Routing in the Internet of Things (IoT)

Rolland Vida
Convergent Networks and Services

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IoT challenges

- IoT nodes are heterogeneous
  - Some have important resources
    - Smart phones, cars, coke machines
    - Connected to electricity, or easy to recharge
    - No size limitation
    - Big computing capacity, much memory
    - Many different radio interfaces, direct connection to the Internet

- Nodes with limited resources
  - Sensors, smart tags
  - Limited CPU, memory, **battery life**
  - Usually only 1 radio interface, mostly in sleep mode
  - No direct connection to the Internet
• The nodes with limited resources also have to connect somehow to the Internet
  ▪ To send their data (to the cloud)
  ▪ To be queried from distance

• Multi-hop communication and routing
  ▪ Traditional routing solutions are too resource-hungry
  ▪ The goal is the fast and reliable transmission

• LLN – Low Power and Lossy Networks
  ▪ Connections are by default unreliable, low transmission speed, high packet loss rate
    ▪ Small capacity antennas, unfriendly environment (rain, snow, frost), interferences, mobility
  ▪ The goal is energy efficiency, not communication efficiency
    ▪ No problem is no continuous connection or packets are lost
    ▪ Unattended operation for years – self-configuration, self-management
IoT routing

- In traditional networks if a connection is broken, a new path has to be found rapidly
  - To minimize packet loss
  - E.g., IP/MPLS Fast Reroute in OSPF

- In LLN, link failures are usual, but transient
  - If we would react to them, the network would become unstable (too much control plane overhead)

- In traditional networks big data traffic (video, VoIP), no possibility for buffering if a link is broken

- In LLNs low data traffic, a transient loss can be easily handled with buffering or local redirection
  - No need to reconfigure the entire topology

- In traditional networks static metrics, to ensure path stability

- In LLNs dynamic metrics, changing in time
  - The networks can adapt
**LLN vs. WSN**

- A wireless sensor network is a special type of LLN

<table>
<thead>
<tr>
<th>WSN</th>
<th>LLN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous network, similar sensors</td>
<td>Heterogeneous network, different nodes</td>
</tr>
<tr>
<td>Devices deployed with a specific goal,</td>
<td>Devices with different tasks, cooperating to find a gateway to the Internet</td>
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<tr>
<td>based on the needs of a specific</td>
<td></td>
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<tr>
<td>application</td>
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<tr>
<td>P2MP or MP2P communication (between</td>
<td>P2MP, MP2P or P2P communication</td>
</tr>
<tr>
<td>sink and sensors)</td>
<td>(between two IoT devices)</td>
</tr>
<tr>
<td>Usually no IP support</td>
<td>IP based communication</td>
</tr>
</tbody>
</table>
RPL – IPv6 Routing Protocol for Low Power Lossy Networks

- IETF ROLL WG – Routing Over Low power Lossy (2008)
  - RPL protocol (say Ripple) – RFC 6550 (2012)

- IPv6 distance vector routing protocol
  - Builds a DODAG-ot (Destination Oriented Directed Acyclic Graph)
  - Using an objective function (OF) that takes into account several metrics and/or constraints
  - Several different OFs might be used in the same time, each building its own DODAG
    E.g., 1) The smallest ETX*, but only over nodes supporting encryption
    2) The lowest delay, but only over nodes that have solar panels

* ETX – Expected Transmission Count
  - Shows the quality of a radio connection – how many times should I probably send a packet to be sure that it is received
  - Value between 1 and \(\infty\), expected value based on past experience
Building a DODAG

- Starts at the root node – LBR (LLN Border Router)
  - Gateway to the Internet
  - Many LBRs can exist in the same network

- New ICMPv6 control messages for RPL
  - DIO – DODAG Information Object
  - DAO – DODAG Destination Advertisement Object
  - DIS – DODAG Information Solicitation
Building the DODAG

- Edges – LLN connections
- Values – e.g. ETX
  - Can change in time
  - Using an average value some stability can be ensured
- Goal (OF) – minimize ETX
Building the DODAG

- The LBR sends a DIO message to its neighbors
  - Link local multicast
- Nodes A, B, C receive and handle it
  - Many DIOs can be received in the same time, from different LBRs
  - Based on the OF and other criteria, they decide to join the DODAG or not
  - If yes, the LBR is marked as parent
Building the DODAG

