Poster Abstract: Interconnecting Low-Power Wireless and Power-Line Communications using IPv6

Joel Höglund†, Niclas Finne†, Joakim Eriksson†, Nicolas Tsiftes†, Adam Dunkels†,
Cedric Chauvenet‡∗, Mathieu Pouillot‡, Pierre-Emmanuel Goudet‡,
Bernard Tourancheau∗, Denis Genon-Catalot‡
†SICS, Sweden, ‡Watteco, France, ∗CITI Insa-Lyon, France

Abstract

Wireless sensor networks for building automation and energy management has made great progress in recent years, but the inherent indoor radio range limitations can make communication unpredictable and system deployments difficult. Low-power radio can be combined with low-power Power-Line Communication (PLC) to extend the range and predictability of indoor communication for building management and automation systems. We take the first steps towards exploring the system implications for integration of low-power wireless and PLC in the same network. We leverage IPv6, which allow networks to exist over multiple physical communication media as well as the RPL routing protocol for low-power lossy networks.

1 Introduction

Sensor networks are becoming increasingly important in the area of The Smart Grid. By using sensors for monitoring individual devices, buildings as well as the grid itself, the electrical utility companies get a better basis for planning their production and distributing load in the grid, thereby increasing efficiency. In addition, individual customers can get a better understanding of their power consumption and eventually be given incentives for power savings through more accurate billing. To reduce installation and maintenance costs, power meters are equipped with a low-power PLC or RF communication device, providing reachability with a low overhead. To avoid the installation and maintenance costs of custom gateways, devices in the smart grid requires interoperability and integration with existing networks and devices [1].

Interoperability is also meaningful for Home Area Networking (HAN) or Home Control. In a heterogeneous networking context, each device of the house reports its activity, or is efficiently controlled with RF or PLC seamlessly. The data is gathered and processed to optimize the energy consumption of the house. Interoperability between RF and PLC allows using the existing electrical grid as a network medium regardless of obstacles such as walls, floors, or metal. Furthermore, RF brings connectivity to every device in the house without the need of electrical outlets, providing mobility. Using both RF and PLC media enables the choice between the best media for controlling each device.

Many proprietary standards exist for both wireless sensor networks and power-line communication (PLC) networks. The diversity of standards has not been an issue as long as these networks have operated separately. But to build large-scale energy monitoring and control systems, it is desirable to interconnect heterogeneous networks of sensor devices while adhering to standards.

With this work, we demonstrate the feasibility of using IP-based communication for both wireless and low-power PLC sensor networks, with usable performance for standard UDP and TCP traffic. This has the potential to provide simplified system integration and more efficient deployments.

2 Power Consumption is Crucial

PLC nodes that are attached to power lines have a continuous power supply, but their power consumption must nevertheless be low, for two reasons. First, the power consumption of the node affects the physical size of the components that convert the power from the power line into power that can be used by the sensor node circuitry. Second, building automation systems are often intended to reduce the total power consumption of a building. The power consumed by the sensor network infrastructure must therefore be significantly lower than the electrical power that it saves. Even if each individual sensor node consumes a modest amount of power, the sum of hundreds or thousands of nodes in a building can add up to a significant amount of power.

For wireless nodes, power consumption must be low to achieve long system lifetime. Since the radio transceiver is the most power consuming component, duty cycling of the radio is essential. Many techniques for radio duty cycling has been developed.

3 Low-power IPv6 Routing

The IETF ROLL working groups is, as of the fall 2010, close to finalizing a specification for a new *Routing Protocol for Low power and Lossy Networks*, RPL, which our system implements. The key routing structure in RPL networks are directed acyclic graphs, DAGs. Using RPL the DAGs are actively maintained, as opposed to how for example AODV works, where routing paths are constructed on demand. In RPL, a Trickle timer ensures that updates are more frequent when there are changes in the network and more rare during stable periods. Based on the Trickle timer, the root node of a DAG sends status messages, called DAG Information Objects, DIOs, which other nodes use to get the network status and to detect eventual inconsistencies. Nodes that want to be reachable transmit a Destination Advertisement Object (DAO) to the DAG root which register the routing information on how to reach that specific route [3, 4].

An advantage of RPL is the possibility to define multiple routing topologies in the same network, which can be optimized for different routing metrics. High priority traffic can be allowed to take the shortest latency path, even if it consumes more energy than an alternative used for traffic with lower priority.

4 System Design

We use the Contiki operating system, which provides both a IPv6 stack, RPL routing through ContikiRPL [2]. and several radio duty-cycling mechanisms. We use duty cycling for the wireless transceivers with the ContikiMAC protocol.

We use two hardware platforms, one for the wireless nodes and one for the power-line nodes. As the wireless platform, we use the Tmote Sky mote which is equipped with an IEEE 802.15.4-compliant radio transceiver, a set of sensors, and an MSP430 microcontroller with 48 kilobytes of ROM and 10 kilobytes of RAM.

