Impact of the Initial Preferred Parent Choice in Wireless Industrial Low-Power Networks

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ICube lab, CNRS / University of Strasbourg, Illkirch, France

teleshermeto@unistra.fr, gallais@unistra.fr, theoleyre@unistra.fr

1. Introduction

The Internet of Things has emerged in the last years as a concept that leads to a wireless Internet that connects a myriad of smart systems, from temperature sensors, HVAC systems, to intrusion detectors [1]. All these objects are expected to be deployed in homes, warehouses, streets, or amusement parks.

Industry 4.0 is currently an emerging approach, aiming to re-use the IoT concepts in the automation world. The so-called Industrial Internet of Things (IIoT) relies on wireless technologies that are able to provide a high Quality of Service (QoS) for a plethora of industrial applications such as vehicle automation, smart grid, automotive industry or airport logistics. All those applications share similar network performance requirements regarding low-latency and high network reliability.

To provide Quality of Service (QoS) for industrial-like wireless networks, the IEEE 802.15.4-2015 standard was published in 2016 [2]. Time-Slotted Channel Hoping (TSCH) is among the Medium Access Control (MAC) schemes defined in this standard, and targets specifically the low-power, deterministic and reliable wireless industrial networks. TSCH relies on a strict schedule of the transmissions such that each application has enough transmission opportunities while avoiding transmission collisions. When a node is not involved in a transmission or reception, it can safely switch its radio interface off to save energy.

To construct an accurate schedule, the network needs to select the best route(s) for each flow, and to allocate enough transmission opportunities to each node along the path to the sink. Estimating the link quality is consequently of prime interest: Selecting a suboptimal preferred parent implies that many packets have to be retransmitted to be correctly received by the next hop. The routing topology is in other words inefficient and the incriminated nodes may quickly run out of energy. Iova *et al.* [3] highlighted the presence of oscillations in RPL, with many parent changes when using a dynamic link quality metric.

In this letter, we propose to focus on the initial parent choice when a node has to join the network. We share here our experimental characterization, which focuses on the convergence phase.

2. Convergence of RPL when using a default initial metric

Let us consider the topology depicted in Figure 1. In this letter, we propose to focus on the initial parent choice when a node has to join the network. We share here our experimental characterization, which focuses on the convergence phase.

We assume that RPL is used for routing [4]. Let us consider that RPL uses the ETX metric (i.e. average number of transmissions before receiving an acknowledgment) to select the best routes. RPL relies on an objective function to translate a link metric into a *rank*, denoting the virtual distance between the node and the border router. To use the best routes, a node selects as preferred parent its lowest ranked neighbor [4]. The ranks of nodes in its vicinity are derived from the respective estimated quality of the links with these nodes. Unfortunately, measuring the ratio of packet errors requires to exchange first some data packets. Thus, an initial default link quality may be associated with the inactive neighbors. While the 6TiSCH-minimal draft [5] does not recommend any default ETX value for inactive neighbors, the OpenWSN[1] implementation uses a fixed default link cost equal to 4, thus assuming that the ETX toward an inactive neighbor is 4.

Let consider the Figure 1, with a multihop topology of 6 nodes, including the sink. Each node (N) computes its rank based on the rank of its preferred parent (P), and its link quality:

$$rank(N) = rank(P) + \text{MinHopRankIncrease} * \text{ETX}(\text{N} \rightarrow \text{P})$$

with `MinHopRankIncrease` being a constant (by default equal to 256), and (ETX(N→P)) denotes the ETX metric from N to P.

If a default ETX value is used when a link is unprobed. Thus, the node N selects as preferred parent its neighbor with the lowest rank, i.e. the node A. After the association, the link (N,A) is used, and the link quality estimation is refined, with the correct ETX value: its rank is finally updated (1537). Since the node B provides now a lower

[1] http://www.openwsn.org

rank with default ETX value (4*256+260<1537), *N* changes its preferred parent to *B* (which will give a lower rank using the default value 1284). We can note that the node *N* probes iteratively each of its neighbors as preferred parent.

