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Quality-of-service aware routing for static and mobile IPv6-based low-power and lossy sensor networks using RPL

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ABSTRACT

The Internet of Things (IoT) has emerged as a paradigm over the last few years as a result of the tight integration of the computing and the physical world. The requirement of remote sensing makes low-power wireless sensor networks one of the key enabling technologies of IoT. These networks encompass several challenges, especially in communication and networking, due to their inherent constraints of low-power features, deployment in harsh and lossy environments, and limited computing and storage resources. The IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) [1] was proposed by the IETF ROLL (Routing Over Low-power Lossy links) working group and is currently adopted as an IETF standard in the RFC 6550 since March 2012. Although RPL greatly satisfied the requirements of low-power and lossy sensor networks, several issues remain open for improvement and specification, in particular with respect to Quality of Service (QoS) guarantees and support for mobility.

In this paper, we focus mainly on the RPL routing protocol. We propose some enhancements to the standard specification in order to provide QoS guarantees for static as well as mobile LLNs. For this purpose, we propose OF-FL (Objective Function based on Fuzzy Logic), a new objective function that overcomes the limitations of the standardized objective functions that were designed for RPL by considering important link and node metrics, namely end-to-end delay, number of hops, ETX (Expected transmission count) and LQL (Link Quality Level). In addition, we present the design of Co-RPL, an extension to RPL based on the corona mechanism that supports mobility in order to overcome the problem of slow reactivity to frequent topology changes and thus providing a better quality of service mainly in dynamic networks application. Performance evaluation results show that both OF-FL and Co-RPL allow a great improvement when compared to the standard specification, mainly in terms of packet loss ratio and average network latency.

1. Introduction and motivation

Internet-of-Things (IoT) is considered as the key component of the future Internet in our everyday life. It is built with thousands of smart objects that are usually small and inexpensive devices and thus can be embedded in almost any object like meter, industry machinery, home equipment, and light switches.

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With the emergence of low power and lossy networks, new ways of communication were needed. In order to standardize the communication between these low powered devices, IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) has been proposed by the IETF Routing Over Low power and Lossy networks ROLL Working Group as a standard routing protocol for IPv6 routing in low power and lossy networks.

The inherent LLNs of low data rates, high probability of node and link failures, and scare energy resources, have turned the design of RPL challenging and different from previous routing proposals. Moreover, RPL is still under development, although having gained maturity, and is open to improvements. In this paper, we study and extend RPL, as it is the standard routing protocol for the low power and lossy networks. Our work differs from the previous works and contributes to the state-of-the art in three aspects. First, we provide a deep analysis of the RPL protocol based on our simulation and real experimentation [2,3]. This study allows us to conclude that RPL provides several advantages that fit the LLNs applications, and presents some limitations related to the selection of the best path to the root, which cannot sufficiently satisfy the antagonistic requirements of LLNs applications. In addition, the large amount of packet loss ratio reflects the inability of RPL nodes to quickly react to the frequent topology changes, mainly in the case of mobile nodes.

Second, we present a new objective function, OF-FL, based on Fuzzy Logic whose purpose is to provide better characterization of the best path to the network sink as compared to existing objective functions. The key idea in this work is to combine several node and link routing metrics using Fuzzy-Logic technique so that to provide a more generic characterization of the quality of neighbor nodes based on several metrics in order to select the best neighbor. The design of OF-FL comes from the need of satisfying the different application requirements of LLNs including real time applications, highly available applications and reliable applications. OF-FL also provides a configurable routing decision based on the fuzzy parameters.

Third, and for the aim of applying RPL in mobile low power and lossy networks, we present Co-RPL, an extension to RPL that allows to make RPL suitable for highly dynamic networks. In fact, mobility management is a fundamental yet challenging area in low power wireless networks as many mobility applications require routing data with quality of service guarantees. However, the RPL standard specification does not consider the case of dynamic topologies where mobile nodes usually change their positions. In order to make RPL adequate for mobility, we propose Co-RPL, an enhancement of RPL that allows the nodes to react to the topology changes while maintaining the quality of service contracts of mobile LLNs. We have also concluded from this analysis that the current specification does not consider the case of instability of the DAG structure (including the sink and the RPL routers). Finally, we present a comparative study in terms of stability, latency, reliability and power consumption distribution comparing the performance of Co-RPL against the RPL standard specification and we show that Co-RPL outperforms RPL and can be applied in mobile wireless sensor networks (MWSNs).

The rest of this paper is as follows. Section 2 overviews the most relevant research efforts related to the amendment of the RPL standard specification. In Section 3, we describe our proposed objective function in order to optimize routing decisions between nodes in the RPL-based network, and we present our mechanism Co-RPL that allows to overcome the limits of RPL mainly in the case of mobile networks. Section 4 presents the performance evaluation results of the proposed approaches. Finally, Section 6 closes the paper with discussions about ongoing work and future directions. Table 1 outlines the organization of this paper.

Table 1
Structure of the paper.

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2. Related work

In what follows, we first present the main features of the RPL routing protocol. Then, we survey the most recent works that have proposed some enhancements to the RPL standard specification, in an attempt to meet the quality of service requirements of static as well as mobile networks.

2.1. Overview on the RPL routing protocol

IPv6 Routing Protocol for Low Power and Lossy Networks (RPL) is a routing protocol specifically designed for Low power and Lossy Networks (LLN) compliant with the 6LoWPAN protocol. It currently shows up as an RFC proposed by the IETF ROLL working group. However, RPL has gained a lot of maturity and is attracting increasing interest in the research community [3].

RPL is a distance-vector and a source routing protocol that is designed to operate on top of several link layer mechanisms including IEEE 802.15.4 PHY and MAC layers. It targets *collection-based networks*, where nodes periodically send measurements to a collection point, as well as point-to-multipoint traffic from the central point to the devices inside the LLN.

RPL is based on the topological concept of *Directed Acyclic Graphs* (DAGs). The DAG defines a tree-like