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mRPL: Boosting mobility in the Internet of Things

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ABSTRACT

The 6loWPAN (the light version of IPv6) and RPL (routing protocol for low-power and lossy links) protocols have become *de facto* standards for the Internet of Things (IoT). In this paper, we show that the two native algorithms that handle changes in network topology – the Trickle and Neighbor Discovery algorithms – behave in a reactive fashion and thus are not prepared for the dynamics inherent to nodes mobility. Many emerging and upcoming IoT application scenarios are expected to impose real-time and reliable mobile data collection, which are not compatible with the long message latency, high packet loss and high overhead exhibited by the native RPL/6loWPAN protocols. To solve this problem, we integrate a proactive hand-off mechanism (dubbed smart-HOP) within RPL, which is very simple, effective and backward compatible with the standard protocol. We show that this add-on halves the packet loss and reduces the hand-off delay dramatically to one tenth of a second, upon nodes' mobility, with a sub-percent overhead. The smart-HOP algorithm has been implemented and integrated in the Contiki 6LoWPAN/RPL stack (source-code available on-line mrpl: smart-hop within rpl, 2014) and validated through extensive simulation and experimentation.

1. Introduction

The next generation Internet, commonly referred as *Internet of Things* (IoT), depicts a world populated by an endless number of smart devices that are able to sense, process, react to the environment, cooperate and intercommunicate via the Internet. For over a decade, low-power wireless network research contested the complexity of the Internet architecture for sensor network applications. However, as the state-of-the-art progressed, academic and commercial efforts invented new network abstractions based on the Internet architecture. The *Internet Engineering Task Force* (IETF) designed some protocols and adaptation layers that allow IPv6 to run over the IEEE 802.15.4 link layer. The *IPv6 over Low-power Wireless Personal Area Networks* (6LoWPAN) working group [2] designed header compression and fragmentation for IPv6 over IEEE 802.15.4 [3]. The IETF *Routing Over Low-power and Lossy networks* (ROLL) working group designed a routing protocol, referred as RPL [4], which is the *de facto* standard routing protocol for 6LoWPAN. These standard IP-based protocols are thus a fundamental building block for the IoT.

6LoWPAN as an adaptation layer is able to support routing in the link layer and the network layer [5,6]. Two routing schemes of mesh-under and route-over are devised to support link and network layer routings respectively. In a mesh-under organization, the adaptation layer performs the mesh routing and forwards packets to the destination via multiple radio hops. The mesh-under design is suitable for single-hop networks, where all nodes are within the transmission range of each other. In a route-over scheme, the routing decision is taken at the network layer, where nodes act as IP routers. Each link layer hop is an IP hop and the IP routing forwards packets between these links.

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The route-over routing supports a multi-hop mesh routing communication, suitable for large-scale deployments.

Mobility support is becoming a requirement in various emerging IoT applications [7–9], including health-care monitoring, industrial automation and smart grids [10–12]. Many recent research projects and studies have considered the cooperation between mobile and fixed sensor nodes [13–16]. In clinical monitoring [17], patients have embedded wireless sensing devices that report data in real-time. In oil refineries, the vital signs of workers are collected continuously in order to monitor their health situation in dangerous environments [18]. In fact, many applications require timeliness and reliability guarantees for transmitting critical messages from source to destination, but providing *Quality of Service* (QoS) in low-power and mobile networks is very challenging.

In this work, we are considering a wireless clinical monitoring application that collects patients' vital signs. Patients are mobile nodes that generate traffic and freely move while maintaining their connectivity with the fixed nodes infrastructure. All nodes in our system model are simple sensor nodes featuring low-power CC2420 radio. Fig. 1 illustrates the system model, where a MN moves from the vicinity of Node 8 toward Node 7. We propose a hand-off mechanism that quickly detects mobile entities and locally updates the routing tree. *Hand-off is referred as the process of switching a MN from one point of attachment to another.* In this process, the standard RPL routing performs normally while the mobile nodes run a hand-off algorithm. We build the mobility enabled RPL based on smart-HOP, which is a hard hand-off mechanism that was designed and tested in a generic network architecture, in a protocol-agnostic way [19,20].

