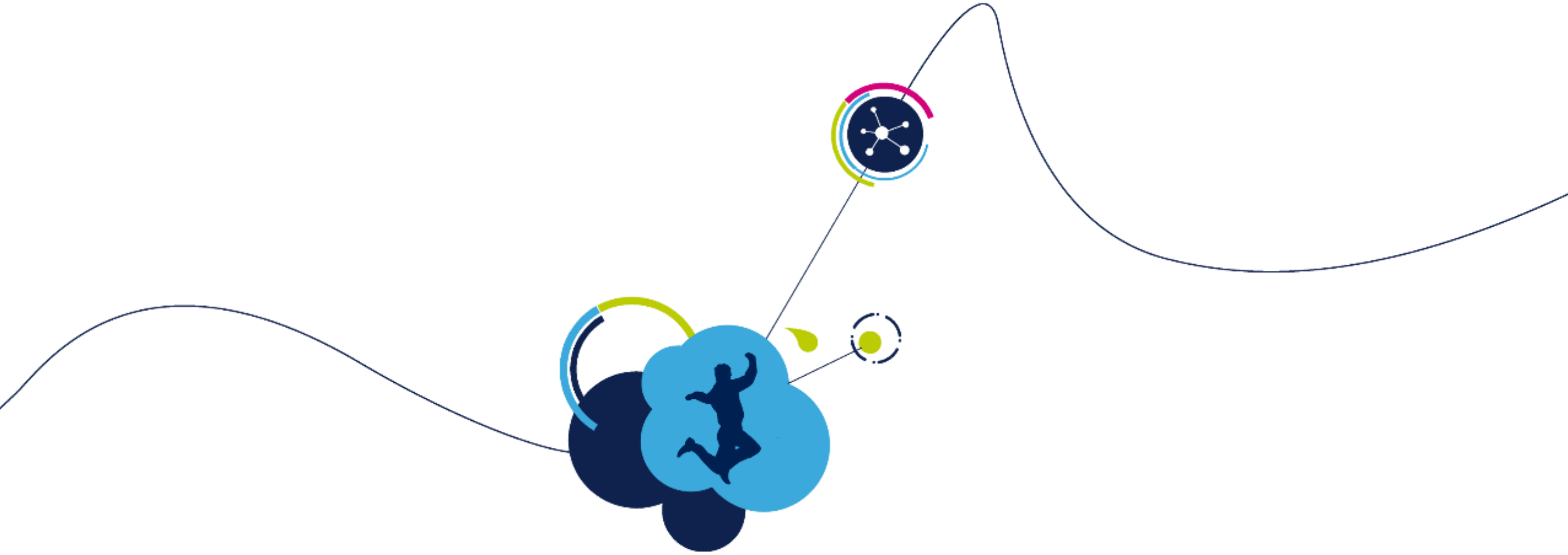
Bluetooth Low Energy Protocol Stack: PHY

- 2.4 GHz ISM Band Transceiver
  - Divided into 40 RF Channels
  - 2 MHz channel Spacing.
  - Two types of channels (3 Advertising and 37 Data)



Source : Bluetooth® SIG

- Bluetooth Low Energy Power Consumption
- Maximize Bluetooth Low Energy Application Throughput
- Voice over Bluetooth Low Energy
- Over The Air (OTA) FW Upgrade over Bluetooth Low Energy



Bluetooth Low Energy Power Consumption

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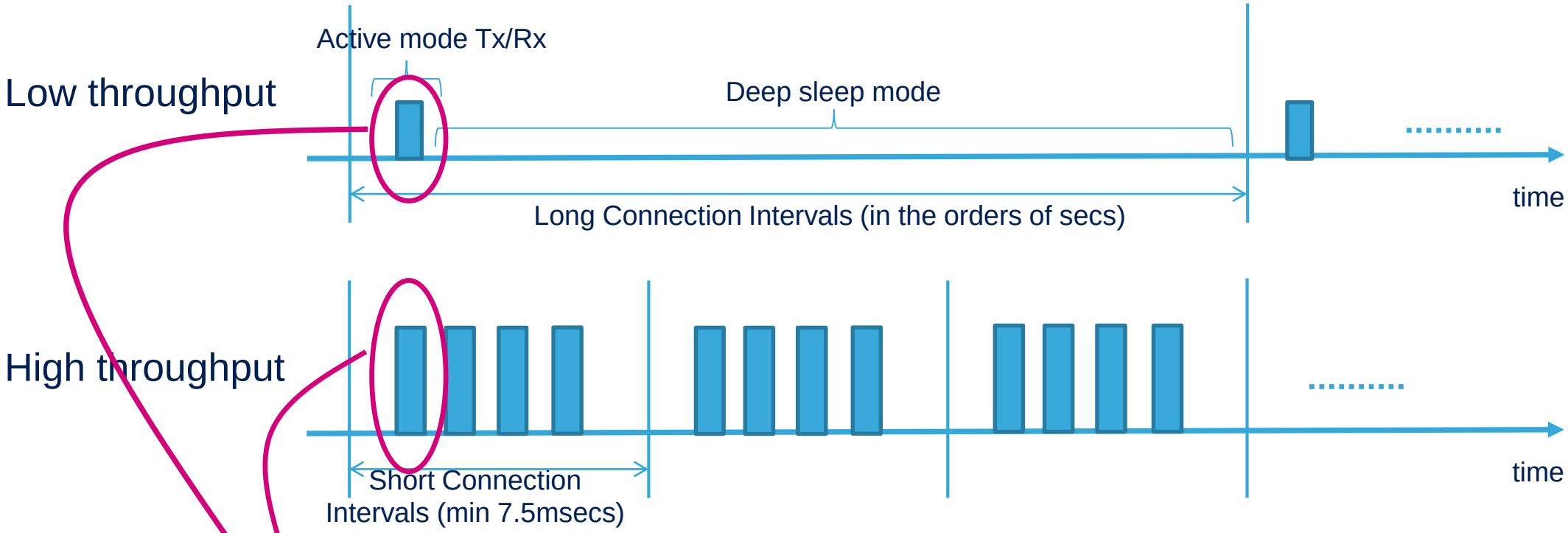
Bluetooth Low Energy Technology

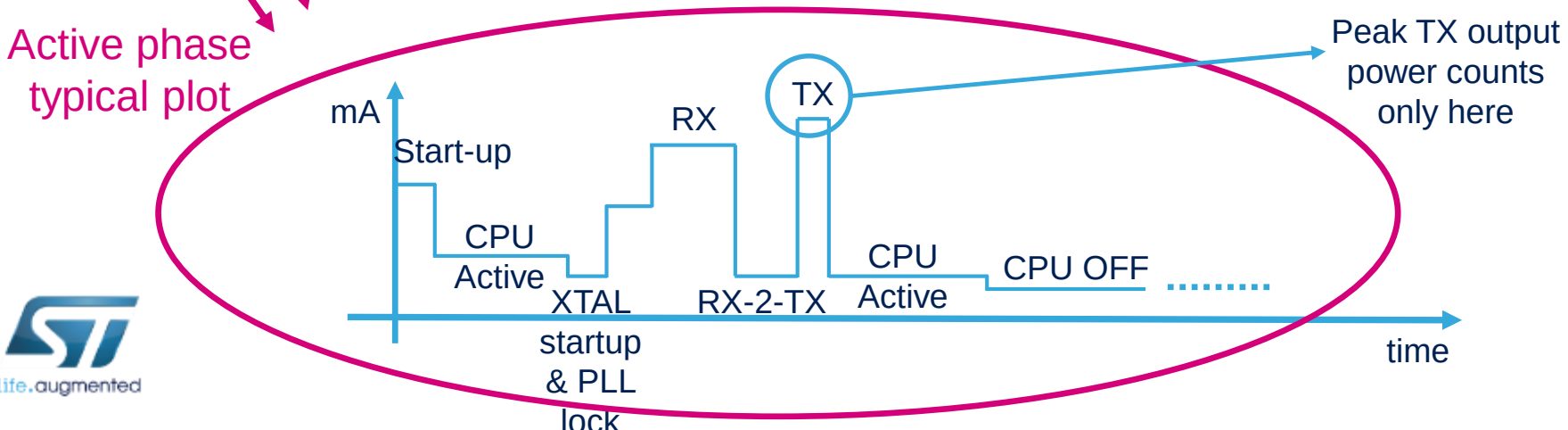
- From *bluetooth.org*:
  - *Bluetooth low energy is the power-version of Bluetooth that was built for the Internet of Things*
  - *The power-efficiency of Bluetooth with low energy functionality makes it perfect for devices that run for long periods on power sources, such as* ***coin cell batteries or energy-harvesting*** *devices*
- Power efficiency is a key aspect, along with:
  - RANGE
  - APPLICATION THROUGHPUT
- Need to look at the whole picture. It is a trade-off balance!

Range

- Many applications require long-range connectivity: asset tracking, home/electronic appliances control, etc…
- Environmental obstacles, causing multipath fading, reduce range from ~30 mt. (line-of-sight) to ~10 mt.
- BlueNRG product family: **+8dBm** TX output power (NO external PA) guarantee 80 to 100 meters range.
- Is +8dBm against “low energy”? Not necessarily. Look behind the peak current consumption: the key number is the **AVERAGE power consumption**.

Typical Scenarios





Evaluating Average Power Consumption

- Key factors affecting average power numbers:
  - HW operating conditions:
    - High-speed clock start up time
    - Low-speed clock accuracy
    - RAM retention
    - Supply voltage level
    - Power management architectures
    - Deep sleep modes of the radio core
  - Bluetooth low energy protocol application typical use cases:
    - during Advertising: how frequently, how many payload bytes, how many channels
    - during Connection: connection interval length, how many packets per connection event, how many bytes per packet
    - during Scanning: scanning interval and scanning window lengths

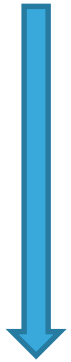
Low Power Modes

- Deep sleep mode can represent most of the application time.
- Efficient management of low power modes lowers significantly avg pwr consumption.

BlueNRG-1 flexible low power architecture

Sleeping Mode	Consumption	Notes
RUNNING	1.9mA	Core running
CPU HALT	1.5mA	WFI instruction
WAKETIMER	900nA	GPIOs and Timer Wakeup
NOTIMER	500nA	GPIOs only Wakeup

Highest pwr



Lowest pwr

Low Power library combines requests coming from the application with the radio operating mode

Context Save/Restore

- Exiting low power modes should NOT result in losing application context and peripheral configurations, and/or radio stack re-initialization
- When the BlueNRG-1 exits from SLEEPMODE_WAKETIMER and SLEEPMODE_NOTIMER a reset occurs
- Low Power Library saves peripherals configuration and application context before deep sleep, restoring it upon exiting from low power state:
  - **CPU returns to execute the next instruction after the low power function call**
  - **No need to re-initialize peripheral and radio stack**
  - **RAM retention is guaranteed**

BlueNRG-1 Power Consumption Tool

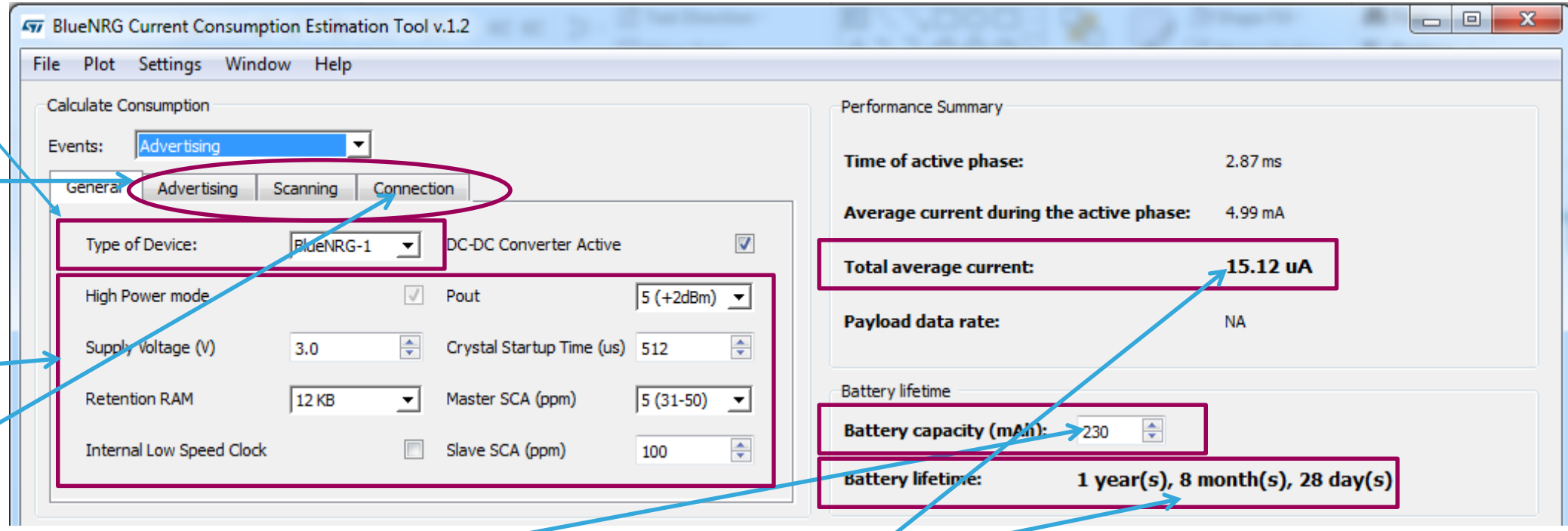
- Accurate estimate of average current consumption and battery lifetime

