NimBLE - portable Bluetooth stack from Apache Mynewt

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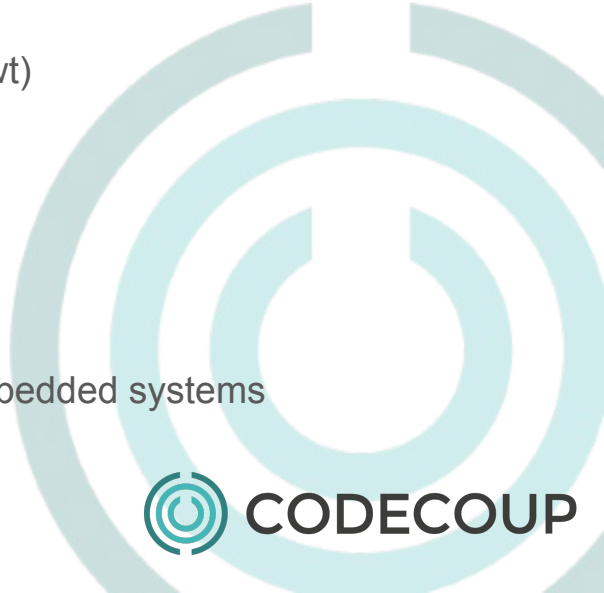
Agenda

- About
- Short Bluetooth Low Energy introduction
- Apache Mynewt
- NimBLE
- Supported BLE features
- NimBLE Bluetooth LE stack architecture
  - controller
  - host
- GAP (Scanning, Advertising, Pairing etc)
- GATT
- NimBLE Ports
- Future work

About

- Me
  - Embedded software engineer
  - Works with embedded Linux and Android platforms since 2007
  - Since 2015 involved in couple RTOSes development
  - Focused on Local Connectivity (Bluetooth, NFC)
  - Open Source contributor (BlueZ, Linux, Zephyr, Apache Mynewt)

- Codecoup
  - Founded in 2015
  - Support in Bluetooth, Linux, Android, RTOS, Open Source, embedded systems
  - Internet of Things projects
  - www.codecoup.pl

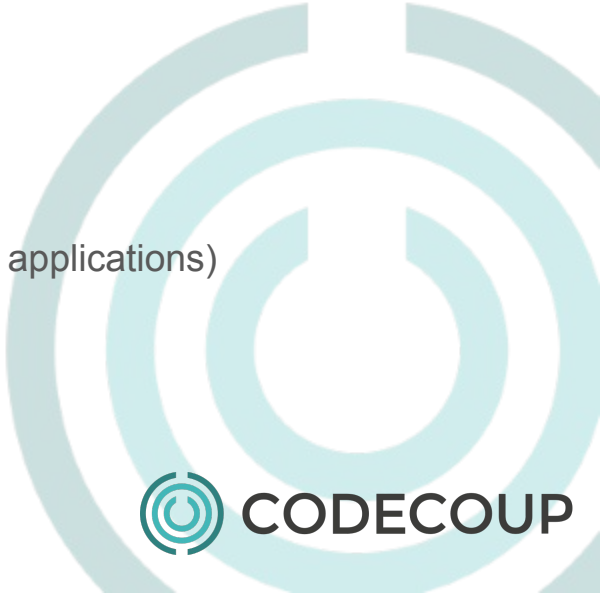


History of Bluetooth Low Energy

- Introduced with Bluetooth 4.0 released in June 2010
- Bluetooth 4.1 released in December 2013
  - Link Layer Topology
  - LE L2CAP Connection Oriented Channels
- Bluetooth 4.2 released in December 2014
  - LE Secure Connection
  - Link Layer Privacy
  - Data Length Extensions (up to 2.5x speed increase)
  - IP Support Profile released
- Bluetooth 5 released in December 2016
  - 2M PHY
  - Coded PHY (LE Long Range)
  - Advertising Extensions, Periodic Advertising
- Bluetooth Mesh released in July 2017