- The DIO timer of node C expires
- C sends a multicast DIO message to its neighbors
- The LBR ignores it, as it come from a higher ranked node
  - Rank(LBR) = 0, Rank(C) = 1
  - Needed to avoid loops
- B marks C as an alternative parent
- E joins the DODAG, marks C as a parent
The DIO timer of node A expires
- Sends a multicast DIO message to its neighbors
- The LBR ignores it
- B marks A as an alternative parent
- As the OF (ETX) value is better if B connects through A, B deletes the LBR and C from its parents
Building the DODAG

- The construction of the DODAG is continuous
- The DODAG is continuously maintained
MP2P (Multi-Point to Point) traffic

- MP2P traffic along the DODAG, from each node to the LBR
  - UPWARD routing

- The LBR connects to the Internet

- A node can participate in parallel in several DODAGs
P2MP (Point to Multi-Point) traffic

- DOWNWARD routing
  - Routing information has to be built

- DAO (DODAG Destination Advertisement) messages
  - If a node joins a DODAG, sends a DAO to its parents
  - Can be initiated by the LBR as well, or any intermediate node in the DODAG
    - Marked in the DIO message going downwards
    - The DAO timers (DelayDAO) are set so as to expire first at higher ranked nodes in the DODAG
  - The advertise in the DAO message the network prefix reachable through them

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P2MP (Point to Multi-Point) traffic

- LLN nodes sometimes are not able to store routing entries
  
  - If yes – **storing mode**
    - If possible, it aggregates the prefix of its children with its own prefix, and send this aggregated value forward
  
  - If not – **non-storing mode**
    - Source-routing: the DAO message contains the path
  
- Either storing mode or non-storing, the hybrid solution was not standardized
  - Even if it was included in the first drafts

- Advantages and drawbacks
  - In storing mode routing entries have to be stored, but short messages
  - In non-storing mode nothing has to be stored but long messages, increased energy consumption

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**P2P (Point-to-Point) traffic**

- Between any two S (Source) and D (Destination) nodes
  - If non-storing mode:
    - From S, we have to go towards the LBR along the DODAG
    - Then source routing from the LBR to D
  - If storing mode:
    - Shortcut at the first common ancestor
DODAG maintenance

- **Grounded DODAG**
  - A DODAG that corresponds to an OF and the given constraints

- **Floating DODAG**
  - A DODAG that does not meet the necessary criteria
  - Transient state, marked in the DIO message by setting the G (Grounded) bit

- What happens if the connection breaks between B and D?
  - D deletes B from its parents
  - As D does not have other parents, it becomes the root of a floating DODAG
D sends a multicast DIO message to its neighbors, letting them know about the change

- Node I has an alternative parent (E), still connected through it to the grounded DODAG

- As D is not part of the DODAG anymore, I deletes it from its parents
F does not have an alternative parent, so it stays in the floating DODAG of D.

F sends a multicast DIO message to its neighbors.

G and H do the same and follow F in the floating DODAG of D.
A floating DODAG was formed, with D being the root

They delete all the paths related to LBR

The floating DODAG tries to rejoin the grounded DODAG…
- I sends a multicast DIO message

- D receives it, learns that it could join the LBR DODAG through I

- D starts a timer related to node I
  - The setting of the timer depends on the rank of node I
  - D wants to be as close to LBR as possible
Suppose that a radio link is established between A and F

- A sends a multicast DIO message
- F receives it, starts a timer related to node A
The timer of node F expires
F joins the grounded DODAG through A, deletes D from its parents
F sends a multicast DIO message
G and H join the grounded DODAG through F
D sees that it could join the grounded DODAG through F

D starts a timer related to F, besides the already running time related to I
DODAG maintenance

- The timer related to F expires first
- D joins the grounded DODAG through F
- The floating DODAG disappears, the problem was handled without forming cycles
Joining

