FTF 2016
TECHNOLOGY FORUM

IPv6 OVER BLUETOOTH® LOW ENERGY

6LoBLE

ALEXANDRU ANDREESCU
SOFTWARE ENGINEER
FTF-HMB-N1962
MAY 17, 2016

Session Introduction

- The session aims to explain how Bluetooth® low energy devices will be connected to the Internet via IPv6
- Two major use-cases
  - Adding IPv6 support to existing BLE use cases is a big advantage (medical or fitness data straight to the Cloud)
  - Using Bluetooth® low energy as a new bearer for existing IPv6 connected devices (802.15.4 lightbulbs or thermostats can now also be controlled via BLE from a remote IPv6 enabled device)
- The presentation is relevant for all who want to add BLE connectivity to IPv6 ready products, add IPv6 capability to existing BLE products
- Time slot is 1 hour of which 10 minutes are allocated for questions. Questions will also be taken during the session itself

Session Objectives

- After completing this session you will be able to:
  - **Understand** how IPv6 frames are transported over Bluetooth® low energy
  - **Appreciate** the capabilities of the Kinetis KW41 MCU for IPv6 over Bluetooth® low energy Applications
  - **Differentiate** 6LoBLE from the classic 6LoWPAN
  - **Understand** how IPv6 and Bluetooth® low energy will evolve in the IoT space

AGENDA

- Introduction to 6lo
- BLE Specifics Pertaining to IPv6 Communication
- Transporting IPv6 over Bluetooth® Low Energy
- Kinetis KW41Z MCU Features for 6LoBLE
- Demo of IPv6 Communication over BLE
- Future Improvements for IPv6 Transport over BLE

INTRODUCTION TO 6LO

Introduction to 6lo

- Internet of Things assumes connectivity for all nodes
  - Ideal protocol for connecting billion devices: **IPv6**

- 6lo
  - Internet Engineering Task Force (**IETF**) Working Group
  - IPv6 over Networks of Resource-constrained Nodes
  - Adaptation layers for technologies such as 802.15.4, NFC, etc.

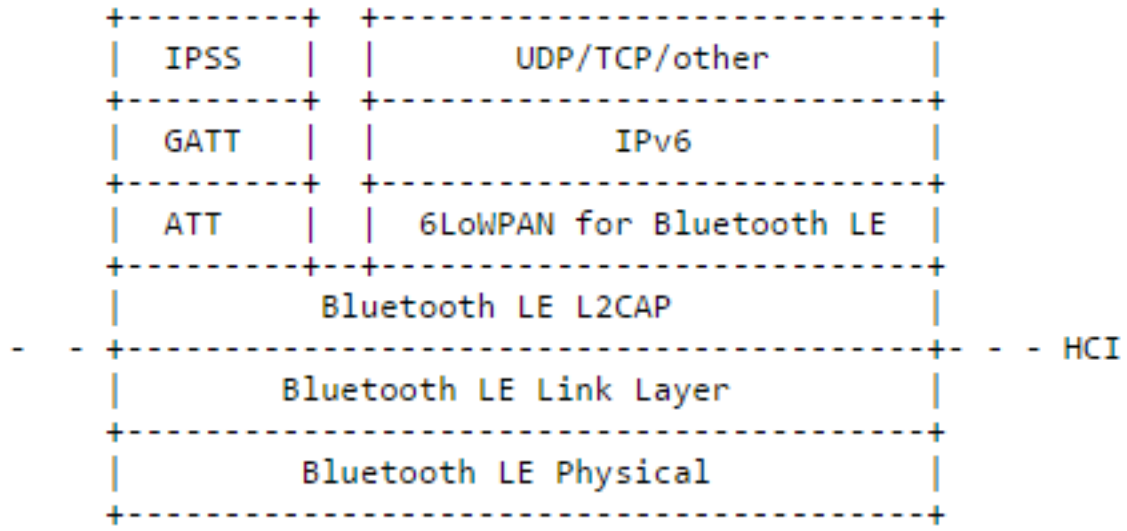
- 6loBLE (IPv6 over Bluetooth® Low Energy) - **RFC 7668**
  - Transport IPv6 over BLE using existing 6LoWPAN techniques

