Bluetooth

- Universal radio interface for ad-hoc *wireless connectivity*
- Interconnecting computer and peripherals, handheld devices, cell phones – designed as replacement for IrDA
- Short range (~10m), low power consumption, *license-free* 2.4 GHz ISM
- Voice and data transmission
Characteristics

- **2.4 GHz ISM band**
- **79 RF channels**
  - Frequency hopping (spread spectrum) with 1600 hops/s
  - Hopping sequence in a pseudo random fashion, determined by a master
- **Voice link – SCO (Synchronous Connection Oriented)**
  - FEC (forward error correction), no retransmission
- **Data link – ACL (Asynchronous Connection Less)**
  - Acknowledgments
- **Topology**
  - Overlapping piconets (stars) forming a scatternet

Piconet & Scatternet

- Master vs. slave devices
- Master determines “hopping pattern”
- Each piconet has a unique hopping pattern
- Original BT: up to 7 slaves (more parked/standby)
- Scatternet: piconets share members
**Piconet & Scatternet**

- All devices in a piconet hop together
  - Master gives slaves its clock and device ID (48-bit address)
- Scatternet: Linking of multiple co-located piconets through the sharing of common master or slave devices
  - Devices can be slave in two piconets or slave in one piconet and master of another
  - Devices “jump back and forth” between the piconets

**SCO Payload Types**

<table>
<thead>
<tr>
<th>Payload Type</th>
<th>HV1</th>
<th>HV2</th>
<th>HV3</th>
<th>DV</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>audio (10)</td>
<td>audio (20)</td>
<td>audio (30)</td>
<td>audio (10)</td>
</tr>
<tr>
<td></td>
<td>FEC (20)</td>
<td>FEC (10)</td>
<td></td>
<td>Header (1)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Payload (0-9)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2/3 FEC</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CRC (2)</td>
</tr>
</tbody>
</table>
ACL Payload Types

<table>
<thead>
<tr>
<th>Type</th>
<th>Header</th>
<th>Payload</th>
<th>FEC</th>
<th>CRC</th>
</tr>
</thead>
<tbody>
<tr>
<td>DM1</td>
<td>(1)</td>
<td>(0-17)</td>
<td>2/3</td>
<td>(2)</td>
</tr>
<tr>
<td>DH1</td>
<td>(1)</td>
<td>(0-27)</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>DM3</td>
<td>(2)</td>
<td>(0-121)</td>
<td>2/3</td>
<td>(2)</td>
</tr>
<tr>
<td>DH3</td>
<td>(2)</td>
<td>(0-183)</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>DM5</td>
<td>(2)</td>
<td>(0-224)</td>
<td>2/3</td>
<td>(2)</td>
</tr>
<tr>
<td>DH5</td>
<td>(2)</td>
<td>(0-339)</td>
<td></td>
<td>(2)</td>
</tr>
<tr>
<td>AUX1</td>
<td>(1)</td>
<td>(0-29)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Communication

- 625 µs
- Channels: M (Message), S (Speech)
- Time: t

Computer Science and Engineering - University of Notre Dame
Bluetooth Versions

- **Bluetooth 1.1**
  - also IEEE Standard 802.15.1-2002
  - initial stable commercial standard
- **Bluetooth 1.2**
  - also IEEE Standard 802.15.1-2005
  - eSCO (extended SCO): higher, variable bitrates, retransmission for SCO
    - AFH (adaptive frequency hopping) to avoid interference
- **Bluetooth 2.0 + EDR (2004, no more IEEE)**
  - EDR (enhanced date rate) of 3.0 Mbit/s for ACL and eSCO
  - lower power consumption due to shorter duty cycle
- **Bluetooth 2.1 + EDR (2007)**
  - better pairing support, e.g., using NFC
  - improved security
Adaptive Frequency Hopping

Bluetooth Versions

- Bluetooth 3.0 + HS (2009)
  - speeds up to 24Mbps (using co-located Wi-Fi link!)
- Bluetooth 4.0
  - Classic Bluetooth
  - Bluetooth High Speed
  - Bluetooth Low Energy
- **Bluetooth Low Energy (BLE):**
  - Marketed as Smart Bluetooth
  - Lower power, lower cost
  - Use in healthcare, fitness, security, entertainment devices
  - 40 channels
Bluetooth Low Energy (BLE)