1. Select the device

2. Select the type of event

3. Configure the HW operating conditions

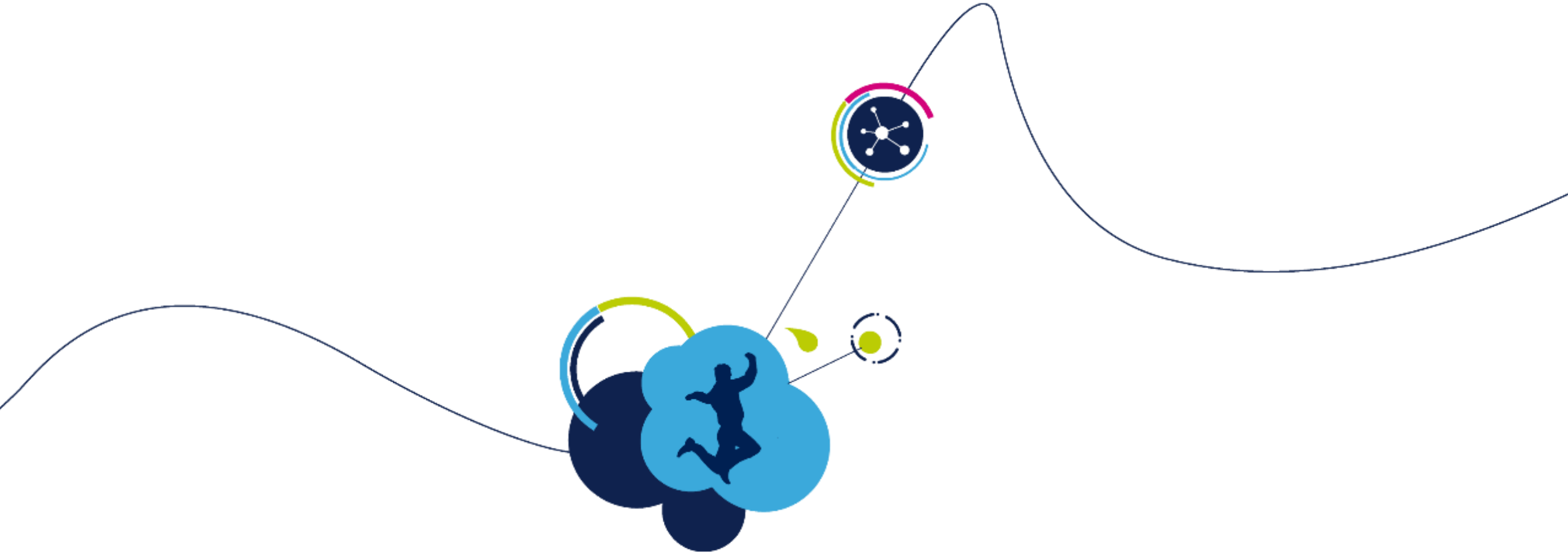
4. Configure the application use case scenario



5. Specify the Battery capacity

6. Read the average current and the estimated battery lifetime

http://www.st.com/content/st_com/en/products/embedded-software/wireless-connectivity-software/stsw-bnrg001.html



Maximize Bluetooth Low Energy Application Throughput

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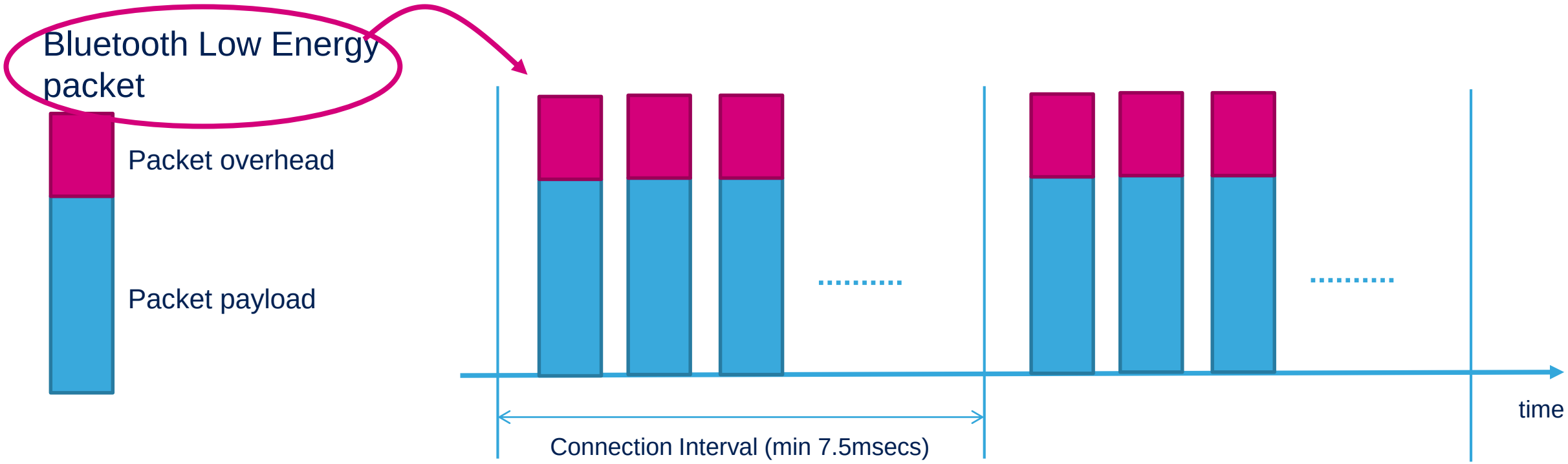
Application Throughput

- Let’s start with obvious: 1 Mega bits per second is just wrong.
  - 1Mbps is at PHY layer BUT overhead is added by the **communication protocol**.
  - Elements that limit Bluetooth low energy throughput:
    - Maximum packet length
    - Time delays in between packets
    - Overhead bytes in a packet: packet length, data integrity check, and general packet information.
- Protocol theoretical maximum application throughput is ~270-kbps.
- Few devices reach even half of it, due to un-optimized Stacks and poor radio and/or controller design, OS limitations, etc...

Throughput (1/2)

In a Master-Slave Bluetooth low energy connection:

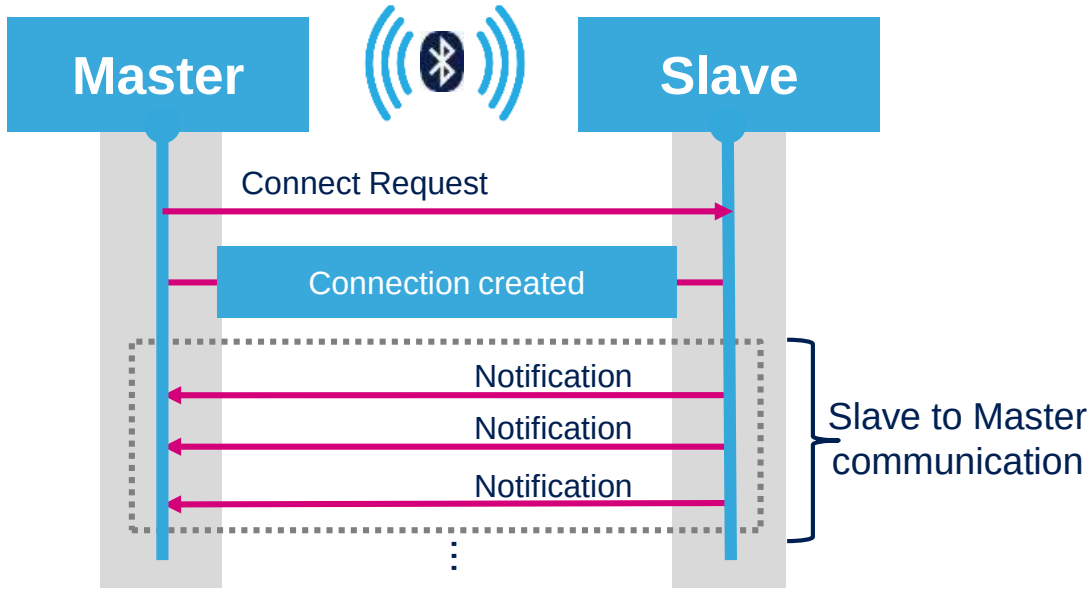


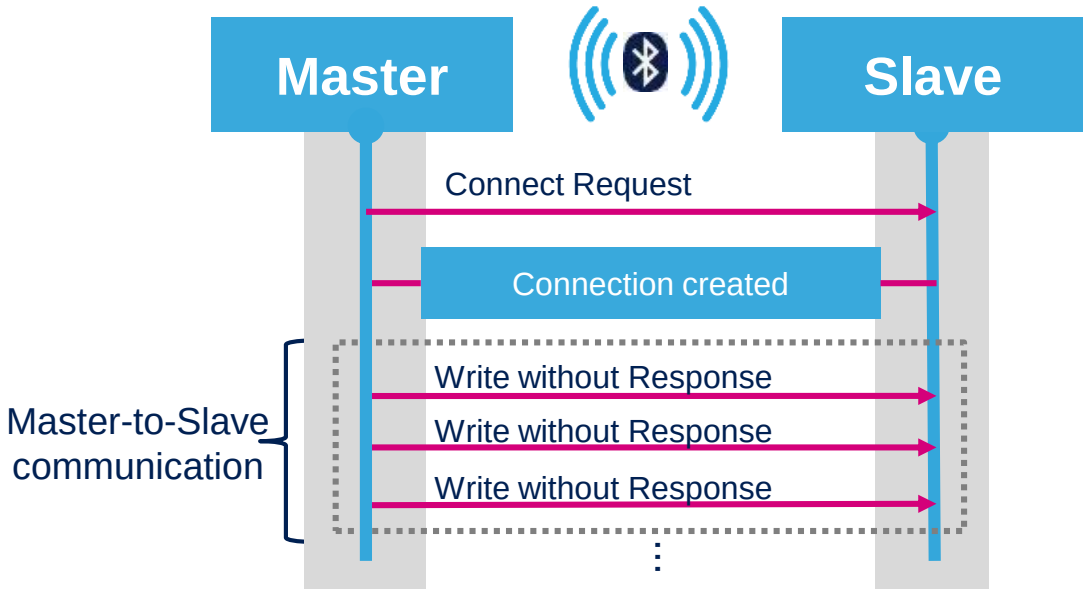
- The theoretical maximum application throughput is:
  - *$Throughput_{kpbs}$ = (# Pkts_ConnEvt) * (# Bytes_Pkt - Tot_Overhead_Pkt)/ (Conn_Interval)*

Throughput (2/2)

- Bluetooth low eEnergy protocol provides 2 type of packets that do NOT require acknowledge
  - NOTIFICATIONS: messages sent from Slave (Server) to Master (Client)
  - WRITES WITHOUT RESPONSE: messages sent from Master (Client) to Slave (Server)

- No acknowledgements allow multiple packets in a single connection interval: throughput is maximized