Technology overview

- Much simpler comparing to Bluetooth Classic
- Short range wireless technology (typically up to 100 meters, possible 1km+)
- Operates at 2.4 GHz (IMS band)
- Designed for low power usage (coin battery)
- Fast connection establishment
- Simple modulation to minimize transceiver complexity
- Multiple PHYs supported (Bluetooth 5)
  - 1 Mbps bandwidth over the air (~0.27 Mbps max throughput for applications)
  - 2 Mbps bandwidth over the air
  - Coded PHY - S2 and S8 coding
- Frequency hopping to combat interferences
- Use both FDMA and TDMA



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Technology overview (II)

- Short data packets (27 bytes, 255 with Data Length Extension)
- 40 physical channels
  - 3 for advertising, 37 for data (Bluetooth 4.2 and older)
  - All channels used for advertising with Advertising Extensions (Bluetooth 5)
- Channel selection algorithms #1 and #2
  - #2 introduced in Bluetooth 5 improves spectrum usage and WiFi coexistence

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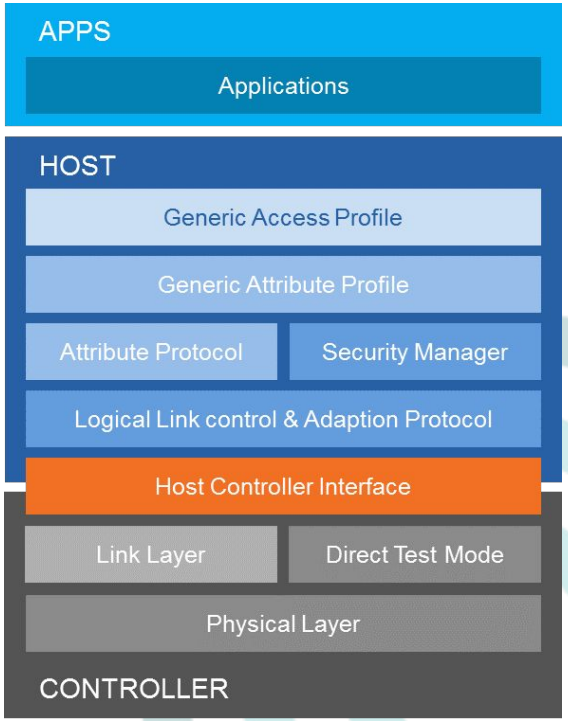
Technology overview (III)

- Connectionless roles
  - observer and broadcaster
- Connection oriented roles
  - central and peripheral
- Security
  - Encryption and authentication
- Generic Attribute Profile (GATT)
  - Server exposes list of attributes (characteristics grouped as services) called database
  - Client can discover services, read, write and enable notifications
- L2CAP Connection Oriented Channels



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Bluetooth SIG

- The Bluetooth Special Interest Group (SIG) is the body that oversees the development of Bluetooth standard (Core specification, profile specifications)
  - Over 30000 companies are part of Bluetooth SIG as of now
  - Two levels of membership available:
    - Adopter (free) → license to build products and use trademarks
    - Associate (paid) → access to working groups, i.e. can actively develop specification
- Adopted Core and Profile specifications and corresponding test specifications are available publicly on Bluetooth SIG website
  - https://www.bluetooth.com/specifications/adopted-specifications
- Qualification Process is available to ensure newly developed devices are compliant with specification
  - PTS test tool (free for members) provides semi-automation for testing/qualification process

Apache Mynewt

https://mynewt.apache.org

- An Open Source RTOS for 32-bit MCUs
- Permissive Apache 2.0 license
- Community driven under Apache Foundation
- Small memory requirements (<16KB RAM, <64KB Flash)
- Rich in features
  - Preemptive RTOS, multitasking, mutexes, semaphores, timers etc.
  - Unified buffer management (mbuf)
  - Event driven model (timers, IO etc.)
  - Flash filesystem (NFFS)
  - Console - UART and RTT
  - Networking (Bluetooth 5, Bluetooth Mesh, LoRa, COAP and more)
  - Secure bootloader and image update

