Inspiring the next class of Bluetooth low energy devices

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The waves of Bluetooth low energy applications
How did we get here?

- Early applications
- Proliferation
- Ubiquity

Annual Shipments

- 2012: 100Mu
- 2014: 500Mu
- 2016: 1Bn
- 2018:
- 2020:

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Igniting the explosive growth of IoT

Expected number of IoT devices shipped in 2020

- 1.6bn Smart Home (60% CAGR)
- 1.8bn Smart City (50% CAGR)
- 0.6bn Industrial (20% CAGR)
- 1.1bn Other (40% CAGR)

New ecosystems. New opportunities for ARM partners and developers

Source: Gartner, 2015
Billions of devices....

Need not mean billions of batteries
Takes more than the radio to be low-power

- Radio Core
  - RF PHY
  - Link layer controller
- Baseband
- Link layer firmware

+ Host Controller
  - ARM CORTEX
    - Processor Technology
+ Sub 1V Physical IP
  - ARM ARTISAN
    - Physical IP

Sub 1V radio

60% better battery life

Sub 1V SoC

Energy harvesting
1 Volt operation makes energy harvesting viable

- Light energy – solar panels, photo sensors/diodes
- Mechanical energy – vibration, mechanical stress/strain
- Thermal energy – heaters, friction, human body
- RF ambient – Wi-Fi, power lines, cell towers, transmitted
- Electromagnetic energy – inductors and coils (RFID, toll tags)
- Natural energy – wind, water flow, ocean currents, and solar
- Human body – vibration, thermal, chemical (glucose)
- Other energy – biological and chemical sources
Solar energy harvesting applications

**ARM solar concept example**
- 1 Volt beacon application
- Small solar cell from SolChip

**Solar powered window sensor**
- Between panes of glass
- Motion/glass break, light, temperature sensors
- Bluetooth Smart radio
- Overnight energy storage
RF Ambient: Energy harvesting

RF Energy
- WiFi
- Cell Towers
- Broadcast Power

RF Ambient: Energy harvesting

PMIC/Charge Pump

Bluetooth SMART

RF Energy
- WiFi
- Cell Towers
- Broadcast Power
Low-voltage radio frees you to think differently

- Think thin
- Think unattended
- Think battery less
- Think disposable

1.2v Zinc/Air – Micro Beacon (2.1 year life @ 1sec beacon)

1v Solar Cell Demo Platform
Applications: Present and future

I Volt micro-beacon
- ARM Cordio BT4 Bluetooth Smart test chip
- Eddystone Beacon
- Type 13 Earing aid battery (Zinc/Air)
- 1 Sec beacon interval
- Battery life: 2.1 years!

The Dash: the world’s first Hearable
- True wireless smart hearphones
  - Getting rid of the 3.5mm headphone jack
- Biometrics
  - Heart rate, Pedometer
- Music player with storage
- Communicator
  - Audio (Speaker and Microphone)
- Touch/swipe control
- 32-bit ARM Processor
How is ARM addressing this need?
Adding Bluetooth low energy to IoT endpoints

Business and technical challenges

Design needs
- Wireless standards expertise
- RF: Low power radio designs
- Analog: Efficient power management and clocks
- Digital: Modem and protocol processing
- Software: Firmware and application design

Testing needs
- Radio functionality
- Production tests
- Inter-operation and Co-existence
- Qualification and certifications

Business needs

Radios are difficult to build – Cost and TTM constraints
Standard are evolving - Need to keep the radio current
A diverse team of specialists is needed
ARM Cordio – Radio connectivity solutions

Hardware and software solutions from “RF PHY to application”

- Self-contained radio sub-system
  - RF PHY, baseband, link layer controller and firmware delivered in a hard-macro
- Optimized for low-power
- Focusing on Bluetooth® low energy and 802.15.4

- Software stack and profiles
- Bluetooth Qualified radio and software
- Reduced risk and improved TTM
Cordio BT4.2: Bluetooth low energy solution IP

The only complete Bluetooth low energy connectivity solution - RF to stack, all in house

