Poster Abstract: Temperature Hints for Sensornet Routing

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ABSTRACT

Real-world experiments have shown that the transmission power and the received signal strength of low-power radio transceivers used in sensornets decrease when temperature increases. We analyze how this phenomenon affects the network layer, and find that temperature fluctuations may cause undesirable behavior by sensornet routing protocols such as CTP and RPL. Furthermore, we present an approach to make these protocols robust to temperature fluctuations by augmenting the ETX link metric with *temperature hints.*

Categories and Subject Descriptors

C.2.2 [**Network Protocols**]: Routing protocols

Keywords

Wireless sensor networks, Temperature, Routing, RPL

1. INTRODUCTION

Several real-world wireless sensor networks deployments have shown diurnal and seasonal variations in the quality of wireless links [5, 8]. Controlled experiments have shown that these variations are highly correlated with changes in the ambient temperature [1, 2, 3]. A temperature increase of 40°C (a typical diurnal fluctuation recorded in outdoor environments [4, 8]) can decrease the Received Signal Strength (RSS) by as much as 8 dB, and may drive the Packet Reception Ratio (PRR) of a good link to zero [3].

To make sensor networks robust to temperature fluctuations, we need to study how the temperature affects communication protocols, and devise appropriate measures to mitigate adverse behavior. Whilst the literature contains extensive knowledge about what happens to link quality metrics when the temperature fluctuates, it has hitherto been unclear how it affects the performance at higher layers. Routing protocols are of particular interest because their performance is strongly affected by variations in link quality.

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Popular implementations of RPL [9], such as ContikiRPL and TinyRPL, construct a routing topology by minimizing the Expected Transmission Count (ETX). This metric is inversely proportional to the PRR, which is sensitive to temperature fluctuations. Our preliminary results, obtained from an experiment in a temperature-controlled indoor testbed [3], indicate that RPL[1] exhibits undesirable behavior in the presence of temperature fluctuations.

We propose to augment ETX with *temperature hints* to forecast link quality with higher accuracy than what can be obtained from using a simple moving average of PRR statistics. This approach is inspired by Ravindranath et al. [6], who have shown that *in-network* metrics can be augmented with hints from external sensors to improve protocols' performance. To the best of our knowledge, however, this is the first study on using *temperature hints* to improve a routing protocol.

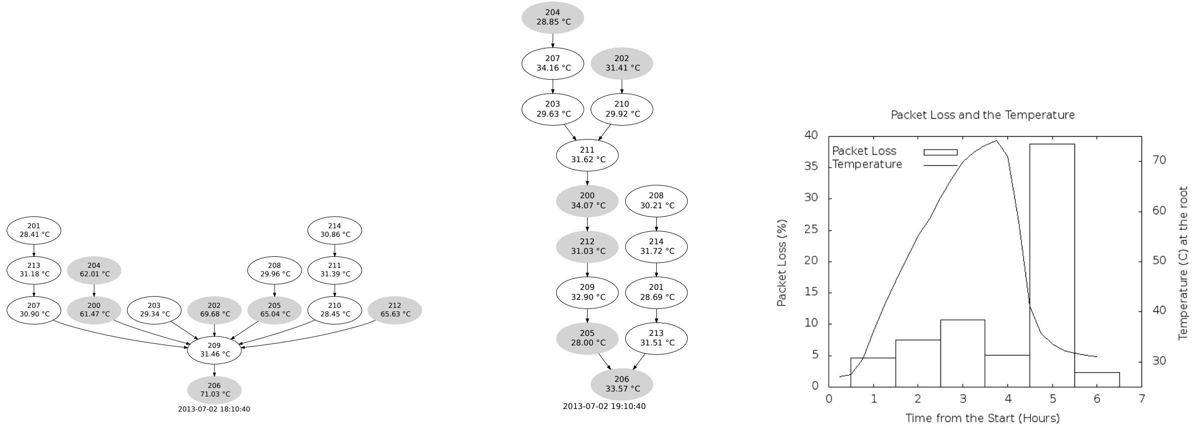
2. EMPIRICAL EVIDENCE

The basis of this work is the first-order model of the Signal to Noise Ratio (SNR) presented by Boano et al. [3] showing that in low-power radios SNR decreases linearly with temperature. Since PRR increases (and decreases) with the SNR, it is clear that ETX increases with the temperature and we hence hypothesize that temperature affects the behavior of RPL.

To investigate the effect of temperature fluctuations on RPL, we conduct an experiment in a temperature-controlled testbed composed of 15 Maxfor MTM-CM5000MSP nodes [3]. The temperature of nodes 200 and 206 (root node) can be controlled between room temperature (≈ 30°C) and 72°C, whereas the temperature of three other nodes can be varied in the range $[0, 72]$°C. We gradually increase the temperature of the five nodes for three hours up to 72°C, and then let the temperature cool them down quickly (see Fig. 1(c)). All nodes run Contiki with ContikiRPL. Each node, except for the RPL root node, sends a message to the root every minute. The nodes log their preferred parent node and the temperature measured using the on-board SHT11 sensor.

Fig. 1(a) depicts the network topology 4 hours after the beginning of the experiment, when all temperature-controlled nodes (highlighted in gray) have high temperatures. After another hour, the topology is quite different, as shown in Fig. 1(b). During this hour, the temperature decreased considerably in the temperature-controlled nodes.

[1] In this paper, RPL refers to ETX-based RPL implementations.



(a) RPL tree after 4 hours

(b) RPL tree after 5 hours

(c) Packet loss

Figure 1: RPL suffers packet losses due to the delayed response to the temperature change.

Based on the ETX estimation, RPL changes the topology to minimize the path-ETX: this should minimize the loss rate at the root. However, Fig. 1(c) shows that the packet loss rate increases considerably during the 5^{th} hour when the topology changes. At this point the node-temperatures have returned to the levels at the start of the experiment, but the diameter of the RPL-tree has increased considerably.

ETX based on historical data is a poor estimation of the future link conditions when the temperature changes rapidly. Therefore, the topology changes only after it suffers packet losses. In addition, once a link is selected, RPL ignores other good links unless the path cost increases considerably. This is the reason for RPL retaining the suboptimal topology in Fig. 1(b) even after the nodes have cooled down.

3. TEMPERATURE-HINTED ETX

Our preliminary experiments indicate that the performance of ContikiRPL suffers from the short term validity of the ETX predictions under temperature fluctuations. Therefore, we propose to augment the ETX metric with *temperature hints*, a solution applicable to sensor platforms equipped with temperature sensors.

To obtain a reasonable estimation of the temperature trend, each node records the EWMA of the temperature differences at a suitable sampling interval. Nodes announce the EWMA value in DAG Information Object (DIO) messages in RPL metric containers. The temperature information can be propagated quickly by resetting the *Trickle timer* whenever there is a significant change in the measured temperature. Such knowledge of the temperature trend enables the routing protocol to forecast near-term topological changes. Furthermore, it can be used to trigger *passive probing* [7] to prevent RPL from settling into a sub-optimal topology.

4. CONCLUSIONS

This paper shows the unstable behavior of an ETX-based RPL implementation under temperature fluctuations. We propose *temperature-hinted ETX* as a solution to this problem. We are currently planning experiments to further investigate this problem and to evaluate the effectiveness of the proposed solution.

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