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Apache Mynewt (II)

- Modular
  - Most components comes as packages
  - Application enables only packages it uses
- Highly configurable
- Release every 3-4 months
  - 1.4.1 released July 2018
  - 1.5 expected October 2018
- Comes with own build and packages management system (newt)
  - Used for configuring, building, installing and debugging
- Support for Linux, MacOS and Windows
- Portable
  - ARM Cortex-M (M0/M3/M4/M7), MIPS, RISC-V, ARC
  - nRF52DK, nRF52840, nRF51DK, RuuviTag, BLE Nano/Nano2, STM32F4DISCOVERY, Arduino Zero, NUCLEO-F401RE/F767ZI, FRDM-K64F, BBC micro:bit, Adafruit FeatherPortable, HiFive1 DevKit

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Apache NimBLE

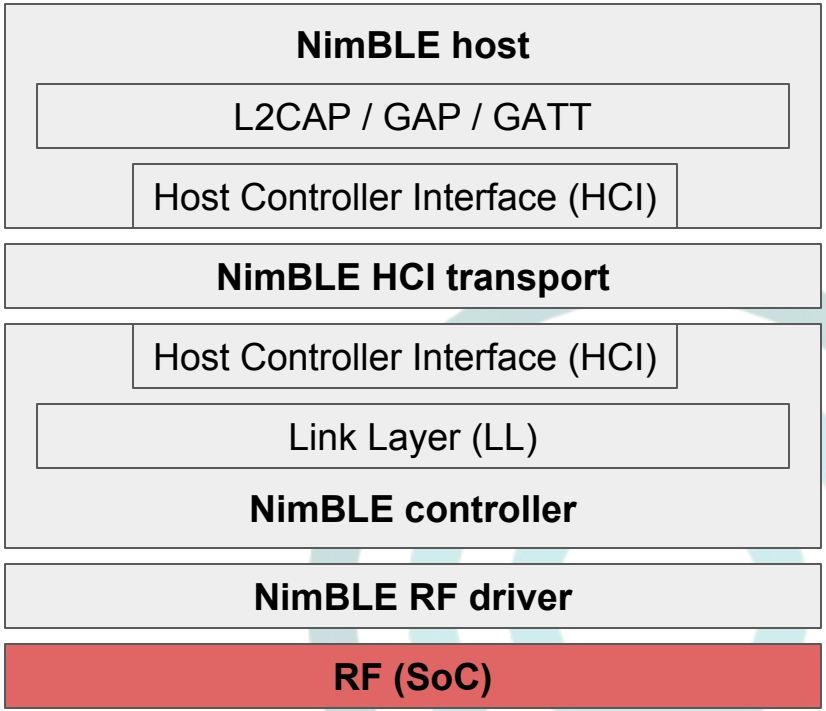
- Originated as part of Apache Mynewt project
- Permissive Apache 2.0 license
- Community driven under Apache Foundation
- https://github.com/apache/mynewt-nimble
- 1.0.0 released on June 2018
  - Future releases planned every few months
  - Released independently of Apache Mynewt
- BT SIG Qualifable (host)

NimBLE Bluetooth Low Energy features

- Core Specification 5.0
  - 1M, 2M and Coded PHY
  - Advertising Extensions
- Low Energy only
- Generic Access Profile (GAP)
  - central, peripheral, observer, broadcaster
  - privacy
  - multiple concurrent roles
- Security Manager
  - Legacy Pairing, Secure Connections
- Generic Attribute Profile (GATT)
- L2CAP Connection Oriented Channels
- Bluetooth Mesh

NimBLE architecture

- Split between host and controller allows for different builds
  - combined host + controller
  - host-only works with external controller
  - controller-only works with external host
- Fully configurable using syscfg parameters
  - number of supported connections, max packet lengths etc. can be configured
  - features can be enabled/disabled to adjust RAM/flash usage
- Decoupled to separate repository (mynewt-nimble) for easier reuse