Bluetooth Qualified

120% more battery life than best-in-class radio

Lowest power Bluetooth low energy radio IP that is proven in silicon

Enables smaller, cheaper and more reliable devices

Only 11 external BOM components
Complete and qualified BLE 4.2 solution

- The only complete Bluetooth low energy connectivity solution - RF to stack, all in house
  - RF front end + modem + protocol processing logic + link layer controller + firmware + Stack and Profiles
  - Bluetooth 4.2 Qualified and listed: QDID 68817, 70034, 69046

- Implementation Features
  - TSMC 55nm LP/ULP, Native Sub-volt solution
  - Radio IP delivered as hard macro with interface RTL and link layer firmware in ROM
  - 120% more battery life than best-in-class

<table>
<thead>
<tr>
<th>PPA</th>
<th>TSMC 55LP/ULP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance/Sensitivity [dBm]</td>
<td>-95</td>
</tr>
<tr>
<td>Power Active (RX/TX)(mW)**</td>
<td>6.7/7.2</td>
</tr>
<tr>
<td>Power Sleep (nW)****</td>
<td>&lt; 800 nW</td>
</tr>
<tr>
<td>Area (transceiver)****</td>
<td>&lt; 1.9 mm²</td>
</tr>
</tbody>
</table>

** power consumption numbers at 1V
*** Includes area of internal linear regulators

*Using beaconing mode for battery life calculations

[Graph showing best-in-class vs. ARM for Zinc Air (1.3V) and AAA (1.5V)]
ARM Cordio: Smallest footprint BLE solution

Optimized for low-cost IoT node devices
- Single antenna pin with integrated PA, LNA and RX/TX switch. Components saved 7
- Integrated capacitive DC-DC down converter. Components saved 3
- Integrated crystal oscillator load capacitors. Components saved 4

Industry’s smallest total footprint BLE solution
- Only 11 external BOM components
- Sub-volt solution, works with cheaper Zinc-air and alkaline batteries
- Enables smaller, cheaper and more reliable devices

![Graph of lowest external bill of material (BOM) count]
Cordio BT4 software products

- Cordio BT4 Profiles
  - Production-ready profiles and sample applications
- Cordio BT4 Stack
  - Memory efficient, full-featured stack
- Cordio BT4 Link
  - Robust, full-features, portable link layer

Bluetooth 4.2 qualified
Cordio BT4.2 Link: Portable and qualified

- Portable and qualified Bluetooth Smart firmware
  - Bluetooth 4.2 Qualified and listed: QDID 70034
  - Ported to five independent radio platforms
  - Portable to any MCU or operating system

- Robust and full featured Link Layer
  - Extended length packets
  - Secure pairing without a PIN
  - Improved privacy
  - Connection topology

- High data throughput
  - Continuous transmission of 248 byte packets
  - Measured link layer throughput: 794 Kbps*

<table>
<thead>
<tr>
<th>PA</th>
<th>BLE 4.2 Link</th>
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<tbody>
<tr>
<td>Performance/Throughput (Kbps)</td>
<td>~800</td>
</tr>
<tr>
<td>Area (Code/RAM)</td>
<td>configuration dependent*</td>
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</table>

**Configuration**

<table>
<thead>
<tr>
<th>Configuration**</th>
<th>Code</th>
<th>RAM</th>
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<tbody>
<tr>
<td>Advertising only</td>
<td>12.2k</td>
<td>3.1k</td>
</tr>
<tr>
<td>Slave only</td>
<td>41.6k</td>
<td>3.1k</td>
</tr>
<tr>
<td>Slave+master</td>
<td>48.3k</td>
<td>8.5k</td>
</tr>
<tr>
<td>Slave+master per connection</td>
<td></td>
<td>-0.6k</td>
</tr>
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**16KB instance 1V ROM is 0.034 mm2
4KB instance of 1V RAM is 0.052 mm2
These are 1V instances using ARM physical IP @TSMC 55 LP/ULP

* Demonstration application available
2016 changes in standards will generate demand

- **Bluetooth Smart**
  - Major update in 2016 targeting the home
  - Enhancements - long range, higher data rate, mesh networking
  - Follow-on update late ’16/’17 will have a major impact on consumer audio. “Hearables” the new wearables.