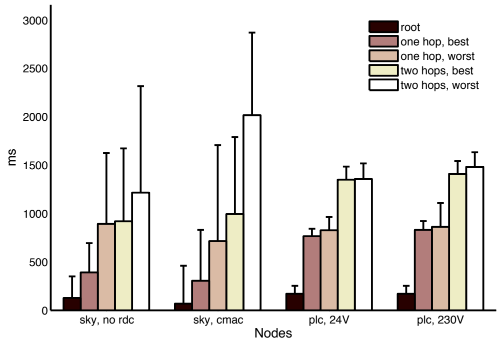

Figure 1. Ping Return Trip Times

As the PLC platform, we use the Watteco PLC development platform.

The Watteco platform provides a PLC transceiver that is manufactured in two types: one for 230 V power lines and one for 24 V systems. We use the 24 V as our development platform due to safety concerns.

The PLC transceiver has an interface that is similar to wireless IEEE 802.15.4 transceivers. Packets are sent and received in IEEE 802.15.4 frames that use the exact same packet headers and packet sizes as wireless IEEE 802.15.4 transceivers. This is intended to make porting easier between wireless and PLC systems.

At the Medium Access Control (MAC) layer we use Contiki's CSMA/CA protocol that does senses the underlying medium to check for collisions and retransmits packets if there is a collision or if no link-layer acknowledgment is received. The CSMA/CA mechanism uses a randomized exponential back-off with a starting duration of 0.5 seconds. At the Radio Duty Cycling (RDC) layer, we use two mechanisms: ContikiMAC, which is a low-power listening duty cycling scheme, and NullRDC, which does not duty cycle the underlying link layer. At the link layer, we use either IEEE 802.15.4 or PLC, depending on the hardware on which the software is running.

5 Preliminary Evaluation

We measure the performance of a duty cycled low-power radio network based on IEEE 802.15.4 and the performance of two low-power PLC networks, one 24 V network and one 230 V network. We perform experiments with ICMP ping messages over ContikiRPL and measure latency and packet reception ratio.

We measure the performance in three testbeds: one indoor wireless testbed and two PLC testbeds. The indoor wireless testbed consists of 24 Tmote Sky motes located in the roof of one office floor. The nodes are placed to get a maximum of two hops between all nodes. We use one PLC testbed with 6 nodes that communicate over 24 V lines, and one setup with three nodes that communicates over standard 230 V lines. In all three configurations, a designated node is connected to a PC through a USB serial port. This PC routes IPv6 packets between the low-power network and an IPv6 Ethernet network.

To measure system latency we performed series of ping-tests, using the default 64 bytes ICMPv6 payload. For both the Sky and the PLC platform we test the latency of zero, one and two network hops. The latency results are shown in Figure 1. We see that in our setup, the latency of the single-hop PLC experiment is high: this was due to a serial port driver that enforced a low bit rate, which also affected the multihop PLC measurements. In the PLC low voltage configuration there is very little noise, since it is filtered by the platform's power supply to be used as a debug platform. As a result, the packet loss ratio is below 1% for all tested number of hops. Message loss is due to collisions with ICMPv6 control messages.

When conducting the same experiment on nodes with 230 V using one electric phase, we observe a similar round trip latency, but the packet loss ratio rises up to 6% for the the one hop-case and 12% for the two hop-case because of external noise caused by electrical activity. We also perform the two-hop experiment in a 3-phase configuration, with one node on each phase, so that each hop is across two phases, which gives the highest delays and a 12% message loss. The level of noise is dependent on the environment and the link quality between two nodes is directly related to the electrical topology.

The experiments in the low-power radio testbed reveal an even higher variance of latency, which depends on the placement of the nodes and the intensity of external interference. A node that is located two hops from the sink can have an average round trip time of 920 ms, while a node one hop from sink, yet having an unfortunate placement, has an average RTT of 890 ms. A small numer of highly delayed messages cause the standard deviation of the RTT to be relatively high. Looking at the mean values, however, we observe a more significant difference between one-hop latency and two-hop latency: 800 ms compared to 560 ms.

An additional observation is that when using no duty cycling of the radio, nodes were more likely to choose a two-hop route to the sink. This circumstance resulted in a longer round-trip delay compared to that when using ContikiMAC, but fewer packets got lost. With no duty cycling, message losses are 1% or below for all nodes, whereas with duty cycling and two-hops the losses ranges from 1% to 20%, with the higher value for the three nodes with the worst placement.

6 Conclusions

Being able to interoperate across PLC and low-power wireless has the potential to make deployments of sensor networks for building automation and the smart grid more efficient. We present preliminary work on integrating low-power wireless IPv6 networks and IPv6 PLC networks using the RPL protocol. Our preliminary results suggest that the performance of a low-power PLC network is on par with a low-power duty cycled 802.15.4 network.

Acknowledgments

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7 References

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