- When a node appears (it is switched on, or it moves the the given area), it starts listening to DIO messages
  - If it receives such messages, it decides which DODAG to join
  - If it receives nothing, or if it wants to speed up the process, it sends a DIS message
    - **DODAG Information Solicitation**
    - Triggers the sending of DIO messages from its neighbors
  - If still no DIO is received, it has the choice to become the root of a floating DODAG
    - Starts sending its own multicast DIO messages
### Active Internet Drafts

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<th>Document</th>
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<th>Date</th>
<th>Status</th>
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<tbody>
<tr>
<td>draft-ietf-roll-admin-local-policy-03</td>
<td>Forwarder policy for multicast with admin-local scope in the Multicast Protocol for Low power and Lossy Networks (MPL)</td>
<td>2015-02-06</td>
<td>RFC Ed Queue (to 28 days)</td>
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<tr>
<td>draft-ietf-roll-applicability-home-building-09</td>
<td>Applicability Statement: The use of the RFL protocol suite in Home Automation and Building Control</td>
<td>2015-03-25</td>
<td>IESG Evaluation (for 5 days)</td>
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<tr>
<td>draft-ietf-roll-applicability-template-06</td>
<td>ROLL Applicability Statement Template</td>
<td>2014-11-10</td>
<td>I-D Exists In WG Last Call Jan 2013</td>
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<tr>
<td>draft-ietf-roll-mpl-parameters-configuration-03</td>
<td>MPL Parameter Configuration Option for DHCPv6</td>
<td>2015-01-20</td>
<td>I-D Exists In WG Last Call Oct 2012</td>
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<tr>
<td>draft-ietf-roll-trickle-ngsrt-11</td>
<td>Multicast Protocol for Low power and Lossy Networks (MPL)</td>
<td>2014-11-24</td>
<td>IESG Evaluation, Revised I-D Needed (for 67 days)</td>
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### RFCs

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<tr>
<td>5548</td>
<td>Routing Requirements for Urban Low-Power and Lossy Networks</td>
<td>2009-05</td>
<td>RFC 5548 (Informational)</td>
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<tr>
<td>5673</td>
<td>Industrial Routing Requirements in Low-Power and Lossy Networks</td>
<td>2009-10</td>
<td>RFC 5673 (Informational)</td>
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<tr>
<td>5826</td>
<td>Home Automation Routing Requirements in Low-Power and Lossy Networks</td>
<td>2010-04</td>
<td>RFC 5826 (Informational)</td>
</tr>
<tr>
<td>5867</td>
<td>Building Automation Routing Requirements in Low-Power and Lossy Networks</td>
<td>2010-06</td>
<td>RFC 5867 (Informational)</td>
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<tr>
<td>5926</td>
<td>The Trickle Algorithm</td>
<td>2011-03</td>
<td>RFC 6206 (Proposed Standard)</td>
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<tr>
<td>5581</td>
<td>Routing Metrics Used for Path Calculation in Low-Power and Lossy Networks</td>
<td>2012-03</td>
<td>RFC 6581 (Proposed Standard)</td>
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<tr>
<td>5552</td>
<td>Objective Function Zero for the Routing Protocol for Low-Power and Lossy Networks (RPL)</td>
<td>2012-03</td>
<td>RFC 6552 (Proposed Standard)</td>
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<tr>
<td>5619</td>
<td>The Minimum Rank with Hysteresis Objective Function</td>
<td>2012-09</td>
<td>RFC 6679 (Proposed Standard)</td>
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<tr>
<td>5997</td>
<td>Reactive Discovery of Point-to-Point Routes in Low-Power and Lossy Networks</td>
<td>2013-08</td>
<td>RFC 6997 (Experimental)</td>
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<tr>
<td>6098</td>
<td>A Mechanism to Measure the Routing Metrics along a Point-to-Point Route in a Low-Power and Lossy Network</td>
<td>2013-08</td>
<td>RFC 6098 (Experimental)</td>
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<tr>
<td>7102</td>
<td>Terms Used in Routing for Low-Power and Lossy Networks</td>
<td>2014-01</td>
<td>RFC 7102 (Proposed Standard)</td>
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<tr>
<td>7416</td>
<td>A Security Threat Analysis for the Routing Protocol for Low-Power and Lossy Networks (RPL)</td>
<td>2015-01</td>
<td>RFC 7416 (Informational)</td>
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