Building IPv6 Mesh Network with Zephyr OS

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Sensor Networks

- Reliable communication
- Power efficient
- Standard compliant
- Low cost
Elements of the Network

- Border Router
- Router
- Leaf node
- Controller

- Star
- Mesh
- Bus
IP Mesh Networks in Zephyr

RPL (Route Over)

OpenThread (Mesh Under)
Sensor Network with Zephyr OS

- Technologies
  - IEEE 802.15.4
  - 6LoWPAN
  - IPv6
  - RPL
  - UDP
  - CoAP
  - IPv4
  - TCP
  - HTTP, Websocket

- Roles
  - Leaf node
  - Router
  - Border router

- Topologies
  - Star
  - Mesh
IEEE 802.15.4

- Low-rate wireless personal area network
- FFD / RFD
- TSCH
- CSMA-CA
- Security

Some of Operating Bands

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Channels</th>
<th>Data rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>868.0 – 868.6 MHz</td>
<td>1</td>
<td>20 kb/s</td>
</tr>
<tr>
<td>902.0 – 928.0 MHz</td>
<td>10</td>
<td>40 kb/s</td>
</tr>
<tr>
<td>2400 – 2483.5 MHz</td>
<td>16</td>
<td>250 kb/s</td>
</tr>
</tbody>
</table>

IEEE 802.15.4
- IPv6, RPL
- 802.15.4 MAC
- 802.15.4 PHY
- UDP, TCP (TLS/DTLS)
- HTTP, CoAP, Websocket
- 6LoWPAN
6LoWPAN

- IPv6 over Low-Power Wireless Personal Area Networks
- Fragmentation / reassembly of IPv6 packets
- Header compression / decompression
- Omits any other header fields that can be reconstructed
- Mesh routing support (mesh under)
- Adapted and used over
  - IEEE 802.15.4
  - Bluetooth

Protocols and Standards:

- HTTP, CoAP, Websocket
- UDP, TCP (TLS/DTLS)
- IPv6, RPL
- 6LoWPAN
- 802.15.4 MAC
- 802.15.4 PHY
6LoWPAN Header Compression (examples)

### IEEE 802.15.4 Header [22 Bytes]

<table>
<thead>
<tr>
<th>Header</th>
<th>Source Address (00:12:4b:00:00:00:00:01)</th>
<th>Destination Address (00:12:4b:00:00:00:00:02)</th>
</tr>
</thead>
</table>

### Link-Local Unicast (fe80::0212:4b00:0:1 -> fe80::0212:4b00:0:2) [6 Bytes]

<table>
<thead>
<tr>
<th>Dispatch</th>
<th>IPHC</th>
<th>Next Header</th>
<th>UDP Ports</th>
<th>UDP Checksum</th>
</tr>
</thead>
</table>

### Link-Local Multicast (fe80::0212:4b00:0:1 -> ff02::1) [7 Bytes]

<table>
<thead>
<tr>
<th>Dispatch</th>
<th>IPHC</th>
<th>McastGrp</th>
<th>Next Header</th>
<th>UDP Ports</th>
<th>UDP Checksum</th>
</tr>
</thead>
</table>

### Global Unicast (2001:5a8:4:3721:0212:4b00:0:1 -> 2001:4860:b002::68) [10 Bytes]

<table>
<thead>
<tr>
<th>Dispatch</th>
<th>IPHC</th>
<th>CID</th>
<th>HL</th>
<th>Dst IID(0068)</th>
<th>Next Header</th>
<th>UDP Ports</th>
<th>UDP Checksum</th>
</tr>
</thead>
</table>
RPL

- Pronounced ripple
- Low-Power and Lossy Networks (LLNs)
- Restricted in limited processing power and memory
- Routers and their interconnect are constrained
- Interconnected by a variety of links, such as IEEE 802.15.4
- Mesh routing support (route over)
- Supports star and mesh topologies
- Potentially comprising up to thousand of nodes

HTTP, CoAP, Websocket
UDP, TCP (TLS/DTLS)
IPv6, RPL
6LoWPAN
802.15.4 MAC
802.15.4 PHY
RPL Traffic Flows

- Up towards the DAG root for many-to-one
- Down away from the DAG root for one-to-many
- Point-to-point

![Graph showing RPL traffic flows with nodes ranked from 1 to 4 and connections between them.](image-url)
RPL control messages

- **DIO (DAG Information Object)**
  - A DIO carries information that allows a node to discover an RPL Instance, learn its configuration parameters and select DODAG parents.

