Low-Power Interoperability for the IPv6 Internet of Things

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Internet of Things
Fall 2015
Introduction

- The Internet of Things is a current ‘buzz’ term that many see as the direction of the “Next Internet”.
- This includes activities such as Smart Grid and Environmental Monitoring.
- This is a world of ubiquitous sensor networks that emphasizes energy conservation!
- This paper provides an overview of the low-power IPv6 stack.
1. Interoperability at the IPv6 layer
   - Contiki OS with uIPv6 stack provides IPv6 Ready stack.

2. Interoperability at the routing layer
   - Interoperability between RPL implementations in Contiki and TinyOS have been demonstrated.

3. low-power interoperability
   - Radios must be efficiently duty cycled.
   - Not yet done!!
Figure 1. The low-power IPv6 stack consists of the standard IPv6 protocols at the network layer and transport layers, and of new protocols from the network layer and down.
Contiki MAC Layer Choices

- X-MAC
- Contiki-MAC
- LPP Low Power Probing
LPP (Low Power Probing)

Figure 4. A simplified representation of LPL for packet-based radios and LPP. Preamble and packet durations are not drawn to scale.

Koala paper 2008
IPv6 for Low-Power Wireless

- IPv6 stack for low-power wireless follows IP architecture but with new protocols from the network layer and below.

- 6LoWPAN adaptation layer provides header compression mechanism based on IEEE 802.15.4 standard to reduce energy use for IPv6 headers.
  - Also provides link-layer fragmentation and reassembly mechanism for 127-byte maximum 802.15.4 frame size.
- IETF ROLL (Routing over Low-power and Lossy networks) group designed RPL (Routing Protocol for Low-power and Lossy networks) for routing in multi-hop sensor networks.

- RPL optimized for many-to-one traffic pattern while supporting any-to-any routing.

- Supporting different routing metrics, RPL builds a directed acyclic graph (DAG) from the root node for routing.

- Since CSMA and IEEE 802.15.4 are most common, the issue becomes the radio duty cycling layer.
Radio Duty Cycling Layer

- To reduce idle listening, radio transceiver must be switched off most of the time.
- Figures show ContikiMAC for unicast and broadcast sender \(\text{similar to X-MAC}\).
- ContikiMAC sender “learns” wake-up phase of the receivers.
- Performance relationship between RPL and duty cycling layer yet to be studied.
ContikiMAC Unicast

Send data packets until ack received

Sender: D D D D A
Receiver: D A
Reception window: D
Data packet: A
Acknowledgement packet: A
Transmission detected

Figure 2. ContikiMAC, from Dunkels et al. [2].

Send first data packet when receiver is known to listen

Sender: D D A
Receiver: D A
Reception window: D
Data packet: A
Acknowledgement packet: A
Transmission detected

Figure 3. ContikiMAC sender phase-lock.
ContikiMAC broadcast is the same as the A-MAC broadcast scheme.
Figure 5. Contiki and TinyOS IPv6 interoperability, from Ko et al. [6]. We demonstrated interoperability at the network layer, the MAC layer, and the link layer, but without radio duty cycling.
Interoperable radio duty cycling is essential!

Thus far interoperability demos have ONLY been with *always-on* radio layer.

Two implementations with good performance on their own can have *sub-optimal* performance when mixed.
Results suggest IoT implementations need to be tested for performance and NOT just correctness.

Contiki simulation tool (Cooja) can be used to study challenges of low-power IPv6 interoperability.
Low-Power Interoperability

Three challenges:

1. Existing duty cycle mechanisms **NOT** designed for interoperability.
   - e.g., ContikiMAC and TinyOS BoX-MAC have no formal specifications.
   * Mentions 802.15.4e group for standardization

2. Duty cycling protocols are typically timing sensitive.
   - Makes testing of interoperability difficult.
3. Current interoperability testing is done via physical meetings of separate protocol developers.
   - This bounds the testing time.
   - Hence, this strategy is not well-suited for interoperability testing of duty cycling protocols.
Conclusions

- While IPV6 provides IoT interoperability, attaining low-power interoperability for the Internet of Things is still an open problem because:
  - Existing protocols for LLNs are not designed for duty cycling.
  - Existing duty cycling protocols are NOT designed for interoperability.