- Bluetooth low energy is a new, open, short range radio technology
  - Blank sheet of paper design
  - Different to Bluetooth classic (BR/EDR)
  - Optimized for ultra low power
  - Enable coin cell battery use cases
    - < 20mA peak current
    - < 5uA average current

BLE Basic Concepts

- Everything is optimized for lowest power consumption
  - Short packets reduce TX peak current
  - Short packets reduce RX time
  - Fewer RF channels to improve discovery and connection time
  - Simple protocol and state machine
**“Exposing State”**

- Good at small, discrete data transfers
- Data can triggered by local events
- Data can be read at any time by a client

---

**BLE Architecture / Protocol Stack**

```
Applications
Generic Access Profile
Generic Attribute Profile
Attribute Protocol
Logical Link Control and Adaptation Protocol
Host Controller Interface
Link Layer
Physical Layer
```

- Apps
- Host
- Controller

---
BLE Device Modes

• Dual Mode
  – Bluetooth BR/EDR and LE
  – Used anywhere BR/EDR is used today

• Single Mode
  – Implements only Bluetooth Low Energy
  – Will be used in new devices/applications

BLE Physical Layer

• Two types of channels
BLE Physical Layer

• Advertising channels avoid 802.11

BLE Link Layer

• Link Layer state machine
BLE Link Layer

- **Possible states:**
  - **Standby:** not transmitting or receiving any data, and is not connected to any other device
  - **Advertiser:** periodically broadcasting advertisements
  - **Scanner:** actively looking for advertisers
  - **Initiator:** actively trying to initiate a connection with another device
  - **Master:** connected to another device as a master
  - **Slave:** connected to another device as a slave
BLE and Smart Health

My pulse is …

My blood glucose is …

My temperature is …

Bluetooth in Health Care

• Workgroup formed in 2006 to develop standard to support existing and emerging medical devices and to bring compatibility and interoperability

• Medical device manufacturers, silicon suppliers, and other supporters of the Bluetooth standard worked together to produce a Health Device Profile that was approved in 2008
The Bluetooth Health Device Profile works with Bluetooth chips that support streaming data rates of up to 2.1Mbps. That means that it can support medical devices as complex as ECGs, which need to stream data. It is equally applicable for simple devices such as weight scales that only need to transmit small quantities of information. It builds on the underlying capabilities of the Bluetooth standard, which include:

- Excellent resistance to interference from wireless LANs, through the use of adaptive frequency hopping
- Best-in-class security, including immunity from “man-in-the-middle” attacks, by utilizing public key cryptography
- Low power consumption (devices frequently enter low power sleep states)
- A rigorous qualification program to ensure interoperability
- Excellent range – up to 1km range products are available
- Global applicability, using the 2.4GHz band
- Low cost

IEEE 11073 is a standard that describes how data is represented by medical devices and how these devices connect to each other. Real-time: data from multiple devices can be retrieved, time correlated, displayed, and processed in fractions of a second. Plug-and-play: devices detect, configure, and communicate without human interaction.
## Bluetooth Health Device Profile

**ISO/IEEE 11073-20601**

<table>
<thead>
<tr>
<th>Data Format</th>
<th>Data Model</th>
<th>HDP Profile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological Data Types</td>
<td>Environmental Data Types</td>
<td>Fitness Data Types</td>
</tr>
<tr>
<td>Data Configuration &amp; Setting Data Types</td>
<td>Common Data &amp; Command Structure</td>
<td>Bluetooth Connectivity &amp; Transport</td>
</tr>
</tbody>
</table>

## Configurations

**Scenario 1: Non-Streaming Data**

- **Bluetooth Device (SRC)**
- **Computation Engine (SNK)**
- **PC**
Configurations

SCENARIO 2: STREAMING DATA

- Bluetooth Device (SRC)
- Computation Engine (SNK)
- PC

SCENARIO 3: CONCURRENT STREAMING AND NON-STREAMING DATA

- Pulse Oximeter
- Weight Scale
- Bluetooth Device (SRC)
- Computation Engine (SNK)
- PC
SCENARIO 4: DUAL ROLE DEVICE

Pulse Oximeter

Bluetooth Device (SRC)

Weight Scale

Bluetooth Device (SRC)

Dual Role Device (SRC/SNK)

Display Console

Computation Engine (SNK)

PC

SCENARIO 5: COMBINATION DEVICE

Pulse Oximeter with Thermometer Capability

Bluetooth Combination Device (SRC)

Computation Engine (SNK)

PC
Configurations

ZigBee

- IEEE 802.15.4 (similar to Bluetooth and IEEE 802.15.1)

- Pushed by Chipcon (now TI), Ember, Freescale (Motorola), Honeywell, Mitsubishi, Motorola, Philips, Samsung...

