Wireless IoT Technologies and Applications - Bluetooth Low Energy

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“The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment.”

- Gartner

“IoT is the integration of devices with an open architecture data storage and application facility, i.e. cloud, to enable new sensor and data driven experiences that increase productivity, convenience, and security for operational entities and individual users.”

- Sensors Online
Why we care?

The INTERNET of THINGS

- Anything Any Device
- Anyone Anybody
- Anytime Any Context
- Any Place Anywhere
- Any Service Any Business
- Any Path Any Network
IOT Is Already Here

Source: Cisco IBSG, 2012
Key enablers of IoT:

- Sensors
- Processors
- Network Bandwidth
- Energy Efficiency
- Quality and reliability
- Cost-effectiveness
- Security and privacy
- Ubiquitous wireless connectivity
- IPv6
1st Generation Device: Nest Thermostat

Installation
Nest Labs claims that most customers can install the device in 30 minutes or less.

MAIN UNIT
Contains display, sensors and controls. Plugs into the base unit.

BASE UNIT
Mounts on wall and connects to heating and cooling system wiring.

STAINLESS STEEL RING
Used to set the temperature and control the interface.

RF SHIELD FRAME
(Shield removed to show components)

BATTERY
For levelling during installation.

TEMPERATURE AND HUMIDITY SENSOR

REMOTE OPERATION
Mobile apps enable Nest to be operated remotely via Wi-Fi using a smartphone, tablet or laptop. The iPad app is shown below.

Visual Cues
The display's background is normally black, but changes to orange when heating and blue when cooling.

IoT Wireless Connectivity

- Multiple Standards
- Power consumption largely dependent on transmission range and protocol

IEEE 802.11 (Wi-Fi®)
IEEE 802.15.4 (ZigBee™)
Cellular 2G/3G/4G
IEEE 802.16 (WiMAX)
UWB
Bluetooth™
NFC/RFID
Land Mobile Radio

## Comparison of PAN Wireless Connectivity

<table>
<thead>
<tr>
<th>Standard</th>
<th>BLE</th>
<th>Zigbee</th>
<th>NFC</th>
<th>WiFi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Current</td>
<td>10-16mA</td>
<td>30-40mA</td>
<td>50mA</td>
<td>116mA</td>
</tr>
<tr>
<td>Frequency Band</td>
<td>2.4GHz</td>
<td>2.4GHz</td>
<td>13.56MHz</td>
<td>2.4GHz; 5GHz</td>
</tr>
<tr>
<td>Data/Chip rate</td>
<td>1-Mbps</td>
<td>250Kbps</td>
<td>106-424Kbps</td>
<td>1,300Mbps</td>
</tr>
<tr>
<td>Range</td>
<td>~50m</td>
<td>100-300m</td>
<td>&lt;20cm</td>
<td>~50m</td>
</tr>
<tr>
<td>Latency</td>
<td>2.5ms</td>
<td>20ms, 30ms from sleep</td>
<td>Polled typically every sec</td>
<td>1.5ms</td>
</tr>
<tr>
<td>Network Topology</td>
<td>Star, Point-to-point</td>
<td>Star, Mesh, Cluster Tree</td>
<td>Point-to-point</td>
<td>Star</td>
</tr>
<tr>
<td>Scalability</td>
<td>Good</td>
<td>Very Good</td>
<td>Poor</td>
<td>Very Good</td>
</tr>
<tr>
<td>Application Area</td>
<td>PAN / Healthcare</td>
<td>Industrial / Building</td>
<td>Commerce / Marketing</td>
<td>Home / Office</td>
</tr>
</tbody>
</table>

Note: BLE stands for Bluetooth Low Energy, NFC stands for Near Field Communication, WiFi stands for Wireless Fidelity.
Why Choose BLE?

Ultra-low peak, average and idle power consumption
- ~15mA peak current
- ~5μA average current
- Run for years on standard coin-cell batteries

Low implementation costs
- Reuse as much Bluetooth RF as possible
- Remains Royalty free

Cross-vendor interoperability
Why Choose BLE? (Cont.)