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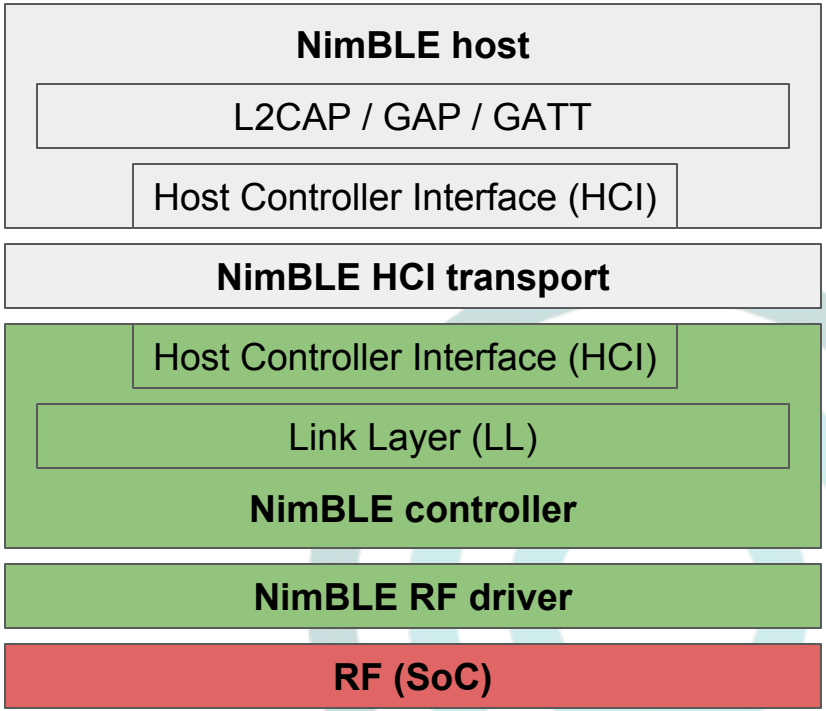
NimBLE controller

- Complete Link Layer implementation
- Uses standard HCI interface
- RF drivers available for various SoCs from Nordic Semiconductor
  - nRF51xxx (without 2M and Coded PHY)
  - nRF52xxx (without Coded PHY)
  - nRF52840
- Support for other RF/SoC possible
- Can be used without NimBLE host (blehci)
  - interfaces with any Bluetooth host stack using UART H4 transport
  - works with BlueZ
  - 28 kB ROM / 2 kB RAM (default)
  - 39 kB ROM / 3 kB RAM (all features)



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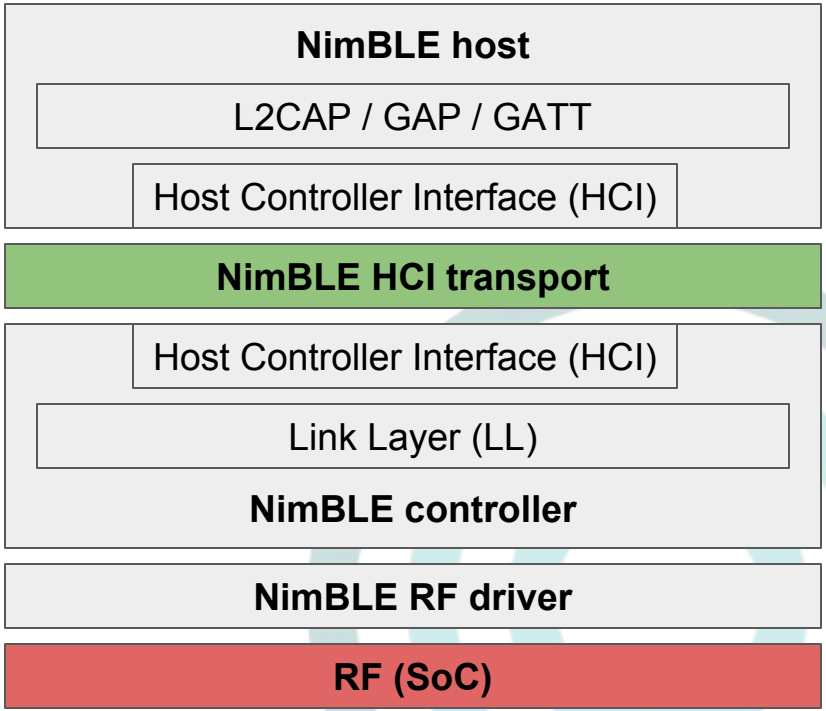
NimBLE HCI transport

