GETTING STARTED WITH KINETIS KW41Z - BLE/802.15.4 SOLUTIONS FOR THE IOT

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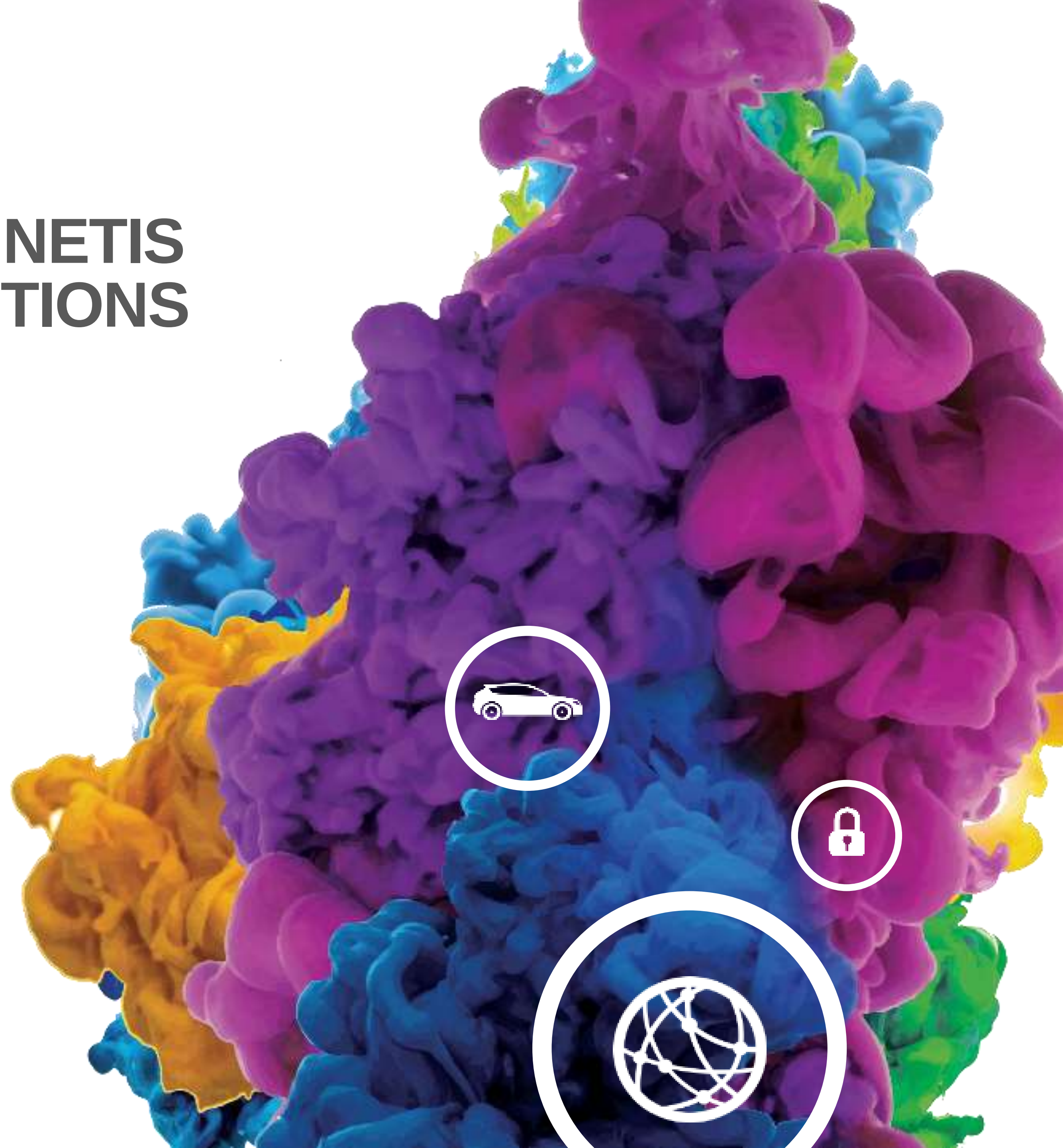
AMF-CNS-T2642 | JUNE 2017



SECURE CONNECTIONS
FOR A SMARTER WORLD

NXP Value Proposition for the IoT Market

LOW POWER

- Ultra-efficient dynamic power
- Ultra-low static power consumption with full SRAM retention
- Low-power peripherals
- Tools for low power design, e.g. power estimation, power profiler, and consumption calculator

SECURE

- Multiple levels of scalable security for ultimate flexibility and protection
- Ensuring communications, software and physical systems are protected from todays threats

CONNECTIVITY

- State-of-the-art RF performance
- Choice of connectivity to fit application
- Interoperable connectivity
- Integrated RF transceivers supporting Bluetooth Smart, IEEE 802.15.4, Thread and zigbee

USER EXPERIENCE

- ‘Tap-N-Pair’ NFC Commissioning for best-in-class consumer experience
- Bring voice detection & triggering features to wide range of products

QUICK TO MARKET

APPLICATION-IN-A-BOX

- Complete kits simplify design and lower risk – get to final product design quickly
- Full ecosystem including application software and cloud connectivity

NXP Solutions for IoT

NXP products and solutions for:

- Microcontrollers & Microprocessors
- Connectivity: Bluetooth Smart, 802.15.4, Thread, zigbee
- Near Field Communications (NFC)
- Secure Element

Targeted solutions for:

- Simplified device commissioning
- Secure commissioning and user authentication
- Secure processing/transactions
- Voice recognition and triggering
- Always-on sensor processing
- Interoperable wireless connectivity

NXP Kinetis Wireless Solutions Agenda

- KW41 Family Overview
- Bluetooth Low Energy (BLE)
- Thread
- BLE+Thread
- Wireless Framework
- Modular Gateway

Kinetis KW41Z/31z/21z Wireless MCU

KW41Z Family – Single Chip Solution for the IoT

- ✓ **Multi-Protocol Radio** – High performance radio supporting Bluetooth Smart/Bluetooth Low Energy (BLE) v4.2, Generic FSK and IEEE 802.15.4 (Thread) based standards

- ✓ **Large Memory** – Enough memory to adequately contain desired networking stack(s) with ample room remaining for custom applications

- ✓ **Low-Power** – Low transmit, receive and standby currents that maximizes battery life, including standard coin-cells

- ✓ **Complete Enablement** – Fully compliant, certified Bluetooth Low Energy, Thread and 802.15.4 MAC/PHY. Support for Generic FSK, BLE Mesh, SMAC, multiple RTOSes, MCUXpresso SDK and MCUXpresso and IAR IDEs.

Kinetis KW41Z/31Z/21Z

Core/System

- Cortex-M0+ running up to 48 MHz
- Four independently programmable DMA controller channels

Memory

- Up to 512kB Flash
- Up to 128 kB SRAM

Radio

- Support for BLE v4.2, 802.15.4, Generic FSK
- -95 dBm in BLE mode, -100 dBm in 802.15.4 mode
- -30 to +3.5 dBm programmable output power
- 6.8 mA Rx & 6.1 mA Tx (0dBm) current target (DC-DC enabled)
- On-chip balun with single ended bidirectional RF port

Communications/HMI/Timers

- 2xSPI, 2xI2C, LP-UART, GPIO with IRQ capability (KBI)
- Carrier Modulated Timer (CMT) for infrared transmissions
- Hardware Capacitive Touch Sensing Interface (TSI)
- 3xFlexTimer (TPM) with PWM & quadrature decode support
- Low Power (LPTMR), Programmable Interrupt (PIT) and RTC timers

Analog

- 16-bit ADC with integrated temperature sensor and battery monitor
- 12-bit DAC and 6-bit High-speed Comparator

Security

- AES-128 Accelerator and True Random Number Generator
- Advanced flash security

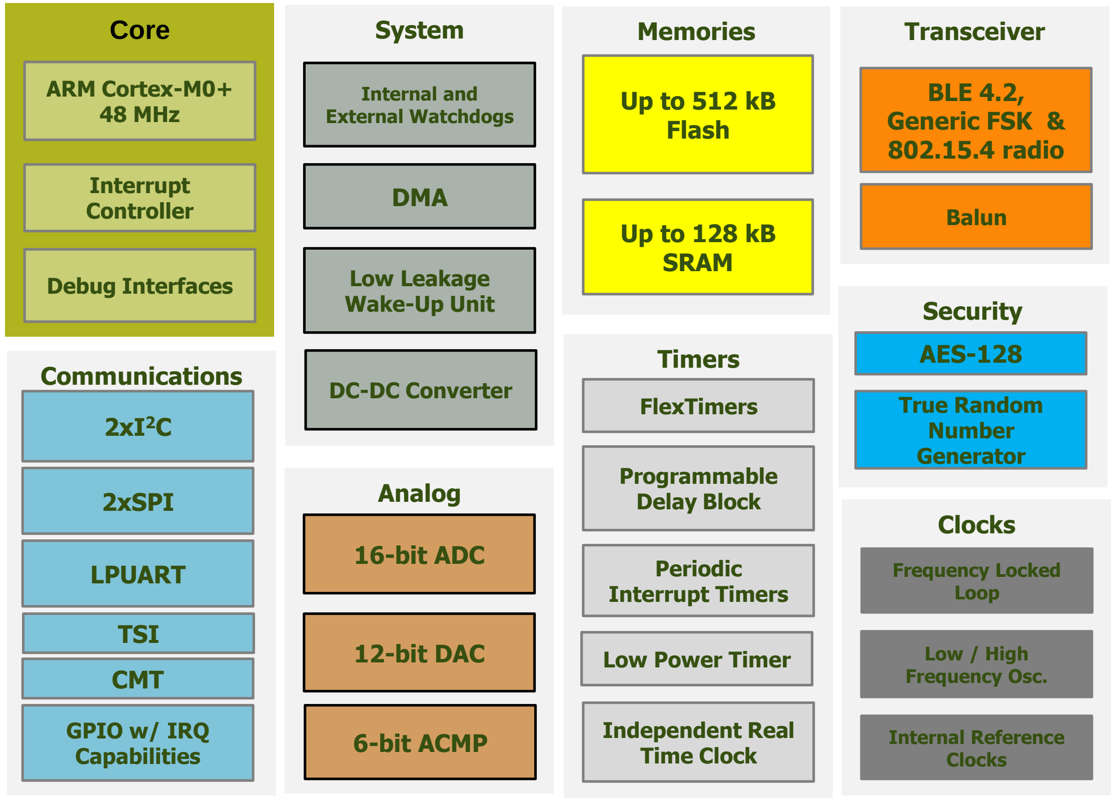
Integrated DC/DC Converter

- Normal: 1.71V to 3.6V
- Buck : 2.1V to 4.2V for coin cell operation
- Boost : 0.9V to 1.795V for single alkaline battery operation

Unique Identifiers

- 80-bit unique device ID programmed at factory
- 40-bit unique media access control (MAC) sub-address can be used for Bluetooth Low Energy or IEEE 802.15.4 MAC Address

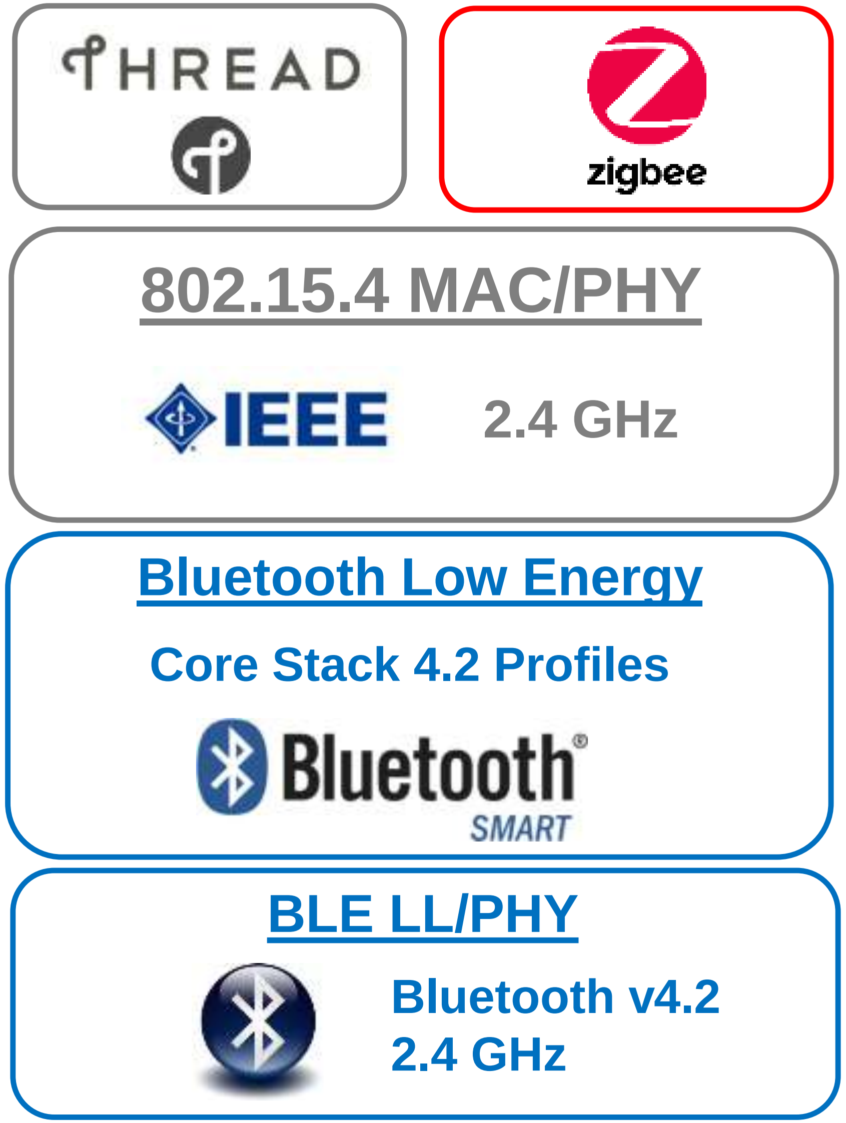
-40ºC to +105ºC (QFN), -40C to + 85C (WLCSP)



Device	Memory (Flash/RAM)	Protocol	Package
MKW21Z512VHT4 **MKW21Z256VHT4**	**512 kB / 128 KB** **256 kB / 64 KB**	802.15.4	7x7 48-pin Laminate QFN
MKW31Z512VHT4 **MKW31Z256VHT4** **MKW31Z512CAT4**	**512 kB / 128 KB** **256 kB / 64 KB**	BLE v4.2 / Generic FSK	7x7 48-pin Laminate QFN 3.9x3.8 WLCSP (Jun'17)
MKW41Z512VHT4 **MKW41Z256VHT4** **MKW41Z512CAT4**	**512 KB / 128 KB** **256 KB / 64 KB**	BLE v4.2 / Generic FSK / 802.15.4 (Supports concurrent operation)	7x7 48-pin Laminate QFN 3.9x3.8 WLCSP (Jun'17)

Features	Description
Software and Protocol Stacks	Bluetooth Smart Host Stack & Profiles IPv6 over BLE Generic FSK (250 kbps, 500 kbps, 1Mbps) zigbee 3.0 (December) Thread Stack, IEEE 802.15.4 MAC Thread + BLE Multi-Protocol Stack KSDK, RTOSes, IAR & MCUXpresso Support

Complete Enablement: Software



THREAD

zigbee

802.15.4 MAC/PHY

IEEE 2.4 GHz

Bluetooth Low Energy

Core Stack 4.2 Profiles

Bluetooth SMART

BLE LL/PHY

Bluetooth v4.2
2.4 GHz

- ✓ Qualified Bluetooth Low Energy v4.2 Stack + Application Profiles
- ✓ Thread R1.1 Compliant Network Stack
- ✓ Thread + BLE Combo Stack
- ✓ zigbee 3.0 (December)
- ✓ IEEE 802.15.4 MAC/PHY
- ✓ IPv6 over BLE
- ✓ Generic FSK at 250, 500 and 1000 kbps
- ✓ SMAC w/ Connectivity Test for Regulatory Certification
- ✓ Support for Host MCU and MPU (Linux®) Processors
- ✓ Full integration with MCUXpresso SDK
- ✓ Multiple RTOS, including FreeRTOS and uCOSII (BLE)
- ✓ MCUXpresso IDE
- ✓ IAR Embedded Workbench®

KW41Z/31Z/21Z Targeted Applications

High Connectivity, Portable Devices, Powered Optimized Applications

Security & Proximity

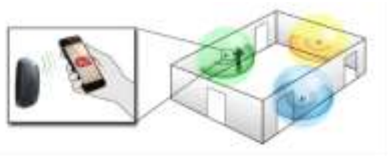
Healthcare / Fitness

Smart Home
Home and Building Automation

PC Peripherals

Remote Controls

Beacons

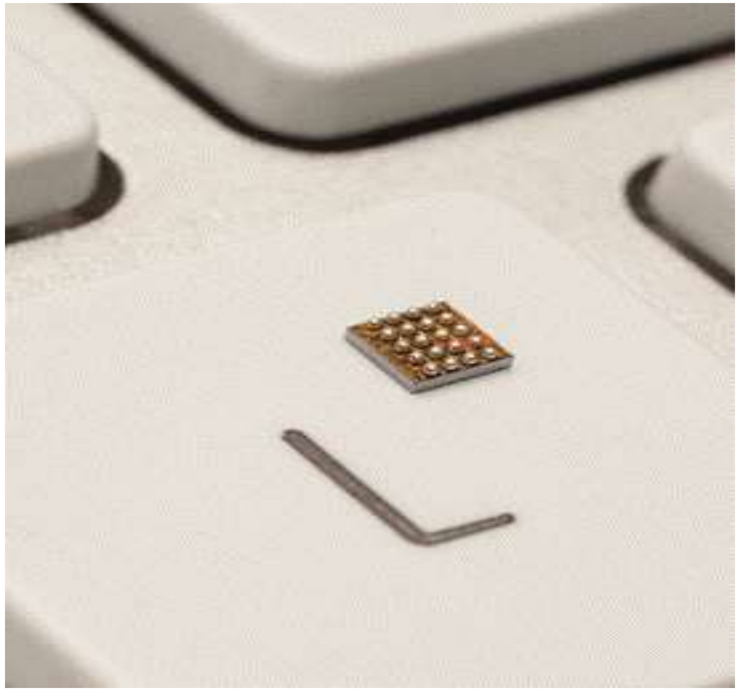


Remote Keyless Entry

Wireless Software Stacks

BLE

Bluetooth Low Energy Host Stack Facts & Figures



- KW41Z Low Memory BLE Stack footprint
  - **80 - 130 kB flash** and **15 - 30 kB RAM** for BLE Stack, Profile and custom application (including KSDK, RTOS and drivers)
  - **90 kB flash** and **5 kB RAM** for bare metal BLE stack
- Runs on a Cortex^{TM} M0+ @32MHz (20% CPU bandwidth max.)
- Compliant to the Bluetooth® LE v4.2 specification
- The host stack can function with virtually **any** BLE v4.0, v4.1, v4.2 **controller**.
- It is **RTOS agnostic** and can run in a non-preemptive mode (bare-metal). Some loop-based scheduling is still required.
- Coexists with the 802.15.4 MAC and upper network stacks in the same **dual mode firmware** for KW41Z
- Support for **embedded** application development or **Hosted** mode (external MCU/MPU)
- **IAR Embedded Workbench** and **MCUXpresso IDE** support

Enablement: Smartphone App – Kinetis BLE Toolbox

BLE Toolbox include support for the following BLE profiles:

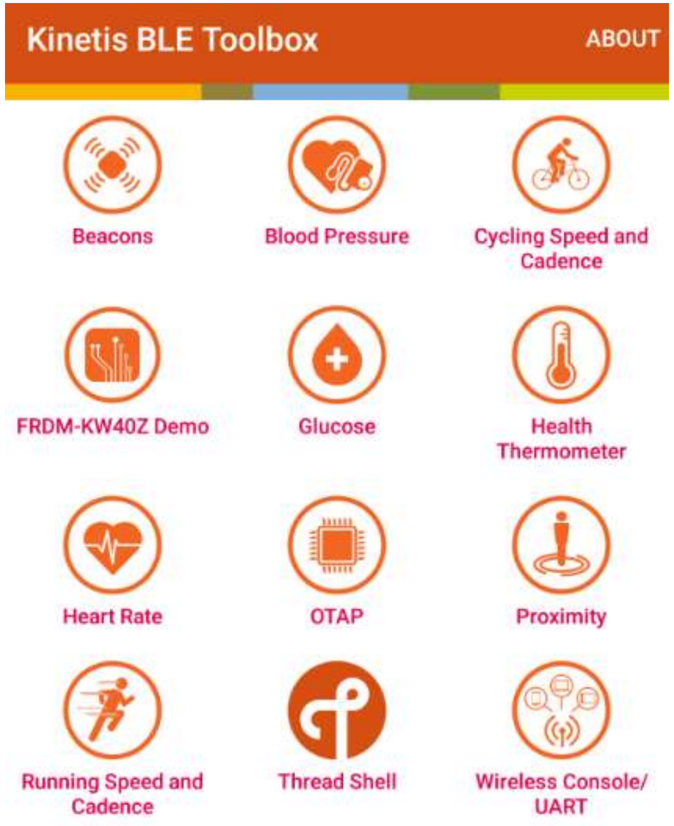
- Glucose
- Blood Pressure
- Cycling Speed and Cadence
- Health Thermometer
- Heart Rate
- Proximity
- Running Speed and Cadence

Also includes Beacon monitoring and support for customs profiles, including:

- Over the Air Programming (OTAP)
- Wireless UART

Also supportsThread + BLE

Download today from iTunes App Store (iOS) or Google Play (Android)



IPv6 over BLE

Bluetooth stack:

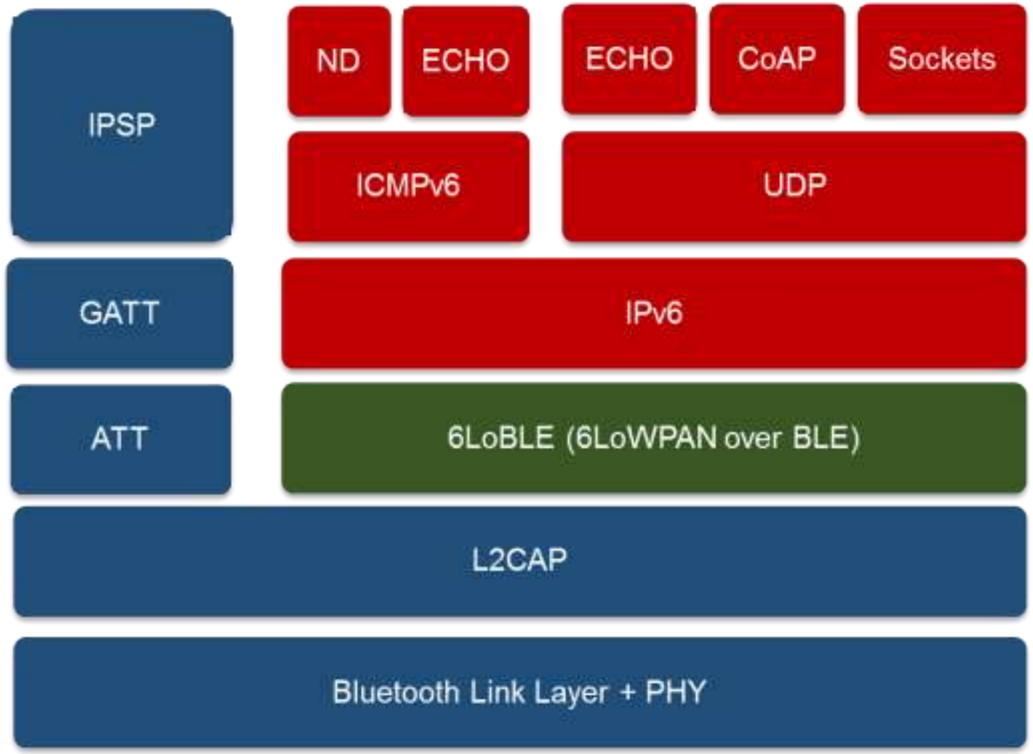
- GATT-based profile Internet Protocol Support Profile (IPSP)
- L2CAP Connection Oriented Channels as bearer for 6lo traffic

Adaptation layer:

- 6LoBLE: optimization of IPv6 packets for Bluetooth

IPv6 Stack:

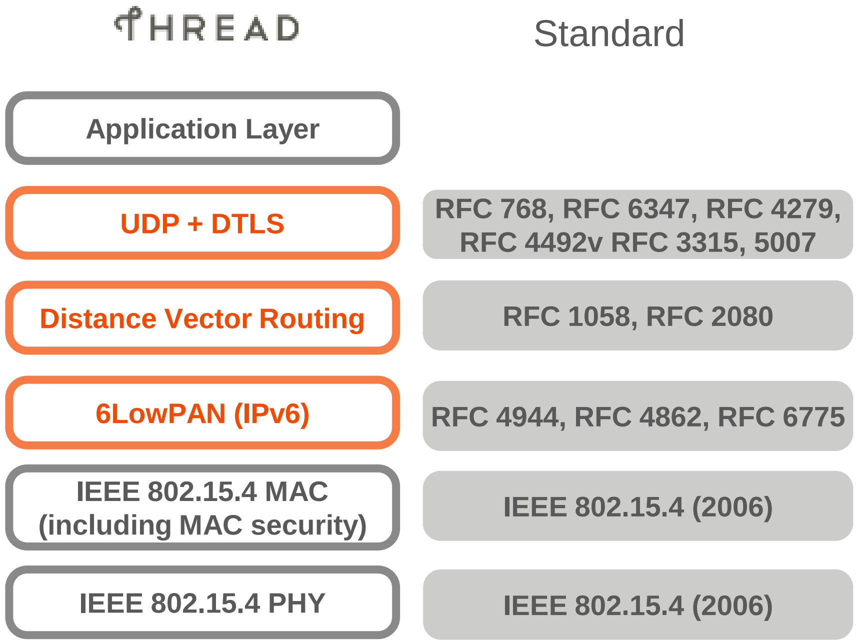
- ICMPv6, UDP, CoAP, ND, etc.



