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A Reinforcement Learning-based Link Quality Estimation Strategy for RPL and its Impact on Topology Management

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Abstract

Over the last few years, standardisation efforts are consolidating the role of the Routing Protocol for Low-Power and Lossy Networks (RPL) as the standard routing protocol for IPv6-based Wireless Sensor Networks (WSNs). Although many core functionalities are well defined, others are left implementation dependent. Among them, the definition of an efficient link-quality estimation (LQE) strategy is of paramount importance, as it influences significantly both the quality of the selected network routes and nodes' energy consumption. In this paper, we present RL-Probe, a novel strategy for link quality monitoring in RPL, which accurately measures link quality with minimal overhead and energy waste. To achieve this goal, RL-Probe leverages both synchronous and asynchronous monitoring schemes to maintain up-to-date information on link quality and to promptly react to sudden topology changes, e.g. due to mobility. Our solution relies on a reinforcement learning model to drive the monitoring procedures in order to minimise the overhead caused by active probing operations. The performance of the proposed solution is assessed by means of simulations and real experiments. Results demonstrated that RL-Probe helps in effectively improving packet loss rates, allowing nodes to promptly react to link quality variations as well as to link failures due to node mobility.

Keywords: RPL, topology and mobility management, link quality estimation, experimental evaluation.

1. Introduction

The future Internet of Things (IoT) foresees information systems seamlessly integrated with smart objects, i.e. daily objects empowered with computation and communication capabilities [1, 2]. This vision will require sensors and actuators deployed on a large scale for ubiquitous sensing and remote control of physical systems. In this context, Wireless Sensor Networks (WSNs) will represent a key enabler to guarantee low-cost and rapid deployment of IoT devices exploiting multi-hop data delivery over wireless links. Efficiency and reliability of multi-hop data forwarding will be essential to support future IoT systems and guarantee their robustness [3].

In general, the main objective of WSN routing protocols is to enable reliable communication while minimising resource consumption [4]. This is particularly important in low-power and lossy networks (LLNs), because they are characterised by unreliable links whose quality may significantly fluctuate over time influenced by external interference or obstacles. In this context, the selection of the optimal path is however challenging, as gathering topology information requires communication and processing overhead that contrasts with the limited computational and energy capabilities available to constrained devices.

Recently, significant efforts were put into defining a common routing protocol for IP-based WSNs, which have led to the standardisation of RPL, a gradient-based routing protocol that aims at building a robust multi-hop mesh topology over lossy links with minimal state requirements [5]. However, several studies have demonstrated that RPL is affected by reliability issues. The root cause of this unreliability is the lack of responsiveness to variations of network conditions that arise in real-life scenarios due to node mobility, or environmental factors, such as interference, multi-path effects, irregular radios patterns among the others [6]. Hence, many extensions have been recently proposed for the original RPL specification to support routing optimisations and more efficient mechanisms for route discovery and topology repair, especially under mobility [7, 8, 9, 10, 11, 12, 13, 14]. However, *tweaking routing procedures does not solve the core problem of how to proactively maintain up-to-date information about links quality and network routes in a highly efficient manner.*

More generally, the availability of a highly efficient, accurate, and adaptive link-quality estimation (LQE) framework is essential to allow any routing protocol to select the best routing path under time-varying network conditions. It is well known that transmitting data over links with high quality improves both the network throughput, by

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