- Combined (host + controller) build uses shared memory for HCI transport (nimble/transport/ram)
- External controllers can be used with other transports
  - UART H4 (nimble/transport/uart) standard UART H4 interface
  - Socket transport (nimble/transport/socket) IPC socket for interfacing controller on Linux host (native simulator build)
  - SPI (nimble/transport/emspi) proprietary HCI transport for interfacing controllers made by EM Microelectronics



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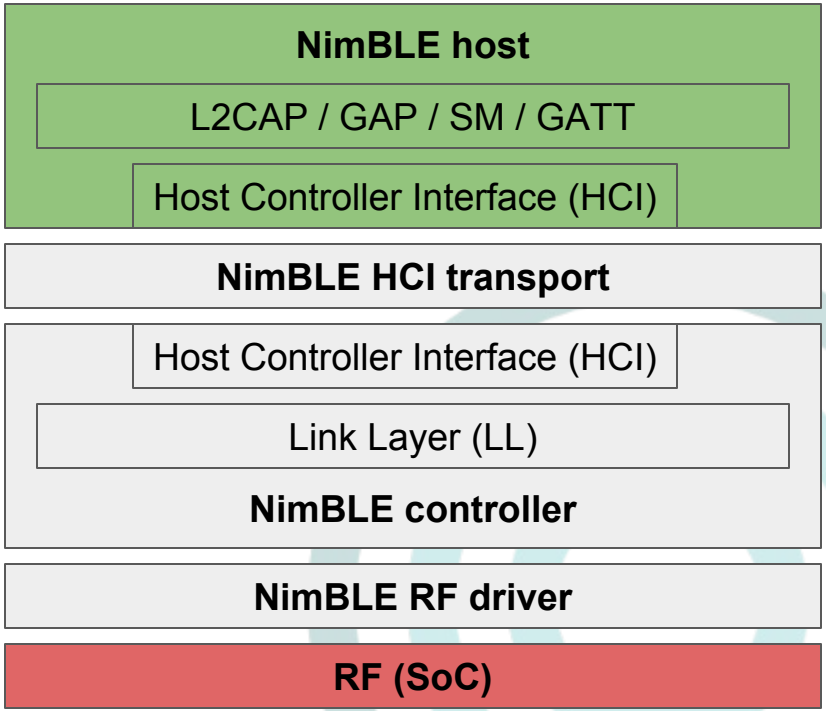
NimBLE host

- Highly configurable
  - complete features can be disabled to reduce memory usage
  - even single GATT procedures can be disabled, if necessary
  - 50 kB ROM / 3 kB RAM (default)
  - 65 kB ROM / 4 kB RAM (L2CAP CoC, Advertising Extensions, SM SC and Mesh)



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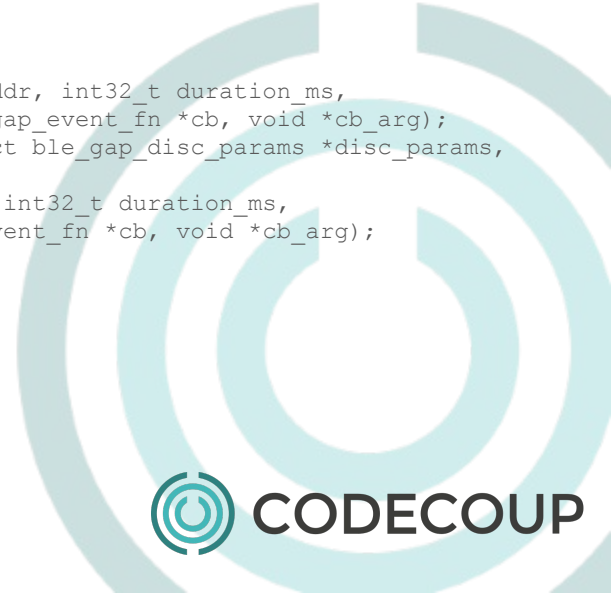
NimBLE host API