Thread

THREAD Overview

- IPv6 based
- Lightweight and low latency
- Not a whole new standard
- Collection of existing IEEE and IETF standards
- Runs on existing 802.15.4 based products
- 250+ devices on a PAN
  - Direct Addressability of devices
  - Flexible network with full point to point connectivity of all devices
  - No single point of failure
  - Enable low cost bridging to other IP networks
  - Simple security and commissioning
  - Low Power support for sleeping devices

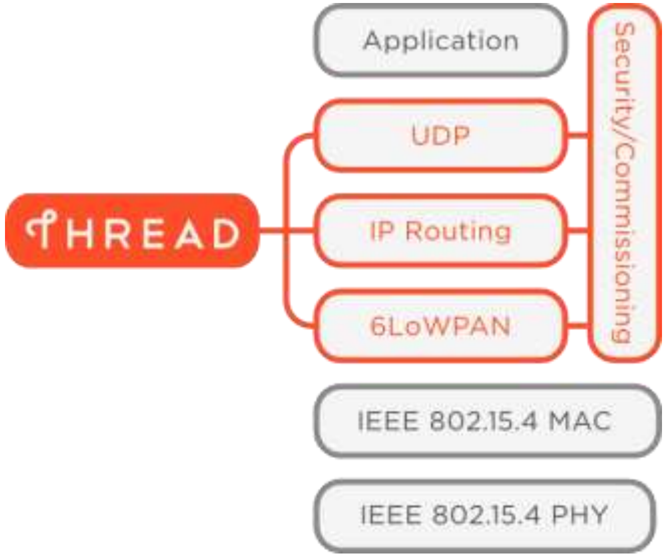


THREAD	Standard
Application Layer	
UDP + DTLS	RFC 768, RFC 6347, RFC 4279, RFC 4492v RFC 3315, 5007
Distance Vector Routing	RFC 1058, RFC 2080
6LowPAN (IPv6)	RFC 4944, RFC 4862, RFC 6775
IEEE 802.15.4 MAC (including MAC security)	IEEE 802.15.4 (2006)
IEEE 802.15.4 PHY	IEEE 802.15.4 (2006)

Thread

- A secure wireless mesh network for your home and its connected products
  - Built on well-proven, existing technologies
  - Runs on existing 802.15.4 silicon
- Uses 6LoWPAN with IPv6 addressing
- UDP Transport
  - Includes mandatory security architecture
  - Simple and secure to add / remove products
  - Scalable to 250+ products per network
  - Doesn’t require dedicated repeaters
  - Designed for very low power operation
  - Overcomes wireless interference

Can support many popular application layer protocols and platforms



A software upgrade can add Thread to currently shipping 802.15.4 products

Thread Specification is available to Thread Group members

Thread + BLE

Multi-Protocol Application

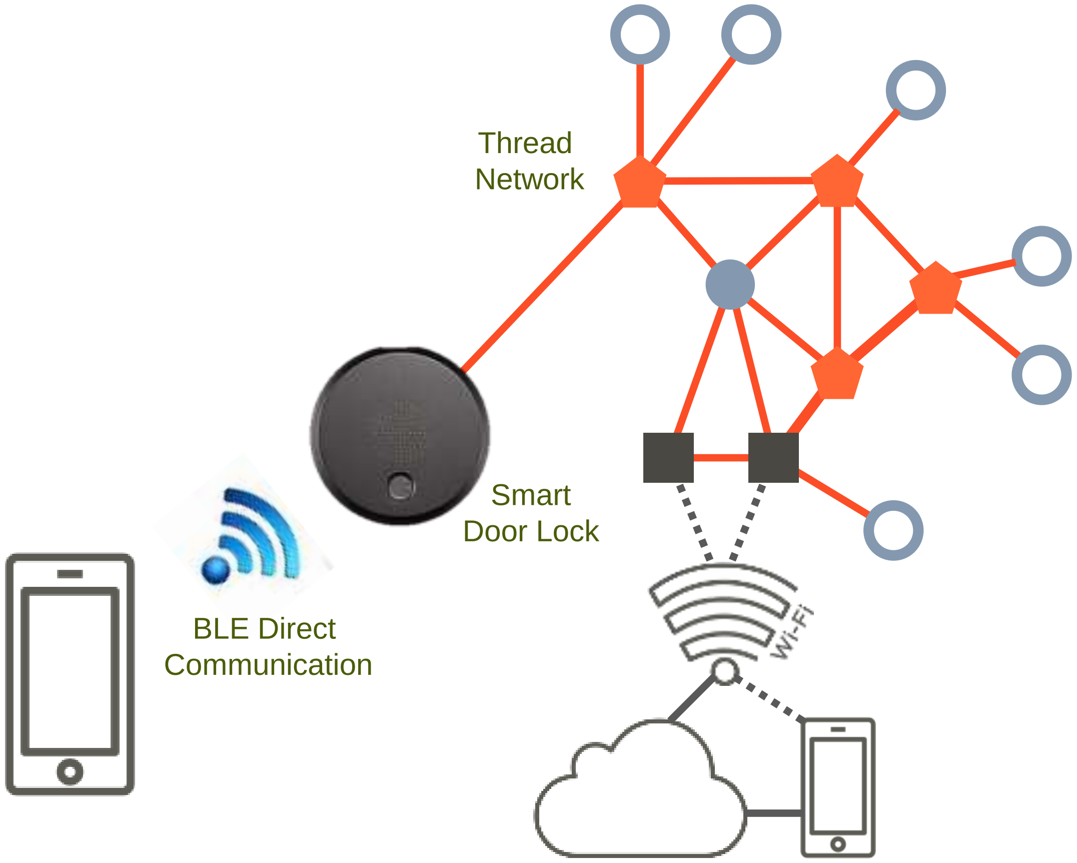
Door Lock using Thread and Bluetooth Low Energy

Smart Door Lock contains KW41Z Multi-Protocol Radio

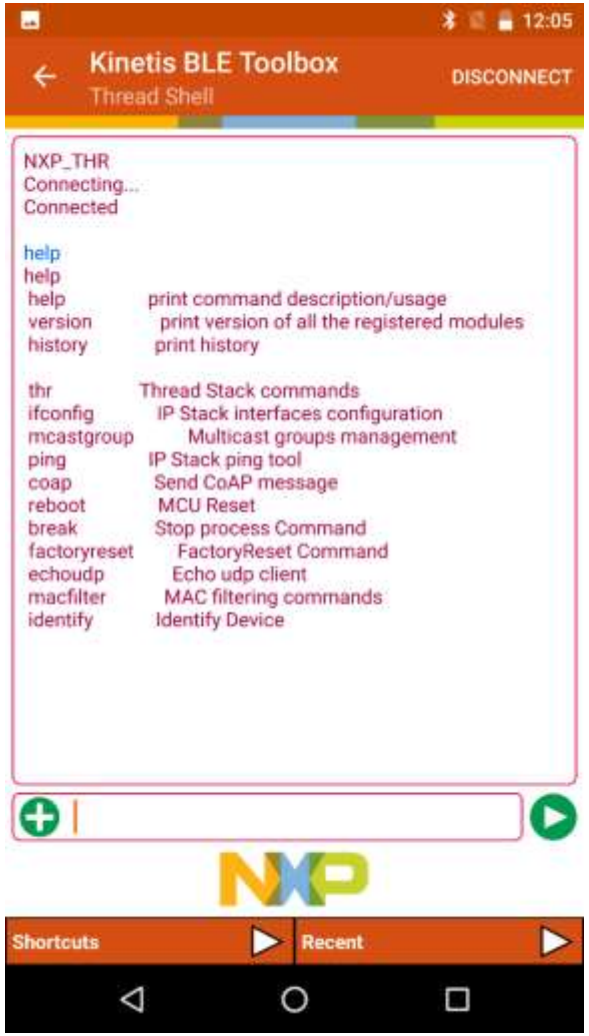
- Bluetooth Low Energy
- Thread (802.15.4)

Direct and Network Controlled and Monitoring

- Out-of-band commissioning of device on Thread network using BLE
- Control directly from BLE enabled phone
- Control and monitoring using cloud connected Thread mesh network



Thread + BLE KW41 Demo Application

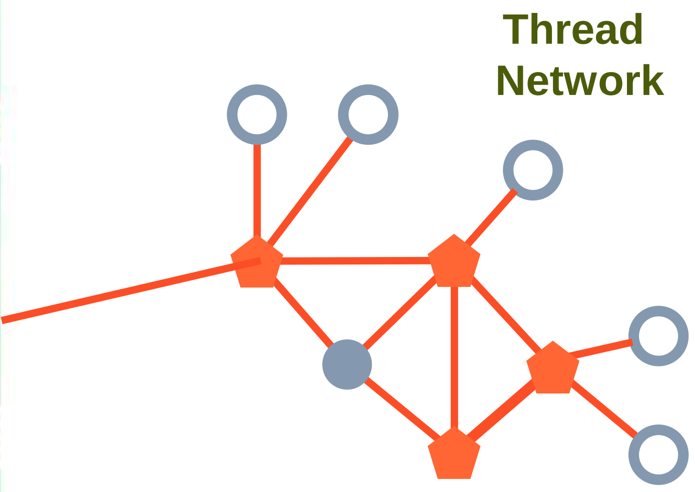


```
NXP_THR
Connecting...
Connected

help
help
 help          print command description/usage
 version        print version of all the registered modules
 history       print history

 thr          Thread Stack commands
 ifconfig       IP Stack interfaces configuration
 mcastgroup         Multicast groups management
 ping          IP Stack ping tool
 coap          Send CoAP message
 reboot         MCU Reset
 break         Stop process Command
 factoryreset       FactoryReset Command
 echoudp         Echo udp client
 macfilter        MAC filtering commands
 identify        Identify Device
```

BLE UART to Thread Shell

BLE Direct Communication

FRDM-KW41Z



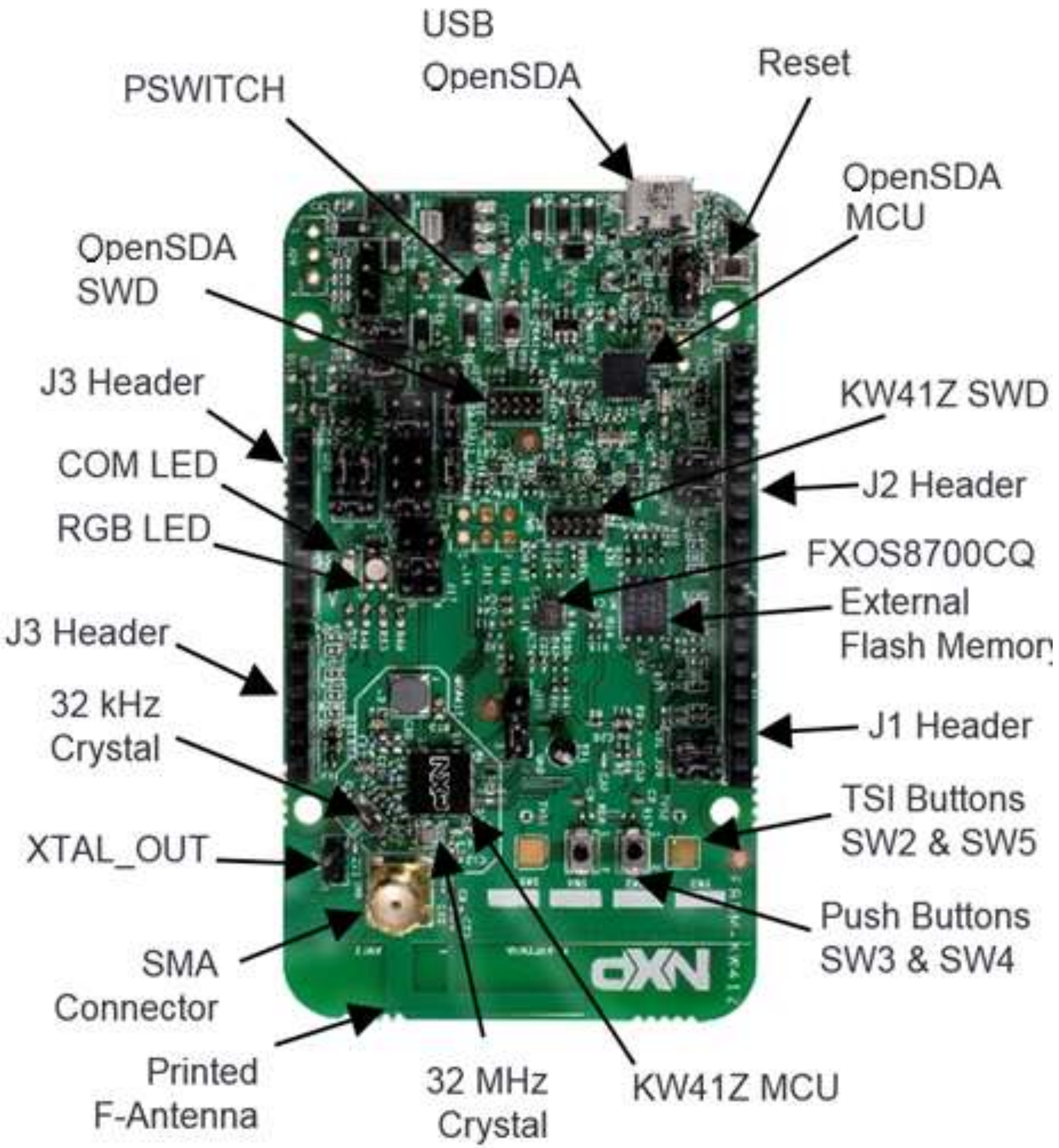
KW41Z Enablement

KW41Z Development Hardware

- **FRDM-KW41Z** Freedom Development Hardware
  - Can be configured as Host or Shield for connection to Host Processor
  - Supports all DC-DC configurations
  - PCB inverted F-type antenna
  - Minimum number of matching components
  - FCC Part15 & EN300 328 compliant
  - Serial Flash for OTA firmware upgrades
  - On board NXP FXOS8700CQ digital sensor, 3D Accelerometer (±2g/±4g/±8g) + 3D Magnetometer
  - OpenSDA and JTAG debug
  - Full KSDK support
  - Resale $145 (2 boards/kit)

- **USB-KW41Z** USB Dongle
  - Ideal for BLE/802.15.4 sniffer or connection to PC/Tablet
  - FCC Part15 & EN300 328 compliant
  - Resale $60

FRDM-KW41Z Hardware Overview



Kinetis KW41Z Connectivity Modules

Rigado
KW41Z512
Arrow

Weptech
KW41Z512
Arrow
EBV

Volansys
KW41Z512

Lierda
KW41Z512
KW31Z256

SMK Japan
KW21Z512

SMK US
KW40Z160
KW41Z512

Not Pictured: Accton (Taiwan), Argenox (AMR), Technexion (Taiwan/Avnet)

Note: See Kinetis W Connectivity Module deck for more details

Introducing …

MCUXpresso Software and Tools

for Kinetis and LPC microcontrollers

MCUXpresso IDE

Edit, compile, debug and optimize in an intuitive and powerful IDE

MCUXpresso SDK

Runtime software including peripheral drivers, middleware, RTOS, demos and more

MCUXpresso Config Tools

Online and desktop tool suite for system configuration and optimization

Summary: Kinetis KW41Z/31Z/21Z

A **true single chip** wireless MCU solution for the IoT

✓ **Multi-Protocol Radio**

- Integrated, high performance radio capable of running two stacks concurrently saving board space, development time and cost.

✓ **Large Memory Footprint**

- Large Flash and RAM capacity for running networking stack(s), application profiles and customer application.
- Future proof design with over-the-air upgrade support

✓ **Low Power**

- Low power design to support products that can run for years on small batteries
- Integrated DC/DC converter with buck and boost support

✓ **Comprehensive enablement**

Certified software stacks, support for professional and complimentary software development tools, development hardware and reference designs for simpler system design, keeping the BOM cost low, system complexity low. and a fast time to market

www.nxp.com/kinetis/wseries

NXP Kinetis Wireless Solutions Agenda

- **KW41 Family Overview**
- **Bluetooth Low Energy (BLE)**
- **Thread**
- **BLE+Thread**
- **Wireless Framework**
- **Modular Gateway**

BLE

Bluetooth®, SMART, SMART READY?

If a products bears this logo…	It's compatible with products bearing any of these logos…
Bluetooth® SMART READY	Bluetooth® SMART READY Bluetooth® Bluetooth® SMART
Bluetooth®	Bluetooth® SMART READY Bluetooth®
Bluetooth® SMART	Bluetooth® SMART READY Bluetooth® SMART

Bluetooth = Bluetooth Basic Rate/Enhanced Data Rate

Bluetooth Smart = Bluetooth Single Mode = Bluetooth Low Energy

Bluetooth Smart Ready = Bluetooth Dual Mode = Bluetooth Basic Rate/Enhanced Data Rate + BLE

Bluetooth and Bluetooth Low Energy

Bluetooth® “Classic”

- Master to client networks (headset to handset, etc)
- **Low latency**, moderate data rates (hundreds kbps)
- Good for audio from low-rate voice to streaming music
- In billions of handsets all around the world

Bluetooth® Low Energy

- Master to client networks (sensing device to handset)
- Optimized for “sleepier” sensor devices
  - **Improved battery life** 10-20x over Bluetooth classic
- When connected, low latency, low- to moderate data rates.
- Available in latest handsets

Bluetooth LE v4.2 Features

LE Secure Connections

- Alignment of security levels and features between BT classic & LE
- Key Exchange using Elliptic Curve Diffie-Hellman (ECDH)

LE Privacy v1.2

- Controller based Resolvable Private Addresses (RPAs)

LE Data Length Extension

- Longer payload lengths – up to 244 octets of application payload

IP Connectivity

- IPSP Internet Protocol Support Profile

BLE Architecture

BLE System Architecture

Generic Access Profiles (GAP) – what we can do…

Generic Attribute Profile (GATT) – how things are organized

Attribute Protocol (ATT) – protocol for accessing data

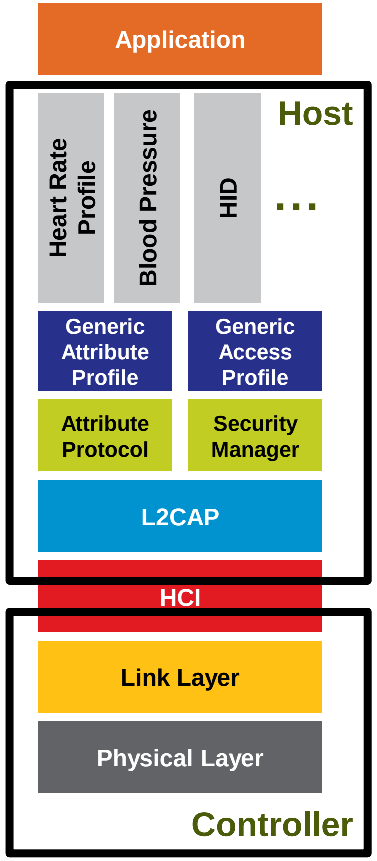
Security Manager (SM) – secures data

Logical Link Control and Adaptation Protocol (L2CAP) – multiplex logical to physical links

Host Controller Interface (HCI) – interface between Host and Controller

Link Layer (LL) – packets and control

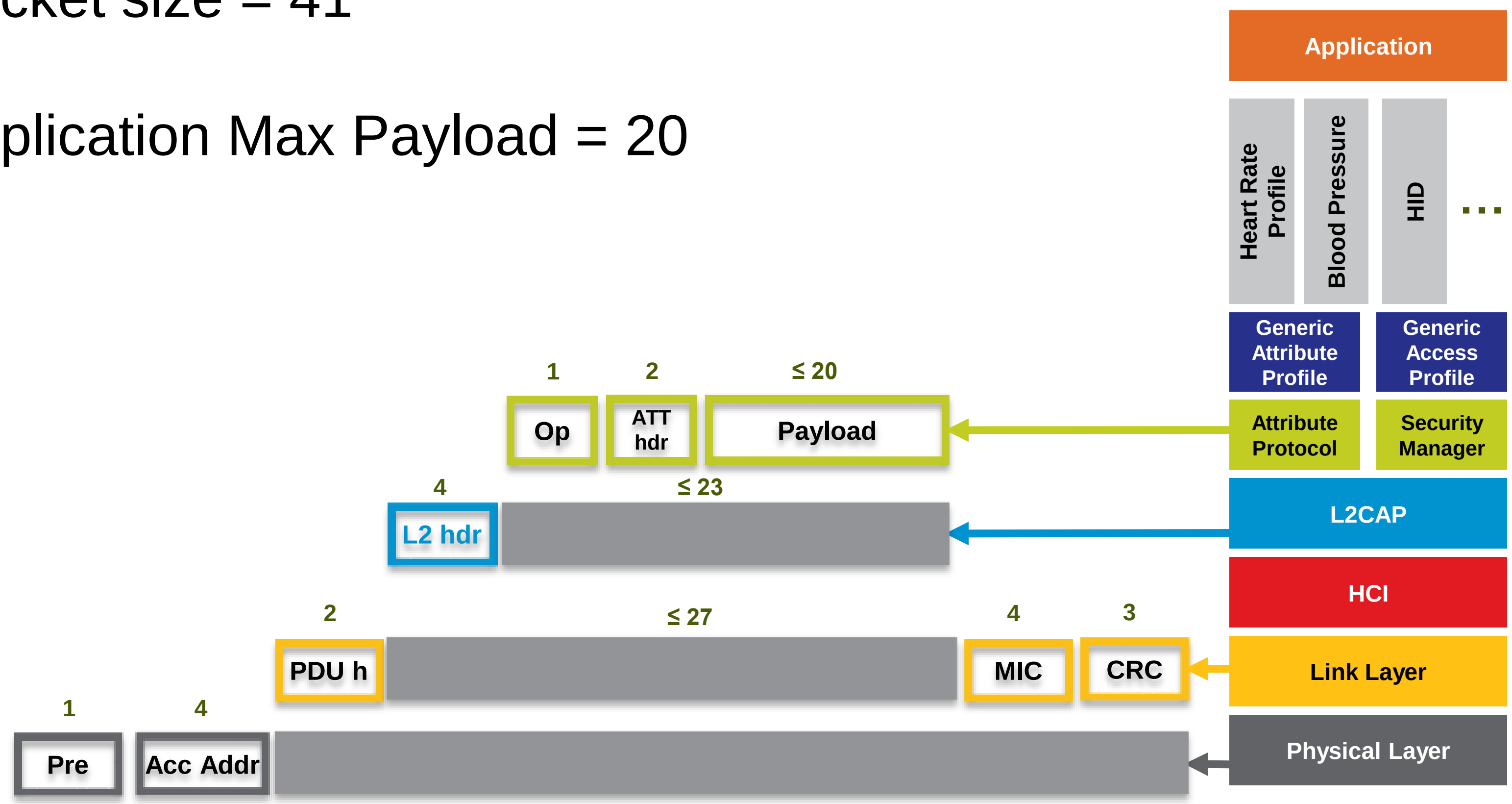
Physical Layer (PHY) – transmits/receives bits



BLE Data Packet

Packet size = 41

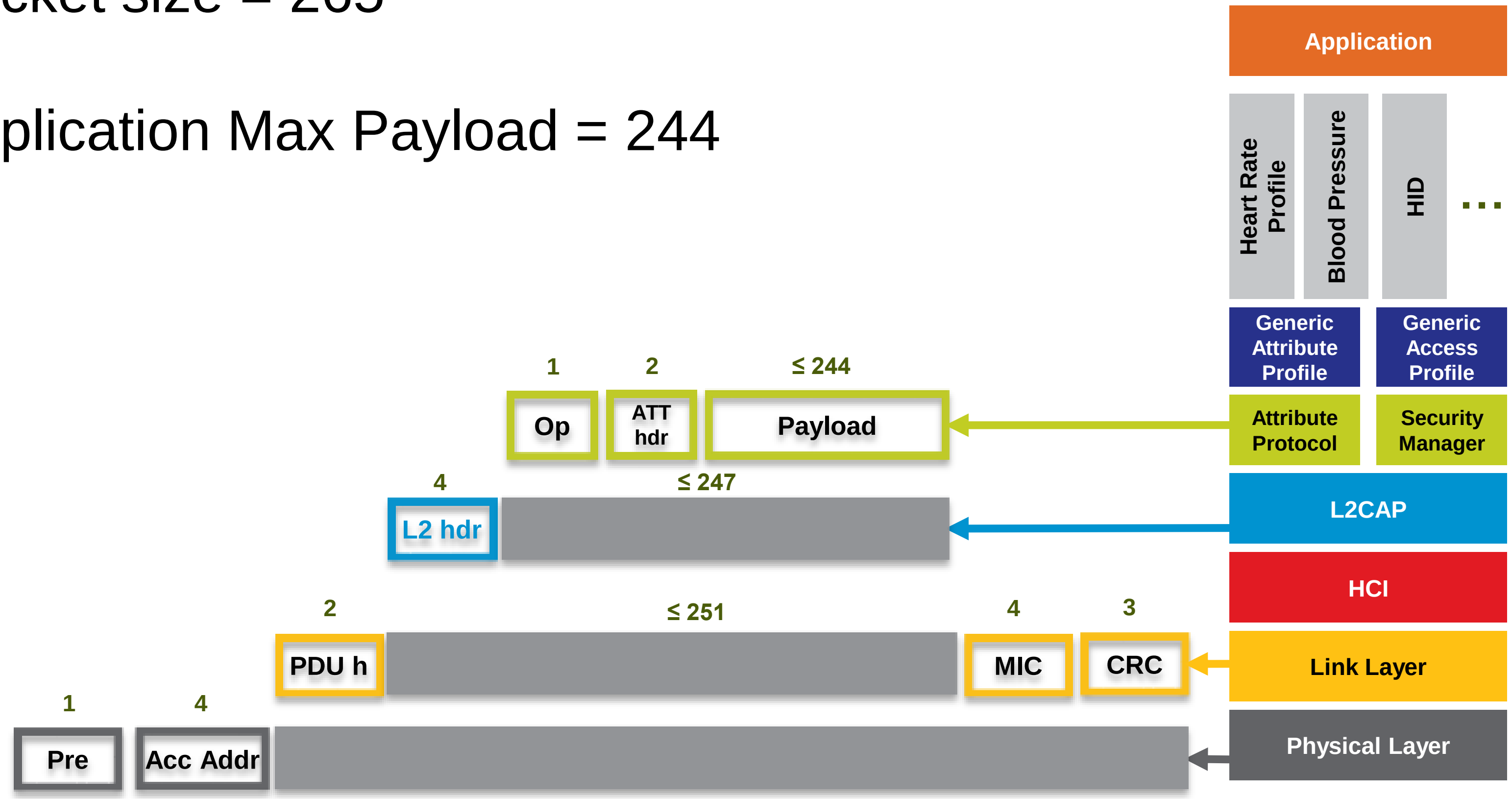
Application Max Payload = 20



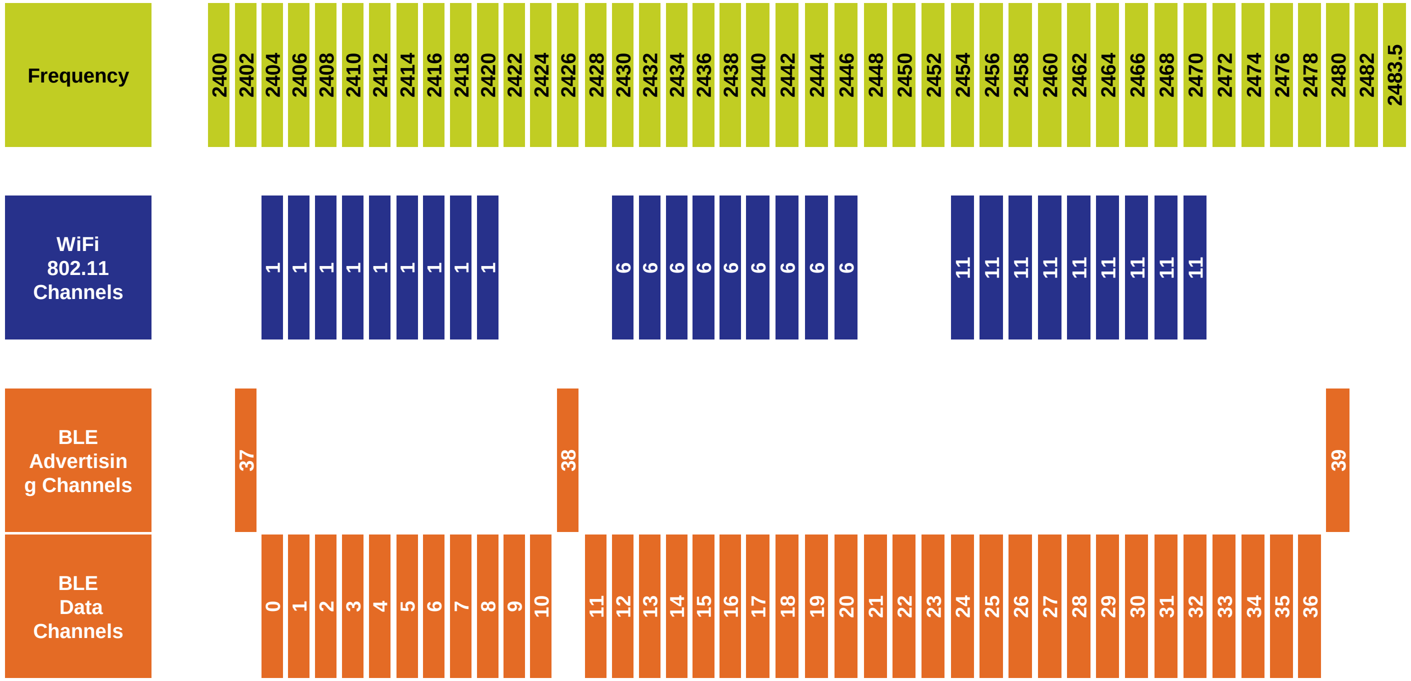
BLE Max Data Packet

Packet size = 265

Application Max Payload = 244



BLE Channel Assignment



Frequency	2400	2402	2404	2406	2408	2410	2412	2414	2416	2418	2420	2422	2424	2426	2428	2430	2432	2434	2436	2438	2440	2442	2444	2446	2448	2450	2452	2454	2456	2458	2460	2462	2464	2466	2468	2470	2472	2474	2476	2478	2480	2482	2483.5
WiFi 802.11 Channels			1	1	1	1	1	1	1	1	1					6	6	6	6	6	6	6	6	6				11	11	11	11	11	11	11	11	11							
BLE Advertising Channels		37												38																											39		
BLE Data Channels			0	1	2	3	4	5	6	7	8	9	10		11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36			