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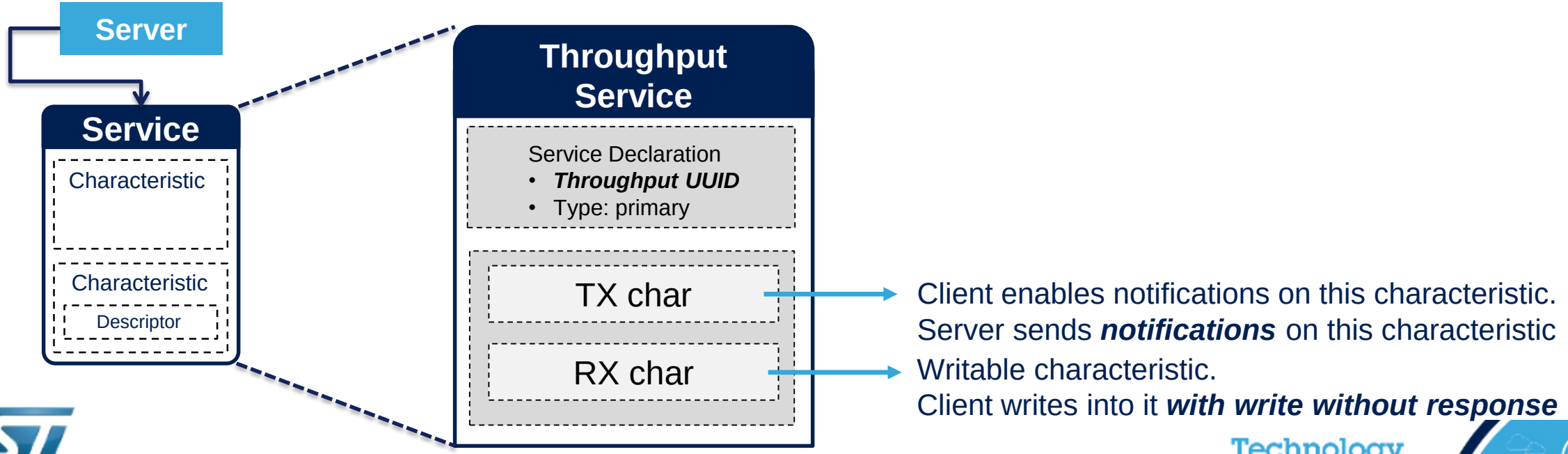
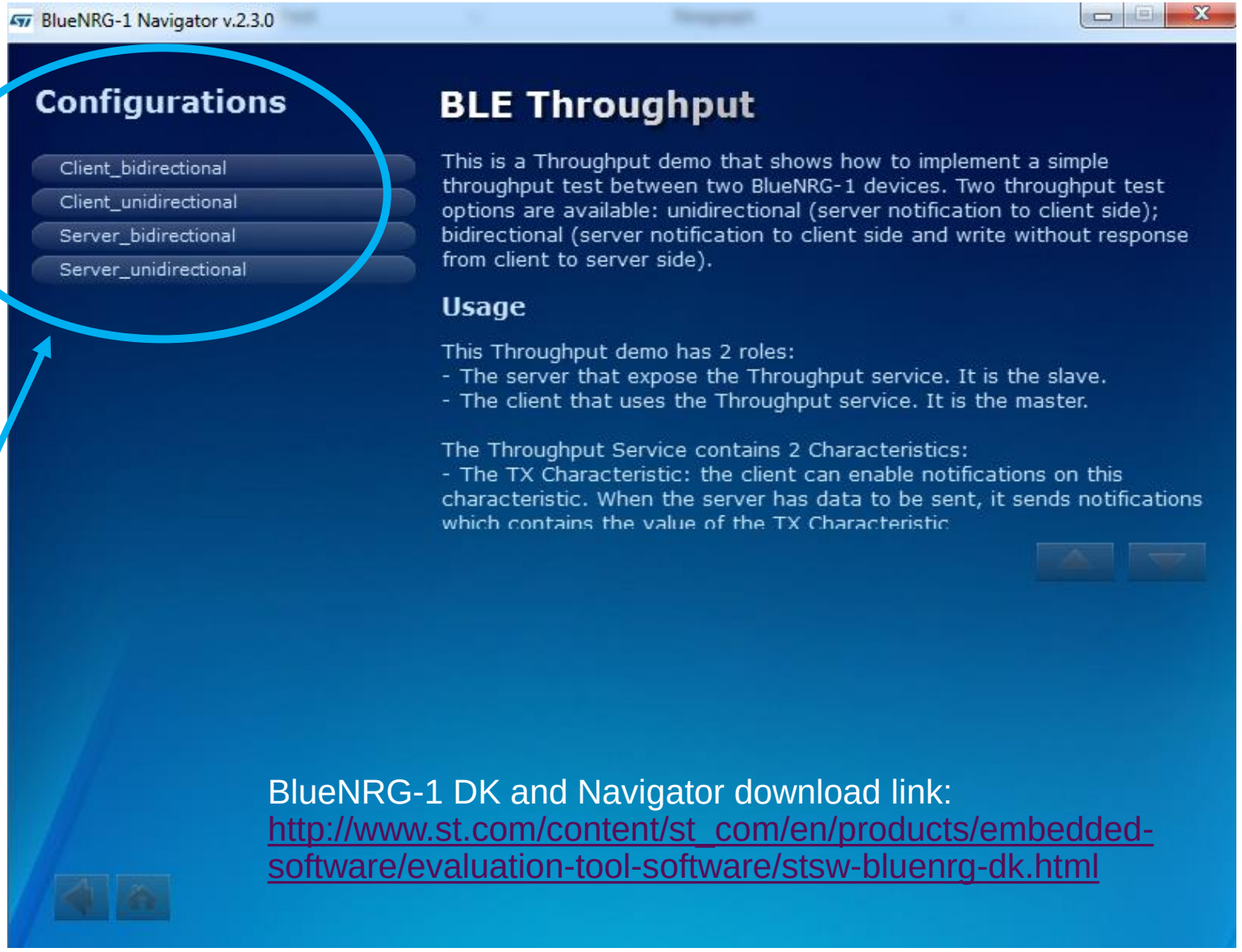
Throughput Demo

- BlueNRG-1 “Throughput demo” provides 2 different scenarios:
  - **Unidirectional**: *Notifications* from Server to Client only.
  - **Bidirectional**: Simultaneously *Notifications* from Server-to-Client and *Write without response* from Client-to-Server



BlueNRG-1 Navigator Tool

- BlueNRG-1 Navigator: user friendly PC GUI
- Select and run demonstration applications easily, without requiring any extra hardware:
  - BlueNRG-1 Bluetooth low energy demonstration applications
  - BlueNRG-1 peripheral driver examples
- Directly download and run the selected prebuilt application binary images on the BlueNRG-1 platform without a JTAG interface.
- You can select either Bidirectional or Unidirectional prebuilt applications



BlueNRG-1 DK and Navigator download link:
http://www.st.com/content/st_com/en/products/embedded-software/evaluation-tool-software/stsw-bluenrg-dk.html

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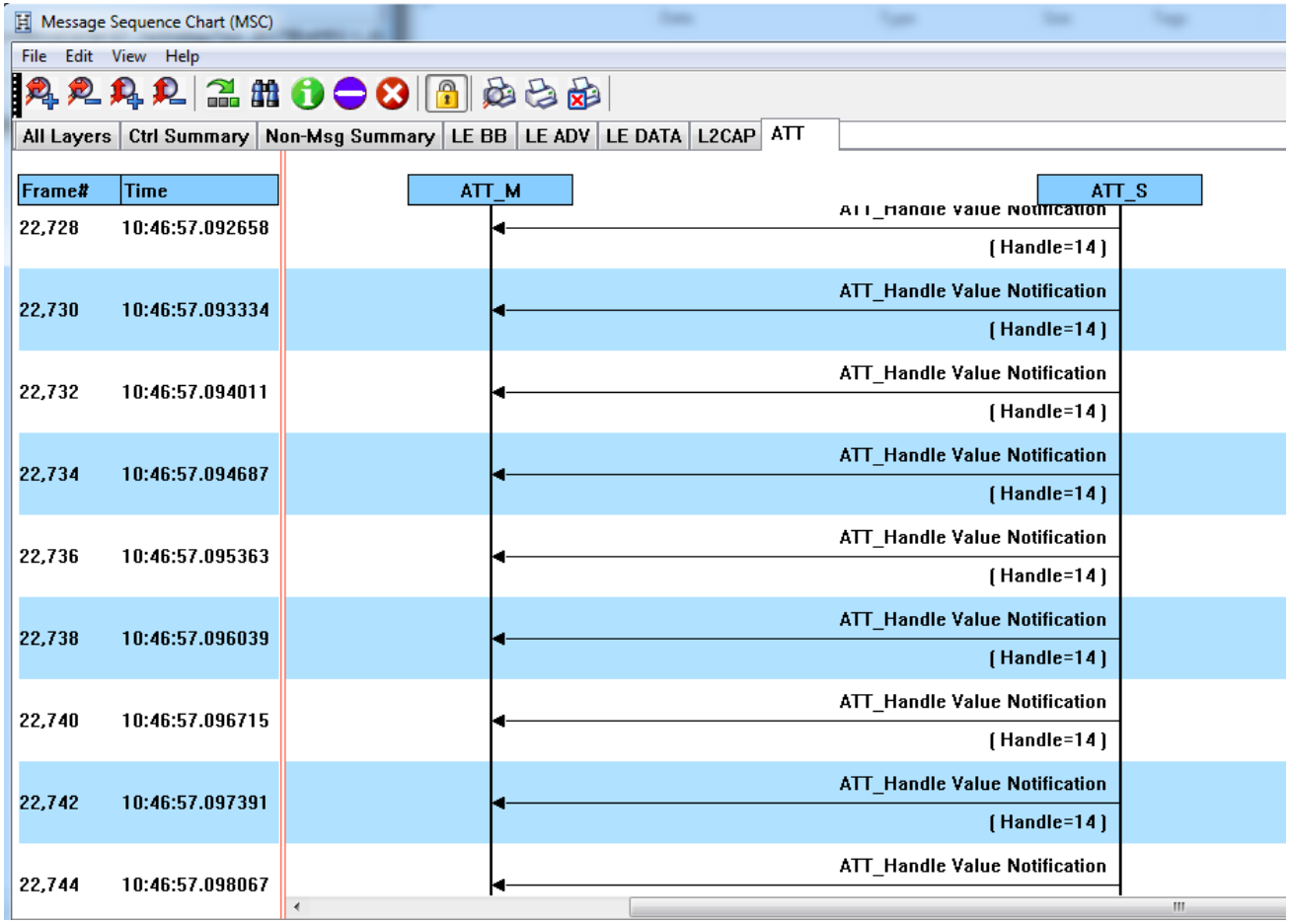
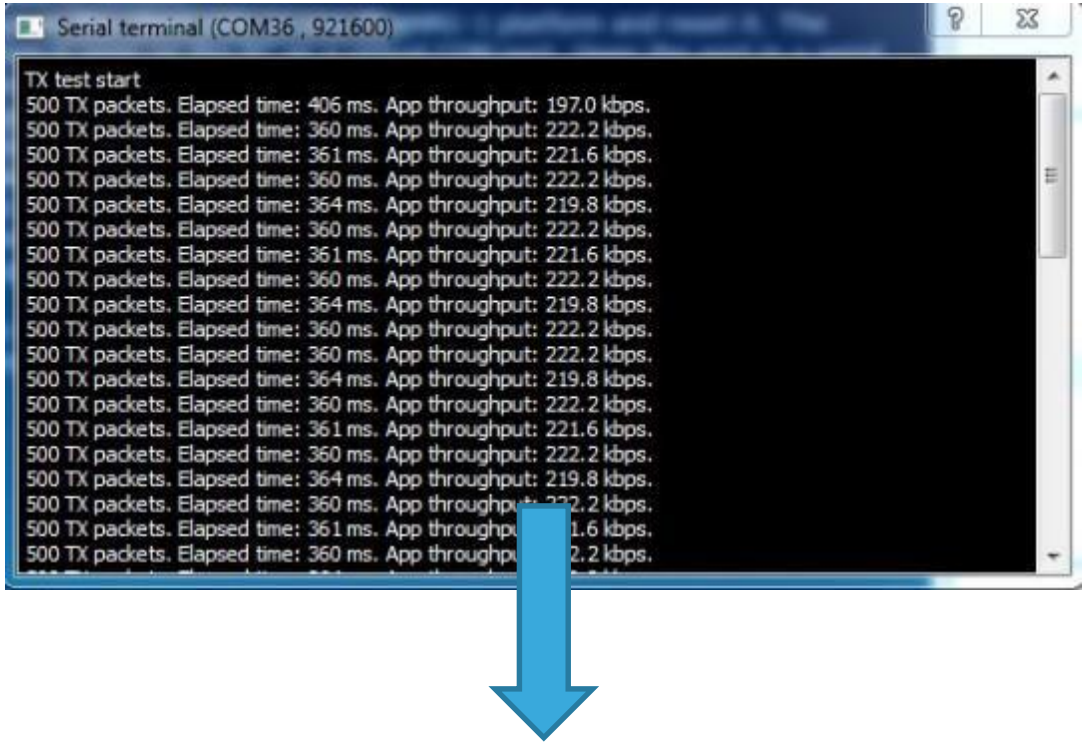
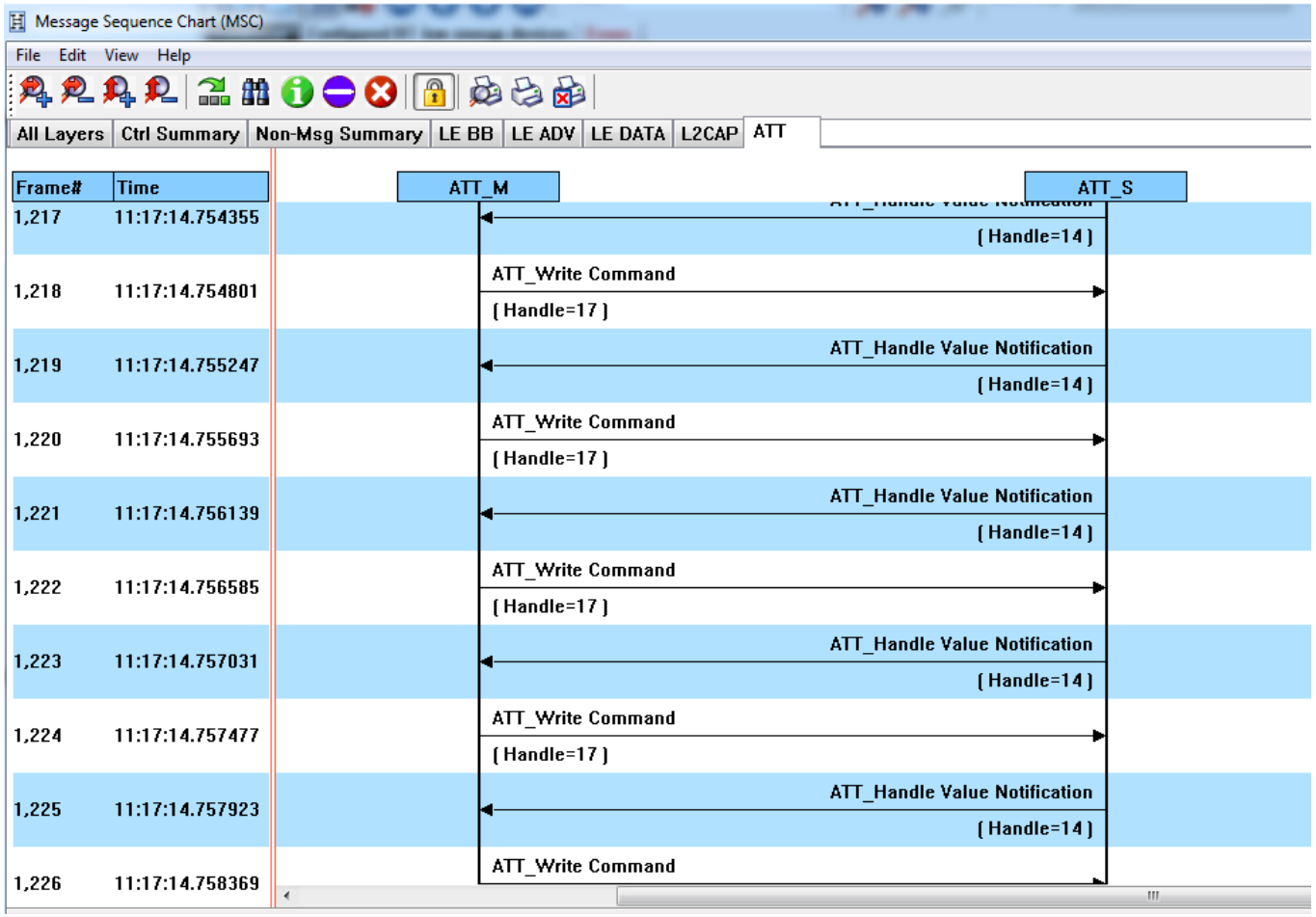
Unidirectional scenario

