Competition: Reliability through Timeslotted Channel Hopping and Flooding-based Routing

Pedro Henrique Gomes
Ming Hsieh Department of Electrical Engineering
University of Southern California
pdasilva@usc.edu

Thomas Watteyne
Inria Paris
EVA team
thomas.watteyne@inria.fr

Pradipta Gosh
Ming Hsieh Department of Electrical Engineering
University of Southern California
pradiptg@usc.edu

Bhaskar Krishnamachari
Ming Hsieh Department of Electrical Engineering
University of Southern California
bkrishna@usc.edu

Abstract

The recent IEEE802.15.4e-2012 standard proposes medium access variants for improving the efficiency of low-power and lossy networks. The Timeslotted Channel Hopping (TSCH) mode enables wireless networks that can support applications with high-reliability requirements, such as smart factories, process automation and smart buildings. In TSCH-based networks, time is sliced into time slots and channel hopping is used to combat external interference and multi-path fading. The IETF 6TiSCH working group currently standardizes different scheduling approaches and what routing protocol to use. OpenWSN is the de-facto open-source implementation of TSCH/6TiSCH.

We propose to participate in the EWSN Dependability Competition by utilizing a modified version of OpenWSN in which we employ controlled flooding as a routing protocol. We believe the channel hopping nature of IEEE802.15.4e TSCH will yield high reliability, and controlled flooding will yield low latency and resilience to topological changes.

Lessons learnt from participating in the competition will be fed back to the IETF 6TiSCH standardization group; the code developed will be contributed to the OpenWSN open-source project (www.openwsn.org).

1 Introduction

The Internet of Things (IoT) is emerging as one of the biggest technologies for the growth of productivity in the next decade. Wireless communication will play an important role in the spread of IoT. The number of connected devices is expected to exceed 50 billions by 2020 and most of these nodes cannot be connected by wire. In order to enable critical applications such as smart factories or smart buildings, the networking protocols have to deal with the non-deterministic nature of wireless links. In the case of the 2.4 GHz Industrial Scientific and Medical (ISM) band – specified by the standard IEEE802.15.4 and employed in most IoT technologies such as WirelessHART, ISA100.11a and ZigBee – reliability is a major challenge because of the large number of co-existing systems that use this frequency band.

In face of the increasing adoption of wireless technology, the new IEEE802.15.4e standard [1] specifies a Timeslotted Channel Hopping (TSCH) medium access layer that targets critical applications. TSCH is a schedule-based protocol that slices time into slots and uses multiple frequencies concomitantly. It also employs Frequency Hopping Spread Spectrum (FHSS) in order to reduce the impact of multi-path fading and external interference [4]. Frequency Hopping requires network synchronization and exploits *frequency diversity* by sending packets on different channels at every time slot. Specifically, in TSCH networks, time slots have an associated *channel offset* which is converted into a *frequency* using a pseudo-random hopping pattern. The frequency to be used can be any one of the 16 available frequencies in the 2.4 GHz band.

Every node in a TSCH-based network follows a schedule that can be designed either by a central entity or in a distributed form. The schedule consists of a sequence of "atomic" resource units (time-frequency allocations) that continuously repeats over time. Medium access within each resource unit can be either *reserved* or *shared*. In the former, interference-free access is granted to a pair of transmitter/receiver nodes; in the latter, access is contention-based. Even though reserved access may optimize the chances of packet delivery, the overhead of building a schedule (either centralized or distributed) may be prohibitive in dynamic scenarios. The use of shared time slots is a simple solution for unknown and dynamic topologies and is better suited for routing protocols that take advantage of the broadcast nature

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of wireless transmissions.

The Routing Protocol for Low-Power and Lossy Networks (RPL) is a distance-vector protocol specified in IETF RFC6550 for operating on top of the IEEE802.15.4 standard. It is based on the concept of Destination Oriented Directed Acyclic Graphs (DODAGs), and organizes a network in a multi-parent oriented structure for collection applications. Every node in the RPL structure has an associated rank that decreases toward the sink, ensuring loops are detected and repaired. RPL is the *de facto* routing protocol for the Internet of Things and has been tested and implemented in different scenarios, showing good convergence time in dynamics networks and low energy overhead [2].