Inversely, *N* will not select *C* or *D* as parent although they provide a better path to the border router. Indeed, their rank with the default value would be 1304 and 1324 respectively. Unfortunately, the rank of *B* (with its actual ETX) is 1028, strictly inferior to the default rank of the other possible parents. A too large ETX default value for inactive neighbors prevents to select the best parents eventually.

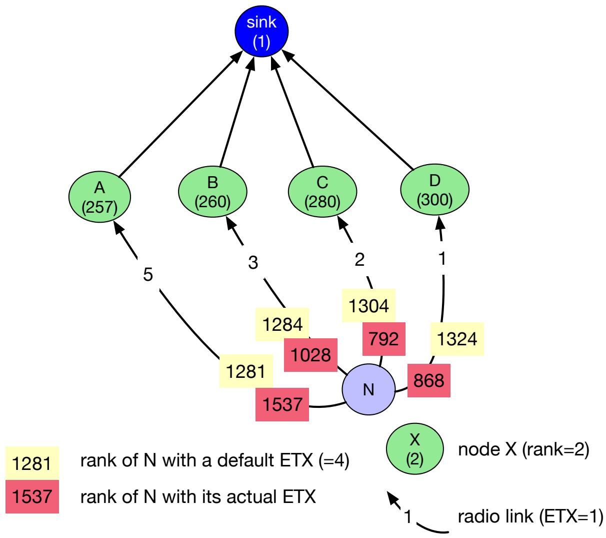

Figure 1: Convergence of the preferred parent choice when using a default ETX value

The problem becomes even trickier to handle with temporal variations, very common for this kind of scenario [6]. For inactive neighbors, the link metric was evaluated a long time ago and does not reflect the current quality. De facto, these neighbors will never be considered again to serve as preferred parent, except if the current one crashes or its link quality becomes very bad (i.e. ETX > 4).

For higher network densities, a node may limit the number of neighbors to be included in its neighbors table. In such scenarios, the node would exclude periodically from its table bad neighbors or even nodes that have stayed a long time without communicating. Later, they might be added back with the default link cost until they are probed again. With this inclusion/removal, a node may consider again a bad neighbor when a parent changing is required.

3. Initial Link Quality Estimation with a Reservation Based MAC layer

IEEE 802.15.4-2015-TSCH requires a strict schedule of the transmissions. Each cell is identified by its timeslot and channel offset, and is allocated to a set of transmitters. During a shared cell, several transmitters can transmit using a backoff value to regulate the contention. Typically, all the nodes have to stay awake during a shared cell so that a broadcast packet is received by all the nodes with a single radio transmission. Inversely, dedicated cells are contention free, and are allocated to a set of transmitters and receivers which do not mutually interfere.

When executed on top of the IEEE 802.15.4-2015-TSCH, a node has consequently to reserve an amount of transmissions opportunities (*cells*) after having selected its preferred parent. Reserving a set of cells in the scheduling matrix allows the node to transmit its data packets in a contention free manner.

However, estimating the link quality for inactive neighbors is particularly challenging. Reserving some contention-free cells for probing each neighbor would provide a very accurate link quality estimation, but would also waste a large amount of radio resource. Inversely, the probes may be broadcasted [7], with transmissions being scheduled in the cells dedicated to broadcast (with contention). Unfortunately, the collisions may distort the estimation.

Moreover, changing the preferred parent over a reservation-based MAC layer is very expensive. A node has to *reinstall* a new set of cells for its new parent. Meanwhile, the data packets use the shared cells, prone to collisions. Thus, routing instabilities negatively impact both the reliability and the overhead.

For this purpose, we used the FIT IoT-Lab[2] testbed of Strasbourg to measure the number of preferred parent changes, and the reliability before the network converges. We used the OpenWSN[1] stack, which implements both

[2] https://www.iot-lab.info/

IEEE802.15.4-TSCH and RPL protocols. We selected 31 nodes to highlight the instability which arises even in small-scale topologies.