BLE Link Layer

Define all connection procedures

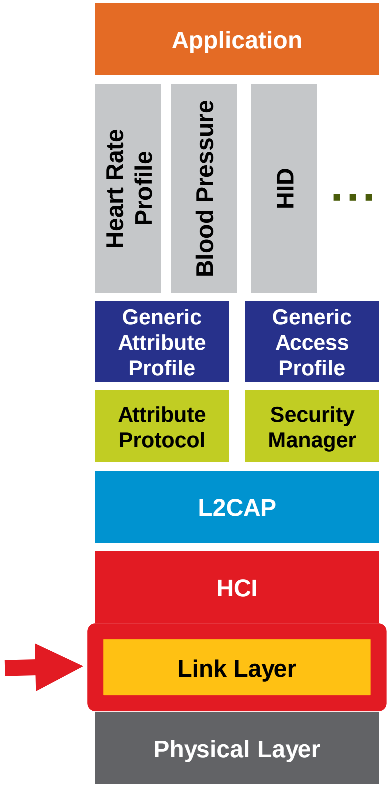
Define the frequency hopping mechanism

Manages the timing events during connection

Determine when a connection is lost

Bit Stream Processing

- CRC, whitening, encryption



BLE Link Layer States

Standby State

Does not transmit or receive packets

Advertising State

Transmitting advertising channel packets

Known as an “Advertiser”

Scanning State

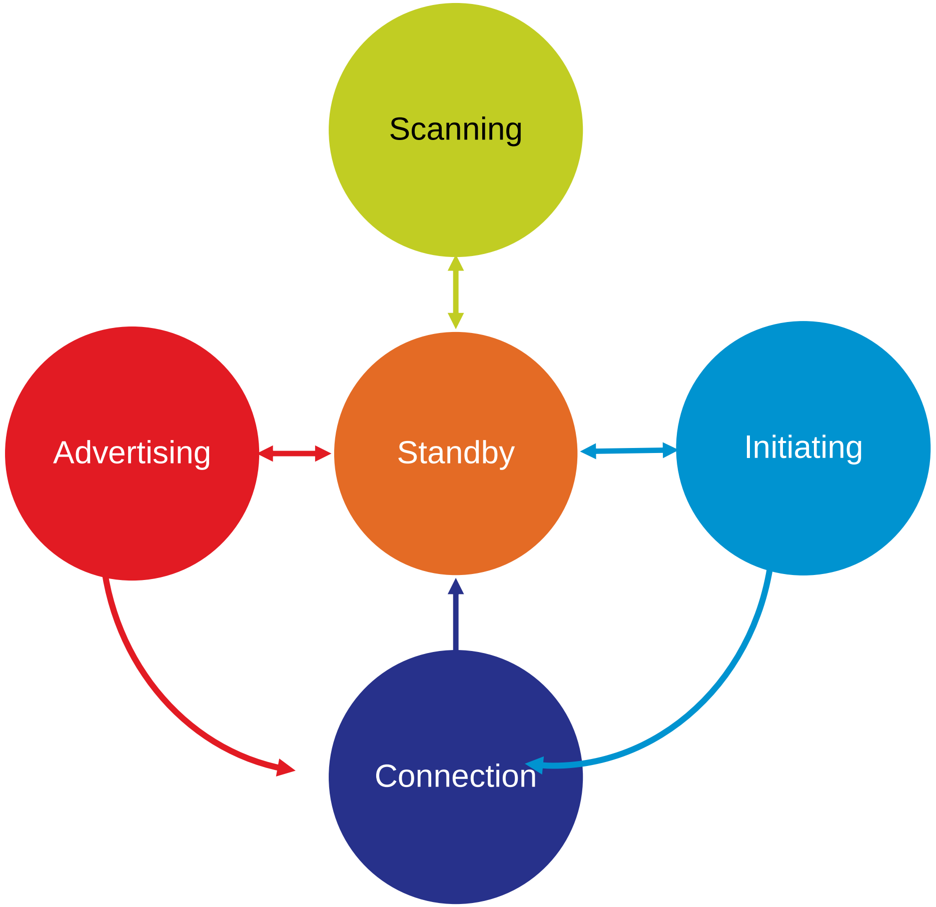
Listening for Advertisers

Known as a “Scanner”

Initiating State

Initiates Connection to the Advertiser

Known as “Initiator”



BLE Link Layer States

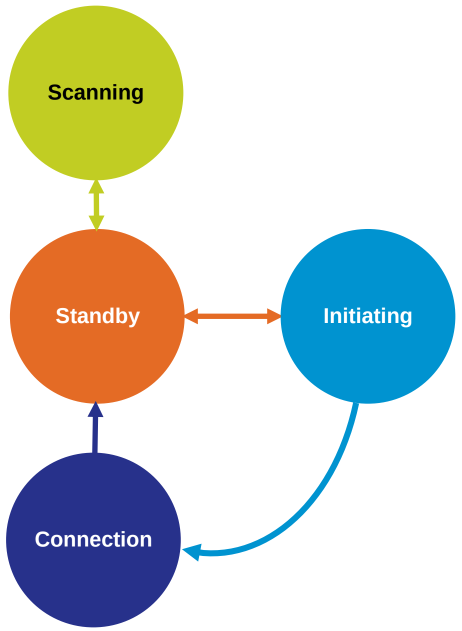
Connection State

Master Role

Entered from Initiating State

Communicates with a device in Slave Role

and defines the timings of transmissions

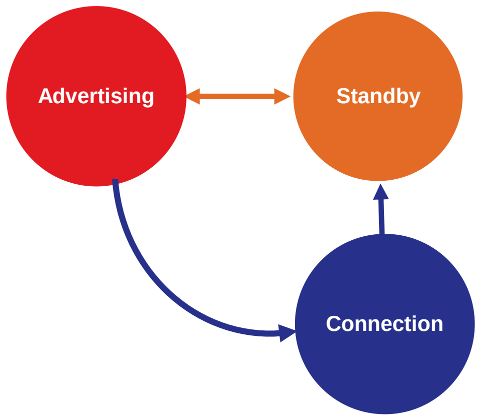


Slave Role

Entered from Advertising State

Communicates with a single device

in the Master Role



Advertising

Packets meant to discover slaves and connect to them or to broadcast data and connection is not required

Each packet can carry up to 31 bytes of payload

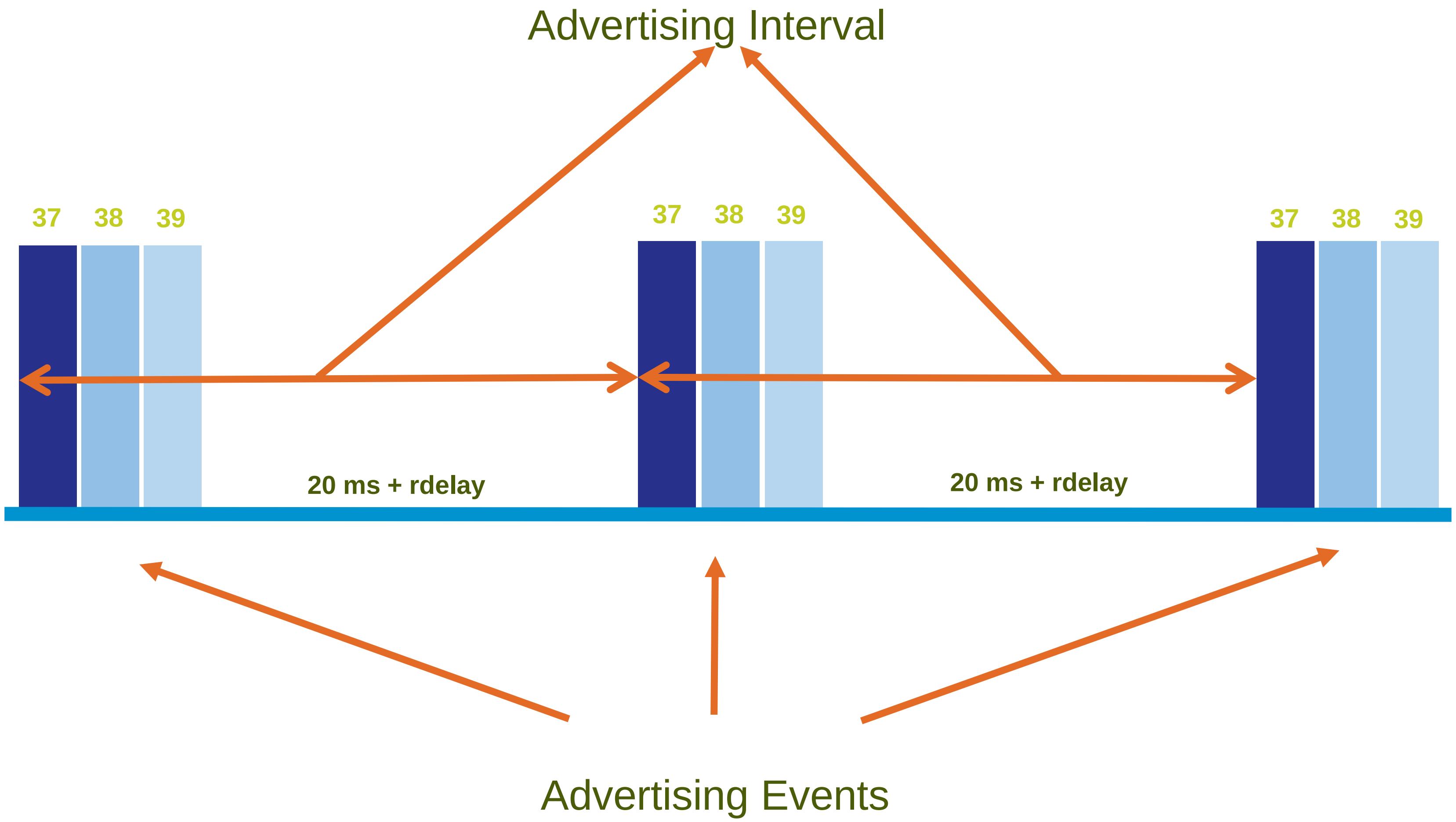
- Useful to filter devices when scanning

These packets are sent in a broadcast at a fixed interval on the 3 advertising channels

Advertising interval can be from 20ms to 10.24 s in 0.625ms steps

Advertising Interval

ADV Interval = 20 ms



Beacon

Non-connectable device that broadcast packets that include identifying information via advertising packets

There are several Beacon protocols:

- iBeacon
- AltBeacon
- Eddystone

The packet structure depends on the protocol used

Coupled with a Smartphone application which reacts to each beacon

Uses **ADV_NONCONN_IND** ADV PDU

Connection

When the master finds a suitable slave, issues a connection request (CONN_REQ)

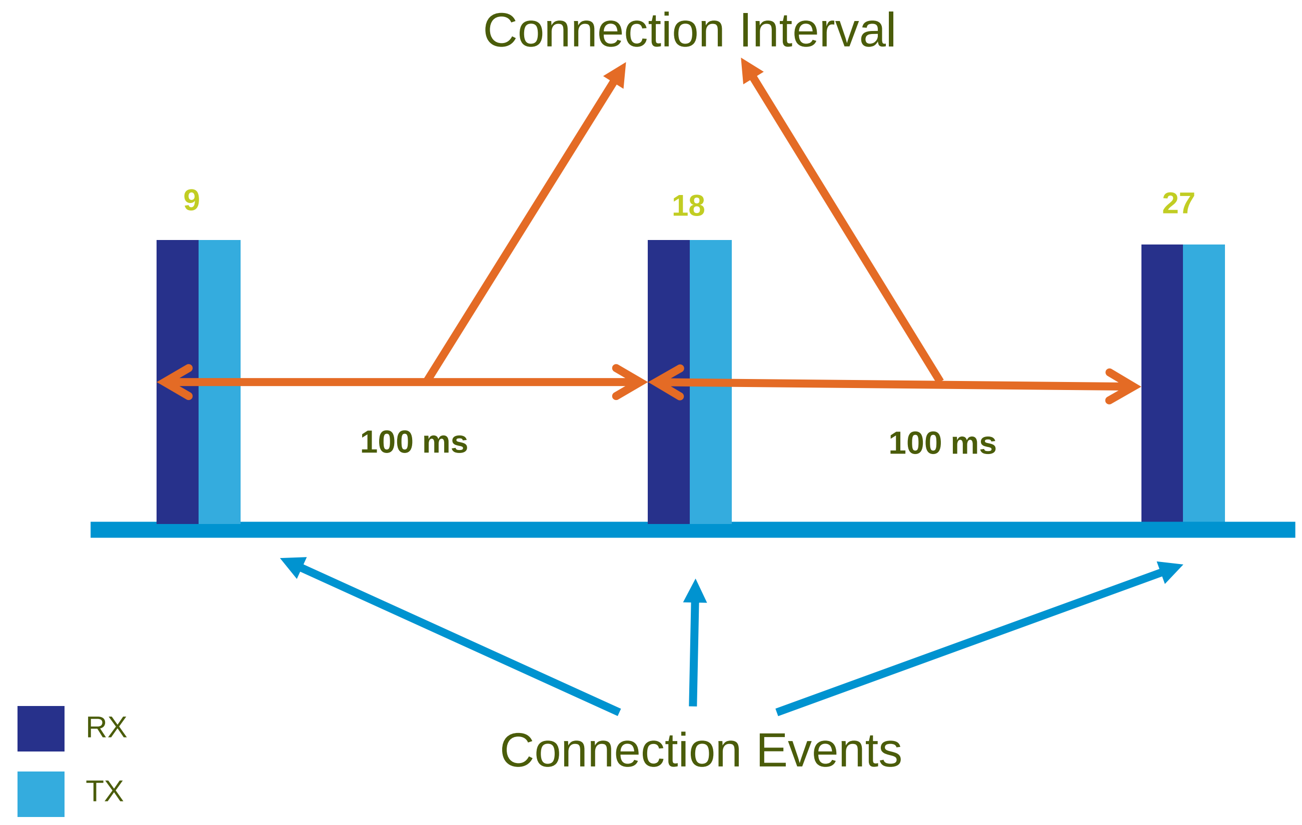
During the connection request, the master establishes specific parameters to be used during the connection:

- Connection Interval
- Slave latency
- Connection supervision timeout
- Hop Increment

The slave might request an update to these parameters but the master will decide if use the new parameters or keep the previous

Connection (2)

Conn Interval = 100 ms
Hop Increment = 9



Calculating Theoretical Throughput

Connection Interval = 7.5
Packets per connection = 6
Bytes sent per packet = 20

$$AppThroughput = \frac{1000ms \ * PacketsPerConn \ * BytesPerPacket}{ConnInterval}$$

Given this formula, the expected throughput is: ~128 Kbps

Example taken from the book “Getting Started with Bluetooth Low Energy” by Kevin Townsend

BLE Host Controller Interface (HCI)

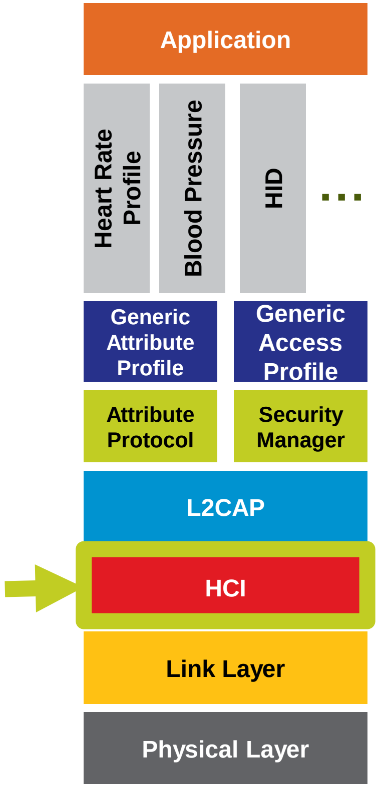
Provides a uniform command interface between the Host and the Controller

Reuse existing Bluetooth HCI Interfaces and transports

Keeps existing HCI packet formats

BLE commands added for new functionality

- Support for Scanning / Advertising Modes
- Example commands
  - LE Encrypt Command
  - LE Rand Command
  - LE Receiver Test Command
  - LE Transmitter Test Command



BLE Logical Link Control and Adaptation Protocol (L2CAP)

Connection-oriented and connectionless data services to upper layer protocols

Permits higher level protocols and applications to transmit and receive **upper layer data packets**

Similar in function and features to Bluetooth Classic L2CAP

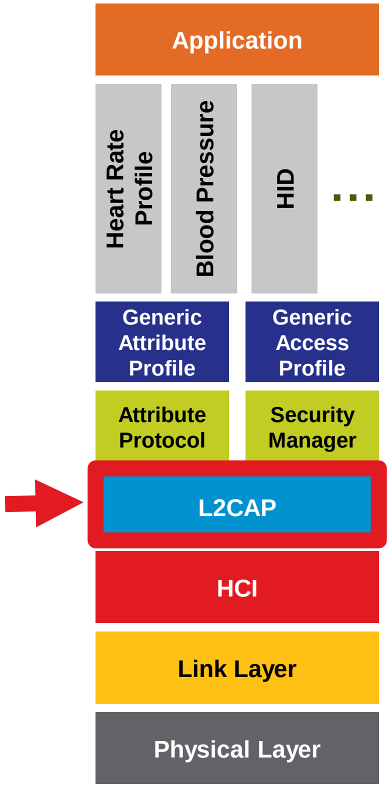
- Reuses existing L2CAP packet format

Fixed Channel IDs (CID)

- CID – local name representing a logical channel end-point on the device
- Reduces the traffic between devices thus saving power

L2CAP functions include:

- Protocol/channel multiplexing
- Segmentation and reassembly (SAR)
- Per-channel flow control
- Error control and retransmissions



BLE Generic Access Profile (GAP)

Discoverability modes and procedures

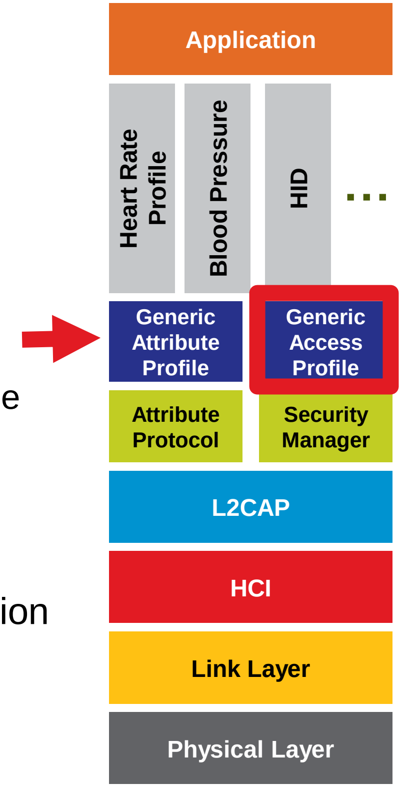
- Allows a device to be discovered by another device
  - Non-discoverable – Cannot be discovered by any device
  - Limited Discoverable Mode – Discoverable for a limited time period
  - General Discoverable – Discoverable for a long time period

Connection modes and procedures

- Allows a device to make a connection with another device
  - Non-connectable – device does not allow a connection to be established
  - Directed Connectable – device accepts a connection request from a known peer device
  - Undirected Connectable – device accepts a connection request from any device

Security/Bonding modes and procedures

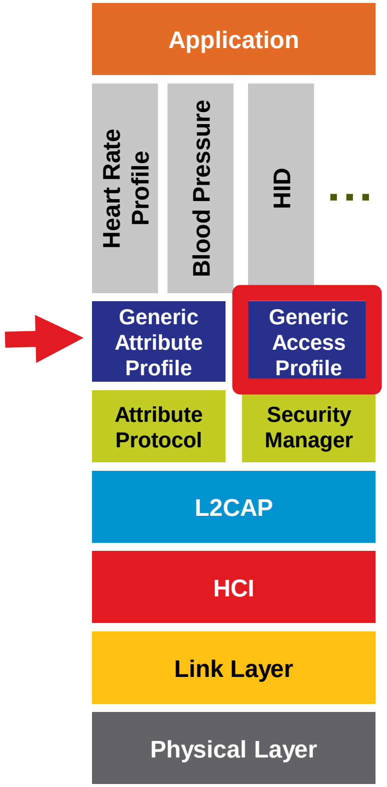
- Allows two connected devices to exchange and store security and identity information
  - Non-Bondable – device does not allow a bond to be created with a peer device
  - Bondable – device allows a bond to be created with a peer device



BLE Generic Access Profile (GAP)

Profile roles

- Broadcaster – Sends connectionless data in Advertising Events
- Observer – Receives connectionless data in Advertising Events
- Peripheral – Device that accepts establishment of LE physical link
- Central – Device that initiates the establishment of a physical connection.



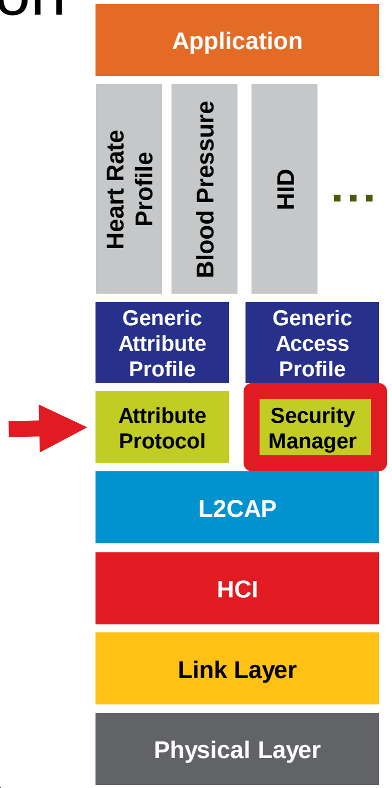
BLE Security Manager

Performs the pairing procedure and the link encryption procedure

Security level depends on the device IO capabilities and OOB data exchange capabilities

Long Term Key is calculated, distributed and stored for future connections

LTK is not distributed by the device when LE Secure Connections is used



BLE Security (2)

There are 4 methods for key generation that relates directly on how secure the connection will be:

Legacy Just Works: Key is 0

Legacy Passkey: The key can be from 0 to 999999

Out of the band: Exchange key via NFC, Thread or any other protocol

LE Secure Connection: Devices calculate the key using Elliptic Curve Diffie-Hellman protocol.

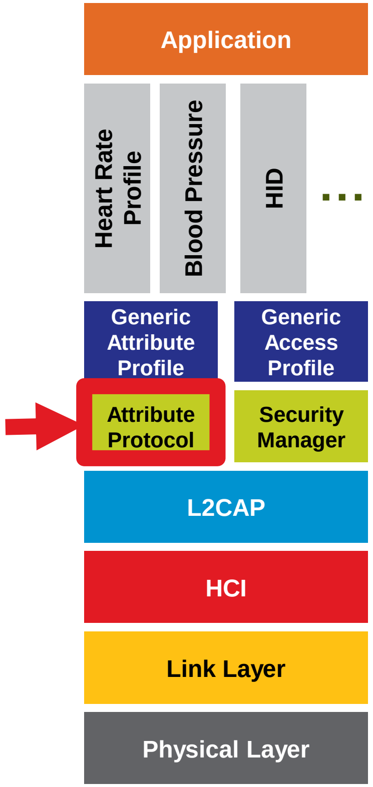
Just Works, Numeric Comparison, Passkey or OOB for authentication

BLE Attribute Protocol (ATT)

Allows a device referred to as a **Server** to expose a set of attributes and their associated values to a peer device referred to as a **Client**

Attributes exposed by **Server** can be discovered, read, written by a **Client**, and can be indicated and notified by the **Server**

Attributes are the smallest data entity defined by the ATT



BLE Attribute Protocol (ATT)

Attribute Type

A universally unique identifier (UUID) is used to identify every attribute type

What the attribute represents so the client can understand the attributes exposed by the server

128-bit value, may be shortened to 16-bits

Attribute Handle

Used for accessing the attribute on a server

Attribute Value

Data contained by the attribute

It can represent a measurement value, unit value(km, hours, inches, etc) and information about a device.

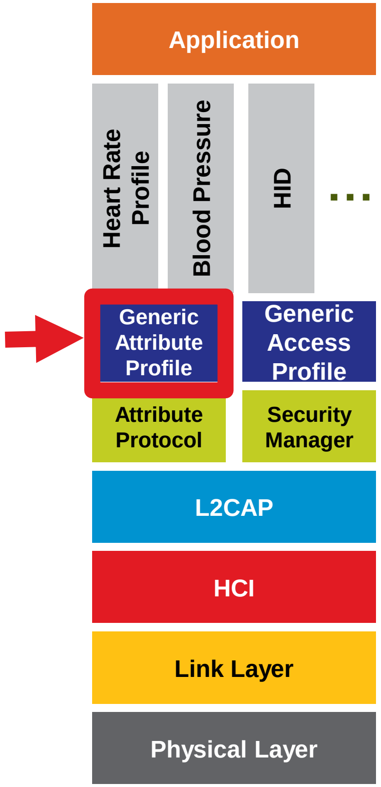
BLE Generic Attribute Profile (GATT)

GATT can be defined as a group of attributes with a common purpose, hence, services were created.

It provides the methods in which the services can be discovered and can be used.

GATT establish a strict hierarchy to organize attributes in a reusable and practical manner.

Allows the access and retrieval of information between client and server to follow a concise set of rules that together constitute the framework used by all GATT-based profiles



BLE Generic Attribute Profile (GATT)

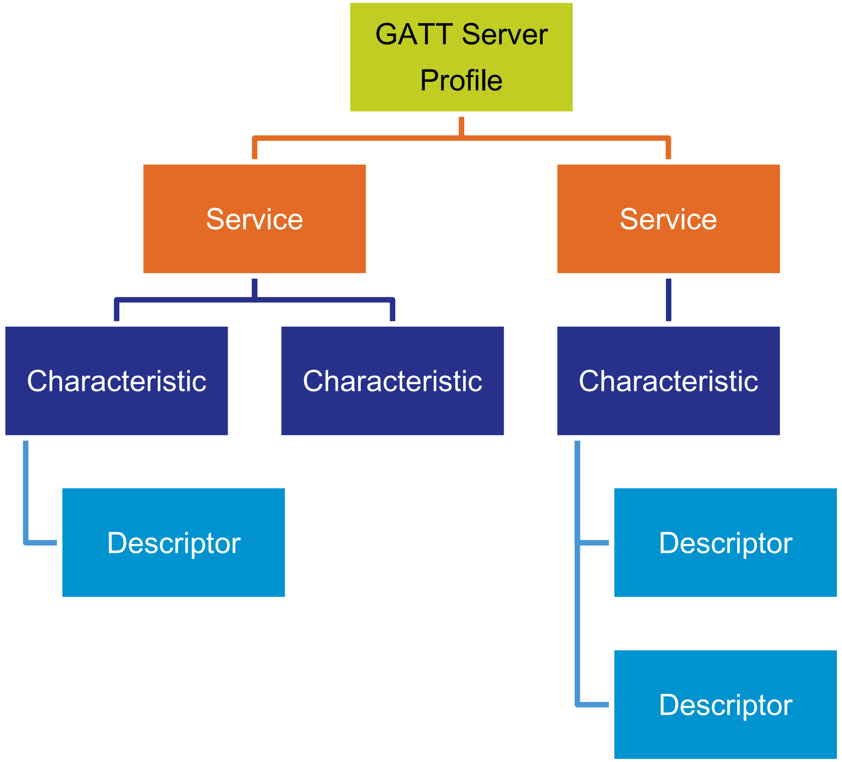
Server

- Corresponds to the ATT server
- Contains all Attributes
- Sends server-initiated updates using indications and notifications
- Responsible of storing and making the user data available to the client

Client

- Corresponds to the ATT client
- Sends requests to a server and receives responses
- GATT does not know anything in advance about the server’s attributes, to find out what they are the Client request a service discovery.

BLE GATT Profile Hierarchy



Profile defines the main behavior of the device. It is formed by a collection of services.

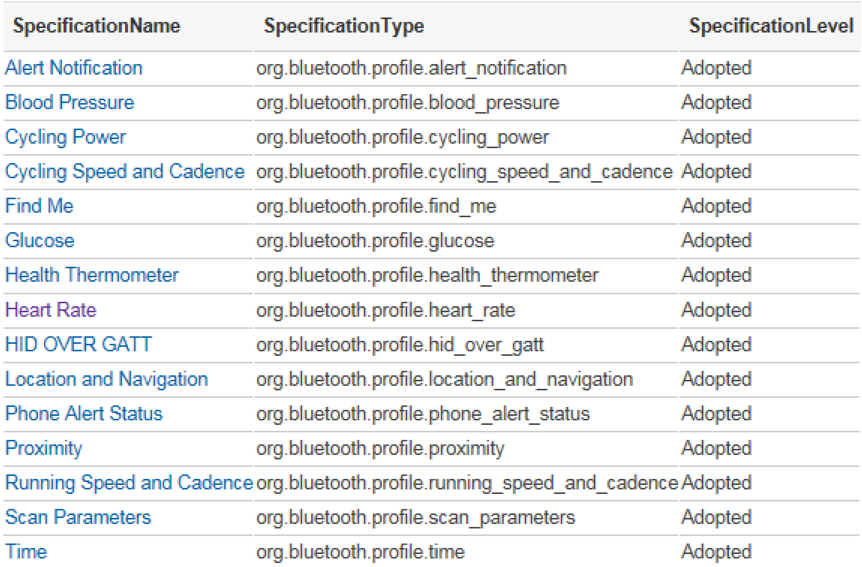
Service is a collection of data and behaviors to accomplish a particular function or feature

Characteristics is a value used in a service. Contains user data.