We propose a solution to deploying a dependable wireless system based on TSCH at the medium access layer. Because of the link unreliability created by RF interference, and since there will be no prior knowledge about network topology, we plan to adopt a controlled flooding-based routing approach. The network runs completely based on shared time slots and data packets (containing sensor information) will be broadcast. Relay nodes are responsible for forwarding the information toward the sink. We adopt a hybrid routing approach that is based on RPL multi-parent trees, where forwarding nodes retransmit only packets received from neighbors with higher rank to avoid loops.

2 Controlled flooding-based routing

External interference is one of the main factors that impacts the reliability of a wireless link. It can be sourced from other wireless systems that work on the same frequency band, or even from microwave ovens and other machinery. Jamming attacks can also intentionally degrade network performance. How much a given link is affected depends on the frequency and the location of the interference source. In general, different frequencies suffer distinct degradation, which justifies the use of FHSS as a way of exploiting *frequency diversity*. Similarly, links at different locations are differently affected by external factor, which justifies the use of multiple paths for reaching the sink as a way of exploiting *space diversity* [3].

Multipath routing is easily obtained using broadcast messages. Flooding is a well-known technique in which each node that receives a frame retransmits it to its neighbors. It has the advantage of being a low-overhead protocol that increases the delivery ratio because it transmits multiple copies of the same message through multiple paths. The drawback is the overhead created by the large number of duplicate messages. Different solutions may be implemented to avoid the exponential growth of messages and the creation of loops. We take advantage of the existing multi-parent RPL routing structure and use the neighbors' rank to drive the flood of packets toward the sink. In the forwarding method, all relay nodes only retransmit packets that come from neighbors with higher ranks, as shown in Fig. 1.

3 Implementation

Our solution is based on the OpenWSN [5] implementation. The network runs with reduced timeslot durations and the acknowledgement packets are eliminated, since all messages are broadcast. The slotframe structure consists of 20

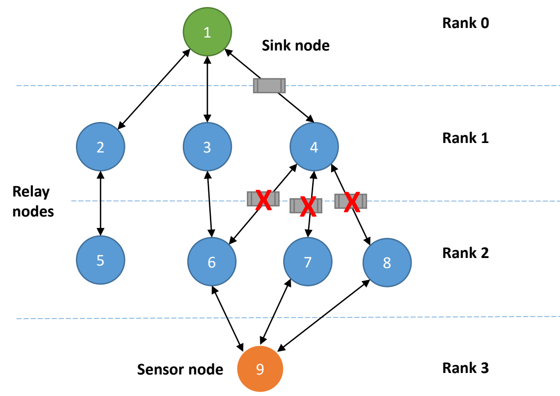

Figure 1. Example of controlled flooding. Node 4 forwards the packet to neighbors, but only Node 1 (the sink) accepts it. Other nodes at higher ranks drop the packet to prevent routing loop.

time slots, of which 10 are inactive (sleep-mode), and the remaining 10 are used for contention-based access (shared slots). Varying the portion of active slots allows us to explore different trade-off values between power consumption and latency. In each shared slot, nodes are able to sleep if no packet is received after *TsTxOffset* + *TsLongGT*, which is typically equal to *5.3ms*.

The RPL structure is used as a framework for generating the collection tree. We simplify RPL packet formats and functionality to optimize the network. The DIO messages, used to calculate the ranks and announcing the DODAGs, are embedded into IEEE802.15.4e Enhanced Beacons (EB). We also eliminate other types of messages, such as DAOs. In the end, the network runs based on EBs and broadcasts data packets with sensing (light intensity) information.

4 Conclusion

Reliability is a hard-to-achieve requirement in low-power lossy wireless networks, especially in the crowded 2.4 GHz band. Exploiting diversity in both frequency and space is a viable countermeasure to the high level of interferences that may disrupt critical applications. The proposed solution for a dependable network is based on FHSS to exploit *frequency diversity*, and flooding routing to exploit *space diversity*.

5 References

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