Multicast Forwarding in 6LoWPANs with Contiki-NG

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About the speaker

- Lecturer, E&EE, University of Bristol
- Research Associate, University of Bristol: Jan. 2012 – Nov. 2015
- Research Associate, Loughborough University: Mar. 2009 – Nov. 2011
- Co-Founder, Contiki-NG – Oct 2017 –
- Maintainer, Contiki OS – 2012 – 2017

Research Groups:
Communication Systems and Networks (@BristolCSN)
Digital Health Engineering (@BrisDigiHealth)
Today’s Talk

• Crash Course in 6LoWPAN (and IPHC and NHC)
• Why Multicast in 6LoWPANs?
• IETF’s Position
• RPL-Specific Multicast
• Multicast in Contiki-NG
IPv6 over 802.15.4

127 bytes max frame size
IPv6 over 802.15.4

Simple UDP message

- 56% overhead…
6LoWPAN Header Compression

Simple UDP message

- ≈ 20% best-case overhead…
- Exact compression levels vary
- Can only compress UDP if immediately after IPv6

(IMPORTANT for later, bear with me…)
Why Multicast in 6LoWPANs?

One-to-many traffic:
• Service discovery
• Network management
• Code dissemination
  (although some might disagree…)

Can lead to:
• Network-wide energy consumption: Reduced
• Scalability: Improved
• Network utilisation: Reduced
Wireless is Great, We Love Wireless

Wireless Medium Advantage
Well. Sort of...
Well. Sort of...

Must be able to identify and handle duplicates!
MPL: What the IETF Proposes
MPL (Trickle Multicast) Concept

Datagram Cache

Disagree

Trickle Reset

ICMPv6 \{3, 4, \ldots, 8\}

ICMPv6 \{3, 4, \ldots, 7\}

Forward 8

Time

Disagree

Trickle Reset

3 4 5 6 7 8

3 4 5 6 7
MPL and 6LoWPAN compression

IPv6 | HBHO | Data
--- | --- | ---
8 bytes

MPL Option HBHO acts as “Unique” Message ID
IETF: MPL

- No topology maintenance
- Routing-independent
- Reliable
- Density-aware
- Part of Thread

✗ Complex (> 10KB Prog Mem)
✗ “Sluggish”
✗ Datagrams may arrive out of order
✗ Sensitive to misconfigurations
✗ It is broadcast flooding, really…
RFC6553 (RPL Option):

“The RPL Option is carried in an IPv6 Hop-by-Hop Options header, immediately following the IPv6 header.”
RFC7731 (MPL):

“The MPL Option is carried in MPL Data Messages in an IPv6 Hop-by-Hop Options header, immediately following the IPv6 header”
The Outcome:

- Different HBHO needed for \{ uni, multi \} cast traffic
- Can no longer compress UDP
Can we do better under RPL?

SMRF, ESMRF & BMFA
IETF: RPL MOP3

12. Multicast Operation

This section describes a multicast routing operation over an IPv6 RPL network and, specifically, how unicast DAOs can be used to relay group registrations. The same DODAG construct can be used to forward unicast and multicast traffic. This section is limited to a description of how group registrations may be exchanged and how the forwarding infrastructure operates. It does not provide a full description of multicast within an LLN and, in particular, does not describe the generation of DODAGs specifically targeted at multicast or the details of operating RPL for multicast -- that will be the subject of further specifications.

The multicast group registration uses DAO messages that are identical to unicast except for the type of address that is transported. The main difference is that the multicast traffic going down is copied to all the children that have registered with the multicast group, whereas unicast traffic is passed to one child only.

Nodes that support the RPL Storing mode of operation SHOULD also support multicast DAO operations as described below. Nodes that only support the Non-Storing mode of operation are not expected to support this section.

The multicast operation is controlled by the MOP field in the DIO.

- If the MOP field requires multicast support, then a node that joins the RPL network as a router must operate as described in this section for multicast signaling and forwarding within the RPL network. A node that does not support the multicast operation required by the MOP field can only join as a leaf.