- **802.15.4**
  - Thread will help expand adoption
  - Combo Bluetooth Smart/802.15.4 market will expand expecting 12% market by ’19
  - ARM will have 802.15.4 support in ‘16 to support these trends
Enablement
Simplifying connectivity enablement

Radio IP → IC level → Board level → Certifications → End product level

ARM CORDIO
Radio Core IP

Radio IP → Digital Baseband → Link and Stack Software

Bluetooth SMART
4.2 qualified
Enablement deliverables

Addressing all phases of productization

- GDSII, Simulation models (.v), Timing models (.lib) Physical abstraction (.lef), Pad library/Power mgmt. (COA database), LVS netlist (.cdl)
- RTL blocks for Host MCU interface
- Test vectors and scan abstraction (.ctl, .wgl)
- Link Layer SW Stack in ROM
- Pass-through BT qualification

- Reference Designs, BOM/AVL
- PCB Layout template
- Antenna guidance
- Host Stack, profiles, and SDK
- Radio Control Tool and mfg. test guidance

- Pass through BT qualification for end product
- Guidance on Regulatory Type Approvals
- Manufacturing Test Guidance
Complete and qualified solution

Complete Bluetooth low energy 4.2 solution from one company

- Radio sub-system
- RF PHY
- Link-layer
- Stack
Cordio BT4 Radio IP evaluation tools

**Evaluation Kit:**
- Based on Cordio BT4 demonstration chip
  - BT4 Radio IP + ARM Cortex-M0+ processor Host
  - Full Bluetooth Smart protocol stack and profiles
- Benefits and usage
  - RF performance evaluation
  - Power Consumption Assessment
  - Demonstration Vehicle: Sensors and Beacons
  - SDK Development Platform: MCU Firmware/Applications development

**Radio Control Tool (RCT)**
- Windows/LabVIEW based, Source code provided
- Uses standard Direct Test Mode commands (DTM)
- TX and RX test modes
  - Power Consumption Evaluation
  - Radiated or conductive RF performance evaluation
  - Regulatory or manufacturing test control
Demonstration platforms
Ultra low power solutions

Customer Evaluation Board

- 1.5 V AAA Alkaline Battery

Micro-Beacon

- 1 Volt Zinc/Air Hearing Aid Battery
- 1 Volt Solar Cell

Development Modules

- Prototyping
- FPGA Platform support

MEMS Sensors

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<tr>
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<table>
<thead>
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<tbody>
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<tr>
<td>enable</td>
<td>enabled</td>
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Bluetooth Smart UriBeacon

<table>
<thead>
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<th>UriBeacon</th>
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<tbody>
<tr>
<td>advertised tx power levels (dBm)</td>
<td>lowest</td>
<td>-80</td>
</tr>
<tr>
<td></td>
<td>low</td>
<td>-60</td>
</tr>
<tr>
<td></td>
<td>medium</td>
<td>-40</td>
</tr>
<tr>
<td></td>
<td>high</td>
<td>-20</td>
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Ecosystem
Turn-key subsystem for IoT

- Speed-up development with IoT subsystem for Cortex-M and mbed OS
- Physical implementation completed by 3 engineers in 3 months
- Logic, RF, Flash on the same die – TSMC 55 ULP
Enabling developers to scale

Software, Tools and Cloud for connected device development

- Tools and examples for rapid prototyping
- Integrated connectivity support and security software
- Cloud prototyping and device management
ARM Cordio - Simplifying IoT Connectivity

The only complete Bluetooth low energy solution from RF to Stack - ‘all in house’
  Bluetooth low energy 4.2 Qualified

Low-voltage radio frees you to think differently
  Sub 1 V – 120% more battery life than best-in-class

Standard leadership
  ARM is an active and contributing member of Bluetooth SIG, IP is ready when standard is ready
Thank You