BLE SPECIFICS PERTAINING TO IPv6 COMMUNICATION

BLE Specifics for IPv6 Communication

- Bluetooth® LE v4.1 and above
  - Internet Protocol Support Profile (IPSP)
  - L2CAP Credit Based Channels
- Discovery on ATT channel:
  - Internet Protocol Support Service (IPSS)
  - GATT-based service
- IPv6 Communication:
  - L2CAP Connection Oriented Channels
  - Protocol Service Multiplexer (PSM): 0x0023

Protocol Stack



BLE Specifics for IPv6 Communication (2)

- Bluetooth® LE Packet Sizes and MTU
  - IPv6 requires a minimum MTU of 1280 octets
  - L2CAP layer fragmentation and reassembly replaces RFC4944 fragmentation (6LoWPAN)
  - Bluetooth® v4.1 : Maximum PDU size: 27 octets
  - Bluetooth® v4.2 : Maximum PDU size: 251 octets (~ **10x** less fragments)

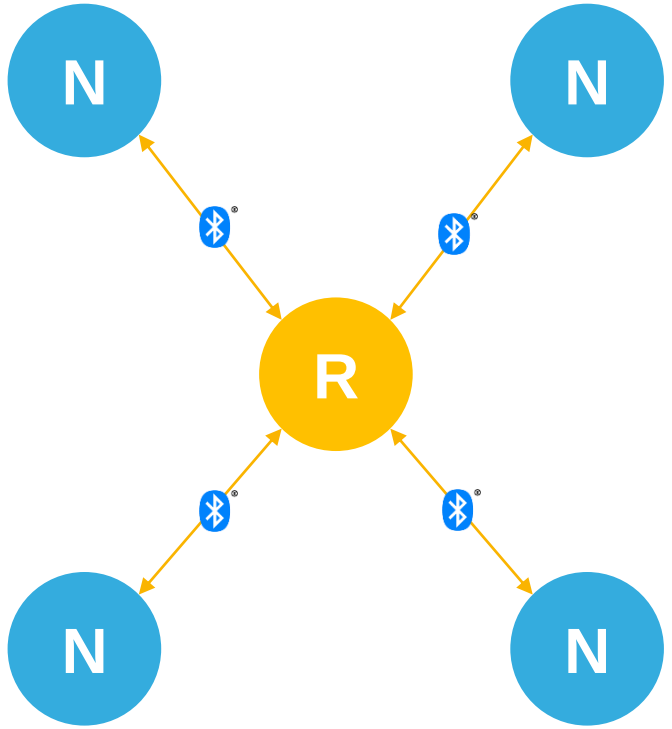
- Bluetooth® LE Addresses
  - 48-bit device address: public or random
  - Random addresses: static or private
  - Private addresses (RECOMMENDED): resolvable or non-resolvable
  - Address conflict managed by the GAP Central device

BLE Specifics for IPv6 Communication (3)

- Hub and spokes topology

- IPSP Router
  - GAP Central
  - Manages multiple connections

- IPSP Node
  - GAP Peripheral
  - Communication with other IPSP Nodes via the IPSP Router