Two main mechanisms are employed in RPL and 6LoWPAN that partially cope with mobility. First, the periodic transmission of control packets, scheduled by the *Trickle* algorithm, can detect topological changes. During this process, RPL resumes a fast global routing update that causes a high overhead. Second, the *Neighbor Discovery* (ND – defined in RFC 4861) mechanism, assesses the neighbor reachability in a regular basis. At each activation, the ND protocol floods the entire network with router advertisements, also leading to a high overhead. A short activation interval (that reduces the overhead) leads to low responsiveness to network/topological changes. However, in the revised ND mechanism of 6LoWPAN, router advertisement packets are transmitted upon receiving router solicitation messages [21].

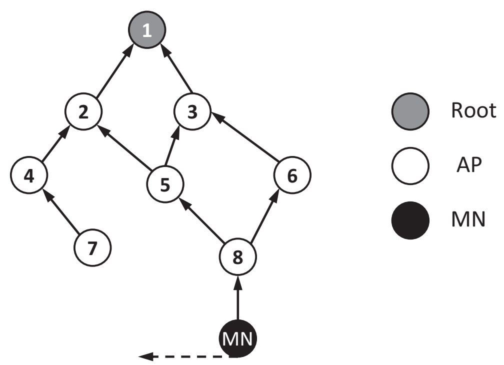

Fig. 1. An example of having mobile node within an RPL tree, where the MN moves from the vicinity of AP_8 toward AP_7.

Why smart-HOP? Hand-off has been widely studied in Cellular and wireless local area networks [22–25]. However, it has not received the same level of attention in low-power networks. Cellular networks perform centralized hand-off decisions typically coordinated by powerful base-stations. Contrarily to Cellular networks, WiFi networks have a distributed architecture where hand-off is triggered when the quality of the service degrades. In low-power networks, a centralized approach is not feasible as the access points are assumed to have scarce resources. smart-HOP [19,20] considers the main features of low-power networks, the link unreliability and the existence of a single low-power radio per node. It manages hand-offs in a distributed way and leads to very short disconnection times.

Why integrating smart-HOP in RPL? There are four main RPL features that motivated us to grant it with mobility support: (i) the proactive feature of RPL that generates and maintains stable routing tables. A periodic broadcast of control messages among all nodes maintains the paths and link states between them. In reactive routing protocols; such as AODV [26] and DSR [27], routes are established upon request, so they do not respond quickly to environmental changes due to mobility or link degradation. RPL maintains the route in the background with minimal overhead. Moreover, for an application with limited mobility and the requirement of an infrastructure, RPL is very suitable, (ii) unlike other proactive routing protocols (e.g. OSPF [28]), RPL exchanges local information among neighbors to repair routing inconsistencies, instead of globally advertising control messages, (iii) RPL runs a tree-based structure that is suitable for data collection WSN applications, and (iv) the IPv6-based addressing in RPL naturally performs the interoperability with other Internet devices.

Contributions. Building on our previous works [19,20], we provide fast and reliable mobility support in RPL. The proposed mobility solution keeps the standard RPL protocol unchanged while providing backward compatibility with the standard implementation, i.e. standard and smart-HOP-enabled nodes can coexist and inter-operate in the same network. The main contributions of this paper are:

1. Efficient hand-off mechanism for RPL with good performance, correctly delivering nearly 100% packets with at most 90 ms hand-off delay and $< 1\%$ additional overhead upon nodes' mobility in high traffic scenarios.
2. Smooth integration and backward compatibility with the standard RPL/6LoWPAN.
3. Collision avoidance mechanism (to avoid collision during the hand-off process while collecting packets from neighbor APs) and loop avoidance mechanism (to avoid closed loops in RPL routing upon mobility).
4. Simulation (Cooja) analysis and experimental validation with commodity hardware platforms in a reliable environment.