Toward deterministic industrial network

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Vers les Réseaux Industriels Déterministes

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La volonté d'utiliser l'Internet des Objets dans le secteur de l'industrie offre de nouvelles perspectives pour développer des technologies standards à bas cout, mais exige également des extensions et adaptations à ces nouveaux applicatifs. Les standards actuels reposent sur des systèmes de détection d'erreur et de retransmissions qui engendrent des latences et des comportements imprévisibles du système. Ce papier présente un algorithme appelé Collaboration Leapfrog qui étend les fonctionnalités de routage offertes par le protocole RPL dans un réseau multi-sauts. Leapfrog s'appuie sur la diversité spatiale du medium pour créer des chemins parallèles permettant ainsi d'anticiper les éventuelles pertes de paquets. A travers une implémentation dans le simulateur Cooja, nous montrons que notre extension permet de mieux maitriser la gigue des paquets de données pour la traversée du réseau.

Mots-clefs : TSCH, RPL, Deterministic Networks, Leapfrog Collaboration, Internet of Things, Industrial IoT.

1 Introduction

The Industry 4.0 is an emerging concept which consists in re-using the Internet of Things (IoT) technology to simplify the production chains, ease the deployment and make the factories more flexible and adaptable. To this aim, what we call the wireless industrial networks must be deterministic.

The standardized protocols for deterministic industrial-type applications IEEE 802.15.4-TSCH [IEE16] and IETF ROLL RPL [WTB+12] are a solid baseline toward the Industry 4.0. However, they still do not assure the transmission of the information with predefined and predictable delay.

In [MPT+17],[PMT+17], the authors proposed the Leapfrog Collaboration (LC), a communication scheme in which parallel transmissions over two paths are scheduled to offer very low jitter performance. In this study, we extend LC by reducing the total number of transmissions in the network to allow eventually for higher network efficiency.

2 Background

2.1 TSCH

In 2016 the IEEE802.15.4-2015 standard [IEE16] was published to provide Quality of Service (QoS) in IoT networks. Time Slotted and Channel Hopping (TSCH) is among the proposed Medium Access Control (MAC) layer protocols. TSCH combines Time Slotted, to schedule transmissions over time division, and Channel Hopping, to avoid collisions in communication over frequency reservation.

Under TSCH, the time is divided into timeslots of equal length while a set of timeslots construct a slotframe. The timeslots are large enough to transmit a frame and receive an acknowledgement. Each of them are labeled with an Absolute Sequence Number (ASN), a variable that counts the number of timeslots since the network was established. Each timeslot is associated with a channel offset which is translated into a physical frequency, for collision avoidance purposes.

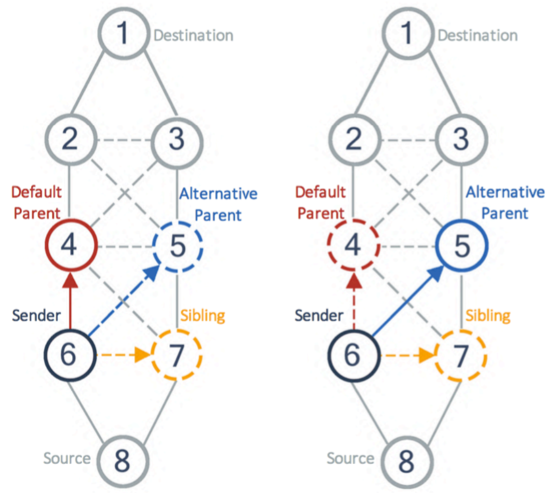

Fig. 1: Unicast transmission from node ID6 to its Default Parent (DP) (in red plain line) and from node ID6 to its Alternative Parent (AP) (in plain blue). When node ID6 is transmitting to node ID4, node ID5 and 7 can overhear the transmission. When node ID6 is sending to node ID5, node ID4 and 7 can overhear the transmission.

2.2 RPL

The IETF ROLL working group developed the IPv6 Routing Protocol for Low-Power and Lossy Networks (RPL) [WTB+12]. RPL builds a Destination Oriented Directed Acyclic Graph (DODAG) to enable hop by hop forwarding. It is particularly made for Low power and Lossy Networks (LLNs) and thus propose different mechanisms to react in case of failure.

The DAG is constructed from a rank allocated to each node. A rank can be seen as a metric representing the distance from the node to the root node. Each node broadcasts this rank to their neighbors in DIO (DAD Information Object) messages and builds the DAG according to an Objective Function (OF) by comparing with their own rank. A node that receives a lower rank from its neighbor will registered it as its parent toward the root. Moreover, RPL comes with a repair mechanism process. Upon a node or link failure, RPL triggers a local or global repair of the DODAG. However these mechanisms require large delay and the network may not be able to forward data packets during this time. With our proposal, we enable the usage of an alternate path in real time while a node or a link has failed because duplication is organized beforehand.

2.3 Problem statement

Industrial networks need to be deterministic in order to provide the necessary support for close loop monitoring or safety applications. It means that when a packet is issued on the network, we need to make sure the packet will be received by the destination, and moreover that the packet will arrive to the destination in a bounded delay. The IoT technologies are usually not made for that, the primary focus is usually on energy efficiency, or scalability.