Descriptor describe the value or allows configuration of the server with respect to the characteristic

BLE GATT Adopted Profiles

Continually updating profile and service support as available from Bluetooth SIG



SpecificationName	SpecificationType	SpecificationLevel
Alert Notification	org.bluetooth.profile.alert_notification	Adopted
Blood Pressure	org.bluetooth.profile.blood_pressure	Adopted
Cycling Power	org.bluetooth.profile.cycling_power	Adopted
Cycling Speed and Cadence	org.bluetooth.profile.cycling_speed_and_cadence	Adopted
Find Me	org.bluetooth.profile.find_me	Adopted
Glucose	org.bluetooth.profile.glucose	Adopted
Health Thermometer	org.bluetooth.profile.health_thermometer	Adopted
Heart Rate	org.bluetooth.profile.heart_rate	Adopted
HID OVER GATT	org.bluetooth.profile.hid_over_gatt	Adopted
Location and Navigation	org.bluetooth.profile.location_and_navigation	Adopted
Phone Alert Status	org.bluetooth.profile.phone_alert_status	Adopted
Proximity	org.bluetooth.profile.proximity	Adopted
Running Speed and Cadence	org.bluetooth.profile.running_speed_and_cadence	Adopted
Scan Parameters	org.bluetooth.profile.scan_parameters	Adopted
Time	org.bluetooth.profile.time	Adopted

https://developer.bluetooth.org/gatt/profiles/Pages/ProfilesHome.aspx

Heart Rate Sensor – gatt_db.h

- Heart Rate Primary Service

```
PRIMARY_SERVICE(service_heart_rate, gBleSig_HeartRateService_d)

    CHARACTERISTIC(char_hr_measurement, gBleSig_HrMeasurement_d, (gGattCharPropNotify_c))
        VALUE_VARLEN(value_hr_measurement, gBleSig_HrMeasurement_d, (gPermissionNone_c), 22,
             2, 0x00, 0xB4)
        CCCD(cccd_hr_measurement)

    CHARACTERISTIC(char_body_sensor_location, gBleSig_BodySensorLocation_d,
                         (gGattCharPropRead_c) )
            VALUE(value_body_sensor_location, gBleSig_BodySensorLocation_d,
                         (gPermissionFlagReadable_c), 1, 0x01)

    CHARACTERISTIC(char_hr_ctrl_point, gBleSig_HrControlPoint_d, (gGattCharPropWrite_c) )
            VALUE(value_hr_ctrl_point, gBleSig_HrControlPoint_d,
                         (gPermissionFlagWritable_c), 1, 0x00)
```

Heart Rate Sensor – gatt_db.h (2)

- Device Information Primary Service

```
PRIMARY_SERVICE(service_device_info, gBleSig_DeviceInformationService_d)

    CHARACTERISTIC(char_manuf_name, gBleSig_ManufacturerNameString_d, (gGattCharPropRead_c) )
        VALUE(value_manuf_name, gBleSig_ManufacturerNameString_d, (gPermissionFlagReadable_c), 9, "Freescale")

    CHARACTERISTIC(char_model_no, gBleSig_ModelNumberString_d, (gGattCharPropRead_c) )
        VALUE(value_model_no, gBleSig_ModelNumberString_d, (gPermissionFlagReadable_c), 8, "HRS Demo")

    CHARACTERISTIC(char_serial_no, gBleSig_SerialNumberString_d, (gGattCharPropRead_c) )
        VALUE(value_serial_no, gBleSig_SerialNumberString_d, (gPermissionFlagReadable_c), 7, "BLESN01")

    CHARACTERISTIC(char_hw_rev, gBleSig_HardwareRevisionString_d, (gGattCharPropRead_c) )
        VALUE(value_hw_rev, gBleSig_HardwareRevisionString_d, (gPermissionFlagReadable_c), sizeof(BOARD_NAME),
             BOARD_NAME)

    CHARACTERISTIC(char_fw_rev, gBleSig_FirmwareRevisionString_d, (gGattCharPropRead_c) )
        VALUE(value_fw_rev, gBleSig_FirmwareRevisionString_d, (gPermissionFlagReadable_c), 5, "1.1.1")

    CHARACTERISTIC(char_sw_rev, gBleSig_SoftwareRevisionString_d, (gGattCharPropRead_c) )
        VALUE(value_sw_rev, gBleSig_SoftwareRevisionString_d, (gPermissionFlagReadable_c), 5, "1.1.3")

    CHARACTERISTIC(char_system_id, gBleSig_SystemId_d, (gGattCharPropRead_c) )
        VALUE(value_system_id, gBleSig_SystemId_d, (gPermissionFlagReadable_c), 8, 0x00, 0x00, 0x00, 0xFE,
             0xFF, 0x9F, 0x04, 0x00)

    CHARACTERISTIC(char_rcdl, gBleSig_IeeeRcdl_d, (gGattCharPropRead_c) )
        VALUE(value_rcdl, gBleSig_IeeeRcdl_d, (gPermissionFlagReadable_c), 4, 0x00, 0x00, 0x00, 0x00)
```

Heart Rate Sensor – gatt_db.h (2)

- GATT Primary Service

```
PRIMARY_SERVICE(service_gatt, gBleSig_GenericAttributeProfile_d)
     CHARACTERISTIC(char_service_changed, gBleSig_GattServiceChanged_d, (gGattCharPropRead_c |
                          gGattCharPropNotify_c) )
             VALUE(value_service_changed, gBleSig_GattServiceChanged_d, (gPermissionNone_c), 4, 0x00, 0x00,
                          0x00, 0x00)
             CCCD(cccd_service_changed)
```

GAP Primary Service

```
PRIMARY_SERVICE(service_gap, gBleSig_GenericAccessProfile_d)

    CHARACTERISTIC(char_device_name, gBleSig_GapDeviceName_d, (gGattCharPropRead_c) )
            VALUE(value_device_name, gBleSig_GapDeviceName_d, (gPermissionFlagReadable_c), 11, "FSL_BLE_HRS")

    CHARACTERISTIC(char_appearance, gBleSig_GapAppearance_d, (gGattCharPropRead_c) )
            VALUE(value_appearance, gBleSig_GapAppearance_d, (gPermissionFlagReadable_c), 2,
             UuidArray(gGenericHeartrateSensor_c))

    CHARACTERISTIC(char_ppcp, gBleSig_GapPpcp_d, (gGattCharPropRead_c) )
            VALUE(value_ppcp, gBleSig_GapPpcp_d, (gPermissionFlagReadable_c), 8, 0x0A, 0x00, 0x10, 0x00, 0x64,
             0x00, 0xE2, 0x04)
```

Custom Service

A custom service might be useful when none of the adopted fits your application

Custom services and characteristics must use 128-bit UUID

Considerations for a custom service

1. Define the functions to be performed by the new service
2. Define the characteristics to be used, its value, property and permissions
3. Create descriptors if necessary
4. Create the custom service on the BLE stack

Summary BLE Roles

Depending on the layer, the device roles uses different names:

- At Link layer
  - Master
  - Slave
- At GAP (non-beacon)
  - Central
  - Peripheral
- At GATT
  - Server
  - Client

HRS Demo

NXP Kinetis Wireless Solutions Agenda

- **KW41 Family Overview**
- **Bluetooth Low Energy (BLE)**
- **Thread**
- **BLE+Thread**
- **Wireless Framework**
- **Modular Gateway**

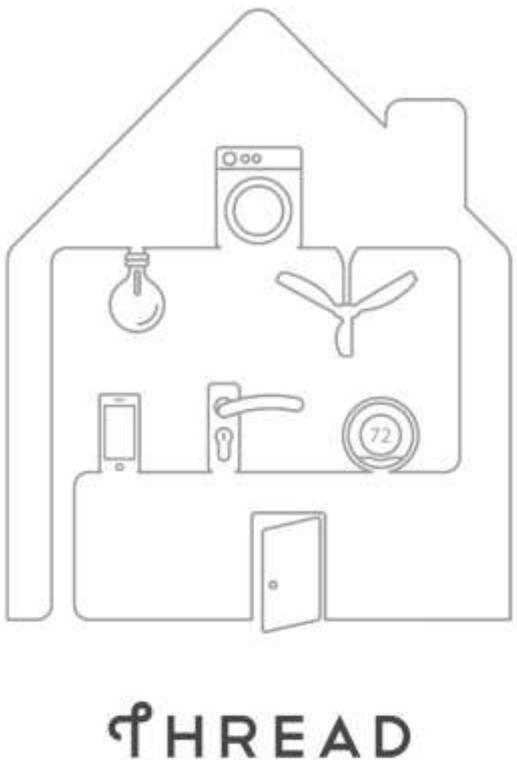
Thread

Intro to Thread

The Need For a New Wireless Network

More and more products are being connected in the home

- Direct internet access
- Simple to add and remove from the network
- Must be secure
- Robust
- Battery operated for years

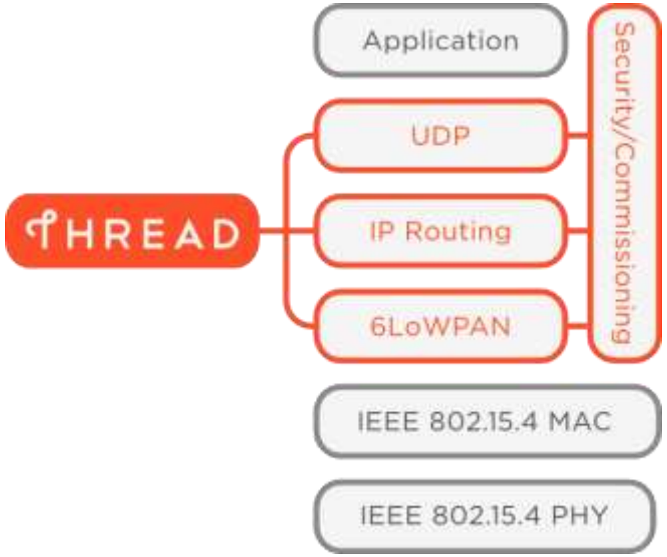


Existing protocols did not meet these requirements

Thread Group was formed by 7 companies to solve the problem

A secure low-power wireless IPv6 mesh networking protocol

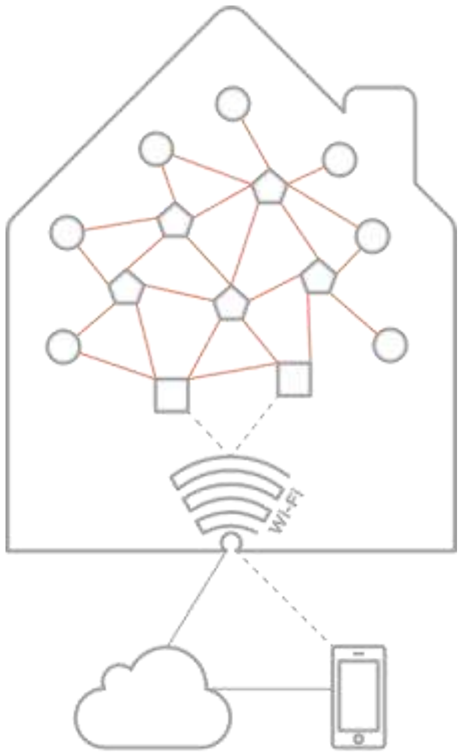
- Open, worldwide protocol built on top of 802.15.4
- Every node has a unique IPv6 address
- Low power end nodes
- Simple for consumers to add or remove nodes
- Scalable up to 250+ nodes
- Secure – AES128 encryption
- No single point of failure
- Network operates without cloud connection
- Fast time to market
- Only IP-based mesh networking protocol available



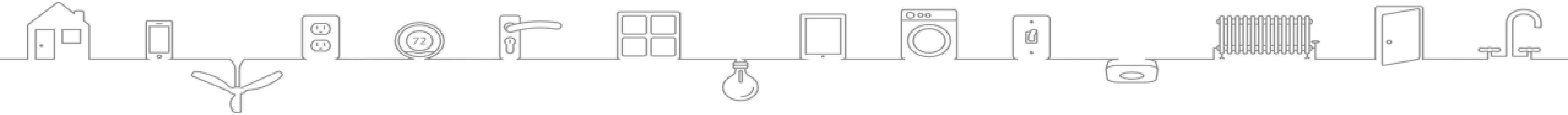
Target Applications

Thread is designed for all sorts of products in the home

- Appliances
- Access control
- Climate control
- Energy management
- Lighting
- Safety
- Security



Devices working together to form a cohesive mesh network



About Thread Group

7 Founding Companies, grown to 12 Sponsor Companies, 230+ member companies

NXP founding company

A market education group offering product certification

Promoting Thread’s use in connected products for the home

Thread will offer rigorous product certification to ensure security and interoperability

Board of Directors

President: Grant Ericsson - Nest Labs

VP of Marketing: Sujata Neidig - NXP

VP of Technology: Skip Ashton - Silicon Labs

Secretary: Bill Curtis - ARM

Treasurer: Kevin Kraus - Yale Security

Director: Landon Borders – Haiku Home

Director: Christian Federspiel – OSRAM

Director: Rolf De Vegt - Qualcomm

Director: Mark Trayer - Samsung Electronics

Director: Jean-Michel Orsat - Somfy

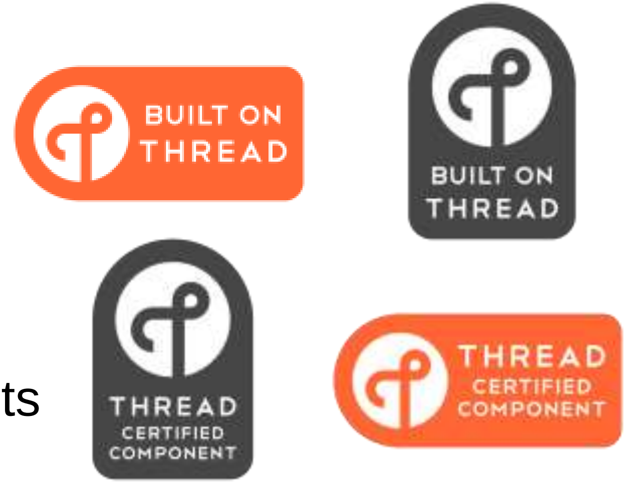
Director: Greg Blackett – Tyco

Thread Certification

All Thread devices will require network certification to use Thread certified logo on commercial products

Validation of device behavior

- Commissioning
- Network functionality and interoperability
- Device operation in network

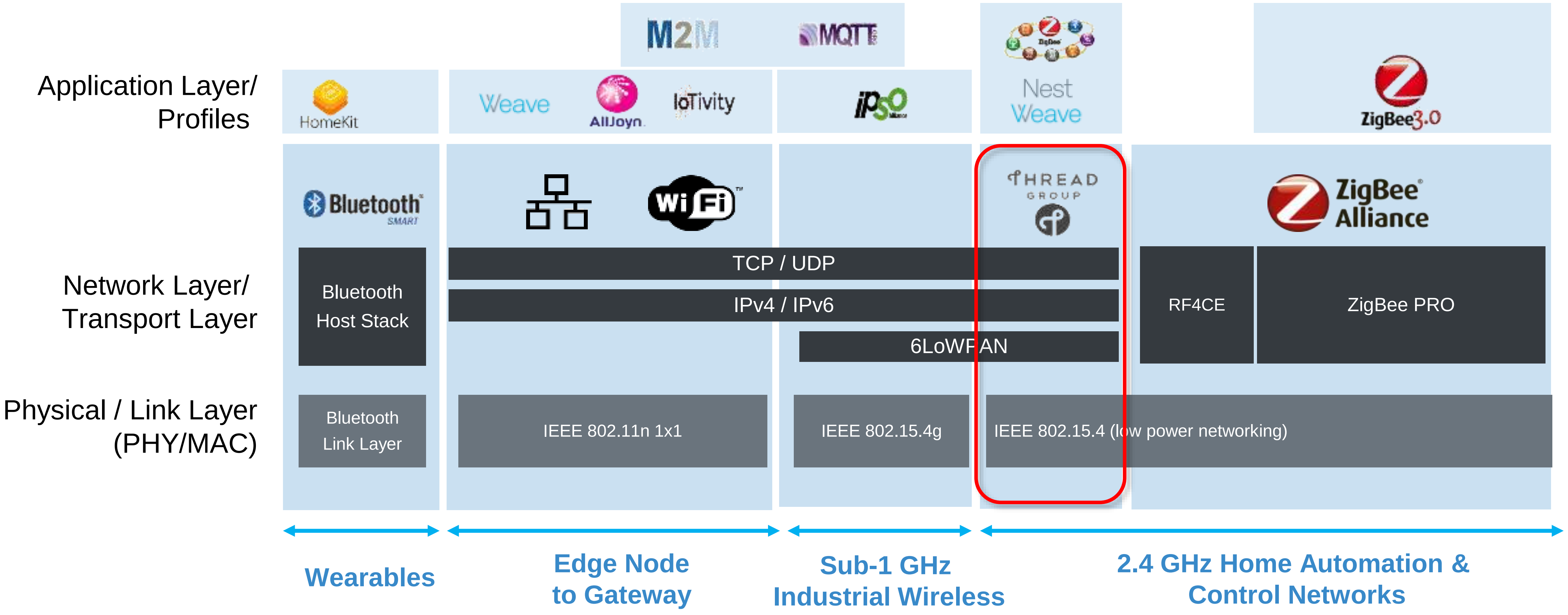


The certification program addresses both components and end products

Sponsor and Contributor Members have access to standard test harness and sample commissioning app

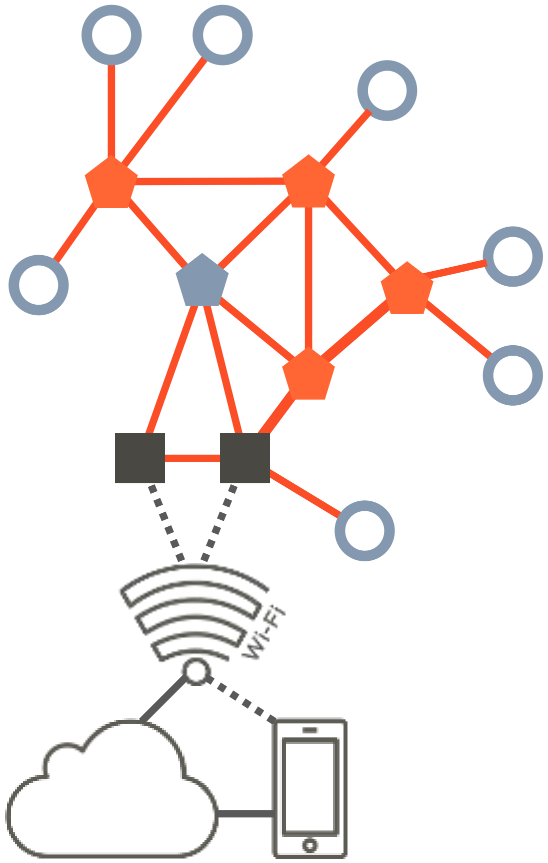
Certification through an approved 3rd party test lab

IoT Connectivity Landscape – Where does Thread play?



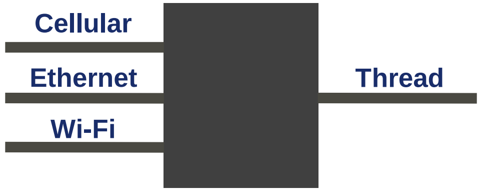
Thread Networking Architecture

Network Architecture



- ○ End Device or Router Eligible End Device
- ⬟ Active Router
- ⬟ Leader
- ■ Border Router
- — Thread Network Link

Network Topology Roles



Border Router

Border Router forwards data to and from the cloud

Also can provide Wi-Fi connectivity in the home

Thread Leader

Master of network parameters
Coordinates commissioners
Routes traffic among devices

Thread Active Router

Routes traffic among devices
Thread Routers form backbone of the Thread mesh
Leader-eligible

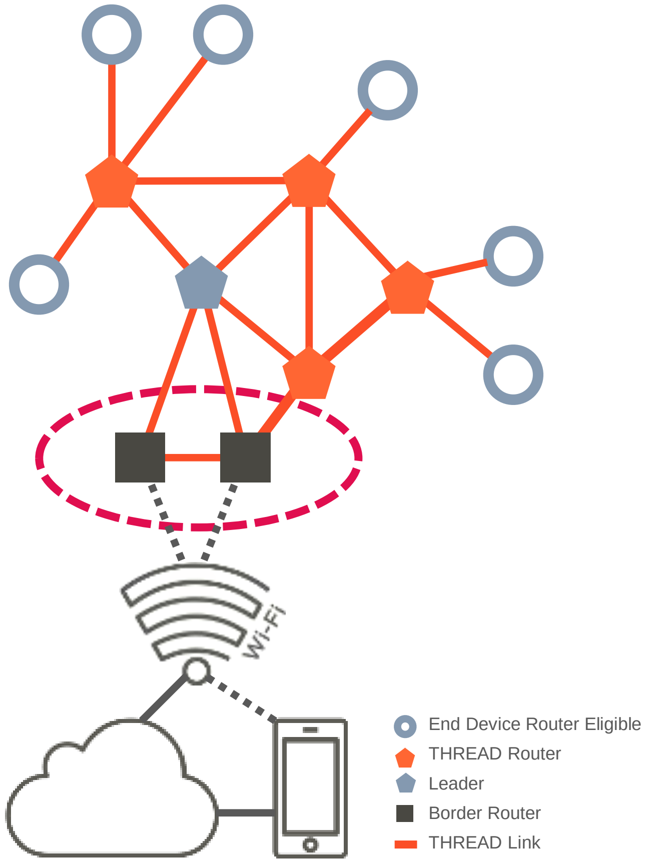
End Device

Designed for low power
May be powered or sleepy
May be router-eligible if powered

Many + One + Up to 31 + Up to 512 per Active Router

Thousands of Devices per Network (16k)

Thread Border Router



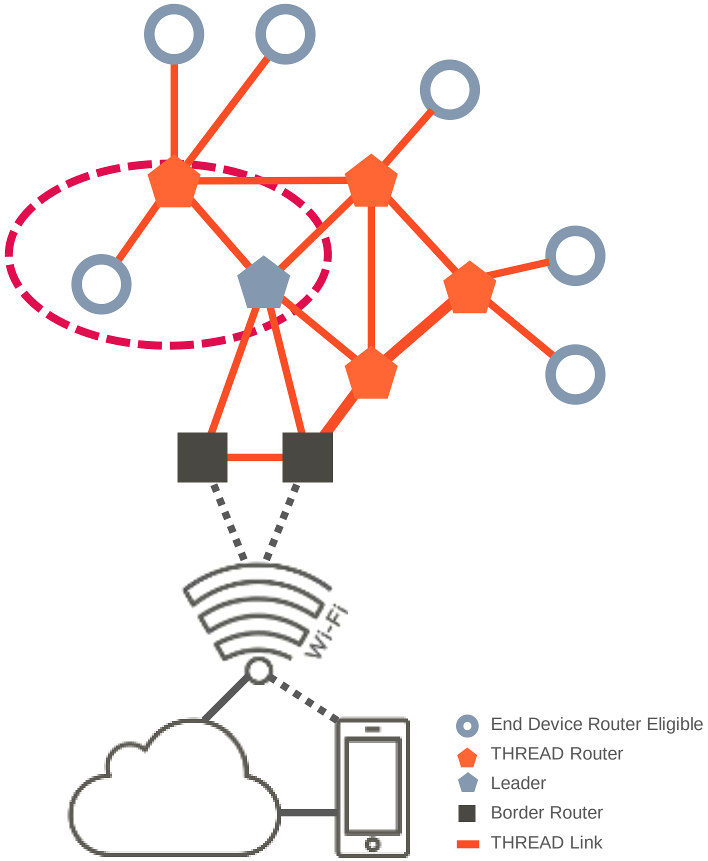
The **Border Router**

- Provides a bridge between a Thread network and a home LAN or other upstream IP infrastructure.
- Is usually a superset of Router Eligible Device
- Has at least one additional interface other than IEEE 802.15.4 (e.g.: Wi-Fi, Ethernet, USB)
- Multiple Border Routers can exist in a Thread Network
  - However a border router is not required either.

The **Border Router**

- Can be a specialized networking device
  - Wireless Access Point (WAP)
  - Home Gateway
- Or can be embedded in a consumer product
  - Thermostat
  - Appliance

Thread Router Eligible End Device



A **Router Eligible End Device** can play multiple roles at runtime

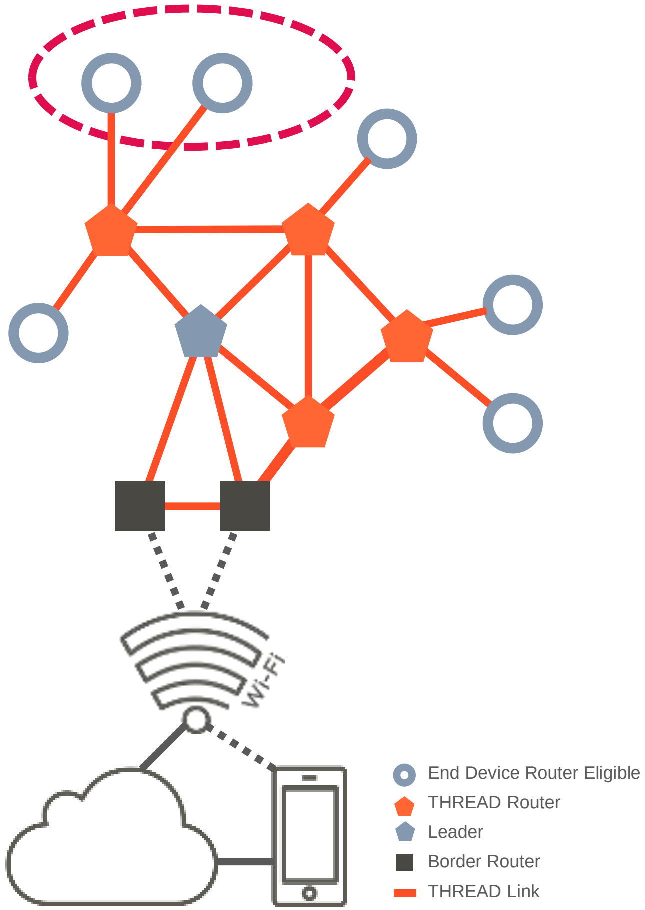
Leader
If it is the initial device in the network partition, or the node selected when the original leader becomes unavailable

Router Eligible End Device (REED)
Immediately after joining a network through an existing Active Routers or if the network has sufficient connectivity and does not need more routers

Active Router
A REED requests the Leader for it to become an Active Router when the network has relatively limited connectivity. e.g.: when total number of existing Active Routers is < 16

A **Router Eligible Device** is regularly a device meant to remain mains powered and **always on**

Thread End Devices



An **End Device**

- Does not have routing capabilities
- Communicates through a parent Active Router, but does not use data polling
- Cannot become a router (is not router eligible)

An **End Device** can be mains powered but may **periodically be turned off** or has a high capacity battery with recharge

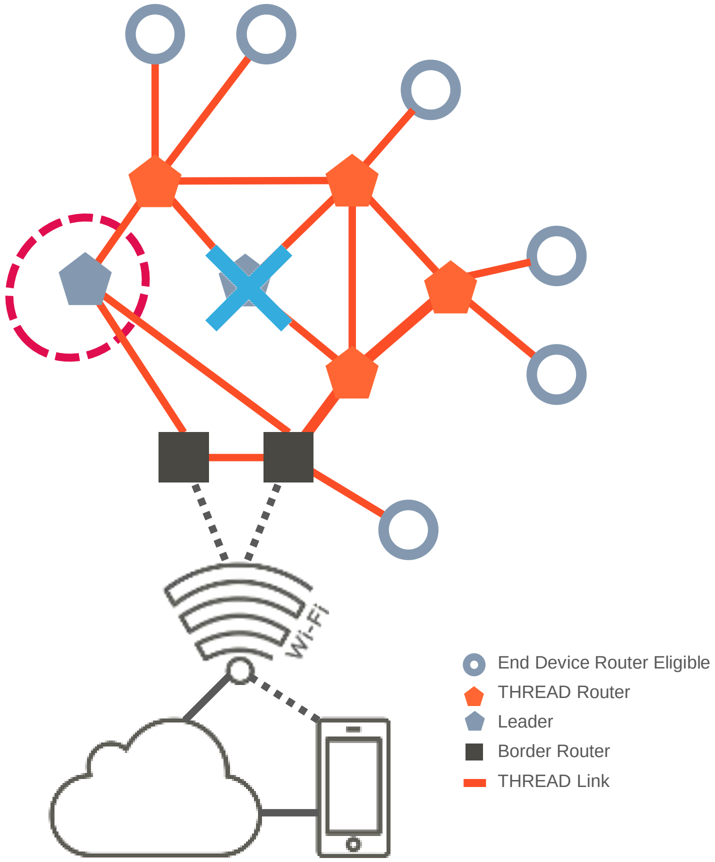
A **Sleepy End Device**

- Does not have routing capabilities
- “Sleepy End Device” (SED), mostly having its radio transceiver turned off
- Communicates through a parent Active Router, and uses data polling to receive packets
- Cannot become a router (is not router eligible)