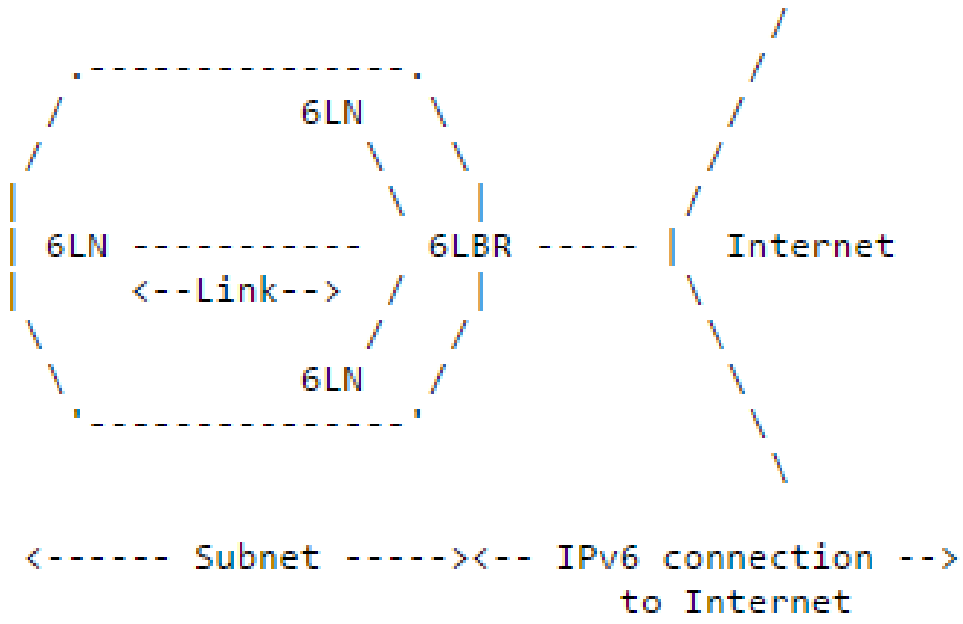
TRANSPORTING IPv6 OVER BLUETOOTH® LOW ENERGY

Transporting IPv6 over Bluetooth® Low Energy

- Multilink model
  - Link local multicast constrained to Bluetooth ® link

- 6LoWPAN Node (**6LN**)
  - IPSP Node
  - Communicate with other 6LN using prefix
  - Joins the all-nodes multicast address

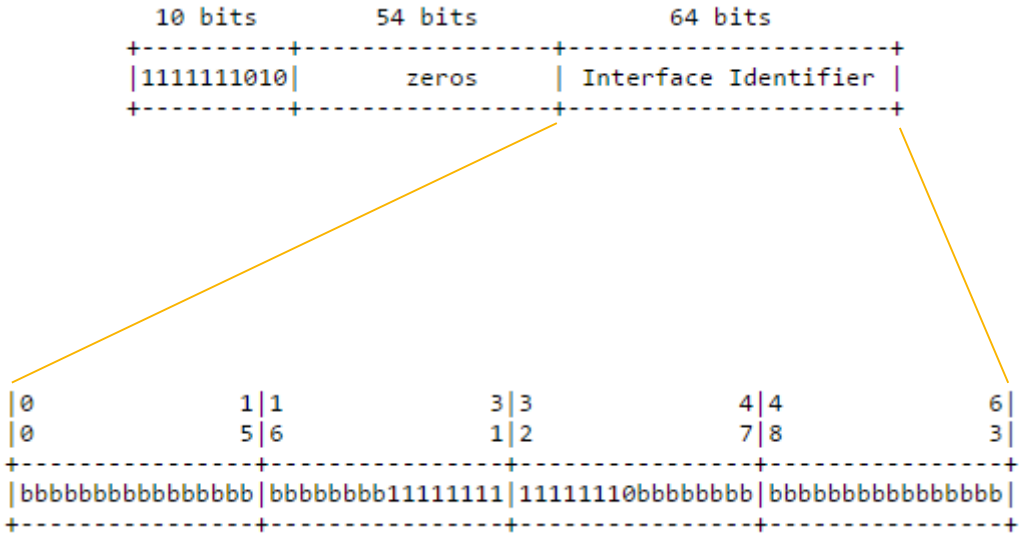
- 6LoWPAN Border Router (**6LBR**)
  - IPSP Router
  - Prevents address collision
  - Forwards packets to other 6LN
  - Forwards multicast packets to registered devices



Transporting IPv6 over Bluetooth® Low Energy (2)

- Stateless address auto-configuration (**SLAAC**)