- Extensive API to use all host features
- API allows for detailed control over all Bluetooth parameters
  - unlike e.g. Linux or iOS which provide more high-level APIs thus hiding some details

- GAP API available in ble_gap.h

```
int ble_gap_adv_start(uint8_t own_addr_type, const ble_addr_t *direct_addr, int32_t duration_ms,
                      const struct ble_gap_adv_params *adv_params, ble_gap_event_fn *cb, void *cb_arg);
int ble_gap_disc(uint8_t own_addr_type, int32_t duration_ms, const struct ble_gap_disc_params *disc_params,
                 ble_gap_event_fn *cb, void *cb_arg);
int ble_gap_connect(uint8_t own_addr_type, const ble_addr_t *peer_addr, int32_t duration_ms,
                    const struct ble_gap_conn_params *params, ble_gap_event_fn *cb, void *cb_arg);
```



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NimBLE host API (2)

- GATT client and server API available in ble_gatt.h
- All GATT client procedures available as function calls

```
int ble_gattc_disc_all_svcs(uint16_t conn_handle, ...);
int ble_gattc_disc_all_chrs(uint16_t conn_handle, uint16_t start_handle, uint16_t end_handle, ...);
int ble_gattc_read(uint16_t conn_handle, uint16_t attr_handle, ...);
int ble_gattc_read_long(uint16_t conn_handle, uint16_t handle, uint16_t offset, ...);
int ble_gattc_write_no_rsp(uint16_t conn_handle, uint16_t attr_handle, ...);
int ble_gattc_write(uint16_t conn_handle, uint16_t attr_handle, ...);
int ble_gattc_notify(uint16_t conn_handle, uint16_t chr_val_handle, ...);
```

- ...and more!

NimBLE host API (3)

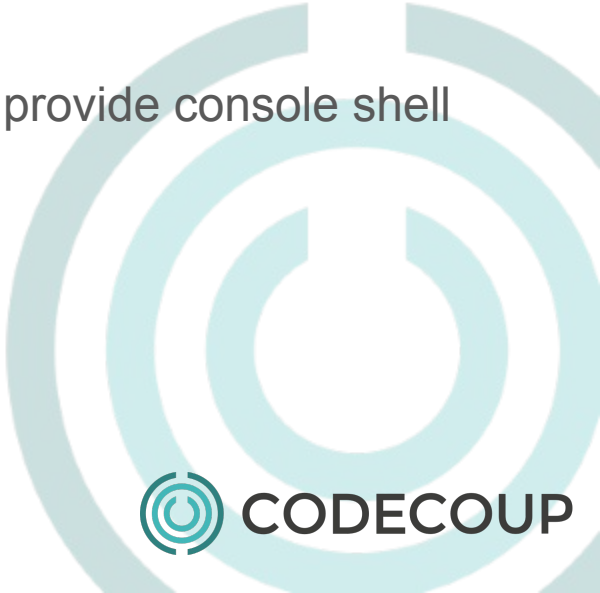
- GATT database can be registered using full service description

```
static const struct ble_gatt_svc_def gatt_svr_svcs[] = {
       {
       /* Service: Heart-rate */
       .type = BLE_GATT_SVC_TYPE_PRIMARY,
       .uuid = BLE_UUID16_DECLARE(GATT_HRS_UUID),
       .characteristics = (struct ble_gatt_chr_def[]) { {
              /* Characteristic: Heart-rate measurement */
              .uuid = BLE_UUID16_DECLARE(GATT_HRS_MEASUREMENT_UUID),
              .access_cb = gatt_svr_chr_access_heart_rate,
              .val_handle = &hrs_hrm_handle,
              .flags = BLE_GATT_CHR_F_NOTIFY,
       }, {
              /* Characteristic: Body sensor location */
              .uuid = BLE_UUID16_DECLARE(GATT_HRS_BODY_SENSOR_LOC_UUID),
              .access_cb = gatt_svr_chr_access_heart_rate,
              .flags = BLE_GATT_CHR_F_READ,
       }, {
              0, /* No more characteristics in this service */
       }, }
       },
};

/* … */
ble_gatts_add_svcs(gatt_svr_svcs);
```