A **Sleepy End Device** has a limited capacity battery, usually non rechargeable (e.g.: coin cell)

No Single Point of Failure

- No need to recognize specialized devices within the network
- Leader makes decisions but upon failure another Router will become Leader
- Network will add Routers to improve connectivity when required



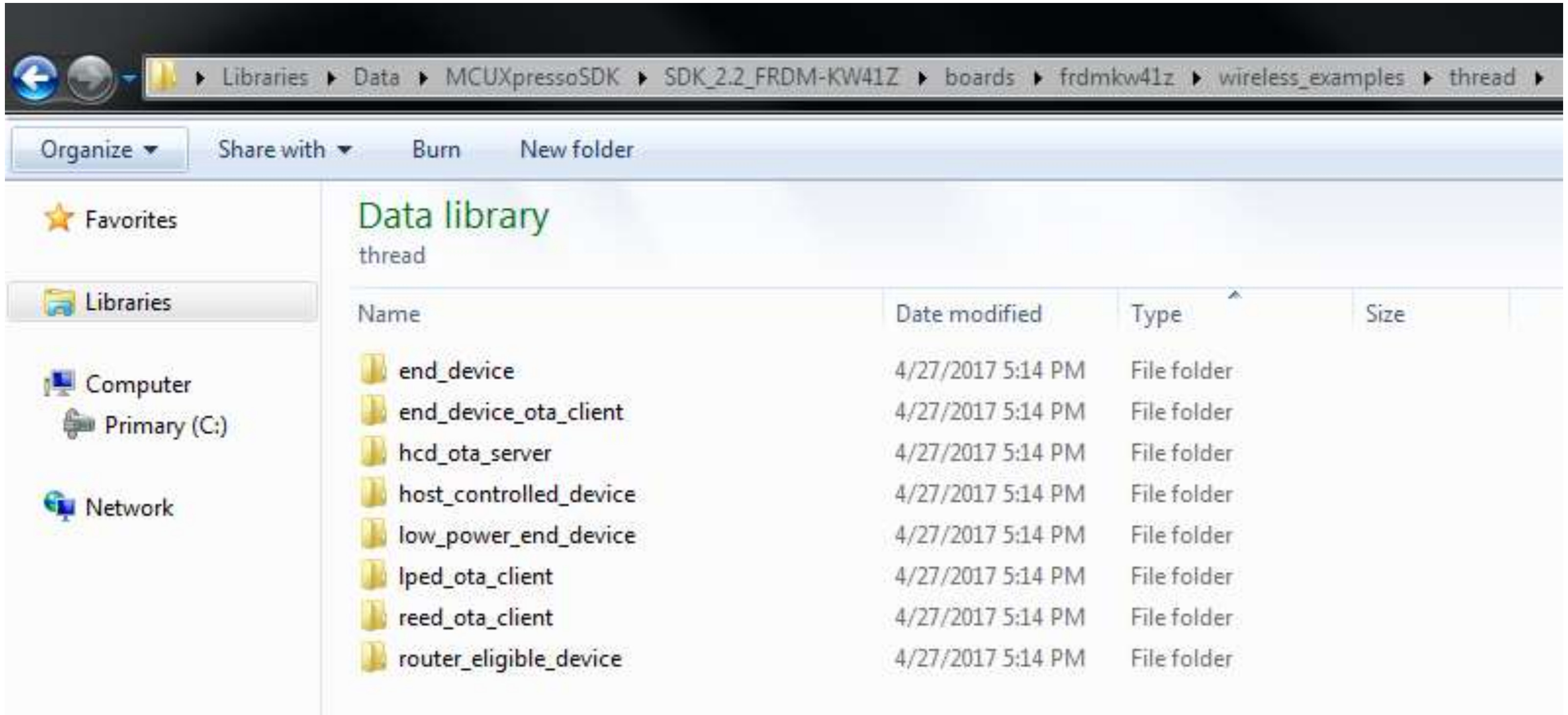
Getting Thread

MCUXpresso SDK for KW41Z

- Contains all the KW41Z Wireless Connectivity solution stacks:
  - Thread v1.1
  - IEEE 802.15.4
  - SMAC
  - Bluetooth Low Energy v4.2
  - Generic FSK Link Layer software
- Also contains MCUXpresso SDK sources
- Supports the FRDM-KW41Z and USB-KW41Z development boards
- Supported IDEs:
  - MCUXpresso IDE
  - IAR for ARM
- Available Now!

Installation

- Thread examples found at: **\boards\frdmkw41z\wireless_examples\thread**

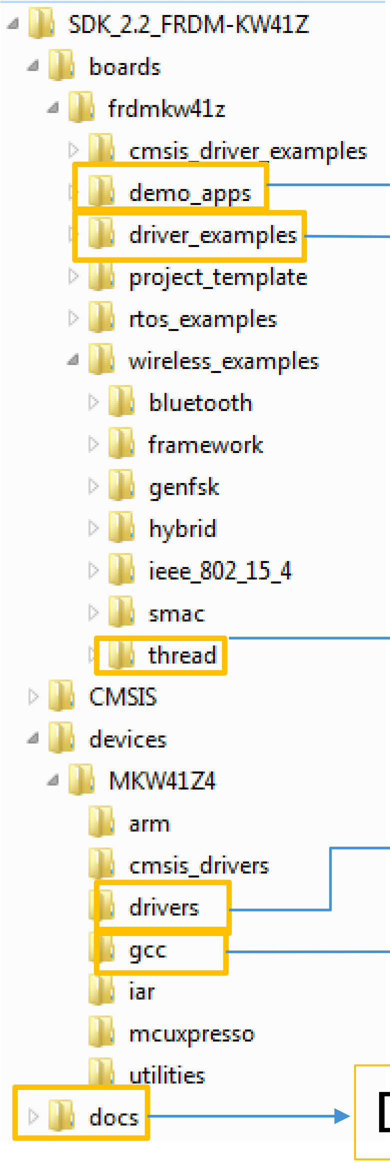


Libraries ▸ Data ▸ MCUXpressoSDK ▸ SDK_2.2_FRDM-KW41Z ▸ boards ▸ frdmkw41z ▸ wireless_examples ▸ thread ▸

Data library
thread

Name	Date modified	Type	Size
end_device	4/27/2017 5:14 PM	File folder	
end_device_ota_client	4/27/2017 5:14 PM	File folder	
hcd_ota_server	4/27/2017 5:14 PM	File folder	
host_controlled_device	4/27/2017 5:14 PM	File folder	
low_power_end_device	4/27/2017 5:14 PM	File folder	
lped_ota_client	4/27/2017 5:14 PM	File folder	
reed_ota_client	4/27/2017 5:14 PM	File folder	
router_eligible_device	4/27/2017 5:14 PM	File folder	

KW41Z Connectivity Software Package File Structure



```
SDK_2.2_FRDM-KW41Z
  boards
    frdmkw41z
      cmsis_driver_examples
      demo_apps
      driver_examples
      project_template
      rtos_examples
      wireless_examples
        bluetooth
        framework
        genfsk
        hybrid
        ieee_802_15_4
        smac
        thread
  CMSIS
  devices
    MKW41Z4
      arm
      cmsis_drivers
      drivers
      gcc
      iar
      mcuxpresso
      utilities
  docs
```

MCUXpresso SDK Demos

MCUXpresso SDK Driver Examples

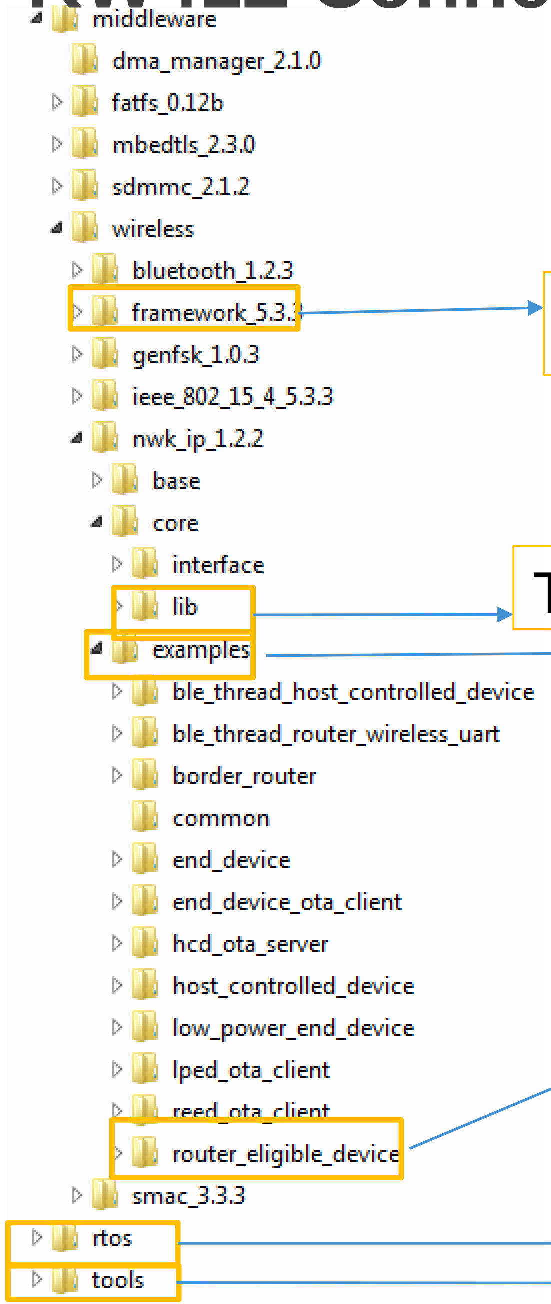
Thread Examples Project Files

MCUXpresso SDK Driver Source Code

MCUXpresso SDK Demo Linker Files

Documentation

KW41Z Connectivty Software Package File Structure (Continued)



```
middleware
  dma_manager_2.1.0
  fatfs_0.12b
  mbedtls_2.3.0
  sdmmc_2.1.2
  wireless
    bluetooth_1.2.3
    framework_5.3.3
    genfsk_1.0.3
    ieee_802_15_4_5.3.3
    nwk_ip_1.2.2
      base
      core
        interface
        lib
      examples
        ble_thread_host_controlled_device
        ble_thread_router_wireless_uart
        border_router
        common
        end_device
        end_device_ota_client
        hcd_ota_server
        host_controlled_device
        low_power_end_device
        lped_ota_client
        reed_ota_client
        router_eligible_device
    smac_3.3.3
rtos
tools
```

Wireless Framework Source: Linker Files, MemManger, TimerManager, etc

Thread Library Binary

Thread Examples Source

Basic Thread Example

FreeRTOS Source

HostSDK

Thread Documentation

- Kinetis Thread Stack Demo Applications User Guide
- Kinetis Thread Stack 1.1 Release Notes
- Kinetis Thread Stack API Reference Manual

- Kinetis Thread Stack and FSCI Bootloader Quick Start Guide
- Kinetis Thread Stack Application Development Guide
- Kinetis Thread Stack OTA Firmware Update User’s Guide
- Kinetis Thread Stack Shell Interface User’s Guide
- Kinetis Thread Host Control Interface Reference Manual

Thread Details

So how many addresses does a Thread device get?

Once joined to a network, a Thread device will get:

Thread internal only!!!

OK to be used by application

At least 3 Unicast IPv6 addresses to the Thread Interface:

Link local address (LL64):	**fe80**::**b86f:ab39:9875:7a33**
Mesh local address (ML16, RLOC):	**fd9b:91a1:52d5:e428**::ff:fe00:**400**
Mesh local address (ML64, ML-EID):	**fd9b:91a1:52d5:e428**::**b457:d8d4:dd35:aea0**

LL64 interface ID is based on IEEE **802.15.4 Random Extended Address**

Routing Locator RLOC interface ID is based on IEEE 802.15.4 **Short address (6-bits Router ID + Child ID)**

Mesh Local Endpoint Identifier ML-EID interface ID is random

Mesh Local Prefix **MLP** is **consistent for a Thread network**, the value is generated according to IPv6 RFC 4193

Two All Thread Nodes multicast addresses:

Link local all Thread Nodes(Multicast):	**ff3**2 40:fd**9b:91a1:52d5:e428**::1
Realm local all Thread Nodes(Multicast):	**ff3**3 40:fd**9b:91a1:52d5:e428**::1

Scope
2 – Link local
3 – Realm Local

Group ID
1 – Multicast all nodes
2 – Multicast all routers

Optional will also get:

Unique local address (ULA):	**fd01::3ead:5d45:9bf0:94d5:4234**
Global unique address (GUA):	**2602:306:839b:bcca:8948:9563:2313:93cc**

Unique Local Prefix is defined in each Border Router

Unique Local Address ULA is random

Global Prefix retrieved from the ISP via prefix delegation

Global Unicast Address GUA assigned via DHCPv6 or random if assigned via SLAAC

Use `ifconfig` command in Kinetis Thread Stack shell to obtain IP address configuration

Thread Scopes

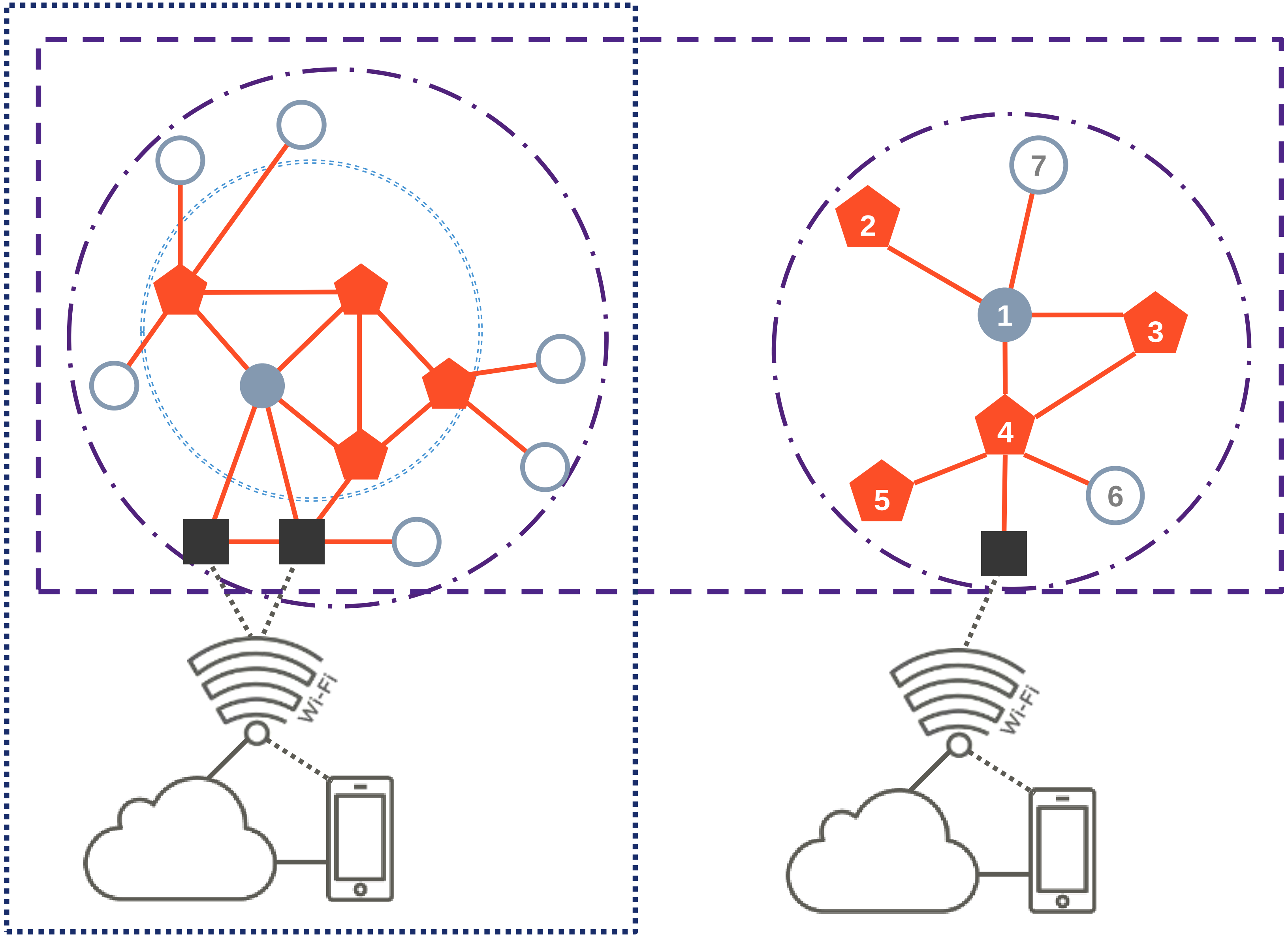
Scopes specify the boundaries of networks when using and forwarding packets for an address

Link Local single-hop within radio range

Mesh Local multi-hop within the PAN

Unique Local multi-hop within the PAN and inter-PAN for the same network

Global internet addressable



http://www.iana.org/assignments/ipv6-address-space/ipv6-address-space.xhtml

Multicast

ff33:40:fd9b:91a1:52d5:e428::1

Realm Local

Mesh-Local-Prefix

Group ID

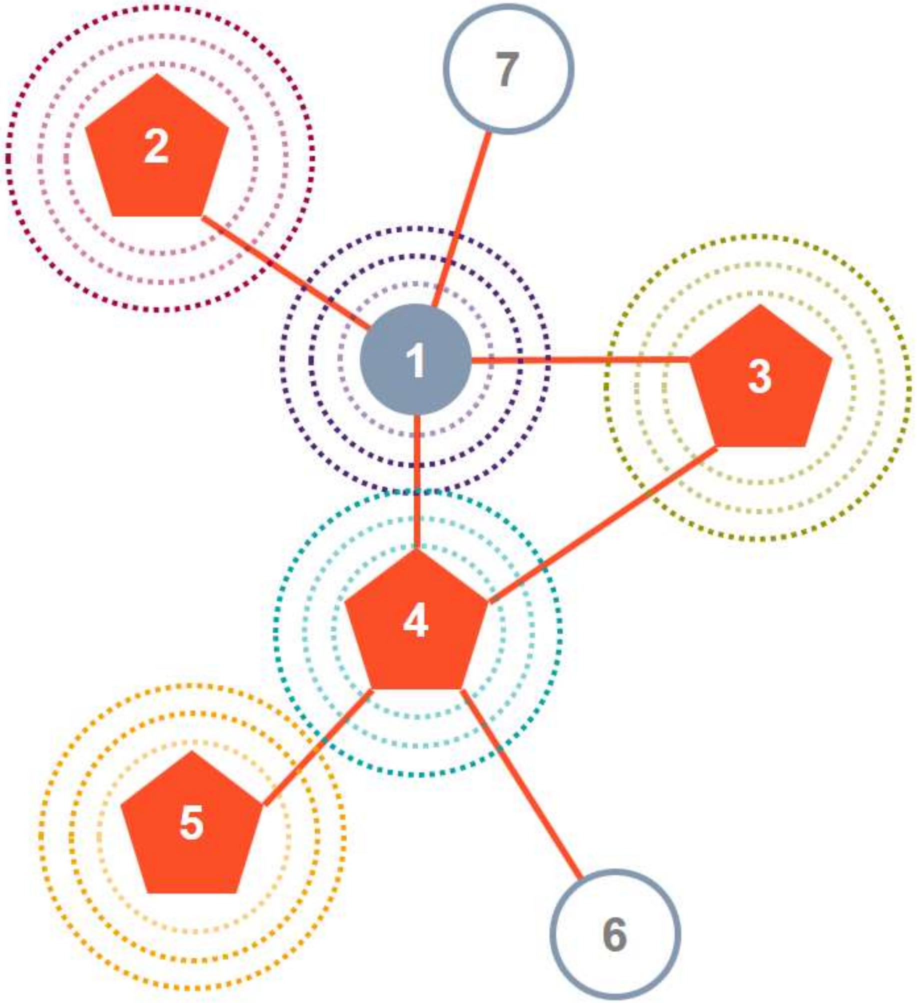
1 – all nodes

2 – all routers

Realm local all Thread nodes

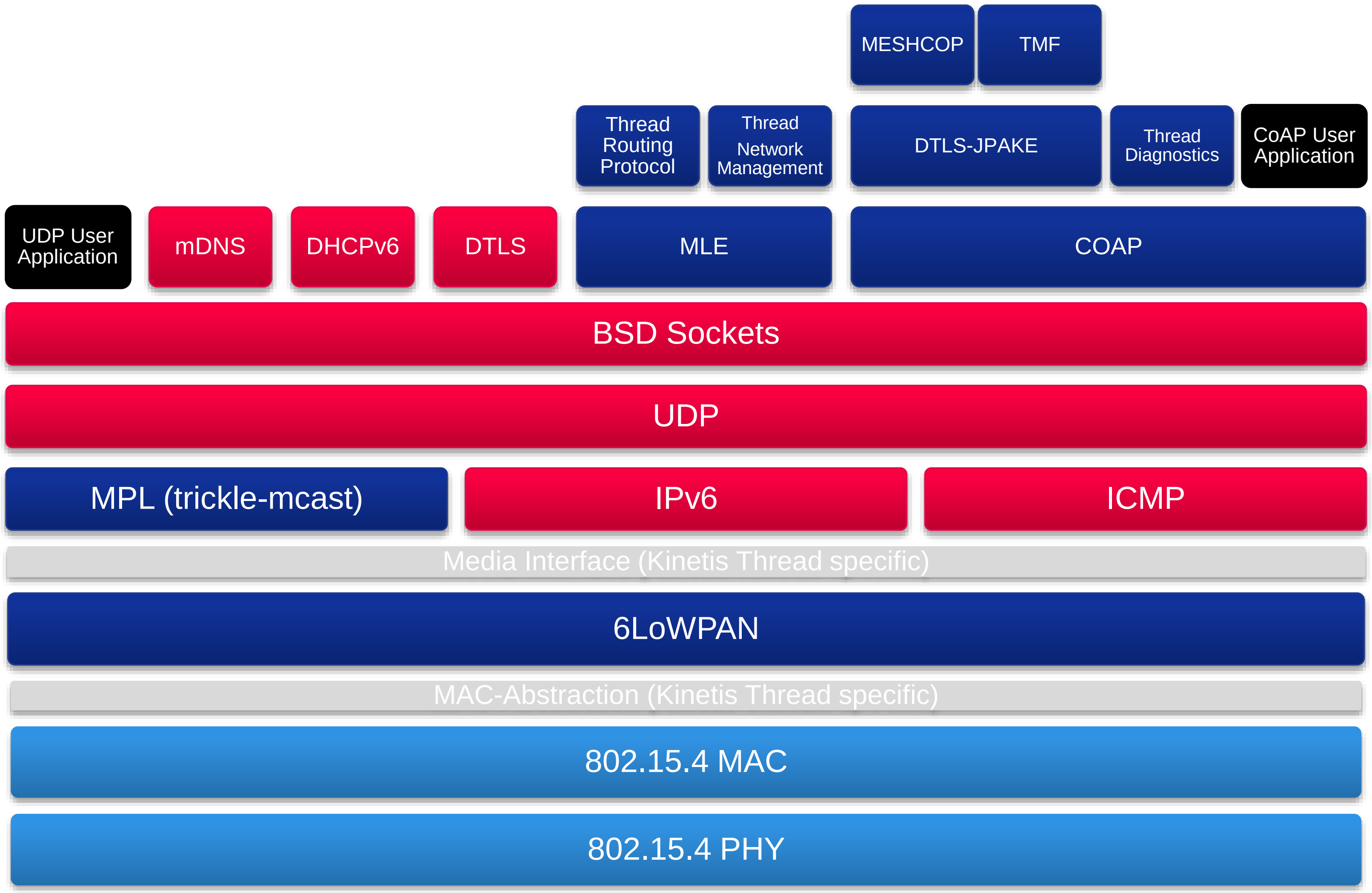
Packets can reach every node of the network as long maximum of 2 “hops” away from the requester

The packet gets forwarded three more times every tim



Thread Layers

Thread End Device - High Level Block Diagram



MESHCOP
TMF

Thread Routing Protocol
Thread Network Management
DTLS-JPAKE
Thread Diagnostics
CoAP User Application

UDP User Application
mDNS
DHCPv6
DTLS
MLE
COAP

BSD Sockets

UDP

MPL (trickle-mcast)
IPv6
ICMP

Media Interface (Kinetis Thread specific)

6LoWPAN

MAC-Abstraction (Kinetis Thread specific)

802.15.4 MAC

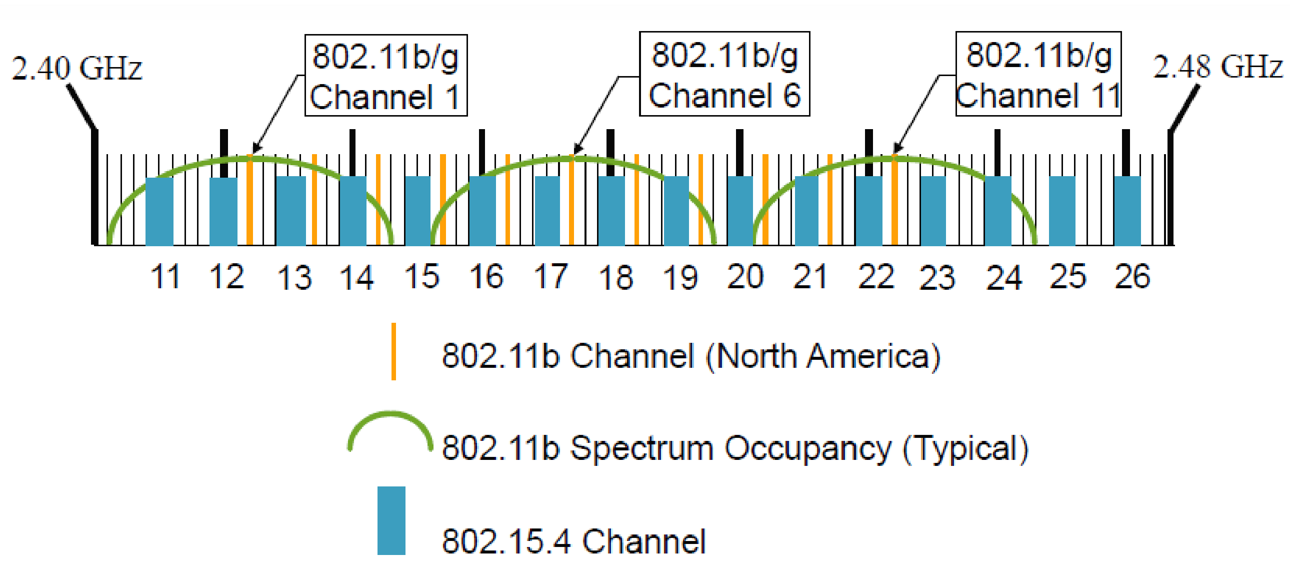
802.15.4 PHY

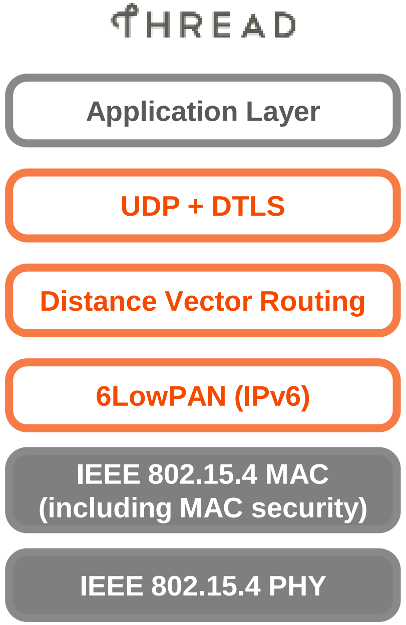
🟥 Generic IPv6 stack components
🟦 Standard IEEE 802.15.4 PHY-MAC
■ Thread specific components
⬜ NXP Specific

802.15.4 and 6lowpan

IEEE 802.15.4 - PHY

IEEE 802.15.4 channel occupancy on 2.4GHz





THREAD

- Application Layer
- UDP + DTLS
- Distance Vector Routing
- 6LowPAN (IPv6)
- IEEE 802.15.4 MAC (including MAC security)
- IEEE 802.15.4 PHY

802.15.4 open channels when Wi-Fi fully utilized the band

- 15, 20, 25, 26.