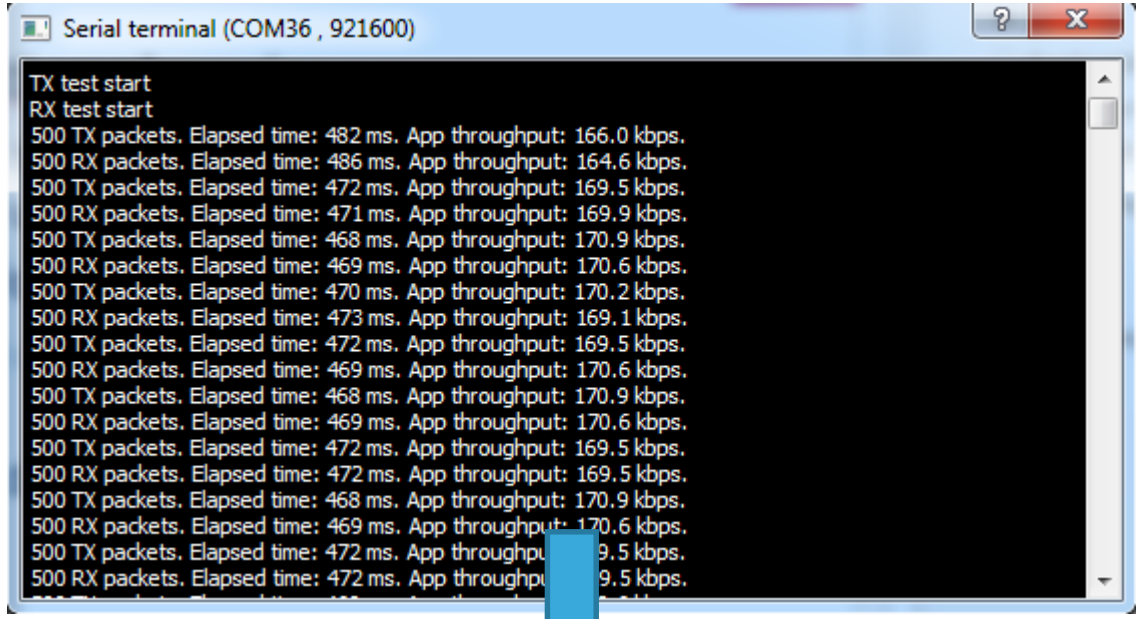




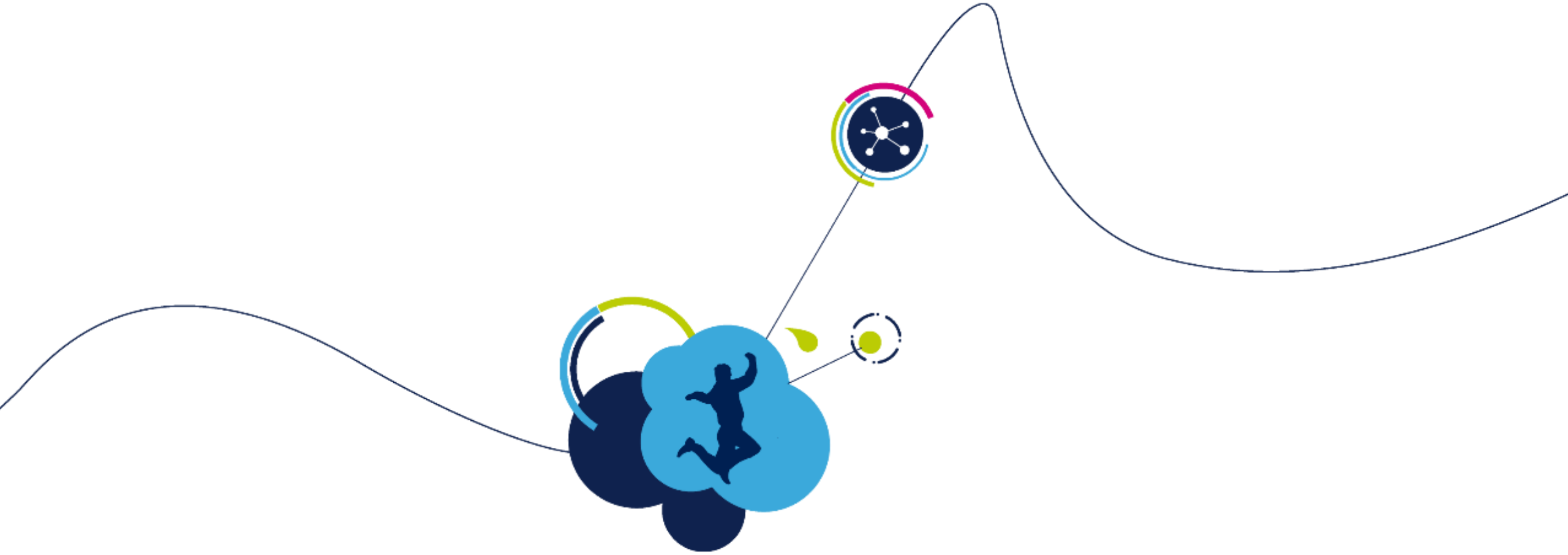
Average application throughput: **~220-kbps**

Bidirectional Scenario





average **~170-kbps for both notifications (TX packets) and write without response (RX packets)**



Voice Over Bluetooth Low Energy

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BlueVoice

- From *bluetooth.org*:
  - *One of the most popular applications for Bluetooth has been wireless audio: ... This uses a version of Bluetooth called BR/EDR (basic rate/enhanced data rate) optimized for sending a steady stream of high quality data in a power efficient way*.

- Is voice and audio possible using Bluetooth low energy instead?

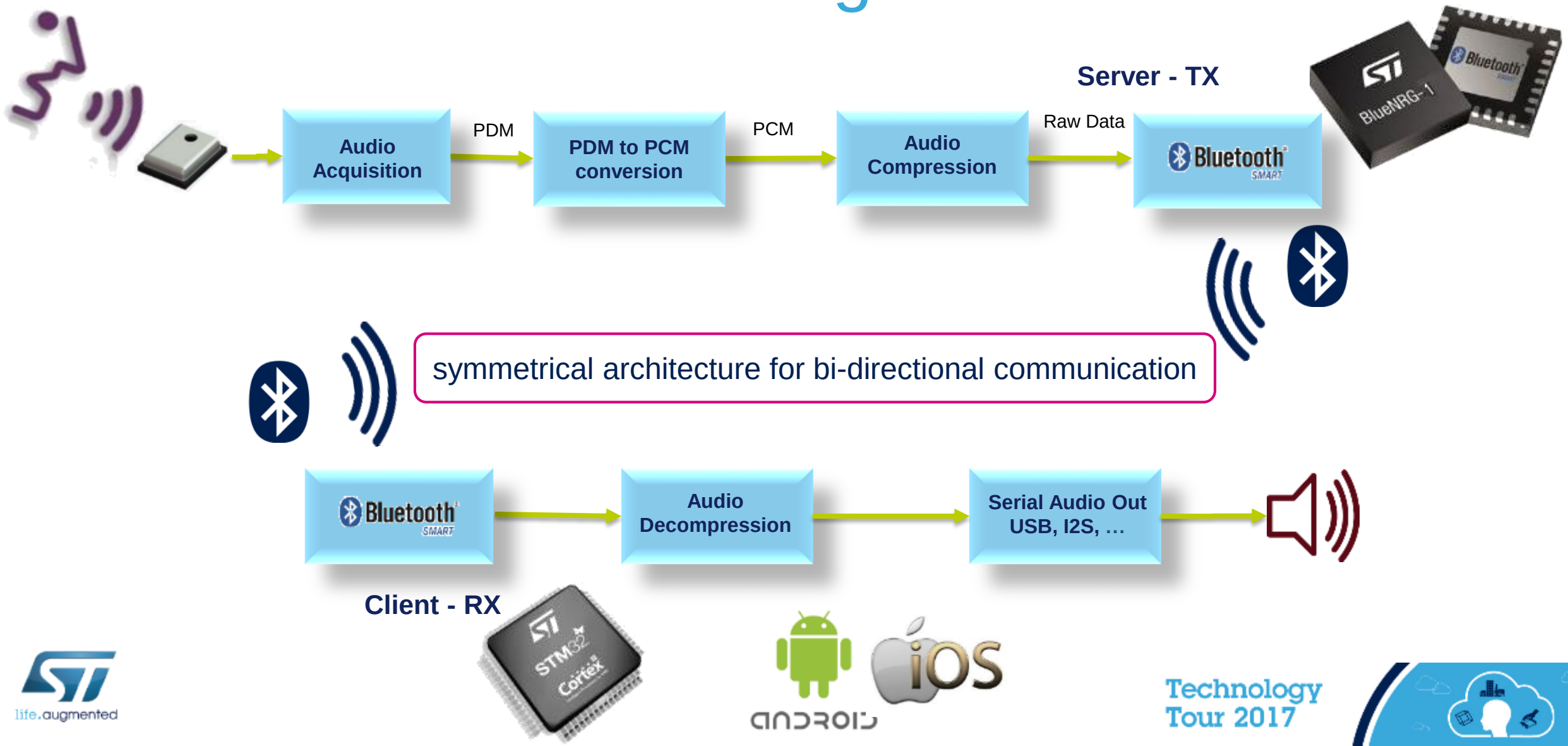
- BlueVoice library is real-world example of voice and music streaming over a Bluetooth low energy link