- **DIS (DAG Information Solicitation)**
  - A DIS solicits a DODAG Information Object from an RPL node

- **DAO (Destination Advertisement Object)**
  - A DAO propagates destination information upwards along the DODAG

- **DAO ACK (Destination Advertisement Object – Acknowledgement)**
  - Reply from Border Router to node upon reception of DAO message.
RPL Mesh Construction

Border Router

Node A

DIO

DAO from Node A

DAO-ACK to Node A

DAO Forward from Node B

DAO ACK to Node B

DIS

DIO

Node B

DIO

DAO to BR

DAO-ACK Forward

DIS

DIO
Mesh Network

- A (Rank = 1)
- B (Rank = 2)
- C (Rank = 3)
- D (Rank = 2)
- E (Rank = 4)
- F (Rank = 5)
- G (Rank = 4)
- H (Rank = 6)
- I (Rank = 6)
- K (Rank = 5)

Route and Neighbor connections as shown in the diagram.
Link failure

Graph with nodes labeled A to K, each with a rank from 1 to 6. Arrows indicate the route and neighbor connections.
CoAP (Constrained Application Protocol)

- Constrained machine-to-machine web protocol
- CoAP transactions provide reliable UDP messaging
- Low header overhead and parsing complexity
- Asynchronous transaction support
- Supports resource discovery
- URI and content-type support
- Methods resemble HTTP method requests and responses
- Resources are identified by URIs
RPL Border Router

- Ethernet/WiFi uplink
- 802.15.4
- 6LoWPAN
- IPv6
- RPL
- UDP
- CoAP
- TCP
- IPv4, HTTP, Websocket
- RNDIS/ECM
HTTP & Websocket

- Bi-directional
- Full duplex communication over single TCP connection
- Long running connection with established context
- Designed to work over HTTP ports 80 & 443
- Enables interaction between a web client (e.g browser) and server
- Efficient use of bandwidth
- Developer tools can be used to inspect the Websocket frames
- Supported in Google Chrome, Microsoft Edge, IE, Firefox, Safari and Opera.
## Zephyr RPL Border Router

<table>
<thead>
<tr>
<th>IP address</th>
<th>Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>fe80::212:4b00:0:5</td>
<td>LED on</td>
</tr>
<tr>
<td>fe80::212:4b00:0:3</td>
<td>LED on</td>
</tr>
<tr>
<td>fe80::212:4b00:0:4</td>
<td>LED on</td>
</tr>
<tr>
<td>fe80::212:4b00:0:7</td>
<td>LED on</td>
</tr>
<tr>
<td>fe80::212:4b00:0:6</td>
<td>LED on</td>
</tr>
</tbody>
</table>
## Sample Web UI Routes list

### Zephyr RPL Border Router

<table>
<thead>
<tr>
<th>IPv6 prefix</th>
<th>Link address</th>
</tr>
</thead>
<tbody>
<tr>
<td>fde3:2cda:3eea:4d14:212:4b00:0:5/128</td>
<td>00:12:4B:00:00:00:00:05</td>
</tr>
<tr>
<td>fde3:2cda:3eea:4d14:212:4b00:0:4/128</td>
<td>00:12:4B:00:00:00:00:04</td>
</tr>
<tr>
<td>fde3:2cda:3eea:4d14:212:4b00:0:3/128</td>
<td>00:12:4B:00:00:00:00:03</td>
</tr>
<tr>
<td>fde3:2cda:3eea:4d14:212:4b00:0:7/128</td>
<td>00:12:4B:00:00:00:00:07</td>
</tr>
</tbody>
</table>
Sample Web UI Topology view 1

Zephyr RPL Border Router

[Topology Diagram]

- Interfaces
- RPL
- Neighbors
- Routes
- Topology
Sample Web UI Topology view 2

Zephyr RPL Border Router

<table>
<thead>
<tr>
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<th>RPL</th>
<th>Neighbors</th>
<th>Routes</th>
<th>Topology</th>
</tr>
</thead>
</table>

Diagram showing the topology with nodes labeled NBR, N3, N4, N5, N6, N7, N8, N9, N10.
Memory Footprints with Zephyr on FRDM-K64F

Border Router
- IEEE 802.15.4
- 6LoWPAN
- RPL
- IPv6 and IPv4
- TCP and UDP
- CoAP
- HTTP
- Websocket
- Minimal JSON
- Support for 25 Nodes

Flash ~ 160K
RAM ~ 110K

Leaf Node
- IEEE 802.15.4
- 6LoWPAN
- RPL
- IPv6
- UDP
- CoAP

Flash ~ 85K
RAM ~ 26K
• FRDM_K64F
  • Ethernet

• CC2520 EM
  • IEEE 802.15.4
Future Plans

- Reuse parts of Border Router application for BLE Mesh Provisioner
- Extend Border Router support to OpenThread
- Provide a gateway between BLE and RPL/15.4 mesh
Q & A