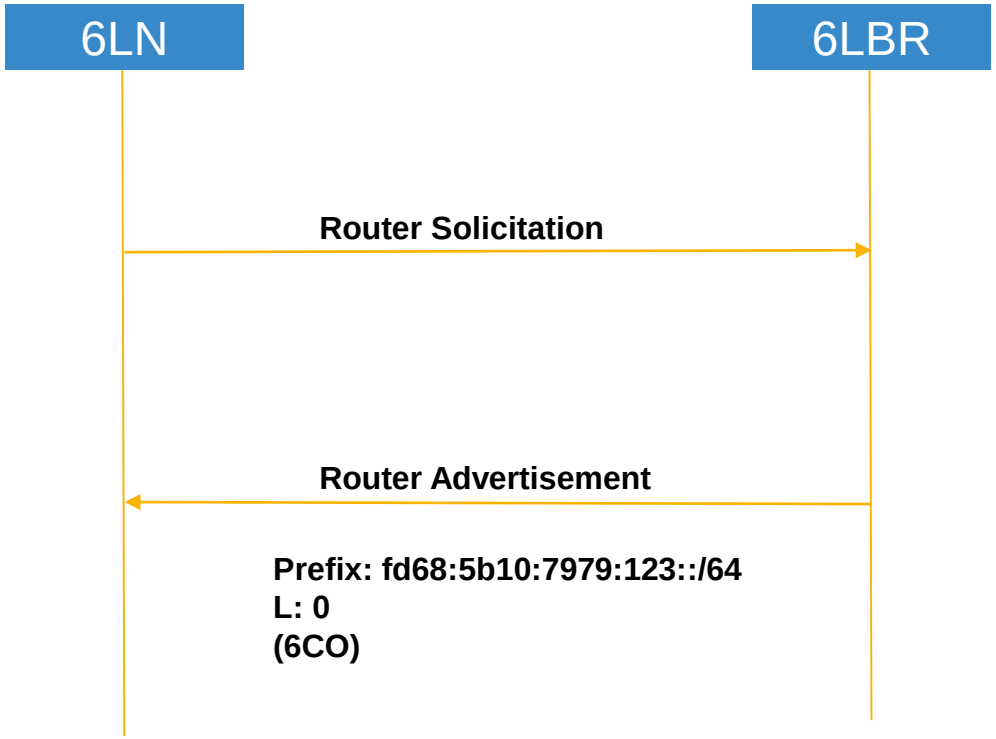
- SLAAC for Link-local addresses
  - FE80::/64 prefix and a 64-bit Interface Identifier (IID)
  - IID formed from the 48-bit Bluetooth® address



Transporting IPv6 over Bluetooth® Low Energy (3)

- SLAAC for non-link-local addresses
  - Require a global prefix – Prefix Information Option (**PIO**)
  - 6LoWPAN Context Option (**6CO**)
- ICMPv6 messages :
  - Router Solicitation (**RS**)
  - Router Advertisement (**RA**)
- On-Link flag (L) is set to zero. 6LN always sends packet to 6LBR

Prefix and Router Discovery



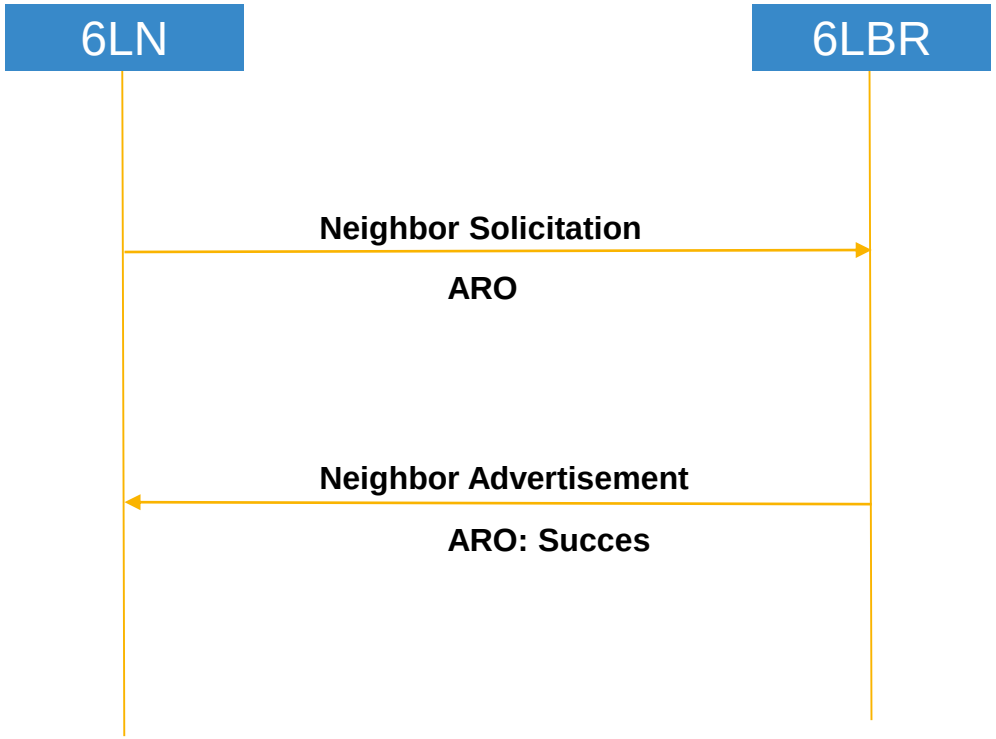
Transporting IPv6 over Bluetooth® Low Energy (4)