IEEE® 802.15.4 MAC Functions

- Ensures reliable and secure data transfers
- Essential foundation for technologies like ZigBee® or Thread

- Collision avoidance algorithm through clear channel assessment
- Acknowledgement-based transmissions and re-transmissions
- Integrity checks with CRC-16

- AES-128 data encryption and CCM* block ciphers authentication

- Allows star or peer-to-peer topologies
- IEEE® standard 64-bit or short, dynamic 16-bit addressing
- Dynamic device addressing allowing routed meshes in upper layers

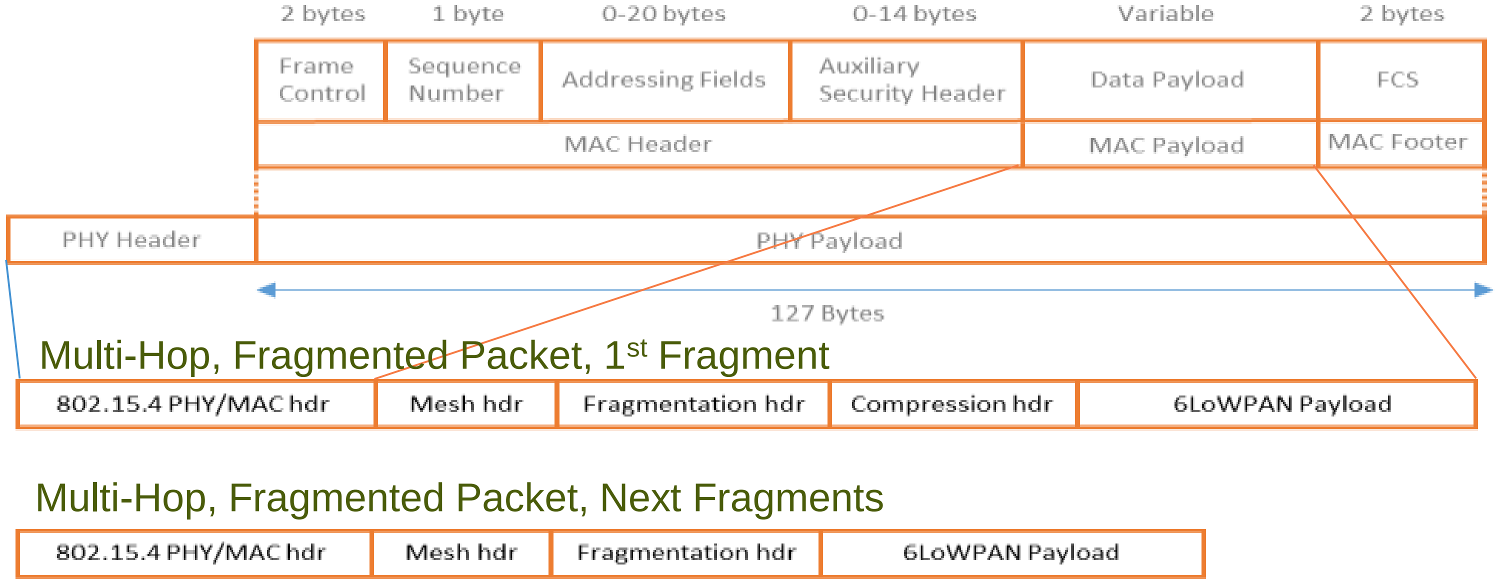
- Optional slotted mode with superframe-based duty cycles
- Device segregation based on capabilities and roles in a network: coordinator and end device

6LoWPAN

- **6LoWPAN** is an adaptation layer between the IEEE 802.15.4 MACPHY and IPv6 layer used as an IPv6 Media Interface within the constraints and requirements of both standards

- 6LoWPAN functionality in Thread is based on RFC 4944 and RFC 6282 and achieves the following:

1. **IPv6 header compression** from 40+ bytes to <10 bytes
2. **IPv6 packets fragmentation and reassembly** to / from smaller MAC-PHY payloads
3. **IPv6 packets forwarding across multiple hops** using the mesh header



Thread Management Layer

Network Partitioning and Merging

- **Partitioning** – A set of Active Routers (with their children) which become disconnected from the current leader will create a new Thread network **partition**, having a new partition Leader.

- This can happen as current Leader has been turned off or removed or when nodes are moved out of connectivity range

- The new Leader chooses a new partition ID within the same Thread network

- If 2 or more different partitions become re-connected (Router or REEDs can hear routing advertisements from other partitions), the nodes in partitions with a lower partition ID will re-attach and **merge** to the partition with highest ID

REED Upgrade and Downgrade

- A **Router Eligible Device** joins the network as a **REED,** but will request a Router ID from Leader and **upgrade** to an Active Router if total number of Active Routers in partition less than a threshold (currently 16)

- If there are enough Active routers when joining, the node will remain a REED

- A REED will also request a Router ID when a new node attempts to join and there are not enough Active Routers in the range of the new node to accept that as a child

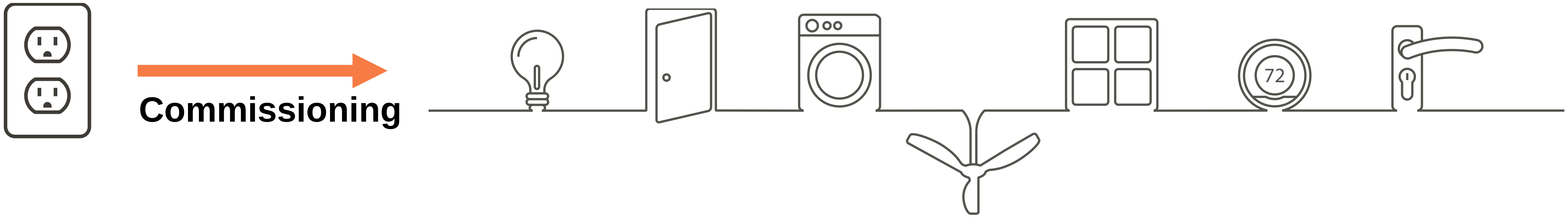
- An Active Router will release the Router ID and **downgrade** to a REED when the total number of Active Routers is above a threshold (currently 23) and other inter-connectivity criteria for neighbors and children are met

Commisioning

Commissioning

MeshCoP or Mesh Commissioning is a protocol for securely authentication, commissioning and joining new untrusted radio devices to a mesh network

Adding new devices it’s the process of a human administrator



Commissioning

Commissioning Roles

Commissioner currently elected authentication server and the authorizer to provide network credentials C

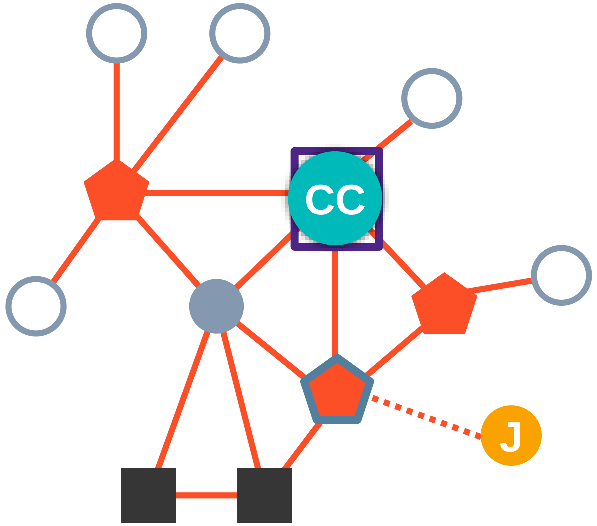
Border Agent any device capable of relaying messages between a Thread Network and a Commissioner BA

Commissioner Candidate a device capable of becoming a commissioner and either intends or is currently petitioning the leader to become the Commissioner

CC

Joiner the device to be added by a human administrator to a commissioned Thread networ J

Joiner Router existing Thread router or REED in the secure Thread Network that is one hop away from the **Joiner**



Commissioner

- Protocol

Discovery Commissioner Candidate (smartphone with WiFi) discovers a Thread Network through one of its Border Agents

Authentication Commissioner Candidate securely connects to the Thread Network using the commissioning credential

Registration Commissioner Candidate registers its identity with its Border Agent

- Thread Management

Petitioning border agent unicast to the Thread Network Leader a request to petition its Commissioner Candidate to be one elected Commissioner

Management commissioners may manage the network by getting and setting parameters such as: commissioner credentials, network name, security policy.

Joiner

- Joiner Protocol

Discovery Joiner discovers the Thread Network using 802.15.4 Discovery messages

Provisional Join unsecure local-only link to the joiner router

Joiner Authentication DTLS handshake messages to a Joiner Router

- Joiner Finalization

Entrust handoff of network credentials to the Joiner

Provisioning if the joiner appealed for a specific commissioning application, do vendor-specific provisioning

Session Close DTLS Alert mechanism.

MeshCOP Credentials – **Joiner needs**

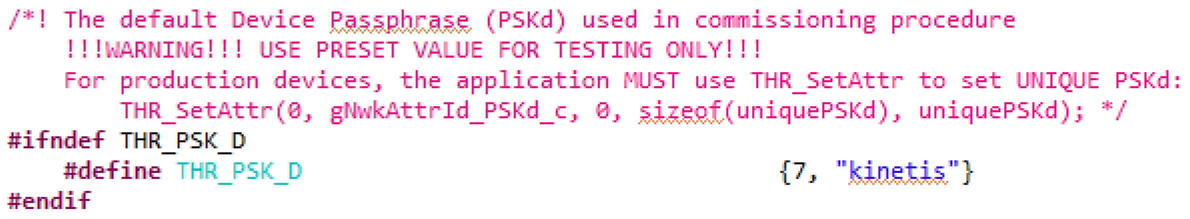
- Joining Device Credential

Device Password set by the manufacturer

The Commissioner and the Joiner share the **Device Credential** using some out-of-band mechanism such as scanning a bar code or entering a serial number from the joiner device label

- Pre-shared key for the device PSKd

The **joining device** passphrase is used in conjunction with a PAKE cipher suite creating a **PSKd** to establish a secure session



```
/*! The default Device Passphrase (PSKd) used in commissioning procedure
    !!!WARNING!!! USE PRESET VALUE FOR TESTING ONLY!!!
    For production devices, the application MUST use THR_SetAttr to set UNIQUE PSKd:
        THR_SetAttr(0, gNwkAttrId_PSKd_c, 0, sizeof(uniquePSKd), uniquePSKd); */
#ifndef THR_PSK_D
    #define THR_PSK_D                                                {7, "kinetis"}
#endif
```

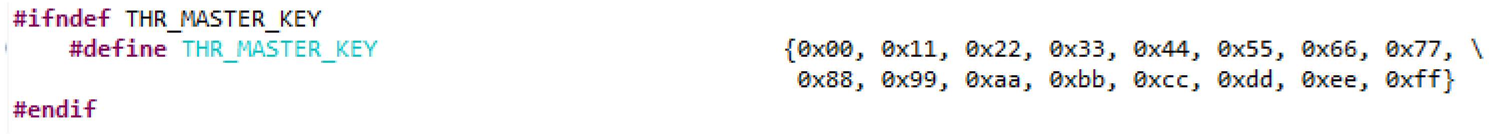
Network Credentials – **Joiner Gets**

All the security and network parameters required for a device to be part of a Thread network as contained in the Joiner Entrust message

Network Master Key base key information for link layer & MLE security

xPANID value used by Thread to uniquely identify Thread networks in wireless range

Mesh Local Prefix used for realm-local traffic within the mesh, consistent for a Thread network



```
#ifndef THR_MASTER_KEY
    #define THR_MASTER_KEY                                  {0x00, 0x11, 0x22, 0x33, 0x44, 0x55, 0x66, 0x77, \
                                                             0x88, 0x99, 0xaa, 0xbb, 0xcc, 0xdd, 0xee, 0xff}
#endif
```

Thread Security

Security Overview

Commissioning

Establish a secure session between a commissioner and a joining device

DTLS with **elliptic curve J-PAKE** to authenticate and provide network credentials

MAC & Mesh Management Layers

AES128 encryption for all messages as defined by IEEE 802.15.4 specification

Thread Network

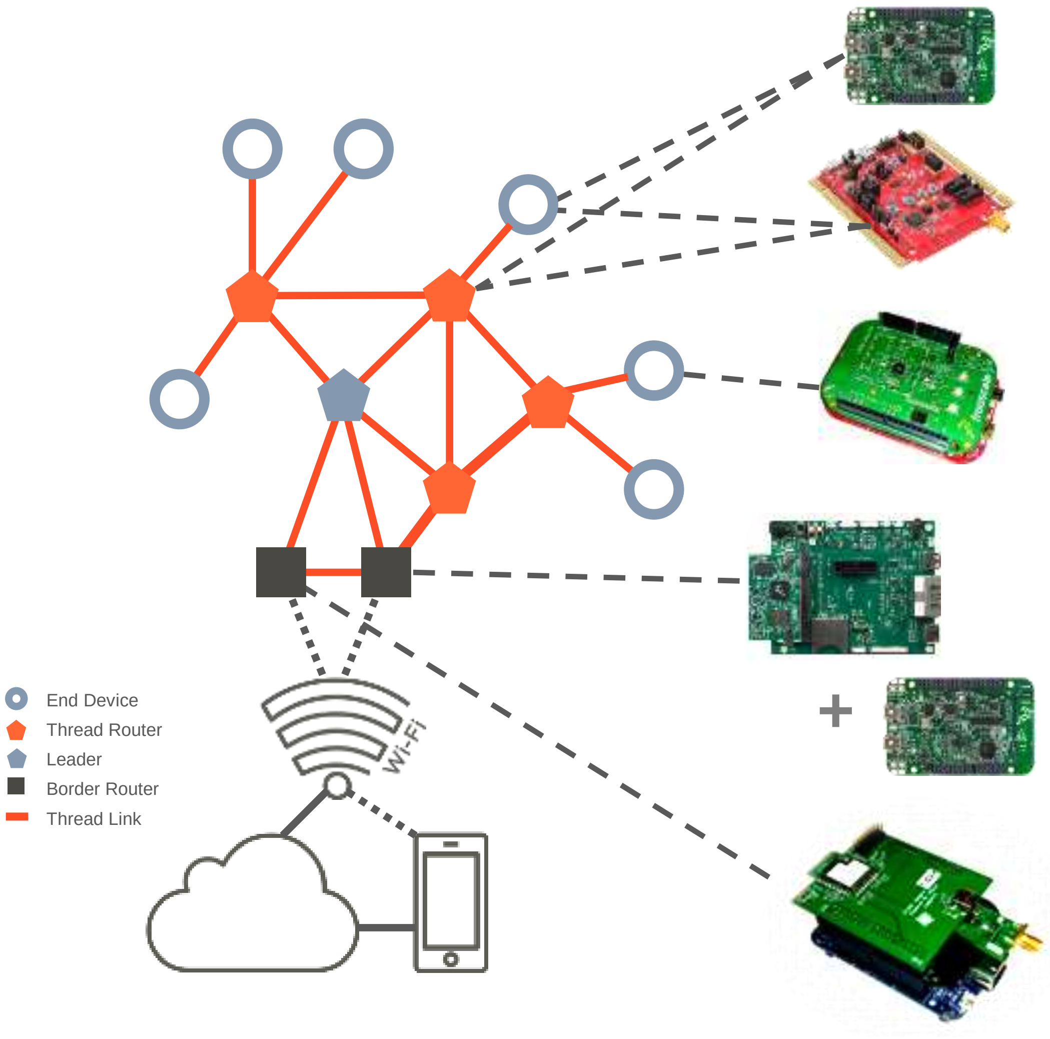
Automatic **key rotation** mechanisms for parameterizing, changing, and negotiating shared network keys change after a time interval

Generic IP layer

Capable of carrying multiple **DTLS** or **TLS** flavors

NXP Kinetis & i.MX Thread Platforms

NXP’s Thread Hardware Offering



NXP Kinetis KW2xD, KW41Z
Thread Router / REED / End Device
Tower Board and Freedom Board
Kinetis SDK and FreeRTOS

NXP Kinetis KL46 + MCR20A Transceiver
Thread End Device
Freedom Board
Kinetis SDK and FreeRTOS

NXP i.MX6 UltraLite EVK + FRDM-KW24D or FRDM-KW41Z
Thread Border Router / Cloud gateway
Provides IP data routing and infrastructure integration
i.MX6UL EVK & Freedom Board
Runs Linux operating system

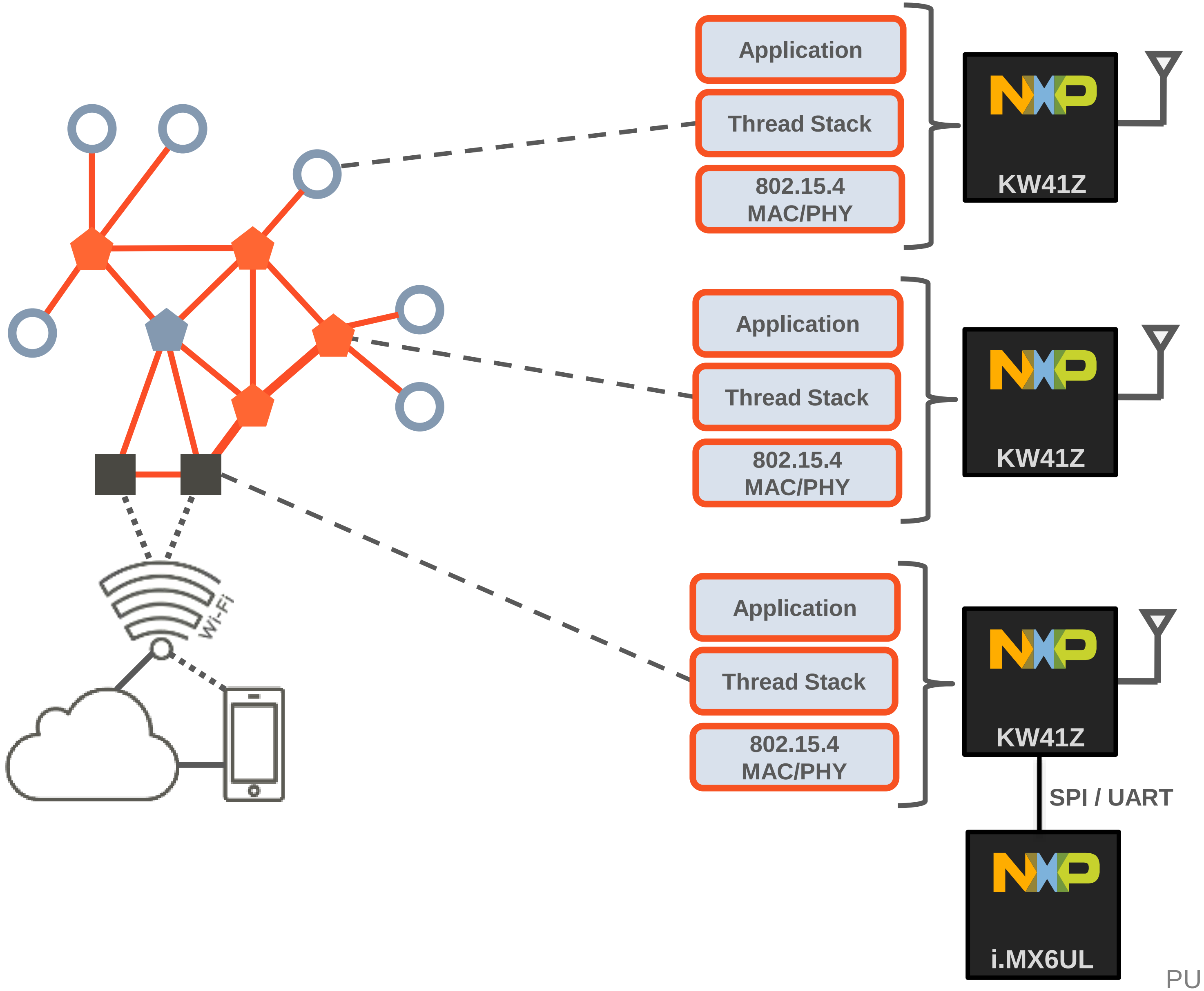
NXP Kinetis K64F + MCR20A Transceiver
Border Router with Ethernet & upcoming Wi-Fi support (QCA400x)
Freedom Boards
Kinetis SDK and FreeRTOS

THREAD
CERTIFIED
COMPONENT

NXP’s KW41Z and KW2xD Thread Stacks are **Now Certified!**

The most **complete** Thread end to end platform available!

KW41Z/21Z Thread Device Type Code Estimates



End Device
256kB Flash
30kB RAM

Router Device
320kB Flash
50kB RAM

Border Router
320kB Flash
50kB RAM

Links of Interest

Links of interest

- Kinetis Thread: www.nxp.com/Thread
- Thread Group: www.threadgroup.org

- KW41Z: www.nxp.com/KW41Z
- FRDM-KW41Z: www.nxp.com/FRDM-KW41Z
- USB-KW41Z: www.nxp.com/USB-KWKW41Z

THREAD Demo

NXP Kinetis Wireless Solutions Agenda

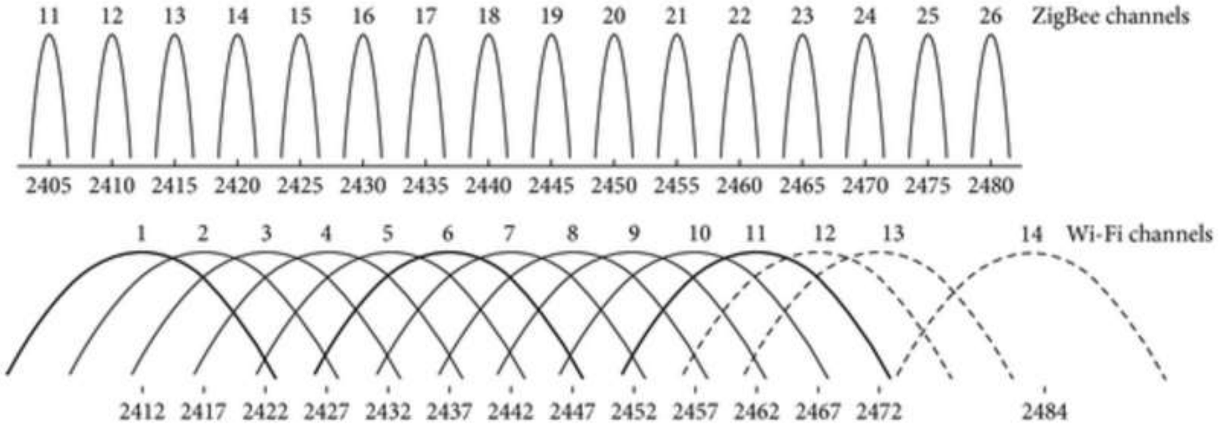
- KW41 Family Overview
- Bluetooth Low Energy (BLE)
- Thread
- BLE+Thread
- Wireless Framework
- Modular Gateway

BLE+Thread

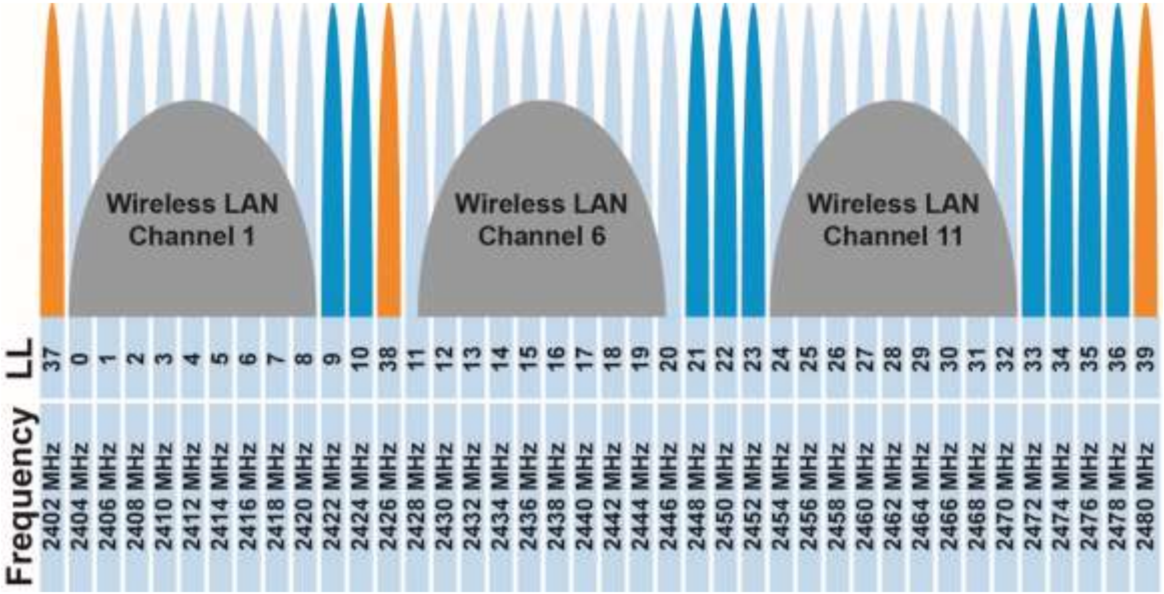
Introduction

KW41 deals with three types of coexistence

- Internal: Two protocols in the same chip (i.e. BLE + 802.15.4)
- Inter-IC: Two chips in the same board (i.e. KW41 + Wi-Fi chip)
- External: KW41 design + 2.4 GHz environment (i.e. Wi-Fi Routers, 802.15.4 networks, Bluetooth devices)



Wi-Fi + 802.15.4 Spectrum


Wireless LAN Channel 1
Wireless LAN Channel 6
Wireless LAN Channel 11
LL
37 0 1 2 3 4 5 6 7 8 9 10 38 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 39
Frequency
2402 MHz 2404 MHz 2406 MHz 2408 MHz 2410 MHz 2412 MHz 2414 MHz 2416 MHz 2418 MHz 2420 MHz 2422 MHz 2424 MHz 2426 MHz 2428 MHz 2430 MHz 2432 MHz 2434 MHz 2436 MHz 2438 MHz 2440 MHz 2442 MHz 2444 MHz 2446 MHz 2448 MHz 2450 MHz 2452 MHz 2454 MHz 2456 MHz 2458 MHz 2460 MHz 2462 MHz 2464 MHz 2466 MHz 2468 MHz 2470 MHz 2472 MHz 2474 MHz 2476 MHz 2478 MHz 2480 MHz

Wi-Fi + BLE Spectrum

Introduction (continue)

The KW41Z includes a 2.4 GHz transceiver that supports the following protocols:

- BLE
- 802.15.4 (Thread, ZigBee…)
- Generic FSK

Inter-ICs (off-chip) coexistence may be enabled by using three GPIOs to signal RF activity and request access to the medium.

