What is Bluetooth Mesh?

- New standard which came out in 2017
- Many-to-many, multi-hop topology
- No new Bluetooth HW required
- Broadcast & relay in a flooding/ripple fashion
- Mainly for signaling – not large data transfer
- Message publication & subscription
- Multi-level security
- Greatly extended range
Mesh in terms of Bluetooth

**BR/EDR**
for continuous connections

- pairing (1:1)
  - audio streaming
  - wireless speakers
  - wireless headsets
  - in-car infotainment

2016: 730M | 2020: 930M

**Low Energy (LE)**
for short burst connections

- pairing (1:1)
  - data transfer
    - sports & fitness devices
    - medical & healthcare devices
    - peripherals & accessories

- broadcasting (1:m)
  - localized info sharing
    - Pol information
    - item finding
    - way finding

2016: 573M | 2020: 975M

- mesh networking (m:m)
  - large device networks
    - building automation
    - sensor networks
    - asset tracking

2016: 12M | 2020: 380M

Launching mid-2017
Mesh in terms of LE roles

Central - Peripheral
• Connection-oriented, between two devices
• Sensor as peripheral, your phone or PC as the central

Observer - Broadcaster
• Observer scans for advertising packets
• Broadcaster sends advertising packets for everybody who is scanning
• The natural choice for Mesh
Node Types

- GATT Client
- GATT Proxy
- Provisioner
- Relay
- Friend
- Low-Power Node
Node Lifecycle

- **Provisioning**: ECDH, OOB, Network Key, Address
- **Blacklisting**: Key Refresh
- **Configuration**: Node Composition, Application Key(s), Group Subscription & Publication
Node Composition: Elements & Models

**Elements**
- Unique Network Address
- Implements one or more Models

**Models**
- OpCode addressing
- States & Messages
- Client & Server
Mesh Protocol Layers

- Models
  - states / messages / behavior
  - opcodes, multiplexing models

- Access Layer
  - heartbeat/friendship, application
  - encryption & authentication

- Upper Transport Layer
  - segmentation & reassembly
  - message format, network encryption
  & authentication

- Lower Transport Layer

- Network Layer

- Advertising Bearer

- GATT Bearer (Optional)

  - message transport
## Anatomy of a Mesh Network PDU

<table>
<thead>
<tr>
<th>Field Name</th>
<th>Bits</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>IVI</td>
<td>1</td>
<td>Least significant bit of IV Index</td>
</tr>
<tr>
<td>NID</td>
<td>7</td>
<td>Value derived from the NetKey used to identify the Encryption Key and Privacy Key used to secure this PDU</td>
</tr>
<tr>
<td>CTL</td>
<td>1</td>
<td>Network Control</td>
</tr>
<tr>
<td>TTL</td>
<td>7</td>
<td>Time To Live</td>
</tr>
<tr>
<td>SEQ</td>
<td>24</td>
<td>Sequence Number</td>
</tr>
<tr>
<td>SRC</td>
<td>16</td>
<td>Source Address</td>
</tr>
<tr>
<td>DST</td>
<td>16</td>
<td>Destination Address</td>
</tr>
<tr>
<td>Transport PDU</td>
<td>8 to 128</td>
<td>Transport Protocol Data Unit</td>
</tr>
<tr>
<td>NetMIC</td>
<td>32 or 64</td>
<td>Message Integrity Check for Network</td>
</tr>
</tbody>
</table>
# Mesh Network Addresses

- 16-bit Network address with several categories/ranges

<table>
<thead>
<tr>
<th>Category</th>
<th>Address</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unassigned</td>
<td>0000000000000000</td>
<td>No address assigned (typically used when not publishing or subscribing)</td>
</tr>
<tr>
<td>Unicast</td>
<td>0xxxxxxxxxxxxxxx</td>
<td>Every element has a unique unicast address</td>
</tr>
<tr>
<td>Virtual</td>
<td>10xxxxxxxxxxxxxx</td>
<td>Special group addresses authenticated using a 128-bit virtual label UUID</td>
</tr>
<tr>
<td>Group</td>
<td>11xxxxxxxxxxxxxx</td>
<td>Fixed (all nodes, all friends, etc) or dedicated (application specific)</td>
</tr>
</tbody>
</table>
Relaying

• Time-to-Live (TTL, 7-bit, i.e. max 127)
• Decrypt with Network Key
• Decrement TTL

If TTL > 0:
• Re-encrypt with Network Key
• Send out to Network
• Application layer payload remains encrypted & untouched
  • Relay Node may not even have the Application Key
Publish & Subscribe

Nodes
- Switch 1
- Switch 2
- Switch 3
- Switch 4
- Switch 5
- Switch 6
- Switch 7

Groups
- Hall
- Den
- Kitchen
- Living
- Deck

Nodes
- Light 1
- Light 2
- Light 3
- Light 4
- Light 5
- Light 6
- Light 7

Publish
Subscribe
Security Features

• Authentication during provisioning
• Two level encryption
  • Network
  • Application
• Replay protection
  • IV Index (32-bits)
  • Sequence number (24 bits)
  • IV Index Update procedure
• Key Refresh
  • Node Blacklisting
Segmentation & Reassembly

• A message can be either unsegmented or segmented
• Payload
  • Unsegmented: 15 bytes
  • Segmented: 12 bytes per segment, max 32 segments = 384 bytes
  • Contains 4 or 8 byte MIC at the end, reducing usable payload size
• Unsegmented messages are inherently unreliable
• Segments of a segmented message are acknowledged by the receiver
  • One-segment “segmented” message can be used for reliable sending
Friendship

- 100% duty-cycle scanning needed for reliability, but consumes a lot of power
- Mix of battery & mains powered nodes
- Solution: pair up stable power supply nodes (Friends) with Low Power Nodes (LPNs)
- Friends queue up messages for the LPN
- LPN queries the Friend periodically if there are any messages for it
IMPLEMENTATION STATUS & PLANS
Support in Zephyr* OS

• Available starting with Zephyr 1.9
• All mandatory features implemented
• Tested against multiple other implementations
• Ported to MyNewt
  • Multiple valuable fixes ported back to Zephyr
• Demos possible with many popular supported Zephyr boards
  • Come to the Zephyr booth to see it in action!
• Minimum RAM footprint (entire OS with Mesh) is ~12kB
  • Fits even the most constrained 16k boards, like BBC micro:bit

*Other names and brands may be claimed as the property of others.
Support in Linux*

- meshctl tool released with BlueZ 5.47
  - GATT Client
  - PB-GATT Provisioner

- Ongoing work both in user space (BlueZ) and kernel
  - Advertising & Scanning managed in the kernel
    - Controlled through mgmt API extensions
  - Essentially everything else in a user space meshd

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Future development

• Mesh Vendor HCI Extensions
  • Supported both by Linux & Zephyr

• More features
  • Friend support for Zephyr

• More standard models

• More demos with various boards
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