- 6LN must register its non-link-local address with the 6LBR

- ICMPv6 messages :
  - Neighbor Solicitation (**NS**)
  - Neighbor Advertisement (**NA**)

- NS sent with an Address Registration Option (**ARO**)

Address Registration



Transporting IPv6 over Bluetooth® Low Energy (4)

- Header Compression
  - Based on RFC 6282 (compression for IPv6 on 802.15.4)
  - Increased efficiency when:
    - RA with 6LoWPAN Context Option (**6CO**) matching each **PIO**
    - Neighbor discovery with address registration option (**ARO**)
  - Elision of source, destination or both IPv6 addresses:
    - Full IP Address (on link-local or last registered) – 128 bits
    - Prefix when compression context available – 64 bits
    - IID – 48 bits elided

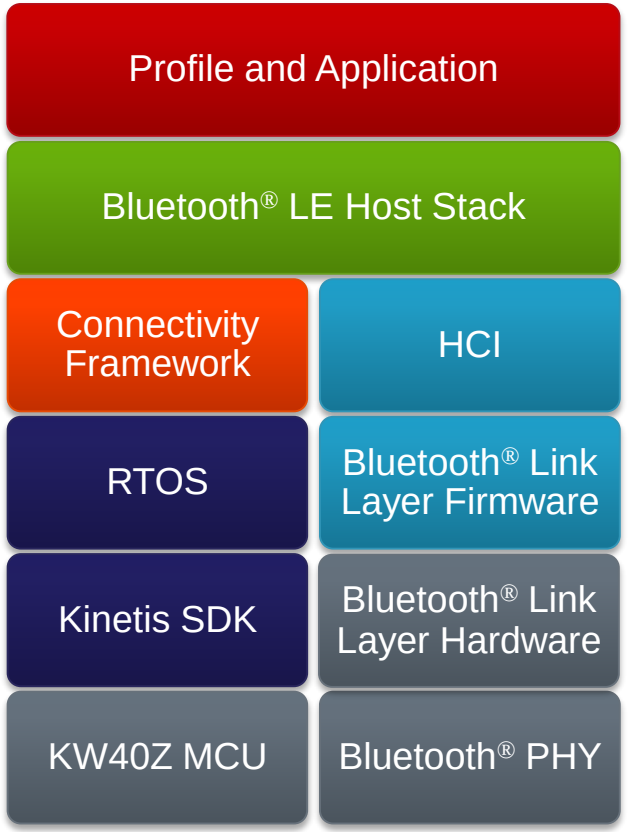
KINETIS KW41Z MCU FEATURES FOR 6LoBLE

Kinetis KW41Z Features

- ARM® Cortex®-M0+ CPU Up to 48 MHz
- Footprint that supports IPv6 stack
  - Up to 512 KB Flash and 128 KB SRAM
- 2.4 GHz Bluetooth® low energy v4.2 and IEEE® 802.15.4-2011 Compliant
- AES Accelerator and True Random Number Generator
- Dual-Mode BLE and 802.15.4
  - Supports concurrent Thread and BLE