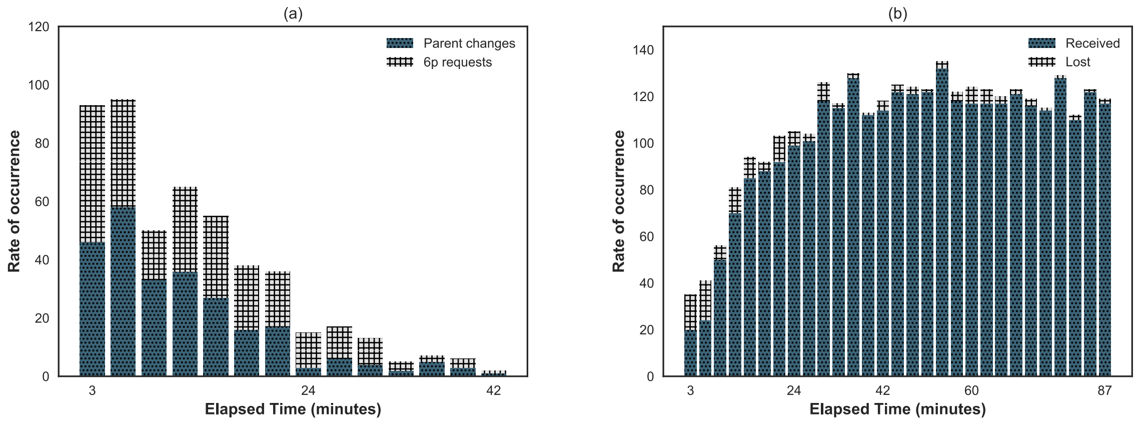

Figure 2 – (a) Number of parent changes/6p commands and (b) the distribution of packet losses during the convergence.

Figure 2(a) exhibits this instability during the convergence phase. We measured the number of parent changes and the number of requests generated by the 6P protocol to modify the schedule. They denote the convergence of the stack. We can observe a high frequency of parent changes and 6P requests. The nodes switch their preferred parents even if the link quality estimation has varied slightly. Because at first a node does not know the link quality to an inactive neighbor, it uses the default link cost. Then, nodes will keep changing their preferred parent until they find a neighbor that fulfills the reliability requirement (i.e. ETX $\leq$ 4). In addition, the instability also affects the Packet Delivery Rate as shown in Figure 2(b). The proportion of lost packets is much higher during the convergence phase, as the nodes 'blindly' select parents using the default link quality value. The packets are even dropped because the node has no transmission opportunity toward its preferred parent. Using a hysteresis function [8] would reduce the number of parent changes, but at the price of using very suboptimal parents.

4. Conclusion

In this paper, we highlighted the impact of the default link quality metric for non-probed links on the routing convergence. Changing several times its preferred parent is particularly expensive in TSCH: new transmission opportunities have to be reserved in the schedule, requiring many control packets. Besides, many data packets may be dropped before the new cells are reserved. Our experiments highlighted the need of estimating accurately the link quality **before** attaching to a preferred parent. Using initially a default link quality is suboptimal, and leads to several parent changes. A more accurate passive link quality estimation would be very beneficial in this situation.

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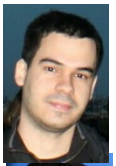
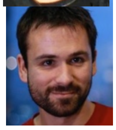


Rodrigo Teles Hermeto is a PhD student at University of Strasbourg (France). He holds a master degree from Federal University of Ceará (Brazil). His research interests include the Industrial Internet of Things, MAC layer for wireless networks and Testbeds for the Internet of Things.



Antoine Gallais is an associate professor at University of Strasbourg since 2008. He received a PhD from the University of Lille, France (2007), and a HDR habilitation from the University of Strasbourg (2017). His main research interests lie in the areas of wireless sensor and mobile ad hoc networking, mobility management and performance evaluation.

Fabrice Théoleyre is a full researcher at CNRS and University of Strasbourg, France. He received a PhD from INSA of Lyon (2006), and a HDR habilitation (2014) from the University of Strasbourg. He is a senior IEEE member. His research interests comprise wireless networking, with a focus on the Industrial Internet of Things with strict guarantees.