Wireless-based links suffer from interferences or bad link quality, which imply packet losses [PGS+17], [KPCT17]. As a result, due to multiple retransmissions, such situation introduces delays and losses in the network. In the following Section we will present the leapfrog collaboration algorithm that exploits the radio medium natural characteristics and create multiple parallel duplication to offer more reliability and make the network deterministic.

3 Leapfrog Collaboration

Leapfrog Collaboration (LC) allows nodes to transmit multiple times the same data packet to different parents to create multiple parallel paths (see Fig. 1). Furthermore, by using replication and overhearing

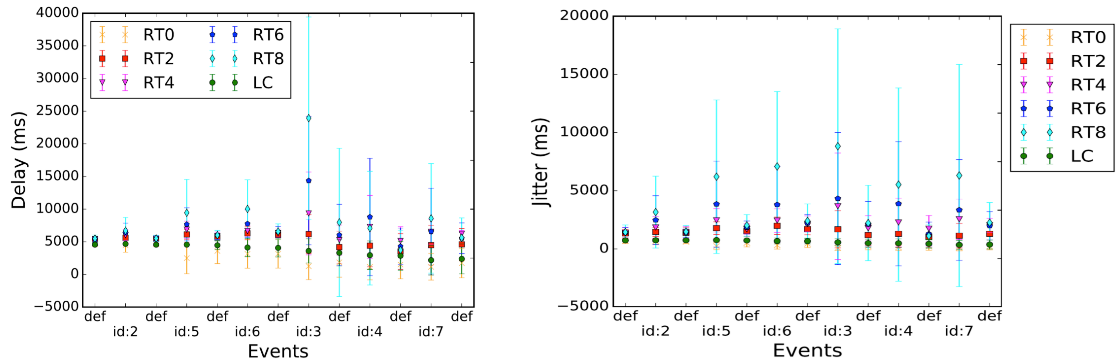

Fig. 2: Average end-to-end delay (left) and jitter (right): ID8 to sink ID1.

operations, each node will have a second chance to listen (and receive) the same data packet.

3.1 Alternative parent selection

As previously presented, the RPL protocol allows each node to have a set of parents (i.e., neighbor nodes having a lower rank than the node itself). The neighbor node which has the lower rank in the parent set is usually chosen as a Default Parent (DP) in LC. To choose its Alternative Parent (AP), a node will select another parent from its parent set that has a common parent with the node DP. So the node will check if its Default Grand Parent (DGP), the DP of its DP, is in the set of parents of a potential AP. A node will select the potential AP that has the lower rank as its AP. For instance in Fig. 1 the node ID6 has its DP node ID4 and DGP node ID2, and since ID2 is in the set of parents of node ID5, ID6 may register ID5 as its AP. In order to transmit this new information we introduce the Leapfrog Beacon (LB) messages.

3.2 Packet Replication

Each node transmits twice in Unicast to its DP and its AP. Given the AP selection, this allows the data packet to be transmitted over two parallel paths.

3.3 Overhearing

Finally, under Overhearing operation, nodes take advantage of the broadcast properties of the radio medium to offer more opportunities to receive the data packet by listening to other unicast transmissions. Thus, a node may have up to 4 opportunities to receive a data packet: unicast from its son, unicast from its son to the AP, and again these two opportunities on the alternate path.

3.4 Packet Elimination

Within LC, a node may receive several times the same data packet. A node may receive a data packet because it is the DP of a node, and then another copy of the same message because it is the AP of another node. In addition, by using the overhearing operation, a node may receive additional copies. To avoid multiplying packet transmissions, we introduce packet elimination operation. Once a node receives the first copy of a data packet, it will simply discard the following copies.

4 Performance evaluation

4.1 Simulation set-up

In order to evaluate the efficiency and the benefits of the new extension, we conducted a large set of simulation by using COOJA (an emulator for Contiki OS) and emulating the Z1 motes.

Our simulation is based on eight fixed nodes (including the sink), as depicted in Fig. 1. RPL is running and builds the DODAG. We compare the proposed scheme against the default TSCH-RPL network under various number of retransmissions, (i.e., RT2, RT4, RT6 and RT8). In order to have an approach closest to reality, we configured the radio links quality to vary over time; we start with a configuration where all radio links are good (around 90%) and we kill a node for 5 minutes. Then we put this node back up for another 5 minutes and then kill another node. We continue like this by killing and recovering all nodes in the network one by one. This allows us to evaluate the reactive adaptation of the deployed network.

4.2 Performance Results

Fig. 2 shows the average end-to-end delay and jitter for both LC and the base TSCH implementation (RTx, where x is the maximum number of link-layer retransmissions). In the x axis *def* means all nodes are up and running and *id:X* means node IDX is down. LC reduces both the end-to-end delay and jitter when compared to the retransmission-based approaches of IEEE802.15.4-TSCH (i.e., RT2, RT4, RT6 and RT8). Indeed, it decreases by up to 28%, 41%, 46% and 54%, respectively. Using Acknowledgement in LC with one possible retransmission, we reach a reliability higher than 95%. We see here that LC is a good solution to provide robustness in a multi hop network. Using two alternate paths allows to be robust again a node failure without any delay to detect this loss.

Acknowledgments

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