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Survey Paper

RPL in a nutshell: A survey

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ABSTRACT

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. The absence of surveys about RPL motivates us to write this paper, with the objective to provide a quick introduction to RPL. In addition, we present the most relevant research efforts made around RPL routing protocol that pertain to its performance evaluation, implementation, experimentation, deployment and improvement. We also present an experimental performance evaluation of RPL for different network settings to understand the impact of the protocol attributes on the network behavior, namely in terms of convergence time, energy, packet loss and packet delay. Finally, we point out open research challenges on the RPL design. We believe that this survey will pave the way for interested researchers to understand its behavior and contributes for further relevant research works.

1. Introduction

6LoWPAN [1] is a milestone protocol that bridged the gap between low-power devices and the IP world. It is an IP-based technology for Low-Power Wireless Personal Area Networks (LoWPANs), such as Wireless Sensor Networks, that combines IEEE 802.15.4 [2] and the IPv6 protocols [3]. This integration provided a new dimension in the design of LoWPANs as it allows for a full interoperability with the Internet.

Since the specification of 6LoWPAN [4], routing has been considered as one of the key issues in 6LoWPAN networks that are worth investigation. Indeed, there have been several endeavors for specifying an efficient routing protocol for 6LoWPAN-compliant LLNs, such as for instance, Hydro [5], Hilow [6], and Dymo-low [7]. All these proprietary solutions did not gain a lot of space in the arena, and an increasing need for a standard solution has arisen. To address this gap, the IETF ROLL working group [8,9] has proposed a routing protocol, referred to as *RPL* (Routing Protocol for Low power and lossy networks), which is the main candidate for acting as the standard routing protocol for IP smart object networks (also referred to as LLN). A key feature of RPL is that it is designed for networks with lossy links, which are those exposed to high Packet Error Rate (PER) and link outages. Although RPL is still a RFC, it has gained a lot of maturity turning it as a promising standardized routing solution for Low Power and Lossy Networks. In fact, several research works have focused on the design and deployment of RPL protocol and real-world implementations have been showing up [10–13], etc. The increasing popularity of RPL is due to several factors, including its flexibility to adapt to different topologies, QoS support and other interesting features that we present next.

To the best of our knowledge, this is the first comprehensive survey of the RPL protocol. In [14], the authors presented an overview on the 6LoWPAN and RPL technologies. As compared to this survey, Ref. [14] only provides a brief tutorial-like introduction of the RPL protocol and does not

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comprehensively describe the protocol behavior/mechanisms, nor does it discuss the recent works tied to RPL. This survey is roughly divided into two majors parts: The first part spans over Sections 2–5 which present an overview of RPL and its main features. The second part (i.e. Sections 6–7) provides a comprehensive review on the latest development and research works related to RPL and points out underlying research challenges.

The remainder of the paper is organized as follows. Section 2 presents the design objectives and network architecture of the RPL protocol. In Section 3, we present the routing protocol specification namely the protocol control headers and network construction operations. Section 4 describes network management mechanisms pertaining to fault-tolerance, QoS, and security. In Section 5, we present an experimental performance evaluation to understand the impact of RPL attributes on the network behavior. In Section 6, we compare RPL with its competitors and provide a literature review of relevant and recent works around the RPL protocol. Finally, Section 7 concludes the paper and discusses open research challenges with respect to RPL design and deployment.

2. Protocol overview

2.1. Design objectives

RPL is a distance–vector (DV) 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. Point-to-point traffic is also supported in RPL. A key feature in RPL is that it represents a specific routing solution for low power and lossy networks [14,15], which stand for networks with very limited resources in terms of energy, computation and bandwidth turning them highly exposed to packet losses. In fact, it has been specifically designed to meet the requirements of resource-constrained nodes as mentioned in the routing requirement terminology document [16]. In particular, RPL-enabled LLNs take into account two main features (i) the prospective data rate is typically low (less than 250 kbps), and (ii) communication is prone to high error rates, which results in low data throughput. A lossy link is not only characterized by a high Bit Error Rate (BER) but also the long inaccessibility time, which strongly impacts the routing protocol design. In fact, the protocol was designed to be highly adaptive to network conditions and to provide alternate routes, whenever default routes are inaccessible.

RPL is based on the topological concept of *Directed Acyclic Graphs* (DAGs). The DAG defines a tree-like structure that specifies the default routes between nodes in the LLN. However, a DAG structure is more than a typical tree in the sense that a node might associate to multiple parent nodes in the DAG, in contrast to classical trees where only one parent is allowed. More specifically, RPL organizes nodes as *Destination-Oriented DAGs* (DODAGs), where most popular destination nodes (i.e. sinks) or those providing a default route to the Internet (i.e. gateways) act as the roots of the DAGs.

A network may consist of one or several DODAGs, which form together an *RPL instance* identified by a unique ID, called *RPLInstanceID*. A network may run multiple RPL instances concurrently; but these instances are logically independent. An node may join multiple RPL instances, but must only belong to one DODAG within each instance. Fig. 1 shows an example of RPL instances with multiple DODAGs.

One of the relevant features of the RPL routing protocol is that it combines both *mesh* and *hierarchical* topologies. On the one hand, an RPL-based network topology is inherently hierarchical as it forces underlying nodes to self-organize as one or several *DODAGs*, based on parent-to-child relationship. On the other hand, RPL supports the mesh topology as it allows routing through siblings instead

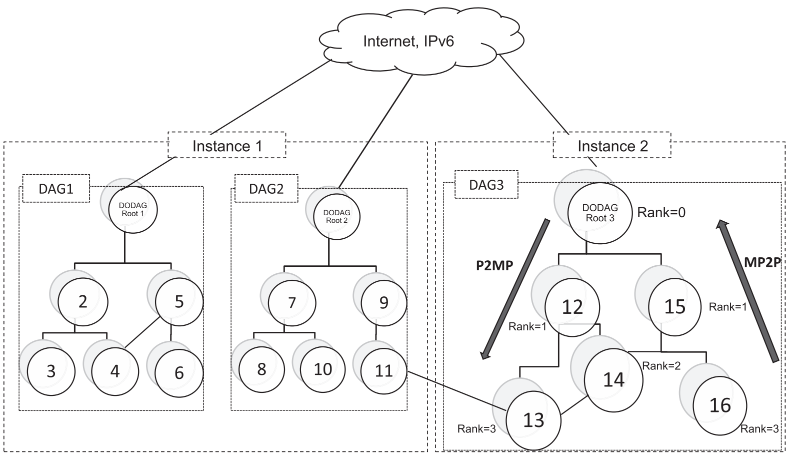

Fig. 1. A RPL network with three DODAGs in two instances.