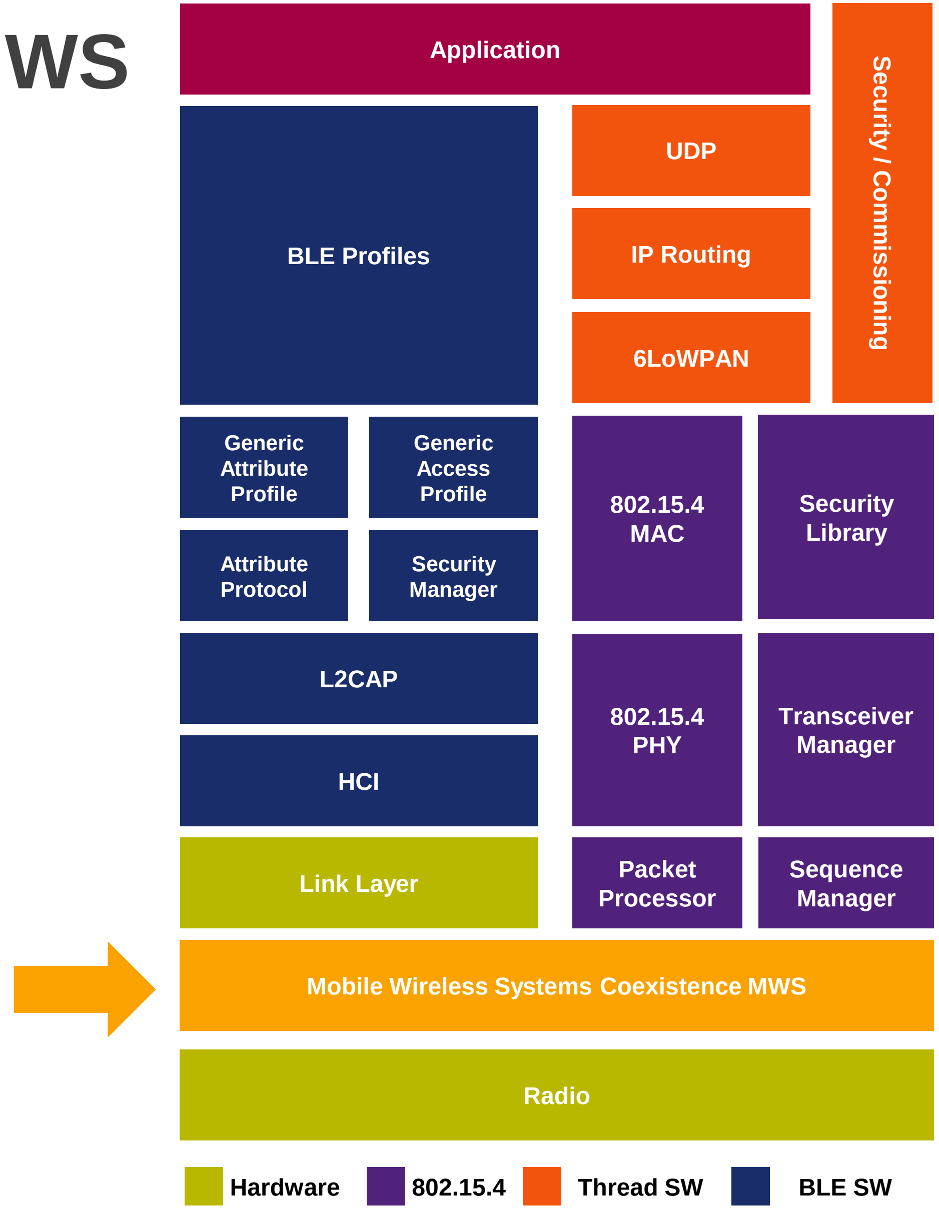
Pin name	Direction	Description
RF_ACTIVE	Output	Signals when the transceiver becomes active
RF_STATUS	Output	Signals RF activity type (RX/TX) and the priority of the sequence
RF_DENY	Input	Signals if the access to the medium is granted or not

Mobile Wireless Systems Coexistence MWS

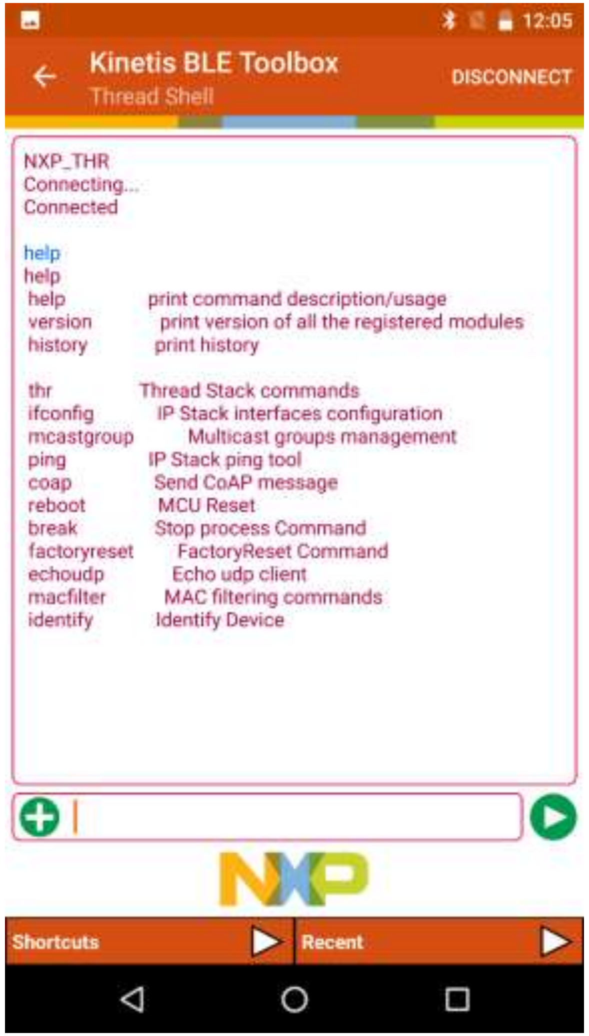
Is a set of APIs included in the Connectivity Framework

Allows Link Layers and higher layers control the access to the resources.

Allows inter-ICs coexistence (i.e. BLE + external Wi-Fi chip)



Thread + BLE KW41 Demo Application



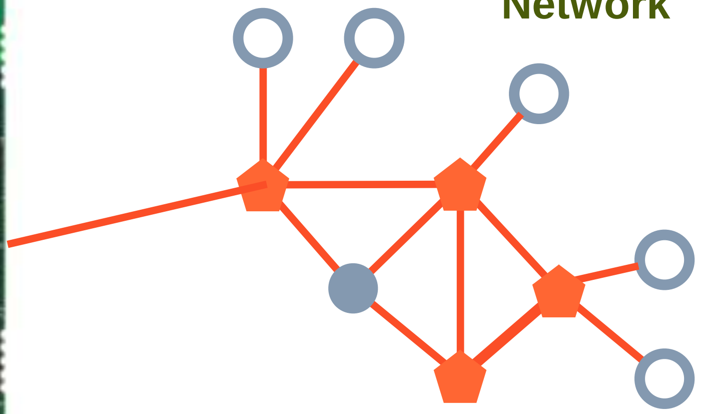
```
NXP_THR
Connecting...
Connected

help
help
 help          print command description/usage
 version         print version of all the registered modules
 history        print history

 thr          Thread Stack commands
 ifconfig         IP Stack interfaces configuration
 mcastgroup           Multicast groups management
 ping          IP Stack ping tool
 coap          Send CoAP message
 reboot          MCU Reset
 break          Stop process Command
 factoryreset       FactoryReset Command
 echoudp         Echo udp client
 macfilter         MAC filtering commands
 identify         Identify Device
```

BLE UART to Thread Shell

BLE Direct Communication

FRDM-KW41Z

Thread Network



BLE+Thread Demo

hsdk

Host SDK (Host Software Development Kit)

Overview

The Kinetis Wireless Host SDK consists in a set of cross-platform C language libraries which can be integrated into a variety of user defined applications for interacting with Kinetis Wireless Microcontrollers.

- The Kinetis Wireless Host SDK is meant to run on Windows OS, Linux OS, Apple OS X ® and OpenWrt

- The HSDK software is designed to help developers interact with Host SDK from Python and C programming languages

Host SDK - THCI

The Host SDK implements two physical layers for transporting THCI:

- UART - for direct UART

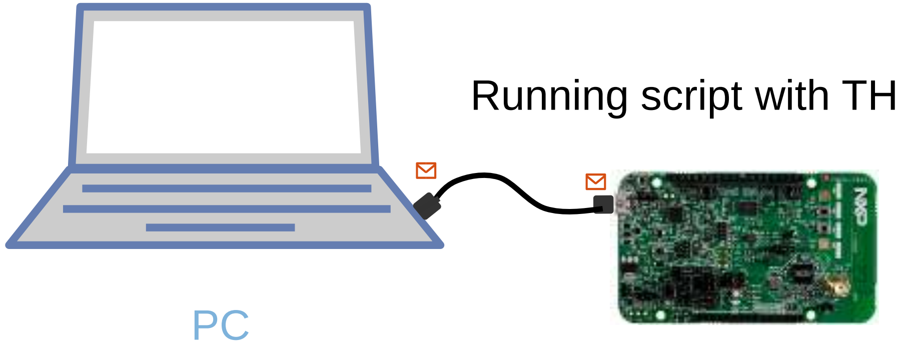
The UART layer handles sending and receiving THCI frames over a serial interface to a Thread-enabled device.

C sample codes:

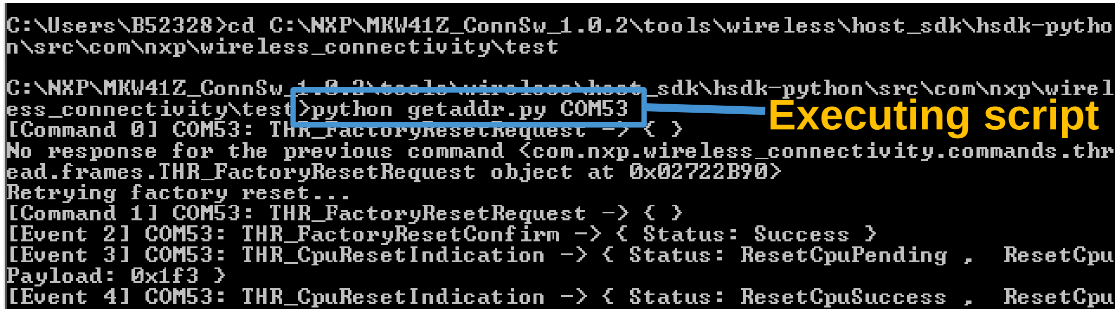
<installation path>NXP\MKW41Z_ConnSw_1.0.2\tools\wireless\host_sdk\hsdk\demo

Python sample codes:

<installation path>\MKW41Z_ConnSw_1.0.2\tools\wireless\host_sdk\hsdk-python\src\com\nxp\wireless_connectivity\test



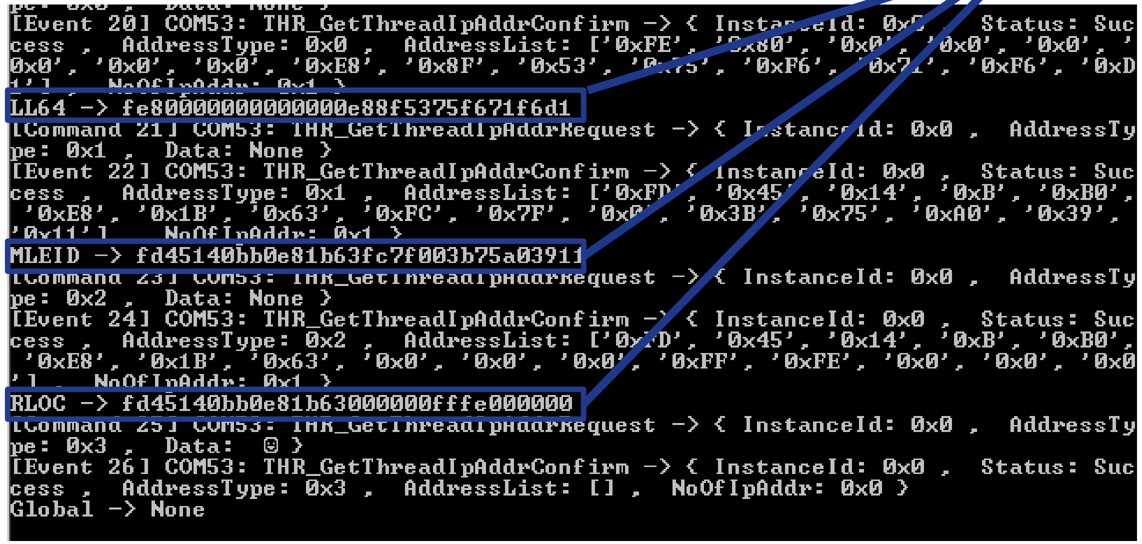
*Thread Host Controlled Device



```
C:\Users\B52328>cd C:\NXP\MKW41Z_ConnSw_1.0.2\tools\wireless\host_sdk\hsdk-pytho
n\src\com\nxp\wireless_connectivity\test

C:\NXP\MKW41Z_ConnSw_1.0.2\tools\wireless\host_sdk\hsdk-python\src\com\nxp\wirel
ess_connectivity\test>python getaddr.py COM53
[Command 0] COM53: THR_FactoryResetRequest -> { }
No response for the previous command <com.nxp.wireless_connectivity.commands.thr
ead.frames.THR_FactoryResetRequest object at 0x02722B90>
Retrying factory reset...
[Command 1] COM53: THR_FactoryResetRequest -> { }
[Event 2] COM53: THR_FactoryResetConfirm -> { Status: Success }
[Event 3] COM53: THR_CpuResetIndication -> { Status: ResetCpuPending ,  ResetCpu
Payload: 0x1f3 }
[Event 4] COM53: THR_CpuResetIndication -> { Status: ResetCpuSuccess ,  ResetCpu
```

The script "getaddr.py" sends THCI commands from the PC host to the board.

It performs a factory reset, creates a network and then it gets the device's IPv6 addresses

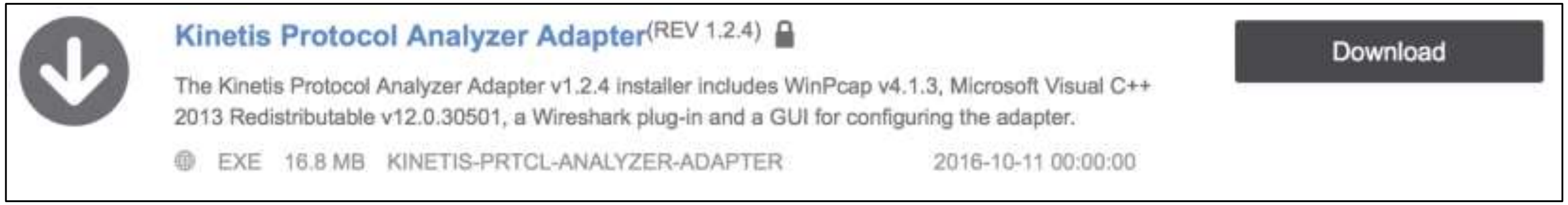


```
pe: 0x0 ,  Data: None }
[Event 20] COM53: THR_GetThreadIpAddrConfirm -> { InstanceId: 0x0 ,  Status: Suc
cess ,  AddressType: 0x0 ,  AddressList: ['0xFE', '0x80', '0x0', '0x0', '0x0', '
0x0', '0x0', '0x0', '0xE8', '0x8F', '0x53', '0x75', '0xF6', '0x71', '0xF6', '0xD
1'] ,  NoOfIpAddr: 0x1 }
LL64 -> fe80000000000000e88f5375f671f6d1
[Command 21] COM53: THR_GetThreadIpAddrRequest -> { InstanceId: 0x0 ,  AddressTy
pe: 0x1 ,  Data: None }
[Event 22] COM53: THR_GetThreadIpAddrConfirm -> { InstanceId: 0x0 ,  Status: Suc
cess ,  AddressType: 0x1 ,  AddressList: ['0xFD', '0x45', '0x14', '0xB', '0xB0',
 '0xE8', '0x1B', '0x63', '0xFC', '0x7F', '0x0', '0x3B', '0x75', '0xA0', '0x39',
'0x11'] ,  NoOfIpAddr: 0x1 }
MLEID -> fd45140bb0e81b63fc7f003b75a03911
[Command 23] COM53: THR_GetThreadIpAddrRequest -> { InstanceId: 0x0 ,  AddressTy
pe: 0x2 ,  Data: None }
[Event 24] COM53: THR_GetThreadIpAddrConfirm -> { InstanceId: 0x0 ,  Status: Suc
cess ,  AddressType: 0x2 ,  AddressList: ['0xFD', '0x45', '0x14', '0xB', '0xB0',
 '0xE8', '0x1B', '0x63', '0x0', '0x0', '0x0', '0xFF', '0xFE', '0x0', '0x0', '0x0
'] ,  NoOfIpAddr: 0x1 }
RLOC -> fd45140bb0e81b630000000fffe000000
[Command 25] COM53: THR_GetThreadIpAddrRequest -> { InstanceId: 0x0 ,  AddressTy
pe: 0x3 ,  Data:  ☺ }
[Event 26] COM53: THR_GetThreadIpAddrConfirm -> { InstanceId: 0x0 ,  Status: Suc
cess ,  AddressType: 0x3 ,  AddressList: [] ,  NoOfIpAddr: 0x0 }
Global -> None
```

SNIFFING

Sniffer with Wireshark + USB-KW24D512

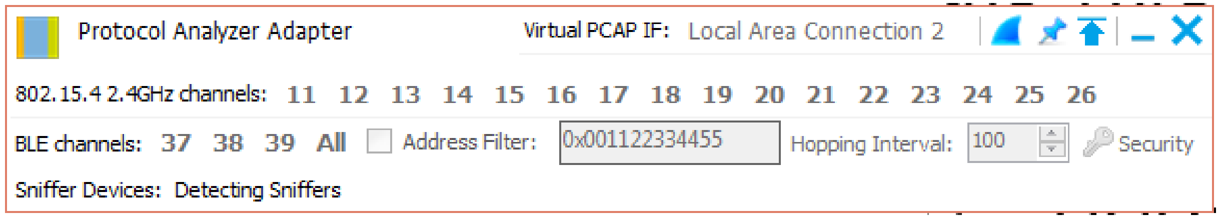
- Download and install the **Kinetis Protocol Analyzer Adapter** for USB-KW41Z or USB-KW24D512
- Direct link



Kinetis Protocol Analyzer Adapter (REV 1.2.4)

The Kinetis Protocol Analyzer Adapter v1.2.4 installer includes WinPcap v4.1.3, Microsoft Visual C++ 2013 Redistributable v12.0.30501, a Wireshark plug-in and a GUI for configuring the adapter.

EXE 16.8 MB KINETIS-PRTCL-ANALYZER-ADAPTER 2016-10-11 00:00:00



Protocol Analyzer Adapter Virtual PCAP IF: Local Area Connection 2

802.15.4 2.4GHz channels: 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26

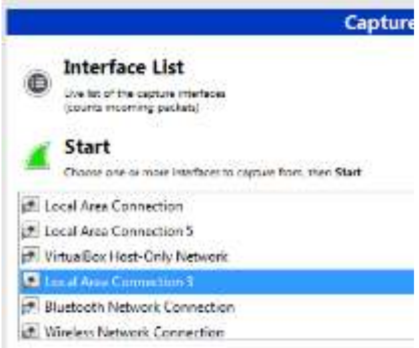
BLE channels: 37 38 39 All □ Address Filter: 0x001122334455 Hopping Interval: 100 Security

Sniffer Devices: Detecting Sniffers

- Support both Wireshark and Ubiqua.

WIRESHARK

ubiqua protocol analyzer edition



Capture

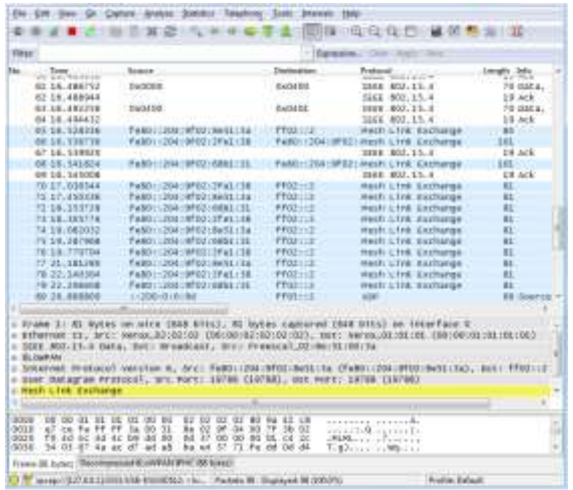
Interface List

Live list of the capture interfaces (counts incoming packets)

Start

Choose one or more interfaces to capture from, then Start

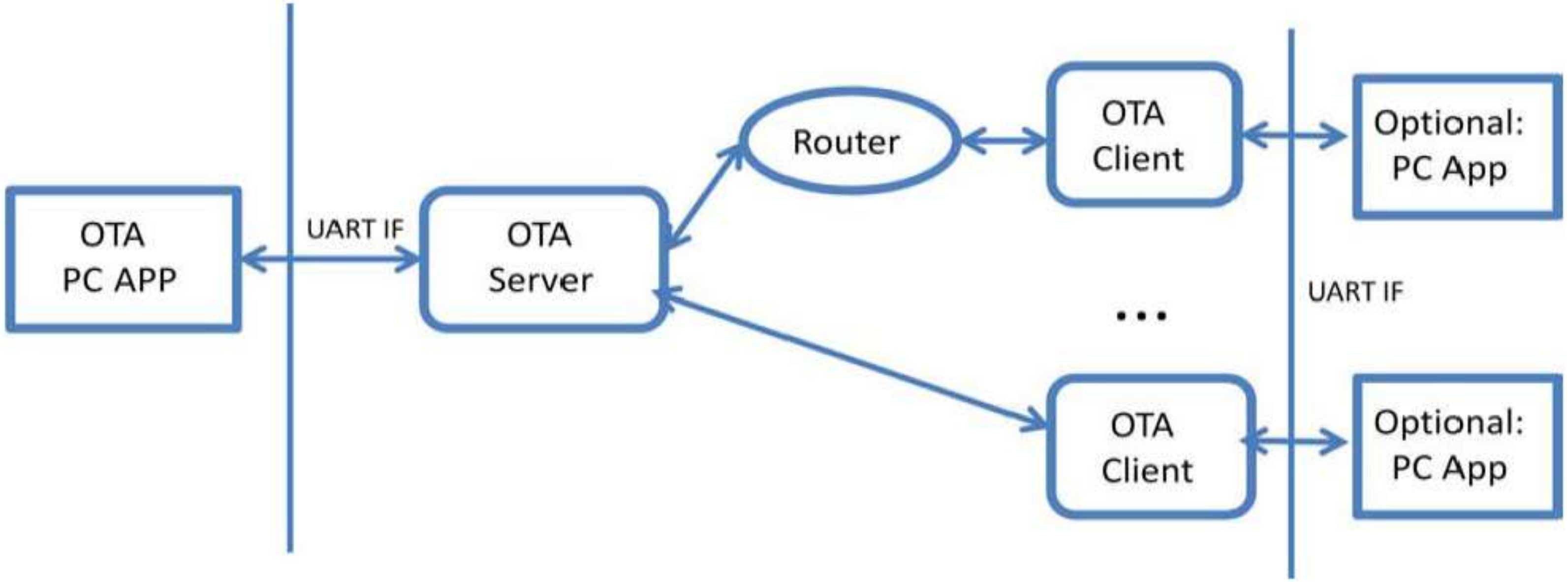
Local Area Connection
Local Area Connection 5
VirtualBox Host-Only Network
Local Area Connection 3
Bluetooth Network Connection
Wireless Network Connection



Over The Air Updates

Over-The-Air (OTA) Updates

- For large networks, or for in the field updates, send new firmware wirelessly
- One server node sends the updated firmware, with one or more client nodes receiving.
- Uses Test Tool, a Windows program that communicates with the server node via FSCI (using a UART or USB interface to the board).



NXP Test Tool

- PC Software to communicate over serial paths to wireless development boards
  - FSCI Serial Communication for Host PC control and development prototyping
  - Used for Over-the-Air Update based Out-of-the-Box Examples
- Detailed instructions found in **\docs\wireless\Thread\Kinetis Thread Stack OTA Firmware Update User's Guide.pdf**

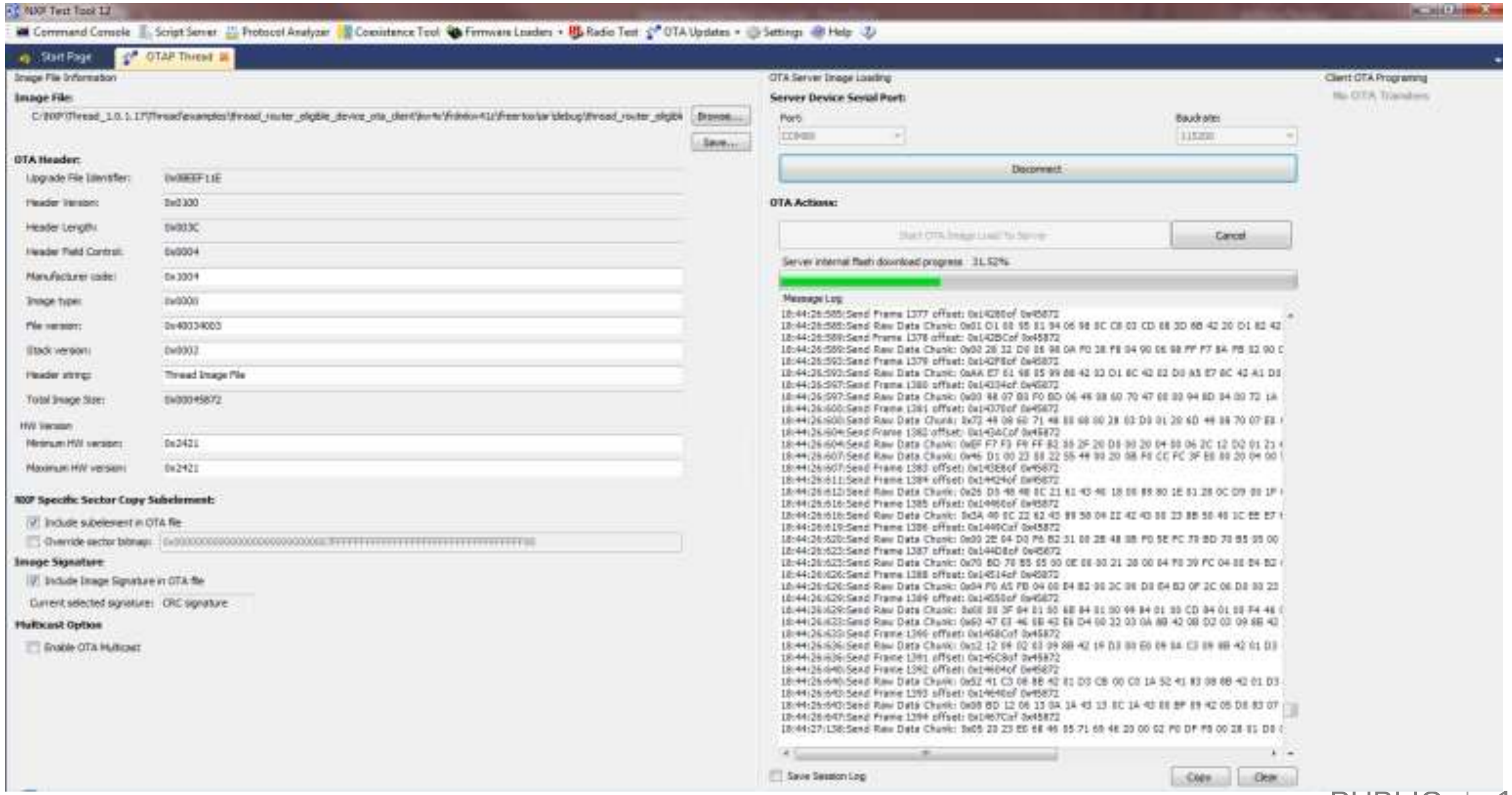


Image File Information

Image File:

C:\NXP\Thread_1.0.1.17\Thread\examples\thread_router_eligible_device_ota_client\frdmkw41z\freertos\iar\debug\thread_router_eligib

OTA Header:

Upgrade File Identifier:	0x0BEEF11E
Header Version:	0x0100
Header Length:	0x003C
Header Field Control:	0x0004
Manufacturer code:	0x1004
Image type:	0x0000
File version:	0x40034003
Stack version:	0x0002
Header string:	Thread Image File
Total Image Size:	0x00045872

HW Version

Minimum HW version:	0x2421
Maximum HW version:	0x2421

NXP Specific Sector Copy Subelement:

☑ Include subelement in OTA file

☐ Override sector bitmap: 0x000000000000000000000000000007FFFFFFFFFFFFFFFFFFFFFFFFFFFFFFF00

Image Signature

☑ Include Image Signature in OTA file

Current selected signature: CRC signature

Multicast Option

☐ Enable OTA Multicast

OTA Server Image Loading

Server Device Serial Port:

Port: COM80

Baudrate: 115200

OTA Actions:

