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Using multiparent routing in RPL to increase the stability and the lifetime of the network ☆,☆☆

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ABSTRACT

Energy is a very scarce resource in Wireless Sensor Networks. While most of the current proposals focus on minimizing the global energy consumption, we aim here at designing an energy-balancing routing protocol that maximizes the lifetime of the most constraint nodes. To improve the network lifetime, each node should consume the same (minimal) quantity of energy. We propose the *Expected Lifetime* metric, denoting the *residual time* of a node (time until the node will run out of energy). We design mechanisms to detect energy-bottleneck nodes and to spread the traffic load uniformly among them. Moreover, we apply this metric to RPL, the *de facto* routing standard in low-power and lossy networks. In order to avoid instabilities in the network and problems of convergence, we propose here a multipath approach. We exploit the Directed Acyclic Graph (DAG) structure of the routing topology to probabilistically forward the traffic to several parents. Simulations highlight that we improve both the routing reliability and the network lifetime, while reducing the number of DAG reconfigurations.

1. Introduction

Routing in Wireless Sensor Networks (WSN) has been extensively studied in the last decade. These networks are highly unreliable, prone to multihop interference, and to a time varying link quality. Moreover, the devices composing them are very limited in terms of memory, processing power and battery [1]. In this type of environment, a *good* routing protocol should:

(a) save energy, since most of the nodes are battery powered [2];
(b) deal with lossy links, for both control and data packets [2];
(c) avoid routing loops, and enable fast convergence [3].

RPL is considered as a *de facto* routing standard for the Internet of Things [4]. It aims at optimizing the routing scheme for the convergecast traffic pattern (i.e., all the packets are sent to a collection of *border routers*, connected to the Internet). RPL is based on a Destination-Oriented Directed Acyclic Graph (DODAG) rooted at the border routers. The DODAG is constructed based on a *rank*, denoting the *virtual distance* of each node to the root. RPL reflects the current evolution of this research area: it introduces redundancy in the routing structure, to be fault-tolerant.

However, in our opinion, the current version of RPL presents two ways of improvement. First, the Roll working group has focused on efficiently constructing a routing

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structure. We have now to provide metrics and mechanisms to make RPL energy-efficient: the topology (i.e., the DODAG) should be constructed based on energy criteria. Second, a node selects one preferred parent to construct the DODAG without loops, and to compute its own rank. However, only this preferred parent is used for routing: the other ones have just a *backup* purpose. We are convinced we should rather exploit this diversity to distribute the traffic load in the network and to create energy-balanced paths.

While adding more sinks could help better distributing the traffic load [5], this also increases the deployments cost. We consider here only one sink per network. In this case, two main approaches to save energy exist in the literature. The first one, minimizes the global energy consumption: the ETX metric for instance, aims at selecting energy-efficient links [6]. However, the nodes with the best links will be chosen uppermost to route packets: they will deplete their energy faster. The second one, uses in priority the nodes with a large residual energy to forward most of the traffic [7]. Still, these nodes, with possibly bad links, will receive most of the traffic and will consequently run out of energy faster. Clearly, we should not have a small collection of nodes that forwards most of the traffic.

We take here an alternative approach that balances efficiently the energy among all the nodes, based on a multipath solution. Indeed, multipath routing has been widely used in the literature to improve the reliability [8], to be fault-tolerant [9], to balance the load for congestion avoidance [10], or for QoS improvement [11]. While QoS is an important issue [12–14], we aim here at rather splitting the load to balance the energy consumption, and improve this way the network lifetime. We think that each path should consume the same quantity of energy. More precisely, all the nodes with the lowest residual energy (denoted *bottlenecks* in this paper) should be equally energy-balanced.

We have proposed in [15] a novel routing metric that allows a node to estimate how much time it has to live before running out of energy. We define here this metric for multipath routing protocols, to create an energy balanced topology. The improvements brought by this paper are:

1. We extend the *Expected Lifetime* metric for the multipath scenario and we detail how to estimate it for each node.
2. We identify the bottleneck nodes in this new context, and we construct accordingly a Directed Acyclic Graph (DAG) that equalizes the *Expected Lifetime* among the weakest nodes.
3. We address the stability problem: the routing DAG should limit the number of reconfigurations, in order to avoid oscillations and to minimize the energy consumption. We highlight that multipath helps surpassing these problems. A node changes its preferred parent only when it becomes useless (i.e., it does not forward traffic anymore), avoiding this way the sudden routing reconfigurations. Less reconfigurations also mean less control packets, which minimizes the energy consumption.
4. We propose an algorithm to split the traffic among several paths, while balancing the energy equally among them.

2. Related work

2.1. RPL: Routing protocol for low-power and lossy networks

RPL is a distance vector protocol for low-power and lossy networks [4]. Starting from a border router, RPL constructs a Destination-Oriented Acyclic Graph (DODAG) using one or several routing metrics.

The DODAG construction is based on the *rank* of a node, which depicts its relative distance to the DODAG root. An *Objective Function* defines how a collection of routing metrics have to be combined to compute the rank. In order to have a loop-free topology, the rank must strictly monotonically increase from the root towards the leaves of the DODAG.

The construction and the maintenance of the DODAG are ensured by DODAG Information Object (`DIO`) messages periodically broadcasted by all the nodes. These packets contain information such as the *DODAG identifier*, the Objective Function, the rank of the node, or the metrics used for path calculation.

When a node receives a `DIO`, it inserts the emitter in the list of the possible successors, i.e., next hops to the border router. From all the successors in this list, the node will choose its preferred parent and send it all its traffic. It then computes its own rank with the Objective Function and starts broadcasting itself `DIO` messages. The simplest Objective Function – OF0 [16] – consists in choosing the preferred parent as the one advertising the lowest rank. Then, the node adds a small increment to the rank of its preferred parent to compute is own rank while maximizing the number of siblings.

The DODAG structure creates and maintains multiple routes towards the border router. However, RPL only uses a single path to route the packets (through the preferred parent). Pavković et al. [17] extended RPL to be used opportunistically with IEEE 802.15.4-2006: a node sends a data packet to the first available parent, instead of waiting for the preferred parent to be available. However, their focus is on offering QoS for delay-sensitive packets and not on improving the network lifetime.

Hong and Choi [18] proposed to choose the preferred parent using the hop count and then to select as the forwarding node the parent offering the best link quality. However, this can be equivalent to choosing the best parent among the worst available ones. Besides, a collection of nodes may still forward most of the traffic, and will run faster out of energy.

2.2. Energy aware routing

If we aim at minimizing the average energy consumption, ETX may take into account the link reliability to construct only energy-efficient routes [6]. However, we would not optimize the network lifetime, since a small number of nodes with a high ETX and close to the border routers may have to forward most of the traffic.