Applications samples

- Located in apps/ folder
- Blinky - ‘Hello World’ sample
- Provide code reference for API usage for most subsystems
  - blehci, blehr, bleprh, btshell - BLE samples
  - blemesh - Bluetooth Mesh
- btshell - application that enables all BLE features and provide console shell for user to control every aspect of NimBLE stack



NimBLE Ports

- Support for multiple OSes
  - Apache Mynewt
  - FreeRTOS
  - RIOT
  - Linux

NimBLE updates for porting

- Move NimBLE to separate repository (was as subdir in Mynewt core)
- Make sure only OS API calls are used to interact with OS
  - Refactored code which accessed various OS structures directly (not portable)
  - Missing OS API calls added
- Fix build outside Mynewt tree
  - Unused dependencies (#include) to Mynewt components removed
  - Build with stubbed Mynewt-specific subsystems
  - Add conditional compilation for Mynewt-specific code
- Port necessary Mynewt structures to external builds
  - Memory pools and memory buffers (mbufs) are inherent structures for data buffers in Mynewt and thus also NimBLE
- Change OS API calls to portable versions (os_* → ble_npl_*)

NimBLE 1.0+ (with NPL)

- OS abstraction layer defined (nimble/include/nimble/nimble_npl.h)
  - Events and event queues
  - Mutexes
  - Semaphores
  - Callouts (timers)
  - Ticks time handling
  - Few auxiliary calls (mostly to make controller integration easier)
- Common code required to build NimBLE (porting/nimble)
  - Components “extracted” from Mynewt (os_mbuf, os_mempool, os_cputime)
  - Stubbed headers for subsystems specific to Mynewt (logs, stats, trace)
  - NimBLE initialization code
- NPL implementation for supported OS-es (porting/npl)
  - Mynewt **also** implements NPL - it’s just a shim to call original os_* APIs

NimBLE in RIOT OS

- NPL for RIOT OS merged to NimBLE repository (porting/npl/riot)
- NimBLE provided in RIOT OS as package (pkg/nimble)
  - Built from NimBLE repository **without** extra patches required (minor workarounds required by RIOT OS port are merged to NimBLE repository)
  - Minimal extra setup required - see sample app in examples/nimble_gatt
- Works:
  - All Bluetooth Core features implemented in NimBLE
  - nRF52xxx MCU (combined controller + host build with HCI over shared memory)
    (note: controller needs exclusive access to TIMER0, RTC0, RADIO, CCM and AAR)
- Does not (yet) work, but possible:
  - Host on other MCUs (possible with specific HCI transport implementation)
  - Bluetooth Mesh (not ported in NimBLE 1.0, will be available in next NimBLE release)
- Implemented during RIOT hackathon on May 2018 in Paris
  - Credits: Andrzej Kaczmarek and Hauke Petersen

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Future Work

- BT SIG qualification of controller
- Support for periodic advertising
- More samples implementing Bluetooth Profiles
- Improvements to Mesh (sync with Zephyr)

Community and Contributing

- Found a bug or work on new feature? Contribute!
- Mynewt NimBLE uses GitHub for development
  - https://github.com/apache/mynewt-nimble
  - Pull requests should be sent against master branch
- Discussions
  - Mailing list: dev@mynewt.apache.org
  - Slack channel: https://mynewt.slack.com/messages
- More information on https://mynewt.apache.org

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