Server internal flash download progress: 31.52%

Message Log

```
18:44:26:585:Send Frame 1377 offset: 0x14280of 0x45872
18:44:26:585:Send Raw Data Chunk: 0x01 D1 08 95 81 94 06 98 8C C8 03 CD 68 3D 6B 42 20 D1 82 42
18:44:26:589:Send Frame 1378 offset: 0x142BCof 0x45872
18:44:26:589:Send Raw Data Chunk: 0x00 28 32 D0 88 98 0A F0 38 F8 04 90 06 98 FF F7 84 FB 82 90 C
18:44:26:593:Send Frame 1379 offset: 0x142F8of 0x45872
18:44:26:593:Send Raw Data Chunk: 0xAA E7 61 98 85 99 88 42 32 D1 8C 42 82 D0 A5 E7 8C 42 A1 D8
18:44:26:597:Send Frame 1380 offset: 0x14334of 0x45872
18:44:26:597:Send Raw Data Chunk: 0x00 48 07 B0 F0 BD 06 46 08 60 70 47 68 80 94 8D 04 00 72 1A
18:44:26:600:Send Frame 1381 offset: 0x14370of 0x45872
18:44:26:600:Send Raw Data Chunk: 0x72 49 08 60 71 48 88 68 00 28 03 D0 01 20 6D 49 08 70 07 E8
18:44:26:604:Send Frame 1382 offset: 0x143ACof 0x45872
18:44:26:604:Send Raw Data Chunk: 0xEF F7 F3 F9 FF 82 30 2F 20 D0 30 20 04 00 06 2C 12 D2 01 21
18:44:26:607:Send Raw Data Chunk: 0x46 D1 00 23 88 22 55 49 90 20 08 F0 CC FC 3F E8 80 20 04 00
18:44:26:607:Send Frame 1383 offset: 0x143E8of 0x45872
18:44:26:611:Send Frame 1384 offset: 0x14424of 0x45872
18:44:26:612:Send Raw Data Chunk: 0x26 D3 48 48 8C 21 61 43 46 18 08 89 80 1E 81 28 0C D9 80 1F
18:44:26:616:Send Frame 1385 offset: 0x14460of 0x45872
18:44:26:616:Send Raw Data Chunk: 0x2A 40 8C 22 62 43 89 50 04 22 42 40 08 23 8B 50 48 1C EE E7
18:44:26:619:Send Frame 1386 offset: 0x1449Cof 0x45872
18:44:26:620:Send Raw Data Chunk: 0x00 2E 04 D0 F6 B2 31 00 28 48 08 F0 5E FC 78 BD 70 B5 05 00
18:44:26:623:Send Frame 1387 offset: 0x144D8of 0x45872
18:44:26:623:Send Raw Data Chunk: 0x70 BD 70 B5 05 00 0E 00 00 21 28 00 04 F0 39 FC 04 00 B4 B2
18:44:26:626:Send Frame 1388 offset: 0x14514of 0x45872
18:44:26:626:Send Raw Data Chunk: 0x04 F0 A5 FB 04 00 E4 B2 00 2C 06 D0 04 B2 0F 2C 06 D0 30 23
18:44:26:629:Send Frame 1389 offset: 0x14550of 0x45872
18:44:26:629:Send Raw Data Chunk: 0x00 00 3F 04 01 50 6B 84 01 50 69 84 01 80 CD 84 01 88 F4 46
18:44:26:633:Send Raw Data Chunk: 0x60 47 C3 46 6B 43 E6 D4 00 22 03 0A 88 42 0B D2 03 09 6B 42
18:44:26:633:Send Frame 1390 offset: 0x1458Cof 0x45872
18:44:26:636:Send Raw Data Chunk: 0x12 12 04 02 63 09 88 42 19 D3 80 E0 04 0A C3 09 8B 42 01 D3
18:44:26:636:Send Frame 1391 offset: 0x145C8of 0x45872
18:44:26:640:Send Frame 1392 offset: 0x14604of 0x45872
18:44:26:640:Send Raw Data Chunk: 0x52 41 C3 08 8B 42 01 D3 CB 00 C0 1A 52 41 83 08 8B 42 01 D3
18:44:26:643:Send Frame 1393 offset: 0x14640of 0x45872
18:44:26:643:Send Raw Data Chunk: 0x08 BD 12 06 13 0A 1A 43 13 8C 1A 40 88 BF 89 42 05 D8 83 07
18:44:26:647:Send Frame 1394 offset: 0x1467Cof 0x45872
18:44:27:138:Send Raw Data Chunk: 0x05 20 23 E6 68 46 85 71 68 46 20 00 02 F0 DF F8 00 28 81 D0
```

☐ Save Session Log

Client OTA Programing

No OTA Transfers

NXP Kinetis Wireless Solutions Agenda

- **KW41 Family Overview**
- **Bluetooth Low Energy (BLE)**
- **Thread**
- **BLE+Thread**
- **Wireless Framework**
- **Modular Gateway**

Modular IoT framework

Developers need a development platform, not another IoT board…

- Solving real problems that IoT developers face:
  - Leveraging easy-to-use optimized, modular solutions
  - Providing a marketplace to take makers from idea to product

Easy-to-use

Optimized in an end-product design

Functional modularity

+

Open Source

Flexible connectivity

System Support

+

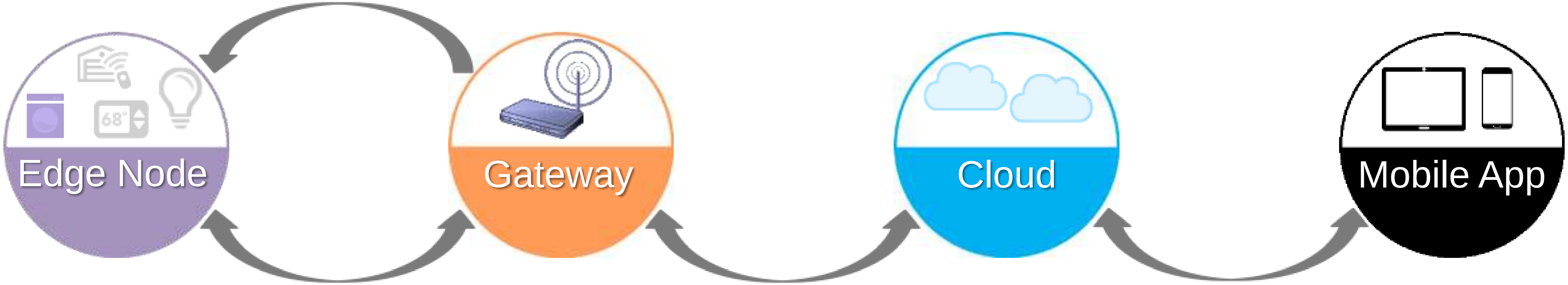
NXP
Solution

Proven Partner Ecosystem

Modular IoT Framework: Integrated Development Experience

- Easily connect Edge Nodes to the Gateway with commissioning
- Exchange data between Edge Nodes and Getaway via secured mesh connectivity
- Communicate with the Cloud from the Gateway via secured connectivity
- Monitor & control your Edge Nodes via the Cloud using application HMI

1 **Easily connects**
Thread Edge Nodes and Border Router



Edge Node

Gateway

Cloud

Mobile App

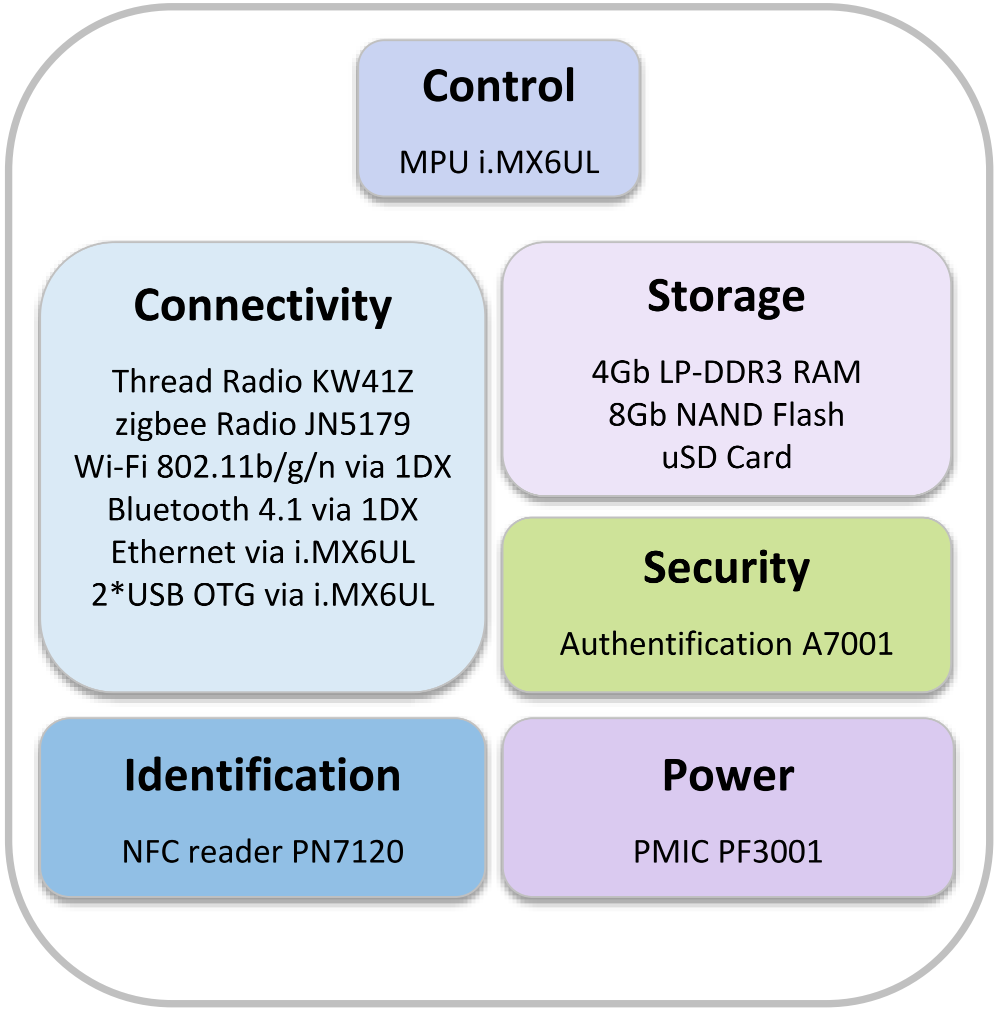
2 **Exchange data**
with Thread connectivity

3 **Communicate data**
with secure Cloud protocols

4 **Monitor and Control**
Edge Nodes with Application HMI

Modular IoT Gateway

Modular IoT Gateway: Optimized Combination of Technology



Control

MPU i.MX6UL

Connectivity

Thread Radio KW41Z
zigbee Radio JN5179
Wi-Fi 802.11b/g/n via 1DX
Bluetooth 4.1 via 1DX
Ethernet via i.MX6UL
2*USB OTG via i.MX6UL

Storage

4Gb LP-DDR3 RAM
8Gb NAND Flash
uSD Card

Security

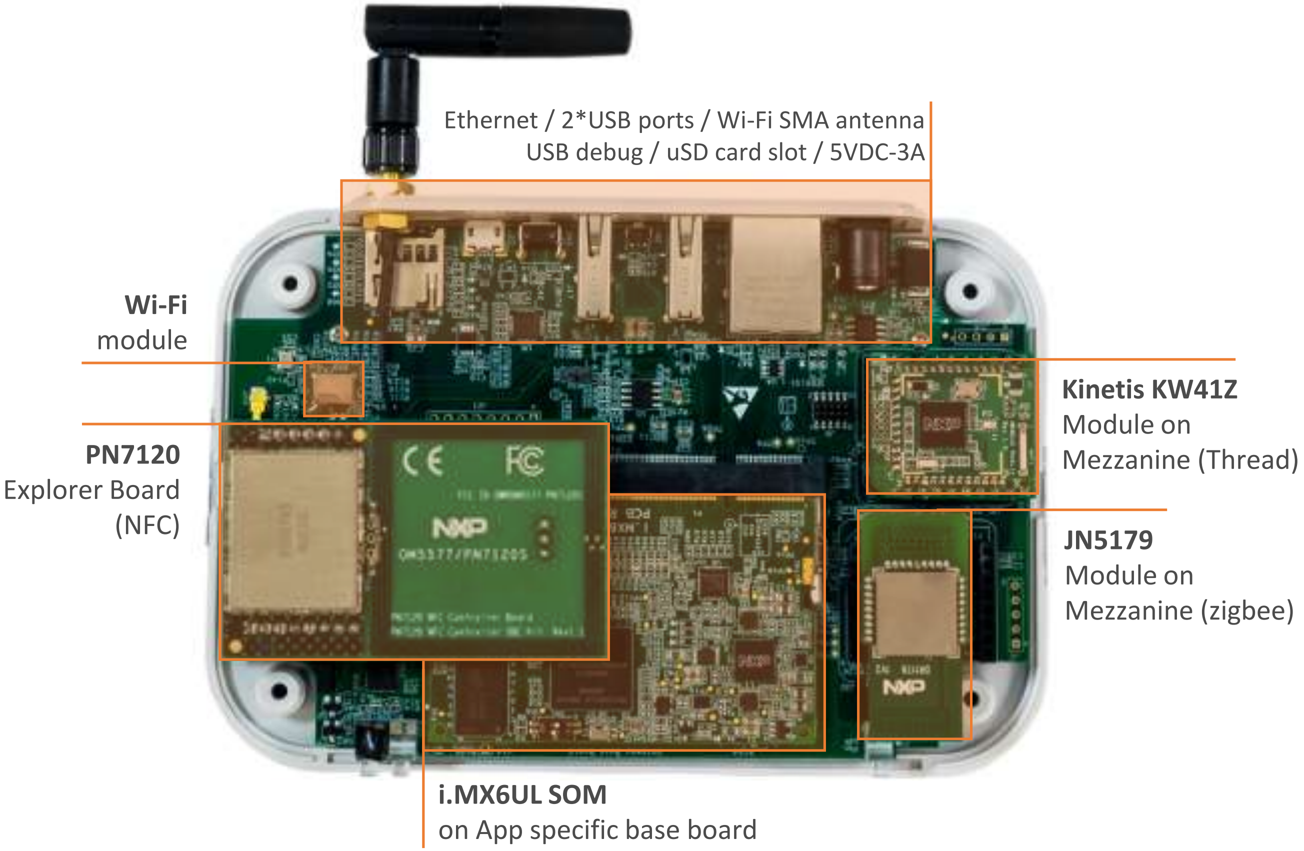
Authentification A7001

Identification

NFC reader PN7120

Power

PMIC PF3001



Ethernet / 2*USB ports / Wi-Fi SMA antenna
USB debug / uSD card slot / 5VDC-3A

Wi-Fi
module

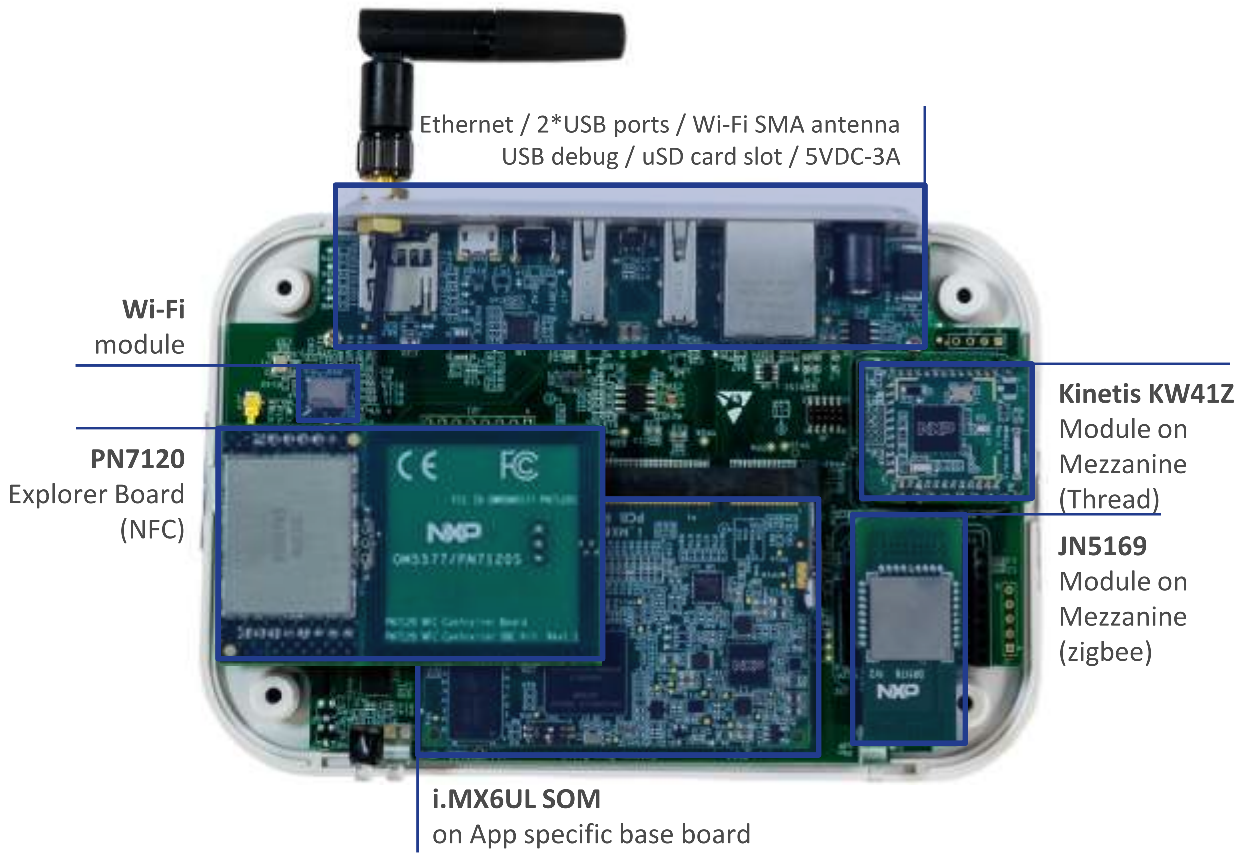
PN7120
Explorer Board
(NFC)

Kinetis KW41Z
Module on
Mezzanine (Thread)

JN5179
Module on
Mezzanine (zigbee)

i.MX6UL SOM
on App specific base board

Modular IoT Gateway Overview



Ethernet / 2*USB ports / Wi-Fi SMA antenna
USB debug / uSD card slot / 5VDC-3A

Wi-Fi
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PN7120
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(NFC)

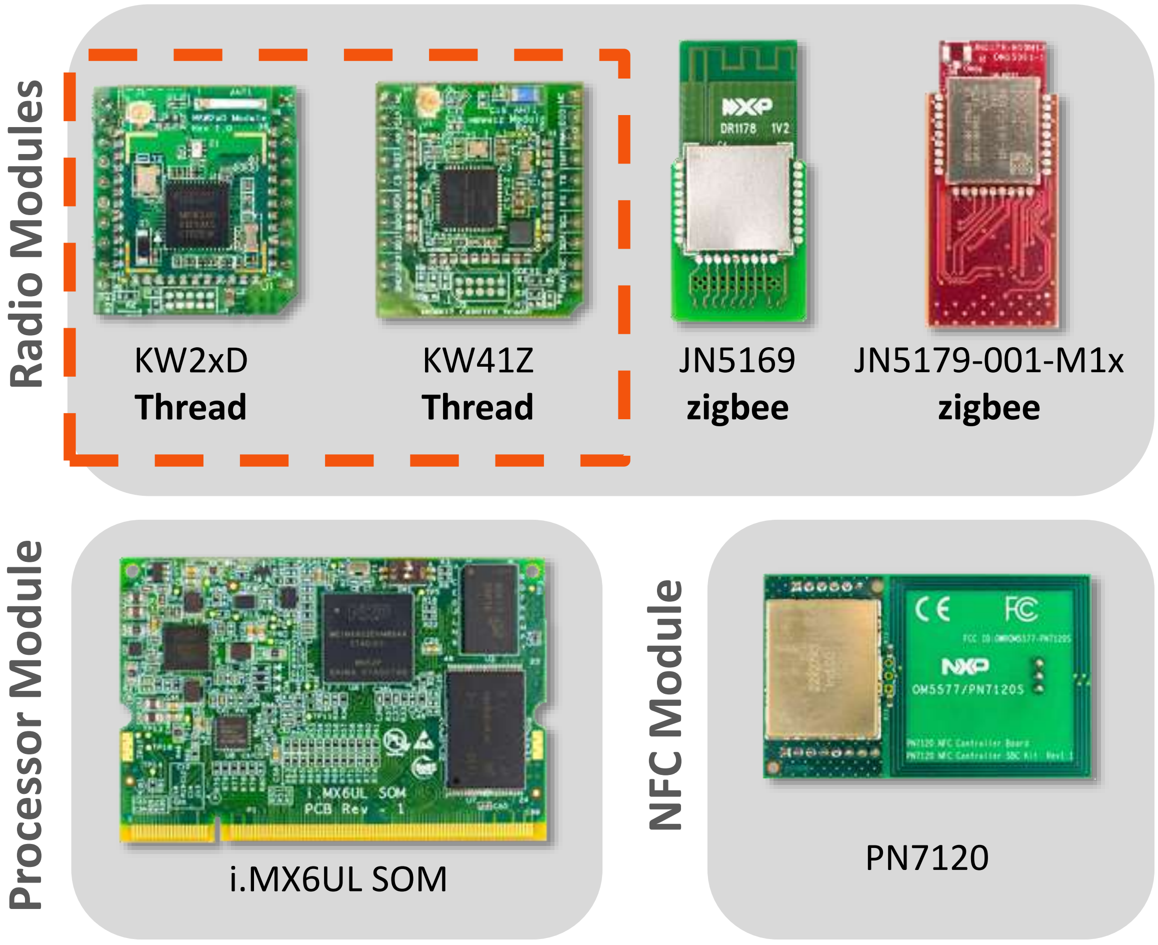
Kinetis KW41Z
Module on
Mezzanine
(Thread)

JN5169
Module on
Mezzanine
(zigbee)

i.MX6UL SOM
on App specific base board

Shipping Today:
NXP Part # SLN-NTW-GTWY

Hardware Modules



Radio Modules

KW2xD
Thread

KW41Z
Thread

JN5169
zigbee

JN5179-001-M1x
zigbee

Processor Module

i.MX6UL SOM

NFC Module

PN7120

Modular IoT Gateway | Multi-protocol interoperability

- Pre-integrated, tested and certified southbound mesh support for the a wide array of wireless protocols, with flexibility to work together or independently, enabling end-to-end wireless communications in LNN configurations.

Southbound Mesh:

zigbee

THREAD

Northbound:

WiFi

EtherNet

Application Layer Support
- ✓ CoAP per Thread Spec.
- ✓ CoAP Observe Funct.
- ✓ zigbee 3.0
- ✓ MQTT

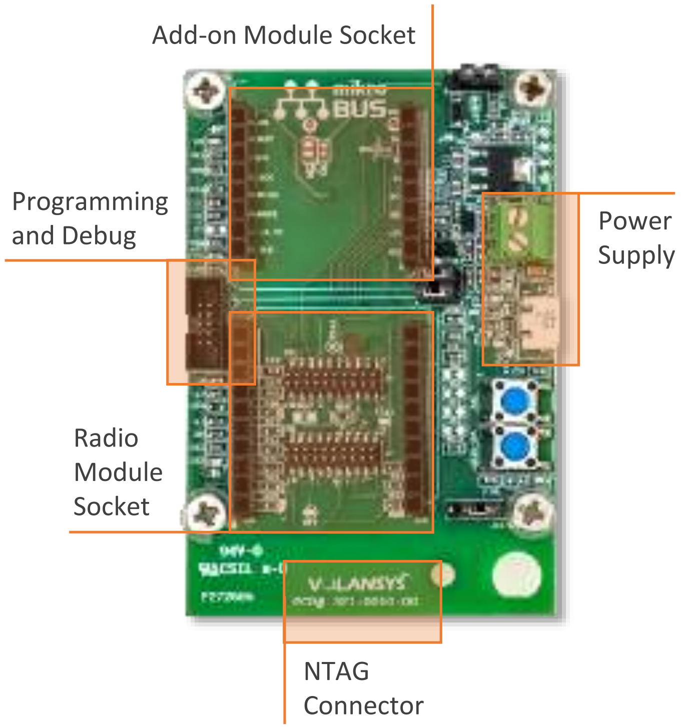
NFC Tap & Connect Commissioning

Intrepid Smart App Commissioning

Currently Shipping Integrated Development Experience v1.0 !!

Modular IoT End Node

Modular Simple Edge Node: Platform and Modules



Shipping Today
with Modular IoT Gateway
Part# SLN-NTW-GTWY

Hardware Modules

Radio Modules

KW2xD
Thread

KW41Z
Thread

JN5169
zigbee

JN5179-001-M1x
zigbee

Sensor/Actuator Add-on Modules

Integrated Development Experience

Modular IoT Framework v1.0

- Best starting point for i.MX / Kinetis smart connectivity developers to go from concept to production.

- Solutions focus is on implementation efficiency.

- Get Kinetis edge devices connected in mesh to the i.MX Gateway and to the cloud using less:
  - Time
  - Effort
  - Expertise

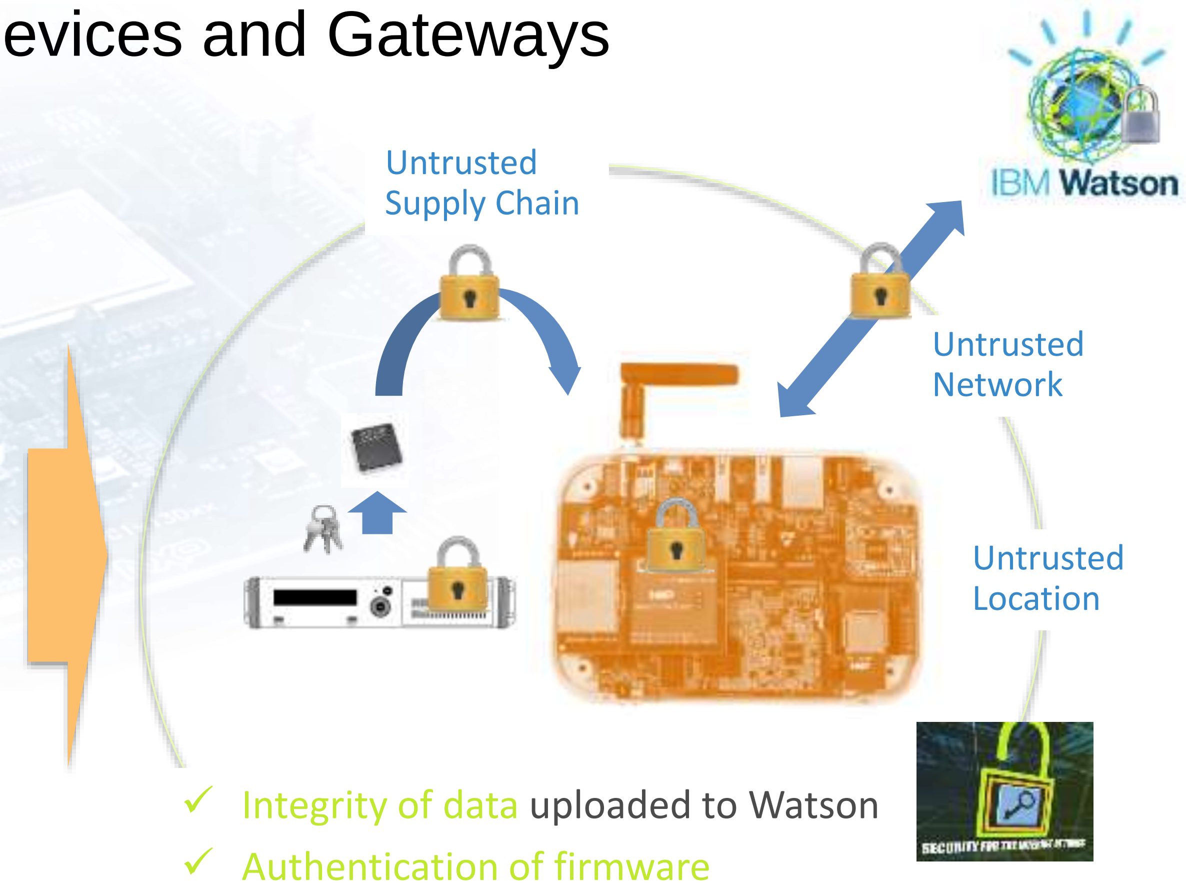
NXP Security Technology provides strong authentication and key management solution for devices connected to the IoT

- Coming Soon: Enabling Trust into IoT Devices and Gateways

A-series Security IC

The Trust Anchor

- Isolation of Device Credentials from Application SW
- Ultra-Secure, hardware-based, **key storage**
- Best-in Class **Tamper Resistance**
- Support to widely used secure messaging standards (TLS)
- **Factory key pre-injection** (die individual) in certified, secure environment



- ✓ Integrity of data uploaded to Watson
- ✓ Authentication of firmware
- ✓ Secure Auto-connect to network or infrastructure
- ✓ Lock of Business model (access to services)

How To Engage with NXP IoT Solutions

…to begin your Thread Development:

- **Where to get more information and to purchase the kit:**
  - www.nxp.com/modulargateway

- **Online Technical Documentation:**
  - www.nxp.com/go/modulargateway *(access required)*

- **Community Support for the Modular Framework:**
  - https://community.nxp.com/groups/modular-framework

NXP Kinetis Wireless Solutions Agenda

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SECURE CONNECTIONS
FOR A SMARTER WORLD