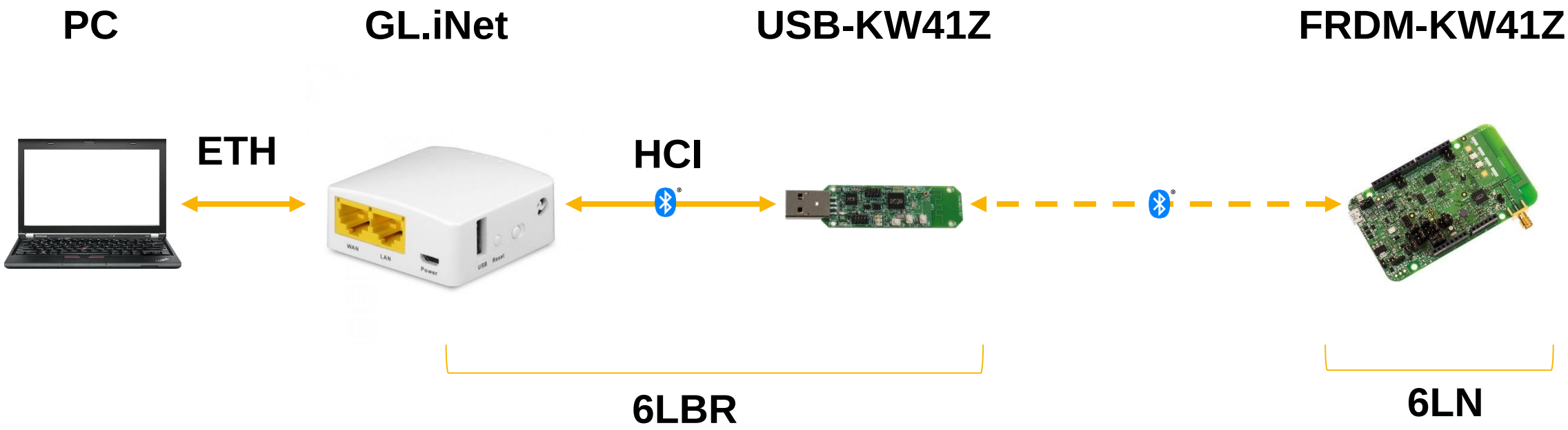
Kinetis KW41Z Software Offering

- Implementation of the Bluetooth® LE host specification v4.2
  - Long LE Frames support
  - Link Layer enhanced controller privacy with address resolution
  - LE Secure Connections with ECDH
- Host Controller Interface (HCI) layer with software or UART transport options
- Bluetooth® LE Link Layer firmware library that interacts with the corresponding hardware.
- Connectivity Framework middleware collection
- Kinetis SDK v2.0 driver support for KW41Z
- RTOSes available in Kinetis SDK: FreeRTOS, uCOS/II and bare-metal non-preemptive scheduler.
- Applications and library support for IAR Embedded Workbench and Kinetis Design Studio (gcc).



DEMO OF IPv6 COMMUNICATION OVER BLE

Demo of IPv6 Communication over BLE



Demo of IPv6 Communication over BLE (2)

- FRDM-KW41Z
  - Implements IPSP Node and GAP Advertiser.
  - Public Address: 00:04:9F:00:66:66
  - SLAAC: FE80::02:04:9F:00:66:66 (RFC 4291: “u” bit must be set to 1)

- USB-KW41Z
  - Implements HCI App over UART

- GL-iNet
  - OpenWRT DESIGNATED DRIVER (Bleeding Edge, r49031)
  - Packages used: kmod-bluetooth, kmod-bluetooth_6lowpan, tcpdump

Demo of IPv6 Communication over BLE (3)

- Network configuration (root@OpenWrt:~# vim /etc/config/network)

```
config globals 'globals'
        option ula_prefix 'fd68:5b10:7979::/48'

config interface 'lan'
        option type 'bridge'
        option ifname 'eth1'
        option proto 'static'
        option ipaddr '192.168.1.1'
        option netmask '255.255.255.0'
        option ip6assign '60'
        option ip6hint '450'

config interface 'BLE'
        option proto 'static'
        option ifname 'bt0'
        option ip6assign '64'
        option ip6hint '123'
```

Demo of IPv6 Communication over BLE (4)

- DHCP configuration (root@OpenWrt:~# vim /etc/config/dhcp)

```
config dhcp 'lan'
        option interface 'lan'
        option start '100'
        option limit '150'
        option leasetime '12h'
        option dhcpv6 'server'
        option ra 'server'
        option ra_management '1'

config dhcp 'BLE'
        option interface 'BLE'
        option ignore '1'
        option ra 'server'
        option ra_default '1'
```

Demo of IPv6 Communication over BLE (5)

- LAN interface: br-lan
  - IPv4 static address for SSH
  - IPv6 address from DHCPv6

```
root@OpenWrt:~# ifconfig br-lan
br-lan    Link encap:Ethernet  HWaddr E4:95:6E:40:28:00
          inet addr:192.168.1.1  Bcast:192.168.1.255  Mask:255.255.255.0
          inet6 addr: fd68:5b10:7979:450::1/60 Scope:Global
          inet6 addr: fe80::e695:6eff:fe40:2800/64 Scope:Link
          UP BROADCAST RUNNING MULTICAST  MTU:1500  Metric:1
          RX packets:5232 errors:0 dropped:0 overruns:0 frame:0
          TX packets:5275 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:513352 (501.3 KiB)  TX bytes:969336 (946.6 KiB)
```