Voice controlled TV remote

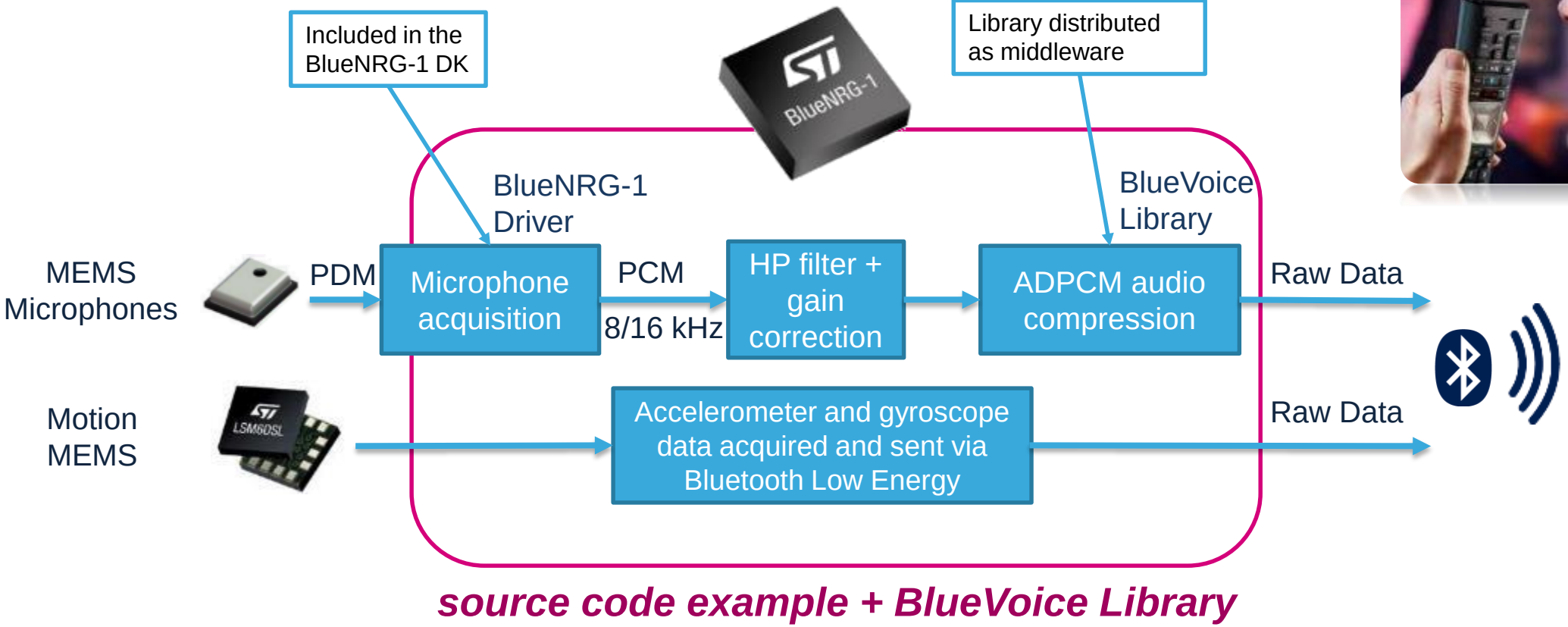
Wearables

Smart Home

BlueVoice Architecture: Audio Processing and Transmission



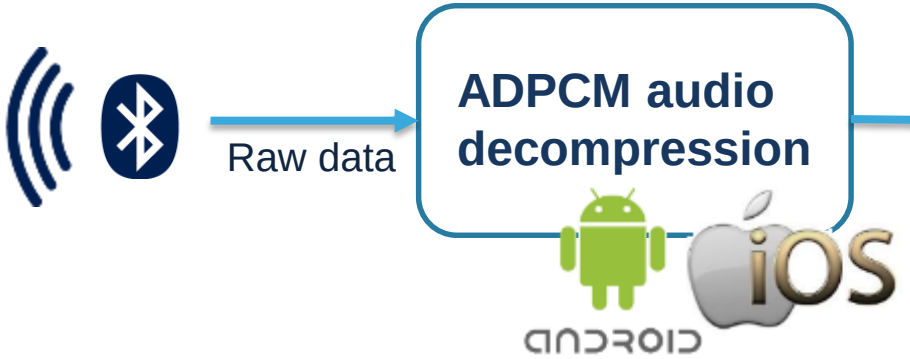
Transmitter



source code example + BlueVoice Library

Receiver

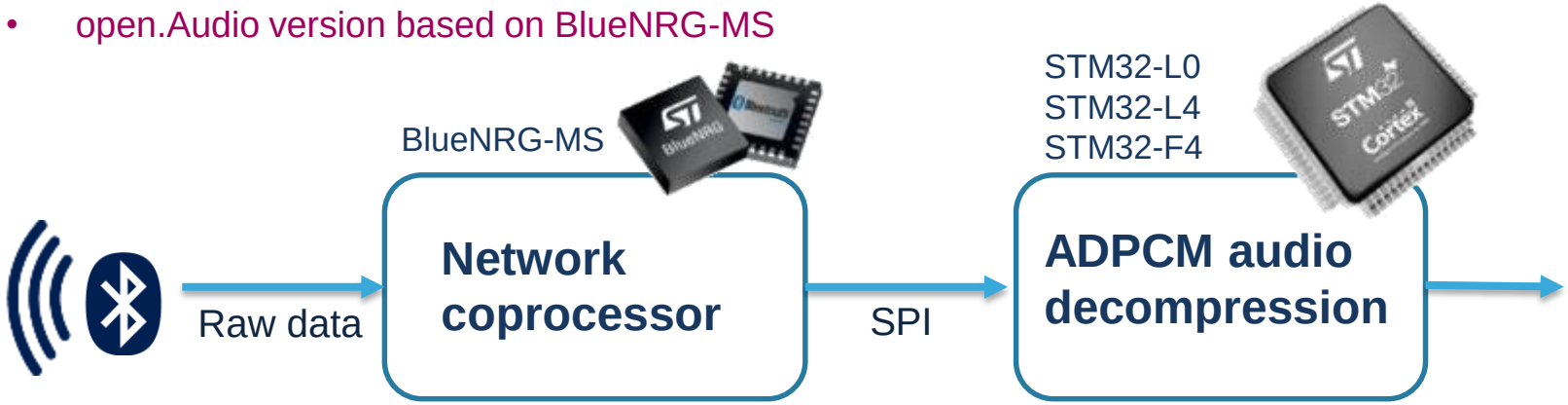
Architecture 1: BlueMS app



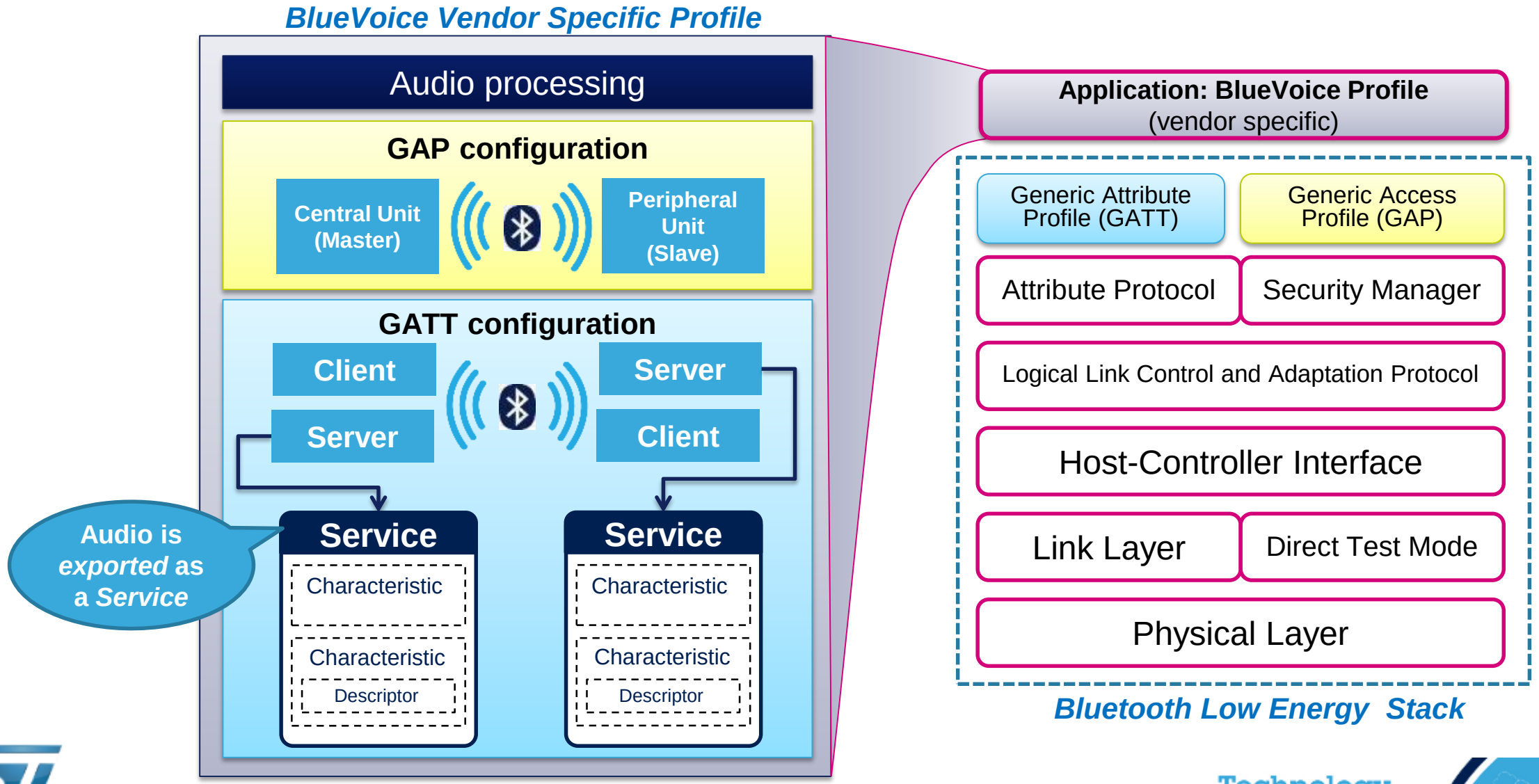
(*) 16 KHz version is compatible only with selected Android smartphones

Architecture 2: BLUEVOICELINK1

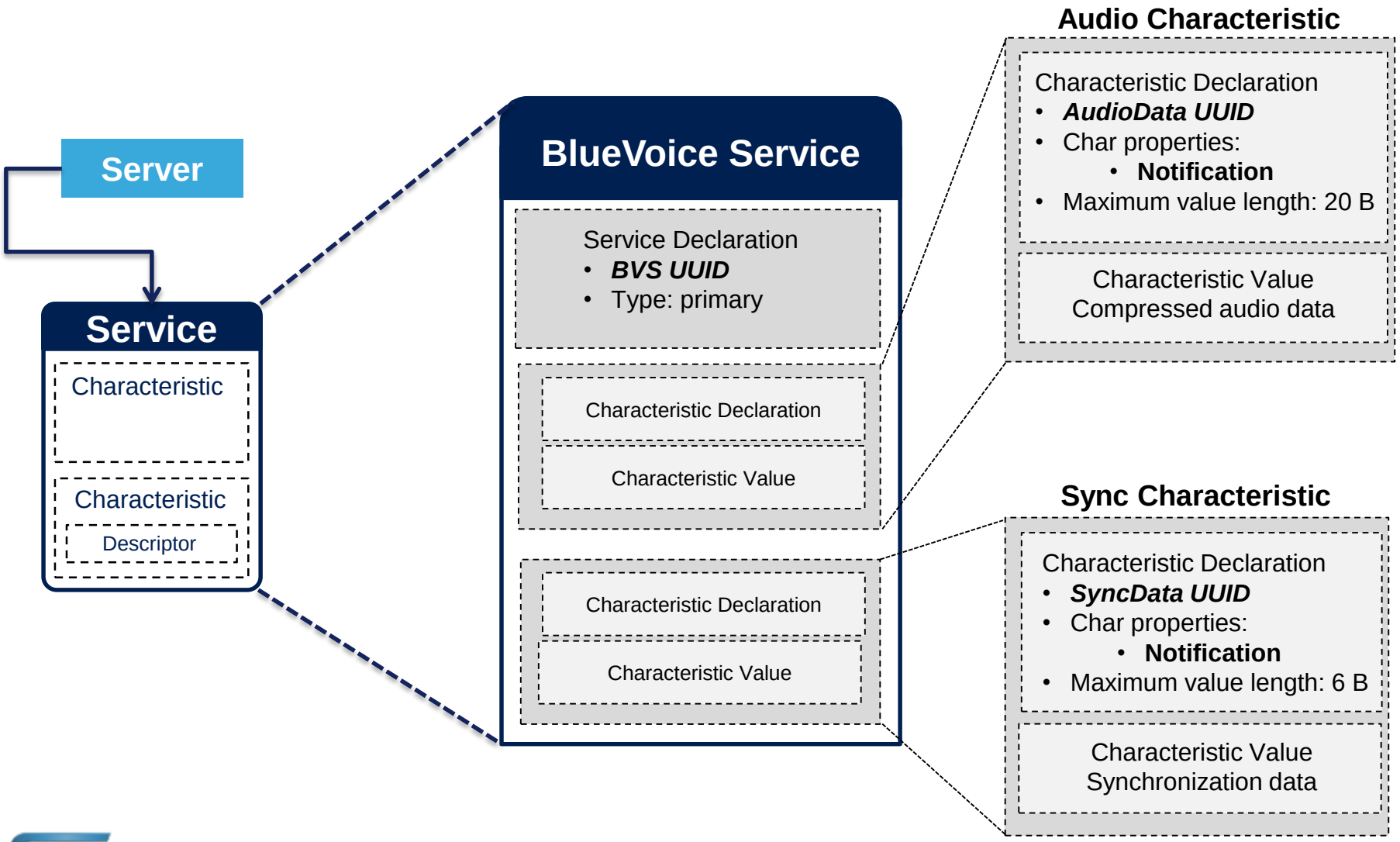
- open.Audio version based on BlueNRG-MS