- Widely available in consumer electronic products
BLE Shipment Forecast

Bluetooth enabled device shipments worldwide (billions)

Source: IHS Technology

BLE Market Opportunities

Bluetooth Smart growth 2013-2014

- Health & Wellness: +77%
- Beacons & Retail: +106%
- Consumer Electronics: +107%
- Smart Home: +232%

Source: ABI Research

Evolution of Bluetooth Low Energy (BLE)

Bluetooth 4.0

- Core Specification was adopted in 2010

Wireless devices streaming rich content like video and audio

Devices that connect with both

Sensor devices sending small bits of data, using very little energy
Evolution of Bluetooth Low Energy (BLE)

Bluetooth 4.1
- Mobile wireless coexistence
- Smart Connectivity
- Improved Data Transfer

Bluetooth 4.2
- Flexible Internet Connectivity (IPV6)
- Improved privacy and security
- Increased data throughput
<table>
<thead>
<tr>
<th></th>
<th>Classic Bluetooth (BR/EDR)</th>
<th>Bluetooth Low Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2400 to 2483.5MHz</td>
<td>2400 to 2483.5MHz</td>
</tr>
<tr>
<td>Modulation Scheme</td>
<td>GFSK</td>
<td>GFSK</td>
</tr>
<tr>
<td>Number of Channels</td>
<td>79</td>
<td>40</td>
</tr>
<tr>
<td>Channel Bandwidth</td>
<td>1 MHz</td>
<td>2 MHz</td>
</tr>
<tr>
<td>Nominal Data Rate</td>
<td>1 - 3 Mbps</td>
<td>1Mbps</td>
</tr>
<tr>
<td>Application Throughput</td>
<td>0.7 – 2.1Mbps</td>
<td>&lt;0.3Mbps</td>
</tr>
<tr>
<td>Nodes / Active Slaves</td>
<td>7</td>
<td>Not Limited (Application</td>
</tr>
<tr>
<td></td>
<td></td>
<td>dependent)</td>
</tr>
<tr>
<td>Robustness</td>
<td>Adaptive Frequency Hopping</td>
<td>Adaptive Frequency Hopping</td>
</tr>
<tr>
<td>Security</td>
<td>56 to 128 bit</td>
<td>128bit AES</td>
</tr>
<tr>
<td>Connection Latency</td>
<td>100 ms</td>
<td>3 ms</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>20 dBm / 4 dBm / 0 dBm (Class</td>
<td>-20dBm to 10dBm</td>
</tr>
<tr>
<td></td>
<td>1/2/3)</td>
<td></td>
</tr>
<tr>
<td>Peak Current</td>
<td>&lt; 30mA</td>
<td>&lt; 15mA</td>
</tr>
</tbody>
</table>

*Bluetooth Low Energy is designed for sending small chunks of data with low overhead at very low average power!*
BLE Protocol Stack

**Profiles**
- Application Specific data
- GAP
  - Device discovery, connections
- GATT
  - Data organization
- ATT
  - Protocol for data access
- L2CAP
  - Protocol Multiplexer

**HCI**
- Interface between host and controller

**Link layer**
- Packets and radio control

**Physical layer**
- Transmission / reception of bits

https://developer.bluetooth.org/TechnologyOverview/Pages/BLE.aspx
BLE Physical Layer

3 Advertising channels
• For device discovery and connection setup
• Avoid known Wireless LAN channels

37 Data channels
• Use Adaptive Frequency Hopping for co-existence and robustness
BLE Link Layer

Link Layer procedures

• A simple state machine

Link Layer procedures

• Advertising
• Scanning
• Initiating connections
• Connected

Topologies

• Point-to-point
• Star
Master (Initiator) sends a connection request to the slave (Advertiser) while slave responds to establishes a connection.