Demo of IPv6 Communication over BLE (6)

- Testing LAN connection
  - Ping from PC to the Router LAN address fd68:5b10:7979:450::1

```
C:\>ping  fd68:5b10:7979:450::1

Pinging fd68:5b10:7979:450::1 with 32 bytes of data:
Reply from fd68:5b10:7979:450::1: time=1ms
Reply from fd68:5b10:7979:450::1: time=1ms
Reply from fd68:5b10:7979:450::1: time=1ms
Reply from fd68:5b10:7979:450::1: time=1ms

Ping statistics for fd68:5b10:7979:450::1:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 1ms, Maximum = 1ms, Average = 1ms
```

Demo of IPv6 Communication over BLE (7)

- Attach USB-KW41Z as a device via UART

```
root@OpenWrt:~# dmesg | grep tty
[    0.000000] Kernel command line:  board=GL-INET  console=ttyATH0,115200
rootfstype=squashfs,jffs2 noinitrd
[    0.718970] ar933x-uart: ttyATH0 at MMIO 0x18020000 (irq = 11, base_baud =
1562500) is a AR933X UART
[    0.727464] console [ttyATH0] enabled
[   11.919689] cdc_acm 1-1:1.1: ttyACM0: USB ACM device

root@OpenWrt:~# hciattach /dev/ttyACM0 any 115200 noflow nosleep
Device setup complete

root@OpenWrt:~# hciconfig
hci0:   Type: BR/EDR  Bus: UART
        BD Address: 00:04:9F:00:00:16  ACL MTU: 500:4  SCO MTU: 0:0
        DOWN
        RX bytes:231 acl:0 sco:0 events:16 errors:0
        TX bytes:88 acl:0 sco:0 commands:16 errors:0
```

Demo of IPv6 Communication over BLE (8)

- Create Bluetooth link

```
root@OpenWrt:~# hciconfig hci0 up
root@OpenWrt:~# hciconfig hci0 reset
root@OpenWrt:~# hcitool lescan
LE Scan ...
00:04:9F:00:66:66 IPv6_NODE

root@OpenWrt:~# echo "connect 00:04:9F:00:66:66 1" >
/sys/kernel/debug/bluetooth/6lowpan_control

root@OpenWrt:~# ifconfig bt0
bt0       Link encap:UNSPEC  HWaddr 00-04-9F-FF-FE-00-00-16-00-00-00-00-00-00-00-00
          inet6 addr: fe80::204:9fff:fe00:16/64 Scope:Link
          inet6 addr: fd68:5b10:7979:123::1/64 Scope:Global
          UP POINTOPOINT RUNNING MULTICAST  MTU:1280  Metric:1
          RX packets:0 errors:0 dropped:0 overruns:0 frame:0
          TX packets:10 errors:0 dropped:0 overruns:0 carrier:0
          collisions:0 txqueuelen:0
          RX bytes:0 (0.0 B)  TX bytes:610 (610.0 B)
```

Demo of IPv6 Communication over BLE (9)

- Start tcpdump to monitor ICMP messages on bt0 in another terminal

```
root@OpenWrt:~# tcpdump -i bt0 -vv ip6
```

- Network restart or reload if global address not assigned by router on bt0

```
root@OpenWrt:~# /etc/init.d/network restart
root@OpenWrt:~# /etc/init.d/network reload
```

- Configure firewall (root@OpenWrt:~# vim /etc/config/firewall)

```
config defaults
        option syn_flood '1'
        option input 'ACCEPT'
        option output 'ACCEPT'
        option forward 'ACCEPT'
```

Demo of IPv6 Communication over BLE (10)