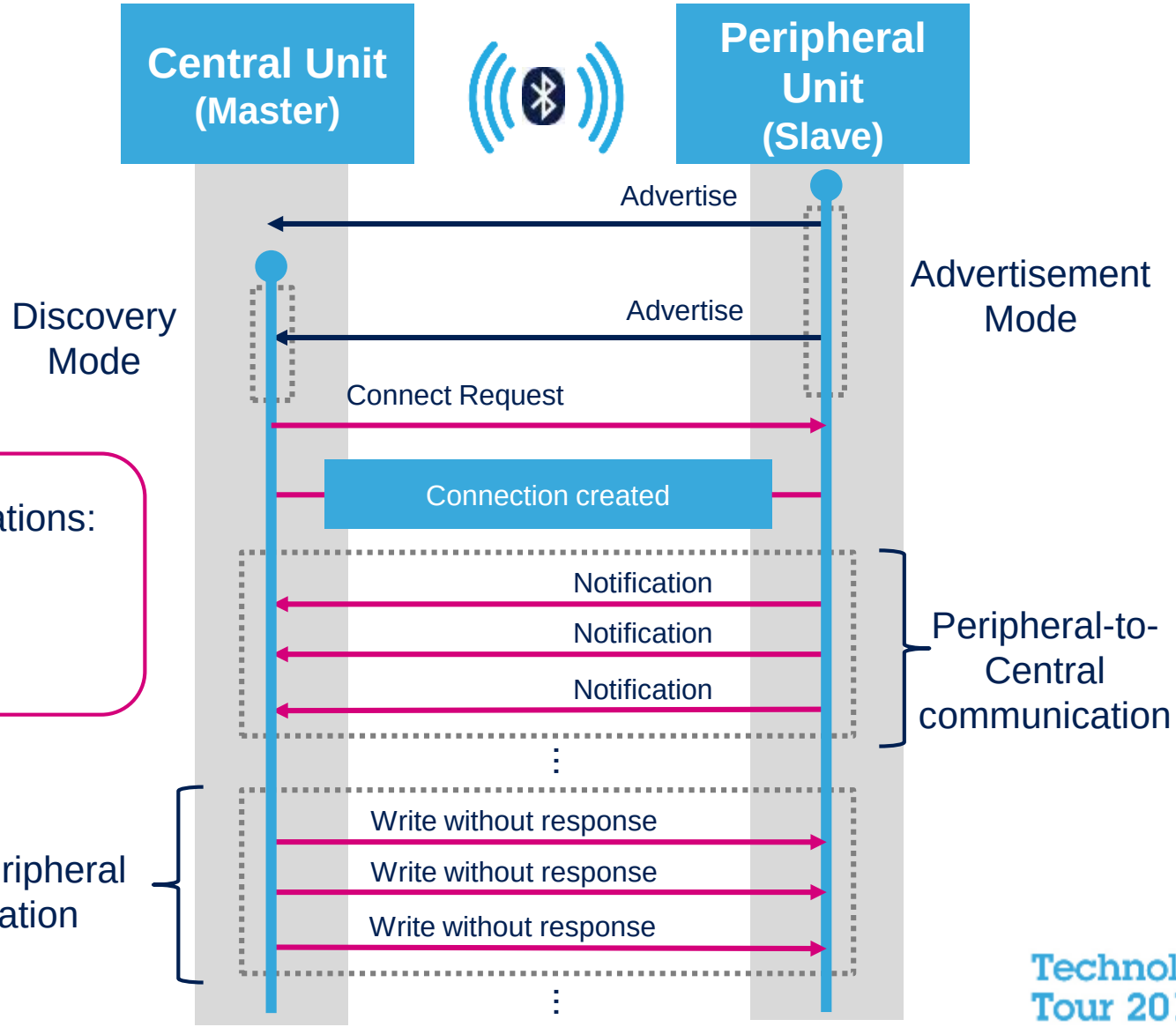
BlueVoice Mapping Over Protocol Stack



BlueVoice Server Attributes

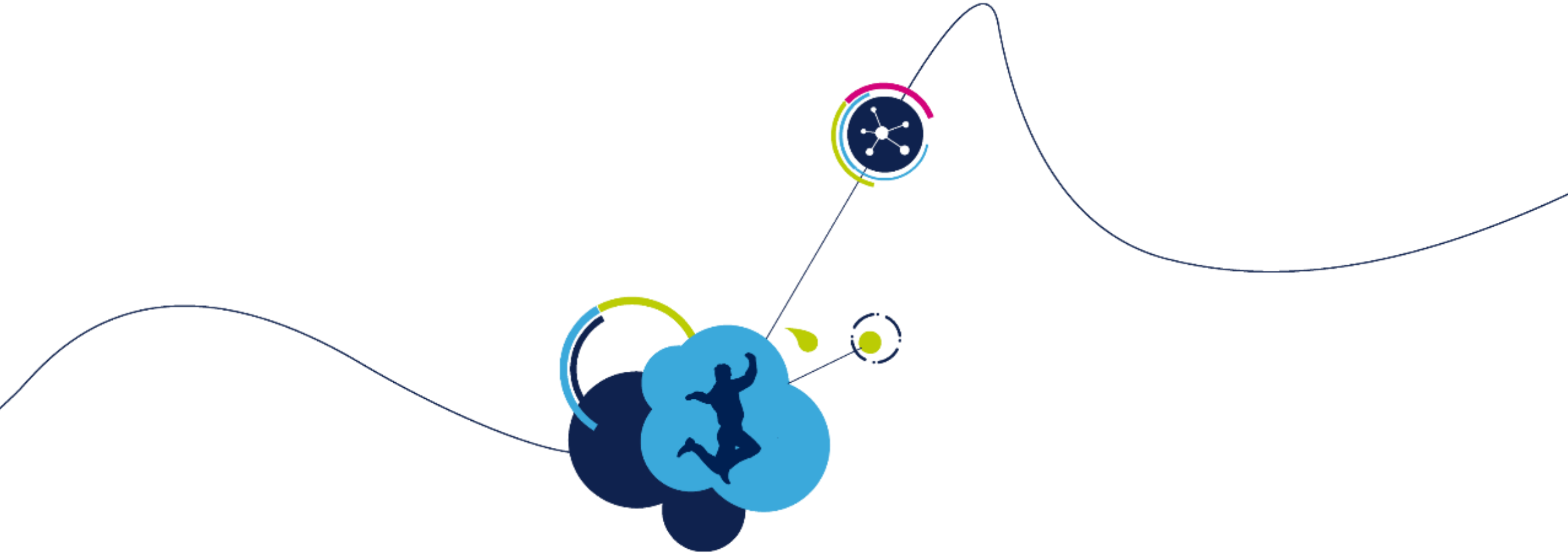


BlueVoice Packet Exchange Sequence



No response is required for Notifications:

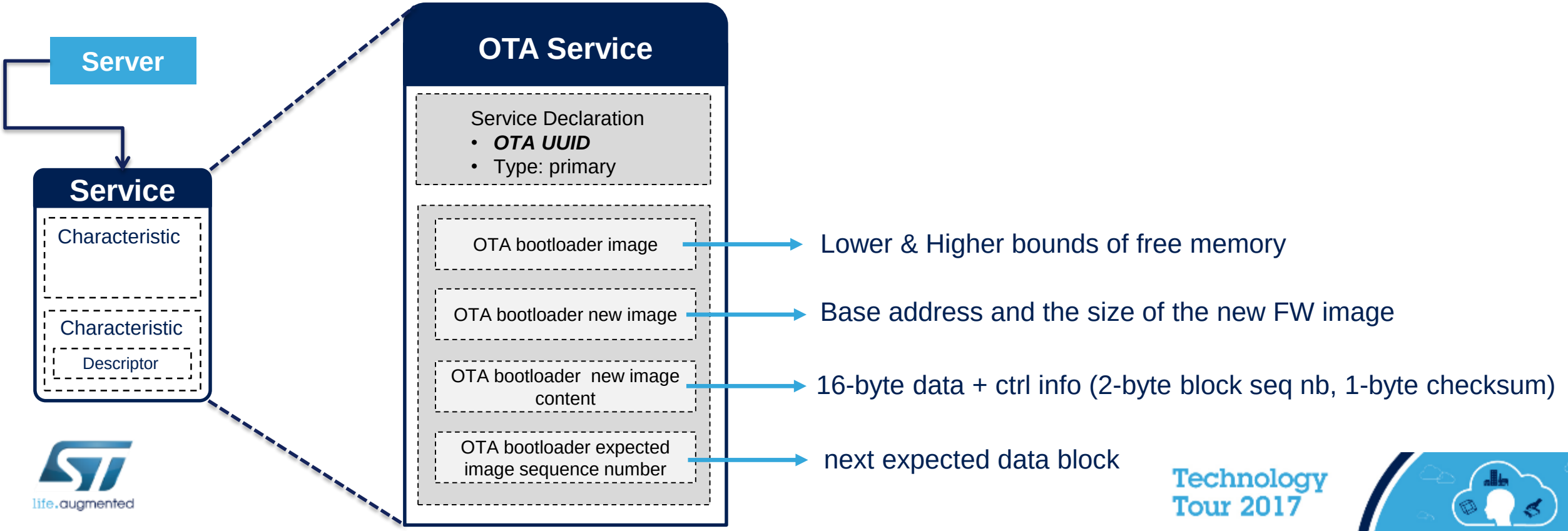
- OK for Audio streaming
- Optimal Bandwidth exploitation



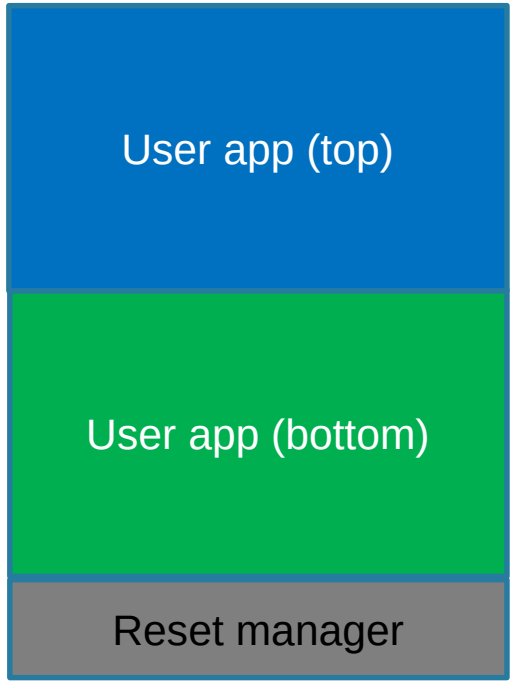
Over-The-Air (OTA) FW Upgrade

Over The Air (OTA) FW Upgrade

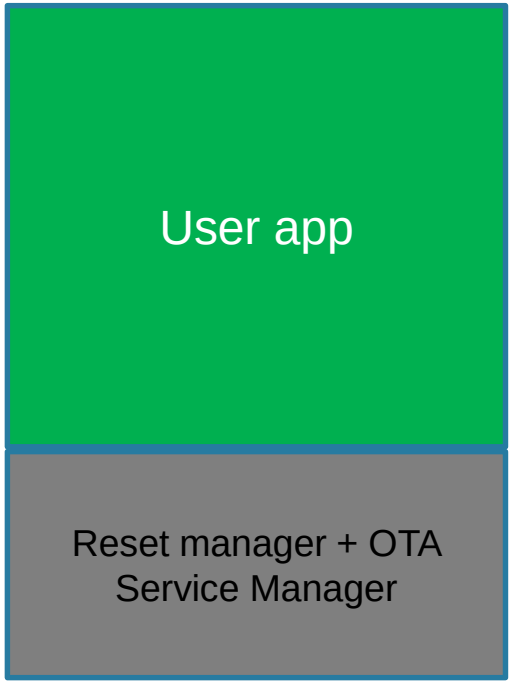
- What if your device already in the field needs an application FW update?
  - **Over the air (OTA) firmware upgrade** is a protocol that allows a Slave to receive a FW image from a Master over the Bluetooth low energy link (and write it in Flash memory).
  - A Vendor Specific **OTA service** is defined. It coexists with other services used by any application running on the radio stack.



Flash Partition Options



OTA Reset Manager: **two applications** with OTA Service & Characteristics



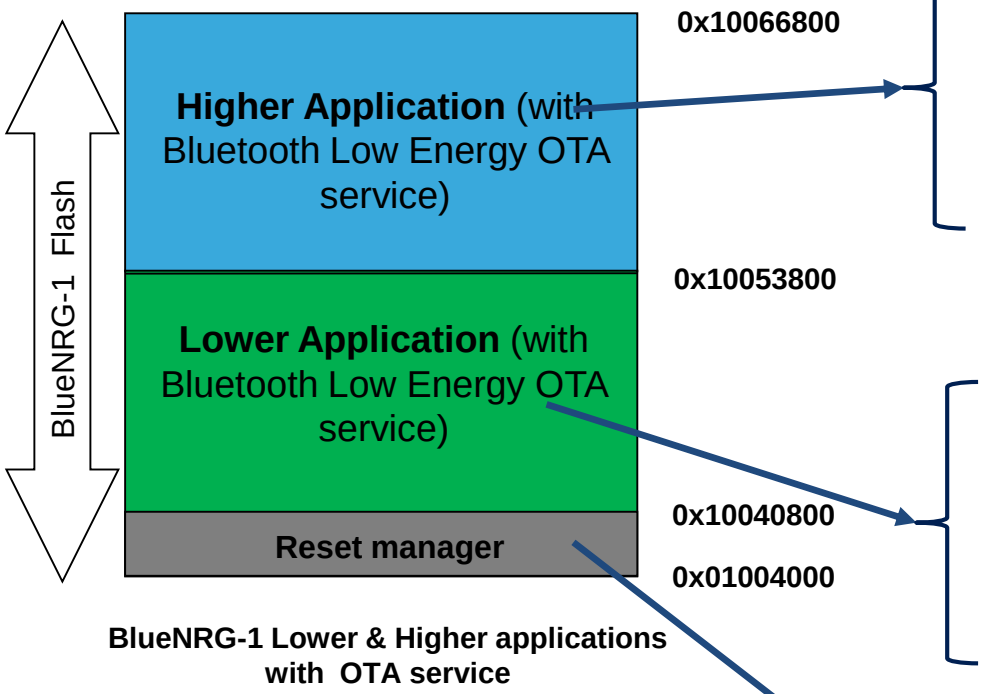
OTA Service Manager**: one application** with no OTA Service & Characteristics

- Reset manager:
  - jump to valid application
- OTA service manager:
  - download new flash image

OTA FW Upgrade Properties

	Lower & higher applications with OTA Reset manager	One a application with OTA Service Manager	Notes
Fail safe	Yes	Yes	
Device always working	Yes (*)	No	(*) In the event of unsuccessful upgrade, the old version of the application will be still operational
OTA Service & Characteristics	Yes	No	
Upgrade policy	Upgradable	Fixed	
Bluetooth Low Energy stack	Upgradable	Upgradable	
Application	Upgradable	Upgradable	
Max Application size	76 kB	98 kB	

Flash Layout and Architecture: opt #1



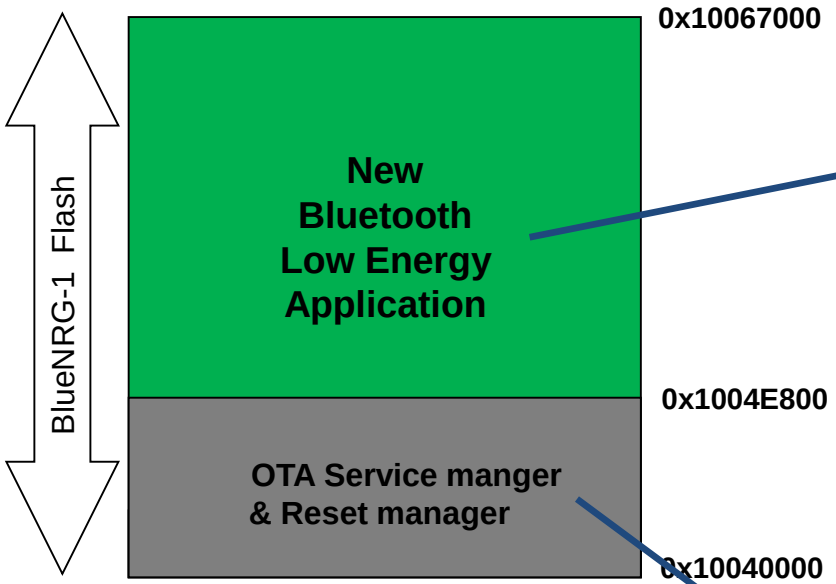
BlueNRG-1 Lower & Higher applications with OTA service

- Defines the OTA service in order to provide itself the OTA FW upgrade capability.
- Accepts new application image packets over the air and store them in a specific Flash section (Lower Application storage area).