Once a connection is established:
- Master informs slave of hopping sequence, connection interval and slave latency
- Packets are transmitted at the same frequency during a connection event
- Master and slave alternate sending and receiving packets until either side stops
Effects of BLE Connection Parameters

Increases in Connection Interval Parameters:

- Lowers the average current consumption
- Increases communication latency
- Increases the numbers of connectable slaves

BLE Location Based Shopping Experience

**Consumers:**
Enhances in-store experience by informing and motivating buying decisions when it matters most.

**Retailers:**
New way to drive sales by delivering actionable content and offers at the point of sales.

- **Store Entry**
- **Area of Store / Department**
- **POS Display**
Intelligent sensors and devices can be controlled and monitored remotely through BLE enabled Smart Home Hub.
The Blue Maestro Pacif-i monitors a baby’s temperature and transmits the data to an app on a parent’s smartphone. It also features a proximity sensor that can alerts parents when the child wanders off or loses / hides the pacifier.

Public Transport: BLE iBeacons

Smart Public Transport
Bucharest, Romania - 2015

- 500 iBeacons network
- 500 buses and trolleybuses
- 7000 visually-impaired people officially registered
- 12000 total potential users

Planting: BLE Flower Monitor

http://www.parrot.com/zh-hk/products/flower-power/
Increased Speed:

A 100% increase in speed, without increasing energy consumption, will enable faster data transfers in critical applications, such as medical devices, increasing responsiveness and lowering latency.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Maximum Data Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZigBee</td>
<td>250 kbit/s</td>
</tr>
<tr>
<td>Thread</td>
<td>250 kbit/s</td>
</tr>
<tr>
<td>Z-Wave</td>
<td>100 kbit/s</td>
</tr>
</tbody>
</table>

BREAKING NEWS
A 100% increase in speed will be introduced in 2016!
Increased Range:

The range of BLE, set to increase up to 4x, will transform smart home and infrastructure applications, and will deliver an extended, more robust connection for full-home or outdoor use cases.

Looking Forward (Cont.)

Mesh Network makes easy to implement the Internet of Things

**ASTRI BLE Digital Baseband and RF**

**Electrical Specifications**

- **Frequency Band:** 2.400GHz ~ 2.4835GHz
- **No. of Channels:** 40
- **Channel Width:** 2MHz
- **Tx Power:** -20dBm ~ 10dBm
- **Rx Sensitivity:** -85dBm
- **Modulation:** GFSK
- **Modulation Index:** 0.45 ~ 0.55
- **Data Rate:** 1Mbps
- **Robustness:** Adaptive Frequency Hopping
- **Encryption:** 128bit - AES
- **Packet Length:** 80bit ~ 376bit
ASTRI BLE HCI Controller TX Test

Host Controller Interface (HCI) Test

ASTRI BLE Test Board

Baseband BLE Advertising Packets

FPGA Board with Baseband signal

ASTRI Register Control Software running on Host Computer

Communicate with Antenna

Generic HCI Tester Software from TI running on Host Computer

UART

BLE Advertising Event reported to 3rd party HCI software
ASTRI BLE HCI Controller RX Test

Host Controller Interface (HCI) Test with commercial products

- Commercial BLE Advertising Device from TI
- ASTRI BLE Test Board
- FPGA Board with HCI Controller function
- IF ADC signals
- UART

Commercial BLE Advertising Event reported to 3rd party HCI software

Generic HCI Tester Software from TI running on Host Computer

ASTRI Register Control Software running on Host Computer
ASTRI BLE Future Plan

Support for the BLE 4.2 standard:

IPv6 enabled Bluetooth Smart Things

IPv6 Bluetooth Smart

LE Secure Connections

LE Data Packet Length Extension

BLUETOOTH 4.2

- Speed
- Capacity

2.5x

10x
Key IP Blocks Technology Improvement:

- Energy efficient RF transceiver architecture
- < 10mA peak current consumption
- Very low sleep current in the sub-μA range
End of Presentation
Thank you. Questions are welcome.

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