- Route Solicitation / Route Advertisement tcpdump

```
12:23:48.735864 IP6 (hlim 255, next-header ICMPv6 (58) payload length: 24) fe80::204:9fff:fe00:6666 > ip6-
allrouters: [icmp6 sum ok] ICMP6, router solicitation, length 24
          source link-address option (1), length 16 (2): 00:04:9f:ff:fe:00:66:66:00:00:00:00:00:00
            0x0000:  0004 9fff fe00 6666 0000 0000 0000
12:23:48.739579 IP6 (hlim 255, next-header ICMPv6 (58) payload length: 120) fe80::204:9fff:fe00:16 >
fe80::204:9fff:fe00:6666: [icmp6 sum ok] ICMP6, router advertisement, length 120
        hop limit 64, Flags [managed], pref medium, router lifetime 0s, reachable time 0s, retrans time 0s
          source link-address option (1), length 8 (1): 00:04:9f:ff:fe:00
            0x0000:  0004 9fff fe00
          mtu option (5), length 8 (1):  1280
            0x0000:  0000 0000 0500
          prefix info option (3), length 32 (4): fd68:5b10:7979:123::/64, Flags [onlink, auto], valid time infinity,
pref. time infinity
            0x0000:  40c0 ffff ffff ffff ffff 0000 0000 fd68
            0x0010:  5b10 7979 0123 0000 0000 0000 0000
          unknown option (24), length 24 (3):
            0x0000:  3000 ffff ffff fd68 5b10 7979 0000 0000
            0x0010:  0000 0000 0000
          rdnss option (25), length 24 (3):  lifetime 18000s, addr: fe80::204:9fff:fe00:16
            0x0000:  0000 0000 4650 fe80 0000 0000 0000 0204
            0x0010:  9fff fe00 0016
          advertisement interval option (7), length 8 (1):  1800000ms
            0x0000:  0000 001b 7740
```

Demo of IPv6 Communication over BLE (11)

- Neighbor Solicitation / Neighbor Advertisement tcpdump

```
14:07:57.926542 IP6 (hlim 255, next-header ICMPv6 (58) payload length: 56)
fd68:5b10:7979:123:204:9fff:fe00:6666 > fd68:5b10:7979:123::1: [icmp6 sum ok] ICMP6, neighbor
solicitation, length 56, who has fd68:5b10:7979:123::1
          unknown option (33), length 16 (2):
            0x0000:  0000 0000 0000 0004 9fff fe00 6666
          source link-address option (1), length 16 (2): 00:04:9f:ff:fe:00:66:66:00:00:00:00:00:00
            0x0000:  0004 9fff fe00 6666 0000 0000 0000

14:07:57.926763 IP6 (hlim 255, next-header ICMPv6 (58) payload length: 24) fd68:5b10:7979:123::1 >
fd68:5b10:7979:123:204:9fff:fe00:6666: [icmp6 sum ok] ICMP6, neighbor advertisement, length 24, tgt
is fd68:5b10:7979:123::1, Flags [router, solicited]
```

Demo of IPv6 Communication over BLE (12)

- Send PING from PC to FRDM-KW40Z

```
C:\>ping  fd68:5b10:7979:0123:204:9FFF:FE00:6666

Pinging fd68:5b10:7979:123:204:9fff:fe00:6666 with 32 bytes of
data:
Reply from fd68:5b10:7979:123:204:9fff:fe00:6666: time=300ms
Reply from fd68:5b10:7979:123:204:9fff:fe00:6666: time=296ms
Reply from fd68:5b10:7979:123:204:9fff:fe00:6666: time=297ms
Reply from fd68:5b10:7979:123:204:9fff:fe00:6666: time=295ms

Ping statistics for fd68:5b10:7979:123:204:9fff:fe00:6666:
    Packets: Sent = 4, Received = 4, Lost = 0 (0% loss),
Approximate round trip times in milli-seconds:
    Minimum = 295ms, Maximum = 300ms, Average = 297ms
```

FUTURE IMPROVEMENTS FOR IPv6 TRANSPORT OVER BLE

Future Improvements

- Disadvantages:
  - Requires a link layer connection – not a good case for low power devices
  - No link-layer multicast support
  - Topology is limited to a star model

- Solutions
  - Using advertisements channels
    - Can send packets to multiple devices
    - Does not requires setting up and maintaining a connection
  - Using mesh under routing solutions enables other topologies

Advantages for IPv6 over BLE

- Every Bluetooth® low energy device will have an IPv6 Address
- Increased interoperability for IPv6 ready IoT devices
- Clients will not worry about what Link Layer do their products support
- No more gateways needed when switching bearer

SECURE CONNECTIONS
FOR A SMARTER WORLD

ATTRIBUTION STATEMENT