- Defines the OTA service in order to provide itself the OTA FW upgrade capability.
- Accepts new application image packets over the air and store them in a specific Flash section (Higher Application storage area).

Starts after reset and give control to the latest updated Bluetooth Low Energy application.

Flash Layout and Architecture: opt #2



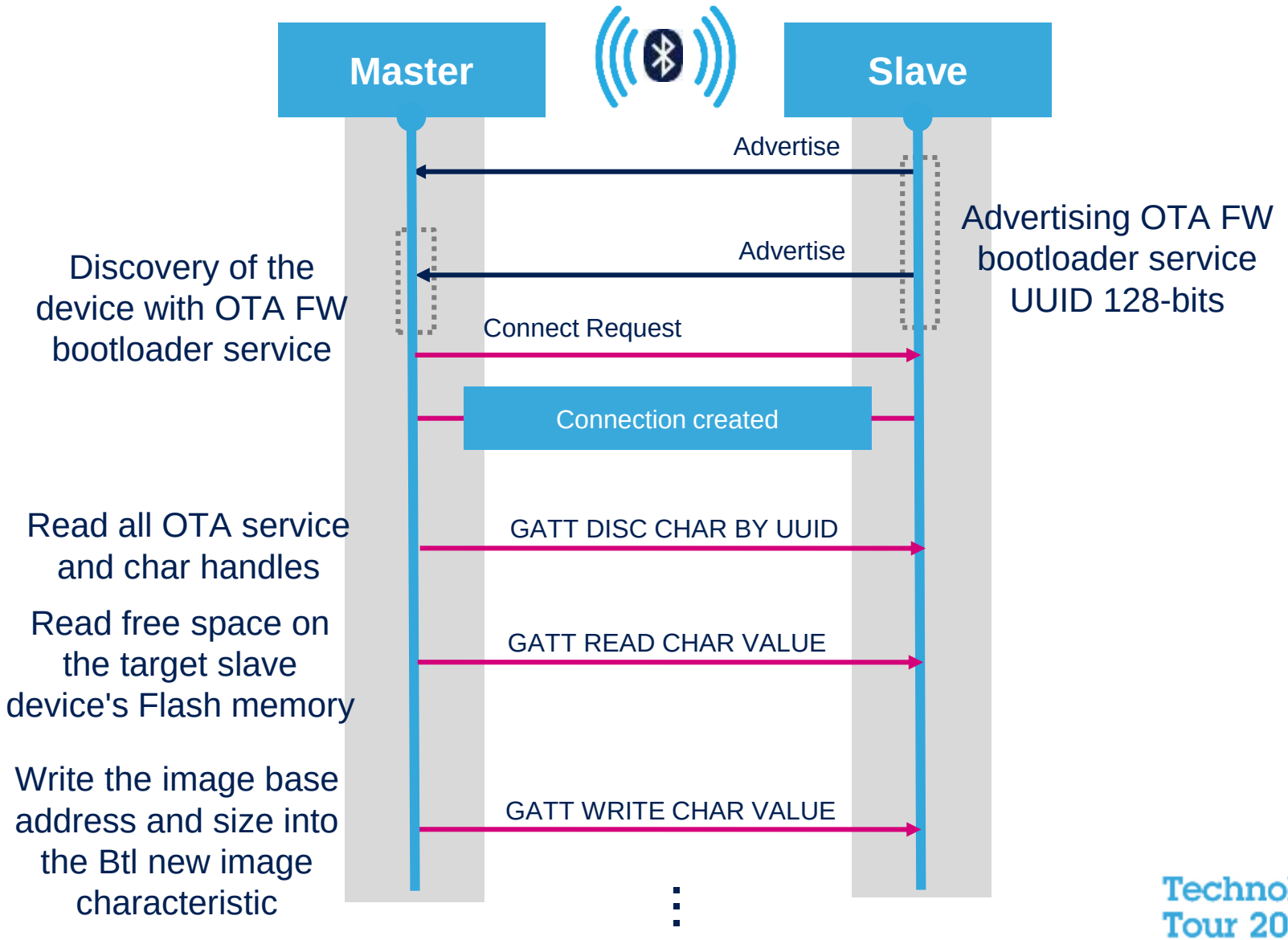
Bluetooth Low Energy OTA service manager

flash memory layout

- Application image downloaded through the OTA service manager.
- OTA FW upgrade service is NOT required: needs to simply jump to the OTA service manager (a specific API is provided).
- Always placed at fixed flash address.

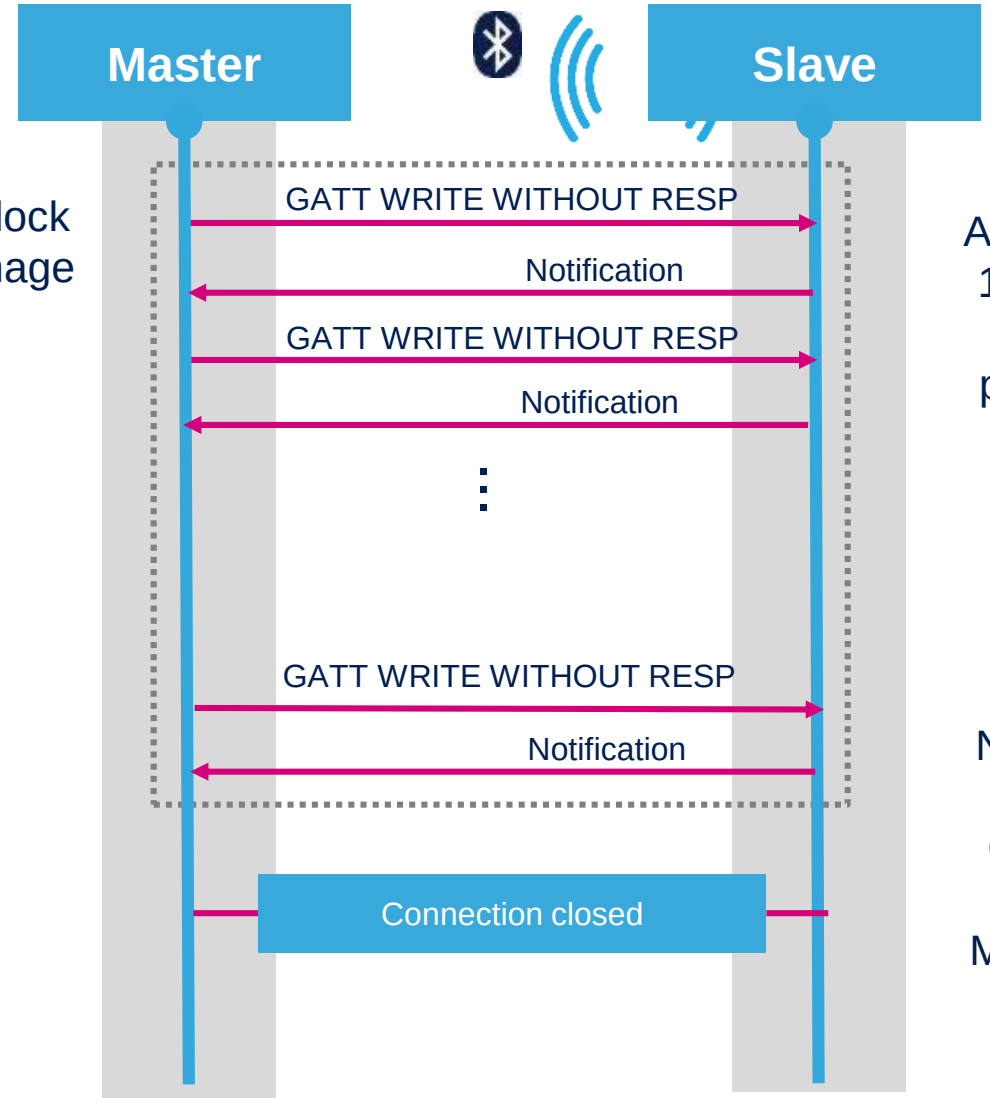
- Contains only the OTA service & characteristics to provide OTA firmware upgrade capability.
- Includes the OTA reset manager capability to give control to the latest updated & valid application.

OTA Protocol 1/2



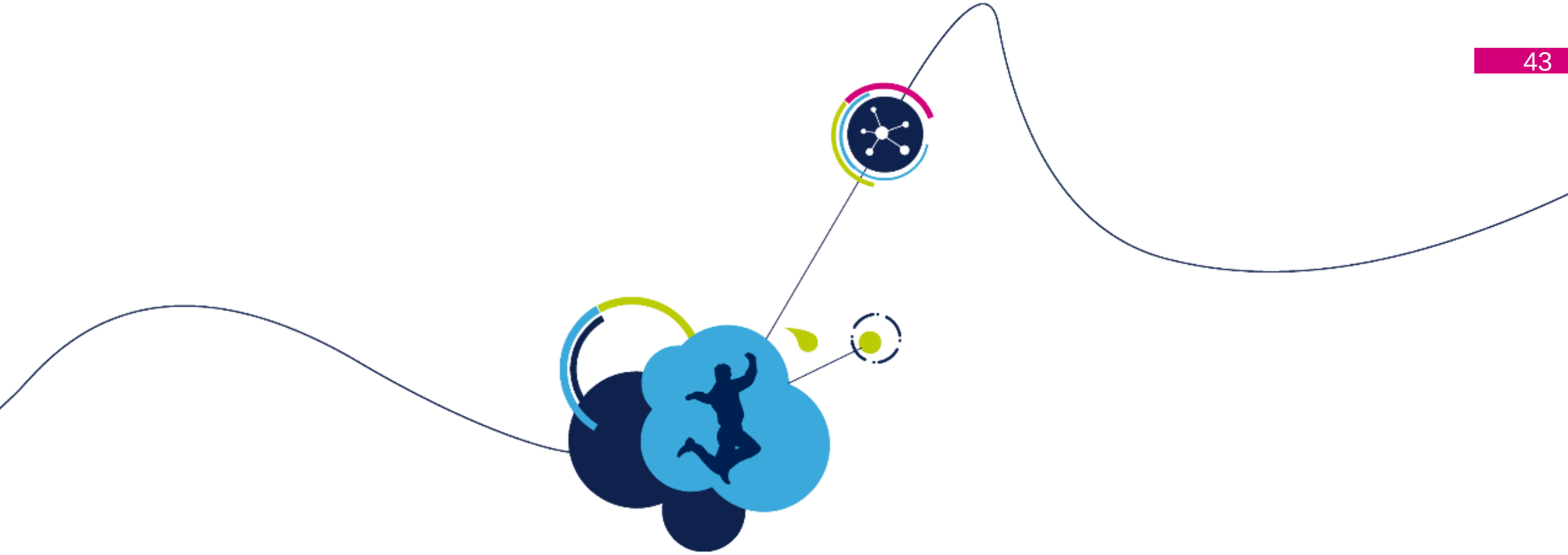
OTA protocol 2/2

Data transfer: 16 bytes block on the Bootloader new image content characteristic



As slave's internal buffer filled up by 16 byte blocks, it writes into Flash. Notification sent back to Master providing with the block number of the next expected block

Nb of bytes downloaded on the Slave Flash equal to the image size. OTA protocol writes a validity tag on Slave Flash. OTA Reset/Service Manager jumps to the new application



Bluetooth Low Energy Roadmap

Flexible Bluetooth Low Energy

connectivity solutions: Plug-in for MCU or Programmable Bluetooth Low Energy

Scalable MCU + Bluetooth Low Energy bundle

Programmable Bluetooth Low Energy processor

STM32 + BlueNRG-MS

Scalable Performances **with Bluetooth Low Energy** Connectivity

- Pluggable Bluetooth Low Energy architecture
- One Bluetooth Low Energy, Multiple MCU choices
- Full-featured MCU peripherals
- Memory and MIPS scalability
- Package / GPIO flexibility