- More than 260 members
  - about 15 promoters, 133 participants, 111 adopters
  - must be member to commercially use ZigBee spec

- ZigBee platforms comprise
  - IEEE 802.15.4 for layers 1 and 2
  - ZigBee protocol stack up to the applications

Not Part of Profile Spec, but requires coordination with other standards bodies
ZigBee

- Design goal
  - Low power consumption
  - Simple Design
  - Low cost

- History
  - ZigBee-style networks began ~1998
  - IEEE 802.15.4 was first completed in 2003
  - ZigBee Alliance was established in 2002

ZigBee Core Market

- Industrial and Commercial
  - Monitors
  - Movement sensors
  - Automation

- Personal Healthcare
  - Patient monitors
  - Remote diagnosis
  - Data loggers

- Building Automation
  - Security
  - Lighting
  - Fire and safety systems

- Automotive
  - Service controls
  - Inventory tracking
ZigBee Protocol Stack

Application

Application Layer (AL)
Application Framework (AF)
ZigBee Device Objects (ZDO)
Application Support Sublayer (ASP)

Network (NWK)
Star / Mesh / Cluster-Tree

MAC
Device Types, Channel Access

PHY
868 MHz / 915 MHz / 2.4 GHz

Device Type

• **Full Function Device (FFD)**
  – Network router function
  – Any topology

• **Reduced Function Device (RFD)**
  – Easy and cheap to implement
  – Limited to star topology

• **Personal Area Network (PAN) Coordinator**
  – Maintains overall network knowledge
  – Needs most memory and computing power
Basic Topology

Star Network

Cluster Tree Network
ZigBee PRO: Mesh Network

Comparison

<table>
<thead>
<tr>
<th>Technology</th>
<th>Classic Bluetooth Technology (802.15.1)</th>
<th>Bluetooth Low Energy Technology</th>
<th>ZigBee</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radio Frequency</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
<td>2.4 GHz</td>
</tr>
<tr>
<td>Distance / Range</td>
<td>10 to 100 meters</td>
<td>10 to 100 meters</td>
<td>10 to 200 meters</td>
</tr>
<tr>
<td>Over-the-air Power</td>
<td>1 mW</td>
<td>0.2 mW</td>
<td>&lt;0.1 mW</td>
</tr>
<tr>
<td>Application Throughput</td>
<td>7 to 1771.2 bps</td>
<td>1.6 Mbps</td>
<td>Unlimited</td>
</tr>
<tr>
<td>Security</td>
<td>128-bit AES and application layer user defined</td>
<td>128-bit AES and application layer user defined</td>
<td>128-bit AES and application layer user defined</td>
</tr>
<tr>
<td>Robustness</td>
<td>Adaptive fast frequency hopping, FEC, fast ACK</td>
<td>Adaptive fast frequency hopping</td>
<td>Adaptive fast frequency hopping</td>
</tr>
<tr>
<td>Latency (from a non connected node)</td>
<td>&gt;3ms</td>
<td>&lt;3ms</td>
<td>&lt;1 ms</td>
</tr>
<tr>
<td>Power Consumption (max 15 mA with battery)</td>
<td>0.01 to 0.3 (depending on use-case)</td>
<td>15 mA</td>
<td>15 mA</td>
</tr>
<tr>
<td>Service discovery</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Profile support</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Primary use cases</td>
<td>Mobile phones, gaming, headsets, i.e., audio streaming, automotive, PC’s, consumer electronics, etc.</td>
<td>Mobile phones, gaming, PC’s, watches, sports &amp; fitness, healthcare, automotive, consumer electronics, etc.</td>
<td>Fixed location industrial, building &amp; home automation, AIO/SmartEnergy</td>
</tr>
</tbody>
</table>