RFC 6550 discusses multicast, specifies group management, but not forwarding
IETF: RPL MOP3

- RPL DODAG
  - tree-like structure
- Trees are good!
- Mode of Operation 3 (Storing with Multicast)

× Only Handles Group Management
× Superficial Datagram Forwarding
Stateless Multicast RPL Forwarding (SMuRF)

- RPL in MOP3 for Group Management
- Lightweight (<1KB)
- Cross-Layer Optimisations

Written to play nicely with ContikiMAC

Joint work with Loughborough University

- G. Oikonomou, I. Phillips, "Stateless Multicast Forwarding with RPL in 6LoWPAN Sensor Networks", in Proc. 2012 IEEE International Conference on Pervasive Computing and Communications Workshops (PERCOM Workshops), Lugano, Switzerland, pp. 272-277, 2012
SMRF can only Forward Downwards
Code Footprint

Program Code Size (bytes)

- uIPv6 Core
- RPL Engine
- Multicast Support

<table>
<thead>
<tr>
<th>Platform / Algorithm</th>
<th>Sensinode / cc2430</th>
<th>Tmote Sky / MSP430</th>
<th>Raven / AVR</th>
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<tr>
<td>No Multicast SMRF TM</td>
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Enhanced SMRF

- SMRF extension
- Can route up as well as downwards

BMFA: 
SMRF + Duplicate Detection

G. Papadopoulos, A. Georgallides, T. Tryfonas, G. Oikonomou, "BMFA: Bi-Directional Multicast Forwarding Algorithm for RPL-based 6LoWPANs", in Proc. InterIoT, ser. LNICST, 190, pp. 18-25, 2016

The research leading to these results has received funding from the European Union’s Seventh Framework Programme (FP7/2007-2013) under grant agreement no 609094.
BMFA: Identifying Unique Datagrams
BMFA: Identifying Unique Datagrams
## Duplicate Detection: Flow Label

```
+-------------+-------------+-------------+-------------+-------------+
| Version     | Traffic Class| Flow Label  |
+-------------+-------------+-------------+-------------+-------------+
| +-------------+-------------+-------------+-------------+-------------+
| Payload Length| Next Header  | Hop Limit   |
+-------------+-------------+-------------+-------------+-------------+
| +-------------+-------------+-------------+-------------+-------------+
| Source Address|
+-------------+-------------+-------------+-------------+-------------+
| +-------------+-------------+-------------+-------------+-------------+
| Destination Address|
+-------------+-------------+-------------+-------------+-------------+
```


Still pretty fast...

End-to-End Delay (sec)

Network Density / Multicast Traffic TX Period
... and Energy Efficient
• First release Nov 2017.

• Focus on standard-based, interoperable systems
  o 6LoWPAN, 6TiSCH, RPL, CoAP, DTLS, LWM2M etc.

• Focus on modern practices, protocols, platforms

• Dependable communication
  o Security: link-layer (IEEE 802.15.4) and application-layer (DTLS)
  o Reliability: brand-new RPL. 99.999% in RPL/TSCH mesh!
Routing with Contiki-NG

**RPL Classic**
- Based on the original, implementation from Contiki
- Uses Storing Mode
- MOP2 and 3

**RPL Lite**
- Non-Storing: Source routing, no routing tables in forwarding nodes.
Multicast Support in Contiki-NG

MPL
(But from a now very old version of the I.D.)
• Just works…

SMRF, ESMRF
• Only with RPL Classic / Storing Mode
The Big Gotcha!

6LoWPAN
The Big Gotcha!

6LoWPAN
The Big Gotcha!

With the technologies discussed today, multicast traffic CANNOT traverse the 6LoWPAN boundary in either direction!
Be nice to...

- Investigate (and optimize?) multicast over TSCH
- Multicast for Non-Storing RPL
Thank You!

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