BlueNRG-1

ARM Cortex-M0 core (32MHz)
160kB Flash, 24kB RAM
Up to 15 GPIO

BlueNRG-2

ARM Cortex-M0 core (32MHz)
256kB Flash, 24kB RAM
Extended Data Packet
Up to 15 GPIO

BlueNRG-1 / -2
The single-chip solution

- Wireless Sensor Networks (WSN)
- Beacon, Tags and Finders
- Automotive applications
- Smart remote controllers
- Healthcare monitoring

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BlueNRG-1 / -2 Bluetooth Low Energy Highlights

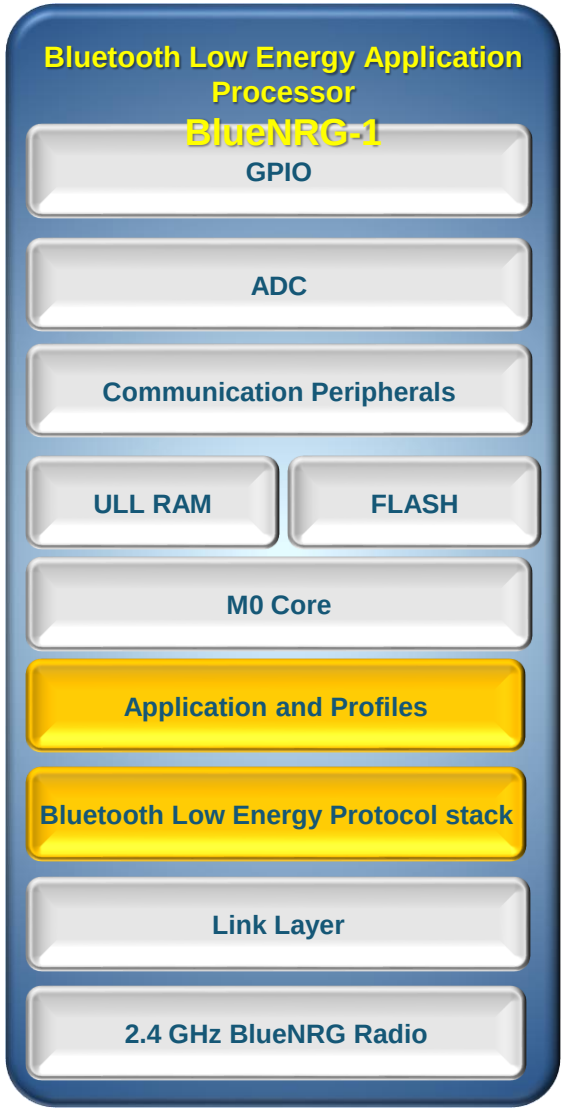
Core & Memories
- Cortex-M0 @ 32MHz
- RAM: 2x12KB Ultra Low Leakage
- Flash: 160KB or 256KB (BlueNRG-**2**)

Peripherals
- Up to 15xGPIO
- 1xSPI, 3xI²C, 1xUART, 1x10-bit ADC
- 16 or 32MHz Xtal and 32KHz for RTC

Extended Operating range
- 1.7 up to 3.6V
- -40 up to +105°C
- AEC-Q100 Automotive Grade

BlueNRG-MS radio
- Up to **+8dBm** and down to -88dBm
- Rx 7.3 mA and Tx 8.2 mA @ 0dBm
- Sleep current < **1µA**

Packages
- BLUENRG-134/-234: WCSP34 2.65x2.65
- BLUENRG-132/-232: QFN32 5.0x5.0
- BLUENRG-132Y: QFN32 with AEC-Q100
- SPBTLE-1S (module): 13 x 11



Bluetooth Low Energy Offering Roadmap

MODULE

CHPSET

Bluetooth Low Energy 4.1

SPBTLE-RF

FCC, CE
Cortex-M0
Master & Slave
Output power: +4dBm
11.5x13.5x2

Bluetooth Low Energy 4.2

SPBTLE-1S

FCC, CE
Cortex-M0
160KB Flash, 24kB RAM
I²C, SPI, UART, ADC
Output power: +4dBm
11.5x13.5x2

Bluetooth Low Energy 4.2

SPBTLE-2S

FCC, CE
Cortex-M0
256KB Flash, 24kB RAM
I²C, SPI, UART, ADC
Output power: +4dBm
11.5x13.5x2

Bluetooth Low Energy 5.0 + 802.15.4

SPBTLE-xxx

FCC, CE
Cortex-M0
160KB Flash, 24kB RAM
I²C, SPI, UART, ADC
Output power: +4dBm
11.5x13.5x2

Bluetooth Low Energy4.1

BlueNRG-MS

ARM Cortex-M0 Core
Master and Slave
concurrent
RX:7.3mA
TX: 8.2mA@0dBm
Sensitivity: -88dBm
QFN, CSP package

BlueNRG

ARM Cortex-M0 Core
Master and Slave
RX:7.3mA
TX: 8.2mA@0dBm
Sensitivity: -88dBm
QFN, CSP package

Bluetooth Low Energy4.2

BlueNRG-1

ARM Cortex-M0 Core
160KB Flash
24kB RAM
I2C, SPI, UART
10 bit ADC
RX:7.3mA
TX: 8.2mA@0dBm
Sensitivity: -88dBm
QFN, CSP package

Bluetooth Low Energy4.2 + Ext.Data Rate

BlueNRG-2

ARM Cortex-M0 Core
256KB Flash
24kB RAM
I2C, SPI, UART
10 bit ADC
RX:7.3mA
TX: 8.2mA@0dBm
Sensitivity: -88dBm
QFN, CSP package

Bluetooth Low Energy5.0 + 802-15.4

BlueNRGxxx

ARM Cortex-M0+ Core
256KB Flash
64kB RAM
RX:3.8mA
TX: 4.0mA@0dBm
Sensitivity: -95dBm
QFN, CSP package

Q4 13 | **Q1 15** | **Q2 16** | **Q2 17** | **Q4 17**

Application Processor
Network Processor
In development

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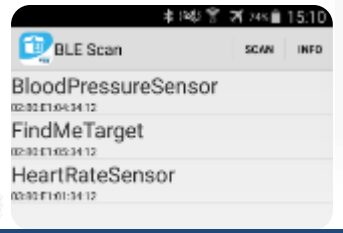
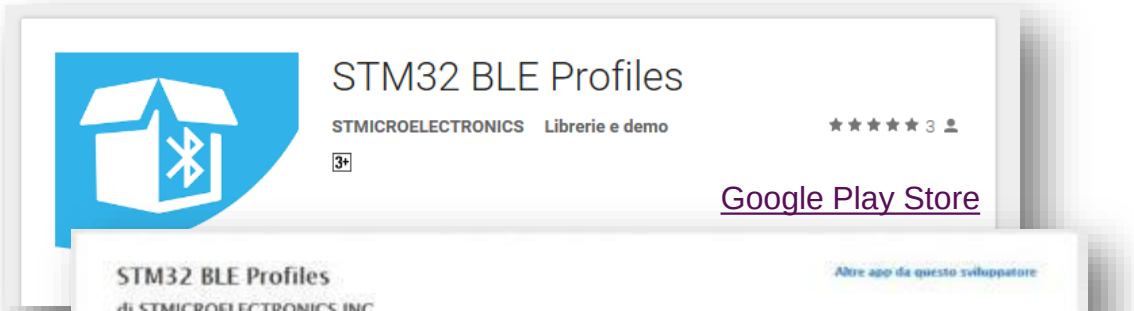
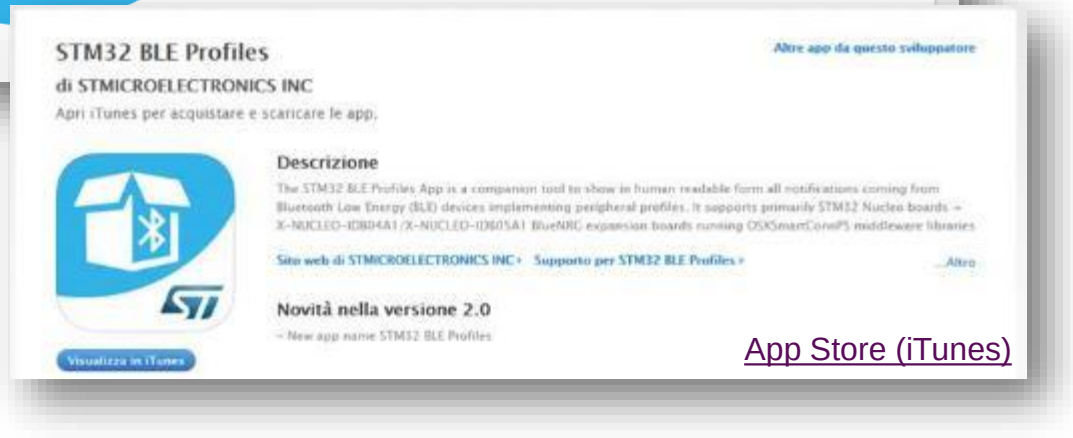
Bluetooth Low Energy Profiles

SmartApp for iOS/Android







"STM32 Bluetooth Low Energy Profiles" is a companion tool to show all notifications coming from Bluetooth Low Energy (Bluetooth Low Energy) devices implementing peripheral profiles (e.g. Heart rate, Blood Pressure, Glucose, Health Thermometer, Alert, Proximity, etc.) It supports primarily STM32 Nucleo boards + X-NUCLEO-IDB04A1/X-NUCLEO-IDB05A1 BlueNRG expansion boards running OSXSmartConnPS middleware libraries and examples.

BlueNRG Bluetooth Low Energy

Available Profiles

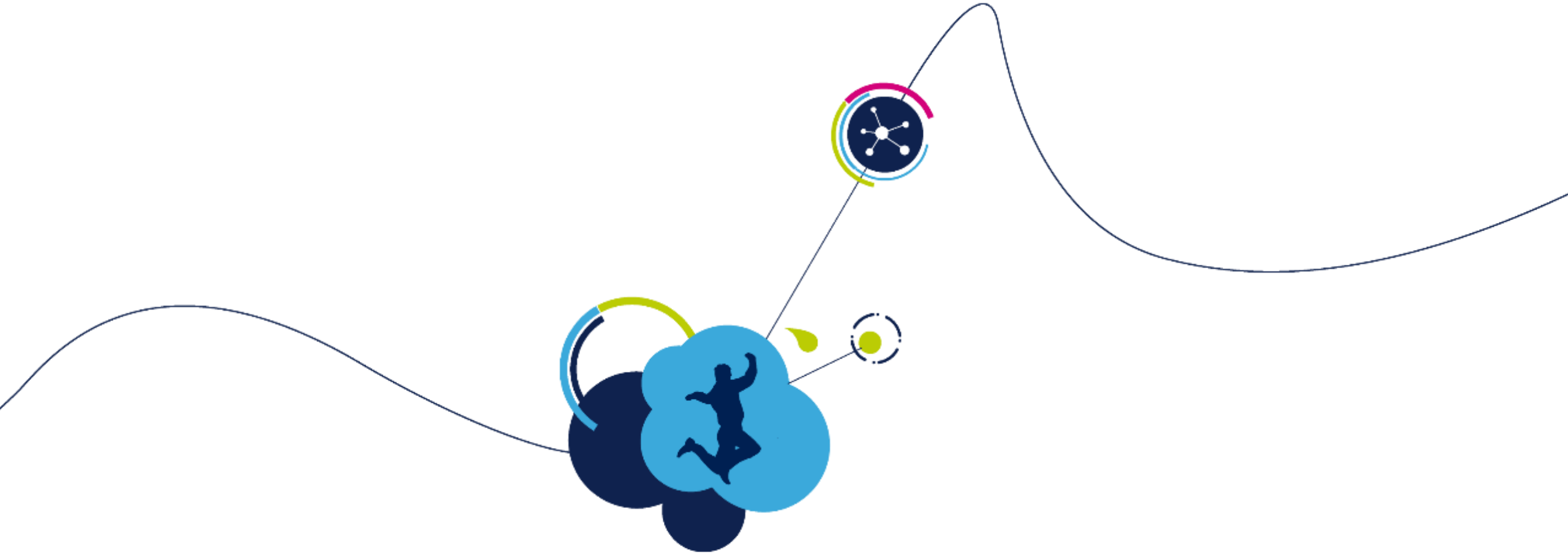
A growing portfolio of pre-certified profiles

- *Alert Notification Client Profile*
- *Alert Notification Server Profile*
- *Blood Pressure Profile*
- *Find Me Locator Profile*
- *Find Me Target Profile*
- *Glucose Sensor Profile*
- *Health Thermometer Profile*
- *Heart Rate Profile*
- *HID device*
- *Phone Alert Profile*
- *Proximity Monitor Profile*
- *Proximity Reporter Profile*
- *Time Server Profile*
- *Time Client Profile*
- *A4WP (Alliance 4 Wireless Power)*

Bluetooth Low Energy: Conclusion

- Ultra Low power
- Compatible with all major platforms (iOS, Android, Windows, Linux)
- Secure
- Easy to use (already part of most phone and tablets)
- Fast evolving standard: more range, higher data rate, upcoming Mesh and Voice profiles

Bluetooth Low Energy: One Wireless Standard to rule the IoT!



Thank you

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